Neotectonic Activity of Konitsa Area and the 1996 Earthquakes*

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ABSTRACT: Two moderate size earthquakes of magnitude M_S = 5,4 and M_S = 5,7 occurred on 26 July 1996 and 6 August in the area of Konitsa, northwestern Greece. They damaged mainly the city of Konitsa and some neighbouring villages.

Both earthquakes were associated by large rock falls from the steep mountainous slopes that in some cases reached the inhabited area of the city. Moreover a number of small soil fissures has been observed into the zone of the most important fault of the region, that is the Konitsa fault. This seismic activity had also direct influence on springs where significant variations of the water discharge have been observed.

In this work, data from the geological and seismotectonic studies are considered and a detailed geological mapping of Konitsa city was carried out. The very good agreement between tectonic data on the major faults and the seismic stresses of the area from the fault plane solutions of the earthquakes was identified. Even if the moderate magnitude earthquakes do not usually allow a surface rupture, it is likely that the earthquakes nucleated on the Konitsa fault. Finally, both the regional tectonic structure and the local geological conditions influence the seismic hazard of the area.
Key-words: *Western Greece, Tymphe mountain, Konitsa city, active faulting, soil fractures*.

ΠΕΡΙΛΗΨΗ: Την 26η Ιουλίου 1996 σημειώθηκε στην περιοχή της Κόνιτσας σεισμική δόνηση μεγέθους Μ = 5,4 ενώ ένας νέος μεγαλύτερος σεισμός στις 6 Αυγούστου (τοπική ώρα 01.46) με μέγεθος Μ=5,7 έγινε ιδιαίτερα αισθητός σε ολόκληρη την Ήπειρο Από τη σεισμική αυτή δραστηριότητα επλήγη σοβαρά η πόλη της Κόνιτσας και λιγότερο οι περιφερειακές κοινότητες σε μία ακτίνα περίπου 10 χλμ. και ευτυχώς δεν υπήρξαν ανθρώπινα θύματα.

Στα πλαίσια της παρούσας μελέτης έγιναν γεωλογικές παρατηρήσεις στην ευρύτερη περιοχή και μελέτη της νεοτεκτονικής της εξέλιξης με έμφαση στη σχέση της με τις επιφανειακές εκδηλώσεις των σεισμών. Επιπλέον λεπτομερής γεωλογική χαρτογράφηση σε κλίμακα 1:5.000 της πόλης της Κόνιτσας, καθώς και ένας αριθμός γεωτρήσεων σε διάφορες θέσεις, για να μελετηθούν οι τοπικές εδαφικές συνθήκες.

Η κυριότερη νεοτεκτονική δομή της ευρύτερης περιοχής είναι το ρήγμα της Κόνιτσας. Πρόκειται για μια μεγάλη ζώνη διαρρήξεων με διεύθυνση Β 50°-60° που το συνολικό άλμα της φθάνει τα 1000 m η οποία παρουσιάζει κατά θέσεις εντυπωσιακές κατοπτρικές επιφάνειες και μια μεγάλου πλάτους ζώνη μυλονιτίωσης. Με βάση τα τεκτονικά στοιχεία η διεύθυνση των εφελκυστικών τάσεων είναι ΒΔ-ΝΑ, διεύθυνση που συμπίπτει με αυτή που δίνει ο μηχανισμός γένεσης του σεισμού. Επιπλέον, η ανάλυση δορυφορικών εικόνων που ελήφθησαν μετά το σεισμό έδειξε βύθιση της πεδιάδας της Κόνιτσας της τάξεως των 5,6 εκατοστών.

Ένας αριθμός μικρών εδαφικών ρωγμών παρατηρήθηκε μέσα στην πόλη της Κόνιτσας και επί της παλαιάς εθνικής οδού. Οι εδαφικές αυτές διαρρήξεις που έχουν διεύθυνση Β 40°-50° και συνολικό μήκος 800 περίπου μέτρα, αναπτύχθηκαν μέσα στη ζώνη του μεγάλου ρήγματος της Κόνιτσας.

Παράλληλα σημειώθηκαν αποσπάσεις και καταπτώσεις βράχων στην εθνική οδό, στο φαράγγι του Αώου και σε κατοικημένες περιοχές της Κόνιτσας, ενώ παρατηρήθηκε θολότητα, αύξηση της θερμοκρασίας και έντονη οσμή καθώς και σημαντικές μεταβολές της παροχής του νερού στις πηγές και γεωτρήσεις.

Σε ότι αφορά την σεισμική επικινδυνότητα της περιοχής, η πόλη της Κόνιτσας είναι δομημένη πάνω σε χειμαρρώδεις αποθέσεις και πλευρικά κορήματα, που χαρακτηρίζονται από λιθολογική ετερογένεια και μεταβαλλόμενο πάχος. Τα υλικά αυτά βρίσκονται πάνω στα ασβεστολιθικά πετρώματα, τα οποία όμως λόγω τεκτονισμού είναι πλήρως κατακερματισμένα. Η τεκτονική δομή της περιοχής και η ανομοιομορφία του γεωλογικού υποβάθρου ως χώρου θεμελίωσης έπαιξε καθοριστικό ρόλο στη συμπεριφορά των κατασκευών κατά τη σεισμική δραστηριότητα.
Λέξεις-κλειδιά: *Δυτική Ελλάδα, όρος Τύμφη, Κόνιτσα, ενεργά ρήγματα, εδαφικές διαρήξεις.*

INTRODUCTION

On July 26, 1996 (22.30 local time) a seismic shock of M_S = 5,4 occurred in the area of Konitsa which was felt throughout Epirus, while on August 6 (01.46 local time) the main shock of magnitude M_S = 5,7 took place. Mainly affected by these earthquakes was the city of Konitsa and less the regional communities over an area of about 10 km. No human casualties were recorded. In the city of Konitsa 208 houses became non-habitable

* Νεοτεκτονική δραστηριότητα στην περιοχή της Κόνιτσας και οι σεισμοί του 1996.

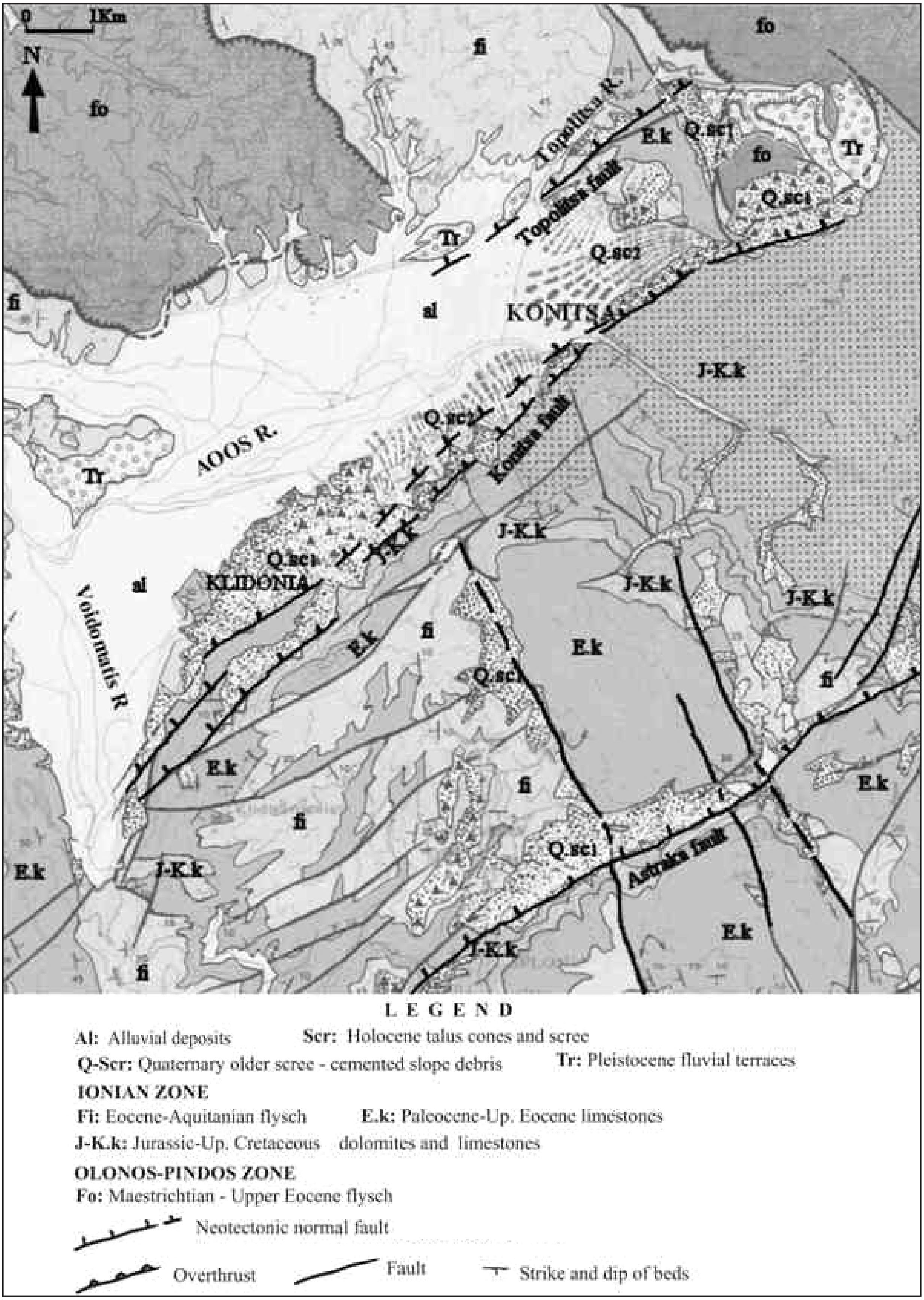


Fig. 1. Simplified geological map of the studied area (based on the map of IGSR, 1966).

(22% of the total) and 278 temporarily non-habitable (29%). The destructions affected old stone-built houses as well as new houses built with reinforced concrete. In the villages Kallithea, Iliorachi, Kavassila and Masi the observed destructions refer mainly to old constructions. In parallel, severe rock falls were observed on the national road, at the abrupt valley of Aoos river and in inhabited areas of Konitsa city.

Within the frame of the present work, geological observations concerned the wider region, as well as studies of the neotectonic evolution and its relationship with the surface manifestations of the earthquakes were realized. A detailed geological mapping of Konitsa city was also carried out in scale 1:5.000 and boreholes were drilled in various sites in order to define the prevailing soil conditions.

GEOLOGICAL SETTING

Preneogene formations

The broader area of Konitsa consists mainly of the sedimentary series of the Ionian geotectonic zone (Aubouin, 1959; IGSR & I.F.P., 1966), (Fig. 1). The older formations are gray, massive, bituminous dolomites and platy micro-brecciated limestones with layers of black limestones of Upper Jurassic-Lower Senonian age followed by thick-bedded, micro-brecciated limestones of Upper Senonian age. The limestone sequence ends with white-gray, micro-brecciated limestones of Paleocene-Upper Eocene age (Mavridis & Manakos, 1987).

The transition with the flysch series takes place through a formation of 15-20 m thickness, consisting of alternations of marls and thin-bedded marly limestones. The flysch series consists of rhythmic alternations of clays, sandy clays and fine-grained to coarse-grained sandstones. To the north and west of Konitsa city, formations of the Pindos geotectonic zone, accompanied by sliding limestone blocks of the Pelagonian zone, are thrusted over the Ionian zone. Due to the main overthrust on the ionian flysch sediments, small internal thrusts have been formed as well as isoclinal and asymmetric folds.

The recent geological formations are represented by fluvial terraces of Aoos, Voidomatis and Sarantaporos rivers as well as scree and talus cones of varied lithology and cohesion. These quaternary deposits constitute the basement of most the city and are described in detail below, according to their characterization in the geological map of Konitsa, in scale 1:5.000 (Fig. 2).

Pleistocene

- *Cohesive scree*

The cohesive scree deposits reach a 50 m total thickness. They consist of angular limestone breccias, often hosting great limestone blocks with clay-marly cementing material. The upper horizons are particularly cohesive and locally suffered of karstification phenomena. Based to comparative observations of the lithology, cohesion, thickness, type of cementing material and its stratigraphic position, a Lower Pleistocene age can be attributed.

- *Fluvial terraces*

They are polymict materials carried by Aoos river and Topolitsa stream, consisting of various-sized limestone, ophiolithic and sandstone cobbles including intercalations of lenticular layers of sands and clays (Fig. 3a).

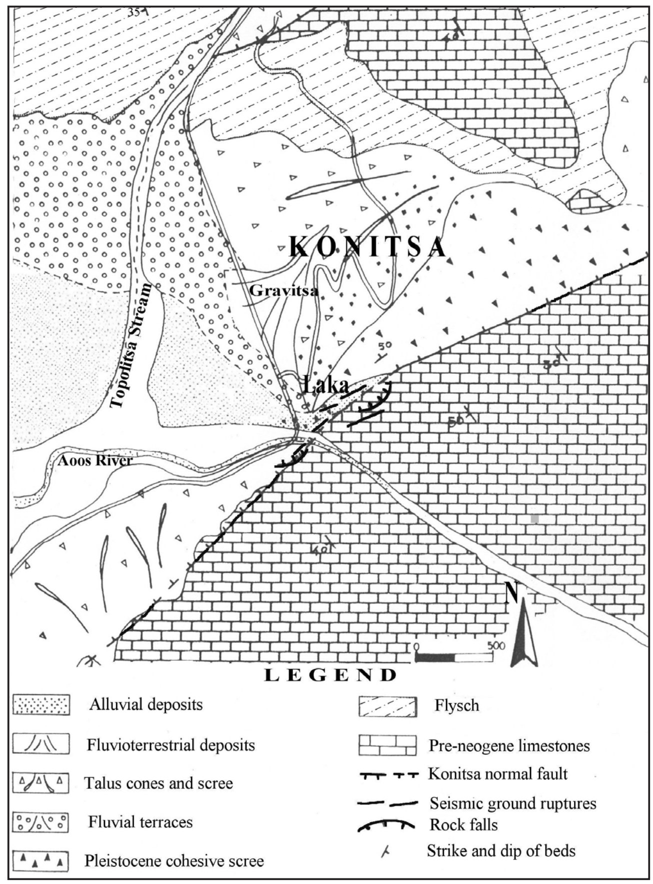


Fig. 2. Detailed geological map of the Konitsa city area.

Fig. 3a. Pleistocene clastic deposits.

- *Old fans*

It is the wider formation in Konitsa city, of Upper Pleistocene age. It represents torrential deposits of low cohesion, consisting of irregular cobbles, sands and gravels with lenticular intercalations of brown-red clays more frequent in their upper members. There is a clear lithological grading from coarse materials to the fines, along a NE-SW direction.

Holocene

- *Clastic deposits*

They are unconsolidated fluvial and torrential deposits as well as loose scree (Fig. 3b).

- *Historical earthfills*

Materials of various lithological origin occurring from excavations or demolition of constructions. According to the field observations, boreholes and opened pits, an horizon of old earthfills of significant thickness occurs, including old foundations and fragments of earthenware of the Classic period in 3-4 m depth. The total thickness of the earthfills, is estimated to be 5-7 m.

TECTONIC ACTIVITY

During its geological evolution, the area of Konitsa has undergone the activity of strong compressional then extensional tectonic stresses.

The mountains of Konitsa wider area exhibit large cover folds in the Ionian zone, with NW-SE trending axes (AUBOUIN, 1959; IGSR & I.F.P., 1966). The folds formed during the Oligocene-Lower Miocene timespan and accompanied the thrusting of the Pindos cover nappe over the Ionian parautochtonus. These folds are affected by perpendicular oblique-slip faults formed during subsequent extensional tectonic phases.

To the east, the large Tymphe massif (2497 m) that slightly dips to the SE, was later uplifted in the footwall of the NE-SW trending, NW dipping Konitsa normal fault. The Konitsa plain corresponds to the hanging wall of this major fault. This NW-SE extension took place during the Plio?-Pleistocene (BOUSQUET, 1976). The Tymphe mountain is crossed by numerous faults of NE-SW and NW-SE to WNW-ESE directions. It should be pointed out that the hydrographic network of the region is almost totally controlled by the two aforementioned fault directions.

The Konitsa fault (Fig. 4) constitutes the main neotectonic structure that guides the Aoos and Voidomatis rivers basin. It is a great fault zone with a N 50°-60° direction and a 25 km length, presenting locally impressive polished or corrugated surfaces (Fig. 5). This normal fault brings to contact the Mesozoic limestones with the flysch and affects the quaternary deposits as well. The maximum downthrow observed between Konitsa city and Klidonia village is of about 1000 m (Fig. 7).

Fig. 3b. Holocene clastic deposits.

Fig. 4. Panoramic view of Konitsa fault at the eastern part of the city.

The orientation of the recent extensional stresses was obtained by measuring the slickensides on the surfaces of this fault (Fig. 6a). In Fig. 6b, the NW-SE direction of extension is illustrated, that coincides with the seismic tectonic stress of the wider region (LOUVARI, 2000), (Fig. 6c).

According to its morphotectonic and dynamic characteristics, the normal fault of Konitsa is the most important active fault in the wider area. It is associated to a very large mylonitization zone, whose thickness indicates its great throw.

Astraka fault is a great parallel fault with 700 m visible downthrow since the Miocene. The vertical offset of this fault shows all the stratigraphic units of the Ionian zone. Along Topolitsa stream, to the north-west of Konitsa, another normal fault of N 50° direction and dip 75° to the NW, brings into tectonic contact the Eocene limestones and holocene scree.

The block diagram of the broader Konitsa area as well as a geological cross section with the main geological and neotectonic structures is illustrated in Fig. 7.

A second group of faults of NW-SE direction has influenced the region and particularly the thick Tymphe limestone massif. Aoos and Voidomatis rivers generally follow this orientation and have incised deep ravines with

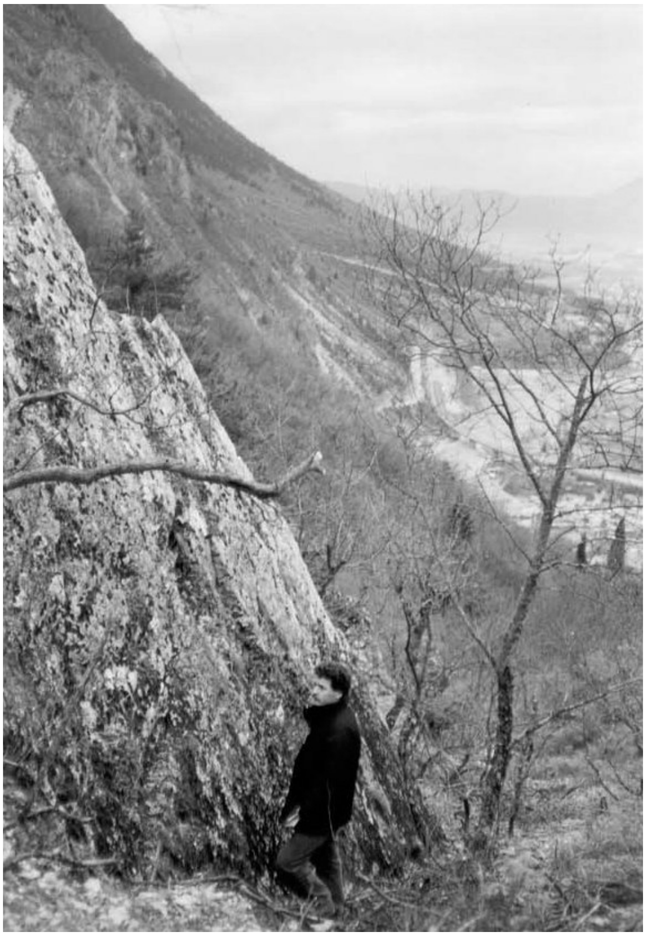


Fig. 5. Polished surface of the Konitsa fault.

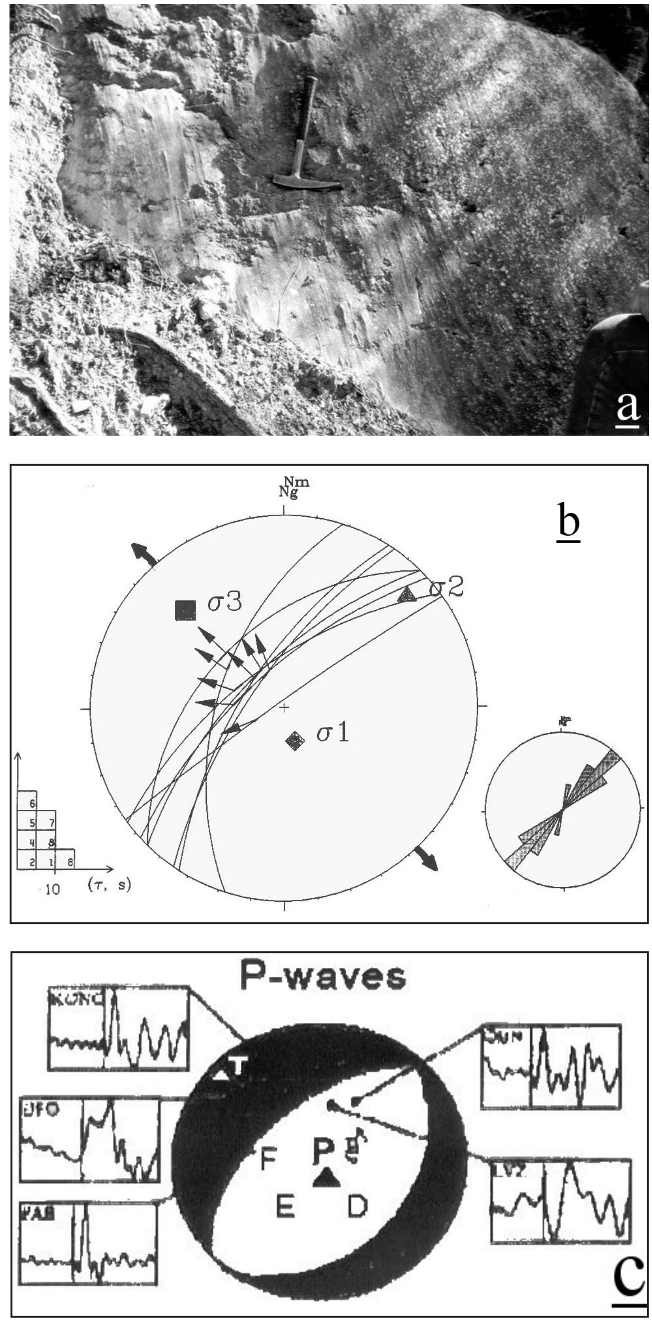


Fig. 6. Slickensides (a) and stereographic projection (b) showing the position of principal stresses axes. (c) The fault plane solution of 1996 earthquake (LOUVARI, 2000).

almost vertical slopes of up to 1000 m height.

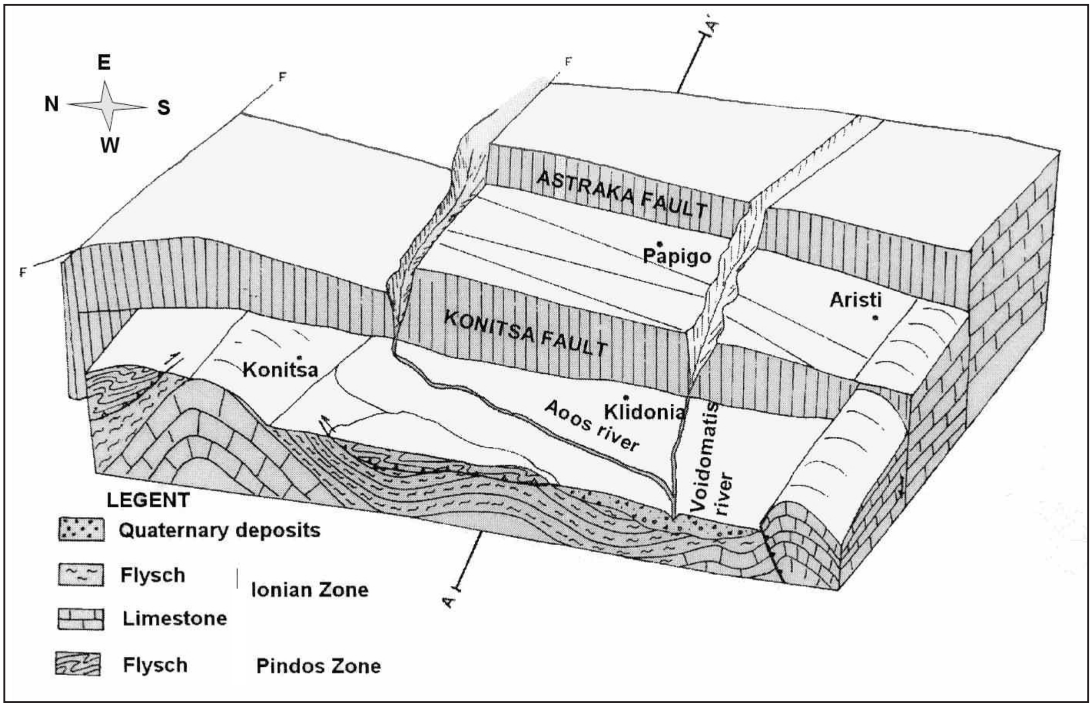
The important NE-SW trending normal Konitsa fault is surprisingly located near the clearly compressional front of the Aegean Arc, whereas extensional tectonics of the internal Aegean arc is mainly expressed in more internal regions of central Greece. This location of the Konitsa fault may be explained by the results of a recent detailed GPS study (AVALLONE *et al*., 2004). This study shows that Central Greece (south of the Sperchios fault zone) undergoes an about 7° /Ma clockwise rotation relative to Northern Greece (and Europe). The pole of this rotation is located in Western Greece, near the Amvrakikos gulf to the SW of Konitsa fault. This deformation can explain the existence of active extensional tectonics on the Konitsa fault.

SEISMOLOGICAL DATA

The area of Konitsa does not present a strong seismicity. However, it is suffered of destructive earthquakes that have epicenters in other regions of Epirus, mainly in the area of Ioannina as well as in South Albania.

Significant earthquakes (PAPAZACHOS & PAPAZACHOU, 1997) had their epicenters in Albania and occurred in 1860 (M_S = 6.4), 1919 (M_S = 6.3), 1920 (M_S = 6.3), 1926 (M_S = 6.1) and 1960 (M_S = 6.5). Near Konitsa, the epicenters (Fig. 8) of small to medium seismic events (MS = 4.0-5.5) coincide with the geological fault zones of NE-SW direction (MOUYIARIS, 1994).

Concerning the 1996 activity, the epicenter of the earthquake of 26th July (40.03 N, 20.63 E) was 12 km to the WNW of Konitsa and the epicenter of the 6th August earthquake (10.08 N, 20.67 E) with 8 km depth, was about 10 km to the SW of the city, in Aoos river valley.



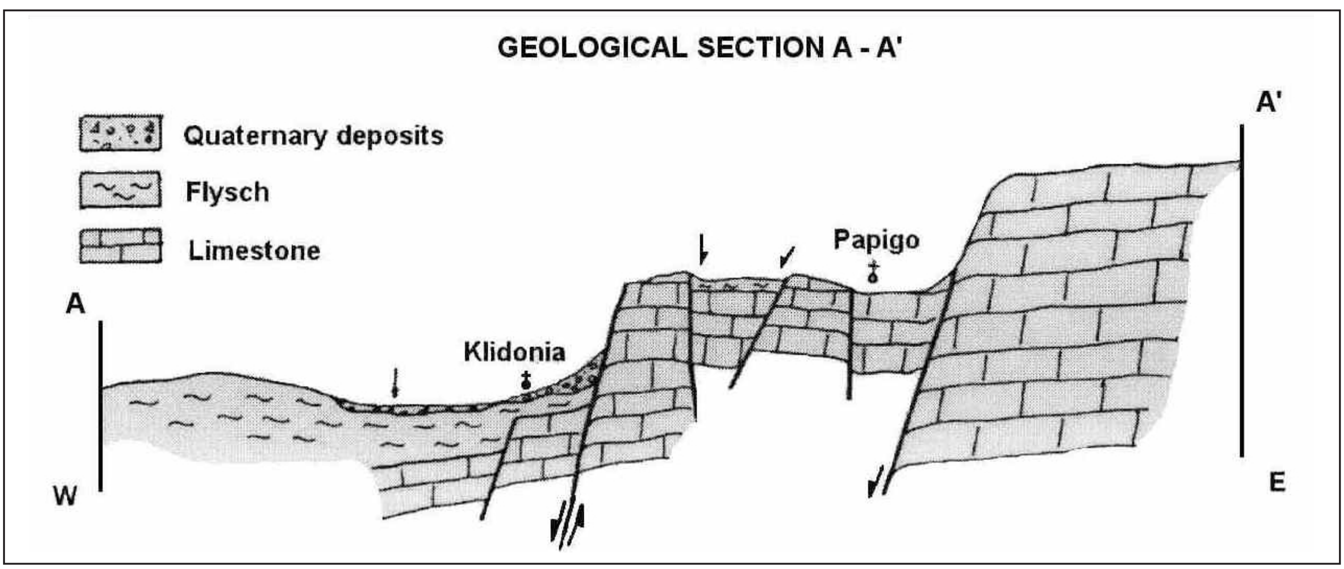


Fig. 7. Block diagram and geological cross section of the broader Konitsa area.

From July 26 to end of the year, about 200 seismic shocks have been recorded in the region. Louvari (2000) attributes the earthquake to a normal fault of NE-SW direction, approach that is consistent to the tectonic data. Papanastassiou (2001), based on the spatial distribution of earthquakes occurred in the area the last six months of 1996 as well as the focal mechanism of the main shock and the strongest aftershocks, points also the good agreement of tectonic and seismic data.

Interferometry data (INSAR) obtained after the 1996 earthquakes, show a subsidence of the order of 5.6 cm of the Konitsa plain, corresponding to the hanging wall of Konitsa fault (Egli, 1998).

SECONDARY PHENOMENA

The seismic activity in the area of Konitsa resulted in the manifestation of the following secondary phenomena:

Soil fractures

A number of small soil fissures have been observed mainly in the Konitsa city and to the south of Aoos river, on the old national road. These cracks of N 40^o-50^o direction, aperture 1-2 cm and some meters length, were located into a zone of about 800 m total length in parallel to the great fault of Konitsa (Fig. 9).

Furthermore, the occurrence of some dispersed soil

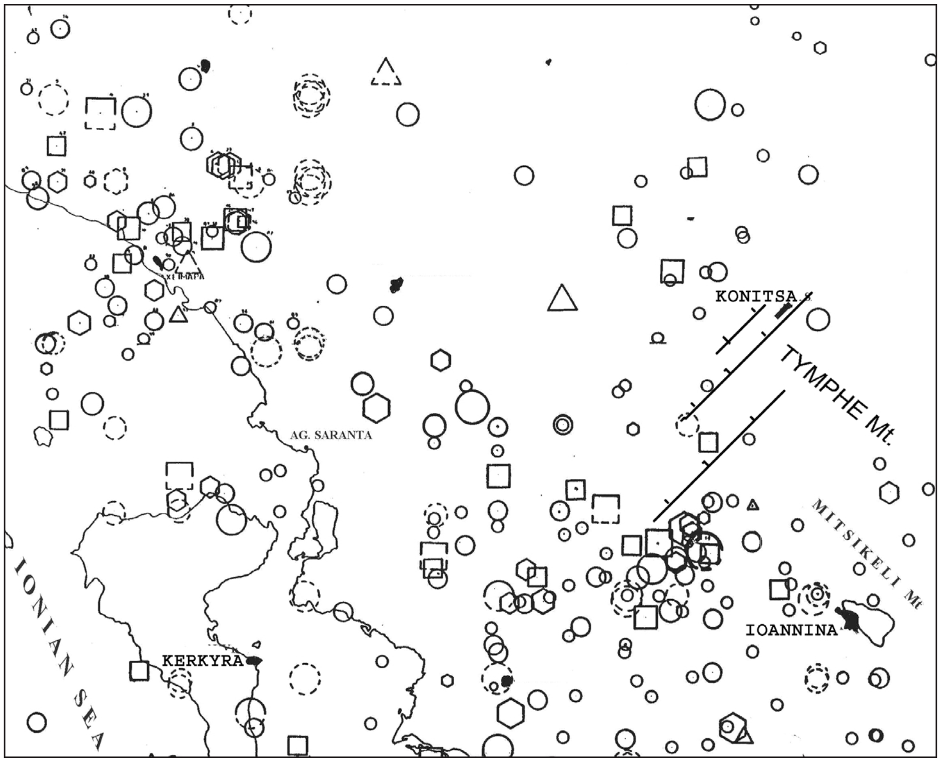


Fig. 8. Earthquakes epicenters for the period 1900 – 1994 (Mouyiaris, 1994). The Topolitsa, Konitsa and Astraka faults, from North to South, are also noted.

fissures of various directions is due either to depression of the stone-built retaining walls of the cultivation terraces or the subsidence of the existing earthfills.

There is an excellent compatibility of seismic and tectonic data, but the absence of vertical displacement does not allowed the determination of a coseismic slip vector. Furthermore, the occurrence of some dispersed soil fissures of various directions is due either to depression of the stone-built retaining walls of the cultivation terraces or the subsidence of the existing earthfills.

Rock falls

Intense rock falls on the national road, from the steep slopes of the footwall of Konitsa fault have been observed after the earthquake on July 26th. Numerous rock falls took also place in the abrupt slopes of Aoos valley and continued also during all the aftershocks.

It is also worth mentioning that, after the information by the local people, extended rock falls took place before the earthquake manifestation (on July 21st) from the almost vertical morphological slopes at the northern end of the fault zone of Konitsa.

Moreover, rock falls have also occurred at the site 'Kastro' (castle) of Konitsa, which reached inhabited areas of the city. In this site, a small soil fracture parallel to the great vertical joints existing to the mountain rocks was formed during this earthquake.

Other phenomena

The seismic activity had also direct influence on the springs and water boreholes of the area, where turbidity, temperature increase, intense H_2S smell and significant variations of the water discharge have been observed, while drawdown of a borehole level per 45 cm took also place. The greatest changes were observed to the abundant sulfate springs along the Konitsa fault zone.

According to information from the residents, strong sparkles occurred in Aoos valley during the earthquake manifestation in the night of 26th July 1996. Their occurrence could be attributed to the rock falls consisting of bituminous limestones, which include several silex layers.

CONCLUDING REMARKS

In the summer of 1996, the area of Konitsa was affected by destructive earthquakes that occurred on July 26th (Ms = 5,4) and August 6th (Ms = 5,7). These earthquakes with epicenters at a distance of 12 km WNW and 10 km SW respectively from Konitsa city, produced soil cracks of small size along a total length of 800 m, rock falls and variation in the springs discharge and the boreholes water level.

These earthquakes took place in an area of very important neotectonic faults, including the great fault of Konitsa of NE-SW direction, presented impressive polished surfaces and a very large mylonitization zone.

The earthquake focal mechanism after LOUVARI (2000) and PAPANASTASSIOU (2001) is consistent with the geometrical and kinematic characteristics of Konitsa fault. Radar interferometry data show a subsidence of the order of 5.6 cm to the Konitsa plain, the hanging wall of Konitsa fault (EGLI, 1998).

Based on the identity of tectonic data with the focal mechanism solution and the coseismic deformation evidences as well, it can be considered that the earthquakes nucleated on the Konitsa fault.

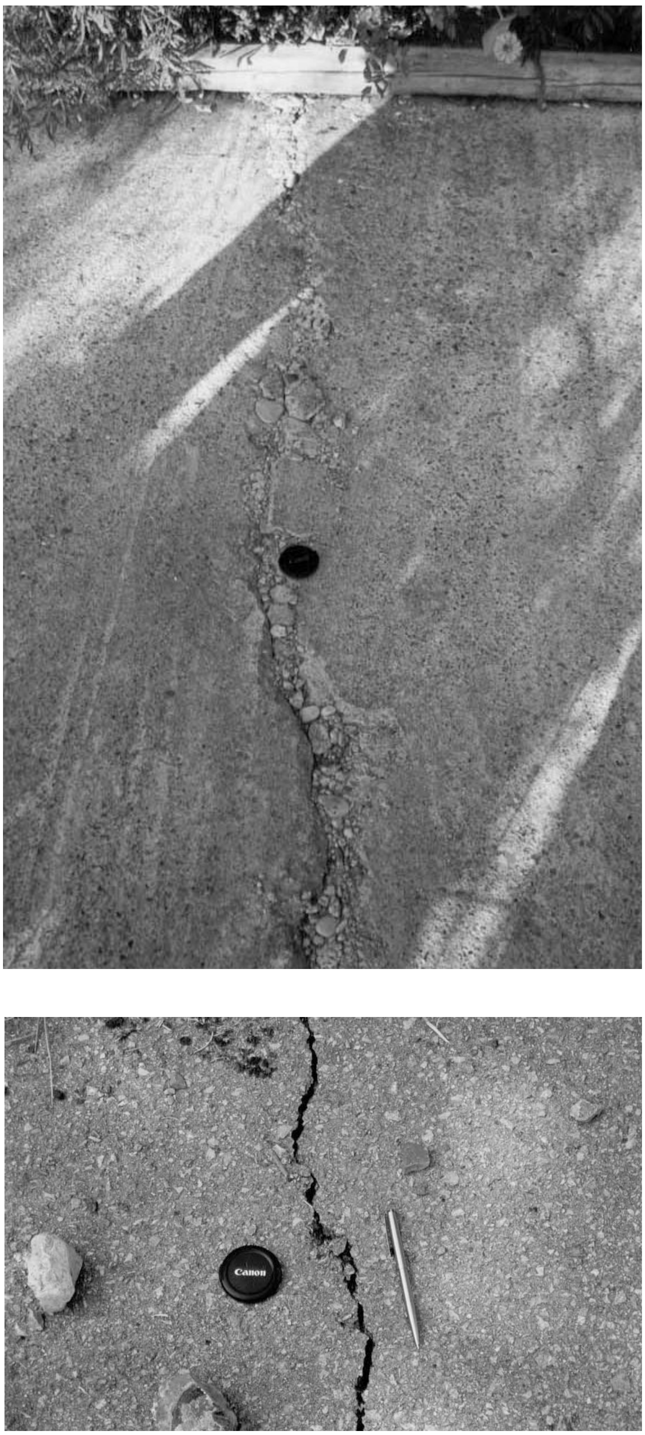


Fig. 9. Seismic soil fissures observed in the Konitsa city during the 1996 earthquake activity.

Concerning the seismic risk, the detailed map of the area, the observed seismic cracks as well as the data from the exploratory boreholes and excavations showed unfavorable conditions due to the quality of the foundation basement. Konitsa city is founded on torrential deposits and scree, characterized by lithological heterogeneity and varied thickness and cohesion, while in the district where the greater number of damages was observed, loose materials of old earthfills (including foundation traces from the ottoman period) are dominant. These materials cover the limestone rocks, which are intensively fractured. This variety of lithological composition and cohesion of the geological formations in addition to the presence of the great mylonitization zone of Konitsa fault, played decisive roles in the behavior of constructions during the earthquakes.

ACKNOWLEDGEMENTS

We would like to express many thanks to Denis Sorel, for his valuable and constructive remarks on this paper.

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