CRACK INDUCED ANISOTROPY IN THE PATRAS AND VOLOS AREA DEDUCED FROM THREE-COMPONENT SEISMOGRAMS OF LOCAL EARTHQUAKES AND ITS RELATION WITH STRESS AND STRAIN

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A B S T R A C T

Three component seismograms from local earthquakes recorded during two field experiments in the summers 1991 (Patras area) and 1992 (Volos area) have been analyzed in order to detect shear-wave splitting. In the western part of the Gulf of Corinth, the observed S-wave splitting is likely to be due to crack-induced anisotropy, as the fast S axis and hence the hypothetical cracks which may generate it, would be oriented in the East-West direction, roughly parallel to the major compressive stress axis. The network in the Volos area was denser, and concentrated near the northern side of the Almiros basin. The preliminary analysis of the data also show S-wave splitting , with a fast axis E-W, also consistent with a crack-induced anisotropy related to the present strain field.

ΑΝΙΣΟΤΡΟΠΙΑ ΛΟΓΩ ΡΗΓΜΑΤΩΝ ΣΤΙΣ ΠΕΡΙΟΧΕΣ ΤΗΣ ΠΑΤΡΑΣ ΚΑΙ ΤΟΥ ΒΟΛΟΥ ΑΠΟ ΣΕΙΣΜΟΓΡΑΜΜΑΤΑ ΤΡΙΩΝ ΣΥΝΙΣΤΩΣΩΝ ΤΟΠΙΚΩΝ ΣΕΙΣΜΩΝ ΚΑΙ ΣΥΣΧΕΤΙΣΗ ΜΕ ΤΟ ΠΕΔΙΟ ΤΩΝ ΤΑΣΕΩΝ

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Π Ε Ρ Ι Λ Η Ψ Η

Σεισμογράμματα τριών συνιστωσών από τοπικούς σεισμούς που καταγράφηκαν κατά τη διάρκεια δύο πειραμάτων στη περιοχή της Πάτρας το 1991 και του Βόλου το 1992 αναλύθηκαν για τη μελέτη της ανισοτροπίας με τη μέθοδο του διαχωρισμού των διευθύνσεων πόλωσης των S-κυμάτων. Στο δυτικό τμήμα του Κορινθιακού Κόλπου η παρατηρούμενη ανισοτροπία αποδίδεται σε ρήγματα επειδή ο άξονας με τη μεγαλύτερη ταχύτητα έχει διεύθυνση Α-Δ, περίπου παράλληλη με την διεύθυνση των συμπιεστικών τάσεων στη περιοχή. Το δίκτυο στη περιοχή του Βόλου ήταν πυκνότερο και συγκεντρωμένο στο βόρειο

τμήμα της λεκάνης του Αλμυρού. Η πρώτη ανάλυση των δεδομένων δείχνει επίσης διαχωρισμό των S κυμάτων, με τον γρήγορο άξονα να έχει διεύθυνση Α-Δ, που βρίσκεται σε συμφωνία με τη δημιουργία ανισοτροπίας λόγω ρηγμάτων που σχετίζονται με το παρόν πεδίο των τάσεων.

INTRODUCTION

We present here preliminary results concerning the anisotropy of the upper crust in Greece, obtained from the analysis of three component records during two field experiments, in summer 1991 in the Patras-Aigion area (two months) and in summer 1992 in the Volos area (two months).

This study was based on the model proposed by Crampin (e.g., Crampin, 1985; Crampin and McGonigle, 1981) that the present stress field in tectonic areas controls the orientation of cracks of the upper crust, and hence has a significant and detectable effect on seismic waves due to the resulting anisotropy of the elastic parameters: This is the EDA (extensive dilatancy anisotropy), particularly noticeable through the splitting of the S wave, which is the separation of the incident S wave in two nearly orthogonal quasi S waves travelling at different velocities. Numerous field studies confirm the presence of an upper crust anisotropy in relation with the stress field direction (e.g., Zollo and Bernard, 1989; Iannacconne and Deschamps, 1989 ; De Chaballier et al., 1992).

For the Patras experiment, our aim was to study anisotropy in relation with the regional stress or strain deduced from the seismic activity recorded during two months, and from the geodetic measurements (GPS). We used two kinds of three component stations: analogue recorders (Lennartz, 3 channels) with velocimeters, and digital recorders (Reftek, 16 bits, 6 channels) with velocimeters and accelerometers, in total 31 three component stations, which were installed with a spacing of about 10 km. As the main objective of the network was to record P and S phases of the local seismicity for mapping the active zones, these stations were located in the mountains north and south of the Corinth Gulf, in order to avoid the site effects of sedimentary basins, which usually present high noise level and produce large delays in the P and S wave arrival times. Nevertheless, we also installed a Reftek station at the southern end of the delta of Nafpaktos, where the recent sediments are expected to be the deepest, and where we expected a large anisotropy effect. Several questions were addressed : What is the lateral variability of the direction of crack-induced anisotropy? What is the relation between the stress deduced from focal mechanism of local earthquakes and the deformation ? Could the deformation be inherited by previous tectonic phases with a different strain orientation from the present one ? Could the depth range be constrained for the anisotropic volume ? Unfortunately, the mean spacing between stations was a priori too large to allow a site to site correlation.

The network in the Volos area was denser (23 three component stations with a 3 to 5 km spacing), and concentrated near the northern edge of the Almiros basin. Part of the stations were installed between the two normal faults which were recently activated, one in 1980 and the other possibly in 1950. We expected a rotation of the direction of the cracks and a higher crack density in the area close to the step separating the two faults. The other part of the network was installed in the basin, south of the fault scarp, where we expected a different anisotropic signature with respect to the sites on the outcropping bedrock on the northern side of the fault.

PRELIMINARY RESULTS FOR THE PATRAS AREA

The 31 three component stations are mapped in Figure 1. The events used in this study are those selected by Rigo et al.(see joint paper). An example of S-wave splitting is presented in Figure 2. The polarization vectors of the horizontal velocity in the S window are plotted as a function of time for Malamata station (in the Nafpaktos basin). We clearly see the two S-waves, the fast one with a direction of polarization N50E and the slow one arriving with a delay of about 0.1 s, with a different polarization. Usually, split S waves are nearly orthogonal to each other. Here, however, the angle between the two S significantly differs from 90°, and we did not carry yet the waveform modeling which would explain this unusual observation.

We selected the records which are in the S window, i.e., records for which the near-surface incidence angle of the seismic ray is smaller than the critical angle (above which the free surface effect has a destabilizing effect on the polarization of the S wave). The S-window effect is described in more details in Booth and Crampin (1985) and Bernard and Zollo (1989). Four stations have been analyzed up to now: Malamata, Psaromita, Elaia and Sotena. In Figure 3, the direction of the fast S-wave polarization is plotted on an equal area projection of the upper hemisphere for the selected events. We see that for a given site, the directions obtained are very similar, within 10°. Two ranges of direction of polarization are identified: One is N55E-N75E, for Malamata and Psaromita, and the other N105°E-N120°E at Elaia and Sotena stations. The mean time delay at Malamata is about 0.1 seconds, greater than those for the other stations (0.05s): This larger delay for Malamata suggests a thicker anisotropic volume, or a stronger crack density (or both) in the thick sediments of the Delta. The directions of rapid S at Elaia and Sotena are compatible with the maximum compressive stress deduced from the focal mechanisms (see Hatzfeld et al,.(1990), and see Figure 5 in Rigo et al., this issue): The NNE-SSW extension is supposed to preferentially open cracks orientated in the same direction, giving rise to a rapid S polarized also in that direction, which is indeed observed. However, for Sotena, the azimuthal distribution is not good enough to unambiguously interpret the homogeneous direction of polarization obtained in terms of an anisotropy effect, as similar location and focal mechanism of seismic sources also provide a constant first S polarization.

Patras-91

Stations 3Chan.

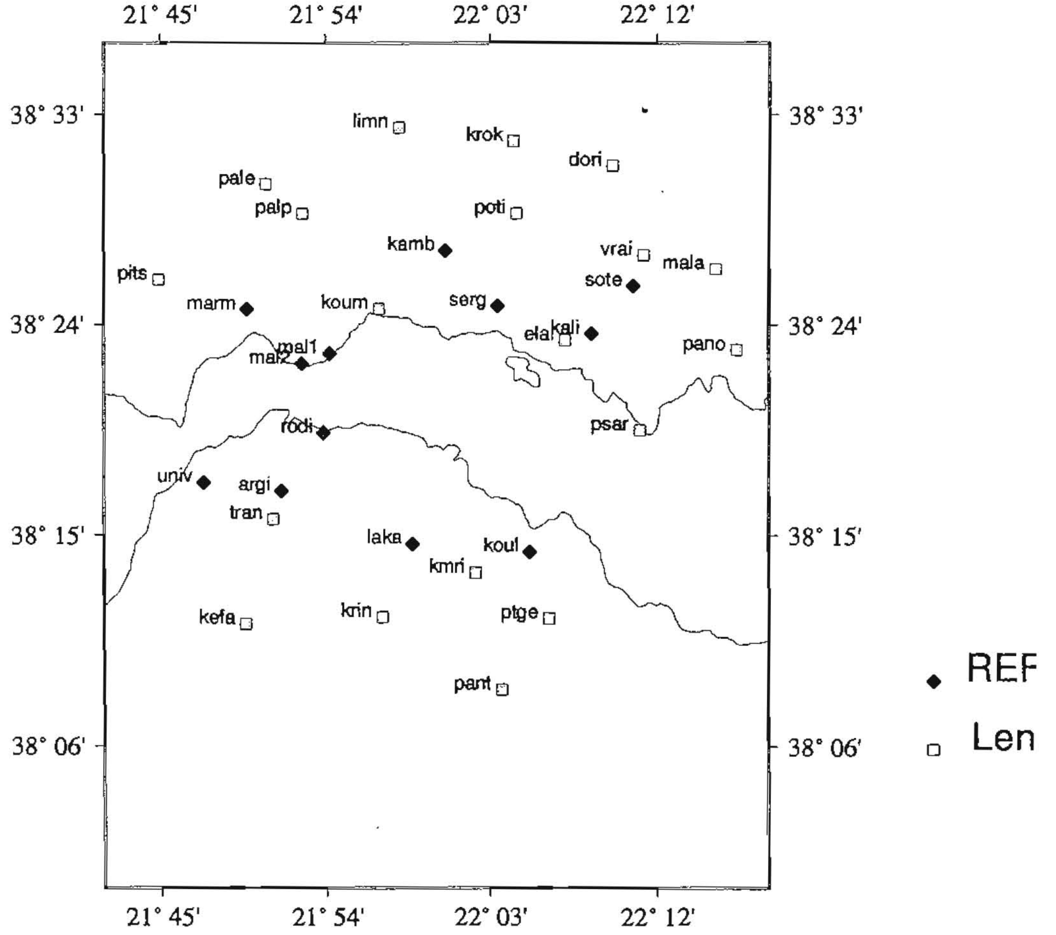

Fig.1. Map of the three-component network used in Patras experiment (Len is for Lennartz recorders and Ref for Reftek recorders).

The direction N55E-N75E at Malamata significantly differs from the E-W to WSW-ENE orientation of the maximum compressive stress deduced from the focal mechanisms (see Figure 5 in Rigo et al., this issue). Possibly, tectonic stress and strain

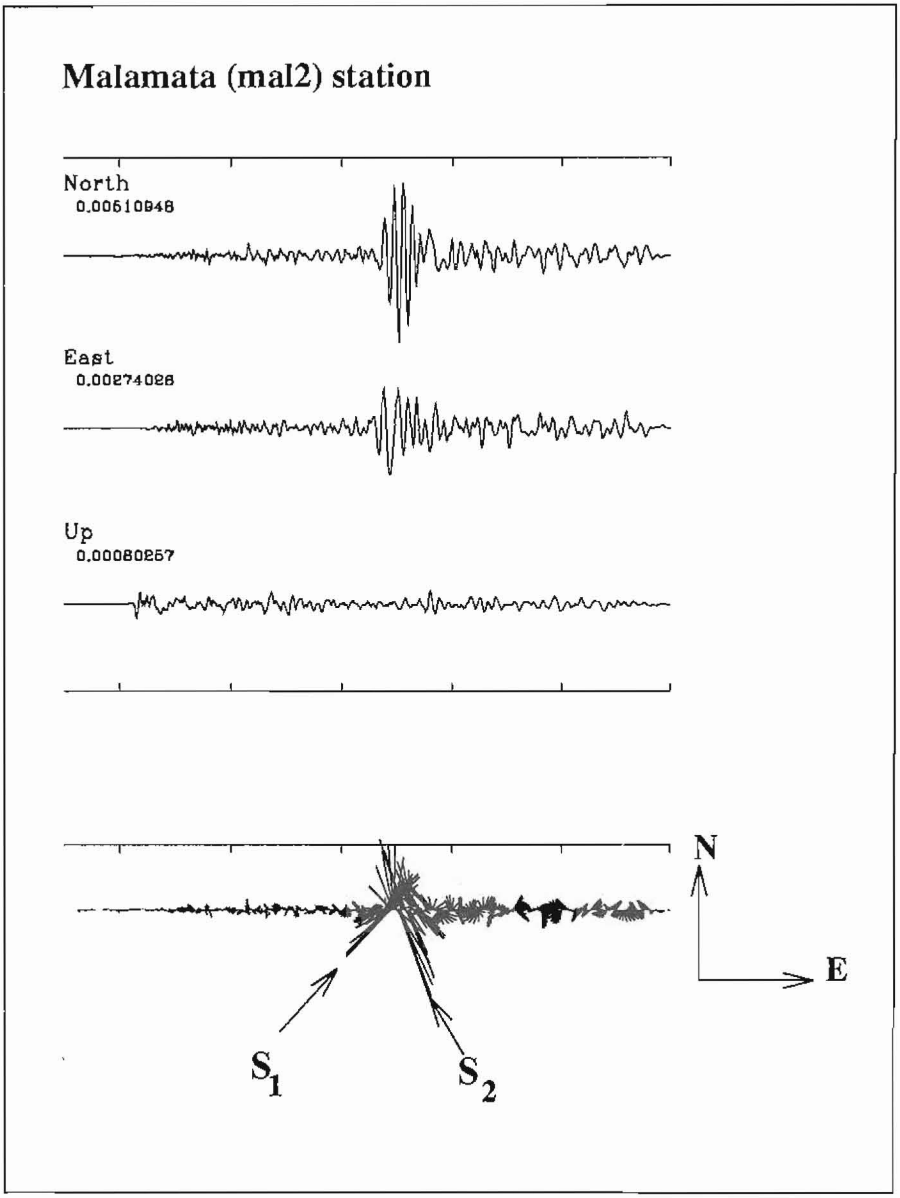

Fig.2. Three component velocity record and horizontal polarigram in the North-East plane. The two successive main directions of polarization of the split S-wave are indicated by arrows (S1: fast, S2: slow).

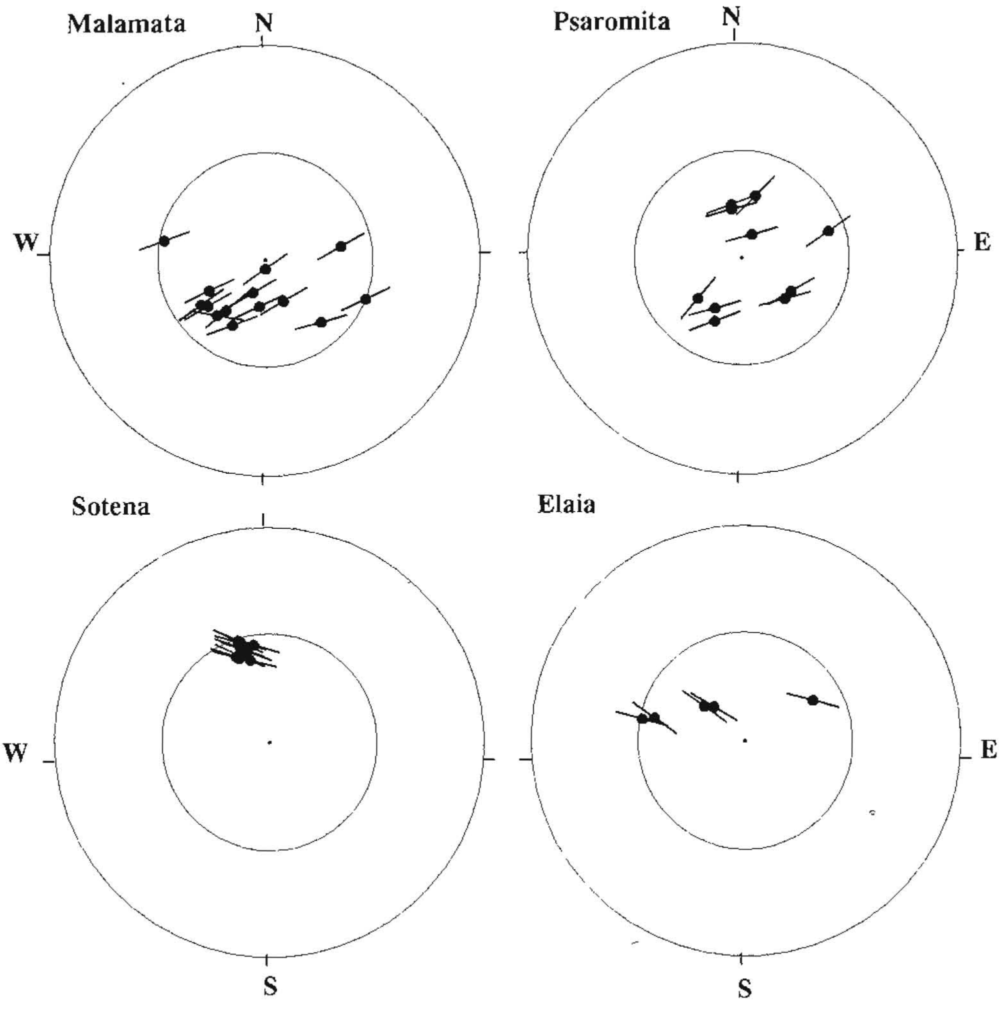

Fig.3. Polarizations of the local fast S waves, plotted on the upper hemisphere, equal area projection. The inner circle represents 45° incidence angle.

rotation may occur there, as the site is at only 10 km from the western extremity of the Corinth Gulf, where the tectonic strain significantly changes for building the Gulf of Patras, whose geometry differs from that of the Corinth gulf. We can not conclude yet if the direction of fast S-polarization reflects the local stress field or a particular structure related to the sedimentation of the delta. The rapid S direction at Psaromita is also significantly different from the expected W-E to WSW-ENE direction. At this site, it may be possible that inherited fracturation of the pre-tertiary carbonate platform may partially control the anisotropy.

Although certainly not sufficient for allowing any reliable conclusion, these preliminary observations and results for four stations are very promising; the complete set of anisotropy direction for the 31 sites will most probably bring a much better understanding of these rapid S direction.

PRELIMINARY RESULTS FOR THE VOLOS AREA

We used 21 Reftek stations with a spacing about 2 to 5 km, near the northern edge of the Almiros basin. Unfortunately, the seismic activity was significantely lower than in Patras (5 to 20 events per day for Volos with respect to 150 events per day for Patras).

The very preliminary analysis of the data show S-wave splitting, as for the Corinth Gulf, with a fast axis orientated E-W, consistent with the present regional stress field. The comparison of records at stations on the bedrock to records at stations on the thick plioquaternary sediments of the basin shows that the anisotropy is not significantly affected by these sediments, contrary to the observation in delta of Nafpaktos: The anisotropy is hence probably distributed between the surface and at least several kilometers in depth. However, even with short distances between stations of a few kilometers, the fluctuations of the anisotropy parameters appear quite large, indicating strong heterogeneities in the crack distribution within the upper crust.

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