Mapping active fault-induced changes in soil and vegetation. Roer Graben (Belgium).

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ABSTRACT

The recent seismic activity of the border faults of the Roer Graben has regional and local effects on topography as well as on the composition, chemistry and wetness of soils and on the vegetation overburden. Though sometimes quite important and visible on air photos and satellite imagery, these effects are most often quite subtle and a high spectral resolution is necessary to detect them. The objectives of our investigation were to map and quantify the variations in topography, soils and vegetation at the limit of the crustal blocs separated by known faults and to study the causes of these variations in relation with the fault activity, geometry and deformational mechanism. We focussed our analysis on the following phenomena: (1) change in soil mineralogical and physical composition (lithology) due to the vertical or lateral displacement of the faults that produce a contact between different lithological units, (2) change in soil moisture when a fault is acting as a dam, (3) change in the nature and density of vegetation related to soil composition or wetness and (4) vegetal stress related to water or to soil chemistry. After calibration of the image data and a field spectral measurement campaign, the hyperspectral data have been processed with different techniques, mainly based on ENVI concepts of minimum noise fractions (MNF), pixel purity index (PPI), n-dimensional visualizer and analyser, spectral endmembers, spectral unmixing and SAM classifications, in interactive and automatic “hourglass” modes. Due to the very specific local effects of the presence of a fault trace, the images have been split in local subsets. Hyperspectral data proved effective to discriminate or identify small changes in the spectral properties of the surfaces. A high spatial resolution was needed to delineate detailed changes in the landscape. It is well accepted by the scientific community studying structural geological effects that a pixel size of 3m x 3m is optimal. Thermal images have been used in the study of soil wetness and vegetation wetness (evapotranspiration). A detailed LIDAR DEM provided by the Ondersteunend Centrum GIS-Vlaanderen of the Vlaamse Landmaatschappij was used to study the topographic effect of faulting when present. A particularly fruitful approach is the combination of topography and spectral imagery to delineate the expression of the faults. Testing this in an area submitted to periglacial geomorphology where the faults were already studied in detail with the combination of geomorphological, geophysical and geological (trenching) investigations, brings new information on the effects of these specific faults on their surrounding environment. The effects of the faulting on spectral signatures of vegetation inside single plots of land have been evidenced where the faults traces were known or interpolated. However, the anthropogenic effects outrange the geologic related effects, and it was not possible to propose new fault traces in general. However, candidates for fault-related hyperspectral variations were proposed where no other indices in morphology were evidenced.

Keywords: Hyperspectral signatures, Geology, Active Tectonics, Seismicity, Vegetation, Roer Graben

1. INTRODUCTION

Recent investigations of strong historical earthquakes [1],[2] and paleoseismic studies conducted in the Roer Graben [3],[4],[5] demonstrated that large earthquakes with magnitude greater than 6.0 can occur in northwestern Europe. Thus, it is now widely recognised that this highly densely populated industrialized region contains a high risk for that type of natural events. To evaluate the potential of the occurrence of such earthquakes, it is fundamental to first identify at the Earth surface the trace of the faults which can generate such earthquakes and then to study their activity in the geomorphology and the geologic archives.

Since 1996, scientists of the Royal Observatory of Belgium developed methodologies to identify slow active faults. They are based on morphological observations, detailed geologic mapping and geophysical prospection. They were applied successfully in the Roer Graben, the most seismic active zone of northwestern Europe. The techniques allow to identify with great precision (1 m) the surface trace of an active fault in the geologic context of the Roer Graben. Unfortunately, the control of the fault trace position is purely local. For this reason, it is important to use other methodologies to complete the cartography of active faults at a larger scale (kilometric to deca – kilometric).

The recent activity of the border faults of the Roer Graben have regional and local effects on topography as well as on the composition, chemistry and wetness of soils and on the overlying vegetation. Though sometimes quite important and visible on air photos and satellite imagery, these effects are most often quite subtle and a high spectral resolution is necessary to detect them. Thus, we conducted investigations using high spectral resolution to map and quantify the variations in topography, soils and vegetation at the limit of the crustal blocs separated by the known faults and to study the causes of these variations in relation with the fault activity, geometry and deformational mechanism.

We focussed our analysis on the following phenomena:

- change in soil mineralogical and physical composition (lithology) due to the vertical or lateral displacement of the faults that produces a contact between different lithological units
- change in soil moisture when the fault is acting as a dam
- change in the nature and density of vegetation related to soil composition or wetness
- vegetal stress related to water or to soil chemistry

Active normal faults – The case of the western border of the Roer

Along a seismogenic normal fault, one crustal block (the footwall) delimited by the fault undergoes continued uplift through many earthquake cycles, whereas the other one (the hangingwall) is subsiding. Surface rupture along a fault produces a fault scarp with a free face and a sharp crest. As surficial material are usually low-consolidated, debris of this material accumulates quickly at the base of the scarp. Below the debris slope, a wedge of alluvium overlaps the debris slope and the lower original surface that was offset by faulting. The debris and wash slopes form a colluvial wedge that provides stratigraphic evidence for a surface faulting event. With the time, the scarp degradates with a decrease in the slope angles. It is important to note that the space created at the base of the scarp in the hangingwall is also favourable for the accumulation of aeolian sediments.

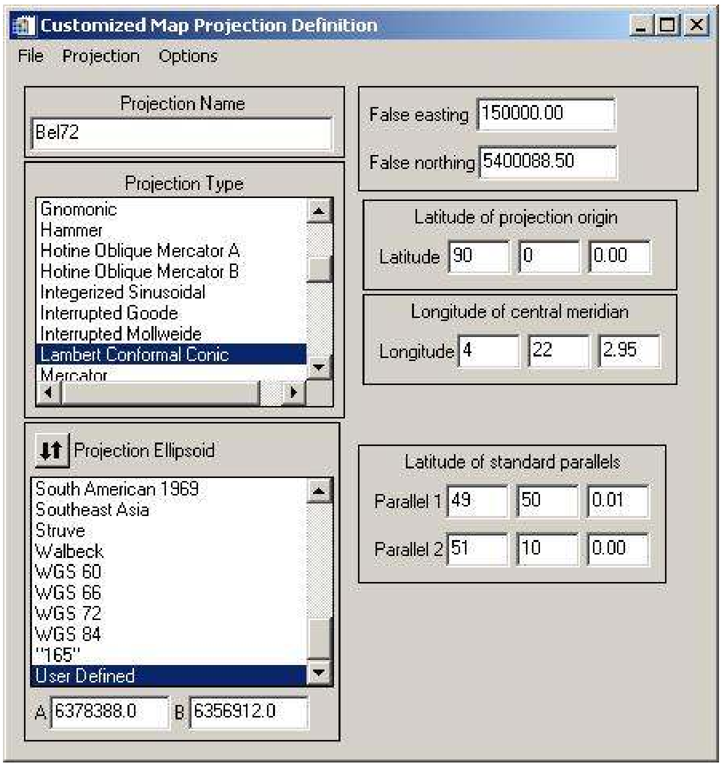
This is a typical situation along the Bree fault scarp, a part of the western border of the Roer Graben. The Bree fault separates the Kempen Plateau (to the west) from the Roer Graben (to the east), and its geomorphic signature consists of a 10 km long sharp scarp slope with 15-20 m of topographic offset. The scarp displaced the main terrace of the Maas river formed during the Cromerian (between 700 and 400 ka B.P.). It corresponds to the northeastern border of the Kempen Plateau, which is the footwall and consists of terrace gravels (Zutendaal gravels) deposited by the Maas River. In the hangingwall, the Zutendaal gravels have been eroded by the Rhine, which afterwards deposited the Bocholt sands. These formations are the basement on which the Maas formed its more recent terraces which are the typical landscape of the region. The region was later covered by aeolian sands during the Riss and Weichselian glacial events, and Holocene sediments are mainly alluvial deposits. At the fault, the base of the Zutendaal gravel is vertically displaced over more or less 35 m and aelioan deposits accumulated in the hanging wall at the contact of the fault. This means that at the scarp and at a few dm of the surface, it exists generally along the Bree scarp a sharp contact between terrace gravels and aeolian cover sands.

Field observations indicated also that the fault is a hydrological barrier. In many places, the watertable is near the surface in the footwall whereas its top is at depths greater than 15 m in the hanging wall.

2. DATA PRE-PROCESSING

2.1 Raw Mosaic

We used the radiometrically, geometrically and atmospherically corrected CASI data, acquired on the 23th of June 2003. The mosaic is composed of 10 flight lines (strokes) of 11 km long and 900 m wide each, with a lateral overlap of one third. The flight lines have a SE-NW orientation. The images were georeferenced in the Lambert Belgium 72 projection system (fig. 1).



Projection Name: Bel72

Projection Type: Lambert Conformal Conic

Projection Ellipsoid: User Defined

A 6378388.0 B 6356912.0

False easting 150000.00

False northing 5400088.50

Latitude of projection origin: Latitude 90 0 0.00

Longitude of central meridian: Longitude 4 22 2.95

Latitude of standard parallels:

Parallel 1 49 50 0.01

Parallel 2 51 10 0.00

Figure 1. The Lambert 72 projection for Belgium used in this project

The raw mosaic of the 10 strokes has a dimension of 11 km X 6km, with 96 spectral bands ranging from 0.4050 to 0.9470 µm.

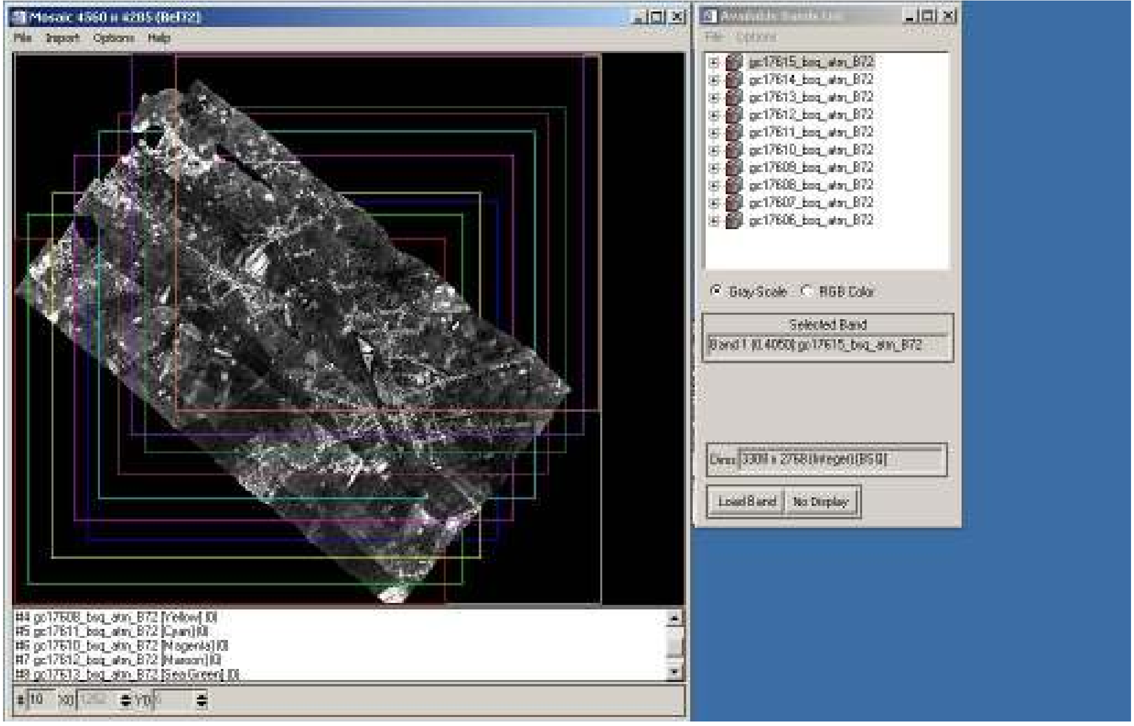


Figure 2. Mosaic of flight strokes

The fault traces are almost parallel to the flight lines. Therefore the order of the superposition is important, and was, from SW to NE: 6-7-9-8-11-10-12-13-14-15, which means that image 8 is above 9 and image 10 is above 11 (fig.2.).

2.2 Rotation and Spatial Subset

A clockwise rotation of 50 degrees and a spatial windowing of the whole area were performed in order to bring the file size from 3.6 Gb to 1.5 Gb to fasten further processing. Resampling by nearest neighbour does not modify the radiometric values (fig.3.). The georeference is kept and vector overlays are still possible.

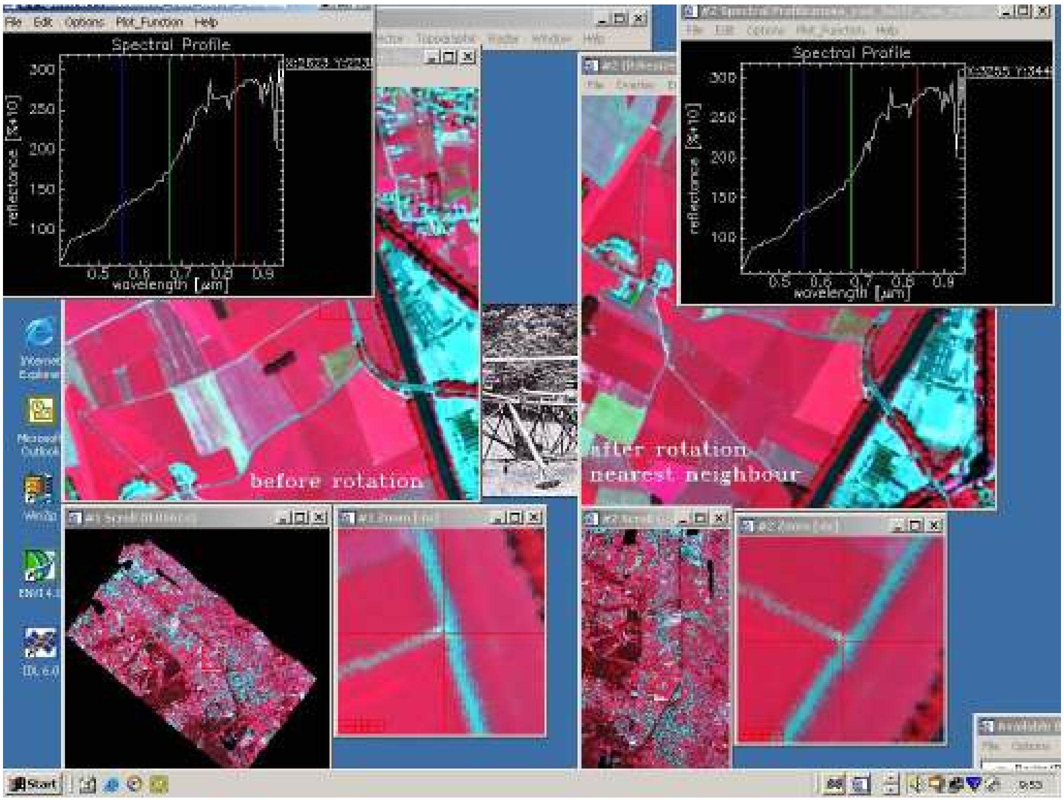


Figure 3. Example of spectral signature at a crossroad before and after rotation.

2.3. Bad Values Masking

A visual interpretation of a colour composite, associated with spectral curves edition show the presence of data that have to be removed prior to further automatic procedures. These undesired data have several sources:

- presence of clouds or important haze: some cirrus is present in the strips, as well cloud shadows and haze (fig.4)

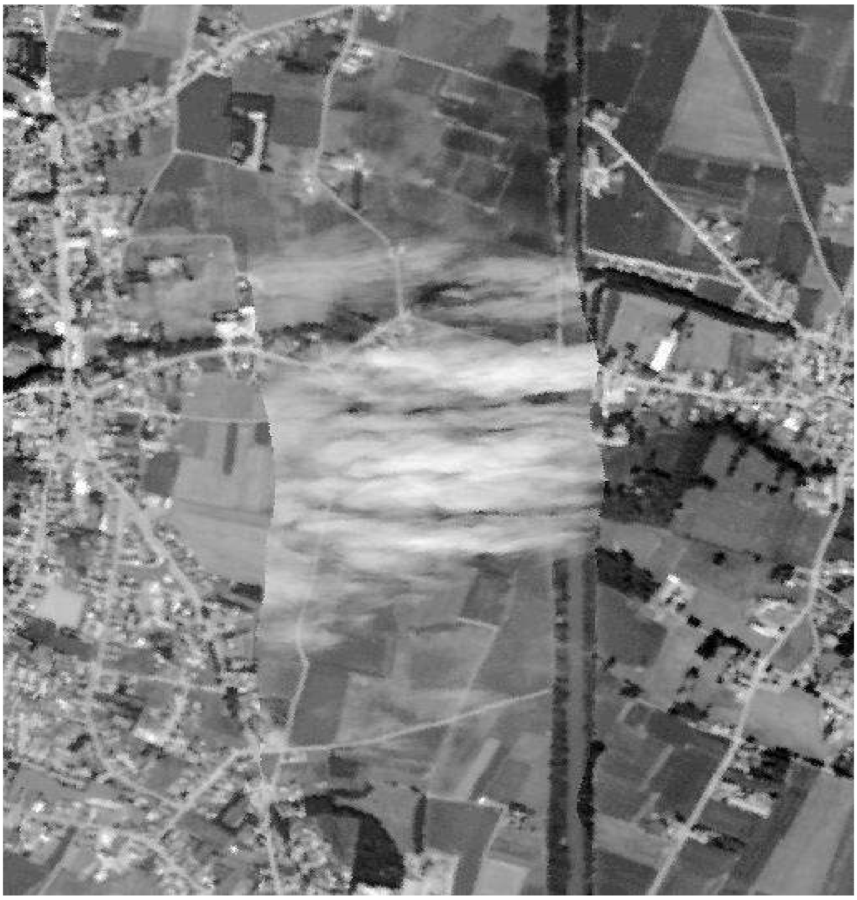


Figure 4. Local presence of clouds

- mosaicking process: the oblique individual strokes are stored in rectangular files with outside filling by zero values. During the mosaicking, these zero values have to be ignored. However, zero reflectance values are also present in the spectral signatures of some pixels (e.g. water in the NIR, and very dark shade). If the pixel in the underlying stroke is the same as the one containing zeros in the overlying one, the spectral curve will be correct. In some situation, it is no the case due to geometric differences between strokes. This happens for the banks of the Zuid-Willemsvaart, where water pixels „containing zero values in the NIR, in the overlying image correspond to trees in the underlying image (fig.5).

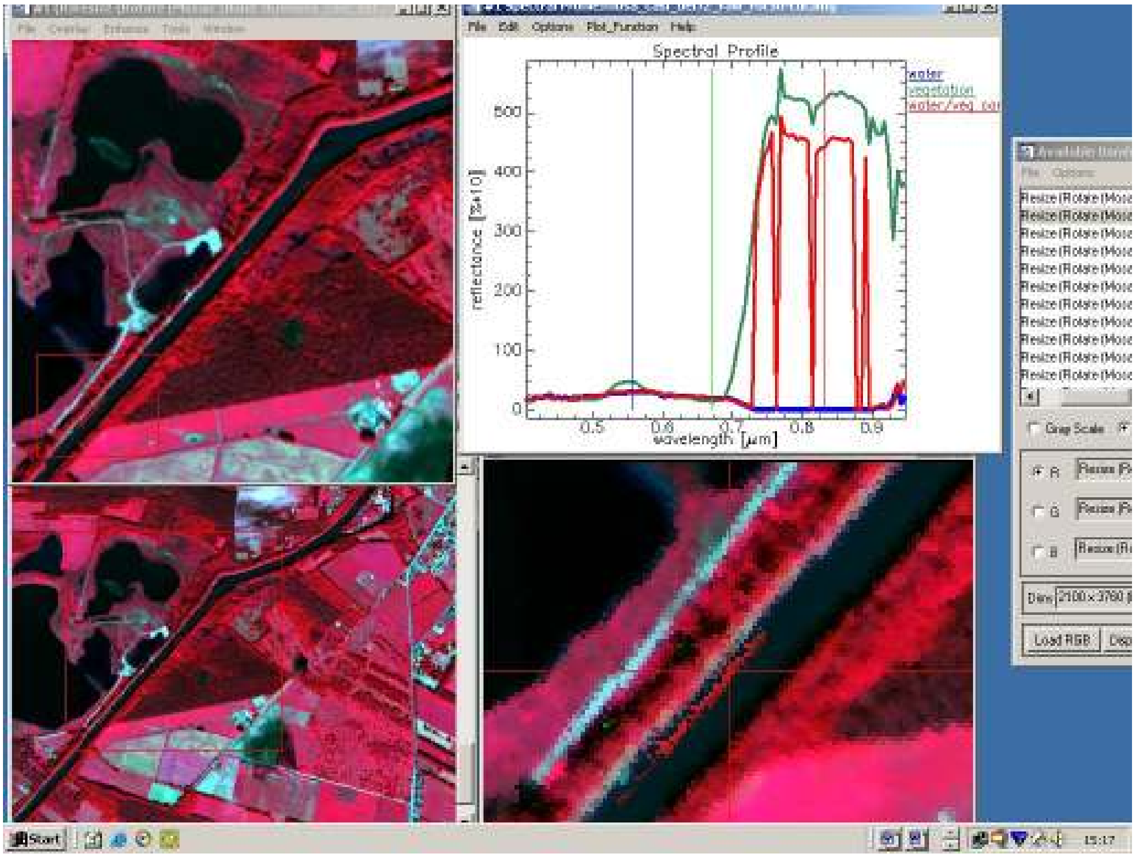


Figure 5. Errors introduced during the mosaicking process

- Non adjacent stripes (fig. 6)

Figure 6. Gaps in the mosaic

- The combination of the removal of invalid values leads to a final mask (fig.7.).

Figure 7. Final mask. The areas in white in the image will be excluded from the data processing.

3. DATA PROCESSING

3.1 Locating the fault traces and the trenches on the images

Vector overlay allows comparing the fault traces and the landscape.

Though no general rule can be put forward concerning the indirect effects of the presence of faults, many indices can be found, showing local effects. The most important expressions of the faults are :

1. Topographic effects showing a gentle 2-3 m composite scarp slope just at the east of the fault plane. This is the expression of the “colluvial wedge”
2. Changes in vegetation: the upper plateau of the Maas terrace is occupied by forest whereas the foot is occupied by meadows
3. Wetness effects, the water table being closer to the surface on the western side. This is expressed in subtle changes in the spectral signatures of vegetation. The effects are however local and change with the climatic and topographic conditions and with the nature of vegetation.

The two first phenomena are rather obvious to observe, even on black and white air photographs, and do not need to be measure further with detailed spectral features.

The principal interest of hyperspectral data remains thus to detect the expression of the fault trace on rather flat areas and in a single type of vegetation. To reach this objective, we used several approaches of information extraction:

1. colour composites of three single spectral bands (fig.8) or of linear combinations of 3 or more than 3 (NDVI, brightness indexes,…)
2. MNF minimum noise fraction colour composites.
3. The classical ENVI « hourglass » MNF-PPI-nD visualizer-SAM
4. 3D visualisation (using the LIDAR DEM provided by the VLM)
5. Unsupervised classifications

Figure 8. True colour composite

Minimum Noise Fraction, Pixel Purity Index computation and N-Dimension Spectral analysis lead to a Spectral Angle Mapper classification shown in figure 9.

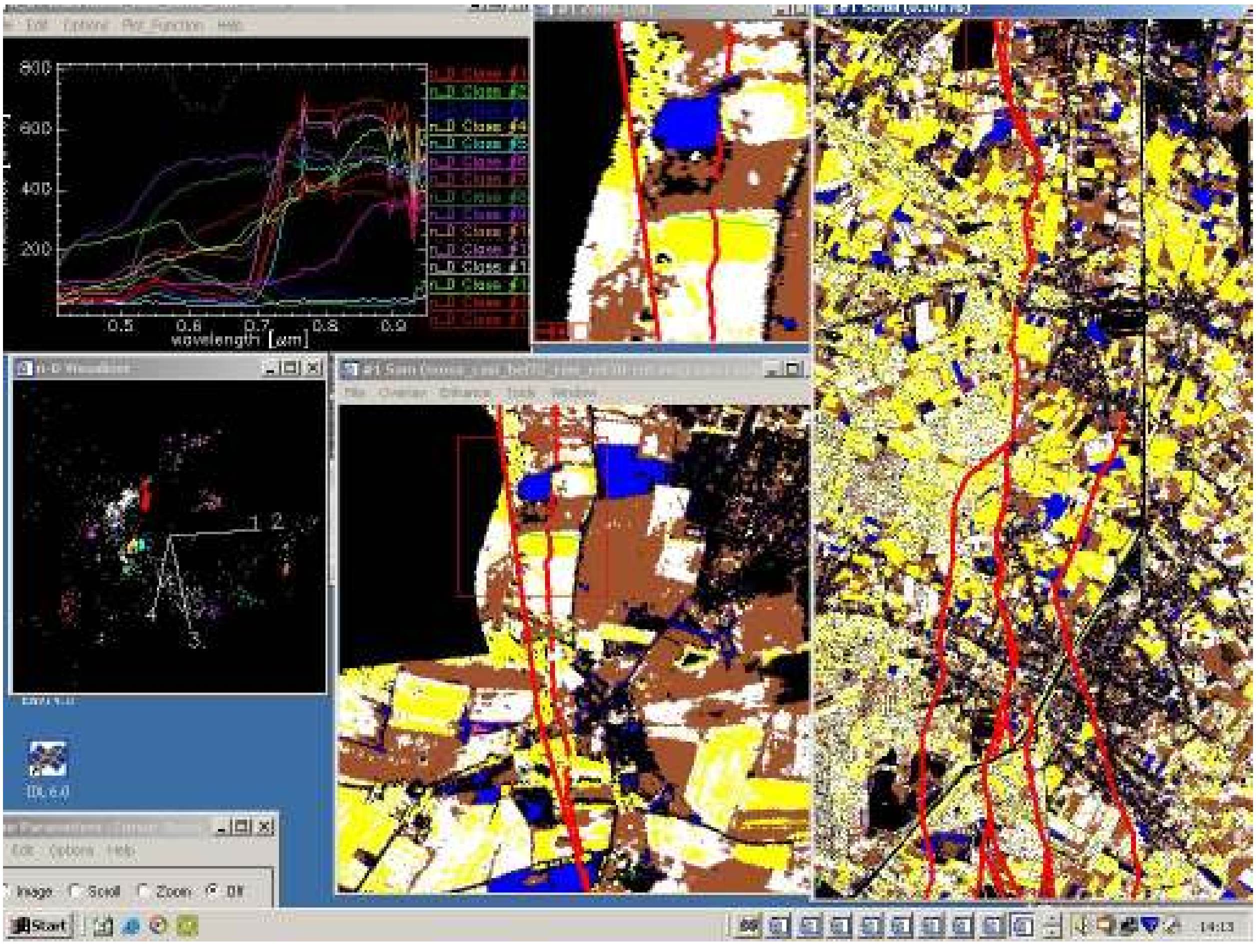


Figure 9. ENVI "hourglass" MNF-PPI-SAM classification. The variations of spectral signatures are well evidenced.

3D visualisation is particularly efficient to illustrate topographic and spectral features. Figures 10 shows an example of a superposition of DEM and VNIR colour composites.

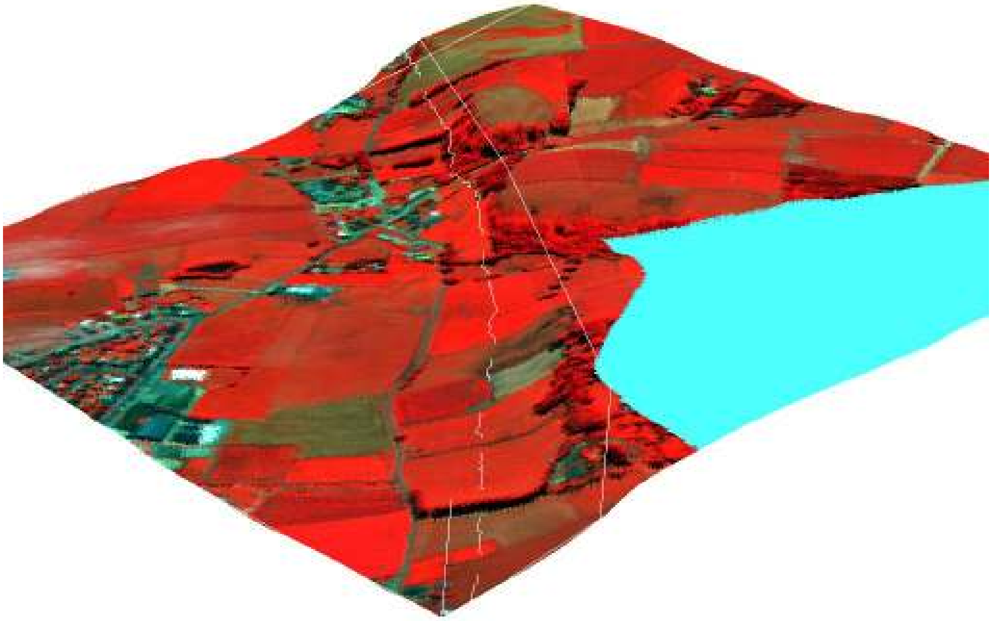


Figure 10. DEM and VNIR colour composite near Houben.

4. RESULTS AND CONCLUSION

Seventeen sites (indicated on fig. 11) have been interpreted From south to north:

1. Spectral contrast spreading in two contiguous meadows east of De Bek. There is no expression in morphology but the fault trace is evidenced by geophysical methods.
2. Contrast in the grass of a football field north of Armenbos.
3. Small scarp on bare soil (continuation of site 2)
4. Contrast in a meadow. No a priori knowledge of the presence of a fault and no topographic feature
5. Well known trace visible in morphology
6. Known trace with visible surface expression
7. Possible passage of a fault (not known)
8. Known fault position in trench n. 4
9. Clearing with change in signature of natural vegetation and change of slope
10. Valley of Itter at Rooiermole/Slagmolen. Nice spectral contrasts in a meadow. This is due to a change in the red edge (red-NIR) shape and position, and to the accurate position and depth of the red absorption and green reflection. Though well expressed on the hyperspectral images, the contrast in vegetation is not discernable in the field. This is a new discovery and an electric profile will be realised to cross-check the presence of a fault.
11. Palaeo thalweg cut by the fault east of Steenberg. The delimitation of the fault position by the topography is not accurate due to continuous erosion of the small scarp (heavy rains, storms) but the position of the trace is clearly assessed by spectral signatures limiting the palaeo thalweg, cause by a difference in vegetation and wetness. Confirmed by trench 3.
12. Contrasts in the forest close to site 11
13. Scarp (man made ?)
14. Contrasts visible in the Infra Red range only. To be checked.
15. Marked scarp and difference in spectral signature. Well known contrast in the vicinity of Trenches 1 and 2 . (Both 14 and 15 are in the Houben area).
16. Site where the faults separates in 3 branches near Bree. One of them is well evidenced.
17. Site where the fault separates in three branches near the city of Bree. One of them is visible.

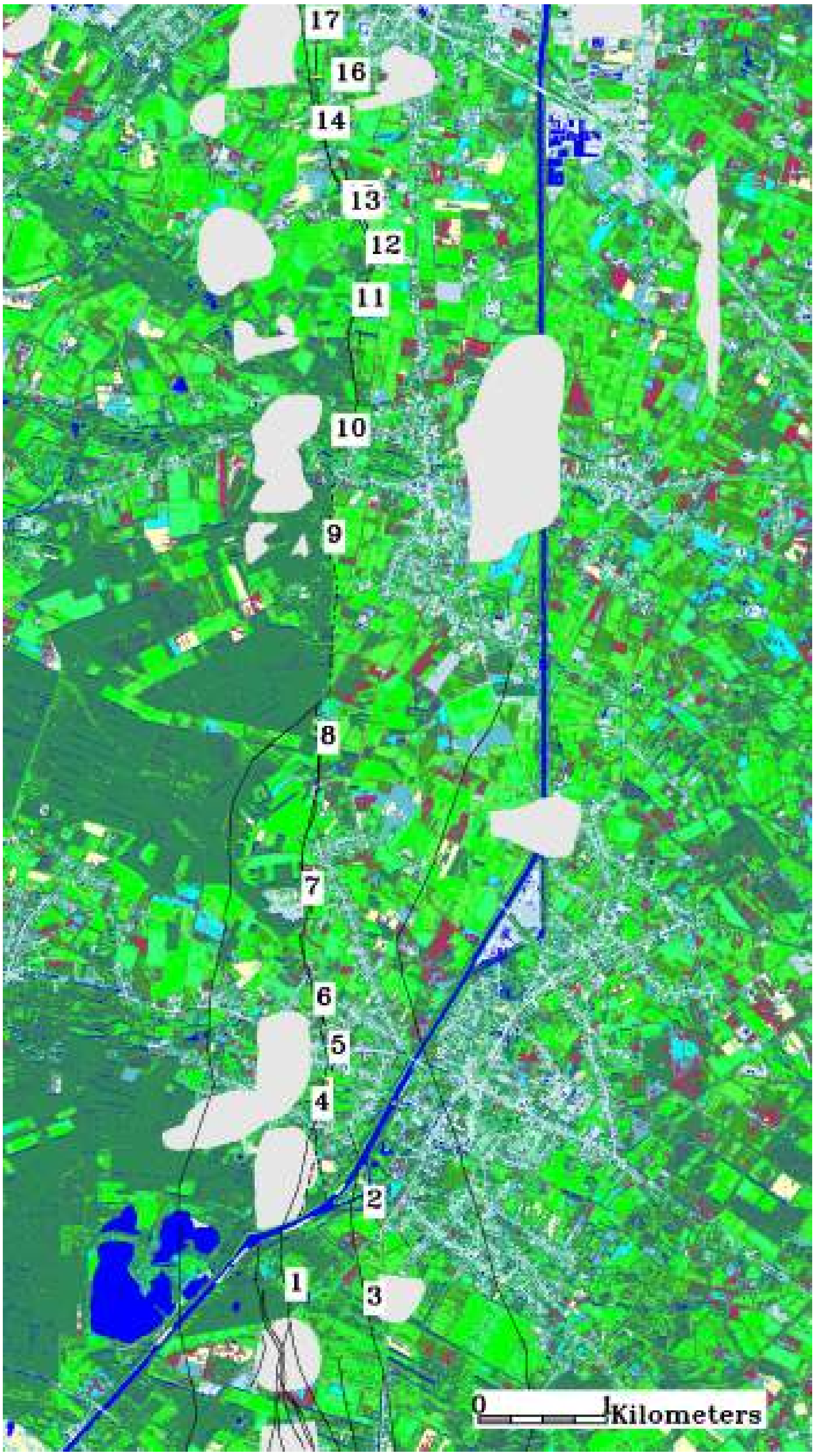


Figure 1l. Locations of the sites on a classification image.

To conclude:

- The location of the fault traces in the Roer graben are know with precision in places where geophysical profiles have been realized, or where trenches have been opened.
- Regional and local effects on topography as well as raw variations in the composition, chemistry and wetness of soils and on the overlying vegetation are sometimes important enough to be visible on air photos and satellite imagery, needing no further (hyper)spectral investigation.
- The same effects can be also quite subtle and not even detectable on low resolution DEM's and multispectral imagery. It was thus useful to test new methodologies like hyperspectral airborne surveys to complete the cartography of active faults in the area.
- Though no general rule could be outlined, it has been demonstrated that the complex variations of soils and vegetation linked to the presence of active faults can be locally evidenced on the base of hyperspectral signatures.

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