Qualitative assessment of satellite images in the detection and mapping of lineaments: Case study for neotectonic faults in Central Macedonia (N. Greece)

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Abstract

Lineaments are large-scale linear features on the Earths' relief that can be identified either on maps, aerial photographs and satellite images or in other primary or secondary representations of the surface of the Earth. One of reasons why these lineaments and their interpretations are of great scientific interest to geoscientists is because they are likely to indicate or imply the presence of possible faults. Remote sensing images having different spatial and spectral resolution as well as spatial and temporal coverage, are nowadays an important source of information for the identification of lineaments. The purpose of the present study is to assess the efficiency of processed satellites images, acquired by different spaceborne remote sensing instruments on various satellites (LANDSAT, SPOT, ERS, ENVISAT, TerraSAR-X), in highlighting lineaments. The province of Central Macedonia (N. Greece) is selected as study area, due to its special scientific interest and existance of a plethora of geological information.The evaluation is carried out with reference to selected neotectonic (active) faults.

1. Introduction

Lineaments are linear features on the Earths' relief that can be identified either on maps, aerial photographs and satellite images or in other primary or secondary representations of the surface of the Earth or even on more complex products that involve integrated use of images, Digital Elevation Models (DTMs) and 3D visualizations (e.g. Dimadi and Tsakiri-Strati, 2004) and whose interpretation is of great scientific interest to geoscientists. Hobbs (1904) originally defined lineaments as significant lines of the landscape that reveal the hidden architecture of the rock basement. O'Leary et. al. (1976) redefined lineaments as mappable, simple or complex linear features of surfaces whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differ from the pattern of adjacent features, presumably reflecting some sub-surface phenomenon (Astaras, 1990). The term "photo-lineaments" was being used in the past, as aerial photographs were the only means to map these features for many years. Ever since new remote sensing instruments, both airborne and spaceborne, were introduced, the term “lineaments” has been established in geosciences to practically include linear features recognized on any kind of imagery (Mouratidis, 2005).

Satellite images provide geologists with a unique opportunity to synoptically observe the complex interaction of large-scale geological structures that make up the “face of the Earth” as seen from above. Additional digital image processing techniques can be performed on the satellite data, in order to enhance specific geological features. Lineaments detected on imagery usually represent traces of discontinuities such as bedding planes, lithological boundaries, joints and fractures on the earths’ surface, but more importantly they can indicate or imply the presence of possible faults. Experience and careful judgement are required to distinguish a diagnostic lineament from those surfacial linear features that have no origin in depth (e.g. hills, cliffs of erosion, drainage network, vegetation patterns) (Mostafa and Zakir, 1996). A quantitative analysis of lineaments based on visual interpretation can be subjective (Mouratidis, 2005) and lead to contradictions between studies. In this respect, one conservative approach is to delineate only the most clearly discernible, longer lineaments (Novak & Soulakellis, 2000). Nevertheless, the unarguable contribution of lineament research in tectonics, seismic risk, exploration of minerals, oil and water and several other applications, have established lineament identification as a standard technique for various purposes beyond the scientific domain (Mostafa and Zakir, 1996).

In this paper, another less subjective and interesting aspect of lineament studies is addressed, concerning the qualitative performance of satellite imagery in lineament detection. This aspect is constantly becoming more and more attractive due to the plethora of available satellite images acquired by different sensors (LANDSAT, SPOT, ERS, ENVISAT, TerraSAR-X). The evaluation is carried out on the basis of predefined targets, namely important faulting structures that are of special geological interest in the province of Central Macedonia, N. Greece.

2. Study area and data

2.1. Study area

The broader area of interest is located in Central Macedonia, Northern Greece (Figure 1) and is adjacent to the city of Thessaloniki, which is the second most populated city in Greece (about 1000000 habitants). This region presents great interest for various scientific research disciplines, including geological and earthquake applications, subsidence and other geophysical or environmental studies. The relief of the study area varies from completely flat areas to mountainous regions with steep slopes. Elevation values vary from zero (and in some cases a few

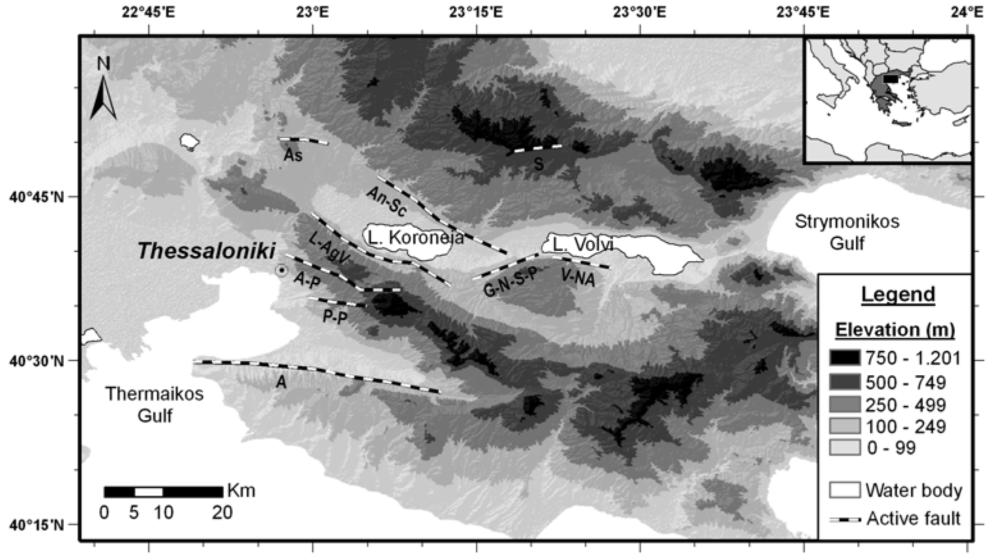

Figure 1. *Location of the broader study area and neotectonic (active) faults used for the evaluation of satellite imagery. A-P: Asvestohori-Polihni fault, L-AgV: Lagina-Agios Vasilios fault, P-P: Pilea-Panorama fault, A: Anthemountas fault, As: Assiros fault, An-Sc: Analipsi-Scholari fault, G-N-S-P: Gerakarou-Nikomidino-Stivos-Peristeronas fault, S: Sohos fault, V-NA: Loutra Volvis-Nea Apollonia fault (after Tranos et al., 2003; Zervopoulou & Pavlides, 2005 & Vamvakaris et al., 2006)*

meters below mean sea level) to up to a maximum of 1201m (Hortiatis/Kissos). Vegetation consists mainly of agricultural areas (51%), shrubs (21%), forests (12%) and pastures (7%) (Greek Ministry of Agriculture, 1994).

The main focus of research in the study area is concentrated in the Mygdonia Basin, approximately 30 km east of the city of Thessaloniki. It is a basin of tectonic origin named after a former homonymous lake, which included the contemporary lakes of Koroneia and Volvi (Figure 1). This basin constitutes the most seismically active region in Northern Greece and has been the epicentral area of the most recent severe earthquake (1978, M_s=6.5). Dominated by a N-S extensional stress (Martinod et al., 1997), Mygdonia and its complex structure, as well as the surrounding area, have been the subject of several multidisciplinary studies (see e.g. Vamvakaris et al., 2006; Chatzipetros et al., 2005 and references therein).

2.2. Satellite images

Two major categories of satellite imaging are currently being exploited for geoscience applications; (a) SAR (Synthetic Aperture Radar) images using microwaves and (b) multispectral images operating in the visible (VIS) - infrared (IR) part of the electromagnetic spectrum.

The nature of the surface phenomena involved in radar imaging is inherently different from that of VIS/IR images. When VIS/IR radiation strikes a surface it is either absorbed, reflected, or transmitted. The absorption is based on the molecular bonds in the (surface) material. Thus, this imagery provides information on the chemical composition of the target.

When radar microwaves strike a surface, they are reflected according to the physical and dielectrical properties of the surface, rather than the chemical composition. The strength of radar return is affected by slope, roughness, and vegetation cover. The conductivity of a target area is related to the porosity of the soil and its water content. Consequently, radar and VIS/IR data are complementary, as they provide different information about the target area. An image in which these two data types are intelligently combined can present much more information than either image by itself (Leica Geosystems, 2008).

For the purposes of this study both VIS/IR and SAR images were used, covering respective wavelength ranges (Table 1) and having different spatial resolution and coverage (Figure 2).

Table 1. *Spectral coverage of the satellite data*

Satellite/Sensor	Type	Wavelength range
LANDSAT-5/TM & 7/ETM+	VIS/IR	0.45μm - 12.5μm
SPOT-5/HRG	VIS/IR	0.48μm - 1.75μm
ERS/SAR & ENVISAT/ASAR	Radar (SAR)	3.75cm - 7.5cm (C-band)
TerraSAR-X	Radar (SAR)	2.4cm - 3.75cm (X-band)

Note that when it comes to the actual visual result, high spatial resolution radar images (e.g. 3 m for TerraSAR-X data) are by no means equivalent to high resolution images in the VIS/IR spectrum (e.g. 5m for SPOT-5). This phenomenon occurs due to the nature of microwaves and the speckle (inherent noise in SAR imagery) that significantly reduces the quality of the image. Nevertheless, as a general rule of thumb, 30m resolution imagery (e.g. LANDSAT-5/TM or ENVISAT/ASAR) can be used for mapping at about 1:200,000 scale, while 5m resolution (e.g. SPOT-5 or TerraSAR-X data) could be efficiently used for up to 1:25,000 mapping scales.

2.3. Selection of neotectonic faults

Taking into account the spatial coverage of the satellite images, as well as several other factors such as their spatial and spectral resolution and processing possibilities, specific active faults in the study area were selected to facilitate compare-

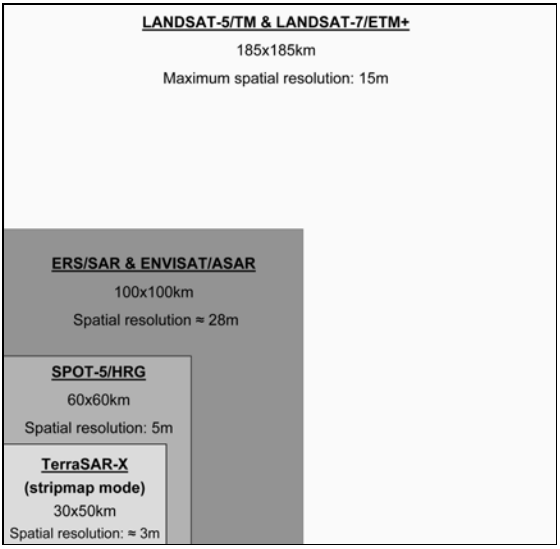

Figure 2. *Spatial resolution and coverage of the satellite images used in this study*

sons between the satellite data. More specifically, the following comparisons were considered intriguing: LANDSAT against SPOT, ENVISAT against TerraSAR-X, LANDSAT against ERS and SPOT against TerraSAR-X. Several of the Mygdonia basin faults were selected (Figure 1), namely the Lagina-Agios Vasilios (L-AgV), Assiros (As), Analipsi-Scholari (An-Sc), Gerakarou-Nikomidino-Stivos-Peristeronas (G-N-S-P), Sohos (S) and the Loutra Volvis-Nea Apollonia (V-NA) faults, as well as important faults close to Thessaloniki such as the Asvestohori-Polihni (A-P) and Pilea-Panorama (P-P) faults. Finally, the important Anthemountas (A) fault of the homonymous adjacent basin of Anthemountas was included.

3. Image preprocessing

The step of preprocessing in digital image analysis of remote sensing data includes techniques destined to prepare the data for further processing and analysis. SAR and multispectral VIS/IR images require some common as well as some specific preprocessing procedures.

Speckle is a type of noise (but also contains information) in SAR systems, which occurs due to the coherency of the radar signal and the presence of statistically distributed reflecting targets within each resolution cell, resulting in a grainy “salt and pepper” appearance of SAR imagery. Because any image processing done before removal of the speckle results in the noise being incorporated into and degrading the image, in principle, images should not be rectified, corrected to ground range, or in any way be resampled, enhanced or classified before removing speckle noise. Although functions using nearest neighbor interpolation methods are technically permissible since they do not alter the pixel values, they are still not advisable (Leica Geosystems, 2008). On the other hand, speckle reduction is in all cases performed at the expense of spatial resolution and geologists in general appear to prefer a higher resolution SAR image for interpretation (Gupta, 2003). In another approach, Barbieri & Lichtenegger (2005) suggest that best SAR interpretation results occur by simultaneously analyzing unfiltered and filtered images.

SAR imagery is also dominated by inherent geometric distortions that are nonlinear across each scene and cannot be properly corrected by simply using tie points and polynomial rectification. The distortions are a function of the terrain and the SAR look angle, with major distortions along the radar line of sight, especially for non-flat areas. For this reason, true (physical) radar sensor model that correspond to the physical reality of the viewing geometry and take into account all the distortions generated in the image formation, as well as a digital elevation model, are necessary in order to geometrically correct (orthorectify) SAR images to the maximum possible extend (see Toutin, 2004). It should also be noted that geometric distortions in SAR imagery also result in “terrain induced radiometric effects”, that is, distortions in the brightness of the image pixels (Barbieri & Lichtenegger, 2005).

Orthorectification does not have such a profound effect on multispectral images, but it is still necessary, especially in mountainous terrain.

4. Data processing and analysis

For the identification of lineaments on satellite images, two major surface features are used: (a) the geomorphic features, cause by relief and (b) the tonal features, caused by contrast or tonal differences (Astaras, 1991).

As the quality of mapping lineaments depends mostly on the applied technique of image processing, some enhancement techniques make lineaments easier to recognize and permit the separation of real lineaments from false ones that are mainly topographic features (Mostafa and Zakir, 1996). In this study, some of the standard techniques suggested in relevant bibliography are applied to each dataset separately, in order to enhance linear features and compare the results.

4.1. ENVISAT/ASAR

We used geocoded ENVISAT/ASAR descending (N-S) image and apply a “Gamma Map” filter to reduce speckle (Figure 3). This kind of filtering assumes gamma distribution of the data, which is closer to the statistical distribution of radar data than the Gaussian distribution. It applies different thresholds for detecting

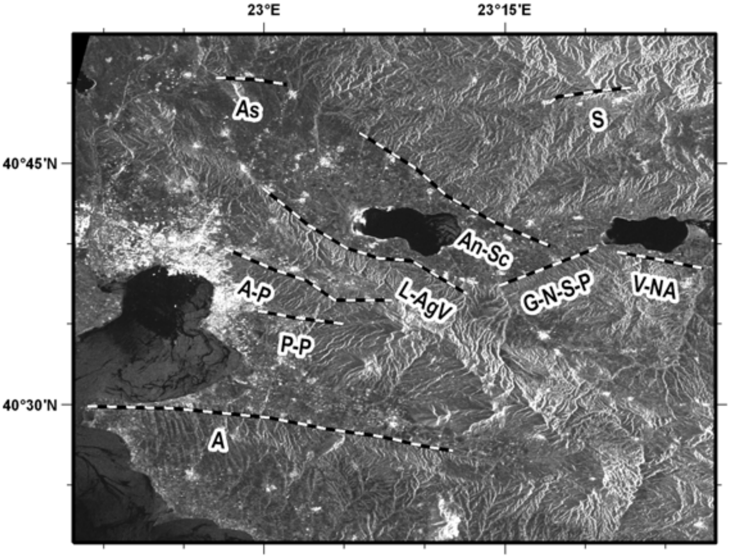

Figure 3. Gamma Map (9x9) filtered, descending ENVISAT/ASAR image and faults

separate kernels containing point scatterers, lines and edges. After this distinction is made, the respective filter is applied to that kernel. Filtering with this technique results in a smoothed image with sharp borders and linear features (Barbieri & Lichtenegger, 2005), which is convenient for the present study. On the other hand, Lee and Sigma filters that use the coefficient of variation [Sqrt(Var)/(Mean)] as a scene-derived parameter (Leica Geosystems, 2008), perform well for regional interpretation of morphological features.

Furthermore, adopting a similar methodology to Kuntz and Siegert (1999), the ENVISAT/ASAR image was subjected to separate speckle and texture filtering operations. Various filtering products (e.g. 7x7 gamma map filter for speckle reduction, 15x15 enhanced Lee variance filter, and 31x31 enhanced Lee variance filter) were then combined into an artificial RGB composite image by assigning each filter product to a different color channel.

4.2. ERS

ERS SAR is similar to ENVISAT/ASAR since they both operate in C-band and have identical spatial resolution. The difference is, we used orthorectified ERS-2 imagery, in both ascending (S-N) and descending (N-S) acquisitions (Figure 4) to considerably reduce the effect of radar shadowing and to have the opportunity to compare orthorectified SAR data against orthorectified VIS/IR images.

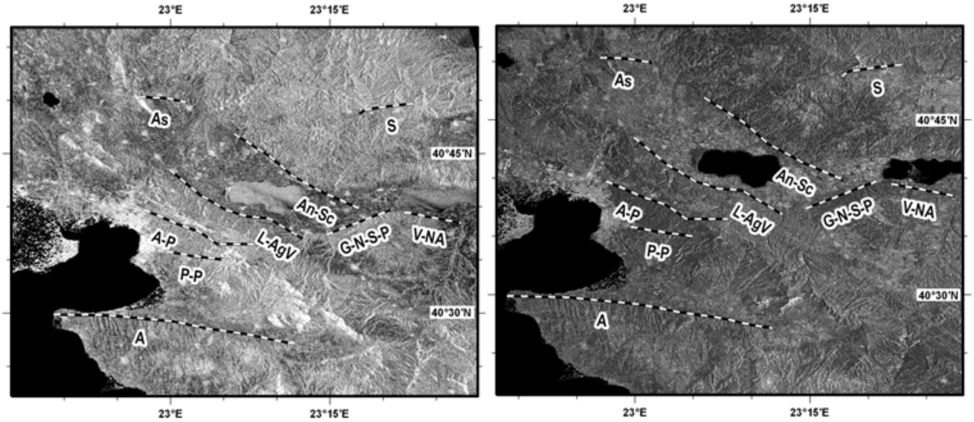

Figure 4. *Ascending (left) and descending (right) orthorectified ERS-2 images and faults*

4.3. TerraSAR-X

We used geocoded TerraSAR-X imagery (stripmap mode) with 3m spatial resolution. Speckle was suppressed using a 9x9 Gamma Map filter (Figure 5).

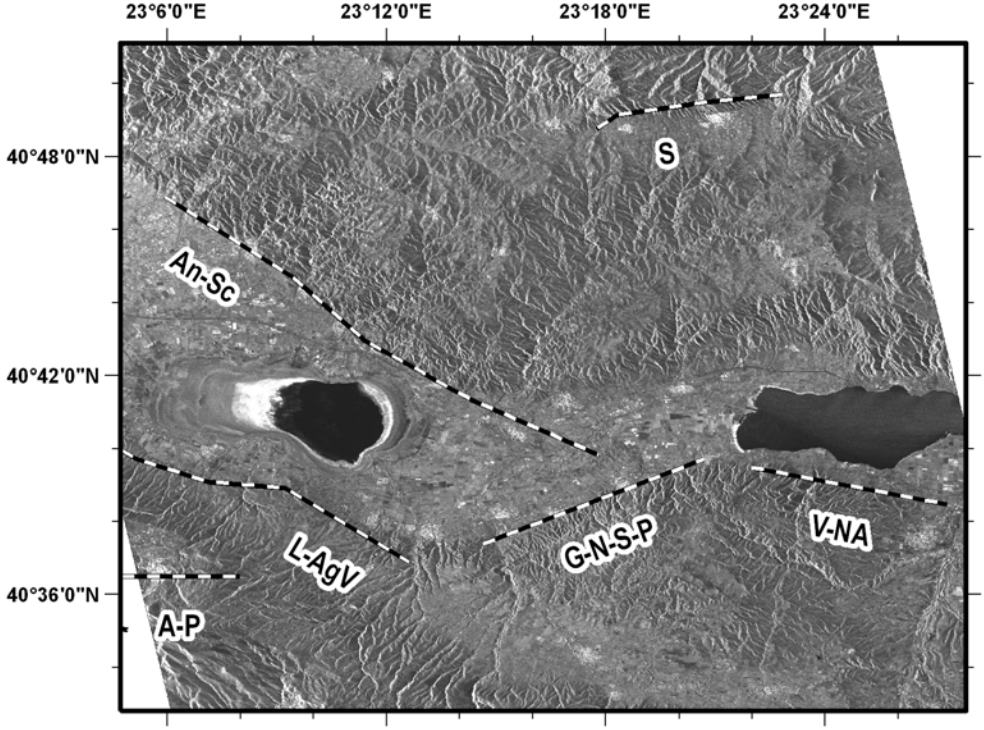

Figure 5. *Gamma Map (9x9) filtered TerraSAR-X image and faults*

4.4. LANDSAT-5/TM and Lansat-7/ETM+

Multispectral data bands tend to be strongly correlated. The Principal Component Analysis (PCA) is a technique commonly used to compress redundant information in the multispectral dataset. After implementing PCA techniques on orthorectified LANDSAT imagery, the combination of band 7 (mid-infrared, 2.08 - 2.35μm), PC-1 and PC-2 in RGB was adopted by Novak and Soulakellis (2000), as a representative example of optimum false color composite (Figure 6) of the data for geological investigations. Note that LANDSAT-7/ETM+ multispectral image was previously pan-sharpened (via PCA technique) using the equivalent panchromatic image, in order to increase its spatial resolution to 15m.

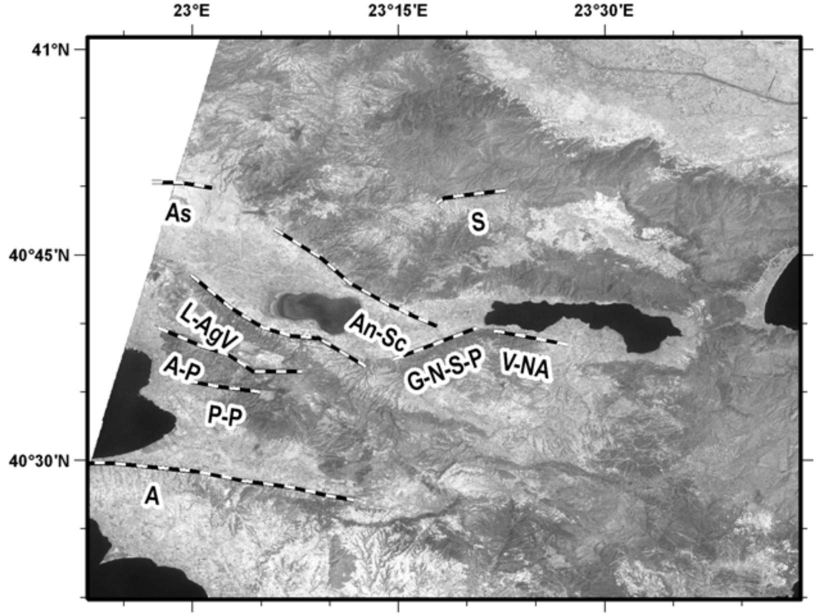

Figure 6. *Grayscale print of false color composite (R,G,B,=ETM7, PC1, PC2) ETM+ image and faults*

4.5. SPOT-5/HRG

Though SPOT data (Figure 7) have increased spatial resolution compared to LANDSAT images, they possess significantly less spectral resolution especially in the infrared domain. Hence, spectral techniques such as PCA may be applied, like in the case of LANDSAT images, by using the 4 available bands. Orthorectification is equally important, but requires the existence of a higher resolution digital elevation model compared to LANDSAT data.

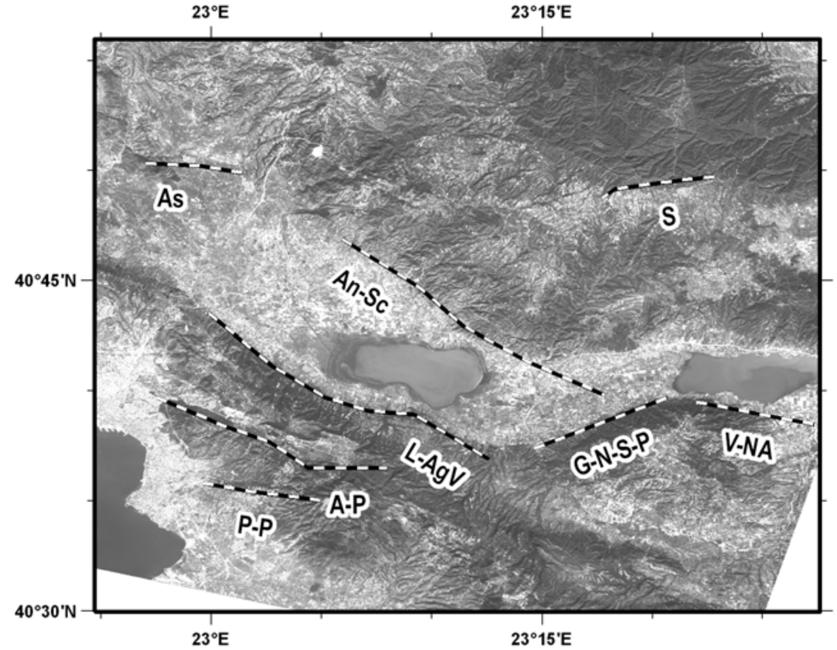

***Figure** 7. SPOT-5 panchromatic 5m resolution image and faults*

5. Results and conclusions

In the case of SAR images, inherent geometric distortions impose considerable quality constraints. Even if the images are properly orthorectified, the actual radiometry of the originally severely distorted areas cannot be retrieved (only interpolated). This phenomenon can reduce quality performance in high slope areas contrary to flat surfaces. Additionally, the quality or even capability of lineament identification highly depends on orientation since, owning to radar shadows, which are oriented parallel to the azimuth direction, linear features parallel or sub-parallel to the azimuth direction are considerably enhanced, whereas those perpendicular or almost perpendicular to the azimuth direction are relatively suppressed. It should not be neglected though that shadows comprise a very useful tool for geoscientists, since selective shadowing due to the side-looking illumination of radar systems resulting in different brightness levels can highlight linear features.

For ERS and ENVISAT/ASAR data, availability of both ascending and descending orthorectified images, although in generally very useful, in this case it proved to be of less importance, because the direction of faults in the study area are, in their majority, perpendicular or almost perpendicular to the azimuth direction (satellite flight direction), so they are in all cases less emphasized. Combination of filtered images did not produce better results and though such combinations appear to be interesting for other applications, they should be carefully interpreted.

TerraSAR-X data are a major improvement, mainly due to their increased spatial resolution, which considerably contributed to the enhanced imaging of the neotectonic faults.

Concerning VIS/IR data, the spectral range restrictions of SPOT images reduces their applicability for geological studies. On the contrary, the relative reduced spatial resolution of LANDSAT images is less important and is to a certain extend compensated by the higher spectral resolution of the data.

The phenomena involved in radar imaging are quite different from that in VIS/IR imaging. Because these two sensor types give different information about the same target (physical vs. chemical), they are complementary datasets. If the two images are correctly combined, the resultant image conveys both chemical and physical information and could prove more useful than either image alone.

In this context, processing methods incorporating multi-sensor data, like for example merging SPOT and LANDSAT images, combining C, X, and L band SAR data, or fusing SAR and multispectral images are strongly suggested for lineament studies. Nevertheless, such techniques were beyond the purposes of this work and were avoided in order to have “clean” comparisons between the various images.

Finally, further techniques such as integration of the images with digital elevation models and 3D visualizations can maximize the contribution of remote sensing satellite data to morpho-seismotectonic studies.

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