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SOURCE PARAMETERS OF LARGE AND SMALL EARTHQUAKES IN CORINTH GULF (C. GREECE)

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ABSTRACT

The gulf of Corinth is one of the most seismically active grabens in the world. Hig seismic energy release characterizes the area during the last decade, with the occurrence o several strong earthquakes along the gulf. The activity starting in the eastern part of the gul with the 1981 Alkyonides' sequence. These shallow events produced surface faulting strikin in E-W direction and formed an antithetic faulting system. In July-August 1991, a dens network of digital stations was installed around the western margins of the gulf, recording ar important microearthquake activity. About 5000 events were recorded having magnitudes les than 3.5, among which 2000 were located. The seismicity was concentrated around Aigio where two major parallel faults are observed, striking E-W and dipping toward the north: th Aigion and the Eliki faults. The northern margin is also characterized by high activity arounc the Naupactos and Eupalio area, where the observed faults are of small scale. The depth distribution varies mainly from surface to 12 km. However, an important activity is locatec beneath, between 12 and 25 km depth. The depth distribution of several events beneath 20-25 km and down to 50 km, may probably consist evidence of an active subduction taking place. About 500 fault plane solutions were computed, the majority revealing normal faulting with a mean E-W direction. Furthermore, strike-slip and reverse mechanisms are also observed.

On November 18, 1992, a moderate earthquake of magnitude 5.9 occurred near Galaxidi, followed by low aftershock activity, which was recorded by a temporary local network installed after the mainshock. The source parameters of the mainshock calculated using teleseismic body wave recordings, indicate shallow earthquake and normal faulting, a pattern also revealed by the aftershock's analysis.

The combination of reliable seismological data obtained over the last 15 years with geodetic studies in the area, indicate that the main deformation occurs along major faults located in the vicinity of the southern margin of the gulf, dipping toward the north. The northern margin, although characterized by high activity level, does not reveal evidence of major scale active structures.

INTRODUCTION

The gulf of Corinth, a WNW-ESE trending, 120 km long and 25 km wide active asymmetric graben, is one of the most active areas in the Mediterranean region (Higgs, 1988; Roberts & Jackson, 1991), with a history of repeated large earthquakes and a high level of background seismicity (Papazachos & Papazachos, 1989; Makropoulos & Burton, 1981; Ambraseys & Jackson, 1990). The high activity of the area is expressed in tectonics, topography, geomorphology (i.e uplift of the coastline relative to sea level) (Vita-Finzi & King, 1985; Doutsos & Piper, 1990; Doutsos & Poulimenos, 1992). The gulf of Corinth graben is surrounded by faults, the larger of them located along the southern shore of the gulf dipping toward the north, while the northern shore is a southward faulted flexure (Keraudren and Sorel, 1987), which affect Quaternary and recent formations, activated since lower Pliocene time (Mercier et al., 1976; 1989). Historical resources reveal that large earthquakes occurred along the Gulf of Corinth. The first earthquake reported in the area occurred in 373 BC

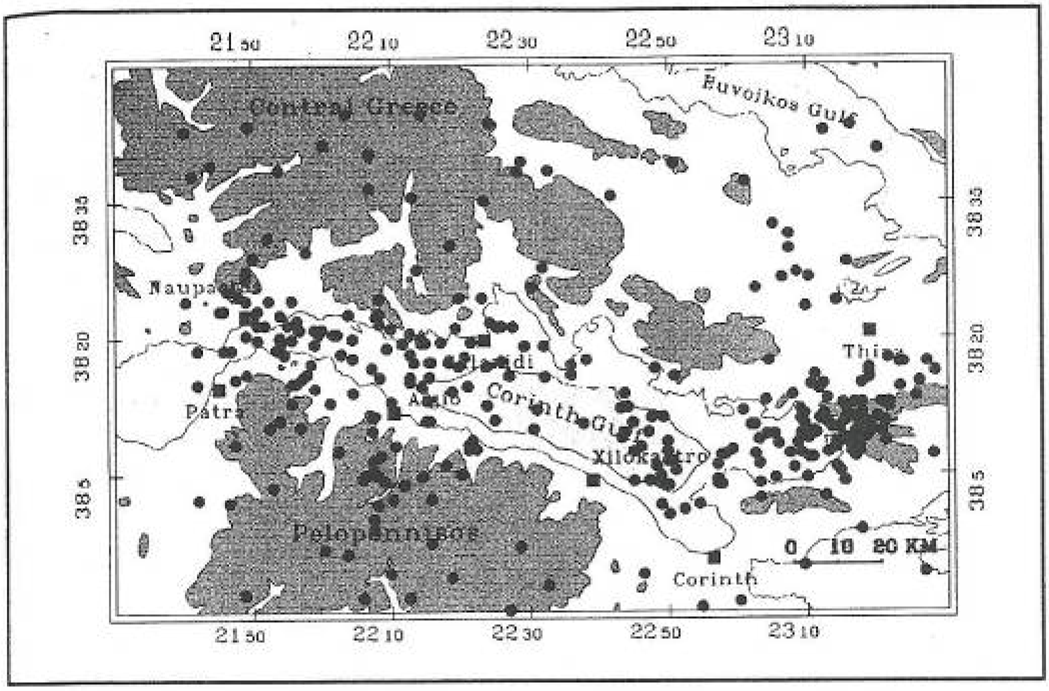

Figure 1. Seismicity map during the period 1964-1994, with a magnitude $M_s \geq 4.5$

and completely destroyed the city of Eliki. On February 21, 1858 the old town of Corinth collapsed by an earthquake. This event forced the people to rebuild a new town near the sea that was destroyed again on April 22, 1928 by another earthquake (Sieberg, 1932). On December 26, 1861, an earthquake occurred near the city of Aigion producing an E-W surface rupture of about 13 km long, with a 100cm coseismic slip, dipping toward the north (Schmidt, 1867). After the installation of the WWSSN network, two moderate shallow events occurred in the area; the first near Eratini on July 6, 1965, and the second near Antikyra on April 8, 1970. These events reveal normal faulting in E-W direction (McKenzie, 1972; P. Papadimitriou, 1988).

On February 24, 1981, a large earthquake occurred in the eastern part of the gulf (near Alkyonides islands) followed by two large events. Following these events, a temporary network of 14 MEQ-800 stations was installed, in order to record the aftershock activity. In 1991 and for a period of two months, a temporary network of 60 digital stations was installed in the western Gulf of Corinth, around Rio-Antirrio to monitor the micro-earthquake seismic activity. On November 18, 1992, an earthquake occurred near the city of Galaxidi and a temporary digital network was installed in the area in order to record the aftershocks. In this paper, data concerning the recent activity over the period 1981-1992 are used to discuss the seismic regime and the evolution of the gulf.

SEISMOLOGICAL EXPERIMENTS

The gulf of Corinth has been extended as a result of back-arc spreading behind the southwestward Hellenic trench (Le Pichon et al., 1982). Extensional deformation continues today and events are spread over the entire area (fig. 1). During the period 1981-1992 three temporary networks were installed around the gulf of Corinth to record the aftershocks (for the cases of the February 24, 1981 and November 18, 1992 events) or the seismic activity

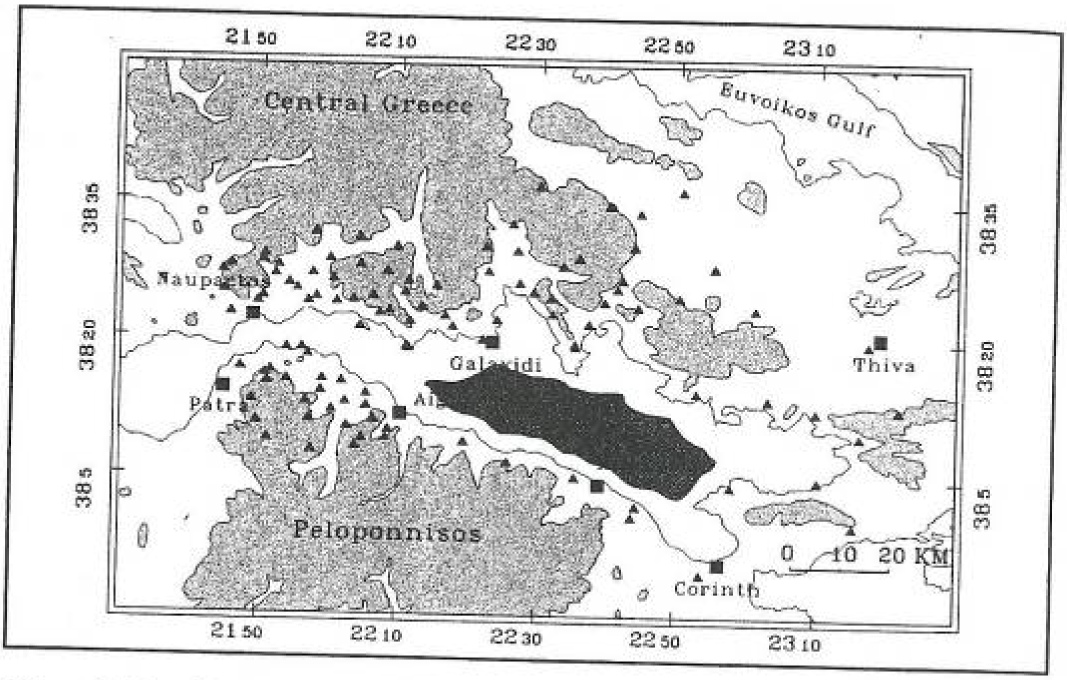

Figure 2. Map of the temporary stations installed during the three seismological experiments., in 1981, 1991 and 1992.

of the area (July-August, 1991). The location of the stations during the three experiments is presented in figure 2. For each experiment we discuss the data separately.

Corinth experiment (1981)

On February 24, 25 and March 4, three earthquakes of magnitudes M_s=6.7, 6.4 and 6.4 respectively, occurred in the eastern part of the gulf of Corinth (fig. 3). Surface breaks with a northward-dipping slip vector, were observed on the southern margin of the gulf following the first and second event and further fresh faulting with a southward dip, appeared later on the northern side of the gulf as a result of the March 4 event. By March 4, a network of 14 MEQ-800 portable smoked-paper seismographs was installed in the area. The array remained operational for five weeks and at the same time, studies of surface faulting, shoreline changes and morphology, were carried out.

The source parameters of the three large earthquakes were calculated using teleseismic body-waveform inversion. Synthetic modeling of the long period P- waveforms of WWSSN records was used by Jackson et al., (1982). Won Young et al., (1984), applied the same technique on GDSN long period records. Bezzeghoud et al., (1986) and P. Papadimitriou, (1988), used Kikuchi and Kanamori (1982) method on broad-band signals obtained from the short period GDSN records, reshaping the instrument response and applying a broad-band Butterworth filter. The main difference of this technique compared to the others is the calculation of the source time function, which in this case is a complex source, probably due to the complexity of stress relaxation on the fault surface. The focal depths of the events are determined between 8 and 10 km and the fault plane solutions indicate normal faulting striking E-W.

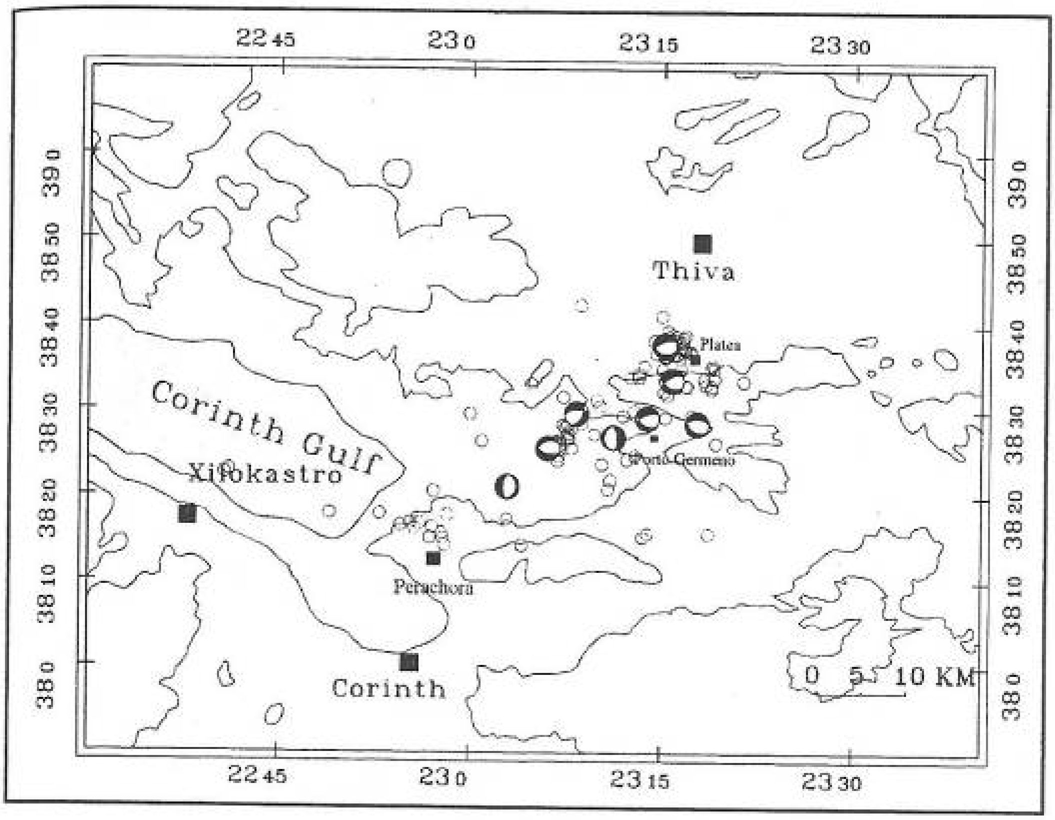

Figure 3. 1981 Corinth experiment, 133 selected aftershocks and 8 focal mechanisms.

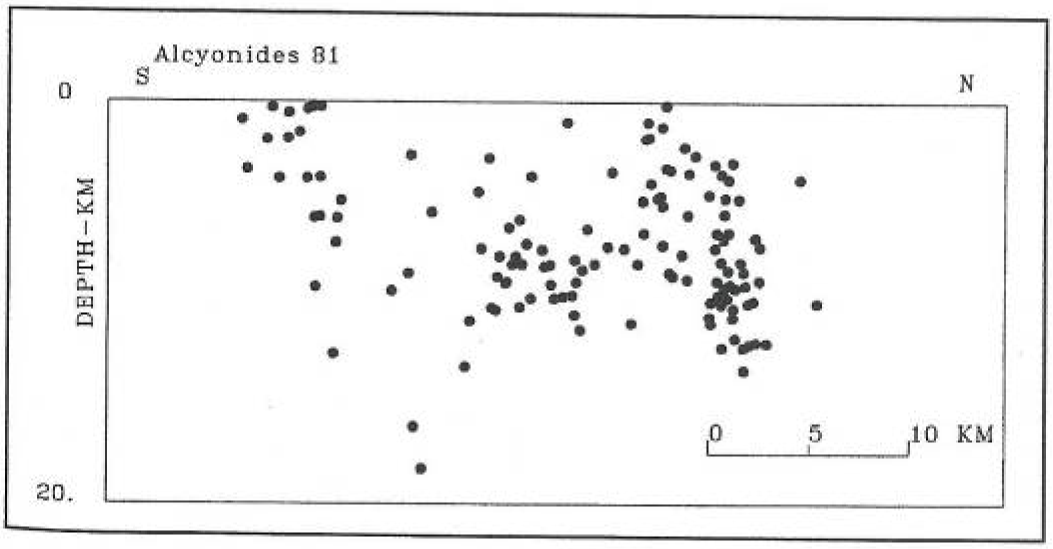

Figure 4. 1981 aftershocks, cross-section in NE-SW direction

Figure 3 presents 133 selected aftershocks located with an accuracy of ±2 km in epice
and ±4 km in depth, 26 of them providing reliable fault plane solutions (P.Papadimitriou, 1982; K
et al. 1985). In the figure, only 8 representative focal mechanisms are plotted for clarity reasons.
events are predominantly concentrated between the north dipping faulting, associated with the
two earthquakes and the south dipping faulting, associated with the third event, while a cluster lie
the footwall southeast of the third earthquake. The events form a zone 60 km long and 20 km w
and are distributed in three clusters; one in Perachora peninsula (southern cluster), one west of P
Germeno (central cluster) and another near Platea (northern cluster). A longitudinal cross-sectio
NE-SW direction is presented in figure 4. The distribution in depth varies essentially between surf
and 10 km, with a few events located deeper than 10 km. The aftershock activity is appare
greater in the northeast than it is in the southwest. A percentage of this pattern is probably an artif
due to the station's distribution, which allows a greater selectivity where the higher concentratio
observed, however, apart from that, the above effect is certainly real. Reliable fault plane soluti
computed by projecting upward-going rays in a lower hemisphere focal sphere are displayed in fig
3. Normal faulting is indicated by all the fault plane solutions, in agreement with the sou
parameters of the three large earthquakes, although a slight component of left or right late
horizontal shear is also present, probably due to an internal deformation occurring between the t
parallel main fault segments activated by the three large events.

Rio-Antirrio experiment (1991)

During the summer of 1991, a dense network of 60 portable digital seismographs
installed for a period of two months (July-August), in the western part of the gulf of Corinth, aro
the Rio-Antirrio and Aigio area. The stations were equipped with 1 or 2Hz seismometers. A numb

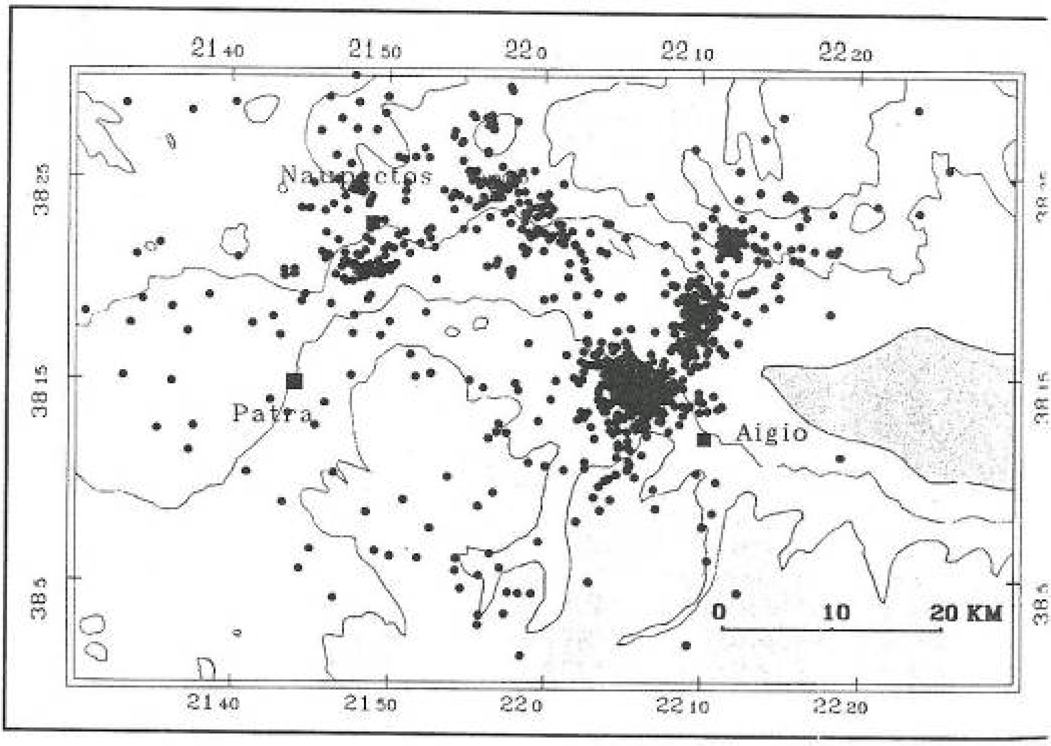

Figure 5. 1991 Rio-Antirrio experiment, all the events.

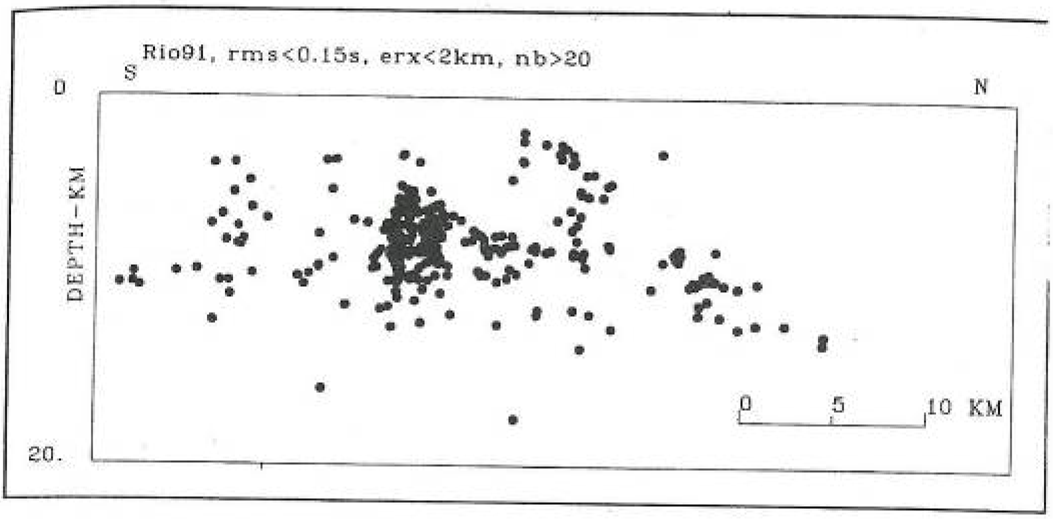

Figure 6. 1991, Rio-Antirrio experiment, cross-section in N-S direction.

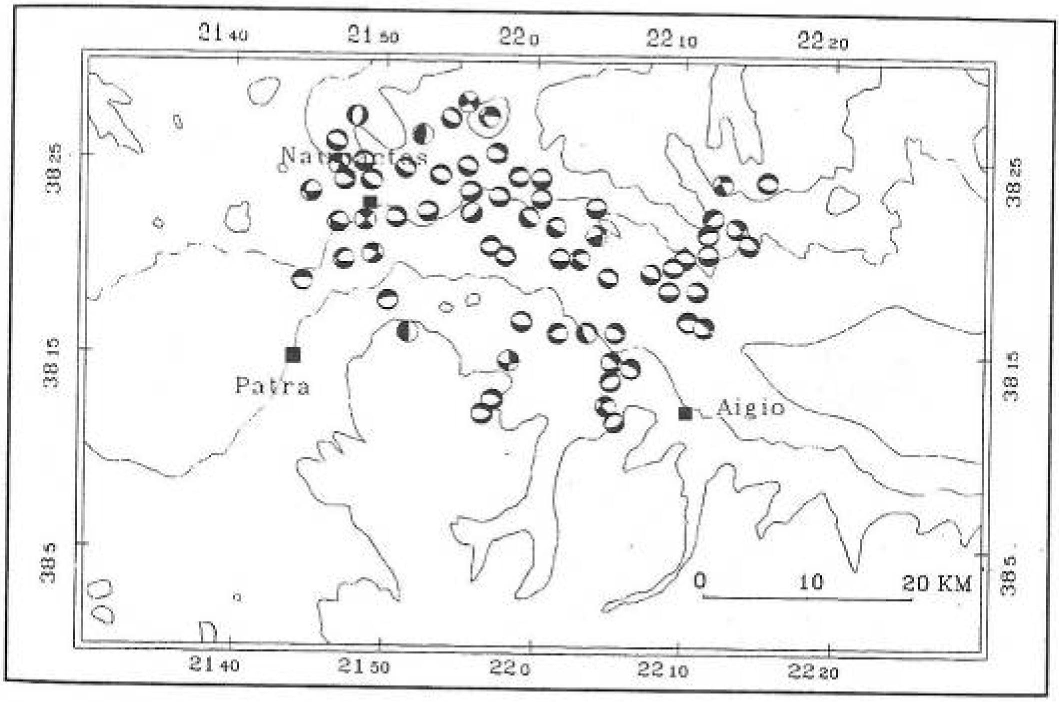

Figure 7. 1991 experiment, selected fault plane solutions.

of about 5000 events was recorded. The time-reading precision is estimated ±.05sec for the P-waves and ±0.1sec for the S-waves. During the month of July, 1300 events (analyzed in this study) were located while 600 of them located with a precision of about ±1 km in epicenter and ±2 km in depth.

Figure 5, presents the location of all the events. The seismicity is distributed beneath the sea and for a few kilometers inland, on both margins of the gulf. The events form essentially three clusters, the most important one near the town of Aigion (eastern cluster), one near Eupalio (central cluster) and another near Naupaktos (western cluster). A cross-section in N-S direction (fig. shows a focal depth distribution essentially between 2 and 12 km, distinguishing three groups; c located southern dipping north, one central located under the town of Aigio, dipping vertically a one northerner, located under the sea and the northern margin of the gulf, dipping north. An abser of seismicity within the two first kilometers of the crust is observed becoming more significant in t south. This effect is not an artifact of calculation and could be related to the rheological properties the shallow crustal layers.

More than 300 focal mechanisms were computed using P-waves' first motion polariti Figure 7, shows the distribution of 65 focal mechanisms where the two nodal planes are very w constrained (the deviation for both nodal planes being less than 10°). Normal faulting is indicated . the major part of the fault plane solutions, although some present varying amounts of left or rigt lateral strike-slip component. Some strike-slip and reverse focal mechanisms are also observed. Th pattern is in agreement with the one proposed by Rigo et al., (1993; 1995) who additionally used waves' horizontal polarization directions to invert the fault plane solution parameters.

Galaxidi experiment (1992)

On November 18, 1992, an earthquake of M_s=5.9 occurred in the central part of the gu of Corinth near Galaxidi. No surface ruptures were observed on either sides of the gulf. In order t

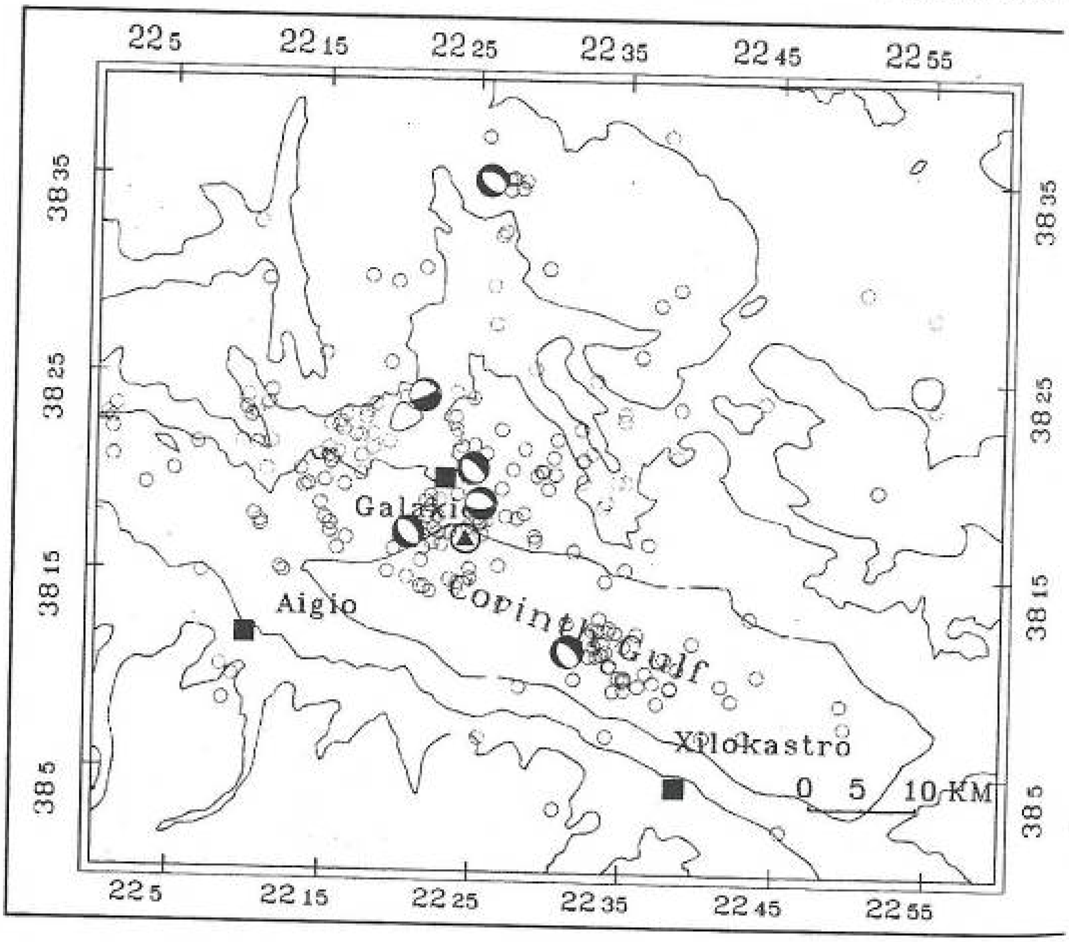

Figure 8. 1992 Galaxidi experiment, epicenters and selected focal mechanisms.

study the aftershock sequence a network of 35 portable seismographs was installed in the area for a period of 10 days.

The source parameters of the main shock were determined by body wave analysis. The inversion of the ground displacement was obtained from teleseismic records of the worldwide broad-band stations (Briole et al. 1993). Similar results were obtained by Karakaisis et al. (1993) using long period body waves inversion and records from the WWSSN network. The centroid depth is calculated at 8±2 km and the obtained fault plane solution represents normal faulting with: strike=80°±10°, dip=60°±5° and rake=-95°±10°. The calculated seismic moment is $5.2x10^{17}$ Nm and it is clearly released by two different sub-events represented in the source time function by two identical lobes with a total duration of 4 seconds.

The installation of the temporal network started on November 22, and remained operational for 10 days. 255 events have been located, from which 195 have more than 6P and 1S readings, RMS <0.5sec and location error both in epicenter and depth smaller than 5 km (Kementzetzidou et al., 1993; Karakaisis et al., 1993). Figure 8 shows the distribution of all the microearthquakes and the location of the big event. The seismicity recorded during this experiment is spread between Aigio and Xilokastro. Around the epicentral zone of the main shock we can distinguish three clusters: one near Xilokastro (eastern cluster), one near Galaxidi (central cluster) and one near Eratini (western cluster). A cross section (fig. 9) trending in the N-S direction (perpendicular to the Aigion fault) clearly shows that the depth distribution is dipping toward the north, while varying between 4 and 14 km.

Six lower hemisphere focal mechanisms, located around the epicentral area, are presented in fig. 8, indicating normal faulting in E-W and SE-NW directions.

DISCUSSION

Figure 10 presents the focal mechanisms of the most important earthquakes occurred in the gulf of Corinth and for which the fault plane solutions were calculated by body wave inversion methods. We remark that the focal mechanisms of the large and small events show a homogeneous

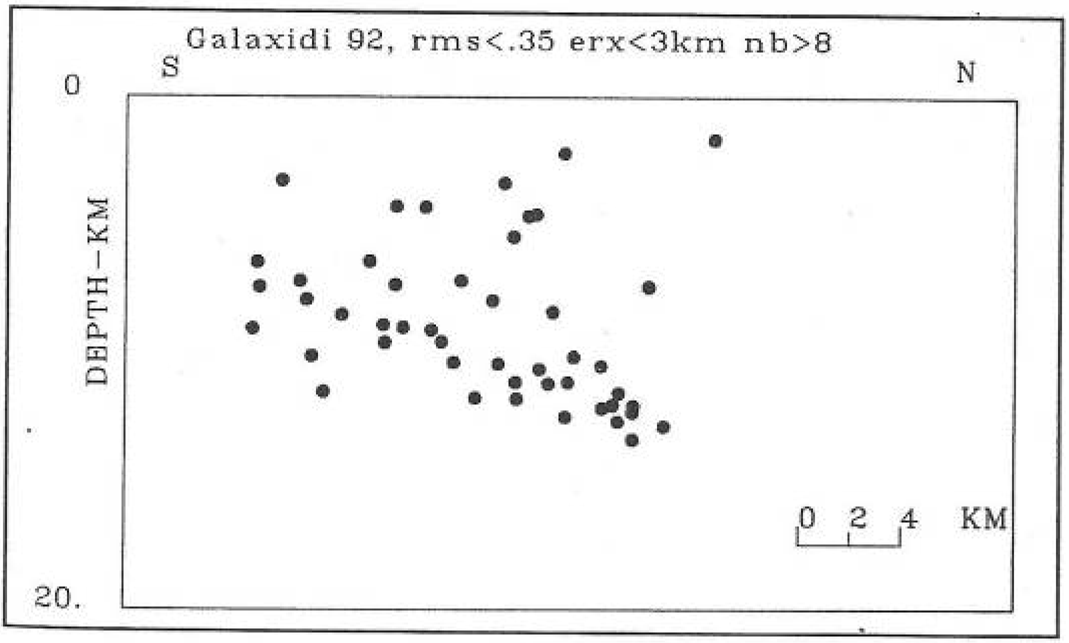

Figure 9. Galaxidi 1992 experiment, cross-section in N-S direction.

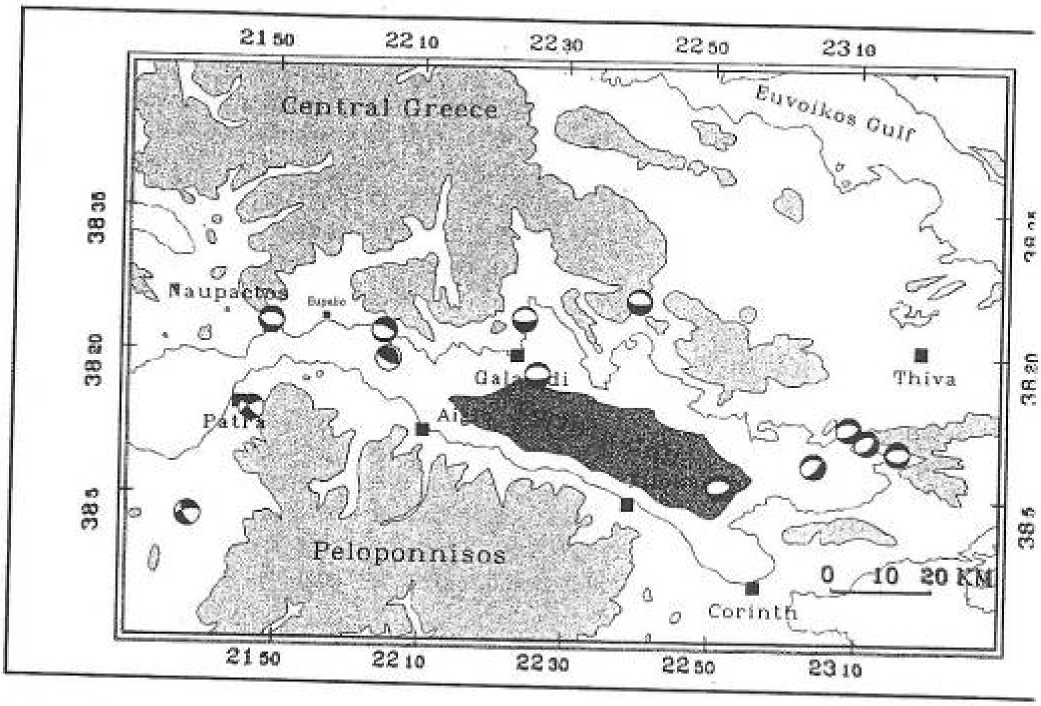

Figure 10. All the available fault plane solutions calculated by body wave inversion.

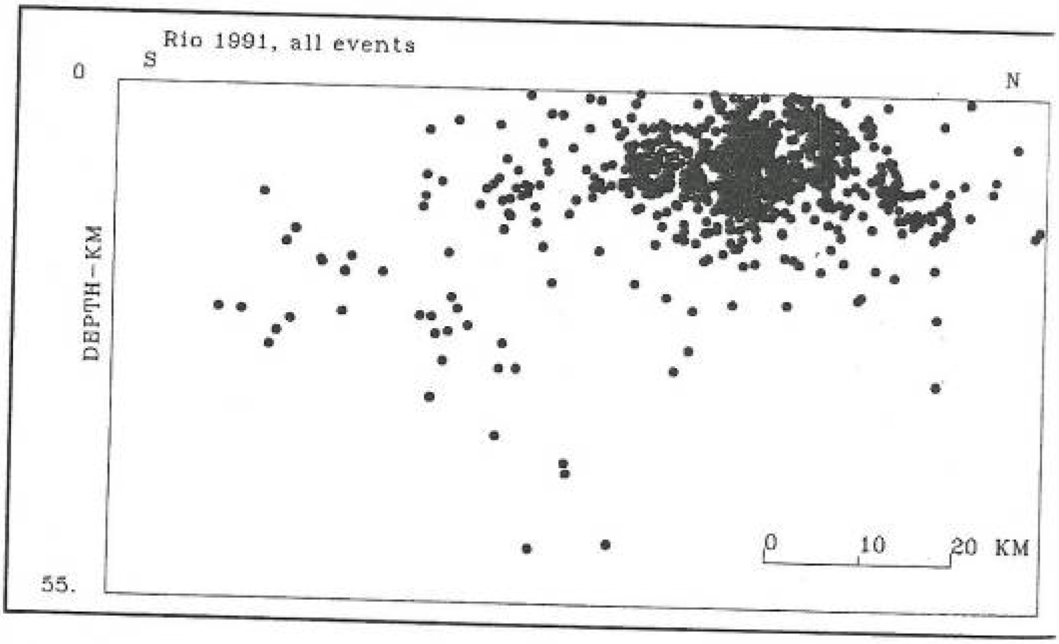

Figure 11. Rio-Antirrio 1991, cross-section in N-S direction.

stress pattern that indicates normal faulting in E-W direction and N-S extension. The depths of t large events calculated by body wave inversion methods were located near the seismogenic layer 8-12 km depth. The focal depths of the aftershocks of the large events determined by HYPO71 (L