Reprinted from

Symposium on Machine Processing of Remotely Sensed Data and Soil Information Systems and Remote Sensing and Soil Survey

June 3-6, 1980

Proceedings

The Laboratory for Applications of Remote Sensing

Purdue University
West Lafayette
Indiana 47907 USA

IEEE Catalog No.
80CH1533-9 MPRSD

LINEAMENT MAPPING IN NORTHERN SWEDEN FROM LANDSAT IMAGES USING ORTHOGONAL IMAGE TRANSFORMS

L. CHRISTER ANDERSSON AND HANS HAUSKA

University of Lulea

I. ABSTRACT

The emphasis of this paper is put on mapping of geological linear structures, and in particular the correlation between these structures orientation and geological or geophysical data. It is also the intention of the authors to present a method to map these structures more objectively than up to now.

II. INTRODUCTION

The application of the remote sensing technique on geological problems, as a complement to ground geological survey, is of increasing importance. Especially LANDSAT, with its comprehensive synoptic and multispectral sensor-system, has become a powerful tool in most geological interpretation tasks. Ever since the first images produced by LANDSAT became available (1972), they have been recognized as particularly useful in mapping of large linear geomorphic features, i.e. lineaments.

The concept "lineament" will in this paper be defined as: a nongenetic term for a clearly discernible linear feature on the surface of the earth, which reflects a subsurface phenomenon.

A great amount of effort has been put into studying the genesis and geological implications of the lineaments. In many different geological environments it has become obvious that the lineament is a surface expression of subsurface geological structural features.[1] These structures can include or at least be influenced by such varying phenomena as fault zones, fracture zones, fold axis, rock contacts, veins, dykes or weakness zones.

To find and interpret the lineament can be of considerable importance for geological surveying and mineral exploration.

III. CONDITIONS

The most important sulphide-ore province in Sweden, the Skellefte field, is in many cases poorly known in its deep-seated geology. This depends mainly on two reasons.

1. Ground geological mapping is unreliable due to a about 1-20 m thick cover of Quaternary deposit of till, which is hiding 99 % of the area.

2. Geophysical methods have up to now a rather limited depth-penetration, and also a profound ambiguity in the interpretation of deeper structures.

These conditions together with the fact of a decreasing near-surface ore supply, is a driving force to investigate deeper geological layers. Remote sensing and particularly lineament mapping must in this view take an important place amongst new deep mineral exploration methods.

IV. LINEAMENT MEASURES

One of the main advantages with digital images, compared to photographic images, is of course the processing ability with the aid of computers. This is especially the case with lineament mapping, which usually is performed manually after more or less subjective criteria. An alternative method to achieve lineament mapping is to apply objective lineament measures, which can be extracted from the image by digital calculations.

The fact that manual lineament interpretations suffer from subjective impressions of the interpreter, is usually due to the vast amount of information and the complexity of the images.

Examples of objective lineament measures that can be computed are:

1. the orientation of lineaments
2. the relative intensity of lineaments
3. the extension of lineaments

One analytical tool which can be used to obtain these data in an objective manner is transforming and filtering the image using digital orthogonal transforms, e.g. Fourier transform. For this purpose software routines performing FFT and lineament analysis have been implemented on a minicomputer of make NORD-10.[2]

V. FFT AND LINEAMENT PROCESSING

A. THE TWO-DIMENSIONAL FOURIER TRANSFORM

The discrete two-dimensional Fourier transform of an image is defined as

$$\hat{F}(u,v) = \frac{1}{N} \sum_{j=0}^{N-1} \sum_{k=0}^{N-1} F(j,k) \cdot$$

$$\cdot \exp(-\frac{2\pi i}{N}(uj+vk)) \qquad (1)$$

and the inverse transform

$$F(j,k) = \frac{1}{N} \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} \hat{F}(u,v) \cdot$$

$$\cdot \exp(\frac{2\pi i}{N}(uj+vk)) \qquad (2)$$

Since the transform kernel is separable and symmetric can the two-dimensional transform be computed as sequential row and column one-dimensional transforms[3] according to

$$\hat{F}_k(u,k) = \frac{1}{\sqrt{N}} \sum_{j=0}^{N-1} F(j,k) \cdot$$

$$\cdot \exp(-\frac{2\pi i}{N} uj) \qquad (3)$$

and

$$F(u,v) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} F_k(u,k) \cdot$$

$$\cdot \exp(-\frac{2\pi i}{N} vk) \qquad (4)$$

The software is optimized such that the transform basis functions (the exponential terms) only have to be computed once. The conjugate symmetric properties of the transform are also used throughout the whole analysis process, all to minimize CPU-time.

B. LINEAMENT ANALYSIS AND FILTERING

The analysis and enhancement process is in general performed according to the following outline:

INPUT	ORIGINAL IMAGE ↓ FFT	FILTER ↓↑
ANALYSIS	FREQUENCY DOMAIN ↓	↓ FFT^{-1}
LINEAMENT-OUTPUT	1.ORIENTATION 2.INTENSITY	3.EXTENSION (ENHANCED IMAGE)

Lineament analysis. The original image is preprocessed by the Hanning truncation function, to reduce the so-called leakage in the frequency domain.[4] The leakage is due to the normally quadratic truncated image, which gives an sin(u)/u · sin(v)/v frequency function. The two-dimensional sinc-function will result in a considerable difference between the discrete and continuous Fourier transform. The preprocessing algorithm follows:

$$\hat{F}'(j,k) = F(j,k)[1/2 -$$

$$-1/2 \cdot \cos\frac{2\pi j}{N-1} \cdot \cos\frac{2\pi k}{N-1}] \qquad (5)$$

After truncation by the Hanning-function the real positive original image is transformed by the FFT-routine, resulting in two new "images", namely the real and imaginary part of the complex frequency domain. These images are converted from rectangular to polar coordinates obtaining an amplitude and a phase image. To obtain the important property of invariance for spatial shifting, which is a characteristic of the amplitude domain, this calculation is necessary. This invariance can be explained as follows:

$$F(j-j_o,\ k-k_o) \Leftrightarrow$$

$$\Leftrightarrow \hat{F}(u,v)\exp(-\frac{2\pi}{N}(j_o+k_o)) \qquad (6)$$

if $F(j,k) \Leftrightarrow \hat{F}(u,v)$

which gives

$$|\hat{F}(u,v)\exp(-\frac{2\pi}{N}(j_o+k_o))| =$$

$$=[\hat{F}^2(u,v)[\cos^2(\frac{2\pi}{N}(j_o+k_o)) +$$

$$+\sin^2(\frac{2\pi}{N}(j_o+k_o))]]^{1/2} =$$

$$= |\hat{F}(u,v)| \qquad (7)$$

In the frequency domain the amplitude image is scanned radially outward from the DC-frequency towards higher frequencies. This is done in sectors with an aperture of 5^o. The distribution of amplitude peaks in the image gives information about the orientation and the relative intensities of the existing lineaments. If the scanning routine detects relatively high amplitude values in one given sector, this indicates the existence of lineaments. The orientations in the spatial domain (original image) of these lineaments are perpendicular to the sector in the frequency domain.

Using this scanning method one usually has to take the inverse scale change property in the frequency domain into consideration. This is necessary only if the digital image has been sampled non-equidistantly in the two different coordinate directions.

Lineament filtering. The intensities of the lineament obtained in the previous analysis step are thereafter used to compute a suitable lineament enhancement filter. The algorithm (8) simply utilizes the mean amplitude values in the different sectors as a control unit measure for the amplification in the sectors.

The filter which is applied to the amplitude image, can be expressed in polar coordinates as follows:

$$|\hat{F}(r,\varphi)|' = |\hat{F}(r,\varphi)| \cdot$$

$$\cdot a(\varphi) \cdot b(r) \qquad (8)$$

where

$a(\varphi)$ - amplification parameter, is dependent on the mean amplitude values in the particular sector; higher attenuation if higher mean amplitude values.

$b(r)$ - "gradient" amplification; higher attenuation if higher frequencies.

The user has a possibility to, in an interactive way, change the degree of amplification. He may also add constraints to the filter, as for instance a suppression of certain specified lineament orientations.

After reconversion to the rectangular coordinate system the inverse FFT-routine is applied to the filtered frequency domain. The new version of the original image obtained from the process will be more easily interpreted in terms of lineaments than the original image.

Throughout the entire process we use as a general assumption the fact that a lineament should have a narrow, long stretched shape. This assumption naturally suites our definition of a lineament.

One of the disadvantages with the present technique is the use of the global operator. There is a possibility that a significant number of local geologically meaningful lineaments are suppressed by the procedure. This risk is to a certain extent eliminated by the possibility to divide the input image into a number of subimages.

VI. THE EASTERN PART OF THE SKELLEFTE FIELD - AN EXAMPLE

A. GEOLOGY AND IMAGE DATA

The analysis and enhancement procedure outlined above have been used to perform a lineament interpretation in an area of size 40 x 30 km. The area is located between the towns Boliden and Skellefteå. The peninsula in this particular district mostly consists of Precambrian, Svecofennian supercrustal rocks, like volcanites and metasediments (phyllites). The bedrock has later on been intruded by granites of different ages and composition.

The general tectonic trend in the area is a WNW-SES strike, with a steep dip to the south. A dominant part of the surface (99 %) is covered by a 1-20 m thick deposit layer of Quaternary till (boulder clay) derived from glacial erosion. The geomorphic structures of the till, like drumlins, have a main trend of a N 40-50° W strike. The topographic relief in the area is rather smooth.

The image used is a subimage from LANDSAT-scene 1039-09331. That is, the image was sampled on August 31, 1972, with a sun elevation of 33°, and a sun azimuth of 161°. We have in this first interpretation only used one spectral band, namely band 6 (0.7 - 0.8 μm). A crude radiometric correction of the image to reduce sixline striping, and a geometric correction including rotation to north and deskewing of the image have been performed.

B. RESULTS

In the original image (Fig. 2) one may notice a general NW orientation in the existing lineaments, but it is not possible in this image to separate the glacial and the geological lineament structures. After application of the analysis and filtering procedure this is however very simple. Fig. 1 shows a simplified presentation of the result from a global analysis applied to the whole image.

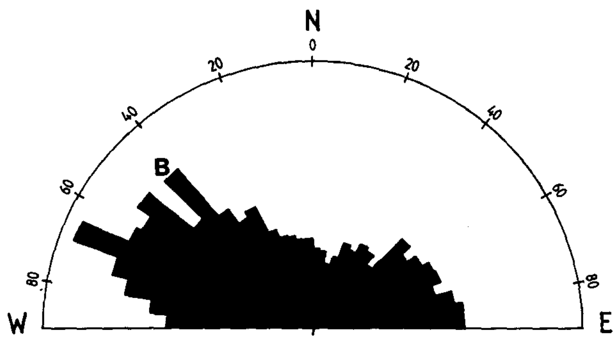

Figure 1. Global analysis results

The rose-diagram clearly presents the earlier discussed general geological lineament direction (A) and the glacial geomorphic feature direction (B). Unfortunately we do not know to what extent six-line striping contributes to trend (A). A guess is that the extra peak-length (C) should be attributed to the striping. The rose-diagram also shows that the low sun elevation does not produce any extra non-meaningful lineaments of importance.

The global filtering procedure was performed to separate the two main lineament structures (A, B). Therefore the degree of attenuation in these particular directions was high, relative to other directions. The result is presented in Fig. 3. The image clearly shows the extension of the different lineaments, and also indicates the differences in lineament "wave-length" between the two main structures. It looks like the geomorphic structures have a thinner texture.

Fig. 4 is an example of a result from a non global analysis, where the original image has been divided into 16 subimages. The five most distinct lineament directions, in each of the different subimages are plotted by a solid line. The main trend of the gravimetric anomaly in the area is plotted by a dashed line for comparison (no dashed line; no data). The quite good correlation between the lineaments and the gravimetric data can be an example of the proposed depth-penetration in lineament analysis. Particularly interesting is the detection of the gravimetric feature marked by arrows, thus there is no indication at all of this structure in the geological map. (Do not mix up the depth-penetration ability of lineament mapping with the penetration of the radiation, which in this case is insignificant).

A further example on this ability in lineament mapping is given in Fig. 5, where the strikes of the metasediments(dashed lines) are detected through the cover of till deposits (solid lines). This 20x15 km big test area is a subimage of the original image (Fig. 2), and covers mainly phyllites.

VII. CONCLUSIONS

The digital lineament analysis technique presented in this paper has the following properties:

- existing lineaments in the image are enhanced in an objective way
- the technique gives an estimate on the relative intensity and the orientation of the lineaments.

We believe that the technique could be further improved using input images that have been preprocessed using the Karhuenen-Loeve transform. Another improvement could be achieved - in particular in decreasing analysis costs - by using Hadamard or Haar transforms and thus significantly reducing computing times.

It is a disadvantage of the present technique that we use a orthogonal transform which compute a great number of redundant data.

IX. ACKNOWLEDGEMENTS

The work reported in this paper is sponsored by the Swedish Board for Technical Development under control no. 76-6669, 77-6345.

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(4) Brigham, E.O.(1974), The Fast Fourier Transform, Prentice-Hall Inc., Engelwood Cliffs N.J.

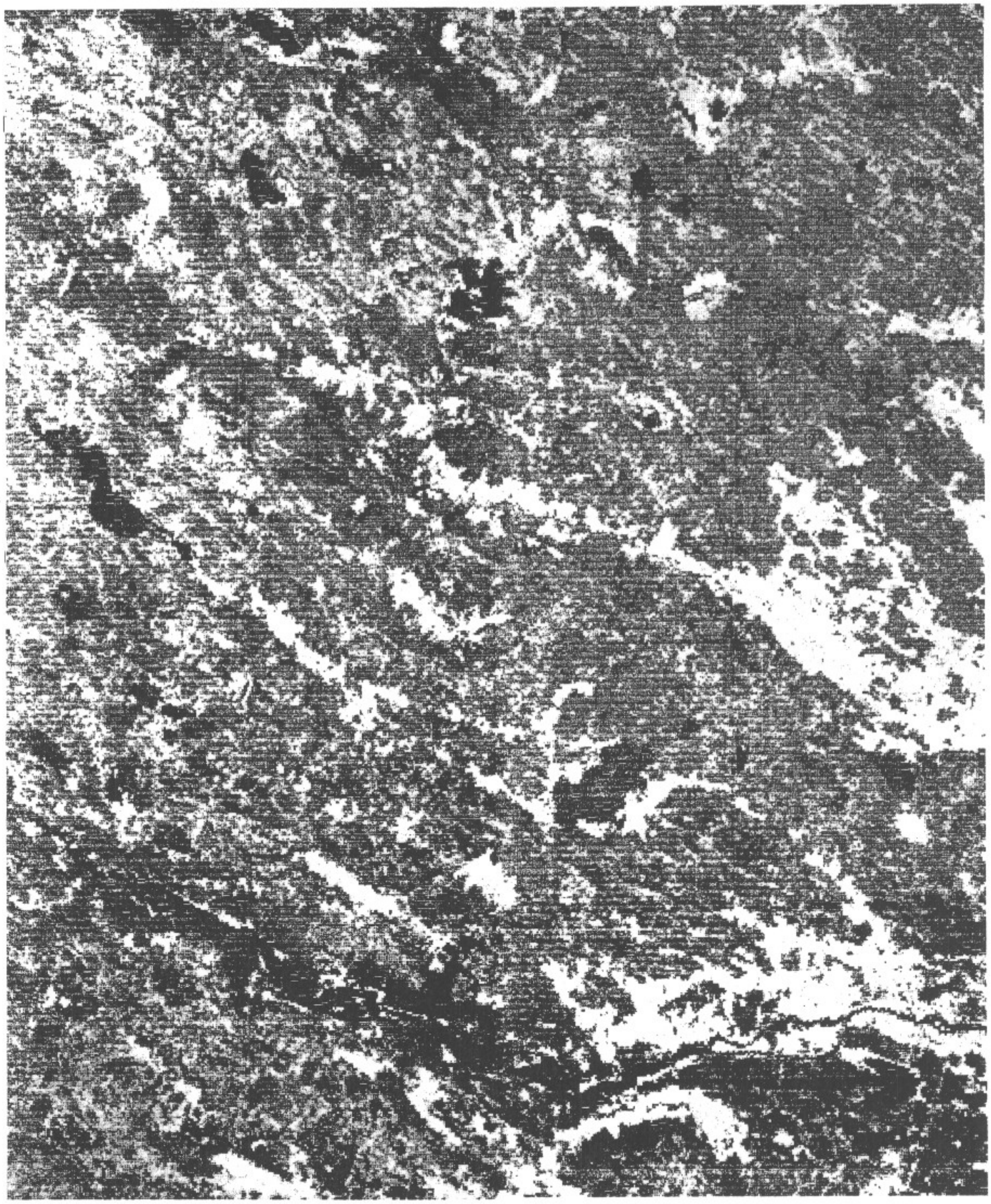

Figure 2. Original subimage from LANDSAT-scene 1039-09331. The image range over the eastern part of the Skellefte ore-mining province. The Skellefte river is crossing the image in its lower parts.

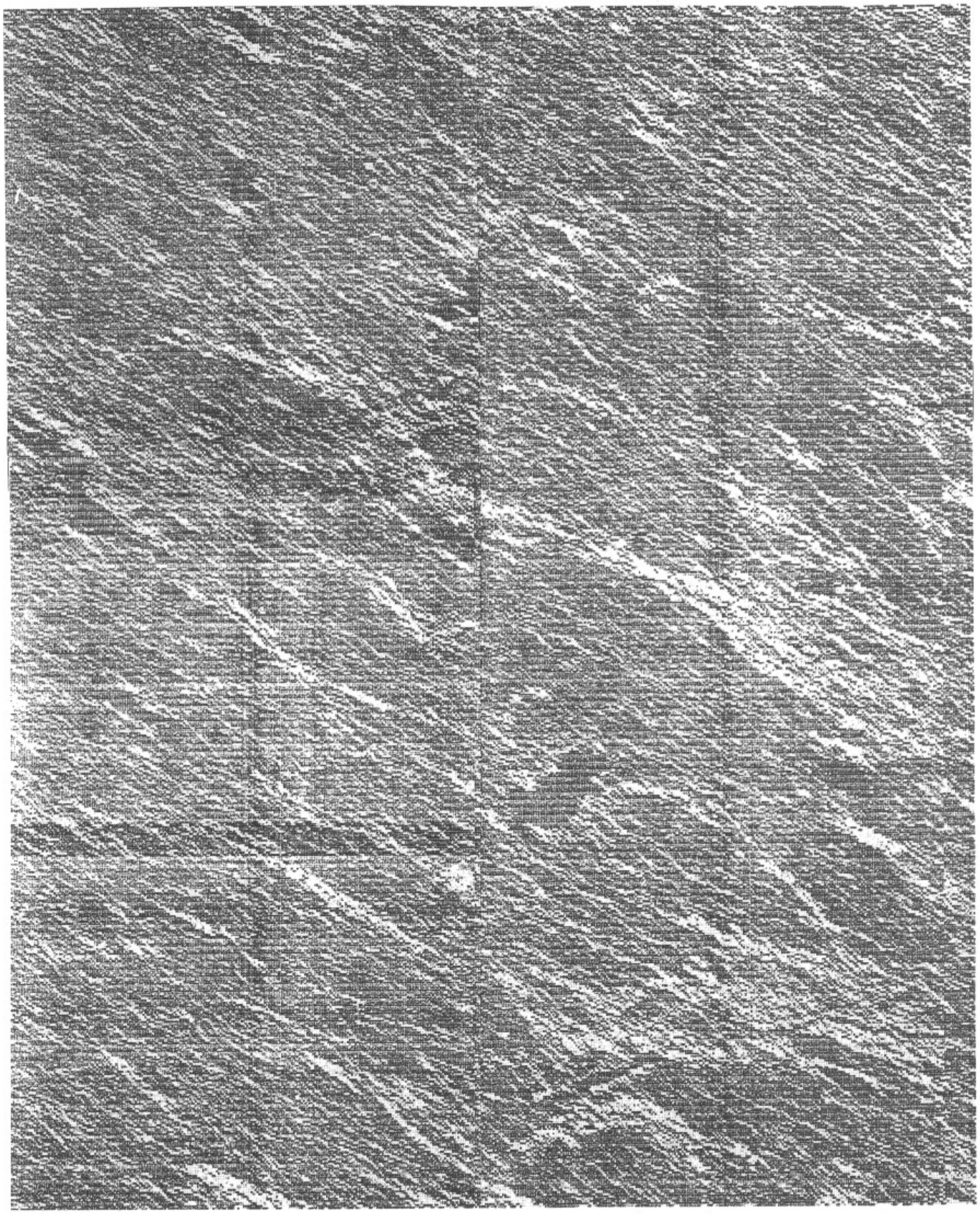

Figure 3. Lineament enhanced image. The original image (Fig. 2) has been strongly enhanced in mainly two directions according to the global analysis (Fig. 1).

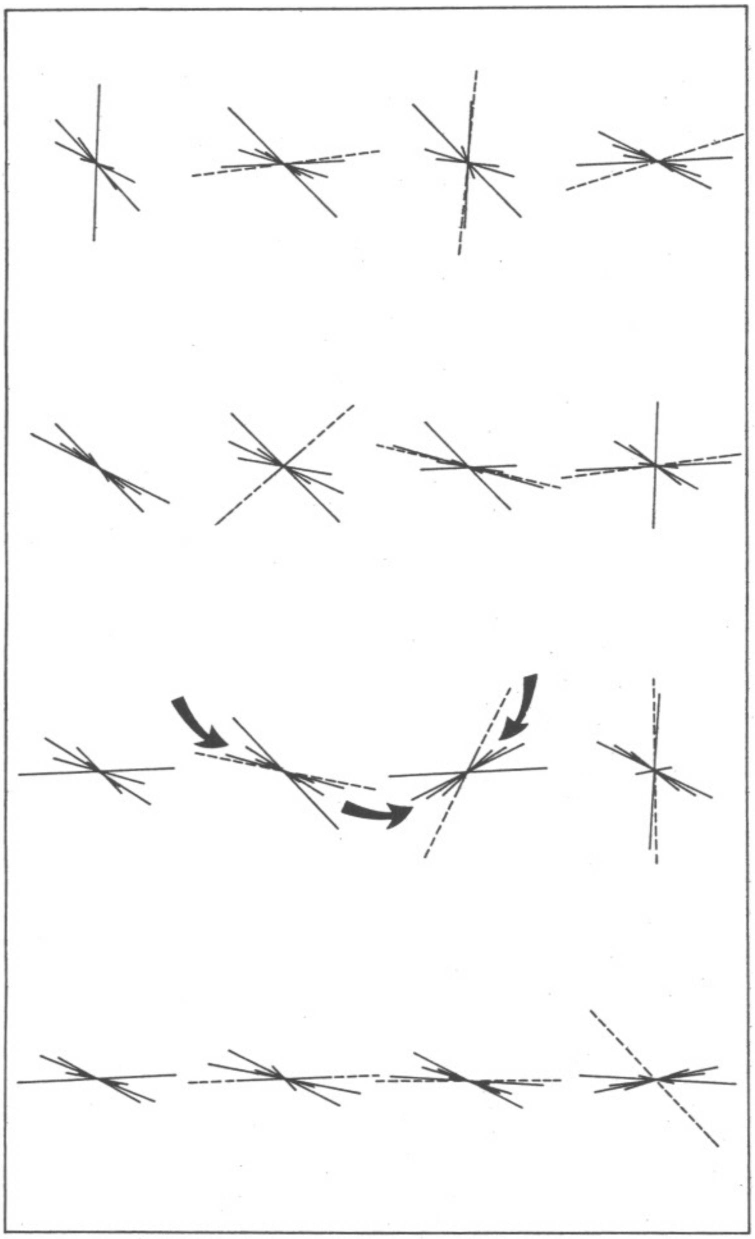

Figure 4. Lineament analysis results. The solid lines are the result from a non-global analysis, of the original image (Fig. 2), and compared to the main trend of the gravimetric anomaly (dashed lines).

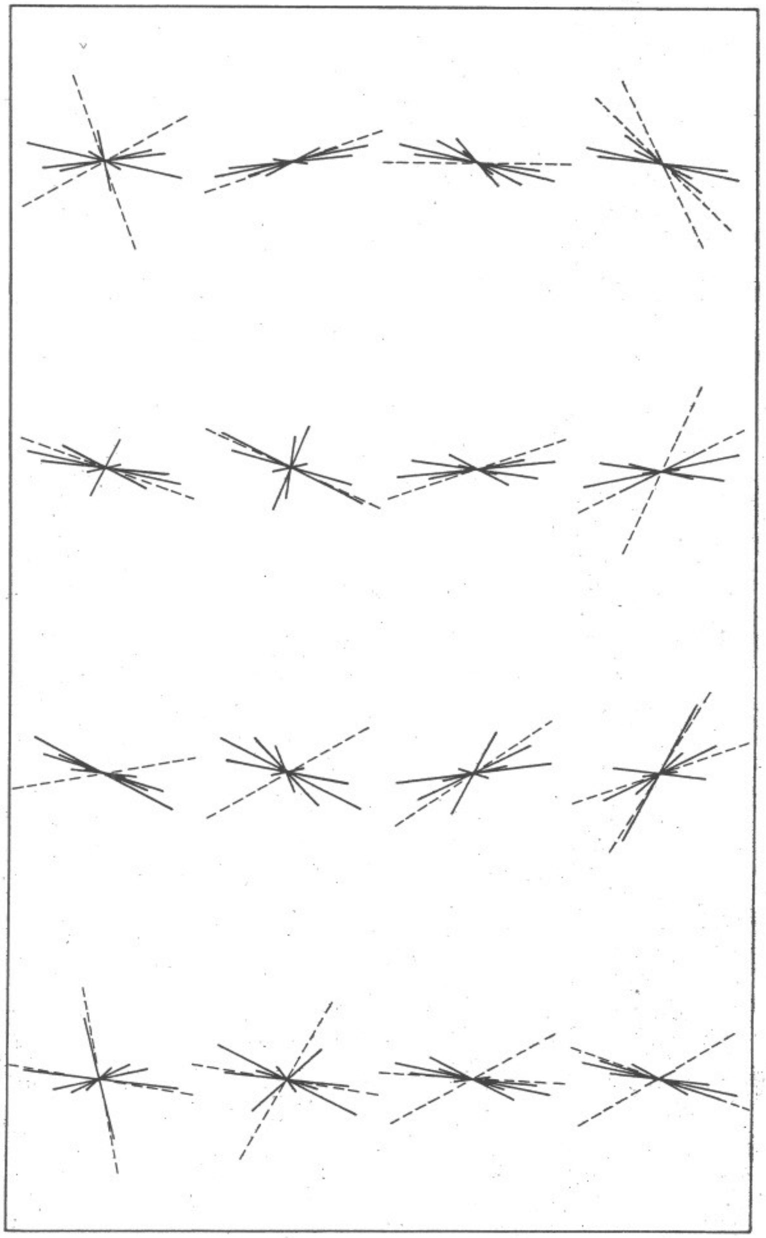

Figure 5. Lineament analysis results compared to the strikes of metasediments. The image is a sub-image of the original image (Fig. 2).

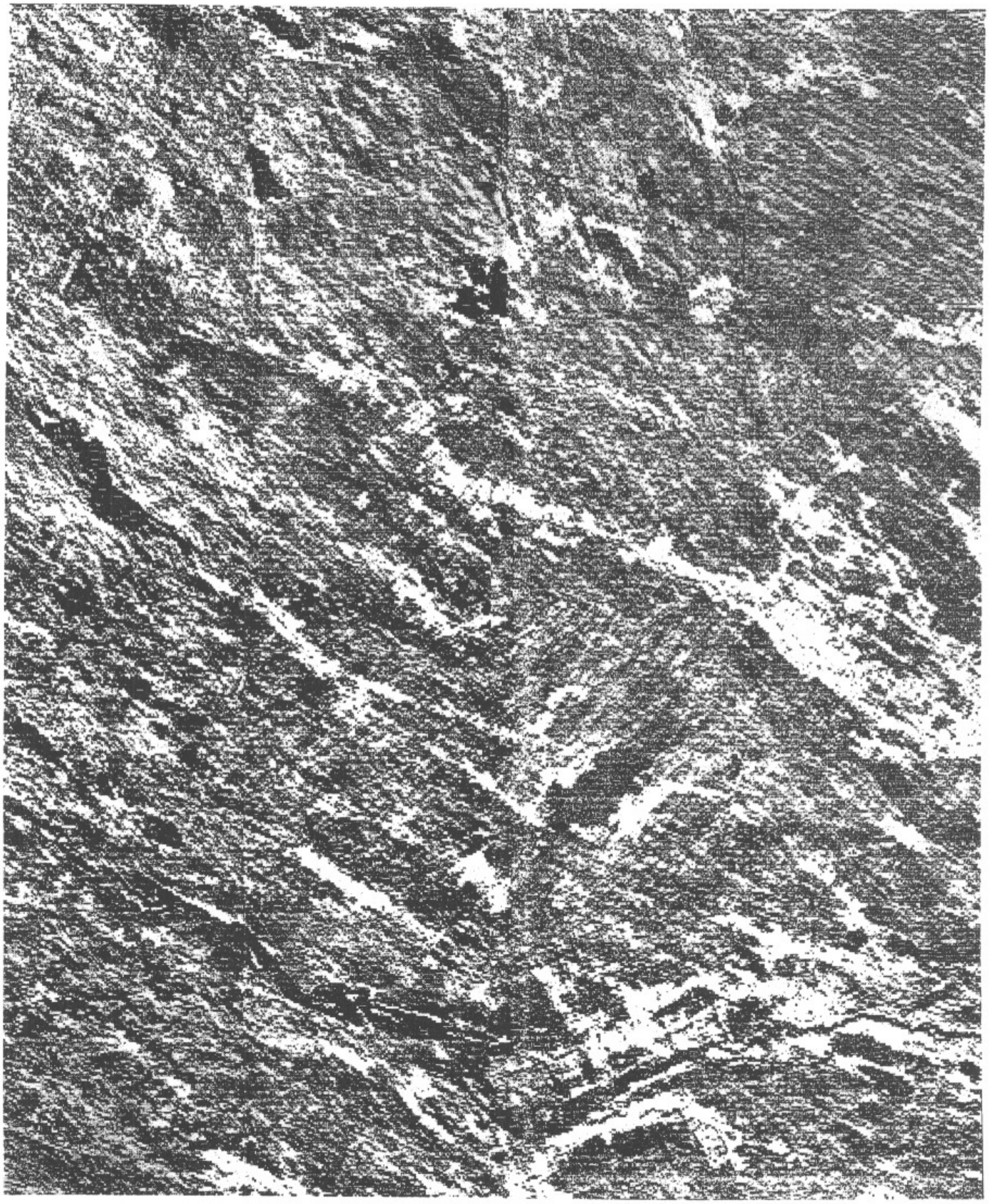

Figure 6. Lineament enhanced image. A non-global filtering process according to the analysis results in Fig. 4 has been performed.

L. Christer Andersson: MS in mining engineering (applied geophysics) 1979 from University of Luleå. He is presently employed as Research Engineer at the Department of Geophysics, University of Luleå, Sweden.
He is a member of the Nordic Association for Applied Geophysics and the Swedish Society for Automated Image Processing.

Hans Hauska: BS (equivalent) in Physics 1966 from Humboldt-University, Berlin. Fil. lic. in Cosmic Ray Physics 1969 from Uppsala University, Sweden and Fil. dr. from Uppsala University in 1972. Junior lecturer in physics at University of Luleå since 1972. He was a Post-doctoral Research Fellow of the European Space Agency at the Laboratory for Applications of Remote Sensing, 1974-1976. He is presently employed as Senior Research Engineer at the Dept. of Physics, University of Luleå.
He is a member of ASP and the Swedish Society for Automated Image Processing.