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Automatic fracture analysis from digital elevation models

Report of specialization project
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Contents

1 Abstract

In this report, the concept of lines and their extraction methods (manual and automatic) are defined in general and I compared their advantages and disadvantages. One of the features that can help in the automatic extraction of lines is the magnetic properties of materials. To understand this issue, different types of magnetic materials have been investigated and 12 Norwegian soil samples have been measured in the VSM laboratory. The size of the grains in the materials has an effect on their magnetic properties, which is also reported by presenting hysteresis loop diagrams.

2 Introduction

2.1 Lineament extraction

Many geological forms, such as fault plane scratches, two plate interfaces, elongated minerals and sands, cast flutes, and fold hinges can be considered as lines. Linear structures related to the deformation of rocks are called lineaments. The analysis of lineaments is the basis of structural and tectonic studies of a region. The use of remote sensing methods to identify and extract contours is one of the effective factors in choosing this method due to its wide coverage and investigation of inaccessible areas and saving time and money. In fact, the mapping of geological contours is considered a very important issue for solving problems in various fields, especially mineral exploration, because structural contours are among the effective and controlling factors of mineralization and can be used to identify channels of penetration and placement of magmatic fluids containing valuable elements or hydrocarbon traps. Also, these lineaments can cause water penetration into the depths of the earth and lead to the formation of all kinds of changes.

Visual analysis of the lines and matching them with the geophysical data of the work area is very common and effective to a large extent, but it is highly dependent on the experience and geological knowledge of the interpreter, and the interpretations of different people can have significant differences. It is better to use automatic methods to increase the speed and quality of the process of identifying and extracting lines. To find these automatic algorithms, we need geophysical data from the magnetic potential field or gravity field

2.2 Magnetic Materials

The orbital and spin motions of electrons as well as their interactions with one another are the source of magnetism. Describe how materials react to magnetic fields to give a better understanding of the various types of magnetism. Simply said, some materials have significantly stronger magnetic properties than others. The major difference is that whereas in some materials there is a very strong connection between atomic moments, in other materials there is no collective interaction of atomic magnetic moments. The following five categories can be used to categorize the magnetic behavior of materials:

- Diamagnetism
- Paramagnetism
- Ferromagnetism
- Antiferromagnetism
- Ferrimagnetism

Materials in the first two groups don't have magnetic ordering and don't show any collective magnetic interactions. Below a specific threshold temperature, the materials in the latter three groups display long-range magnetic order. Typically, we define magnetic materials as ferrimagnetic and ferromagnetic ones (ie., behaving like iron). The final three are typically regarded as "nonmagnetic" because of how weakly magnetic they are. [3]

Diamagnetic materials are composed of atoms that have no net magnetic moment and only develop negative magnetism if placed in a magnetic field. If we plot M vs H we can see that the magnetization is zero when the field is zero 1. The susceptibility of diamagnetic materials is also characterized by temperature independence. In paramagnetic materials, however, some atoms show a net magnetic moment due to the unpairing of electrons in half-filled orbitals. The most important element of this group is iron. These materials generate positive magnetism when exposed to a magnetic field, but like the diamagnetic group, their magnetization becomes zero when the magnetic field is removed. The M vs H diagram has shown in figure 2 [3]

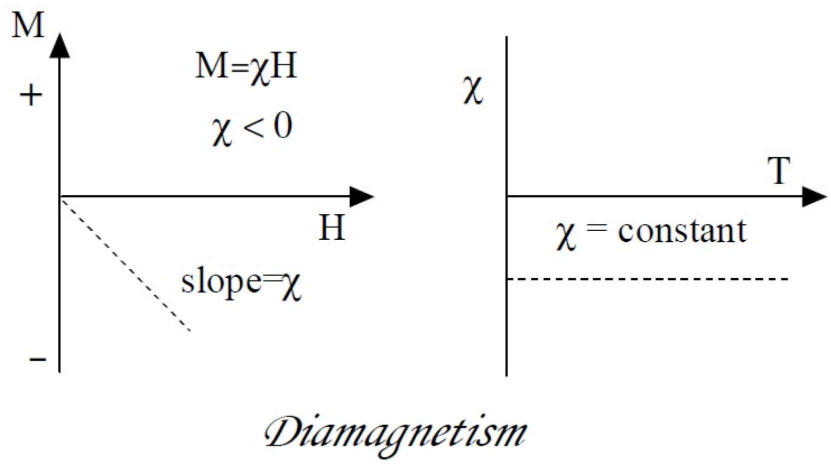

Figure 1: Parameter M represents magnetization and H represents Magnetic field

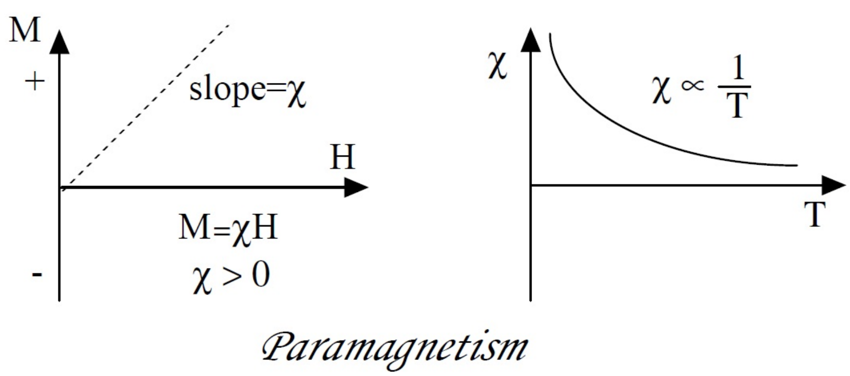

Figure 2: Parameter M represents magnetization and H represents Magnetic field

In contrast to paramagnetic materials, ferromagnetic materials' atomic moments show extremely potent interactions. These interactions, which are brought about by electronic exchange forces, cause the atomic moments to align either parallel or antiparallel (figure 3). Exchange forces are enormous, 100 million times stronger than the earth's magnetic field, or comparable to a field on the order of 1000 Tesla. Even in the absence of a magnetic field, ferromagnetic materials have parallel moment alignment that results in significant net magnetization. Ferromagnetic materials exhibit spontaneous magnetization and have a magnetic ordering temperature, which is two separate properties. [3]

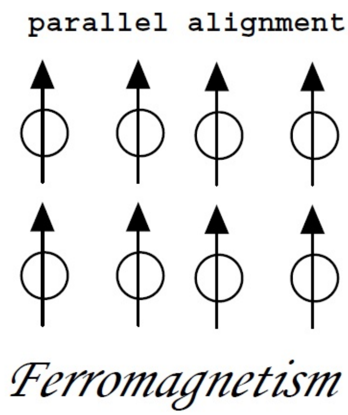

Figure 3: Caption

The crystal structure of ionic compounds, such as oxides, can lead to the occurrence of more intricate types of magnetic ordering. Ferrimagnetism is one sort of magnetic ordering. Here in figure 4 is a straightforward illustration of the magnetic spins in a ferrimagnetic oxide. One well-known ferrimagnetic substance is magnetite. In fact, until Néel in the 1940s, when he supplied the theoretical foundation for comprehending ferrimagnetism, magnetite was thought to be a ferromagnet. [3]

Additionally, antiferromagnetic materials have no hysteresis or remanences, only a modest positive susceptibility that changes oddly with temperature. The behavior of susceptibility at a threshold temperature, known as the Néel temperature, provides a hint of antiferromagnetism (TN). With a negative intercept, which denotes negative exchange interactions, the susceptibility for paramagnets obeys the Curie-Weiss equation above the transition region. (figure 5 [3]

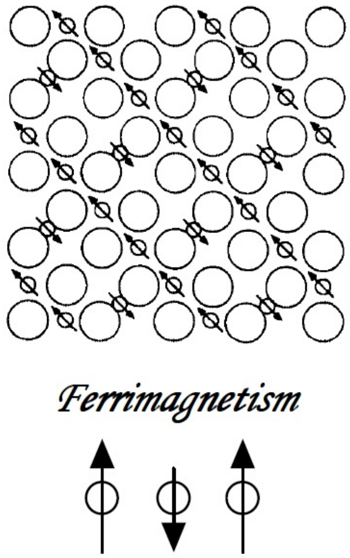

Figure 4: Caption

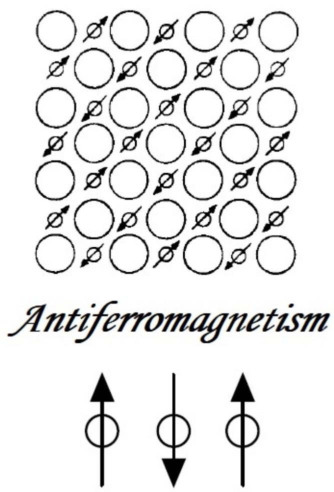

Figure 5: Caption

2.2.1 Hysteresis loop

[h!] Once a field has been applied and removed, ferromagnets can still remember it. A graph of the variation in magnetization with a magnetic field is known as a hysteresis loop, and this characteristic is referred to as hysteresis. In a lab setting, a magnetic field of 1-2 Tesla is used to evaluate the saturation magnetization (Ms). Most magnetic minerals can generally be saturated at this field strength. The magnetization does not disappear when the field is zero but instead endures as a saturation remanence (Mr). The generated magnetization eventually drops to zero as the negative field strength increases. Coercivity is the field at this point (Hc). Saturation once more occurs when the field is increased in the negative direction, but this time it happens in the opposite way.[3]

The coercivity of remanence (Hr) is another hysteresis characteristic. This reverse field reduces the saturation remanence to zero when it is applied and subsequently withdrawn. It always exceeds coercive force in size. The various hysteresis parameters rely on the temperature, stresses, grain size, domain state, and other factors in addition to their inherent features. Hysteresis characteristics can be used to size the magnetic grains in natural samples because they rely on grain size. see figure 6 [3]

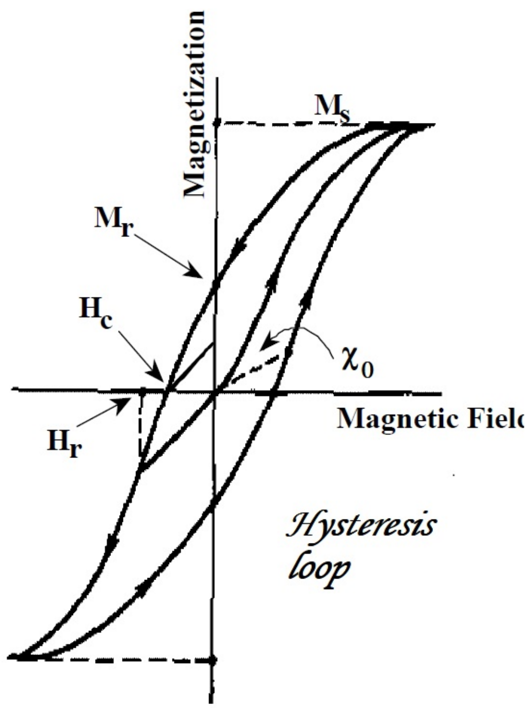

Figure 6: Chematic of a hysteresis loop

3 Theory

3.1 Discussion of article [1] about manual extraction of bedrock lineaments from high-resolution LiDAR data

In this article published by Thomas Scheiber, three factors (Scale, Illumination Azimuth, and operator) that can affect output parameters have been investigated. For this purpose, an ArcGIS file geodatabase has been given to 6 operators with different backgrounds and they have been requested to aim at mapping fractures lineaments in the whole image by drawing just straight lines. Three hill-shaded images illuminated from Three different azimuths (45, 180, and 315) and mapped in three different scales (1:20000, 1:10000, and 1:5000) were chosen from a 5*5 Km area within Rolvsnes granodiorite covering the island of Goddo. As you can see in Figure 11, the density of lineaments in this area is high, and this could be one of the reasons why Scheiber chose this area for investigation. The high density of the lines can cause more differences in the interpretations of the operators, and as a result, it is easier to study the influencing factors in the interpretation of individuals.

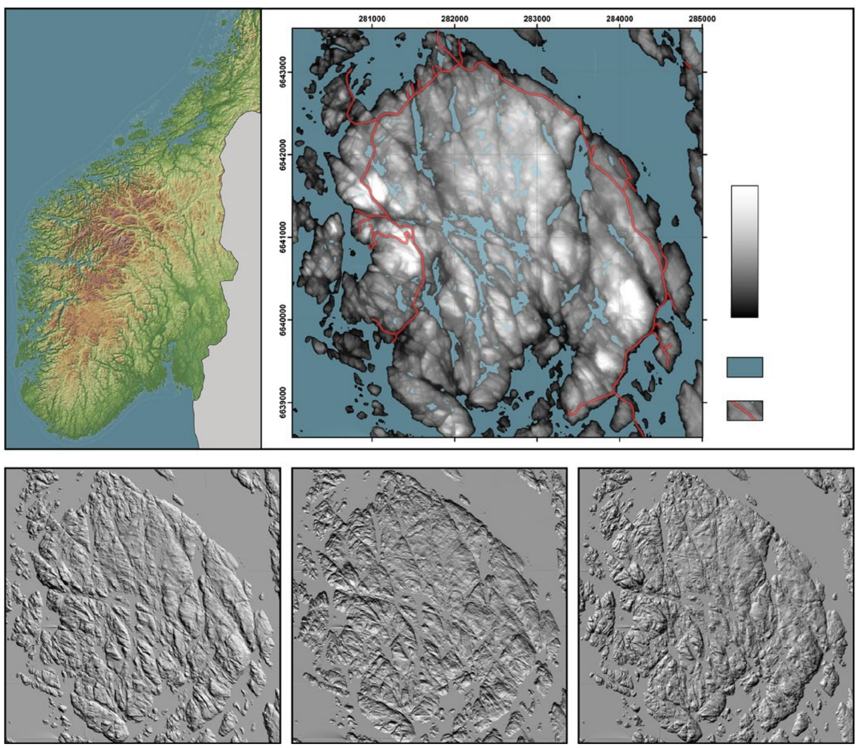

Figure 7: (A) Relief map of mid- and southern Norway. Star indicates the location of the study area. (B) LiDAR DEM of the Goddo island. (C–E) Hillshaded DEMs highlighting fracture patterns on Goddo island. Different illumination azimuth angles are indicated by white arrows. The solar elevation is 045° for all hillshade images.

A total of 54 datasets have been extracted by 6 operators and presented with rose diagrams that are sensitive to the choice of bin width and starting point. Rose diagrams produced by MARD application. One limitation of the moving average method by calculating a mean value (as implemented in MARD) is that it may potentially be influenced by outliers, i.e. spurious maxima.[4] To draw multiple rose diagrams that are drawn for the purpose of comparison, it is better to use the same parameters in each one.

According to the number of lineament maps drawn by the operators, a general conclusion can be drawn that in larger scales where more lineaments can be recognized, more maps can be drawn. Also, the number of maps can vary with each illumination.

In the general conclusion, it can be seen that all three parameters are effective in drawing lineament maps. It can be seen that the orientations of the peaks overlap in all three scales, but they can be different at lower heights. According to figure 8, it can be concluded that the maximum height is lower in larger scales and subsequently the diversity of orientation is also greater in larger scales. Also, the results of the operators are more similar on larger scales and the effect of illumination is less.

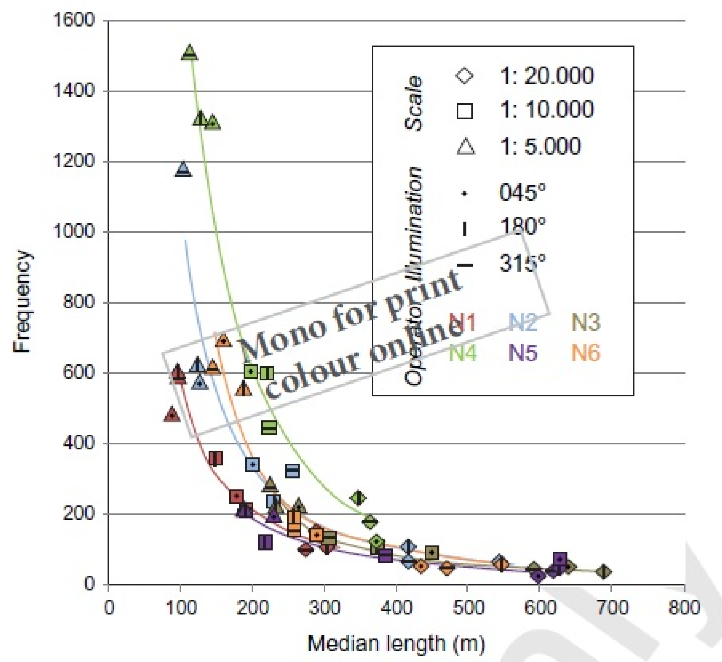

Figure 8: All data sets' median lineament length versus frequency graphic. Each operator's power trend lines show the scale dependency. [1]

In smaller scales where the effect of illumination is greater, it is possible to clearly see the difference in mapping in different azimuths. At larger scales, the data sets become more similar.

Due to the different shapes in several rose diagrams, we can see the great influence of the operator, especially on smaller scales, in the extracted maps. This is the most important reason for needing an automatic system for drawing lineament maps.

Another thing that can be discussed is the length of the output parameters, which has an inverse relationship with the number of drawn lines. As a result, the larger the scale and the number of lines, the shorter their length. The length of the lines also changes with the direction of illumination, but no systematic relationship between them has been observed.

As expected, the number of lines and their length in the maps drawn by each operator is different and depends on the perspective and method of each one.

3.2 Discussion of article [2] about Aeromagnetic mapping of deep-weathered fracture zones

This article examines the problems and obstacles of tunneling and railway construction in the regions of greater Oslo Fjord and the railway tunnel through Lieråsen. These obstacles, which are due to geological infrastructure, in addition to creating a weakness in safety, involve high costs for manufacturing companies. The cause of these obstacles in the railway tunnel between Asker and Drammen was the change of the clay and the linear weakness zones, which caused the mountain to fall and peel off. Also, in the region of Oslo Fjord, the draining of the groundwater level and the settlement of marine clay above the tunnel caused great financial losses to the residents of the region.

In order to investigate the geology of the region, some geological views presented by scientists such as Lidmar-Bergström (1989, 1995), Riis (1996), Reusch (1902,1903a), and Holtedahl (1953) were examined. Lidmar Bergström believed that the Clay minerals such as kaolinite and smectite, which were formed as a result of chemical weathering in tropical conditions in the early Jurassic and Cretaceous, are the weak point of the region in this sub-Cretaceous etch-surface. Reusch defined his hypothesis with the name 'superimposed valleys' based on the fact that the river Numedalslågen was able to erode through the high Skrim mountains because of its clear path in the soft sediments that are on the crystalline rocks. Holtedahl disagreed with the theory of Reusch and believed that the valleys were created in the Oslo Fjord region along the regional fractures. Of course, these fractures have not been found in the Aeromagnetic maps.

Odleiv Olesen and his colleagues presented a solution to a more detailed study of the region's geology. For this purpose, a total of 7 Aeromagnetic maps from the northern and southwestern areas have been used as data in this study. In this study, the filtering technique was used to enhance the signal of the area. The signal taken due to the signal-to-noise ratio is used to categorize the weathering into two "probable" or "possible" categories. The anomalies with a range of amplitude of -5m and less are in the "probable" category and the anomalies with a range of amplitude between -5m and -2m are placed in the "possible" category. Magnetic field modeling is done using IGMAS interactive forward modeling software. The magnetic susceptibility of the fresh and weathered bedrock is compared to investigate the effect of tropical weathering on magnetism.

4 Methods

4.1 Manual lineament interpretation

In general, the basis of visual interpretation is tonal contrast or texture pattern, which are related to geomorphological features. Lineament studies (M.F.Ramli, N.Yusof, M.K.Yusoff, H.Juahir, H.Z.M.Shafri) show that most researchers in visual interpretation use standard methods such as filtering and enhancement for image processing. Techniques used by interpreters include using false color, principal component analysis in RGB, combining satellite bands and principal component bands, or using separate bands. Other techniques that have been used so far include: combining satellite images superimposed on a digital elevation model (DEM). Fusion of low-resolution multispectral images with their corresponding high-resolution pan images using DEM.[5]

Choosing between a color image in an RGB environment and a grayscale image is primarily a matter of personal preference, however, research has shown that the human eye responds more frequently to a grayscale environment than to a color environment. As a result, interpretations of structural studies that have a high spatial frequency are easier and more accurate in the grayscale environment. Another technique that can be used to increase image resolution is to combine low-resolution multispectral images with high-resolution pan images. Also, the use of DEM can improve the quality of interpretation by increasing the power of understanding three improbable linear images. Another important advantage of DEM is the ability to simulate illumination from a point source at a certain height and azimuth, which can produce hillshade images that are useful for detecting vegetation or any suspicious lines. However, the use of hillshade maps should be done with great accuracy, because shadows can create fake lines.[5]

On the other hand, most researchers do not want to use filtering and prefer to keep the images in their normal condition. Using a directional filter can produce artifacts that are sometimes indistinguishable from true linear trends. [5]

The main problem of visual interpretation is the significant influence of subjectivity on the result. In this method, the results cannot be reproduced and the criteria cannot be expressed quantitatively, because they are usually sensory impressions and depend on the interpreter. For this purpose, the researchers suggest that the interpretation of linear maps of the same place be done by several interpreters, or one person interprets at least twice with a time interval of one week or more, and finally, the results are compared.[5]

4.1.1 LiDAR

Light Detection And Ranging Images data sets with spatial high resolution and also the capability of scanning even through vegetation made a considerable revolution in Digital Elevation Modelling. LiDAR is quick, cost-effective, and powerful. however, it has some biases such as 1)Scale: At the larger scale, both the number and orientation variability of picked lineaments increase, whereas the line length generally decreases. 2) Illumination azimuth: Linear features perpendicular to the illumination source are preferentially enhanced. and 3) Operator: inter-operator result reproducibility is generally poor.

A DEM from LiDAR data commonly shows the earth's surface in great detail and the ground resolution often approaches or even surpasses 1m

Relief shading is the most common method to visualize landforms from DEM. generally with a source of illumination in the northwest

Lineament perceivable in DEM: any possible discontinuity like

- Natural geographic features
- Bedrock structures such as faults and fractures
- Quaternary deposits
- Animal path
- Road, Power lines, Railways and etc

Extract lineament information:

- GIS: higher lineament density and more uniform distribution of orientation
- Manual interpretation by human Spatial assessment but poor quality

Manual lineament mapping:

- Results are different with different operators
- Relation between the feature size to the spatial resolution
- the angle between the feature orientation and illumination direction
- the tonal and textural information influence the results of remote sensing analyses

Since photographs and high-quality satellite images became available, Remote sensing technologies have been developed tools to identify and cover a wide range of geological and geomorphological features, that we can not survey by foot. Afterward, LiDAR data sets with the capability of scanning even through vegetation covers made big progress in the production of DEM models. A DEM using LiDAR data can identify the earth's surface details with even over 1 m resolution. Any possible discontinuity can be represented by lineament perceivable in DEM.

In addition to GIS software, reading and interpreting GeoTIFF data is also possible in Python. Figure 9 plot shows this data in three different blurs. One of the advantages of interpreting this data in Python is that it is possible to specify a smaller range than the entire range to examine. For example, in the mentioned picture, the box (9, 59.2), (9.1, 59.15) is taken from the entire plot area.

4.2 Automatic lineament extraction

In the automatic identification of lineaments, computer algorithms are used, whose performance is based on techniques(such as Hough and Haar transforms) that identify pixels in a gray environment that suddenly changes by filtering or improving the edges of adjacent.

The main problem of automatic extraction of lineaments is that in some situations, many fake lines are produced, which must be removed using complex edge-linking algorithms. In addition, low-contrast mountain environments produce dense short lines that are difficult to relate to important tectonic structures. To overcome these problems, the STA technique is used. The principle of STA is to detect a line of pixels as a vector element by examining the local variance of the gray level in the digital image and connecting the preserved line elements along their expected directions. The combination of the STA technique with the Hough transform is called START, which was first used by Raghavan et al. (1995) [5]

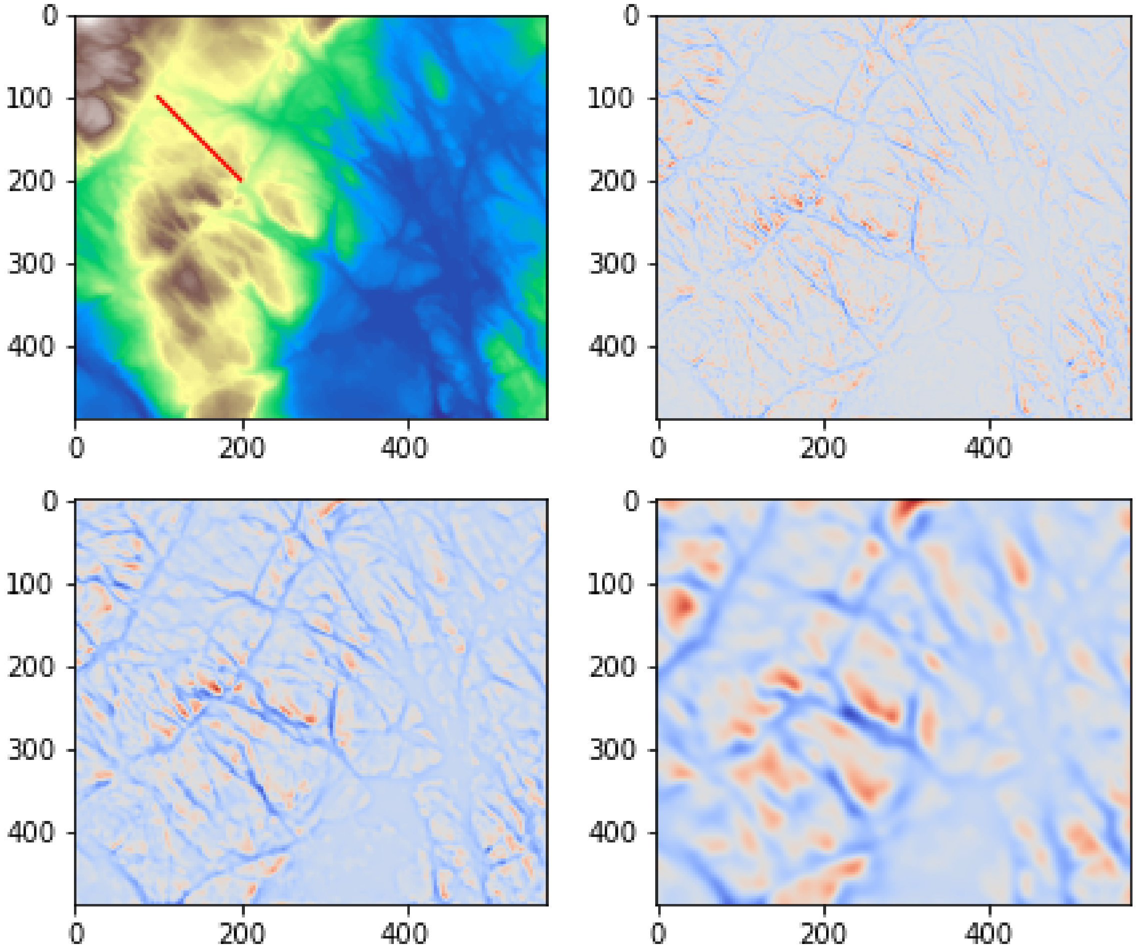

Figure 9: This plot has been given from Geotiff data in Python programming

To optimize linear extraction, it is important to understand the parameter settings in automated extraction. Sarp (2005) compared the accuracy achieved by manual and automated lineament extraction and found that the reliability of automated extraction in identifying errors was much lower than manual interpretation. The only software currently capable of automatically extracting lineaments is PCL Geomatica, which is the reason for the popularity of this software.[5]

4.3 Method of magnetic hysteresis measurements

The hysteresis loop of magnetic materials is the best option to describe their characteristics. One of the setup methods to determine the hysteresis loop at ambient temperature is the vibrating sample magnetometer (VSM). The magnetic characteristics of materials are measured using vibrating sample magnetometer (VSM) systems as a function of the magnetic field, temperature, and time.

They are perfect for quality and process control, production testing, and research and development. A VSM can easily accommodate powders, solids, liquids, single crystals, and thin films. With the help of data acquisition, control, and analysis software that runs on a personal computer, modern commercial VSMs operate nearly automatically, making them usable by non-specialists. This has significantly expanded the measurement technique's usefulness in a wide range of measurement applications. [6]

A magnetic moment m will be induced in a material if it is exposed to a constant magnetic field H. In a VSM, a sample is positioned inside appropriately positioned sensor coils and subjected to sinusoidal motion, or mechanical vibration. Due to the consequent variations in magnetic flux, the sensing coils experience a voltage that is proportional to the magnetic moment of the sample.[6]

The hysteresis loop provides the relationship between the magnetization M and the applied field H in the case of a standard recording medium. Figure 1 shows a schematic representation of a magnetic recording medium's hysteresis loop.[6]

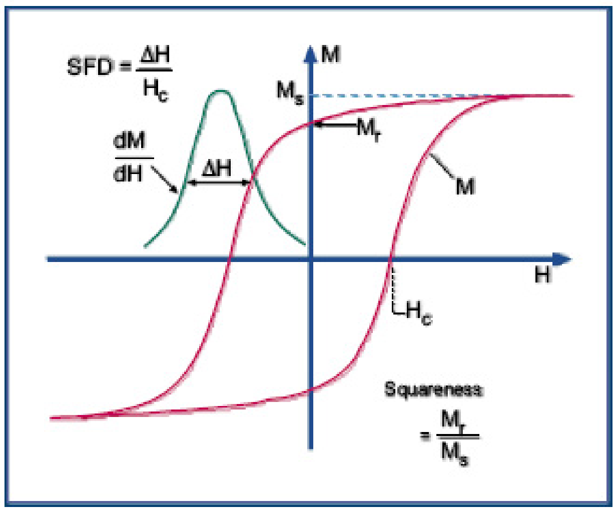

Figure 10: The saturation magnetization Ms, remanence Mr, coercivity Hc, squareness ratio SQR, S*, which is related to the slope at Hc, and switching field distribution SFD are the parameters retrieved from the hysteresis loop that are most frequently employed to describe the magnetic properties of magnetic media. Figure 1's loop depicts the behavior for the simple axis of magnetization (i.e., in the anisotropy direction). The magnetization of the rectangular-shaped loop shows irreversible changes.

[6]

4.3.1 Magnetic Measurments

In this experiment, I measured the instantaneous magnetism of 12 samples of Norwegian soil with a VSM device. For this purpose, the mass of the samples was measured and I put them in a saturated state. To use a vibrating sample magnetometer device, we must first place the sample in a constant magnetic field. If the material in question is magnetic, it becomes magnetized when it is placed in

Figure 11: vibrating sample magnetometer

a constant field. The magnitude of the magnetic field used in this experiment was set to 1 Tesla once and 300 milliTesla the second time.

As the sample vibrates, pick-up coils look for variations in the magnetic stray field. The magnetic stray field is a magnetic field that develops surrounding the sample as a result of the sample's magnetic dipole moment. According to Faraday's Law, the variations in the magnetic stray field will cause an electric current to flow through the pick-up coils. The fluctuating magnetic field's impact on the electric current will be amplified by amplifiers. Then, a computer system is linked to these amplifiers. The computer system is equipped with software that can evaluate the sample's degree of magnetization as well as the extent to which the sample's magnetization was influenced by the strength of the constant magnetic field.

You can see the results obtained from the samples in the appendix. In the field of 300 millitesla, the graphs are shown considering the hysteresis loop.

5 Results and Discussion

5.1 Uses of lineament mapping

Geologists have been interested in linear features on the surface of the Earth for a long time. Since the advent of satellite and aerial photography, this interest has increased most quickly in geological investigations. Several geologists recognized the existence and significance of linear geomorphic features from the beginning to the middle of the 20th century. These features were the surface expression of weak zones or structural displacement in the Earth's crust.[7]

According to studies, lineaments and groundwater flow and yield are closely related. Lineaments typically have zones of localized weathering, enhanced permeability, and porosity beneath them. Instead of focusing on the lineament itself, several researchers investigated associations between groundwater production and the number of lineaments within a certain area or lineament density (Hardcastle, 1995). Groundwater surveys, development, and management, therefore depend on the mapping of lineaments that are strongly related to groundwater yield and occurrence. In the last two decades, several types of thematic layers have been prepared using remote sensing and GIS, and their integration for various uses has become commonplace.[7]

5.1.1 Manual versus automatic mapping

Any visual interpretative technique, including lineament mapping, is subjective, therefore the outcome could be debatable. The results can't be replicated to a great extent since different analysts can't agree on the identification criteria, which are typically impossible to articulate in quantitative terms and instead depend on sensory perceptions (Wladis 1999). The identification of the lineament itself, whether it is a lineament or not, and how far the lineament goes all entail subjectivity. Particularly in densely forested or expansive valley environments, it may be challenging to locate the lineament satisfactorily (Gustafsson 1994).

Manual mapping of lineaments requires high skill and experience of the interpreter and its reproducibility is limited. However, the ability to correct errors and distinguish geological lines from non-geological lines such as roads and canals is more than the automatic method. On the other hand, the speed of line extraction is higher in the automatic method. By completing the automated process in a familiar environment and common software for the user, the popularity of this method can be increased. In addition, general software does not need to change the data format, which helps to speed up the processing of images. The difference between the two methods are given in table 1

Table 1: comparison between visual and automatic lineaments extraction
[5]

Visual	Automatic
Depends on the quality of the images and performance	Depends only on the quality of the image
Partly depends on the complexity of the research area	Totaly depends on the complexity of the research area
Strongly depends on human experience and ability	completely depends on mathematical functions
takes a lot of time	very quickly
Strong effect on human subjectiveness	little effect on human subjectiveness
Capable of distinguishing types of lineaments (Geological or Man-made)	Can not recognize the types of lineaments
Simple but Subjective	Complex but Objective
Operator can learn	Training of algorithms
Non-uniform approach to different images	uniform approach to different images

5.2 Magnetic hysteresis data of Norwegian soil samples

Sample size and grain shape are related to magnetic characteristics. The samples with a regular morphology have a big size, a nearly flawless crystal structure, and strong magnetic characteristics. The samples have an uneven shape, relatively low crystallinity, and more nonmagnetic phases on the surface, which leads to a drop in magnetic characteristics because there wasn't enough reaction time.

The curves of the figures 12 and 13 and 14 show the changes in the magnetic properties of the material based on the size of the grains at a constant temperature and a constant magnetic field with a magnitude of 300 mT.

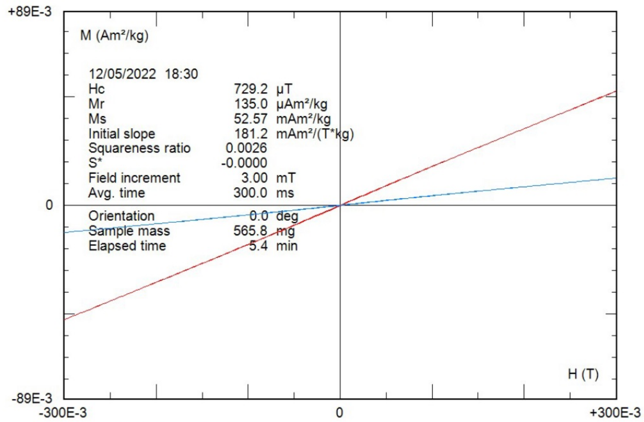

Figure 12: Comparison between big and small grain size of a soil sample. the blue curve represents a smaller grain size and the red curve represents a bigger grain size

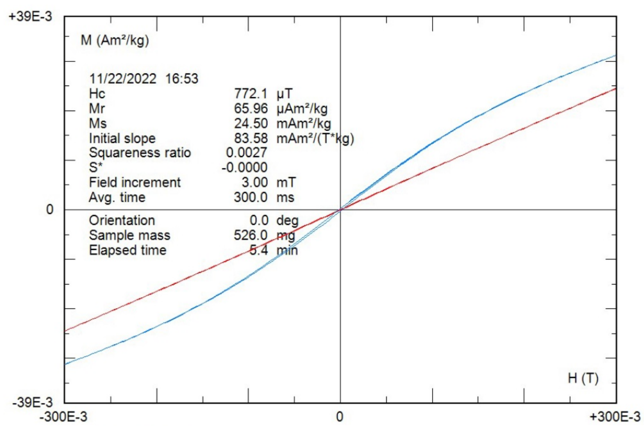

Figure 13: Comparison between big and small grain size of a soil sample. the blue curve represents a smaller grain size and the red curve represents a bigger grain size

6 Conclusion

Lineaments, fractures, faults, and generally weak areas in an area can give us useful information about the topographical position of the area. Also, by examining the lines based on their orientation or geometric features, it is possible to categorize the line sets of the region. There are various methods, both in manual and automatic extraction of lines, which should be chosen according to the application and purpose of extraction and considering the positive and negative points of each technique. Automatic extraction of lines is more used in laboratory research for issues such as earthquake probability than manual extraction which is more reliable.

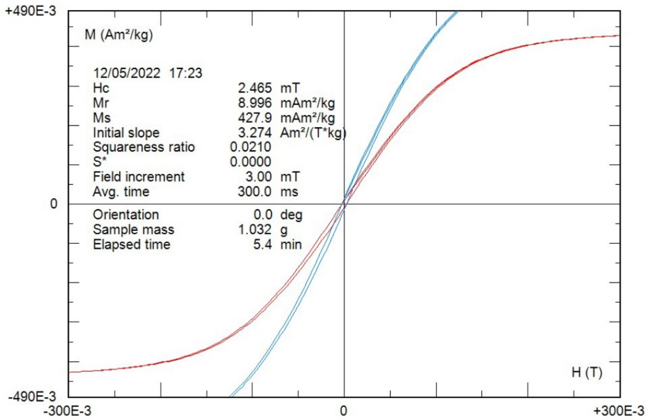

Figure 14: Comparison between big and small grain size of a soil sample. the blue curve represents a smaller grain size and the red curve represents a bigger grain size

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