# *IDENTIFICATION OF SMALL-SCALE ACTIVE FAULTS NEAR METROPOLITAN AREAS: AN EXAMPLE FROM THE ASVESTOCHORI FAULT NEAR THESSALONIKI*

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## *ABSTRACT*
The recent damaging earthquake close to Athens (7 Sept 1999, $M_W$=5.9) has re-emphasized the significant social and economic impact of medium-magnitude earthquakes near major metropolitan centres. Such earthquakes often occur on faults that have been "silent" or exhibit low seismic activity for a large time-period. On the 29th of June 1999, almost 2 months before the Athens event, a number of small-magnitude events occurred close to the city of Thessaloniki (N.Greece), which is the second largest Greek city, with a largest event of $M_W$=3.7. The seismic activity was located in the Asvestochori region and was felt throughout the whole Thessaloniki area. The same area has often in the past been the origin of similar small-scale seismic sequences or isolated small-scale events.
In order to monitor the seismic sequence a network of 9 portable seismographs was installed immediately after the sequence initiation and operated for almost 2 months. The final hypocentral distribution allowed the identification of a hidden fault, dipping under the city of Thessaloniki. with a depths range between 1-7km and a width is ~3km. The largest aftershock exhibited a purely normal slip, with a fault strike of ~140°, identical to the strike of the neighbouring mountain belt and the direction of neotectonic faults identified in the same area. The fault orientation, its position and its low-level but constant seismicity suggest it as a possible candidate for many catastrophic historical events that have occurred in the vicinity of Thessaloniki, but have not been yet accurately located.

## *INTRODUCTION*
The broader Aegean area is characterized by the high level of seismicity throughout the whole Europe. One of the most interesting features of the seismicity distribution is that it extends throughout the whole back-arc area, up to Northern Greece, where the highest seismicity level is found in the Serbomacedonian massif (e.g. Scordilis, 1985). The city of Thessaloniki, which is the second largest Greek metropolitan area, is located close on the border of this zone and as a result has suffered from a large number of damaging events originating in this massif. The most recent of these events was the 1978 Mygdonia basin event ($M_W$=6.5), which had a significant impact on Thessaloniki both in human losses and

building damages. However, historical information suggest that the city of Thessaloniki has been seriously affected by other seismic sources located much closer to the city, such as the 1902 (M=6.5) Assiros or the poorly located 1759 (M=6.5?) events.
In the present study a fault system in the Asvestochori area is examined as a possible candidate for the 1759 event, by studing a recent small-scale seismic sequence in the area. The results reveal a normal fault which is dipping under the city of Thessaloniki. The seismicity distribution suggest that the fault can possibly extend further to the NW and SE, thus being capable of generating a much larger event close to Thessaloniki.

## *DATA PROCESSING*

Starting on the $29^{th}$ of June 1999, several small scale shocks with a largest event of M=3.7 occurred close to Thessaloniki, in the Asvestochori area. This area has been also examined previously using data from a local seismic monitoring experiment (Hatzidimitriou et al., 1990), due to the frequent observations of small-scale events (up to M=3.5-4.0). Moreover, tectonic investigations in the area have identified a number of faults, which have been characterized as active.
A few days after the initiation of the seismic sequence, a temporary network of 9 stations was installed in the vicinity of Thessaloniki by the Geophysical Laboratory of the University of Thessaloniki in order to monitor the seismic sequence. All stations were equipped with Reftek recorders, while 3-component CMG-40T (broadband up to 30s) and LE3D-1Hz seismometers were used in all stations. The network operated for approximately 2 months during which more than 150 local earthquakes were recorded. After a preliminary data processing, locations were determined using HYPOELLIPSE Y2K and an appropriate initial model for the area based on recent tomographic results (Papazachos, 1998). Finally, 69 local events were selected as the best quality data set.
For further processing, the data were inverted using the VELEST software (Kissling et al., 1994). VELEST inverts the travel time data-set simultaneously for a joint determination of earthquake parameters and a minimum 1-D velocity structure model. Deviations from the 1-D structure are handled though appropriate station corrections introduced at each station. For the determination of the epicentre and velocity model distribution various initial velocity models based on regional results (Scordilis, 1985; Papazachos, 1998) were tried. However, the examination of the determined epicentres revealed the existence of 25 earthquakes located at very shallow depths (usually negative). Furthermore, examination of their waveform characteristics showed an enhancement of high frequencies, with large pulse-type Rayleigh waves and almost impossible to recognize S-waves. Most of these events

occurred almost at the same time each day and almost exclusively at two locations. Examination of these locations revealed that they coincided with the location of the two largest marble quarries in the area. Therefore, it was suggested that these "strange" events corresponded to quarry blasts and not earthquakes. This hypothesis was confirmed by the first-motion pattern, which showed only compression as a first motion at all recording stations. The distribution of these quarry blasts, as well as the corresponding earthquake distribution is shown in Figure (1).

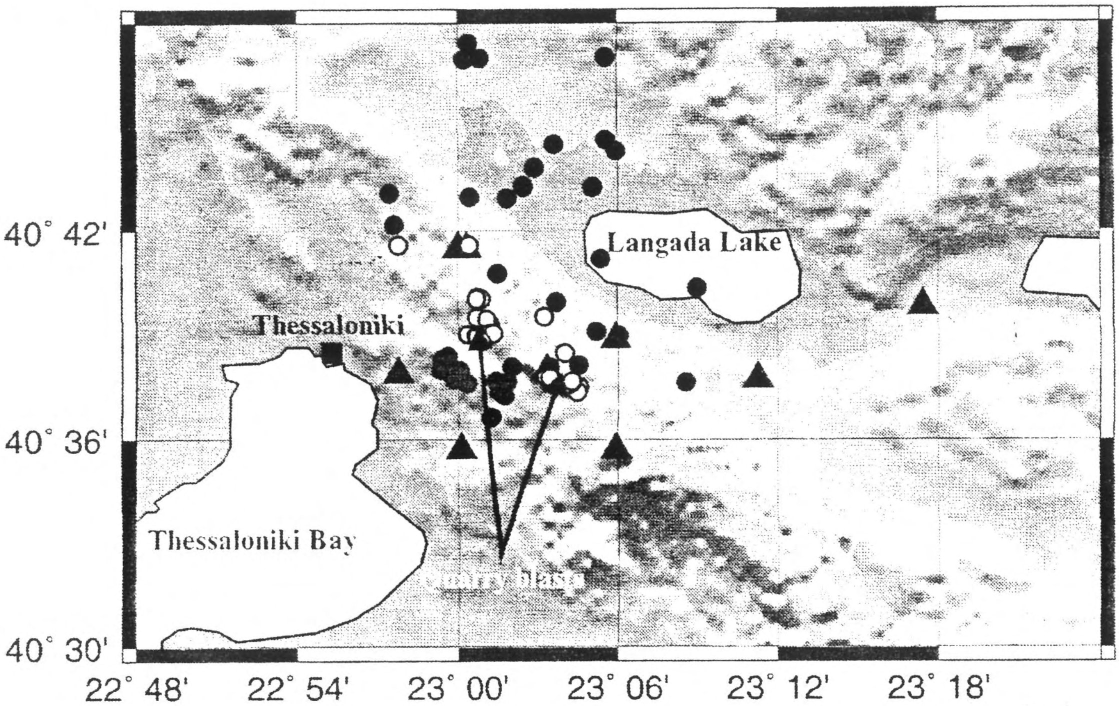


**Figure 1.** Earthquakes (solid circles) and quarry blasts (open circles) recorded during the monitoring of the June 1999 Asvestochori sequence. The recording stations are also denoted by solid triangles.

From Figure (1) it is clear that all but three of the quarry blasts are located in two places. These three isolated blasts were excluded from further processing in order to avoid possible misidentifications and all remaining blasts were fixed to their average positions, which where also confirmed by GPS measurements. The standard error of the blast positions with respect to these average locations is of the order of 500-1000m, which is indicative of the relocation accuracy of the results presented in the present study.

Using the new blast positions, the data set was re-inverted, having their positions held fixed, in order to determine a final velocity model, as well as appropriate station corrections for the temporary network. This final velocity model is presented in Table 1.

In order to create a more complete view of the seismicity distribution for the Asvestochori sequence, the final earthquake data set was examined in order to identify events which had also been recorded by the

**Table 1.** Final velocity model determined for the examined area

| Depth (km) | $V_P$ (km/s) | $V_S$ (km/s) |
|---|---|---|
| -1 | 5.26 | 2.88 |
| 0 | 5.29 | 2.90 |
| 1 | 5.36 | 3.26 |
| 2. | 5.76 | 3.38 |
| 3 | 5.79 | 3.58 |
| 4 | 6.16 | 3.70 |
| 6 | 6.23 | 3.47 |
| 8 | 6.27 | 3.44 |
| 10 | 6.30 | 3.45 |
| 12 | 6.30 | 3.48 |
| 16 | 6.30 | 3.53 |
| 20 | 6.42 | 3.61 |

regional network of the Geophysical Laboratory of the University of Thessaloniki. Five such events were identified, which were used as equivalent "blasts" in order to calculated appropriate station corrections for the regional network with respect to the examined area. For this estimation the velocity model of Table 1 was appropriate extended to larger depths (up to Moho) using a regional model (Papazachos, 1998).
Using the finally determined station corrections, 8 additional events of the Asvestochori sequence which were recorded by the regional netwotk but occurred before the installation of the temporary network were relocated. The final earthquake distribution (blasts have been removed) is presented by open circles in Figure (2), where the Asvestochori sequence is identified by grey circles. In total 21 events of the sequence were relocated. It should be noted that using only the regional network determinations without the appropriate station corrections resulted in a systematic eastward shift of 3 to 5 km of the determined epicentres.

## *DISCUSSION*

The determined earthquakes of the Asvestochori sequence exhibit a NNW-SSE distribution, which is in good agreement with the neotectonic fault direction in the area. This is also seen in the inset figure, which shows a cross-section (A-B) of the seismicity distribution normal to the fault direction (~140$^{o}$). It can be seen that the seismicity extends between 1-7.5km, while the corresponding fault length is ~3km, which is quite larger than the predicted length of ~1km (Papazachos and Papazachou, 1997) corresponding to the largest event of $M_W$=3.7. This suggests that the seismic activity extended to a much larger fault area than the one that ruptured during the largest event. The fault is dipping towards the city of Thessaloniki with a dip of ~55$^{o}$. This dip is confirmed by the only fault plane solution which was determined for the sequence from the local network, which corresponds to the largest aftershock after the main $M_W$=3.7 event. The fault plane shows a normal pattern and the SW dipping plane has a dip angle of ~55$^{o}$, similar to that determined by the seismicity distribution. The position of the fault and its possible continuation towards the NW or SE, as indicated by the small-magnitude seismicity and previous studies (Hatzidimitriou et al., 1990), suggest that it is a potential candidate for the 1759 event which was located very close to Thessaloniki, as revealed by the damage distribution (Papazachos and Papazachou, 1997). Therefore, its earthquake potential and the assessment of the possible strong ground motion in the city of Thessaloniki should be further studied in the future, due to its close proximity to the metropolitan area of Thessaloniki.

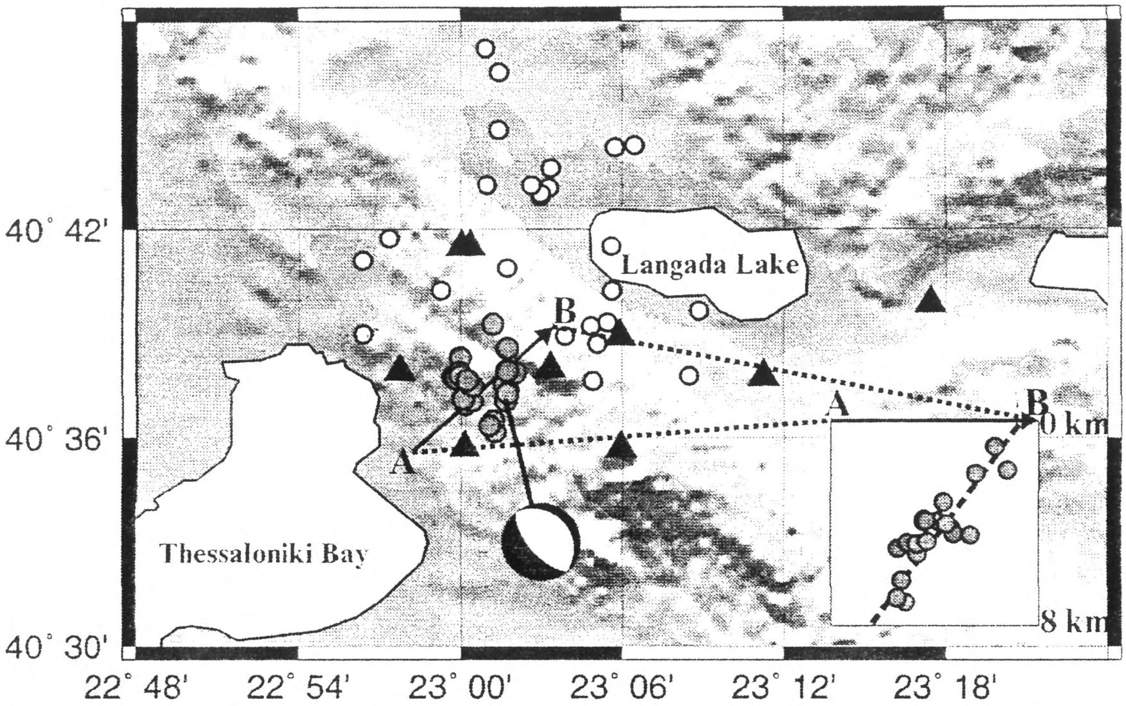


**Figure 2.** Earthquakes distribution recorded from the local network. The June 1999 Asvestochori sequence is denoted by grey circles, while the inset figure presents a cross-section normal to the fault direction.

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