

# Historical Earthquakes: New Intensity Data Points Using Complementary Data from Churches and Monasteries



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**Abstract** The Vrancea seismogenic zone denotes a peculiar source of seismic hazard which represents a major concern in Europe, especially to Romania and neighbouring regions from Bulgaria, Serbia and Republic of Moldova. The strong seismic events that can occur in this area can generate the most destructive effects in Romania and may affect high-risk manmade structures such as nuclear power plants, chemical plants, large dams and pipelines located within a wide area including the Northern zone from the Republic of Bulgaria and the SW of the Moldavia Republic. A major part of the information for determining the design basis earthquakes consists of a complete set of historical earthquake data. Therefore, it is necessary that the available historical records to be collected, extending as far back in time as possible. Most of these historical records will be of descriptive nature, including such information as the number of houses damaged or destroyed, the behaviour of population etc. But from such information a measure of the intensity scale value of each earthquake in modern macroseismic intensity scale values may be determined. During the past project “*Bridging the gap between seismology and earthquake engineering: from the seismicity of Romania towards a refined implementation of seismic action EN1998-1 in earthquake resistant design of buildings (BIGSEES)*”, the authors developed the macroseismic intensity map of

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Romania by using newly compiled information about the damages experienced by 115 churches and monasteries after 10 strong earthquakes ( $M_w > 6.9$ ) occurred in Vrancea zone starting with XVth century.

**Keywords** Historical seismicity · Intensity seismic hazard map  
Macroseismic intensity

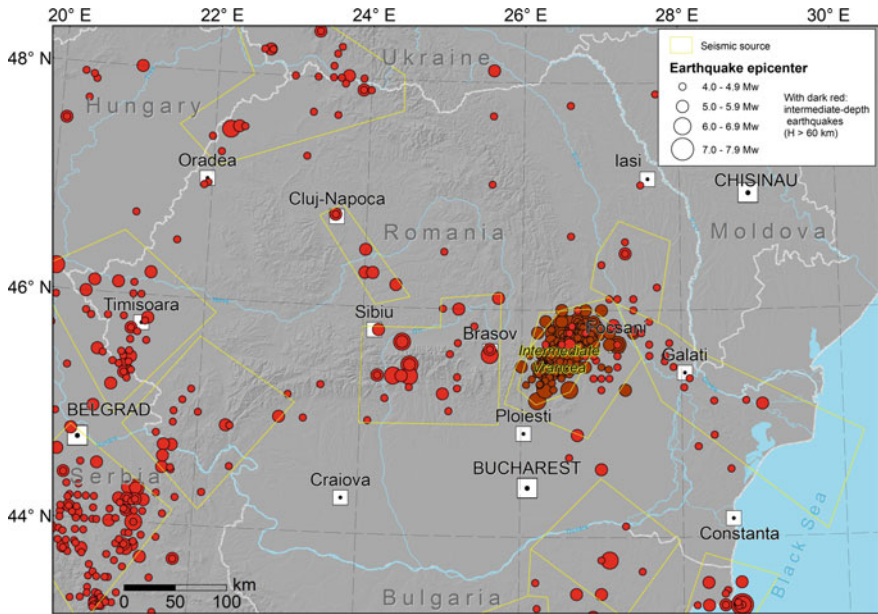
## 1 Introduction

Historical seismicity is seismicity for which evidence can be found in the historical record of humankind. For pre-instrumental earthquakes, however, this evidence is preeminent. Their existence, interpretation and use are of major interest to seismic hazard analysis, and are playing a key role in defining and litigating the seismic design of many critical facilities in last time. The historical data, consisting of written evidence of the effects of earthquakes on humans, their civilization and the environment, has been used to determine earthquake location and size, the strength of ground motions and its frequency of occurrence in most parts of the world.

Historical records differ greatly in the length, completeness and quality of the earthquake histories they portray. As we go back in time, the minimum size earthquake mentioned in any given history will usually increase. Typically, only those events which led to disastrous consequences are mentioned in ancient records. Additional information about these events would have been of great benefit to present-day seismologists and engineers. Of practical interest is the estimate of the time duration of the earthquake. These details provide the analyst with much information that allows an improved estimation of seismic hazard from future great earthquake in the area.

Seismic activity in Romania is confined to the crust, except the Vrancea zone, where earthquakes with focal depth down to 200 km occur. Figure 1 displays the spatial distribution of earthquake epicentres in Romania and surrounding areas considering also magnitudes and focal depths. The statistical analysis of the earthquake catalogue compiled in the frame of the BIGSEES Project (2017) gives at a mean return interval of 100 years a magnitude  $M_w 7.5$  for Vrancea intermediate-depth seismogenic zone and much lower magnitudes for crustal seismogenic zones:  $M_w 5.7$  for Banat and Danubian zones (located in South-West of Romania) and  $M_w 5.6$  for a very active zone in Central Romania (Fagaras-Campulung).

The strongest event in the documented history and originating in Vrancea area occurred on October 26, 1802, having a 7.9 magnitude ( $M_w$ ) and a depth of 150 km, according to ROMPLUS catalogue (NIEP 2017). It was felt over a large area in Europe: in the Balkans up to Constantinopolis (Istanbul), up to Moscow and Sankt-Petersburg in the North (North-East) and to Mediterranean Sea in the South-West, as stated by Rogozea et al. (2016) and references therein. Actually, a peculiarity of earthquakes occurring at intermediate depths (70–200 km) in Vrancea



**Fig. 1** Seismicity and seimogenic zones contributing to seismic hazard of Romania. *Datasource* BIGSEES Project 2017

zone is the quasi-elliptical shape of the macroseismic field with the major ax oriented along NE–SW direction; events with magnitudes higher then 6 can be felt in the whole Balkan area up to Turkey (in the South) and to Poland (in the North).

During the last century in Vrancea seismogenic zone 4 strong earthquakes ( $M_w > 7$ ) occurred at intermediate depths: October 6, 1908 ( $M_w$  7.1) at 125 km depth, November 10, 1940 ( $M_w$  7.7) at 150 km depth, March 4, 1977 ( $M_w$  7.4) at 94 km and August 31, 1986 ( $M_w$  7.1) at 131 km. In spite of being the most destructive event in the previous century, the 1977 earthquake had numerous precedents in Romania. The historical record here extends to Roman times and includes similar intermediate–depth earthquakes with magnitudes of 7 or greater about 2–3 times per century. Over the past several centuries, earthquakes with likely magnitudes of 7 or greater caused damage in Bucharest in 1681, 1738, 1802, 1829, 1838 and more recently in 1940, 1977.

A major part of the information for determining the design basis earthquakes to important structure like nuclear power plants, bridges etc. is a complete set of historical earthquake data. Therefore, it was necessary that the available historical records be collected, extending as far back in time as possible. Most of these historical records will naturally be of descriptive nature, including such information as the number of houses damaged or destroyed, the behaviour of population etc.; from such information a measure of the intensity scale value of each earthquake in modern macroseismic intensity scale values may be determined.

## 2 New Intensity Data by Using Complementary Data from Churches and Monasteries

In estimating intensity scale values for historical earthquakes, account should be taken of the fact that information obtained from old chronicles, from churches, monasteries and individuals who may have experienced the event shows a tendency to exaggerate the importance of damage and other phenomena associated with earthquakes. There are many data on the historical earthquakes. Many writers and journalists along time made many descriptions on earthquake effects on churches, monasteries etc. Authors collected, centralised and analysed also information from literature. For example, many descriptions of damages and macroseismic effects induced by the earthquake of 1802 ( $M_W = 7.9$ ,  $h = 150$  km) are from Mihail Sadoveanu. In the novel “Jderi Brothers” he stated that in many places from Bucharest around Bucharest Cathedral the earth unbind, went out oil, water and sand and many large slits with transversal dimensions between 50 and 150 cm occurred. Considering the effects on the natural environment and taking into account the characteristics of the monasteries (building material, size of constructive elements etc.) values of macroseismic intensity (intensity data points, IDP) were associated to the recorded damages. Some examples are discussed below.

After the strong earthquake of 1620 ( $M_W = 7.5$ ;  $h = 150$  km), Vasile Lupu, prince of Moldova, started Putna (MO/1) monastery rehabilitation, in fact its recovery. The restoration of the Church at Putna Monastery was completed in the year 1662. The large earthquake of 1738 ( $M_W = 7.7$ ;  $h = 130$  km) seriously damaged the church, the walls of the enclosure and towers of the four corners.

Stavropoleos Monastery (MO/76) (44.431789 latitude; 26.098869 longitude; altitude = 79 m) in downtown Bucharest (the word “*stavropoleos*”, name in Greek translates as “*cross town*”) was build up in 1724. Another period in the building of the Stavropoleos church (1730–1733) extended the altar, built the side apses in stone columns and carved porch. The monastery was strongly affected by the earthquake 1802 ( $M_W = 7.9$ ;  $h = 150$  km). The effects were devastating. Another earthquake took place on January 23, 1838. French consul in Bucharest, noted that “*disasters caused in this city of this event are huge and cannot be evaluated*”. The structure of the church and inn was so severely affected that on November 15, 1840, the Department of Internal Affairs is forced to submit an address in which require demolition of the tower Stavropoleos. In 1940, when the church was restored after an absence of decades, the monastery was less affected by the 7.7 magnitude event.

Bogdana Monastery (MO/104) (47.842480 latitude; 25.917498 longitude; altitude = 372 m) is located in the heart of historic Bukovina, in Rădăuți, on one of the roads leading to Putna Monastery. Here in Rădăuți, Dragoș Vodă has established one of the royal residences and founder Bogdan I, the first voivode of Moldavia is buried here in wooden church in 1367. Moldova have information to historian Ioan Neculce in 31 mai/June 11, 1738 ( $M_W = 7.7$ ;  $h = 110$  km) ... have made a great earthquake, the Golia monastery from Iași fell and many houses and many other

monasteries in Focșani; disaster followed by a “great plague in Iasi”, at Bacău overturned Răchitoasa Monastery (Corfus I., (1967)—“Notes old”, Iași, Junimea), Solomon church was destroyed, monastery Bogdana (Rădăuți) collapsed; also in some places the ground cracked and “went out water and sand”.

Comana Monastery, located in the homonymous village on the meadow of Neajlov river, is mentioned in a charter issued by the chancellery of Vlad Țepeș on September 27, 1461. In 1588, Radu Șerban, the local nobleman, built a new monastery on the old foundation. Between 1699 and 1701, governor Șerban Cantacuzino started the works of restoration of the monastery. In August 1709, hard times came for Comana monastery. The state of the monastery is sporadically recorded in some writings: “...because of the earthquakes, like that of 1701 ( $M_w = 7.1$ ;  $h = 150$  km), and because of lack of care, the monastery is in danger of ruining” (Ghenadie Enăceanu notes in quoted work *Catagraphy* from 1834, quoted by Maria Valeria Picu). This reflects a sad reality, as at Comana Monastery there were: “a chapel in the wall of monastery and the four towers totally broken down, the walls of the surrounding courtyard were totally broken and cracked” (Archives of the state Bucharest. *Ministry of Public Instruction Fund, Wallachia, File 4/1828, f.3*). In 1854, after the earthquake of 1838 ( $M_w = 7.5$ ), “*demolition and rebuilding*” of the monastery is done, as Cezar Bolliac says. The earthquake of October 26, 1802 ( $M_w = 7.9$ ;  $h = 150$  km) caused great damages to the whole construction, and in 1854 a new restoration began, conducted by architect J. Schlatter, after the earthquake of 1838 ( $M_w = 7.5$ ). The church of monastery was retrofitted after the earthquakes of 1977 ( $M_w = 7.4$ ;  $h = 94$  km) and 1986 ( $M_w = 7.1$ ;  $h = 131.4$  km).

### 3 Maps with Maxim Macroseismic Intensities Observed Along Time in Romania

Newly collected data regarding seismic damages of 115 monasteries has been synthesized and analyzed through the engineering point of view, considering materials and dimensions of the buildings, towers etc. Some of the resulting intensities presented in Table 1 are completing the known macroseismic field of each event, and data may be used to construct the isoseismic map of the maximum possible Vrancea earthquake. Figures 2, 3, 4, 5, 6 and 7 show the intensities evaluated from the analysis of the damage records at the specific sites.

The estimated intensity values for the 1738, 1802 and 1940 events are consistent with map of the macroseismic intensities expected in the case of a Vrancea “maximum credible” earthquake (Marmureanu et al. 2011) where the shape of isoseismal surfaces are elongated much more towards NE than to the SW. The sites with maximum intensities observed in the last century (IX and X MSK) are shifted towards East with respect of the epicentre area, inside or at the edges of the Focșani depression (a foredeep basin formed in front of the East Carpathians, where sediments are reaching even 14 km depth).

**Table 1** Macroseismic intensities values (MSK64 scale) evaluated using historical data from churches and monasteries

Name of monastery (M) or church (C)	Earthquakes									
	1471	1516	1590	1620	1701	1738	1802	1838	1940	1977
	M <sub>w</sub> = 7.5 H = 110 km	M <sub>w</sub> = 7.5 H = 150 km	M <sub>w</sub> = 7.3 H = 100 km	M <sub>w</sub> = 7.5 H = 150 km	M <sub>w</sub> = 7.1 H = 150 km	M <sub>w</sub> = 7.7 H = 130 km	M <sub>w</sub> = 7.9 H = 150 km	M <sub>w</sub> = 7.5 H = 150 km	M <sub>w</sub> = 7.7 H = 150 km	M <sub>w</sub> = 7.4 H = 94 km
Putna (M)		IX	IX	IX½		IX½	IX½			
Bogdana (M)					X					
Probota (M)			IX				VIII½			
Moldovița (M)		IX½						IX½		VIII½
Neamț (M)	IX½									
Sihăstria (C)										
Secu (M)										
Sf. Nicolae, Iassy (C)								IX½		
Bistrița Neamț (M)		IX½					IX			
Coșula (M)										VIII
Golia (M)				IX½		IX½	VIII½			
Cașin (M)							IX½	IX		
Sf. Trei Ierarhi (M)					IX½	IX	IX½	IX½		
Cețațuia (M)							IX½			IX½
Hlincea (M)										
Domn. Bărlad (C)							X	IX½	VIII	VIII
Sf. Ilie Bărlad (C)									VIII	
Domn. Vaslui (C)									IX	
Rafaila (M)							IX½-X		IX	
Făstâci (M)									IX	
Sămurărești (M)									IX½	IX½
Vîforâta (M)				IX½			X		X	
Sf. Gh. Nou Buc. (M)							IX½	IX½		

(continued)

**Table 1** (continued)

Name of monastery (M) or church (C)	Earthquakes									
	1471	1516	1590	1620	1701	1738	1802	1838	1940	1977
	M <sub>w</sub> = 7.5 H = 110 km	M <sub>w</sub> = 7.5 H = 150 km	M <sub>w</sub> = 7.3 H = 100 km	M <sub>w</sub> = 7.5 H = 150 km	M <sub>w</sub> = 7.1 H = 150 km	M <sub>w</sub> = 7.7 H = 130 km	M <sub>w</sub> = 7.9 H = 150 km	M <sub>w</sub> = 7.5 H = 150 km	M <sub>w</sub> = 7.7 H = 150 km	M <sub>w</sub> = 7.4 H = 94 km
Antim (M)						IX½	IX½	X	X	
Icoanei (C)								X	IX	
Stavropoleos (M)							IX½	IX½		
Zlătari (C)					X		X	IX½		IX½
Cărmădarii Sus (C)								X		
Precupești Noi (C)										X
Patriarch. Cathedral							IX½		IX½	IX
Radu Vodă (M)								IX½		
Comana (M)		X			X		X	IX½		VIII½
Răești (M)							IX½	IX½		VIII½
Curtea de Argeș (M)			IX½				X	IX½		
Zămfira (N)								X	IX	IX
Brâncoveni (M)				IX½			IX½	IX½	IX½	
Bistrița-Vâlcea (M)				IX½				IX½		
Arnăuți (M)					X			IX½		IX
Nucet (M)						X	X	X	IX½	
Dealul (M)						IX		IX	IX½	
Căldărușani (M)					IX½	IX½				
Sitaru (M)							IX½	IX	IX	VIII
Glavacioc (M)				IX½			X	IX½	IX	IX
Pissiotă (M)					IX½			IX½	IX½	VIII½
Mamui (M)				X				IX	IX	IX
Clocociov (M)							IX½	IX		VIII½

(continued)

**Table 1** (continued)

Name of monastery (M) or church (C)	Earthquakes									
	1471	1516	1590	1620	1701	1738	1802	1838	1940	1977
	M <sub>w</sub> = 7.5 H = 110 km	M <sub>w</sub> = 7.5 H = 150 km	M <sub>w</sub> = 7.5 H = 100 km	M <sub>w</sub> = 7.5 H = 150 km	M <sub>w</sub> = 7.1 H = 150 km	M <sub>w</sub> = 7.7 H = 130 km	M <sub>w</sub> = 7.9 H = 150 km	M <sub>w</sub> = 7.5 H = 150 km	M <sub>w</sub> = 7.7 H = 150 km	M <sub>w</sub> = 7.4 H = 94 km
Stelea (M)						IX½	X			
Negru Vodă (M)				X			IX½	X		
Coșuna (M)	IX½							IX½	X	
Domn. Pitești (C)							IX½			
Popănzălești (M)								X		IX½
Pasărea (M)								X		
Plătărești (M)							IX½			
Mărcuța (M)										VIII½
Snagov (M)					X	IX½			IX½	IX½
Gura Motru (M)				X		IX				
Câmpina (C)									VIII½	VIII
Căciulați (C)									VIII½	VIII
Comarnic (C)									VIII	VIII½
Hurezi (M)						IX½				
Govora (M)										VIII
Oenele Mari (C)								X		
Celic Dere (M)									IX½	
Saon (M)									IX½	
Cocoș (M)									IX	
Topolonița (M)							IX			VIII½
Sfânta Ana (M)										VIII½
Cozia (M)		IX½						X		



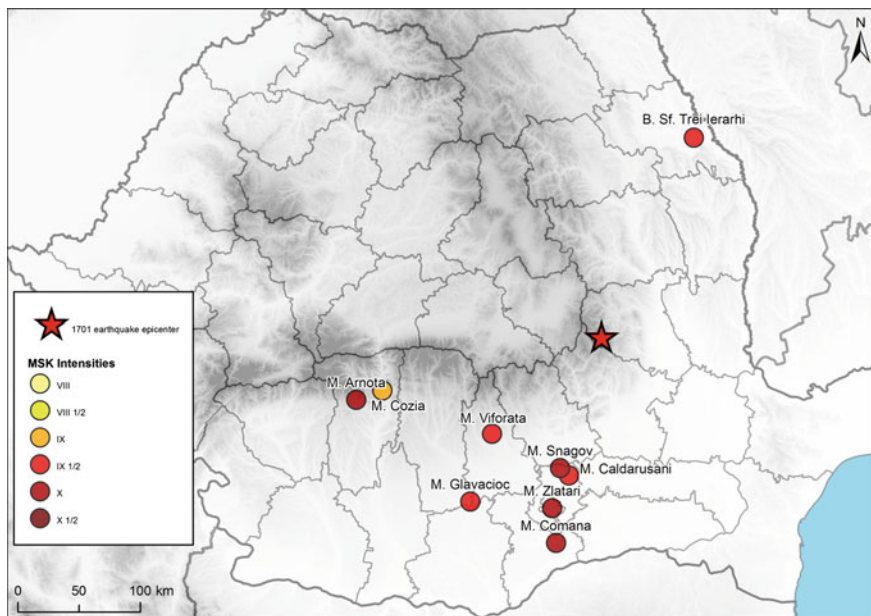


Fig. 2 IDP's evaluated for Vrancea earthquake of June 12, 1701:  $M_W = 7.1$   $h = 150$  km

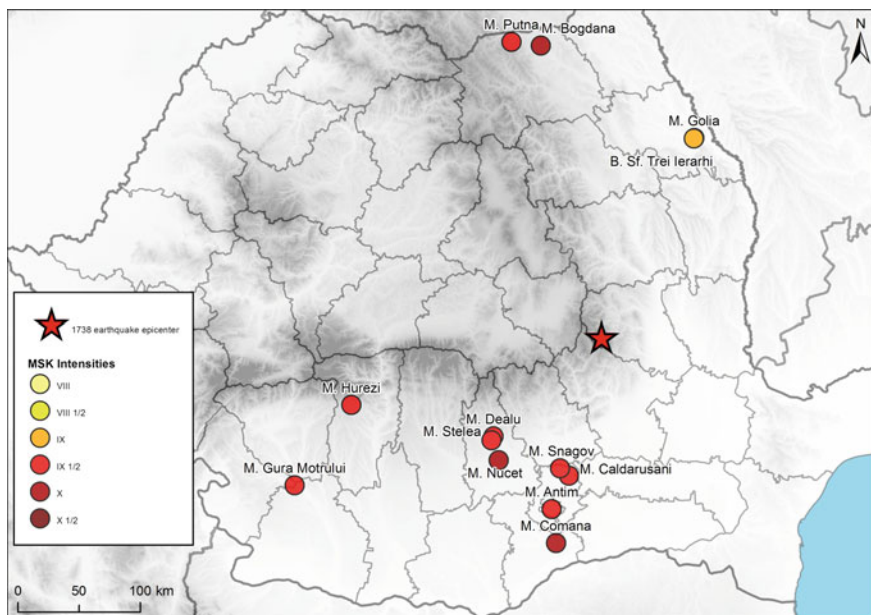


Fig. 3 IDP's evaluated for Vrancea earthquake on June 11, 1738,  $M_W = 7.7$

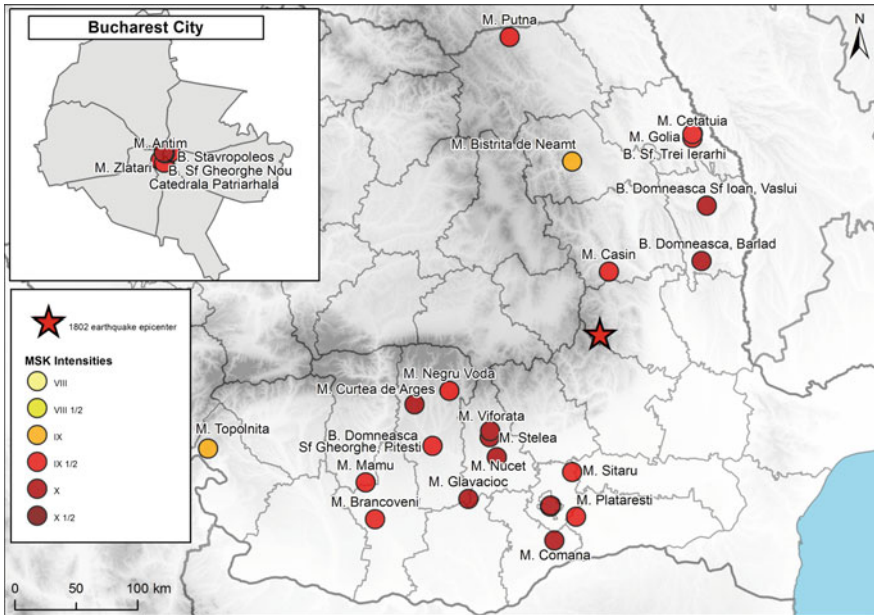


Fig. 4 New IDPs for Vrancea earthquake on October 26, 1802.  $M_W = 7.9$

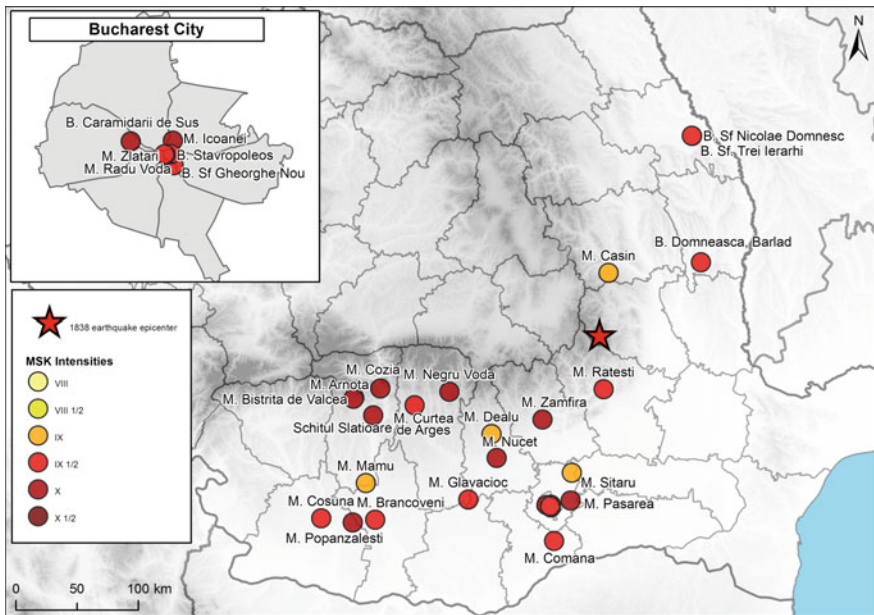
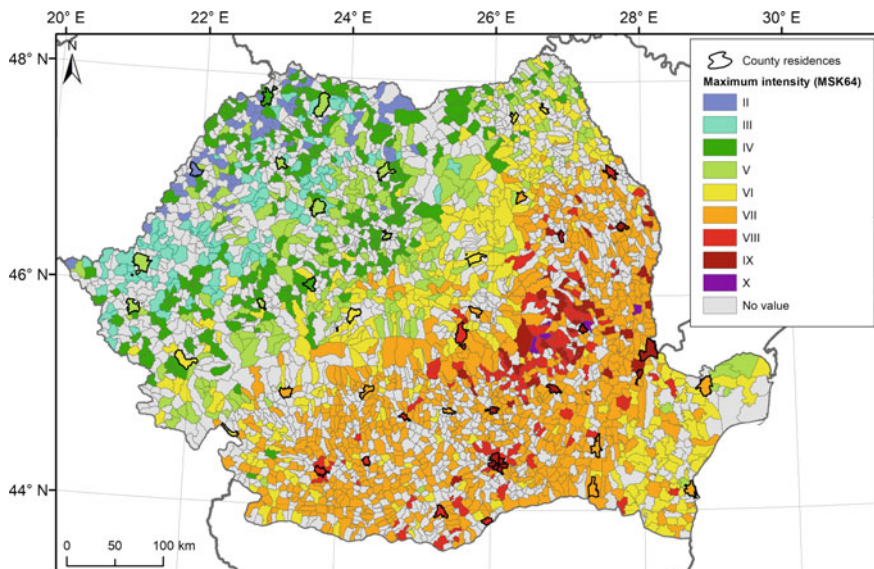


Fig. 5 IDP evaluated for Vrancea earthquake on January 23, 1838.  $M_W = 7.5$





**Fig. 8** Maximum observed macroseismic intensities due to Vrancea intermediate-depth earthquakes. New intensity data points using complementary data from churches and monasteries where averaged within each land administrative unit for each earthquake considered in this study

In Fig. 8 is presented the observed macroseismic intensity map of Romania by using newly compiled information about the damages experienced by 115 churches and monasteries after strong intermediate-depth earthquakes ( $M_w \geq 6.9$ ) occurred in 1471, 1516, 1590, 1620, 1701, 1738, 1802, 1838, 1940, 1977, 1986 and 1990. The new information is compiled together with relevant macroseismic data published by Constantin et al. (2011), Kronrod et al. (2013), Marmureanu (2016) and Rogoza et al. (2014, 2016). For each seismic event were computed the mean values of the intensity data points available within the administrative units, as defined nowadays. For the map presented in Fig. 8 only the maximum value among the earthquake means is reported in each land administrative unit.

Many attempts have been made to correlate the observed intensity with recorded ground motion parameters, as well as the hazard assessment for future events, which require a regression relationship between intensity and strong-ground-motion parameters. Enescu et al. (2001) elaborated an estimation method of the seismic hazard generated by strong and deep Vrancea earthquakes considering only the strong earthquakes produced in the area after 1940 (Table 2). It was observed that all epicentres are situated on a line oriented NE–SW and the corresponding maximum macroseismic intensities  $I_0$  occur on a line which is parallel to the epicentre's line at distance of about 23 km.

**Table 2** Strong Vrancea earthquakes ( $M_{GR} > 6.5$ ) after 1935

Date	Time	$\Phi^\circ$ N	$\lambda^\circ$ E	h(km)	$M_{GR}$	$M_W$	$I_0$
Nov. 10, 1940	01:39:07	45.8	26.70	150	7.4	7.7	X
March 4, 1977	19:22:15	45.34	26.30	94	7.2	7.4	IX
August 30, 1986	21:28:37	45.53	26.47	131	7.0	7.1	VIII
May 30, 1990	10:40:06	45.82	26.90	90	6.7	6.9	VIII

## 4 Concluding Remarks

Strong, intermediate-depth (70–200 km) earthquakes in the Vrancea area (Romania) occur irregularly, but not infrequently. They have caused a high toll of casualties and extensive damage *over the last several centuries*. The three strongest earthquakes ( $M > 7$ ) that occurred in Vrancea during the last century (1940,  $M_W = 7.7$  and  $h = 150$  km; 1977,  $M_W = 7.4$  and  $h = 94$  km; 1986,  $M_W = 7.1$  and  $h = 131.4$  km) caused large damage over a wide European territory, including distant, long period elements of the built environment. The quake of March 4, 1977,  $M_W = 7.4$  caused significant damage in Romania & Bulgaria and was felt up to Central Europe.

This study is of interest to seismologists and other earth scientists who want to gain an understanding of how historical information is used in estimating earthquake hazard *along time of centuries* in Romania, engineers who want to know more about the seismic input to be used in design and risk calculations, decision makers and other public officials who want to make decisions, particularly that related to the seating and evaluation of nuclear plants etc. Typically, only those events which led to disastrous consequences are mentioned in historical records, however it is not to be neglected that smaller earthquakes can lead to a more insightful seismic hazard evaluation.

In estimating intensity scale values for historical earthquakes, account should be taken of the fact that information obtained from old chronicles, from churches, monasteries and individuals who may have experienced the event shows a tendency to exaggerate along time the importance of damage and other phenomena associated with earthquakes.

The results on seismic hazard obtained in BIGSEES Project provide a very solid background for the upcoming update of the EN 1998-1 National Annex.

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## References

- Constantin AP, Pantea A, Stoica R (2011) Vrancea (Romania) subcrustal earthquakes: historical sources and macroseismic intensity assessment *Rom. J Phys* 56(5–6):813–826
- Enescu D, Marmureanu G, Enescu BD (2001) A procedure for estimating the seismic hazard generated by Vrancea earthquakes and its application. I. “Etalon” earthquake. In: 2nd national conference on earthquake engineering, Bucharest, November 8–9, 2001, pp 1–10, Paper I
- Kronrod T, Radulian M, Panza G, Popa M, Paskaleva I, Radovanovich S, Gribovszki K, Sandu I, Pekevski L (2013) Integrated transnational macroseismic data set for the strongest earthquakes of Vrancea (Romania). *Tectonophysics* 590:1–23
- BIGSEES Project (2017). BIGSEES earthquake catalog. <http://bigsees.infp.ro/Results.html>
- Mănăstiri Ortodoxe (MO) No. 1, 76, 104. Edit. De Agostini Hellas SRL; Vouliagments 44-46,16673 Atena; Editor: Petros Kapnistos; [www.deagostini.ro](http://www.deagostini.ro)
- Marmureanu G, Cioflan CO, Mărmureanu A (2011) Intensity seismic hazard map of Romania by probabilistic and (neo)deterministic approaches, linear and nonlinear analyses. *Rom Rep Phys* 63(1):226–239
- Marmureanu G, Cioflan CO, Marmureanu A, Manea EF (2016) Main characteristics of November 10, 1940 strong Vrancea earthquake. In: Vacareanu R, Ionescu C (eds) The 1940 Vrancea earthquake. Issues, insights and lessons learnt. Proceedings of the symposium commemorating 75 years from November 10, 1940 Vrancea earthquake. Springer Natural Hazards Series, Springer International Publishing, pp 72–83. [https://doi.org/10.1007/978-3-319-29844-3\\_30](https://doi.org/10.1007/978-3-319-29844-3_30)
- Marmureanu G (2016) Certainties and uncertainties in seismic hazard and risk assessment of strong Vrancea earthquakes. Romanian Academy Ed., Bucharest
- NIEP (2017) Romplus earthquake catalog. <http://www.infp.ro/catalog-seismic>
- Rogozea M, Marmureanu G, Radulian M, Toma D (2014) Reevaluation of macroseismic effects of the 23 January 1838 Vrancea earthquake. *Rom Rep Phys* 66(2):520–538
- Rogozea M, Radulian M, Popa M (2016) Comparison of three major historical earthquakes with three recent earthquakes. In: Vacareanu R, Ionescu C (eds) The 1940 Vrancea earthquake. Issues, insights and lessons learnt. Proceedings of the symposium commemorating 75 Years from November 10, 1940 Vrancea earthquake. Springer Natural Hazards Series, Springer International Publishing, pp 267–283. [https://doi.org/10.1007/978-3-319-29844-3\\_30](https://doi.org/10.1007/978-3-319-29844-3_30)