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CCI 2014 TC 16 I5CB 009

J-CROSS

ARISTOTLE UNIVERSITY OF THESSALONIKI

SEISMICITY STUDY IN THE CROSS BORDER AREA OF FLORINA AND PELAGONIA BASIN

THESSALONIKI 2019

This project is co-funded by the European Union and by National Funds of the Participating Countries

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WP-3

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PREFACE

A study on the seismicity and seismic hazard is undertaken across the borders of Greece and the Republic of North Macedonia. This is a part of a project named "Joint Cross Border Cooperation for Securing Societie against Natural and Man-Made Disasters (J-CROSS) funded by Interreg IPA Cross border Cooperation Programme "Greece - Republic of North Macedonia 2014-2020."

The J-CROSS project came as a result of a the excellent cooperation between the Region of Western Macedonia, Greece and the Pelagonia Region, Republic of North Macedonia, which lasts for a long period.

Given that the whole geographic area suffers from many hazards (earthquakes, floods, landslides, etc) such projects (like J-CROSS) are the proper answer to security policy against risks from natural (e.g. earthquakes), as well as from man-made disasters (e.g. TAP pipelines). Large infrastructure projects are planned and accomplished in the broader area, like transportation (road and rail) networks, logistic centres and recently natural gas pipelines. For such development projects, financial support obtained from organizations like European Union, European Investment Bank, among others. In previous years both regions established close cooperation through projects in the field of economy, environment and social cohesion.

We can not avoid risks due to factors like those referred above. Taking into account all the aforementioned risks, J-CROSS catch the opportunity to minimize the severity of risks in both areas by common plans which developed and implemented practical actions.

So we can work together in order to minimize risks (like the deadly floods of 2016 in Skopje, the large earthquake in western Macedonia during 1995, among others), in a way that this can be considered as a paradigm in other cross border areas.

THE INVOLVED WORKING TEAM

THE PRESENT STUDY IS A PRODUCT OF MANY DIFFERENT ACTIONS:

1) FIELD WORK

2) NEW INSTALLATION OF INSTRUMENTS

3) FORMER RESEARCH THAT WAS MADE AND

4) PUBLISHED BOOKS AND RELATED STUDIES

AND CARRIED OUT BY THE SCIENTIFIC TEAM OF THE ARISTOTLE UNIVERSITY OF THESSALONIKI - GREECE AND OTHER RELATED SCIENTISTS, AS WELL AS BY A SUPPORT TEAM OF TECHNICIANS.

CONTENTS

INTRODUCTION

Two largest cities are situated in the area of the project's application. These are: Florina (in the Greek part) and Bitola (in the part of the North Macedonia). The city of Florina is the capital of the prefecture of Florina (population more than 17.000, census of 2011), while the city of Bitola is the capital of the municipality of Bitola (population more than 100.000 (census of 2011). Additionally in Bitola area more than 7.000 inhabitants live in 11 villages that comprise wider urban area of the city. Most of the villages owned to the municipality o Bitola are situated in a mountainous area. The municipality of Florina has 25 villages with a population about 8.000 people. More of them (18) are in the plain of Florina.

Important infrastructures are installed in both parts. Strezevo dam which is a very critical infrastructure of the Pelagonia region, some eighteen kilometres away from Bitola in a N-NW direction.

Four dams are situated in the area around Florina and two of them (Parori and Papadias dams) were installed very near to the borders region. The other two are the dams of Kolchiki and Triantafilias.

Another important infrastructure is the Mining Power Complex of Bitola which is situated in a new municipality since 1975, Novaci. The main activity of the plant is the production of coal and electricity.

A same critical infrastructure is situated in the Florina Municipality (ex-municipality of Meliti). Florina power stations is one unit coal-fires power plant. This supercritical plant is owned by Public Power Corporation S.A. and began its operation in 2003. It is powered by lignite coal. It is known as Meliti-Achlada unit. The dam of Papadia is responsible for cooling the machines of the power station, as well as for water supply to Meliti and the villages around.

In both cities (Florina and Bitola) the existing stock reflects the history of urban development. Buildings done by stones or bricks of one or two storey high are dominated in the center of the cities and the close surrounding area. In the decade of '70 the modern part of the cities were constructed in accord with rules and seismic codes for safety. Two general types prevailing the residential building stock in both cities: mansonry and reinforced concrete. Based on the new techniques and the modern materials in the new parts of the cities one can observe multi-storey buildings.

During the present project we will find and apply techniques and methods for danger mitigation. Danger may comes from a trigger of a large earthquakes which can cause heavy damages, homeless people, injuries and moreover deaths based on many reasons. Another danger can come from landslides and especially by those which can run close to inhabited places. Finally danger can depend on cracking of dams and the consequent floods.

For this reason both sides (Greece and North Macedonia) schedule events for actions where all partners, as well as protection and Rescue Directorate, Red Cross, representatives of the municipalities, citizens associations related to this issue, representatives of the public enterprises and volunteer teams, will plan for SAR (Search and Rescue) in order to face with success such conditions.

PART 1

SEISMOTECTONICS AND SEISMICITY IN FLORINA AND SURROUNDING AREA

1.1. SEISMOTECTONIC CHARACTERISTICS OF THE BROADER AREA

Much information is available on active tectonics and deformation in the broader Aegean area. Papazachos and Comninakis (1970) first suggested that the subduction of the Eastern Mediterranean oceanic plate under the Aegean was related to the northward motion of the African plate with respect to the Aegean and the identification of intermediate–depth earthquakes beneath the southern Aegean. McKenzie (1972) showed that the northward motion of the Arabian plate pushes the smaller Anatolian plate that is moving westerly relative to the Eurasian plate along the North Anatolian Fault (NAF), with an average velocity of about ~24 mm/yr. This motion is accommodated by an additional N–S deformation of ~11 mm/yr in the Aegean, resulting in a total SW motion of ~35 mm/yr of the south Aegean relative to Eurasia. The dextral strike–slip faulting in the northern Aegean, of northeasterly strike, is consistent with several fault–plane solutions of recent strong earthquakes (e.g. Papazachos et al., 1998).

The Kefalonia Transform Fault Zone (KTFZ) that bounds this zone from the west. The KTFZ consists of an active boundary between the continental collision of Adriatic microplate and Eurasia to its north, and the subduction of the east Mediterranean oceanic crust beneath the Aegean microplate to its south. The dextral strike–slip nature of the KTFZ was firstly introduced by Scordilis et al. (1985) who determined the fault plane solution of the 1983 Kefalonia M=7.0 earthquake, and then confirmed by waveform modeling (Kiratzi and Langston, 1991; Papadimitriou, 1993). The dextral strike–slip sense of motion is documented by the fault plane solution of the 2003 Lefkada M=6.2 main shock, the 2014 Kefalonia doublet (M=6.1

and 6.0) and the 2015 Lefkada M=6.5 main shock all associated with fault segments comprised in the KTFZ.

The Florina Basin, the target of this study, is located in Northwestern Greece consisting an intermountain graben composed of metamorphic rocks and formed as a result of extensional stresses following the Alpine orogenesis (Koukouzas et al., 2015 and references therein). Historical and instrumental catalogs comprise an adequate number of strong (5.0≤M≤6.0) earthquakes (Papazachos and Papazachou,

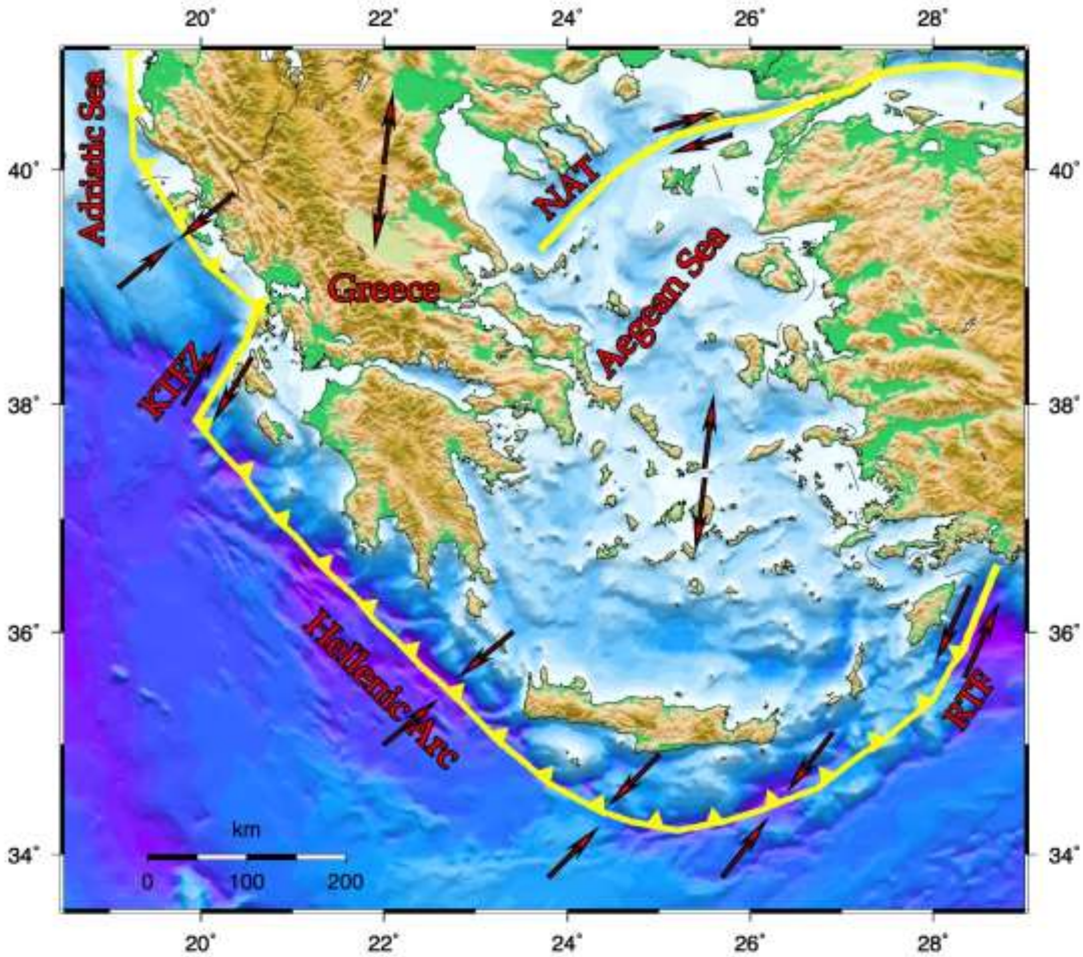

Fig.1. Main Seismotectonic properties of the broader Aegean region. Thick yellow lines denote the major active boundaries. NAT: North Aegean Trough, KTFZ: Kefalonia Transform Fault Zone, RTF: Rodos Transform Fault

2003) in the broader area of northwestern Greece (detailed descriptions on the macroseismic effects which are given in a later section).

1.2. HISTORICAL SEISMICITY

Information for the stronger (M≥6.0) earthquakes that occurred in the area of Greece is available since the 6th century BC (Papazachos and Papazachou, 2003) and are available from the catalog complied in the Geophysics Department of the Aristotle University of Thessaloniki (http://geophysics.geo.auth.gr/ss/station_index_en.html). Although the epicentral coordinates and the magnitudes in the preinstrumental era are estimated with a relative uncertainty, they do follow the known and discriminant alignment of instrumental epicentral distribution, associated with fault zones and active boundaries (Fig. 2). The complete data sample that was selected to be plotted (see periods of completeness and the respective threshold magnitude in the legend of Figure 2) for expressing the seismicity manifestation, and consequently the degree of active deformation, throughout the area of Greece, provides a quantitative comparison as well between the different parts of the Greek territory.

Given that smaller earthquakes may occur in a diffuse way, whereas the stronger ones are associated with major fault segments incorporated in fault populations, their spatial distribution signifies the location of the seismic zones, i.e. the weak zones of the brittle lithosphere that accumulate strain energy culminating in earthquake generation. Figure 2 then reveals that the study area (Florina and the area around the city) is characterized by low seismicity, relatively to other certain areas in Greece. The closest major faults associated with M≥6.0 are at a distance from the city that secures severe damage due to seismic activity.

For seismic hazard evaluation purposes, however, it is important to take into account the occurrence of strong earthquakes even at longer distances from the point of interest, that have resulted to appreciable macroseismic intensities, i.e. I≥4 in MSK. For this reason, the macroseismic descriptions of these earthquakes are given in the following, as they have been taken from Papazachos and Papazachou (2003), along with the spatial distribution of the macroseismic effects, being evaluated for the construction of isoseismal curves, taken from Papazachos et al. (1997). Some of these shocks and a short description of the damages caused referred below.

1709, 40.6° N, 21.3° E, h=n, M=(6.0), Kastoria (VII)

A firman issued on 10 December 1711 reports that some parts of mosques built by the Sultans Mehmet and Suleyman in the castle of Kastoria were destroyed by the earthquake (Ambraseys and Finkel 1999).

1812, May 29 40.5° N, 21.3° E, h=n, M=(6.5) Kastoria (VIII)

According to a note written on a church book found in Kastoria, a large earthquake occurred on 17 May 1812 (old calendar). Mosques, chimneys and houses fell down. People left their houses and went to the mountains and roads and built shacks to live. The earthquakes lasted three months (Vavritsas et al., 1986).

1894, August 23, 40.3° N, 21.4° E, h=n, M=(6.1), Siatista (VII)

The earthquake caused destructions in the area between Siatista, Selistras (Eratyra) and Kastoria, it was strongly felt in Bitola and Korca (Ambraseys 1999).

1896, September 28, 41.1° N, 20.7° E, h=n, M=(6.1), Yugoslavia (VIII, Ochrida)

The earthquake was destructive in the area of the lake Ochrida and in Strunga (Michailovic, 1951).

1906, September 28, 02:30, 40.9° N, 20.7° E, h=n, M=6.0, Ochrida (VIII, Starovo)

The earthquake caused destructions in the area of Ochrida and particularly in Starovo and in Strouga. The aftershocks continued up to October. Isoseismals are cited in the atlas of UNESCO (Shebalin et al., 1974).

1911, February 18, 21:35:12, 40.9° N, 20.80° E, h=n, M=6.7, S. Yugoslavia (IX, Ochrida)

The earthquake caused large destructions in the area of the Ochrida lake. In the village Starovo (Pogrades), the 50% of the houses were destroyed. One person was killed and 4 were seriously injured. In Ochrida, many houses were damaged, while the meizoseismal area includes Strouga too. Some damage was also observed in Monastiri (Vitola) and in Florina. The inhabitants stayed under tents for a long time. The height of the vibration of the lake reached 0.5m. The shock was strongly felt in the whole area between the Albanian mountains and the Axios river. It was moderately felt in Corfu and lightly in Trikala. It was also felt in Belgrade and in the cape of Mikale in Italy (Lecce), (AOA, 1912; Critikos, 1932a; Michailovic, 1951). The main-shock was followed by aftershocks, the largest of which occurred three minutes after the main-shock (21:38:30, M=5.6). Isoseismals of the earthquake are cited in the atlas of UNESCO (Shebalin et al., 1974) and by Papazachos et al. (1997).

1912, February 13, 08:03:53, 40.9° N, 20.6° E, h=n, M=6.1 Albania (VII, Pogrades)

The earthquake caused damage in Pogrades (Karnik, 1969).

1960, May 26, 05:10:11, 40.63° N, 20.657°E, h=n, M=6.5, Albania (VIII+, Polene)

The earthquake was destructive in the upper part of the river Osoumi in Albania where 500 houses were seriously damaged, 9 persons were killed and 95 were injured. The damage expanded up to the area of Korytsa where fissures were observed in 95 houses and one person was injured. It was strongly felt in villages of the prefectures of Jannena, Kastoria, Kozane, Corfu (BGINOA, 1960). Isoseismals are cited in the atlas of UNESCO (Shebalin et al., 1974a, b) and by Papazachos et al., (1997). It was preceded by shocks the largest of which occurred in the same day with the main shock (00:48, M = 4.4) and was followed by aftershocks the largest of which occurred on 9 July (22:42, M = 4.7).

1994, September 1, 16:12:42, 41.15° N, 21.20° E, h = n, M=6.1, S. Yugoslavia (VII, Bitola)

Many people were injured and some damage was caused in the Bitola area. It was strongly felt in the area of Florina (VI, Niki, Ag. Germanos) and in other parts of Greece up to Larisa. (NEIC, 1994; BGINOA, 1994). Isoseismals are cited by Papazachos et al. (1997).

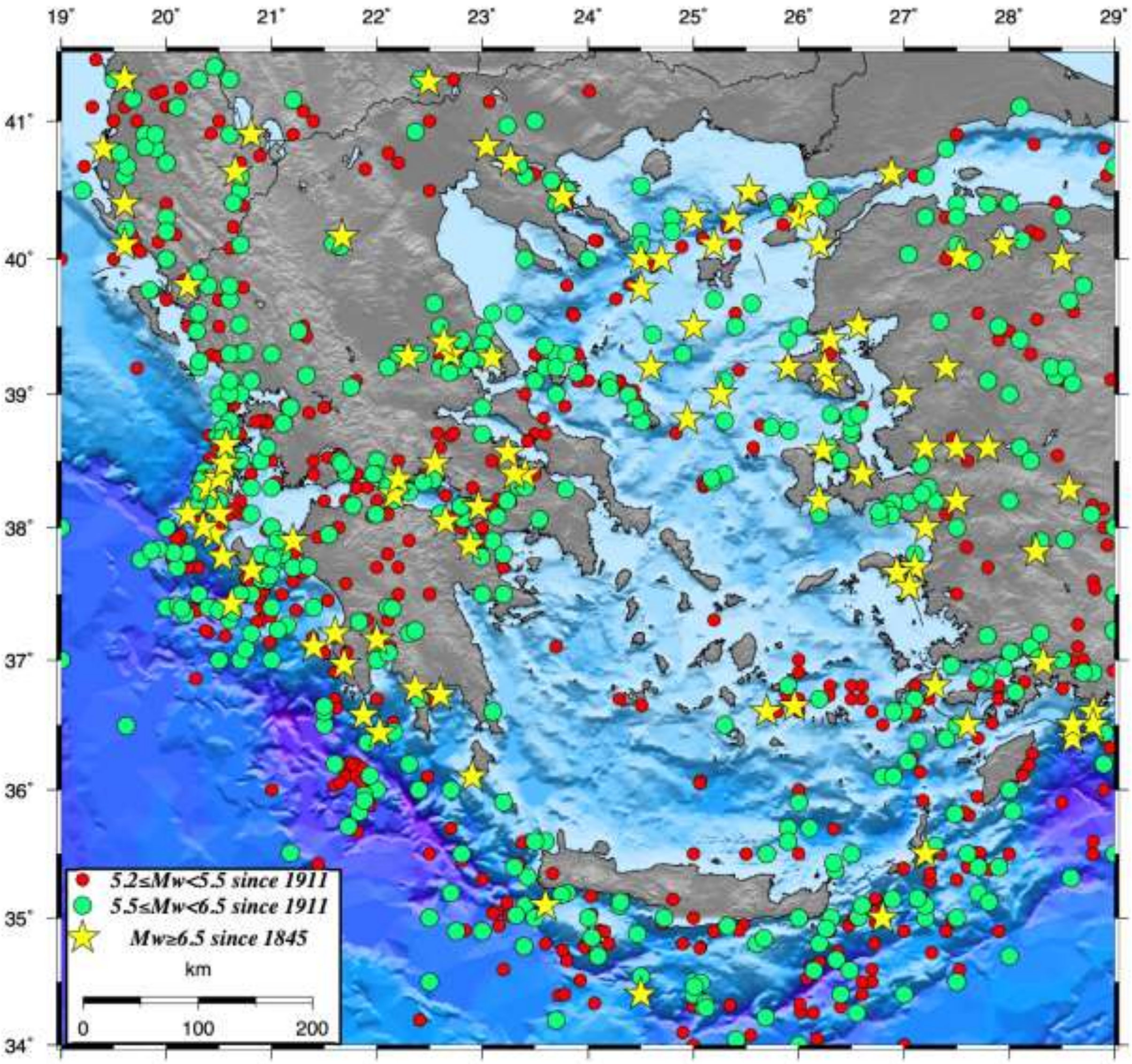

Fig.2. Epicentral distribution of moderate and strong earthquakes of the complete data sample as is given in the figure legend.

1904 April 4, 10:25:55, 41.8° N, 23.0° E, M=7.7, South Bulgaria, (X, Kresna)

The earthquake was preceded by large foreshocks, the largest of which was also destructive and occurred 23 minutes before the main shock (10:02:34, M=7.1). It was followed by aftershocks, the largest of which occurred on 10 April, but its epicenter was more north (42.7° N, 22.8° E, M=6.0). Another strong shock occurred on October 5 (41.9° N, 23.1°, M=6.4).

1904,Apr.4, 41.85°N, 23.00°E, M=7.1, Bulgaria

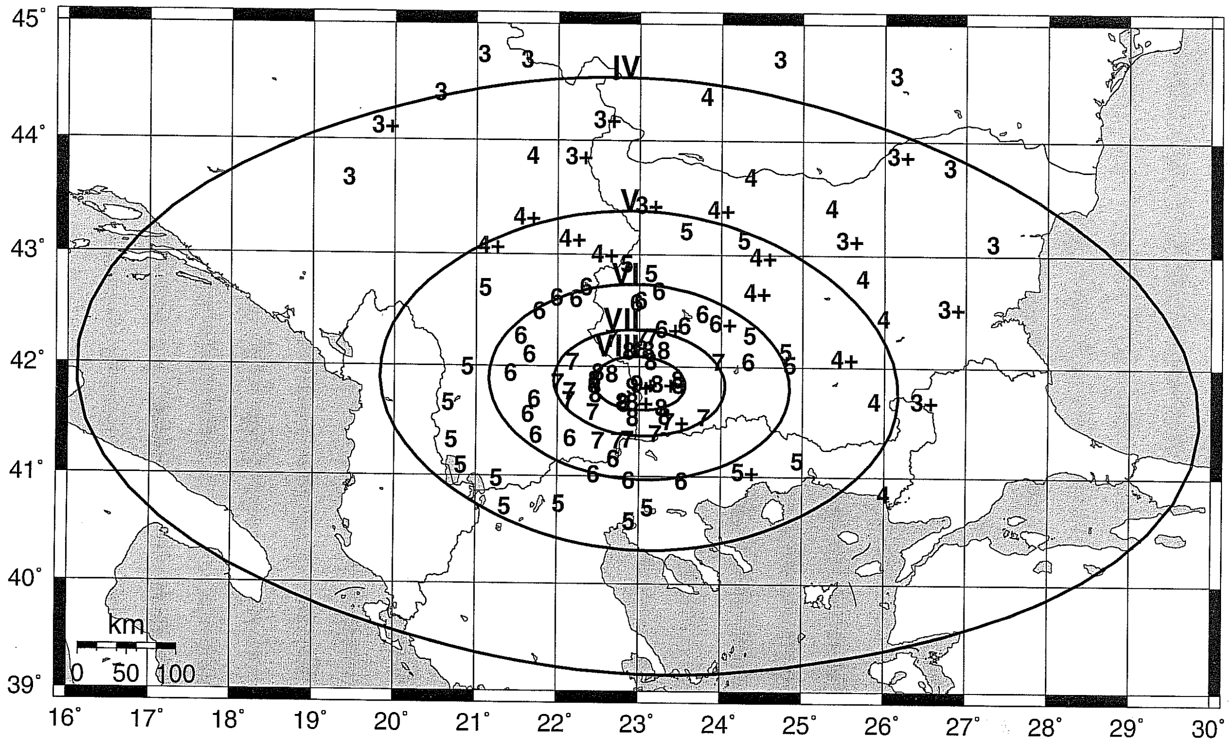

Fig.3. Isoseismal curves of the south Bulgaria earthquake, on the 4th of April 1904 (M7.1) (Papazachos et al., 1997).

The epicenter of the first earthquake (M=7.1) was in the area of the villages Kila, Kiustentil, Doupnitsa, while the epicenter of the second one was more south in the area of Kresna, Rekovo and Tzoumayia. These earthquakes destroyed many villages and caused ground realignments and changes in the flow of springs in the epicentral area. It caused also damage in Bulgaria, Austro – Hungary up to the

Russian borders, as well as in the whole Macedonia and the rest northern Greece up to Volos.

Figures 3 and 4 evidence that the macroseismic intensity at the area of Florina was around 5 from the first earthquake and around 6 from the second, values that w

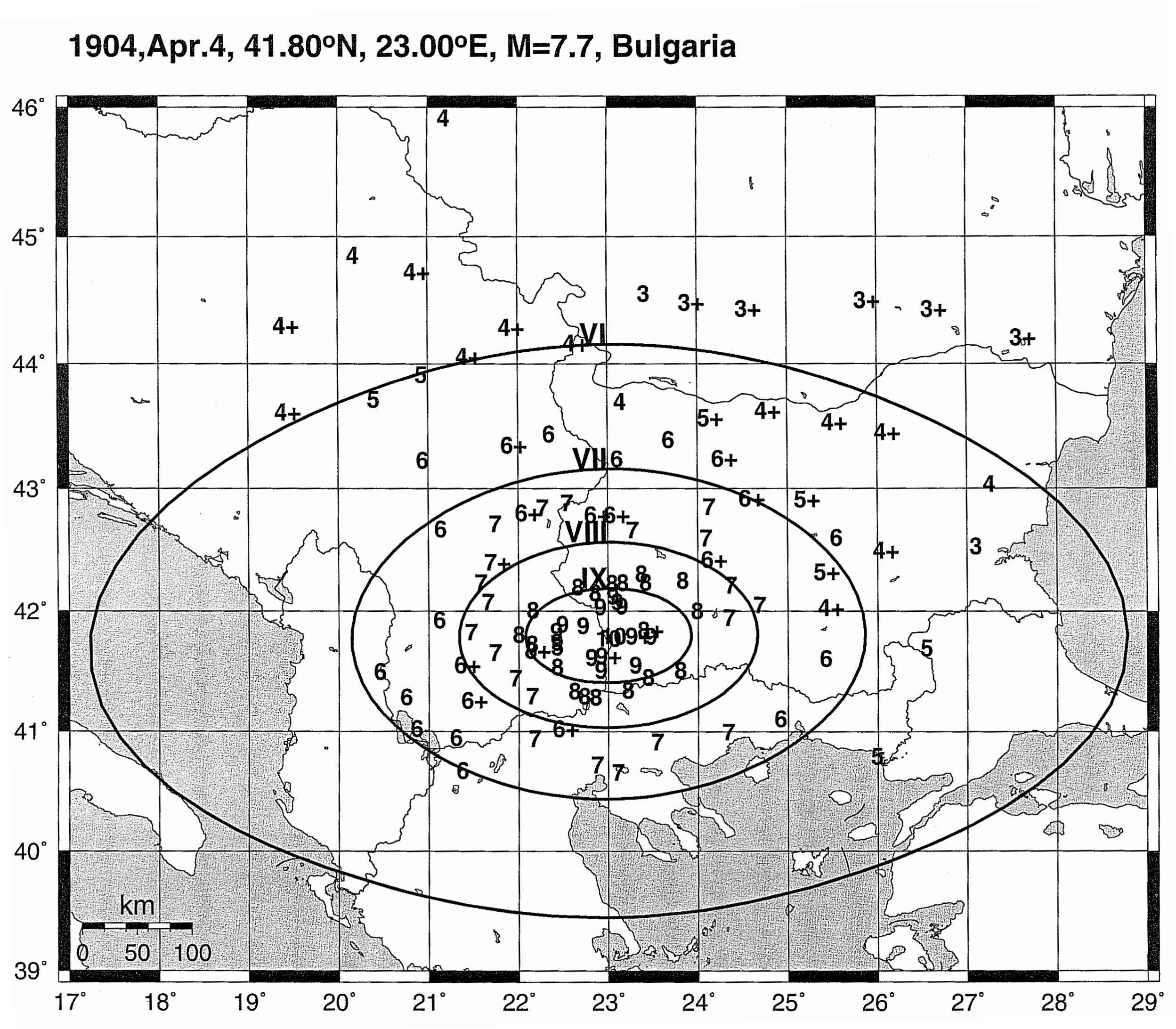

Fig.4. Isoseismal curves of the south Bulgaria earthquake, on the 4th of April 1904 (M7.7) (Papazachos et al., 1997).

were derived because of the appreciable damage caused there.

1905 June 1, 04:42:15, 42.05° N, 19.50° E, M=6.6, Yugoslavia, (IX, Shkoder)

The earthquake caused large destructions in the area of lake Shkoder where it destroyed 6,500 houses, killed 120 people and injured 500. Large cracks were observed in the ground and disturbances of ground water. Aftershocks lasted up to July of 1906. The earthquake was felt in Yugoslavia, Bulgaria and Italy.

Figure 5 evidences that the macroseismic intensity at the area of Florina was around 4, value that implies light damage at the area.

1905,Jun.1, 42.05°N, 19.50°E, M=6.6, Albania

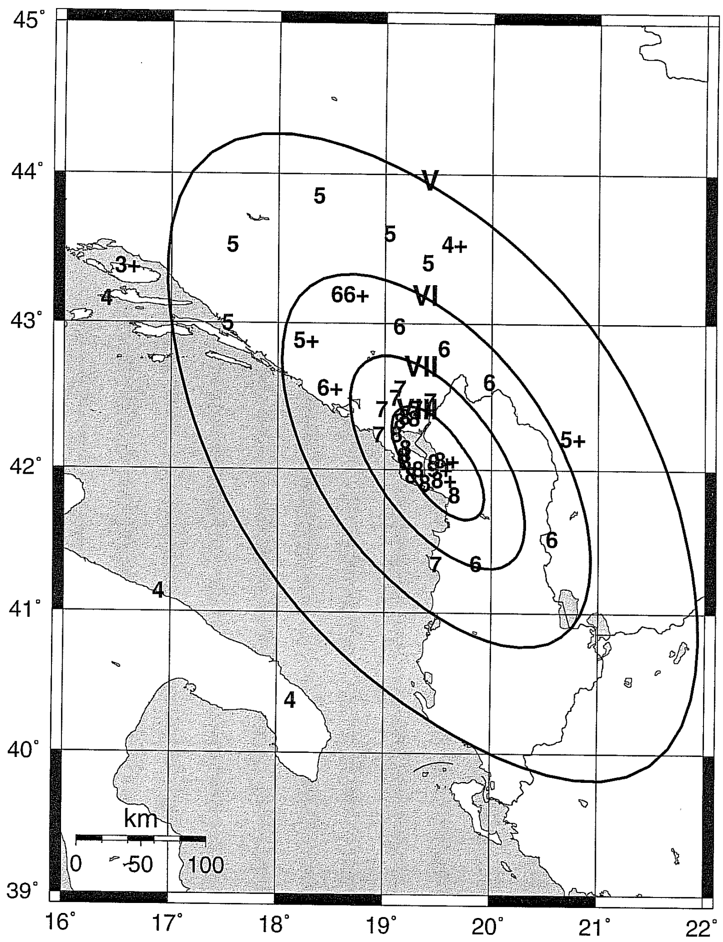

Fig.5. Isoseismal curves of the Shkoder earthquake, on the 1st of June 1905 (M6.6) (Papazachos et al., 1997).

1911 February 18, 21:35:12, 40.9° N, 20.80° E, M=6.7, Yugoslavia, (IX, Ochrida)

The earthquake caused large destructions in the area of Ochrida lake. In the village Starovo (Pogrades), the 50% of houses were destroyed. One person was killed and 4 were seriously injured. In Ochrida, many houses were damaged, while the meizoseismal area includes Strouga too. Some damage was also observed in Monastiri (Vitola) and in Florina. The inhabitants stayed under tents for a long time. The height of the vibration of the lake reached 0.5m. The shock was stronlgy felt in the whole area between the Albanian mountains and the Axios river. It was moderately felt in Corfu and lightly in Trikala. It was also felt in Belgrade and in the cape of Mikale in Italy (Lecce). The main shock was followed by sftershocks, the largest of which occurred three minutes after the mainshock (21:38:30, M=5.6).

Figure 6 evidences that the macroseismic intensity at the area of Florina was between 6 and 7, a value implying appreciable damage caused at the point of interest.

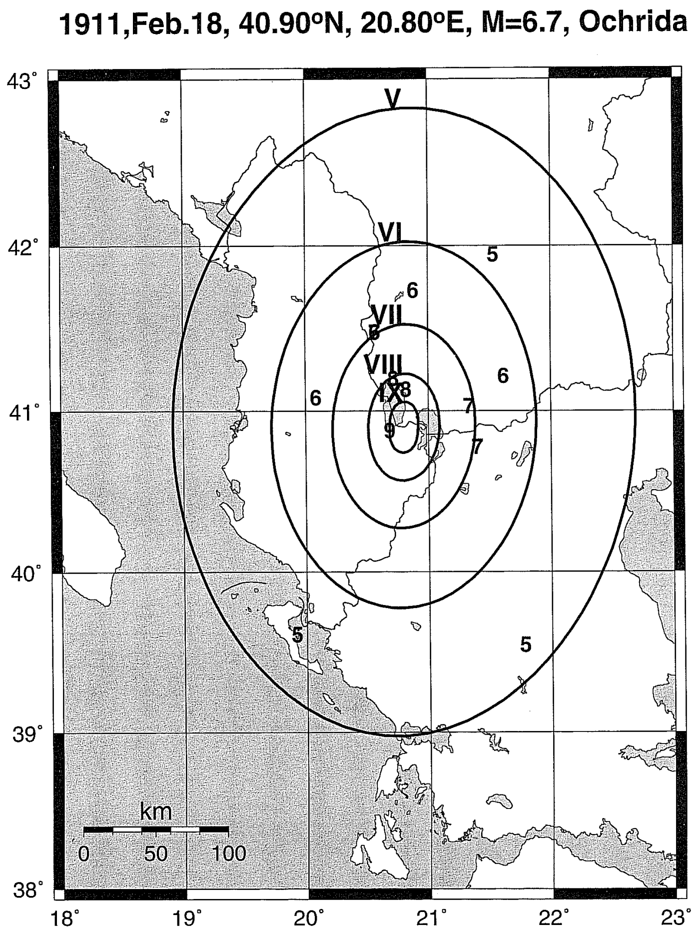

Fig.6. Isoseismal curves of the Ochrida earthquake, on the 18th of February 1911 (M6.7) (Papazachos et al., 1997).

1931 March 8, 01:50:28, 41.28° N, 22.49° E, M=6.7, Yugoslavia, (X, Valandovo)

The earthquake caused damage in 36 villages in the area of Valandovo where 2.000 houses, in a total of 3,257 were destroyed and 10,000 people became homeless and 159 people were killed. Numerous fissures were observed in the ground and the railway lines were deformed. Due to the subsidence of the ground, bridges collapsed with a result the traffic to be held up for two days.

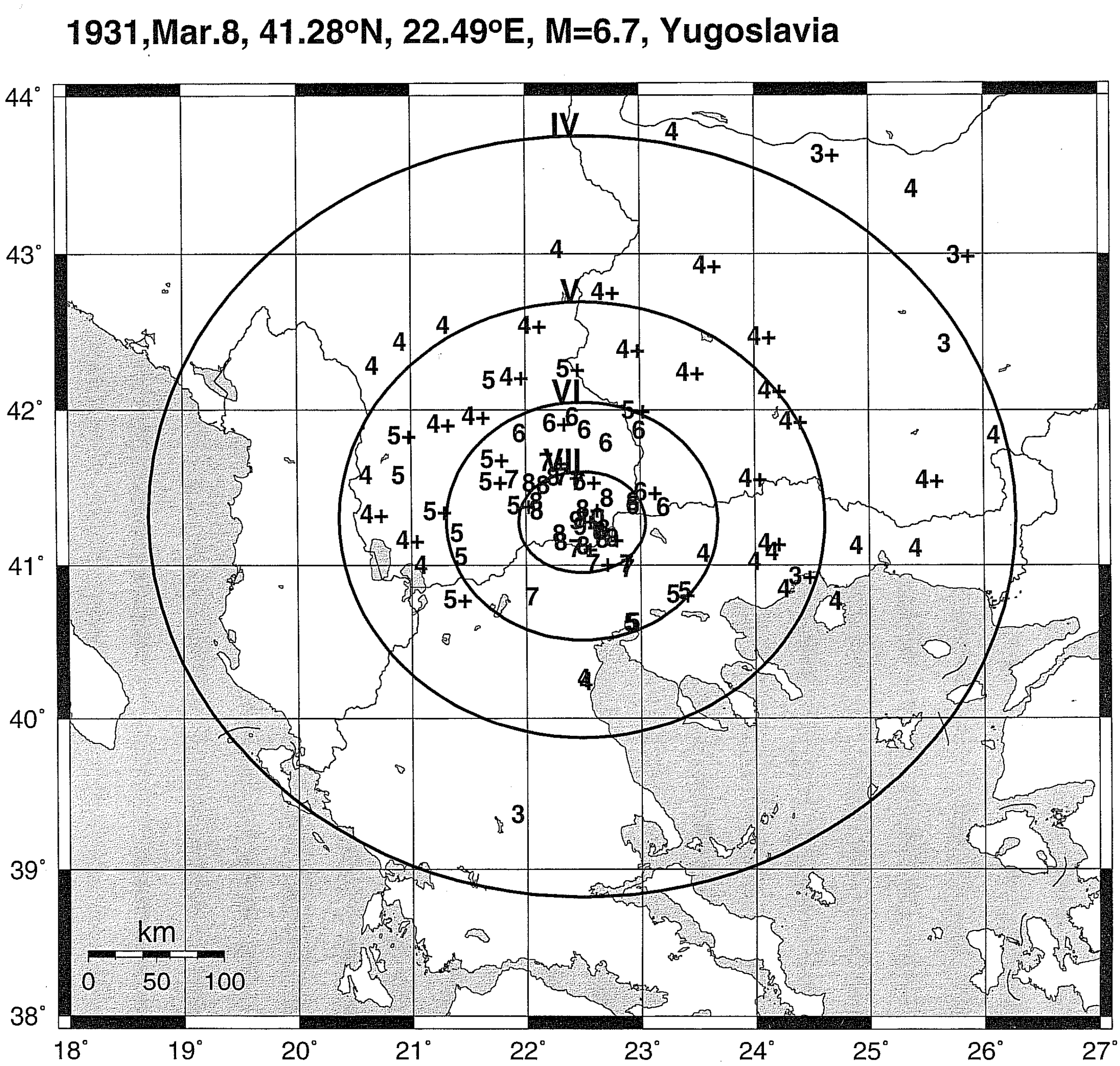

Fig.7. Isoseismal curves of Valandovo earthquake, on the 8th of March 1931 (M6.7) (Papazachos et al., 1997).

Stromnitsa, Doirani and Florina were also hit. In Idomene 4 houses collapsed and the building of the railway station, the custom house and the building of the police station suffered serious damage so that it was impossible for the officers to stay inside these buildings. In Doirane 8 houses and 1 church collapsed, and 2 people were injured. In Gevgeli, the building of the railway station partially collapsed with the result the station master and other 6 persons to be injured. The railway station in Edessa suffered serious damage. In the village Mouries of the prefecture of Pella, 24 houses became uninhabitable and 90 dilapidated. In Kilkis, many houses were fissured and in Serres serious fissures occurred in 10 houses.

In Sofia of Bulgaria, in Ano Tzoumayia and in Petritsi, the inhabitants left their houses frightened and 4 people were killed. In Thessaloniki, the shock woke up the inhabitants and many of them got out frightened in the streets. Houses suffered fissures in Depo and in Ag. Triada and a building in the corner of Tsimiski and Ag. Sofias streets. The earthquake was strongly felt in Drama, Xanthe, Thassos, Komotine and less in Karditsa and in Lecce of southern Italy.

Figure 7 evidences that the macroseismic intensity at the area of Florina was 5+, a value implying appreciable damage caused at the point of interest.

1960 May 26, 05:10:11, 40.63° N, 20.65° E, M=6.5, Albania (VIII+, Polene)

The earthquake was destructive in the upper part of the river Osoumi in Albania where 500 houses were seriously damaged, 9 persons were killed and 95 were injured. The damage expanded up to the area of Korytsa where fissures were observed in 95 houses and one person was injured. It was strongly felt in villages of the prefecture of Jannena, Kastoria, Kozene, Corfu. It was preceded by shocks the largest of which occurred in the same day with the main shock (00:48, M=4.4) and was followed by aftershocks the largest of which occurred on 9 July (22:42, M=4.7).

Figure 8 shows that the macroseismic intensity at the area of Florina was 5+, a value implying appreciable damage caused at the point of interest.

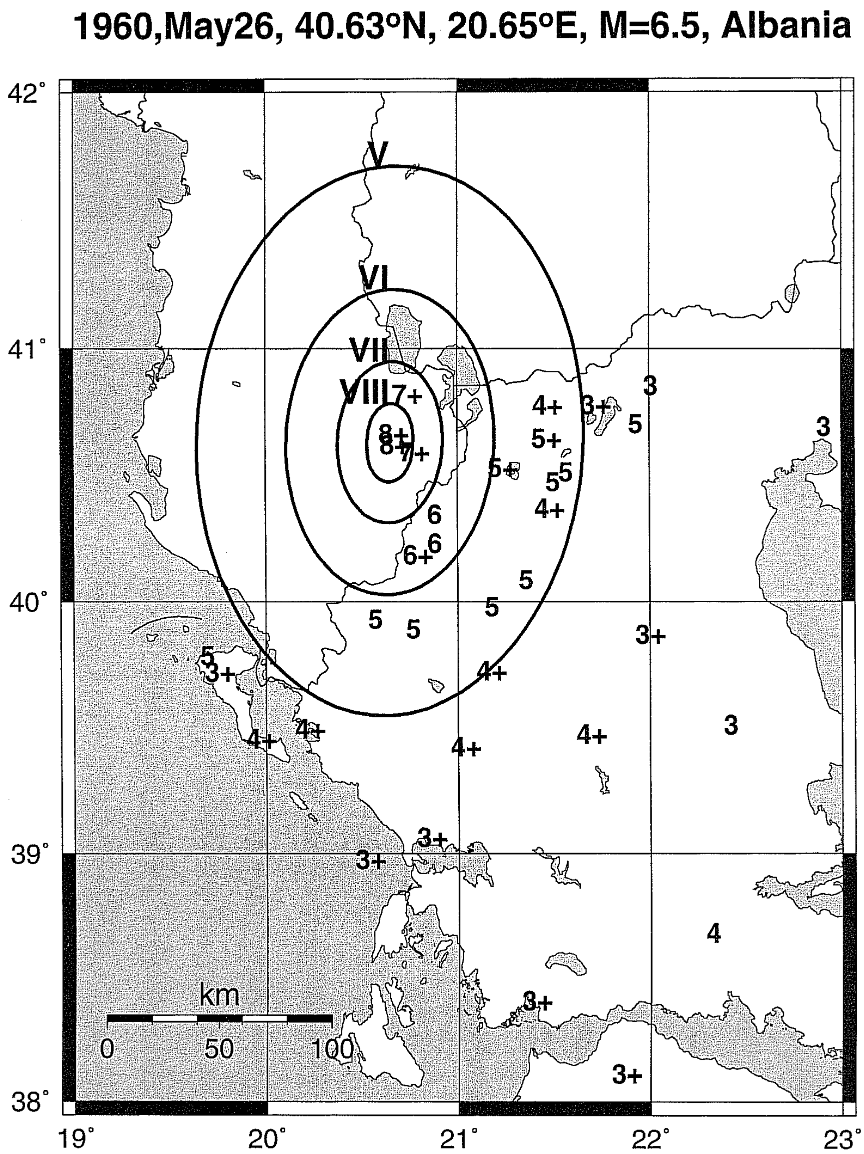

Fig.8. Isoseismal curves of the Albania earthquake, on the 26th of May 1960 (M6.5) (Papazachos et al., 1997).

1963 July 26, 04:17:12, 42.00° N, 21.40° E, M=6.1, Yugoslavia (IX, Skopje)

The earthquake destroyed Skopje in Yugoslavia. It killed 1070 people and injured 3300 from which 1200 seriously. A large fire which followed completed the destruction. The total damage was 500,000,000 dollars. It was felt in several places of northern Greece up to Thessaloniki. It was followed by shocks, the largest of which occurred in the same day with the main shock (04:54, M=4.2).

1963,July26, 42.00ºN, 21.40ºE, M=6.1, Skopje

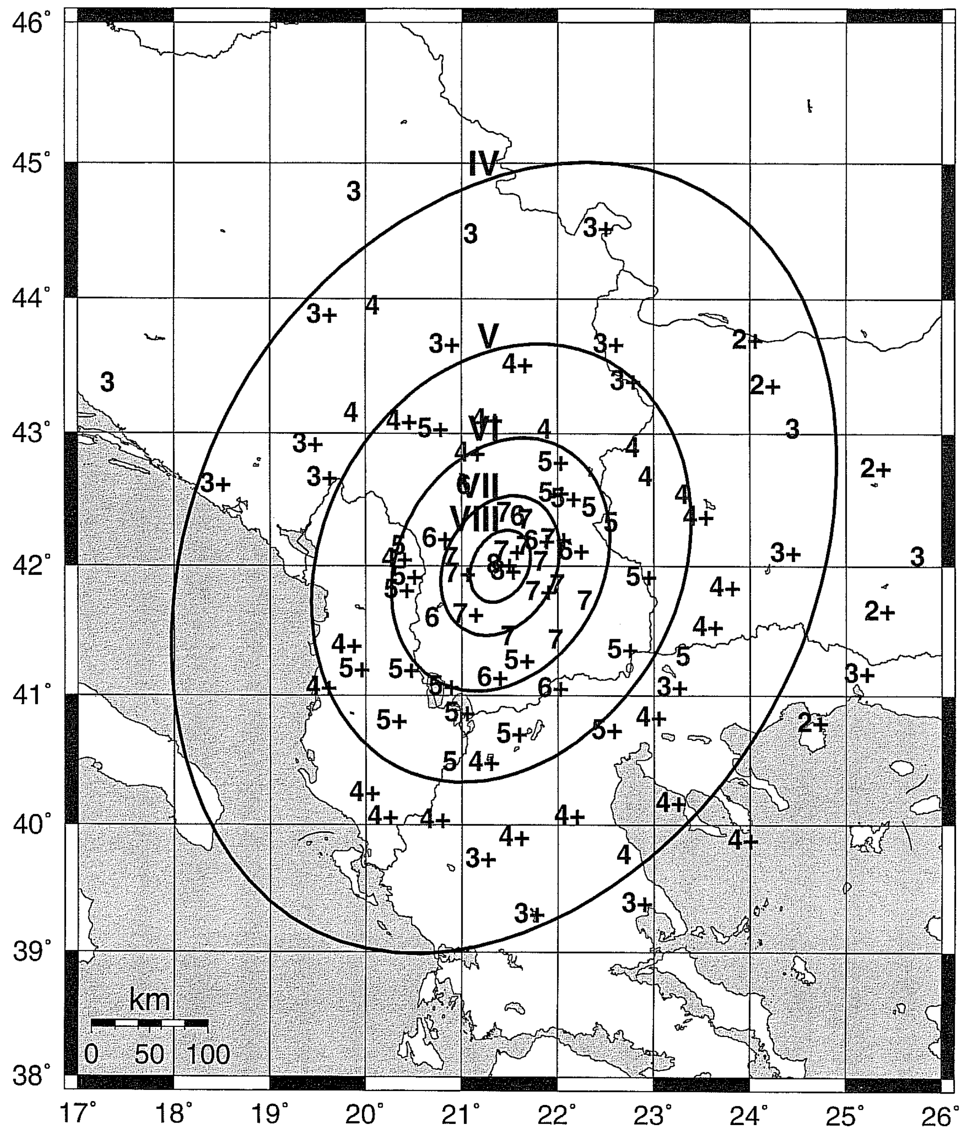

Fig.9. Isoseismal curves of Skopje earthquake, on the 26th of July 1963 (M6.1) (Papazachos et al., 1997).

Figure 9 shows that the macroseismic intensity at the area of Florina was 5+, a value implying appreciable damage caused at the point of interest.

1967 May 1, 07:09:02, 39.47º N, 21.25º E, M=6.4, Arta (IX, Drosopighe)

It caused serious damage in the prefectures of Arta and Jannena and smaller in the prefectures of Trikala and Karditsa. Totally, 940 houses were destroyed, 2567 suffered non repairable damage, 2674 serious damage and 4609 lighter damage. According to press reports, 9 people killed and 56 injured.

1967,May1, 39.47°N, 21.25°E, M=6.4, Drosopighe

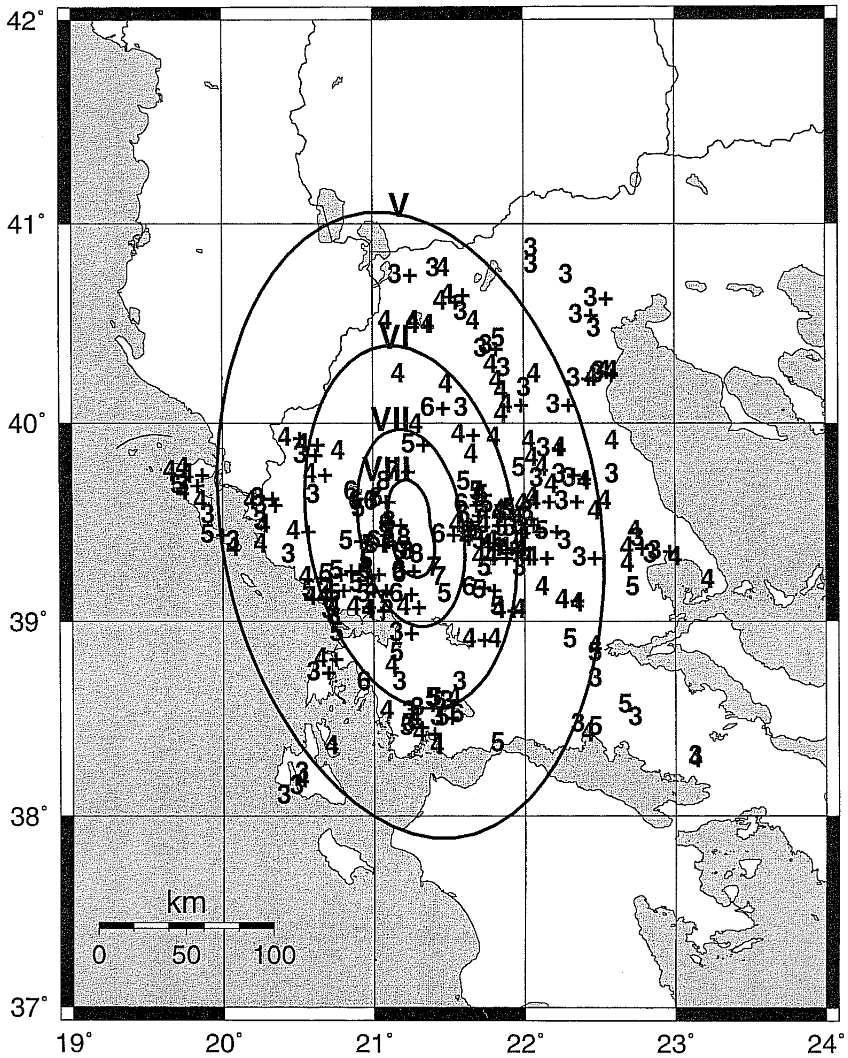

Fig.10. Isoseismal curves of the Drosopighe earthquake, on the 1st of May 1967 (M6.4) (Papazachos et al., 1997).

The largest intensities were observed in Drosopighe (IX), Melissourgoe (VIII+), Theodoriana, Athamanio, Tetrakomo (VIII) of Arta, Pramada, Megalo Peristeri (VIII), Metsovo, Vathypedo (VII+) of Jannena. It was preceded by a shock on 25 March (18:21, M=4.0) and was followed by many aftershocks, the largest of which occurred in the same day with the main shock (09:50, M=5.3).

Figure 10 shows that the macroseismic intensity at Florina was 4+, a value implying light damage in the area.

1967 November 30, 07:23:50, 41.39° N, 20.46° E, M=6.3, Albania (IX, Peshkope)

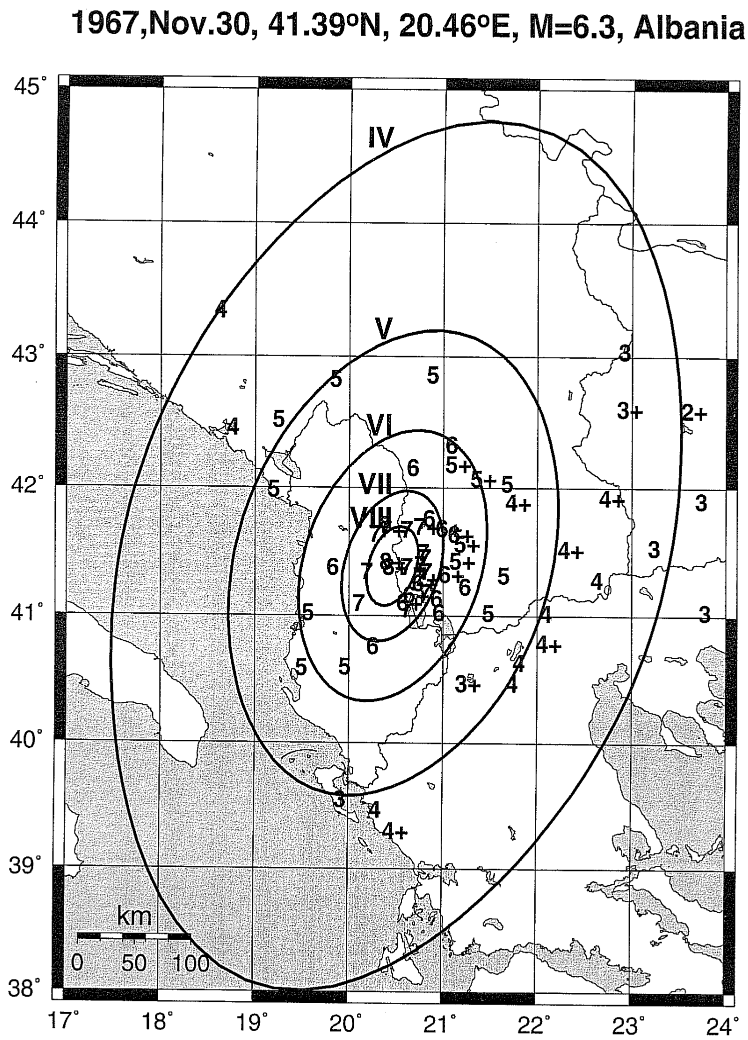

Fig.11. Isoseismal curves of Albania earthquake, on the 30th of November 1967 (M6.3) (Papazachos et al., 1997).

The epicenter of this earthquake is near the border of Yugoslavia and Albania. In the area of Peshkope in Albania it destroyed or damaged 6336 houses killed 12 people and injured 174, while in Yugoslavia killed 8 people and injured 40. It was felt in Greece up to Serres and in Emathia. It was preceded by a shock on 19 November

(01:30, M=4.4) and was followed by aftershocks, the largest of which occurred on 2 December (12:44, M=5.5).

Figure 11 shows that the macroseismic intensity at Florina was 4, a value implying negligible damage in the area.

1969 October 13, 39.69° N, 20.65° E, M=5.8, Jannena

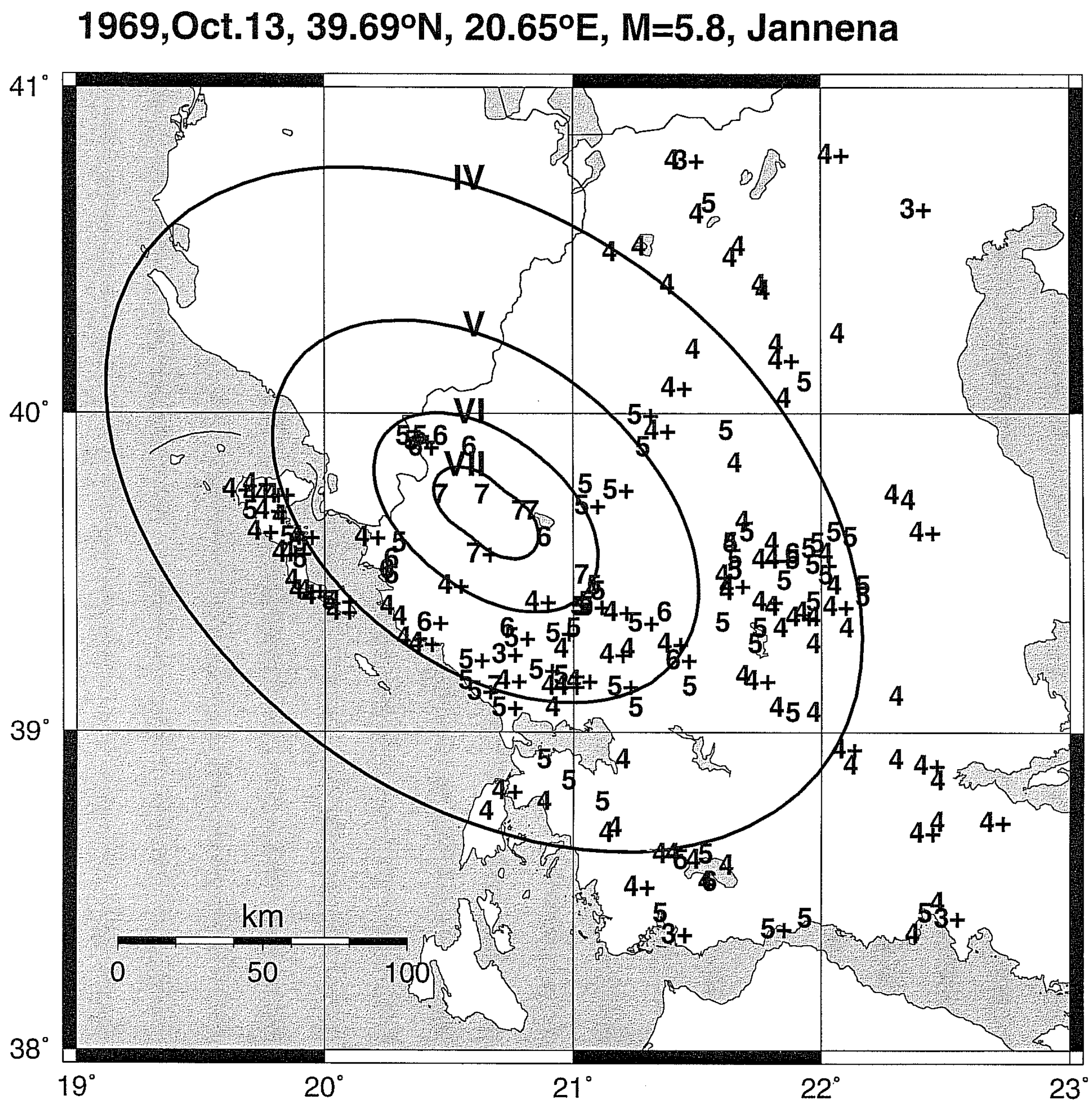

Fig.12. Isoseismal curves of Jannena earthquake, on the 13th of October 1969 (M5.8) (Papazachos et al., 1997).

The magnitude of this earthquake is smaller than 6.0 and therefore detailed descriptions on associated macroseismic effects are not collected. The macroseismic intensity in the area of Florina is 4 (Fig. 12), which means light damage in this area.

1994 September 1, 16:12:42, 41.15° N, 21.20° E, M=6.1, Yugoslavia (VII, Bitola)

Many people were injured, and some damage was caused in the Bitola area. It was strongly felt in the area of Florina (VI, Niki, Ag. Germanos) and in other parts of Greece up to Larisa.

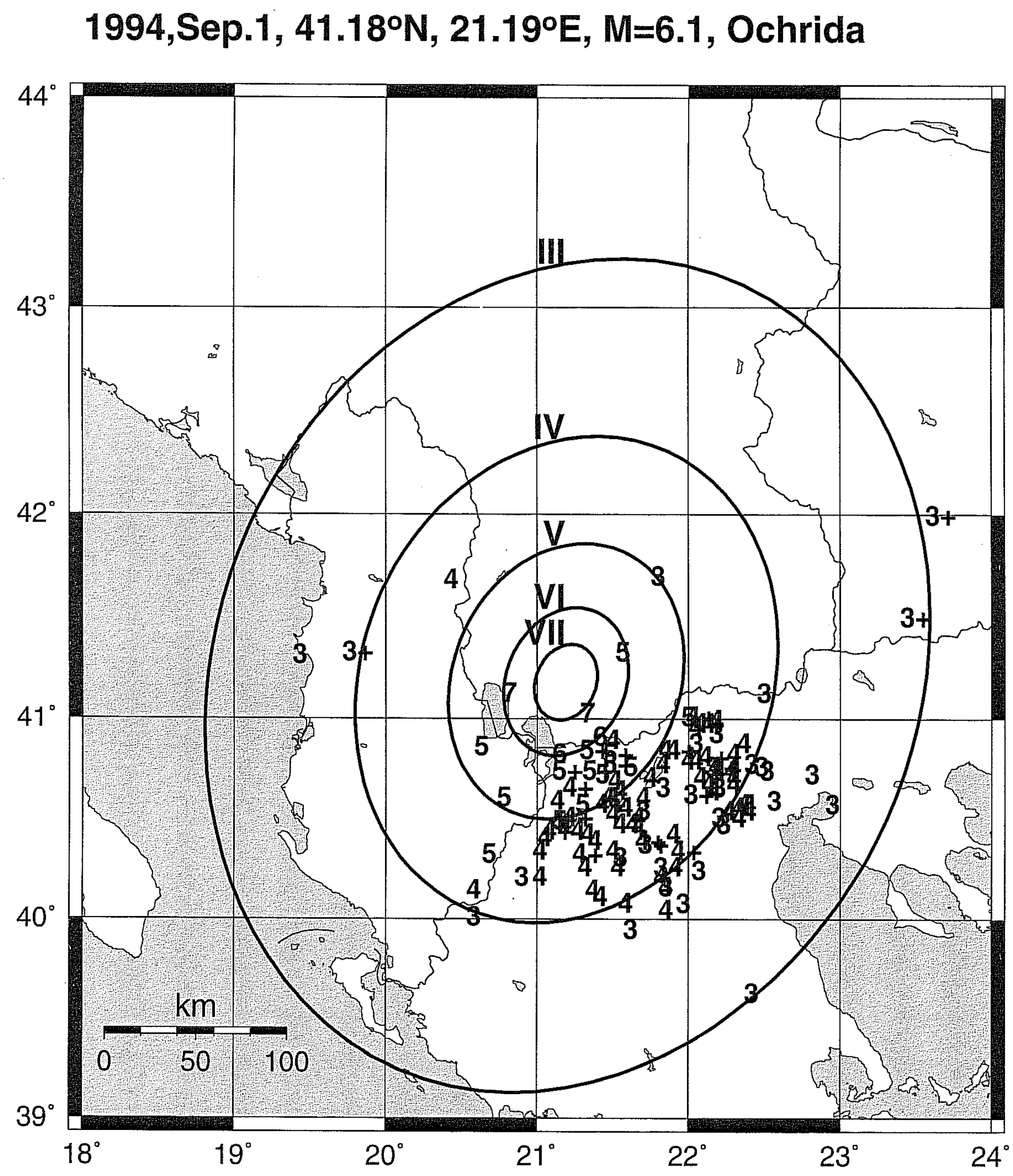

Fig.13. Isoseismal curves of the Ochrida earthquake, on the 1st of September 1994 (M6.1) (Papazachos et al., 1997).

1995 May 13, 08:47:17, 40.16° N, 21.67° E, M=6.6, Grevena (IX+, Knide)

The earthquake caused destructions in the area of Grevena and Kozane. In the area of Grevena the villages Knide (IX+), Kalamitsi, Varis (IX), Taxiarches, Kokkinia, Vatolakkos, Poros, Lanadakia, Kalochios, Pylirioi and Pontine (VIII) were destroyed and in Kozane area, the villages Chromio, Daphnero (IX), Podiane, Kaesareia, Rymnio (VIII).

1995,May13, 40.16°N, 21.67°E, M=6.6, Kozani

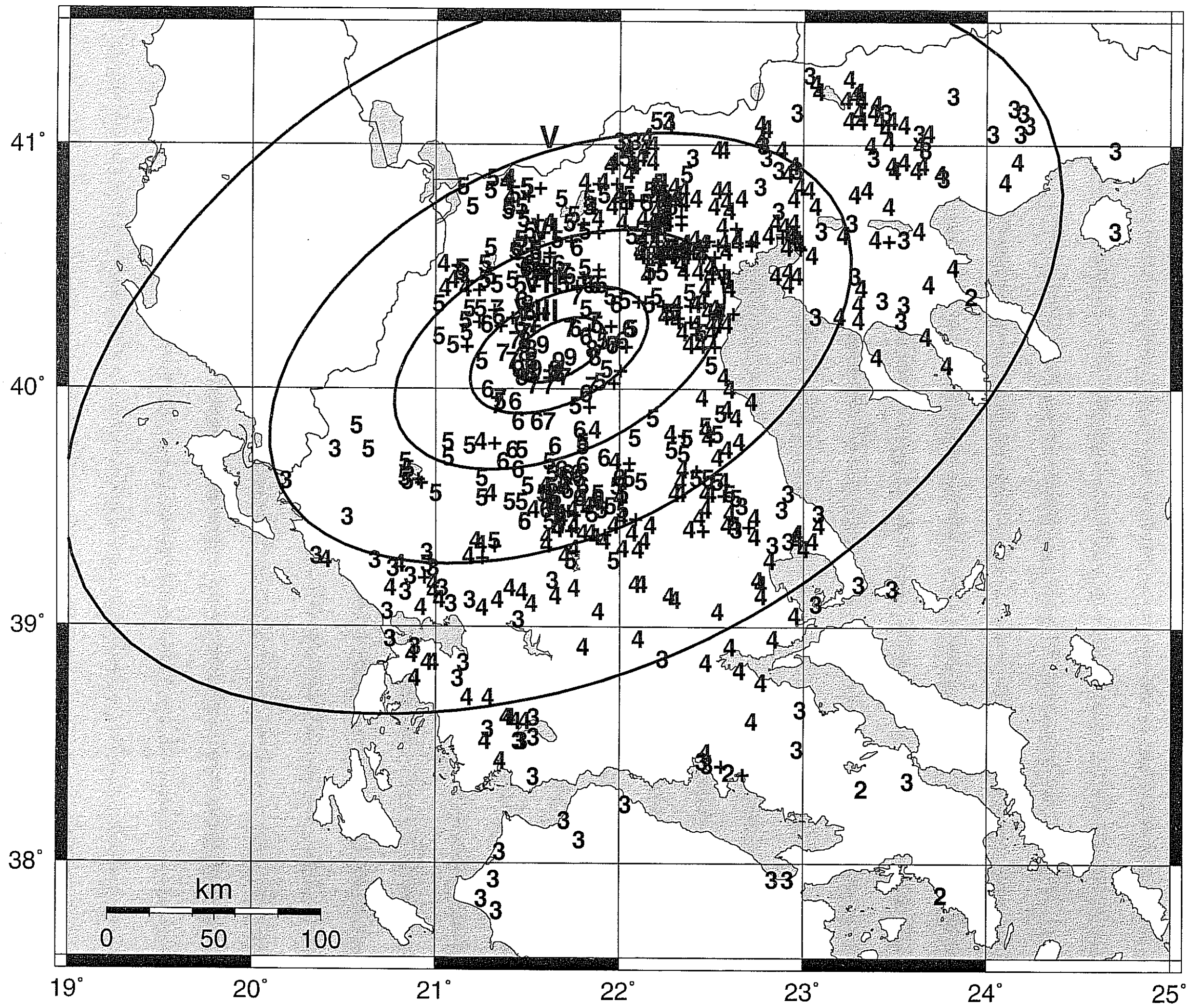

Fig.14. Isoseismal curves of the Kozani earthquake, on the 13th of May 1995 (M6.6) (Papazachos et al., 1997).

In the Grevena prefecture, from 9590 buildings, 1924 collapsed or destroyed and 1599 suffered serious damage, while in the Kozane prefecture from 43184 buildings the 7693 collapsed, destroyed or suffered serious damage. Twenty people were injured. The estimated damage is about 450 million U.S. dollars. Along a rupture zone of total length of 30 km oriented in a ENE direction, ground fissures of up to 15 cm displacements were observed. In this zone the maximum damage (I≥VIII) occurred. The earthquake was preceded by foreshocks the largest of which occurred four minutes before the main shock (08:43, M=4.5) and was followed by many aftershocks the largest of which occurred on 17 July (23:18, M=5.5).

Figure 14 reveals that the macroseismic intensity at Florina was 5, a value implying moderate damage in the area.

1.3. FAULT PLANE SOLUTIONS OF STRONG EARTHQUAKES AND THE REGIONAL STRESS FIELD

Brittle deformation in intra-continental regions is usually associated with distributed faulting and seismic activity. This is well expressed in the rapidly deformed Aegean region (Fig. 15) where the earthquakes and active faults are distributed over Greece and western Turkey, as being part of the back arc Aegean region, reaching up to Albania, North Macedonia and Bulgaria. The regional kinematic details are roughly drawn in Figure 15 with arrows imprinting relative plate motion (contraction, stretching and horizontal motion), along with reliable fault plane solutions of earthquakes with M≥5.0, shown as lower hemisphere equal area projections, that provide information on the spatial distribution and orientation of the principal stress axes.

In the Greek mainland the extensional deformation was the driving mechanism for the formation of fault bounded basins, striking WNW – ESE, like in the study area. Fault plane solutions of smaller magnitude earthquakes, namely the ones occurred on the 17th of February 2013, determined by moment tensor inversion, exhibited normal faulting on a fault striking almost E – W and dipping to the north at a dip angle of 50° (Mesimeri et al., 2017).

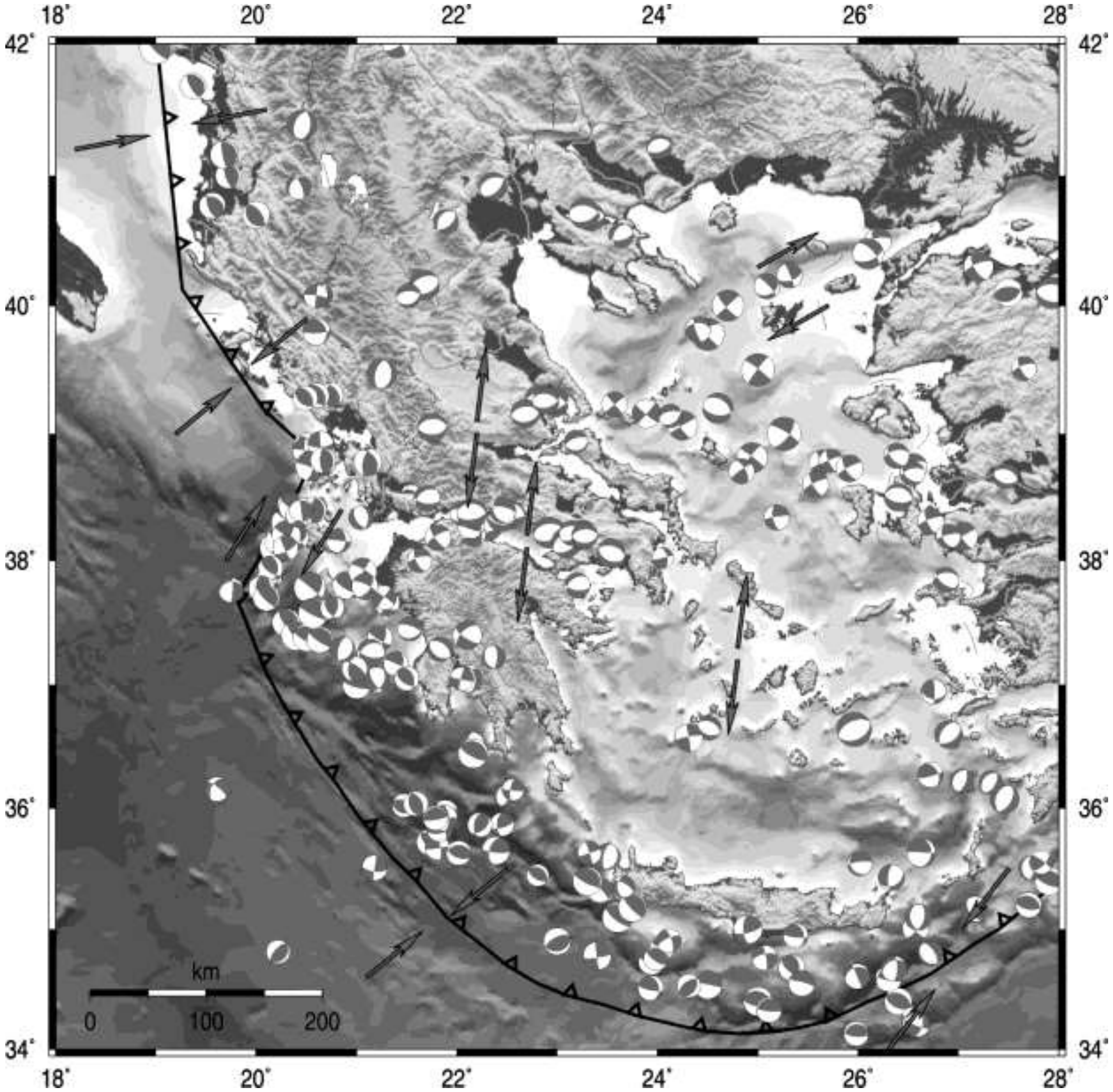

Fig. 15. The main active boundaries, the spatial distribution of the earthquakes with M≥4.0, and the available focal mechanisms in the last few decades. The arrows indicate the different kinematics (contractional by convergent arrows, strike-slip by parallel arrows and extensional by divergent arrows).

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PART 2

MONITORING OF THE SEISMIC ACTIVITY AND IDENTIFICATION OF THE RELATED ACTIVE STRUCTURES

2.1.Introduction

Microseismicity studies conducted by the deployment of temporal local networks contribute to a better understanding of the underlying mechanism of seismogenesis. Imaging of major faults along with identification of smaller ones could be achieved through this procedure. This line of research is followed for the Florina Basin (Fig. 1) located in Northwestern Greece. It consists an intermountain graben composed of metamorphic rocks and formed as a result of extensional stresses following the Alpine orogenesis (Koukouzas et al., 2015). Information on strong earthquake activity has been described in the previous chapter.

More recently and in particular in 2012, an increase in the seismic activity was observed on the western part of the area near Lake Prespa forming two small clusters (blue circles in Fig. 1). Increased seismic activity started near Florina with the largest earthquake (M_w=4.1) on 17 February 2013, and for several months it was continued with a big number of low magnitude earthquakes. The detectability of the Hellenic Unified Seismological Network (HUSN) (hexagons in Fig. 1 inset map) is not adequate to efficiently record the microseismicity. Therefore, six seismological stations were installed in the area (triangles Fig. 1) and their recordings were used in combination with the ones of HUSN.

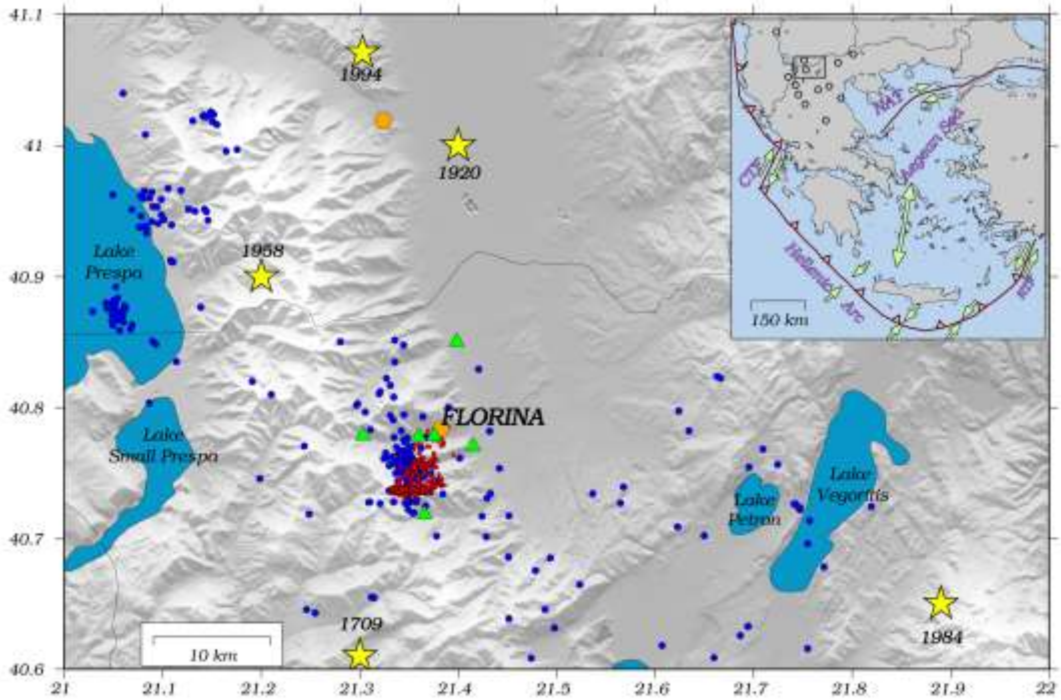

Fig. 1 Morphological map of northwestern Greece along with the relocated epicenters of earthquakes recorded by the permanent network that occurred during 2012-2014 January (blue circles) and these from the temporal network during July 2013 – January 2014 (red circles). The earthquakes with M≥5 (both historical and instrumental) are depicted by stars. Inset Map. The back-arc Aegean and the surrounding area, with the dominant seismotectonic features: Hellenic Arc, North Aegean Trough (NAT), the Cephalonia (CTF) and Rhodes (RTF) Transform Faults. The study area is enclosed in the rectangle (Mesimeri, et al. 2017)

2.2 Seismicity in 2012-2014

Data from both the regional and the temporal local networks were used, and the available recordings were gathered from 13 broadband digital stations of HUSN, which is in operation since 2008 and covers adequately the area of Greece, located at epicentral distances less than 150 km (hexagons Fig. 1 inset map) from Florina, with sampling rate of digitization 100 samples/sec. Phases of 521 earthquakes that occurred during 2012 – 2013 were collected from the monthly bulletins of the

Geophysics Department of Aristotle University of Thessaloniki and the National Observatory of Athens (NOA). The local seismic network was installed at the end of July 2013 and operated until the end of January 2014. It was consisted of 6 stations equipped with three component broadband seismometers (Guralp CMG40T) and high resolution (24 bits) digitizers (Reftek 130-01) with sampling rate 125 samples/sec (triangles in Fig. 1). Time and station location were accurately evaluated by GPS receivers. Approximately 1,500 earthquakes, with at least 4 P- and 3 S- phases, were detected after visual inspection of the waveforms with P and S -phases manually picked (Mesimeri, et al. 2017).

The relocated seismicity (Mesimeri, et al. 2017) shown in Figure 2a reveals a seismic zone mainly divided in two clusters. Blue and red colors were used to denote epicenters recorded by the permanent and the local networks, respectively. Yellow circle and star denote the two largest shocks recorded by the permanent network whereas the size of symbols is proportional to the events magnitudes (Fig. 2b). The denser cluster is located at the southernmost part of the study area (south of 40.74° N), the vast majority of them being recorded by the local network and aligned in a narrow almost E-W oriented seismic zone. A second cluster including the two largest earthquakes of the sequence is positioned to the north. Although the general trend of the seismic zone is rather N-S, taking into account the orientation of the southern cluster, the local morphology, the regional stress regime and the focal mechanisms of the largest earthquakes, a cross section attempted along the line N-N′ (Fig. 2b), normal to the alignment of the clusters. The hypocentral distribution along this profile defines a seismic zone generally dipping to the north with focal depths ranging from 2 km to 8 km. However, a clear separation between the southern cluster and the rest of the activity is observed.

Seismic activity started in the cluster which includes the largest earthquake at depths ~4.5 km – 6 km (blue symbols in Fig. 2). This cluster with dimensions 2 x 2 km dipping at 45° to the north was considered to be associated with the fault segment which produced the M_w=4.1 earthquake. The length of this seismic zone agrees with a fault corresponding to an M_w=4.1 earthquake derived from scaling laws (Wells and Coppersmith, 1994; Papazachos et al., 2001).

In both the map and the cross section (Fig. 2) a narrow, very well defined south dipping zone is shown. It has an almost east – west orientation and almost vertical dipping, with focal depths ranging between 2 km and 4.5 km. All these events were recorded by the local network and are shown with the red symbols in Fig. 2. Low magnitude events were recorded there, with the largest one having a magnitude of M_w=3.4.

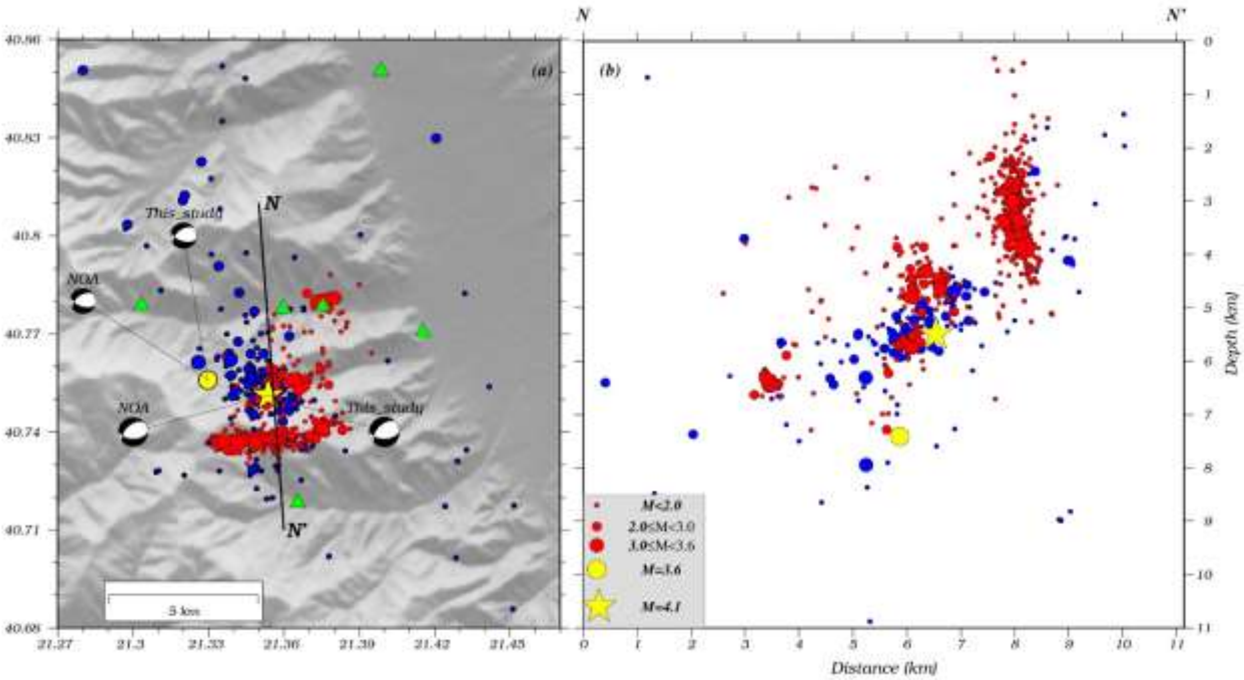

Fig. 2 (a) Epicentral distribution of the relocated earthquakes along with fault plane solutions of the two strongest events of the sequence. The locations obtained from recordings of HUSN are depicted with blue circles, with red circles are shown the locations obtained from the local network. N-N′ is normal to the strike cross section. (b) Cross section of the relocated earthquakes along the line of N-N′. (Mesimeri, et al. 2017)

2.3. Seismicity 2015-2019

Seismicity for the period 2015 – June 2019 is shown in the following six maps. The first one with all the earthquakes between 2015 and June 2019 and the next five ones, with the yearly seismicity.

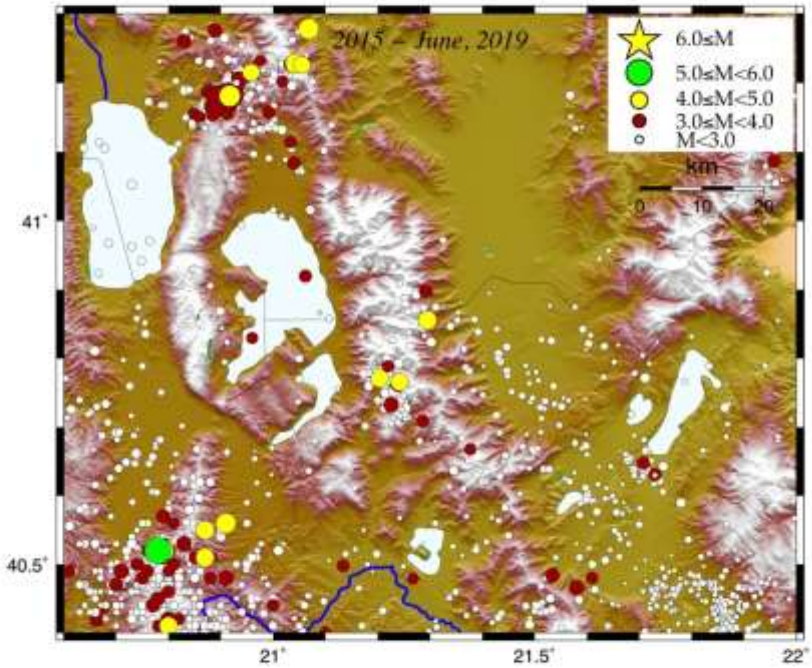

Fig. 3 Seismicity distribution in the study area during 2015-June, 2019.

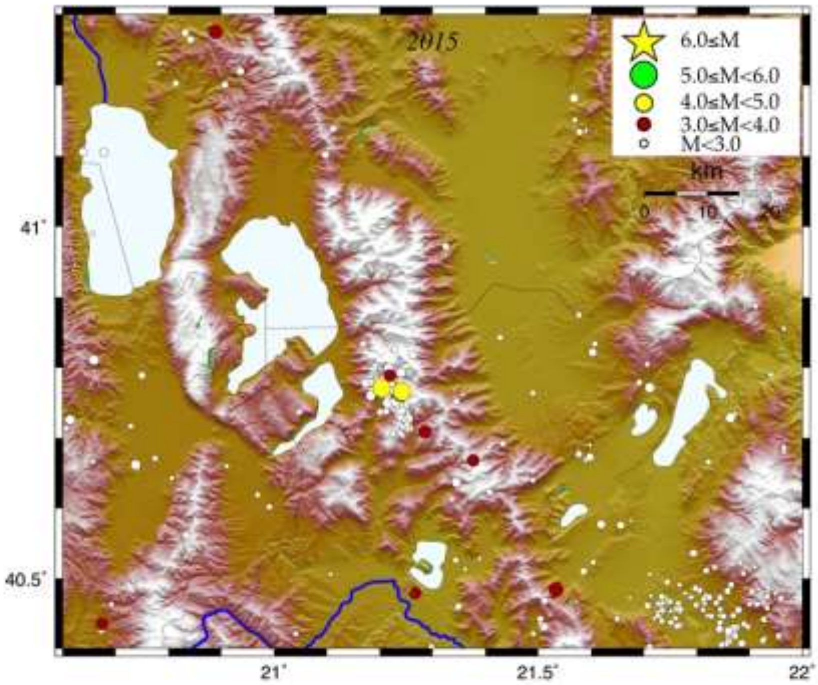

Fig. 4 Seismicity distribution in the study area during 2015.

During 2015 there is a cluster with two earthquakes with magnitudes M>4.0 in the mountainous area west of the epicentral area of the previous years which is included in the data of the previous local experiment. Another cluster is observed in the southeastern part of the map with all the earthquakes there with magnitudes M<3.0. The last seismic cluster has been occurred in the area of mine activities south east of Ptolemais. There are also a few individual earthquakes with magnitudes 3.0<M<4.0 occurred during this year.

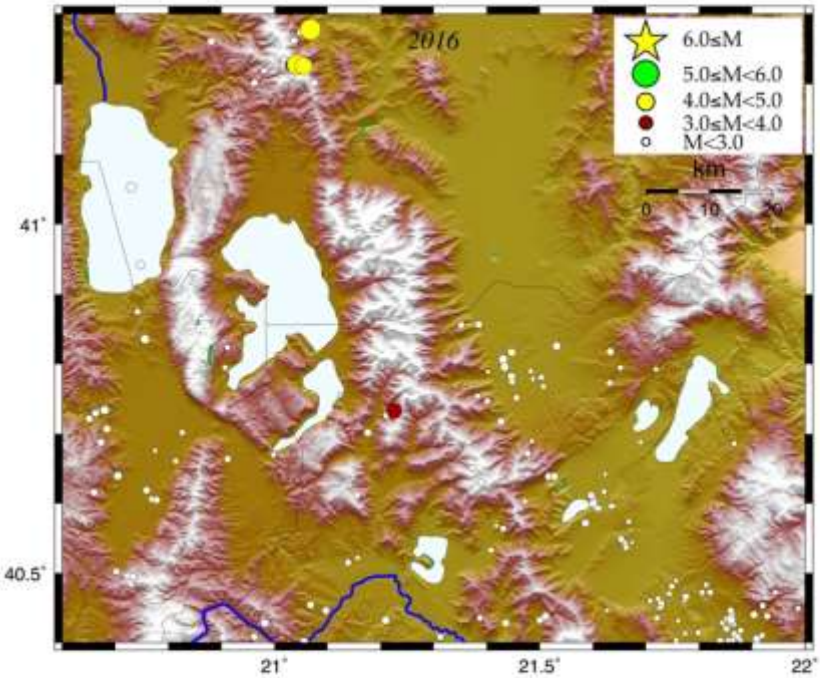

Fig. 5 Seismicity distribution in the study area during 2016.

In 2016, seismic activity is lower in comparison with the previous year. There are three earthquakes with M>4.0 in the territory of North Macedonia, northeast of lake Ohrid. Only one earthquake with M> 3.0 is observed east of lake Mikri Prespa. In the southeasternmost part of the map the seismic activity is continued although with lower number of earthquakes in comparison with the previous year. Some activity is also observed in the basin east of Florina with all the shocks with magnitudes M<3.0

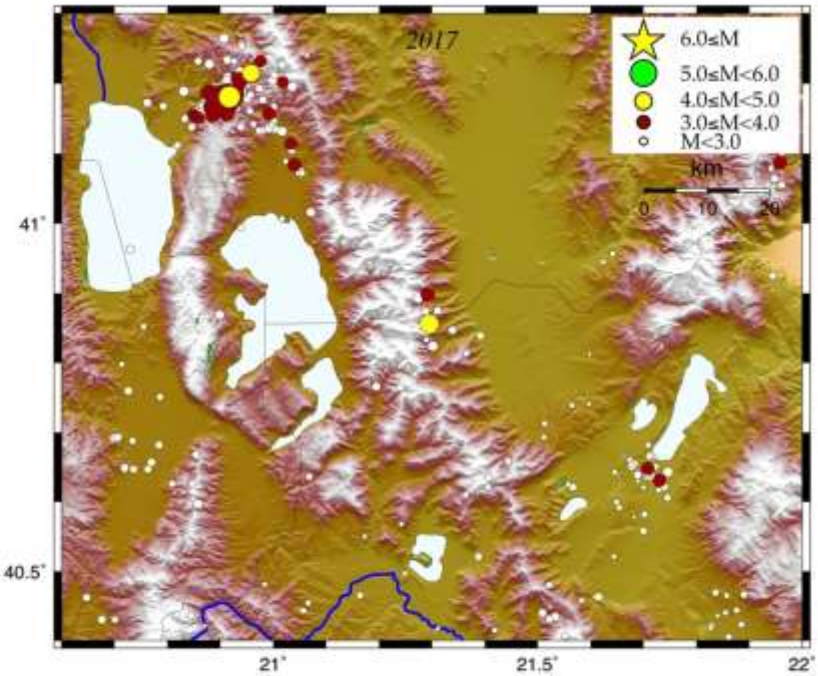

Fig. 6 Seismicity distribution in the study area during 2017.

In 2017, the highest activity is observed in the territory of North Macedonia again, Northeast of lake Ohrid. Two earthquakes with M>4.0 occurred there, accompanied by several with 3.0<M<4.0. One more cluster but smaller in the magnitudes and the number of shocks occurred in the area close to the southern banks of lake Vegoritis. This cluster comprises two earthquakes with M>3.0 and several shocks with M<3.0. Although much weaker than in the previous years, the area in the southeast part of the map remains active.

In 2018, seismic activity in the whole area is very low. No earthquake with M>4.0 occurred and only a few shocks with 3.0<M<4.0. The seismic activity in the southeastern part of the area is continued. Seismic activity is also observed in the basin east of Florina with low magnitude shocks.

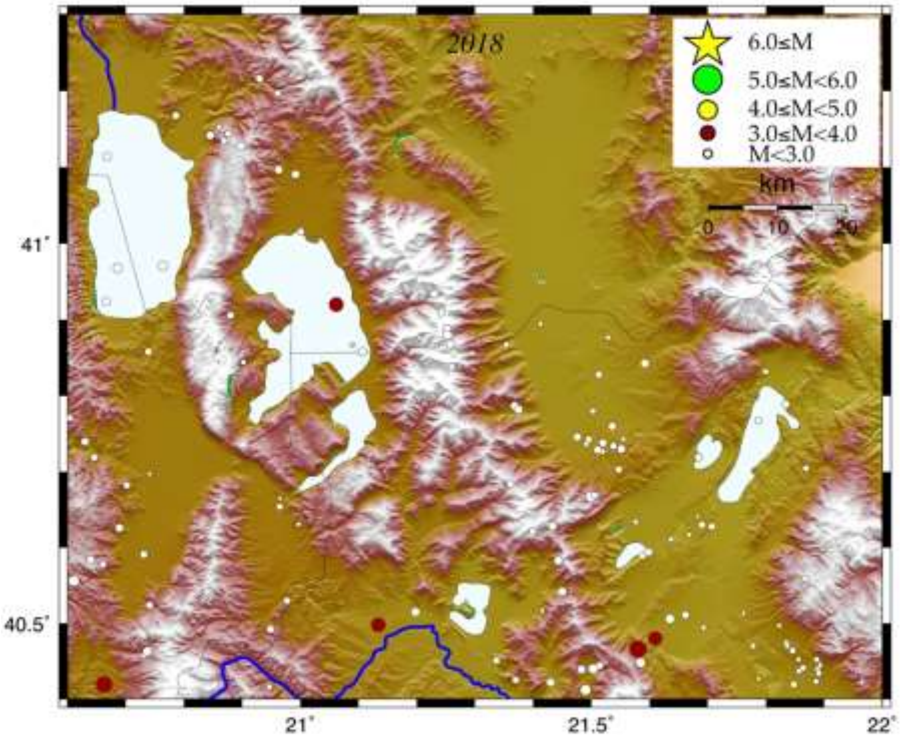

Fig. 7 Seismicity distribution in the study area during 2018.

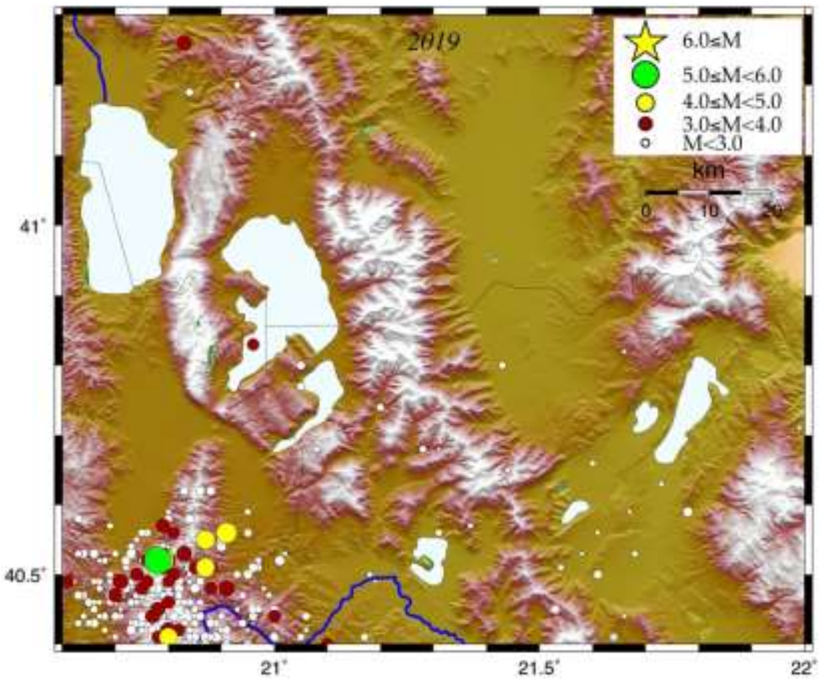

Fig. 8 Seismicity distribution in the study area during January-June 2019.

In 2019, the more spectacular seismic activity appears in the southwest part of the area along the Greece-Albania borders. An earthquake of magnitude M5.1

occurred there on June 01, 2019 which is associated with a few shocks of magnitudes M≥4.0 and other smaller aftershocks. In the rest of the area seismicity is very low. The only activity with shocks of very low magnitude in the area south southwest of Vegoritis lake.

2,4. Installation and operation of the local digital seismological network in 2018-2019

In order to improve the accuracy of the focal coordinates' determination, and consequently the more precise identification of the active tectonic structures in the study area, a local digital seismological network of high resolution was installed in the prefecture of Florina in a zone near and along the borders with North Macedonia. Five (5) seismological stations were installed, equipped with broad band seismometers, of Guralp CMG40–T type, along with five recording systems of high resolution digitizers (24 bits) Reftek 130–01 type. The digitization is performed with a sampling rate of 100 samples/second. The location identification and the continuous time correction is achieved by the use of GPS systems, with which each recording system is equipped. The installation and operation of the network was started on September 17, 2018. This seismic network operated for more than seven months, until April 22, 2019. The recordings of the local network along with the ones of a permanent seismological station, which is in operation in the area, are used for the seismicity location. The permanent station is maintained by the Department of Geophysics of the Aristotle University of Thessaloniki and belongs to the Hellenic Unified Seismographic Network (HUSN). This is also a broad band station and its characteristics are similar with the ones of the temporary installed stations.

Information on the stations names, geographical coordinates and altitudes of the installation location is given in Table I. The seismological station with code name FNA is the permanent one.

Table I. Information on the code names and location of each seismological station of the local network that has been installed in the study area in the framework of the research project. Florina (FNA) is permanent station which belongs to the Hellenic Unified Seismographic Network (HUSN).

Seismological Station Name	Station Code Name	Latitude (ö°i)	Longitude (ë°Å)	Altitude (m)
Alona	ALON	40.7787	21.3034	1025
Florina	FNA	40.7842	21.3825	750
Itea	ITEA	40.8186	21.5173	613
Kladorachi	KLAD	40.8253	21.3954	684
Marina	MARI	40.8614	21.4936	596
Neos Kafkasos	NKFK	40.8892	21.4722	597

The seismological stations, shown in Figure 9, were installed at locations in the study area, with the aim to record earthquakes close to the Greek–North Macedonia borders. Since the expected earthquakes in the area would be of low magnitude, the interstation distance was selected to be as small as possible.

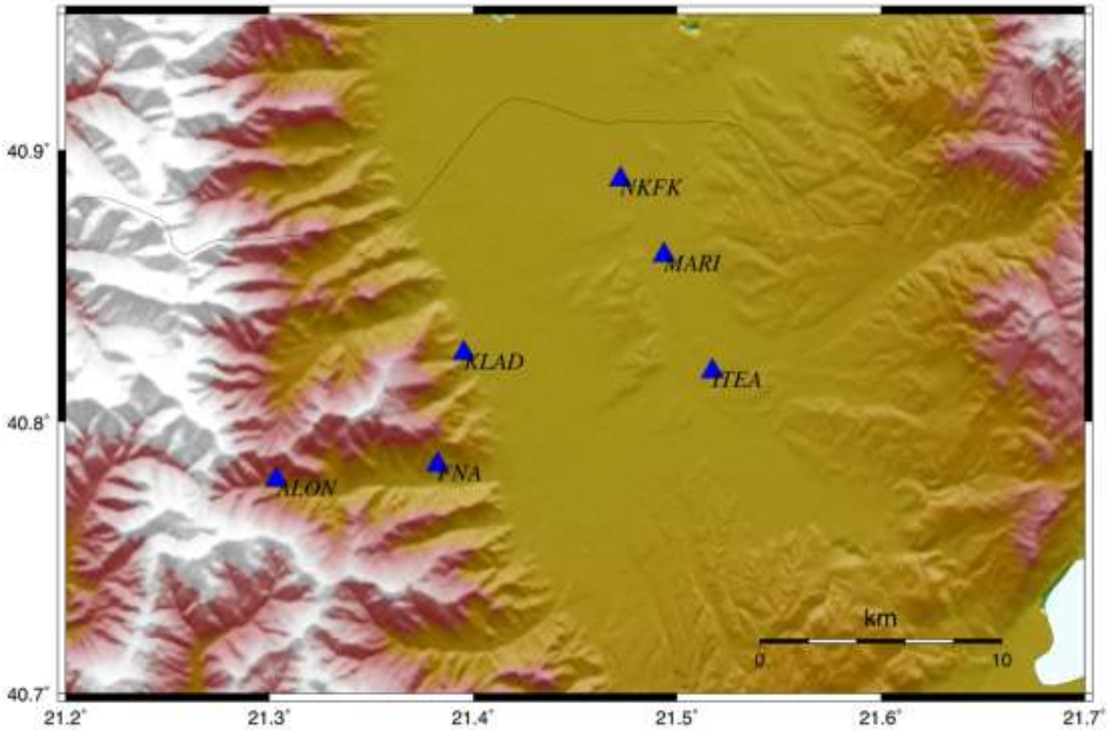

Fig. 9. The locations of the 6 local seismological stations (blue triangles), which have been installed in the study area, the recordings of which are used for the purposes of the project.

In Figure 10, four pictures showing housing and instrumentation of four seismological stations are depicted. Figure 10a shows the building where the station ALON installed. Figures 10b, 10c, 10d show the installed equipment at the stations Kladorachi, Marina and Neos Kafkasos, respectively.

(a) (b) (c) (d)

Fig. 10. Housing and equipment of the local seismological stations (a) Alona (b) Kladorachi (c) Marina and (d) Neos Kafkasos.

2.5. Recordings and location of local earthquakes

During the six months of the operation of the local seismological network all the shocks having recordings with time difference between P and S arrivals less than ten seconds were analyzed. Figure 11 depicts the recordings of a local earthquake at the station KLAD. From top to the bottom the E-W, N-S and the Vertical components, respectively, are shown. This shock occurred on September 23, 2018, 04:55 UTC, its magnitude equals to M=0.8 and it occurred in an epicentral distance of 12.4 km from the station KLAD at a focal depth of 9.2 km.

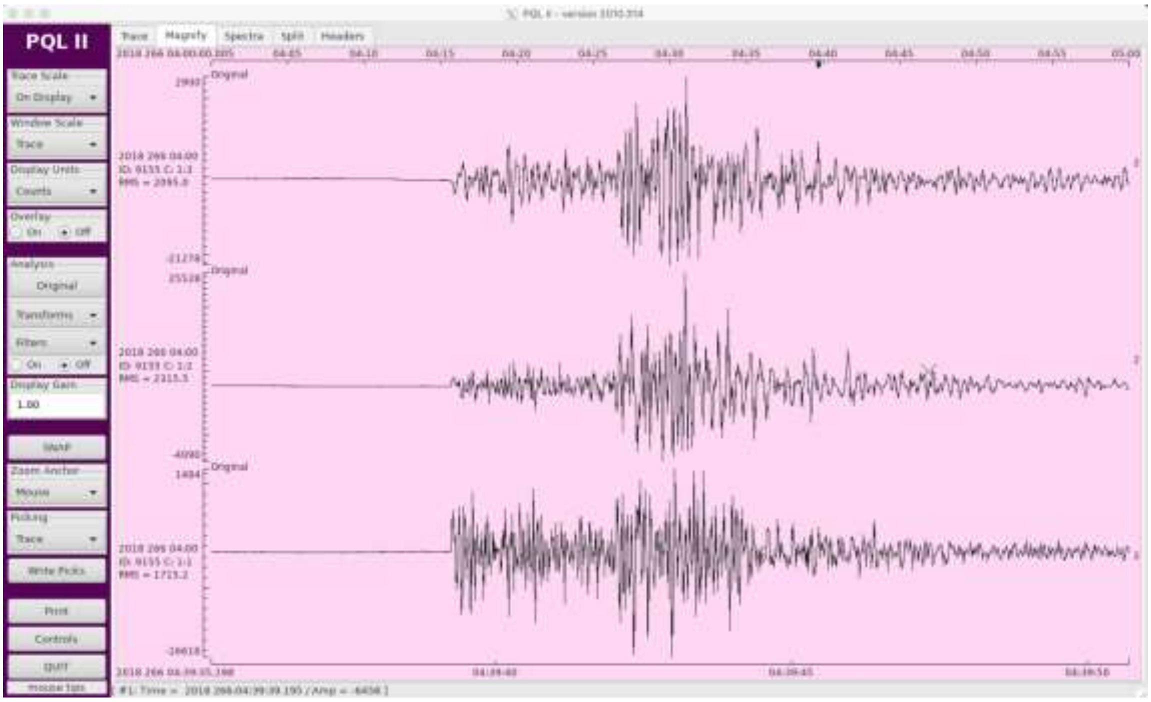

Fig. 11. Recordings of the three components (E-W, N-S and Z) at station KLAD of the local earthquake which occurred on September 23, 2018.

After phase picking, which was done manually after thorough inspection of the waveforms, the recorded earthquakes were located using the Hypoinverse program (Klein, 2002). The necessary 1D velocity model of the crust and the velocity ratio (v_p/v_s) which have been proposed by Mesimeri et al. (2017) are used. These data were derived after a thorough analysis and relocation of numerous microearthquakes in the study area, using the double difference technique and waveform cross correlation. These shocks occurred during a microseismic excitation that started in

February 2013 and lasted almost one year. The data used here derived from a dense local network which installed around the epicentral area and operated for six months.

In the six months of the local network operation, 192 earthquakes having recordings in three or more stations were analyzed. Their local magnitudes were calculated applying the formula proposed for the area of Greece by Scordilis et al. (2016). Table 2 gives information on the time of occurrence, epicentral coordinates, focal depths and the magnitudes of these earthquakes.

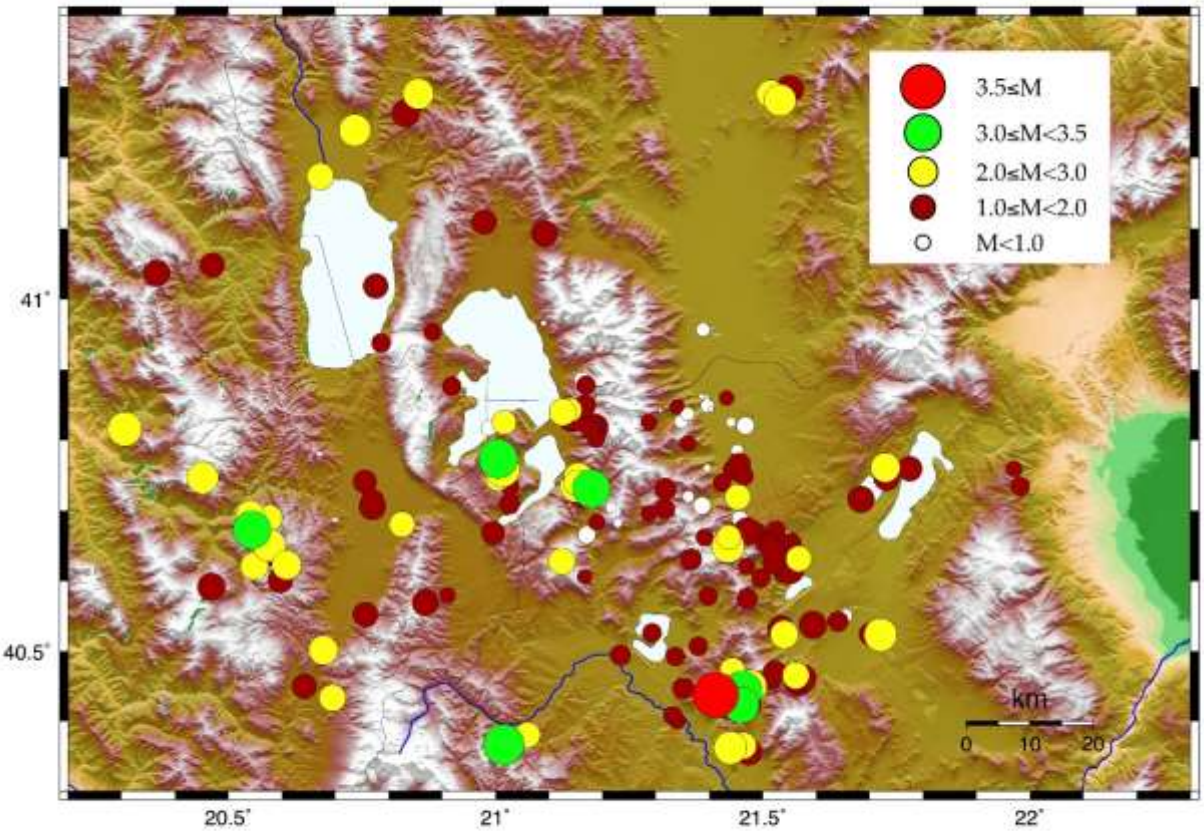

Fig. 12. Epicenters of the local earthquakes that occurred during the period of the operation of the local seismological network. The size and the color of the symbols denote the magnitude of the earthquakes.

Table II. Information on the occurrence time (2 first columns, epicentral coordinated (3rd and 4th column), focal depth and magnitude (the 5th and 6th column, respectively)

Year	Occurr. Date	Latit.	Longit.	Depth	M
2018	0918193029.47	40.7293	21.4422	11.43	0.1
2018	0920221133.92	40.4495	20.6423	7.29	1.7
2018	0922122623.88	40.4000	21.3405	7.02	1.1
2018	0922123342.91	40.4077	21.3320	7.02	1.3
2018	0923043935.87	40.7192	21.4535	15.42	2.1
2018	0923045517.85	40.6887	21.4573	9.16	0.8
2018	0925051738.33	40.8602	21.3948	2.97	0.3
2018	0925072113.16	40.8598	21.4322	8.12	1.0
2018	0927015256.70	40.8623	21.3862	1.68	0.3
2018	0928101052.59	40.6492	21.4352	16.71	2.7
2018	0930142726.75	40.7612	21.7298	17.43	2.4
2018	1001020304.85	40.6715	21.4922	18.64	1.0
2018	1001074556.95	40.7458	21.7315	15.20	1.7
2018	1002162702.75	40.6315	21.5675	8.26	2.1
2018	1002200331.93	40.8253	21.4403	10.55	0.5
2018	1004110837.47	40.7202	21.3613	12.91	0.6
2018	1005032900.22	40.7307	21.3182	12.65	1.5
2018	1005051722.51	41.2897	20.8555	6.63	2.5
2018	1007015554.13	40.6307	21.3658	1.70	1.5
2018	1013001838.12	40.8235	21.1872	9.79	0.8
2018	1013002042.91	40.8115	21.1900	10.55	1.0
2018	1017133844.00	40.8322	21.1430	1.36	1.9
2018	1017184830.15	40.5237	21.5403	7.05	2.3
2018	1017184951.70	40.5315	21.5342	7.07	1.8
2018	1017190321.28	40.0205	21.3930	7.04	1.8
2018	1017203933.72	40.8428	21.1387	1.45	2.0
2018	1017204227.69	40.8185	21.1825	9.93	0.7
2018	1017232905.84	40.5797	20.9102	6.97	1.1

Year	Occurr. Date	Latit.	Longit.	Depth	M
2018	1018040453.77	40.8178	21.1853	9.99	1.9
2018	1018041545.28	40.8132	21.1807	10.20	0.9
2018	1018132000.58	40.8020	21.1880	10.38	1.2
2018	1018170108.09	40.6803	20.8248	7.97	2.1
2018	1018213805.71	41.0367	20.3660	6.99	1.8
2018	1018231111.13	40.8420	21.3088	10.10	0.2
2018	1019004246.13	40.8182	21.1908	10.42	1.0
2018	1019005044.37	40.8037	21.1752	11.32	0.5
2018	1019005223.30	40.8863	21.1625	4.06	0.8
2018	1019051909.39	40.8200	21.1813	9.77	1.3
2018	1019052342.09	40.8155	21.1818	10.75	0.9
2018	1021010052.39	41.0185	20.7758	6.85	1.7
2018	1021051805.98	40.5743	21.4710	7.13	1.4
2018	1021085018.24	40.8117	21.1810	10.22	0.9
2018	1021090549.13	40.6212	20.5488	6.96	2.3
2018	1021103614.65	40.6507	20.5762	7.45	2.7
2018	1021103730.97	40.6227	20.6093	7.02	2.4
2018	1021103907.63	40.6725	20.5442	7.22	3.1
2018	1021105044.11	40.6897	20.5773	7.11	2.1
2018	1021111849.82	40.6005	20.5972	6.96	1.7
2018	1021133330.08	40.6408	20.5753	7.06	1.9
2018	1021134658.64	40.6945	20.5412	7.17	2.3
2018	1026024924.42	40.6530	21.5015	14.70	1.1
2018	1026030635.41	40.6702	21.4713	20.53	1.9
2018	1027120305.18	40.7607	21.3962	9.27	0.4
2018	1027192439.04	40.5783	21.3980	7.07	1.3
2018	1101022304.02	40.9380	20.7858	6.83	1.3
2018	1103194234.90	41.0925	21.0917	4.90	1.8
2018	1104061004.07	40.8282	21.1490	1.75	1.5
2018	1105124853.84	40.8777	21.1697	8.60	1.3
2018	1110042046.72	40.6622	21.4367	16.09	2.0
2018	1111164423.57	40.7595	21.7752	21.80	1.7

Year	Occurr. Date	Latit.	Longit.	Depth	M
2018	1115215514.12	40.7055	20.7695	7.09	1.8
2018	1115220110.54	40.7410	20.7555	7.10	1.6
2018	1115220545.05	40.6153	21.5420	7.00	1.7
2018	1115221317.74	40.6200	21.5363	4.20	1.4
2018	1116185045.67	40.6157	21.5513	7.00	1.9
2018	1117161712.09	40.7953	21.3602	5.53	1.1
2018	1121034113.11	40.6963	21.2870	25.62	1.1
2018	1122041614.08	41.1087	20.9783	6.91	1.7
2018	1123074447.10	40.4652	21.5620	7.78	2.2
2018	1125055834.31	40.7070	21.3863	8.80	0.9
2018	1126171601.97	40.4290	21.4613	6.35	2.9
2018	1126171832.62	40.4557	21.5663	7.17	1.9
2018	1126173151.92	40.4617	21.5757	7.58	1.8
2018	1126173208.99	40.4240	21.4708	6.29	1.9
2018	1126173441.42	40.4572	21.5635	7.43	1.5
2018	1128183038.41	40.6542	21.5537	12.37	1.3
2018	1128212750.38	40.6575	21.5193	11.68	1.6
2018	1128230846.13	40.6547	21.5248	9.39	1.7
2018	1128234505.18	40.4402	21.4390	7.91	2.0
2018	1130222816.84	40.4375	21.4123	8.73	3.7
2018	1130224554.76	40.4653	21.5600	7.65	1.3
2018	1130230812.46	40.4197	21.4367	8.10	1.7
2018	1130233901.34	40.4422	21.4433	8.15	1.4
2018	1201000825.68	40.4507	21.4118	7.66	1.2
2018	1201042816.69	40.4425	21.4613	8.73	3.3
2018	1201043007.80	40.4448	21.4538	8.23	1.7
2018	1201043754.32	40.4562	21.5185	7.50	1.1
2018	1201074341.73	40.4235	21.4595	5.84	3.0
2018	1201082000.68	40.6722	21.5245	13.91	1.3
2018	1201130420.38	40.4467	21.3517	7.66	1.5
2018	1203013523.33	40.7160	21.6840	10.24	1.8
2018	1203053246.30	40.4698	21.5223	7.61	1.6

Year	Occurr. Date	Latit.	Longit.	Depth	M
2018	1205194858.05	40.5502	21.6552	7.01	0.7
2018	1205194908.12	40.5423	21.6412	7.02	1.4
2018	1206061354.48	40.8398	21.1258	7.27	2.2
2018	1210161208.34	40.8497	21.3380	10.33	0.8
2018	1210162049.52	40.8482	21.3393	10.44	1.0
2018	1210162821.08	40.8500	21.3385	10.45	0.2
2018	1212101844.99	41.1733	20.6723	7.01	2.2
2018	1212232034.38	40.5915	20.4682	7.05	1.9
2018	1213005917.71	40.8173	20.9877	6.73	0.8
2018	1214042603.78	40.5260	21.2930	21.39	1.3
2018	1214053844.05	40.8253	21.0162	9.00	2.0
2018	1214152026.06	40.7715	21.3593	47.11	0.1
2018	1215062441.26	40.5372	21.5938	7.75	1.9
2018	1216223532.00	40.6682	20.9957	15.38	1.6
2018	1217031052.33	40.4923	21.3368	57.50	1.3
2018	1217061344.55	41.2627	20.8322	7.04	1.9
2018	1217061356.89	41.2385	20.7367	7.05	2.6
2018	1223041338.76	40.5242	21.7007	3.11	1.5
2018	1223110037.90	40.6202	21.4700	15.62	1.1
2018	1231054655.71	40.9567	21.3883	1.75	0.7
2019	0101222943.29	40.8488	21.3962	4.05	0.7
2019	0107205047.49	40.8447	21.4027	3.65	0.3
2019	0108053151.01	40.7452	21.0037	7.00	2.0
2019	0113002927.65	40.7470	21.3607	3.28	0.2
2019	0113142611.71	40.5690	20.8685	7.34	1.8
2019	0113181610.38	40.7590	21.9703	9.67	1.1
2019	0117013442.27	40.3803	21.0600	7.32	2.1
2019	0118174255.49	40.6390	21.5287	7.03	1.6
2019	0118203002.54	40.8767	20.9182	5.25	1.3
2019	0118221843.05	40.7345	21.9818	7.16	1.3
2019	0118235517.90	40.6655	21.1710	1.31	0.9
2019	0119000122.73	40.6058	21.1668	10.95	1.0

Year	Occurr. Date	Latit.	Longit.	Depth	M
2019	0120215200.83	40.6040	21.4967	7.04	1.3
2019	0122051834.45	40.7135	20.7697	6.84	1.6
2019	0123213339.11	40.6618	21.3913	13.98	1.2
2019	0201000637.86	40.9533	20.8822	7.05	1.2
2019	0202180440.70	40.5232	21.7208	6.98	2.7
2019	0207082910.66	40.7628	21.0035	4.65	2.5
2019	0207103537.54	40.7095	21.0260	3.18	1.4
2019	0207152458.35	40.7738	21.0050	4.91	3.2
2019	0207161958.19	40.7578	21.0133	4.72	2.8
2019	0207205405.95	40.5012	20.6778	7.02	2.4
2019	0208181013.50	40.7342	21.0272	3.70	1.3
2019	0209011613.23	40.5520	20.7565	7.28	1.7
2019	0210020701.75	40.1830	21.4907	6.97	3.2
2019	0210024215.83	40.1637	21.4675	6.98	1.5
2019	0210174614.34	40.6393	21.3665	15.43	0.8
2019	0213172552.48	40.4333	20.6950	7.11	2.2
2019	0215042421.44	41.2895	21.5147	6.80	2.3
2019	0215052512.63	41.2807	21.5325	6.80	2.6
2019	0215075835.85	41.2965	21.5505	6.79	1.9
2019	0219232751.46	40.8132	21.1780	7.55	1.3
2019	0220182418.55	40.5422	22.2207	7.09	0.0
2019	0224195306.82	40.7803	20.6705	7.25	0.3
2019	0226045135.18	40.7465	20.4518	6.84	2.6
2019	0301052617.12	40.6065	20.5682	7.20	0.0
2019	0301103212.77	40.6870	20.7003	7.23	0.3
2019	0302025703.26	40.5025	20.7713	6.85	0.3
2019	0302142148.04	40.5373	20.8162	6.75	0.3
2019	0311013520.34	40.4942	21.2335	8.35	1.4
2019	0312232025.82	40.7572	21.4452	6.75	1.4
2019	0313075457.46	40.8207	21.4680	4.79	0.9
2019	0313175109.51	40.8268	21.3475	10.14	0.7
2019	0315031555.43	40.3650	21.4635	7.04	2.2

Year	Occurr. Date	Latit.	Longit.	Depth	M
2019	0315031634.08	40.3618	21.4398	7.04	2.7
2019	0315144450.15	40.3558	21.4742	6.98	1.8
2019	0317232729.67	40.7022	21.3167	12.15	1.4
2019	0318135033.59	40.8160	20.3063	7.20	2.8
2019	0320101335.30	41.0480	20.4698	7.02	1.7
2019	0322035219.41	40.6833	21.1895	6.20	1.1
2019	0325002330.87	40.5068	21.3795	8.62	1.3
2019	0325055841.64	40.7395	21.4240	14.74	1.2
2019	0327033905.36	40.4603	21.4422	8.18	1.5
2019	0328193317.90	40.6562	21.5133	16.25	1.1
2019	0329204224.65	40.8257	21.2873	7.56	1.1
2019	0330132022.73	40.7310	21.1797	4.89	3.1
2019	0402004159.64	40.8372	21.3590	11.07	0.7
2019	0402225228.18	40.6280	21.1240	3.65	2.2
2019	0403164730.47	40.7858	21.4525	1.92	0.6
2019	0403234849.99	40.4498	21.4770	8.62	2.7
2019	0404150120.58	40.7652	21.4558	5.33	1.6
2019	0406060546.58	40.7490	21.4648	5.21	1.3
2019	0406233006.08	40.7192	21.1573	1.72	1.4
2019	0406234859.67	40.7343	21.1507	1.75	2.6
2019	0406235115.62	40.6825	21.2292	3.69	0.5
2019	0406235125.53	40.7377	21.1667	1.69	1.5
2019	0406235221.75	40.7313	21.1657	1.70	1.7
2019	0406235455.41	40.7353	21.1572	1.70	1.1
2019	0407000121.13	40.7412	21.1508	1.70	1.4
2019	0407005212.53	40.6992	21.2217	2.23	0.7
2019	0407010257.17	40.7042	21.2165	2.30	0.6
2019	0407094849.04	40.8490	21.1668	1.68	1.5
2019	0407125901.04	40.6250	21.5188	6.99	1.4
2019	0407172307.00	40.7463	21.1553	1.72	2.5
2019	0407172404.97	40.7393	21.1517	1.72	2.1
2019	0407193702.11	40.7397	21.1825	1.70	1.3

Year	Occurr. Date	Latit.	Longit.	Depth	M
2019	0412055122.77	40.3663	21.0155	6.71	3.3
2019	0412133515.51	40.4722	21.4433	5.37	2.1
2019	0417161705.55	40.9660	21.0900	4.66	0.3
2019	0418122314.45	40.6450	21.5175	31.10	1.6

The epicenters of all the earthquakes located as described earlier, are depicted with circles of different color and size, which is proportional to their magnitudes, on the map of Figure 12. The stronger earthquake has magnitude M=3.7 and occurred on November 30, 2018, 22:28 UTC, in the southern part of the area. Its focal depth was calculated equal to 6.8 km. The seismic activity is mainly distributed along the mountainous area of Pindos, mainly in the Greek territory. The seismic activity in North Macedonia and Albania is lower, including mainly shocks with magnitudes in the range $2.0 \leq M < 3.0$, but we should take into account that their epicentral distances from the installed network are greater.

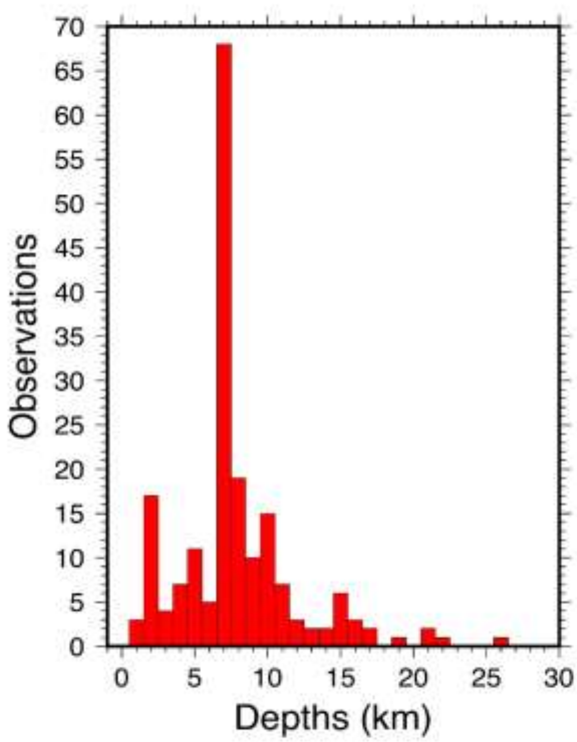

Fig. 13. Histograms of the focal depths of the local earthquakes that occurred during the period of the operation of the local seismological network, the epicentral distribution of which is shown in Fig. 12.

Figure 14 focuses on the seismicity which is distributed inside and near to the area of the operation of the local seismological network. Inside the network seismic activity is very low with the occurrence of about fifteen earthquakes. All of them have magnitudes $M \leq 1.5$. In the area south of the local network, seismicity is higher, although considerably lower than seismic activity shown on the previous map in the mountainous area to the west and northwest. The larger earthquake here occurred on September 28, 2018 10:10 UTC, with magnitude M=2.7 and focal depth 16.7 km. This earthquake is depicted with large red symbol in figure 14. No seismic activity is observed in the area north of the seismological network.Another activity is also observed close to the lakes Petres and Vegoritis at the easternmost part of the study area.

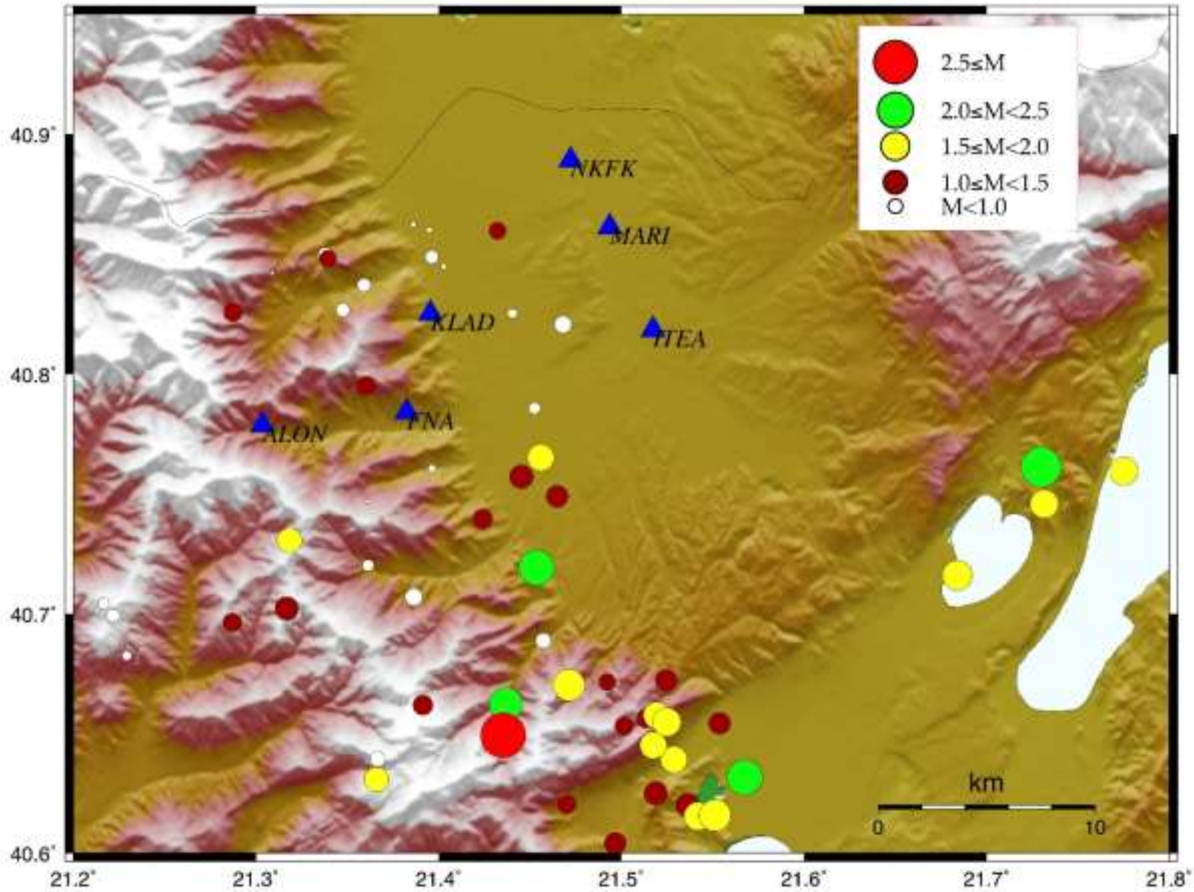

Fig. 14. Same as Figure 12 zoomed at the area of Florina basin.

The operation of the network will be continued, and the recordings will be continuously collected, and analyzed. Then relocation will be performed using modern techniques. The highly accurate earthquake data will be used to study the seismotectonic properties of the area and the physics of the earthquake sources.

2.6 References

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PART 3

3.1. Background seismicity of the area

The area covered in the present study (cross border between Greece and North Macedonia) is bounded between latitudes φ= 40.24 -41.24° and longitudes λ= 20.24 - 22.00°. The area almost extends 100 Km from South to North and 200 Km from West to East. Earthquakes of all kind of magnitudes (small, medium, large) were reported or they were recorded since historical era up to the present. In Figure (15) the seismicity map of the whole region is demonstrated covers the time span 552 A.D. – 2018 (see Appendix). The shocks are marked by different symbols a different colour (specially the large ones). The earthquakes used in this work are restricted to shallow depths only, given that an absence of deep events is a "regime" in the area.

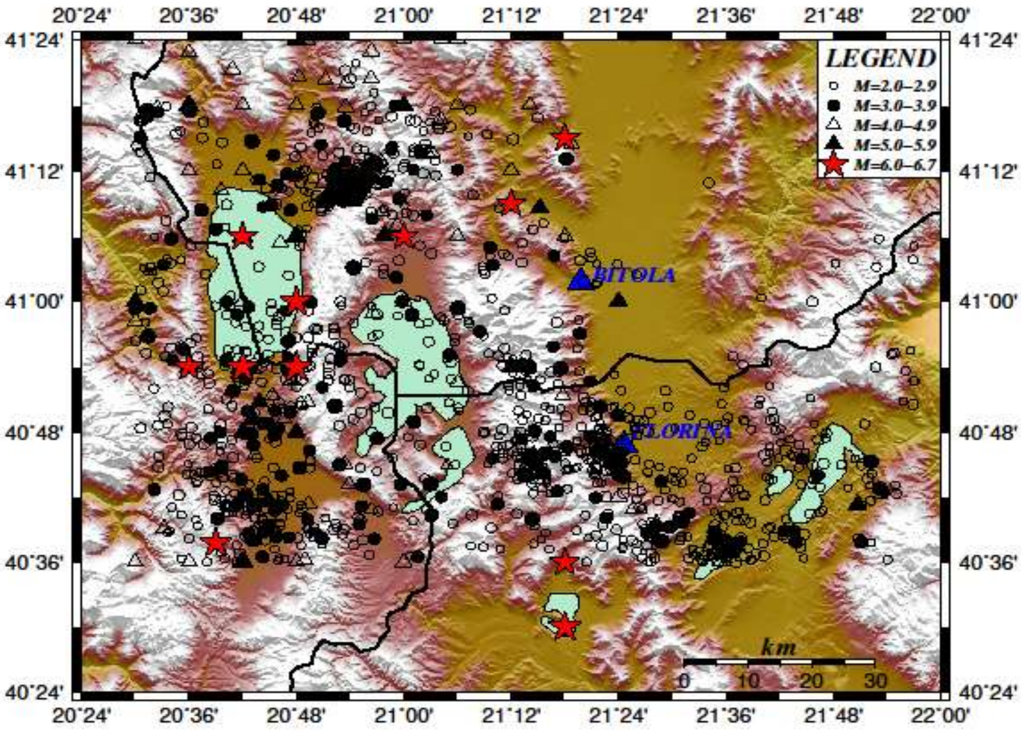

Fig. 15. The earthquake epicentres with magnitude M≥2.0 which occurred in the region, during the time period 552 A.D. – 2018. All the magnitude symbols are illustrated in the legend. The position of Florina and Bitola is also appeared with a blue triangle (see Appendix at the end of the present).

Almost the 95% of shocks generated are limited in depths lower than 20 km, as it is depicted in Figure (16a), where one can see a North-South section of the previous Figure (15), while in Figure (16b) we drew the 3D cross section of the same direction.

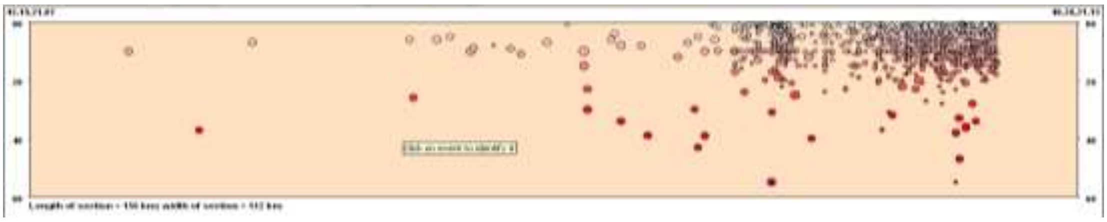

Fig. 16a. The cross section (of North –South direction) of the events occurred in the area. Their depths lower than 20 Km are obvious for the majority of them.

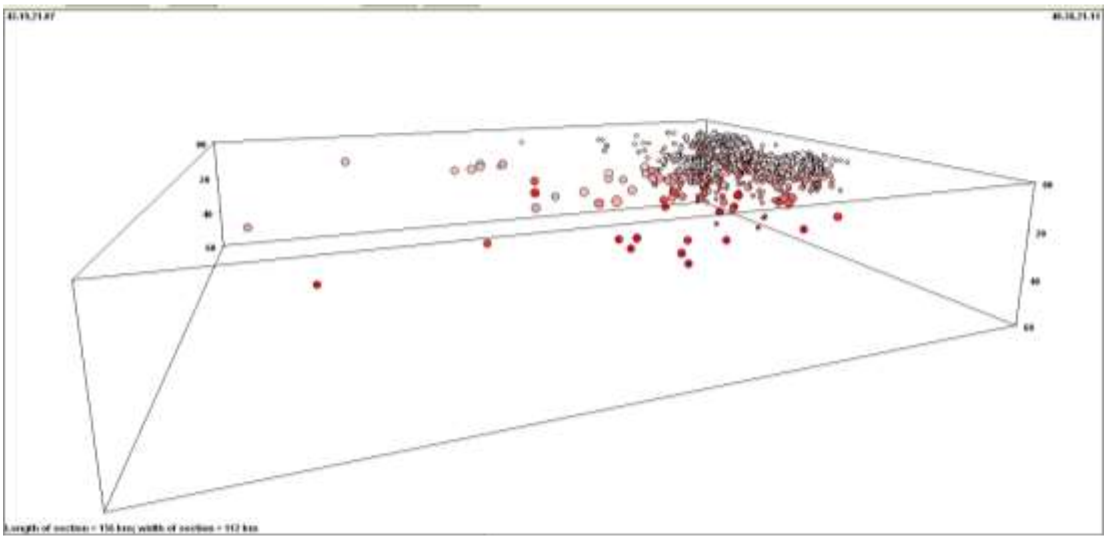

Fig. 16b. The 3D cross section (of North –South direction) of the events occurred in the area, Their depths lower than 20 Km are obvious for the majority of them.

We can observe from Figure (15) that there are some clusters of earthquakes with various magnitudes which are in the northeast part of Ochrid lake, around Florina ana near the tectonically active area of Amynteon and Vegoritis lake. Among them we can see with red stars the nine large and catastrophic shocks which generated in the area. They are of magnitude M≥6.0. In the center of each star is a number which is in accord whith the number written in legend of the map (Fig 17) where one can see at once the year and the magnitude of the corresponding large earthquake. The mean foacal depth of the earhquakes generated in the examined area is 8 Km and this fact makes these shocks, specially the large ones very dangerous.

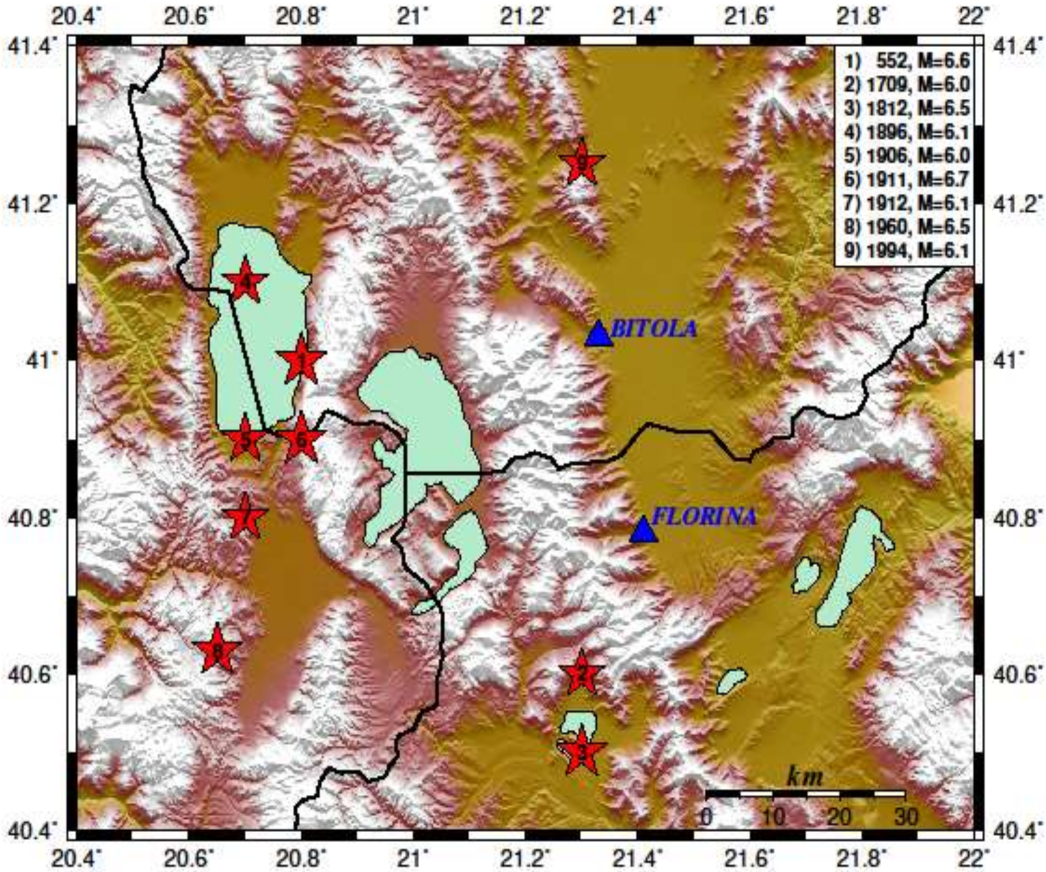

Fig. 17. The large earthquake (M≥6.0) epicenters occurred in the broader area during the time period 550 A.D.- 1994. The sites of Florina and B;itola denoted with a blue triangle.

As we can show the largest event was the one generated in 1911 in the southeast side of Ochrid. lake and is of magnitude M=6.7. This particular shock is in a distance of 50 Km from both cities, Florina and Bitola and according the reports of that epoch caused serious damages to the prerefered cities.

3.2. Quantitative seismicity of the entire area

The magnitude-frequency equation was introduced by Gutenberg and Richter (1944), most known as G-R law or magnitude - frequency relationship:

$$LogN_k = a_k - bM \qquad (1)$$

for expressing the number N, of earthquakes which occur in a region during a given time period in relation to their magnitudes, M, where k is the number of years covered by the data sample. The values of the parameters a_k and b, were numerically determined by the same authors for various regions of the world. They also suggested that b-values range from 0.45 to 1.50, while Miyamura (1962) found that b-values change from 1.40 to 1.80 according to the geological age of the tectonic area.

In order to relate b-values with the fracturing of the rocks, experimental studies in the laboratory have been made by Mogi (1963, 1967), using heterogeneous materials and the results obtained strongly suggested an explanation of the difference of b-values in various tectonic areas. On the other hand Scholz (1968), conducting the same kind of experiments, concluded that the parameter b decreases when the tectonic stress is increasing and conversely. Tsapanos (1990) produced a paper which covered the tectonic regions of the circum-Pacific ocean for different time periods. He found that the regions of the American continent concluded for low b-values which connected with old and more structurally stable massif which manifests a low degree of mechanical heterogeneity. In all other Pacific regions higher b-values calculated which indicated younger rock materials which have a higher degree of heterogeneity. On the other hand the parameter a_k depends on the seismicity of the region, from the area covered by the earthquake epicentrers and from the time t in which the shocks occurred. Low b-values means that the region is under great stress and this could be an evidence for an earthquake genesis.

In order to evaluate the seismicity parameters our first effort is to find accurate, homogeneous and complete data. Homogeneous means that all magnitudes to be expressed in the same magnitude scale. For this reason the data used here are extracted from the catalogues of seismological networks of Athens , Thessaloniki and for the recent years (after 2005) from the Hellenic Seismological Network from where one can found accurate data and homogeneous data. The size of the events is expressed in moment magnitude, M_w. Completeness means that we have all earthquakes above a determinate magnitude for a specific time period. So we have seven periods of completeness which are tabulated below in Table 3.

Table III. The competeness periods and the corresponding magnitudes for the data used in the eligible area..

Completeness

Magnitude	Year
$\geq$ 2.0	2017
$\geq$ 3.0	2008
$\geq$ 4.0	1995
$\geq$ 4.5	1967
$\geq$ 5.1	1923
$\geq$ 5.9	1911
$\geq$ 6.0	since historical era (552 A.D.)

Based on this we applied the least- squares method in order to calculate the parameters a_k and b of the equation (1). So we found a_k =5.89 and $b = -0.87$. In order to compute the quantitative seismicity parameters, we usually make the reduction of the parameter a_k as an expression of 1 year, which is $a_1 = 3.84$. This comes from the relation:

$$a_1 = a_k - \ell ogk \tag{2}$$

We observe a fine goodness –of- fit in the line of the magnitude-frequency plot (Fig. 18), which is a product of the detailed elaboration of the data used. In details the number of the data used, in correlation with their magnitude ranges are illustrated below in Table 4:

Table IV. The number of data used in relation to magnitude range

Magnitude Range	Number of Data
2.0 – 2.9	1010
3.0 – 3.9	220
4.0 – 4.9	100
5.0 – 5.9	51
6.0 – 6.7	9

Papaioannou and Papazachos (2000) divided Greece and the surrounding area in 67 seismogenic sources. According with this division our eligible region is a part of the seismogenic source with number 34. They found with different data set and or different time span approximately same results for the parameters of magnitude-frequency law. They found $a_1 = 3.76$ and $b = -0.86$.

The quantities that proposed to express the measures of seismicity are functions of the parameters a_1 and b A common measure of seismicity is the mean return period T_m with magnitudes M or larger which occur in this area:

$$T_m = \frac{10^{bM}}{10^{a_1}} \tag{3}$$

In Table 5 we listed the mean return periods for specific earthquake magnitudes. Such earthquakes magnitudes found in the region under investigation, during the preparation of the earthquake catalogue of the territory. The last magnitude (M6.7) is the largest observed in the examined region

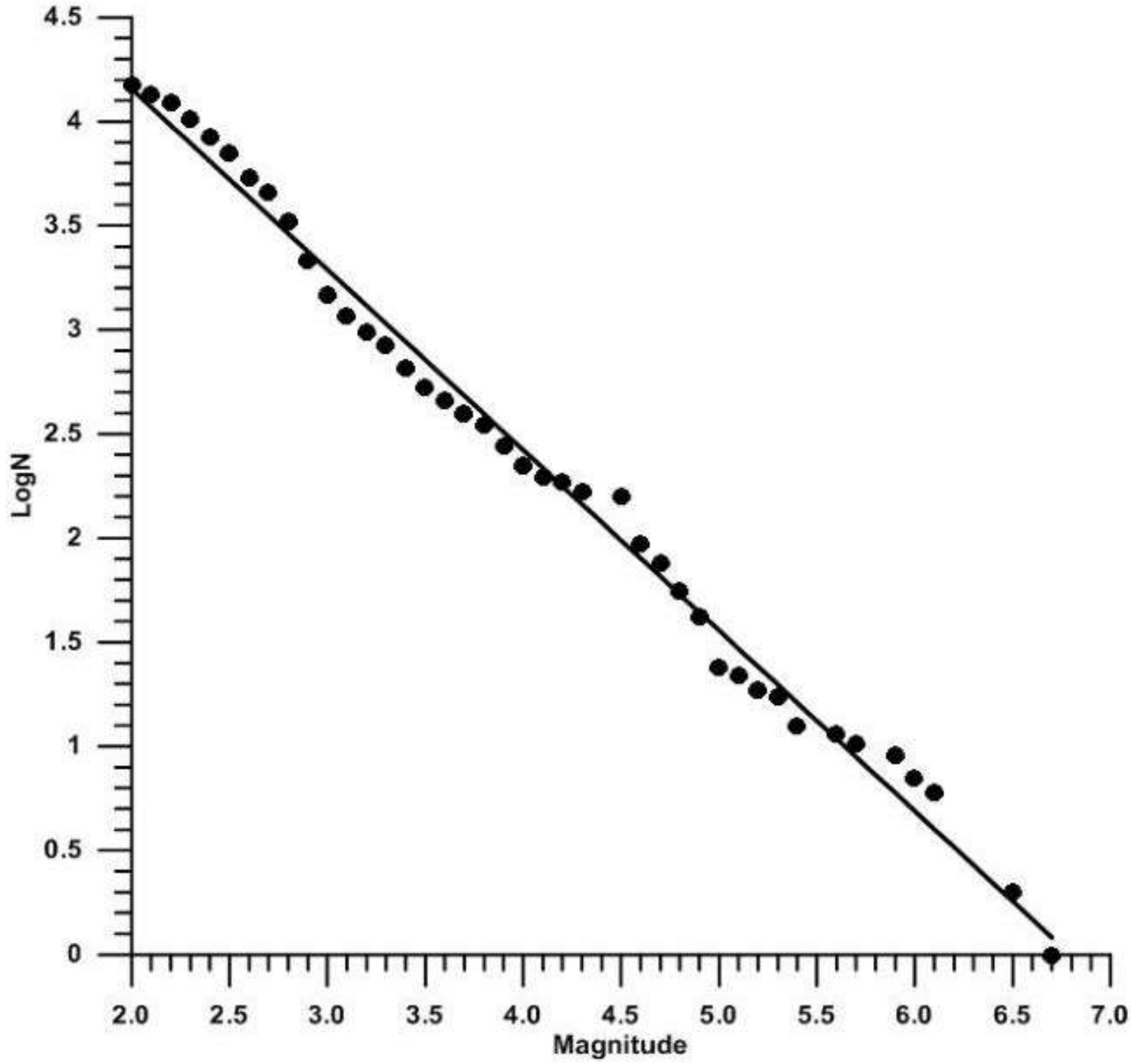

Fig. 18. Magnitude – frequency distribution of the earthquakes occurred in the examined region .

Table V. The competeness periods and the corresponding magnitudes for the data used in the eligible area.

Magnitude (M_w)	**Mean Return Period (T_m, in years)**
4.0	0.4
4.5	1.2
5.0	4.2
5.5	8.8
6.0	24.0
6.5	65.3
6.7	97.5

Based on the above Table we can say that the region experienced of an earthquake with magnitude M_w=6.7 (the largest ever occurred) every 97.5 years.

Another measure of seismicity is the most probable maximum magnitude $\overline{M}_w$, which may occurs in a region during a given time period t and its mathematical expression is:

$$\overline{M}_w = \frac{a_1 + \ell og t}{b} \quad (4)$$

Results based on equation (4) portray in Table 6.

Table VI. The most probable maximum magnitude during given time periods in the eligible area.

Time (t, in years)	**Most probable maximum magnitude $\overline{M}_w$,**
1	4.4
10	5.6
25	6.0
50	6.4
75	6.6
100	6.7
300	7.3

Table 6 reveals that the most probable maximum magnitude e.g. for a time period of 100 years is 6.7. A first look on Tables 5 and 6 reveals an interest observation. The mean time period for a magnitude 6.7 is **97.5** years, while the maximum magnitude ever occurred in the area (6.7) in a time span of **100** years, which means they are identical. So we can conclude that we can expect an earthquake of magnitude 6.7 every 100 years. This observation verifies the excellent quality of the data used for this study.

Another most popular seismicity measure is the probability, P_t, that an earthquake with magnitude M_w will generate in this region during a time span, *t*, espousing a Poisson probability distribution and is given bellow by equation (5):

$$P_t = 1 - e^{-10^{(a_1 - bM)}} \cdot t \qquad (5)$$

Results based ob equation (5) listed in Table 7.

Table VII. The probabikity (P) of occurrence of an erathquakes magnitude during a given time span (T) in the eligible area.

T	1	10	20	25	50	75	100	300
M	**P_1**	**P_{10}**	**P_{20}**	**P_{25}**	**P_{50}**	**P_{75}**	**P_{100}**	**P_{300}**
4.0	**0.899**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
4.5	**0.569**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
5.0	**0.266**	**0.955**	**0.998**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
5.5	**0.107**	**0.679**	**0.897**	**0.941**	**0.997**	**1.000**	**1.000**	**1.000**
6.0	**0.041**	**0.341**	**0.566**	**0.647**	**0.876**	**0.956**	**0.985**	**1.000**
6.5	**0.015**	**0.142**	**0.264**	**0.318**	**0.535**	**0.683**	**0.784**	**0.990**
6.7	**0.010**	**0.097**	**0.185**	**0.226**	**0.401**	**0.537**	**0.641**	**0.954**

As it is obvious from Table 7 the probabilities have been assessed for earthquakes with magnitudes 4.0, 4.5, 5.0, 5.5, 6.0, 6.5 and 6.7, while the time spans are for 1, 10, 20, 25, 50, 75, 100 and 300 years. The probability that the large earthquakes of magnitudes 6,0, 6.5 and 6.7 which are going to be generated during the next 100 years in the region is 98%, 75% and 64%, respectively. Speaking about critical infrastructures (e.g. dams) probabilistic models for 50 or 100 or even 500 years are in use.

3.3. Useful considerations

A careful analysis of earthquakes in the broader area of Florina and Bitola is undertaken. The actions scheduled in the start state of the project are successfully finished. The basic reason is to evaluate the seismicity of the area and provide useful seismic parameters to engineers, regulators and planners in order to mitigate adverse social and/or economic effects of an earthquake and allows them to plan earthquake-resistant designs. The basic definitions, the theories and the background research, made in the examined area are given anf all determinations for maximum magnitudes are outlined. Trial are made in order to check the available completeness offered by known sources (National Observatory of Athens and Aristotle University of Thessaloniki) After this the seismicity of the broader area was examined from a quantitative point of view. For this scope the well-known Gutenberg-Richer relationship applied. The obtained results are reliable, In the examined area we can observed both historical and recent earthquakes (Table 8). This Table is directly related with Fig. (17). Earthquakes plotted in this Figure are those portrayed in Table (8). So have to use all those data which are of different quality. For this reason we used a method which includes the Bayes statistics and allows the use of both historical and instrumental data.

A network of 5 portable seismographs were installed since the beginning of the project in the border area. During the six months operation the instruments recoded almost 200 events. Though these events are microearthquakes some selected of them are in the used data set. Also it is obvious that the area which considered of low seismicty, reveals another status. We observed two clear concentrations: a) Around Prespa lake in the Greek part and b) is an elongated shape accumulation of events, started from the cross-border area and with a South-Southeast direction stops further inland in Greece. This is one long tectonic line in NNW-SSE direction defined in west margins of this basin, north and south of the city of Florina and its continuation observed further northern to North Macedonia little northern from the city of Bitola. This fault traced as photo-line in satellite pictures. This affects the gneiss of the Vitsi –Nymfaio geological formation. Although this

NNW-SSE direction edging fault of Bitola-Florina considered as a active one (Bitola earthquake of 1994 with M-6.1 generated from this fault), studies made regarding this fault as a part of an old ruptures system which shaped the basin of Bitola-Florina in its initial stage.

Table VIII. The List of the parameters of the nine large and catastrophic earthquakes occurred in the examined area. There are six earthquakes of historical era (550-1911) and only three during the modern time. the largest earthquake is the one occurred during 1911 in Ochrid lake with magnitude M=6.7 and intensity I=IX (9).

YEAR	MONTH/ DAY	Φ°	λ°	MAGN.	PLACE	INT.
552		41.00	20.80	6.6	OCHRID LAKE	X
1709	10 00	40.60	21.30	6.0	KORESTIA	VII
1812	05 29	40.50	21.30	6.5	KASTORIA	VIII
1896	09 28	41.10	20.70	6.1	OCHRID LAKE	VIII
1906	09 27	40.90	20.70	6.0	OCHRID LAKE -STAROVO	VIII
1911	02 18	40.90	23.60	6.7	OCHRID LAKE	IX
1912	02 13	40.80	20.70	6.1	POGRADETS	VII
1960	05 26	40.63	20.65	6.5	KORITSA	VIII
1994	09 01	41.25	21.30	6.1	BITOLA	VII

Another main fault which shape the valley of Florina-Bitola in the southern of the city of Florina, Mainly it is extended along the southern bank of the Sakoulevas river and in the basis of the slopes of the mountainous part of the city and descends to the north direction. It extends in a W-E and because of this, it is vulnerable to the current field of tendency and because of a recent seismicity can consider as an active fault.

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PART 4

4.1. Seismic hazard 0f the area

It is well known that seismic hazard assessment, namely the computation of long-term probabilities of occurrence of earthquakes of the specified size in a given area during a given time interval, is a prerequisite for seismic risk reduction and urban planning. More over important infrastructures are installed in both parts. Strezevo dam which is a very critical infrastructure of the Pelagonia region, some eighteen kilometres away from Bitola in a N-NW direction.

Four dams are situated in the area around Florina and two of them (Parori and Papadias dams) were installed very near to the borders region. The other two are the dams of Kolchiki and Triantafilias.

Another important infrastructure is the Mining Power Complex of Bitola which is situated in a new municipality since 1975, Novaci. The main activity of the plant is the production of coal and electricity.

A same critical infrastructure is situated in the Florina Municipality (ex-municipality of Meliti). Florina power station is one unit coal-fires power plant. This supercritical plant is owned by Public Power Corporation S.A. and began its operation in 2003. It is powered by lignite coal. It is known as Meliti-Achlada unit. The dam of Papadia is responsible for cooling the machines of the power station, as well as for water supply to Meliti and the villages around.

The seismic hazard in Greece has been widely studied using a number of different techniques and seismic measures. Papaioannou and Papazachos (2000) assessed time-independent and time-dependent seismic hazard for 144 broad sites (cities, towns , villages) of Greece in terms of expected macroseismic intensities at each of these sites, while Lyubushin et al., (2002) estimated the seismic hazard in terms of maximum values of peak ground acceleration for the some cities of Greece using Bayesian procedure. The purpose of the present study is to assess the level of the seismic hazard of the cities of Florina and Bitola in terms of the probabilities of exceedance of a specific peak ground acceleration (PGA) value, during a given time interval and the maximum possible peak ground acceleration at the site of the city and the surrounding area. The same procedure is also going to apply in the sites of the critical infrastructures. The methodology for probabilistic seismic hazard assessment (PSHA) developed by Kijko and Sellevoll (1992), as well as by Kijko and Graham (1999). This approach has been specially developed for PSHA at a specified site and it allows the incorporation of different types of information. Either incomplete (historical) or instrumental earthquake records with varying threshold magnitudes for completeness or a combination of both can be taken into account. The technique does not rely on the definition of seismic source zones which is advantageous for regions where the interpretation of earthquake observation in terms of faults and geological structure nay be difficult (Mantyniemi et al., 2001). Site-specific analysis of seismic hazard requires knowledge of the attenuation of the chosen ground-motion descriptor as a function of distance. The attenuation law in use for Greece and the adjacent regions for shallow earthquakes deriver by (Skarlatoudis et al., 2003) and is given by equations (6). The effect of the soil conditions (rock, intermediate and soft) soil) was assessed, as well. The equation (6) stands for shallow earthquakes and as was aforementioned in the area under investigation only shallow earthquake occur. The area under investigation fulfils the most of the aforementioned conditions.

$$\log PGA = 0.86 +).45 M_w - 1.27 \log(R^2 + 7^2)^{1/2} + 0.1F + 0.06S \pm 0.286 \quad cm/s^2 \qquad (6)$$

for magnitudes $4.5 \leq M_w \leq 7.0$ and for distances $R \leq 160$ Km.

Parameter S describes soil classification but takes values 1 (corresponding to rock), 0.5 (intermediate soil conditions) or 0 (alluvium). The approach based on the concept of the “design” or the “floating” earthquake (Krinizsky et al., 1993), was used to derive the maximum PGA at the examined sites.. This approach can be seen as a special cases of the technique known as “scenario” earthquake (Ishikawa and Kameda, 1993). The purpose of specifying such a “scenario” earthquake is to avoid surprises such as very high PGA values at the site origination from faults that have not been mapped. Based on the above probabilistic seism hazard maps constructed showing PGA for 10% probability of exceedance in 50 years (return period 475 years) considering local soil conditions.

As it was referred in the seismicity part of the present study an earthquake with magnitude M_w=6.1 occurred during September of 1994 near to Strevezo dam about 15 Km away. The probabilistic seismic hazard acceleration for this dam during its construction was:

- a(max) = 0.13 g for projected earthquake and
- a(max) = 0.17 g for maximum possible earthquake

How the dam responded to this strong motion which was also in close distance? The soil around the dam is mainly rocky so by the application of equation (6) we found the PGA value of 14g. The value found is similar to those of 0.13g and 0,17g given above. This is obvious in figure (19).

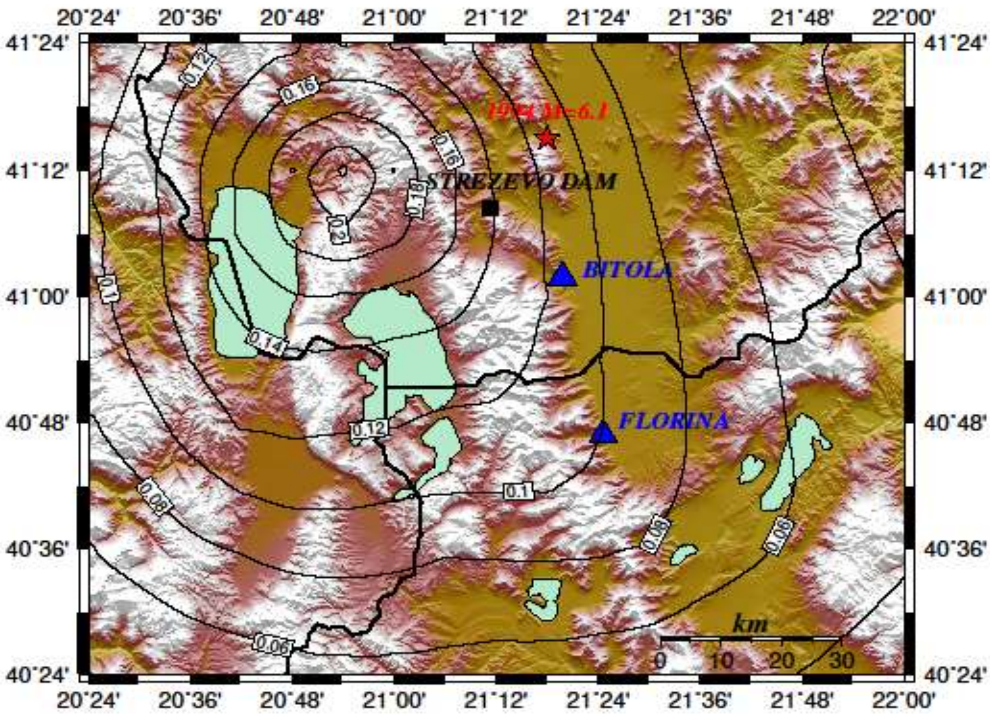

Fig. 19. The PGA value to Strezevo dam. A "product" of a large earthquake with magnitude M_w=6.1 which occurred some 15 km away from the dam's site. This strong motion did not affect to the dam given that the PGA values of its construction is very close with the PGA comes from the earthquake of 1994.

As we aforementioned there are important infrastructures founded in both areas of Florina and Bitola. All of them (dams and power plants) are in potential danger from the strong motion which “comes: from earthquakes occurred in the area. Large earthquakes generated in the whole area as we indicated in the seismicity section of the present report and this is well shown in Figure (15).

So following the same methodology we estimated the PGA values for the whole area. All the important infrastructures installed in the area, as well as the cities of Florina and Bitola are indicated in Figure (20a, b and c)

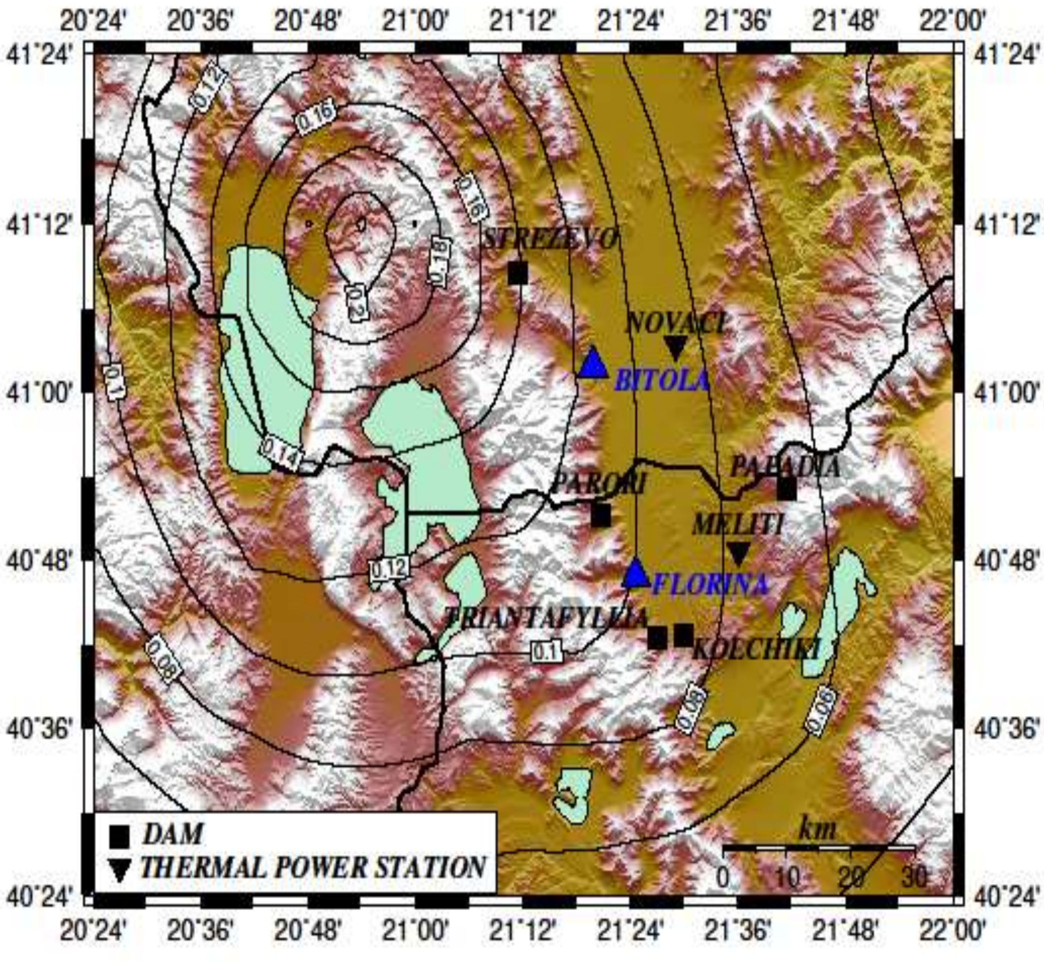

Fig. 20a. The PGA values to the broader area of Florina and Bitola. Dams are marked with quadrate symbol, while power plants are presented with a reverse triangle.

Soil conditions are considered and are for rocky terrain.For these rocky soil conditions we found relatively low PGA values which are between 0.14g for Strevezo dam (the highest) and 0.08g for Kolchiki dam, as well as for Meliti and Novaci pawer plants (the lowest). The city of Bitola has a value of 0.12g and Florina slightly lower to 0.10g.

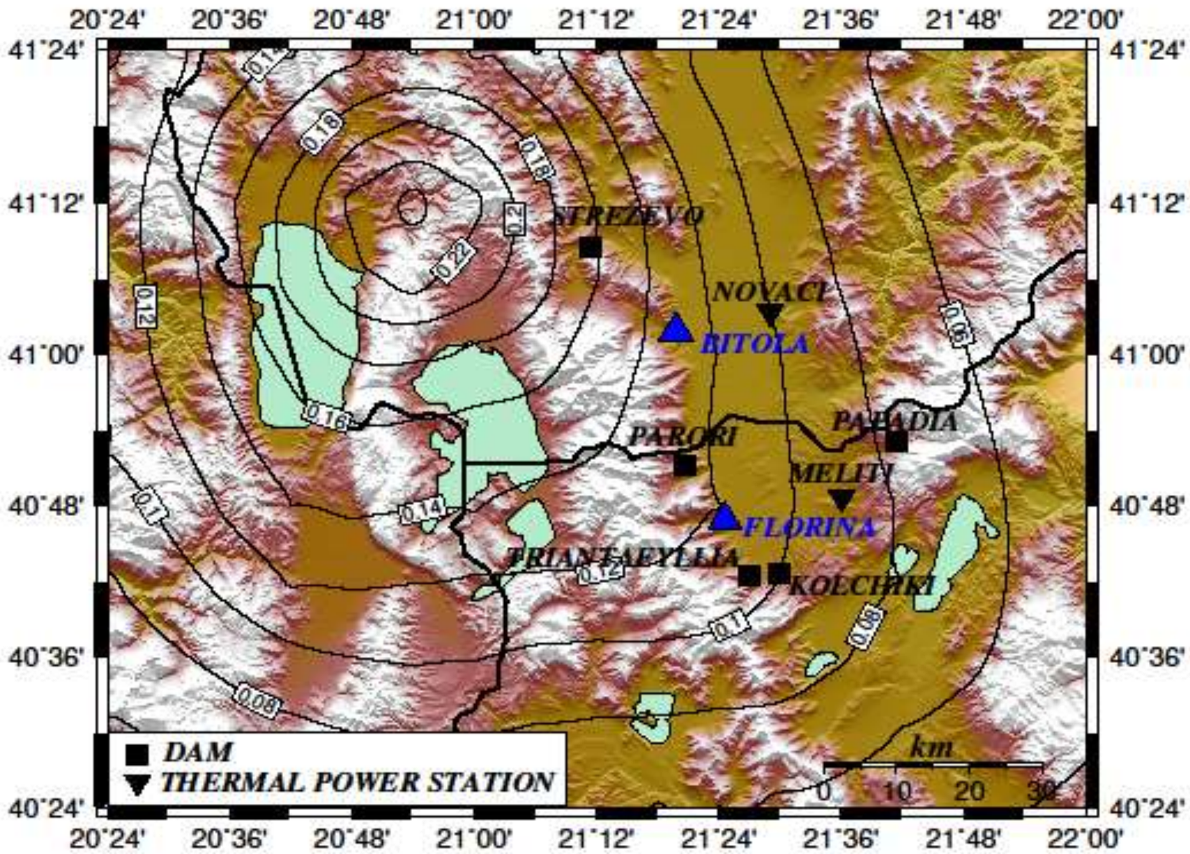

Fig. 20b. The PGA values to the broader area of Florina and Bitola. Dams are marked with quadrate symbol, while power plants are presented with a reverse triangle. Soil conditions are considered and are for intermediate terrain.

Intermediate soil conditions means a mix of both rocks and soft terrain. Here we can obesrve that the PGA values are slightky larger that those found for rock soili (Fig. 20a). For these intermediate soil conditions we found highly PGA values which are between 0.14g for Strevezo dam (the highest) and 0.09g (the lowest) for for Meliti and 0.10g for Novaci power plants. The same value (0.10g) is observed for Kolchiki dam and Novaci power plant . The city of Bitola has a value of 0.13g and Florina slightly lower to 0.12g.

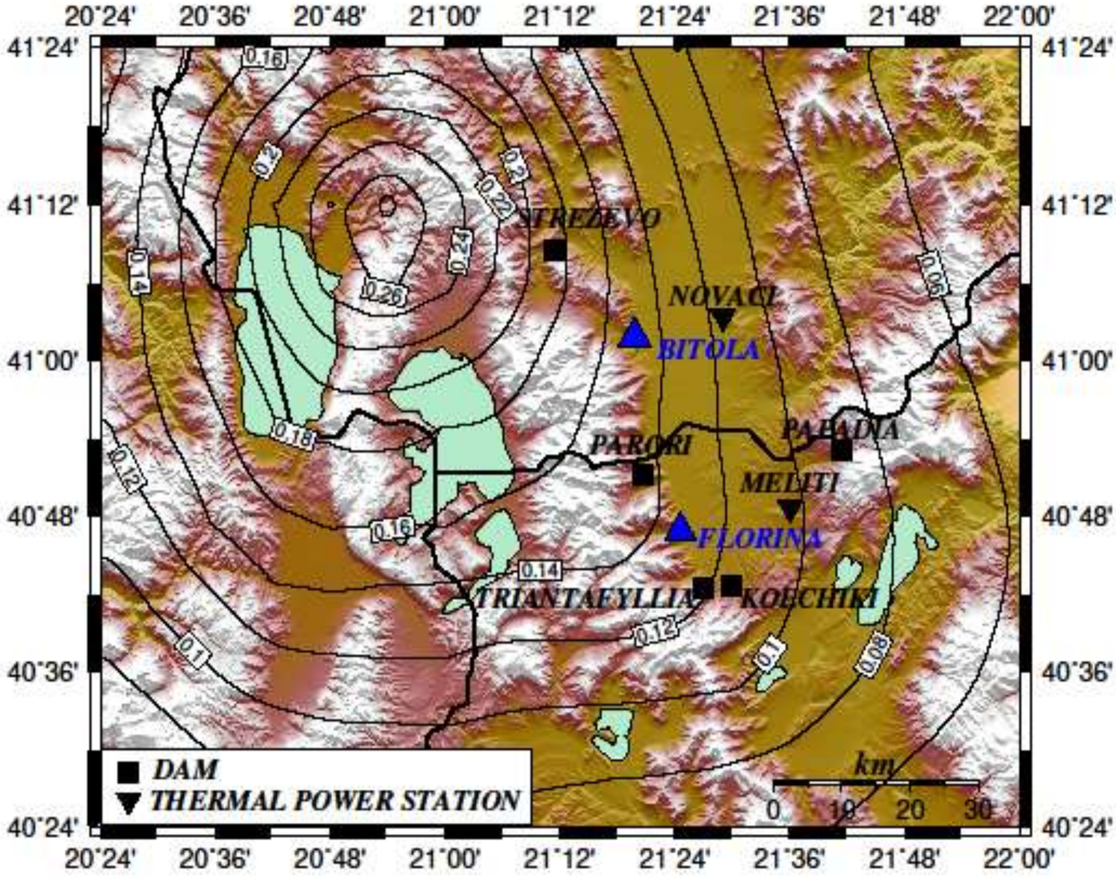

Fig. 20c. The PGA values to the broader area of Florina and Bitola. Dams are marked with quadrate symbol, while power plants are presented with a reverse triangle. Soil conditions are considered and are for soft terrain.

For these soft soil conditions we found relatively high PGA values which are between 0.18g for Strevezo dam (the highest) and 0.11g for Meliti power plant (the lowest). For Kolchiki and Triantafyllia dams, as well as for Novaci power plants vakues of 0.12g calculated. The city of Bitola has a value of 0.15g and Florina slightly lower to 0.13g. Honestly speaking these are the real values of Bitola and Florina given that both cities are situated on similar tectonic basins (Florina and Pelagonian basins) as far as their deformation and sedimentation history is concerned. They are both sub-basins of a long (more than 150 km) generally NW-SE trending sedimentary basin, which is a graben bounded by NW-SE to NNW-SSE striking normal faults. Their sites in basins with a sedimantation history may be not a good choise because large earthquakes produce severe damages in such soils.

These faults were formed during an extensional stage following the main alpine orogenetic event (Pavlides, 1985: Pavlides and Mountrakis., 1987), probably due to orogen collapse.

Given that the critical infrastructures (power plant units and dams are of great socio- economic importance) their antiseismic design correspond to the period for which they design, as well as to the soil in which the founded. Figure (21) illustrates the probability of ground motion exceedance in next 100yrs for rock soil conditions for a return period of 949 years.

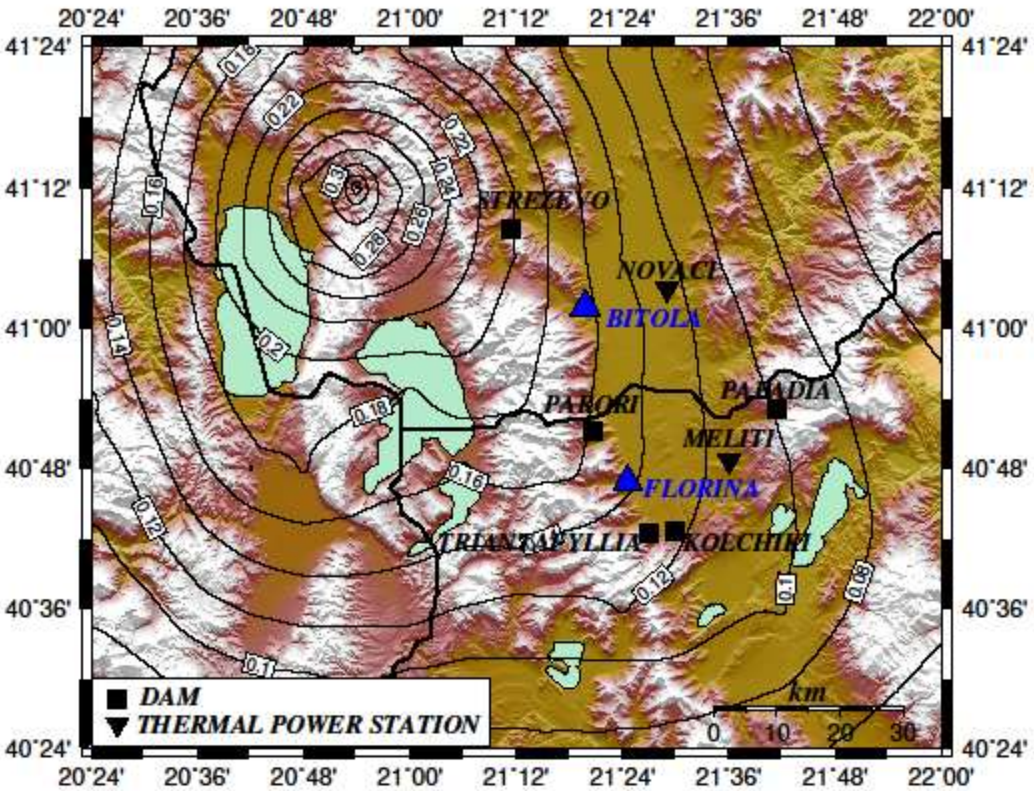

Fig. 21. The PGA values to the broader area of Florina and Bitola. Dams are marked with quadrate symbol, while power plants are presented with a reverse triangle. The probability of ground motion exceedance in next 100yrs for rock soil conditions and a return period of 949 years demonstrated.

Table IX. Probability of the ground motion exceedance in the next 100 years (yrs) for the critical infrastructures installed to the area under study. Probabilities of 90%, 95% and 98% for 949, 1950 and 4950 return periods estimated, respectively. (a) Rock site conditions are taken into account and (b) Soft site conditions considered.

(a)

Rock site conditions	Probability of ground motion exceedance in next 100yrs		
Name	90% 949yr return period	95% 1950yr return period	98% 4950yr return period
Strezovo dam	0.204g	0.280g	0.393g
Kolchiki dam	0.125g	0.198g	0.304g
Triantafyllia dam	0.136g	0.196g	0.332g
Parori dam	0.167g	0.235g	0.326g
Papadia dam	0.096g	0.136g	0.203g
Meliti thermal power station	0.114g	0.159g	0.249g
Novaci thermal power station	0.123g	0.172g	0.244g
Florina	0.149g	0.208g	0.322g
Bitola	0.162g	0.226g	0.334g

(b)

Soft soil site conditions	Probability of ground motion exceedance in next 100yrs		
Name	90% 949yr return period	95% 1950yr return period	98% 4950yr return period
Strezovo dam	0.269g	0.371g	0.522g
Kolchiki dam	0.170g	0.249g	0.402g
Triantafyllia dam	0.180g	0.274g	0.426g
Parori dam	0.218g	0.306g	0.418g
Papadia dam	0.128g	0.183g	0.270g
Meliti thermal power station	0.152g	0.213g	0.339g
Novaci thermal power station	0.161g	0.219g	0.313g
Florina	0.201g	0.281g	0.470g
Bitola	0.210g	0.299g	0.447g

Figure (22) illustrates the probability of the ground motion exceedance in next 100yrs for soft soil conditions for a return period of 949 years.

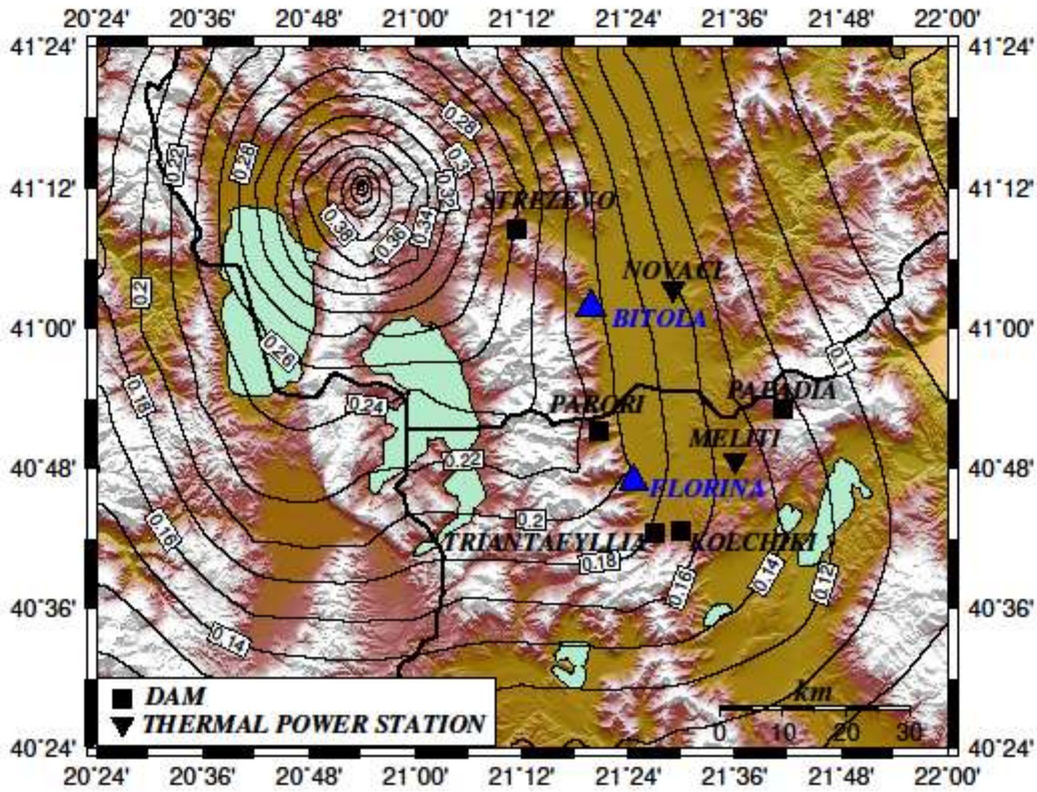

Fig. 22. The PGA values to the broader area of Florina and Bitola. Dams are marked with quadrate symbol, while power plants are presented with a reverse triangle. The probability of the ground motion exceedance in next 100yrs for soft soil conditions and a return period of 949 years illustrated.

It is obvious from figures (21 and 22) , as well as from Table 9 that the PGA values for antiseismic design are shorter in hard soil conditions. Another useful information is that the PGA values are higher (for both soil condition) as one wants the antiseismic design for larger return periods

4.2. Seismic risk

Vulnerability is a factor which indicates how certain building types respond to earthquakes. *Earthquake Risk* is the results on environment (structures, etc) and to people. It is a quantity which depends on both seismic hazard and vulnerability. The scope in nowadays is the reduction of the vulnerability, given that the seismic hazard at a site depends on natural factors, as seismicity, properties of foundation soil, etc). These factors can not be controlled yet by special scientists for the moment.

One way to reduce vulnerability to earthquakes is to foreshadow their occurrence and evacuating inhabitants at risk. Because this is not very easy for the time, alternatively we can examine very carefully the site for their installation and designed and built them so that in an earthquake they are not dangerous and the possible costs of repairs is reduces. Ground shaking is most intense near a rupturing fault, decreasing with the distance but the local geology affects the intensity. For example: **soft sediments amplify the shake.**

Phenomena connecting with such soil conditions are the *landslides* and *flooding*. Both are examined separately for the area. Dropping few words about these phenomena we can say that *landslides* are a hazard factor observing in mountains after heavy rains and where slopes are already unstable because of soil type. The other phenomenon, flooding, is a result from ground level changes, from ponding up of rivers by an earthquake induced landslide or failure of dams.

After hazard phenomena identification, an earthquake, called the *design earthquake*, is useful because through this quantity, one can estimate the PGA values at a given site during a selected time interval. Alternatively the *design earthquake* is useful for assessing the maximum peak ground acceleration at a selected site. The concept of the *design earthquake* describes the worst scenario at a site for which we assume the genesis for a maximum earthquake at very short distances , e.g. 10 Km. The approach should therefore provide more conservative results. Methods to evaluate this deign earthquake given by scientists during the time (Cornell , 1968; Consentino et al., 1977; Veneziano et al., 1984; McGuire 1993 . Kijko and Gaham, 1998, Tsapanos, 2003, among others).

Based on such studies we estimated for the whole eligible region the *design earthquake* which is :

$$M_w^{\max} = 6.76 \pm 0.22 \tag{7}$$

this value is in very good agreement with the most largest recorder earthquake in the area which is 6.7, occurred near Ochrid lake during 1911. The method is reliable because the error of the magnitudes estimation is also revealed. (Tsapanos and Burton, 1991), based on third asymptotic distribution of extremes, defined the seismic hazard for 50 seismic countries globally distributed. They based on the magnitude of the earthquake most likely to be largest during 85 years. For the whole Yugoslavia they assessed a magnitude M7.1.

Seismic hazard maps can be drawn up for land use planning and dangerous zones of high level of seismic risk can clearly observe. Such maps have already given in previous pages of the present. However in practice it is not easy to achieve a good correspondence between seismic risk and land use, especially in establishing settlements, where moving already existing structures to less hazardous sites may well be considered prohibitively expensive. After a devastating earthquake the benefit of rebuilding an entire city at a different site in the hope of avoiding same future damages may be considered. The question that posed in such situation concerned the expenses needed.

The PGA values estimated at sites contributes significantly to the determination of the national seismic codes, according to which buildings of different importance (ordinary, hospitals , plants, etc) must be constructed and it conditions the priority of intervention for existing buildings. The estimated "design" PGA values offer a seismic hazard scenario and is considered as a tool for engineers, regulators, and planners to mitigate adverse social or economic effects of an earthquake and allows then to plan earthquake-resistant designs. Given that intensive building construction and an obvious increasing of urban population, specifically in Florina and Bitola, especially during the decades of 1990 and 2000 the effects of disastrous earthquakes occurrence would be even more dramatic. So it is important to estimate the seismic risk with the greatest accuracy, raise public awareness and improve disaster planning and management in the whole area under examination.

4.3. Some conclusions

A seismic hazard is the probability that an earthquake will occur in a given geographic area, within a given window of time, and with ground motion intensity exceeding a given threshold. This is associated with potential earthquakes in a particular area, and a seismic hazard map shows the relative hazards in different areas. Seismic hazard can express by values or by hazard maps. The second alternative can be used for land-use planning, mitigation, and emergency response.

Such studies of seismic hazard are useful for the seismic risk reduction, which means,

a) Total absence of damages or only slight damages which are repairable during the life time of a structure (e.g 50 years).

b) The technical structure to suffer some damages (no collapse) by the maximum expected seismic motion at site of the structure.

Given that the Meliti_Achlada power plant unit is of great importance (socio-economic) its antiseismic design was proposed at 0.26g which corresponds to a mean return period of 2000 years (personal communication), Almost same PGA values (0.22g) assessed for this power plant for a return period period of 1950 yrs and soft soil conditions and for the next 100 years. Such hazard studies and useful maps with expected seismic motion in PGA are given in the present work and concern the broader area of the cities Florina and Bitola and the surrounding area of the sites where critical infrastructures are existed (dams, power plants, etc). It Is well known that the historic part of the cities are founded in soft soil, given that both are situated in basins, as was aforementioned.

Based on the information given above we can see that the two main cities of the area (Florina and Bitola) are in accord with the antiseismic codes, as probability of the ground motion exceedance in the next 100 years (yrs) for 949 yrs (90%) return periods. A large part of the two cities were installed in basin where the soft soil is the dominant ground. This is of great danger given that the amplitude of the seismic waves in soft soil-foundation structures enlarged caused in this way heavy damages or/and casualties in several cases. Our belief is that in such cases different antiseismic codes are imperatives, offering much safety in population lived around.

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A P P E N D I X

INFORMATION ON THE EARTHQUAKES OCCURRENCE SINCE HISTORICAL TIMES IN THE BROADER AREA. The first two columns referred on the year/date and time occurrence. The columns 3rd and 4th indicated the epicentral coordinates. Depth and magnitude (MAG) revealed to columns 5th and 6tn, respectively

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
552	0000000000.00	41.0000	20.8000	0.00	6.6
1395	1000000000.00	40.9000	22.3000	0.00	6.7
1709	0000000000.00	40.6000	21.3000	0.00	6.0
1812	0529000000.00	40.5000	21.3000	0.00	6.5
1894	0823000000.00	40.3000	21.4000	0.00	6.1
1896	0928000000.00	41.1000	20.7000	0.00	6.1
1906	0927023000.00	40.9000	20.7000	0.00	6.0
1911	0218213512.00	40.9000	20.8000	0.00	6.7
1911	0222020800.00	41.1000	20.7000	0.00	5.9
1912	0213080353.00	40.8000	20.7000	0.00	6.1
1923	0423230800.00	42.3000	21.3000	0.00	5.3
1926	0616031200.00	42.0000	20.5000	0.00	5.1
1931	0128055515.00	40.6000	20.7000	0.00	5.9
1941	0624151610.00	41.0000	20.5000	0.00	5.2
1948	0326030212.00	41.3000	21.0000	0.00	5.1
1953	0107000128.00	41.3000	20.6000	0.00	5.3
1953	0107011857.00	41.3000	20.6000	0.00	5.6
1958	0315062708.00	40.9000	21.2000	0.00	5.4
1960	0312115400.00	41.8300	20.9400	0.00	5.7
1960	0526051011.00	40.6300	20.6500	0.00	6.5
1966	0630192129.00	41.1800	20.8500	19.00	4.7
1967	0926050537.40	41.5300	20.9400	39.00	4.5

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
1967	1130075349.60	41.3800	20.6000	39.00	4.7
1967	1130081129.00	41.4500	20.5600	12.00	4.6
1967	1130081317.50	41.4000	20.5000	30.00	4.5
1967	1130095128.00	41.6000	20.6000	34.00	4.8
1967	1202141857.00	40.7000	21.4000	33.00	4.9
1967	1204004851.00	41.1700	20.6600	10.00	4.5
1967	1221000940.00	42.1600	20.6200	26.00	4.8
1967	1230212720.30	40.6600	21.4700	34.00	4.5
1968	0221010041.90	40.6000	21.0000	0.00	4.9
1970	0317170056.80	41.4000	21.0700	43.00	4.6
1971	0131091416.70	41.3000	21.2350	10.00	4.5
1971	0925193154.40	41.3990	20.8200	0.00	4.8
1972	0216063140.80	40.7700	21.3770	0.00	4.6
1972	0916140626.60	41.3540	20.6810	6.00	4.8
1972	0926143913.60	40.7190	20.8980	0.00	4.5
1972	1202224014.70	41.6010	20.8740	0.00	4.8
1973	0414021526.90	40.8560	20.7550	11.00	4.6
1973	0706142427.10	41.8810	21.7300	11.00	4.5
1974	0310215105.90	40.8760	21.1000	32.00	4.5
1974	0322170220.10	40.6520	20.5540	28.00	4.7
1975	0920212936.00	40.6000	21.5900	14.00	4.5
1976	0715194128.20	40.7650	20.7230	1.00	4.5
1976	0718220938.00	40.9700	20.5000	15.00	4.5
1977	0701124039.00	40.7040	20.7400	38.00	4.7
1977	0817223252.10	41.3820	20.9400	10.00	4.7
1977	1103090516.00	42.7370	20.6750	37.00	4.5
1977	1218002932.20	40.7700	21.2950	7.00	4.6
1978	0516082342.40	41.1370	20.9600	10.00	4.5
1979	1006064000.80	41.5490	20.8550	8.00	4.5
1979	1126103206.50	41.2700	21.0670	24.00	4.5
1981	0307065315.00	42.9200	20.5680	10.00	4.7
1981	0322054405.80	40.6890	20.8230	1.00	4.7

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
1981	0322114650.80	40.6030	20.8160	7.00	4.7
1981	1024064019.00	42.0020	20.5030	10.00	4.9
1981	1121010007.30	40.8020	21.3720	10.00	4.5
1982	0714161451.90	42.1730	21.3150	6.00	4.6
1982	0827225033.40	40.6810	21.4270	21.00	4.5
1983	0225182211.90	42.0020	21.6380	9.00	4.9
1983	0702161647.10	40.8100	20.7090	23.00	4.9
1983	0702163851.40	40.8460	20.7310	22.00	5.0
1983	0905083049.70	41.3330	20.8930	0.00	4.7
1983	0905083149.60	41.3410	20.9390	10.00	4.5
1983	0905084937.80	41.3390	20.8540	10.00	4.5
1983	1222112752.00	42.0690	21.2880	5.00	4.5
1983	1228082151.60	40.8430	20.8080	5.00	4.6
1983	1228082727.50	40.8790	20.7910	4.00	4.9
1984	0709185713.00	40.6880	21.8450	36.00	5.3
1984	0819040806.30	41.6290	20.7990	6.00	4.5
1988	1021021821.30	41.2970	20.8920	10.00	4.9
1989	0526120817.30	40.9110	20.7270	10.00	4.5
1991	0712014155.10	41.4280	20.9100	7.00	4.5
1991	0808070324.70	41.6200	20.8320	4.00	4.5
1992	0330193202.20	41.1020	20.9640	12.00	5.1
1992	0331220103.40	41.1160	20.9880	5.00	4.5
1992	0415215148.00	41.3420	20.8050	10.00	4.5
1992	0813045229.30	40.9820	20.9430	3.00	4.8
1994	0001161242.00	41.2500	21.3000	0.00	6.1
1994	0901162312.70	41.1430	21.2530	25.00	5.3
1994	0928032307.90	41.8980	20.6380	9.00	4.5
1994	1108081146.50	40.8450	20.8220	6.00	4.5
1995	0509011440.00	40.7500	20.8900	16.00	4.7
1995	0513084517.00	40.1600	21.6700	0.00	6.6
2004	0621125406.00	40.7480	21.0810	9.00	4.0
2004	1008004756.00	41.2400	21.3130	13.00	4.5

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
2007	0525091739.00	40.8210	20.7780	3.00	4.3
2008	0107085537.00	41.1450	20.7380	6.60	3.0
2008	0107093536.00	41.1480	20.7530	3.40	3.2
2008	0109195101.00	41.1780	20.7650	1.20	3.3
2008	0112114930.00	41.1870	20.7320	1.50	3.0
2008	0114004314.00	40.7550	21.8700	9.30	3.7
2008	0201102814.00	40.8130	20.7490	2.80	3.1
2008	0408061906.00	40.6670	20.6530	0.00	3.4
2008	0517095308.00	40.6890	21.1740	0.00	3.3
2008	0613051157.00	41.1920	20.7970	16.30	3.0
2008	0613220411.00	40.6310	21.6270	7.20	3.1
2008	0614005232.00	41.1840	20.9670	14.10	3.3
2008	0628033114.00	40.6850	20.7610	1.60	3.5
2008	0628033709.00	40.6880	20.7240	0.00	3.7
2008	0628050239.00	40.7120	20.5350	12.60	3.1
2008	0628050828.00	40.6930	20.7480	0.50	3.2
2008	0701101746.00	40.6620	21.5170	2.00	3.7
2008	0701104821.00	40.6550	21.4970	9.40	3.3
2008	0701123158.00	40.6550	21.4690	14.70	3.7
2008	0701205934.00	40.6440	21.4520	14.40	3.0
2008	0716211115.00	40.8330	20.7610	17.60	3.0
2008	0726040302.00	40.8300	20.7880	13.10	3.3
2008	0728214925.00	40.7030	21.8880	2.60	4.2
2008	0729213506.00	40.7130	21.8860	0.40	3.6
2008	0731002737.00	40.9800	21.0150	0.40	3.6
2008	0928071152.00	40.6860	20.6860	0.00	3.1
2009	0214025821.00	40.6660	21.2390	11.40	3.6
2009	0309235834.00	41.2910	20.6010	0.60	3.4
2009	0310055147.00	41.2820	20.5220	0.00	3.0
2009	0310083258.00	41.2970	20.5410	0.00	4.0
2009	0310221030.00	41.2930	20.5220	2.00	3.4
2009	0311154541.00	41.2510	20.5090	1.60	3.1

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
2009	0731071328.00	40.9270	20.5900	0.10	3.3
2009	1010002840.00	40.8970	20.7200	5.70	4.2
2010	0118084550.00	40.7630	21.2820	13.60	3.2
2010	0312154438.00	41.1700	20.8660	1.20	3.0
2010	0722012526.00	41.2400	20.8460	0.00	3.0
2010	0726022825.00	40.9990	20.8270	0.00	3.1
2010	0911154712.00	40.6810	20.9400	0.00	4.0
2010	0911155237.00	40.6580	20.9170	0.10	3.2
2010	1211045531.00	40.6320	21.4800	1.80	3.9
2010	1211053710.00	40.6360	21.4710	0.00	3.0
2011	0125130603.00	40.7260	20.6990	4.40	3.0
2011	0126110335.00	40.7390	20.6400	15.00	3.0
2011	0126111112.00	40.7480	20.6610	0.00	3.4
2011	0223112329.00	40.7030	20.7090	4.00	3.0
2011	1024064923.00	40.9510	21.3280	14.00	3.2
2012	0318114347.00	40.7930	21.2730	13.70	3.0
2012	0327193207.00	40.7370	21.2610	7.80	3.3
2012	1125201844.00	40.9190	21.0850	0.00	3.3
2012	1228055038.00	40.7710	21.3590	6.40	3.4
2013	0119214917.00	40.9900	21.1010	1.50	3.8
2013	0123203054.00	40.8830	20.7040	0.00	3.1
2013	0212110639.00	40.9400	20.7860	0.00	3.3
2013	0217120648.00	40.7340	21.3990	0.10	3.4
2013	0217121930.00	40.7530	21.3910	1.00	3.0
2013	0217164849.00	40.7770	21.3600	2.70	4.0
2013	0416033005.00	40.7690	21.4060	2.40	3.2
2013	0526002343.00	41.0830	21.1610	0.10	3.2
2013	0526023317.00	41.0560	21.1670	0.00	3.1
2013	0613200633.00	40.7930	21.3460	6.20	3.1
2013	1110145042.00	40.9540	21.1410	1.80	3.1
2013	1129065032.00	40.7470	21.3910	0.10	3.0
2014	0117194233.00	40.7990	20.6590	2.40	3.0

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
2014	0222114228.00	40.7680	21.2640	0.00	3.5
2014	0626151341.00	40.7320	21.4090	6.10	3.7
2014	0713111808.00	40.9000	21.2340	7.00	3.8
2014	0713115544.00	40.9050	21.2210	3.00	3.0
2014	0917123323.00	40.7910	21.2120	2.50	4.2
2014	0927084203.00	40.7500	21.2500	13.50	3.0
2014	1019173011.00	41.1900	20.9000	0.10	3.0
2014	1021103229.00	41.1870	20.8670	0.10	3.4
2014	1116021754.00	40.6660	20.8210	0.20	3.1
2014	1215065021.00	40.6790	20.7590	0.10	3.1
2015	0331131632.00	40.7890	21.2200	0.00	3.0
2015	0402094818.00	40.6680	21.3770	12.30	3.1
2015	0429144754.00	41.2760	20.8890	0.00	3.6
2015	0624042520.00	40.7670	21.2420	0.00	4.1
2015	0626204155.00	40.7700	21.2040	1.60	4.1
2015	0627160147.00	40.7630	21.2390	0.00	3.9
2015	0918195328.00	40.7090	21.2860	0.00	3.3
2016	0306031151.00	40.7330	21.2260	4.00	3.9
2016	0521163308.00	41.2780	21.0680	0.00	4.8
2016	0521164129.00	41.2280	21.0430	0.10	4.6
2016	0521171639.00	41.2260	21.0550	0.00	4.0
2016	0521173722.00	41.2270	21.0320	1.50	3.1
2017	0121155549.00	40.6470	20.7630	3.00	2.2
2017	0215022526.00	40.6570	20.7700	7.90	2.4
2017	0222123156.00	40.6590	21.4440	16.50	2.1
2017	0328152433.00	41.1930	20.8890	2.20	2.9
2017	0406075355.00	40.7600	20.7260	12.20	2.4
2017	0407101108.00	41.0640	21.9480	12.10	2.3
2017	0408031455.00	40.7670	21.1950	8.90	2.5
2017	0412085830.00	41.2650	20.9070	1.50	2.8
2017	0419094255.00	41.1720	20.7620	0.10	2.5
2017	0422114106.00	40.6210	21.4070	17.00	2.0

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
2017	0422121510.00	41.0540	20.5300	12.60	2.0
2017	0422121920.00	40.6350	21.4080	20.00	2.0
2017	0422162127.00	41.0460	20.5240	1.90	2.0
2017	0422194307.00	41.0640	20.5590	4.30	2.4
2017	0503081646.00	40.7650	21.2400	13.80	2.2
2017	0508115506.00	41.0520	20.5270	17.00	2.3
2017	0508151905.00	41.0590	20.5650	0.00	2.7
2017	0508194643.00	41.0640	20.5850	0.00	2.3
2017	0509043552.00	41.0520	20.5160	24.30	2.0
2017	0509125220.00	41.0960	20.5670	0.00	3.4
2017	0509125822.00	41.0460	20.5320	0.00	2.2
2017	0515111842.00	40.6680	20.8540	9.70	2.3
2017	0530093037.00	40.8390	21.3920	1.70	2.2
2017	0531152812.00	40.9250	21.9440	0.00	2.1
2017	0601084501.00	40.9900	20.5270	0.50	3.1
2017	0612100832.00	40.8690	20.8990	0.00	2.7
2017	0615202013.00	41.1650	20.8910	14.40	2.1
2017	0615231057.00	41.1670	20.9040	0.10	2.3
2017	0618000058.00	41.1940	20.9330	0.00	3.3
2017	0618060001.00	41.1720	20.9150	0.00	2.7
2017	0620131034.00	41.1840	20.9310	0.00	3.8
2017	0620204658.00	41.1940	20.9180	0.70	2.1
2017	0622021324.00	41.1990	20.9280	2.80	2.2
2017	0622131234.00	41.1900	20.9140	2.00	2.3
2017	0623013515.00	41.1850	20.9310	0.90	2.0
2017	0623072412.00	41.2070	20.9330	0.00	2.2
2017	0624134125.00	41.2100	20.9150	1.80	2.5
2017	0625014002.00	41.1670	21.0020	0.00	2.0
2017	0625203450.00	41.2170	20.9370	1.80	2.9
2017	0625230254.00	41.1570	20.9910	0.00	3.3
2017	0626004854.00	41.1470	21.0010	0.00	2.1
2017	0626011525.00	41.1330	20.9790	0.00	2.5

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
2017	0626071731.00	41.1420	20.9630	8.30	2.0
2017	0626114657.00	41.2060	20.9410	0.10	3.5
2017	0626125640.00	41.2000	20.9340	0.10	2.2
2017	0626162812.00	41.1350	21.0040	0.00	2.4
2017	0626235232.00	41.1670	20.9070	10.60	2.2
2017	0627212656.00	41.1980	20.9510	7.70	2.0
2017	0628015241.00	41.1890	20.9330	0.10	2.8
2017	0628073057.00	41.1380	20.8460	5.00	2.3
2017	0628112912.00	41.1780	20.8900	0.10	2.5
2017	0628113857.00	41.1710	20.9020	20.60	2.2
2017	0628133641.00	41.1780	20.9150	0.00	2.5
2017	0628175821.00	41.1720	20.9130	0.00	2.3
2017	0628182048.00	41.1720	20.8970	12.50	2.4
2017	0628185247.00	41.1810	20.8830	0.00	3.2
2017	0629003709.00	41.1320	21.0170	0.00	2.8
2017	0629024139.00	41.1840	20.9030	0.10	2.8
2017	0629041825.00	41.1990	20.9380	2.50	2.1
2017	0629054938.00	41.1780	20.9200	4.30	2.3
2017	0629063451.00	41.1770	20.9010	0.10	2.9
2017	0629072002.00	41.1790	20.9110	3.30	2.6
2017	0629124427.00	41.1790	20.9000	9.60	2.1
2017	0629191012.00	41.1790	20.8880	9.80	2.1
2017	0630113334.00	41.1940	20.9170	0.50	2.7
2017	0630184133.00	41.1730	20.9040	22.40	2.1
2017	0630200826.00	41.1740	20.8710	0.00	2.3
2017	0630231606.00	41.1860	20.9030	10.00	2.0
2017	0631180134.00	41.2020	21.0180	4.30	3.0
2017	0701095321.00	41.2270	20.9800	0.00	2.6
2017	0701233638.00	41.2320	20.9260	0.20	2.0
2017	0702075821.00	41.2050	20.9990	0.00	2.8
2017	0702093909.00	41.2150	20.9580	0.00	4.0
2017	0702115309.00	41.1630	20.9050	0.00	2.3

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
2017	0702123144.00	41.1870	20.9200	0.10	2.8
2017	0703010937.00	41.1680	20.8920	0.00	2.9
2017	0703015412.00	41.1910	20.9140	0.00	3.4
2017	0703111820.00	41.1810	20.9160	1.40	4.9
2017	0703114710.00	41.1520	20.9030	3.00	2.4
2017	0703115449.00	41.1690	20.9060	1.50	2.5
2017	0703120829.00	41.1650	20.9290	0.00	2.8
2017	0703121713.00	41.1650	20.8910	9.90	2.5
2017	0703122142.00	41.1550	20.8450	5.70	2.5
2017	0703123125.00	41.2280	20.8790	2.30	2.8
2017	0703140120.00	41.1710	20.8920	3.50	2.5
2017	0703143450.00	41.1760	20.9220	5.20	2.6
2017	0703150808.00	41.1710	20.8980	5.00	2.4
2017	0703154939.00	41.1940	20.9240	6.90	2.5
2017	0703161414.00	41.1760	20.9270	0.00	3.4
2017	0703180324.00	41.1730	20.9000	0.00	3.8
2017	0703182422.00	41.1810	20.8980	0.00	3.1
2017	0703182816.00	41.1880	20.9010	0.00	3.4
2017	0703183012.00	41.1730	20.8890	0.10	3.9
2017	0703192209.00	41.2020	20.9350	9.30	2.6
2017	0703192939.00	41.1910	20.9180	5.00	2.5
2017	0703200559.00	41.1790	20.8800	2.50	2.7
2017	0703203737.00	41.1750	20.8980	2.50	3.0
2017	0703204558.00	41.1810	20.9160	3.40	2.6
2017	0703210159.00	41.1750	20.8810	2.50	2.7
2017	0703210353.00	41.1560	20.8730	4.40	2.9
2017	0703213415.00	41.1710	20.8990	0.10	3.0
2017	0703213936.00	41.1600	20.8860	2.50	2.2
2017	0703220728.00	41.1780	20.9160	1.70	2.6
2017	0703224028.00	41.1940	20.8990	8.70	2.7
2017	0703233736.00	41.1720	20.8830	2.50	2.7
2017	0703234234.00	41.1540	20.8530	7.00	2.7

YEAR	OCCUR. DATE	LATIT.	LONGIT.	DEPTH	MAG.
2017	0703235035.00	41.1690	20.8810	6.70	2.6
2017	0704013255.00	41.2030	20.9400	0.00	2.8
2017	0704015833.00	41.1520	20.9140	13.60	2.3
2017	0704023223.00	41.1820	20.9030	0.40	2.2
2017	0704031025.00	41.1630	20.8590	2.50	2.2
2017	0704031717.00	41.1650	20.8920	0.10	3.0
2017	0704035200.00	41.1660	20.8840	4.00	2.3
2017	0704035932.00	41.1730	20.8750	10.00	2.4
2017	0704050135.00	41.1870	20.9060	2.50	2.6
2017	0704063640.00	41.1670	20.8810	0.10	3.5
2017	0704074727.00	41.1920	20.9020	0.00	2.6
2017	0704082652.00	41.1670	20.9110	2.30	2.3
2017	0704082754.00	41.1870	20.8860	0.00	3.5
2017	0704095955.00	41.1930	20.9740	0.00	2.4
2017	0704103115.00	41.1630	20.8760	0.00	2.7
2017	0704103742.00	41.1750	20.9050	3.60	2.3
2017	0704103907.00	41.1840	20.9230	6.20	2.7
2017	0704104502.00	41.1740	20.8720	0.10	2.8
2017	0704111040.00	41.1890	20.8310	0.60	2.9
2017	0704111928.00	41.1880	20.8780	0.10	3.3
2017	0704114304.00	41.1820	20.9150	0.00	2.4
2017	0704122007.00	41.1910	20.8710	8.70	2.5
2017	0704184638.00	41.1670	20.8950	8.40	2.7
2017	0704194116.00	41.1910	20.8850	9.00	2.4
2017	0704194653.00	41.2070	20.9280	0.00	2.5
2017	0704200708.00	41.1730	20.8900	8.40	2.4
2017	0704203357.00	41.1760	20.8750	0.30	2.3
2017	0704220515.00	41.1840	20.9030	0.00	3.8
2017	0704220541.00	41.1660	20.9170	1.40	3.8
2017	0704221132.00	41.1910	20.8880	0.00	2.5
2017	0704231623.00	41.1840	20.9000	1.70	3.0
2017	0704233710.00	41.1810	20.8960	0.10	3.1

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2017	0704233819.00	41.1730	20.9050	8.60	2.2
2017	0704233946.00	41.1910	20.8990	7.70	2.3
2017	0705010201.00	41.1730	20.8980	10.90	2.8
2017	0705011349.00	41.1790	20.9070	8.70	2.0
2017	0705042932.00	41.1600	20.8920	12.10	3.9
2017	0705064157.00	41.1590	20.9110	13.20	2.7
2017	0705074737.00	41.1870	20.9290	8.90	2.3
2017	0705115156.00	41.1800	20.9140	13.70	3.3
2017	0705124746.00	41.1810	20.9120	0.00	2.8
2017	0705161057.00	41.1380	20.9390	0.00	2.3
2017	0705195803.00	41.1760	20.8980	0.00	2.7
2017	0706022012.00	41.2010	20.9460	11.00	2.5
2017	0706063159.00	41.1820	20.9090	9.90	2.7
2017	0706091255.00	41.1870	20.8760	0.00	3.6
2017	0706131924.00	41.1820	20.9000	0.10	2.9
2017	0706173406.00	41.1730	20.9070	0.10	2.5
2017	0706230700.00	41.1750	20.9250	0.20	3.2
2017	0707005242.00	41.1690	20.8810	4.90	2.0
2017	0707010739.00	41.1990	20.9310	0.00	2.2
2017	0707023243.00	41.1760	20.8960	0.10	2.9
2017	0707045432.00	41.1960	21.0360	0.00	2.8
2017	0707051619.00	41.1740	20.9240	0.70	2.5
2017	0707051826.00	41.1550	20.9120	0.30	3.3
2017	0707060233.00	41.1730	20.8990	1.70	2.2
2017	0707101337.00	41.1800	20.9170	0.40	2.5
2017	0707171755.00	41.1750	20.8990	9.20	2.6
2017	0707193840.00	41.1630	20.8820	11.10	3.3
2017	0707210513.00	41.0740	21.0510	0.20	2.8
2017	0707220412.00	41.1830	20.8900	5.40	3.8
2017	0707223029.00	41.1570	20.8700	13.10	2.3
2017	0707223220.00	41.1830	20.9040	9.70	2.4
2017	0707223746.00	41.1750	20.8880	10.30	2.7

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2017	0708000844.00	41.1810	20.8900	1.60	2.3
2017	0708004932.00	41.1780	20.9020	0.00	2.8
2017	0708011707.00	41.2090	20.9540	0.00	2.2
2017	0708090755.00	41.1850	20.8970	0.10	2.1
2017	0708151047.00	41.1970	20.9380	0.70	2.7
2017	0708163020.00	41.1630	20.8960	0.20	2.9
2017	0708193134.00	41.1700	20.9170	0.30	3.6
2017	0708195726.00	41.1840	20.9330	0.10	2.5
2017	0708205259.00	41.1760	20.9240	1.00	3.4
2017	0708212709.00	41.1850	20.9210	0.00	2.1
2017	0708220206.00	41.1670	20.8900	0.00	2.4
2017	0708232321.00	41.2120	21.0020	1.60	2.2
2017	0708233751.00	41.1450	20.8600	6.70	2.0
2017	0709095650.00	41.1940	20.9380	0.10	2.1
2017	0709104431.00	41.2110	20.9570	0.00	2.6
2017	0709112828.00	41.1720	20.9220	0.10	2.2
2017	0709124720.00	41.1790	20.9250	0.00	2.0
2017	0710001207.00	41.1540	20.8540	0.00	2.7
2017	0710021638.00	41.1800	20.9090	0.10	2.7
2017	0710023704.00	41.1540	20.8840	0.00	3.1
2017	0710023922.00	41.1690	20.8980	0.00	3.3
2017	0710030543.00	41.1650	20.8970	0.00	2.4
2017	0711014030.00	41.2030	20.9270	3.40	2.4
2017	0711085345.00	41.1120	20.8190	15.40	2.1
2017	0712200235.00	41.1880	20.9390	4.30	2.8
2017	0712221953.00	41.2070	20.9330	1.10	3.4
2017	0712234933.00	41.1790	20.9510	0.00	2.7
2017	0714040746.00	41.1660	20.9010	0.00	2.3
2017	0714062630.00	41.1730	20.8800	3.20	2.5
2017	0714165815.00	41.2320	20.9760	8.10	3.0
2017	0714165931.00	41.1730	20.9210	0.10	3.2
2017	0714213906.00	41.1630	20.8950	0.00	3.0

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2017	0716040219.00	41.1840	20.9570	0.80	2.2
2017	0719185831.00	41.1690	20.8930	1.40	2.0
2017	0719194810.00	41.1770	20.9300	0.00	2.4
2017	0720035335.00	41.1700	20.8770	10.70	2.2
2017	0720092224.00	41.1830	20.9020	0.00	2.2
2017	0720140247.00	41.1550	20.8500	1.70	3.1
2017	0720201944.00	41.1690	20.8950	0.00	2.7
2017	0720205621.00	41.1570	20.8560	4.40	2.0
2017	0720210245.00	41.1500	20.8330	10.00	2.2
2017	0722015302.00	41.1720	20.8880	0.10	2.4
2017	0722024943.00	41.1650	20.8680	8.40	2.5
2017	0723013259.00	41.1610	20.8540	0.20	2.8
2017	0723234116.00	41.1780	20.9100	6.70	3.2
2017	0724010650.00	41.1620	20.8560	13.60	2.3
2017	0724020201.00	41.2340	20.9130	1.40	2.5
2017	0724223904.00	41.1890	20.9040	0.10	3.2
2017	0725052817.00	41.1880	20.9230	8.10	2.1
2017	0725064427.00	41.2050	20.9120	0.00	2.6
2017	0725171149.00	41.1510	20.8590	1.30	3.1
2017	0726115354.00	41.1840	20.8870	9.40	2.5
2017	0726192010.00	41.1640	20.8860	20.00	2.4
2017	0727001626.00	41.1650	20.8730	0.00	2.0
2017	0727004738.00	41.1720	20.8800	1.80	2.5
2017	0727030046.00	41.1650	20.8610	13.50	2.2
2017	0727030927.00	41.1720	20.9040	1.60	2.3
2017	0727073754.00	41.1680	20.8670	19.90	2.5
2017	0727175147.00	41.1610	20.8530	15.20	2.1
2017	0728220950.00	41.1570	20.8620	12.60	2.9
2017	0913075155.00	41.2370	20.9750	0.10	2.1
2017	0918060655.00	40.6370	21.7130	0.00	2.7
2017	0919073614.00	40.6550	21.6830	14.10	2.2
2017	0920065001.00	41.1900	20.9410	0.00	2.6

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2017	0927163613.00	40.6390	21.6890	4.70	2.4
2017	0927165857.00	40.6510	21.6780	13.50	2.6
2017	0927172516.00	40.6480	21.7080	0.00	3.3
2017	0928184559.00	40.6660	21.7120	1.80	2.3
2017	1002000249.00	40.6270	20.8470	0.10	2.0
2017	1002081245.00	40.6260	20.8090	7.60	2.1
2017	1007022631.00	41.2270	21.0170	1.70	2.3
2017	1009075417.00	41.1720	20.9170	0.10	3.0
2017	1011062239.00	40.6310	21.7300	0.00	3.3
2017	1013023033.00	40.6460	21.7060	15.00	2.2
2017	1014095538.00	40.8560	21.2960	4.10	4.3
2017	1014102400.00	40.8240	21.3020	15.60	2.9
2017	1014123752.00	40.8980	21.2920	5.10	3.5
2017	1014152807.00	40.8460	21.3390	18.60	2.4
2017	1014185645.00	40.8920	21.2740	4.30	2.8
2017	1014225214.00	40.8140	21.3650	18.70	2.0
2017	1016034103.00	40.8740	21.2880	9.90	2.2
2017	1017091837.00	41.1810	20.9020	0.00	2.4
2017	1021121003.00	40.6400	21.7060	0.50	2.2
2017	1023140346.00	40.6450	21.7090	8.50	2.2
2017	1024114134.00	40.6220	21.7390	13.20	2.4
2017	1109182626.00	40.6510	21.7220	14.60	2.0
2017	1111194850.00	40.6430	21.7460	0.10	2.8
2017	1111201108.00	40.6060	21.7450	1.90	2.0
2017	1113102538.00	40.6820	20.7840	1.80	2.3
2017	1127111622.00	40.9630	20.7300	0.00	2.4
2017	1128110432.00	40.6920	20.6990	8.30	2.5
2017	1128110504.00	40.6930	20.7060	10.20	2.4
2017	1128224405.00	40.9940	20.9390	0.00	2.0
2017	1129004041.00	40.6490	20.7200	7.70	2.5
2017	1129182613.00	40.6470	20.7360	8.00	2.2
2018	0103223050.40	41.1680	20.7860	0.00	2.0

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2018	0105015121.50	40.6260	20.6890	9.40	2.2
2018	0105084947.60	40.9060	20.8800	13.10	2.0
2018	0110191728.70	40.7300	21.5520	0.10	2.3
2018	0110194158.20	40.7380	21.5200	7.40	2.1
2018	0110213341.80	40.7600	21.5360	6.00	2.1
2018	0111025450.40	40.7460	21.4760	16.70	2.1
2018	0112180737.60	41.7520	21.8570	1.20	2.4
2018	0113170601.20	40.7400	20.6300	0.30	2.1
2018	0121180527.90	40.6280	21.4340	19.50	2.2
2018	0123110421.20	40.8430	21.5920	0.80	2.3
2018	0126101228.50	41.1420	20.8450	7.20	2.2
2018	0202142353.10	41.9480	21.4790	8.00	2.1
2018	0203082854.10	41.1140	20.6680	1.10	2.2
2018	0316133108.90	40.9710	20.7640	0.00	2.4
2018	0503083627.30	40.7870	21.3680	13.30	2.3
2018	0504221159.00	40.8800	21.2530	7.50	2.4
2018	0525225013.40	41.3530	20.8900	1.80	2.9
2018	0525225918.80	41.3410	20.9010	2.80	2.8
2018	0525232116.70	41.3640	20.9110	1.70	2.1
2018	0603192908.70	41.9210	21.5360	0.00	2.5
2018	0614001314.90	41.4940	20.5060	0.00	2.8
2018	0625042830.50	41.3190	20.9440	0.00	2.2
2018	0716002356.70	40.7820	21.3750	5.40	2.3