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ON THE DYNAMICS OF THE 13 MAY 1995, M6.6 KOZANI-GREVENA AFTERSHOCK SEQUENCE

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On 13 May 1995, a destructive earthquake of M6.6 occurred in the area of Kozani and Grevena Prefectures, West Macedonia, Greece, on the coordinates 40.158N, 21.673E at the southern foothills of M. Vourinos (see Figure 1).

The Harvard CMT focal mechanism of the main event (Figure 1) indicates almost purely normal faulting with nodal plane azimuths, dips and rakes respectively (240°, 31°, -98°) or (70°, 59°, -85°). The centroid depth is estimated between 10-13 km. The first nodal plane is consistent with N65° oriented ground ruptures dipping to the NW, observed over a distance of 15 km in the area of Paleochorion (Fig. 1) and is, therefore, assumed to represent the actual fault plane.

The main event was followed by a long aftershock sequence which has been subject to extensive investigation by the Universities of Athens and Thessaloniki, the University of Grenoble, and the ING Rome (Hatzfeld et al., 1995a). The seismological network (Fig. 1) comprised 40 stations (15 three-component, 25 vertical component); it was fully operational from 19 to 25 May 1995. From more than 1000 events recorded during this period, 671 provided data for adequate determination of focal parameters and of those, 622 were located with a precision better than 1km in both ERH and ERZ using HYPO71. The magnitudes of these events fall in the range $2<M<5.4$. The distribution of the aftershock epicenters is shown in Figure 2.

Surface ruptures observed by Pavlides et al (1995) and according to these authors, their pattern "resembles an imbricate fan with a main fault, an antithetic one, etc." (see Fig. 1).

Focal mechanisms were determined for 504 events, for which the nodal planes could be constrained to better than 10° in both azimuth and plunge). The results are summarized in Figure. 3, in the form of statistics of the P and T axes and the P-T plane. The stress field (P-T plane) exhibits a rather complex pattern with prominent clusters in the N-S and N330° directions and a secondary feature at N300°. Such a stress field pattern is, in turn, expected to generate faulting in the E-W, N60°-N70° and N30 directions. There is also a diffuse distribution of the P-T plane in the interval N340°-N360°, expected to generate faulting at N70° to E-W. It should be emphasized that these faulting directions are in remarkable agreement with the orientations of the observed surface ruptures.

The azimuth of the P axis (σ_1) lies mainly in the NE-ENE direction (N40°-N80°) with a prominent cluster at N100°-N110°. The dip of the P axis varies in the range 80°-50° but is, in general lower than 70°. Thus, an average of 30-40% of the total compressional stress acts on the horizontal plane. The azimuth of the T axis (σ_3) is consistent in the NNW direction. Such a stress field generates normal to oblique-slip / strike-slip faulting, while some reverse mechanisms are also observed.

Using the P-T plane information, earthquake foci information and tomographic inversion with relocation, we attempted to discriminate the clusters of earthquakes belonging to the main and the antithetic faults and delineate the extent of these zones.

The general conclusions are summarized below:

1. The main fault has a length of approx. 20 km and terminates in the area of Nisi village, as reported in Pavlides et al (1995), in what appears to be a barrier - an undefined as yet structure - associated with very high P wave velocities and probably determining the (NE-SW) direction of Aliakmon river channel in the west side of the activated area (see Figs 1 and 2). The focal mechanisms located at the (apparent) termination of the main fault are oblique to strike slip and some reverse as well. The main fault and the aftershocks occurring in association with it show right lateral slip. The main fault appears to be listric, curving at high rates below the depth of 5-6 km and associated with a low P wave velocity zone extending to depths comparable to those of the main shock (Figure 4). This effect may be the result of mechanically weaker material causing, in turn, the fault to listrate. Near the base of the main fault and the seismogenic layer we observe low angle to horizontal slip mechanisms.

2. The antithetic faults: Most of the observed surface ruptures have probably been identified with clusters of earthquake activity. A specific example is the cluster located in the SW corner of the activated area, which is believed to correspond to E-W trending fault segments near the village of Agapi and the cluster located in the area of Knidi, which is believed to be associated with E-W faulting in the valley of Siatista (Hatzfeld et al., 1995b). The focal mechanisms of the antithetic faults appear to be normal to oblique slip and left lateral.

3. A small number of events appear in the NNW-SSE direction, mostly associated with oblique slip mechanisms. Surface ruptures in the same direction have been observed as well, but direct associations cannot be made.

A possible geodynamic model leading to the above pattern may be as follows:

A. The stress field with NE directed σ_1 axis and NNW directed σ_3 axis generates deformation by shearing in conjugate planes. The main fault is in the NE-SW direction and the conjugate fault in the E-W direction; internal rotation may be expressed by the fan like pattern of the distributed antithetic faults with oblique slip mechanisms
B. An alternative model which also takes into consideration the aforementioned NNE-SSW 'barrier' at the west end of the activated area involves a stress field generated by a NE-SW couple as per Figure 5. The normal main faulting is in the N60°-70° direction and shearing with substantial strike-slip component in the conjugate NE-SW and WNW-ESE directions. However substantial inverse secondary faulting in the N330°-340° has not been extensively observed. According to this model, the main shock occurred by normal faulting in the N60°-70° direction and the subsequent activity was mainly expressed in terms of internal block deformation by shearing in the conjugate NE-SW (partially) and WNW-ESE (mainly) directions.

The above models appear adequate to explain the observations but although they may be supported by geological observations, they should still be considered to be preliminary, requiring refinement and augmentation when additional multi-disciplinary data becomes available. If however one of these models turns out to be representative of deformation in the area, it does have considerable consequences in the understanding of the geodynamic evolution of West Macedonia and Northern Greece as a whole, which will also be discussed.

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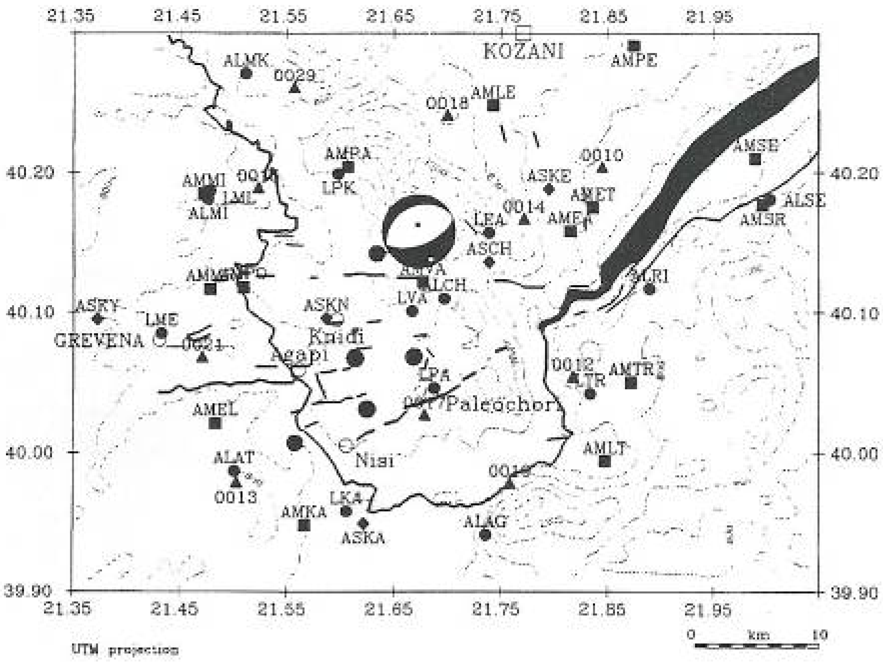

Figure 1. The CMT focal mechanism of the main shock, the epicenters of M>5 after-shocks and the seismographic network. The dashed line indicates the surface rupture attributed to the main shock.

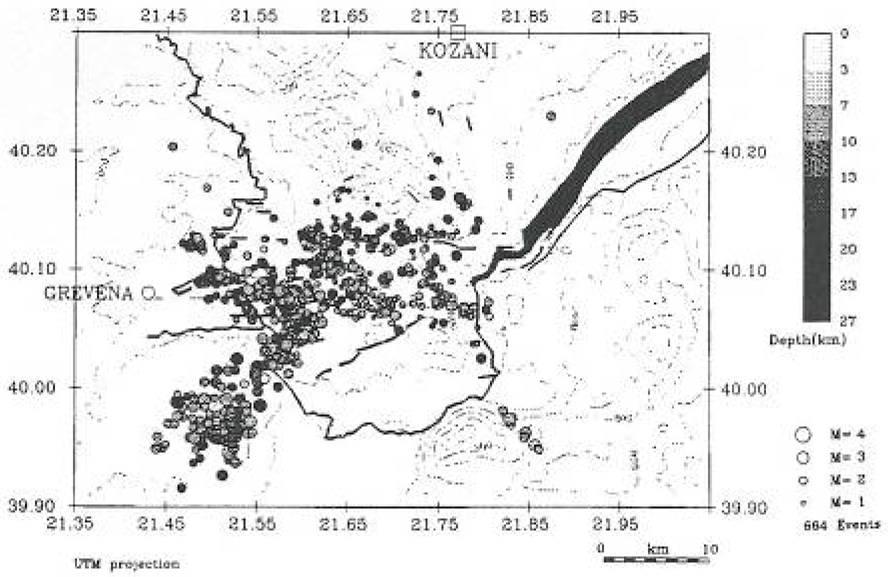

Figure 2. Distribution of the aftershock sequence epicenters, 19-25 May 1995. The dashed line indicates the surface rupture attributed to the main shock.

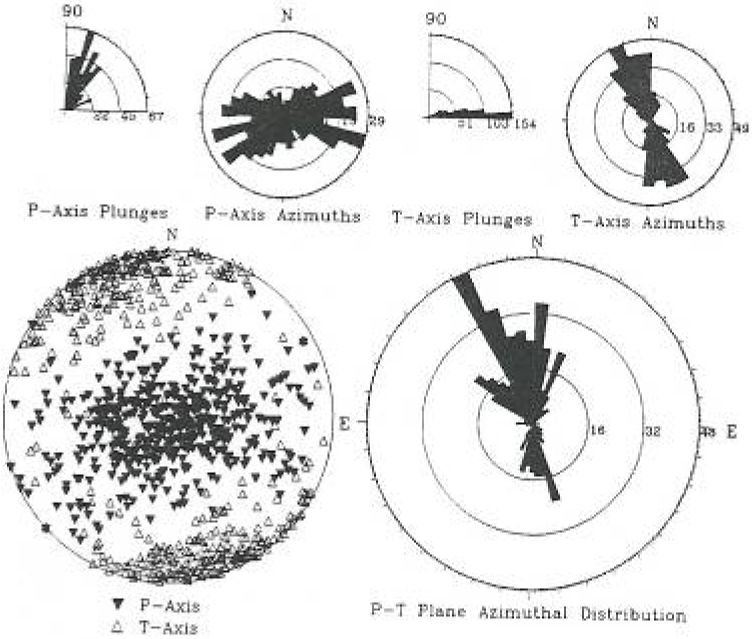

Figure 3. Summary of the seismotectonic features of the Kozani-Grevena aftershock sequence in terms of P and T principal stress axes statistics.

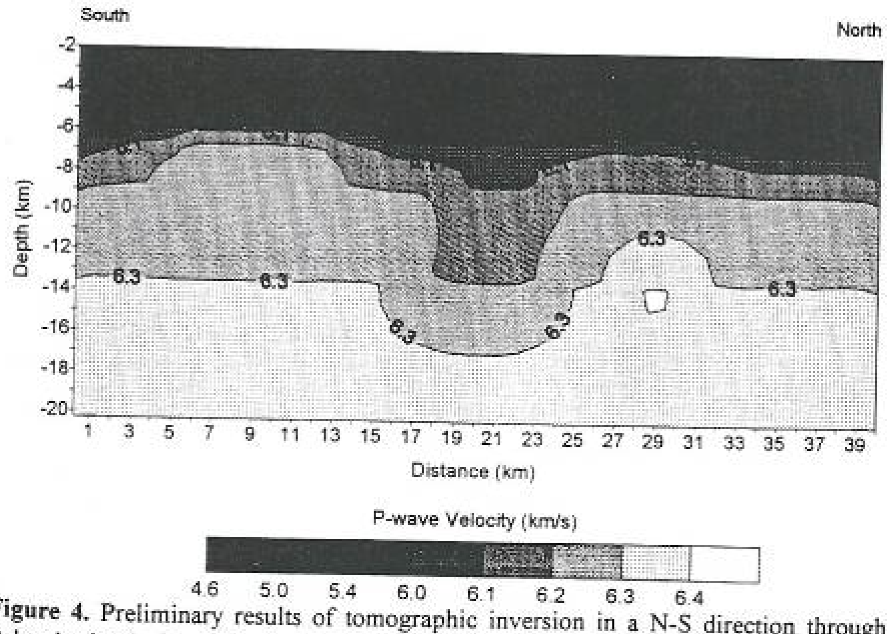

Figure 4. Preliminary results of tomographic inversion in a N-S direction through Paleochori. The low velocity zone at depths of 10-15km is comparable to the focal depth of the main shock.

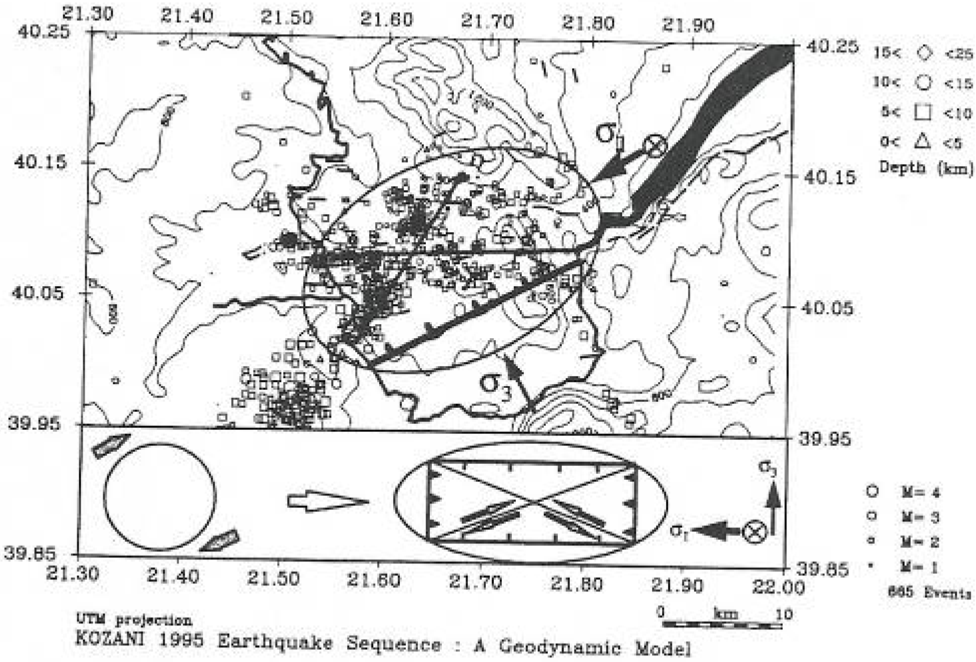

Figure 5. A first approach to a geodynamic model that may explain the observations in Figures 2 and 3.