UPPSALA UNIVERSITET

Institutionen för geovetenskaper
Geoinformatiklaboratoriet

GIS Exercise
6 October 1999

Thomas Gumbricht

DETECTING FAULTS AND FRACTURE ZONES WITH VLF

Requirements
The project requires a PC with Windows95/98 or Windows NT, ArcView 3.0 (or later), and the ArcView extensions Spatial Analyst and 3D Analyst. The necessary data are available on the Earth server at Geocentrum: earth2/_Sharedfiles/geoinformatik/data/...

Objectives
This aim of the project is to show how raw geophysical data is captured to GIS and how GIS can be used for manipulating and interpreting such data in relation to other data. The objective of the project is that the students should gain skills in data capture and interpolation, as well as in image interpretation and spatial data modeling. 3D visualization is introduced.

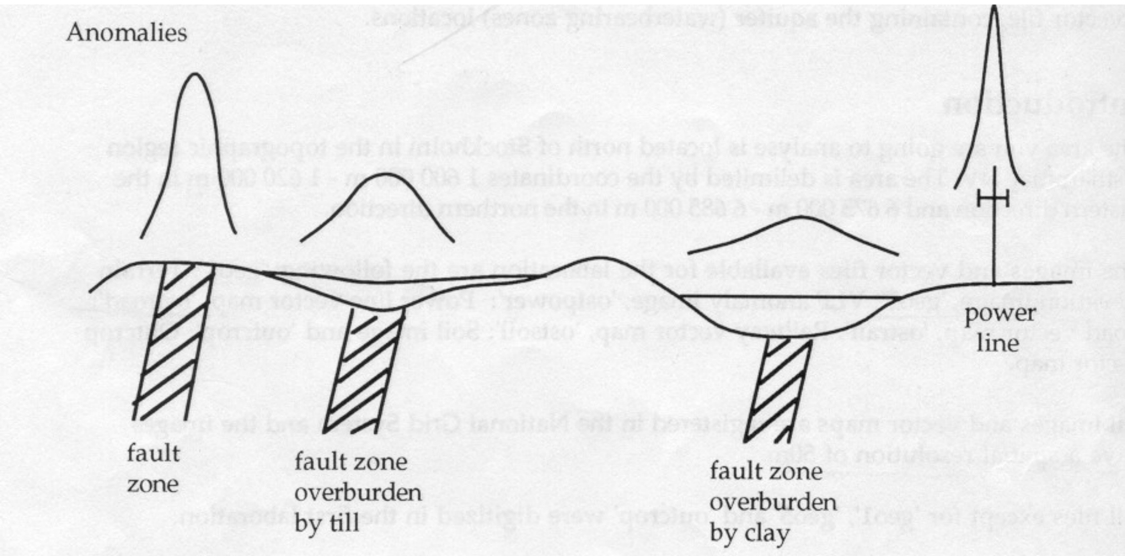
Task
To pass the exercise a thematic map showing interpreted VLF anomalies in a 3D scene must be handed in.

Introduction

In the landscape a variety of both natural and human features act as electrical conductors. Among natural features, water filled tectonic zones are the most important conductors near the surface. Very Low Frequency (VLF) wavelengths (long wavelength) have frequencies in the band 10 to 30 kHz, those wavelengths have very good penetration in soil and water (they are used for broadcasting to submarines). Conductors close to the surface are induced by the VLF electromagnetic waves and thus give rise to secondary electromagnetic fields, with the same frequency as the primary electromagnetic waves. Conductors parallel to the source are strongest, and conductors perpendicular to the emitting source are almost negligible.

The strength of the secondary, induced, VLF signal can be used to detect tectonic zones, and is commonly used for locating aquifers in rocks. The strength of the signal from an aquifer (tectonic zone) is dependent on the size of the zone, the concentration of electrolytes in the water and the soil covering the zone. Aquifers cause more or less wide and high anomalies (changes in the secondary VLF field), depending on the extensions of the overburden, the material that covers the zones, and properties of the zone itself. A wide and deep extension of the zone will cause a stronger anomaly that a thin and shallow zone. A more conductive overburden will lead to a weaker anomaly. Overburden of clay will hence cause more damping than an overburden of till.

Power lines are good conductors, and will give rise to very distinct anomalies.



Electromagnetic VLF data over the study area (Örebro sv) is in the file **../geoinformatik/data/sgu/em10fsv.xyz**. The data was collected from aeroplane, with a flight line separation of 200 meters (m) and a sampling interval of 40 m. Flight altitude was 30 m, and flight direction north-south. The detection instrument is a Dual-VLF receiver that measures the signal from several emitting sources (radio stations) simultaneously. The Swedish Geological Survey (SGU) have used airborne VLF (or RAMA) measurements since 1972. More information can be found on the home page of SGU – http://www.sgu.se/detsgu/geofysik/flyget/elekmagn/vlf_s.htm.

Preparing the raw data

The VLF data is supplied in exactly the same format as the gamma radiometric data for the exercise Uranium gamma radiation and radon gas risk. If you need more help have a look at that exercise.

The data file is a matrix showing values flight line per flight line. The columns in the matrix represent east co-ordinate (Rikets nät – RAK 38), north co-ordinate (Rikets nät – RAK 38), RAMAXR (real component in X), RAMAXI (imaginary compnent in X), RAMAYR (real component in Y), RAMAYI (imaginary compnent in Y), RAMAZR (real component in Z), RAMAZI (imaginary compnent in Z), and RAMATOT (weighted total component). X and Y for the VLF/RAMA data are defined so that X is along the flight line (which is north-south in the data).

```
Line 1449800
/  RAK-Y    RAK-X RAMAXR  RAMAXI  RAMAYR  RAMAYI  RAMAZR  RAMAZI RAMATOT
 1449800 6550000    -806     162     438     -40     -43       6     934
```

Remark: the Swedish co-ordinate system (RAK) uses X for the north-south axis. The GIS ArcView, however, puts X on the east-west axis. So in the example above Y and X (the two first columns) represent X and Y for the GIS (not Y and X as it shows – these are for RAK).

Open the file with the raw data (em10fsv.xyz) and have a look at it. The first thing you must do is to get rid of all strings with text and to change the non-recorded points to have a unique numerical value. In the raw data the non recorded points are marked with an asterisk "*". (without quotation marks).

The first flight line is at easting 1449800 and the last at 1475200. As the flight lines are 200 meters apart the data set contains 128 flight lines. South is at 6550000 and North is at 6575000, with 40 m sampling interval this means 626 samples per flight line. To get the data into ArcView you must change it to comma delimited ASCII text.

`1449800 6550000  -806  162  438  -40  -43   6  934`	Raw data
`1449800,6550000,-806,162,438,-40,43,6,934`	ArcView accepted format

There is a prepared file with comma delimited data structure (**../geoinformatik/data/sgu/em10fsv.txt)** that you can use.

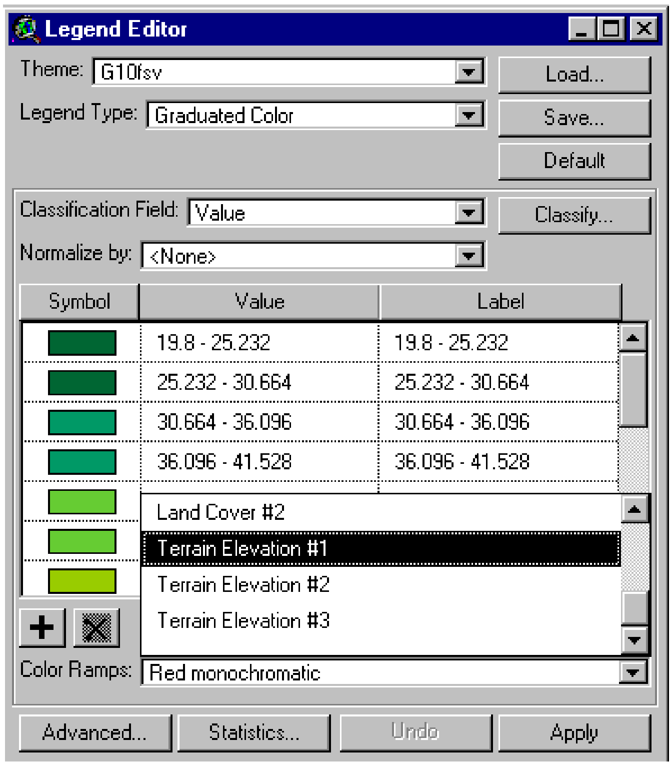
Digital Elevation Model (DEM)

In the exercise you shall use a digital elevation model (DEM) in combination with the VLF data. To fit the interpolation of the VLF data to the same area and resolution as the DEM you must add the DEM to your view before interpolating. Start ArcView with a new empty project. Under File in the project menu check that the Extension Spatial Analyst is marked. Add the DEM (remember to add the DEM as Grid Data Source):

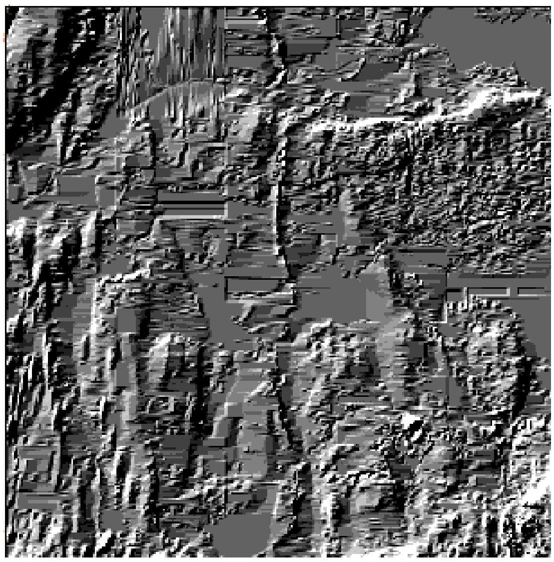
Theme	Data directory ..data/arbetsstuga2000/arcview/	Meta data directory ..data/arbetsstuga2000/
Digital elevation model	..metria/hojddata/g10fsv	..html/hojd

Look at the Theme Properties of the DEM. The DEM has a resolution of 50 meters with 501 times 501 cells covering the study area. In comparison with other data the values in Swedish DEM represent point values at nodes rather than averages over cells – thus there are 501 instead of 500 values covering the 25 km. To fit the VLF data to the DEM you must interpolate the VLF data to the same system.

Before continuing have a look at the DEM. Open the Legend Editor and classify the DEM into 25 classes, and apply one of the special DEM Color Ramps (furthest down among the defined color ramps). Legend Type must be set to Graduated Color. Return to the View, make sure the DEM is the active theme and under Surface in the menu Compute Hillshade.



Have a look at the Hillshade that you just calculated. You shall now combine the Hillshade with the DEM. Make the DEM the active theme. Again open the Legend Editor and press the Advanced button in the lower left corner. Select the Hillshade as Brightness theme and Apply. Play around with the possibilities for setting color ramps and parameters for the brightness theme until you get a satisfying image – the aim is that you should be able to see the valley systems over the study area (indicative of tectonic zones).



Interpolate the point data to a grid

Now we are ready to work with the VLF data. Click Tables in the project window, then click Add and navigate to the directory where you did put the matrix with comma delimited text (the extension should be .txt). Set List Files of Type to Delimited Text (*.txt). Add the data to your project. Open a new empty View. From the View menu select Add Event Theme. In the dialogue box that appears check that the correct columns are chosen for X and Y. Add the theme to the view. As the file is large it will take a while. Be patient.

Click the check box for the new theme – you will then see how data points are added flight line by flight line. Make the new theme active and Convert To Shapefile under Theme in the menu. Delete the original theme.

Before continuing you need to set map units and distance units for the view. The theme that you have added (and the ones you are going to add) are all in the co-ordinate system rikets nät. Rikets när uses meter as distance units. Under View in the menu choose Properties and set map units to meters, distance units can be set to meters or kilometres.

To work with the VLF data you should interpolate it and convert it to a grid theme with the same extension and resolution as the DEM. From the View menu chose Surface and Interpolate Grid.. (if this option is not available it is because the extension Spatial Analyst is not running).

Set Output Grid Extent to be the same as for the DEM theme. Set Output Grid Cell Size to 50 or the same as DEM, Number Of Rows and Number Of Columns should both automatically become 501. Click OK. In the next dialogue box select interpolation method and Z field to interpolate – start with RAMATOT. It is recommended that you decrease the number of points for the interpolation to 6 (or a low fixed radius) as the interpolation routine is not very fast in ArcView.

Note: Spatial Analyst only supports two interpolation methods Inverse Distance Weights (IDW) and Spline. However, the programming language of ArcView (Avenue) supports more methods including Kriging – but to use them you must first learn to write the script for that (which is not to complicated though).

The interpolation might take a few minutes (or even more). This is a good time for a coffee break.

Have a look at your interpolated surface. Check the range of values to make sure that you interpolated the correct Z value. Open the Theme Properties (under Theme in the menu). The resolution should be 50 meters and the number of rows and columns 501. Note that the Status is Temporary.

Classify the data

Open the **Legend Editor** to classify your data. In the legend editor Classify the data into 30 to 50 classes. Set Color Ramp to Full Spectrum and see if you can identify any anomalies. You probably can. The value range in the data is rather large, so you might encounter problems when classifying the data. When you are satisfied with your classification save it as a file and note the name of the legend file (you must load it later in the exercise).

To see if any of the anomalies are related to faults and/or other structural features in the bedrock you should add the themes over tectonics and bedrock, also add a theme of wells:

Theme	Data directory ..data/arbetsstuga2000/arcview/	Meta data directory ..data/arbetsstuga2000/
Tectonics	..sgu/berg/tekt10f.shp	..html/databesk
Bedrock	..sgu/berg/berg_10f.shp	..html/kodberg
Wells	..sgu/brunnar/brunn10f.shp	..html/brunn10f

To see if any anomaly is associated with the bedrock use the classifier to set the polygons of the bedrock theme to transparent, but with boarders in black – thus you will see the transition zones between various formations. Also display the vector data with the DEM as background. You should be able to see the valley systems associated with the tectonic zones.

Image enhancement

Image enhancement is used for improving the visual interpretability of digital images. Image enhancement methods include *inter alia*, classification, thresholding, stretching and filtering. You already have classified your image. To enhance the contrast between anomalies and the background VLF signal you should apply an edge enhancement filter. Under the Analysis menu choose Neighborhood Statistics and apply a 5 x 5 or larger size rectangular standard deviation filter. A standard deviation filter gives a high value to the central pixel in the kernel when the variation in numerical value among the pixels in the kernel is large (i.e. when you have an edge or transition zone). As the fault zones give a wide anomaly (several pixels wide) you need a filter of corresponding size.

Have a look at the edge enhanced image use the Legend Editor to classify the filtered theme – classify it by loading the legend file that you created for the original VLF interpolated theme. You should be able to see more anomalies on the edge enhanced image.

The filter types Range and Variety also work as edge enhancement filters. Try those filters as well. Also try to filter a filtered image. To test the difference between a filtered image and its source use the Map Calculator under the Analysis menu.

Analyze the origin of VLF anomalies

As you will have noticed most anomalies are not related to the tectonic zones or transition zones in the bedrock. To test the influence of power lines you should add the theme from Gröna kartan that have this data. The theme with the power lines is **P_10fsv** in the directory **../arbetsstuga2000/metria/gronkart/vector/.** The theme **P_10fsv** contains all kinds of line features and you must use the query builder to extract only power lines. Have a look in the html file ..arbetsstuga2000/html/kodgron to find out the numerical code for power lines. Use the Query Builder to select those values. When you have the power lines selected use the Convert to Shapefile option under the Theme menu to create a theme with only the power lines. Add the new theme to the view. There is no doubt that power lines are the major causes of the large and distinct anomalies seen in the image.

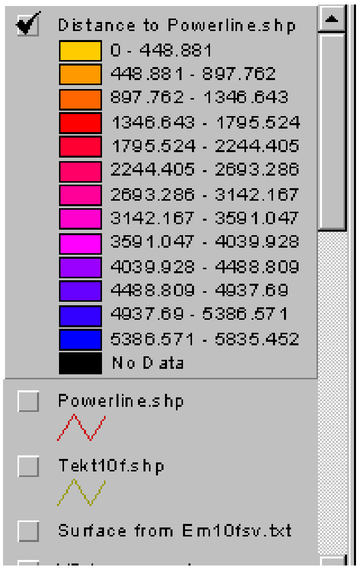
With the power lines displayed on top of the VLF data try to identify fault zones in your image. Screen digitize the fault zones – if you do not know screen digitizing have a look at the exercise Introduction to screen digitizing, or the exercise Vector data and topology.

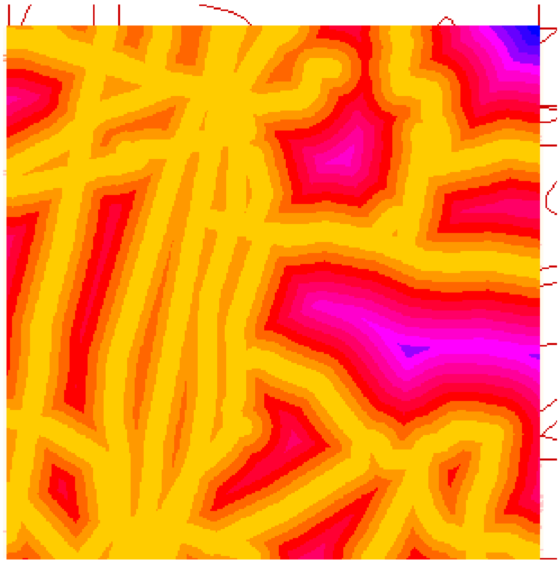
As you can see from the themes with tectonic zones and power lines, the former have more of an east-west orientation while the latter are more north-south oriented. Thus when it becomes your turn you should try to use the VLF component that reflects the east-west but not the north-south structures.

Further image enhancement

As the anomalies caused by the power lines are larger than the other anomalies, we want to get rid of the anomalies caused by the power lines. The general steps for that is to calculate distances from the power lines and set the value of the cells affected by power lines to zero, or an average value. The first option is simpler but then you should use the image with filtered standard deviation values as input (where zero equals no variation).

Make sure the power lines is the active theme, under the Analysis menu Find Distance. Set output grid properties to be equal the existing grid files (the DEM and the interpolated VLF signal).

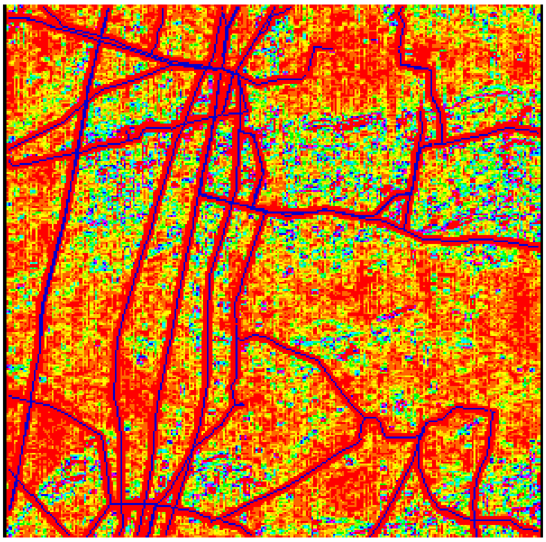




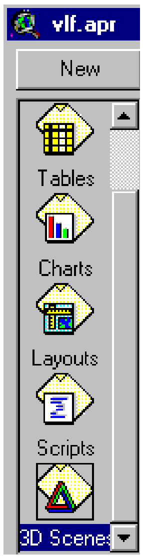
Have a look at the result, if the values are wrong, your map and distance units are probably not correct. In order to identify all areas affected by the power lines you can use the Map Query function under the Analysis menu. Query the proximity grid theme for values larger than 200 meters – the result should be a Boolean image having the value 0 at all points closer to power lines then 200 meters and the value 1 for all other locations. This image can be used as a mask for changing the VLF values of all cells affected by the power lines. Just multiply the mask and the theme with the filtered standard deviation.

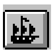
To analyze the difference in VLF signal between cells affected by the power lines and unaffected cells make sure that the Query you just did is the active theme. In the Analysis menu do Summarize Zones. Select one of the grid themes with the VLF anomaly (whether filtered or not depend on how you want to proceed) as theme containing variable to summarise. Analyze the result – it will be obvious that the anomalies from power lines have higher values.

The image to the right shows the VLF anomaly after filtration with a standard deviation filter and with all cells affected by power lines, and other extreme values, forced to zero (no variation). The remaining anomalies (mainly caused by natural features) are more easily detected. The whole process for creating the image to the right was a combination of thresholdning and stretching. The image could be used for on screen digitizing of anomalies.



3 D visualization

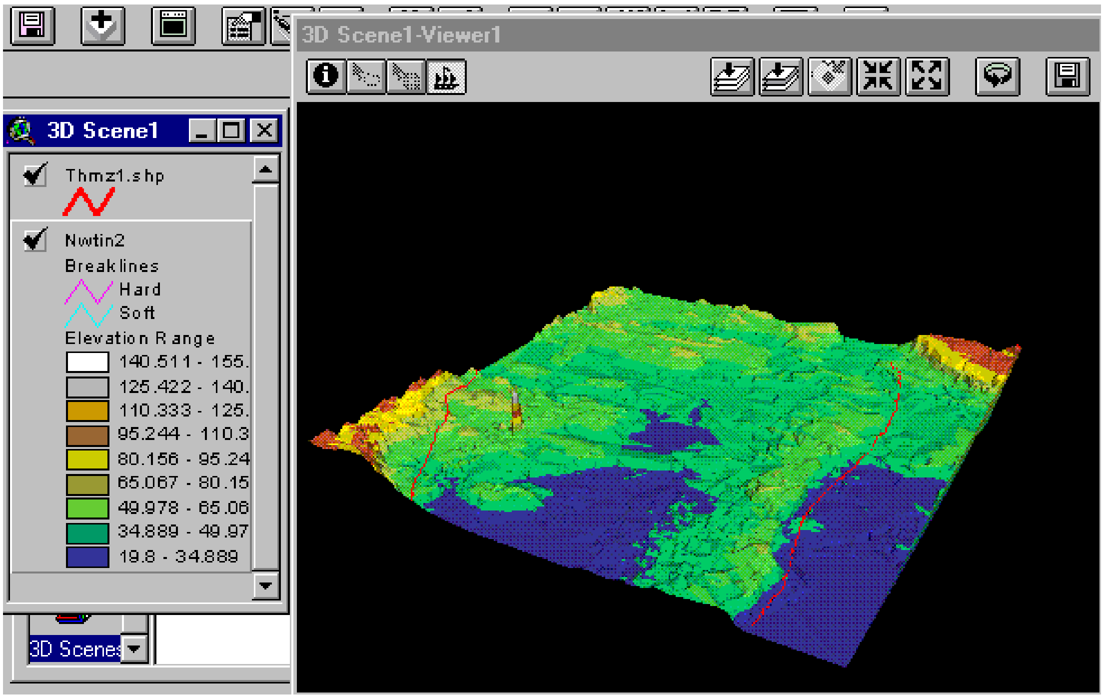


Go to the project window and start the 3D analyst Extension under the File menu. Return to the view. Make sure the DEM is the active theme. Under Theme in the menu choose Convert Grid to TIN, accept the default values suggested for conversion. Save the TIN in your working directory. Do not add the theme to the View. Instead close the view and return to the project window. A new type of document 3D Scenes has been added to the project window – but you must use the scroll bar to see it. Click on the 3D scenes icon and then New to create a 3D scene in your project. The 3D scene consists of two windows – one viewer and one table of content. With the 3D scene active use the Add theme button to add the TIN theme that you created from the DEM. Navigate to the directory where you saved the TIN, remember to change the Data Source Type to TIN Data Source. Use the little sail ship,  to rotate the 3D image.

Most of the other tools in the 3D scene are familiar. There are a few new ones, including Select Features, , and Rotate Viewer, .

There is almost no vertical resolution in the 3D scene that you created. To set the 3D exaggeration factor press 3D scene in the menu and then Properties. Use the Calculate button next to the Vertical Exaggeration Factor, and Apply. In the 3D scene Properties you can also change the change the sun azimuth and sun altitude of the 3D scene – try to change them to see what happens.

The next step is to add the tectonic zones to your 3D scene. Again use the Add theme button, and add the shape file with the tectonic zones (..sgu/berg/tekt10f.shp). Make the theme active and under the Theme menu choose Convert to 3D Shape File. For Z value you should choose surface (default). Save the 3D shape file in your working directory and add it to the 3D scene. In the 3D scene below the Color Ramp has been changed a little to highlight the low laying areas as lakes. You should have approximately the same 3D scene.



Your turn

The task for the exercise is that you should use interpolation and image enhancement to identify faults in the study areas. These faults should be digitized as line features. The line features should be converted to 3D and displayed in the 3D scene over the area.

Start by interpolating the real and imaginary components of the X direction. Then use image enhancement methods (filtering, thresholding, classification, map calculation) to identify the faults in the area. Create a new theme and use screen digitizing to capture the faults you identify. Convert the faults to 3D shape format and add them to the 3D scene that you already created. To test the idea of fault zones being aquifers you can use the theme with well data (brunnar) supplied with SGU. In the figure below the wells are displayed on the 3D surface extruding downwards (negative values) dependent on water capacity (this classification is done in the 3D properties of the theme). The 3D scene should be handed in to pass the exercise; you can choose to send it in as paper or electronically. Do not forget to put your name on the handin.