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# Millennial Record of Earthquakes in the Carpathian-Pannonian Region: Historical and Archaeoseismology

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This is a short essay on earthquakes in the Carpathian-Pannonian region and its surroundings. Earthquakes have been recorded using seismographs since 1902 in Hungary. The relatively small number of seismic events and the long return period of major earthquakes make it necessary to use historical data in order to assess seismic hazard. Historical earthquake catalogues aim for exhaustiveness both in time and space, but they are limited by the lack of documentary data. A simple arithmetical assessment is provided to estimate our lack of knowledge of past seismic events. All destructive earthquakes of the twentieth century (above magnitude 5) are included in the catalogue (100%). Of the seismic events which took place in the seventeenth, eighteenth, and nineteenth centuries, only 23% are on record, while this figure drops to 4.6 percent for the eleventh–sixteenth centuries and 0.2 percent for the first millennium AD. On average, we have no information about 90% of the destructive earthquakes which occurred in the Carpathian-Pannonian region over the course of the past two millennia. According to both instrumental measurements and historical sources, there were relatively few earthquakes in the central era of the period of time in question. This era coincides roughly with the two centuries of Ottoman rule (the sixteenth and seventeenth centuries). Were there really few earthquakes over the course of these two centuries, or we do not have the relevant records? We contend that warfare resulted in the destruction of settlements and the annihilation of documents.
Fragile historical documents can be supplemented by the study of robust edifices, an approach to the study of the past which is known as archaeoseismology. Evidence of damage and destruction can be identified, and earthquake parameters can be assessed. One can find evidence corroborating other sources indicating an earthquake (e.g. Savaria), and one can also identify traces of previously unknown seismic events (Visegrád). One can also assign intensity values to the existing historical records. Damage observed to a Roman road in Savaria, to the medieval donjon of Nagyvázsony offers support for our fundamental contention. In order to understand the seismic hazard that was faced in the Carpathian-Pannonian region, renewed study of historical sources and new archaeoseismological investigations are needed.

Keywords: earthquakes, archaeoseismology, historical sources, Carpathian-Pannonian region

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## *Introduction*

Earthquakes cannot be predicted. There are abundant references on the internet and in the secondary literature concerning seismic events that allegedly were successfully forecast. Several natural anomalies were harbingers of the 1975 Haicheng event in China, and an evacuation order was issued by an exceptionally cautious civil protection leader, who was in a position of power at the time and who thus probably saved tens of thousands of lives. In contrast, there was no foreshock or any other kind of anomaly on the basis of which predictions might have been made concerning the 1976 Tangshan earthquake, which hit the city at night and caused at least 250,000 deaths. The few successful cases when an earthquake was predicted should be seen as lucky coincidences at most, not suitable for generalization.[1] How can we reduce damage to people and property by earthquakes in the future? Anything that happened in the past can happen in the future. We therefore need to learn as much as we can about the past. This may help us prepare for events in the future.[2] In the following, we provide a very short overview on the seismic history of the Carpathians and the Pannonian Basin.

## *Historical Seismology*

Measurements of seismic activity using sophisticated instruments began in Hungary in 1902. For any moment before this date, we have data on seismicity based on historical documents only. Grossinger[3] was the first to summarize these documents in a Latin catalogue published in 1783, immediately followed by a German translation of Sternberg,[4] both of whom listed 150 events. A century later, Jeitteles[5] described 220 earthquakes from the same period in great detail, noting felt features and damage. After a few short communications, Réthly[6] published his monumental catalogue, listing events up to the end of 1917. Two hundred and thirty-five of these events are recorded from the same period as Grossinger. Réthly was the first to distinguish between main shock

1 Hough, *Predicting the Unpredictable.*
2 Ambraseys, "Archaeoseismology."
3 Grossinger, *Dissertatio.*
4 Sternberg, *Geschichte.*
5 Jeitteles, "Geschichte der Erdbeben."
6 Réthly, *Kárpátmedencék.*



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and aftershocks. He gave catalogue entries in the original language and added Hungarian translations with references to the original sources. His catalogue is an exemplary work in every sense.[7]

Zsíros[8] prepared a computerized catalogue containing more than 20,000 events. Most of the information concerning these events came from instrumental measurements taken after 1970. Comparing his methods with previous studies, we found that he increased the data given by Grossinger more than fourfold (!) for the period which came to an end in 1783. References are provided for all of the data. This catalogue has been supplemented by new data compiled using instruments by researchers at the Seismological Observatory in Budapest. Figures 1 and 2, which illustrate the temporal and spatial distribution of earthquakes in the Carpathian-Pannonian Basin, are based on this database.

Historical earthquake catalogues are prepared with the intent of making a complete listing of known events for a given area. The best examples to follow are the catalogues compiled by Guidoboni and Comastri[9] for the Mediterranean region, by Ambraseys[10] for the Mediterranean and the Middle East, and, to cite a local example, by Hammerl and Lenhardt[11] for Lower Austria.

Our ability to provide a complete account of catalogue of seismic events, however, depends, of course, on the availability of sources. Hungary is characterized by a lack rather than an abundance of sources, in part because of its stormy history.

Earthquakes of magnitude 5 or larger are plotted by decade in Figure 1. A magnitude 5 earthquake causes structural damage to buildings. Earthquakes and seismic events which took place after 1901 were measured using new instruments, so these measurements were used to plot them on the graph, while other sources, including narrative sources, were used to plot seismic events before this. The part of the graph which covers earthquakes of a magnitude of five or more in the twentieth century can be considered complete, as it is based on data provided by relatively sophisticated instruments. The graph offers the impression that, the further one goes back in time, the fewer earthquakes there were. Clearly, this is unlikely. This difference is a sign, rather, of the lack of sources.

7 Ambraseys, *Earthquakes*, 6.

8 Zsíros, "Earthquake activity."

9 Guidoboni and Comastri, *Catalogue*.

10 Ambraseys, *Earthquakes*, 6.

11 Hammerl and Lenhardt, "Erdbeben."



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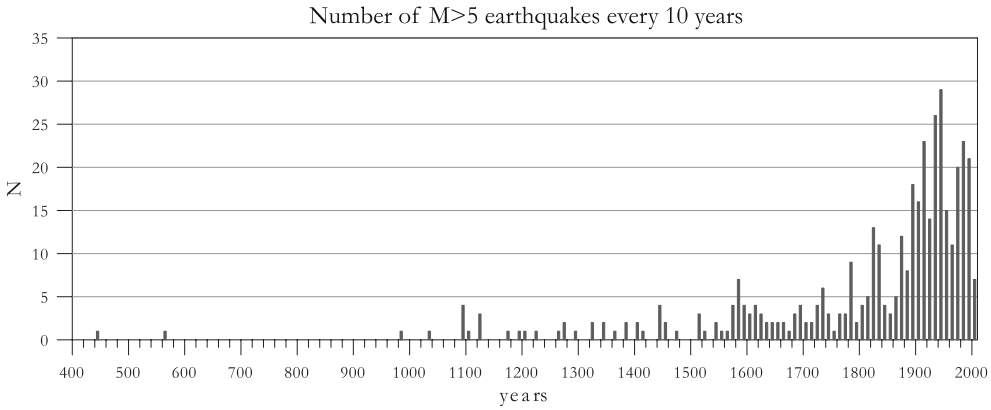


Figure 1. Number of known earthquakes in the Carpathian-Pannonian region and surroundings in the past two millennia. Magnitude 5 and larger events are shown for each decade. See also Figure 2 for the investigated area.[12]

We assume that there were similar numbers of earthquakes in previous centuries. The locations and times of seismic activities are consequences of processes of plate tectonics, which hardly show significant variations over the course of centuries or even millennia.[13] On average, there were 15 events every decade in the twentieth century, coming to a total of 205 earthquakes. The approximate parameters of these events are known. Between 1600 and 1900, sources indicate that there were on average five events per decade, coming to a total of 144 earthquakes, instead of the 615 ones if we assume that earthquakes occurred with the same frequency as in the twentieth century. This means that there are no records in the available sources of three fourths of the destructive earthquakes (which would mean 461 events). There are scattered records of earthquakes before 1600, including decades for which there are no indications that there were any earthquakes whatsoever. Between 1000 and 1600, the sources indicate only 57 earthquakes, which would be 4.6% of the 1,230 quakes which probably occurred. There are only three records of three earthquakes from the first millennium. In other words, if one were to rely entirely on these sources, one would conclude that 0.2% of all the earthquakes which occurred in the period of time covered in this discussion took place over the course of this period of 1,000 years (Fig. 1). If, in contrast, we were to make the logical assumption that earthquakes were as common in the first millennium as they were in the twentieth

12 *Earthquake Catalogue.*

13 Bada et al., "Present-day stress field."



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century, we can conclude that the sources make no mention of 99.8% of all earthquakes. Historical observations for 1 to 1900 AD indicate only 5.2 percent of the number of earthquakes which we can assume to have taken place. These are the earthquakes that are listed in the aforementioned catalogues. Calculations of seismic risks are based on these data, as are the hazard maps (Table 1).

Table 1. Known earthquakes and earthquakes assumed to have taken place in the Carpathian-Pannonian region and surroundings. For the area studied see Figure 2.

| Interval | Duration in years | Number of earthquakes assumed to have occurred | Number of earthquakes recorded | Percentage recorded/ occurred |
|---|---|---|---|---|
| 1900–2000 | 100 | 205 | 205 | 100% |
| 1600–1900 | 300 | 615 | 144 | 23% |
| 1000–1600 | 600 | 1,230 | 57 | 4.6% |
| 1–1000 | 1000 | 2,050 | 3 | 0.15% |
| 1–1900 | 1900 | 3,895 | 204 | 5.2% |
| 1–2000 | 2000 | 4,100 | 409 | 10% |

There are various mathematical methods available to assess the seismicity of any region, be it as large[14] or small.[15] The simple arithmetic used in the present study is intended to reveal major gaps in our knowledge and emphasize the importance of further study.

Why do we know so little about past earthquakes of the period before sophisticated instruments were available to detect and measure seismic activity? There are three major factors to be considered. (1) Were any records of earthquakes created at all? (2) Were the records preserved? (3) If a source was created, do we know of it, have we analyzed it, and was it included in the earthquake catalogue?

There are more than 4,000 Roman inscriptions in Pannonia dating to the period between the first and the fifth centuries AD.[16] Most of them were unavailable to Réthly. Roman inscriptions rarely mention earthquakes. Rather, they note completion of construction or reconstruction of a building. Thorough historical and archaeological study of the sites is necessary if we wish to interpret these inscriptions accurately. People of the Early Middle Ages rarely left any written records in the region. Late medieval sources, especially sources found

14 For the Pannonian Basin, see Tóth et al., "Seismic hazard."

15 For the Vienna Basin, see Nasir, "Assessing the completeness."

16 Kovács, "Römische Inschriften."



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in the territory of the Kingdom of Hungary, are substantial, and many of them have either been published in print or are available online. There are about half a million medieval charters of a legal nature. They do not provide much information concerning seismicity. Travelogues, reports by envoys, and geographical and historical handbooks[17] probably provide the most substantial amount of data, if one approaches them with an open mind. Private correspondence, frequent from the sixteenth century onwards, and reports published in foreign journals beginning in the seventeeth century provide a considerable amount of data. It is too easy to rely on the monumental catalogue compiled by Réthly and his successors. One must be aware that his data were gathered up until the late 1910s, and later amendments and additions were made.

Zsíros,[18] who was aware of this deficiency, found a significant number of new sources and added the data he found in them to his catalogue. Additionally, he added geographic coordinates to the sites, assigning intensity and magnitude values to seismic events. His sources are precisely referenced. However, word-by-word citations and especially translations on this scale constitute a task beyond the capabilities of one person. The extent and precision of Zsíros's work is shown by the fact that he identified three times the number of earthquakes (460) identified by Réthly, making note of 1,453 events during the period covered by Grossinger until 1783.

If there were historical records produced, did they survive tumultuous centuries of history in the Carpathian-Pannonian region? Figure 2 shows the maximum extent of Ottoman rule in the sixteenth and seventeenth centuries. This meant severe destruction of life and property due to incessant warfare and robbery. This part of the region also seems to be characterized by a low number of earthquakes (Fig. 2), while there were significantly more to the west and east. Recurring warfare in the sixteenth and seventeenth centuries resulted in the destruction of towns and cultural centers (especially monasteries) and depopulation in general. One third of medieval churches of Pest County are known from archaeological evidence only, because the relevant historical documents were lost.[19] Written records were neither produced nor preserved during this period. No Gothic buildings, ecclesiastic or secular, survived in Buda, which was the medieval capital and royal seat of Hungary. The royal archives and library, the city archives, the royal registries and charters, records of city councils,

17 Csukovits, "Források."

18 Zsíros, *A Kárpát–medence.*

19 Tari, *Pest megye*, 210–14; F. Romhányi, "Medieval ecclesiastical buildings," 259.



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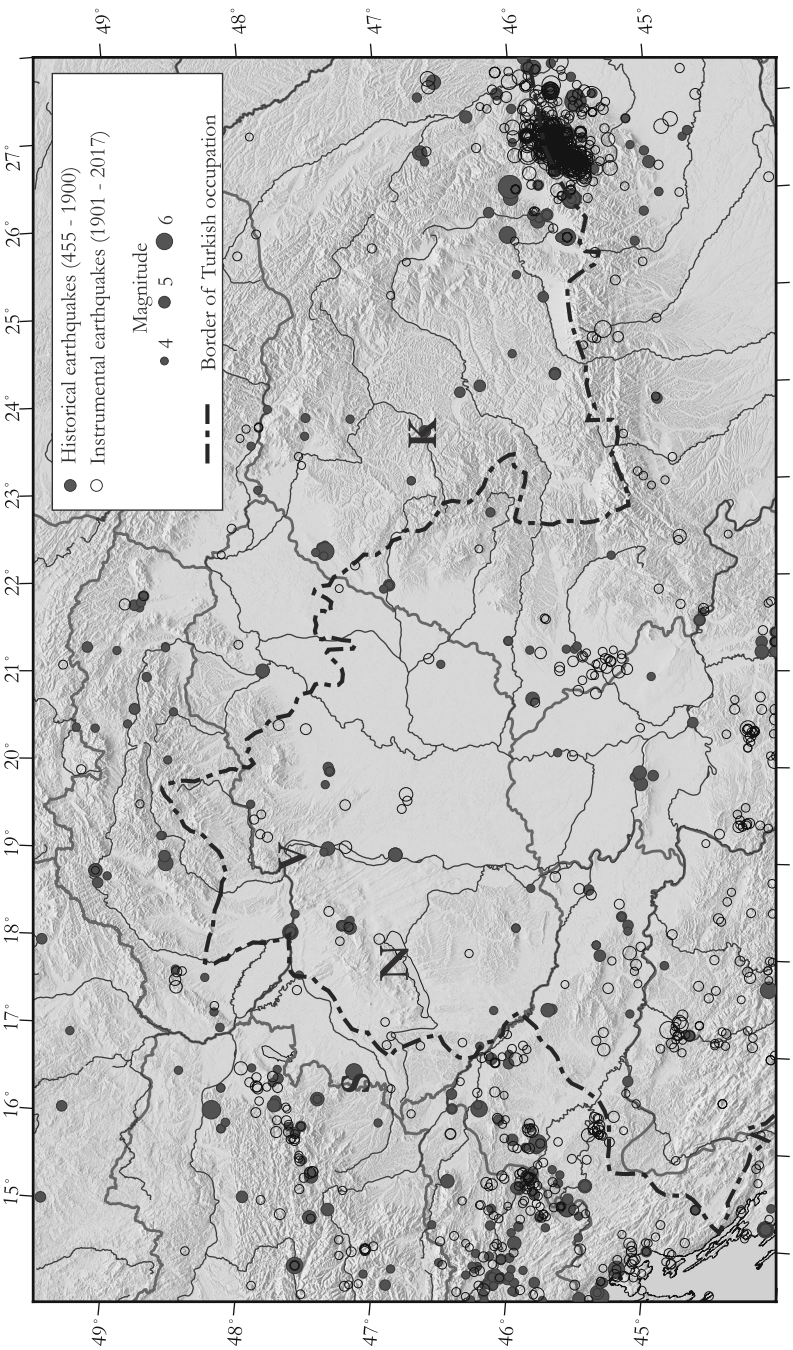


Figure 2. Earthquakes measured using instruments and earthquakes to which there are references in historical sources larger than magnitude 4 in the Carpathian-Pannonian region and surroundings.* One notes the low number of earthquakes in the central part. Is it due to a lack of seismic activity or a lack of historical records? A dotted line marks the largest northern extent of Ottoman rule in the sixteenth and seventeenth centuries.** Recently discovered earthquakes are indicated by capital letters: Nagyvázsony (N), Visegrád (V), and Cluj-Napoca (K). S – Savaria.

* Source: *Earthquake Catalogue.* ** Szalay, *A magyar nemzet.*



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financial records, and private correspondence were all lost due to the wars with the Ottomans.[20] Particularly painful is the loss of *historia domus* records, which were dutifully written and preserved by monks in each monastery. These were major sources of Réthly's studies in other regions. Turkish-language records, written in the Arabic alphabet, are certainly available, waiting to be studied.

When creating Figure 2, we asked whether the Carpathian-Pannonian region was really relatively free of major destructive earthquakes in its center or not. Is it true that there were many major earthquakes in the west and the east but almost none in the center? We cannot offer an answer based on the small number of surviving historical records. Given the methods on which it is based, archaeoseismology may yield a more nuanced understanding of seismic activity in the Carpathian-Pannonian region, and it may well provide significant quantities of new data, irrespective of the historical record. Two examples illustrate this point below.

## *Archaeoseismology*

Archaeoseismology is the study of seismic activity in the past on the basis of archeological sites. It has not yet been used in Hungary. An archaeoseismologist studies archeological excavations and surviving edifices for deformations caused by earthquakes.[21] If one can exclude other causes (foundation problems, damages caused by warfare, etc.),[22] earthquake intensity is assessed, and attempts are made to establish, within a limited framework, the time of earthquake. The nature of the damage helps localize the fault responsible for the shocks(s). This method is a suitable approach to finding corroborating evidence of suspected historical earthquakes (e.g. Savaria)[23] and identifying seismic events unrecorded in historical sources (Visegrád).[24] Additionally, one can assign intensity values to earthquakes, independently from historical records (Buda,[25] Kolozsvár[26]).

Archaeoseismology was essentially invented in Greece as way of explaining layers of collapsed edifices excavated in the palace of Knossos, Crete.[27] The first

20 Zolnay, "A történeti forrásanyag," 30–34.
21 Marco, "Recognition"; Kázmér, "Damage."
22 Ambraseys, *Earthquakes*.
23 Varga, "Magnitude."
24 Kázmér et al., "Tizenhatodik századi."
25 Ibid.
26 Kázmér, "Evidence."
27 Evans, *Minos*; Jones and Stiros, "Advent of archeoseismology"; Jusseret, "Contextualising."



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handbook was published in Athens.[28] Large-scale field surveys[29] were followed by clear essays on methodology in Italy[30] and Spain.[31] Progress is being made in attempts to produce analogue models first and foremost in Portugal,[32] and Germany is in the vanguard in computer analysis.[33] There are examples of widespread use of archaeoseismology in Turkey[34] and Israel[35] and novel studies elsewhere in the Mediterranean region, including Algeria,[36] Tunisia,[37] Libya,[38] Egypt,[39] Jordan,[40] Lebanon,[41] and Syria,[42] to name a few.

The Mediterranean region lies along the collision zone between the European and the African plates, in a so-called plate margin environment, where seismicity is high. Additionally, there are rare but major earthquakes in intraplate environments, far from any plate margin. Archaeoseismology is eminently suitable as an approach to the study of past earthquakes in this region. However, the findings are often met by skepticism. The Lower Rhine Graben, centered around Cologne, was recently identified as possibly the seismically most active region of intraplate Europe, as proven by two millennia of archaeological documentation of past earthquakes.[43] In the Carpathian-Pannonian region, Manfred Kandler, an Austrian archaeologist, was the first to suggest that collapsed walls in the Roman city of Carnuntum near Vienna were destroyed by an earthquake or earthquakes. His ideas were initially rejected, and this prompted him to publish his findings in Hungary.[44] As other studies began to be published supporting[45] and throwing

28 Stiros and Jones, *Archaeoseismology*.

29 Karcz and Kafri, "Evaluation"; Nikonov, "Methodology"; Korjenkov and Mazor, "Seismogenic origin."

30 Galadini et al., "Archaeoseismology."

31 Silva et al., "Archaeoseismic record."

32 Vasconcelos et al., "Experimental investigations."

33 Hinzen et al., "Quantitative methods" for monumental buildings. We appreciate the role of Morais and others "Cyclic behaviour" on using computer models to describe the behavior of vernacular buildings.

34 Akyüz and Altunel, "Geological"; Benjelloun et al., "Construction."

35 Ellenblum et al., "Crusader castle"; Marco, "Earthquake-related damage."

36 Roumane and Ayadi, "Archaeoseismology."

37 Bahrouni et al., "Historical"; Kázmér, "Why seismic hazard."

38 Bacchielli, "Cyrenaica earthquake."

39 Karakhanian et al., "Archaeoseimological studies."

40 Al-Tawalbeh et al., "Archaeoseismic analysis."

41 Lewis, "Baalbek."

42 Meghraoui et al., "Evidence"; Kázmér and Major, "Distinguishing damages"; Kázmér and Major, "Safita castle."

43 Reicherter et al., "Aquisgrani terrae"; Hinzen et al., "Archeoseismic study."

44 Kandler, "Erdbebenkatastrophe."

45 Decker et al., "Earthquake of Carnuntum."



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into question his contentions,[46] his views gained some acceptance. Recently, an international conference was organized dedicated to the Carnuntum earthquake of the 4th century AD.[47]

There are a few promising initiatives elsewhere in the Carpathian-Pannonian region. A large portion of the Roman city wall in Siscia (modern Sisak in Croatia) lies, collapsed, several meters from the foundation.[48] Damage observed to St. Michael's Church in Cluj-Napoca (in Transylvania, Romania) indicates an earthquake of intensity IX, far larger than anything suspected before.[49] Major subsidence in the floor of the Franciscan monastery at Visegrád indicates that there was a major earthquake, causing liquefaction, at some point between 1513 and 1540. Both the monastery and the adjacent church were ruined.[50] Using numerical techniques to model the process of deformation and damage, we

Figure 3. Uneven subsidence of a Roman road in Savaria. This kind of deformation is often caused by seismically induced liquefaction of the subsoil. Szombathely, Roman garden. #2156

46 E.g. Hammerl et al., "Carnuntum case."
47 Konecny et al., *Carnuntiner Erdbeben.*
48 Skrgulja and Kázmér, "Deformed Roman monuments."
49 Kázmér, "Evidence for earthquake."
50 Kázmér et al., "Tizenhatodik századi."



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arrive at data on the energy released,[51] and we can draw conclusions as to whether the damage was caused by a sudden, seismic shock or continuous loading.[52]

Preliminary information is given on two sites to show that archaeoseismological research is possible and desirable in Hungary. A Roman road in Savaria (modern Szombathely) shows asymmetric subsidence which may be attributable to seismic activity (Fig. 3): a person or a horse-drawn cart could not move or stand on the 1.5-meter wide tilted edge of the road. This kind of deformation seems a prime example of uneven subsidence caused by seismic-generated liquefaction. A minor trench or a hand boring might reveal sandy subsoil to corroborate the presence of liquefiable sand. Stairs of the spiral staircase from the fifteenth-century donjon in Nagyvázsony were displaced by roughly 4 cm, obviously caused by lateral loading, possibly due to an earthquake (Fig. 4).

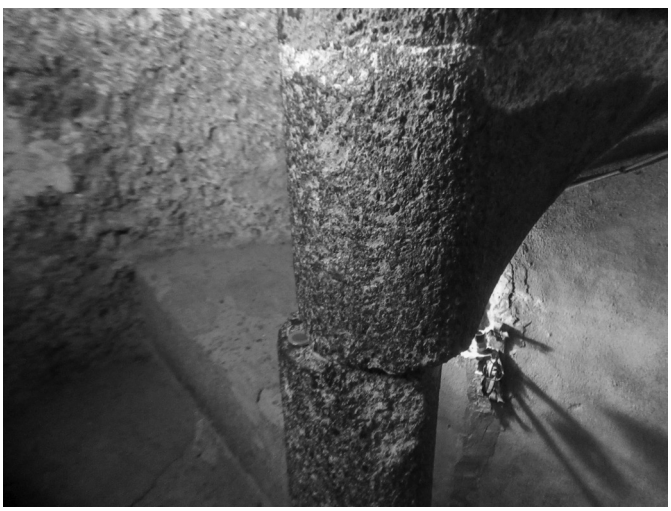

Figure 4. Displaced steps of the spiral staircase in Nagyvázsony donjon. A coin with a diameter of 24 mm for scale. #0376

Historical seismology is like a large-resolution snapshot: a single event is documented in great detail. An earthquake which took place in 1202 AD in the Middle East, which was the largest earthquake known to have taken place there, offers an example of a dramatic seismic event which has been thoroughly studied. It was recorded at more than hundred sites within a circle with a radius

51 Morais et al., "Preliminary estimation."

52 Besharatinezhad et al., "Modelling."



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of 500 km.[53] Later, the fault responsible was identified in Mount Lebanon.[54] The more snapshots we have, the more accurate our hazard assessment.

Archaeoseismology is like a deep borehole: a single site might record successive construction-destruction-reconstruction events over the course of centuries. Although recurrent episodes of damage to the same edifice are not easy to recognize and date, a few promising results are available. For instance, the crusader fortress of Al-Marqab on the coast of Syria,[55] the Roman theater in Capitolias (modern Beit-Ras in Jordan),[56] and the Byzantine dead city of Umm al-Jimal (also in Jordan) each offer evidence of at least two successive seismic events. While dating is still ambiguous at the Jordanian sites, we find evidence for reconstruction after the first earthquake and abandonment after the second event. Usually, historical sources and archaeoseismology work hand-in-hand, especially when dating is considered.

## *Summary*

Earthquake hazard can be reliably assessed only if we are aware of past seismicity. The relatively small number of seismic events and long return period of major earthquakes make it necessary to use historical data in seismic hazard assessment. However, the lack of documentary data in the central region of the Carpathian-Pannonian region makes this a challenging task. This area practically coincides with the maximum extent of two centuries of Ottoman rule in the sixteenth and seventeenth centuries. An arithmetic assessment suggests that we have no record of 90 percent of the destructive earthquakes which, in all likelihood, occurred in the Carpathian-Pannonian region over the course of the past two millennia.

We suggest that, by using archaeoseismology, we can contribute previously unknown data to this discussion. Damage caused by earthquakes can be recognized, and earthquake parameters can be assessed. Preliminary studies identified previously unknown seismic events (Visegrád) and assigned intensity values to historical records. The damage observed on a Roman road in Savaria and in the medieval donjon of Nagyvázsony offer two examples of the potentials of archaeoseismology. Renewed extensive study of historical sources and the

53 Ambraseys and Melville, "Analysis."

54 Daeron et al., "Sources."

55 Kázmér and Major, "Distinguishing damages."

56 Al-Tawalbeh et al., „Two inferred Antique earthquakes."



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further use of archaeoseismological investigation are needed if we seek to arrive at a nuanced understanding of seismic hazard in the Carpathian-Pannonian region.

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