FAULT PLANE SOLUTIONS OF MICROEARTHQUAKES AND TECTONIC ANALYSIS IN THE WESTERN PART OF THE GULF OF CORINTH (GREECE)

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A B S T R A C T

As part of the seismological experiment organized in the Patras-Aigion area in the summer 1991, we were able to calculate about 200 fault plane solutions of shallow earthquakes with magnitudes (M_L) between 1.8 and 3.2. These solutions are constrained by a combined inversion of P first motion polarities and S-wave polarization directions, from digital three-component seismograms, using the probabilistic approach developped by Zollo and Bernard (1991). This technique involves a carefull selection of S-wave observations which may be contaminated by crustal anisotropy and/or free surface effects. We can distinguish two families of fault plane solutions : normal faulting on planes oriented ~ E-W and strike-slip faulting. Most of the events may be explained by a fault plane dipping north at an angle varying from 25° to the west to 50° to the east. The interpretation of this microseismicity is associated with tectonic field observations and SPOT image analysis which allow us to recognize and precisely map the active faults and to study the location, time and spatial scales of the deformation.

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Π Ε Ρ Ι Λ Η Ψ Η

Με βάση το σεισμολογικό πείραμα που οργανώθηκε στην περιοχή του Αιγίου-Πατρών το καλοκαίρι του 1991 (σχετική εργ. του Παπαδημητρίου και συνεργατών), μας δόθηκε η δυνατότητα να υπολογίσουμε περίπου 200 μηχανισμούς γένεσης επιφανειακών σεισμών με μεγέθη μεταξύ 1.5 και 3.2. Οι λύσεις αυτές προσδιορίσθηκαν με αντιστροφή των πρώτων αποκλίσεων των P κυμάτων και της διεύθυνσης πόλωσης των S κυμάτων. Τα δεδομένα προέρχονται απο ψηφιακές καταγραφές και η μέθοδος ανάλυσης που χρησιμοποιήθηκε είναι αυτή

των Zollo and Bernard (1991). Αυτή η τεχνική χρειάζεται την προσεκτική συλλογή δεδομένων για τα S κύματα έτσι ώστε να υπάρχουν ενδείξεις για ανισοτροπία του φλοιού και/ή επιδράσεις της ελεύθερης επιφάνειας. Δύο οικογένειες μηχανισμών γένεσης μπορούν να διακριθούν: κανονικά ρήγματα με προσανατολισμό περίπου Α-Δ καθώς και ρήγματα strike-slip. Οι περισσότεροι σεισμοί μπορεί να θεωρηθεί οτι προέρχονται απο ένα ρήγμα που κλίνει προς το βορρά με κλίσεις που ποικίλλουν απο 25° στο δυτικό τμήμα σε 50° στο ανατολικό τμήμα. Η ερμηνεία αυτής της σεισμικότητας σχετίζεται με παρατηρήσεις τεκτονικής στο πεδίο καθώς και με ανάλυση εικόνων SPOT και μαςbδίνει τη δυνατότητα τόσο να αναγνωρίσουμε και να χαρτογραφήσουμε τα ενεργά ρήγματα όσο και να μελετήσουμε τις κλίμακες των παραμορφώσεων.

INTRODUCTION

The Gulf of Corinth, commonly described as an E-W half-graben structure, is one of the most active tectonic areas of continental Greece. The presence of Holocene scarps and quaternary uplifted marine terraces in the Corinth region demonstrates the recent activity (the last few 10^5 years) of the normal faults bordering the Gulf. Since ancient time many earthquakes have been reported and during the last century at least 4 earthquake sequences of magnitude 6 or more have occurred in this area (Ambraseys & Jackson, 1990), e.g. Helike in 1861 (M≈6,7; Schmidt, 1881), Eratini (WSW of Itea) in 1965 (M_S=6.4), Corinth in 1981 (M_S=6.7, 6.4, 6.4; Jackson et al., 1982), Ĩtea in 1992 (M_S=5.9-6.0). The rate of north-south extension across the Gulf is estimated to be 1 cm/yr based on a comparison between geodetic measurements from the begining of the century and from 1988 (Billiris et al., 1991). Thus, due to these seismological and tectonic features, the Gulf of Corinth is an appropriate area for a detailed study of crustal deformation processes in a continental extensional frame.

We started in 1991 a multidisciplinary study in the Patras-Aigion area combining seismological, tectonic and geodetic (see joint paper by Rigo et al., this volume) studies. We choose the western part of the Gulf of Corinth for the following reasons : the last large earthquake of magnitude _ 7 occurred in 1861 rupturing the Helike fault near Aigion; the western part of the Gulf is less studied than the eastern part where the 1981 earthquakes of Corinth occurred (Jackson et al., 1982; King et al., 1985). We present here the results and a possible interpretation of part of the seismicity recorded during the summer 1991 in the Patras-Aigion area. Tectonic studies, field work and satellite image analysis, will help us to interpret more accurately the seismicity and the deformation mode deduced from focal mechanisms.

TECTONIC FRAME

Field observations and satellite (SPOT) image analysis allow us to precisely map the fault surface traces over the entire Gulf (Fig. 1). On the southern coast of the Gulf, we find the most important normal faults dipping north like the Xylokastron fault and the Helike fault (south of Aigion). All these faults represent an "en échelon" fault system. They have a characteristic length of 15-20 km and few meters high (1-6 m) clear Holocene scarps, the total topographic relief being 1000-1500 m. On the northern side, there are some generally smaller antithetic normal faults dipping south with also cumulative scarps of Holocene age (e.g. Delfi fault).

The most important active structures at the western extremity of the Gulf are, from east to west, the Helike fault, the Aigion fault and the Psathopyrgos fault, all three dipping north and edging the southern coast of the Gulf. In 1861, a M=6.7 earthquake occurred in Helike near Aigion (Fig. 1). The surface ruptures have been described by Schmidt (1881) as being 1-2 m high along the trace of the Helike normal fault. Mud volcanoes and subsidence of the littoral zone (floading of a 100-200 m wide stripe by the coast) were also observed. This earthquake is probably a characteristic event of the Helike normal fault.

There are also some normal faults dipping south on the northern side, particularly on the Trizonia Island. These last ones are only 2-5 km long and thus cannot generate earthquakes larger than M_S=6. For these reasons, we are expecting that the large part of the seismicity in this area will be connected with the activity of the southern normal faults.

MICROSEISMIC DATA AND PROCESSING

60 portable digital stations (Fig.1) were installed during July and August 1991 in the Patras-Aigion region, and recorded over 5000 events. This paper is based only on the 3000 events that occurred during August. The epicentral locations were computed with the Hypo 71 program. At first, using all the events, we determined the mean P velocity between 0 and 15 km depth searching the minimum of the mean rms of all the locations (Fig. 2). In this way, we obtained a mean P velocity of 5.6 km/s in agreement with Melis et al., (1989), the Vp/Vs ratio being 1.80. To obtain a more precise P velocity model, we selected 190 events with the following criteria : 1) they were very well-located (~ 0.5 km); 2) they were recorded by more than 10 stations; 3) they had a good azimuthal distribution of stations. We then modified the velocity structure (Table 1), keeping a mean P velocity of 5.6 km/s between 0 and 15 km, in order to obtain incidence angles that will allow to determine fault plane solutions for all these events. The P velocity between 15 and 30 km depth is not well constrained due to insufficient data sampling in these depths and we choose a mean P velocity of 6.5 km/s. The epicenters were relocated with the modified velocity model. In order to analyse the seismicity, we selected 850 well-located (~ 1 km) events in the network, recorded by more than 5 stations, the magnitude (M_L) being between 1.8 and 3.2 (Fig. 3). The seismicity appears to be diffuse in all the network with the presence of 4 clusters, the most important being under the city of Aigion at a depth of about 8 km. The seismicity is distributed between 0 and 15 km depth, the maximum of the activity being between 6 and 11 km depth.

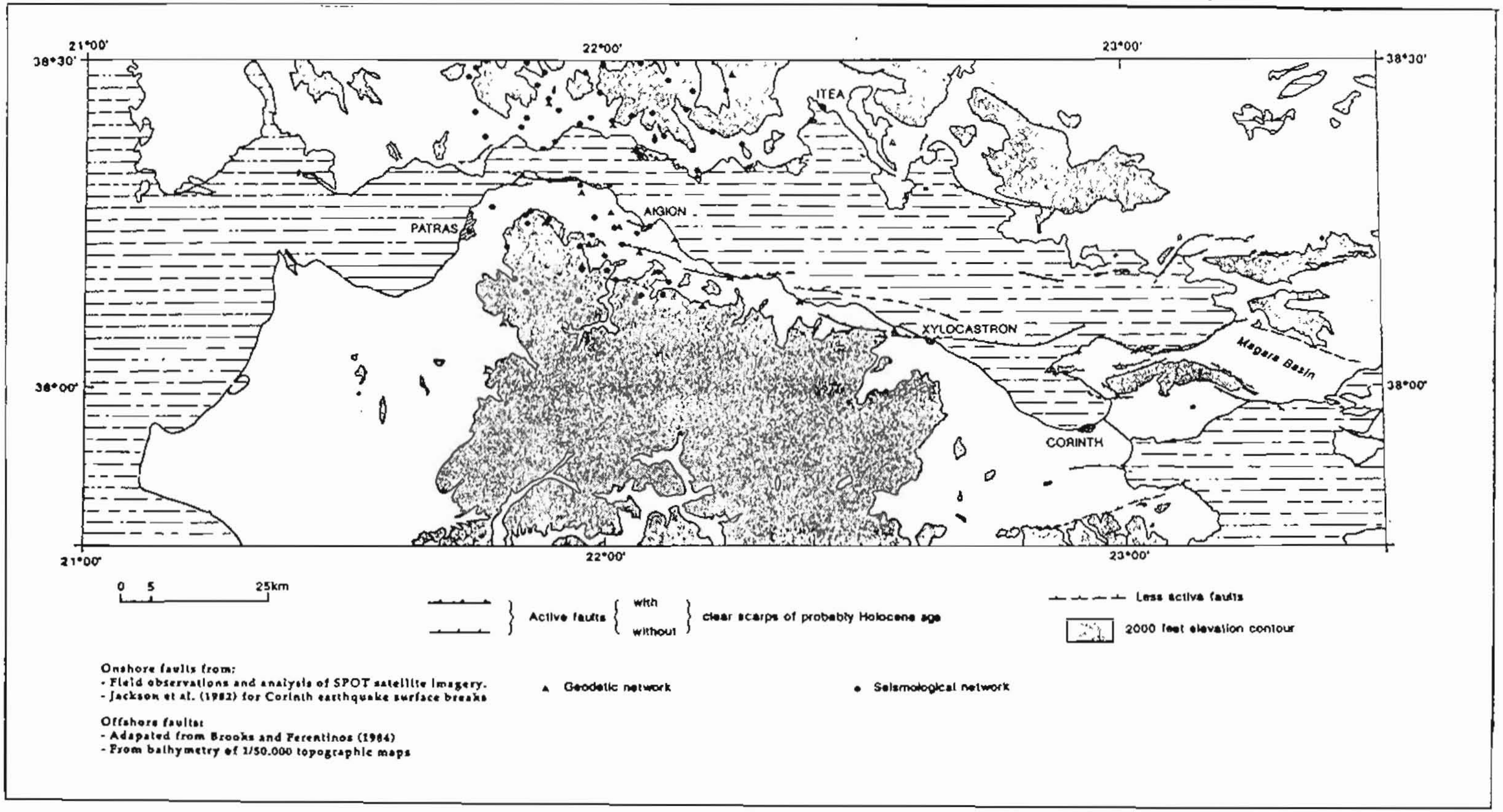


Fig.1. Tectonic map of the Gulf of Corinth.

FOCAL MECHANISMS

Among the 190 first selected events, we determined 145 focal mechanisms using the P first motion polarities. Among those, 90 are well-constrained. In figure 4, two examples are shown which concern the two largest events recorded in the network.

To better constrain the fault plane solutions, we inverted together the S-wave polarization directions obtained from the digital three-component seismograms and the P polarities, using the probabilistic approach developped by Zollo & Bernard, (1991). De Chabalier et al., (1992) have shown the efficiency of this method using microearthquake data.

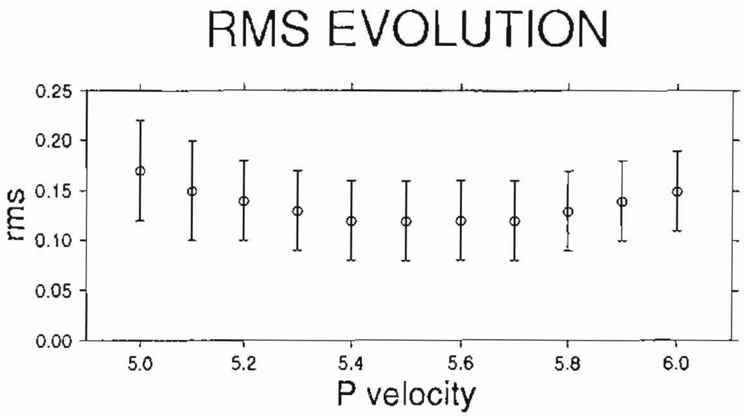


Fig.2. Mean rms of locations versus mean P-wave velocity between 0 and 15 Km.

Table 1. Final P velocity model.

depth	P velocity
0 - 4 km	4.8 km/s
4 - 7.2 km	5.2 km/s
7.2 - 8.2 km	5.8 km/s
8.2 - 10.4 km	6.1 km/s
10.4 - 15 km	6.3 km/s
15 - 30 km	6.5 km/s

In order to determine S-wave polarization directions a selection of observations is necessary. A first selection criterium imposed by the method, is that the incidence angle of the ray path at the station should be sub-critical (less than 45°). Then, for the well-constrained fault plane solutions, we checked that the S-wave polarities agreed with the focal mechanism first found from P waves only. Some stations clearly recorded complicated S-waves for most events, indicating either crustal anisotropy or complicated structure beneath the station. When the anisotropy is clearly identified, we applied a correction to the polarization to obtain the true S-wave polarization direction. Then, using these directions and the P first motion polarities, we calculated the new focal mechanism by inversion.

We present here a selection of 47 representative fault plane solutions (Fig. 5) among the 145 determined. These fault plane solutions are consistent in each cluster. East-west normal fault mechanisms are observed as expected, but also few strike-slip mechanisms are present. We can subdivide the area in three parts: the eastern part showing E-W trending normal faults dipping north at 40-60°; the western part showing also E-W trending normal faults but with a plane dipping north at 15-30°; the central part showing almost only strike-slip mechanisms. Thus, there seems to be a change in the fault geometry at depth between the eastern and the western part of the studied area with a transition zone in the central part.

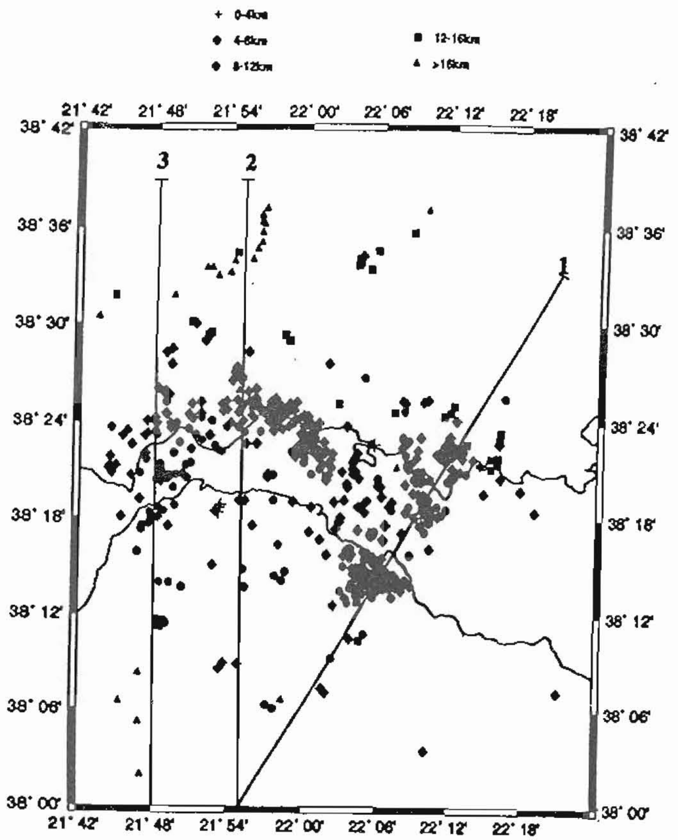
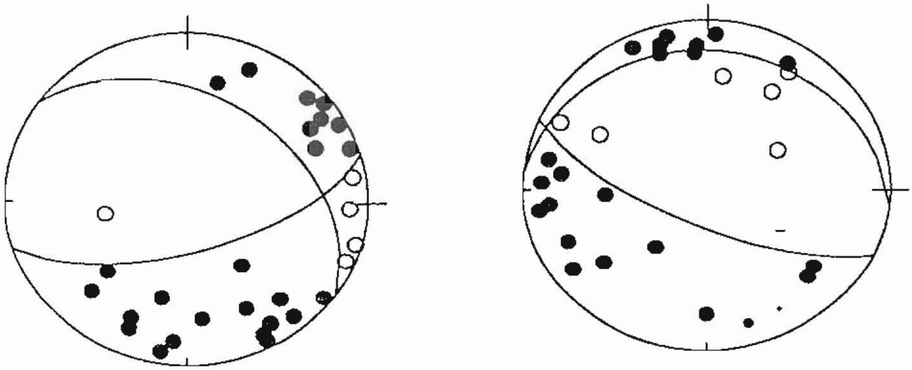


Fig.3. Epicentral location map of the 850 best-located events of August 1991.



91-08-05 14H03
$M_L = 3.12$

91-08-23 16H47
$M_L = 3.00$

Fig.4. 2 examples of fault plane solutions. Black circles denote P compressional polarities, open circles denote P dilatational polarities.

INTERPRETATION AND DISCUSSION

To try to understand more precisely what happens, we show three vertical cross-sections across the Gulf (Fig. 6) where the seismicity and the focal mechanisms are projected on the vertical plane of the sections. Most of the seismicity is confined between depths of 4 and 12 km (to the west) and 15 km (to the east) confirming the small thickness of the seismogenic layer.

On cross-section 1, we can clearly identify one plane of seismicity dipping north at an angle of 35-40°. This plane, if continued towards the surface, would crop out just north of Aigion under the sea. The scarp that can be observed on shore in the Aigion harbor most probably is part of this fault (Aigion fault). The fault plane solutions of events located along this plane show normal faulting with a nodal plane dipping north at about the same angle (35-45°). The simplest interpretation is that this plane represents a major fault plane. A cluster of seismicity is located beneath the city of Aigion at a depth of 8 Km. Although no clear structure appears in this cluster, the fault plane solutions are very consistent one with each other with a nodal plane dipping north at an angle of 50°-65°. This suggests that the cluster is located on a fault plane, dipping north at 50°-60° and cropping out at the Helike fault. Figure 7 shows our interpretation of cross-section 1: the two identified fault planes join themselves through a decollement surface at a depth of around 15 Km.

Cross - sections 2 and 3 differ from cross-section 1: the seismicity defines a plane dipping north at a very shallow angle. This structure is confirmed by the fault plane solutions of events which show normal faulting with a nodal plane dipping north at a shallow (~ 15°) angle. One hypothesis is that it represents a decollement surface which continues eastward beneath the Aigion area, but without seismic evidences.

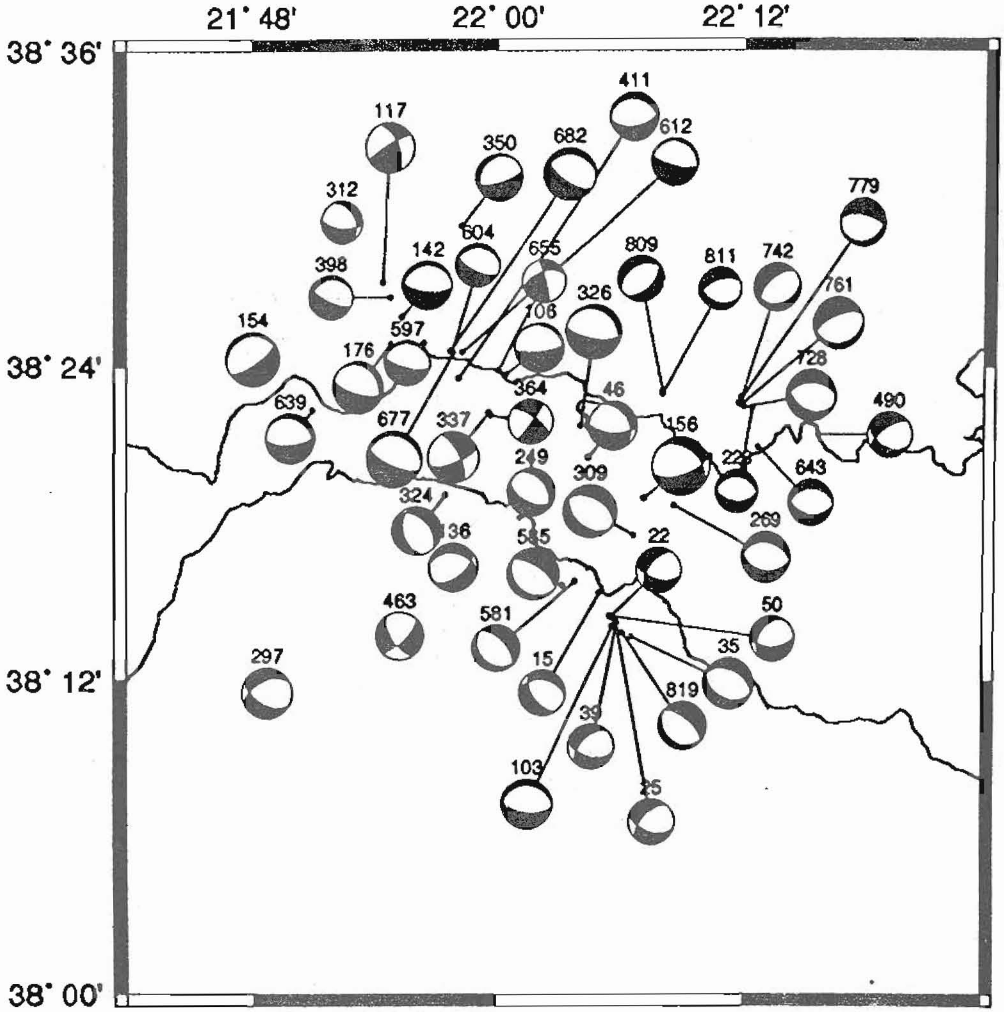


Fig.5. Map of the 47 best constrained fault plane solutions.

CONCLUSIONS

The analysis of the data obtained during the seismological experiment carried out during the summer 1991, shows a main zone of activity dipping north in the Patras-Aigion region. The

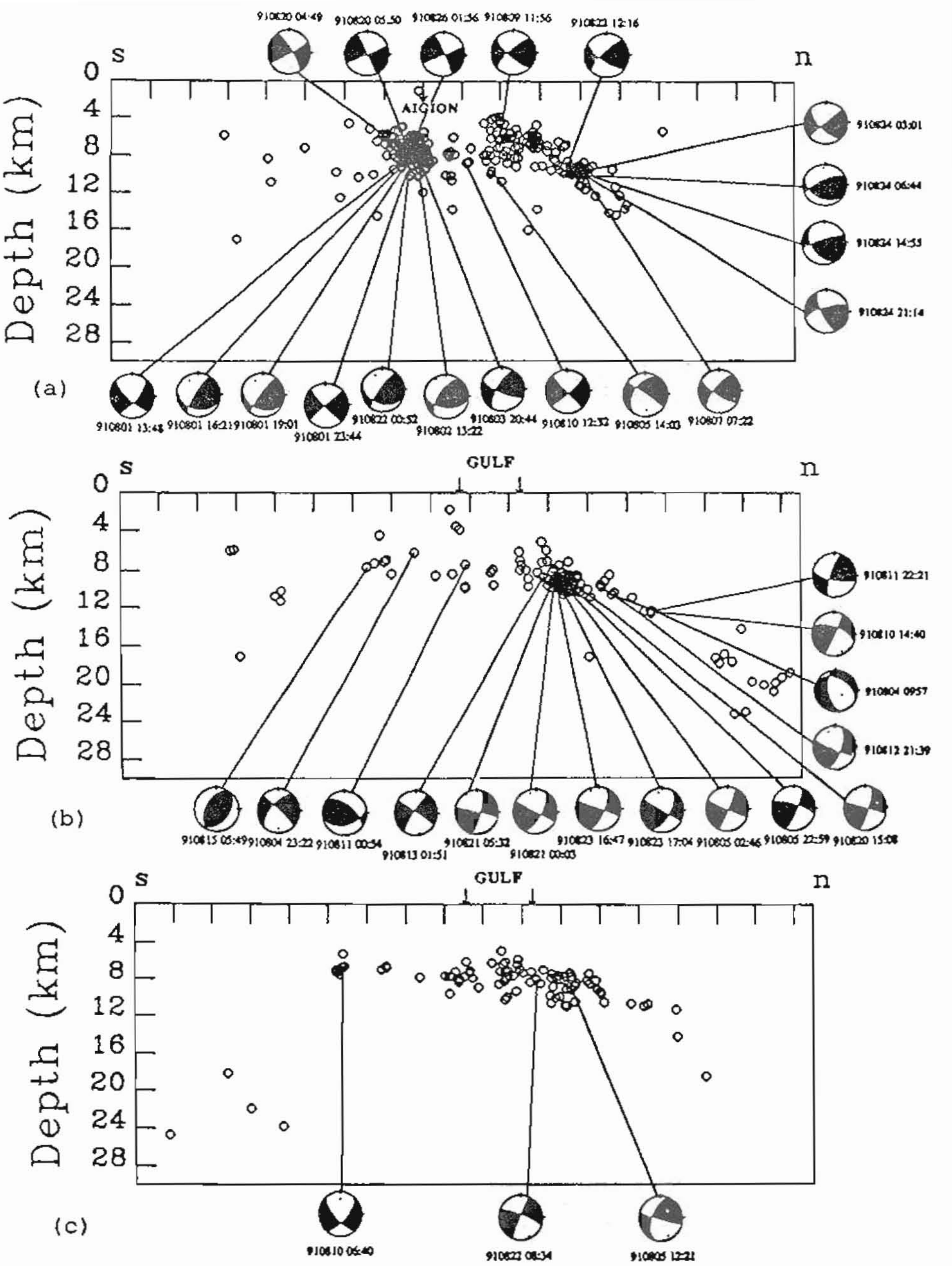


Fig.6. Vertical cross-sections 1(a), 2(b) and 3(c).

seismogenic layer appears to be at most 15 km thick. Both the seismicity and the fault plane solutions, combined with the tectonic analysis, suggest a change of dip of the active structure between the east (~ 50°) and the west (~ 20°). The eastern and western parts are separated by a transition zone with strike-slip mechanisms that probably accomodate the relative deformation between the two zones. One possible interpretation is the existence of a decollement zone at 12-15 km depth on the east becoming somewhat shallower on the west (~ 8-12 km depth). The presence of this flat active structure could explain the small activity of the Psathopyrgos fault with a low topographic relief (450 m).

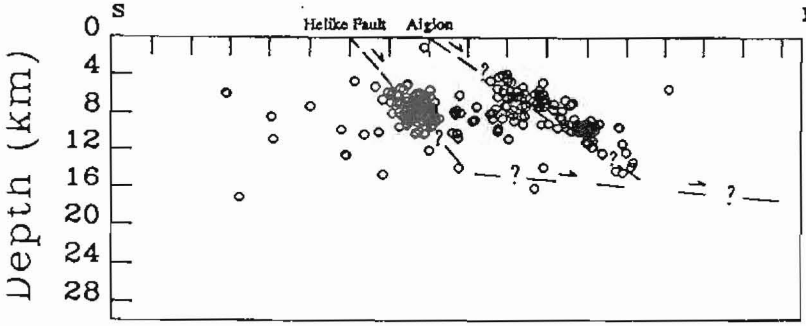


Fig.7. Tectonic interpretation of the cross-section 1.

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