

## Historical seismicity of the Kyparissiakos Gulf, western Peloponnese, Greece

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**ABSTRACT** The historical seismicity of the Kyparissiakos Gulf, western Peloponnese, Greece, is reviewed covering the time period from the 5<sup>th</sup> century B.C. up to A.D. 1910. Previous earthquake catalogues and other studies, little known seismological archives and archaeological reports were taken into account. A parametric historical catalogue of the area was compiled.

**Key words:** historical earthquakes, Kyparissiakos Gulf, Greece, SEHELLARC.

### 1. Introduction

The region of the western Peloponnese is characterized by very high seismicity with respect to many other areas of Greece. This is due to that it marks the African-Eurasian plate convergence in the western segment of the Hellenic Arc. The seismicity of the region, which is documented by the record of both instrumental and historical earthquakes, has been of particular interest for the seismic hazard assessment in the area of Pylos town, which was the test-site for the EC-FP6 SEHELLARC (SEismic and tsunami risk Assessment and mitigation scenarios in the western HELLENic ARC) project (see Papoulia *et al.*, 2014).

A preliminary seismic hazard study for the area of Pylos and the surrounding region of south-western Peloponnese was published by Slejko *et al.* (2010). The earthquake catalogue used in that study was derived from three data files: 1) the historical and early instrumental Greek earthquake catalogue, which covers the period from 550 B.C. to A.D. 1963; 2) the modern Greek instrumental earthquake catalogue, which covers the period from 1964 to 2006; 3) the recent earthquake locations from 2007 to 2010 inclusive. As regards the data sets for the time period from 1911 up to 2010, they were compiled from the earthquake catalogues of the Institute of Geodynamics, National Observatory of Athens (NOA) for the time period 1964 - 2010 and of the Geophysical Laboratory of the University of Thessaloniki for the time period 1911 - 1963. These catalogues are accessible at <http://www.gein.noa.gr/el/seismikotita/katalogoi-seismwn> and <http://geophysics.geo.auth.gr/ss/>, respectively. The historical earthquake catalogue before 1911 was compiled on the basis of the catalogue presented by Papazachos and Papazachou (1997) modified according to the publications of Papadopoulos *et al.* (2000); Papadopoulos and Plessa (2001); Papadopoulos and Vassilopoulou (2001). However, for the special needs of the seismic hazard assessment in Pylos, a further investigation of historical earthquakes was carried out by us.

In this paper we present the results of the historical seismicity investigation which included not only earthquake events that occurred in the western Peloponnese and were used in the hazard assessment study by SEHELLARC Working Group (2010) but also events which were reviewed after the publication of that study. From this point of view our results are of interest which goes beyond the research groups that worked for the SEHELLARC project. Translations of Greek texts to English were prepared by us unless otherwise specified.

## 2. Historical seismicity revisited

Catalogues of the Greek historical seismicity containing information about earthquakes occurring in western Peloponnese include among others Mallet (1853, 1855); Schmidt (1879); Georgiades (1904); Sieberg (1932); Galanopoulos (1961, 1981); Shebalin *et al.* (1974); Papazachos and Papazachou (1989, 1997, 2003); Guidoboni *et al.* (1994); Spyropoulos (1997); Ambraseys and Finkel (1999); Guidoboni and Comastri (2005); Ambraseys (2009). In addition, studies focusing closer in the area of interest were published by Galanopoulos (1950). A systematic effort for updating and revising the earthquake catalogue of the Hellenic Arc and trench, including the area of study, can be found in the publications by Papadopoulos and Plessa (2001); Papadopoulos and Vassilopoulou (2001); Papadopoulos (2011).

In this section we reexamined the historical seismicity in western Peloponnese from the antiquity up to 1910. Among others we examined little known earthquake events and reassessed earthquake parameters. A summary list of the earthquakes examined is contained in Table 1. Our investigation was based on published catalogues and other earthquake studies, on archaeological reports as well as on little known diaries and earthquake archives, the most important being the systematic and reliable archive organized in NOA for the time period from 1893 to 1915 inclusive [Anonymous (1893-1901, 1902-1915): see more explanations in Papadopoulos *et al.* (2000)].

The experience from modern Greek seismicity is that the instrumental earthquake epicentre as a rule is placed very close to the area where the maximum seismic intensity is felt. This is valid particularly for shallow earthquakes of no large magnitude, which is the majority of cases examined in this paper. Therefore, this rule was adopted for the earthquake epicentre determination unless it is specified otherwise. Earthquake magnitudes were determined by applying two groups of empirical relationships between surface-wave magnitude,  $M_s$ , and seismic intensity,  $I$ , developed by Papadopoulos (2011) from a data set of the Greek instrumental seismicity for the time period 1911 - 2005. The first group includes 4 linear relationships between  $M_s$  and  $I_{max}$  while the second group includes 18 linear relationships between  $M_s$  and  $\log A_i$ ;  $A_i$  is the surface of perceptibility area of intensity degree  $i$ . For both groups relationships for inland, coastal, offshore and all earthquakes were developed. Inland earthquakes had epicentral distance,  $\Delta$ , more than 20 km inland from the closest sea-shore, while coastal earthquakes had  $\Delta$  up to 20 km either inland or offshore from the closest sea-shore.

In this paper, the general rule for magnitude calculation is to use one relationship from the first group and at least one from the second group provided that intensity data are available. Intensities are estimated according to the MM (Modified Mercalli) scale. Intensity information can be found in the relevant publications cited separately for each one of the earthquakes

Table 1 - Parametric historical earthquake catalogue for the area of the Kyparissiakos Gulf. Key: n. = code number, Mo = month, D = day, H = hour, m = minute, s = second,  $\varphi_N$  = geographic latitude (in degrees and minutes),  $\lambda_E$  = geographic longitude (in degrees and minutes),  $h$  = focal depth, n = shallow earthquake, ni = interplate earthquake, i = intermediate-depth earthquake,  $I_m$  = maximum intensity in MM scale,  $M$  = magnitude equivalent to  $M_s$ , R = reliability of the earthquake event in a 4-grade scale with 1 representing very uncertain event and 4 representing absolutely certain event,  $nI$  = number of intensity points available in the respective references (see text).

n.	Year	Mo	D	H	m	s	$\varphi_N$	$\lambda_E$	$h$	$I_m$ , Site	$M$	R	$nI$
1	400 BC						37 36	21 36	n	$\geq$ VI Olympia	6	3	1
2	2 <sup>nd</sup> c.BC								n	Olympia		3	
3	6 <sup>th</sup> c. AD								n	Filiatra		3	
4	1428	5								Methoni, Koroni	3		
5	1642	5	30				36 42	22 00	n	Koroni		4	1
6	1684	9								Kalamata		3	
7	1736									Koroni		3	
8	1752	12	25						n	Skafidia, Elis		3	
9	1796	8								VI-VII Pylos		3	
10	1805	4	18	19	30		37 03	22 30	n	Kalamata		3	1
11	1834	01	01							Olympia		3	
12	1838	11	18							Kalamata		3	
13	1841	12	31							Pyrgos		3	
14	1842	4	18	09	40		37 06	22 12	n	IX Messini	6.3 0.2	4	8
15	1846	6	10	02	00		37 12	22 00	n	IX Mikromani	6.2 0.3	4	27
16	1875	4	24				37 18	21 42	n	VII-VIII Kyparissia	6.0 0.1	4	1
17	1885	3	28	18	23		37 09	21 54	n	VIII-IX Messini	6.0 0.2	4	8
18	1886	8	27	21	32		37 06	21 42	ni	IX-X Filiatra	6.8 0.3	4	126
19	1887	3	5	22			37 12	21 42	n	V-VI Kalamata	5.5 0.1	3	2
20	1894	7	26				37 42	21 42	n	VI-VII Douka, Elis	5.7 0.2	3	1
21	1896	12	28	23	30				n	VII Jannitsa	5.5 0.2	4	4
22	1898	11	9	18	15		37 18	21 42	n	VII Kyparissia	5.6 0.2	4	9
23	1899	1	22	7	50		37 12	21 42	n	IX Kyparissia	6.1 0.2	4	25
24	1903	8	11	4	32	54	36 12	23 24	i	IX-X Mitata Kythira	6.6 0.2	4	262
25	1909	3	8	15	55		37 42	21 12	n	VII Katakolo	5.5 0.3	4	6
26	1909	7	15	0	28		37 54	21 30	n	VIII-IX Chavari	6.0 0.2	4	10
27	1910	12	27	3	54	30	37 54	21 12	n	VII-VIII Lechaina	5.7 0.2	4	2

examined. The earthquakes of 1875, 1887, 1894, 1899 and of July 15, 1909 were taken as examples and their magnitude calculation is analysed in next lines after the descriptions of these earthquakes. For a few events, however, earthquake magnitude or epicentral coordinates were adopted from other authors. The three empirical formulas applied here are the next:

$$M = (4.12471 \pm 0.25587) + (0.24996 \pm 0.0328) I_{max}, \text{ coastal} \quad (1)$$

$$M = (3.36678 \pm 0.50747) + (0.3345 \pm 0.05995) I_{max}, \text{ inland} \quad (2)$$

$$M = (3.79929 \pm 0.24227) + (0.63188 \pm 0.06547) (\log A_v), \text{ coastal} \quad (3)$$

where  $M$  is surface-wave magnitude,  $I_{max}$  = maximum seismic intensity,  $A_v$  = surface of the area (in km<sup>2</sup>) covered by the isoseismal of degree  $V$ .

All the event dates are those of, and have been corrected to (unless otherwise noted), the current Gregorian or New Style (NS) calendar. If Julian calendar is used then it is referred to as Old Style (OS) calendar. No intervention has been made in the documentary sources reproduced. Where needed we just inserted our comments within brackets. For instance, the word [earthquake] has been inserted by us, while the word (earthquake) is as it stands in the original document. Orientation maps can be found in Figs. 1 and 2, while earthquake epicentral locations are plotted in Fig. 3.

### 2.1. 400 B.C., Alfios River, Elis, NW Peloponnese

According to Xenophon's Hellenics (3.2.23 - 24 and 4.7.4), this was an earthquake which occurred while king Agis of Sparta invaded against the Elis province in north-western Peloponnese. Centuries later the same information was repeated by Pausanias (8.3 - 4) [translations from Greek can be found in Guidoboni *et al.* (1994)]. Although it remains unclear if damage was caused, we considered that very likely this earthquake was strongly felt, for that caused king Agis to retreat his army. Therefore, a maximum intensity of at least VI was assigned for the epicentral area between Olympia and Alfios River. Intensity of VIII was assigned by Papazachos and Papazachou (1989) but later those authors avoided to assign intensity (Papazachos and Papazachou, 1997, 2003). The event date is not precisely known but estimates range between 403 and 399 BC. Very likely it occurred one or two years before the death of Agis, that is in 399 B.C. Schmidt (1867) confused this earthquake with the 426 B.C. one in the north Evoikos Gulf, central Greece. We adopted surface-wave magnitude  $M_s = 6.0$  from Papazachos and Papazachou (2003).

### 2.2. 2<sup>nd</sup> century B.C., Olympia, Elis, NW Peloponnese

Repaired damage observed in four of the statues of the temple of Zeus at Olympia, customarily known as the Ersatzfiguren, has been assigned by competent critics to every conceivable century, from the fifth to the first century B.C. but some authors preferred the first century after a hypothetical earthquake at about 36 B.C. [see review in Dinsmoor (1941)]. In a further examination of fallen columns, of the chryselephantine statue as well as of the reconstruction of both the east and west façades of the temple, Dinsmoor (1941) showed that the repairs were of far more drastic character than has yet been imagined. According to Dinsmoor (1941), the repairs of the statue were caused, not by mere deterioration of the ivory, but by an earthquake, while an obvious cause



Fig. 1 - Orientation map for Peloponnese and the surrounding areas. Key: AT = Athens, DE = Delphi, EL = Elis, HE = Heraklion, KE = Kerkyra (Corfu), KG = Kyparissiakos Gulf, KY = Kythira, LE = Lefkas, ME = Messolonghi, MG = Messiniakos Gulf, MY = Mytilene, IO = Ioannina, RE = Rethymnon, SM = Smyrna, ST = Strofades, ZA = Zakynthos.

of the temple rebuilding was a disastrous earthquake which left the columns standing, though with their drums jutting outwards and inwards. With the support of a collection of historical accounts and inscription information, Dinsmoor (1941) concluded that the repairs of the architecture and the Ersatzfiguren, may now likewise be dated between 169 and 165 B.C., which is the *ante quem terminus* for the earthquake that caused the damage. The year 332 B.C., when the Zanes statues VII - XII at Olympia were erected, certainly marks the *post quem terminus* for the earthquake. According to Nassopoulos (2003), Elida, suffered a lot by wars from 39 to 31 B.C. and, on the other hand, Herodes the great of Judea (~73 B.C. - 4 B.C.) as well as Agrippa (63 B.C. - 12 B.C.), general of Octavian, benefited Elis and particularly Olympia with generous donations since at that time it had suffered a lot from earthquakes.

Earthquake source close to Olympia was tentatively adopted but no intensity and magnitude assignment was made due to the limited information available.

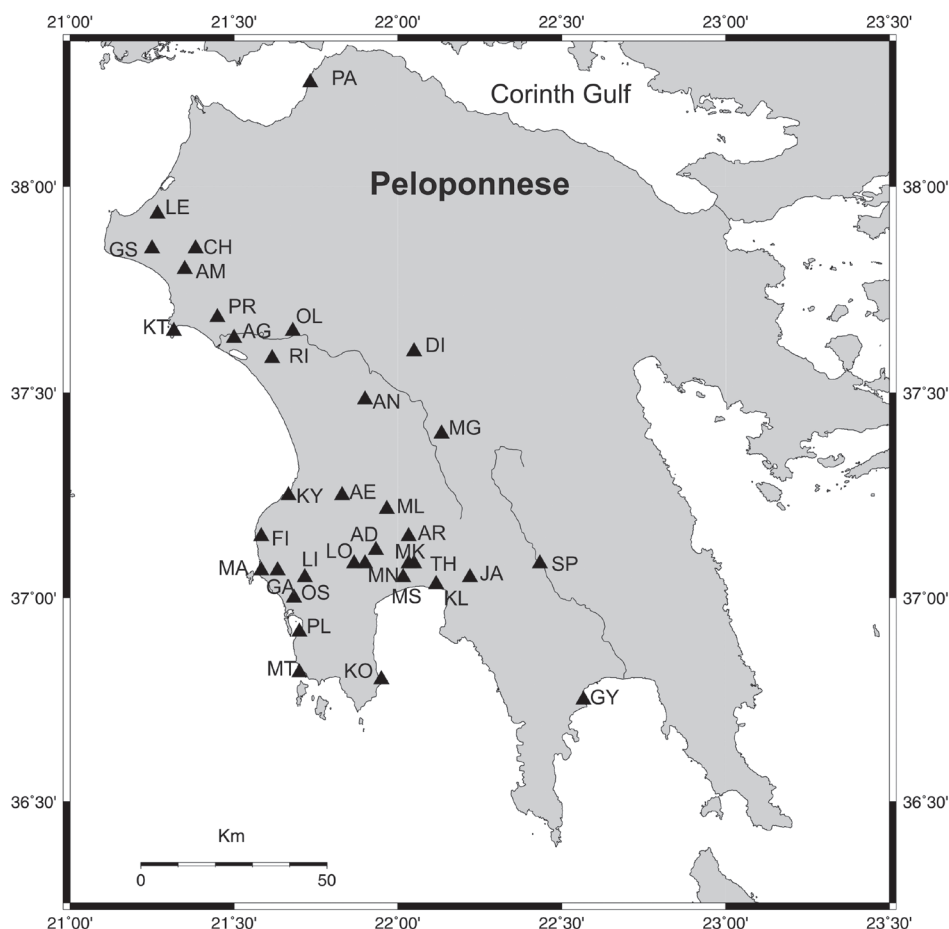


Fig. 2 - Orientation map for localities affected by earthquakes examined. Key: AD = Androussa, AE = Aetos, AG = Agoulinitsa, AM = Amaliada, AN = Andritsaena, AR = Arfara, CH = Chavari, DI = Dimitsana, FI = Filiatra, GA = Gargaliani, GS = Gastouni, GY = Gythio, JA = Jannitsa, KL = Kalamata, KO = Koroni, KT = Katakolo, KY = Kyparissia, LE = Lechaina, LI = Ligudista, LO = Loi, MA = Marathoupolis, MG = Megalopolis, MK = Mikromani, ML = Meligalas, MN = Manesi, MS = Messini, MT = Methoni, OL = Olympia, OS = Osmanaga, PA = Patras, PL = Pylos, PR = Pyrgos, RI = Risovon, SP = Sparta, TH = Thouria.

### 2.3. 6<sup>th</sup> century A.D., Filiatra, Messinia, SW Peloponnese

According to Davis (2005), two earthquakes occurring in 522 and 551 contributed, among other factors, to the drastic decrease of the population of Pylos town. From archaeological excavation it was supposed that a basilica build up during the first half of the 6<sup>th</sup> century in St. Kyriaki, in the coast near Filiatra, very likely was destroyed by the 551 earthquake (Pallas, 1960). However, this interpretation does not fit documentary sources which indicate that both earthquakes of 522 and 551 destroyed settlements around Corinth Gulf [see review in the historiographical work by Evagelatou-Notara (1987 - 1988)]. It appears, therefore, unrealistic that those earthquakes were capable to cause destruction in Pylos or in Filiatra that is at estimated epicentral distances on the order of 200 km. Therefore, we may consider that an unidentified local earthquake occurring in western Peloponnese during the first half of 6<sup>th</sup> century was responsible for the basilica destruction.

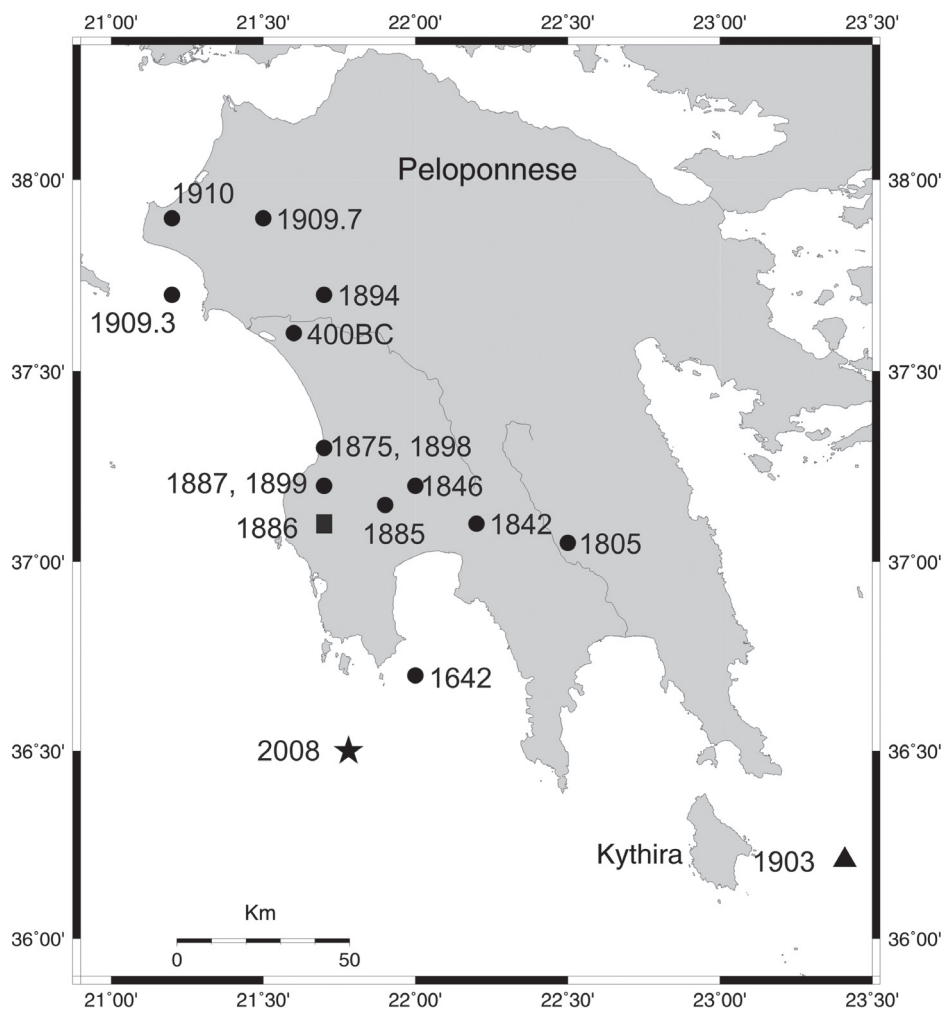


Fig. 3 - Epicentral locations and years of occurrence of earthquakes listed in Table 1. Key: solid circle = shallow earthquake, solid square = interplate earthquake, solid triangle = intermediate-depth earthquake, solid star = epicentre of the large ( $M_w = 6.9$ ) earthquake of February 14, 2008 mentioned in the text.

#### 2.4. 1428 May, Koroni, Messinia, SW Peloponnese

A destructive earthquake occurring in Methoni and Koroni, SW Peloponnese, on an unspecified day of May 1428 was described in the Venetian manuscript *cronaca* (Guidoboni and Comastri, 2005). This earthquake is not known from other sources.

#### 2.5. Earthquakes occurring from 1642 to 1805 in SW Peloponnese

From Ottoman sources we learn that Koroni was again damaged by strong earthquakes on May 30, 1642 as well as some time before June 1736, while Kalamata suffered from another earthquake before September 26, 1684 (Ambraseys and Finkel, 1999; Ambraseys, 2009). In the codex IX, p. 227, 427.1752 of Skafidia monastery, situated to the west of Pyrgos, it is written that “On Monday 11 December 1752 [O.S.] an earthquake happened and another one on the

*next Sunday at dawn*” (Lampros, 1910; Maravelakis, 1939) but Lampros (1910) corrected the date to December 14, which turns December 25, 1752 (NS). One may not rule out that these were moderate earthquakes coming from the Zakynthos source activated since summer 1752. Ottoman documents revealed that Navarino, modern Pylos, was damaged by an earthquake on August 1796 (Ambraseys, 2009). Some years later Kalamata experienced a slight earthquake on April 18, 1805 (Leake, 1835). Due to the little information which is available for these events no magnitudes were calculated, thus being unreliable the magnitude 6.8 assigned to the earthquake of 1642 by Papazachos and Papazachou (2003).

#### 2.6. Earthquakes occurring from 1834 to 1841

Strong earthquakes were experienced in Olympia and Kalamata on January 1, 1834 and on November 18, respectively (Ambraseys, 2009). According to Mallet (1855) a strong earthquake was felt in Pyrgos on December 30, 1840 which very possibly was the one dated on December 31, 1841 by Ambraseys (2009).

#### 2.7. 1842 April 18, Mani, SW Peloponnese

Foreshocks were felt in Kalamata and other places of Greece on April 6 and 7, 1842 (Mallet, 1855). This was the commencement of strong seismic sequence which culminated some days later. In fact, on April 18 at 09.40 the mainshock occurred which was strongly felt in Zakynthos, in Patras with duration 2.5 minutes and in Athens where it was less violent but lasted 2.25 minutes. In the province of Messinian Mani, however, “*some of the inhabitants were crushed beneath the ruins*” (Mallet, 1855). According to the newspaper of Athens “*Ellinikos Paratiritis*” (April 30, 1842), in the town of Messini many houses collapsed to ruins. A strong aftershock shook violently SW Peloponnese on the afternoon of the same day. In the town of Kalamata and in the small village of Androussa, situated to the NW of Kalamata, some damage in houses and churches was caused. In Patras little damage was noted given that the shock was less violent than that of the morning and lasted 2.7 minutes. The shocks were felt in Mt. Taygetos and in Sparta. Aftershocks felt in Kalamata and Patras were reported on April 19 and 25, July 12 and September 12. The one of April 19 was damaging in Kalamata (Ambraseys, 2009).

The very long duration of the shocks at Patras and Athens indicates long distance effect. The shallow earthquake source should be placed at the eastern side of the Messiniakos Gulf (Fig. 1), that is close to the meizoseismal area of Mani, but not far away from Kalamata and Androussa where it also caused some damage. Maximum intensity of IX was assigned at Mani, which is compatible with the intensity ranging from VIII to X assigned by other authors (Galanopoulos, 1960, 1981; Kárník, 1971; Shebalin *et al.*, 1974; Papazachos and Comninakis, 1982; Papazachos and Papazachou, 1989, 1997, 2003). We calculated magnitude  $M_s = 6.3 (\pm 0.2)$ .

#### 2.8. 1846 June 10, Mikromani, SW Peloponnese

After some foreshocks felt in Messinia province from June 6 to 10, 1846 (Schmidt, 1879), the mainshock occurred at 04:00 local time on June 10 (Stamatopoulos, 1997). From press reports compiled by Galanopoulos (1941, 1950) we deduce that this earthquake caused heavy damage to many villages of Messinia but mainly in Mikromani. The death toll reported was 30 in total. Schmidt (1879) reported that ground cracks and soil liquefaction were observed in the meizoseismal area and that a seaquake was felt onboard a ship. Galanopoulos (1950) placed the



epicentre very close to the village of Mikromani which is also adopted by us. The earthquake was felt as far as Zakynthos, Patras, Mytilini and Smyrna (Schmidt, 1879; Galanopoulos, 1950). From an unpublished earthquake archive of Crete, Papadopoulos (2011) showed that the earthquake was felt in that island as well and calculated magnitude of  $M_s = 6.2 (\pm 0.3)$ , which is adopted in this paper.

### 2.9. 1875 April 24, evening, Kyparissia, SW Peloponnese

This was a strong earthquake that occurred evening of Saturday, eve of the Orthodox Easter, causing damage in the town of Kyparissia. According to Schmidt (1879), the church of Anastaseos collapsed, 45 persons killed and another 35 injured. The massive cause of human victims is explained by that apparently the church was full of people gathered together to celebrate Easter. Apart from Kyparissia no other places were reported to have been affected by the earthquake. Then, the epicentre should be placed very close to Kyparissia. Kárník (1971) and Galanopoulos (1981) suggested magnitude 5.5 and 5.75, respectively. Then, magnitude of about 5.6 appears realistic. However, from Eq. (1) we calculated 5.9 and 6.1 for intensity VII and VIII, respectively. Then,  $M_s = 6.0 (\pm 0.1)$  was adopted.

### 2.10. 1885 March 28, Messinia

A strong earthquake shook Messinia and particularly the towns of Messini, Loi and Manesi on March 28, 1885 (Galanopoulos, 1940, 1953). In Messini three people were killed due to building collapse. In Kalamata extensive damage was reported. Shaking was felt as far as Athens, Messolonghi, Zakynthos and Gythio. Magnitude of  $M_s = 6.0 (\pm 0.2)$  was calculated.

### 2.11. 1886 August 27, Filiatra, SW Peloponnese

This was a large, destructive earthquake which ruptured the area of SW Peloponnese. The main source of information has been the detailed report of Marshall (1887), German consul in Patras. Additional information can be found in the reports published by Vidal (1886), Ornstein (1887) and Forster (1890) as well as in a long number of press reports. Based on those sources, Galanopoulos (1941, 1950) was able to summarize the main effects of the earthquake as follows. The towns of Filiatra, Ligudista and Koroni as well as 123 villages were destroyed. Another three towns, namely Kyparissia, Gargaliani and Messini, along with 37 villages suffered heavy damage. Considerable damage was caused in the towns of Pylos, Methoni, Kalamata, Andritsaena, Megalopolis and Pyrgos as well as in 65 villages. About 6000 houses either collapsed or rendered uninhabitable. Serious damage was also caused in churches, such as the dome collapse of the church of Sotiros Metamorphosis in Christianoupolis, near Filiatra. In total, at least 326 persons were killed and at least 796 were injured. According to Marshall (1887), about 50000 people rendered homeless. Aftershocks were felt for about one year. A late, strong aftershock occurred on March 2, 1887 with intensity of VII in Filiatra.

Of interest is the account in the unknown in the seismological literature diary of the contemporary Dionysios Kladis, Zakynthos island (Demetis, 2004): "1886 August 15 [OS], Friday, 11h and 20m, strong earthquake [occurred], according to accurate calculation of telegraphists it was of duration of 40 sec. All walls fissured. However, no major damage happened... But great destruction happened in Filiatra. Because of this terrible earthquake hundreds of ruined houses were counted

*in the town [of Filiatra] and the villages. After the shock, the local holly monastery sent a boat in Strofades [islet], with the aim to learn what happened to our brothers there because of the earthquake; August 18 [OS], Sunday, the boat returned from Strofades and we were informed that great destruction occurred there too. The tower opened in many places. The chapel of the grave of St. [Dionysios] felt. In addition, all buildings are uninhabitable and the priests sleep in open space”.*

Damage in Strofades was also reported by Galanopoulos (1941) who noted that the monastery seriously damaged and some monks were injured. The meizoseismal area, defined by the isoseismal of intensity X (Galanopoulos, 1941), was extended for about 40 km along the western part of Peloponnese from Kyparissia in NW to Koroni in SE. Damage was also reported from the island of Kythira [Newspaper “Foni ton Kythiron”, 1894: see in Papadopoulos (2011)]. In Patras, subsidence was observed in the quay of the port (Triantafyllou, 1995). In Crete, according to the short notes of S. Nikolaidis (Parlomas, 1949) on “1886, August 15, dawn of Saturday, terrible earthquake [occurred], the one that destroyed the south provinces of Peloponnese, non-damaging here in [Crete]...” (Papadopoulos, 2011). The earthquake was slightly felt but of long duration in Heraklion, Crete (Stavrakis, 1890).

From the detailed report of Galanopoulos (1941) it comes out that the earthquake was felt all over Greece but also in many remote places of the Mediterranean Sea. However, the Earth shaking was much longer in places located outwards of the convex side of the Hellenic Arc, that is along the western part of Greek mainland, the Ionian Sea islands and in remote places of the Mediterranean Sea, rather than in the back-arc region, that is in the Greek mainland, the Aegean Sea islands and the western Asia Minor. This is compatible with the clear elongation of the isoseismals along the NW-SE axis, that is outwards of the convex side of the Hellenic Arc.

In Ioannina the shock was felt with long duration and caused great fear to the people. In Kerkyra (Corfu) the duration of the Earth shaking was reported as long as 35 s. The earthquake was felt in remote places, such as Albania, Sarajevo, Trieste, Palermo, Malta, Alexandria, Cairo, Syria, as well as in Smyrna and other places of Asia Minor including Kallipoli and Istanbul (Constantinople). In the islands of Cephalonia and Zakynthos, Ionian Sea, the Earth shaking was of about 32 sec in duration (Chiotis, 1886).

Along a N-S coastal segment about 35 km long, from Agrilio, north of Filiatra, to the bay of Pylos, a local tsunami wave was observed and a coastal strip 10 to 15 m wide was inundated for a while [Galanopoulos (1941): see review in Papadopoulos *et al.* (2014)]. Ground fissures were observed from Katakolo to Gargaliani, while in Marathoupolis ground water came out from fissures (Chiotis, 1886; Galanopoulos, 1941), which is evidence of soil liquefaction. Chiotis (1886) reported that the clean water of the Evinos River became cloudy. Evinos River mouth is situated in the north part of the Patras Gulf, Greek mainland, about 120 km to the north of Filiatra. Chiotis (1886) reported also that no victims were caused in the Strofades monastery since, as it was said, “a distant light was seen by a shepard who notified the monks and they removed”. In addition, the captain of a British boat sailing to the west of Crete observed a flame rising about 400 m above the sea level towards south Peloponnese (Chiotis, 1886). Precursory phenomena, such as luminous phenomena, uneasy animals and underground roar were reported before the earthquake in the meizoseismal area (Galanopoulos, 1941). According to Hieke (2007), the 1960 bathymetric map of Pfannenstiel (1960) showed a submarine volcano west of the Peloponnese which could not be confirmed by modern bathymetric surveys. Pfannenstiel’s (1960) interpretation was supported

by a report of flames on the sea in 1886. It is most likely that the strong earthquake triggered a submarine mud volcano eruption and gas escapes on the Mediterranean Ridge, and burning gas was observed from several places on land and on sea (Hieke, 2007).

The long number of aftershocks does not favour the interpretation that the earthquake was of intermediate focal-depth. On the other hand, the NW-SE elongation of the isoseismals indicate that this earthquake very likely was an interplate event. One may assume that its focal mechanism was similar to that of the Methoni large ( $M_w = 6.9$ ) earthquake of February 14, 2008 (Fig. 1). Then, a plausible interpretation is that the 1886 meizoseismal area should be placed on the hanging-wall domain of the reverse fault activated with the 1886 earthquake. If this is correct the earthquake epicentre should not be located offshore, as suggested by previous authors, but within the meizoseismal area, say between Filiatra and Gargaliani. Magnitude  $M_s = 6.8 (\pm 0.3)$  was adopted from Papadopoulos (2011).

#### 2.12. Earthquakes occurring in 1887 and 1894

Many earthquakes were felt in Kalamata and Gargaliani on March 5, 1887 (Ambraseys, 2009). From Eq. (1) we calculated magnitude 5.4 and 5.6 for intensity V and VI, respectively. Then,  $M_s = 5.5 (\pm 0.1)$  was inserted. During the evening of July 25-26, 1894 there to was a locally damaging shock at Douka in Elis (Ambraseys, 2009). Magnitudes of 5.6 and 5.9 were calculated. Then,  $M_s = 5.7 (\pm 0.2)$  was adopted.

#### 2.13. 1896 December 28, Kalamata, SW Peloponnese

This was a moderate earthquake that occurred near Kalamata. According to a local observer of NOA, the shock was strongly felt by everyone in Kalamata (Anonymous, 1893-1901). It was of vertical direction, which indicates local source. Fissures were caused in a few walls. Small objects, such as bottles and paintings, fell down from walls and tables. In the wall of a watch shop three watches stopped. In the village of Jannitsa, which is situated at the mountain to the east of Kalamata, some old houses collapsed while new ones were fissured. The earthquake was felt as far as Kyparissia and Sparta (Galanopoulos, 1950). An aftershock followed but it was felt by only some people. Aftershocks were felt up to January 26, 1897. Maximum intensity of VII was assigned in Jannitsa. Previous authors determined earthquake epicentre very close to Kalamata and this is adopted here (Galanopoulos, 1960; Kárník, 1971; Shebalin *et al.*, 1974). We calculated magnitude  $M_s = 5.5 (\pm 0.2)$ .

#### 2.14. 1898 November 9, Kyparissia, SW Peloponnese

This was a moderate shock that caused damage in SW Peloponnese. According to a local observer of NOA, in Kalamata the shock was felt with duration of 18 s and consisting of three consecutive vibrations (Anonymous, 1893-1901). Small objects fell, some wall watches stopped and walls of houses fissured. Wind-like noise preceded the shock by about 2 s. The earthquake was strongly felt in Nisi (Messini) where few walls were fissured. In Ligoudista village roof tiles fell from houses while walls fissured. In Androussa roof tiles fell too. The earthquake was strongly felt in Kyparissia and slightly felt as far as Zakynthos, Delfi and Athens, that is about 200 km from Kyparissia (Galanopoulos, 1950). In Aetos village, Trifillia province, a water spring increased and got muddy. We adopted that the earthquake was a foreshock of the strong mainshock of January 22, 1899 (Galanopoulos, 1960). Moderate earthquake size was assessed given that the radius of

perceptibility was about 200 km (Galanopoulos, 1960). Earthquake epicentre was placed near Kyparissia. We calculated magnitude  $M_s = 5.6 (\pm 0.2)$ .

### 2.15. 1899 January 22, Kyparissia, SW Peloponnese

After the very strong foreshock of November 9, 1898 the south-western part of Peloponnese was hit again by a series of strong shocks. According to Anonymous (1893-1901) a shock was felt in Osmanaga, south of Kyparissia, in January 18, 1899. The very strong mainshock occurred on January 22 at 09:49:56. Another strong shock followed about 7 minutes later and another less strong one minute after the second. The observer of NOA at Ligoudista reported that 5 minutes before the mainshock a foreshock occurred. Until the noon of January 22 six strong shocks were reported. The main aftershock period was extended up to January 26 but damaging aftershocks were still strongly felt on April 6 and May 3, 1899.

The extensive destruction caused certainly is the cumulative effect of the series of strong shocks which occurred within a short time-interval of a few hours. The details of the earthquake impact became known from the report of an engineer sent by the government in the earthquake area. The main points of the report were reproduced by Anonymous (1893-1901) and later published by Galanopoulos (1941). Accordingly, it was reported that in the town of Kyparissia 53 houses destroyed, while another 70 and one church were seriously damaged. Many villages of the area suffered mainly because they lie on soft ground while the buildings were constructed without wooden reinforcement. In Filiatra 300 houses and the church of St. Nikolaos rendered unusable but none of them collapsed. In total, about 245 houses destroyed completely, another 275 were heavily damaged and hundreds of others were damaged. No fatalities were reported but about 50 people were injured.

The zone of damage was extended up to Pylos, Kalamata and Jannitsa to the south and SW, up to Arfara, Meligala and Megalopolis to the east and up to Vervitsa, Risovon and Pyrgos to the north (Galanopoulos, 1950). The earthquake was also felt in Athens, in the coastal zone of Epiros, NW Greece, and as far as Albania, Mineo and Catania in Sicily. The contemporary Dionysios Kladis reported in his diary (Demetis, 2004) that at 10:35 local time the earthquake was felt in Zakynthos but no damage was caused.

The strong aftershock of April 6, 1899 caused fissures in house walls in Filiatra and Vervitsa, while it was strongly felt in Amaliada and slightly felt in Patras. Because of the aftershock of May 3, 1899 many houses collapsed in Ligoudista while others rendered uninhabitable. In Gargaliani, Osmanaga and Spitalia house walls were fissured.

Important phenomena were reported in association to the earthquake activity. They included precursory phenomena, e.g., anomalous animal behaviour in the epicentral area, co-seismic ground oscillation of long-period at distant localities, ground failures such as fissures, subsidence, soil liquefaction, landslides, rockfalls and water springs alteration (Galanopoulos, 1941). In Marathoupoli, SW from Kyparissia, a small, local tsunami with runup of less than 1 m was observed while in Zakynthos the wave runup was about 20 to 40 cm [Anonymous (1893-1901), Mitzopoulos (1900), Eginitis (1901): see review in Papadopoulos *et al.* (2014)]. According to Galanopoulos (1941) the tsunami was possibly triggered by submarine slump. However, no damage to submarine cables was reported as it happened with the August 27, 1886 large earthquake.

The maximum intensity felt in Kyparissia and in the surrounding villages was estimated as

high as IX. The earthquake epicentre should be placed within the meizoseismal area close to Kyparissia. From Eq. (1) we found magnitude 6.4 for  $I_{max} = IX$ . We adopted intensity VI for Megalopolis at epicentral distance of about 20 km and found magnitude 5.8 from Eq. (3). Finally we adopted  $M_s = 6.1 (\pm 0.3)$  which is consistent with macroseismic magnitude 6.1 calculated by Ambraseys and Pantelopoulos (1993) as well.

#### 2.16. 1903 August 11, Kythira

This was a large [ $M_s = 6.6 (\pm 0.2)$ : Ambraseys *et al.* (1994)], intermediate-depth earthquake with epicentre near the island of Kythira (Fig. 1) where the maximum destruction was caused in the elevated village of Mitata. Earthquake effects of this event with seismic intensity assignment were reported in 27 localities of Greece (Anonymous, 1902-1915), in 225 localities of Italy (Margottini, 1982) as well as and in 10 localities of Egypt, Asia Minor and Albania (Ambraseys *et al.*, 1994). A recent review of the event can be found in Papadopoulos (2011). In western Peloponnese, the most serious damage was reported from Androussa, Messinia province, where intensity of degree VI was reported (Anonymous, 1902-1915). Earthquake magnitude as high as  $M_s = 6.6$  was adopted from Ambraseys *et al.* (1994).

#### 2.17. 1909 March 08, Katakolo, NW Peloponnese

This was a strong earthquake which caused fissures in many houses in the town of Katakolo, Elis province (Anonymous, 1899-1913). In the city of Pyrgos, it is reported that two brick-work houses collapsed while the telegraph-office building fissured. In Agoulinitza, modern Epitalio, a few wall-plasters fell. Telegraph cables of the Eastern Company connecting Pyrgos and Zakynthos broke (Galanopoulos, 1940). The earthquake was felt as far as Lefkas Island to the NW and Pylos town to the south, that is the maximum radius of perceptibility was  $\sim 230$  km (Galanopoulos, 1940). The shock was preceded by underground roar in Agoulinitza. The earthquake parameters adopted here are from Galanopoulos (1960). Seismic intensity of VI was estimated at Lixouri town, Cephalonia Island, as well as in Zakynthos. Galanopoulos (1981) estimated earthquake magnitude as high as  $M_s = 5.5 (\pm 0.3)$ , which is also adopted here.

#### 2.18. 1909 July 15, Chavari, Elis

This was a strong earthquake which caused total destruction and several human victims in the village of Chavari (Anonymous, 1902-1915) and other villages and towns of the Elis province. According to a local earthquake archive it was felt as far as Rethymnon in western Crete (Papadopoulos, 2011). Precursory phenomena, ground fissures and soil liquefaction were reported. Magnitude  $M_s = 5.7$  was reported by Comninakis and Papazachos (1982) and adopted by Papadopoulos (2011). From Eq. (2) we calculated magnitude 6.0 and 6.4 for maximum intensity VIII and IX, respectively. Finally, magnitude  $M_s = 6.0 (\pm 0.2)$  was adopted. This lethal event is little known and certainly deserves further examination.

#### 2.19. 1910 December 27, Lechaina, Elis

This was another strong earthquake which destroyed several houses in Lechaina and Gastouni of Elis (Anonymous, 1902-1915). We calculated magnitude  $M_s = 5.7 (\pm 0.2)$ .

### 3. Concluding remarks

In this paper the historical seismicity of the area of Kyparissiakos Gulf, SW Peloponnese, Greece, has been reviewed covering the time interval from the 5<sup>th</sup> century B.C. up to A.D. 1910. Among other sources and publications, little known archives were examined, such as the unpublished seismological archive of the NOA for the period from 1893-1915 and the personal diary of Dionisios Kladis, Zakynthos, covering the period from 1874-1907 and published by Demetis (2004). From archaeological reports two little known earthquakes were discussed, one occurring in Olympia area in the 2<sup>nd</sup> century B.C., the other near Filiatra in the 6<sup>th</sup> century A.D. A parametric earthquake catalogue was produced containing 27 earthquake events.

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