GEOLOGICA CARPATHICA, 49, 5, BRATISLAVA, OCTOBER 1998
307–313

MORPHOSTRUCTURE PATTERNS IN SATELLITE MULTISPECTRAL LANDSAT TM IMAGES

ISSAAK PARCHARIDIS

Earthquake Planning and Protection Organization, Xanthou 32, 154 51 Athens, Greece; eppogeo@hol.gr

(Manuscript received February 2, 1998; accepted in revised form September 1, 1998)

Abstract: The possibility of tectonic observations using multispectral remote sensing data is based mainly on morphostructures, which could lead directly to the structural interpretation of the area. This work aims to contribute to the creation of a morphostructure-code with a corresponding key-legend, in order to facilitate the acquisition of tectonic information by users, who do not specialize in remote sensing. The studied area covers a great part of NW Greece (Epirus Prefecture). During the summer and autumn of 1996, this region was affected by strong and disastrous earthquakes (up to 5.6 R). Data from Landsat TM have been selected and processed creating a false colour composite image and then analyzed and interpreted in order to detect the tectonic features.

Key words: NW Greece, Epirus, tectonism, morphostructure, Remote Sensing, Landsat.

Introduction

The direct recognition of tectonic features on satellite multispectral data, is based on the concept of morphostructures which could lead, through their detection and interpretation, to the tectonic analysis of an area. The recognition of the surfacial traces of faults and folds is one of the advantages of remote sensing. For many years the term "lineament" (O'Leary et al. 1976) was used to describe linear features many of which correspond to known geological structures. The possibility of structural observation from satellite data optical or radar, is based mainly on morphotectonics. The term morphotectonics is simply a contradiction for tectonic geomorphology, that is, the study of processes and forms related to any form of tectonic activity (Embleton 1987).

Recently, the term "morphoneotectonic" has been introduced. It is based on the concept that tectonic movements have brought about changes in the Earth's surface. In general these changes appear more marked and evident, the more recent and bigger are the movements (Panizza 1991). The manifestation of tectonic features depends mainly on the character of the rock and on the operating climatic conditions. Chorowicz (1984) mentioned the importance of pattern recognition for geological remote sensing applications, concluding that fundamental geological objects have their distinctive shape and geomorphological expressions and that on the digital images, their automatic recognition by computer is possible. Faults, joints and lineaments most likely have a rectilinear exposure on images and their determination depends on morphological features or on particular patterns. The recognition of folds can be done through geomorphology or the pattern of the elementary geological features. The simple recognition of a fault does not seem to be the most important factor, but the type and the dynamic that characterized it. Of course low-angle faults (nappes) are difficult to interprete since the images provide planar views from above. Such faults have a strongly curved or irregular surfacial trace and can be inferred on the basis of discordance of the foliation (Greiling 1983; Otsuki 1985; Gupta 1991). In the past, lists of classifications of faults and their photo-interpretation criteria have been created (Reading 1980; Slemmons 1982; Scanvic 1983). This paper presents an attempt to directly recognize the types of structure and their movement on the basis of morphotectonic features.

Fig. 1. Sketch map with the study area.

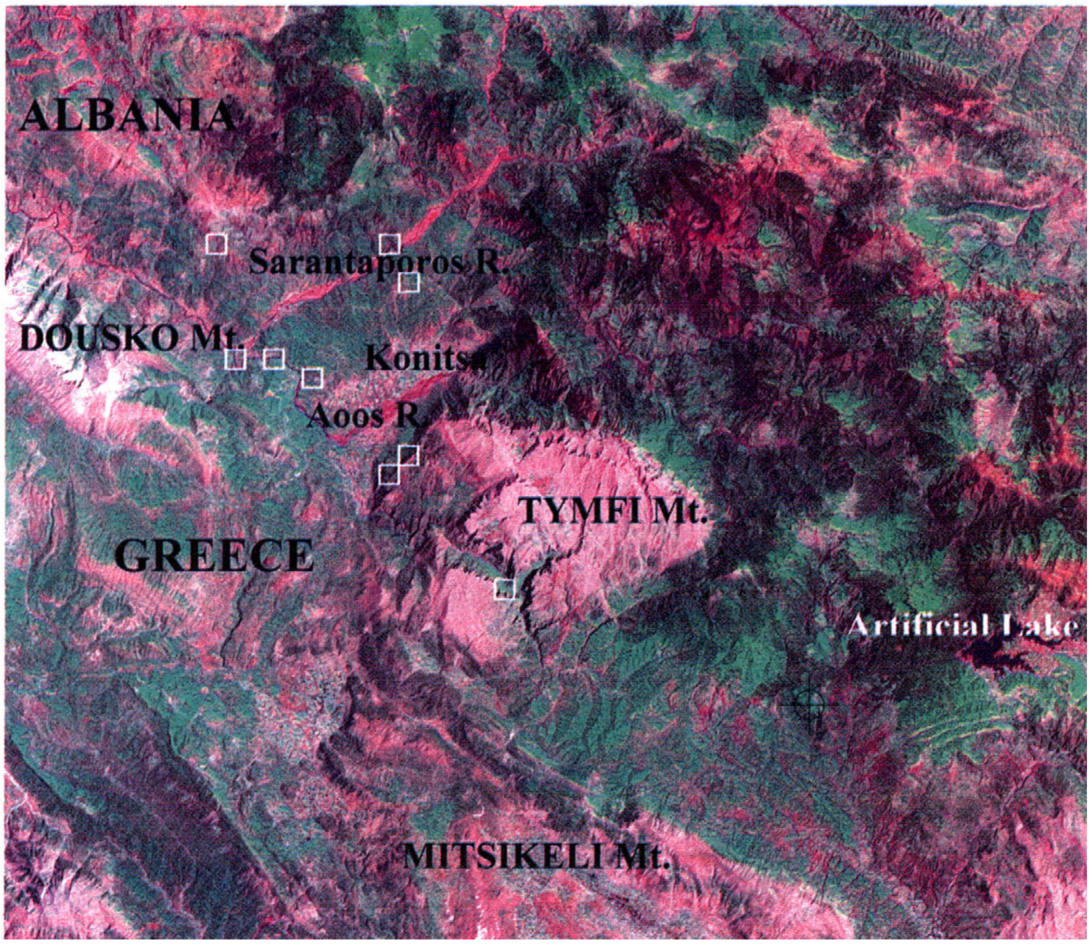

Fig. 2. False Colour Composite image created from 7, 4, 1 spectral bands of Landsat TM satellite as RGB. The white squares represent the epicenters of the main seismic events.

Location and tectonic setting of the area

The Prefecture of Epirus is located in North-western Greece and Konitsa town is in the northern part of it (Fig. 1). The area consists of a great thickness of sedimentary sequence which geotectonically belongs to the Ionian Zone. Locally in the north-eastern part of the region, there are sedimentary formations of the Pindos Zone which are thrust above the Ionian Zone. The most recent sediments in the area are fluvial terraces of the Aoos, Sarantaporos and Voidomatis rivers.

It is obvious that intense tectonic activity affected the area predominantly during the Alpine orogenetic compressive stress. The result of this is the presence of anticlinal and synclinal forms with a NNW-SSE axial direction. These forms are interrupted by a NE-SW transverse fracture zone, named as the Konitsa fracture zone, which is a product of a later extensional stress. A characteristic element of this zone is the attenuation with smaller fractures in the two edges. Another fault system with a NW-SE direction has also affected the area. The rivers Aoos and Voidomatis are related to this fault system (Papanikolaou & Parcharidis 1996).

In the 26 of July 1996 a strong earthquake was occurred in the area with magnitude of 5.2 R followed by less intense earthquakes, while a new greater one affected the area (M = 5.6 R). Dangerous phenomena such as landslides and rock falls have been observed along the active faults.

Information sources

Remote sensing data

A digital image of Landsat 5 TM was selected covering the area (subscene of the 185-032 full scene), with 7 spectral bands, dating 24-6-93 with 0 % cloud cover, 2500 columns and 2500 lines for each band and pixel size 30 × 30 meters.

An important parameter for structural applications is the azimuth and elevation of the sun at the moment of acquisition of the scene. In this case the direction of illumination (from ESE) is more or less perpendicular to the main structures. The sun's elevation is high (beginning of summer) but this does not create any problem for the information recorded because the area is characterized by high relief.

First the raw data was radiometrically and geometrically corrected so that the image can be represented on a planar surface and have the integrity of a map. The next step was to combine the adequate spectral bands and display them in the RGB (Red, Green, Blue) colour system. Different combinations of the TM bands can be displayed to create different composite effects. Different colour schemes can be used to bring out or enhance the feature under study. There are 120 possible colour combinations of the data for a large number of applications. Theory and experience, however, show that a small number of colour combinations are suitable for most applications. The optimum band combination is determined by the terrain, climate and nature of the interpretation project (Sabins 1997). In the present study the selected bands are 1, 4, 7 forming the false colour composite image 7, 4, 1 as RGB (Fig. 2). This combination provides the maximum range of colour signatures for the rock outcrops and is optimum for geological interpretation in semiarid areas. The image shows a region, mainly, of mountains and small plains composed of bare rocks or soil, and cover by scrub and extensive forested areas. The bare rock and soil are represented by magenta and pink tones, the scrub by darker greens and browns and the forested slopes by shades of green. Cultivation of cereals, fruit and vegetables are represented by the bright green patches on the flatter ground especially in the Konitsa Valley and along the rivers. In the center of the image the Tymfi Mt. and the Konitsa Valley are recognized and the Aoos, Sarantaporos and Voidomatis rivers too (in blue colour in the image), forming a rectangular type of network. The anticlinal forms of Mitsikeli and Dusko, with a NNW-SEE direction can be recognized, but are interrupted, in the middle of the image by the transverse fracture zone of Konitsa.

Field information

Two visits to the area, organized by E.P.P.O. (Earthquake Planning and Protection Organization), have been made according to a program of field studies, mapping and evaluation of the geological structures followed by remote sensing observation. In situ observations and measurements have been done mainly in the geological structures which were already recognized on the image.

Seismological data

The seismological data from the last seismic events have also been taken in account (magnitude, coordinates of the epicenters and depths). Earthquake epicentral distribution may delineate active faults. In Figure 2 the epicenters of the main seismic events are plotted (the coordinates of the epicenters were provided by the Earthquake Planning and Protection Organization seismological data base). These are distributed along the Sarantaporos River and the northwestern slope of Tymfi Mountain.

Recognition, description and analysis of the structural patterns

The manifestation of tectonic features depends on many parameters, especially on the rock type and operating climatic conditions. The freshness of appearance and type of geomorphic expression of faults is related to the age of faulting (Matsuda 1975). Geomorphological investigations into faulting can yield considerable information (Doornkamp 1986). A considerable number of geomorphological direct and indirect indicators of tectonic or recent activity exist such as: distortion of river terraces (Popp 1971), prominent high angle scarps (Cotton 1948), fresh sygmoid-shaped of ridges (Migiros et al. 1995), shutter ridges that is topographic ridges that have been offset laterally to shut off drainage channels (Cotton 1948), segmentation and deformation of alluvial fans (Hook 1972; Bull 1977), displacement of synthetic structures (Rogers & Nason 1971), faceted ridges created when scarps cut a topographic ridge (Thornbury 1954), formation of sag ponds (Cotton 1948), offset drainage channels which are especially significant because they also indicate the sense and amount of lateral displacement along a fault (Adams 1975; Parcharidis 1996), river capture (Biancotti 1979). Drainage is also a sensitive indicator of neotectonic events. Streams and rivers can either be displaced by such an event or have their gradients changed. In either case the response may be quite rapid. However, complications exist, because causes other than tectonics can produce similar changes (Cooke & Doornkamp 1990) and last but non least, arcuate scarps or sets of concentric scarps (Slemmons 1982). The above geomorphological characteristics could be detected on remotely sensed imagery at appropriate products and scales, interpreted and correlated allowing us to assess composite fault systems and the overall sense of movement of blocks of the crust which the faults bound. The heterogeneities of the crusts nature and the stress, involved during a period of strong deformation, mean that all the types of fault may occur in an area. Overview of the geomorphology allows delineation of key locations for morphotectonic investigation. The representation of morphostructures, related to faults, through spectral reflectance of the terrain characteristics have been recognized and described for the studied area as follows:

a—Bayonnette type structures (Figs. 3 and 4)

More than one are located in the transversal fracture zone of Konitsa with a NE-SW direction. They are presented like “bayonnettes”, perfectly linear and about 10 km in length. The main topographic feature is the scarp easily recognized from the shadow effect with moderate slope (the sun azimuth is perpendicular to the structure) and the presence of the vegetation along the topographic depression of the scarp. The structure corresponds to a fault with a horizontal movement and an extension regime in the central part of it (better development of vertical displacement). A very characteristic feature is the attenuation of the stress patterns in the two edges of the structure recorded in the image by a minor scarp relief with a polyline edge.

b—Strike slip faults

The Sarantaporos structure (Fig. 5) coincides with the straight part of the homonymous river running through the area with a NE-SW direction and length of 30 km. The total length of the structure is greater but it is not clearly recognized in the image. The drainage network of the area, including the Sarantaporos River, could be characterized as rectangular, which means that is strongly controlled by the tectonic regime.

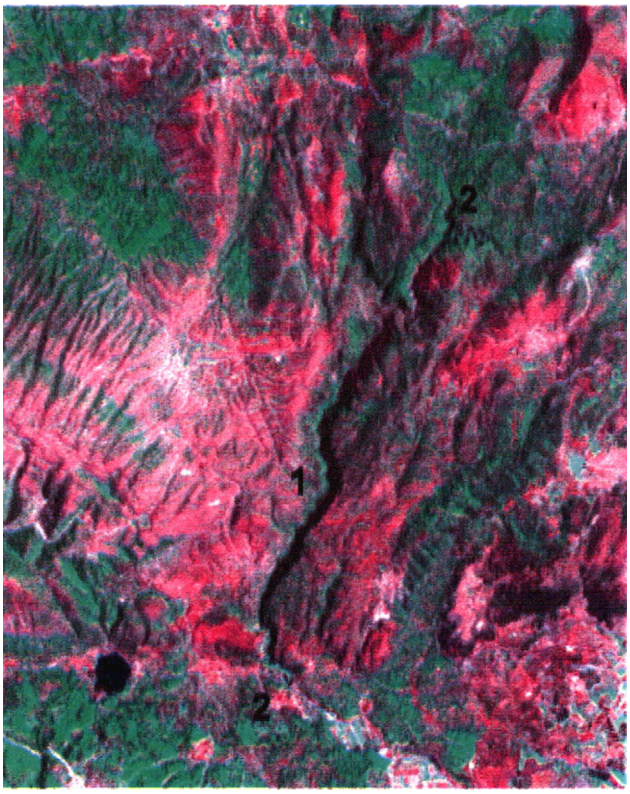

Fig. 3. Bayonnette type structure, extension zone (1), attenuation of the stress (2).

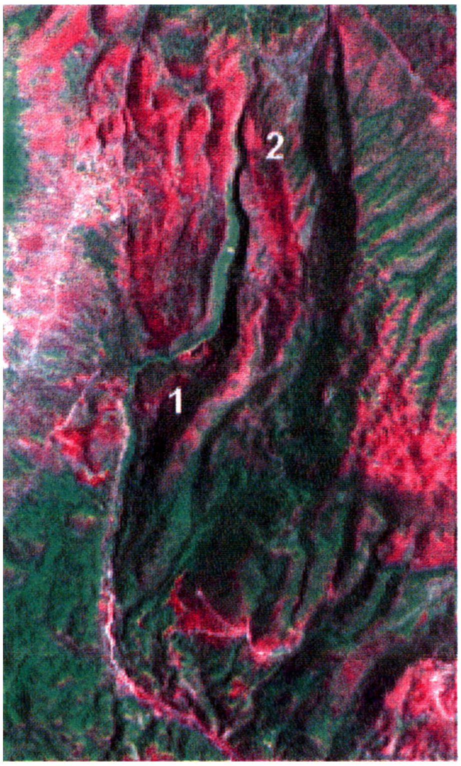

Fig. 4. Bayonnette type structure, extension zone (1), attenuation of the stress (2).

The bluish colour in the river basin corresponds to conglomerates and deposits transported by the river. The basin shows the geomorphic characteristics of a strike-slip fault. The above conclusion is based on facts such as the development of a strike-slip type basin which is elongated, parallel to the strike-slip system, and in this case is relatively deep in relation to its width. Although the displacement along the strike-slip faults is dominantly horizontal, the most obvious motion at any one place may be oblique-slip. This vertical movement is not so clear in the Sarantaporos fault. In the area just before the Sarantaporos meets Aoos the fault forms a larger basin due to the curvature formed by the fault (extension). In addition, morphological criteria, confirming the type of the fault, include a characteristic assemblage of landforms such as offset or deflected streams, small scarps, shutter ridges, combined with in situ information (presence of thermal springs along the basin, commonly associated with strike-slip zones). It is very interesting that in the middle, the river basin is crossed by a fault with a NW-SE direction which provokes a small scale displacement (dextral movement) of the river's route.

The structure along the artificial lake of Aoos sources (Fig. 6) is also a strike-slip fault. It is presented as a linear feature with a NNW-SSE direction. The typical geomorphic features are, the linear canyon, eroded and non scarps, a pond activated actually as a technical lake for energy production, dragging of crests easy detected in the southeastern block (in the center of the image).

c—The Konitsa fault (Fig. 7)

The Konitsa fault is a long well marked fracture zone with a NE-SW direction interrupting the Alpine fold system with a NW-SE axis direction. It is classified as a normal fault but also with a component of horizontal movement according to the geomorphic features recognized on the figure. In this case it is interesting to study the slope and the basic elements of it. The crest of the slope produced by faulting seems to be sharp only in the area of the Konitsa Basin, this continuity is interrupt by small sharp breaks with channels that cross the scarp. The free face, presented as a straight segment, is under shadow because the azimuth of the sun's illumination is perpendicular to the direction of the structure. Locally the free face is modified by the accumulation of debris and gulling. The debris slope is clearly recognized in the image covered by vegetation (light green color in the figure). The Konitsa Basin is the result of the extensive stress of the fault and the Aoos River which crosses the basin is of braided type, with a flow direction from NE to SW, due to the lack of a thick amount of sediments in the basin. In the southwestern part, the fault interrupts the anticline form of Mitsikeli provoking the displacement of the fold's axis, enhancing the horizontal component of the structure which seems to be of left displacement.

Conclusions

The super-synoptic view provided by satellite images is ideal for detecting or re-evaluating the tectonic patterns over

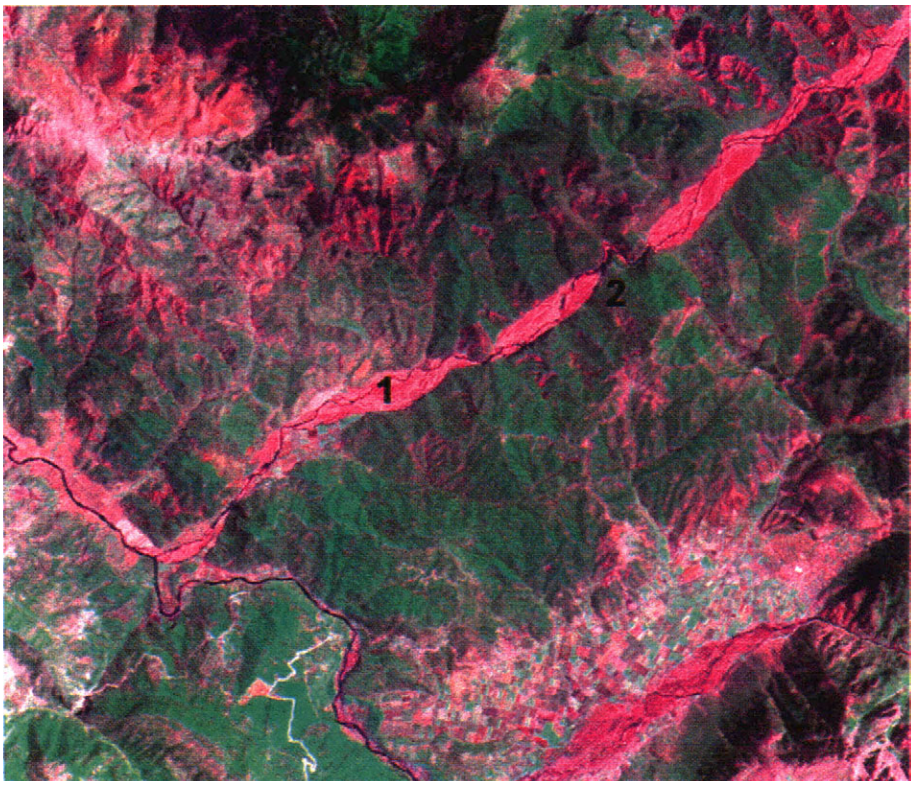

Fig. 5. Sarantaporos River structure with NE-SW direction, material transported by the river and deposited in small basins (1), a small displacement in the river route, due to the activity of a fault, with dextral movement (2).

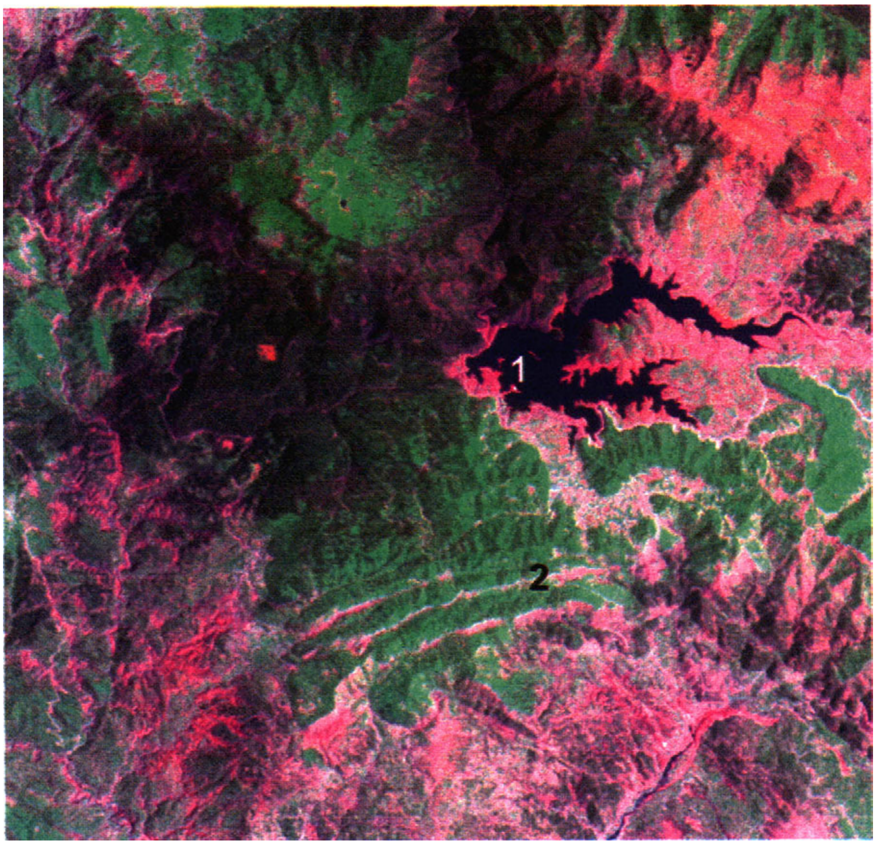

Fig. 6. Structure with NW-SE direction along the artificial lake (1), dragging crests (2).

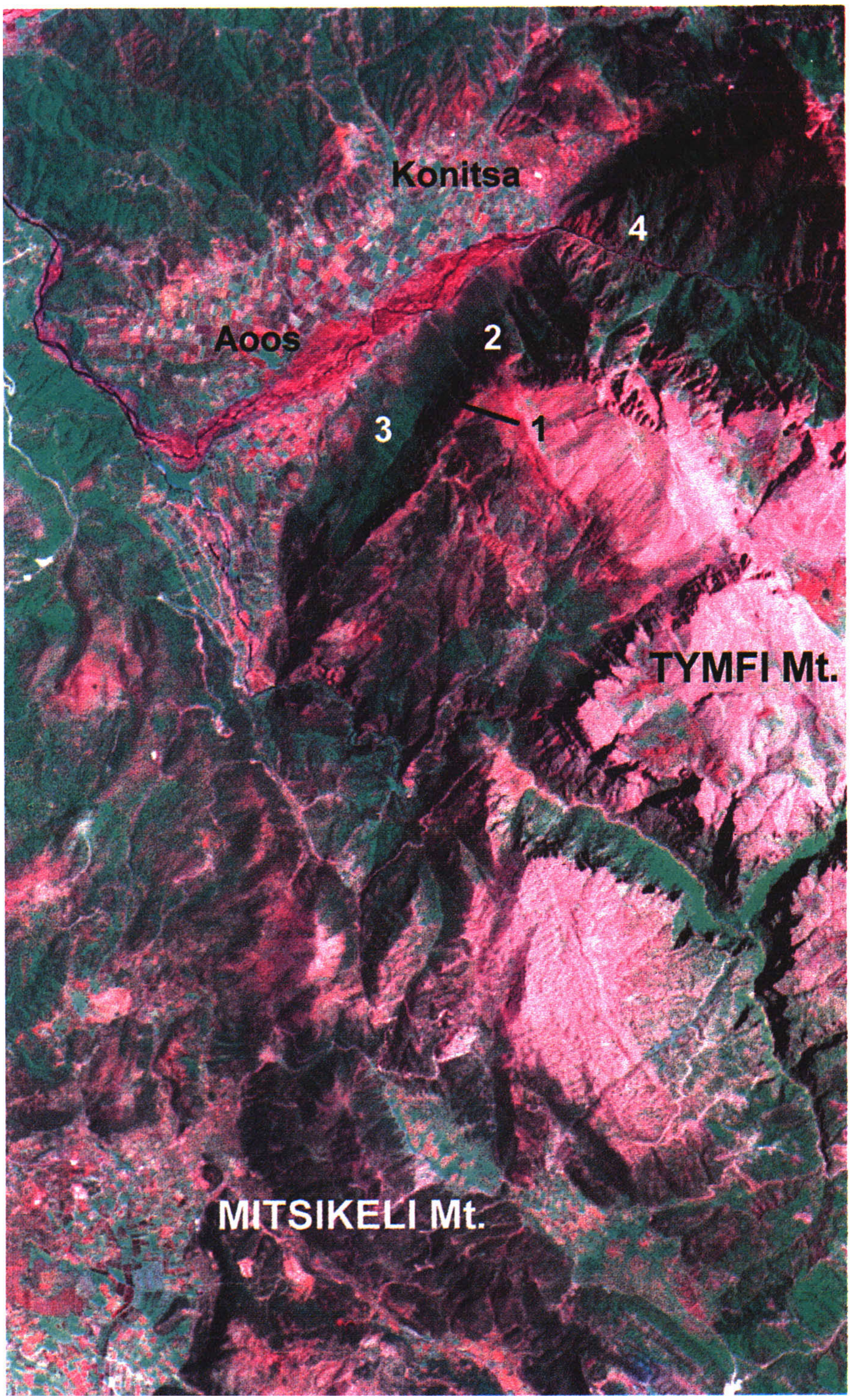

Fig. 7. Konitsa fault with NE-SW direction where the basic slope elements are well recognized, crest of the slope (1), free face (2) and debris slope (3).

large areas. In addition the synoptic view of the satellite images enables widely separated pieces of evidence to be linked in their continuation. The best results come from areas of high relief and recent activity, where the faults are well expressed and the movement directions is clear. Difficulties in the interpretation could arise when their surface expression is deep eroded.

Photographic interpretation or computer aided interpretation of faults is often more reliable than their detection in the field. If multispectral images are available morphostructures may be more distinct on particular spectral bands. For example interpretations using Landsat images may be enhanced by using infrared bands, as shadows are sharp and vegetation patterns are distinct.

A plethora of more sophisticated processing techniques could enhance the information contained in the image even more.

In conclusion the remote sensing techniques and data can be effective in detecting, delineating and describing the character of active faults, and the near future will be very promising when data of very high resolution (1–2 m pixel size) is available.

References

Adams D.P., 1975: Geomorphic evidence for late Holocene tilting in southern San Mateo County, California. *J. Res. US Geol. Surv.,* 8, 72–76.

Biancotti A., 1979: Relations between morphology and tectonic in Cuneese basin. *Geografia Fisicia e Dinamica Quaternaria,* 2, 51–6 (in Italian).

Bull W. B., 1977: The alluvial fan environment. *Prog. Phys. Geog. 1,* 222–270.

Chorowicz J., 1984: Importance of pattern recognition for geological remote sensing applications and new look at geological maps. Remote Sensing for geological mapping. In: Teleki P. & Weber C. (Eds.): *Documents BRGM n. 82, Publication IUGS n. 18,* 29–40.

Cooke R.U. & Doornkamp J.C., 1990: Geomorphology in environmental management: An introduction. *Clarendon Press, Oxford.*

Cotton C.A., 1948: Landscape. *CUP, Cambridge.*

Doornkamp J.C., 1986: Geomorphological approaches to the study of neotectonics. *J. Geol. Soc. (London)*, 143, 335–342.

Embleton C., 1987: Neotectonic and morphotectonic research. *Z. Geomorphol. N. F., Suppl. Bd. 63,* 1–7.

Greiling R., 1983: Fracture patterns, foliations and low-angle thrusts, interpreted from Landsat images and aerial photographs from two basement culminations in the north-central Scandinavian Caledonides. *International Basement Tectonics Assoc., Publ. 4,* 321–330.

Gupta R.P., 1991: Remote Sensing Geology. *Springer-Verlag,* Berlin.

Hook R.B., 1972: Geomorphic evidence for late-Wisconsin and Holocene tectonic deformation, Death Valley, California. *Geol. Soc. Amer. Bull., 83,* 2073–2098.

Matsuda T., 1975: Magnitude and recurrence interval of earthquakes from a fault. *Earthquake, Ser. 2*, 28, 269–283 (in Japanese, abstract in English).

Migiros G., Pavlopoulos A. & Parcharidis I., 1995: Recognition of fracture zones by using spatial models and remote sensing data: an application in western Attica (Greece). *Proc. of the XV congress of the Carpatho-Balcan Geol. Ass., Sept. 1995, Athens (Gr), Geol. Soc. Greece, Sp. Pub. No. 4,* 1041–1049.

O'Leary D.W., Friedman J.D. & Pohn H.A., 1976: Lineaments, linear, lineations some standards for old terms. *Geol. Soc. Am. Bull.,* 87, 1463–1469.

Otsuki K., 1985: Plate tectonics of Eastern Eurasia in the Light of fault Systems. *Science Reports of the Tohuku University, Sendai, Second Series (Geology), 55,* 2, 141–251.

Panizza M., 1991: Geomorphology and seismic risk. *Earth-Sc. Rev.,* 31, 11–20.

Papanikolaou D. & Parcharidis I., 1996: Landsat MSS and TM data for local and regional tectonic observations in the Epirus–Konitsa area. *Symposium on Remote sensing applications, Athens 28-29/11/96. Abstracts*.

Parcharidis I., 1996: Integration of ERS-1 satellite data and DEM—derived spatial models for a geo-structural scenario in the Kozani basin (Greece). *International Meeting on results of the May 13, 1995 earthaquake of West Macedonia: one year after. Abstract.*

Popp N., 1971: Hydrogeographical and geomorphological aspects regarding the problem of the recent vertical movements of the crust in Romania. *Z. Geomorphol., 15,* 445–459 (in German).

Reading H.G., 1980: Characteristics and recognition of strike-slip fault systems. *Spec. Publ. Int. Assoc. Sediment.,* 4, 7–26.

Rogers T.H. & Nason R.D., 1971: Active displacement on the Calaveras fault zone at Hollister, California. *Bull. Seismological Soc. Am.,* 61, 399–416.

Sabins F.F., 1997: Remote Sensing: Principles and interpretation. *W.H. Freeman and Co*., New York.

Scanvic J.C., 1983: The use of Remote Sensing in geosciences. *Bureau de recherches geol. Et minieres, Manuels et methodes, n. 7* (in French).

Slemmons D.B., 1982: A procedure for analyzing fault-controlled lineaments and the activity of faults. *Proceed. 3rd Intern. Confer. On basement Tectonics,* In: O'Leary D.W & Earl L.J. (Eds.): *International basement tectonics Association*, 33.

Thornbury W.D., 1954: Principles of geomorphology. *Wiley,* New York.