Kostas C. Makropoulos * **and Vicki Kouskouna** *

The Ionian Islands earthquakes of 1767 and 1769: seismological aspects.
Contribution of historical information to a realistic seismicity and hazard assessment of an area

Introduction

In the first part of this study (Kouskouna et al., 1993), the importance of historical research towards the enrichment of the number of available sources on earthquakes is discussed. The main interest is focused on those historical earthquakes, for which there is evidence that their return period is of the order of one century or more.

Such efforts are directed towards the combination of historical and instrumental data, in order to complete the seismic hazard picture of the area investigated. The latter assumes complete and homogeneous data sets. In Greece the moderate and major earthquakes of the 20th century have been successfully tested for completeness and homogeneity (Makropoulos et al., 1989). However, due to the problems mentioned in the first part, the historical data do not generally satisfy these requirements, and therefore a more detailed historical investigation is necessary.

In the present study the sources identified during the historical investigation for the two Cephalonia and Leukada earthquakes of 1767 and 1769 are critically evaluated and an assessment of their intensity distribution is attempted.

Seismic background of the area

Based on neotectonic and seismological criteria, Drakopoulos and Makropoulos (1983) divided Greece into thirteen seismic origin zones. The Ionian Islands belong to the Hellenic trench subduction zone, which commences from these islands and, through the southern part of Crete, trends northeast, with maximum expected magnitude 7.5 and mainly shallow foci. Focal mechanisms (Drakopoulos and Delibasis, 1982) and geological information have shown that this region is affected by compressional stresses.

* *Department of Geophysics and Geothermy, University of Athens, Panepistimioupolis, 157 84 Athens, Greece.*

The results for the most probable maximum magnitude in the next 100 years show that the Ionian Islands belong to the high shallow seismicity areas of Greece. In particular the island of Cephalonia has a permanent high level of seismicity and has experienced earthquakes of magnitude greater or equal to 6.0 approximately every 20 years (Makropoulos and Burton, 1985). The occurrence frequency of large earthquakes is at least one with magnitude in the range of 5.5 - 6.0 every 10 years.

The macroseismic information from the 20th century earthquakes shows that the shallow foci in the area (average depths around 10 km) indicate its capability for high degree of intensities and elliptical to strongly elliptical shapes of isoseismals, with major axes mainly in the NW-SE direction, parallel to the coastline and the Hellenic trench.

N	Date	Lat N	Lon E	Ms	Io	Region affected
1	1469 Spring	38.4	20.5	7.2	X	Cephalonia (Argostoli)
2	1612 May 26	38.8	20.8	6.6	X	Leukada
3	1613 Oct. 12	38.8	20.8	6.4	VIII	Leukada
4	1625 June 28	38.7	20.7	6.6	IX	Leukada
5	1630 July 2	38.8	20.8	6.6	X	Leukada
6	1636 Sept. 30	38.1	20.6	7.1	X	Cephalonia (Lixouri)
7	1658 Aug. 24	38.3	20.5	6.8	X	Cephalonia
8	1668	38.4	20.4	6.5	VII	Cephalonia
9	1704 Nov. 22	38.7	20.7	6.6	IX	Leukada
10	1714 July 27	38.2	20.5	6.4	VIII	Cephalonia
11	1722 June 5	38.7	20.5	6.3	VIII	Leukada (Athani)
12	1723 Feb. 22	38.6	20.7	7.0	IX	Leukada
13	1736	38	20.5	6.2	VII-VIII	Cephalonia
14	1741 June 23	38 1/2	20 1/2	6 3/4	VII-IX	Leukada
15	1759 June 14	38.3	20.4	6.3	VIII	Cephalonia
16	1766 July 24	38.1	20.4	6.7	IX	Cephalonia
17	1767 July 22	38.2	20.3	7.2	X	Cephalonia (Lixouri)
18	1769 Oct 12	38.9	20.6	6.8	X	Leukada
19	1783 Mar. 23	38.6	20.5	7.0	X	Leukada (Athani)
20	1783 June 7	38 3/4	20 3/4	6 1/4	VII-VIII	Leukada (Vavkeri)
21	1815	38.7	20.7	6.3	IX	Leukada
22	1820 Mar. 17	38.8	20.6	6.3	IX	Leukada
23	1825 Jan. 19	38.7	20.6	6.7	X	Leukada
24	1834 July 5	38	21	6	VII-IX	Cephalonia
25	1862 Mar. 14	384.	20.5	6.6	IX	Cephalonia (Argostoli)
26	1867 Feb. 4	38.2	20.4	7.2	X	Cephalonia (Paliki)
27	1869 Dec. 28	38.8	20.7	6.6	X	Leukada
28	1885 Dec. 14	38 3/4	20 3/4	5 3/4	VII-VIII	Leukada (Englouvi)

Tab. 1 - Historical earthquakes of Leukada and Cefalonia up to 1885 (from Papazachos and Papazachos, 1989).

The major earthquakes of the area in the last 85 years are grouped in three epicentral areas: northern Leukada (4 events); southern Leukada, northern Cefalonia and Ithaca (7 events); central and southern Cefalonia (4 events). They were strongly felt in the N, E and SE, i.e. in Epirus, Karditsa, Aitolia-Acarnania (Naupaktos, Mesolongion) and eastern Peloponnese (Patras, Rion). The most recent earthquakes in Leukada on November 29 and December 1, 1994 had magnitudes 5.3 and 5.2 respectively, and preliminary reports on the damage assign intensity VII-VIII in the village of Kalamitsi and VI-VII in Karia and Exanthia, in the western part of the island, i.e. a rather concentrated felt area.

The area has repeatedly experienced intensities of the order of X. A series of strong historical earthquakes have been reported from the area since 1469 continuing in the 20th century (28 major historical earthquakes are reported for Leukada and Cephalonia).

Tab. 1 contains the historical earthquakes of the studied area up to 1885 (Papazachos and Papazachos, 1989), while Fig. 1 shows the spatial

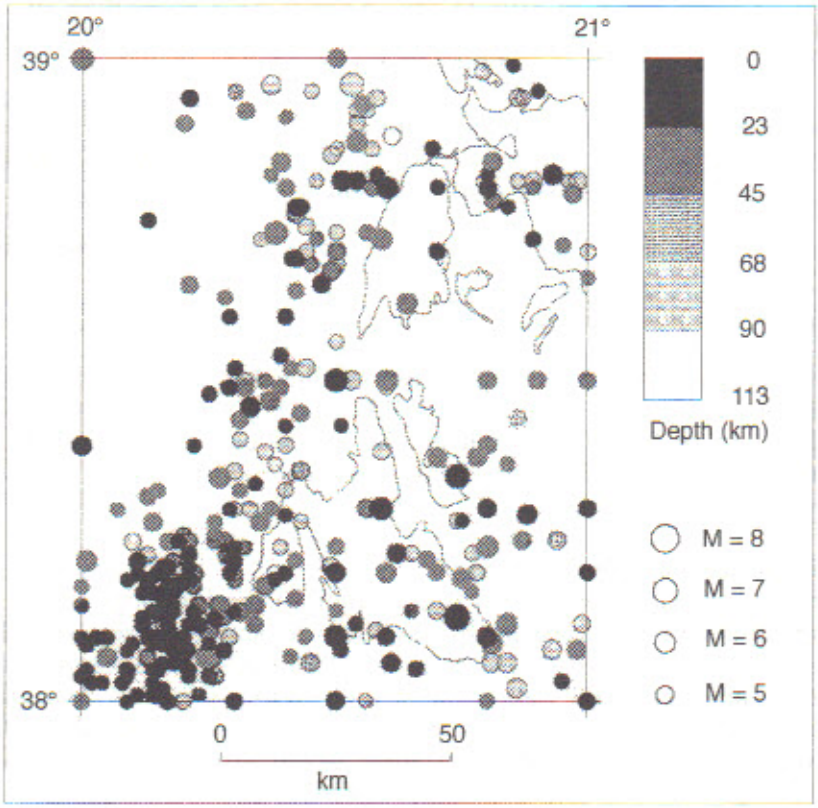

Fig. 1 - Earthquakes of Leukada and Cephalonia in the 20th century with M > 5.5 (Makropoulos et al., 1989).

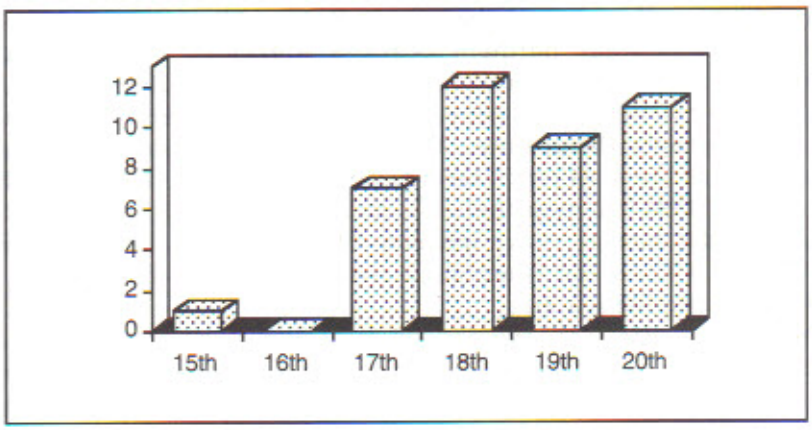

Fig. 2 - Number of strong earthquakes of the area in every century since 1400.

distribution of the 20th century earthquakes with magnitude M > 5.5 (Makropoulos et al., 1989). Fig. 2 summarizes the number of strong earthquakes of the area per century since 1400.

Macroseismic intensity assessment

The 1767 Cephalonia and the 1769 Leukada earthquakes are listed by Papazachos and Papazachos (1989) with the following parameters:

date	*time*	*lat*	*long*	*I o*	*M*	*epicentral area*
1767 07 22	04	38.20 N	20.30 E	X	7.2	Cephalonia (Lixouri)
1769 10 12	18	38.90 N	20.60 E	X	6.8	Leukada

The new evidence concerning the two earthquakes and the affected areas (Tsiknakis et al., 1990, 1993; Albini and Daltri, 1991; Albini, 1991) led to an exploitation of the information on the effects of the two earthquakes, expressed in terms of macroseismic intensity distribution in the whole affected area.

Characteristics of the buildings

For intensity assessment, the information on the buildings of the time generally allows their classification into low resistance classes (A or B), as described in the macroseismic scale modified MSK 64 currently used in Greece. However, in the case of the studied earthquakes, this classification must be performed with special care, taking into consideration the fact that during the period 1700-1766 at least seven strong earthquakes are documented as having caused serious damage in both Cephalonia and Leukada.

Leukada. In the 18th century the houses in the villages were built by

masonry, while in the main town both masonry and wooden frame houses can be found. Prior to the 1825 earthquake the houses in Leukada had a wooden frame (*casa baracata*), a method applied by the Venetians. The antiseismic design was introduced later by the English. However this system was applied only in the houses of Santa Maura, while in the villages the traditional masonry structure was applied. These structures, in order to withstand earthquakes, had thick walls and small openings.

Cephalonia. Around 1780 the misery in the town of Argostoli is described as "a pile of deserted huts", a town with badly built houses, most of which were deserted because of the earthquakes. In Lixouri the damage from the earthquakes was evident in that most houses had nearly collapsed. The streets in Lixouri were full of ruins and it was difficult to walk in the town.

Cephalonia earthquake, 1767 July 22

The research on available sources showed that the time of the mainshock occurrence was "13 hours" (expressed in "Italian hours"), and six aftershocks were reported from almost all the Ionian Islands.

The earthquake struck most main towns and villages of Cephalonia. In Lixouri many deaths were reported and almost the whole town suffered great damage. Great damage was also reported from Lixouri fortress and the surrounding villages (people evacuated their houses). In the town of Argostoli and in the fortress very few houses were left inhabitable. Damage was also observed in the walls of the fortress. Further to the north, in the Paliki peninsula, in the town and fortess of Assos strong shaking was reported, rocks fell, houses were completely destroyed or evacuated. At least one person died and many were wounded. Piles of stones were seen everywere. The houses and churches in the fortress of the town were also destroyed. The above information corresponds to intensity X (MSK 64, modified) in these areas.

The shock struck also the island of Zante, south of Cephalonia. Detailed reports refer to the damage in the main town of Zante, in the eastern part of the island. Despite the great damage, some houses remained untouched. As the financial aid requested from Zante to the Venetian government was not substantial, it is assumed that the above damage was observed in less houses than in Cephalonia. An intensity IX is therefore assigned for Zante.

In Leukada and Corfu there is little information on effects from this earthquake (intensity IV-V?). In addition, effects were reported from the towns of Amphilokhia and Patras, in western Greece. The shock was also felt as far as Meteora (central Greece), as reported by one monastery chronicle (N. Ambraseys, personal communication).

All the above information leads to the conclusion that this earthquake was particularly strong, similar to others that have occurred in Cephalonia also in the 20th century. The ample information on heavy damage distributed around the gulf of Argostoli shows that the meizoseismal area

covers this part of the island. However, the epicentre of the earthquake could just as well be located nearer to the island, so as to justify the damage in central and eastern Zante.

Almost all the descriptions refer to aftershocks, some of which continued until October of the same year.

Leukada earthquake, 1769 October 12

Detailed information on the distribution of damage was derived mainly from the correspondence between the Venetian ruler Andrea Donà and the Venetian Senate (Daltri e Albini, 1991; Kouskouna et al., 1993).

The earthquake occurred on 12 October 1769, at 19 hours ("Italian hours") and it had at least three aftershocks on 13 and 14 October 1769, felt only in Leukada. The casualties were seven dead and many injured.

The mainshock caused serious damage to the town of Amaxiki, the settlement of Perivolaki (one mile away from Amaxiki), the fortress of Santa Maura and the area of Alikes, in the NE part of the island, whilst the villages of the island suffered minor damage.

In the town of Amaxiki 10 churches and 497 houses and shops collapsed completely, and another 3 churches and 329 houses and shops were seriously damaged. The total number (826) of houses and shops in Amaxiki were damaged by the earthquake. Taking into consideration the population of the town (6,000) this figure seems reasonable. Therefore most of the churches (77%), houses and shops (60%) collapsed completely, and the rest suffered serious damage. These figures correspond to intensity IX-X in Amaxiki.

In the fortress damage was observed in the walls, the eastern part of which almost collapsed, together with one arc of the bridge connecting the fortress to Amaxiki. From the buildings inside the fortress, 5 houses collapsed, while the hospital, the monastery, two churches and 5 houses suffered serious to moderate damage, i.e. intensity VIII is assessed for this part of the island.

In Old and New Alikes, SE of Amaxiki, displacement of the salt pans and serious damage of the walls and roofs of the depots was reported, and bricks were strewn everywhere (intensity VIII).

In the villages of Leukada and some villages of Cephalonia the earthquake was felt strongly (intensity IV-V). The earthquake was also felt in Ithaki, Zante, Corfu, Rio, Antrirrio and Naupaktos, which leads to an intensity not higher than III.

Seismological interpretation

The intensities of the two studied earthquakes assessed in the previous paragraph and their distribution are presented in Figs. 3 and 4. In what follows, an attempt is made to correlate this distribution to the distribution of macroseismic effects of other earthquakes of the same area.

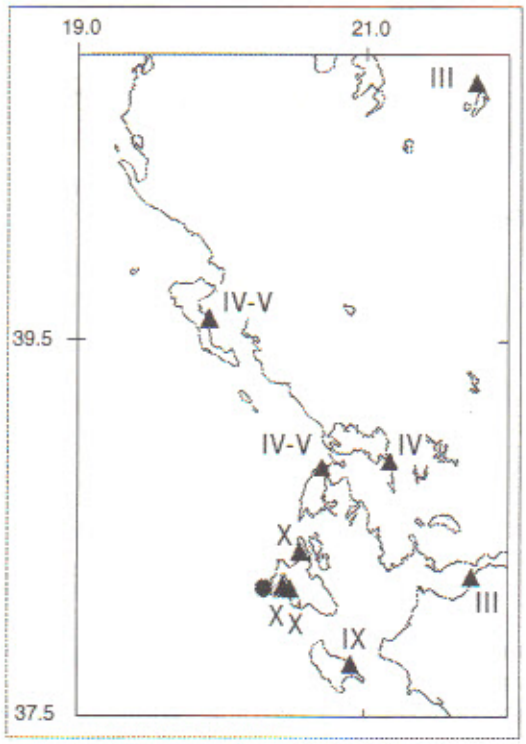

Fig. 3 - Distribution of the effects of the 1767 Cephalonia earthquake.

With regard to the Cephalonia earthquake of 1767, the large number of sources and their thorough study showed that the ample macroseismic information from the island of Cephalonia, the other Ionian Islands and some parts of Greece implies that the magnitude of this event was larger than the Leukada earthquake.

The effects of this earthquake in the meizoseismal area are in agreement with the previously assumed intensity. The effects in Amfilokhia and Patras (intensity IV) and the reports from Meteora (intensity III) are in agreement with the perceptibility radii of this century's earthquakes of the same order of magnitude and epicentral intensity. According to the damage pattern of this earthquake, its macroseismic epicentre is located in central-southern Cephalonia.

The high intensity observed from the 1769 earthquake specifically in the town of Amaxiki, i.e. the small epicentral area, might be attributed to the bad condition of the houses and the unfavorable soil conditions, on which these houses were built. This might also lead to a very local earthquake (epicentre in the northern part of the Leukada island area, near to the town of Amaxiki). In any case, it would not be recommended to assess a

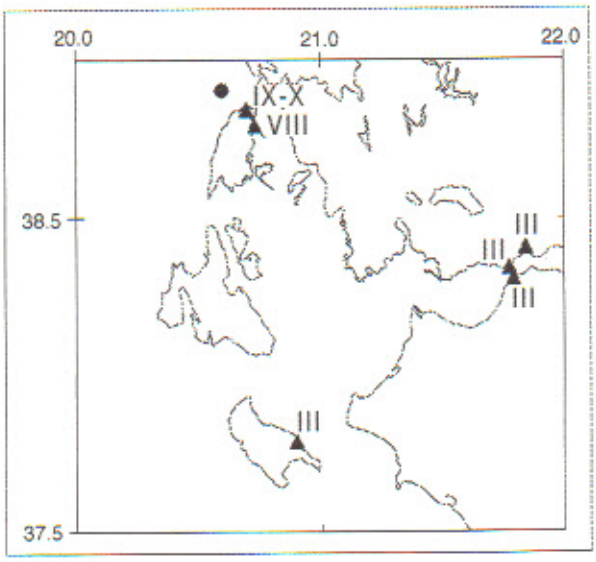

Fig. 4 - Distribution of the effects of the 1769 Leukada earthquake.

magnitude from relationships of the form (M=f(I)), since this degree of intensity is observed only at one site.

The detailed study of the 1769 Leukada earthquake gave firm ground to a preliminary hypothesis that the magnitude of the earthquake has been overestimated. It seems that this event had a smaller magnitude than the one in 1767 and a shallow depth (less than 10 km), resulting in localized macroseismic effects and high attenuation of intensities with increasing distance. In fact, if the 1769 earthquake had a magnitude M = 6.8, one would expect some damage reported from NE Peloponnese and Aitolia-Acarnania from the Leukada event, instead of simply being felt there. In addition, all the earthquakes of this order of magnitude from the area have caused damage at a distance of 120-150 km (Kouskouna et al., 1994), a fact which did not occur in the case of the Leukada event.

The fact that the area has suffered continuously the effects of several earthquakes in a small period of time (Fig. 2) gives credibility to the assumption that a great deal of the damage caused by the two studied earthquakes in buildings in both islands and mainly Leukada is cumulative.

Discussion and conclusions

The seismological analysis of the two historical Ionian Islands earthquakes of 1767 and 1769 revealed interesting information that should not be neglected in seismic hazard studies.

Apart from the purely historical interest, the study of historical earthquakes results in a better estimation of the return periods of major

earthquakes, which results from a more accurate and realistic maximum intensity and hence macroseismic magnitude assessment. The instrumental data, although often useful for calibration, are not sufficient for the evaluation of large return periods. A striking example for the area of Greece is the Atalanti 1894 earthquakes, which were not repeated in the 20th century, and therefore their return period, if based only on instrumental data, is unknown.

The distribution of the effects of the 1767 Cephalonia earthquake is similar to these earthquakes with the same epicentral area (central-southern Cephalonia) in the 20th century. Thus, it is assumed that this event had a magnitude of about 7 1/4, caused maximum intensity X and had a shallow depth.

The Leukada earthquake of 1769 most probably caused a maximum intensity IX in a much smaller area than the previous event. The damage was localized in the northern part of the island. This fact, together with the observation that the earthquake did not cause serious damage to the other Ionian Islands, leads to the conclusion that its magnitude must have been much smaller than the magnitude of the Cephalonia event. In other words, the empirical formula that relates the maximum intensity with macroseismic magnitude does not apply completely in this case.

In conclusion it is stressed that, when dealing with historical earthquakes, their magnitude should be assumed not only from their maximum intensity but also from their damage pattern.

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