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Geological Mapping Using Landsat-7 Satellite Image, Compared With GIS Data. Case Study From Lake Volvi Basin, Central Macedonia, Greece

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Abstract. Geological mapping is one of the fundamental acts that a geologist should perform in order to proceed to higher levels of a research. This includes basically, mapping of lithological units and tectonic lines (faults). Satellite images give geologists a unique opportunity to observe the complex interaction of large-scale geological structures that make up Earth's landscape. Furthermore, digital satellite data can be manipulated and enhanced in order to accentuate the surface expressions of certain geological features. In most of the cases, this is usually done in "ideal" test sites, with absence of vegetation, soil cover, etc. In this paper, various digital image processing techniques were applied on Landsat-7/ETM+ satellite image, in order to produce the most appropriate images for geological mapping, in typical inland Mediterranean terrain. The basin area around Volvi lake was chosen as case study. Boundaries of photo-lithological units and photo-lineaments are drawn on the above satellite image. The results are compared with digitized geological maps of 1/50.000 scale and are evaluated.

Key words: Lithology, lineaments, remote sensing, GIS, Lake Volvi.

Introduction

Different digital image processing techniques have been proposed by geoscientists for lithological and tectonical mapping. Usually, the test areas are remote territories (deserts most of the times) with little geological knowledge about them, but having the great advantage of large-scale surface exposure of rock types. In this paper, we studied an area that was mapped by geologists on the field, the past decades, but having small degree of surface exposure of rocks, since vegetation covers a considerable part of the area. We preferred to study this areas with Landsat-7/ETM+ satellite image, since it combines the good spectral information (many bands) with the satisfactory for geological mapping, spatial resolution (15 m).

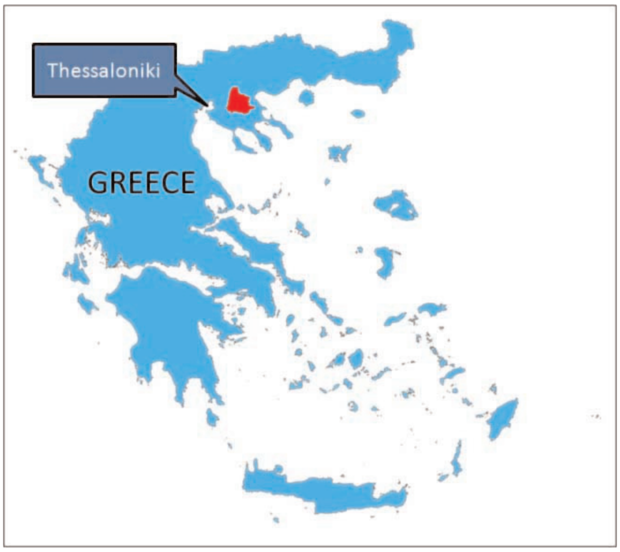

Fig. 1. Location of the study area.

Location and physical background of the study area

The study areas that has been selected, is the basin of Lake Volvi, in Macedonia area, Northern Greece (Fig. 1): The basin of Lake Volvi covers an area of 954.2 km^2 and the heights range from 11 m to 1129 m.

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Concerning its lithology, it consists of recent deposits, clays, amphibolites, limestones and marbles, gabbros, gneisses, granites, rhyolites, schists, phyllites quartzites and ultra-mafic rocks. (geological maps of Institute of Geological and Mineral Exploration/IGME).

The area belongs to the Mediterranean Climate Type, Csa (BALAFOUTIS, 1977), that is, it is characterized by hot and dry summers and mild and wet winters. Also, a big part in the study area, is covered by agricultural land and natural vegetation (broad-leaved forests and sclerophyllus vegetation).

Materials-Methodology

The following data and software were used:

– Geological maps covering the study area. Sheets: Zangliverion, Vasilika, Thermi, Stavros, Sochos, Arnaea and Poliyiros, 1/50,000 scale, source: Institute of Geology and Mineral Exploration/IGME.
– Landsat-7/ETM+ satellite image, covering the study area (http://image2000.jrc.ec.europa.eu)
– Image processing software: ENVI 4.7.
– GIS software: ArcGIS 9.3.

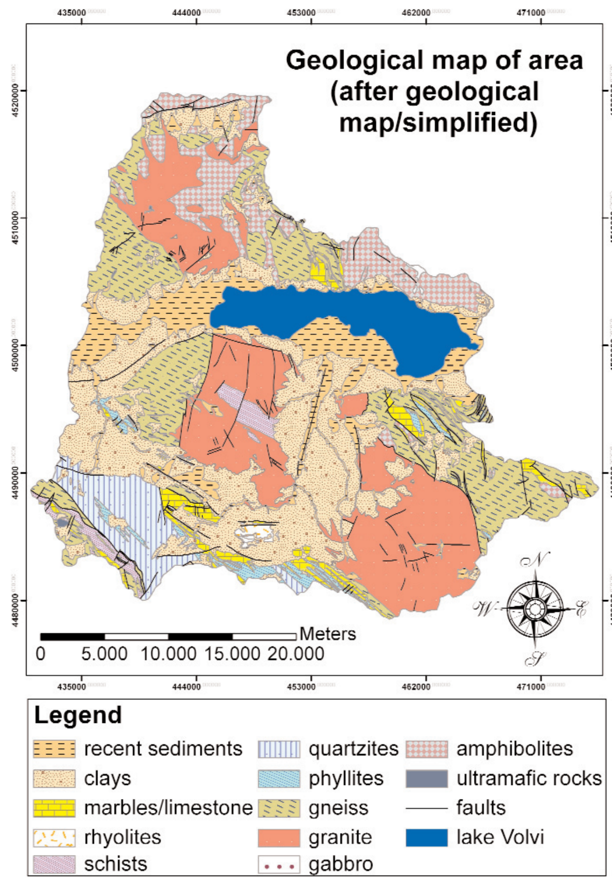

Fig. 2. Geological map (lithology and faults) of the study area, derived from geological maps of IGME (simplified by the authors).

Lithological units and faults were digitized from the maps of IGME. After that, the geological map (simplified lithology and faults) and the rose diagramme were constructed (Figs. 2, 3). Then, certain digital image processing was applied to the satellite images, so that lithological units and photo-lineaments could be extracted. Lithological map and lineaments' map were also produced. Finally, rose-diagrammes were constructed for comparing tectonic data from geological maps and lineaments derived from satellite image.

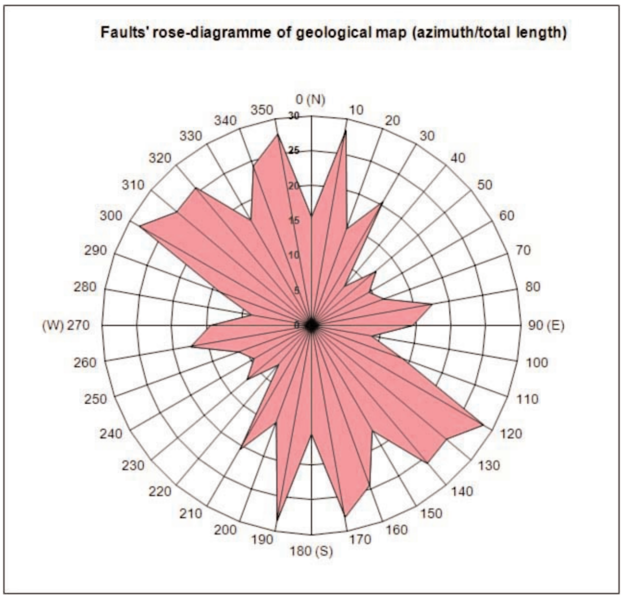

Fig. 3. Faults' rose-diagramme (azimuth/total length per class) of the study area. Source: geological maps of IGME.

Landsat-7/ETM+ image processing

Basics

Landsat-7 ETM+ image contains both multispectral and panchromatic bands with different spatial resolutions (30 m and 15 m). For this reason, an image sharpening methodology (else called merging or fusion) had to be applied, so that all the bands would have the same pixel size and could be processed easier. There are numerous methodologies for this, such as Principal Components Analysis/PCA sharpening, IHS (or HSV) sharpening and Color Normalized (Brovey) sharpening. Among them, the PCA sharpening was chosen because by this technique we can have all 6 multispectral bands (except the thermal one) sharpened at once and not only 3 at a time.

In the PCA sharpening, a principal components transformation is performed on the multispectral data. The PC band 1 is replaced with the high-resolution band (PAN in our case), which is scaled to match the PC band 1, so that no distortion on the spectral information occurs. Then, an inverse transform is performed. The multispectral data is automatically resampled to the high resolution pixel, using a nearest neighbour, bilinear or cubic convolution technique (ENVI User's Guide, 2005).

Landsat-7/ETM+ image processing/lithological mapping

The second step was to produce a Normalized Difference Vegetation Index/NDVI image which has the form NIR-R/NIR+R. In the case of a ETM+ image, the formula becomes 4–3/4+3. This was necessary to be done to extract areas with dense vegetation (bright pixels).

Several image processing techniques, from past-published papers, including HSV and PCA transformation, band ratios, filtering and simple False Colour Composites/FCCs were applied on the Landsat image for extracting lithological boundaries, but the results were not satisfactory.

The best results occurred when a 5/3,4/2,3/1:RGB band ratio FCC image was produced (AMRI *et al.*, 2010). Furthermore, an equalization radiometric enhancement was applied on the above image. As a result, an image occurred which proved to be more suitable for lithological mapping, compared to others, for our study area (Fig. 4). A digitization of lithological boundaries on this image, produced the map of Figure 5.

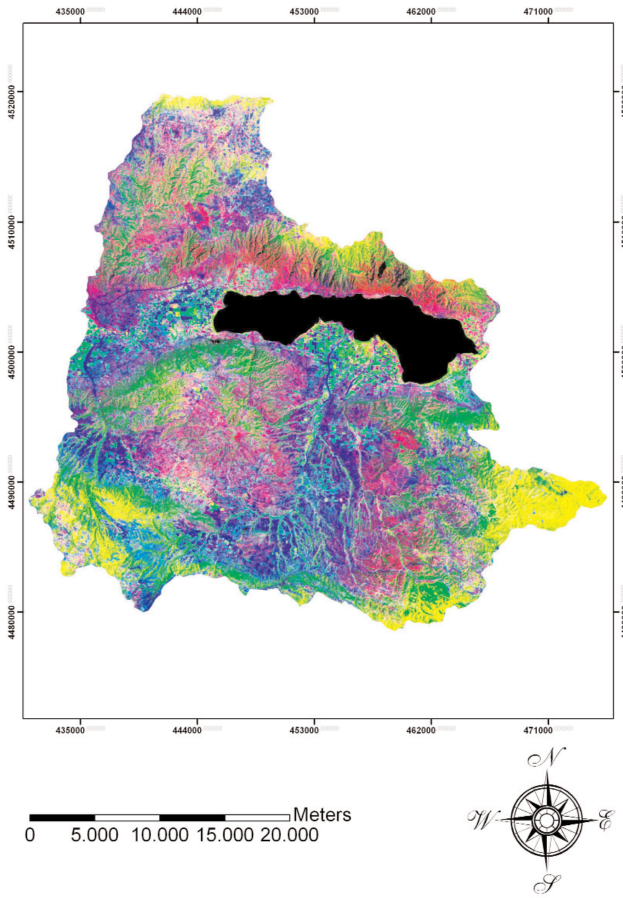

Fig. 4. 5/3,4/2,3/1: RGB Landsat image, for lithological mapping.

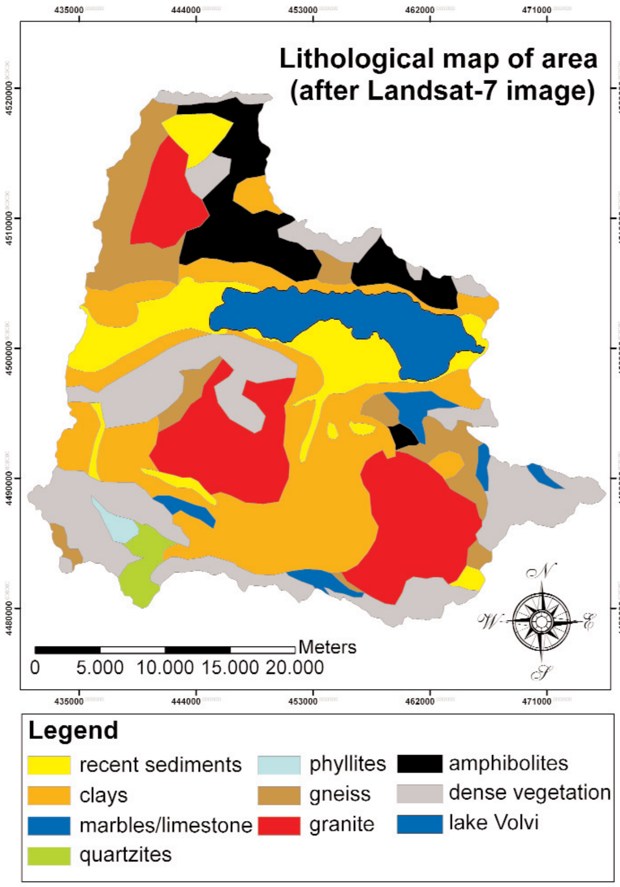

Fig. 5. Lithological map derived from the Landsat-7 image of Figure 4.

Landsat-7/ETM+ image processing/lineaments' mapping

Concerning lineaments, the most suitable methodology applied on the Landsat image, proved to be the 5/3,5/1,7/3:RGB FCC image (RAHARIMAHEFA & KUSKY, 2009). An equalization enhancement was applied on the above image for improvement. After the digitization of lineaments on this image, the image-map of Figure 6 was created. The rose-diagramme of the lineaments drawn, is shown on Figure 7.

Comparison of the derived data and results

Considering that the geological map of IGME is the "correct" source, we come to the following results:

1) The recent sediments around Lake Volvi were mapped with high accuracy.

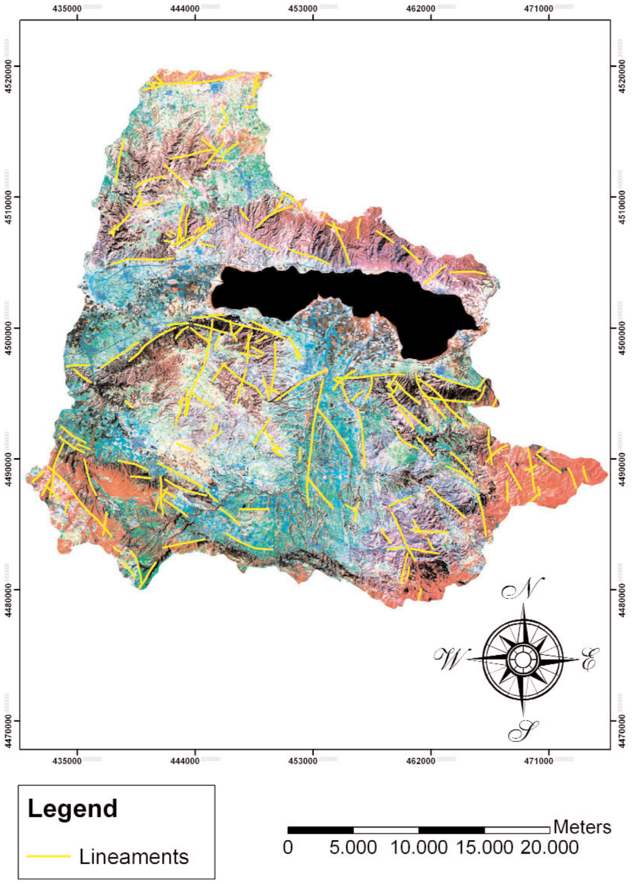

Fig. 6. Lineaments delineated form 5/3,5/1,7/3:RGB Landsat images.

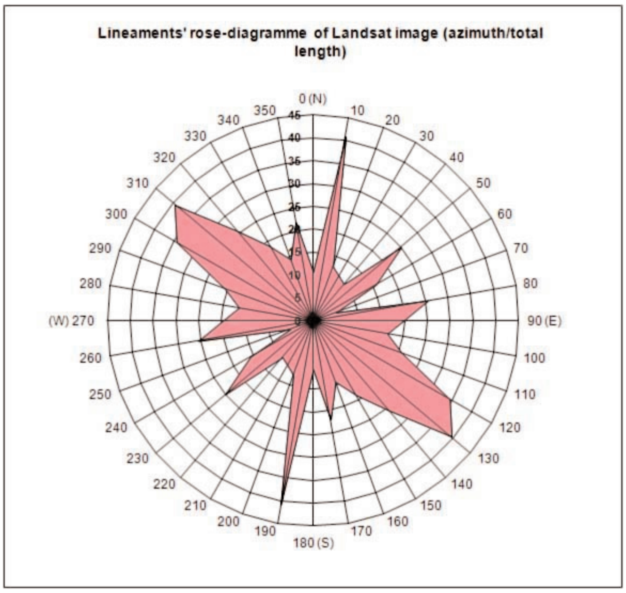

Fig. 7. Lineaments' rose-diagramme (azimuth/total length per class), as derived from Landsat image.

2) Clays were mapped with high accuracy.

3) Marbles and limestones were mapped with moderate accuracy, that is, in some cases they coincide in both the satellite image and the geological map of IGME while in some other, they were mapped in areas were according to the geological map of IGME, there are not present, and vice versa.

4) Quartzites were mapped partly, because of the dense vegetation.

5) Phyllites were mapped partly, because of the dense vegetation.

6) Gneisses were mapped satisfactory, excluding the areas of dense vegetation.

7) Granite was mapped with satisfactory accuracy.

8) Amphibolites were mapped with high accuracy.

9) Rhyolites, schists, gabbro and ultramafic rocks, could not be mapped either because they occupy small areas or because they are located into areas of dense vegetation.

From GIS measurements we found out that the total length of faults of the geological map (323.11 km) is smaller than that of the lineaments delineated from the satellite images (368 km).

From the study of the rose diagrammes, we see that the major strikes (directions) of the mapped lineaments is the same with those of the faults, that is N–W and NW–SE. The minor groups of lineaments on the satellite images that have similar strikes with minor groups of the faults on the geological map, that is NE–SW.

Summarizing, concerning discrimination of lithological units, Landsat-7/ETM+ satellite image proved satisfactory, with the exception of densely-vegetated areas or lithological units that cover relatively small areas.

In the detection of tectonic lines, major similarities were found between the satellite lineaments and the faults of the geological map, concerning strike (direction). The total length of the (photo)lineaments is higher than that of the faults from the geological map and this is caused by the fact that not all lineaments are tectonic lines and a thorough field investigation is the next step. Nevertheless, judging from experience on earlier projects, a significant number of the mapped lineaments will prove that they correspond to faults, meaning that the geological maps need a revision in that field.

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