

Geological data integration

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Summary

This exercise deals with an introduction to digital processing techniques for the integration and interpretation of multiple geologic data sets in a CAD-DBMS/GIS environment. The earth scientist will be introduced to digital processing techniques that can be applied for data visualization, enhancement, and interpretation of multiple geo data sets.

Getting started

The data for this case study are stored on the ILWIS 2.1 CD-ROM in the directory `d:\appguide\chap15`. 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\chap15`. 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\chap15`.

Now you are ready to start the exercises for this case study.

15.1 Introduction

The increasing amount of multiple data sets readily available to earth scientist, has created a need for efficient capture, storage, management, retrieval and analysis of geoscientist data. Today the earth scientist faces the difficult task of relating and integrating vast amounts of different data types, obtained from different sources and compiled on different scales. In order to use all these data for mapping, interpretation and modeling, the earth specialist should ideally be able to spatially link field observations with ancillary spatial data such as aerial photographs, gridded geophysics and geochemistry, satellite imagery, topographic data and point data, such as laboratory results from geochronology, geochemistry and thin sections.

The study area

Bathurst Inlet occurs along a major fault zone that runs along the western side of the inlet. The total displacement along this fault was about 140 km, with vertical movement of about 1 km. This created a deep basin, now drowned by the sea. Intrusive rocks that are resistant to erosion protected the underlying softer sedimentary rocks. This resulted in a butte and cuesta topography in which vertical scarps may be as much as 300 meters high. The variety in relief near the inlet is in sharp contrast with the surrounding area, typical of the Canadian Shield, being characterized by low hills and broad valleys that provide the only variation in relief.

Bedrock Geology of the Pistol Lake Area

The Pistol Lake area comprises the easternmost part of the Archean Hood River Belt, located west of Bathurst Inlet, North-west Territories, Canada (approximately at latitude 67 and longitude 109). Figure 15.1 shows the geological map of the area, generalized from the 1: 10 000 scale map compilation of Henderson et al. (1990).

The Hood river belt is an Archean supra-crustal sequence bounded to the east by an unconformity with Proterozoic lithologies. Internally this part of the Hood river belt consists of thickly bedded turbidites with occasional oxide facies iron formation intruded by granitoid batholiths ranging in composition from diorite to monzogranite. The metasedimentary units occur as a vertical or overturned stratigraphic sequence, in general becoming younger towards the east. An unconformity along the east side of the area separates the Archean rocks from Lower Proterozoic rocks. The Lower Proterozoic stratigraphic sequence consists of various sedimentary rocks deposited in shallow marine, deltaic and fluvial depositional settings.

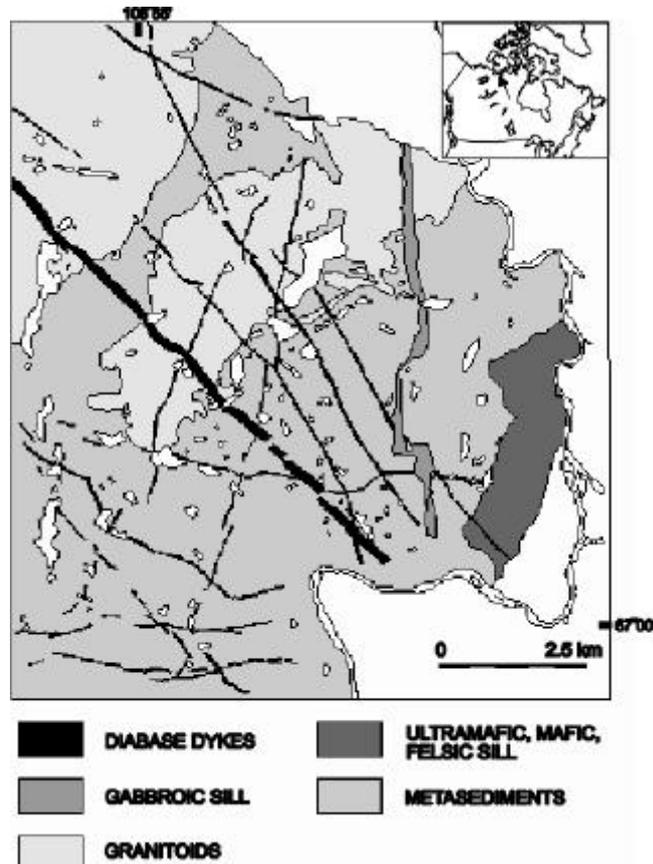


Figure 15.1: Geology map of the eastern Hood River Belt compiled from the 1: 10 000 scale geology map of Henderson et al. (1990)

A regional penetrative S1 cleavage occurs throughout the supracrustal belt. S1 is vertical and strikes on average 25° from northerly striking bedding. No macroscopic F1 fold closures have been observed in the field. Locally S1 is folded into F2 south-plunging fold structures. A crenulation cleavage S2 is axial planar to the F2 folds (Henderson et al., 1991)

An Early Proterozoic ultramafic-mafic-felsic sill, dated at 2023 Ma intruded the supracrustal rocks and forms, at present, the boundary between the Archean rocks and the Proterozoic cover lies to the east. At least three dyke swarms crosscut the supracrustal sequence. The oldest are E-W trending dikes assigned a Late Archean age of 2692 Ma (Rb-Sr mineral and whole rock isochrons; Gates and Hurler, 1973). The SE-NW trending dikes belong to the Proterozoic Mackenzie Dike swarm (with a baddeleyite U-Pb age of 1270 Ma; LeCheminant and Heaman, 1989). The youngest Franklin dikes are trending north and have intruded the granitoids and metasedimentary rocks east of the area (Jefferson et al., 1991).

The area was extensively scoured during the Wisconsin glacialiation, resulting in the bedrock-controlled relief typical for the Canadian Shield. The ice transport direction was parallel to the general structural strike of the bedrock, resulting in a strong N-S to NW-SE grain in the landscape. Vegetation cover in the area is sparse, dominated by lichen and shrub-heath communities found on respectively bedrock and till deposits (Zoltai et al, 1980).

Mineralizations

Gold is found in iron formation beds with narrow widths (rarely greater than 20m) within the upper sequence of a turbidite unit. The iron formations are mixed silicate, oxide and sulfide facies with gold commonly found in the latter. The gold is not vein related and may be syngenetic or early epigenetic, (Henderson, M.N., 1991)

Pyrite or pyrrhotite, or both together, are present locally in oxide iron formation in amounts that may be as great as 10 volume percent. They occur in fine disseminations, veinlets and less commonly as isolated blebs and euhedral crystals in magnetite or in other minerals. Rare arsenopyrite may be associated with the iron sulphides, in most cases as small euhedral crystals and blebs (Roscoe et al., 1987).

15.2 Available data

The following data is available for the study area:

| | |
|-------------|---|
| TM3 ,...TM7 | Landsat TM imagery, bands:,3,4,5, and 7. |
| Spotg | SPOT Panchromatic image. |
| Hrmag | High resolution Aeromag flown by Silverheart, 1989. |
| Bif | Raster map with the banded iron formation. |
| Fault | Raster map with the fault and shear zones. |
| Mastgeol | Vector map with the geology coverage digitized from 1: 10.000 geology map. |
| Bif | Vector map with the banded iron formation outcrops. |
| Fault | Vector map with the faults and shear zones digitized from the geology map. |
| Prospect | Point map with the locations and description of known mineral occurrences. |
| Prospect | Table containing attribute data on the mineral occurrences of the point map Prospect. |

15.3 Image enhancement and integration

15.3.1 Improvement of spectral contrast among lithological units in color composites

The objective of this exercise is to improve the spectral information of bedrock geology in color composites by masking irrelevant spectral response (water, vegetation, sedimentary cover).

In order to map spectral differences between bedrock units we have to consider the spectral responses that mask bedrock spectral signatures. Most likely the spectral response of each pixel of the TM images, due to the limited spatial resolution of the Landsat TM sensor, can be considered as a mixture of spectral signatures from vegetation, water, soil and bedrock. In remote sensing campaigns ground reflectance spectra are measured to characterize “pure” spectral response of ground features. Several workers have tried to unmix vegetation and bedrock spectral response from ground reflectance spectra (Adams and Adams, 1984; Bierwirth, 1990; Cooke et al., 1986)

Because in this study ground spectra are not available, we attempt to eliminate unwanted spectral response by masking pixels that are likely to have pure or high proportions of water, fluvial deposits and green vegetation. To mask green vegetation we can use a NDVI image. The fluvial sediments have a particularly high reflectance in band 3 and water has a low reflectance in band 7. A color composite is created from the masked bands and compared to a color composite of the original (unmasked) bands with respect to the digitized geology map of the area.

For this exercise the following TM bands are needed: TM3, TM4, TM5, TM7.



- Calculate the NDVI from TM bands 3 and 4. Type the following formula on the command line of the main ILWIS window:
- $NDVI = ((TM4 - TM3) / (TM4 + TM3)) * 127 + 128$ ↵
use an Image domain.

The unwanted spectral responses from green vegetation, water and fluvial sediments are masked from TM band 3, 5 and 7. Thresholds are defined as follows:

$NDVI < 150$, $TM7 < 10$, $TM3 > 30$



- Design and implement a MapCalc formula for masking bands 3, 5 and 7 using the thresholds defined above. Make sure that all masked images are assigned the image domain.

$TM3m = \text{iff}((NDVI > 150) \text{ or } (TM7 < 10) \text{ or } (TM3 > 30), 0, TM3)$

- Repeat the same formula for the bands 5 and 7.



- Create color composites of the unmasked and masked bands. Overlay on both the boundaries of the polygon map Mastgeol. Experiment with different stretching percentages to see if you can improve the spectral contrast of the color composite of the masked bands..

Compare the two color composites in terms of spectral response between bedrock units.



- Which units can be better differentiated in the masked color composite ? Can you think of a method in which no pixels are masked but in which the color enhancement of the bedrock units is retained ?

15.3.2 Integrating Landsat TM and SPOT Panchromatic data

The objective of this exercise is to demonstrate a simple method for merging high spatial resolution images with multi-spectral imagery. A image integration technique that has proven to give useful results for geological mapping is the merging of Panchromatic Spot data with 3 multispectral channels from Spot or Landsat (Haydn et al., 1982; Chavez et al., 1991; Grasso, 1993) This integration technique combines the benefits use from the higher spatial resolution (10 m pixel size) of Spot Panchromatic with multi-spectral images. Various techniques to perform this image merge exist. We will one of the most simple approaches in this exercise.



- Enhance the Spotg image with a high pass filter. To do so, select the following menu items: Operations, Image Processing, Filter, Linear, Edgesenh. Type as output Spotgf.
- Stretch the filtered image. To do so, select the following menu items: Operation, Image Processing, Stretch. Select Spotgf as input map. Choose Linear Stretching and give a Percentage of 1. Type as output Spotgfs.
- Mask the image Spotgfs excluding water (darks pixels) and snow (brightest pixels) from the input range. The output name will be Spotgfsm.

- Type the following formula on the command line of the main ILWIS window:

```
Spotgfsm=iff((Spotgfs>225)or(Spotgfs<50),?,
Spotgfs)↵
```

Select domain Image.



- Increase the spatial resolution of TM bands 7, 5 and 3. To do so, select **Operations, Image Processing, Resample**. Specify as georeference: `Spotg` (this assures that the TM bands are densified to the dimensions and pixel size of the Spot Panchromatic image).
- Select a **Bilinear** resampling algorithm. Call the output maps: `Tm3r`, `Tm5r` and `Tm7r`. Click the check box **Show**.

The enhanced Spot Panchromatic image `Spotgfsm` can be merged by normalizing the TM bands by their sum and multiplying with `Spotgfsm` (i.e. Schetselaar transform).



- Calculate three new bands containing the merged images as follows:

```
Red=(Tm7r/(Tm3r+Tm5r+Tm7r))*Spotgfsm↵
```

```
Green=(Tm5r/(Tm3r+Tm5r+Tm7r))*Spotgfsm↵
```

```
Blue=(Tm3r/(Tm3r+Tm5r+Tm7r))*Spotgfsm↵
```

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



- Create a color composite of the red, green and blue channels and compare this image with the color composite of the original TM bands.



- Interpret the merged image by overlaying the geological map.

15.3.3 Image enhancement and colour coding of geophysical data

The objective of this exercise is to use color coding and enhancement techniques for the representation of aeromagnetic data.

Aeromagnetic surveys are carried out to map local variations in the earth's magnetic field, which after subtraction of the International Geomagnetic Reference Field (IGRF) may be interpreted as due to 3-dimensional variations of magnetic susceptibility contrasts in the rocks of the crust. In the last decade qualitative interpretation of aeromagnetic and other geophysical data has improved significantly by representing aeromagnetic data by raster images. Such raster image representations are easier perceived by the human eye compared to the conventional contour maps and in addition can be digitally processed for additional representation and enhancement purposes. In these exercises you will learn some basic techniques to represent aeromagnetic data and other graded data sets using color representations and relief shading functions as an aid to qualitative interpretation.

For this exercise, you need the High resolution Hrmag image (8 bit data) (Siverheart mining company) (flight altitude 50 m; flight line spacing 300 m).

Color coding

The objective of this exercise is to use color coding and enhancement techniques for the representation of aeromagnetic data.



- Display the image Hrmag in gray scale, then close it.
- Double click on the icon **NewRep** in the operation list. Type Hrmag in the text box representation name. Use **Image** as domain and then click the **OK** button.
- Define a full color range from low to high digital numbers by inserting colors steps in the representation. To do it, select from the menu bar **Edit, Insert limit**. Use the following limits and colors.

255-red.
203-yellow.
153-green.
102-cyan.
51-blue.
0-magenta.

Relief shading

A powerful digital processing technique to enhance structural patterns in aeromagnetic data is relief shading in which the high wave number content of the data is enhanced. Mathematically relief shading or artificial illumination can be defined as the dot product between the vector pointing to the illumination source and the normal to the local surface of the aeromagnetic data.

The apparent reflectance (of a Lambertian surface) can be defined as the cosine of the angle between a user defined illumination direction and the surface normal:

$$\cos \Phi = \frac{\bar{n} \cdot \bar{s}}{|\bar{n}| |\bar{s}|} \quad [15.1]$$

The components of the surface normal vector per unit length is defined by the two gradient vectors ΔZ

$$\bar{n} = \begin{pmatrix} \text{DZ}_x \\ \text{DZ}_y \\ 1 \end{pmatrix} \quad [15.2]$$

In practice these gradients are calculated by applying two gradient filters in respectively in x and y directions. (Note that these filters have a smoothing effect because they derive the gradients over 2 pixel distances):

$$\begin{matrix} \text{Dz}_x = & \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & -1 \\ 0 & 0 & 0 \end{pmatrix} & \text{DZ}_y = & \begin{pmatrix} 0 & -1 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} \end{matrix} \quad [15.3]$$

gain=1 offset=0

The vector pointing to the illumination source, s, is defined by two angles:

α :: the azimuth, the angle of the illumination source from north measured in a horizontal plane.

β : elevation angle of the illumination source above the horizon measured in a vertical plane

The x, y, z components of the illumination vector is thus written as:

$$\bar{s} = \begin{pmatrix} \cos\beta\sin\alpha \\ \cos\beta\cos\alpha \\ \sin\beta \end{pmatrix} \quad [15.4]$$

Substituting equations 15.3.2 and 15.3.4 in equation 15.3.1, the relief shading function can be written as:

$$\text{Relief shading} = \frac{\cos\beta * \sin\alpha * \Delta Z_x + \cos\beta * \cos\alpha * \Delta Z_y + \sin\beta}{\sqrt{\Delta Z_x^2 + \Delta Z_y^2 + 1 * \sqrt{(\cos\beta * \sin\alpha)^2 + (\cos\beta * \cos\alpha)^2 + \sin\beta^2}}} \quad [15.5]$$

Now we are going to apply relief shading on the image Hrmag for the following illumination directions:

Table 15.1

| α | β |
|----------|---------|
| 315 | 0 |
| 315 | 45 |
| 45 | 60 |



- Create gradient filters Dzx and Dzy as defined before.
- Double click on the icon **New filter** in the operations list. Use as filters names Dzx and Dzy. Type as gain 0 . 5. Click OK.



- Apply Dzx and Dzy on Hrmag. To do so, select the menu items: **Operations, Image processing, Filter**. Type as output Hrmagdx and Hrmagdy.

Write equation 15.5 as a function:



- Double click on the icon **New Function**. Type Shading as function name.
- Type the following expression on the expression box:

```
(cos(degrad(a))*sin(degrad(b))*(c)+cos(degrad(a))*cos(degrad(b))*(D)+sin(degrad(a))/(sqrt(sq(c)+sq(d)+1)*sqrt(sq(cos(degrad(a))*sin(degrad(b)))+sq(cos(degrad(a))*cos(degrad(b))))+sq(sin(degrad(a)))))
```

- Click the OK button.

You have create a function where:

a and b = Illumination directions define in table 15.2.

c = $\Delta Z_x = H_r \text{mag}_d x$.

d = $\Delta Z_y = H_r \text{mag}_d y$.



- Run on the command line of the main window the function shading to the differents values of a and b of table 15.2:

```
Output=Shading(a,b,c,d)
```

- Use a precision of 0.0001. Accept the default value range and select Grey representation.

15.3.4 Fusion of Aeromagnetic and SPOT Panchromatic data using the HIS transform

To gain insight in the geology of a certain area we often want to analyze one data type in conjunction with another to confirm or complement the patterns in the individual images. For example, It may be interesting to verify if a geophysical anomaly from magnetic sources at depth is related to geological features observed at the surface. The coincidence of subtle patterns in different digital images may lead to more confidence in the interpretation of those features. On the other hand geologic patterns present in only one or the other might supplement the features that can be extracted from the combined interpretation.

In a color composite of Landsat TM bands, in which we combine data of the same sensor, we can assign each band to the primary colors red, green, and blue. However when we combine data of a different nature or from different sensors we can not use the color composite representation, because the numerical variations of the data then will not be represented by proportional color gradations and are therefore difficult to interpret. Instead, we have to transform the Cartesian color representation into quantifiable color attributes that can be distinctly perceived. Such a color coordinate system, shown in Figure 15.2. is the IHS transform in which I= intensity: total brightness of a color, H= hue is the average wavelength of a color and S= saturation is the purity of a color

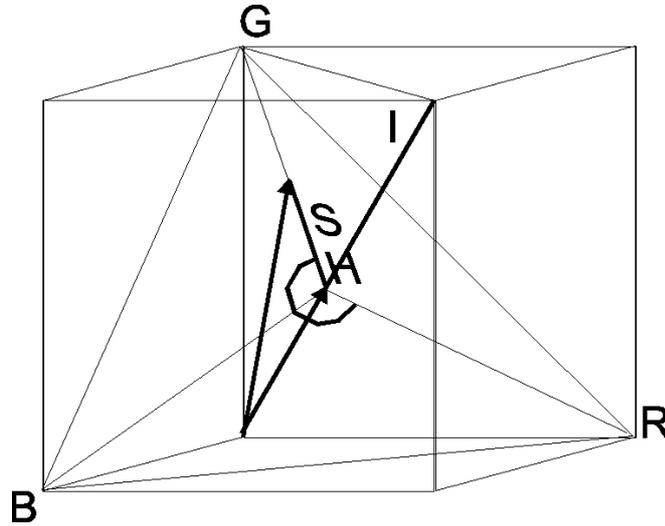


Figure 15.2: The HIS color system (I=intensity, H=hue, S= saturation)

In this exercise we will integrate the aeromagnetic image $H_{r_{mag}}$ with the enhanced SPOT Panchromatic image $S_{pot_{gfsm}}$. The method that we will use for merging these images is to assign the variations in the total magnetic field to HUE and the digital numbers of the enhanced SPOT Panchromatic image to INTENSITY while keeping the Saturation at a constant level.

First two intensity independent Cartesian axes m_1 and m_2 are defined in the triangle plane perpendicular to the I axes in the color cube.

The relationship between m_1 and m_2 and Hue and Saturation are graphically illustrated in Figure 15.3 Normally Hue is defined at 0 at red and its value increases clockwise. However to start at magenta and proceed through blue, green and red, H should be negative and a phase shift of 60 degrees has to be considered Saturation is set at a constant level so that over the full circular range of HUE the vector stays inside the color triangle. One can calculate that the saturation component should be about 60 when the intensity component ranges between 0 and 255. Once M_1 and M_2 are expressed in terms of H and S, we need to transform the M_1 , M_2 and I axes back to RGB in the color cube. It can be shown that the following set of linear equations perform such a transformation.

$$R=0.577*Spotgfsm+2*0.408*60*\cos(\text{degrad}(-60-Harmagt))\downarrow$$
$$G=0.577*Spotgfsm-0.408*60*\cos(\text{degrad}(-60-Hrmagt))+0.707*60*\sin(\text{degrad}(-60-Harmagt))\downarrow$$
$$B=0.577*Spotgfsm-0.408*60*\cos(\text{degrad}(-60-Hrmagt))-0.707*60*\sin(\text{degrad}(-60-Harmagt))\downarrow$$

- Make sure again that all images are assigned an **Image** domain, as the color composite operation currently only accepts the domain **Image**.
- Create a color composite. Overlay the boundaries of the polygon map **Mastgeol** to verify your interpretation.



- Repeat the transformation for different S values and interpret the results.
- Repeat the transformation to combine the relief shaded total field and the original total field images.

15.4 Spatial analysis

In the following exercises we are going to perform some simple spatial analysis tasks to define areas with a high probability for gold mineralizations. As is often the case in frontier prospecting areas, there are only few known mineral occurrences (five) of which information on the style and grade of the mineralization is very limited. Therefore an assessment of the mineral potential by spatial analysis can be done only on a qualitative basis with a hypothetical model. In areas where more information is available, more sophisticated techniques, known as predictive modeling, can be employed (Agterberg, 1989; Bonham Carter, 1990).

Imagine that you are working for a mining company in the Pistol Lake area and you have to test an hypotheses for gold mineralization. Field information is extremely limited, but you do know that gold mineralization in the area is often related to banded iron formation.

First of all you consider the mapped banded iron formation and their near vicinity as targets for exploration.

Secondly consider the shear zones that cross-cut the BIF occurrences, as a higher priority target for exploration as you expect epigenetic enrichment in shear zones.

15.4.1 Reading attribute data from gold prospects

The objective of this exercise is to read attribute data related to a point map of gold mineralizations.

In the Pistol Lake area there are a few locations with known mineral occurrences (Roscoe, 1984 and others) Attribute data of these occurrences are stored in the table `Prospect`. In a GIS we have the capability to link attribute data with their location on a map.



- Retrieve attribute data on the grade, width of mineralized zone, owner etc. for the known mineral occurrences from the table `Prospect`.
- Display a color composite of the TM bands for topographic reference.
- Add a data layer containing the point map `Prospect` as an overlay using appropriate symbol and color annotation.
- Open pixel information and add the point map `Prospect`.

! What is the particular metallic mineral association for gold in this area ?
In which lithological unit are the occurrences located ?

15.4.2 Overlaying maps to visualize spatial associations between gold deposits, BIF outcrops and faults

The objective of this exercise is to check visually the spatial relationship between the BIF outcrops and gold occurrences it would be useful to display the banded iron formation enclaves in relation to the point map `Prospect`.

An essential task to be performed by a GIS in any geoscientific activity is to study the spatial associations between the different spatial data types of a geoscientific data base. It is very important that the GIS user understands how different spatial data can be georeferenced. Furthermore one should be aware of the various ways in which such spatial associations can be represented on the screen. Note that raster data have a fixed scale and georeference. Display of vector and point data is more flexible and can be overlaid on various scales and georeferences.



- If the display of exercise 15.4.1 is still current, zoom in on the area of known gold occurrences. Otherwise display the gold occurrence again with reference to the TM color composite.
- Add as data layer, the segment map `Bif`.
- Study the spatial association between the gold occurrences and BIF outcrops
- Add another data layer, the segment map `Fault`.



How many of the known occurrences are likely to be a secondary gold mineralization ?



- Display the merged image of the SPOT Panchromatic image and the high resolution areomagnetic data.
- Overlay the segment map `Bif` and delineate the anomalies in the geophysical data that are likely related to the banded iron formation.

15.4.3 Creating a distance dependent probability model for gold deposits related to BIF outcrops and shear zones

The objective of this exercise is to model zones of influence by using the distance calculation and defining a probability function.

Distance calculations are used for a wide range of GIS applications and are often used to model zones of influence from points, lines or polygons. The first step in creating buffer zones is to calculate the distances to the source areas. As a result each grid cell will be assigned a value according to the distance of the closest source.

Because it is known that the few gold prospects (4 in total) in this area are related to banded iron formation and it is also known that retrograde metamorphism may have redistributed gold in the surrounding metasediments, a first criterium to define a probability zonation of gold mineralization is to consider the areas within and in the closest vicinity of the BIF outcrops.



- Calculate the distances from the Bif outcrops by using the raster map `Bif` as source map. Select output raster map `Dbif`. To do so, double click on the icon **Distance** in the operations list. Select as a source map `Bif`. Create a representation `Dbif`. Accept the defaults by clicking the OK button.
- Display the point map `Prospect` on the distance map and find out how much distance there is between each of the known gold occurrences and the BIF outcrops.



- Create from the distance map two buffer zones around the BIF outcrops. One from 0 to 75m and other from 75 to 150 m.
- Create a new domain `Buffer`. You do this by selecting: **File, create, New domain**. The domain should be a **class** and click on **Group**. Now you enter the names and the boundary values of the different classes in the domain. To do it select from the menu bar **Edit, Add item**. Use the following upper bounds 75, 150, 100000.
- When you are ready, close the `Buffer` domain.
- The last step is to use the program slicing. Select: **Operations, Image processing, Slicing**. Select raster map `Dbif`. Select output raster map `Buffer` and the domain `Buffer`.
- Display the map `Prospect` on the buffer zones.

We will consider the buffer zone around the BIF outcrops of 75 meters width. By making a cross map between the `Buffer` map and `Prospect` map, dividing the number of prospects that appear in each buffer zone and counting the number of pixels of each buffer zone. You can make a rough estimate of the probability to find a gold deposit in the zone from 0 to 75 m compared to the zone from 75 to 150 meters.

The second criteria to define areas with a high probability for gold mineralization according to the hypotheses to be tested, is the occurrence of shear zones and faults that intersect the banded iron formations and their near vicinity. The line of reasoning is that those fold could have acted as channel ways to transport gold enriched fluids from the BIF's during fault zone activity under greenschist metamorphic condition.

We can model such a selective fluid transport by assigning relative weights in the distance calculation. To simplify our model we will assign a relative weight of 0 (unlimited fluid transport) for the fault zones and 1 for outside the faults.



- Type the following formula on the command line of the main ILWIS window:
`Bifa=iff(isundef(Fault),Bif,Fault)↵`
- Perform the distance calculation again using the Bifa map as source map. Type as output Dbifa.

In order to model a decrease in relative probability from the BIF's outcrops and fault zones a function of the following type can be used:

$$P(\text{gold deposit}) = e^{-b \cdot \text{distance}} \quad [15.9]$$



- Create a probability map according to this formula and adapt constant b in such a way that the fall-off of probability is roughly consistent with the relative probabilities defined for the 75 m buffer zones.
- Type the following formula on the command line of the main ILWIS window:
`Pro=exp(-(0.085)*Dbifa)↵`
- Use a precision of 0.001. Create and use a domain value Pro with precision of 0.001. Create and use a representation for the domain Pro.



- Combine the probability map Pro with one of the remotely sensed images for topographic reference using a suitable representation. Create a legend and map annotation for final cartographic output.

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