



## FAULT POPULATION RECOGNITION THROUGH MICROSEISMICITY IN MYGDONIA REGION (NORTHERN GREECE)

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### ABSTRACT

Seismicity in the broader area of Mygdonia basin in northern Greece is lately characterized by the absence of strong events along active seismogenic faults known to have been activated in the past. Small to moderate magnitude earthquakes not exceeding  $M_L 4.8$  have occurred in the last three decades. In this study, earthquakes occurred in 2000 and 2013 and recorded by the Hellenic Seismological network were investigated. Available P- and S- seismic wave arrivals were used for relocation in order to obtain accurately determined earthquake focal coordinates. For this scope, a Wadati diagram was constructed and a  $V_p/V_s$  ratio equal to 1.78 as well as time delays were included in the HypoInverse process for the estimation of the focal coordinates. In the case of strong spatial or temporal clustering among earthquakes, the HypoDD algorithm was also employed for further improving location accuracy. The relocated seismicity was used in order to reveal the structural and geometrical properties of the local fault population and identify seismogenic faults deprived of a clear surface expression. For this reason, cross sections perpendicular to the main axis of the rupture zones were created, and finally a correlation between the kinematic properties and the current stress field was attempted. It is evident that in the absence of strong earthquakes, microseismicity is the only, however fundamental information to be exploited for the identification of active faults and the hazard assessment since small earthquakes are concentrated in areas with a significant potential for a future strong earthquake.

### INTRODUCTION

The insufficient investigation of minor magnitude seismicity hinders the opportunity for a detailed insight to seismicity processes or seismic sources, since small events are usually related to subsidiary faults which supplement the seismogenic fault population and cannot be alternatively identified. For this reason, well defined earthquake foci are good indicators of the seismogenic sources. The importance of acquiring precisely defined focal parameters of microseismicity is highlighted in this study and lies upon the fact that in the absence of strong events, minor earthquakes which are distributed along causative faults provide significant implications about the active fault zones and the quantification of prominent

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seismogenesis (Bagh et al., 2007; Maggi et al., 2009; Tan et al., 2012). The deployment of a dense and modern seismological network significantly contributes to lower magnitude detectability and recording, consequently improving location accuracy and data provision, dissipating the heterogeneities of the seismicity catalogs of the past. A number of uncertainties inevitably involved in existing earthquake catalogs, necessitates relocation for the definition of the geometrical properties of the active structures. Therefore, the challenge of the present study is the recognition of the seismic sources through local seismicity after compiling a precisely located earthquake catalog for the Mygdonia region (Northern Greece) (Fig.1a and Fig.1b).

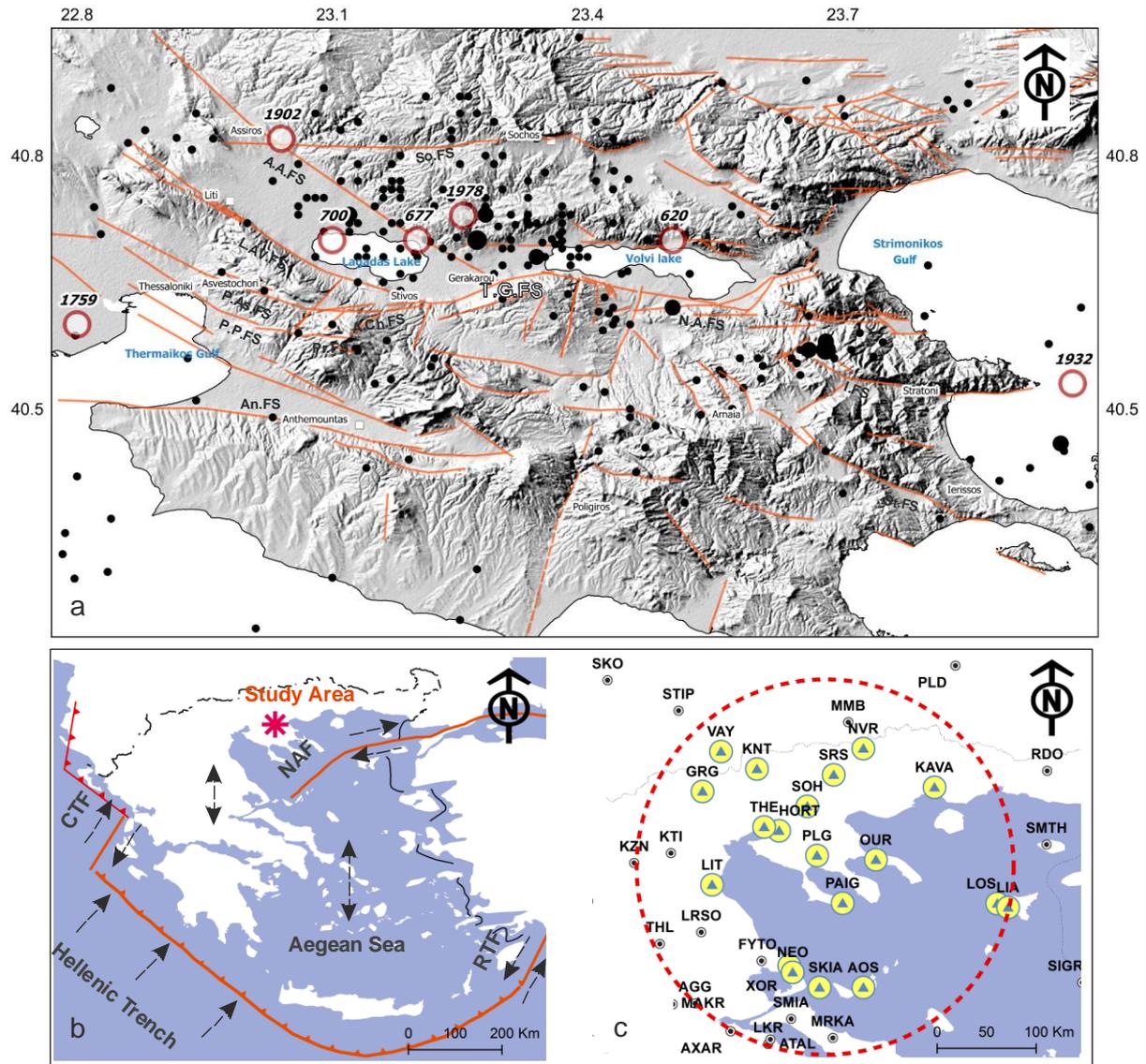


Figure 1. a) Digital elevation model for the Mygdonia basin and the surrounding area. Red lines correspond to important fault zones, such as the East-West "Thessaloniki-Gerakarou" (T.G.F.S) normal fault system which bounds the basin from the south, along with secondary fault segments described in the text (fault information gathered by Pavlides and Kilias, 1987; Tranos et al., 2003; Tranos, 2008). Open red circles correspond to strong historical earthquakes, while black dots are earthquake epicentres with magnitude greater than 4.0 since 1978. b) Simplified map of the broader Aegean sea and the surrounding region including the dominant seismotectonic features, such as the Hellenic Trench (thick red line with triangles), the North Aegean Trough (N.A.T.) which accommodates the westward extrusion of the Anatolian plate into the Aegean, the Cephalonia (C.T.F.) and Rodos (R.T.F.) Transform Faults. The asterisk in red denotes the location of the study area. c) Map of Northern Greece with the installed seismological stations belonging to the HUSN. The red circle encloses stations surrounding the study area in a relatively short distance, which were used for the data re-processing using Wadati methodology and time delays computing for the seismic waves.

Low seismicity rate along with moderate magnitude events characterize the current seismicity pattern for the study area, albeit it has suffered a number of historical earthquakes with maximum macroseismic intensity equal to XI (Assiros, 1902; Papazachos and Papazachou, 2003). The determination of the active fault segments which are causative for the recent seismicity in this back-arc basin as well as the variations of seismicity and its clustering in time and space are the objects of this study, since these rupture zones are always posing a potential societal threat for the city of Thessaloniki.

## SEISMOTECTONIC FRAMEWORK

Mygdonia graben and the surrounding mountainous volumes are defined by the presence of a dense faulting network that largely accommodates extensional tectonic processes, developed in the fast deforming back – arc area of the active Hellenic arc. The seismotectonic properties of the broader Aegean territory (Fig.1b) are attributed to the subduction and the retreat of the Mediterranean oceanic microplate under the fast moving Aegean, giving rise to the South Hellenic Arc (Papazachos and Comninakis, 1971; McKenzie, 1978). The present form of the S-shaped Mygdonia basin is developed after the impact of successive seismotectonic events, associated with extensional deformation, and subsequent rotations of the stress field (Pavlides and Kilias, 1987). As a result, a complicated faulting network that incorporates NW-SE, NE-SW, E-W and NNE-SSW faults was formed, built on pre-existing structures.

The active faults strongly related to the verified strong seismic activity are mainly developed in an E-W direction, controlling the central part of the basin, and the eastern part of Chalkidiki peninsula (Tranos et al., 2003; Mountrakis et al., 2006). One of the predominant active features lies in an E-W direction in the central part of the basin and is associated with the seismic triplet of 1978, "Thessaloniki-Gerakarou" fault zone (T.G.FS) and the semi parallel faults of "Pilaia-Peristera" (P.P.FS), "Pefka-Asvestochori" (P.As.FS) and "Asvestochori-Chortiatis" (A.Ch.FS) faults (Fig.1a). The prolongation of this zone to the east is composed of the "N. Apollonia" Fault zone (N.A.FS) along with subsidiary either antithetic or sub parallel faults, in between the two lakes or at the north of the lake Volvi dipping to the south. The entire region is bounded by elongated E-W faults, such as "Sochos" (S.FS) which comprises an impressive fault zone along the north margin of the basin dipping steeply to the south, as it can be easily pinpointed in aerial imagery. To the south of T.G.FS, "Anthemountas" detachment fault (An.FS) and "Stratoni" fault zone (St.FS) do not currently exhibit significant activity, however they are considered to be responsible for the strong historical earthquake of 1759 in Thermaikos gulf and 1932 in Ierissos. The fault systems aligned in NE – SW orientation follows the inherited structures and mainly consists of the north dipping Lagina – Agios Vasileios fault (L.AV.FS) and its antithetic "Assiros – Analipsi" fault system (A.A.FS.). Along this major fault zones, elongated basins and ridges are formed, bounded by secondary fault zones. "Ierissos" fault system (I.FS.) at the southeast also plays an important role in the geomorphology evolution of the study region.

After the most recent 1978 Stivos strong earthquake (M6.5) and its stronger aftershocks (M5.3 and M5.8), seismicity rate has been reduced, without strong events interrupting normal seismicity. In 1995 Arnea earthquake (M5.8) occurred at the southeastern part of Chalikidiki peninsula (Dimitriou et al., 2000). Fig.2a gives a sufficient temporal description of the earthquake magnitudes for the period 1980 – 2012. The absence of strong seismicity and the limited number of moderate earthquakes after 1978 is the main characteristic of instrumental period. Additionally, the cumulative magnitude-frequency diagram between 2000-2012 (Fig.2b) indicates the low  $M_c=2.4$  cutoff magnitude. Extensive seismologic research has been conducted for this area with most of the studies referring to the 1978 strong event (Papazachos et al., 1979; Soufleris and Steward, 1981; Soufleris et al., 1982) transient local deployments (Hatzfeld et al., 1986/87; Hatzidimitriou et al., 1991; Paradisopoulou et al., 2004, 2006; Papazachos et al., 2000) and Scordilis et al. (1989) investigated long-term seismicity properties at the onset of the seismological network operation.

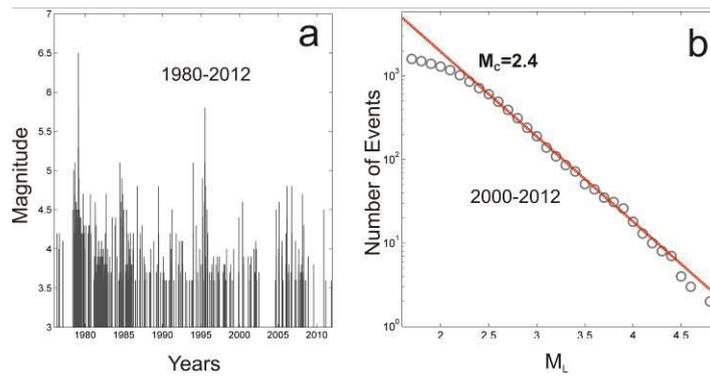


Figure 2. a) Comb plot for magnitudes in the study area against time for the period 1980 – 2012. b) Magnitude distribution of earthquakes for the period 2000 – 2012.

## DATA SET AND RELOCATION PROCEDURE

The accurate determination of earthquake focal parameters is strongly influenced by the crustal structure affecting the propagation of seismic waves and consequently their recordings at the corresponding seismological stations. In the present study, an attempt is made to minimize the effect of crustal heterogeneity on earthquake location. For this reason, seismicity data concerning arrival times of local earthquakes were collected from the Hellenic Unified Seismic Network (HUSN) whose configuration guarantees the detection of even small earthquakes and further contributes to the improvement in the estimation of their focal parameters. Phase data were obtained from the monthly bulletins of the Seismological Station of Aristotle University of Thessaloniki (A.U.Th.) A number of 2086 events occurred between January 2007 and March 2011 exhibiting magnitudes less than 4.8 in the study area. An additional set of earthquake arrivals which fulfill specific requirements was also compiled for the relocation process. This set contains 206 earthquakes with a minimum number of seven  $P$ - and  $S$ - phases, derived from the original raw catalog, preferably recorded by 21 seismologic stations which are installed in a relatively short distance from the study area, in a satisfying azimuthal coverage (Fig. 1c). Magnitudes were acquired from the monthly bulletins and they refer to  $M_L$  magnitude obtained by applying the methodology of Hutton and Boore (1987) on simulated Wood Anderson earthquake recordings. Earthquake relocation processes presuppose the adoption of a velocity model that best approximates the structure of the earth's seismogenic crust. Considering the local velocity models derived from microseismicity analysis (Hatzfeld et al., 1986/1987; Papazachos et al., 2000; Paradisopoulou et al., 2006) the one that fits our data best is the last one, further modified for deeper layers, so as to incorporate longer epicentral distances for half space, proposed by Panagiotopoulos and Papazachos (1985). A schematic figure of the adopted velocity model is given at Fig. 3a.

Considering the pairs of  $P$ - and  $S$ - wave arrivals of the constrained earthquake data set, a cumulative Wadati diagram was constructed (method introduced by Chatelain, 1978). The time difference  $DT = T_S - T_P$  between the arrival time of  $P$ - waves ( $T_P$ ) and  $S$ - waves ( $T_S$ ) is plotted against ( $T_P$ ) for all available pairs of observations (Fig. 2b). There is an evident linear fit, between these values, mostly accurate for pairs of smaller or intermediate distances. The mean slope equals the velocity ratio, found to be  $V_p/V_s = 1.78 \pm 0.04$ . This value seems to be slightly larger than ratios obtained from similar studies regarding the same area, such as 1.74 (Hatzfeld et al., 1986/1987) or 1.76 (Paradisopoulou et al., 2006) however the above experiments were local and of short operation duration. Spatial investigation indicated no significant spatial distribution for the velocity ratio within the graben, implying the absence of specific crustal variations in the seismogenic volume concerning the material of the brittle crust of Mygdonia region that have to be approached in a different way. The travel time of seismic waves depends on the spatial and the azimuthal distribution of the network of the seismological stations around the epicenters. New origin times for the optimal data set, have been obtained with the application of the Wadati method, for both short and long distance seismological stations. Obtaining new origin times lies to the fact that they are deprived of uncertainties regarding the velocity model used in each case (methodology also followed by Akyol et al., 2006; Karakostas et al., 2012). Therefore, the

time difference between the observed and the theoretical travel times was used as time correction in each station, a repeated procedure until the difference between the observed and the theoretical times becomes very small. There is a total number of 57 stations that were finally corrected in time. The obtained corrections for the model vary between -0.5 sec and +0.5 sec for the optimum set of data.

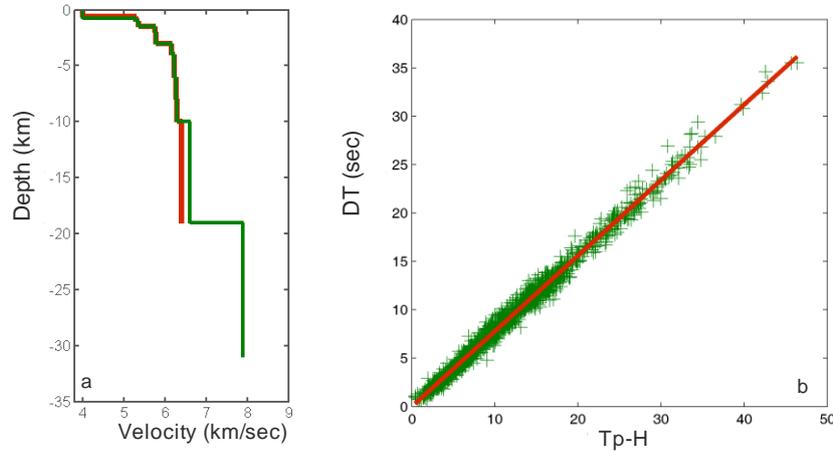


Figure 3. a) The modified velocity model (green line), used in the current study in comparison with the velocity model adopted from Paradisopoulou et al. (2002) (red line). b) Cumulative Wadati diagram, indicating a linear fit (red line) between pairs of DT and Tp-H for the optimized data set of earthquakes.

## SPATIAL AND TEMPORAL DATA ANALYSIS

A number of 2086 earthquakes that occurred during the study period were processed with the Hypoinverse algorithm (Klein, 2002) after taking into consideration the estimated station time corrections and the velocity ratio and the estimated station time corrections. The two data sets of the preliminary and final locations for the optimum earthquakes were compared to each other, so histograms of quality parameters such as the error in origin time (RMS), the mean horizontal error (ERH) and the mean vertical error (ERZ) were constructed in both cases (Fig.4). There is a sufficient indication of an important improvement after the incorporation of station delays within the relocation algorithm.

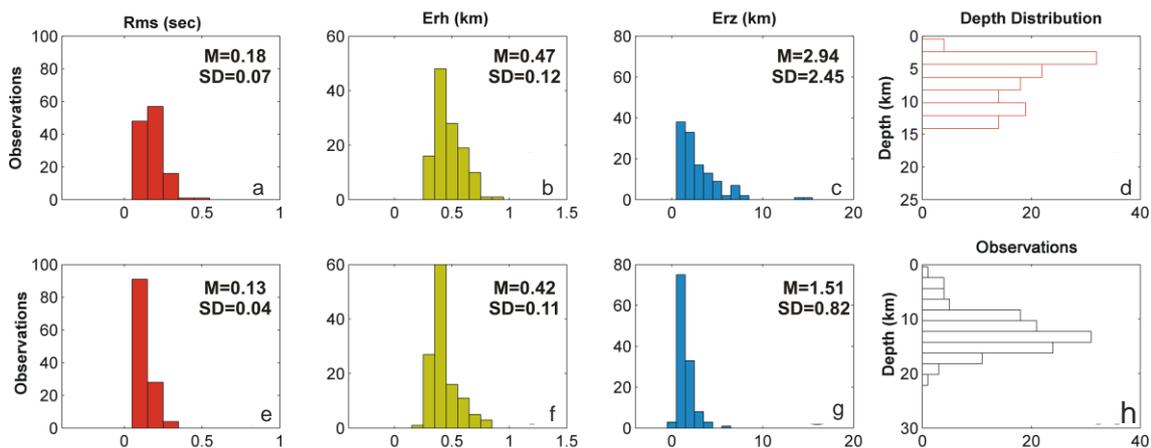


Figure 4). Comparison between residuals estimated for preliminary location (first row) and final relocation process for the modeled set of earthquakes (second row). The mean values (M) along with their standard deviations (STD) are given in each plot. a) root-mean Square error (RMS), b) horizontal uncertainty (ERH), c) vertical uncertainty (ERZ), d) depth distribution for the preliminary results e) root-mean Square (RMS), f) horizontal uncertainty (ERH), g) vertical uncertainty (ERZ), h) depth distribution for the final results.

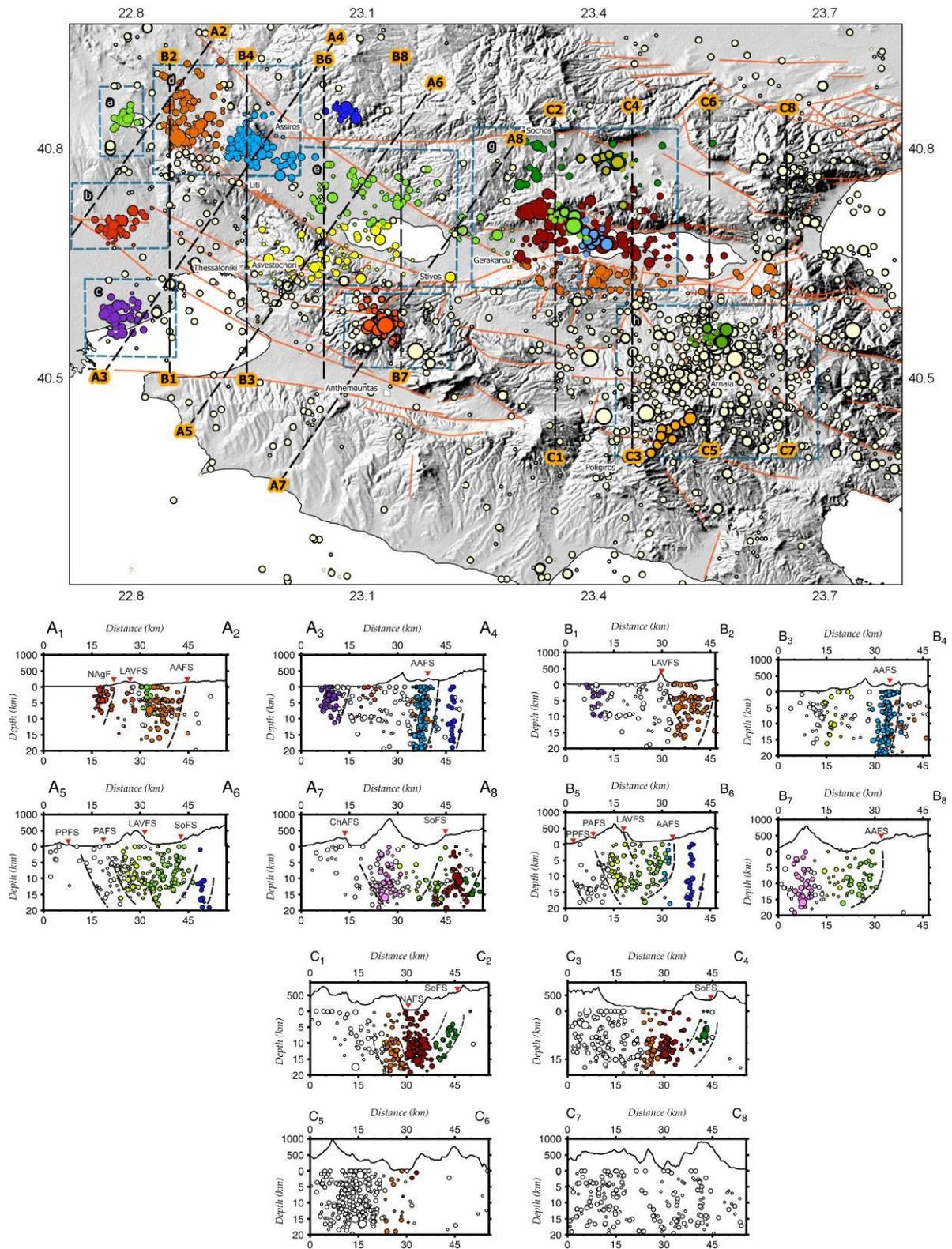


Figure 5). Relocated earthquake epicentres for the study area. Black dashed lines correspond to earthquake profiles, perpendicular and semi perpendicular to the main fault structures. Cross sections in a SW – NE direction along with geomorphological profiles. The red triangle corresponds to locations of known traces of active faults in surface. Colours for seismic clusters are the same as in the map view. Cross Sections in a S-N direction along Lagadas sub area, in a S-N direction along Volvi sub area and in S-N direction over Arnea region, with the corresponding geomorphological profile.

The relocated seismicity (Fig.5) evidences that there are extended areas with scarce activity, even absent. The major normal faults that mostly define the boundaries of the main or smaller elongated basins, are well delineated. Exception of the southeast continental part of the study area, where seismicity is evident in the entire area. As mentioned before, the exploitation of the seismicity was performed in order to define spatial or temporal clusters of earthquakes and assign them to their causative seismic faults, either primary or subsidiary ones that were activated during last years. For this reason, several successive perpendicular or semi perpendicular to the main faults cross sections were constructed for the investigation of foci distribution and their relevance to the geometry of the structures in Volvi, Lagadas and Arnea areas. Twelve cross sections have been constructed in accordance to the least principal stress axis, four of them in a SW-NE direction ( $A_1A_2$ ,  $A_3A_4$ ,  $A_5A_6$ ,  $A_7A_8$ ) perpendicular to the general strike of the NE-SW fault segments that bound the Lagadas sub basin, four South-North profiles ( $B_1B_2$ ,  $B_3B_4$ ,  $B_5B_6$ ,  $B_7B_8$ ) are plotted normal to the most active E-W fault zones covering Lagadas fault systems whereas, four other South – North profiles ( $C_1C_2$ ,  $C_3C_4$ ,  $C_5C_6$ ,  $C_7C_8$ ) are normal to the most active E – W faults which extend to the eastern part of the study area. In all cases cross sections include epicenters in the range of 10km in width. NE-SW successive sections are drawn from west to east.

A cluster in red (in  $A_1A_2$ ) defines a fault zone that dips approximately  $50^\circ$  to the southeast reaching 10km in depth. This dip agrees with the fault plane solutions calculated by Paradisopoulou et al. (2004) and this zone can be associated with "Nea Aghialos" Fault (NAGF) (Tranos et al., 2003). A swarm of green epicenters is found in the front of the northern segment of "Lagina-Agios Vasileios" fault system (LAVFS) with shallow depths and a steep dip to the north. A third cluster is observed with deeper depths up to 17km. If combined with the available fault plane solutions a zone of epicenters along a plane of approximately  $60^\circ$  dip to the southwest, southern than the fault trace of Assiros – Analipsi fault segment (AAFS). At  $A_3A_4$  cross section characteristic zones dipping steeply ( $60^\circ$ ) to the south at large depths (~20km).  $A_5A_6$  crosses the "Pilaia – Peristera" fault system (P.P.FS) in the south and the Sochos Fault to the north. A zone formed by yellow epicenters up to 15km at depth, whereas a steep zone connected to "Sochos" Fault System. Successive South to North profiles are constructed covering part of the same seismic fault system.

Although sections  $B_1B_2$ ,  $B_3B_4$ ,  $B_5B_6$  are not very representative for the NW-SE trending faults since they are semi perpendicular to them, the distribution of foci not show an explicit differentiation. Section  $B_7B_8$  is more representative than the NW-SE ones in the cases of "Asvestochori-Chortiatis" fault systems. In light red color a minor excitation is presented probably attributed to "Peristera" Fault Zone, dipping to the North while in the north earthquakes are distributed along the graben boundaries. Profiles at Arnea region are normal to the East -West fault zones to the sub area of Volvi lake, where main active normal segments of Sochos and "Nea Apollonia" faults dominate. Volvi region that seems to be more seismically active within the last years since there are plenty of epicenters distributed along the fault zones. Fault dips around Volvi boundaries are very well defined.

In cross sections  $C_1C_2$  and  $C_3C_4$  that are normal to "Sohos" Fault which the distribution of foci is well defined and is in total accordance with the geological data dipping at high angles to the south ( $60^\circ$ ), associated with "Sohos" fault zone. However seismicity in sections  $C_5C_6$  and  $C_7C_8$  seems to be clustered enough, because of the activation of subsidiary faults with different orientation and the seismicity pattern seems to be more diffuse rather than distributed around known important faults. Relocated earthquakes estimated by the hypoinverse algorithm were further used as an input to HypoDD double difference algorithm (by Waldhauser and Ellsworth 2000; Waldhauser, 2001) a relative relocation program which was used in order to test the differentiation in the location of the epicenters and foci for those that have mainly occurred closed in time. Thus, the area was subdivided into distinct subsets of data (particularly subsets d,e and g are presented in Fig.6).

In Fig.6 subplots the so far relocated seismicity characterized by the lowest possible uncertainties, shows strong degree of clustering are presented both in a map view and cross sections perpendicular to the main structures. In subset d, two seismic clusters are visible at the northwestern part of the study area (Lagadas sub area) in the vicinity of the termination of NW-SE "Assiros" fault south dipping fault and its antithetic, "Lagina" fault, dipping to the north. Considering the cross sections ( $A_1A_2$ ,  $A_3A_4$ ) foci in both cases are developing zones dipping in high angles at depth. In subset B which is located, close to the southern termination of the above faults. Foci distribution at depth is concentrated between 5-16km (in  $B_3B_4$ ) around Lagadas lake, generated by the bounding faults. Two sub regions are introduced

in the eastern part, around Volvi lake. Not important differentiations are revealed at the spatial distribution of epicenters along "Sochos" fault in the two cases of relocation (Subset e). At sections C<sub>1</sub>C<sub>2</sub> and C<sub>3</sub>C<sub>4</sub> there is a visible gradual dipping of Sochos fault to the south, whereas there is a seismic activity attributed to Nea Apollonia fault. Subplot d (D<sub>1</sub>D<sub>2</sub>, D<sub>3</sub>D<sub>4</sub>) presents the Arnea region and corresponds to the mountainous area southern than Volvi lake, where seismicity seems not to be locally concentrated around major faults but it is dispersed around the fault network.

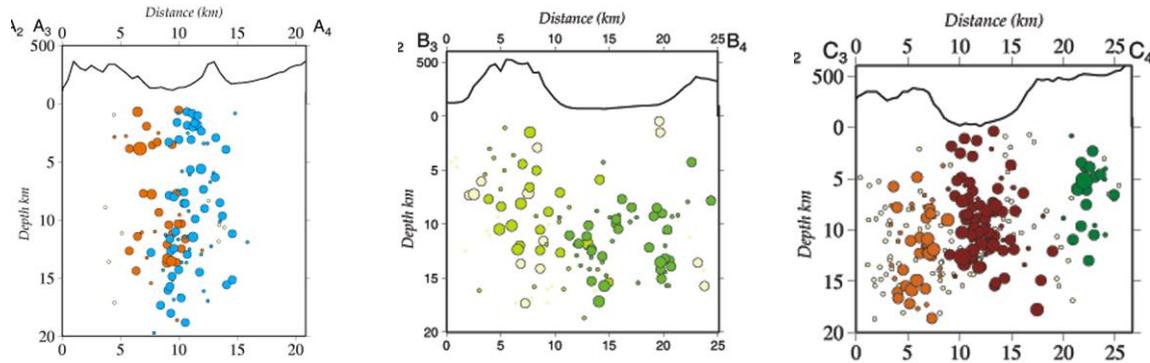


Figure 6) Cross Sections with the corresponding geomorphological profile and available fault plane solutions of subsets in map 2.

The temporal evolution of seismicity can be figured out with the use of an integral space – time seismicity plot (Fig.7) along an East – West strike which coincides with the mean strike of the active faults. In this diagram the evolution of seismicity occurrence can be projected along with time and the concurrent events distributed along fault zones are clear. Two sub regions are introduced, Lagadas and Volvi region from west to east of the area. At first sight the temporal distribution reveals discrete prolonged earthquake bands along the fault zones. In the first years of observation there is a period of a rather low seismicity rate, until the beginning of 2003, where western than Assiros a seismic excitation of minor seismicity (orange color) is observed with small earthquakes which culminate in an earthquake with magnitude equal to 4.2 in 2005.

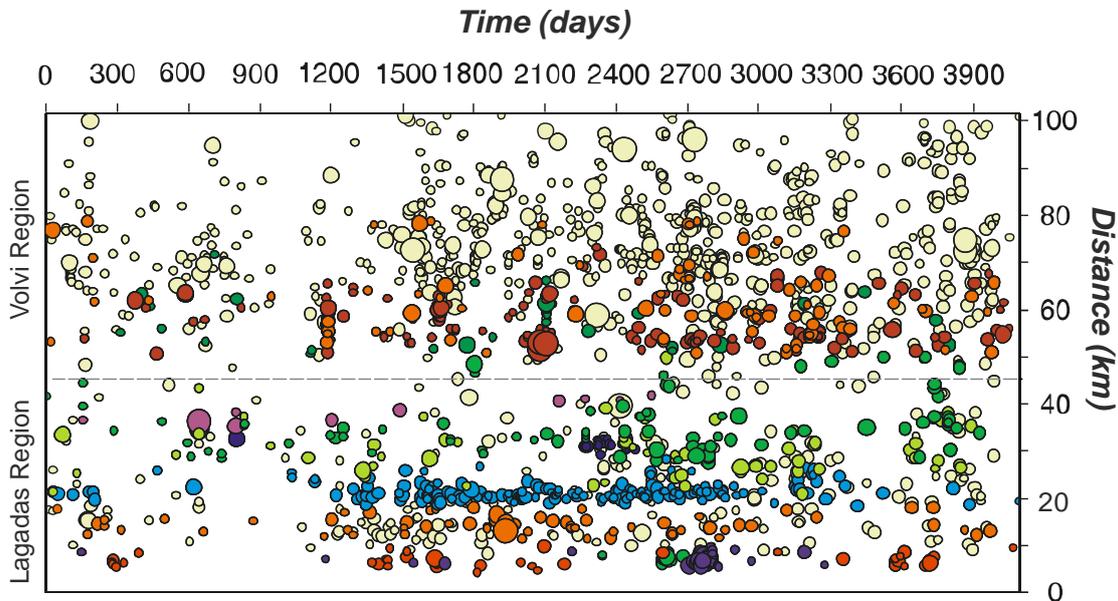


Figure 7) A spatial-temporal evolution plot along an east-west direction line crossing the study area for the time period: 2000-2010. Different colors correspond to specific temporal-spatial clusters, depicted with the same coloring at the corresponding map above, while time is converted to julian days. Dashed line divides the region into the eastern part of Volvi lake and western part of Lagadas lake

At the same time there is a simultaneous seismic excitation (blue color) forming two discrete spatial clusters north of Lagadas lake, as it can be deduced from the corresponding colors of Fig.5.

In 2005 two simultaneous neighbor clusters seem to be developed (Days 1200 to 3200) showing a constant migration of seismicity along two clusters. However there is a time-window where seismicity rate is stronger and it coincides with a seismic burst at the western part. Comparison of these two sub-regions that are distinguished by a pause in seismic activity by a zone that no seismicity leads to the assumption of seismicity localization along the most important seismogenic faults. The same seismic behavior is described in similar cases (Karabulut et al., 2011). There is strong evidence that interaction among fault segments is the prevailing mechanism in Mygdonia area, even related with low magnitude earthquakes. The seismic activity is extended to the southern after 2007. This long term activity seems to be constant in time in the eastern part close to Arnea region.

## CONCLUSIONS

Small earthquakes reveal properties such as the spatial and temporal clustering or migration of events, which can serve as a tool to constrain geometric and kinematic properties at the activated structures (fault segments or fault systems) (Kagan and Jackson, 1991). In our case, the homogeneous process of long term microseismicity taking place in Mygdonia basin in 2000—2013 was relocated in an attempt to unveil properties of the associated fault population. A comparatively uniform value of the velocity ratio, was determined, demonstrating a slightly higher value compared to previous local experiments and is probably attributed to the long period of observations and distant epicentral distances around the study area. The incorporation of the best well-fitted velocity model which influences the arrival of the seismic waves at the seismological stations and the calculation of station time delays individually, showed that there is an important improvement in the location errors. Depths distribution in particular shows its vulnerability and depths have been further reduced compared to the preliminary results and maximum depth has been shifted to greater values (14km), within the accepted thresholds for the specific area in accordance to previous studies. In general, it is evident that low magnitude background seismicity constitutes the seismicity pattern for the study period, with the absence of strong events after 1978 seismic triplet, in the proximity of the two subareas. It is generally noticed that the epicentral area of 1978 earthquake sequence, lacks important seismicity, mainly due to the widespread release of stresses in the area, which hinders the possibility of earthquake occurrence along this fault, since stress recovers as it is stated by Tranos et al. (2003). On the other hand, Arnea region which suffered the last strong earthquake in 1995, a direct consequence of stress increase, as it has been shown in previous research, shows a constant occurrence of minor earthquakes during the eleven years study period, with magnitudes not exceeding magnitudes equal to 4.6. The fault pattern in this area seems more complicated with the existence of numerous small faults. So, one striking observation is that seismicity in Mygdonia is not homogeneous but occurs along seismic bands in space and time, since the space-time plot shows a characteristic migration of small seismic sequence along fault segments.

Our perception about hypocentral distribution was enhanced by the construction of several profiles, perpendicular to the development of the main faults. The seismogenic volume according to the re definition of seismicity epicenters seems to be extending up to 20km where the majority of the strongest events with magnitude greater than 4.0 have occurred. It can be observed that the foci of the earthquakes form seismogenic zones with their dips gradually reducing with depth. Widespread extension in the study area has been measured by different studies, however in every case the fault plane solutions totally agree with the foci distribution and the geometry of the active faults. However, the barrier raised for the clear determination of fault seismogenesis is connected with the fact that the fault network is composed by a synthesis of fault orientations whose strike is aligned with the stress tensor in the region and others that exhibit an NW-SE activation that corresponds to older structures. In Lagadas area it is evident that a large amount of earthquakes are generated along NW-SE sub-basin bounded from "Assiros-Analipsi" and "Lagina" fault zone, with both boundaries seem to be seismogenic. The possible extension of "Sochos" high-angle dipping fault in the north which diminishes to the west seems

to strongly affects the seismicity close to "Assiros" and the foci planes dip with approximately  $70^{\circ}$ - $80^{\circ}$  to the southwest. This fact agrees with what Pavlides and Kilias (1987) affirmed that the structures in the study area are close related to high angle normal faults, is a clue that is evident especially for the south dipping faults. Seismicity concentration in Volvi sub-region behaves in a more uniform way with epicenters more distributed in the southern part of the area, around Arnea while in Volvi lake area seismic excitations are attributed to "Sochos" fault with foci reaching 17km in depth. The southern zones (N.A.FS) are also seismogenic, with lowers dips at depth. Aspects expressed previous research based on limited local network data are now confirmed by a long-term seismicity observation. The spatial distribution of the epicenters and the accurately determined hypocenters illuminate fault geometry, often difficult to distinguish in any other way. In Lagadas area seismicity is adjusted to the coexistence of two characteristic sets of faults that accommodate stress. On the other hand, as far as Volvi area is concerned, it can be deduced that the seismicity pattern is more diffuse and there is a constant migration of seismic activity between different clusters of earthquakes. Strong earthquake interaction under the scope of Coulomb stress changes along thoughtfully mapped faults has also achieved (Tranos et al., 2003) indicating a significant correlation of earthquakes in the case of strong events, from ancient times up to the present.

The complex seismotectonic episodes for the region has been imprinted on the structures of the region and according to paleomagnetic studies (Pavlides et al., 1988; Kissel et al., 1985) indicators show a clockwise rotation of the region and consequently a relative rotation of the active stress field. The deformation zones are schematically shown in Fig.8, where North – South extension dominates at the western part of the region, however at the eastern part NE-SW extension is measured because of the reactivation of the NW-SE faults that have been anti-clockwise rotated. The stress field in Mygdonia graben shows a general N – S extension, exhibiting a spatial variation of the least stress axis orientation from NNW – SSE to NNE – SSW which also agrees with the "S-shaped" basin formation (Vamvakaris et al., 2006; Mountrakis et al., 2006).

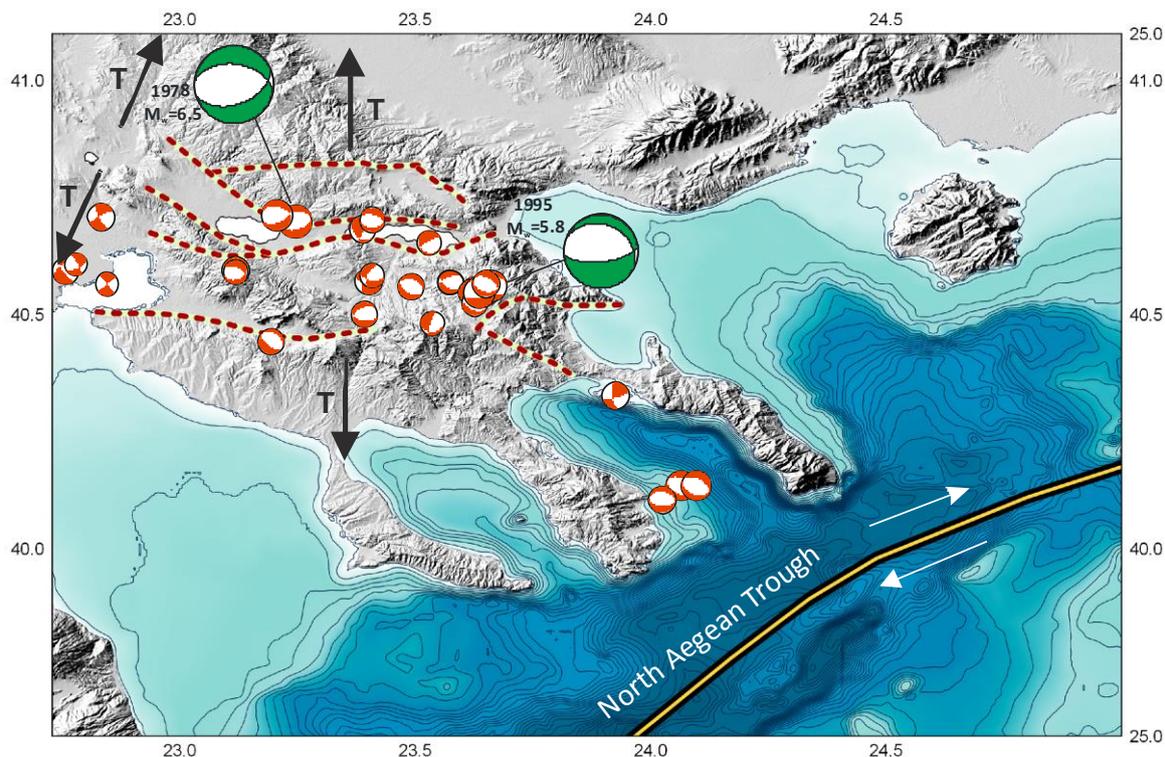


Figure 8) Simplified map which summarises the main active tectonic zones of Mygdonia region in the extensional region of Northern Greece which are under the additional influence of the North Anatolian fault. Fault Plane Solutions of the two strongest recent earthquakes of Thessaloniki and Arnea who verify the orientation of the current stress field. Black arrows correspond to the direction of the extensional axis in the region.

Although, there is a decay of strong seismicity rate during the last years, taking into consideration all available data, behavior of Mygdonia seismicity suggests a successive migration between adjacent segments of the same fault zone. The investigation of background seismicity is underlined since results provide an important contribution to the study of fault interaction, seismotectonic zoning and seismic hazard assessment, in areas where background seismicity is an important process. This approach reveals additional information on the development of the seismogenic structures deprived of clear surface trace, that exist within an active seismotectonic environment such as the seismically active grabens that are met in Greece.

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