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ΤΕΤΑΡΤΟΓΕΝΗΣ ΠΑΡΑΜΟΡΦΩΣΗ ΣΤΗ ΛΕΚΑΝΗ ΤΩΝ ΓΡΕΒΕΝΩΝ (Δ. ΜΑΚΕΔΟΝΙΑ, ΕΛΛΑΔΑ): Η ΣΗΜΑΣΙΑ ΤΟΥ ΔΙΑΤΜΗΤΙΚΟΥ ΚΑΙ ΣΥΜΠΙΕΣΤΙΚΟΥ ΕΝΤΑΤΙΚΟΥ ΠΕΔΙΟΥ

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QUATERNARY DEFORMATION IN GREVENA BASIN (W. MACEDONIA, GREECE): IMPORTANCE OF SHEAR AND COMPRESSION*

by

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I. INTRODUCTION

The area of Grevena was, until recently, considered as one of the most tectonically and seismically inactive regions in Greece (PAPAZACHOS, 1990) and did not seem to be of any particular interest. However, Brunn (1956, p. 266) stressed that the eastern margin of the Meso-Hellenic molassic trench is characterized by the predominance of faulting and that the fractures occurred both before and after the molassic and even the pliocene deposits. He also noted (p. 197) that towards the southern boundary of the Kozani-Servia pliocene basin, sandy marls with freshwater Quaternary fossils (Planorbis and Lymnea) are strongly dipping North, away from the base of the Servia fault, while at the south of the latter, the plio-quaternary formations have undergone strong uplift. Since then very little research had been carried out regarding neotectonic, let alone Quaternary, deformation of the area, as that of Faugeres and Vergely (1974).

The earthquake of 13 May, 1995 came to contradict the notion of seismic inactivity; great damage was caused to a relatively small triangular-shaped region, bounded by the Paleohori - Sarakina fault zone at the south (which may be a prolongation of the prominent Servia fault), the Chromio-Varis fault zone at the north and Aliakmon river at the west. Also, numerous earthquake-related geological effects were caused, as seismic fractures at Knidi, Sarakina, Paleohori, Chromio and elsewhere, liquefaction close to Rymnio and landslides-rockfalls at Agaleoi, Knidi, Rymnio, Kendro and Kalamitsi. Many of the seismic fractures are related to reactivated faults.

The spatial distribution of damage and the above-mentioned phenomena gave us the initiative to study the neotectonic, and mainly quaternary deformation at the area between Mt. Vourinos and the town of Grevena. Three fault zones occur and were studied, namely the Dafnero (DFZ), Paleohori-Sarakina (PSFZ) and Chromio-Varis (CVFZ) ones, in conjunction with the seismic fractures that occurred on the trace or near them (Fig. 1). We then tried to interpret the Quaternary deformation of the area.

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* Τεταρτογενής παραμόρφωση στη Λεκάνη των Γρεβενών. Η σημασία του διατμητικού και συμπιεστικού εντατικού πεδίου.

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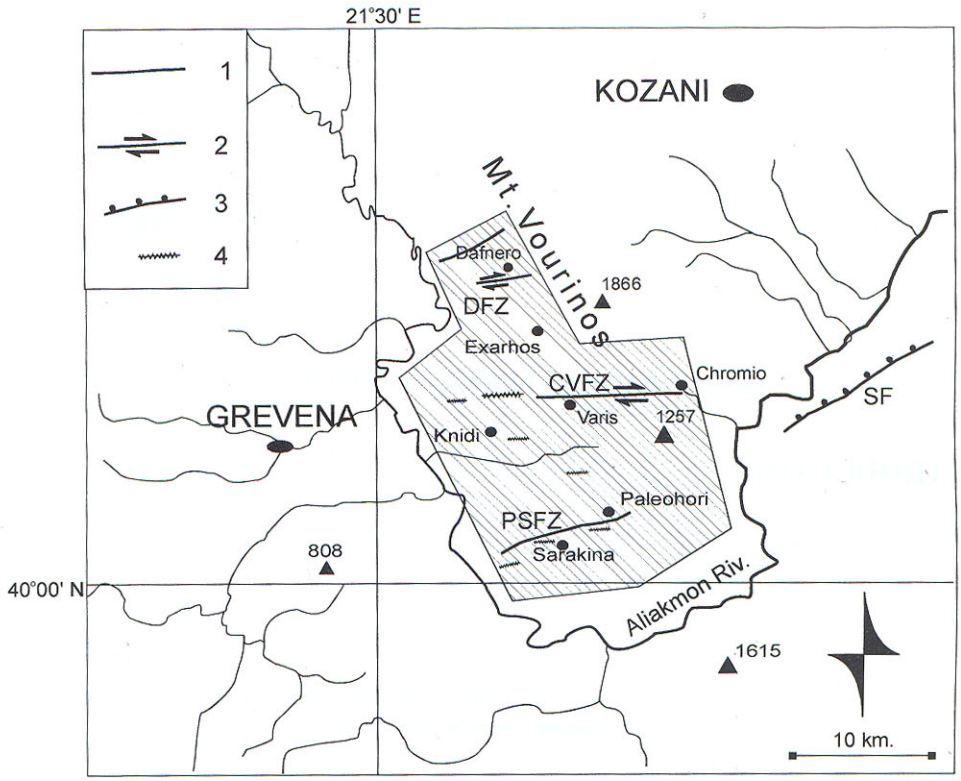

Fig. 1. Location map of the study area (dashed). 1. Faults and fault zones, 2. strike-slip fault, 3. normal fault, 4. earthquake fracture. DFZ: Dafnero fault zone; CVFZ: Chromio-Varis fault zone; PSFZ: Paleohori-Sarakina fault zone; SF: Servia fault.

II. REGIONAL GEOLOGY - NEOTECTONICS

The meizoseismal area is an E-W trending zone, from the northeastern margin of the Meso-Hellenic trench, through the ophiolite complex of Mt. Vourinos and the carbonates of "Eastern Greece" Unit, up to the southern part of Kozani-Servia neotectonic basin. Three tectonic macro-structures can be distinguished: (i) the NW-SE trending margin of the Meso-Hellenic trough, at the east of Grevena; the main outcrops are the Miocene Pentalofos and Tsotyli formations, overlain by Plio-Quaternary mainly fluvial - lacustrine conglomerates, sands and marls; (ii) the ophiolites mass of Mt. Vourinos in the middle and (iii) the lacustrine basin of Kozani –Servia at the east (Pliocene - M. Pleistocene, Brunn, 1956; KOUFOS *et al.*, 1991), faulted against Mt. Vourinos by a NW-SE fault zone (MAVRIDIS and KELEPERTZIS, 1994); its southern border is also tectonic, with the prominent NE-SW Servia fault juxtaposing it against the Mesozoic rocks of Mts. Kamvounia and Titaros. The SW prolongation of Servia fault running through Paleohori, Sarakina and Kendro (villages that suffered great damage), may constitute a separate segment, recognizable by the morphologic escarpment created in the molassic deposits.

Within the structures of Grevena and Vourinos, few faults are recognizable, the majority of which have E-W or NW-SE trends. Some NW-SE and ENE-WSW trending

lineaments that, based on aeromagnetic anomalies, could be interpreted as faults have also been detected in the mountainous mass of Vourinos (MAVRIDIS and KELEPERTZIS, 1994). One of them is the Chromio-Varis-Knidi lineament, which can represent a fault reactivated during the 15 May 1995 earthquake, as all villages lying along its strike were razed (Knidi, Varis) or suffered extensive damage (Chromio).

Dafnero fault zone

At the area of Dafnero, located at the NW edge of Mt. Vourinos, there is an impressive occurrence of an E-W trending fault zone (DFZ) (Fig. 2). The outcrops there consist of Plio-Quaternary deposits that form well-expressed sub-horizontal planation surfaces throughout the eastern part of Grevena basin and comprise: (i) a lower member (visible thickness more than 50 m.) of cohesive monomictic (ophiolitic)

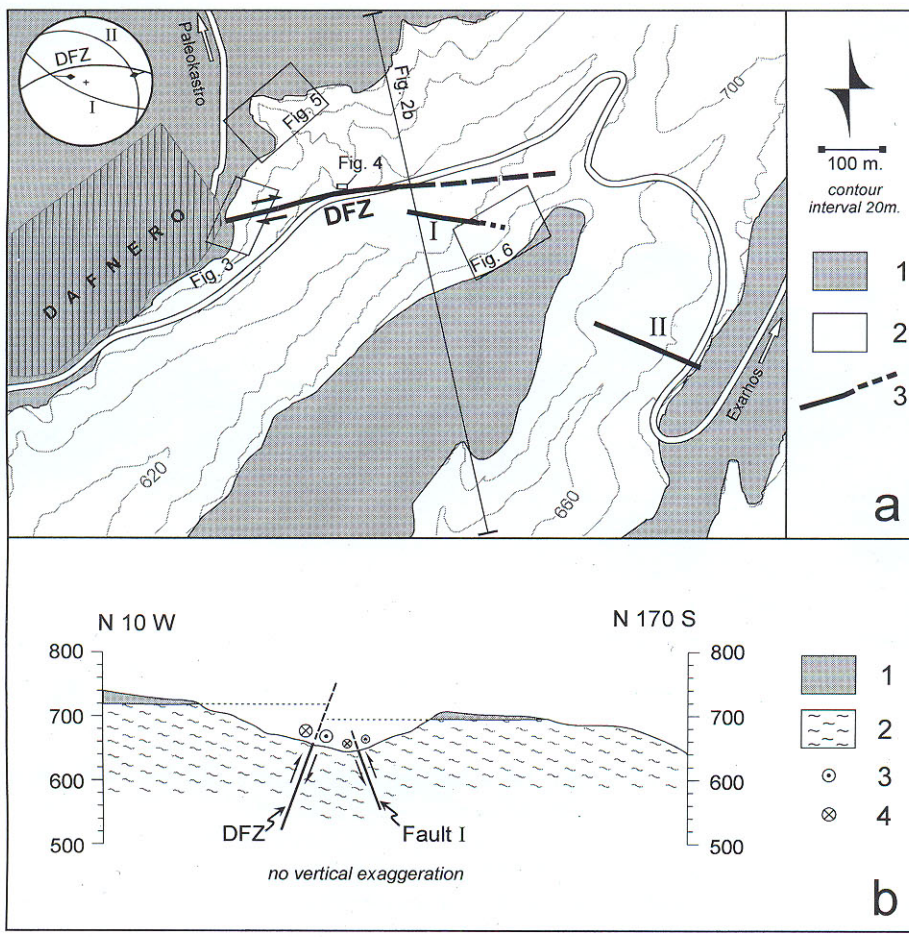

Fig. 2.(a) Geological map of Dafnero. 1: upper member, 2: lower member (see text for description), 3: faults; DFZ: Dafnero fault zone. Inset: stereographic projection (Schmidt lower hemisphere) of the three mapped faults; also shown the displacement vectors of DFZ and fault I. Rectangles show approximate locations of figs 3-6.
(b) Cross section to show the relationship of DFZ with the outcropping Plio-Quaternary deposits. 1: Upper member, 2: lower member, 3: fault displacement towards reader, 4: fault displacement away from reader. Note that fault *I* does not displace the upper member (multimictic conglomeratic breccias).

conglomerates (well-rounded pebbles) with sandy matrix, bearing intercalations of soil horizons, and (ii) the upper member of fairly sorted loose multimictic conglomeratic breccias with a thickness of 10-30 m. All studies so far have left the two members undifferentiated and the age assigned to them is Plio-Pleistocene, according to FAUGERES and VERGELY (1974) and MAVRIDIS and KELEPERTZIS (1994) or Villafranchian, (2.0 Ma BP) according to KOUFOS and KOSTOPOULOS (1993). This age is also accepted by RASSIOS *et al.* (1996).

DFZ has a steep 70° northern dip and striations measured on some of its constituent surfaces were very slightly inclined (plunge = 10-13°), yielding a dextral character with a slight reverse component. It cuts the monomictic conglomerates, as well as the lower part of the overlying upper member. The reverse component of DFZ is clearly shown (i) at the slopes of the stream running at the east of the village, where the multimictic horizon is displaced by approximately 0.50 m (northern-side up) (Fig. 3) and (ii) at a

Fig. 3. The multimictic conglomeratic breccias displaced by DFZ, which runs from bottom right to the centre of the photograph, where person is standing.

natural cut normal to DFZ, where between two shear surfaces the two-generation gouge developed to follow the reverse component of slip (Fig. 4). The latter is also evidenced by the deep incision at the hanging-wall, while in the footwall incision is almost absent, if existing at all (Fig. 5). Also, a set of vains, formed parallel to DFZ has developed at the hanging-wall for a width of about 30 m. Similar observations can be made elsewhere in Greece, where rocks of ophiolitic origin are faulted.

Another fault occurs about 200 m. to the southeast; its has a N 40°E strike and 70° southwestern dip. The fault displaces the monomictic conglomerates, but not the overlying multimictic ones. Striation measured on it showed reverse character with significant (?)right lateral component (36°/220°) (Fig. 6).

No earthquake fractures could be found in the immediate area of DFZ.

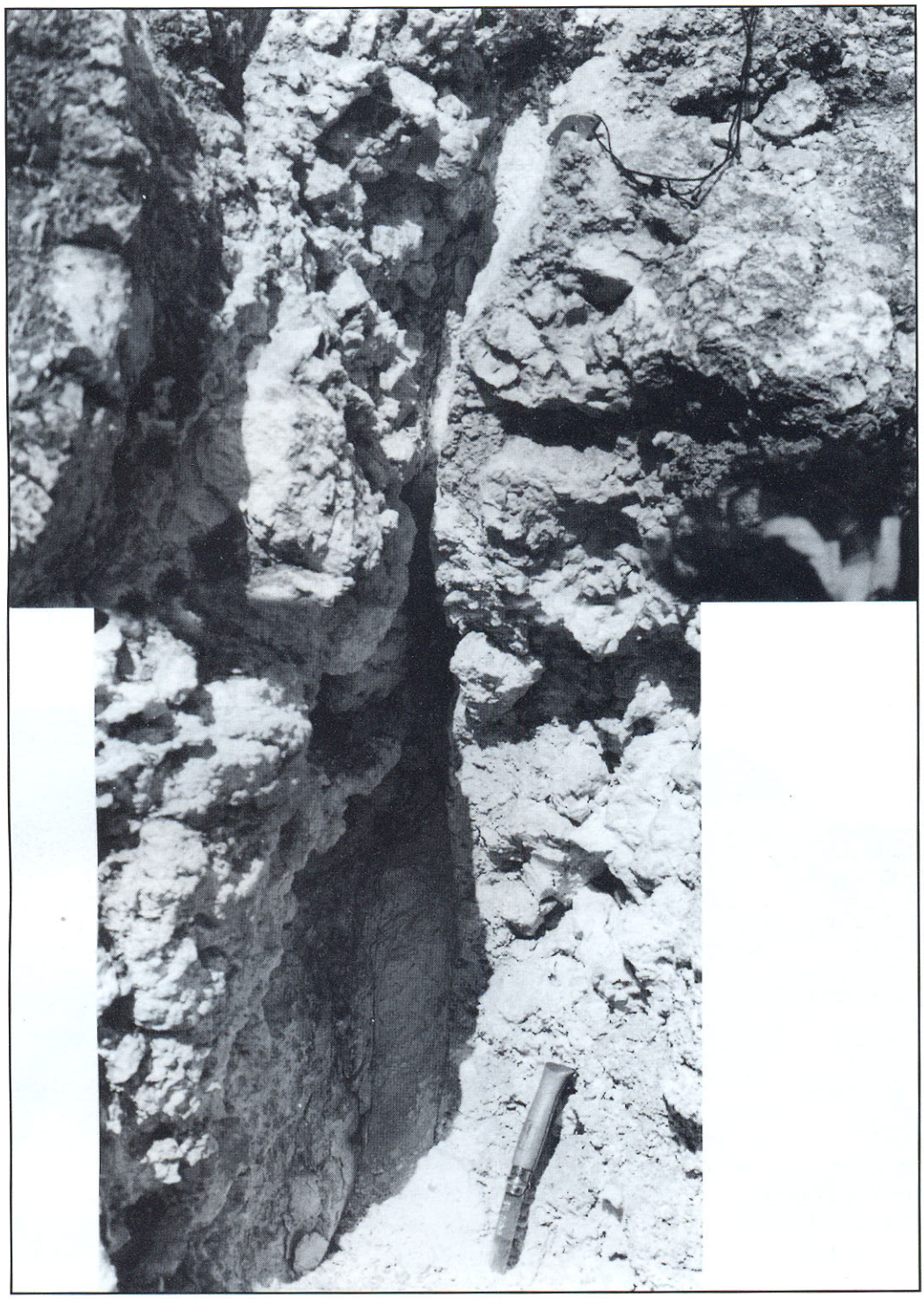

Fig. 4. Gouge developed between two shear surfaces of DFZ, displaying the reverse component of slip. Right-hand side block corresponds to hanging-wall and has moved away from the reader and upwards. Two generations can be distinguished, the "white" post-dating the "brown".

Fig. 5. Deep incision in the hanging-wall of DFZ Height of slopes: approximately 30 m. Also shown the veins developed parallel to the fault zone.

Fig. 6. Fault I, running from bottom right to the middle of photograph (see fig. 2 for location) that displaces the lower member of the Plio-Quaternary deposits. Note also the soil horizons within the lower member (bottom left). No indication whether the fault displaces the upper member (top). People in lower right for scale.

Chromio-Varis fault zone (CVFZ)

This E-W trending large aeromagnetic anomaly, which has been interpreted by PAVLIDES *et al.* (1995) as a Miocene dextral fault, is recognizable in the field as a transverse depression dissecting Mt. Vourinos into a northern and a southern part. However, no geologic indicators of faulting can be found (fault surfaces). However, damage along its strike was particularly severe ($I_o \geq X$ at Knidi, Varis and Chromio).

The most prominent earthquake set of fractures was found at Samara Rahi, just on the western prolongation of CVFZ. It had an E-W strike and a length of more than 2.5 km. Apparent vertical displacement was 35 cm (southern-side-down), while a 5-cm left-lateral offset was measured. Furthermore, numerous old landslides occur, probably related to previous fault activity.

Paleohori-Sarakina fault zone (PSFZ)

This ENE-WSW striking fault zone is discernible through the topographic escarpment it has created in the Miocene deposits of the molassic "Tsotyli" formation, while no actual fault break can be observed. The kinematics of this f.z. still remain to be clarified, as no surficial kinematic indicator could be found. Therefore, it is probable that PSFZ is of analogous character to DFZ, so that the scarp created by it is less prominent than it should be for a normal fault.

A set of approximately E-W trending fractures were found about 500 m. before the northern entrance to Sarakina. The main fracture had a N 110° trend, cut the asphalt road and continued into the adjacent slope. It had no vertical displacement; however, most of the fractures had a 1 mm - 1 cm "heave". The fracture set was *én échelon* arranged and they had a slight dextral offset (Fig. 7).

Along the road that passes through the hills at the south of Paleohori, we found a series of small-scale landslides. Two hundred meters after the road junction to Deskati we found fractures cutting the tarmac and continuing into the soil. They are *én échelon* arranged along an overall E-W trend and a small "graben" has been created between two sets.

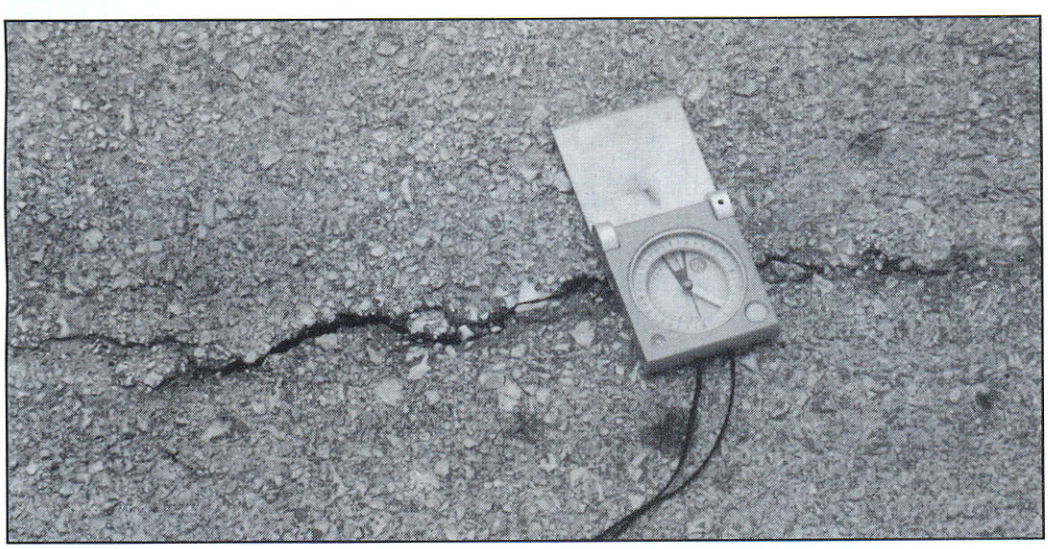

Fig. 7. Earthquake fracture on the road to Sarakina. Strike is N 100° E. Note the 2 mm right-lateral displacement of gravel, at the middle of the photograph.

DISCUSSION - CONCLUSIONS

The meizoseismal area is characterised by low relief with extended sub-horizontal planation surfaces that develop on the Plio-Quaternary deposits. Morphological discontinuities occur mainly where incision has taken place, as the observed faults or fault zones do not cause any conspicuous morphological discontinuity. The Plio-Quaternary deposits in the study area are mostly of fluvial-lacustrine origin; however, ELTGEN (1986) described Late Pliocene marine deposits in Neapoli, 25 km north of Grevena. Therefore, and with the area lying nowadays at an altitude of 700 m., we get an average uplift rate of 0.35 mm yr^{-1}.

The distribution of damage caused by the 13 May 1995 earthquake, with the higher intensities (I≥IX) found along two zones, one E-W between Chromio and Varis and one NE-SW between Rymnio and Kendro (LEKKAS *et al.*, 1995), suggests the reactivation of two major fault zones, namely the Chromio - Varis - Knidi and the Sarakina - Paleohori ones, respectively.

The studied fault zones have E-W or NE-SW trends and the observed earthquake fractures run parallel to them. In none of the fault zones could kinematic indicators be found, so as to verify a normal character of motion. Both DFZ and CVFZ are strike-slip, with some vertical (reverse or normal) component. Besides, no kinematic indicator could be verified for PSFZ, which can be also strike-slip, with some vertical component of displacement. Also, the horizontal component of slip is present (if no the only one) in all the studied earthquake fractures.

A number of proposals has been made for the focal mechanism and accompanying stress field of the recent earthquake of Grevena. PAPAZACHOS *et al.* (1996) said that the seismogenic fault was an ENE-WSW, north-northwest dipping normal fault with some right-lateral component. MAKROPOULOS *et al.* (1996) suggested that the causative fault, as well as all the aftershocks related to it show right-lateral component of slip. They also claimed that the focal mechanisms that lie at the edges of the main fault are oblique to strike-slip, together with some reverse ones. The former suggest NNW-SSE extension, while the latter propose two models, of either shearing in conjugate planes, or a NE-SW shear couple, but they had not observed "substantial inverse secondary faulting in the N330°-340°" (MAKROPOULOS *et al.*, 1996, p.100 and fig. 5). HATZFELD *et al.* (1996) suggest that the shock was due to a normal, north-dipping fault, accompanied by a south-dipping antithetic one.

Our research has shown that the prominent brittle tectonic features in the eastern part of the Mesohellenic trench are strike-slip faults; their strikes are either approximately E-W or ENE-WSW, and some of them, as is the case of DFZ, cut the upper parts of the Quaternary formations that outcrop there. Especially at the area of Dafnero, which lies at the eastern margin of the Meso-Hellenic trough the dominant fault type is that of strike-slip character with slight vertical (reverse) component. On the other hand, no normal-character faults and fault zones with evidence of Quaternary activity have been observed in the surrounding region. Besides, the occurrence of normal faulting is considerably limited, even within the molasse.

Bearing in mind all the aforementioned, we believe that the model of simple extensional deformation during the Quaternary cannot adequately explain neither the quaternary the activity of strike-slip faults, some of them with reverse component, nor the quaternary uplift of marine deposits. On the other hand, all seismological interpretations on the focal mechanism of the Grevena earthquake, despite disagreeing (if

not conflicting) explanations, share the aspect of the horizontal component of slip. Therefore, we believe that the described quaternary deformation indicates that the regional stress field is a composite one and could be represented by a rotational couple type (MARIOLAKOS *et al.*, 1991). Inside this regional stress field of rotational couple type, local stress fields exist as extensional, compressional, and even transpressional and transtensional ones. All the observed neotectonic structures can be interpreted under the influence of such a stress field that can account for the uplift of the whole area, the smooth relief of the landscape, as well as the occurrence of strike slip faults with normal or reverse component, even the occurrence of some folds within the Pliocene deposits in the wider area (FAUGERES & VÉRGELY, 1974, PAVLIDES, 1985).

ABSTRACT

An attempt is made to interpret the Quaternary deformation in the area of Grevena (W. Macedonia, Greece). Field study in the meizoseismal area of the 13 May 1995 earthquake showed that the dominant brittle tectonic structures are E-W (and possibly NE-SW) strike-slip faults that also display some vertical component of displacement. We believe that the Quaternary deformation in the area cannot be explained by simple extension but is the result of a composite stress field.

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