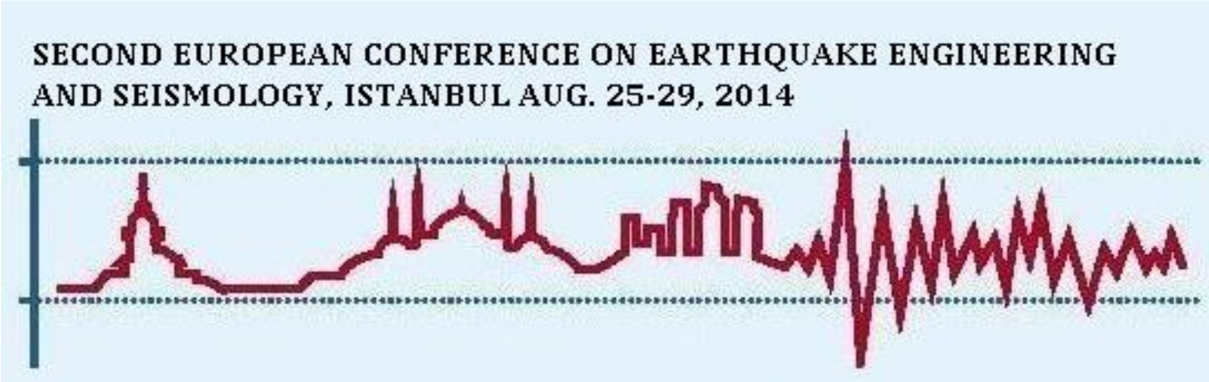

REVISITING THE VARTHOLOMIO (W. PELOPONNESE) DAMAGING EARTHQUAKES SINCE 1909 – A MACROSEISMIC APPROACH

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ABSTRACT

Macroseismic intensity data provide a useful tool for seismic hazard analysis and largely contribute to seismic risk assessment, when vulnerability classification is involved in a detailed manner as in the EMS98 scale. Therefore, relevant information is exploited for the Vartholomio area belonging to the western Peloponnese highly active seismicity zone, between the Ionian Islands and the Gulf of Corinth, and having experienced five damaging earthquakes since the beginning of the 20th century. For these events, a considerable number of macroseismic intensities are available, expressed in various intensity scales (Rossi-Forel, Modified Mercalli, EMS98). These earthquakes are revisited and an effort is made towards harmonization of the intensities expressed in different scales. Furthermore, contemporary newspaper earthquake reports (articles and photographic material) are extensively evaluated and used as additional sources of macroseismic information, in order to re-evaluate in the EMS98 scale and enrich the existing intensity data stock.

INTRODUCTION

Macroseismic intensity reports consist an indisputable measure of the earthquake via its effects used in various studies covering a wide range of seismological applications. For the pre-instrumental era in particular, but even in times when the seismological networks were inadequate to reliably determine focal parameters, the observed macroseismic intensities contribute to assess the epicentre, focal depth and magnitude of given event and/or amount of seismic energy released. It has to be particularly pointed out that macroseismic data are the only information describing earthquake damage of the historical earthquakes, for which no instrumental records exist. In the last decades the importance of macroseismic data knowledge increased substantially due to the development of relevant techniques for reliable evaluations of seismogenic zones in which strong and destructive earthquakes occur and which have to be taken into account in calculations of reasonable earthquake hazard assessments.

Macroseismic data are used to complete the picture of the spatial distribution of seismic intensity for hazard assessment purposes of areas or sites for future construction of national infrastructure (Moldovan et al., 2008). From the observed intensity values distribution and from the individual isoseismal shapes, the focal parameters estimations and intensity attenuation with distance can be determined (e.g. Galanopoulos, 1961; Papaioannou, 1984; Papazachos, 1992, for the area of Greece). Frankel (1994) and Johnston (1996) noted “if a good quality of intensity data is available, the

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moment magnitude and attenuation relationship for an earthquake felt area are comparable to those of instrumental data. For all these reasons, the isoseismal maps still play an important role in many theoretical tasks and engineering applications (Theodulidis and Papazachos, 1992). The problem of drawing relative objective isoseismals is an issue for discussion (Sirovich et al., 2002).

GEOGRAPHY OF THE STUDY AREA

The Vartholomio area is located in the SW part of Greece and reaches, in its southern part, the city of Amaliada, occupying approximately 800 km^2. The seismicity pattern of this region is characterized by a considerable number of moderate earthquakes (M=4.6) and some strong (M=5.7) ones that have occurred from historical times until today.

THE STUDIED EARTHQUAKES

During the 20th century, the study area has experienced five shallow damaging earthquakes of moderate-to-high magnitude (Table.1). The earthquake parameters of the first two events in the early 20th century are based on macroseismic data. The parameters of four events are given by Shebalin et al. (1974a, SHA1974) and Makropoulos et al. (2012, MKK2012). Brief description of damage and felt intensities in Rossi-Forel (RF) scale are quoted in text form in the bulletins of the Geodynamic Institute of the National Observatory of Athens (GI-NOA). For the events after 1950, parameters are based on instrumental data, along with macroseismic intensity lists provided by these bulletins.

Table 1: The five shallow damaging earthquakes of our study

N	Catalogue	Year Mo Da	Hr Min Sec	Lat	Lon	M	Mw	Imax
1	SHA1974	1909 07 15	00 34 7.50	37.90	21.50	5.7		9
1	MKK2012	1909 07 15	00 34 42.0	37.90	21.50	5.7	5.6	
2	SHA1974	1911 01 06	08 30 --	37.90	21.20	4.6		7
3	SHA1974	1954 12 23	16 27 17.6	37.90	21.20	5.5		8
3	MKK2012	1954 12 23	16 27 25.1	37.87	21.19	5.4	5.3	
4	SHA1974	1955 03 28	14 45 45.5	37.70	21.20	5.2		7-8
4	MKK2012	1955 03 28	14 45 52.5	37.60	21.24	5.1	5.1	
5	MKK2012	1988 10 16	12 34 05.8	37.93	20.92	5.7	5.6	

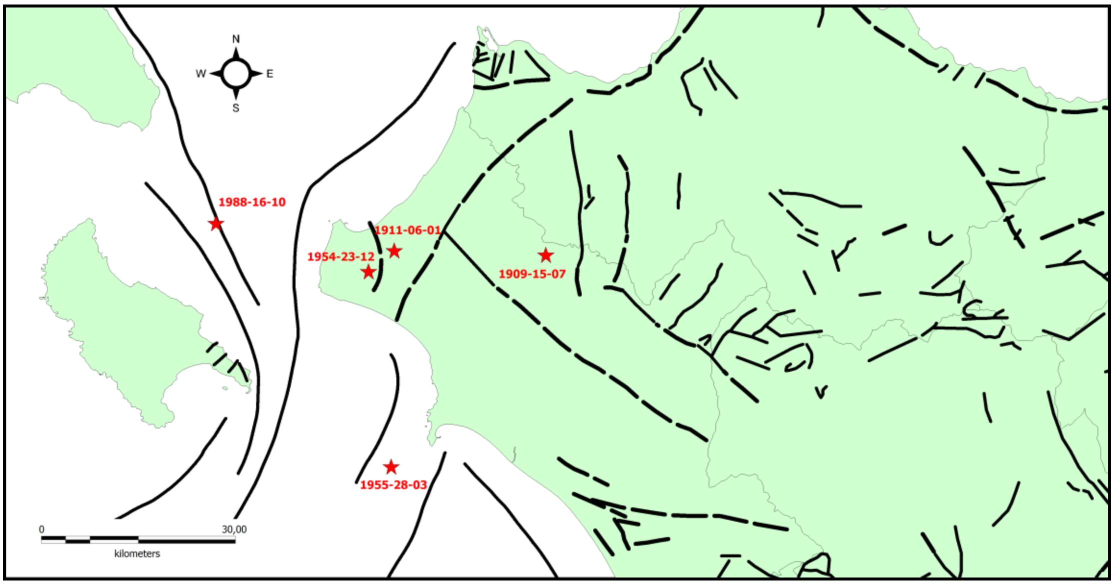

Figure 1: Map depicting the earthquake epicenters and faults of the study area

Several authors presented isoseismal maps for those earthquakes: Shebalin et al. (1974b); Papazachos et al. (1982), Papazachos et al. (1997) and Schenkova et al. (2005), published contour maps or synthetic isoseismals. The intensity distribution in the far-field is well constrained due to the large amount of intensity data points (IDPs). However, in the macroseismic near-field, the isoseismal curves present an irregular pattern, probably due to the small amount of assigned intensities in the beginning of the 20^{th} century, local site effects, regional geology-dependent effects, or complex seismic propagation and low attenuation processes. However, this behavior seems to be common in the earthquakes affecting the entire West Peloponnese area (Misailidis, 2009).

STATE OF THE ART

The National Observatory (GI-NOA) publishes macroseismic information since 1898. Although lists of localities with intensity values and/or intensity maps are provided, the full macroseismic datapoints (geographical coordinates of the localities and corresponding intensities) are not listed. This paper is devoted to provide the full lists of macroseismic datapoints and to review the macroseismic field, in order to understand the attenuation pattern in the study area, which seems to be heavily controlled by the intensity assigned to larger towns, such as Kalamata and Patra. Questions related to the assignment of an intensity level to larger towns (which probably exhibit site effects) and its implications on the overall isoseismal maps compilation are also addressed. In addition, the kriging approach (Schenkova et al., 2007) is adopted in an attempt to draw automatic isoseismal maps for the five studied earthquakes.

Main emphasis is given to the acquisition of a reliable map solution for those earthquakes and, if possible, to the definition of any sophisticated kriging default option, allowing such maps to exploit the majority of observed macroseismic data. For this purpose, a number of kriging option tests on the Greek macroseismic data collected by the GI-NOA from the period 1956 to 2003 were applied. The GI-NOA macroseismic observations generally follow the "questionnaire" procedure using the RF and later the Modified Mercalli (MM) intensity scale. In recent years a macroseismic database was developed aiming to two targets: the semi-automatization of the macroseismic observations collection and the manipulation of information related to macroseismic intensities (Schenkova et al., 2005).

RE-EVALUATION OF THE INTENSITY DATA

The re-evaluation of the macroseismic intensities associated with the earthquakes listed in Table.1, was considered necessary in order to remove some of the inherent uncertainties in the processing, interpretation and assessment of the observational data. To assign the seismic intensities, a re-evaluation of the information contained in the 78 newspaper sheets collected from digital libraries was performed, used for calibration of the intensities published in the GI-NOA monthly bulletins. We estimated the intensities of each locality using the EMS98 macroseismic scale, for a number of reasons: (a) to compare our values with those formerly assigned and published by Papazachos et al. (1982, 1997), Schenkova et al. (2005) etc; (b) to ensure homogeneity with the University of Athens Hellenic Macroseismic Database (HMDB.UoA) (Kouskouna and Sakkas, 2013); and (c) the EMS98 scale is used throughout Europe. In the process of this re-evaluation, our attention was focused on the earthquake effects on buildings, thus providing intensity assessments of a more "objective" nature, keeping in mind that estimates made mainly based on human perception (human reactions and effects on objects) are considered to have a greater degree of subjectivity. Thus, the re-evaluated macroseismic intensities were obtained for 486 sites.

All re-assessments were used to organize a new dataset of intensity data points for each one of the investigated earthquakes. The spatial distribution of the re-evaluated macroseismic intensities is shown in Fig.3,4,6,7,9. Tables 2-6 list the re-evaluated macroseismic intensities of the studied earthquakes, along with the corresponding epicentral distances. Out of all five earthquakes, maximum observed intensity, referring to the 1909 July 15 event, was IX-X (EMS98), for 3 localities: Chavari, Agios Ioannis, Olga.

Throughout this study, it can be seen that the macroseismic field of the Vartholomio area earthquakes is similar to the one associated with earthquakes of the same class of magnitude in the Peloponnese. The asymmetric spatial distribution of the major macroseismic effects that are characteristic to strong subcrustal Ionian earthquakes can be explained by the convolution of the huge energy released in the seismogenic process, with the complex transfer function of the geological structures and of the crustal and subcrustal tectonic systems. An important factor that determines the distribution of macroseismic effects on places affected by earthquakes is the faulting type, as the radiation pattern of seismic energy is asymmetric, with the maximum slip onto the fault plane and the minimum slip onto the nodal plan. There are several observational studies highlighting the close connection between the patterns of macroseismic field and the focal mechanism (e.g. Bakun and Wentworth, 1997).

Another factor that should be taken into account in the evaluation of local macroseismic effects is the topographic factor, the influence of which may often be considerable. In conclusion, the determination of the new, revised macroseismic field of those earthquakes has implied a complex re-analysis and re-interpretation of the information provided by both types of macroseismic information (macroseismic questionnaires and newspapers).

The July 15, 1909, Chavari earthquake

The July 15, 1909 seismic event had a magnitude of 5.7 and occurred at 00:25 GMT (02:25 local time); it is considered as one of the most violent earthquakes to struck Vartholomio area (Fig.1). The epicentral intensity was assigned, after our re-evaluation to IX-X on the EMS98 seismic intensity scale. Seismological studies suggest a multi-shock character of this earthquake, as at least 5 shocks, in 48 hours between the first and the last shock.

This event resulted in human and property loss. The highest damage was concentrated in the eastern part of this area, particularly in urban areas with high population density at the time. This was especially apparent in small towns, such as Chavari, Amaliada, Andravida and Palaiopolis, as well as in many villages; Agios Ioannis, Damiza (today Daphni) and Mpouchioti (today Avgeion), among others. IDPs from neighboring counties and some of the localities affected by this earthquake are given in Table.2. The earthquake caused the loss of 45 people, with 30 reported from Chavari. More than 150 people were found under the collapsed buildings in Chavari, whereas across the entire county, 212 people were injured and 3,000 buildings were severely damaged or destroyed. The majority of the damage was concentrated in Chavari, where more than 1,000 buildings collapsed. The village of Palaeopolis was almost totally destroyed, with 7 people found dead under the ruins. Major damage was reported in the town of Amaliada and in the neighboring areas, a great part of the old building stock was severely damaged, with the collapse of 46 buildings and 8 people injured (newspapers AKROPOLIS 3-7-1909, 7-7-1909, ATHINAI 3-7-1909, 10-7-1909, EMPROS 3-7-1909, 11-7-1909, KAIROI 3-7-1909, 15-7-1909, NEON ASTY 3-7-1909, 7-7-1909, XRONOS 3-7-1909, 9-7-1909).

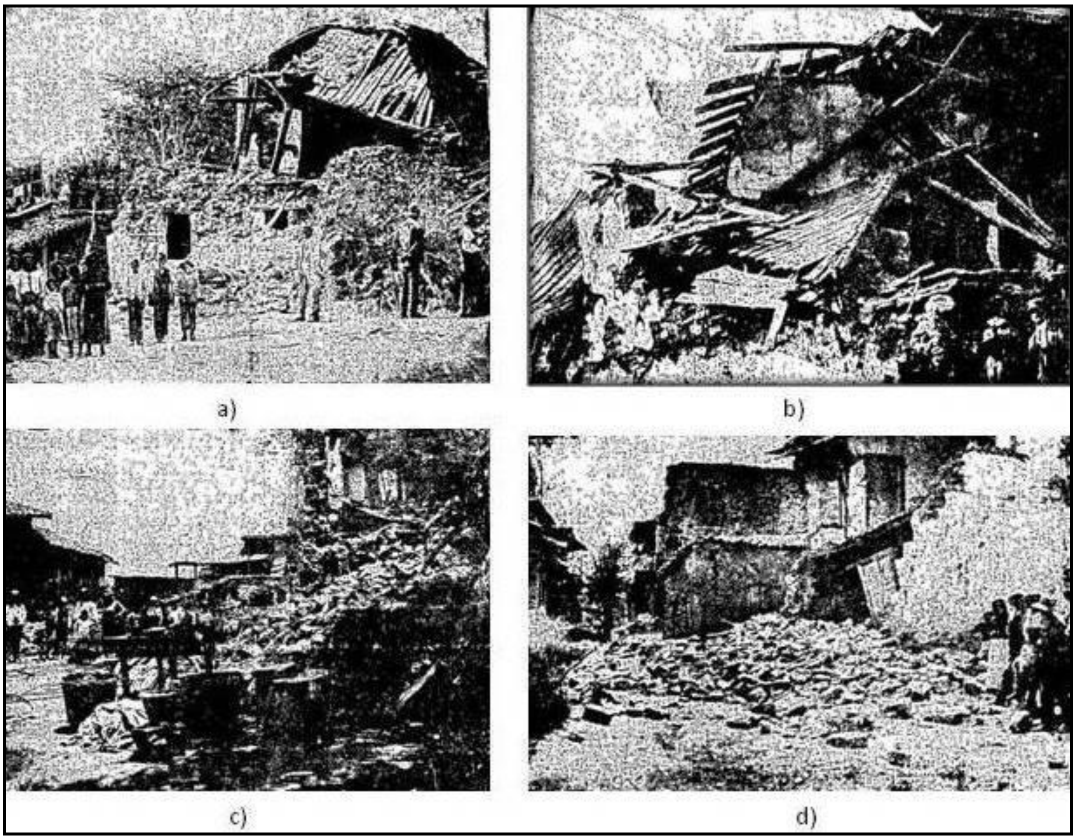

Figure 2: Collapsed builbings in; a), b) Chavari, c) Agios Ioannis, d) Damiza (EMPROS newspaper 7-7-1909) due to the 1909 July 15 earthquake

In Elia area the effects were also significant, with partial or total collapse of some civil buildings and churches. The total cost for the reconstruction estimated at three million drachmas. The event was also felt in Arta and central Greece to the north, up to Nafplion to the east and in Zante to the west. Intensity IV MM was reported from Sparta and to the SW, with minimum effects reaching III-IV MM in the southern part of Messinia (ATHINAI newspaper 5-7-1909).

Table 2: Intensity datapoints of the 1909 July 15 earthquake

1909-15-7					
Places	GI-NOA (MM) 33 IDPs	This Paper (EMS98) 54 IDPs	Places	GI-NOA (MM) 33 IDPs	This Paper (EMS98) 54 IDPs
Chavari	-	9.5	Argostoli	4.0	4.0
Agios Ioannis	-	9.0	Calamate	-	4.0
Ailiades	-	8.5	Calavryta	4.0	4.0
Kalatha	-	8.5	Chalandritsa	4.0	4.0
Kalyvia	-	8.5	Crestaina	fort	4.0
Mouzika	-	8.5	Dimitsana	4.0	4.0
Mpouchioti	-	8.5	Divre	fort	4.0
Palaeopolis	-	8.5	Messene	4.0	4.0
Amaliade	fort	8.0	Missolonghi	fort	4.0
Agrapidochorion	-	7.5	Patras	4.0	4.0
Damiza	-	7.5	Sparte	4.0	4.0
Kolokitha	-	7.5	Strezova	4.0	4.0
Lopesi	-	7.5	Tripolis	-	4.0
Marinaki	-	7.5	Zante	-	4.0
Olga	-	7.5	Astacos	3.0	3.0
Sampanaga	-	7.5	Cyllene	faible	3.0
Sosti	-	7.5	Diavolitsion	3.0	3.0
Mirtian	-	7.0	Arte	F	F
Patali	-	7.0	Contovazaina	F	F
Pyrgos	5.0	7.0	Criecouki	-	-

Sklirou	-	7.0	Daneseiska	-	SGE
Vounagron	-	7.0	Gheorghitsion	F	F
Andravida	-	6.5	Longa	F	F
Traganon	-	6.5	Meligala	F	F
Lechaina	fort	5.0	Nauplie	F	F
Sopoton	5.0	5.0	Philiatra	F	F
Xyrolagkado	-	5.0	Strezova	F	F
Aitolicon	fort	4.0	Valtessinicon	F	F
Andritsaina	4.0	4.0			

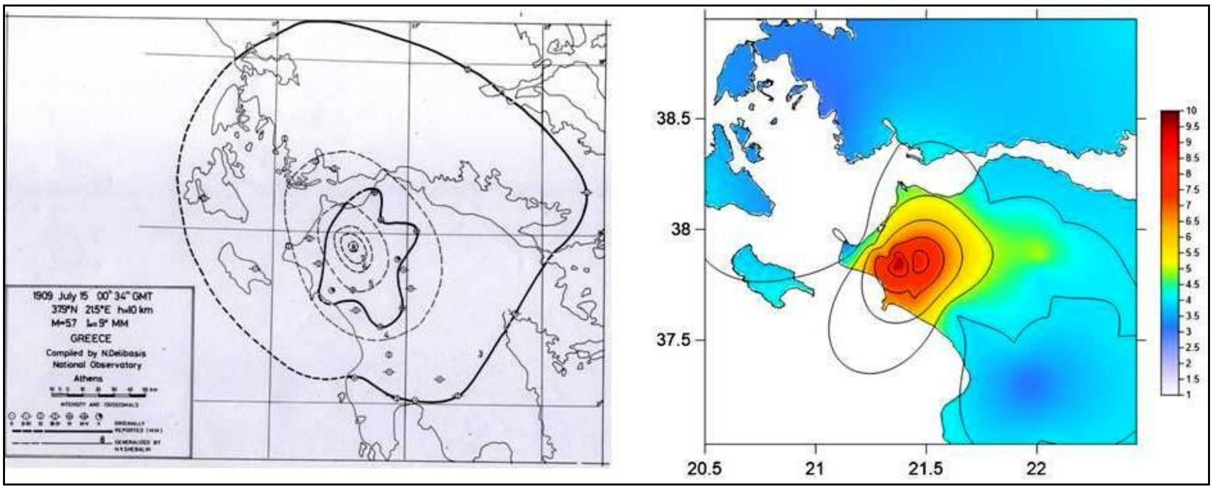

Figure 3: 1909 July 15 earthquake: (Left) SHA1974 isoseismal map, (Right) Re-evaluated macroseismic map

In the isoseismal map of this earthquake (Shebalin et al., 1974b), the maximum intensity in the epicentral area was IX MM; after our re-evaluation, it was concluded that the epicentral intensity reached IX-X EMS98. Moreover, by comparing the two maps (Fig.3), it can be seen that the areas corresponding to intensity VI, VII and VIII EMS98 are more extended than those defined in the first map. In the re-evaluated macroseismic map (Fig.3b), the intensity attenuation is relatively weak in the southwest direction from the epicenter, as it has been observed for some subcrustal earthquakes in this area. Thus, the new IDP map presented in Fig.3b accurately reproduces the two main features of the earthquake: the more extended affected area and the weak southwestern attenuation.

The January 11, 1911, Lechaena earthquake

The 1911 January 11 seismic event had a magnitude of 4.6 and occurred at 08:25 GMT (10:25 local time). The epicentral intensity was assigned, after re-evaluation, at VIII on the EMS98 intensity scale. Newspapers report that the felt aftershocks were at least 120, with 12 hours between the first and the last shock (NEON ASTY newspaper 17-12-1910, Fig.1).

The highest damage was concentrated at the center of Vartholomio area. The majority of damage was reported from Lechaena, Souleimanaga and Vartholomio, where more than 30 buildings collapsed, with a large part of the old ones being severely damaged, and fortunately without death toll, but with many people injured (NEON ASTY newspaper 17-12-1910 and XRONOS 29-12-1909). Isoseismal maps from previous studies are not available for this earthquake and only three IDPs are given in the GI-NOA monthly bulletins. After re-evaluation, we added 11 more IDPs from the newspaper reports (Table.3), which allowed to draw the isoseismal curves for this earthquake (Fig.4).

Table 3: Intensity datapoints of the 1911 January 11 earthquake

1911-06-01					
Place	GI-NOA (MM) 3 IDPs	This paper (EMS98) 14 IDPs	Place	GI-NOA (MM) 3 IDPs	This paper (EMS98) 14 IDPs
Lechaena	-	8.0	Kavvasila	-	4.0
Vartholomion	5.0	7.0	Kapelletou	-	3.5
Souleinamaga	-	7.0	Kourtesi	-	3.5
Gastoune	6.5	6.5	Amaliada	-	3.5
Pyrgos	6.5	6.5	Andravidha	-	3.5
Strousi	-	5.0	Patra	-	3.0
Manolada	-	4.0	Kyllini	-	3.0

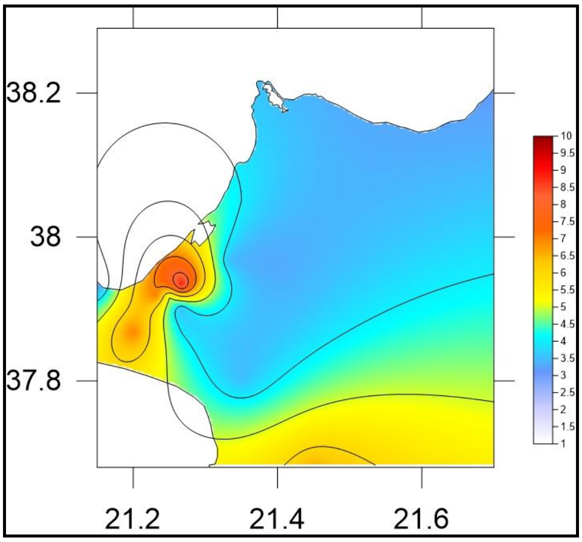

Figure 4: Re-evaluated macroseismic map of 1911 January 11 earthquake

The December 23, 1954, Vartholomio earthquake

The 1911 December 23 seismic event had a magnitude of 5.4 and occurred at 04:27 GMT (06:27 local time). The epicentral intensity was assigned, after re-evaluation, at VIII on the EMS98 seismic intensity scale (Fig.1).

According to the newspaper reports (ELEFTHERIA 28-12-1954), the roads were damaged due to the earthquake; the observers reported that the road paving was cracked. The buildings in Hagia Maura, Kelevi, Neochorion and Vartholomio were generally one floor small housing units and of vulnerability class A (EMS98) which is the most common in the area. Grades of damage that vary from grade 3 (heavy damage) to grade 5 (total damage) were assigned to the building stock (EMS98). In general, many buildings of vulnerability class A suffered damage of grade 5 (total or near total collapse). Also, in many masonry houses (vulnerability class B), gaps in the walls and collapse of parts of the buildings and the inner walls (damage grade 4) was observed (Fig. 5).

Figure 5: Two characteristic photos from the earthquake of December 23, 1954 earthquake. (Left) Collapsed buildings in Agia Maura. (Right) A collapsed medical centre in Vartholomio (ELEFTHERIA newspaper)

In other heavily damaged places, such as Gastouni, the building stock was also greatly affected. Many ordinary brick houses suffered heavy damage or partial collapse. Also, some damage occurred to the roads. Based on these effects, at Vartholomio and Agia Maura intensity of VIII was estimated in EMS98. Another commune that was seriously affected by the earthquake was Chavari (VII-VIII EMS98). Many buildings of vulnerability class A (adobe dwellings) suffered damage grade 4. A few houses of vulnerability class B suffered the same grade of damage (collapse). In Pyrgos, at a distance of 33 km from the epicenter, the earthquake caused serious damage to the houses. These buildings suffered various degrees of damage, from grade 3 to grade 4. At Varvasaena, many chimneys fell down and a few brick houses were partially destroyed. Also, at Kardiakauti, most of the houses were seriously damaged, with a few masonry houses completely destroyed, and many chimneys fell down. We estimated the intensity at both these towns as between VII and VI-VIII EMS98. Most of the churches in all the above mentioned areas were damaged with many of them suffering serious damage, such as heavy damage to the domes and wide cracks in the walls.

After re-evaluation of the earthquake effects, an abnormal distribution of intensities is observed in the shape higher intensities in areas at hundreds of kilometers from the epicenter. For instance, in Aetolikon (Aetoloakarnania) (V-VI EMS98) and Argostolion (Cephalonia) (V-VI EMS98) and also in Zante (V-VI EMS98). These anomalies can be explained by the influence of the local soil conditions (alluvial deposits). This anomalous intensity distribution was also apparent in the Shebalin et. al (1974b) map.

Table 4: Intensity datapoints of the 1911 December 23 earthquake

1954-23-12					
Places	GI-NOA (MM) 48 IDPs	This paper (EMS98) 53 IDPs	Places	GI-NOA (MM) 48 IDPs	This paper (EMS98) 53 IDPs
Hagia Mavra	8.0	8.0	Astakos	5.0	5.0
Kelevi	8.0	8.0	Ithaca	5.0	5.0
Neochorion	8.0	8.0	Kephalonia (REG)	-	5.0
Vartholomio	8.0	8.0	Messologhi	5.0	5.0
Chavari	7.5	7.5	Mytikas	5.0	5.0
Gastouni	7.5	7.5	Naupactos	5.0	5.0
Kardiakauti	-	7.5	Pelopion	5.0	5.0
Kollyrion	7.0	7.0	Asprogherakas	4.5	4.5
Salmoni	7.0	7.0	Leukas	4.5	4.5
Staphidokampos	7.0	7.0	Preveza	4.5	4.5
Varvasaena	7.0	7.0	Volimes	4.5	4.5
Andravida	6.0	6.0	Aeghion	3.0	4.0
Kyllini	6.0	6.0	Araxos	5.0	4.0
Lechaena	6.0	6.0	Corfou	4.0	4.0
Pyrgos	6.0	6.0	Kalamae	4.0	4.0
Aetolikon	5.5	5.5	Kalavryta	4.0	4.0
Amalias	7.0	5.5	Kyparissia	4.0	4.0
Argostolion	5.5	5.5	Olympia	-	4.0
Katakolon	5.5	5.5	Vonitsa	4.0	4.0
Letrinoe	5.5	5.5	Amphissa	3.5	3.5
Ligia	-	5.5	Arta	3.5	3.5
Makrinia (REG)	-	5.5	Hegoumenitsa	3.5	3.5
Patras	5.5	5.5	Andritsaena	3.0	3.0
Thermon	5.5	5.5	Jannina	3.0	3.0
Zante	5.5	5.5	Koroni	3.0	3.0
Agrinion	5.0	5.0	Tripolis	3.0	3.0
Amphilochia	5.0	5.0			

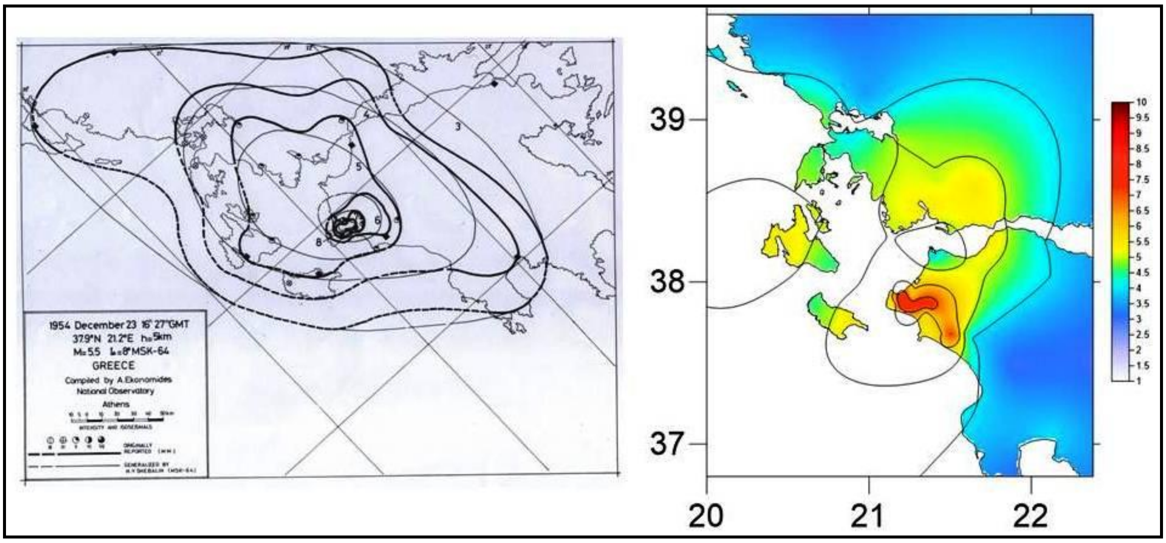

Figure 6: 1911 December 23 earthquake (Left) SHA1974 isoseismal map, (Right) Re-evaluated macroseismic map

The March 26, 1955, Vartholomio Earthquake

The 1955 March 26 seismic event had a magnitude of 5.1 and occurred at 00:46 GMT (02:46 local time). The epicentral intensity was assigned, after re-evaluation, at VII-VIII on the EMS98 seismic intensity scale for 9 places (Fig.1).

Newspapers (ELEFTHERIA 29-3-1955 and KATHIMERINI 29-3-1955) report that a very strong earthquake caused damage in Elia. In the same newspapers it is mentioned that the 15% of the houses in Agia Maura suffered total or near total collapse, 20% in Amalias, 25% in Gastouni and 20% in Keveli. Also, in many masonry houses in Pyrgos gaps were observed in the walls, and collapse of parts of the buildings. The churches of Perachora and Chavari suffered various degrees of damage, from grade 2 to grade 3. In Vartholomio the main church and 3 houses collapsed. The total economic loss was estimated at one million drachmas.

Table 5: Intensity datapoints of the 1955 March 26 earthquake

1955-26-03					
Places	GI-NOA (MM) 49 IDPs	This Paper (EMS98) 53 IDPs	Places	GI-NOA (MM) 49 IDPs	This Paper (EMS98) 53 IDPs
Amalias	7.0	7.5	Ithaca	5.0	5.0
Dounaiika	-	7.5	Kalydona	5.0	5.0
Gastouni	7.5	7.5	Katakolon	5.0	5.0
Hag,Mavra	7.5	7.5	Krestaena	5.0	5.0
Kavasila	7.5	7.5	Patras	5.0	5.0
Keleni	7.5	7.5	Volimes	5.0	5.0
Marathea	-	7.5	Zacharo	5.0	5.0
Roupaki	7.5	7.5	Zante	6.0	5.0
Savalia	7.5	7.5	Aetolikon	4.5	4.5
Vartholomio	7.0	7.5	Gargalianoe	4.5	4.5
Varvasaena	7.0	7.5	Kyparissia	4.5	4.5
Alpochori	7.0	7.0	Lagadia	4.5	4.5
Chavari	7.0	7.0	Messolonghi	4.5	4.5
Kardamas	7.0	7.0	Thermon	4.5	4.5
Kyllini	6.5	7.0	Vrachneika	4.5	4.5
Leukochori	7.0	7.0	Aeghion	4.0	4.0
Neochori	7.0	7.0	Agrinion	4.0	4.0
Paleochori	7.0	7.0	Amphissa	4.0	4.0
Vrochitsa	7.0	7.0	Araxos	4.0	4.0
Andravida	6.5	6.5	Charokopio	4.0	4.0
Lechaena	6.5	6.5	Kalamae	4.0	4.0
Perachora	-	6.5	Kalavryta	4.0	4.0
Pyrgos	6.5	6.5	Leukas	4.0	4.0
Agoulinitsa	6.0	6.0	Pylos	3.5	3.5
Pelopion	5.5	5.5	Tripolis	3.0	3.0

Argostoli	5.0	5.0	Methoni	-	1
Astakos	5.0	5.0			

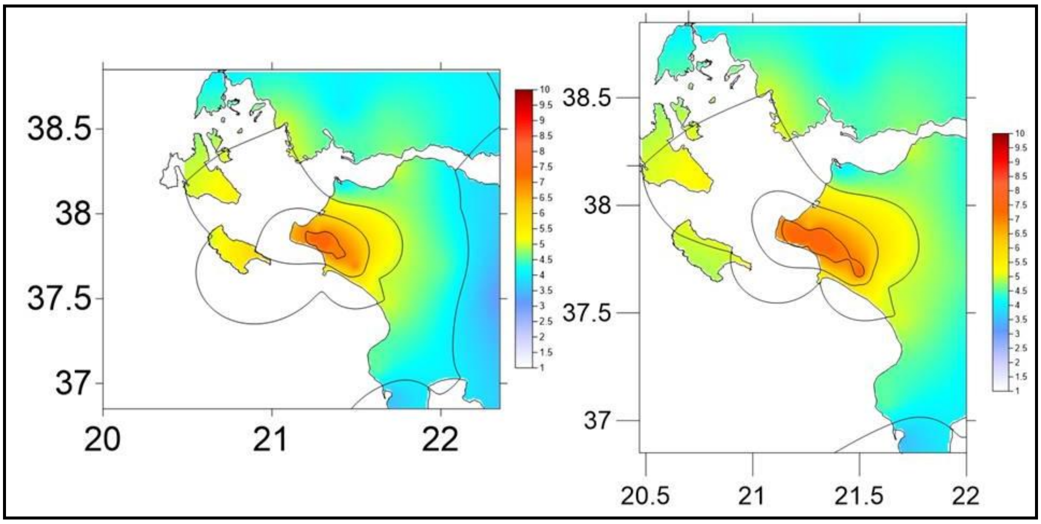

Figure 7: 1955 March 26 earthquake: (Left) Macroseismic map produced by GI-NOA IDPs, (Right) Re-evaluated macroseismic map

The October 16, 1988, Vartholomio Earthquake

The 1988 October 16 seismic event had a magnitude of 5.7 and occurred at 10:34 hours GMT (12:34 local time). The epicentral intensity was assigned, after re-evaluation, at Io VIII on the EMS98 intensity scale (Fig.1).

According to the newspaper KATHIMERINI (17-10-1988) the earthquake caused a collapse and major damage to the buildings in Elia, Achaia, Zakynthos and Aetoloakarnania. Also, the ports of Kyllini and Zante and some civil buildings suffered major damage. More specifically, 2,100 buildings were severely damaged. Particularly in Elia, 60 houses collapsed and 2,000 houses and 10 civil buildings had cracks on the walls.

Figure 8: Photographs after the 1988 October 16 earthquake (KATHIMERINI newspaper)

The majority of damage was concentrated in Vartholomio, Kastro, Neochorion, Machos, Strousio, Lygia, Kyllini, Glyfa, Kato Panagia and Arkoudi, with a total population of 22,000 and 10,000 buildings (newspaper KATHIMERINI 18-10-19). According to the official reports 35% (3,500) had major damage and 25% (2,500) minor damage. The total cost for the reconstruction was estimated at 12billion drachmas.

Many churches in the area were heavily affected, with wide and deep cracks in walls, and/or partial collapse. Some industrial constructions, hospitals and schools in the towns were seriously damaged, as a result of the earthquake. On the basis of the macroseismic data collected after the earthquake, GI-NOA published an isoseismal map, which was revised by Schenkova et al. (2005). This earthquake, before re-evaluation, had 239 IDPs (2 places with intensity VIII, 4 places with intensity VII-VIII and 3 places with intensity VII) and after re-evaluation, it has 300 IDPs (2 places with intensity VIII, 9 places with intensity VII-VIII, 3 places with intensity VII) (Table.6).

Table 6: Intensity datapoints of the 1988 October 16 earthquake

1988-16-10					
Places	GI-NOA (MM) 239 IDPs	This Paper (EMS98) 300 IDPs	Places	GI-NOA (MM) 239 IDPs	This Paper (EMS98) 300 IDPs
Kyllini	8.0	8.0	Manolada	6.5	6.5
Vartholomio	8.0	8.0	Mouzaki	6.5	6.5
Arkoudi	-	7.5	Pantokratoras	6.5	6.5
Glyfa	-	7.5	Savalia	6.5	6.5
Kardiakafti	-	7.5	Vanato	6.5	6.5
Kastro	7.5	7.5	Zante	-	6.5
Kato Panagia	7.5	7.5	Agrinio	-	6.0
Lygia	7.5	7.5	Avgeio	6.0	6.0
Machos	7.5	7.5	Elaionas	6.0	6.0
Neochori	7.5	7.5	Goumera	6.0	6.0
Strousio	-	7.5	Keramidia	6.0	6.0
Agia Mavra	7.0	7.0	Limnochori	6.0	6.0
Gastouni	7.0	7.0	Lousika	6.0	6.0
Tragano	7.0	7.0	Mazaraki	6.0	6.0
Amaliada	6.5	6.5	Oinoi	6.0	6.0
Kalamaki	6.5	6.5	Varda	6.0	6.0
Kardamas	6.5	6.5	Vounargo	6.0	6.0
Lechaina	6.5	6.5			

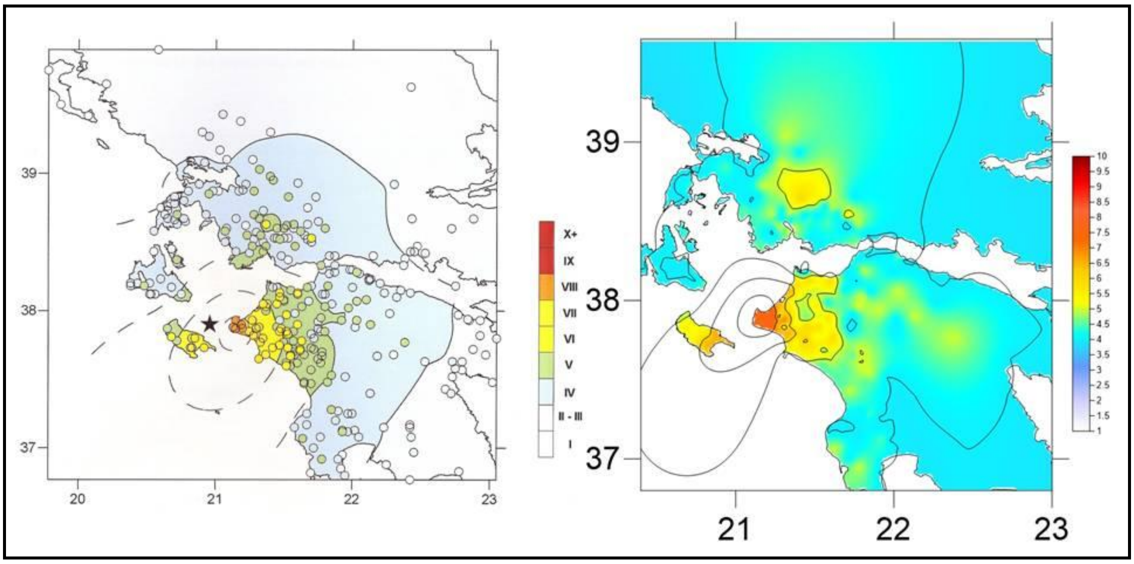

Figure 9: 1988 October 16 earthquake: (Left) Isoseismal curves by Schenkova et al., (Right) Re-evaluated macroseismic map

CONCLUSIONS

Vartholomio area, belonging to the western Peloponnese active seismicity zone, between the Ionian Islands and the Gulf of Corinth, had experienced five damaging earthquakes during the twentieth century, with life and heavy property loss. The strong ground motions caused severe damage, especially in the western part. The directions of the strong shaking were mostly NE-SW.

A review of the macroseismic effects was the objective of this study. After re-evaluation, the new values obtained for the intensities present slight differences from those previously determined. In general, the intensity values obtained in this study are in agreement with the previously published intensities. However, the number of intensity datapoints is considerably higher, thus enabling the drawing of more accurate and detailed isoseismal maps. The analysis of the new maps has also revealed some anomalous distribution of intensity values (varying from 1-2 degrees in intensity) for places close-by, due to the influence of the local conditions identified in the geological maps.

The new macroseismic dataset is fundamental for improving the seismic protection of the buildings and the society against future major earthquakes, where the risk is significant due to the high population density and the high-exposure values.

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