RELOCATION OF THE 2001 EARTHQUAKE SEQUENCE IN AEGION, GREECE

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ABSTRACT

The western part of the Corinth Gulf attracts attention because of its seismically active complex fault system and considerable seismic hazard. Close to the city of Aegion, damaged by the M_L 6.2 earthquake of 1995, a sequence of small earthquakes occurred from February to May 2001. The sequence, comprising 171 events of M_L 1.8 to 4.7, was recorded by a short-period network of the University of Patras, PATNET. As most stations have single component-recording, the S-wave arrival time readings were scarce. A sub-set of 139 events was recorded by at least 5 stations, and in this study we limit ourselves just to that sub-set. A preliminary location is performed by a standard linearized kinematic approach, with several starting depths and crustal models. Then the mainshock is re-located, and finally it is used as a master event to locate the remaining events. The mainshock relocation is performed by a systematic 3D grid search, and the trade-off between depth and origin time is eliminated by a special procedure, the so-called station difference (SD) method. In the SD method, instead of inverting arrival times directly, their intra-station differences are employed. The station corrections, determined from the master event, are also used. As a result, the sub-set is imaged as a relatively tight cluster, occupying space of about 5 by 5 km horizontally and 10 km vertically, with the mainshock inside (at a depth of 7 km). The results should be interpreted with caution, mainly as regards the „absolute“ depth position of the cluster. A more accurate location would require a local network with both P and S readings.

Keywords: Aegion Greece 2001 earthquake sequence, PATNET network, hypocenter relocation, master event method

1. INTRODUCTION

In the region of Aegion, Greece, a town heavily damaged by the $M_L = 6.2$ earthquake of 1995 (*Tselentis et al., 1996*), a sequence of small earthquakes occurred from February to May 2001. The region belongs to the seismically active western part of the Corinth Gulf, in particular to its southern coast, where major tectonic elements include the ESE−WNW oriented normal faults, steeply dipping to the NNE. Many smaller faults can also be distinguished at the surface, and some have been hypothesized also at depth. For example, it has been proposed that low angle faults, marking a detachment zone, cross the major high angle faults at a depth of about 10 km, and this crossing may produce clusters of weak events (*Rietbrock et al., 1996; Rigo et al., 1996; Lyon-Caen and Rigo, 1997*). This geologically interesting complex fault system, as well as the related seismic hazard, calls for detailed studies of these small events. The present paper is devoted to location problems of a selected sub-set of these events.

The whole sequence is composed of 171 events with M_L magnitudes from 1.8 to 4.7. Altogether, 1159 P and 208 S readings were made at 17 short-period telemetred stations of the Patras University network, PATNET (*Tselentis et al., 1996*), (see Fig. 1). Only a few of the strongest events were recorded at a larger number of stations (maximum 15 stations), but most of the events (84%) were recorded at between 3 and 9 stations (Table 1a).

The S-readings are scarce in this sequence, and, due to their uncertainties, they are assigned low weights. In fact, the sum of all the S-reading weights represents only 5% of

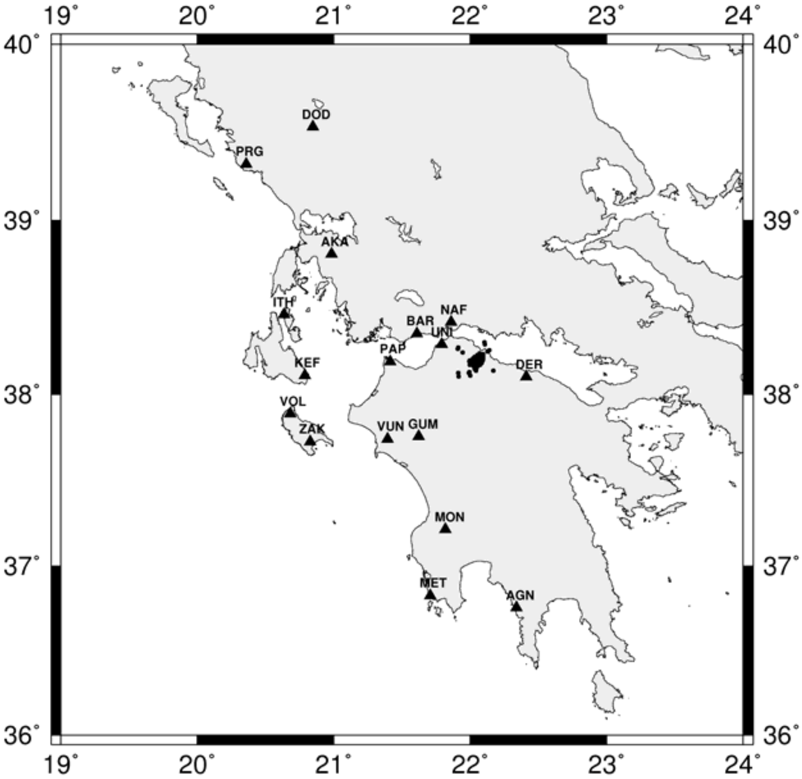

Fig. 1. Region of Western Greece, position of the PATNET stations and the studied earthquake sequence - HYPO71PC location - shown as dots between the stations UNI and DER (for details, see Fig. 2a).

Table 1a. The number of events of the entire sequence recorded by a given number of stations.

Stations:	15	14	13	12	11	10	9	8	7	6	5	4	3
Events:	2	1	3	7	6	8	11	10	35	30	26	16	16

Table 1b. Individual stations and the number of recorded events of the studied subset.

Station	NAF	DER	BAR	GUM	UNI	PAP	MON	AKA	VOL
Events	139	135	128	132	128	125	66	48	41
Station	AGN	ZAK	KEF	DOD	MET	PRG	ITH	VUN	
Events	34	18	14	10	9	8	7	5	

the total sum of the weights of all readings, so their influence on the location is negligible, on average. The deficiency of S-wave readings is caused by the fact that the PATNET stations, with one exception, are equiped with only one-component (vertical) instruments.

Because locations with 3 or 4 stations having no S-wave readings are not well posed, we limit ourselves to the location of events recorded by at least 5 stations. This provides the sub-set consisting of 139 events (81%) with 1047 (90%) of P and 182 (88%) of S readings (see Table 1b). For simplicity, speaking hereafter about this earthquake sequence, we always mean just this sub-set.

The standard location practice in western Greece is based on the well known HYPO71PC location program. We start from the same approach, but the main objective of this paper is to improve the locations. To that goal we combine the following approaches. We apply the HYPO location with several starting depths and several crustal models. We also use a grid search method and innovate it by a procedure specifically designed to decrease the trade-off between the origin time and depth of the mainshock. We then try to estimate the location uncertainty. Finally, we perform a relative location of the whole sequence with respect to mainshock by the master event method.

2. HYPO71PC LOCATION

In the HYPO method, the travel-time dependence on the hypocentral coordinates is linearized, and the hypocentral coordinates and origin time are iteratively estimated by the least square method, using multiple regression.

We tested several crustal models, all being composed of laterally homogeneous layers. Finaly, in this paper we deal with two models, M1 and M3 (Table 2). M1 is a 1D regional crustal model routinely used in the PATNET location practice (*Tselentis et al., 1996*). M3 is a model without discontinuities in the upper crust.

Table 2. Crustal models. *Vp* denotes the P-wave velocity (km/s), *d* is the layer thicknes (km).

	M1		M3	
Layer	*Vp*	*d*	*Vp*	*d*
1	5.7	5	5.85	18
2	6.0	13	6.4	21
3	6.4	21	7.9	∞
4	7.9	∞		

In the following study, the geographical coordinates are transformed to the Cartesian coordinates with the origin at 22.0°E and 38.3°N , the *X* axis is positive to the east, and the *Y* axis positive to the north. To describe the sequence as a whole we introduce the following characteristic parameters: *RA* (average absolute travel-time *L1* residual over all P phases and events), and *XA*, *YA*, *ZA* (average hypocentral Cartesian coordinates).

As the HYPO71PC results depend not only on the crustal model (e.g. M1), but also on the starting depth (e.g. 7 km), we denote the individual experiments as, for example, HY-M1-7. Table 3 gives the characteristic parameters of the whole sequence, found for models M1 and M3, and for the starting depths of 7 and 14 km. It also gives the Cartesian coordinates *MX*, *MY*, *MZ* of the mainshock. In all four HYPO locations listed in Table 3, the majority of hypocenters of the sequence occupies a region of about 10 × 10 × 20 km in *X*, *Y* and *Z* axes respectively, with a single principal cluster inside this volume. We find that the different starting depths in HYPO71PC affect mainly the average depth of the sequence (the *ZA* parameter), both in M1 and M3 models. The effect of the crustal model

Table 3. Parameters (and their mean deviations - given in parentheses) characterizing different HYPO71PC and MEM grid search locations. *RA* (sec) - the average absolute travel-time *L1* residual, *XA*, *YA*, *ZA* (km) - the average hypocentral coordinates of the whole sequence. *MX*, *MY*, *MZ* (km) - hypocentral coordinates for the mainshock. The mainshock locations for the station difference grid search are shown in bold.

Location	*RA*	*XA*	*YA*	*ZA*	*MX*	*MY*	*MZ*
HY-M1-7	0.18 (0.13)	3.99 (2.14)	−11.88 (2.10)	13.15 (3.35)	2.87	−14.44	8.61
HY-M1-14	0.19 (0.14)	4.41 (2.33)	−11.16 (2.48)	15.11 (4.81)	3.19	−14.54	7.76
HY-M3-7	0.21 (0.18)	3.87 (2.13)	−12.03 (2.11)	13.69 (2.90)	2.59	−14.76	10.12
HY-M3-14	0.23 (0.18)	4.28 (2.29)	−11.36 (2.50)	15.63 (4.16)	3.08	−15.78	10.78
MEM-M1	0.15 (0.12)	3.51 (2.10)	−13.44 (1.94)	5.08 (2.66)	**3.11**	**−13.69**	**7.04**
MEM-M3	0.17 (0.13)	3.14 (2.03)	−14.40 (1.85)	6.31 (3.01)	**2.39**	**−14.46**	**7.42**
HC-M3-7	0.18 (0.13)	2.94 (1.99)	−13.91 (1.82)	7.88 (4.95)	2.32	−14.56	6.24

is small, with the exception of the *MZ* for the mainshock. Its depth for model M3 is more near to the cluster average depth *ZA*.

The HY-M3-7 result is demonstrated in Fig. 2. The image is relatively diffuse, and the mainshock is situated on the margin of the principal cluster, especially in the *Z* coordinate. As seen from Table 3, the same is true for all the four HYPO locations.

A question arises whether these results are reliable, or not. For example, the absence of the S-wave readings, and availability of only few recordings at distant stations (Table 1b) may severely bias the source depth, due to the trade-off between depth and origin time.

3. LOCATION OF THE MAINSHOCK BY THE STATION-DIFFERENCE METHOD

To improve the location of the mainshock, we take two measures: the linearized method is substituted by systematic grid search (see, e.g. *Fischer and Horálek, 2000; Janský, 2000*), and the trade-off between depth and origin time is approximately eliminated by a trick. The trick consists in inverting *intra-station differences* of the arrival times. Hereafter, it is called the station-difference (SD) method. The idea is very simple: Instead of minimizing the P-wave travel-time residuals, in SD location we minimize residual differences between stations and a fixed station. Since no station has privilege to be the reference one, the procedure is repeated so that successively every station is fixed once. In some sence, the method is similar to the method of equal differential time (EDT) of *Zhou (1994)*, where the position of hypocenter is determined as the „intersection“ of surfaces, each being defined as the collection of all spatial points that satisfy the time difference between two stations.

The minimization of the depth/time trade-off is efficient mainly for station pairs formed by one near and one distant station, because the travel time to the distant station changes less with the depth than the travel time to the near station and its derivative might have negative sign with increasig depth. On the other hand, as well as with any location method using surface stations only, the depth resolution remains obviously worse than the horizontal resolution.

The grid search is parametrized as follows: the whole studied region is covered by a 3D grid of a 0.2 km step in all three co-ordinates. The accuracy of the source-receiver ray tracing iteration is set to 0.01 km. Performance of the SD grid search for the model M3, as an example, is illustrated in Fig. 3. It shows the misfit function as a function of *X*, *Y*, *Z*. Different curves correspond to different choices of the fixed station. Final location of the mainshock is taken as arithmetic average from all minimum-misfit solutions. The obtained positions of the mainshock in models M1 and M3 are given in Table 3 in bold.

Fig. 3 clearly shows a strong dependence of the misfit on *X* and *Y*, and a weak dependence on *Z*. Slightly weaker dependence on *X* (EW) coordinate, compared to *Y* (NS), is given by the fact that most PATNET stations are to the west of the studied subset. As expected, the depth is still the least resolved parameter (due to absence of the stations along *Z* coordinate), anyway, the elimination of the trade-off with origin time makes the depth more reliable compared to the standard residual approach.

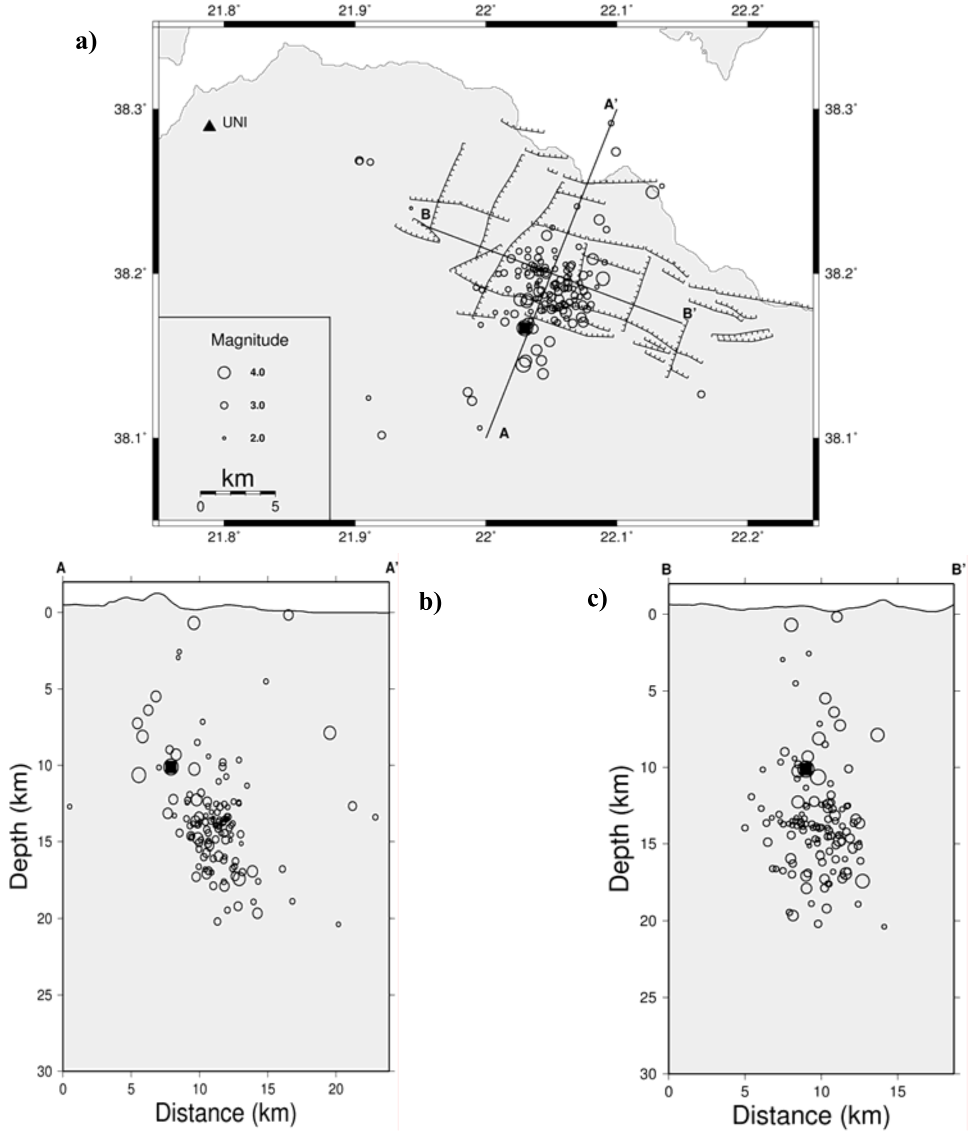

Fig. 2. **a) Preliminary location.** Epicenters of the HYPO71PC location (model M3, starting depth of 7 km). Every event located individually. The mainshock is marked by a square. Main faults in the vicinity of the studied sequence after *Poulimenos (2000)* are also indicated. The position of the nearest station UNI is marked by triangle. **b) Preliminary location.** Results of the same method as in (a), but projected onto the vertical cross-section going through the line AA' in (a). (Only hypocentres with distance less than 5 km from the cross-section are projected). **c)** The same as in (b), but this time the cross-section is drawn through the line BB' in (a). (Only hypocentres with distance less than 10 km from the cross-section are projected this time.)

To quantify the location uncertainty of the mainshock we run the grid search location using the so-called “delete-one jackknifing” (*Tichelaar and Ruff, 1989*), eliminating repeatedly always one from the stations that recorded the event. The standard deviation obtained by this approach (for example of model M3) is 1.20 km, 1.52 km and 4.96 km for the *X*, *Y* and *Z* coordinate, respectively.

Having the final location of the mainshock, we can simply determine its origin time (now de-coupled from the depth). This problem is trivial since the seismic location problem is linear with respect to the origin time. Thus the least-square origin time can be

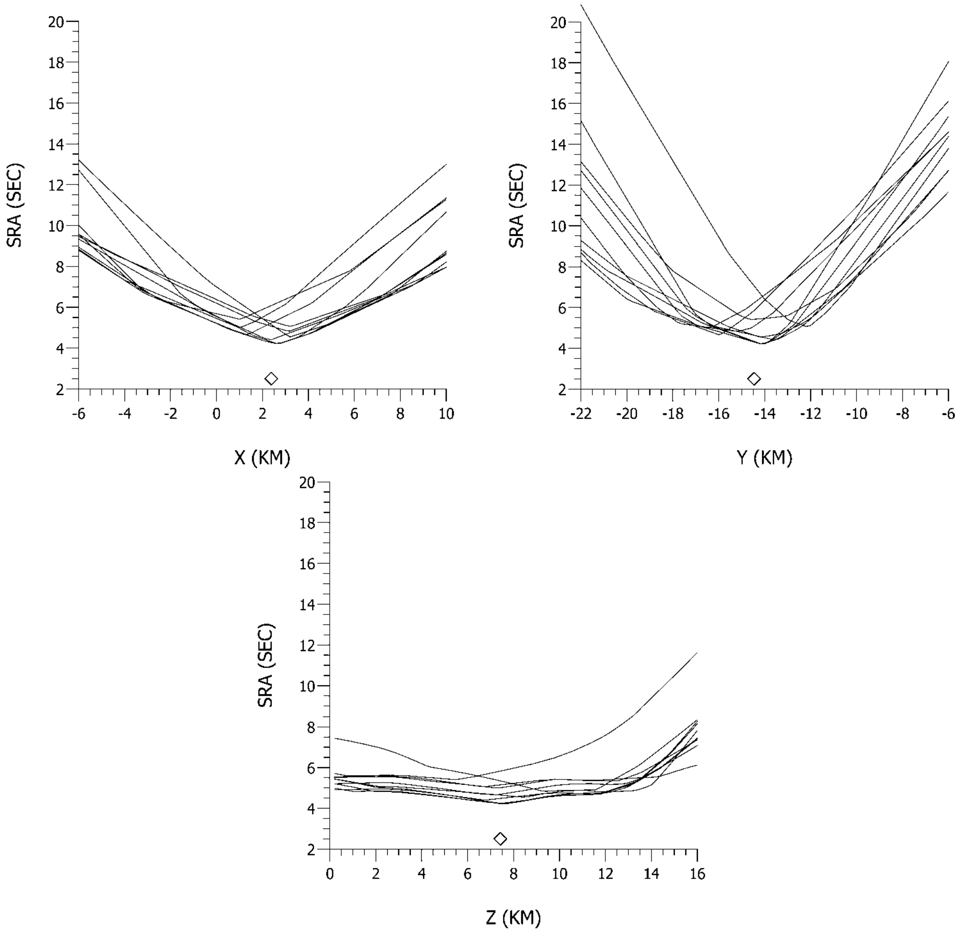

Fig. 3. Misfit of the station-difference (SD) method location of the mainshock in the model M3 (*SRA* gives sum of absolute values of the residual differences, for details, see text), plotted as a function of the *X*, *Y*, *Z* coordinates. The individual curves correspond to the individual choice of the fixed station in the station-difference method. Final location of the mainshock is marked by diamond.

Table 4. Station corrections (sec), determined for mainshock in models M1 and M3.

Station	NAF	DER	BAR	GUM	UNI	PAP	MON	AKA	VOL
M1	0.00	0.05	–0.46	0.28	0.28	–0.05	0.18	0.03	–0.39
M3	0.01	0.02	–0.39	0.46	0.36	0.09	0.17	–0.09	–0.46
Station	**AGN**	**ZAK**	**KEF**	**DOD**	**MET**	**PRG**	**ITH**	**VUN**	
M1	–0.77	–0.35	0.29	0.06	–	0.84	–	–	
M3	–0.82	–0.40	0.24	0.00	–	0.81	–	–	

calculated as arithmetic average from differences between the arrival time and travel time at all stations. Now we can calculate the difference between the theoretical and true arrival time, i.e. the so-called "station corrections", reflecting lateral heterogeneoity of the crust and the local site effects. These station corrections for all PATNET stations, determined separately for crustal models M1, M3, are given in Table 4.

4. LOCATION OF THE SEQUENCE BY THE MASTER EVENT METHOD

In the master event method (MEM) we locate the individual earthquakes of the sequence in a relative sense, i.e., with respect to the mainshock (e.g., *Zollo et al., 1995*). Moreover, we apply the station corrections of Table 4. The grid search is aggain used in this location.

For the MEM location we use the same characteristic parameters as for the HYPO71PC locations. These parameters, determined separately in models M1 and M3, are given in Table 3 as MEM-M1 and MEM-M3, respectively.

It is of interest to mention that if we omit (in the MEM-M1 location) the only one station existing east of the sequence, the station DER, the *XA* parameter increases from 3.51 to 5.44 km, the *YA* parameter increases from –13.44 to –13.12, and the *ZA* parameter increases from 5.08 to 6.12 km. So the role of the DER station is substantial in the location, and its main influence is on the *XA* parameter (the longitude), as expected.

The large difference in the sequence average depth *ZA* for the HYPO and MEM grid search location (see Table 3) may be caused by the fact that the station corrections (Table 4) were applied in our study in the grid search location only. In the HYPO locations only the standard corrections on the station altitude were used. The HYPO location is routinely used by PATNET network for location of events in different regions of the Western Greece, and additional, probably regionally dependent station corrections, are not applied.

To verify the influence of the station corrections, we run the HYPO location in the model M3, using the station corrections from Table 4. The results are given in Table 3 (and as well in Table 5, see bellow) as HC-M3-7. We see that in this case the sequence average depth is indeed much closer to the *ZA* value obtained by the MEM grid search.

Table 5. The average difference in epicenter and depth, EAD and ZAD, respectively (and their mean deviations, given in brackets) for different location pairs of Table 3.

The two locations compared	*EAD* (km)	*ZAD* (km)
HY-M1-7 × HY-M1-14	1.29 (0.79)	3.12 (2.27)
HY-M3-7 × HY-M3-14	1.20 (0.78)	2.50 (1.96)
HY-M1-7 × HY-M3-7	0.53 (0.38)	1.15 (0.92)
MEM-M1 × MEM-M3	1.25 (0.43)	2.87 (1.88)
MEM-M1 × HY-M1-7	2.04 (0.94)	8.28 (2.95)
MEM-M3 × HY-M3-7	2.69 (0.92)	7.66 (2.87)
MEM-M3 × HC-M3-7	1.01 (0.57)	3.93 (2.47)

Further, the sum of root mean square errors of time residuals (for the 139 events) decrease to 21.73 s as compared with 25.60 s for HY-M3-7 location, i.e. by 15%.

So far we had no reason to prefer model M1 or M3. However, an interesting feature of the spatial distribution of foci in the model M1 was a gap between depths from 4.3 to 6.3 km with a quite sharp lid at about 4.3 km. Although the same crustal model was used in HYPO and the MEM grid search, this effect was much less pronounced in the HYPO location. Several experiments with the grid search excluded the possibility that the concentration of foci at about 4.3 km is connected with the addopted parameters of the grid search. We tried to understand whether it is a real feature, or an artifact. For example, the 5 km velocity discontinuity in the model M1 may create an artifact like that (*Lyon-Caen H., personal communication*). This possibility was confirmed by using the model M3, without the discontinuity at the depth of 5 km, for which the grid search foci did not manifest the mentioned artificial concentrations of foci and the gap. That is why the final results in this paper are presented for the M3 model.

Selecting MEM-M3, we arrive at the final location of the sequence. The Cartesian coordinates together with corresponding standard deviations, obtained again by the "delete-one jackknifing", are given in Fig. 4, the geographical coordinates (without the standard deviations) in Fig. 5. Thirty eight outliers, defined more or less subjectively, were omitted. Thirteen of them were events where standard deviation of X or Y was larger than 6 km, or standard deviation of Z was larger than 10 km. Further 25 events had the Z-DZ value negative, where DZ denotes the standard deviation of Z.

Comparing to the HYPO-M3-7 location (Fig. 2), the two main results are as follows: (i) the sequence became clustered more tightly, with the hypocenter inside, and (ii) the cluster moved slightly toward south and to significantly shallower depths. The latter can be also seen from *YA* and *ZA*, given in Table 3.

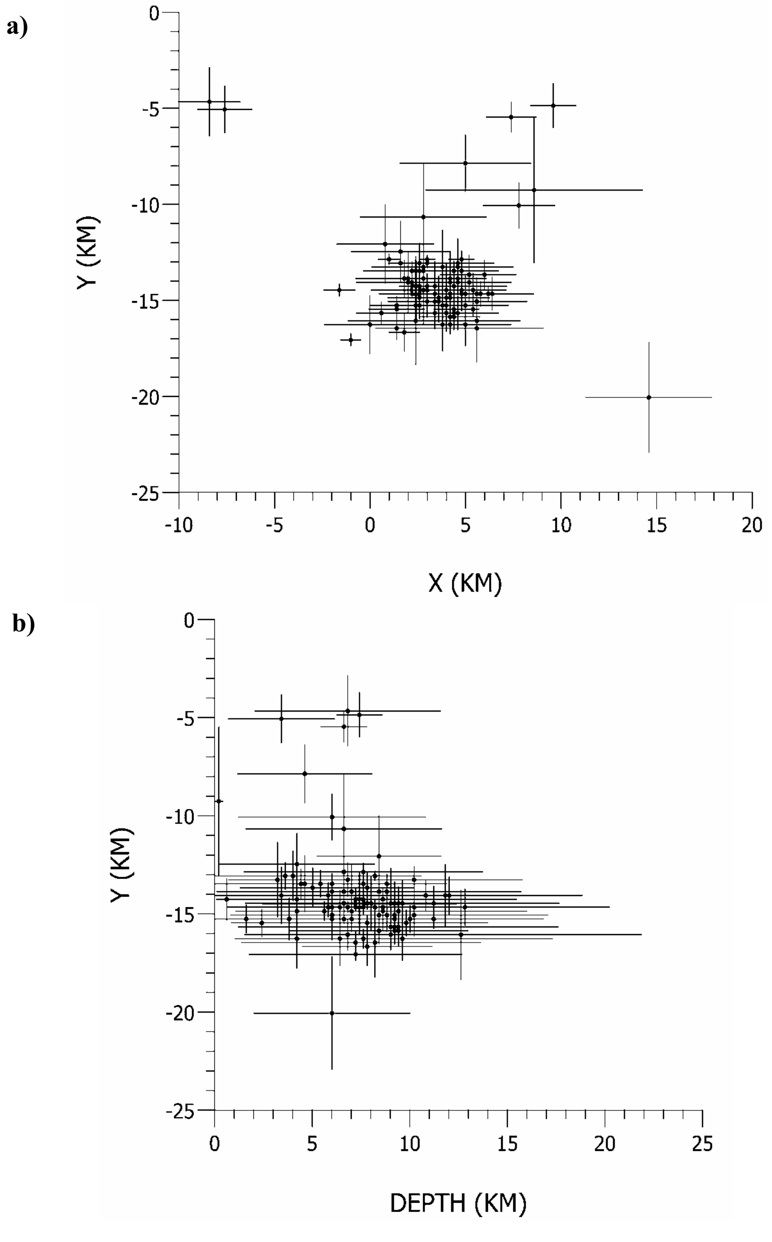

Fig. 4. **a)** Final epicentres of the sequence (found by the MEM grid search location in the model M3) in *XY* Cartesian coordinates, together with their standard deviation. Outliers were omitted (see text). **b)** Final hypocentres of the sequence in *ZY* Cartesian coordinates, together with their standard deviation. Outliers were omitted (see text).

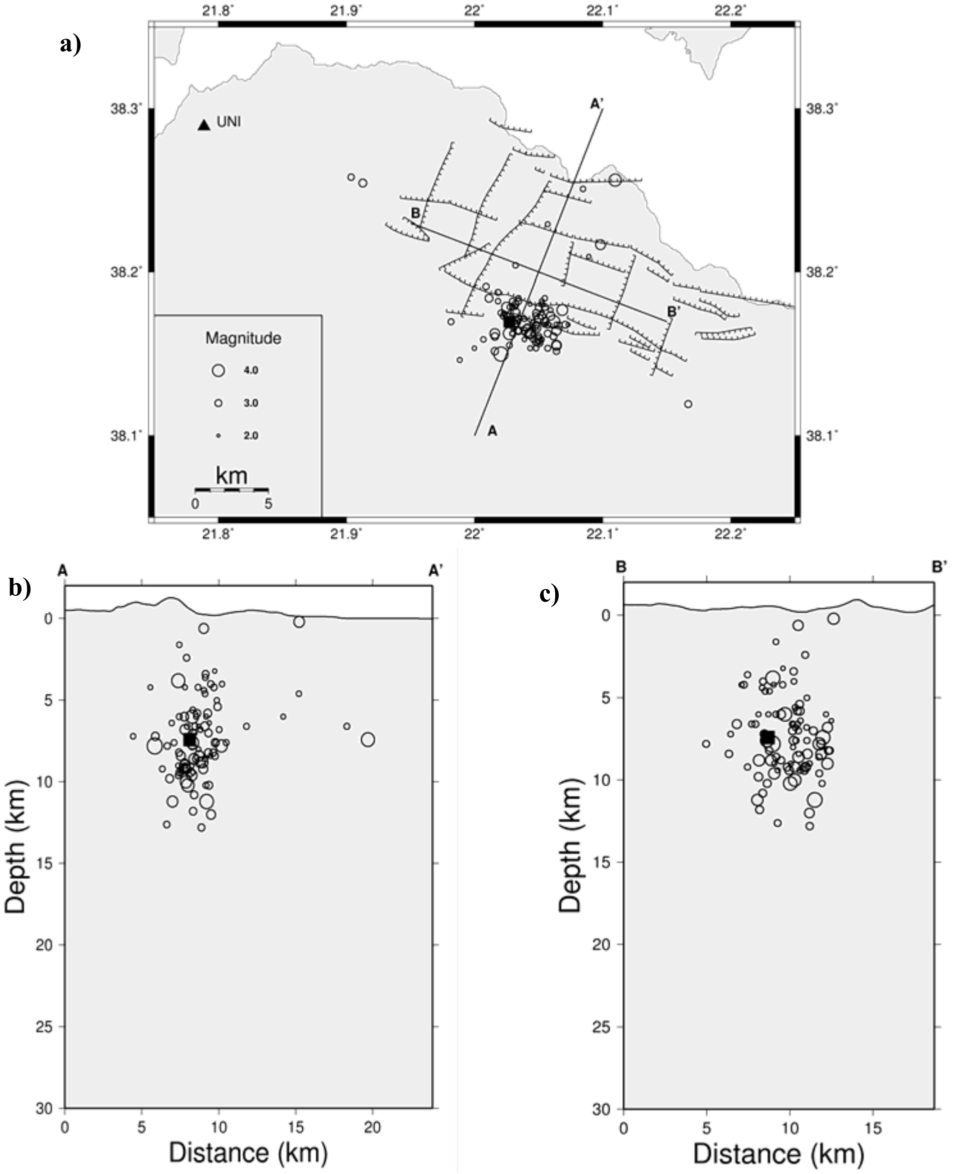

Fig. 5. **a)** Final location of this paper in geographic coordinates. The epicenter of the mainshock (square), found by the SD method. Epicenters of the sequence found by the MEM grid search location (model M3). Shown are also the main faults. The position of the nearest station UNI is marked by triangle. **b)** Final location of this paper. Results of the same method as in (a), but projected into the vertical cross-section going through the line AA' in (a). **c)** The same as in (b), but the cross-section is drawn through the line BB' in (a).

So far we have focused on the average parameters of the whole sub-set. But is also interesting to find out, how the location approach (location method, crustal model) affect hypocenters of the individual events. To measure this effect on average, for the whole set of events, we introduce the following parameters:

$$EAD = \frac{\sum_j \sqrt{\left(X_j - X^j\right)^2 + \left(Y_j - Y^j\right)^2}}{N},$$

$$ZAD = \frac{\sum_j \left|\left(Z_j - Z^j\right)\right|}{N},$$

where X_j, Y_j, Z_j, and X^j,Y^j, Z^j are hypocentral coordinates of the j-th event obtained by two different locations, and N gives the number of events. Thus EAD and ZAD measure the average difference in the epicenter and depth from one method to the other, see Table 5. The table confirms the influence of the starting depth on the HYPO71PC location. The influence of the crustal model on the MEM location is significant in the depth difference (ZAD). The differences between the HYPO71PC versus MEM location are large, especially for ZAD.

5. CONCLUSIONS

According to several HYPO71PC locations of the present paper, a majority of the 139 hypocenters of the Aegion 2001 sequence formed a cluster whose extent is roughly 10 by 10 km (horizontally) by 20 km (vertically), and the mainshock ($M_L = 4.7$) was situated at the top margin of the cluster.

With the objective to improve the location we proceeded in two steps. The mainshock was re-located, and then it was used as a master event to locate the whole sequence. As for the mainshock location, the linearized method was substituted by a systematic 3D grid search, and the trade-off between depth and origin time was eliminated by a special procedure, called the station difference (SD) method. In the SD method, instead of inverting arrival times directly, their intra-station differences are studied. Since no station has a privilege to be a fixed reference station, the method is applied repeatedly so that, successively, every station is considered as the fixed station just once, and the final location is obtained as average of the best fitting solutions from these repeated runs. For crustal model M3, it corresponds to the position at 22.027°E, 38.170°N and the depth of 7.4 km. The uncertainty of the solution, i.e. the standard deviation estimated by the “delete-one jackknifing” equals to 1.20 km for EW, 1.52 km for NS, and 4.96 km for Z coordinate. The relocated mainshock provided also the station corrections.

Finally, using the mainshock as a master event, the cluster, located by the MEM grid search, became narrower, some 5 by 5 km (horizontally) by 10 km (vertically), with the mainshock inside. The results should be interpreted with caution, mainly as regards the “absolute” depth position of the cluster. A more accurate kinematic location would require a local network with P and S readings. Such work is in progress (*Pacchiani at al., unpublished data*) within the framework of the Corinth Rift Laboratory Project.

Tectonic interpretation of the sequence will be possible only after a more detailed high-resolution location using local stations. A partial information on the focal mechanism of the mainshock may be useful (*Zahradník et al., 2004*). Indeed, the *T* axis for that event (azimuth 176° and plunge 67°) is consistent with the ~N10° regional extension obtained from GPS and fault plane solutions of larger events in the Corinth Gulf. On the other hand, major faults outcropping on the southern coast of the western Corinth Gulf are normal faults with ESE-WNW orientation and a steep (~60°) dip to the NNE, but none of the two nodal planes obtained for the April 8 mainshock agrees with these outcropping structures. The relation of the sequence to deeper blind faults remains open. One possibility is that this sequence occurred on older structures reactivated in the present stress field. Those may be former thrust faults related to the nappes empilement of the Hellenides formation (*Lyon-Caen H., personal communication*).

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References

Fisher T. and Horálek J., 2000. Refined locations of the swarm earthquakes in the Nový Kostel focal zone and spatial distribution of the January 1997 swarm in Western Bohemia, Czech Republic. *Stud. Geophys. Geod.*, **44**, 210–226.

Janský J., 2000. Grid search hypocentral location method in simple 1-D media. *Acta Montana IRSM AS CR*, *Series A*, **118**, 71–84.

Lyon-Caen H. and Rigo A., 1997. Seismological observations in the Gulf of Corinth, Proceedings of the 1st workshop on the development of a multiborehole observatory at the Gulf of Corinth, ICDP report, http://www.corinth-rift-lab.org/index_html

Poulimenos G., 2000. Scaling properties of normal fault populations in western Corinth Graben, Greece: implications for fault growth in large strait settings. *J. Struct. Geol.*, **22**, 307–322.

Rietbrock A., Tiberi C., Scherbaum F. and Lyon-Caen H., 1996. Seismic slip on a low angle normal fault in the Gulf of Corinth: evidence from high resolution cluster analysis of microearthquakes. *Geophys. Res. Lett.*, **14**, 1817–1820.

Rigo A., Lyon-Caen H., Armijo R., Deschamps A., Hatzfeld D., Makropoulos K., Papadimitriou P. and Kassaras I., 1996. A microseismic study in the western part of the Gulf of Corinth (Greece): implications for large scale normal faulting mechanisms. *Geophys. J. Int.*, **126**, 663–688.

Tichelaar B.W. and Ruff L.J., 1989. How god are our best models? Jackknifing, bootstraping, and earthquake depth. *Eos Trans. AGU*, **70**, 605–606.

Tselentis G.-A., Melis N.S., Sokos E. and Papatsimpa K., 1996. The Egion June 15, 1995 (6.2 ML) earthquake, Western Greece. *Pure Appl. Geophys.*, **147**, 83–98.

Zahradník J., Janský J., Sokos E., Serpetsidaki A., Lyon-Caen H. and Papadimitriou P., 2004. Modeling the M_L 4.7 mainshock of the February-July 2001 earthquake sequence in Aegion, Greece. *J. Seismology* (in press).

Zhou H., 1994. Rapid three-dimensional hypocentral determination using a master station method. *J. Geophys. Res.*, **99**, 15439–15455.

Zollo A., De Matteis R., Capuano P., Ferulano F. and Innaccone G., 1995. Constraints on the shallow crustal model of the Northern Apennines (Italy) from the analysis of microearthquake seismic records. *Geophys. J. Int.*, **120**, 646–662.