

Remote sensing and GIS techniques applied to geological survey

By:

F. van der Meer

Department of Earth Resources Surveys,

International Institute for Aerospace Survey and Earth Sciences (ITC),

P.O. Box 6, 7500 AA Enschede, The Netherlands.

Tel: +31 53 4874263, Fax: +31 53 4874336, e-mail: vdmeer@ITC.NL

Summary

The objective of these Remote Sensing and GIS exercises is to show how to use a GIS for specific geologic problems and with specific geologic data sets. The training on digital image processing focuses on the usage of field and laboratory spectral data to gain a better understanding of remote sensing products. Advanced image processing techniques will be introduced and applied using Landsat Thematic Mapper data acquired on March, 25, 1989 over the indicated region (Centre Coordinates: Latitude 36° 83', Longitude -4° 75').

Getting started

The data for this case study are stored on the ILWIS 2.1 CD-ROM in the directory d:\appguide\chap14. If you have already installed the data on your hard-disk, you should start up ILWIS and change to the subdirectory where the data files for this chapter are stored, c:\ilwis21\data\appguide\chap14. If you did not install the data for this case study yet, please run the ILWIS installation program (see ILWIS Installation Guide).



- Double-click the ILWIS program icon in the ILWIS program group.
- Change the working drive and the working directory until you are in the directory c:\ilwis21\data\appguide\chap14.

14.1 The geology of the investigated area

The Ronda-Malaga area is located in the southern part of Spain, west of the city of Malaga and South-east of the city of Seville. Geologically the area is part of the Betic Cordillera foldbelt stretching from Alicante to Cadiz in southern Spain. The Betic Cordilleras form the northern part of the Betic-Rif orogenic belt and constitute the westernmost part of the Alpine-Mediterranean chain. Classically, the Betic Cordilleras are subdivided into a northern External Zone and a southern Internal or Betic Zone. These zones are separated by flysch sediments of Early Cretaceous to Early Miocene age, which are restricted to the western Betic Cordilleras.

The External Zone, in most tectonic models for the orogen, is regarded as the passive continental margin of the Iberian continent. On the basis of paleogeographic criteria the External Zone is further subdivided into a Prebetic Zone in the north and a Subbetic Zone in the south separated by Intermediate Units. The Prebetic Zone represents the former shelf environment where shallow marine deposition prevails, whereas the deposits of the Subbetic Zone are characterised by a pelagic facies reflecting deeper marine environments. The Subbetic Zone may be subdivided into a northern and a southern Subbetic Zone mainly formed by calcareous Jurassic limestones, and a median Subbetic Zone formed by marly Jurassic limestones.

The Internal Zone consists of a stack of four nappe complexes composed of essentially metamorphic rocks of Triassic and older ages. These complexes are in descending order: (1) the Malaguide Complex, (2) the Alpujarride Complex, (3) the Mulhacen Complex, and (4) the Veleta Complex. The Mulhacen and Veleta Complexes formerly constituted the Nevado-Filabride Complex, but have been separated because they show a marked difference in metamorphic characteristics. The Veleta Complex is characterised by conditions of metamorphism of relatively low pressure and temperature, whereas the Mulhacen Complex shows an early phase of high-pressure-low-temperature metamorphism. The Alpujarride Complex is characterised by high-pressure-low-temperature metamorphism, however, with generally lower maximum pressures as found in the Mulhacen Complex.

14.2 Available data

The following vector data are available:

Ronda	Polygons of geological mapping units of the Ronda 1:50.000 map sheet.
Lithol	Polygons of lithological mapping units of the Ronda 1:50.000 map sheet.
Fault	Segments of faults in the category: thrust, normal, reverse and strike slip.
Contourh	Contourlines

The available raster data includes:

Tm1 . . 7 Seven bands of Landsat Thematic Mapper.

The following tables are also available:

Spectra Full laboratory reflectance spectra of selected minerals.

Spectm TM resampled spectra of materials.

Ronda Attribute data for the map Ronda.

14.3 Handling vector data

First we will examine the vector data.



- Open the Contourh segment map.
- Add the Fault segment map.
- Use the Layer management option to set the Info on both maps.
- Review the nature of the faults.



What is the contour interval of the Contourh?



- Open the raster map Tm5.
- Add the Fault segment map.
- Add the Ronda polygon map. Click on Boundary only.



Can you see any relationships between the faults and their expression in the image?

For the validation of our classification results and for three-dimensional display we need the geological and lithological data in raster



- Rasterize the polygon maps Ronda and Lithol with the same pixel size as the TM data. First, you have to create a georeference called Ronda. To do it, double click on the icon **NewGeoRef** in the operations list. Type as pixel size 30 (m). Use the following minimum and maximum coordinates:

min x = 304600 min y = 4059700
max x = 334750 max y = 4078850

- Accept the others parameters. Click the OK button.



- Rasterize the segment map Fault with the same pixel size as the TM data. Specify as georeference Ronda.

14.4 Geological exercises on vector and raster data

In this section you will be asked to conduct a number of tasks creating new maps from the available data, to guide in mineral exploration in the area. You may choose whether to perform the tasks on vector or raster data or on a combination of both, however try to aim at limited computational time and a minimum of disk space required for intermediate products.



- Create an attribute map for the Ronda area showing the ages of the formations in a million years. You can use the attribute table Ronda for this task. To do so, select the following items from the main ILWIS menu: **Operations, Raster operations, Attribute**. Select the raster map Ronda and the attribute Age_year. The output map name is Ages.

It is known that copper mineralizations occur along faults within limestones of Jurassic age.



- Create a map showing the possible locations of these mineralizations. Calculate the total area covered by these locations and the average area of the outcrops.

- Check the code of the item of the domain class Ronda which belong to Limestones of Jurassic age.
- Type the following formula on the command line of main window:

```
Cumine=iff(((Ronda="34")or(Ronda="36")or(Ronda="37")or(Ronda="49")or(Ronda="50")or(Ronda="23")or(Ronda="24")or(Ronda="25"))),Fault,?)
```
- Open the map Cumine and analyse its content using the **PixellInfo**. (Hint: you may use the maps Cumine and Ronda.)
- Calculate the histogram of the map Cumine. Analyse the resulting table and calculate the total area. To do so, select from the table menu **Columns, Aggregation**. Then, select the column Area and the function **Sum**. The output column is **Atotal**.
- Calculate the average size of the outcrops using **Columns, Aggregation**. Select the column Area and the function **Average**. The output column is **Avsize**.

The Permian sandstones are known to host gold mineralizations in areas adjacent to Ronda. These predominantly occur along normal faults.

! Are there areas within the Ronda map sheet which may be potential gold deposits?



- Create a lineament density map from the segment map **Fault** using the option **Segdensity** in ILWIS. Adopt a 250 m pixel size to allow sufficient aggregation.
- Double click on the icon **NewGeoRef** in the operations list to create the georeference **Fault**. Give 250 as pixel size. Use the following minimum and maximum coordinates:

min x = 304600	min y = 4059700
max x = 334750	max y = 4078850
- Accept the others parameters.
- Select from the main ILWIS menu the options **Operations, Rasterize, Segment Density**. Call the output map **Fsegden**. Select as georeference **Fault**. The value range is 0-600 and the

precision is 0.1.

- Display and analyse the resulting image with respect to the lithology.

14.5 Creating a Digital Terrain Model

A digital elevation model (DEM) is an image or data array representing the spatial distribution of elevation above some arbitrary datum in the landscape. Thus the DEM describes the altitude or height above a datum of any arbitrary unit which can be contoured using magnetic, gravimetric data etc. A digital terrain model (DTM) includes the spatial distribution of terrain attributes and can be described as a topographic map in digital format. In the following exercise we will concentrate on the digital terrain model. First a DTM will be created for the Ronda map sheet area. The DTM will be used to investigate the geomorphologic characteristics of the terrain in relation to the underlying influence of the geology. A slope map will be calculated and compared with the geology and the fracture pattern. Hillshading techniques are introduced to create an apparent three dimensional view of a two dimensional surface. Finally, the DTM will be used as a height map to create three-dimensional perspective views of the terrain.

Creating a DTM in ILWIS implies (1) digitizing contour lines from existing topographic data (maps) and subsequently (2) interpolating between the contour lines to obtain a rasterized surface of topography. The contours stored in segment map `Contourh` cover several map sheets including the Ronda map sheet but also several adjacent map sheets. We will first subset these segments to the Ronda sheet which will be used to create a DEM.



- Use the option `Subseg` from the operations list or select `Operations, Vector operations, Segments, Submap` to subset the segments of the map `Contourh` to the dimensions of the Ronda map. Use the following minimum and maximum coordinates for subsetting:

min x = 304600 min y = 4059700
max x = 334750 max y = 4078850

- Call the output `Contohs`.
- Use the `Contour interpolation` option to create a DEM. Use the same pixel size as the Ronda geological map. Use `Contohs` as contour map and use the georeference `Ronda`. Call the output `Dem`.

14.6 Hillshading the DTM

A pseudo relief image can be created using artificial illumination of the DTM: a technique known as hillshading. This technique is often used in cartography to create the appearance of a three dimensional view from a digital terrain model. In ILWIS this is done using a standard filter called **Shadow**. The filter **Shadow** is a linear filter with following dimensions:

```
[-3]   [-2]   [-1]
[-2]   [ 1]   [ 2]
[-1]   [ 2]   [ 4]
```

gain = 1 and offset = 127

This filter creates a hillshaded relief map from the digital terrain model with artificial illumination from the North-west. You can create other illuminations by mirroring the values of the filter.

Northeast:

```
[4]    [-2]   [-1]
[2]    [ 1]   [-2]
[-1]   [ 2]   [-3]
```

gain: 0.2



- Create artificial illuminations of the map Dem using the shadowing technique with illumination from the Northwest using the options: **Operations, Image processing, Filter** and apply the filter **Shadow**. The output raster map is Demnw.
- Overlay the faults on the resulting hillshaded image and discuss the expression of faults in the topography.
- Create and apply the filter **Northeast** in order to create artificial illuminations of the Dem using the shadowing technique with illumination from the Northeast. The output raster map is Demne.

14.7 Calculating slopes

In ILWIS, slope and aspect are calculated using the gradient of the slope, calculated from the DEM at each pixel. The filters `Dfdx` and `Dfdy` are gradient filters in X and Y direction respectively that yield the altitude differences in these directions on a pixel by pixel basis. Calculating a slope map is thus a two step process: first the two filtered maps for the gradient in X and Y direction are calculated which are used in an ILWIS standard function to obtain slopes.



- Select from the main ILWIS menu the options: **Operations, Image Processing, Filter**. Select the filter `dfdx` and the map `Dem`. The output is `Dx`.
- Repeat the procedure to the filter `dfdy`. Type as output `Dy`.
- Type the following formula on the command line of the main ILWIS window to create the map `Slope`:

$$\text{Slope} = (\text{hyp}(\text{Dx}, \text{Dy})) / 50) * 100 \downarrow$$
- Display the `Slope` map on the screen and overlie the fault pattern. Do you see any relation?

14.8 Three-dimensional display

In the previous exercises you have experimented with pseudo three-dimensional images, now you will create a real three dimensional image. The DTM is used as a height image over which other maps (e.g. geology, lithology, TM bands) can be draped.



- To get an idea of ‘what the area looks like’ use the option **Display 3D** from operations list. Create a new 3D georeference using the map `Dem`.
- Create the following three-dimensional displays:
`Ronda` draped over the topography.
`Lithol` draped over the topography.
- To use the raster maps, select **Raster Drape**. Deselect **Grid**.
- Create the following three-dimensional displays:
`Tm5` draped over the topography.

The hillshaded relief image, Demnw, draped over the topography.

14.9 Image enhancement

In this section we will perform some standard image processing tricks on the Landsat TM data.

Contrast enhancement



- Apply a stretch to Tm2 and display the result.
- Select the following menu items: Operation, Image Processing, Stretch, Percentage, 1.00. Type TM2s as output.
- Do the zero values resulting from the georeferencing process influence the stretching? If yes, make a subset of the TM data covering the area of the Ronda map (min-max xy coordinates can be found in previous sections).

Filtering

To improve the visual appearance of the TM data we will attempt filtering.



- Try the following filters on Tm5 and evaluate their performance. You first have to create the filters and then apply them to Tm5.
- Use the option New filter from the operations list:

Smoothing:

```
[1] [1] [1]
[1] [1] [1]
[1] [1] [1]
```

Sharpening:

```
[-1] [-1] [-1]
[-1] [-16] [-1]
[-1] [-1] [-1]
```

Accept the defaulted gain and offset values.

Gradient filters:

(a)	(b)	(c)
[1] [1] [1]	[1] [0] [1]	[-1] [-1] [-1]
[0] [0] [0]	[1] [0] [1]	[-1] [-1] [-1]
[-1] [-1] [-1]	[1] [0] [1]	[-1] [-1] [-1]



- To gain more appreciation for these gradient filters overlay the faults onto the resulting images.

Colour compositing



- Create a false-colour composite image with Tm7, Tm5, and Tm4, as red, green, and blue component respectively; and a special colour composite with Tm4=Red, Tm5 =green, and Tm6=blue.
- Display both images and discuss the result. Interpret the colour assignment for the carbonates east of Ronda, the peridotites Southeast of Ronda and the agricultural fields north of Ronda

! What is the meaning of the blue component? Why did you put band 6 in blue? You can overlay the geological boundaries to guide your interpretation.

Selecting three bands for display in a colour composite image is a tedious and time consuming business since many combinations have to be tried certainly when working with ratio images. The *optimum index factor* technique may help to overcome this problem. The OIF for a three band combination is calculated as

$$OIF = \frac{\sum_{i=1}^3 SD_i}{\sum_{i=1}^3 |CC_j|} \quad [14.1]$$

where SD_i is the standard deviation for band i and $|CC_j|$ is the absolute value of the correlation coefficient between any two of the three bands. High values for OIF indicate bands that contain much "information" (e.g. a high standard deviation) with little "duplication" (e.g. a low correlation between the bands). It should be

noted that noise or drop-outs contribute highly to the variance in the image and thus to the OIF value. By using the OIF method, three band colour composites can be evaluated on their effectiveness for display.



- Select the following menu items Operation, Statistics, Maplist, Variance, Covariance and Correlation Matrix.

- Apply the OIF formula for the following band combinations:

$Tm1+Tm2+Tm3$

$Tm4+Tm5+Tm3$

$Tm4+Tm5+Tm6$.



Which combination scores highest and what does this imply?

14.10 Spectral recognition of surface reflectors

Reflectance spectra of minerals and rocks in the visible to short-wave infrared wavelength region are characterised by absorption features caused primarily by two processes: electronic transitions and vibrational transitions. Electronic transitions are changes in the energy states of electrons bound to atoms which require high amounts of energy and thus occur at low wavelengths. Absorption features caused by electronic transitions are generally broad and typical examples are iron absorption bands near 0.9, 0.6 and 0.5 μ m. Vibrational processes, i.e. small displacements of atoms in their resting place in crystal lattice, require far less energy than do electronic transitions. Therefore these features occur at higher wavelengths and are usually sharp. Typical examples are the water absorption features occurring near 1.4 and 1.9 μ m, the Al-OH features near 2.2 μ m, the Mg-OH features near 2.3 μ m, and the carbonate bands near 2.3-2.35 μ m. In this exercise we will investigate spectra of minerals, rocks and vegetation as measured in the laboratory and as they occur in TM images. Laboratory spectra were measured on a Beckman UV5240 spectrometer which measures around 800 spectral bands in the 0.4-2.5 μ m wavelength range. TM spectra were measured in the field. Full reflectance spectra measured on the Beckman laboratory spectroradiometer are stored in the table `Spectra` while the corresponding resampled TM spectra can be found in table `Spectm`.



- Open the tables `Spectra` and `Spectem`. Display and discuss spectra of minerals in TM and full resolution.

A number of target reflectors are unknown in the area and assumed to represent the common mineralogy and weathering products of rock types. The location in the TM image is given in the table below.

☞

- Open the pixel information window and use the six TM bands to find the spectral responses of the unknown ground cover types (indicated as ?1-4) for which are asked to say what they are likely to be based on their reflectance characteristics compared to the materials in Spectm. Add for each of the targets of your table a column with a proper name to table Spectm. Add the values for the reflectances of each target in your table. Display the spectra you extracted from the TM image one by one and try to match them with a standard TM spectrum which was measured in the field. What are the most likely spectra ?1, ?2, ?3, and ?4???

Table 14.1: Spectral signatures of surface reflectors in the Ronda-Malaga TM image

Target	Coordinate	TM 1	TM 2	TM 3	TM 4	TM 5	TM 7
?1	313315 4055295						
?2	309805 4056555						
?3	315006 4059341						
?4	321985 4061355						

14.11 Rationing

A common problem with remote sensing images as described in the previous exercise is the effect of varying illumination caused by topography. Relief causes some slopes to be illuminated more than others thus surfaces with homogeneous reflectance properties will show varying DN values across a scene. Theoretically, any surface should receive the same proportions of energy in all wavebands irrespective of its orientation to the sun. The ratio between two bands for pixels containing the same surface should therefore be the same. Ratio images thus provide a means of correcting differences in illumination due to topography. This also implies a drawback; namely the suppression of albedo. Two spectrally featureless units with differing albedo can be easily recognised in the original spectral bands but are indistinguishable in ratio images. Furthermore rationing noise enhances significantly.

The importance of ratio images is; that they map a spectral gradient. The ratio of two bands describes the difference in spectral values between the two wavelengths and can therefore be used to map iron content, clay content, chlorophyll and water absorption features. Creating ratio images is not a standard function; you have to use the map calculator program for this. Creating ratio images in the map calculator is done using the following general formula:

$$\text{Ratio}(T_{Mi}/T_{Mj})=(T_{Mi}/T_{Mj}) * 127 \quad [14.2]$$



- Create four ratio images: T_{m7}/T_{m5} , T_{m3}/T_{m1} , T_{m5}/T_{m1} and T_{m4}/T_{m3} . Type as output Bnd705, Bnd301, Bnd501 and Bnd403, respectively.

Make sure that all images are assigned an **Image** domain, as the color composite operation currently only accepts the domain **Image**.

- When finished, display these images selecting the **Grey** representation.



Which of the ratio images can be used to identify surface materials with absorption features due hydroxyl, water, carbonate, iron, chlorophyll?

Another way of displaying these ratio images is in the form of a colour composite image.



- Create a colour composite image with Bnd705, Bnd501, and Bnd403, as red, green, and blue components respectively. The relation between relative ratio DN values, colour in the Colour Ratio Component image, and main absorption feature can be read from the table below (relative ratio values are indicated by H= high, M=moderate, L=low in the table).

Table 14.2: The relation between DN value, colour and main absorption features.

Bnd705: Red	Bnd501: Green	Bnd403: Blue	Image colour	Absorption feature
L	M-H	L	Green	Spectrally flat
H	H	L	Yellow	OH ⁻
H	H	H	White	OH ⁻ , Fe ³⁺
L-M	H	H	Light blue	Fe ³⁺
L-M	L-M	M-H	Dark blue	Chlorophyll
M-H	L	M-H	Magenta	H ₂ O
H	M	L	Orange	Chlorophyll, H ₂ O

Recall that the TM bands are positioned at the following wavelengths:

Band 1	0.45-0.52mm	blue
Band 2	0.52-0.60mm	green
Band 3	0.63-0.69mm	red
Band 4	0.76-0.90mm	nearIR
Band 5	1.55-1.75mm	SWIR
Band 6	10.4-12.5mm	TIR
Band 7	2.08-2.35mm	SWIR

14.12 Green Vegetation Index

In order to mask vegetation it is often useful to calculate a green vegetation index. The most commonly used vegetation index is the normalised difference vegetation index, NDVI, defined as

$$\text{NDVI} = (\text{TM } 4 - \text{TM } 3) / (\text{TM } 4 + \text{TM } 3) \quad [14.3]$$



- Calculate the NDVI using the NDVI function.

$$\text{NDVI} = \text{NDVI}(\text{TM } 3, \text{TM } 4) * 127 + 128 \downarrow$$

- Select domain Image.



- Mask from TM bands 4, 5 and 6 the pixels that have a high NDVI value (select a suitable threshold):

$$\text{TM } i = \text{iff}(\text{NDVI} > 150, ?, \text{TM } i) \downarrow$$

where: $Tm_i = Tm_4, Tm_5, Tm_6$.

Make sure that all images are assigned the **Image** domain.

- Create colour composites of $Tm_{4m}, Tm_{5m}, Tm_{6m}$. They correspond to bands 4, 5 and 6 with vegetation masked.
- Compare the result to the original colour composite.

14.13 Multispectral classification

Classification of remotely sensed imagery into groups of pixels having similar spectral reflectance characteristics, is often an integral part of digital image analysis. On the basis of spectral reflectance which training pixels (e.g. pixels known to represent a ground class of interest) exhibit, pixels for which the ground cover type is unknown are classified. Classification routines aim at comparing the observed spectral reflectance of pixels with unknown composition with that of training pixels, and assign the unknown pixel to that group which resembles their spectral reflectance characteristics most. Techniques making use of training data sets are referred to as supervised classification algorithms as opposed to unsupervised classification techniques in which no foreknowledge of the existence of ground classes is required.

In order to train the classifier you will have to sample the image to obtain a set of training pixels which serve as "an example of what to look for" with the classification algorithm. We will sample the following classes: water, urban, limestone, kaolinite, hematite, green vegetation, dry vegetation, and kaolinite. Training areas can be obtained from the exercise 'spectral recognition of surface reflectors'.



- Create a sample set for the classes of interest and run a box classification algorithm to classify the TM data.

Create the map list: $TM1-7 : Tm1-Tm7$ ↴

Background: color composite result of the activity 14.11.

- Cross the resulting image with the `Lithol` map and evaluate the match between limestones in the classification and limestones in the map. What can be concluded?

