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Oskarshamn site investigation

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Identification of short lineaments from LIDAR and magnetic total field data

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May 2007

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Keywords: Laxemar, LIDAR, DEM, Ground geophysics, Magnetic total field, Magnetic susceptibility, Lineament, Deformation zone, Fracture zone.

Abstract

One of the earliest activities within the site investigations in the Laxemar area reported linked lineaments with a minimum length of 1 km. This comparatively large dimension adapts to the needs for a regional model of deformation zones and the linked lineaments have thus been evaluated and partly implemented into the deformation zone model v 1.2 of the Laxemar area. The information density in the Laxemar area has successively increased since and the introduction of dense ground geophysical surveys and an elevation model based on LIDAR data has made it possible to identify 1,399 co-ordinated lineaments longer than 100 m within the Local model area of Laxemar, version 2.1.

Using the ground geophysical data and in particular the LIDAR data, the current activity has identified lineaments longer than 10 m in two subareas at Laxemar. In the same manner as for longer lineaments, such short lineaments may indicate brittle deformation in the bedrock (e.g. deformation zones). The short lineaments are expected to reflect deformation of the bedrock in the length interval above the one covered by detailed fracture mapping on outcrops.

The number of identified lineaments from the current activity are 202 and they support the site investigations by indicating possible deformation zones in the rock, mainly with lengths between 10 to 100 m.

The analysis shows directional distribution peaks at 30–50 degrees and 300–330 degrees for these short lineaments (> 10 m). This is similar to the directions detected in the analysis of longer lineaments (> 100 m) carried out in an earlier activity /4/.

The new co-ordinated lineaments should be viewed as a complementary set of lineaments to the pre-existing co-ordinated and linked lineaments.

Sammanfattning

Ett av de tidigaste arbetena med lineamentstolkningar inom platsundersökningen i Laxemarområdet har resulterat i s k linked lineaments med längder över 1 km vilka har utgjort ett av de huvudsakliga underlagen till den platsspecifika modellen över möjliga deformationszoner (version 1.2) i Laxemarområdet. Sedan dess har nya data tillkommit med högre upplösning, bland annat från täta markgeofysiska undersökningar och luftburen laserskanning, s k LIDAR-mätning. Genom dessa data har det blivit möjligt att identifiera lineament i berggrunden också i längdintervallet under 1 km. I en föregående aktivitet har 1 399 s k koordinerade lineament identifierats med längder längre än 100 m inom den yta som motsvarar det lokala modellområdet för Laxemar version 2.1 /4/.

I föreliggande rapport beskrivs arbetet med att ur LIDAR data med stöd från markgeofysiken fokusera lineamentstolkningen till en än mer detaljerad skala. Målet har varit att identifiera lineament längre än 10 m inom två delområden av Laxemar. Dessa korta lineament, 202 till antalet, förväntas på samma grunder som för längre lineament belysa möjlig deformation i berggrunden i en skala som ligger mellan de tidigare identifierade s k koordinerade lineamenten längre än 100 m och den information som detaljerad sprickkartering ger.

En analys av riktningar hos de korta lineamenten visar huvudriktningar i intervallen 30–50 grader respektive 310–320 grader vilket är påfallande lika de som uppträder bland längre lineament (> 100 m) som analyserats i en tidigare aktivitet /4/.

De nya lineamenten (längre än 10 m) kan ses som ett komplement till de lineament som identifierats i tidigare arbeten.

Contents

1 Introduction

This document reports the results gained from the identification of short lineaments (> 10 m) in LIDAR data/1/ (Light Detection and Ranging) and magnetic data /2, 3/.

The identification of lineaments described in this report is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with the activity plan *"Plan of activities for the establishment of geological models, version 2.1, Laxemar subarea"*. In Table 1-1 the controlling documents for performing this activity are listed. Both the activity plan and the method description are SKB's internal controlling documents.

Johan Berglund, Mats Nyborg (both Vattenfall Power Consultant AB) and Carl-Axel Triumf (GeoVista AB) carried out the identification of the lineaments during June 2006 to October 2006. The work covered two subareas at Laxemar, one of 450×500 m (1546650–1547100/6367000–6367500) and the other 500×200 m (1547050–1547550/6366300–6366500) (Figure 1-1).

The results, i.e. the lineaments and associated attributes, are expected to support the future site investigations at Oskarshamn by indicating the distribution and character of possible shorter fractures and deformation zones in the Laxemar area.

The original results of the work are stored in the primary data bases (SICADA and GIS) and they are traceable by the activity plan name "*Plan of activities for the establishment of geological models, version 2.1, Laxemar subarea*".

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

Activity plan	Number	Version
Plan of activities for the establishment of geological models, version 2.1, Laxemar subarea.	No Number	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för lineamentstolkning baserad på topografiska data	SKB MD 120.001	1.0

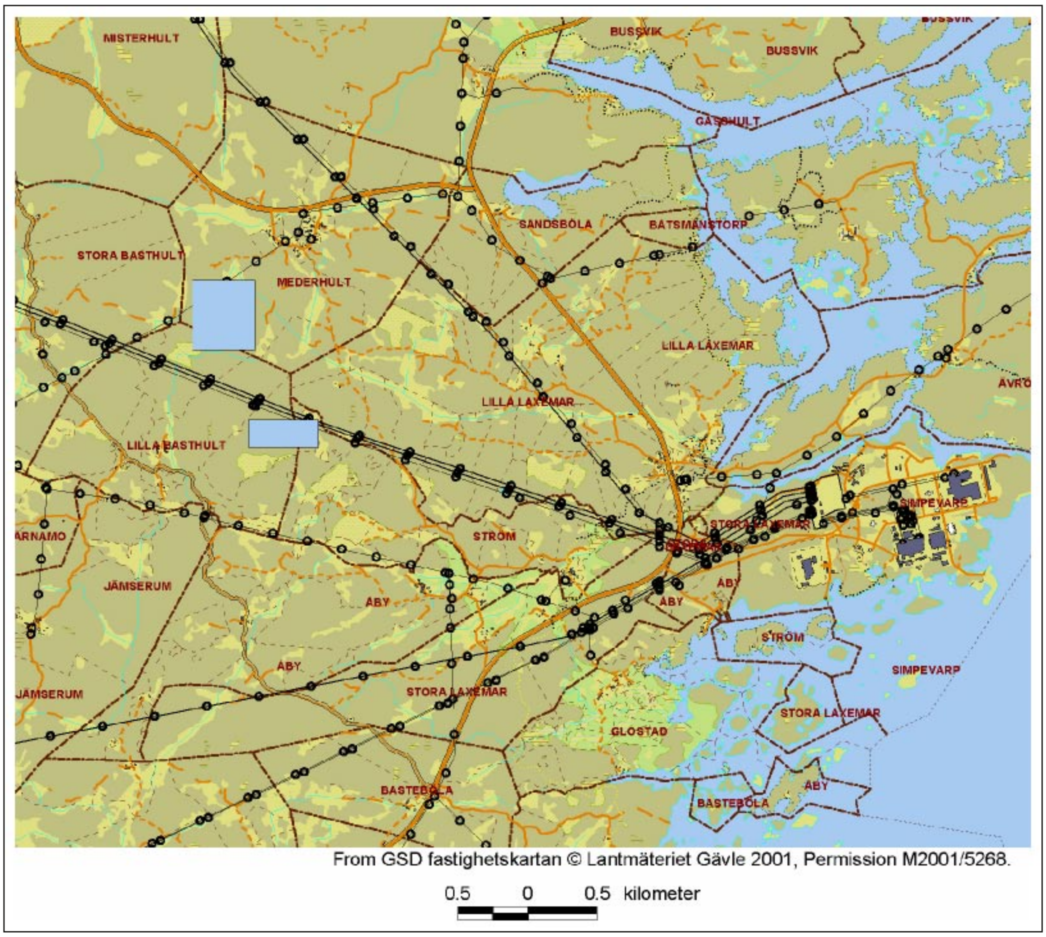


Figure 1-1. *The lineaments were identified within two subareas of Laxemar hereafter named north-west subarea and south-east subarea. The work was carried out in June to October 2006 by Vattenfall Power Consultant AB and GeoVista AB.*

2 Objective and scope

In the present activity we identify short lineaments in LIDAR data and ground magnetic data. The activity results in lineaments, 10 m and longer, within two subareas of the Laxemar area. They are expected to support the site investigations by reflecting the distribution of possible deformation zones in the rock with focus on the length interval between 10–100 m.

These new lineaments should be viewed as a complementary set of lineaments to the pre-existing lineaments /2, 3, 4, 5, 6, 7, 8/.

3 Equipment

3.1 Tools for processing, identification, co-ordination and reporting

The processing, identification, co-ordination and reporting are purely desk-top based, with the use of computers with appropriate software. The software used included:

MapInfo Professional v 8.0 (MapInfo Corporation)

Discover v 7.0 (Encom Technology)

ArcMAP (Environmental Systems Research Institute Inc.)

Microsoft Excel (Microsoft Corp.)

Microsoft Word (Microsoft Corp.)

Adobe Acrobat and Adobe Distiller (Adobe Systems Inc.).

4 Processing, lineament identification and parameterisation

4.1 Definitions

A *lineament* is a linear anomaly on the Earth's surface, straight or gently curved, which has been interpreted on the basis of a 2-dimensional data set, such as a topographic map, a digital elevation model (DEM) and/or a map over the magnetic total field /9/.

A *method specific lineament* is a technical term meaning a lineament defined from a single and specific type of data set. The data set comes from a specific type of investigation method, such as a photogrammetric survey for a digital elevation model, airborne magnetics or airborne EM or ground geophysical measurements; see also Figure 4-1.

A *co-ordinated lineament* is a technical term meaning a single lineament that represents all method specific lineaments that are supposed to indicate the same length section of the actual source structure, see also Figure 4-1.

Method specific and *co-ordinated lineaments* are all supposed to represent a *lineament* according to the general definition explained above. The prefix is used only due to reasons of communication and quality assurance where the names are supposed to associate the reader to a specific interval in the process of defining and describing lineaments.

A *linked lineament* is a technical term meaning a lineament that is composed of one or several co-ordinated lineaments i.e. the co-ordinated lineaments have been joined along the strike into one linked lineament. Linking has, however, not been carried out in the current activity.

4.2 General

The current activity consisted of the following main sub-activities:

- Processing of LIDAR data and preparation of grids, implementation of grids into a GIS.
- Identification of lineaments in LIDAR data and ground magnetic data, co-ordination and parametrization.
- Comparison of identified lineaments with previously identified lineaments.
- Reporting.

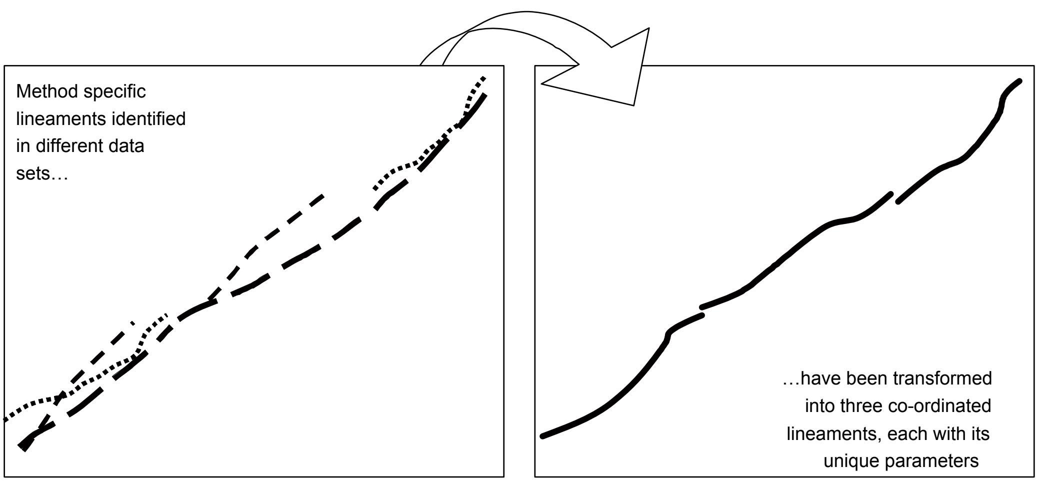


Figure 4-1. *Condensed explanation of the identification and co-ordination of lineaments.*

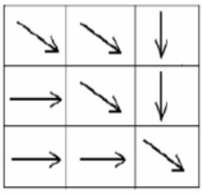
4.3 Processing of LIDAR data and implementation into a GIS

LIDAR data were extracted from the SKB file archive as a set of XYZ text-files. Each file covers an area of roughly 600 by 600 m. LIDAR reflections from e.g. vegetation had been filtered out from the data which means that the data density varied slightly within the area but a typical number would be around 5 samples per m^2.

A method has been developed in order to automatically derive the outlines of the geomorphological domains in reference to small-scale topography. In the literature this normally is referred to as the terrain skeleton or the break lines of the terrain /10/. Terrain skeleton features are typically characteristic lines like ridges (indicated as an edge in a terrain model) or ravines. The most important parameters to study in the terrain models are thus low lying areas and sudden changes of heights, which lead to either aspect changes or slope changes.

For the extraction of local minima (i.e. valleys, sinks etc) a method originally developed for hydrological analysis has been used /11/. The method calculates "hydrology runoff" by reducing the effects of local minima thus ensures that the accumulated runoff units reach the boundaries of the surface. The runoff procedure generates a flow direction based on terrain height, analysing the slope and aspect of the terrain (Figure 4-2).

Using low-pass filters /12/ the terrain model can be filtered to extract the valley structures at certain scales. In Figure 4-3 the structural components at full resolution without using a cut-off frequency at certain scale is visualised.



1	1	1
1	3	3
1	2	9

Figure 4-2. The calculation of hydrological runoff used for indication of low areas in the terrain. This example shows the flow direction for a 3x3 pixel surface. One unit of rainfall is assumed dropped on every location. The runoff result will be calculated as the grid to the right.

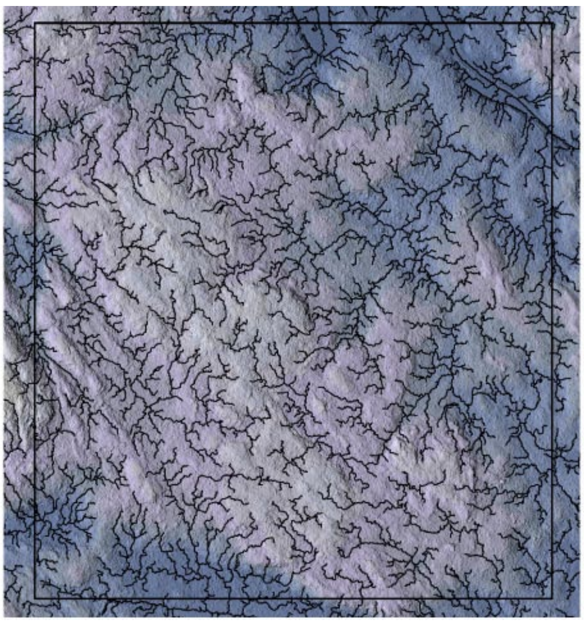


Figure 4-3. Extracted valley structures for the north-west subarea. The image in the background is the shaded relief.

It should be noted that hydrologic processes could be studied on a wide range of scales. The method described indicates low points in the terrain at all scales. A valley structure of minor scale may be located within a structure of larger dimension. This might confuse the interpretation of the data. Furthermore, the stream-network pattern derived is influenced by a number of factors. Except for the structures in the rock, factors like vegetation, soils and other variables influence the movement and quantity of water flow. Also human impacts, such as infrastructure, dams, and man made features like ditches influence the surface runoff pattern. This implies that the extracted pattern using the described methodology only can serve as an indication of geological structures, i.e. lineaments. Linear patterns can thus not directly be indicative for a lineament, but a *possible* lineament. Verification needs to be performed by a field observation, or supported by other data.

The lines associated to steeper slopes (escarpments) along valleys, towards elevated areas, have been extracted from the terrain model using an edge detection technique. Every shaded layer was filtered using a Sobel filter /13/ in order to detect steeper slopes. Furthermore, the maximum edge value (approximately the same as maximum topographic gradient) for every input cell of all the filtered layers was created. Resulting raster layer indicates potential terrain skeleton features associated to such valley edges (Figure 4-4). The areas of maximum edge have been thinned using erosion and dilation operators and transformed to lines.

4.4 Identification of lineaments in LIDAR data and ground magnetic data, co-ordination and parameterisation

Method-specific lineaments have been identified and delineated based on the outcome of the segmentation process as described in section 4.3 in combination with visual inspection of a series of images of the LIDAR elevation model and magnetic total field data. Furthermore the lineaments identified in magnetic data /3/ were imported and used as a support. The method-specific lineaments were then co-ordinated. The identification and co-ordination is a manual process.

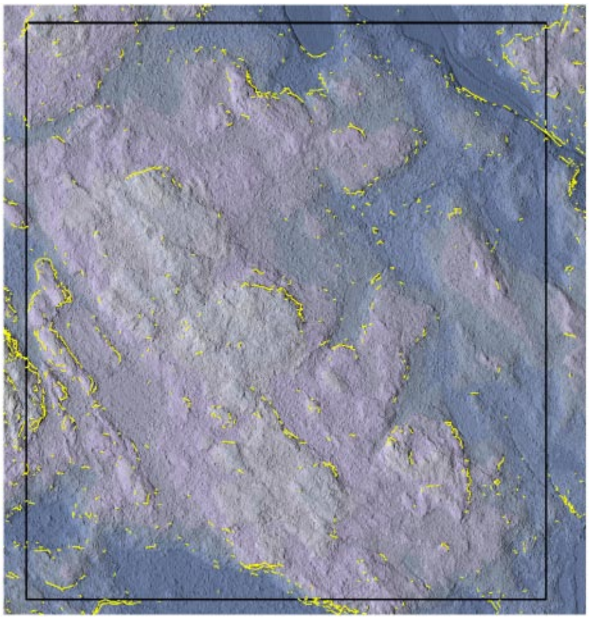


Figure 4-4. *Results of edge detection from analytically shaded, maximum edge value for the north-west subarea.*

The main difficulty in the co-ordination process has been to overcome the difference in spatial resolution between the different data sets (see also Chapter 6). The resolution in the LIDAR data is many times higher than in ground magnetics. In areas where ground magnetics are missing and only helicopter borne magnetics are available, the resolution contrast is even more severe. Due to this it may be difficult to judge whether a lineament identified in LIDAR data also is indicated in the magnetic data. Thus, the magnetisation character of single lineaments has only been assigned where ground magnetics are available.

Lineaments interpreted in LIDAR data, that represent deformed or altered rock, are generally expected to coincide with low magnetisation in the rock. Narrow and short lineaments visible in LIDAR data are however not necessarily visible in the magnetic total field data due to the lower resolution of the latter. This has affected the assignment of the parameter for the magnetic character M_N of a lineament (see Table 4-1). If a lineament identified in the LIDAR data is located in a area where the magnetic field is generally low, it is regarded to have been observed also in magnetic data.

The continuity of lineaments at the border of the studied area is important as the statistical analysis of lineaments involves the lineament length as one source parameter. The length distribution must not be affected by masking operations at the border i.e. the produced sets of lineaments should contain also lineaments with sub-sections located outside the subarea analysed.

Short lineaments that are apparent in the data sets studied but more or less coincide with earlier presented longer lineaments /4/ have been rejected.

The work has been done in three sequences in the approximate scales 1:2,000, 1:1,000 and 1:500, in order to cope with the fact that the human eye perceives different things depending on the scale considered. Lineaments defined by valleys and gullies were drawn first. Finally, linear escarpments or slopes were identified as lineaments. The character of the lineaments observed in the DEM is described in the parameter T_N, see Table 4-1.

Lineaments were not drawn when they represent a structure that already is occupied by another lineament, e.g. when an escarpment parallels a valley lineament.

A lineament may have different character along its course. Lineaments may thus start as a valley lineament, continue as a boundary to a higher area and end as an escarpment. The dominant character defines the parameterisation.

Only straight lineaments are identified in this work, not curvilinear. This is because of the scale considered, in relation to the resolution of the data used.

The lineaments are generally located at a central location between the two adjacent hills or areas of higher elevation. They are interpreted to exist as long as the supporting linear elements in the topography exist, on one or both sides of the lineament.

The result is a set of lineaments longer than 10 m. The parameterisation essentially consisted of assigning a number of parameters according to Table 4-1.

Table 4-1. List of parameters assigned to every co-ordinated lineament.

Name of attribute	Values in this activity	Comment
ID_T	n.a.	Identities have not been assigned to the individual lineaments.
ORIGIN_T	Method specific lineaments	
CLASS_T	n.a.	The individual co-ordinated lineaments have not been classified
METHOD_T	see PLATFORM_T below	
T_N	0 or 1	Visibility in the LIDAR-DEM. 0 if not detected, 1 if detected.
TT_N	1 or 2	Type of feature in the DEM. 1 = valley, 2= escarpment.
M_N	0, 1 or –1	Visibility in data reflecting the magnetisation of the ground. 0 if not detected, 1 if detected. –1 if no dense magnetic data is available.
PROPERTY_N	1 or 2	Number of data sets/properties (M_N-magnetization, T_N-morphology) where the lineament has been identified
WEIGHT_N	0	The weight has not been assigned
CHAR_T	Co-ordinated lineament	
UNCERT_N	0	The uncertainty has not been assigned
COMMENT_T		Free text
PROCESS_T	Image analysis	
DATE_D	20061030	Date when the last change was made in the individual co-ordinated lineament.
SCALE_T	2,000, 1,000, 500	Typical scales in which the identification of a lineament has been carried out
PLATFORM_T	Ground magnetics, LIDAR-DEM	Different combinations of available data sets depending on where the lineament is located
WIDTH_N	0	Has not been specified
PRECIS_N	0	Has not been specified
SIGN_T	Johan Berglund/Vattenfall and Carl-Axel Triumf/GeoVista AB	Name of the interpreter
DIRECT_N	0–360	Calculated average orientation of the lineament
LENGTH_N	In meter	Calculated length in m
COUNT_N	1	By default = 1

4.5 Comparison of lineaments

The comparison of shorter lineaments with earlier identified longer lineaments is implicit in the co-ordination process as described in section 4.4 above. However are also the statistics of the different sets of lineaments, i.e. shorter and longer, compared and commented briefly.

5 Results

The results are stored in the primary databases (SICADA and/or GIS). The data are traceable in SICADA and GIS by the Activity Plan name plan *"Plan of activities for the establishment of geological models, version 2.1, Laxemar subarea"*.

5.1 Short lineaments from LIDAR data and ground magnetic total field data.

The processing of LIDAR data and ground magnetic total field data has resulted in different products displaying the information content in different modes. The segmentation process resulted in a set of discrete representations of valleys and escarpments found in the terrain model. When a structure found as result of the segmentation process show a linear trend, it is considered as potential candidate as lineament (Figures 5-1 and 5-2).

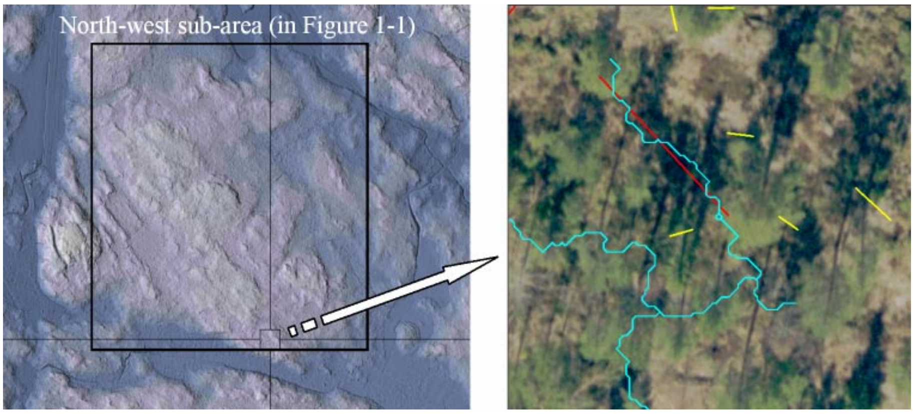


Figure 5-1. *An example of interpreted segmentation data for the north-western subarea. Confirmed co-ordinated lineament (red line in the figure to the right) also found in the digital elevation model as a near-linear valley structure (light blue lines). Yellow lines indicate escarpments found. An orthophoto has been used as background in the figure to the right.*

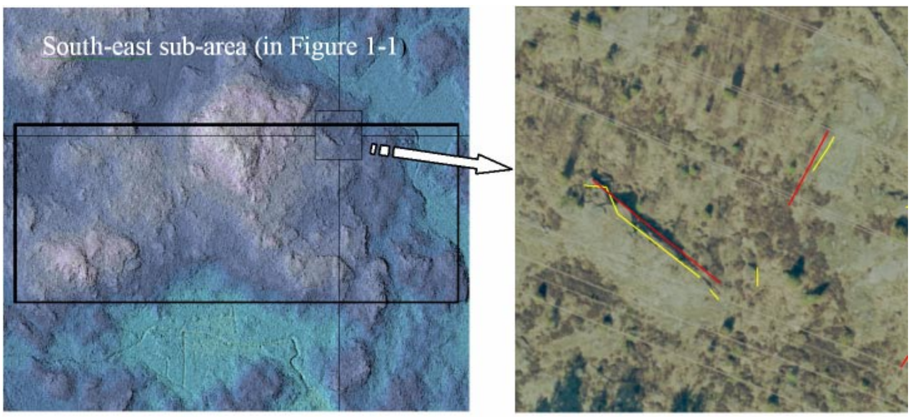


Figure 5-2. *An example of interpreted segmentation data for the south-eastern subarea. Confirmed co-ordinated lineaments (red lines in the figure to the right) also found in the digital elevation model as escarpment structures (light yellow lines). An orthophoto has been used as background in the figure to the right.*

The map of all co-ordinated lineaments in both subareas is shown in Figure 5-3. As can be seen, some of the lineaments continue outside the two subareas. This is required to preserve full lineament length across the area border, which is needed for statistical analysis.

5.2 Distribution of length and direction of the lineaments. Comparison with longer lineaments.

The length distribution of the lineaments in the current activity is shown in Figure 5-4.

The distribution of orientations among the co-ordinated lineaments from the current activity shows two pronounced peaks between 30–50 degrees and 300–330 degrees (Figure 5-5).

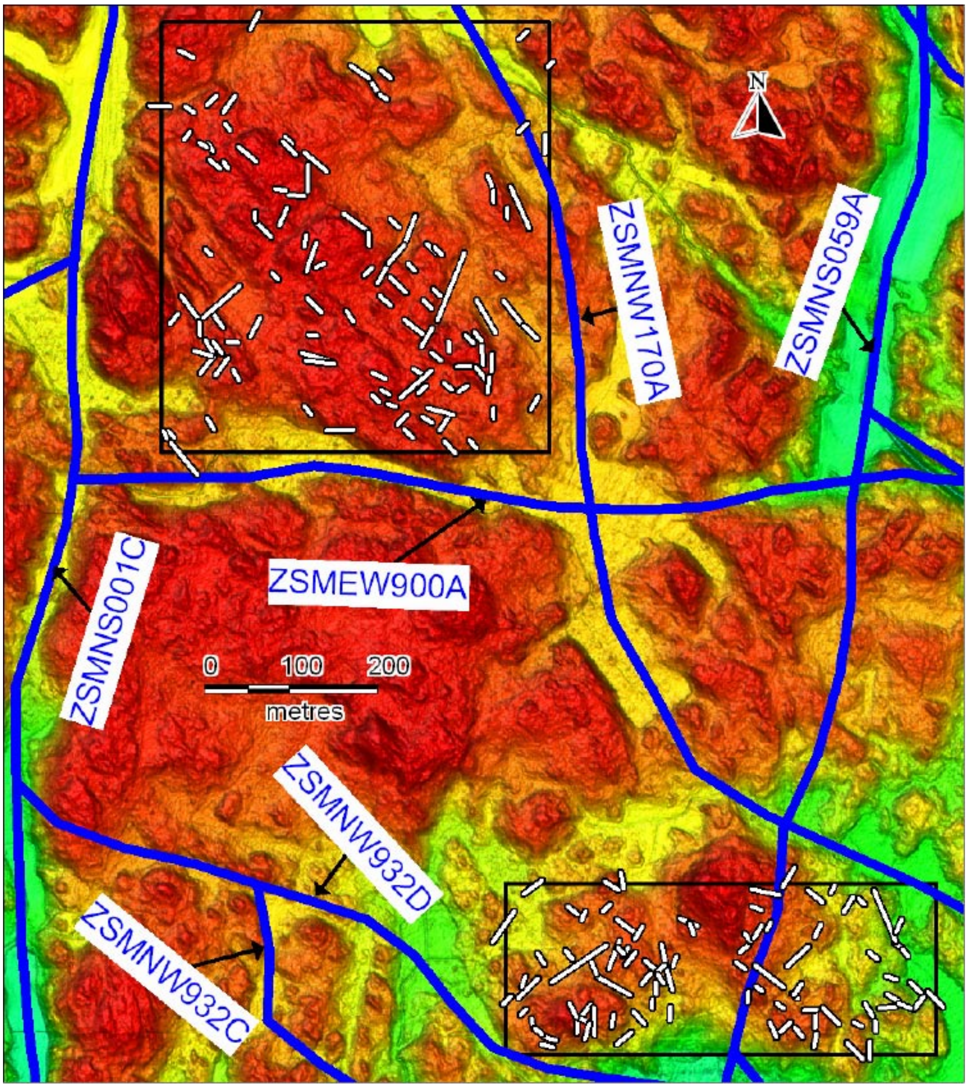


Figure 5-3. Co-ordinated lineaments longer than 10 m (white) identified in the LIDAR-based elevation model and in the ground magnetic total field data. As dark blue thick lines is shown the lineaments from the Deformation zone model version 1.2.

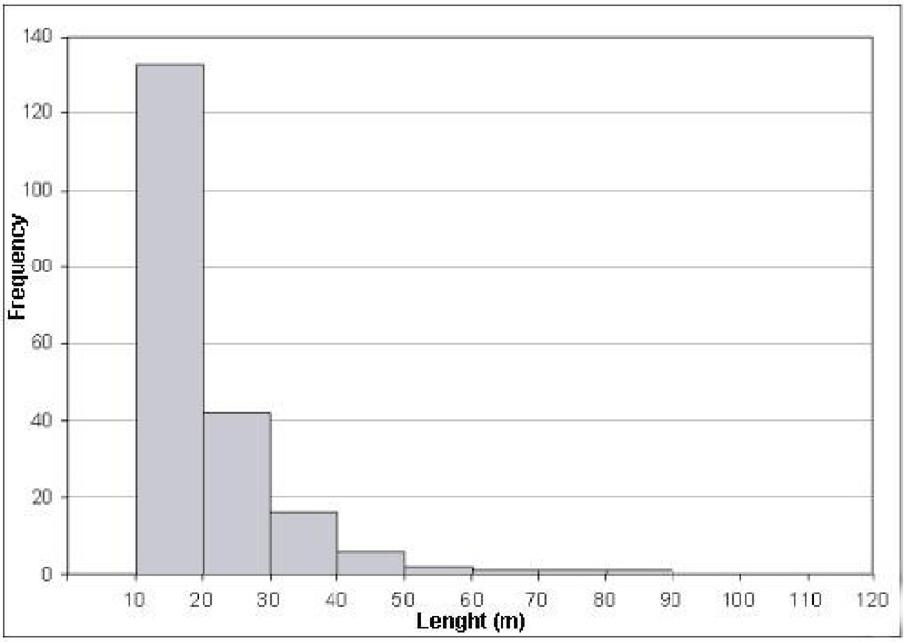


Figure 5-4. *Frequency diagram of the length distribution of co-ordinated lineaments longer than 10 m in the two subareas investigated.*

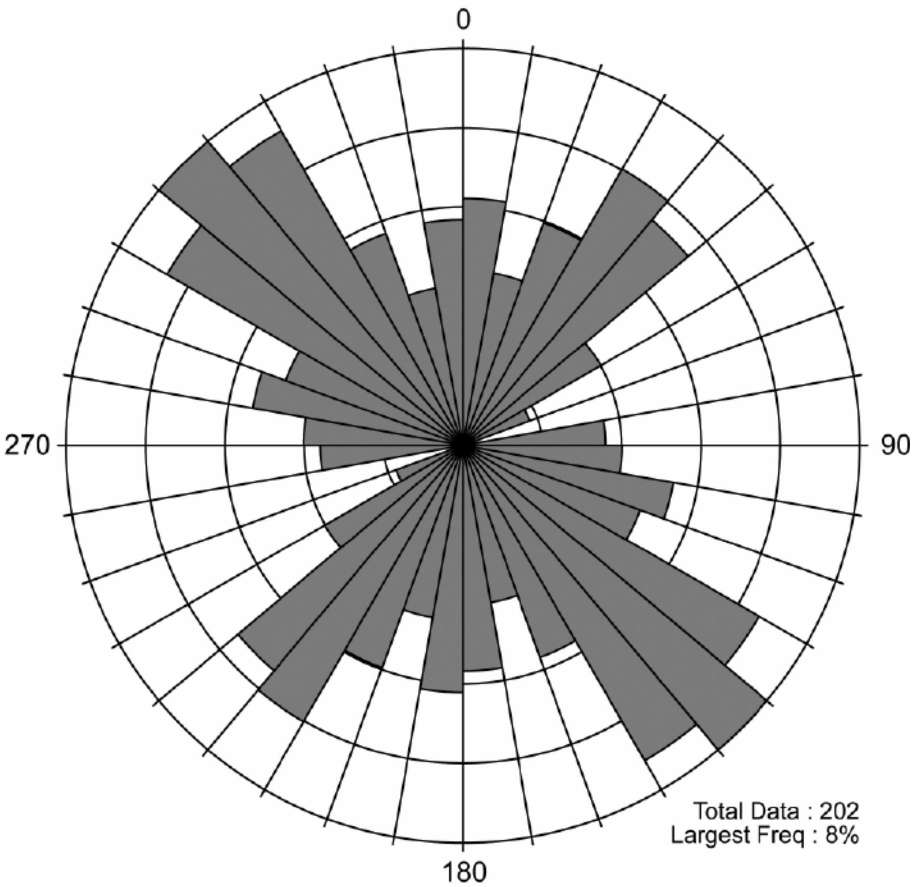


Figure 5-5. *Distribution of the directions of co-ordinated lineaments longer than 10 m in the two subareas investigated shows peaks around 30–50 degrees and 300–330.*

In Figure 5-6 is shown the short lineaments from the current study together with longer lineaments (> 100 m) /4/.

The distribution of orientations among the co-ordinated lineaments longer than 100 m shows a broad peak around 40° to 70° and a more pronounced peak at 300° to 310° /4/. The distribution reflects the lineament orientations over a large area covering more than 13 km^2. Although the current work reports short lineaments from two very small areas, as compared to 13 km^2, the directional distribution among the short lineaments has a similar appearance.

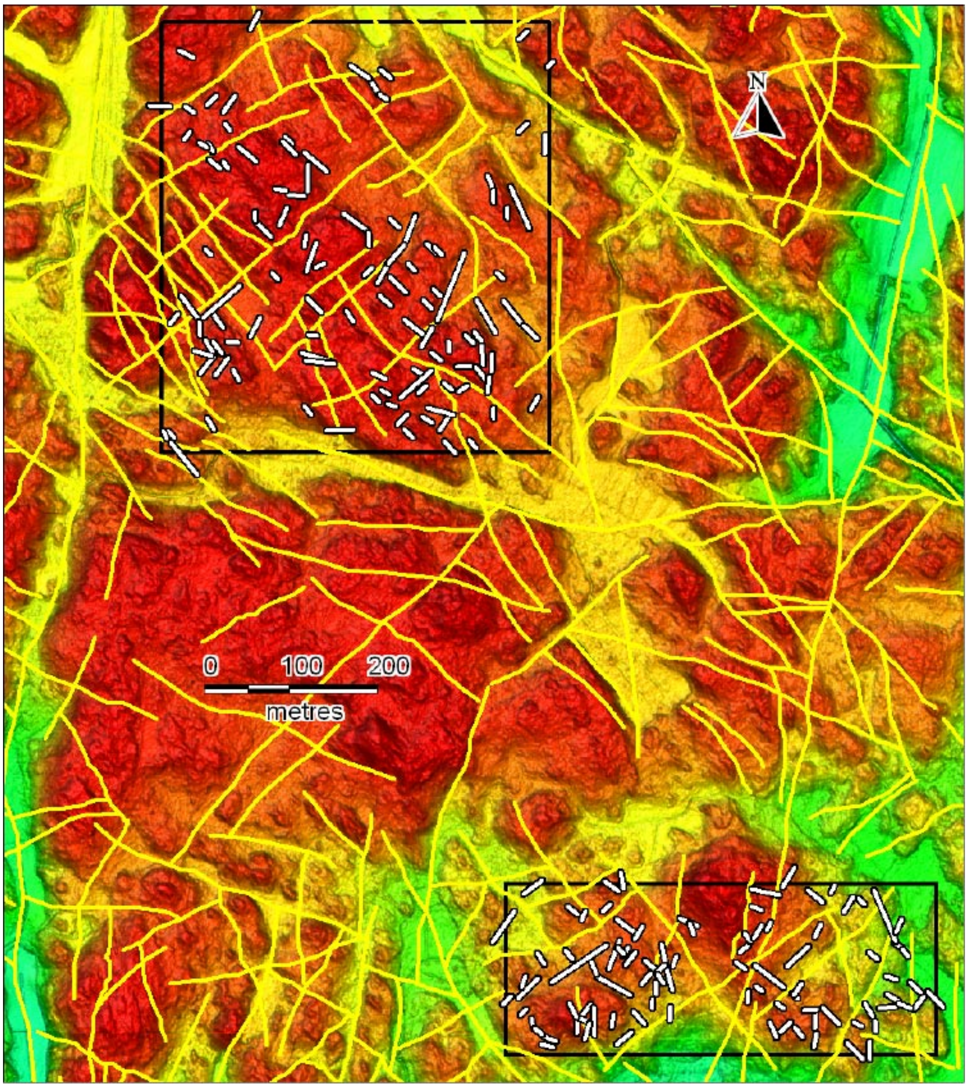


Figure 5-6. *Co-ordinated lineaments longer than 10 m (white) identified in the LIDAR-based elevation model and in the ground magnetic total field data compared with lineaments longer than 100 m /4/ (yellow).*

6 Discussion

The data coverage of the different data sets will affect the result when identifying lineaments and co-ordinating them. The LIDAR-based elevation model has a higher potential as compared to the magnetic total field data to reveal relatively short deformation zones. This is due to the sampling interval where the typical point density in the primary data of the LIDAR survey is at least 15 times higher. There is however dependence on the type and thickness of the Quaternary deposits in the success ratio of the lineament identification when using a LIDAR-based elevation model. In areas with re-worked deposits or thick cover it becomes less successful. The magnetic total field however also reveals magnetic lineaments below a cover. In that sense the two data sets are complementary.

The two types of lineaments identified in this activity have in many cases been shown to indicate the location of brittle deformation /14/. This deformation may in some cases only be manifested by one or a few sub-parallel fractures, not always representing a deformation zone according to the classification used by SKB (e.g. Table 4-1 in /15/). In some cases however the lineaments are related to geological structures other than brittle deformation, such as ductile deformation, lithological changes, alterations, or caused by glacial processes unrelated to structures in the rock.

The high resolution DEM based on LIDAR data is available for both subareas. Dense ground magnetic total field measurements are however not available over the entire north-western subarea. This will lead to fewer short lineaments detected compared to a case where the entire area would have been covered with a dense ground geophysical survey.

In the present activity, the focus has been on lineaments longer than 10 m, as compared to earlier activities where lineaments longer than 100 m and 1 km were of main interest. This change to a shorter cut-off length also will affect the interpreters' threshold level for accepting a lineament. High detail in base data means high threshold; in such detailed data obstacles are easier to find preventing a lineament to be drawn.

The choice to focus on shorter lineaments is expected to give detailed information about the local geometry of possible deformation zones. However the overview becomes deteriorated and it is thus more difficult to draw a single line that uniquely represents a broad and long feature with varying character and geometry. Due to this, earlier versions of lineaments are complementary to the current version of lineaments. The different versions are available for usage by adaptation to the appropriate scale for the problem to analyse.

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