The Strong Vrancea Earthquakes Threatening Bucharest

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Edited by

Mircea Radulian, Constantin Ionescu and Andrei Bala

Cambridge Scholars Publishing

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CONTENTS

Foreword vii
Mircea Radulian

Chapter 1 1
Historical Earthquakes Recorded in Romania and Republic of Moldova from the Times of Stephan the Great to Beginning of XX Century
Andrei Bălă, Igor Cereteu and Catalin Gheablău

Chapter 2 17
Geographical, Geomorphological and Geotectonic Setting of Bucharest City
Irina-Marilena Stanciu, Dumitru Ioane and Antoneta Seghedi

Chapter 3 35
Geologic Model in Bucharest and Surrounding Areas with Direct Applications in Local Seismic Hazard and Microzonation Maps
Andrei Bălă, Viorica Ciugudean-Toma and Dragoș Toma-Dănilă

Chapter 4 53
Hydrogeology Conditions in Bucharest Underground and their Influence on Site Effects during Strong Vrancea Earthquakes
Andrei Bălă, Dieter Hannich

Chapter 5 68
Methods and Conditions of Measuring Static and Dynamic Properties of the Quaternary Layers in Bucharest City
Andrei Bălă, Stefan F. Bălan, Dragoș Toma-Dănilă and Cristian Arion

Chapter 6 86
Integration of Shallow Geophysical Measurements for Local Earthquake Hazard Analyses in Bucharest toward Smart and Resilient City Transition
Florina Chitea

Chapter 7 117
Recent Geodynamic Movements Recorded using the National Networks of Permanent GNSS Stations
Eduard Nastase, Alexandra Muntean and Doru Narvic Mateciuc

Chapter 8 131
Seismic Hazard Assessment in Romania and Implications for Associated Seismic Risk in Bucharest following the Vrancea Strong Earthquakes
Mircea Radulian, Mihaela Popa, Carmen Ortanza Cioflan and Luminița Ardeleanu

Chapter 9 145
Deterministic Seismic Hazard Studies in Bucharest Metropolitan Area
Authors: Carmen Ortanza Cioflan, Bogdan Felix Apostol, Elena Florinela Manea and Alina Coman

Chapter 10 170
The Seismic Risk in Bucharest
Dragoș Toma-Dănilă, Iuliana Armas and Alexandru Țiganescu

Chapter 11 184
Rapid Earthquake Early Warning System (EWS) for Bucharest Area
Alexandru Mărmureanu and Constantin Ionescu

Conclusions and Look into the Future...194
Mircea Radulian, Andrei Bălă, Dragoș Toma-Dănilă and Dragoș Tătaru

Contributors..200

FOREWORD

MIRCEA RADULIAN

Over most of its surface, Romania is shaken quite rarely by shallow earthquakes that fall into the class of moderate seismicity. But exceptionally, seismic activity in Romania, as well as the disastrous effects of earthquakes, are dominated by the presence of a particular seismic source concentrated and isolated in a confined focal volume at intermediate depth (60 - 180 km depth) beneath the Carpathians arc bend (so-called "Vrancea source"). This source leaves its mark on a large part of Romania, but also on an extensive area of the South-Eastern Europe, to such an extent that it is one of the key sources that defines the hazard configuration in Europe. Since historical times, this source has been known to present a real danger to the population, the construction property and able to trigger environmental geological events. As a result of such events, unusually severe effects have been reported several times per century at large distance from the earthquake epicentre.

Due to specific source directivity and wave propagation properties, the damage is amplified in front of the Carpathians arc, towards NE (Moldova, Republic of Moldova and Ukraine) and SW (Muntenia and north Bulgaria). In particular, the impact of Vrancea earthquakes on Bucharest city, as observed over several centuries, was so severe that Bucharest is currently considered the most vulnerable European capital city to earthquakes. For this reason, microzoning and seismic risk studies for Bucharest city have emerged after 1977 and still constitute a priority research direction in Romania. The present book reviews the most significant results obtained in recent years in this field of research. These results refer to several major fields of study that are included in the eleven chapters of the book:

- Geographical, geomorphological and geotectonic framework of the city area;
- Geological modelling in the Bucharest area;
- Hydrogeology conditions in Bucharest underground and their influence upon the site effects;
- Seismic hazard at regional (Romania) and local scale (Bucharest area);
- Application using GNSS technology to evaluate geodynamic movements;
- Geophysical measurements in the city underground;
- Modelling of the local structure in the Bucharest metropolitan area using ambient vibration analysis;
- Early Warning System developed and implemented for Bucharest city;
- Vulnerability and seismic risk scenarios for Bucharest city.

It is worth mentioning that most of the presented results have been obtained within the last Nucleu program, "Multidisciplinary research of the seismic phenomenon in order to increase resilience to earthquakes" (MULTIRISC), financed by the Ministry of Research, Innovation and Digitization of Romania, carried out between 2019 and 2022.

Considering the complexity of the approach, the results presented in the volume were obtained as a result of multidisciplinary researches, involving seismology, geology, geophysics, geotectonics, hydrogeology and geodesy. All these investigations converged towards a common conclusion: for the Bucharest city there are a series of factors that worked together to amplify the effects produced by the Vrancea earthquakes, despites the fact that the epicentral distances are greater than 120 km. Thus, the source radiation characterized by large periods (around 1.5 s for the major earthquakes) and directivity effects towards SW of Vrancea, combined with very efficient wave propagation at depth along this direction and matching the seismic response of the local structure beneath the city and the resonance of the tall buildings to large periods, all these factors together lead to unusual amplifications of strong ground motion and, respectively, of the effects triggered by it. And this potentially endangering situation, together with the vulnerability of the structures built before 1977, and especially those erected in the period 1920 – 1940, explains why in the case of the city of Bucharest we are talking about one of the highest levels of risk reported around the world. In addition, hydrogeological and geophysical on-site investigations regarding the characteristics of the superficial layers, bring additional elements that contribute to increasing the risk caused by the seismic motion (local amplifications, soil liquefaction and instabilities).

This book is an encouragement and a plea to improve knowledge on how to combine in a suitable approach all these factors that control seismic hazard in Bucharest. Unlike many other seismic sources on the globe, we can constrain in advance quite well the coordinates of the future dangerous earthquake, its magnitude range and predominant period of motion and the way the effects will be distributed on the surface. Considering the unique particularities of the study case, we are convinced that by adopting and applying modern investigation techniques and tools, in the near future we will be able to significantly reduce the destruction caused by the earthquakes in Vrancea. A provocative subject is the Early Warning approach which for the present case may benefit of numerous favourable elements, such as the stationarity in space and time of the source, existence of a preferential focal mechanism, possibility to rapidly identify the earthquake origin and magnitude by using relatively simple and robust algorithms.

We believe that this book provides an useful state-of-the-art and will bring a major contribution to the knowledge of the seismic hazard assessment and will offer useful tools and methods of action for all public organisms interested in contributing to the prevention of at least some of the catastrophic effects of earthquakes, as well as to the mitigation of the seismic risk, so that the city of Bucharest becomes a safer and favourable place for its inhabitants and a continuous sustainable development.

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CHAPTER 1

HISTORICAL EARTHQUAKES RECORDED IN ROMANIA AND REPUBLIC OF MOLDOVA FROM THE TIMES OF STEPHEN THE GREAT TO THE BEGINNING OF XX CENTURY

ANDREI BĂLĂ, IGOR CERETEU AND CĂTĂLIN GHEABLAU

1. Seismicity of Romania

The seismicity of Romania is clustered in one main seismic zone, in which important earthquakes occur at intermediate depths of 60-180 km under the Moho interface, Vrancea seismic zone. The active focal volume is like a prism with a cross section of 40 x 70 km, vertically extended 120 km on depth. The intermediate-depth earthquakes generated here, reach magnitudes up to Mw7,9.

Those earthquakes with Mw>7 are considered destructive earthquakes, able to produce the greatest losses in cities situated in the external part of Carpathians arc, like the earthquake of 4 March 1977 which produced only in Bucharest more than 1500 casualties (Moldoveanu et al. 2004, 1125-1147). There are also earthquakes in Vrancea area which are occurring in the crustal part, from 5 – 50 km depth and their epicenters are spread on a greater surface in the Vrancea seismic zone.

Some seismic activity is also recorded in the crust (0 – 50 km depth), in several crustal seismic zones across Romania, some of them continuing in the neighboring countries like Serbia, Ukraine, Bulgaria. Until now they were considered much weaker in both number of earthquakes and magnitudes (Radulian et al. 2000, 57-77). However, beginning with 2023 there were two swarms in Romania, first near Targu Jiu, at the southern margin of South Carpathians and the contact to Getic Depression, where earthquakes of Mw 5,2 – 5,7 have a disastrous effect to more than 200 buildings in the nearby city of Targu Jiu.

Other epicentral zones of local importance can be found in Transylvania, in the area of Jibou and Târnava River, in Maramureş , and the eastern part of the Wallachian Plain (Radulian, Mandrescu, Panza, Popescu et al. 2000, 57-77). In the Southern Carpathians, just between Făgăraș- Câmpulung zone to the east and Danubian zone to the west, a new seismic zone was recently proposed by (Radulian et al. 2019, 3-18) to be denoted as Central South Carpathian zone (CSC).

The Vrancea seismogenic zone is the most important among these seismic zones, having in mind the energy, the extent of the macroseismic effects, and the persistent and confined character of the earthquakes that occur in this area. The Vrancea area is responsible for over 90% of the significant earthquakes in Romania (M_w above 3), releasing over 95% of the seismic energy after Romplus catalog (Oncescu et al. 1999, 43-47).

The Vrancea seismic active zone is the most important among these seismic zones, having in mind the energy, the extent of the macroseismic effects, and the persistent and confined character of the earthquakes that occur in this area. The Vrancea area is responsible for over 90% of all earthquakes in Romania, releasing over 95% of the seismic energy after (Oncescu et al. 1999, 43-47). Two belts of moderate and shallower seismicity are emphasized in the other regions of the country: one along the Southern Carpathians and the eastern edge of the Pannonian Basin, the other which extends from Vrancea zone towards SE on the Peceneaga–Camena faults system (Sokolov et al. 2009, 364-381).

During the last 1,000 years, according to historical data, 17 earthquakes of 7 and over magnitude occurred in Vrancea, which suggests an average rate for energy release of ~60 years. A simple statistics would suggest an earthquake of magnitude 6 and over 10 years, magnitude 7 every 33 years, and magnitude ~ 7.5 every 80 years (Atanasiu 1961, 58-92). On the other hand, some investigations are rather in favor of a non-uniform time distribution, with clustering of the strong events (Radulian et al. 2023, 58-92). This means that large earthquakes tend to occur in clusters, being separated by intervals of lower activity.

2. Historical earthquake data

In Table 1 we summarized the earthquakes with magnitude Mw 5,5 or greater that were mentioned by historical sources in Romania and Republic of Moldova for five centuries. More than 90% of the earthquakes in the table are from Romplus catalogue build in National Institute for Earth Physics (NIEP) and dating from the beggining of its activity. Some magnitudes and intensities come from other contemporary sources. Intensity is given in MSK scale, by making an aproximation from the local characterization of the earthquakes from old sources which are cited. Romplus catalogue (Oncescu 1999, 43-47) included in the beginning (2000) collected information from the catalog of Constantinescu and Mîrza 1980, 171-191 for the period 984–1997. After 1997, the catalogue was permanently filled and updated with data on seismic events produced in Romania and around national borders, see the database build up by (Popa et al. 2022).

Recently, a historical review published in Republic of Moldova provides new information on effects of earthquakes in Republic of Moldova on the base of more than 225 original sources from old books, notes or original manuscripts written in the Romanian language (Cereteu 2015, 23-55), or other languages used at the time in Orthodox Church. The historical records come from the old Moldavian region, which during the time of Stephen the Great (1457 – 1504) was covering the eastern part of Romania and also continuing over Prut river to the Nistru river, which is now the Republic of Moldova.

The earthquakes catalogue of Cereteu (IC catalog, Cereteu 2015, 23-55) includes detailed informations about 81 earthquakes which were felt in old Moldavia territory, attested in the XVI-XIX centuries: 3 events in XVI century, 6 events in XVII century, 22 events in XVIII century and 50 events in XIX century. The main sources from which we learn about these phenomena are medieval chronicles, old notes written on pages books, entries from old archives.

3. The Catalogue of historical earthquakes in Romania and Republic of Moldova

In Table 1 are given the earthquake with magnitude Mw6 or greater that were recorded by historical sources in the regions that now constitute Romania and Republic of Moldova, in the period 1441 – 1916. Magnitudes were cited usually from Romplus catalogue (NIEP) (Popa et al. 2022), in which we have more than 90% of the earthquakes in the table, and from other several contemporary sources. Intensity is given in MSK scale, by making an aproximation from the local characterization of the earthquakes from old sources which are cited.

We try to integrate here the events from IC catalog (Cereteu 2015, 23-55) in our original catalog in Table 1, because it proved to be valuable historic source, which was carefully recorded from old printed books or old manuscripts found and consulted in eastern part of Romania or Republic of Moldova, where the author is a historian. For example, in the classic table of historical earthquakes for the 1802 great earthquake (Saint Parascheva day) there are only 3 sources from Republic of Moldova, while in (Cereteu 2015, 23-55) there are more than 50 citations, directly from old books, from personal hand writtings (see Table 1).

We note the importance of establishing the date of an event from several sources. At the time of the historic events, in the period 1500 – 1922, in these regions the calendar that was still in place was the ancient Iulian calendar until 1 April 1919, when Romania adopted the new Gregorian calendar on the base of a Decree no. 274 from March 6, 1919. At that date there were 13 days difference between the 2 calendars. So in Romania the date of 1 April 1919 becomes 13 April 1919.

In these times in the western part of Romania; in Transylvania, Banat, Bucovina and north-western parts like Crișana and Maramureș, there were in place the Gregorian calendar, which was adopted from sixteenth century on. The best way (in order to avoid confusion) is to record to each event that we can find in both catalogues, both dates, as it was usually custom in Romania from the end of XIX century to write a date. In that way there is no room for error and every reader should know that the first number is the day from Iulian (old) calendar and the second from the Gregorian (actual) calendar, adopted in Romania in 1919. In fact that is one and the same seismic event.

Table 1. Historical earthquakes from 1446 until 1916 in Romania and Republic of Moldova

No	Date; Day; month; year	Moment Magnitude	Intensity MSK	Epicenter	Sources after ROMplus [19]	Sources after Cereteu [2]
1	**10 October 1446**	7,5 Mw [19]	X. Devastating	Vrancea	[29], [36], [37], [31]	
2	**29 August 1471***	**7,5 Mw [1]**	**VIII - IX Catastrophic**	**Vrancea**	[1];[7];[9];[18]; [25];[13];[29]; [36];[41]	(11,12)
3	**29 August 1473**	**7,3 Mw[19]**	**X. Devastating**	**Vrancea**	[1];[19]; [36]; [31]	
4	**24 November 1516***	**7,5 Mw [1]**	**X. Devastating**	**Vrancea**	[1];[18]; [29]; [37]	(14, 15)
5	**(1 April) 1521***				[7];[4];[29]	(16)
6	9 June 1523	6,5 Mw [19]	VIII. Damaging	Vrancea	[7],[4];[29]	(16)
7	19 November 1523	5,9 Mw[1]	VIII. Damaging	Transilvania Mediaș, Sibiu	[29],[36],[37] [34];[42];[13]	
8	19 July 1545	7,1 Mw [19]	X. Devastating	Vrancea	[1], [22], [7]	
9	26 October 1550	6,5 Mw[19]	VIII. Damaging	Făgăraș - Câmpulung		
10	21 August 1552	6,5 Mw [19]	VIII. Damaging	Vrancea		
11	17 August 1569	6,4 Mw [19]	VIII. Damaging	Vrancea		
12	10 April 1571	6,5 Mw[1]	VIII. Damaging	Vrancea	[7];[16]; [23]	
13	10 May 1571	7,1 Mw [19]	X. Devastating	Vrancea		
14	1 April 1578	6,5 Mw [19]	VIII. Damaging	Vrancea		
15	30 April 1590	7,3 Mw[1]	IX. Destructive	Vrancea		
16	**10 August 1590**	6,5 Mw[1]	VIII -X. Devastating	Făgăraș - Câmpulung		
17	1 December 1594	Unknown [1]	VII-VIII Damaging	Transilvania		
18	**21(22) April 1595***	**7,1 Mw [19]**	**X. Devastating**	Transilvania	[13], [34]	(16)
19	8 December 1595	Unknown [1]	VII-VIII	Transilvania		
20	22 November 1598	6,5 Mw[19]	VIII. Damaging	Vrancea		
21	4 March 1599	6,1 Mw[19]	VIII. Damaging	Vrancea	[13]	
22	3 May 1604	6,8 Mw [1]	VIII. Damaging	Vrancea		
23	24 December 1605	7,1 Mw [19]	X. Devastating	Vrancea		
24	13 January 1606	6,8 Mw [19]	VIII. Damaging	Vrancea		
25	**29 Oct./8 Nov. 1620**	7,5 Mw [19]	VIII - IX. Destructive	Vrancea	[9]; [17]; [28]	(17)
26	1 February 1637	7,1 Mw[19]	X. Devastating	Vrancea		
27	19 April 1650	6,5 Mw [1]	VIII. Damaging	Vrancea		
28	9 August 1679	7,5 Mw	VIII - IX. Destructive	Suceava		
29	**19 August 1681***	**7,1 Mw [19]**	**VIII - X. Devastating**	**Vrancea**		(18,19)
30	**16 oct. 1681**	5,4				
31	**18 oct. 1681**	5,4				
32	27 Dec. 1681*	5.9 Mw [19]	VIII Damaging	Vrancea		(20)
33	12 June 1701	7,1 Mw	X. Devastating	Vrancea		
34	11 October 1711	6,5 Mw [19]	VIII. Damaging	Vrancea		

No	Date; Day; month; year	Moment Magnitude	Intensity MSK	Epicenter	Sources after ROMplus [19]	Sources after Cereteu [2]
35	6 April 1730	6,1 Mw [19]	VIII. Damaging	Vrancea		
36	**31 May/ 11 June 1738**	7,7 Mw	IX - X. Devastating	Vrancea	[24]; [43]; [41]	(23,24,27, 28,29,34)
37	**25 March/5 Apr. 1740**	7,3 Mw [19]	X. Devastating	Vrancea		(35)
38	7 December 1746	5,9 Mw[33]	VIII Damaging	Făgăraș - Câmpulung		
39	**16 March 1764****		**X. Devastating**			(39)
40	18 January 1778	6,5 Mw [19]	VIII. Damaging	Vrancea		
41	**26 Sept./9 Oct. 1781****		**X. Devastating**			(46, 47, 48)
42	**5 March. 1787***	**6,5 Mw[19]**	**VIII. Damaging**	**Vrancea**		(51)
43	**26 March./6 Apr. 1790**	7,1 Mw [19]	X. Devastating	Vrancea	[9]; [17]; [25]	(52, 54,55,57)
44	**27 Nov./8 Dec. 1793**	6,2 Mw [19]	VIII. Damaging	Zona Făgăraș - Câmpulung	[9]	(60, 61, 62, 63, 64, 68, 69, 70, 71, 72)
45	**14 March/25 March 1798**	5,9 Mw [19]	VII. Very strong	Zona Brasov	[9];[17]	(75)
46	**14 Oct./26 Oct. 1802**	7.9 - 8,2 Mw [19;28]	X - XII. Catastrophic	Vrancea	[8]; [9];[17]; [44]	(76-99;100- 130)
47	5 March 1812	6,5 Mw [28]	VIII. Damaging	Vrancea		
48	**15 Aug. 1816****		**X.Devastating**			(150-151)
49	**29 Jan./10 Feb. 1821**	6,6 Mw[19]	VIII. Damaging	Vrancea		
50	29 Sept. 1821	6,6 Mw [19]	VIII. Damaging	Vrancea		
51	**5 Nov./17 Nov. 1821**	6,2 Mw [19]	VIII. Damaging	Vrancea	[9];[17]	(169-172)
52	**27 Apr. 1822****		**X.Devastating**			(173-174)
53	**28 Jan./9 Feb. 1823**	5,9 Mw[19]	**VII. Very strong**	Vrancea		
54	**2 oct. / 14oct. 1827**	5,9 Mw[19]	**VII. Very strong**	Vrancea		
55	**14 NoV./26 Nov. 1829**	7,3 Mw [19;28]	VIII- IX. Destructive	Vrancea	[9]; [30];[44]	(183, 184, 185)
56	3 august 1831	6,1 Mw[19]	VII. Very strong	Vrancea		
57	3 august 1834	6,8 Mw[28]	VII. Very strong	Vrancea		
58	**9 Apr./21 April 1835**	6,5 Mw[19]	VIII. Damaging	Vrancea		(187, 188)
59	**11 Jan./23 Jan. 1838**	7,5 Mw [19]	IX. Destructive	Vrancea	[6]; [9]; [30]; [45]	(190 - 203)
60	6 March 1844	6 Mw [19]	VII. Very strong	Vrancea		
61	1 January 1848	6,5 Mw [19]	VIII. Damaging	Vrancea		
62	**16 Oct./28 Oct. 1854**	6,5 Mw [19]	VIII. Damaging	Vrancea, Galati	[28];[6]	(209)
63	16 October 1862	6,5 Mw [19]	VIII. Damaging	Vrancea		
64	13 November 1868	6,8 Mw [19]	IX. Destructive	Vrancea		
65	27 November 1868	6,5 Mw [19]	VII - VIII. Damaging	Vrancea		
66	**13 Dec. /25 Dec. 1880**	6,8 Mw [19]	IX. Destructive	Vrancea		(221)

No	Date; Day; month; year	Moment Magnitude	Intensity MSK	Epicenter	Sources after ROMplus [19]	Sources after Cereteu [2]
67	**19 August 1888***	**6,5 Mw [19]**	**VIII. Damaging**	**Vrancea**		
68	**14 october 1892***	**6,5 Mw [19]**	**VIII. Damaging**	**Vrancea**	[6]; [11]; [12]; [14]; [21];[38]	(222)
69	1 May 1893	6,2 Mw [19]	VII. Very strong	Vrancea		
70	17 August 1893	7,1 Mw	VIII. Damaging	Vrancea		
71	10 September 1893	6,5 Mw [19]	VIII. Damaging	Vrancea		
72	4 March 1894	6,5 Mw [19]	VIII. Damaging	Vrancea		
73	**19 Aug./ 31 Aug. 1894**	7,1 Mw [19]	VIII. Damaging	Vrancea	[16]	(224, 225)
74	11 March 1896	6,6 Mw [19]	VIII. Damaging	Vrancea		
75	24 Nov. 1896	6,1 Mw [19]	VII. Very strong	Vrancea		
76	31 March 1901	7,2 Mw	X. Devastating	Bulgaria Shabla,	[21]	
77	30 July 1901	6 Mw [19]	VII. Very strong	Vrancea		
78	13 Sept.1903	6,3 Mw [19]	VIII. Damaging	Vrancea		
79	06 Feb.1904	6,6 Mw [19]	VI. Strong	Vrancea	[1];[17]	
80	06 Oct.1908	7,1 Mw[22]	VIII - IX. Destructive	Vrancea		
81	25 May.1912	6,7 Mw[19]	VIII. Damaging	Vrancea	[1]	
82	25 May.1912	6,1 Mw[19]	VII. Very strong	Vrancea	[1]	
83	26 Jan.1916	6,4 Mw [19]	VIII. Damaging	Zona Făgăraș - Câmpulung	[1],[30], [20]	

* 9 events that are present with the same date in both catalogues, in [2] and [19].
Gray - 28 events that are found in both catalogues. From them with 9 with the same date (in gray), and 19 with 2 dates (dark grey), first corresponding to Iulian calendar/second corresponding to Gregorian calendar.
** 4 events that are recorded only in Cereteu catalogue[2].

Table 1 has 83 events and some 28 are marked with gray, which means that they are in both catalogues. There are 9 events which have the same date with the date from Romplus catalog (marked *)in Table 1, and 19 which have the same date which appear under two forms in the sources, and denoted date from Iulian calendar/ date from Gregorian calendar. We have identified also in IC catalog (Cereteu 2015, 23-55) some 4 earthquakes which have intensities of VIII – X according to the sources, and were described by more than one source. They were introduced in the historical events of Table 1 (with **) , although they are not found yet in Romplus catalog.

The rest of 56 earthquakes (in IC catalog Cereteu 2015, 23-55) have weak movements, that could not be felt well, so they are recorded by only one or two sources, hence the events can not have an intensity great enough to produce damages, with only the date and the hour (or time) in the written records. This category should be checked carefully in the Romplus catalogue from NIEP and in other sources as well, for the rest of presumably events which do not have a correspondent in Romplus catalogue, because they were less intense (I_0 < VII), or the distance from epicenter was too far, hence they have no damage reported at that time.

The magnitudes given in Table 1 is moment magnitude (Mw), and the values are from ROMplus catalog at every eartquake. Intensity is the maximum intensity in MSK scale as it was appreciated after the distructions produced by the earthquake, time in which it was felt and noted in old books or papers. The MSK scale was used in the eastern part of Europe from the beginning of recordings and it is still in use.

In the Table 1 there are 2 kinds of the references. First there are after the sources that permitted the construction of historical part of Romplus catalog which are in brackets and you can find at the end of Chaper 1. In the last column are the references as they appear in IC catalog (Cereteu 2015, 23-55) with original numbers in paranthesis, but they can be found only in the cited paper as they are in Romanian, with very nice pasages in archaic Romanian language (Cereteu 2015, 23-55 and Cereteu 2019).

The sketch of earthquakes timeline from Table 1 is presented in Fig. 1. It begins in 1446, as the first earthquake was in 10 Oct. 1446. However the second one,was recorded in several Romanian chronicles in 29 August 1471, and it was the most violent earthquake of the 15th century, occurring during the reign of Stephen the Great, which was an prominent Romanian prince which rules over old Moldavia from 1457 – 1504. The Table 1 presents 77 earthquakes with magnitudes greater than 6, until the earthquake from 26 January 1916, which we are considering the last important historic earthquake, from which we have very few direct data, as most of the countries in Europe were already in the first World War I. Some of the events in Fig. 1 are also described in (URL 1) and (URL 2).

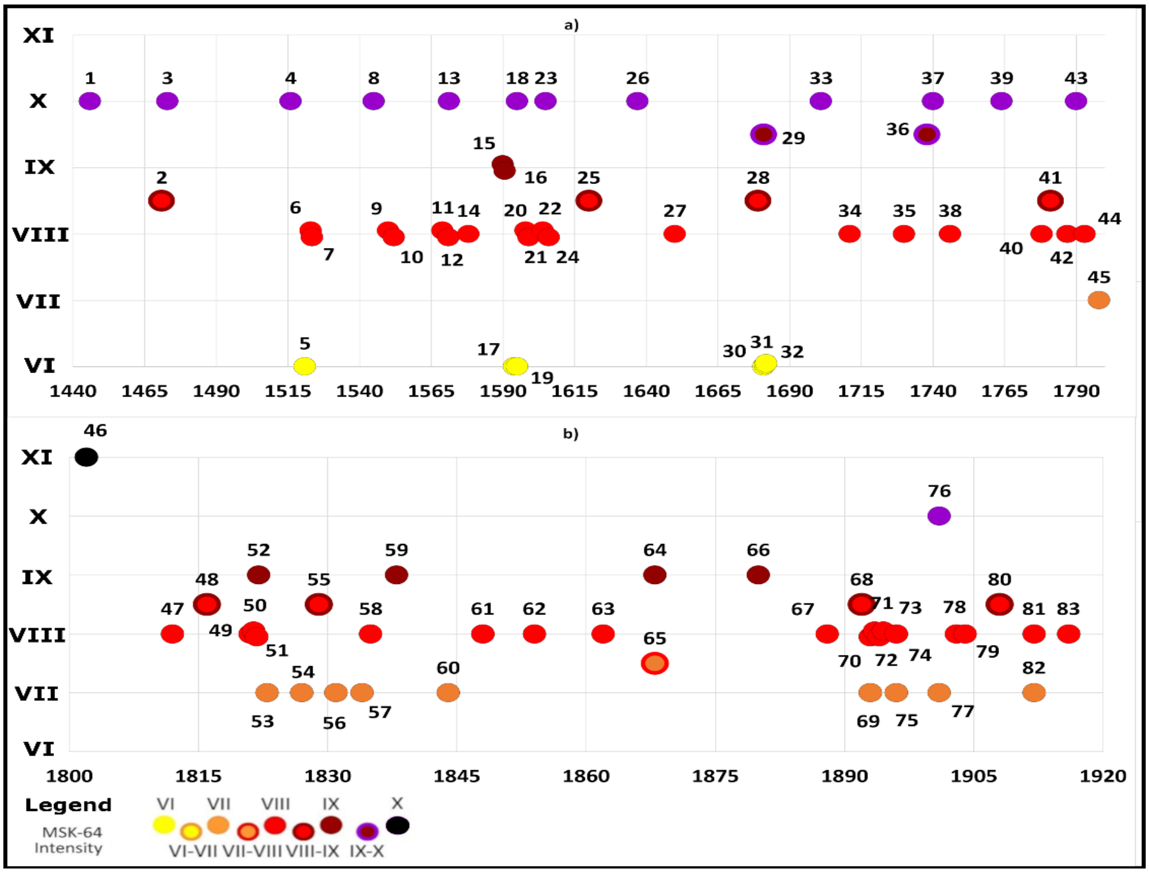

Figure 1. Sketch of the timeline of earthquakes after the intensity in Table 1. a). Period 1440-1790; b). Period 1800-1920. Numbers are corresponding with the order numbers in Table 1.

In the selection of earthquakes presented in Fig. 2, based mainly on the events in Romplus, there are also other events located in Bulgaria and Serbia, which have not entered in catalog from Table 1, except the earthquake from Shabla (1901, Bulgaria) which produce a rather high tsunami (3 m) in Black Sea, which was recorded also in the south-eastern Romanian shore, near Mangalia.

The magnitude and coordinates of earthquakes in Fig 2 is estimated by seismologist based on the description of the effects of every earthquake in a certain location which provide an estimation of the local intensity.

3.1 Notes about the earthquakes in Table 1

Here we have some informations cited from old sources for the most important earthquakes in Table 1. The number of earthquake is that from Table 1. Some of them are from the list that we have until now in which 90% of the events have been found in Romplus catalog and citations are given in brackets and they can be found at the end of the paper.

The others citations which are in paranthesis can be found in the paper of Cereteu 2015, 23-55, which describes a lot of notes in old books about the great earthquakes in the past. The theme is described later in a book (Cereteu 2019), in a separate chapter about Romanian historical earthquakes, in which the text is improved with new cases of old notes discovered by the author about the destructive earthquake, which were felt not only in old Moldavian and Basarabia regions, but also in the entire Romanian space.

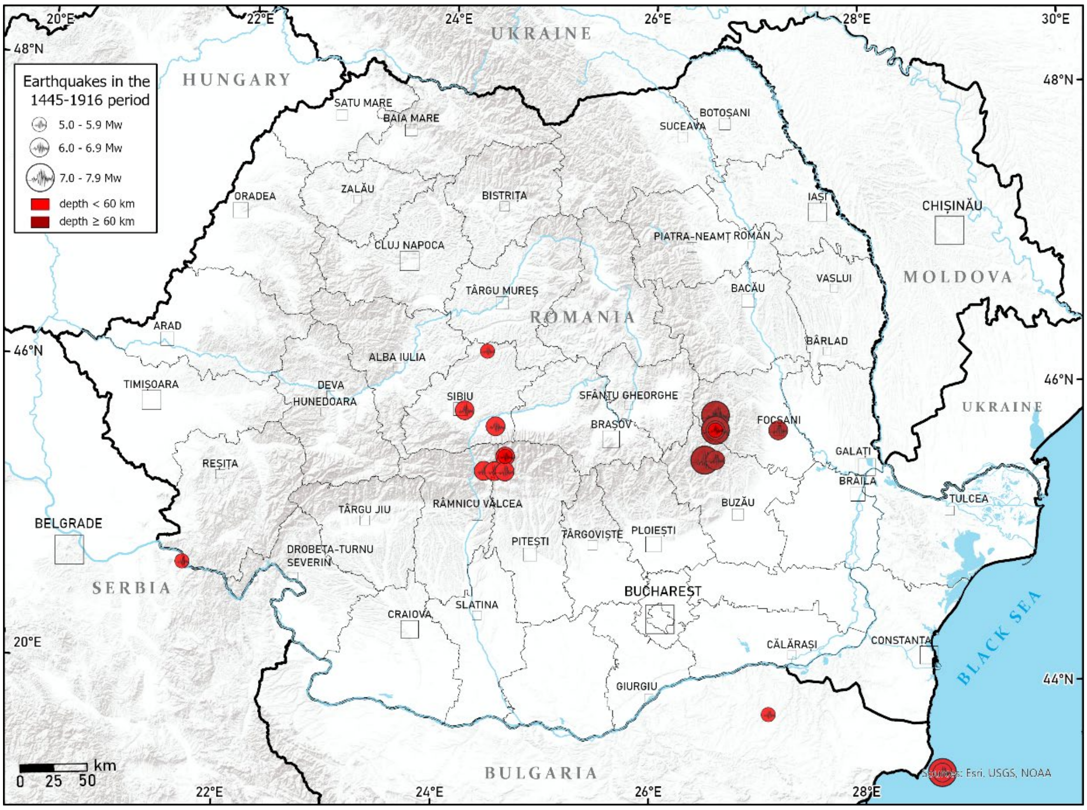

Figure 2. Map of the earthquakes in the catalog (Table 1), which is based predominantly on ROMplus, in the period 1445 – 1916, events with magnitude greater than 5, according to the legend. In Romplus the coordinates assigned for Vrancea region were almost the same so the epicentres are covering each other.

1. First entry in our catalog is the earthquake of 1/10 Oct. 1446 (in sec XV the difference between the 2 calendars was only 10 days). The original description of the earthquake is given in Rogozea et al., 2013, 545-562, from a contemporary source, mentioned first by (Tatevossian and Albini 2010), Muscovites Chronicle written in the late of XV-th century in which the seismic effects felt in Mocow are described: “In autumn 1446, in the first day of October, at 6 at night, when the Grande Duke was released from Kurmysh, Moscow, and Kremlin, all towns were shaken. Not all people which are asleep were awakened by this earthquake, but those who felt it, were afraid for their lives. In the next morning, they told with tears in their eyes what behaved those who were awaked by the shake”. Based on this information, (Tatevossian and Albini 2010) estimated the intensity III-IV (EMS 98 scale) at Moscow, because the earthquake did not wake up all the population of the city. Maximum intensity VIII-IX, came from Constantinescu and Marza 1980, 171-191, as well as Oncescu et al. 1999, 43-47, catalogues, requires also a typical behavior of Vrancea earthquake, with slow attenuation of the waves which propagates to the north-east.

2. One of the strongest earthquakes and best documented in medieval times in Romania was on 19 August 1471, during the Stephen the Great ruling in Moldavia, causing landslides and collapsing of many houses. The seism was felt not only in Moldova, but also in Crimeea, Transylvania and Wallachia.
According to local chronicles, the seismic event from 29 August 1471 was the most violent earthquake of the 15th century, occurring during the reign of Stephen the Great (Rogozea et al. 2013, 545-562). The first news about an earthquake with manifestations in Moldavia is provided by the Moldavian-German Chronicle and the Putna Chronicle, information taken over and reproduced by Grigore Ureche, in which the chronicler mentions that on August 29, 1471 there was a great earthquake over the whole country, while "Stephen the Great and his court were sitting at table, at lunch, 11 hours." (Ureche 1965). The earthquake was of Vrancea origin, had a magnitude greater than 8, and occurred at 11 o'clock and caused great destruction throughout the Romanian space (Cereteu 2019, URL 1).

The chronicles in Tărgoviște wrote that many churches have collapsed and great distruction was in the town. This earthquake from 1471 affected also Brasso and the chronicle of Austrian abbey of Melk mentioned that a great number of houses collapsed and some parts of the walls of the citadel (Rogozea et al. 2013, 545-562). In Brașov, a part of Mount Tâmpa slips over the city, and the citadel of Radu cel Frumos in Bucharest is reported in ruins (Rogozea et al. 2013, 545-562).

3. The 19 August 1473 earthquake was located in Vrancea at 150 km depth in Vrancea area, (after Oncescu et al. 1999, 43-47). Atanasiu 1961, 58-92, declared that he is not sure about the year. Shebalin, et al. 1974) did not consider it an intermediate-depth event and located it differently, while two other catalogues considered 1473 event as a duplicate of 1471 one (Atanasiu 1961, 58-92; Tatevossian and Albini 2010). In the SHARE European earthquake catalogue the 19 Aug.1473 earthquake was removed as a misinterpreted event (Stucchi et al. 2013, 523-544).

4. Another earthquake occurred on November 24, 1516, at the first hour after lunch. This is a well documented Vrancea earthquake, for which there are several independent contemporary sources (Rogozea et al. 2013, 545-562). The earthquake caused damage in Brasov and was felt in Suceava. The event is mentioned in "The Chronicle of Moldavia" by Grigore Ureche, p. 143 (Ureche 1965), who wrote that "… in the same month, there was a great earthquake, in a Monday", without giving other details. The earthquake caused significant damage in Brasov, as mentioned by (Atanasiu 1961, 58-92), based on the story Römer (Römer 1916, 51-56). Several houses and much of the surrounding wall of the city were destroyed. The same information can be found at Nussbacher (Nussbächer 1987, 54-58; 231-233) and Dudaș (Dudaș 1992).

5. There was an earthquake in 1521, which have pose numerous questions about the date. A contemporary source from Brasov states that in 1521 in "Wallachia, Transylvania and Fagaras a strong earthquake was felt" (Hurmuzaki 1911, 251-252). Analyzing this source it is clear that the earthquake took place 1- 2 weeks before the date of the letter (12 June 1521), probably around 1st June 1521. The letter was wrote by Ioan Bornemissa (a nobil of Buda) and sent to citizens of Brasso, Transylvania (Brașov), at this date. The same source is also reported in (Nussbächer 1987, 54-58, 231-233).
Analyzing all available data about the seismic activity during 1521, by the effects felt in Romania, the seismologists advance a hypothesis thought that a possible seismic sequence in the Fagaras-Câmpulung area could have been the cause of the earthquake in 1521 (Rogozea et al. 2013, 545-562).

7. The earthquake of 19 November 1523 was felt in Transylvania mostly and light damage reported in Mediaș. The pillars of Evangelical Church in Sebeș collapse and another source indicates '20 houses collapsed in Sibiu', while the Chronicle of Hutter reports many deaths among old population (Cernodoveanu and Binder 1993).
The earthquake from St. Elizabeth's night (November 19, 1523) was analyzed systematically by 2 studies (Rogozea et al. 2013, 545-562; and Radu and Toro 1996). They adopted for this earthquake an epicenter near Medias (Transylvania) and maximum intensity 7. The authors considered that, for the previous event dated June 9, 1523 the month is recorded wrong (June instead of November) and that in fact we are dealing with a single event.

15; 16;17;18. *Earthquakes from 1590 - 1595*

Florinesco (Florinesco 1958, 57-78) writes that two tremors were felt in Tara Barsei, on April 30, 1590. The probable time of this earthquake is 11 in the morning. This earthquake appears in the Romplus Catalog with an estimated moment magnitude Mw of 7.3, at a depth of 150 km, in the Vrancea seismic zone.
In 1590 a major earthquake occurred on the territory of Romania, this being taken over in Romplus on August 10, 1590 and produced in the Fagaras - Campulung area. The Wallachian chronicler Radu Popescu, in his 'History of the Princes of Wallachia', speaks of the death of Prince Stefan Bathory (Prince of Transylvania between 1571-1575 and King of Poland from 1575 until his death in 1586), and refers to the earthquake of August 10, 1590, when "a great earthquake occurred in Wallachia so that the bells of Brasov rang by themselves and many houses collapsed" (Cernovodeanu and Binder, 1993). This earthquake appears in the Romplus catalog with Mw 6.5 in the Fagaras-Campulung seismic zone (URL 1).

As Mathias Miles relates in the "Sibenburgischer Wurg-Engel" chronic (1770) (47. Miles 1984), on August 10, 1590 a "powerful and frightening earthquake" occurred. It was felt so strongly in Brasov that 'the bells rang, many houses and walls collapsed and the vault of the church shrine cracked from top to bottom' (Nussbächer 1987, 54-58, 231-233).

Mathias Miles chronicler (Miles 1984) talks about the April 21, 1595 event. The author states that: '…the December 1, 1594, April 22, 1595 and December 8, 1595 earthquakes were felt not only in Transylvania, but also in two other Romanian lands (Wallachia and Moldova), in Turkey and Greece', probably speaking of the earthquake from April 22, 1595. The Ottomans, according to the testimony of Jesuit Alfonso Carillo (from Sigismund Barthory's court), have interpreted this earthquake as "bringing evil" to the Ottomans and as a coincidence that in 1595, they (Ottomans) suffered in the same year the most painful defeat from the Romanian army under Vaivoda Mihai Viteazul, ruler of Wallachia, at the time (battle of Calugareni and Giurgiu 1595) (Rogozea et al. 2013, 545-562).
A charter of Prince Alexander Voda, from April 13, 1626, alludes at one of these three earthquakes when reminds us that Malamuc monastery from Gherghița "was torn down and the entire wall fell down; it was a great earthquake in the days of Voivode Mihai Viteazul" (Cernovodeanu and Binder, 1993; Nussbächer 1987, 54-58, 231-233; Rogozea 2013, 545-562).
Except for the first one which is considered a clear Moldavian earthquake (Atanasiu 1961, 58-92), which occurred in Vrancea region, the rest were felt only in Transylvania, where they produce important damages to large buildings especially in Brasov, after local chronicles. Maybe the earthquakes in 22 April 1595 was felt also in Wallachia, and the Ottomans felt too, because they were already in Wallachia, with territorial dispute.

29. There is information about the earthquake of August 19, 1681, which was felt in Iași at 2 o'clock in the morning, preceded by a noise and lasted for half a quarter of an hour. According to other sources, the earthquake occurred at 1:45 a.m. and was felt in Wallachia and Transylvania, with a magnitude of 9 deg. and lasted 15 min. (Nussbächer 1987, 54-58, 231-233). Ion Neculce probably writes about this earthquake that "There were also very large earthquakes. Then the great tower in the fortress of Suceava, called the Nebuisa Tower, fell." (Radu and Toro 1996).

30.31.32 In the same year, other earthquakes were felt in Iași, on October 16 and 18 and on December 27, the last one an hour and a half before dawn, accompanied by a noise (Hurmuzaki 1911, 251-252).

36. At the earthquake of 31 May 1738 in Nicopolis some four mosques collapse, and the fortress of Niš, on the Serbian side of the Danube, reports significant damage. Also 11 monasteries, 15 houses, 15 towers and a church steeple collapse in Iași, while the walls and tower of the Prince's Court in Bucharest are destroyed, see Fig. 3 and (Historia Special 2023), (23. Georgescu 2004).

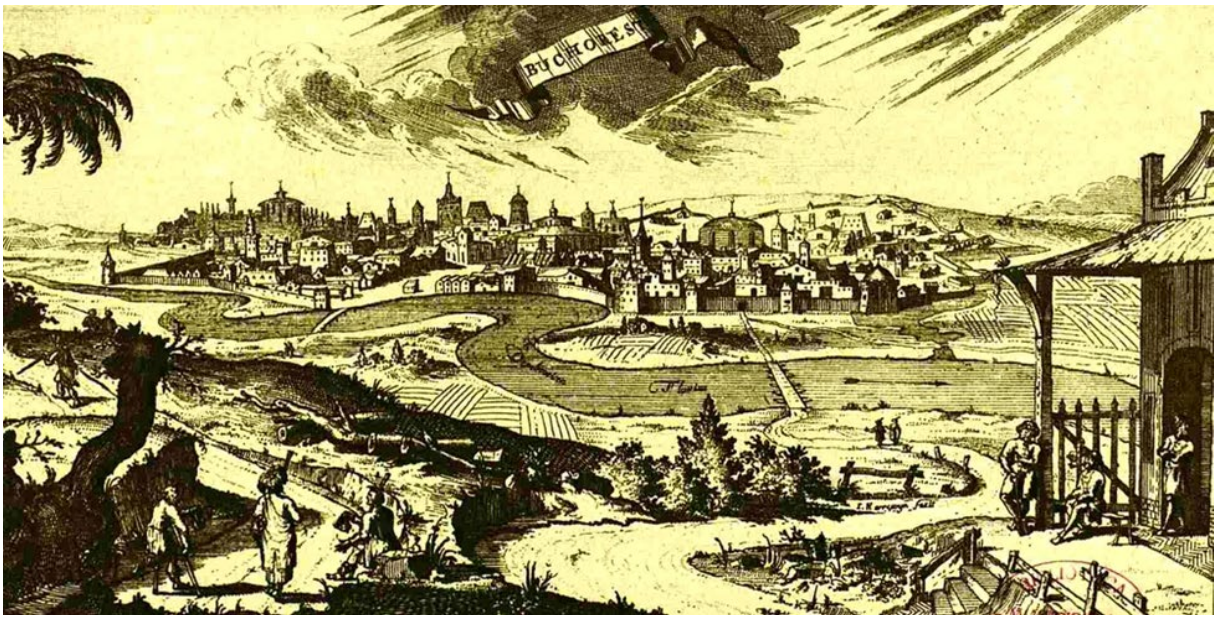

Figure.3. An epoch image of old Bucharest, in which the earthquake of 1738 "filled all the people with terror and dread."

46. ***1802 Vrancea earthquake***

Chronicles and records of the Orthodox Church indicate extensive damage to churches and tall buildings in Bucharest. This is the strongest earthquake ever recorded in Romania, known by contemporary documents as "great earthquake of Good Friday". Felt on an area of 2 million km^2. Despite its intensity, only four people were reported killed. The earthquake occurs on 26 November 1829 at 4 o'clock, causing great panic among population, in Bucharest 150 stone houses are destroyed or severely damaged (Cernovodeanu and Binder, 1993). Felt over a very large area from Tisa to Bug and from Mureș to the Danube (Georgescu 2004).

The earthquake is recorded on November 14, 1829, in IC catalog (Cereteu 2015, 23-55) and sources indicate that it affected the church of the *Three Hierarchs* in Iași, the *Princely Church* in Bârlad, the *Precista Mare Church* in Roman, and other secular and religious buildings. The earthquake is also reported in a German manuscript (1802) (183, 184, 185). The *archpriest* of Odessa wrote that on November 13-14, 1829, an earthquake was felt at 3:45 a.m., which lasted approximately minutes (185).

59. In this earthquake (from 23 January 1838) there were 73 death recorded across the country, of which 8 only in Bucharest (Georgescu 2004). In Wallachia 217 churches collapsed or were severely damaged. A massive landslide barred the Bicaz river forming the Red Lake in Bicaz Pass (Hurmuzaki 1911, 251-252). Priest Gregori Levovski writes in a book (printed in Bucharest in 1765) with circulation in Bessarabia, about the earthquake of January 11, 1838: "Let it be known that in the year 1838, on January 11, the earth shook at 5 hours and 2 minutes. (190-203).

62. Priest Ioan Tacu writes about the birth of his son Nicolai, on October 16, 1854, and together with this family event he also reports an earthquake. The earthquake was felt well, but did not cause visible damage (209).

64. The earthquake was followed by three aftershocks with magnitude over 4. (Ștefanescu 1902, 1-34).

66. On December 25, 1880 (st.n.), at 4.50 p.m. an earthquake was reported in Iași, manifested by several strong tremors of 20 seconds, after which several weaker oscillations and a muffled noise followed (221).

68. ***The case of the Earthquake of October 14, 1892***

The shock was felt at Sofia (Bulgaria) and Bucharest (Romania) at 06h; 54 min. Eastern Europe time. Hepites (Hepites St. 1894), besides other Romanian reports, gave first information about the felt area extension over Bulgaria; Draghiceanu (Draghiceanu 1896, 1 - 89) supplied some data from Transylvania to the compilation of Hepites, proposed an epicentre, and outlined for the first time in Romania the territory shaken by the earthquake. He proposed also the earliest assessments of intensity for some areas of Romania. Watzof (Watzof 1902, 21-33, 77-80) collected reports from Bulgaria of that time; he assessed the intensity in some localities and mentioned that the event was felt in Bucharest, too. But the earthquake was felt also in Moldova as it is stated in IC catalogue (Cereteu 2015, 23-55), where we can find the following citation: "*On October 14, 1892, the last earthquake was also felt in localities throughout Moldova region, such as: Iași, Huși, Focșani, Odobești and others, having a wide extension in Wallachia* ", see also Table 1.

In a paper from 1992 the authors, Glavcheva and Radu 1994, are reviewing completely the parameters of the earthquake of 14 October 1892, beginning with the epicentre location and considering old and contemporary studies like (Hepites 1894; Draghiceanu 1896; Watzof 1902, 21-33, 77-80; [27. Popescu 1939]; [28. Florinesco 1958]; Atanasiu 1961, 58-92; Grigorova 1973; and Karnik 1971). The authors of study (Glavcheva and Radu 1994) arrive at the conclusion that the epicenter was in the north-east part of Bulgaria, close to the border with Romania and they established also principal parameters the depth and the magnitude. The authors of the study Glavcheva and Radu 1994, concluded: "*The epicentre was obviously situated in NE Bulgaria. It corresponds, as a first approximation, to the central point of the innermost isoseismal, the one of intensity 7, with coordinates 43°45' N, 26°55' E. The determination error might be considered as equal to +/- 10 km, because of the scarce information from the epicentral area.*"

Finaly the authors of (Glavcheva and Radu 1994) established the magnitude: "*Applying the generalized regional correlation (Shebalin et al., 1974) to our set of data, the earthquake magnitude should have been about 7.5. In NE Bulgaria especially, only a few, small earthquakes are known. The latter might be a reason to suppose that the magnitude was not greater than 7.*"

The paper (Glavcheva and Radu 1994) is an example of a complete determination of the set of parameters of an earthquake about 100 years old at the time of the review, by combining the results of old sources and new developments in seismology. Finaly the earthquake is linked with the characteristics of the Moho boundary and the magnitude is established at 7 deg. as it is also today.

73. An earthquake with profound echoes in almost the entire Romanian space is the Moldavian event of August 19, 1894. An Akathist (from Râmnic, 1784) states that in southern Moldavia and especially in Dobrogea this earthquake was felt at "2:20 p.m., Friday" and that "the walls of the churches cracked" (224). The same message is conveyed by the note of Theotokis Nikiforos, (‘Words to Apostles of Sundays of all Year’ ,Buzău, 1853), which mentions that "on August 19, 1894, the Earth shook very strongly at about 2:30, so that many houses collapsed" (225).

76. 1901 Black Sea earthquake. A 4 m high tsunami devastates localities on the shore of the Black Sea. Large landslides reported in Dobrich Province and in town of Mangalia, Romania. Light damage to buildings in Bucharest (Papadopoulos et al. 2011, 945).

80. The earthquake had three explosive moments at an interval of three minutes. The last phase generated "frightening jolts" and "formidable underground rumble". It damaged old houses in Bucharest, eastern Wallachia and southern Moldavia (Cernovodeanu and Binder, 1993).

81. and 82. ***The earthquakes from 25 May 1912 in Focsani – Mărășești area.***

The book *Earthquakes in Romania* (Atanasiu 1961, 58-92) continues to be a source of knowledge about historical earthquakes in Romania, capturing much data and knowledge about older ground motions that were felt before the era of continuous seismic recordings have begun.

In Romania, seismic observations were made regularly from 1893 to 1916 under the leadership of Stefan Hepites. In the period 1916–1920, the observations were interrupted due to World War I, to be resumed in 1921 to 1926, for this period they are much less complete. Since 1903, observations of seismic stations in Romania have also been published, macroseismic observations being completely neglected after 1926. It is interesting that the series of earthquakes in 2012 were included in Atanasiu's book (1961) in the chapter Local Earthquakes in Moldova, probably due to their weaker intensity compared to the Vrancea earthquakes, which are the subject of a separate chapter. However, it should be noted that this volume existed only as notes and few papers when he passed away in 1949. Note that this volume was published posthumously with conclusions and some additions by Prof. Emilia Saulea, 12 years after the premature death of Professor Ion Atanasiu. Table 2 presents some of the more important earthquakes in this series, each with its local intensity and the location where the earthquake was felt with the highest intensity. The intensities are on a scale that was used at the time, but as their aftershocks are described, they can be classified on the MSK scale, still used today.

Table 2. The suite of local earthquakes from 1912, near Focșani and Mărășești, after the text of Atanasiu 1961, 58-92.

Date	**Hour**	**Maximum locality**			**Other localities**					
		Intensity			**Intensity**					
25.05. 1912	20 h; 3 min	**Focșani 7**		Odobești 6		Vidra 5		Nămo loasa 4	Corbu 3	Piscu 2
25.05. 1912	22 h; 15 min	**Focșani 6**	**Mărășești 4+**	Odobești 5	**Vîlcăneasa 6**	Vidra 5	Panciu 3-	Nămo loasa 4	Corbu 4+	Piscu 2
25.05 1912	23 h; 15 min	**Focșani 5+**	**Mărășești 5**	Odobești 5	**Vîlcăneasa 5+**	Vidra 4				
26.05. 1912	1 h; 45 min	Focșani 3	**Mărășești 4**	Odobesti 3	Vîlcăneasa 3	Vaslui 3-				
26.05. 1912	5 h;	Focsani 3-	**Mărășești 4**			Cudalbi 3-	Viziru 3-			
27.05. 1912	7 h; 15 min	Focșani 3-	**Mărășești 4+**	**Odobești 4+**		Vidra 3-				
27.05. 1912	11 h;	Focsani 3-	**Mărășești 5**			Vidra 3				

20.06. 1912	13 h; 20 min	**Focșani 3**		Odobesti 2						
25.06. 1912	6h;30 min	**Focsani 3**								

Therefore, from Table 2 it can be seen that in one month, from May 25, 1912 to June 25, 1912, at least 9 earthquakes occurred. that were felt in the Focșani – Marasesti – Vulcăneasa triangle, of which the first three, from May 25, 1912, were also the most intense, between 5+ and 7 and with a maximum in Focșani. They did not have too big consequences, but the first two earthquakes of May 25, 1912 were also introduced in Romplus, having a magnitude calculated from macroseismic data of over 6. The following earthquakes moved towards Mărășești where they culminated with 4-5 intensity, after that the last 2 returned to Focșani, but with much lower intensities, around 3.

Atanasiu (Atanasiu 1961, 58-92) considers them Moldavian earthquakes because of the much lower intensity than the Vrancea ones and with the hypocenter in the earth's crust. Two of the earthquakes of 1912 are mentioned in a recent study (Miles 1984) from the Republic of Moldova, in which they were mentioned as having been felt as far as the Nistru river, Republic of Moldova, as well as in the eastern part of Romania (Iași). A figure with isoseismals from book (Atanasiu 1961, 58-92) of some earthquakes with the epicenter in Marasesti from the 1912- 1913 series is published below.

83. **The earthquake from 26 January 1916** was the greatest crustal earthquake recorded so far in Romania with a magnitude of Mw 6.4, which occurred in Făgăraș-Câmpulung seismic zone of Southern Carpathians.

Using all modern computer programs existent at that time, Oros et al. 2008, manage to fix the new parameters of the earthquake in Table 3, with some error margins that are mentioned.

The earthquake parameters are not so far from the parameters in Romplus (Oncescu et al. 1999, 43-47).

The authors have analyzed the earthquake parameters using a lot of recordings gathered mainly in western Europe in the cities where the seismological service was active in 1916. The first and very valuable recording was in Bucharest in a building that is still existing.

Table 3. The new focal parameters for the 26th January, 1916 Romanian earthquake occurred in Fagaras seismic zone (South Carpathians).

Date	Origin time	Lat. N	Lon. E	H [km]	MLH	Ms	Mw	Reference
26.01.1916	07;38;0.14 ±0.79	45.212 ±3.5km	25.370 ±4.5km	15.7 ±3.3	6.5	6.4		[45]
26.01.1916	07;37;54.0	45.400	24.600	21.0			6.4	[4]

The focal mechanism solutions obtained in this paper were determined with a good accuracy and the recording from Bucharest was included (Oros et al. 2008);

Plane 1: dip=68, strike=284, rake= -136; Plane 2: dip=50, strike=174, rake= -29;

P: trend=305, plunge=42; T: trend=147, plunge=11,

The focal mechanism determined by (Oros et al. 2008) corresponds with normal faulting in good agreement with the extensional tectonic regime characteristic for the Fagaraș- Câmpulung in South Carpathians after (Radulian et al. 2000, 57-77).

3.2. The October 14, 1802 Vrancea earthquake

The earthquake of 14 October 1802, is the most disastrous event ever happened in the Romanian space, and as a result of which many secular and ecclesiastical buildings in the entire region collapsed. The impressive number of testimonies written on old manuscripts and books proves that this natural calamity marked the entire Romanian society many decades after its occurring.

From the numerous testimonies of contemporaries, the tectonic movement occurred on October 14, 1802, at 1:45 p.m. and lasted for about 4-5 minutes, with aftershocks during the night and in the following day. In thiss time, a large number of houses and churches were affected in the Romanian area east of the Carpathians: in Iasi, the churches of Sfântul Spiridon, Sfânta Paraschiva were affected; in Huşi, the catapetheasma from the bishop's church fell; in Bârlad, the church Adormirea maicii Domnului was damaged, whose reconstruction began in 1804; the spire of the Armenian church cracked in Suceava; in Galaţi, the church of the Holy Archangels was demolished; in Focşani, the vault of the Sfãntul Ioan monastery fell (132); the upper part of the church ‘‘Adormirea maicii Domnului’’ from the Căpriana monastery, restored in the period 1802-1820, was seriously damaged (133), after sources in (Cereteu 2015, 23-55).

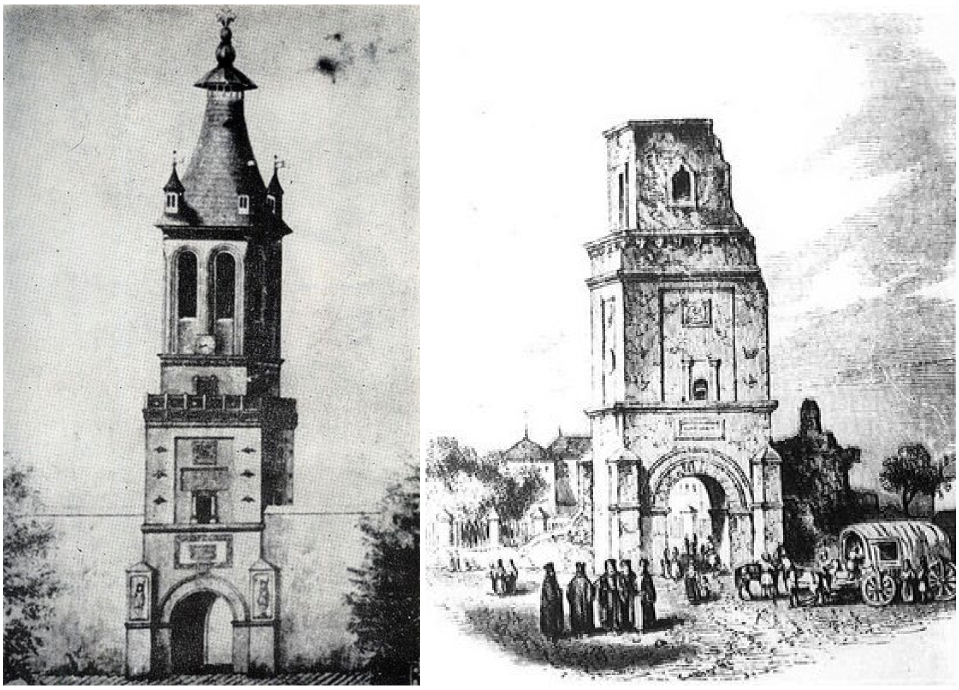

Figure 4. The tower of Colțea before and after the Great Earthquake from 14 Oct. 1802.
After **Minerva. Enciclopedie Română (1929) (Pteancu, Maior, Demetrescu, Florinescu et al. 1929-1930).**

The “Great Earthquake” occurred on the day of Saint Parascheva (1802, October 14) an important orthodox celebration in Romania. It caused numerous victims and disastrous damage to Moldavian and Wallachian parts, but also in nearby historic regions as Russia to north-east and Bulgaria to south-west. It was felt over a very large area (more than 2 million km^2), as far as Constantinople, Kiev, Moscow, St. Petersburg, Warsaw, Varna and Vidin after (Atanasiu 1961, 58-92) and (Ştefanescu 1902, 1-34). The direction of the oscillations was from east to west, in Bucharest. The earthquake lasted two minutes and 30 sec., according to chronicles and recent sources.

The famous Colțea Tower, built over eight decades earlier, had its upper part collapsed (Ştefanescu 1902, 1-34), see Fig. 4. The tower at the Radu Vodă Monastery also collapsed. Almost all the towers in the city collapsed (Atanasiu 1961, 58-92).

The Colţea Tower was a building located in the center of Bucharest. With a height of approximately 50 meters, it was the tallest building in the city for one century. The tower was built between 1709/1714 by the soldiers of Charles XII, King of Sweden, who were retreating through Wallachia, after losing the Battle of Poltava (June 27, 1709), to Peter the Great, Tsar of Russia. The tower quickly became the city's most famous attraction. Curious people climbed it to see the city from above. It was located in the old gate of the Colţei hospital. The bell tower was located almost in the axis of the church, 20 meters to the west, below it being the entrance to the premises; it was a tall square bell tower, which rose above the large gate of the wall surrounding the monastery. The roof, of Baroque style, had four turrets at the corners (Montessus de Ballore 1905).

The Church of St. Spiridon fell and the Church of Sf. Ilie on Calea Rahovei was damaged (Radu and Toro 1996). The Church of Sf. Nicolae became a pile of ruins. The Cotroceni Monastery collapsed completely, with only the gate remaining standing. The Monasteries of Mihai Vodă, Cernica, Plumbuita, Stavropoleos, Sarindar, St. Apostoli, St. Gheorghe Nou, St. Atanasie Bucur, Udricani, Văcărești, Mărgineni and Negru Vodă were severely damaged. Damage occurred also at Şerban Vodă Inn.

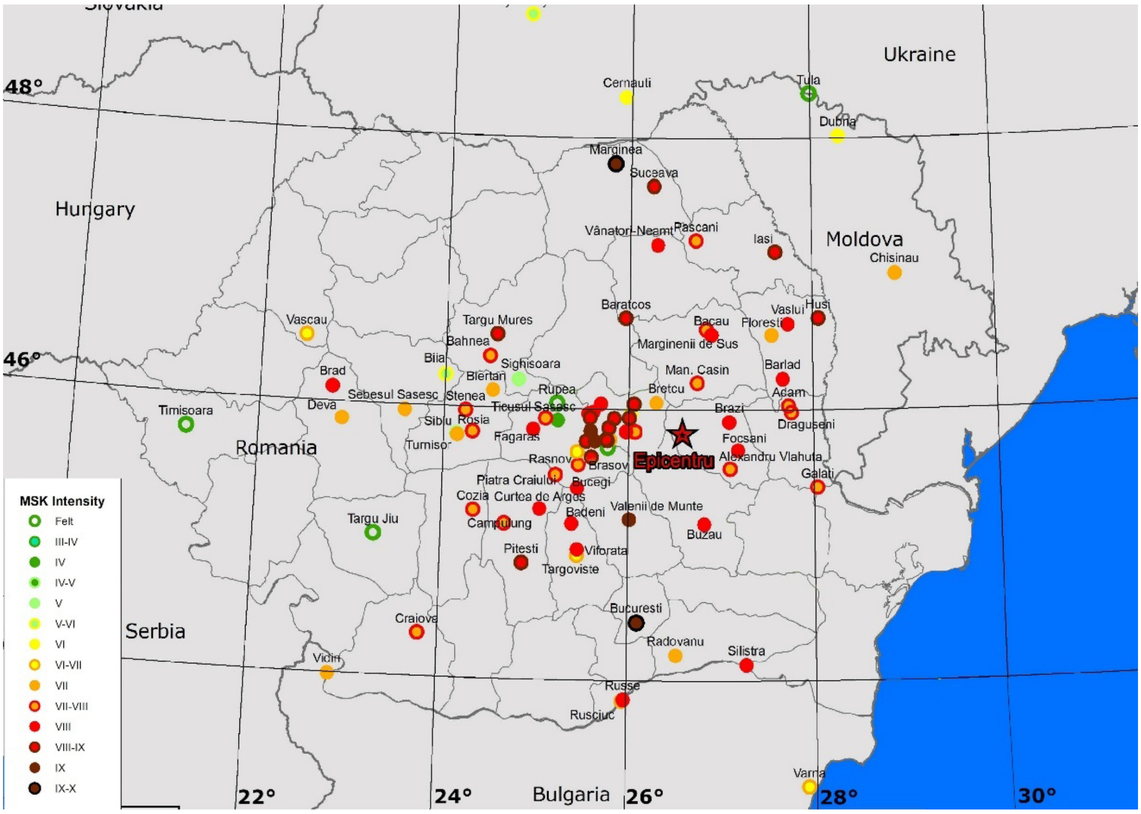

Figure 5. Map of intensities (I_0) felt and recorded in Romania and Republic of Moldova at the earthquake from 14 Oct.1802. Map is made after data compiled from studies (Rogozea et al. 2013, 545-562) and (Rogozea et al. 2016).

According to intensities in Fig. 5, the earthquake from 1802 was felt and recorded mostly in the external part of Carpathians Arc , but with only 2 – 3 points in Republic of Moldova. We have to mention that in (Cereteu 2015, 23-55). we can find some 50 testimonies (73-133), directly from the original sources. At a future research there will be more points with a definition for intensity in these parts.

There are also some 15-20 points inside the Carpathian Arc in which we have a level of intensity as is indicate by original sources (VI – VIII), as this event was the strongest earthquake ever recorded in Europe in the Intra-Carpathian zone.

4. Conclusions

The main conclusion of the present chapter is the unveiling of the paper (Cereteu 2015, 23-55) which has a solid research at the base, which took years to be accomplished. Although the author is a historian researcher (not geophysicist or seismologist), he managed to write all the observations taken from original sources and to elaborate a catalog of 81 historical earthquakes occurring in the old Moldavian space, including the local intensities.

This article includes information about 88 earthquakes in Moldova, attested in the XVI-XIX. The main sources from which we learn about these phenomena are medieval chronicles, old notes on books, dates from the archive etc. In the sixteenth century are recorded three earthquakes; in the eighteenth century - 6; XVIII century - 22 earthquakes; in the nineteenth century - 57 earthquakes. Of the total of 88 earthquakes reported - 26 were felt fall, spring - 24, 20 - winter, 14 - in summer, and four earthquakes (1521, 1692, 1799, 1851) have not indicate date.

From all these events some 25 events are integrated in the original catalog of historical earthquake (see Table 1), elaborated over more than 40 the years at National Institute of Earth Physics (NIEP – Romania). The others are still in observation because it is not possible to be overlooked and we believed that they are 'future' historical earthquakes that will be added one day in Romania and Republic of Moldova.

After considering the important source of new data about the historical earthquake as they were felt in Basarabia (Cereteu 2015, 23-55), the improved catalog given in Table 1 could lead to evaluation of more intensity values for very strong earthquakes. For example, for the largest earthquake ever felt and recorded in the Vrancea region, the event from 14 Oct. 1802, (Saint Parascheva Day). For this catastrophic event, named *The Great Earthquake* in the chronicles of the time, there are recordings in 50 new points, not only for Romania and Republic of Moldova, but also for all Intra-Carpathian zone in Europe. This supplementary information will lead to an improved image of this important event and its aftermath.

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CHAPTER 2

GEOGRAPHICAL, GEOMORPHOLOGICAL AND GEOTECTONIC SETTING OF BUCHAREST CITY

IRINA-MARILENA STANCIU, DUMITRU IOANE AND ANTONETA SEGHEDI

1. Geographical Setting

Bucharest, the capital of Romania, is located in the southern part of the country, in the central area of the Romanian Plain, specifically within the Bucharest Plain, which is a subdivision of the Vlăsiei Plain.

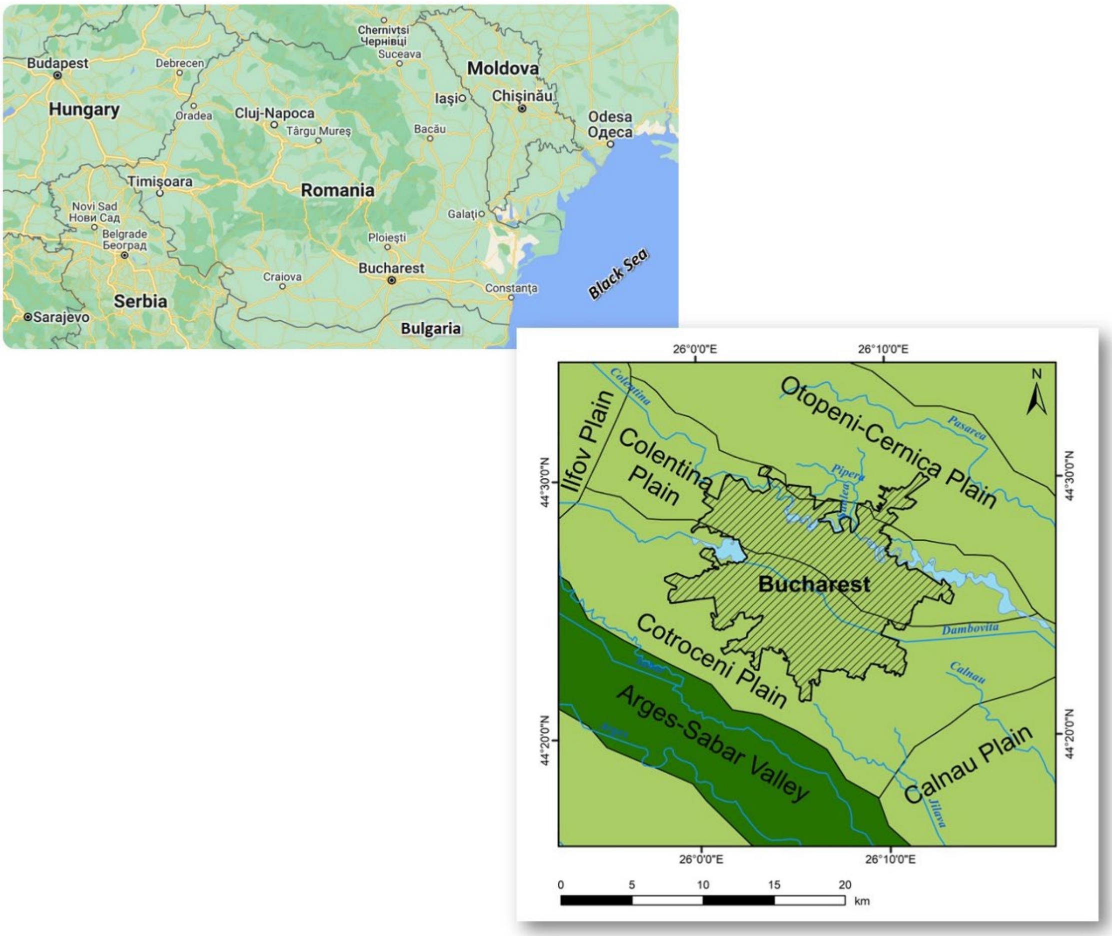

Figure 1. Geographical setting of Bucharest. Physical map of Bucharest area (detail from Posea and Badea, 1984, with modifications) and location of Bucharest within Romania (map data © 2022 Google).

Posea and Badea (1984), considered 4 subdivisions of the Bucharest Plain: Ilfov Plain to the NW, between Sabar and Colentina rivers, and three NW-SE elongated "plains" of roughly equal size, bounded by the Dâmbovița and Colentina rivers (Figure 1):

- Otopeni-Cernica Plain, to the NE, between Colentina and Pasărea rivers;
- Colentina Plain, in the centre, between Colentina and Dâmbovița rivers;
- Cotroceni Plain, to the SW, between Dâmbovița and Sabar rivers.

Bucharest is located in the lower course of the Dâmboviţa river, which flows through the city in a NW-SE direction for approximately 24 km. Originating in the Carpathian Mountains, the Dâmboviţa river eventually merges with the Argeş river downstream of Bucharest. Its main tributary, the Colentina river, crosses the NE part of Bucharest on a similar NW-SE path before joining the Dâmboviţa river a few kilometers beyond Bucharest.

In relation to Romania's major geographical landmarks, Bucharest is positioned approximately 100 km south of the Carpathian Mountains, 65 km north of the Danube River, and ca. 250 km west of the Black Sea.

2. Geomorphology of Bucharest area

In Bucharest area, topographic elevations range from 100–110 meters in the northwest to 50–60 meters in the southeast, reflecting a gently sloping relief in a NW-SE direction. The geomorphology of the city area (Figure 2) is shaped primarily by the Dâmbovița and Colentina rivers.

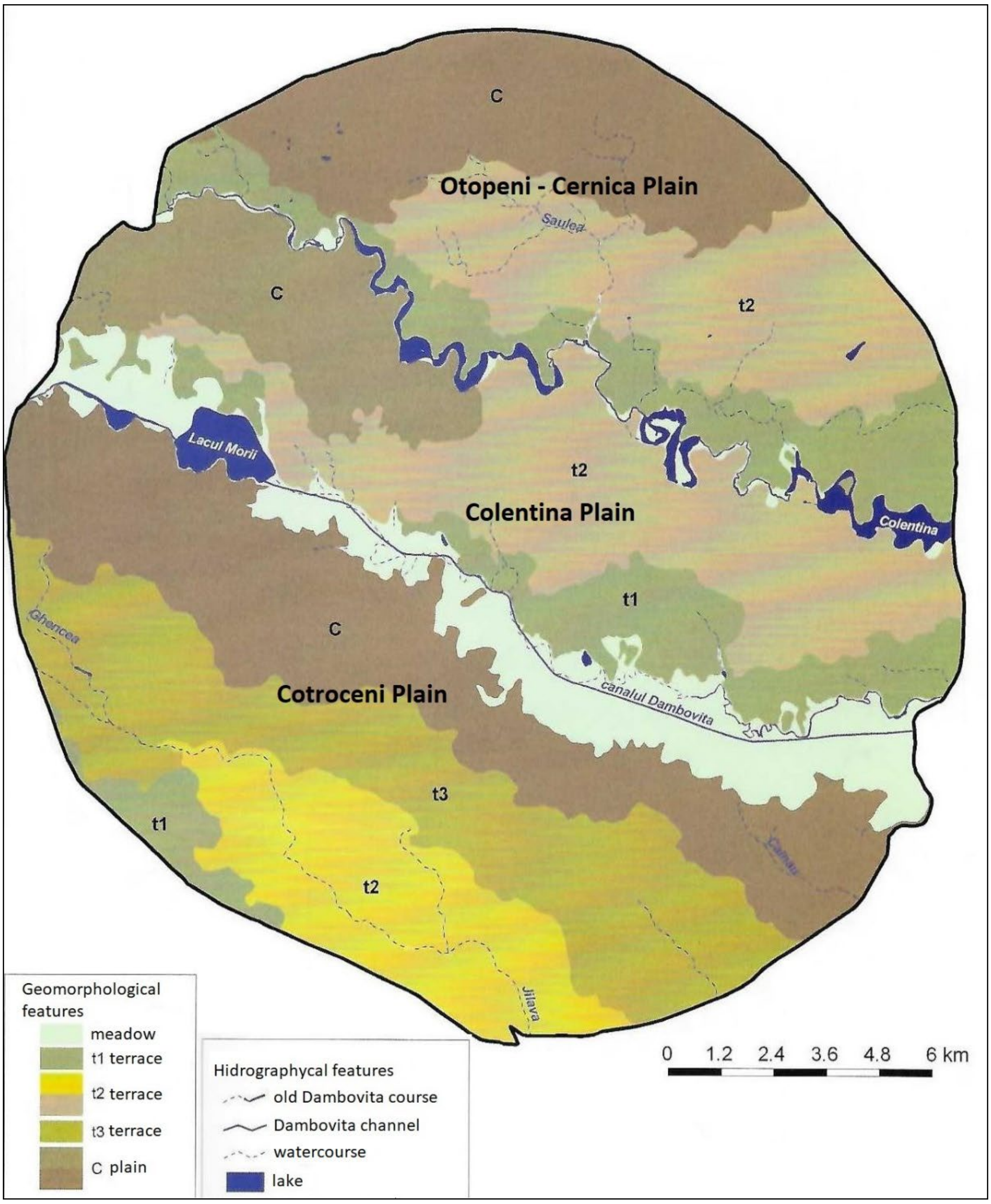

Figure 2. The geomorphology of the Bucharest area (from Enciu et al, 2008, with modifications)

Dâmbovița valley exhibits a distinct asymmetry, with a steep right bank featuring slopes of up to 90° and a height of 10 meters, while the left bank consists of two broad terraces: one at 3–5 meters (t1) and another at

7–8 meters (t2) (e.g., Coteț, 1976; Enciu et al., 2008). The river's floodplain widens from northwest to southeast due to its meandering course. Historically, frequent floods and swampy conditions led to significant anthropogenic modifications of the floodplain, beginning in 1880 (Parusi, 2007). However, near Cățelu, remnants of dried meanders reflect the original geomorphology. Elevated landforms as the result of erosion are a defining feature of the Dâmbovița floodplain: Chiajna, Giulești, Hașdeu, Arhivele Statului area, Dealul Mitropoliei, Radu Vodă, Cățelu (Coteț, 1976). Some of these may have been influenced by local tectonic and geodynamic processes related to strike-slip faulting and horizontal terrain displacements. Much of Bucharest, particularly the historical center, was developed on the t2 terrace along the river's left bank, while the t1 terrace is home to Giulești, Vitan, Dudești, and Cățelu neighborhoods.

The Colentina river, despite its pronounced meandering, follows a generally linear NW-SE course and shares a similar morphology with the Dâmbovița river. Its right bank is steep and elevated, while the left bank features two terraces, rising 7-8 meters (t1) and 10-12 meters (t2) in height (Enciu et al., 2008). The primary challenge posed by the Colentina river was water stagnation, attributed to its low discharge, gentle slopes, and shallow groundwater levels (Zaharia et al., 2016).

The Colentina floodplain is relatively narrow and contains several elevated landforms, such as Plumbuita, Dobroești, and Pantelimon, formed as the result of erosion or local tectonics. It is largely occupied by lakes, including Mogoşoaia, Străulești, Grivița, Băneasa, Herăstrău, Floreasca, Tei, Fundeni, Pantelimon, and Cernica, arranged in the river's meanders.

Both Dâmbovița and Colentina rivers display asymmetric banks, with a higher right (western) riverbank. This suggests that in the area of Bucharest city the rivers have followed segments of regional normal faults that affected the Moesian Platform, as result of a tectonic extensional regime.

Springs emerge at the base of valley slopes and terraces, such as on the right (western) bank of Dâmbovița (i.e., in Roșu village, the Botanical Garden, Carol Davila Street, Belu, Popești-Leordeni) and on the left (eastern) bank of the Colentina (i.e., in Pipera, Pantelimon, Dobroești).

Small depressions, probably caused by differential loess compaction, are common in the Otopeni-Cernica and Cotroceni Plains (Coteț, 1976; Enciu et al., 2008). Historically, several areas of Bucharest, including the Botanical Garden, Cișmigiu Park, Crângași Square, and locations near Victoriei Square, Kiseleff Street, Aviatorilor Boulevard, Pitar Moș Street, Grădina Icoanei Park, and Doamnei Street, were marshes or swamps in the 19th century but were later drained and landscaped.

Additionally, depressions formed by past excavation activities - such as clay extraction on the left bank of the Dâmbovița in the city center or gravel mining in the Colentina basin - were subsequently filled with debris from buildings that collapsed during major earthquakes or were demolished.

Analysis of the river network morphology

The Bucharest city area is crossed by the Dâmbovița and Colentina rivers, flowing on parallel courses, on NW-SE direction (Figures 1 and 3). In the same direction and parallel to the two rivers already mentioned, to the west of the city, flows the Argeș river (Figure 3). A similar situation is observed to the east, in the case of the Pasărea river, and to the south of Bucharest, in the case of the Câlnău river.

Saulea is a left (eastern) tributary of the Colentina river which has developed a more complex catchment, with tributaries mostly on its left (eastern) side. From the source to the river mouth, the course of the Saulea river undergoes several changes in terms of direction, which can be compared with certain trends observed at regional level. Upstream, it follows a N-S direction, then turns to SW-NE direction, and in its downstream half it follows a NE-SW direction. The left side tributaries of Saulea flow along NW-SE and turn to NE-SW direction, while the tributary on the right-side flows on NW-SE direction, then forms a 90° angle at the confluence with Saulea river.

Another tributary flowing on NW-SE direction reaches the Colentina river in the Pantelimon Lake area. On its left side it receives two tributaries flowing on NE-SW direction and at the confluence with Colentina river it also forms a 90° angle.

SW of Bucharest, Ciorogârla and Sabar rivers flow into the Argeş river, following a NW-SE direction. In the same NW-SE direction, the Jilava stream, with its Ghencea tributary, flows into the Sabar river.

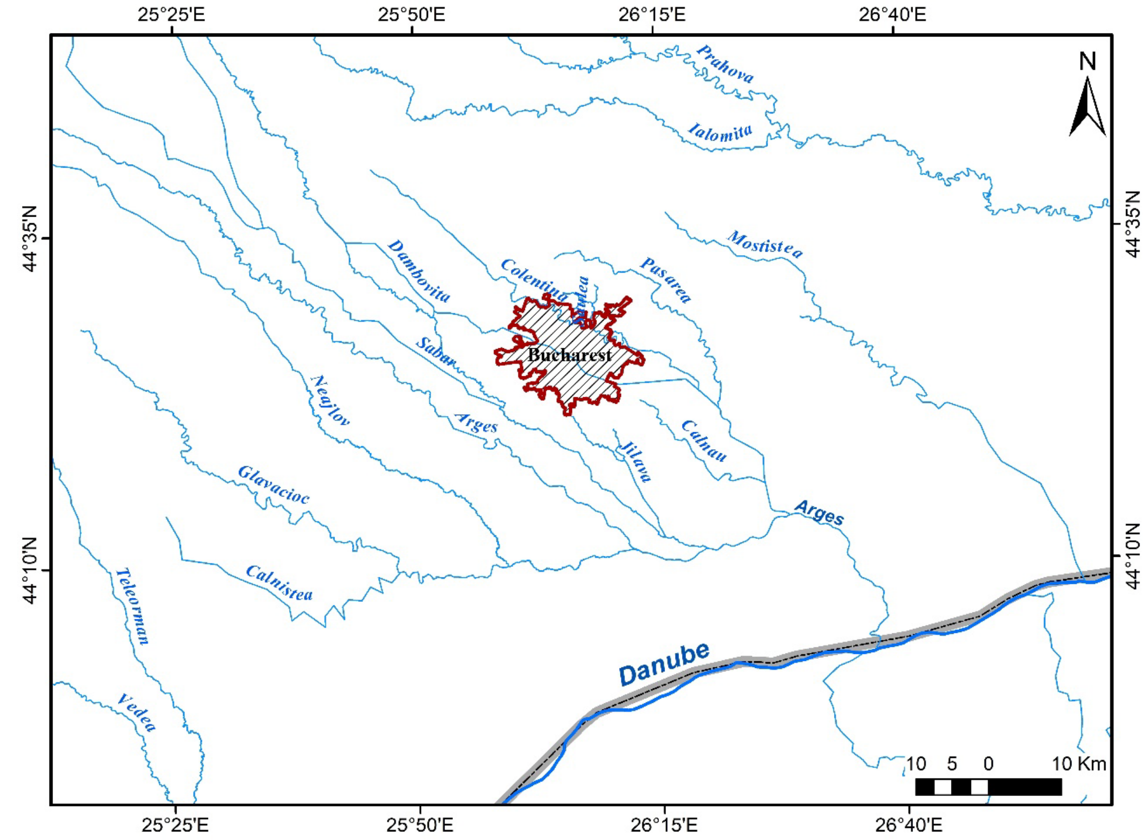

Figure 3. River network in Bucharest area

An examination of the regional river network (Figure 3) reveals several noteworthy patterns:

1) The river network in the region follows a general NW-SE orientation in the Bucharest area and west of the city, maintaining this direction until reaching the Danube. However, east of Bucharest, many rivers gradually shift eastward before flowing into the Danube, while others turn northeastward and flow into the Siret river.

   Fielitz and Seghedi (2005) observed a transition in river morphology, with braided river channels predominating west of Bucharest and highly meandering channels becoming dominant to the east. This shift is attributed to variations in river gradient, sediment composition (coarser vs. finer bedload), and the subsidence affecting the Focșani Depression.

2) Bucharest is located within a "transition zone," where the river network density decreases from west to east. West of the city, the network is denser, whereas eastward, fewer rivers are present.

3) Mostiştea is the easternmost river that follows a NW-SE direction. Overall, its right (western) bank is slightly elevated than its left (eastern) bank. However, in the Mostiştea lake area, the right (western) bank features a steep loess-paleosol slope exceeding 20 meters in height (Panaiotu et al., 2001; Timar-Gabor et al., 2009). These deposits overlie fluvio-lacustrine sediments which contain mammal fossils of Pleistocene age (Panaiotu et al., 2001).

4) The Argeş drainage basin presents an unusual hydrological pattern. The Argeş river and all its tributaries initially follow a NW-SE course, but south of Bucharest, their flow abruptly shifts to a W-E direction.

The morphology of the W-E Argeş valley displays a southern (right) steep bank, ca. 15 m in height, which separates an uplifted, hilly compartment to the south from a northern compartment with flat geomorphology.

This results in a distinct promontory-like area, bordered by the steep slopes of the Argeş river to the north and east and the Danube river to the south (Stanciu, 2020; Figure 4). This W-E oriented Argeş-Danube promontory (Stanciu, 2020; Stanciu and Ioane, 2022, 2023) acts as a natural barrier, forcing the Argeş river approximately 25 km eastward. After the point where Dâmboviţa river flows into Argeş and the Argeş-Danube promontory ends, the Argeş river returns to its NW-SE course and flows into the Danube, in the vicinity of Olteniţa city. A similar sharp directional shift - almost 90° - is observed in the Glavacioc and Neajlov rivers after their confluence with the Câlniștea river, where they change course from NW-SE to W-E (see Figure 3).

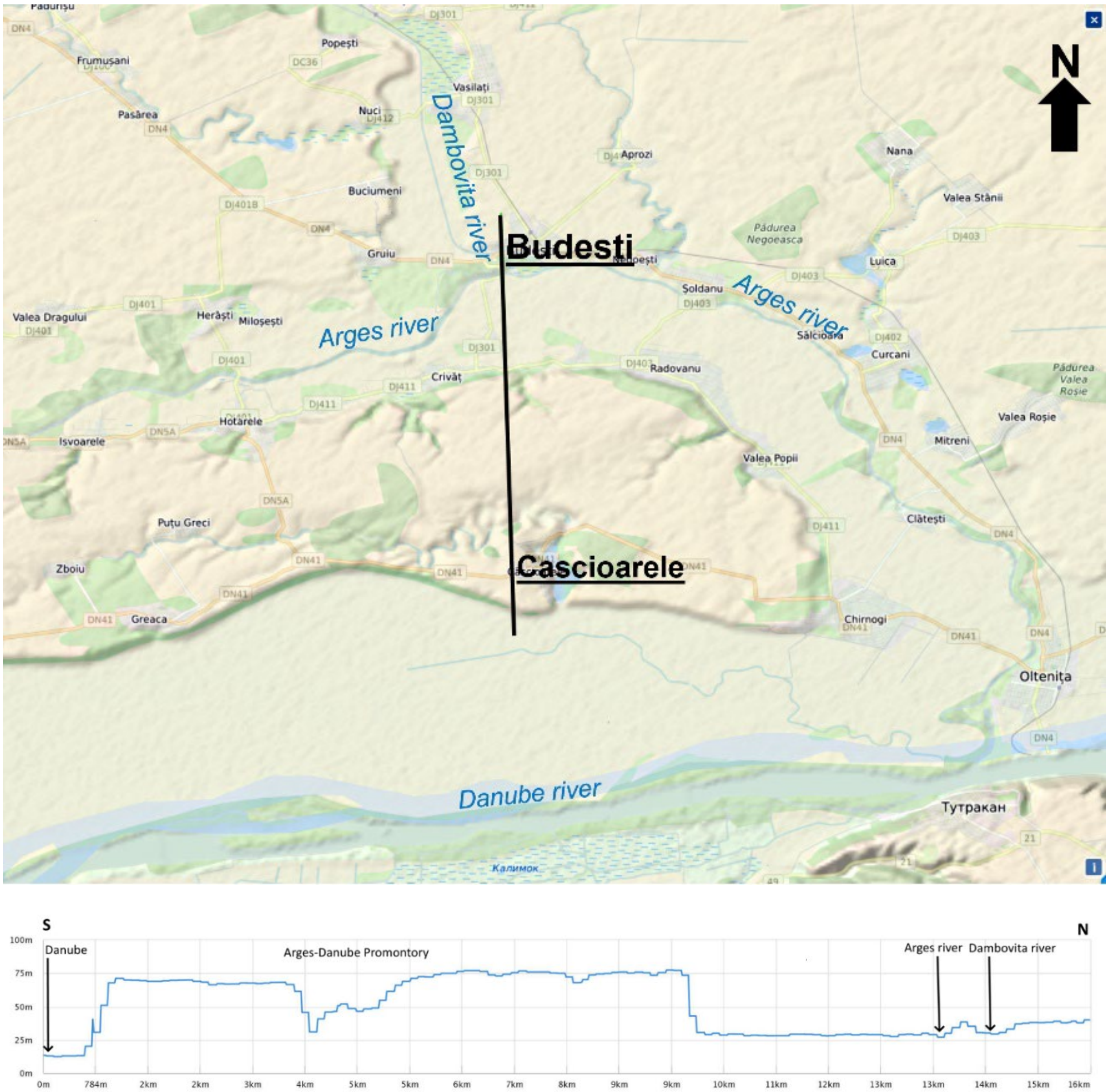

Figure 4. N-S topography profile (Budesti-Cascioarele) across the Argeş-Danube Promontory (modified from Stanciu, 2020, built on data from https://portal.emodnet-bathymetry.eu/, accessed in 2020). Top = location of the topography profile.

The Dâmboviţa river, once characterized by its strongly meandering course and marshy floodplain, has undergone extensive transformations due to channelization, regulation, and land reclamation efforts. Many of its former tributaries within Bucharest are now hidden beneath urban infrastructure, and its length within the city has been shortened by approximately one kilometer (Zaharia et al., 2016). Several of its former meanders have been converted into landscaped lakes, such as those in Carol and Tineretului parks, as well as Cişmigiu Lake. Bacalbaşa (2013) describes the Dâmboviţa river before the anthropogenic changes as "shallow", "running in winding zigzags", with "numerous springs providing drinking water". These springs formed streams that once ran through Bucharest and into the Dâmbovița. One such stream, as noted by Bacalbașa, emerged behind the Bucholtzer Institute, which was located near Calițiі Bridge, now part of Calea Rahovei. Grădina Icoanei, a park in central Bucharest, was historically the site of the Bucureştioara stream's spring. Many springs have left their names in the city's historical landmarks, such as Puțul cu apă rece (i.e., Cold Water Fountain), Puțul lui Zamfir (i.e., Zamfir's Fountain), Puțul cu plopi (i.e., Fountain with Poplar Trees), Puțul cu zale (i.e., Chainmail Fountain), Cişmigiu, Mărcuța, Fântâna Mitropolitului Filaret (i.e., Bishop Filaret's Fountain), etc. Northwest of Bucharest, the Crețulești and Crevedia springs were originally intended as a drinking water supply for the city.

The first documented engineering intervention on the Dâmbovița river took place in 1774, when Prince Alexandru Ipsilanti ordered the construction of a diversion canal upstream of Bucharest. This canal was designed to redirect excess water from the Dâmbovița to the Sabar river during high waters and floods (Georgescu et al., 1966; Zaharia et al., 2016). Following a series of severe floods between 1862 and 1865, a second diversion canal was constructed at Arcuda.

Over time, increasingly complex modifications were implemented to regulate the river's flow, protect Bucharest from flooding, manage wastewater and stormwater, and create recreational spaces for residents (Solacolu, 1988). The key engineering works carried out on the Dâmbovița river include (Zaharia et al., 2016): (1) building of the Lacul Morii reservoir, upstream of the 15-meter-high Ciurel Dam; (2) channelization of the Dâmbovița river within the city (downstream of the Ciurel dam), on a length of 17 km, including 11 weirs which separated slackwater pools; and (3) installation of an underground wastewater drainage system beneath Dâmbovița canal. Additionally, the Dâmbovița is now linked to adjacent watercourses through diversion and supply canals, allowing for inter-basin water transfers to and from the Argeş river.

3. Geotectonic setting

From a geotectonic point of view, Bucharest is situated within the regional geological unit of the Moesian Platform, west of the Intramoesian Fault and close to the external part of the Carpathian foredeep.

The Moesian Platform represents a major tectonic unit of the Carpathians and Balkans foreland, considered with a heterogenous folded basement and thick, slightly deformed, Palaeozoic, Mesozoic and Tertiary sedimentary deposits (Boncev, 1974; Săndulescu, 1974). It forms a W-E elongated, fault-delineated structural unit, which prolongates into the Black Sea up to the continental slope, where it is gradually replaced by the oceanic-type crust (Boncev, 1974; Săndulescu, 1974, 1984; Visarion et al., 1988).

In Romania, the platform is considered to be separated from the Carpathian orogenic belt by the Peri-Carpathian Fault, while geophysical and borehole data suggest the northward underthrusting of the platform deep underneath the Southern Carpathians and the East Carpathian Bend Zone (Săndulescu, 1974; Paraschiv, 1979; Săndulescu, 1984; Visarion et al., 1988; Tărăpoancă et al., 2003). According to Săndulescu (1984), the Moesian Platform extends up to the Trotuş Fault in the north. To the North-East, it is separated from the North Dobrogea Orogene by the Peceneaga-Camena Fault (e.g., Săndulescu, 1984; Visarion et al., 1988; Săndulescu and Visarion, 2000; Seghedi et al., 2005a, b).

In Bulgaria, the Balkans overthrust the southern margin of the platform along the North Prebalkan Fault (Boncev, 1974). Most of the Moesian Platform on Bulgarian territory is part of the Walachian-Prebalkan unit, south and west of the Intramoesian Fault.

The transcrustal Intramoesian Fault is considered a regional fault (e.g., Săndulescu, 1984; Visarion et al., 1988), acting as a deep regional tectonic contact (e.g., Ioane and Caragea, 2015), which separates the Moesian Platform into two compartments, distinct in terms of basement petrographic characteristics (e.g., Mutihac, 1982) and physical properties (e.g., Gavăt et al., 1939, 1974; Socolescu et al., 1974, 1975; Airinei et al., 1983), geotectonic history and geological affinities (e.g., Oczlon et al., 2007). The name "Intramoesian", given by Săndulescu (1984), illustrates the mostly accepted geotectonic role of this fault: separating the Moesian Platform in two distinct tectonic compartments, westward and eastward, with different petrographic facies and geological age, referred to as: Danubian and Dobrogean (Paraschiv, 1979), Wallachian/Wallachian-Prebalkan and Dobrogean sectors (Săndulescu, 1984; Visarion et al., 1988; Săndulescu and Visarion, 2000), West and East Moesia (Oaie et al., 2005; Seghedi et al., 2005a,b), or