MINISTRY OF INFRASTRUCTURES TRANSPORTATION & NETWORKS
EARTHQUAKE PLANNING & PROTECTION ORGANIZATION (EPPO)
RESEARCH UNIT "ITSAK"

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THE AIGIO (C. GREECE) M_W:5.0 EARTHQUAKE OF NOVEMBER 7, 2014

BRIEF INFORMATION ON ACTIVE TECTONICS, SEISMICITY AND ANALYSIS OF THE ACCELERATION RECORDS

THESSALONIKI – GREECE
NOVEMBER 2014

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1. GENERAL INFORMATION

On November 7, 2014 (17:13 GMT) an earthquake occurred in the western part of Corinthiakos Gulf (Central Greece) with magnitude M_W=5.0 (NOA: http://bbnet.gein.noa.gr/mt_solution/2014/141107_17_12_59.37_MTsol.html). According to the information provided by the Hellenic Unified Seismological Network it was a shallow earthquake (centroid depth 6 km) with epicentral coordinates 38.29^{O} N 22.11^{O} E located in the western part of the Corinthiakos Gulf.

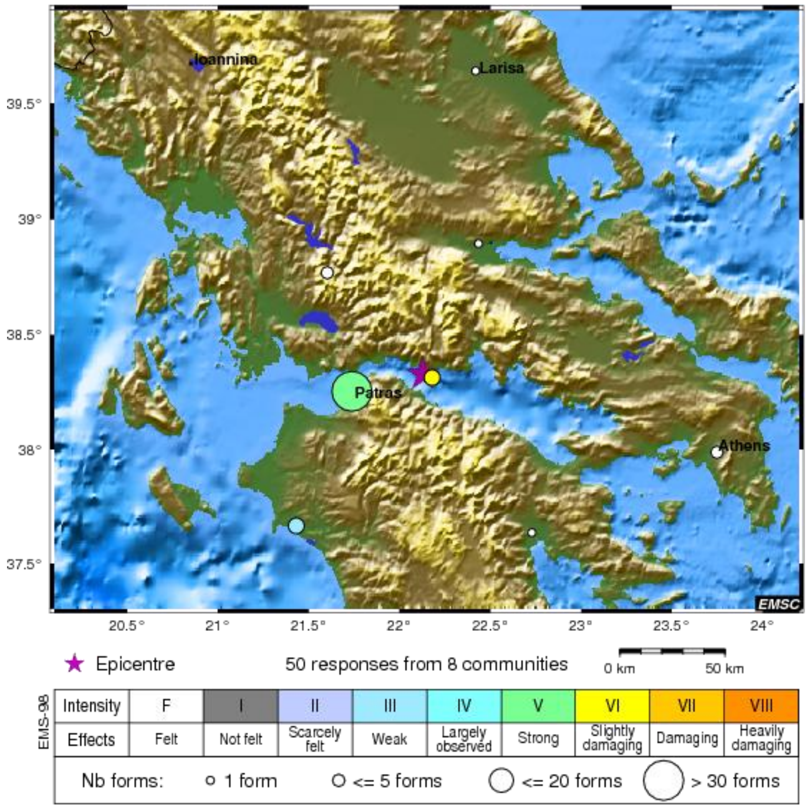

Fig. 1. Geographical distribution of the macroseismic intensities according to the citizens' reports of the earthquake of November 7, 2014 at W Corinthiakos Gulf (source EMSC).

The earthquake was felt at N. Achaia area with macroseismic intensity (I_{EMS}=VI) according to information collected by the Euro-Mediterranean Seismological Center, which was based on citizens' reports following their response. The map in figure (1) (http://www.emsc-csem.org) shows the geographical distribution of the sites and assigned intensities according to the legend. The star represents the earthquake epicenter.

Information from the local office of the Civil Protection authority show that about 30% or the inspected buildings show minor damage. According to press information 90% of damage to structures are related mainly to masonry and not to R/C structural elements, including among the damaged structures are the folkloric museum of Aigion and the main church of the town. Cases are shown in pictures (1) and (2).

Pic. 1. Damage to masonry (www.enikos.gr/society)

Pic. 2. Structure with differential settlement and minor damage http://www.newsbomb.gr/ellada/news/

2. ACTIVE TECTONICS

The region of Corinthiakos Gulf shows high seismicity with the occurrence of disastrous earthquakes during both the historical and instrumental era Papazachos and Papazachou (2003). The last strong earthquake with magnitude M=6.2 occurred on June 15, 1995 at the western part (Tselentis et al. 1996, Bernard et al., 1997).

According to Bernard et al. (2006) the rift of Corinth in Greece has been long identified as a site of major importance for earthquake studies in Europe, producing one of the highest seismic activities in the Euro-Mediterranean region: 5 earthquakes of magnitude greater than 5.8 in the last 35 years, 1 to 1.5 cm/year of north–south extension, frequent seismic swarms, and destructive historical earthquakes (Jackson et al., 1982; Rigo et al., 1996; Clarke et al., 1997; Hatzfeld et al., 2000; Papazachos and Papazachou, 2003;). It appears as an asymmetrical rift, the most active normal faults dipping north, resulting in the long-term subsidence of the northern coast and on the upward displacement of the main footwalls (Armijo et al., 1996). The latter is superimposed on the general uplift of the northern Peloponnesus.

Focused tectonic studies in the area have produced detailed maps of the main presently active faults and assessed their seismic activity through morphological studies, trenching through fault scarps with dating of paleo-earthquakes, and study of uplifted marine terraces (Pantosti et al., 2004). Sakellariou et al. (2003) have mapped offshore faults with high resolution bathymetry carried out by the Hellenic Center of Marine Research.

Palyvos et al. (2008) reported that the Corinth Rift in central Greece is the most rapidly extending area in Europe and the Mediterranean. Fast crustal extension reaches 14–16 mm/yr at the western part of the rift (e.g. Avallone et al., 2004) and is accompanied by highly active normal faulting on land and offshore. Associated seismicity is high, with abundant earthquakes (Mw 6–7) in the historical (Papazachos and Papazachou 1997, 2003; Ambraseys and Jackson, 1997) and instrumental records (Papazachos et al., 2000, 2009).

The map in Figure (2) is a tectonic summary map depicting the major active and non-active faults in the area. A suite of inactive normal faults on the southern gulf margin can be observed. These are associated with abandoned, uplifting and incised synrift basins (Leeder et al., 2008). Topography and onshore and offshore faulting are after Stefatos et al. (2002), McNeill and Collier (2004), Leeder et al. (2005) and Bell et al. (2008).

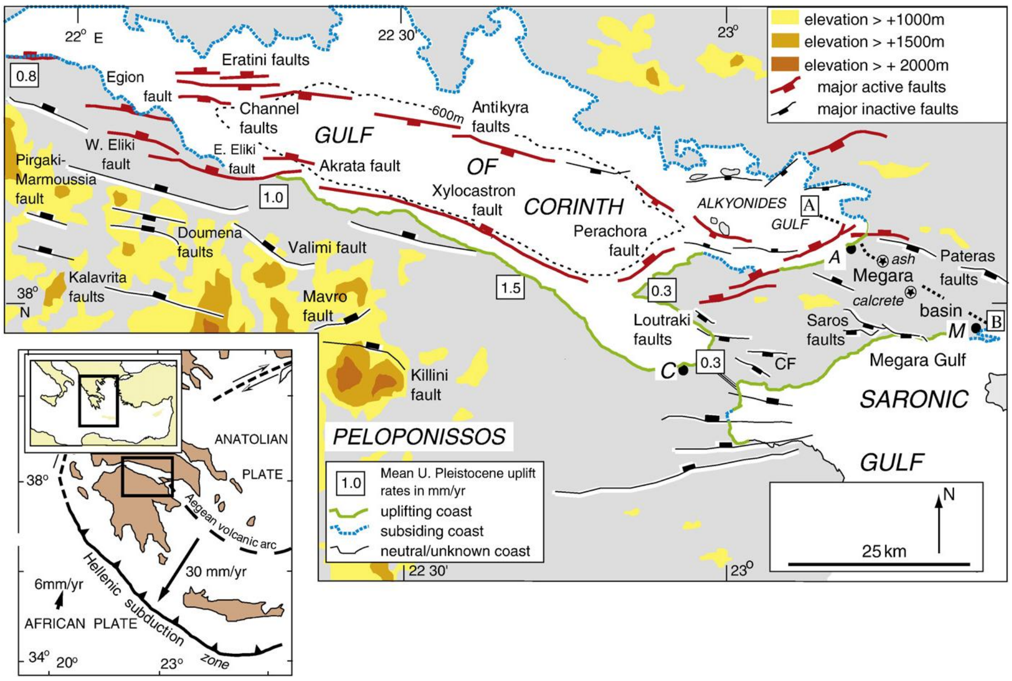

Fig. 2. General location and tectonic summary maps for Gulf of Corinth, Central Greece and (inset) the Aegean context (Leeder et al., 2008).

There are evidences that the recent earthquake is associated with the rupture fault zone of Eliki. Papazachos and Papazachou (2003) associated the known strong (M≥6.0) earthquakes with the faults of Papazachos et al. (2001). Table (I) gives information on the earthquakes associated with this fault located in the western part of the southern coasts of Corinthiakos Gulf.

Table (I). Information on the faults in the southern coast of Corinthiakos gulf, the parameters of the associated earthquakes and the sites with maximum intensity (Papazachos and Papazachou, 2003).

YEAR	LAT.	LONG.	M	SITE WITH MAX. INTENSITY
-373	38.20	22.20	6.8	Eliki (X)

23	38.30	22.10	6.3	Aigio (VIII)
61	38.20	22.00	6.3	Achaia (VIII)
1748	38.20	22.20	6.6	Aigio (IX)
1817	38.30	22.10	6.6	Aigio (IX)
1861	38.25	22.16	6.7	Valimitika (X)
1888	38.23	22.11	6.3	Valimitika (IX)
1965	38.27	22.30	6.3	Eratini (VIII)
1995	38.27	21.15	6.4	Aigio (VIII)

Bernard et al. (2006) suggested that all active normal faults dip at large angles (50° to 60°) and root into an active layer, possibly extending further within it, as the sketch of Figure (3) shows. It is obvious that a separation of the associated earthquakes with every individual fault in a system of parallel faults (as shown in Figure 2) is not possible. Therefore the two faults suggested by Papazachos et al. (2001) in the south-western part of the gulf is better to be considered rather as fault zones than single faults.

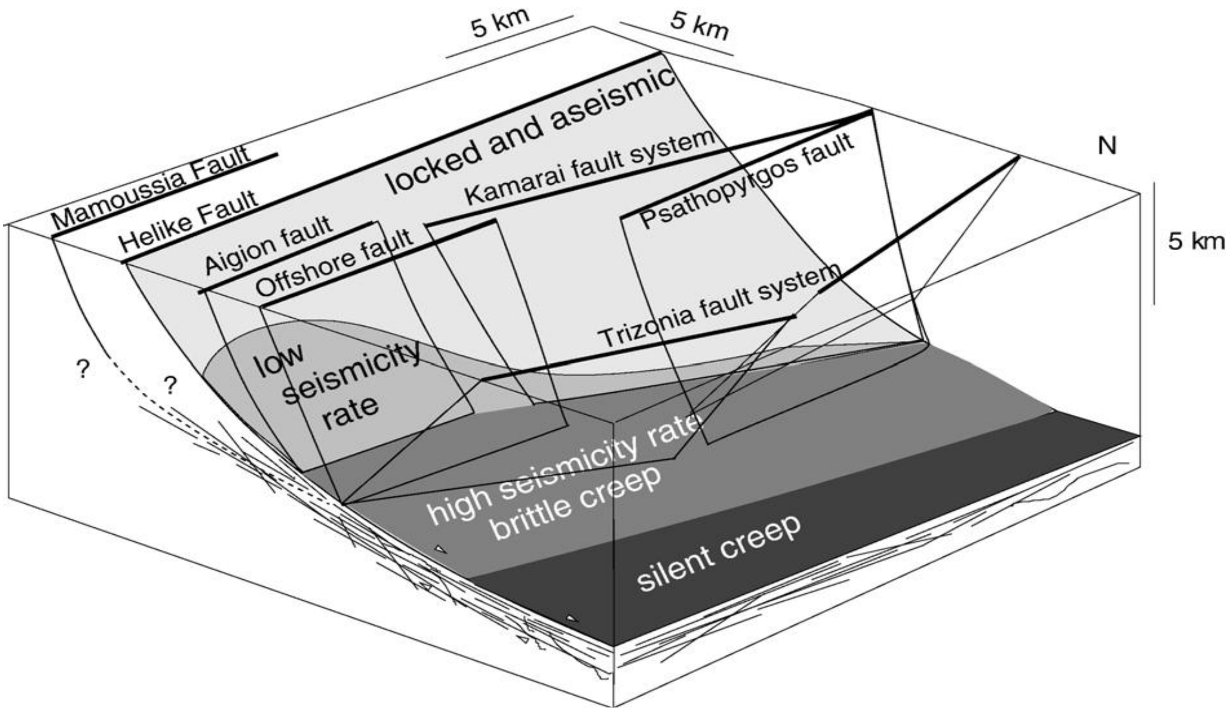

Fig. 3. Sketch of the proposed fault geometry in the western Corinthiakos Gulf (Bernard et al. 2006).

3. SEISMOLOGICAL INFORMATION

The high seismic activity of the Corinthiakos gulf is mostly associated with faulting and high crustal extension as reported above. This activity is expressed by the frequent nucleation of strong earthquakes with magnitudes $6.0 \leq M \leq 7.0$ (Papazachos, 1990; Papazachos and Papazachou, 2003) causing human losses and extensive damage (Papazachos and Papazachou, 1997, 2003).

The map in Figure (4) depicts the faults in the Corinthiakos gulf, the epicenters of the historical earthquakes with 6.0≤M≤7.0 (open circles) and the earthquakes of the instrumental era with 6.0≤M≤7.0 (colored circles) as shown in the legend. The green star marks the location oa the town of Aigio, which is located in the near field of the Eliki ault (Papazachos and Papazachou, 2003).

We must notice that the fault lines shown in the map of Figure (4) are representations of the faults and not a plot of the fault traces. Furthermore, secondary branches of these faults or segments of these faults with almost similar strike, which are named with different names by other researchers, may be considered that they belong to these faults.

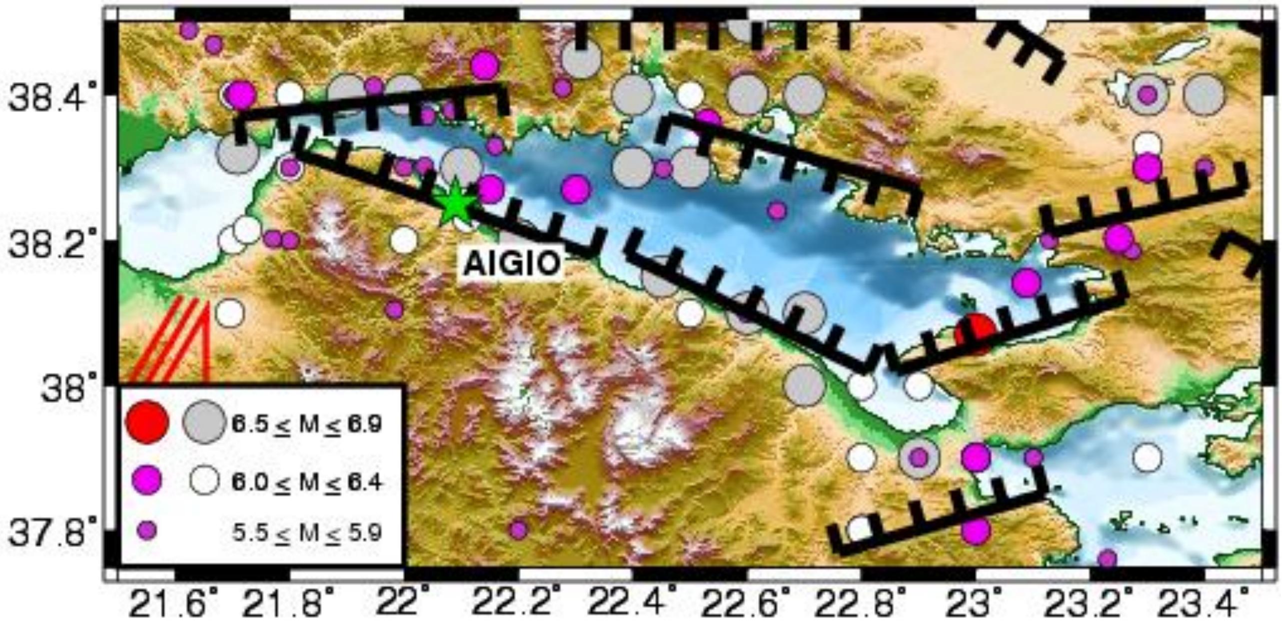

Fig. 4. Epicenters of strong historical (open circles) and instrumental earthquakes (colored circles). The green star shows the location of the town of Aigion.

It is well known that strong earthquakes occur at places where major faults exist. For this reason using the values of the seismicity parameters for the Eliki Fault the mean return period of strong (M≥6.0) earthquakes were calculated and the results are presented in Table (II).

Papazachos and Papaioannou (1993) found that data completeness for earthquakes with M≥6.0 is valid since 1748 and determined the a and b parameters of the GR relation. In order to account for magnitude bound the calculated a and b parameters, determined above were actually used with a modified version of the GR relationship. This modification accounts for the maximum (M_{max}) and minimum (M_{min}) magnitudes of events, that are likely to occur within each seismic source (zone or fault). The modified GR relationship is often called the bounded Gutenberg-Richter recurrence (BGR) relationship and the annual number of earthquakes is given by:

$$N = e^{a-bM_{min}} * \frac{e^{-\beta(M-M_{min})} - e^{-\beta(M_{max}-M_{min})}}{1-e^{-\beta(M_{max}-M_{min})}} \quad (1)$$

where a = a*ln (10) and b = b*ln (10).

If we consider the minimum magnitude for the calculation equal to M_{min}=4.5, the maximum magnitude equal to M_{max}=7.0 (0.2 magnitude units higher in order to consider uncertainty in magnitude assessment of the historical earthquakes) and that T=1/N, then we have that the average return period for magnitudes M=6.0, 6.5 are equal to 114 and 404 years respectively for the Eliki fault. The results for various magnitude classes are shown analytically in Table (II)

Table (II). Mean return period for various magnitude classes of earthquakes in the faults of Eliki (southern coasts of Corinthiakos Gulf) based on equation (1).

M	**ELIKI Fault Tm**
4.5	1.2
5.0	3.3
5.5	9.7
6.0	29.9
6.5	114.1
6.8	404.1
6.9	901.2

The epicenter of the November 7, earthquake was determined within the Gulf of Corinth with a centroid depth 6 km. The parameters for the fault plane solution as it was estimated by the National Observatory of Athens (NOA) is shown in Table (III). In the same table the parameters valid for the typical fault plane solution (FPS) as determined by Papazachos and Papazachou (2003), are also shown. From the comparison one may conclude that the predicted parameters are in good agreement with those of the November 7 earthquake.

Table (III). Fault plane solution of the November 7, 2014 earthquake (after NOA) and parameters for the typical FPS of the Aigion fault (Papazachos and Papazachou (2003).

SOURCE	**FAULT 1**			**FAULT 2**			**Mw**
	STRIKE	**DIP**	**RAKE**	**STRIKE**	**DIP**	**RAKE**	
NOA	248	30	-117	99	64	-75	5.0
TYPICAL FPS	276	31	-79	338	75	178	

The map in figure (5) shows the epicenter of the earthquake of November 7 (red star) and its aftershocks until November 13 (yellow circles) with magnitude M≥2.0. The data source is the home page of the Geodynamic Institute of NOA (http://bbnet.gein.noa.gr/HL/seismicity/

seismicity/last-month). The fault plane solution determined by the same institution is also shown. There is a good agreement of the striking direction of the aftershock zone and the FPS. The grey beach-vball repreents the typical focal mechanism for the Aigion fault as proposed by Papazachos amd Papazachou (1997, 2003). It is clear that the typycal (expected) mechanism and the mechanism of the Npvember 7, 2014 are in excellent agreemt supporting the conclusion that the last event is related to this fault.

On June 15, 1995 an earthquake with magnitude M_W=6.4 occurred in Western Corinthiakos Gulf. The pink star in figure (5) shows its epicenter and the grey circles represent the geographical distribution of the aftershocks with M≥2.5 as determined by Bernard et al. (1997).

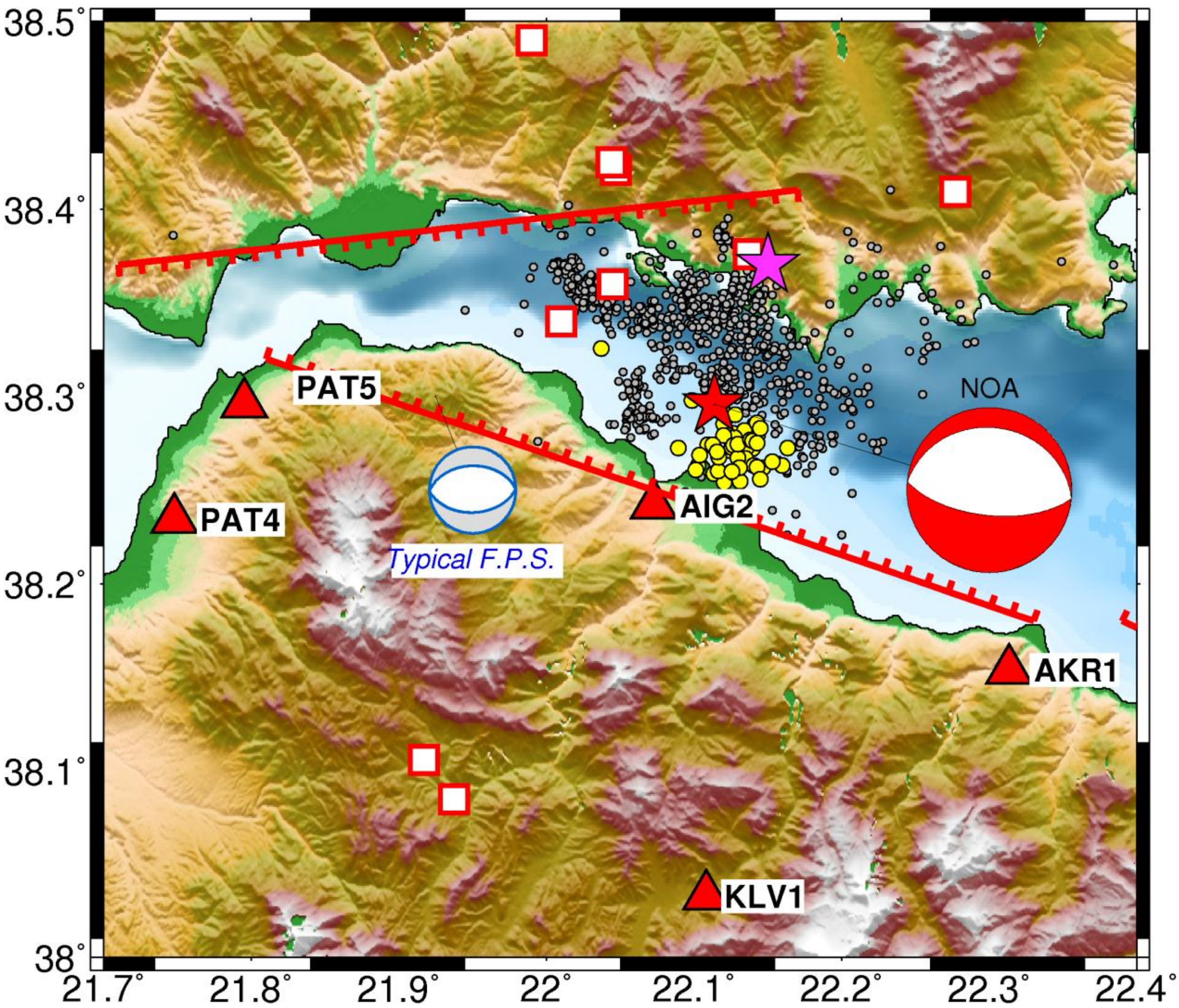

Fig. 5. Map depicting epicenters of the November 7, 2014 main event (red star), its aftershocks until November 13 (yellow circles) and the fault plane solution (data source: NOA). See text for more details.

The white squares denote the epicenters of the earthquakes with magnitude M_W≥5.0 for the period 01.01.1996 – 31.10.2014. It is observed that no earthquake with magnitude M_W≥5.0 occurred in the area until November 7, 2014. If we take into account the sketch diagram of Western Corinthiakos (Bernard et al., 2006) appeared in figure (3) and the geographical distribution of the earthquakes of 1995 and the recent sequence we can observe that that the November 2014 sequence occurred at the shallow zone of low seismicity.

4. GROUND ACCELERATIONS RECORDS

EPPO-**ITSAK** during the last years upgraded its network of accelerographs with the installation in the territory of Greece of a dense network of continuous recording accelerographs. These instruments are of CMG-5TDE of Guralp Systems Ltd (http://www.guralp.com/product-range/5t-accelerometers/) and are equipped with broadband accelerometers, recording unit with 24 bits resolution, GPS timing system and transfer the data in real time at the premises of EPPO-ITSAK in Thessaloniki using the network SYZEFXIS of the public sector of the Hellenic Republic. The red triangles in the map in figure (5) show the geographical distribution of the CMG-5TDE accelerographs in the broader area.

Table (IV) gives information on the peak values of the ground acceleration (cm/sec^2) velocity (cm/sec) and displacement (cm) of the recordings of the CMG-5TD accelerographs shown in figure (5). The recordings were processed and displayed using the software ViewWave© (Kashima, 2005). The acceleration time histories were filtered by band pass 2nd order filter (0.05-40.00 Hz).

TABLE (IV). Results of the analysis of the acceleration records of the September 12, 2012 earthquake off SW Crete Island.

SITE NAME	DISTANCE	ACCELERATION cm/sec^2	VELOCITY cm/sec	DISPLACEMENT Cm
AIGIO (AIG2)	Δ=7 km			
NS-comp		109.7	12.08	1.50
EW-comp		114.7	7.24	0.86
Z-comp		74.5	3.90	0.73
AKRATA (AKR1)	Δ=23 km			
NS-comp		8.7	0.36	0.080
EW-comp		8.8	0.52	0.155
Z-comp		5.6	0.28	0.118
KALAVRYTA (KLV1)	Δ=29 km			
NS-comp		8.3	0.37	0.069
EW-comp		7.8	0.38	0.085
Z-comp		7.9	0.44	0.105
PATRAS 5 (PAT5 - Ag. Andreas Hosp.)	Δ=28 km			
NS-comp		6.5	0.41	0.143
EW-comp		10.2	0.45	0.097
Z-comp		9.1	0.40	0.077

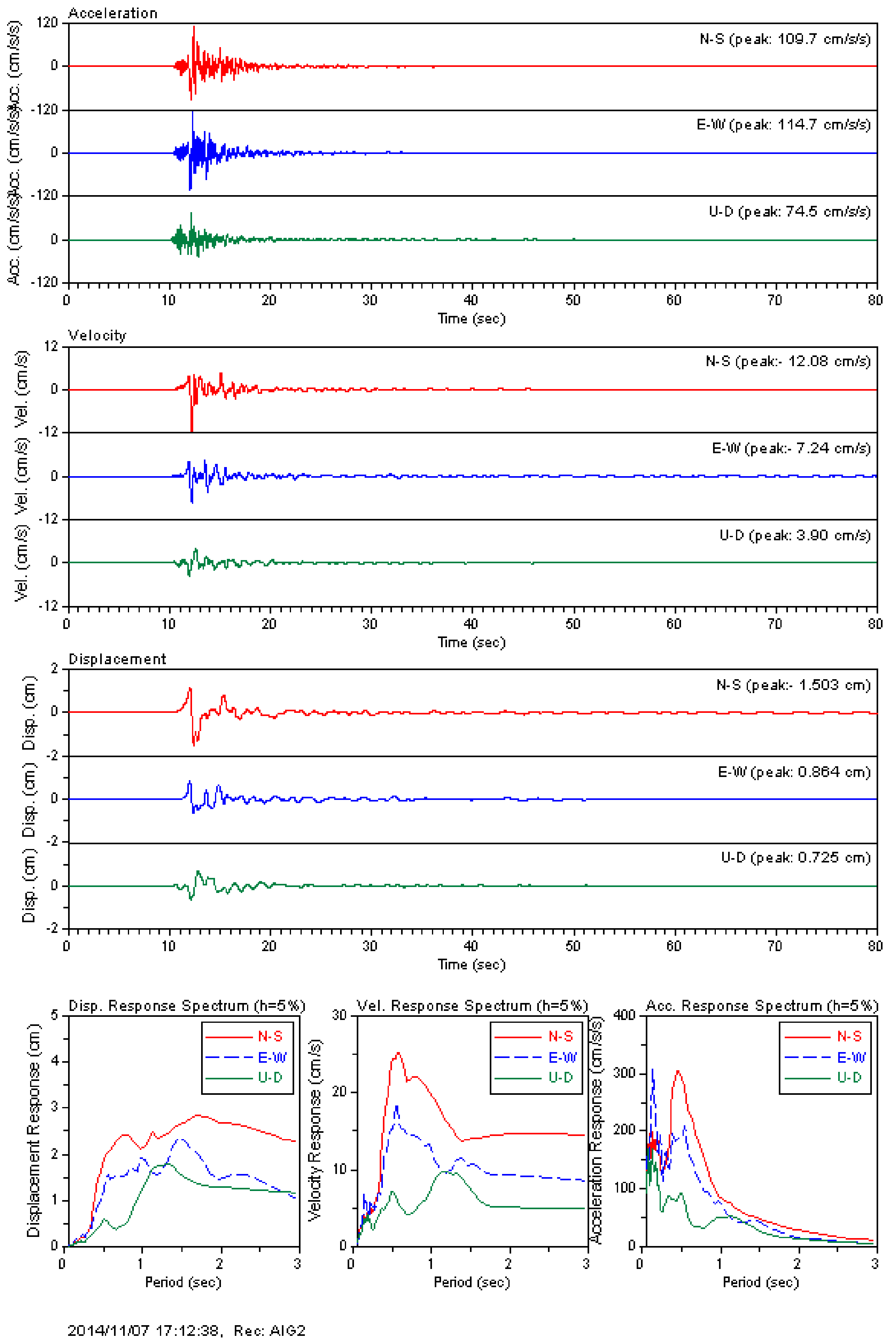

Fig. 6. Analysis of the Aigio (AIG2) record.

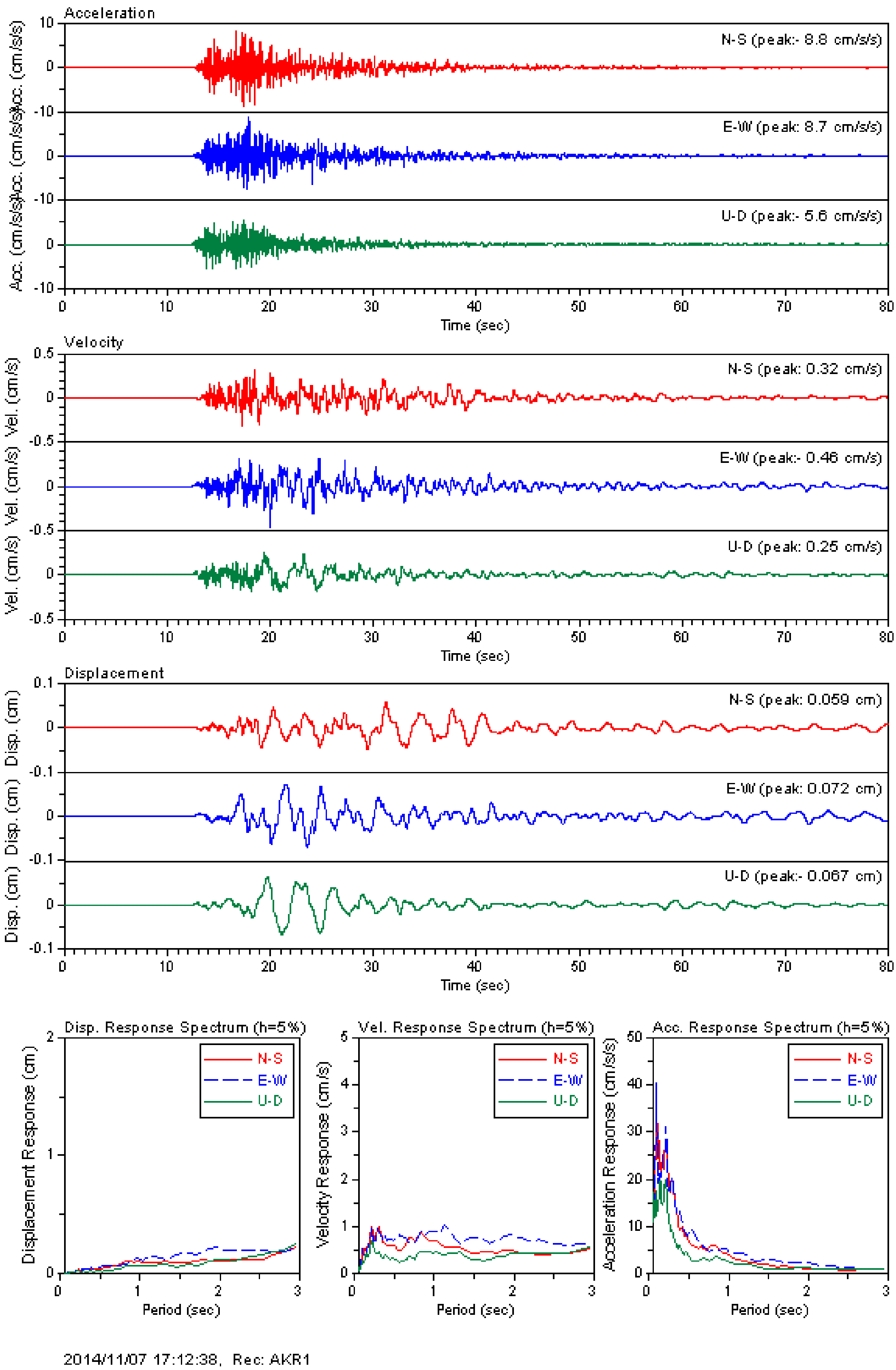

Fig. 7. Analysis of the Akrata (AKR1) record

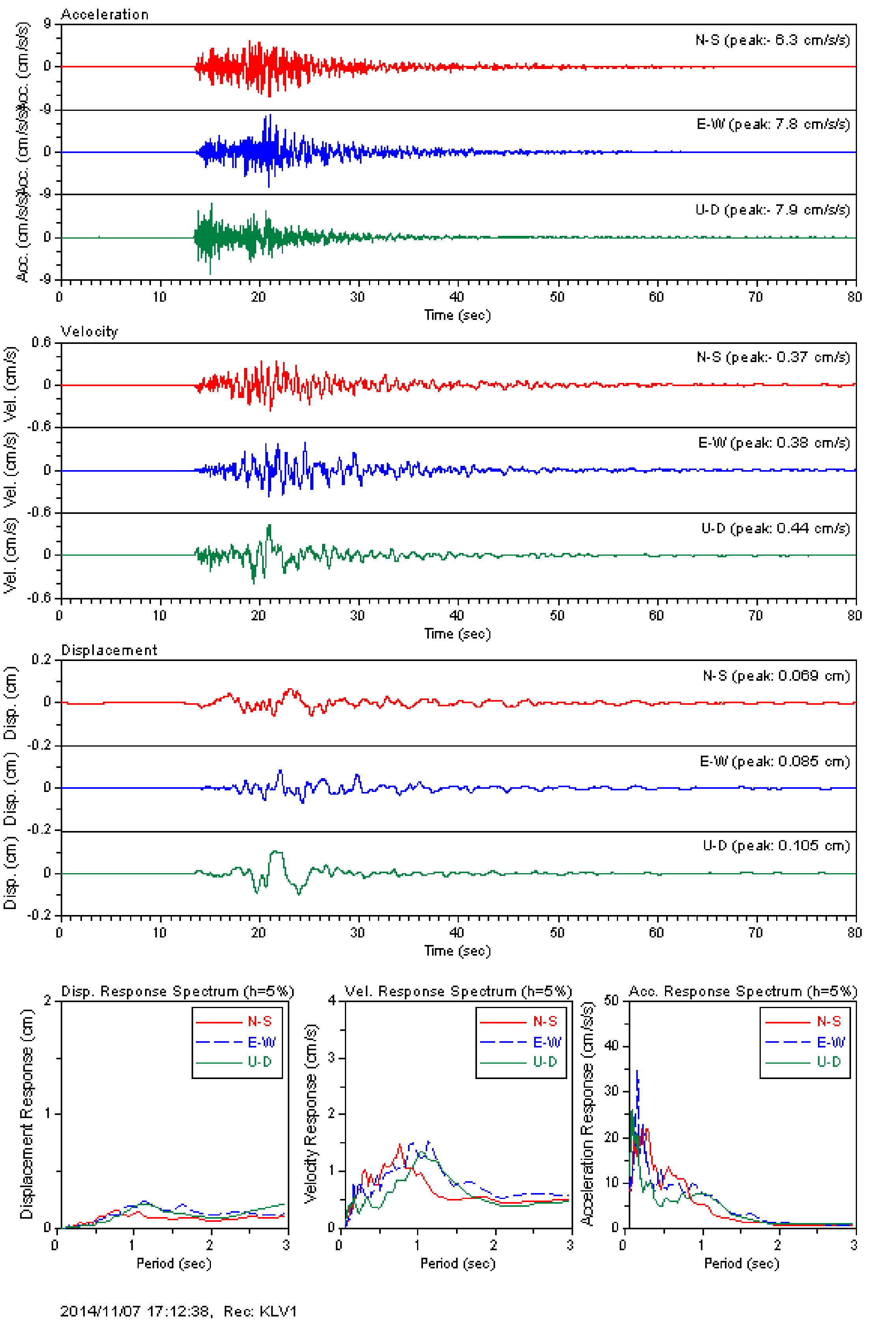

Fig.8. Analysis of the Kalavryta (KLV1) record

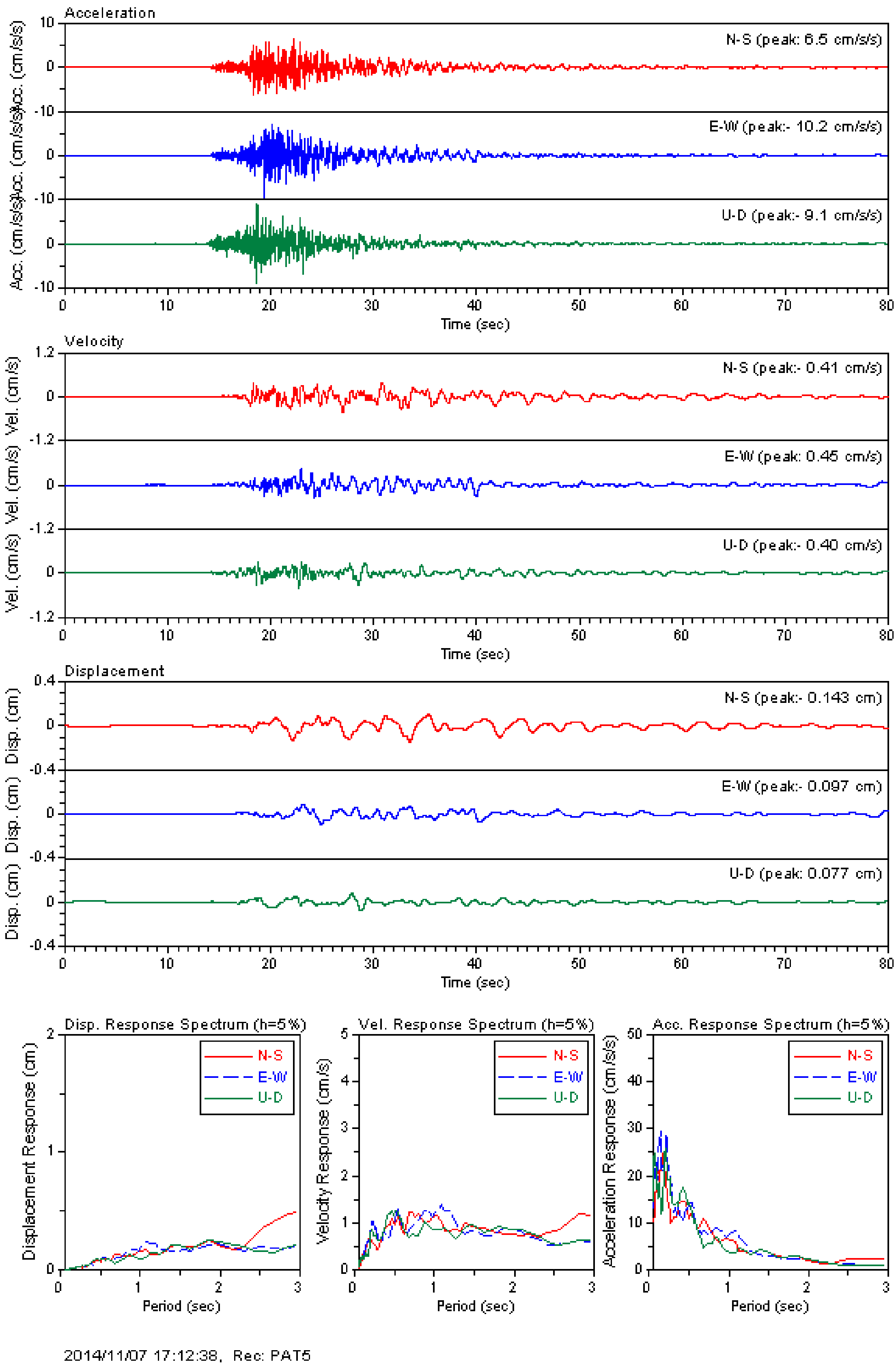

Fig.9. Analysis of the Patras 5 (PAT5) record

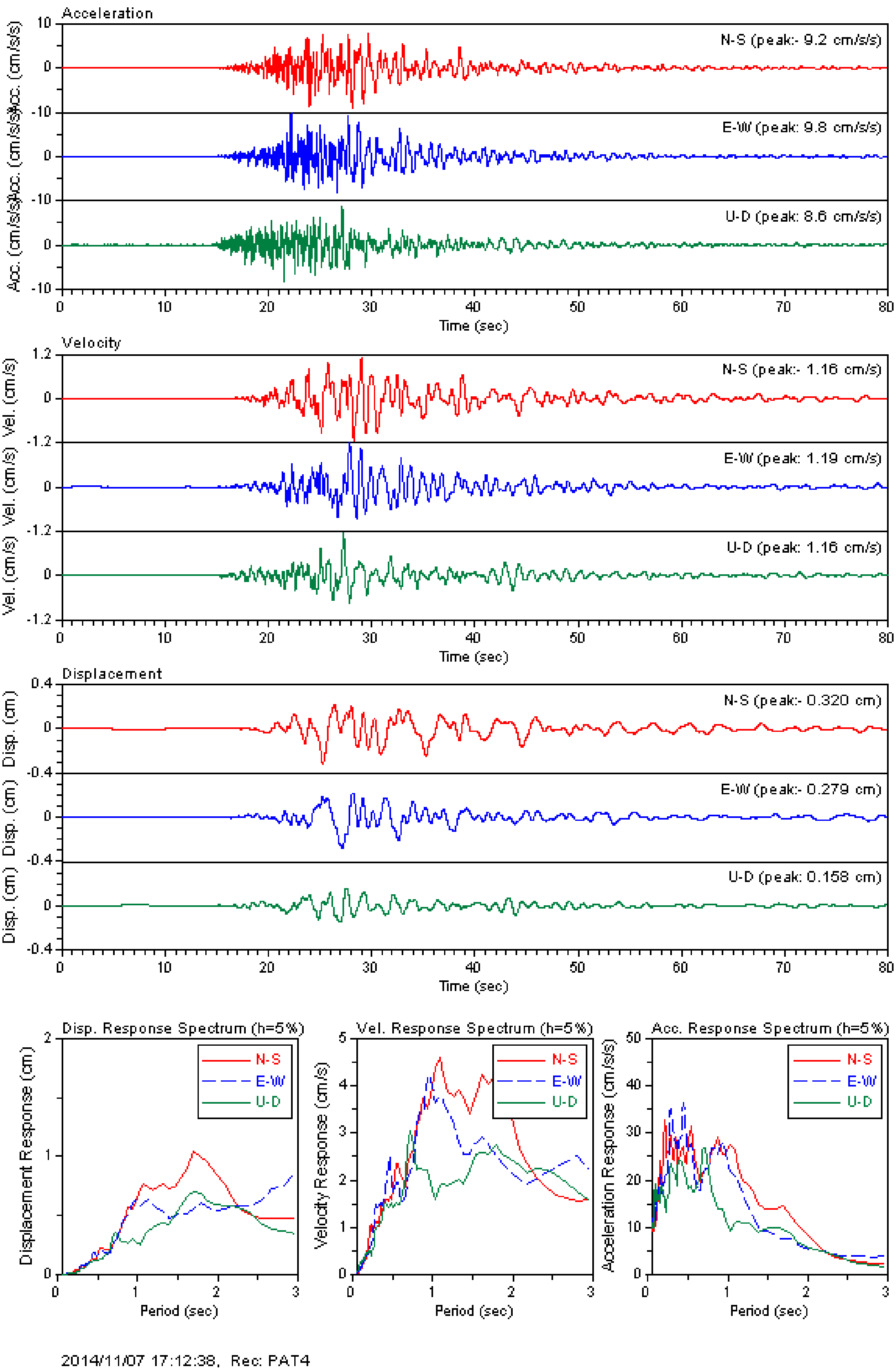

Fig.10. Analysis of the Patras 4 (PAT4) record

(TABLE IV. Cont.)

PATRAS 4 (PAT4 – Rio Hospital)	Δ= 33 km			
NS-comp		9.2	1.18	0.320
EW-comp		9.8	1.19	0.279
Z-comp		8.6	1.16	0.158

The time histories of acceleration, velocity and displacement and their spectra are shown in figures (6), …,(10). Notice the spectral values of the horizontal components especially in the NS direction at about 0.5 sec and the different spectral shape of PAT4 compared to that of PAT5.

5. CONCLUSIONS

On November 7, 2014 a magnitude M_W=5.0 occurred off the northern coasts of Peloponessus close to Aigion. The earthquake was related to a normal faulting rupture which is assassinated to Aigion fault. The focal mechanism is in excellent agreement with the proposed typical focal mechanism for this fault (Papazachos and Papazachou, 2003).

The recorded peak horizontal acceleration at the hospital of Aigion was 12% g. The site is located in the zone II of the greek seismic code with design acceleration 24% g. Minor non-structural damage were observed in the buildings of Aigion.

The results of the present report are preliminary and may subject to revision if more detailed analyses will be carried out.

The uncorrected data of the records in ASCII are available upon request.

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