ROMANIAN EARTHQUAKES DATABASE. PART I: 984–1899

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Received May 31, 2023

Abstract. The main purpose of this study is to create a database that correlates the data from the current catalogue of Romanian earthquakes (ROMPLUS) with the information from other available catalogues, research studies for the events produced between 984 and 1899, historical documents, and mentions in archives or historical papers. The database will contain, in addition to the ROMPLUS available information, the type of event (tectonic or anthropic) and the references attached to each event. In the second step of our analysis (events recorded after 1900), the database will be updated and connected with the catalogue of the earthquake mechanisms.

Key words: earthquakes, catalogue, macroseismic data, seismic database.

DOI: https://doi.org/10.59277/RomJPhys.2023.68.805

1. INTRODUCTION

A reliable and complete catalogue of earthquakes for a region of interest is essential to assess seismic hazard and risk. To investigate the recurrent seismicity of a region we need, besides modern digital recordings, macroseismic and analog recordings as well.

The generic name of "historical seismic data" is used for earthquakes and seismic events produced before the instrumental period. The parameters of these events are determined on the basis of the event origin-time and location and macroseismic effects as they are mentioned in chronicles, old religion writings, old newspapers, etc.

Collecting historical information is a sustained effort and needs a lot of time, patience and attention. Most of the old documents are not accessible or cannot be found. Some documents provide very detailed information about an event or very sparse or contradictory information about other events.

The aim of the present paper is to set a database combining and revising data from the routine catalogue of earthquakes in Romania [1, 2] with any other information from other available catalogues, research studies for the events produced before 1900, historical documents, mentions in archives or historical investigations. In addition to ROMPLUS, the type of event (tectonic or anthropic) and related references to each event are included in the database.

2. SEISMICITY OF ROMANIA

The seismic activity recorded on the Romanian territory is considered to be moderate compared to the global seismicity and has been divided into several epicentral zones, according to [3]: Vrancea – where major destructive events occur (intermediate-depth earthquakes and crustal earthquakes), Bârlad Bassin, Făgăraş – Câmpulung (including the Sinaia events), Danube area, Intramoesian Fault, Banat, Crişana – Maramureş, Pre-Dobrogean Orogen, Transylvanian Basin.

In the Transylvanian Basin there is an increased seismicity at low magnitudes, in the last period, but this is to the greatest extent of anthropogenic nature (quarry blast events).

Earlier studies to determine seismic zones [4, 5] in our country followed the geographical distribution of seismic activity and did not take into account the tectonics of the region. In later studies [3, 6], zones are identified on the basis of tectonic and seismic information, which in turn are correlated with the main tectonic units, active faults, distribution of epicenters (Fig. 1).

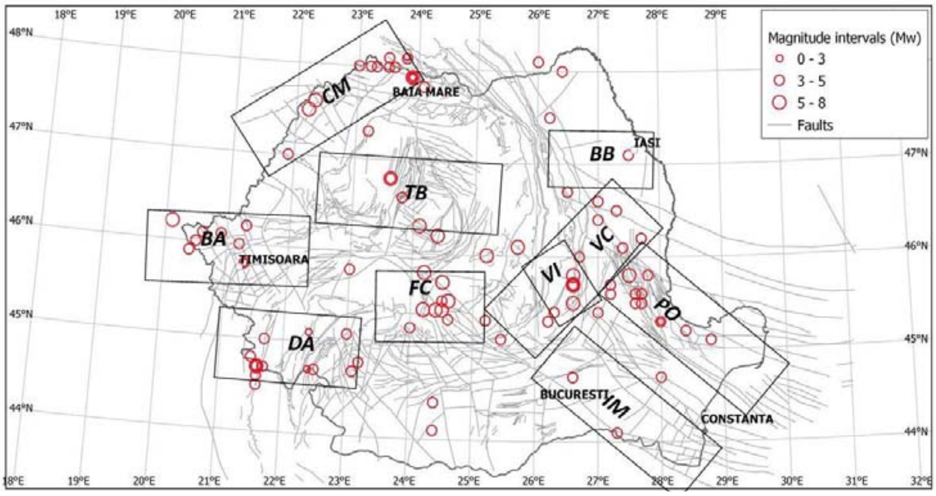

Fig. 1 – The main seismogenic zones map of Romania and the earthquake locations between 984 and 1899: where VI – intermediate-depth earthquakes from Vrancea, VC – crustal depth earthquakes from Vrancea, BB – Bârlad Basin, PO – Predobrogean Orogen, IM – Intramoesian Fault, FC – Făgăraş-Câmpulung, DA – Danubian, BA – Banat, CM – Crişana Maramureş, TB – Transylvanian Basin.

In the revised catalogue and the new-created database, each event will be placed in a specific seismic zone corresponding to the epicentral coordinates. For the events classified as anthropic, their most probable source will be specified.

2.1. CHARACTERIZATION OF SEISMOGENIC ZONES OF ROMANIA

The main seismogenic zones of Romania for the pre-instrumental period are shown in Fig. 1. These zones are Vrancea with crustal and intermediate-depth events (VC and VI), Bârlad Basin (BB), Predobrogean Orogen (PO), Intramoesian Fault (IF), Făgăraş-Câmpulung (FC), Danubian (DA), Banat (BA), Crişana-Maramureş (CM), Transylvania Basin (TB).

A characteristic feature of the major intermediate-depth earthquakes in the Vrancea region is that they are strongly felt toward NE (in Moldova) and toward SW (Muntenia) even at large distance and have less effects in the interior of the Carpathian Arc [7]. For the time period 984–1899, 98 events were identified in this region at depths greater than 60 km. The maximum magnitude estimated in this region is M_w = 7.9 for the event of 26/10/1802 [1, 2].

The seismicity in the overriding crust in the Carpathians arc bend area (Vrancea crustal and Bârlad Basin areas) consists of moderate-sized earthquakes and appears to be distinct from the intermediate-depth source. This seismicity is clustered in space (in the Râmnicu Sărat and Vrincioaia subzones) and time (seismic sequences are frequently generated, either as main shocks accompanied by aftershocks and often by pre-shocks or as earthquake swarms). Apparently, the seismic sequences are common for the eastern part of the area (Râmnicu Sărat region), while swarms predominate in the northern area (Vrincioaia region). The maximum recorded magnitude is M_w = 5.9 for the Vrancea crustal zone and 5.6 for the Bârlad Basin. The intensity associated with these magnitudes is $I_{0\,max}$ = VII (for Vrancea) and $I_{0\,max}$ = VI (for Bârlad Basin) respectively, according to the ROMPLUS earthquake catalogue. Only two events with magnitudes above 5 are reported in the Vrancea crustal zone before 1900:10.06.1734 (M_w = 5.2) and 01.03.1894 (M_w = 5.9). In the Bârlad Basin area only moderate-sized events have been observed (four shocks with M_W > 5.0, but not exceeding M_W = 5.6 [3]).

The seismic activity in Dobrogea region is moderate (only one event of magnitude M_W = 5.3 was observed on 02/11/1871 [1, 2], clustered mainly along the Sfântu Gheorghe Fault (Fig. 1). The maximum possible magnitude in this area was estimated at M_w = 5.5.

Although the Intramoesian Fault is a well-defined deep fault, reaching the base of the lithosphere and extending southeastward towards the Anatolian fault region [7, 8], the associated seismic activity is scattered and weak, with only one event exceeding magnitude 4. The largest earthquake on the Intramoesian Fault recorded in the ROMPLUS before 1900 is the event of 25/11/1897 with M_W = 4.2 [1, 2].

The Făgăraş-Câmpulung region is the area with the largest crustal earthquakes in Romania where earthquakes with magnitude exceeding 6 were recorded several times. Seven events with magnitudes between 5.0 and 6.5 are produced during 1550–1832-time interval [1, 2, 9]. The distribution of epicentres shows a strong clustering in the western part, including the largest events with M_W approximately

6.5 and another in the eastern part (Sinaia region), with smaller events with M_W less than 5.0.

Atanasiu [10] calls the western part, adjacent to the Danube River of the Southern Carpathians orogenic unit, the “Danubian Zone”. In this area the rate of seismic activity is quite high, especially at the border with Serbia, but the magnitude of earthquakes does not exceed 5.8 (M_w). A large earthquake sequence ($M_w \geq 5.0$) recorded in historical time as well as in the instrumental period was recorded along the Oravița-Moldova Nouă fault system between 1879 and1880 [1, 2, 9].

The seismicity in the Banat area is characterized by several earthquakes with magnitude $M_W > 5$, but not exceeding magnitude 5.6 [1, 2, 9].

The seismicity of the Crişana-Maramureş area was determined using mainly historical earthquake information. For the pre-instrumental period, the information extracted from the existing medieval chronicles, concluded that in the Crişana-Maramureş region is a possibility for producing earthquakes with magnitude greater than 6.0 [1, 2]. The maximum historical magnitude was $M_w = 6.2$ (01/07/1829). According to the usual extrapolation procedures, the maximum possible magnitude will be taken as $M_w = 6.5$. The intensity associated with this magnitude is $I_{0\,max}$ = VII. The minimum magnitude chosen in the calculations is $M_w = 3.5$ and the associated epicentral intensity is: $I_{0\,min} = V_{1/2}$, according to ROMPLUS.

The seismic zone in the Transylvanian Basin is defined based on historical information only. Three important earthquakes occurred in this area: one with magnitude $M_w = 5.3$ on 03/10/1880 and two with magnitude $M_w = 5.9$ on 08/01/1223 and 19/11/1523. The maximum magnitude proposed for this area is $M_w = 5.9$ [1, 2].

3. SOURCES FOR COLLECTING INFORMATION ABOUT SEISMIC EVENTS

The analysis of different catalogues raised numerous problems to the researchers due to different and sometimes contradictory mentions for a certain event (different hours, different location, or different date) due to the calendar type used in that period or the interpretation of older documents.

Before 19th century, the documents from the Carpatho-Danubian region were written in Cyrillic characters (Moldova) and in Hungarian (Transylvania, as this part of the country belonged to the Austro-Hungarian Empire at that time), making difficult for today’s seismologists to understand the information and therefore requires careful analysis and experience in interpretation.

Incorrect interpretation of the data can lead to duplicate events in catalogues and incorrect assembly of sources related to a particular earthquake can lead to finding more than one event. When interpreting the documented data, information about construction types (*e.g.*, building materials, number of floors) should be also taken into account.

In the year 1893 Ştefan Hepiteş [11] published, in the Annals of the Institute of Meteorology, the first list of earthquakes between 1838 and 1892. The list included information on the date and time of the earthquake, the total duration of the movement and its maximum amplitude. Hepiteş also wrote the *Special Instructions for the Observation of Earthquakes* and the first *questionnaires* for collecting information on the mode of occurrence and effects of earthquakes. In addition to the meteorological stations, he also set up a macroseismic network.

Mathei M. Drăghiceanu [12], a Romanian geologist and mining engineer, describes in his paper the effects of the major earthquakes of 1802 and 1838.

Grigoriu Ştefănescu [13], a well-known Romanian geologist, collected numerous data on past seismic activity in Romania, all this information being gathered primarily from Perrey [14], Ureche and Kogălniceanu [15], A. Papiu-Ilarian [16], Ioan Neculce [17], Bogdan [18], Brzeski [19]. Although the information collected by Ştefănescu was not organized in the form of a catalogue, it provides valuable information because Ştefănescu tried to link the effects of the earthquakes to the geological conditions in the areas affected by the seismic events.

Montessus de Ballore, a French seismologist, compiled a catalogue of earthquakes throughout the world [20] and a summary catalogue of earthquakes for Romania and Basarabia between 1471 and 1892 [21], using among his bibliographical sources the works of Hepiteş [11], Drăghiceanu [12], Ştefănescu [13] and Perrey [14].

The studies related to the seismic activity in Romania were interrupted between 1908 and 1935 due to the World War I and they were resumed with the establishment of the Romanian Seismological Service, at the Bucharest Observatory, under the direction of Gheorghe Demetrescu [22, 23].

The following note referring to earthquakes is stated in Popescu [24]: "The records that can be found in old catalogues can only be approximate for at least two reasons: firstly, they come from the localities where – by chance – a educated person interested in these natural phenomena lived, which is extremely rare, and secondly, these observers only noted earthquakes that impressed the population by the extent of the damage they caused. As for the time of the earthquake, the notes, if not completely missing, are more confusing than ever: *around noon, shortly before dinner, late at night, during religious services*. As many of the witnesses lived in the cities, the information that can be found in old documents refers to earthquakes and their effects on cities. All this information is presented in the form of tables with lists of events specifying regions, times and effects, or as seismic catalogues containing more precise information.

In 1952, Antal Réthly [25], a German meteorologist and professor of geographical sciences, elaborated a catalogue of earthquakes for the period 455 to 1918, based on previous historical sources, covering Hungary, Moldavia and Transylvania and entitled *Earthquakes of the Carpathian Basin*.

Aurelian Florinesco [26] produced and published a catalogue for events occurring in the 455–1916 time period.

Ion Atanasiu [10], one of the most important Romanian geologists, wrote the *Earthquakes in Romania* monograph in which he deals with numerous problems related to the geology and seismotectonics of Romania based on the study of more than 400 seismic events.

After more than 30 years of work, Corfus [27], on the basis of information found in manuscripts and books in the Romanian Academy Library in Bucharest, published a volume in which chapter XI is dedicated to the earthquakes that occurred on the Romanian territory between 1681 and 1903.

In 1979, Cornelius Radu [28] published, for the first time in Romania, a catalogue of the strongest earthquakes produced on Romanian territory, using as sources of information: records of Romanian seismic stations, seismic bulletins, catalogues, maps, Romanian and foreign scientific papers. The catalogue is structured in two periods: the historical seismicity (the earthquakes produced in Romania before 1900) and the instrumental period (the events recorded after 1900).

The information gathered from chronicles, manuscripts, archived documents, correspondence or mentioned on various papers from churches and monasteries in Transylvania was used by Dudaş [29, 30] in the preparation of his religious books. In the second book [30] is also presented the *The Registry of earthquakes in Transylvania (1471–1900)*. The information contained in these books is of particular interest since, on their basis, some characteristic features have been described in terms of the shape of the isoseisms, the tectonics of the region or the establishment of the foci.

Other manuscript sources used over time were Vlădescu [31], Nicolae Costin [32], *Journal for History and Archaeology* (Gr. Tocilescu), as well as from other manuscripts in the Library of the Romanian Academy or in private collections (Erbiceanu, G. Lahovari, Tartesescu).

The sources stated above were used to update the ROMPLUS catalogue and database with the missing events.

In the case of historical data, the position of the epicentres has been expressed by geographical coordinates: latitude φ and longitude λ, corresponding to the centre of the area of maximum intensity or the point where the maximum intensity I_0 was observed. We used this formula to estimate catalogue data for new entries.

The focus depth was determined based on the relationship:

$$I_0 - I_n = \nu_n \times \log\left(\frac{D_n}{h}\right) \tag{1}$$

where: $D^2 = h^2 + r^2_n$ is the hypocentral distance; r_n is the radius of the n^{th}-order isoseism; ($n = 0$ for maximum intensity, $n = 1,2,...$ for decreasing order intensities); h is the focus depth; v_n is the intensity attenuation coefficient, defined as:

$$\nu_n^{-1} = \log_{10}\left(\frac{D_{n+1}}{D_n}\right) \tag{2}$$

For historical data, a classification of depth into three classes has been adopted:

- *s* – superficial depths ($h = 1 - 4$ km);
- *n* – normal depths ($5 \leq h \leq 60$ km);
- *i* – intermediate depths ($60 \leq h \leq 163$ km).

The first two classes of earthquakes were included in the category of crustal earthquakes and the third class in the category of intermediate-depth events.

The magnitude for the recorded events determined from historical data has been assessed based on the macroseismic intensity at the epicentre (I_0), as a function of seismic region, using the relationships from Table 1 [26].

Table 1

The relation for *Ms* and the regions from Romania where it applies

Relation for M_s	Region where the formula applies
$0.56 \times I_0 + 2.18$	Vrancea intermediate-depth zone ($h = i$)
$0.66 \times I_0 + 1.23$	Vrancea, Câmpulung, Romanian Plain, Oltenia, Dobrogea, Moldova – crustal earthquakes ($h = n$)
$0.66 \times I_0 + 0.52$	Banat, Crișana, Maramureș, Transylvania – crustal earthquakes ($h = n$)

To determine the magnitude from instrumental data, the magnitude calculated from the oscillation duration (τ) was used, according to the formula of Lee *et al.* [33]:

$$M_L = -0.87 + 2.0 \times \log \tau + 0.035 \times k \times (S - P) \tag{3}$$

where: τ – the duration (in seconds), measured at the main station; k – constant; $(S - P)$ – the difference between the arrival times of the S and P phases.

The conversion from the local magnitude scale to the surface wave magnitude scale has been made with the following equation from Bath [34]:

$$M_s = -2.14 + 1.43 \times M_L - 0.018 \times M_L^2. \tag{4}$$

In 1979 Purcaru [35] published a new catalogue for the events produced between 1110 and 1973 in Romania, but unfortunately without mentioning the sources based on which the parameters in the catalog were calculated.

One of the most important existing catalogues is the one compiled by Shebalin *et al.* [36] for the Balkan region within the framework of the UNPD/UNESCO 1974 project (2100 B.C.–1970).

Using the catalogues of Popescu [24], Florinesco [26], Purcaru [35] and Radu [37] Constantinescu and Mârza [38] proposed in 1980 a new catalogue for the period 1022–1979, but without specifying the arguments behind the choice of the location parameters mentioned in the new catalogue.

The currently used catalogue for Romanian earthquakes is the ROMPLUS catalogue, published in 1999 by Oncescu *et al.* [2] and updated every month [1]. The oldest event in the catalogue is the one produced in 984. The main objective of the ROMPLUS catalogue was to unify the magnitudes, the magnitude published in the 1999 catalogue being the moment magnitude (M_w). The transition to the M_w magnitude was achieved through conversion relations. For historical earthquakes, the data were taken from the catalogue of Constantinescu and Mârza [38]. For the period 1980–2013 all events were located or relocated using a phase identification procedure and an inversion program (HYPOPLUS program, adapted from [39]). Since 2014, earthquake location has been performed using the Antelope 5.7 software [40].

An important parameter of a catalogue is the seismic intensity, which is not based on measurements but is estimated according to the reactions of the population, the degree of destruction of buildings, the type and extent of deformations of the earth's surface.

Depending on the intensity, there are two categories of earthquakes:

– *microseisms* – very numerous, insensitive to humans, they are recorded only by seismographic equipment;

– *macroseisms* – felt by humans; phenomena that have more or less importance, depending on the caused damages.

Seismic intensity is a variable parameter for an earthquake, which depends on the distance between the earthquake source and the location of its estimate damages (the maximum value being for crustal earthquakes in the epicentral zone and gradually attenuate with distance from the epicentre), local vulnerability, ground conditions and the subjectivity of the person reporting the effects.

The criteria to establish and define the intensity scales for intensity estimation underwent several transformations over time. For Central and Eastern Europe in 1964 the MSK (Medvedev-Sponheuer-Karnik) scale was created. It has twelve degrees of intensity. In 1992, the European Macroseismic Scale (EMS), based on the MSK scale, was finalized. The EMS scale also has 12 degrees but, unlike the others, it introduces quantitative assessments of the effects of earthquakes by evaluating quantitatively (in percentages) the degree of damage to buildings by classes: few (0–20%), many (10–60%) and most (50–100%). In our country, STAS 3684-54 is used, which allows any earthquake felt in a place to fall within one of the 12 degrees.

4. DATABASE

The information on the seismic events up to 1900 was collected from archived documents from city halls, private libraries or churches and monasteries libraries, personal diaries, newspapers, manuscripts, chronicles and annals, and different catalogues produced over time. Since collecting such a large amount of historical information is very difficult, and the access to documents is becoming increasingly challenging, we thought that keeping such documents in digital format would make it easier to access information and would be a proper way of preserving such documents over time.

The starting point for the database is the ROMPLUS catalogue format. The database (Fig. 2) will also include references, for each event, such as catalogues containing the location of the event, bibliographic references, link to the focal mechanism catalogue, description of seismic stations and instrumentation used in the location, macroseismic and strong motion maps and errors of continuous parameters in the catalogue (*e.g.*, time at origin, latitude, longitude, depth, magnitude), intensity of the event, links to scanned documents (when possible). For the part where localisations will be made on an instrumental basis, the number of stations used in the localisation and the number of phases used to determine the position of the epicentre and the magnitude will be mentioned. The database is designed in such a way that new fields can be added at any time and the information can be easily selected according to the desired parameters. The database should also be completed with a graphical user interface that allows the representation of the parameters contained in the database, thus making a valuable contribution to seismicity, hazard and seismic risk studies.

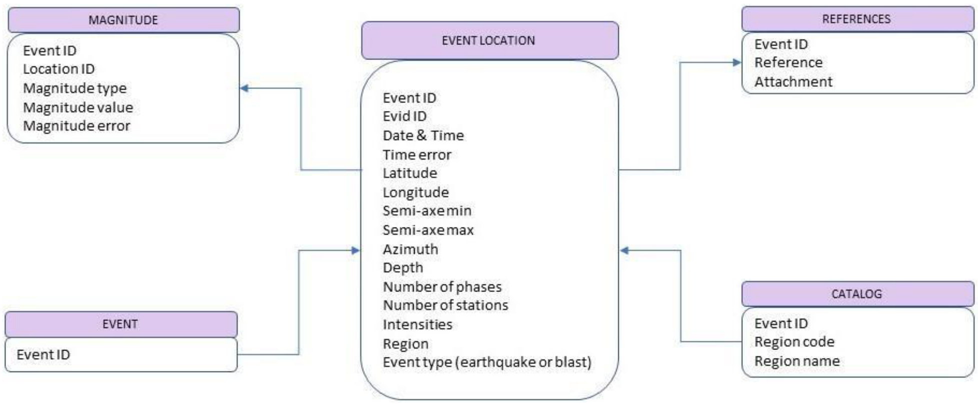

Fig. 2 – New earthquake database structure.

The seismic events will contain a unique identification number and an event type identification code according to the nomenclature proposed by the International Seismological Centre [41] and used by most national and international data centres. This code will contain two characters: the first character represents the “certainty” of the event and the second – the type of the event.

The localization of the historical events in the catalogue was done on a documentary basis and it is assumed that all these events had natural causes and are tectonic earthquakes, so these events will be assigned the code “ke” (known earthquake).

For the 984–1899 time-period, a comparative analysis of the ROMPLUS catalogue was made with the following catalogues (Fig. 3): SHEEC/AHEAD (SHARE European Earthquake Catalogue [42], Radu [28], Constantinescu and Mârza [38], Kondorskaya and Shebalin (KSR) [43], Shebalin *et al.* [36, 44].

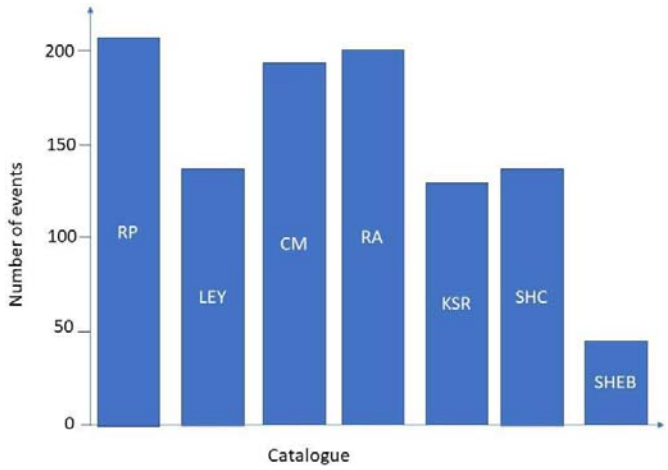

Fig. 3 – Comparison number of events between seismic catalogues legend: RP – [1, 2], LEY – [44], CM – [38], RA – [28], KSR – [43], SHC – [42], SHEB – [36].

5. CONCLUSIONS

The sources of documentary information on which the catalogue analysis is based are represented by seismological studies published by various authors, manuscripts, documents or notes obtained from libraries or archives of churches and monasteries, press articles, chronicles or annals, and different other catalogues. In order to understand and interpret the data contained in documentary sources correctly, it is necessary to obtain information from the period in which those documents were written, relating for example to the type of buildings or the materials from which they were constructed, historical, cultural, religious and habitat factors, the types of official calendars used over time. The use of different calendars (the Julian calendar – the old calendar and the Gregorian calendar – the new calendar) in different periods of time makes it difficult to establish the correct time of occurrence of a particular event. It should also be kept in mind that the transition from the old to the new calendar was not made at the same time in all countries. For example, the changeover to the new calendar took place in Hungary in 1587, in Bulgaria in 1916, in Serbia in 1919 and in Romania at the beginning of October 1924, with 1 October being counted as 14 October. Misinterpretation of dates mentioned in various documents has led to duplication of events in catalogues.

Also, depending on who reported on a particular event, the same earthquake may be located in different countries or regions.

Initially, the ROMPLUS catalogue listed 222 events for the period 984–1900 (Fig. 4). Following the analysis carried out during this work, 7 events were eliminated: 01/01/1091, 01/04/1170, 07/02/1258 (not enough documentary sources were found to confirm the existence of these earthquakes [45]), 10/04/1571 (wrong association of the epicentral area [42]), 31/10/1879 at 10:31 am, duplicate of the event of 31/10/1879 at 18:30 pm, 09/08/1679 at 01:00 am, duplicate of the event of 19/08/1681 at 00:00 am and 29/08/1473, duplicate of the event of 29/08/1471. For 74 events, changes were made to the location parameters, adopting the variant from the SHEEC catalogue [42].

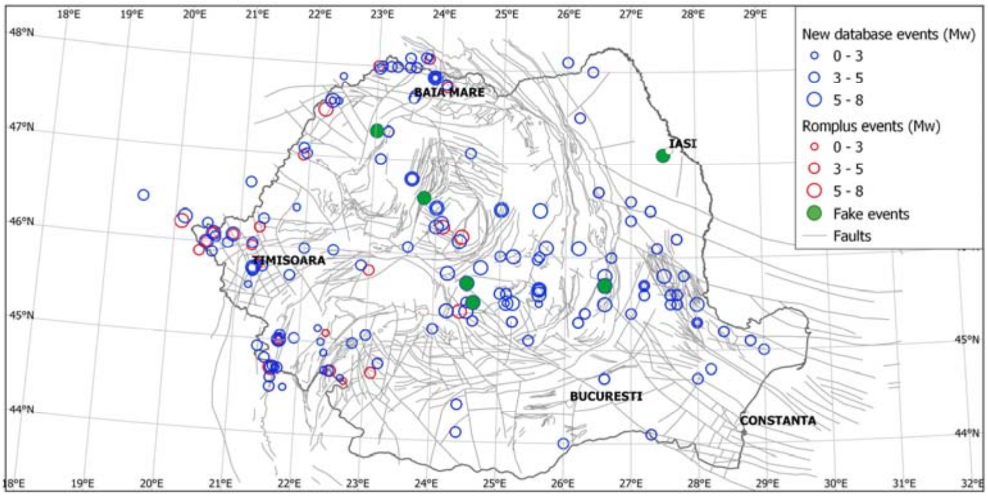

Fig. 4 – Analyzed events for the 984 – 1899 time period.

The study of historical documents led to the discovery of new seismic events, but they could not be included in the catalogue because not enough information was found to confirm their seismic parameters and event type.

We assume that the duplication of events often occurs due to the change of date when switching from the Gregorian to the Julian calendar. Some authors make the conversion from one catalogue to the other, and others reproduce the original date from historical documents.

We are currently working on completing the database presented in this study with information and bringing it up to date. In the further studies, the database will be extended to the present and it will be made available for read and download on Mendeley database (https://data.mendeley.com/).

The building of the national seismic database for the historical period will contribute to the modification and improvement of the hazard map of Romania, both for crustal earthquakes and for the Vrancea intermediate-depth earthquakes [46–48]. We must take into account the fact that in many seismogenic areas the largest earthquakes were recorded in the historical time and therefore the information from the recent period is insufficient to properly define the hazard.

Acknowledgments. The data processed in this paper are recorded by Romanian Seismic Network and owned by the National Institute for Earth Physics. ROMPLUS catalogue (NIEP). This study has been accomplished through the NUCLEU Programme supported by the Ministry of Research, Innovation and Digitalization, MULTIRISC project, PN 19080101: "Multidisciplinary research to characterize seismic and acoustic events using specific analysis techniques". Another part of the work has been supported by the SETTING project (Integrated thematic services in the field of Earth System Observation – a national platform for innovation), co-funded from the Regional Development European Fund (FEDR) through the Operational Competitivity Programme 2014–2020, Contract No. 336/390012.

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