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CONTENT INHALT

Liebe Leserin, lieber Leser!

Die vorliegende Publikation dokumentiert die Beiträge der gleichnamigen Tagung des NKA Projektprograms, die am 25. und 26. November 2021 in Iseum Savariense in Szombathely stattfand.

Archäologie ist ein wichtiges Thema in der integrierten Stadtentwicklung. Die aktuellen Grabungen in den antiken Städten, wie in Savaria, Scarbantia, Carnuntum, Arrabona, Aquincum, Brigetio, Sirmium, Mursa, Aelium Cetium, Napoca etc. belegen dies eindrucksvoll. "Die Stadt unter der Stadt" stößt auf ein immer größer werdendes Interesse bei Bewohnern, aber auch bei Besuchern. Die Themen dieses Bandes beschäftigen sich mit den neuesten Grabungsergebnissen, methodischen Problemen rund um das Thema „Bewahren und Präsentieren" in der Stadtarchäologie hauptsächlich in der Provinz Pannonien. Bei den Vorträgen geht es nicht nur um die Ergebnisse der archäologischen Ausgrabungen, sondern auch die Ausgrabungsmethodik und verschiedene Ausgrabungstechniken. In den letzten Jahren wurden großflächig geophysikalische Untersuchungen von antiken Siedlungen und deren Umgebung durchgeführt. Die Ergebnisse dieser Forschungen tragen dazu bei, die räumliche Struktur und Landnutzung antiker Städte besser zu verstehen.

Die archäologischen Relikte in den modernen Städten werden zunehmend Bestandteil von Umbau- und Neubaumaßnahmen und als "Fenster in die Vergangenheit" inszeniert. Im öffentlichen Raum weisen neue Wegführungen, archäologische Pfade, Pflasterungen und Informationstafeln auf das archäologische Erbe hin.

Der Weg dahin ist nach wie vor steinig: In der öffentlichen und vor allem in der Investorenwahrnehmung gelten Grabungen als schwer kalkulierbares Hemmnis. Die Integration der Funde in zukünftige Projekte gilt als wertmindernd. Das muss nicht sein: Auf der Basis der archäologischen Bestandserfassung können die Innenstädte planerisch und gestalterisch sinnvoll weiterentwickelt und Orts- und Stadtbilder erhalten werden. Entscheidend ist das gemeinsame Handeln!

Savaria – Szombathely, April 2022

Andrea Csapláros
Museumdirektorin
Savaria Museum

Late Roman earthquake in Brigetio?

*Linda Dobosi**
*Miklós Kázmér***

Archaeological evidence at the Komárom/Szőny-Vásártér site in Hungary raised the question of a late Roman earthquake in the civil town of Brigetio, which was investigated by means of archaeoseismology. Modern research excavations at the site were carried out between 1992–2016 uncovering about 3000 m^2 in the centre of the former Roman settlement. Through the detailed study of the documentation made during the excavations, such as maps, drawings, photographs, and field notes evidence for suspected seismic damage was collected from the site. The deformed structures were then compared to similar structures distorted by known earthquakes from published archaeological sites. Using pottery and coins as the basis of dating, an earthquake some time after the middle of the 3rd century A.D. and before the early 4th century was identified. In the absence of standing wall structures, the intensity of the earthquake was estimated using the ESI-07 environmental seismic scale: an intensity IX event is suggested. Historical and archaeological data about earthquakes in the territory of Roman Pannonia indicate that earthquake-induced damage is to be expected at other archaeological sites as well.

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I. Introduction

Recent earthquakes in Croatia, the Zagreb earthquake on 22nd March 2020, and the Petrinja earthquake on 29th December 2020, causing damage to the Archaeology Museum in Zagreb and in the Sisak City Museum, respectively, are warning signs that earthquakes can affect any archaeological site in Pannonia. This is especially true, if a location has already been hit by an earthquake in the past. Therefore, it is important to collect all data available about past earthquakes, which is the key in assessing the earthquake hazard of a site.

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Geologically, Roman Pannonia is situated in the western half of the so-called Pannonian Region, which includes the Pannonian Basin and surrounding orogens. Seismic activity in this tectonically complex area is basically caused by the northward movement and counterclockwise rotation of the Adriatic microplate relative to Europe.[1] The peripherals of the Pannonian Basin, the Eastern Alps and Dinaredes are seismically more active areas than the Pannonian Basin itself, where seismicity can be described as moderate ***(Fig. 1)***. This means, that earthquakes are not frequent in the Pannonian Basin, however, occurring earthquakes can still be strong, magnitude M 6.0–6.5 events.[2] Most active in the Dinaric area is the Medvednica zone near Zagreb, and in the Eastern Alps, the Mur–Mürz–Zilina line crossing the Vienna Basin.[3]

An extensive catalogue of past earthquakes based on historical data shows, that our knowledge about past earthquakes diminishes as we go back in time and written sources become scarce ***(Fig. 2)***.[4] The set of historical data, however, can be effectively supplemented by evidence collected from archaeological sites. The study of earthquake damage caused on historical or ancient buildings falls within the scope of archaeoseismology.

After scrutinizing the remains for deformations in the different structures (floor, wall, etc.), the archaeoseismologist has to exclude other causes for the damage before conclusively stating that it was caused by an earthquake.[5] Although earthquake damage is not straight-forward to identify, there is an established comprehensive classification of earthquake effects in archaeological sites ***(Fig. 3)***.[6]

II. Major earthquakes in the territory of Roman Pannonia (4th – 21st century A.D.)

According to different written sources, more than 20 settlements in the territory of Roman Pannonia were affected by strong earthquakes around or above magnitude M 5.0 between the late Roman times and the present, roughly half of them in present-day Croatia ***(Fig. 4)***. Earthquakes listed here were collected from the historical earthquake catalogues of Hungary, Austria, Slovenia, and Croatia.[7] This data is supplemented by three unmentioned late Roman earthquakes that were discovered through archaeoseismology.

The first earthquake known from historical records in Hungary is the Savaria (Szombathely) earthquake on 7th September 455 (or 456) mentioned in the Annales Ravennates. It is estimated to have had a magnitude of M 6.5.[8]

1 Tóth et alii 2002, 9.
2 Tóth et alii 2002, 12.
3 Tóth et alii 2002, 12.
4 Kázmér – Győri 2020, 284–291.
5 Kázmér – Győri 2020, 291; Kázmér 2015, 501.
6 Kázmér 2015, 501; Rodríguez-Pascua et alii 2011, 20.
7 No earthquakes were found in Serbia or Bosnia Herzegovina that fit these criteria.
8 Varga 2017, 2; Varga 2019, 207–209; Tóth 2014.

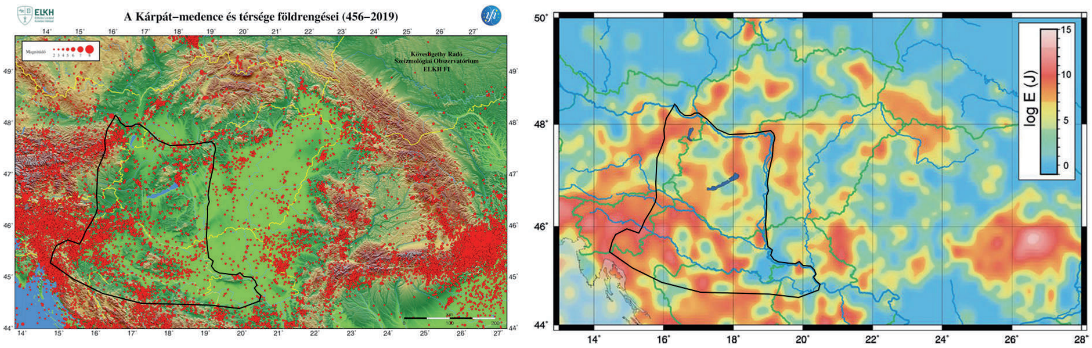

Fig. 1.
Map of seismic activity in the Pannonian Region. The outline of Pannonia province in black. ***a,*** *Earthquakes in the Pannonian Region between 456-2019 (Kövesligethy Radó Szeizmológiai Obszervatórium, http://www.seismology.hu/index.php/hu/szeizmicitas).* ***b,*** *Spatial distribution of the total seismic energy release in the Pannonian region. The darker the area, the more seismic energy was released (Tóth et alii 2002, Fig. 4.)*

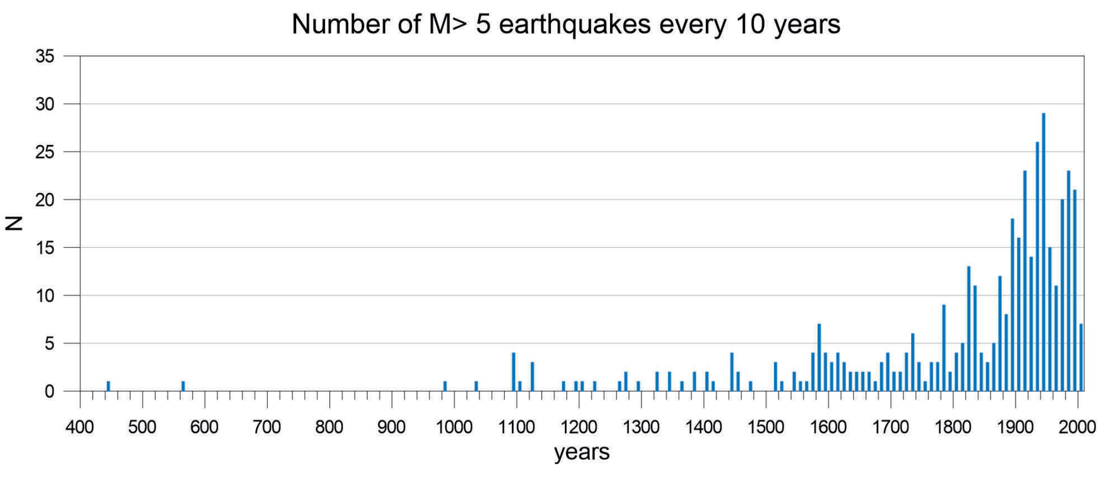

Fig. 2.
Number of known earthquakes in the Carpathian-Pannonian region and surroundings in the past two millennia. In the 20th century 100% of magnitude 5 and larger events are known. In the 17–19th century about 23% are on record. Only 4.6% are known from the 11–16th century, while practically none from the first millennium. Altogether, we have no information about 90% of the destructive earthquakes which occurred during the past two millennia (Kázmér – Győri 2020, Fig. 1.)

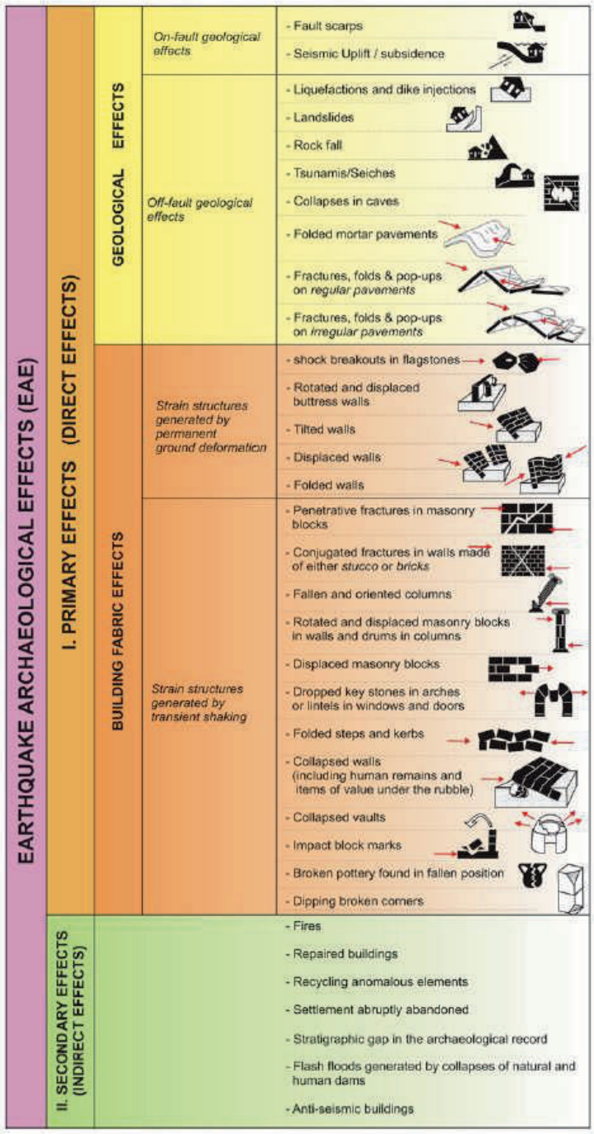

Fig. 3.
A comprehensive classification of Earthquake Archaeological Effects
(Rodríguez-Pascua et alii 2011, Fig. 2)

Several earthquakes occurred in Buda during the 15th and 16th centuries: the earthquake of 21st August 1541 happened at the same time as a solar eclipse.[9] This earthquake was probably responsible for the damage caused to several buildings in Visegrád.[10] Twenty years later, in February 1561 an earthquake was felt in Buda, Pest, Esztergom, Székesfehérvár, etc.[11] Another earthquake is mentioned from 1641, when a bastion of the Buda castle fell down.[12] After several centuries of stillness two earthquakes in the 20th century caused again building damages in Buda: on 11th December 1947 and 28th March 1948.[13]

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9 Varga 2017, 7.
10 Kázmér et alii 2021a.
11 Varga 2017, 7. It is listed as an M 5.6 earthquake in Tóth et alii 2002, 19.
12 Varga 2017, 9.
13 Varga 2017, 9.

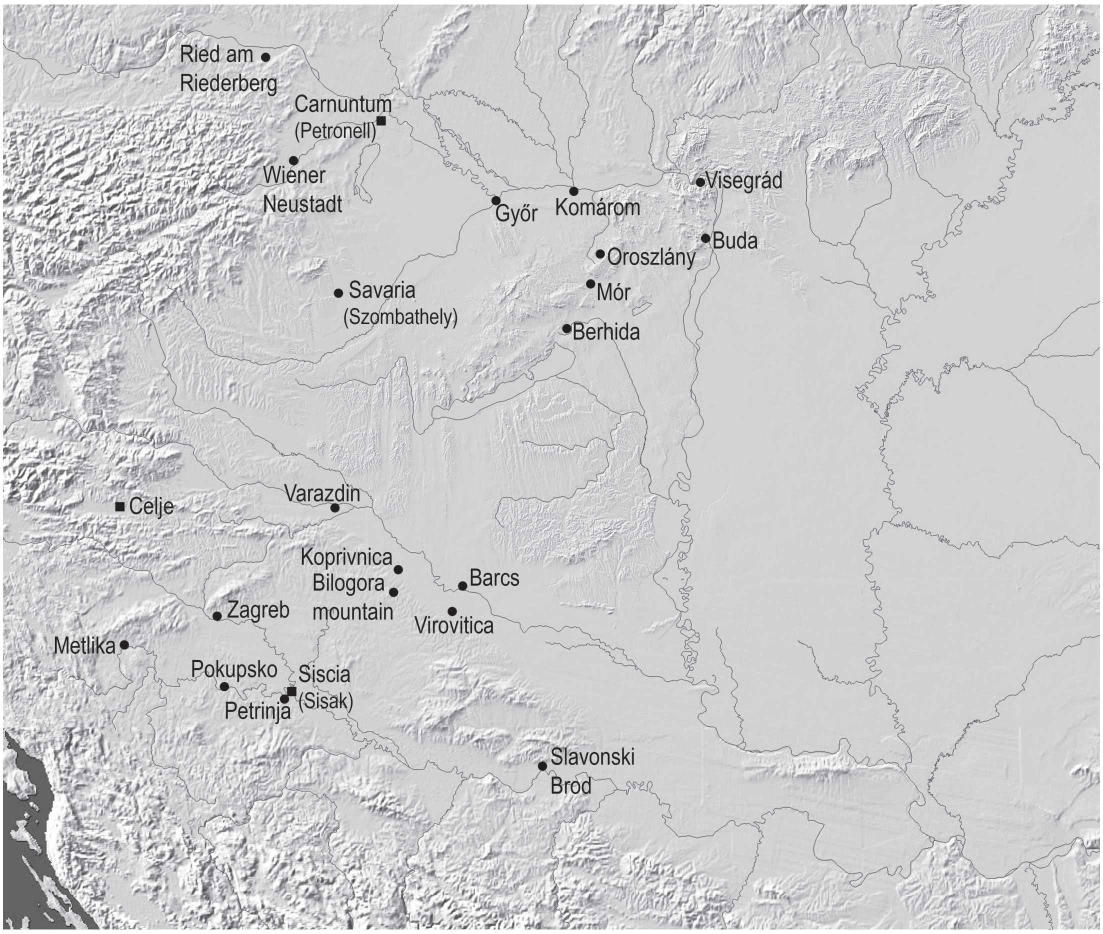

Fig. 4.
Location of historical and archaeological earthquakes in the territory of Roman Pannonia (blank map: B. Holl)

The most destructive earthquake in the Pannonian Basin, the so-called Komárom earthquake (M 6.3) occurred in the vicinity of Komárom and Győr on 28th June 1763 and was followed by more than 80 aftershocks in the next 10 months. The earthquake was felt as far as Leipzig, Dresden, and Beograd and caused 200–300 deaths in Komárom. Building damages were reported in a c. 25 km radius area. The event was preceded by smaller earthquakes in 1599, 1754, 1757, 1759, and probably several others, from which the 1599 earthquake had an estimated magnitude of M 5.6.[14]

Two other earthquakes not far from Komárom were registered later: an M 5.2 earthquake in Mór (40 km from Komárom) on 1th January 1810[15] and an M 4.5 one in Oroszlány on 29th January 2011. South of these was the epicentre of the Berhida earthquake of 15th August 1985, which had a magnitude of M 4.9.[16]

14 Varga 2014; Varga et alii 2021; Zsíros 2004, 121.
15 Zsíros 2004, 130.
16 Zsíros 2004, 130.

The only earthquakes from Austria relevant to our study are the so-called Neulengbach earthquake, and two earthquakes in Wiener Neustadt. The epicentre of the Neulengbach earthquake is estimated to have been in Ried am Riederberg near the border of Roman Pannonia and Noricum. This was the strongest known earthquake in Austria and took place on 15th September 1590.[17] The earthquakes in Wiener Neustadt were smaller: the one on 27th February 1768 was around M 5.0, and the other on 13th July 1841 M 4.0.[18]

In the territory of Roman Pannonia, the Medvednica–Zagreb area was affected by the highest number of strong earthquakes. Repeated earthquakes caused damage to the buildings of Zagreb and its surroundings from the 18th century: on 13th October 1775, on 9th November 1880, on 17th December 1905, on 2nd January 1906[19] and again on 22nd March 2020.

In the epicentral area of Pokuplje, less than 50 km to the south, lay the epicentre of the M 6.2 Petrinja earthquake of 29th December 2020.[20] In the same area, near the border of Roman Pannonia and Dalmatia another earthquake hit Pokupsko on 18th December 1861.[21] To the northeast, on the border of Croatia and Slovenia a strong earthquake shook Metlika (Slovenia) on 11th February 1699.[22]

Near Varaždin an earthquake might have occurred in 1459 and another caused damage on 20th June 1974 in several places, including Celje.[23] Along the Drava River on both the Croatian and the Hungarian side of the border several earthquakes occurred near Bilogora. Apart from the Bilogora earthquake on 27th March 1938, another took place in Koprivnica on 25th May 1694 then again on 8th November 1778, and near Virovitica on 8th July 1757. On the Hungarian side Barcs was hit by smaller earthquakes twice: on 12th July 1836 and later in 1927.[24] Southeast from this area, along the Sava River an M 5.6 earthquake shook Slavonski Brod on 13th April 1964.[25]

Besides the earthquakes known from historical records, three earthquakes from 4th-century Roman Pannonia are attested by exclusively archaeoseismological methods: in Carnuntum and in Siscia. The question of a mid-fourth-century Carnuntum earthquake arose already in the late 1980s, when M. Kandler collected earthquake-induced damages from the Carnuntum excavations.[26] The earthquake caused two types of damages: 1, toppled walls broken off from their intact foundations along horizontal lines could be observed in the legionary camp, the *canabae* and the civil town of Carnuntum, as well as in the Bruckneudorf and Stupava *villae rusticae*. 2, A broken and displaced foundation was found in the bathhouse of

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17 Hammerl 2017, 2. It had an estimated magnitude of M 5.75 according to Hammerl 2017, 2. or M 6.3 according to Tóth et alii 2002, 20.

18 Hammerl 2017, 4. The 1768 earthquake is listed as M 5.6 in Tóth et alii 2002, 20.

19 Herak et alii 2009, 215.

20 Markušić et alii 2021.

21 Herak et alii 2009, 215.

22 Herak et alii 2009, 215; Atanackov et alii 2021, 4; Tóth et alii 2002, 20.

23 Herak et alii 2009, 217.

24 Herak et alii 2009, 217.

25 Tóth et alii 2002, 22.

26 Kandler 1989.

the auxiliary camp.[27] In recent years new evidence came up and suggested that in the 4th century two earthquakes took place: the first, weaker earthquake can be dated to after 333 A.D., while the stronger one to after 348 A.D.[28] or maybe shortly after 360.[29] The earthquakes were followed by intensive rebuilding in the civil town in the second half of the 4th century.[30]

Archaeological evidence shows that an earthquake hit Siscia as well, sometime between the second half of the 3rd century and the beginning of the 5th century A.D. The toppled and rebuilt city wall of Siscia was found in the 2000s at the archaeological site next to the 18th-century St. Quirinus church in Sisak (Croatia). The first wall built during the Severan dynasty was made of bricks with a width of 1.2–2.0 m. After its collapse the city wall was rebuilt in the late Roman times. An earthquake able to destroy such a massive city wall must have been a major, intensity IX earthquake. This event was almost certainly larger than the adjacent Petrinja M 6.2 earthquake in 2020.[31]

Celeia also suffered an intensity VII-IX seismic event in Late Roman times.[32]

In summary, a large number of settlements or sites in the territory of Roman Pannonia are known to have been affected by earthquakes in the past. Although some areas are more prone to earthquakes than others, the discovery of earthquake-induced damages should not come as a surprise at most archaeological sites in Pannonia.

Archaeoseismology. Signs of earthquakes on archaeological sites and more?

Destruction horizons are not easy to attribute to natural or man-made causes or simply to the neglect or abandonment of buildings.[33] A *deus ex machina* attribution is often invited as an explanation: earthquake,[34] either with or without further justification. As there is no handbook of archaeoseismology written yet (except the classic volume of S. Stiros and R.E. Jones),[35] one has to turn to various articles to learn about methods[36] and for the features earthquakes leave behind in archaeological objects: for walls,[37] for floors,[38] for whole buildings, standing[39] or ruined.[40]

27 Decker et alii 2006, 483–485.
28 Maschek 2019, 73.
29 Konecny 2021, 12.
30 Maschek 2019, 75.
31 Kázmér – Škrgulja 2021.
32 Kázmér et alii 2021b.
33 Driessen 2013.
34 Sintubin et alii 2011.
35 Stiros – Jones 1996.
36 Galadini et alii 2006.
37 Marco 2008; Kázmér 2015.
38 Bottari et alii 2008.
39 Karakhanian et alii 2008; Kázmér – Major 2015.
40 Korjenkov – Mazor 2003.

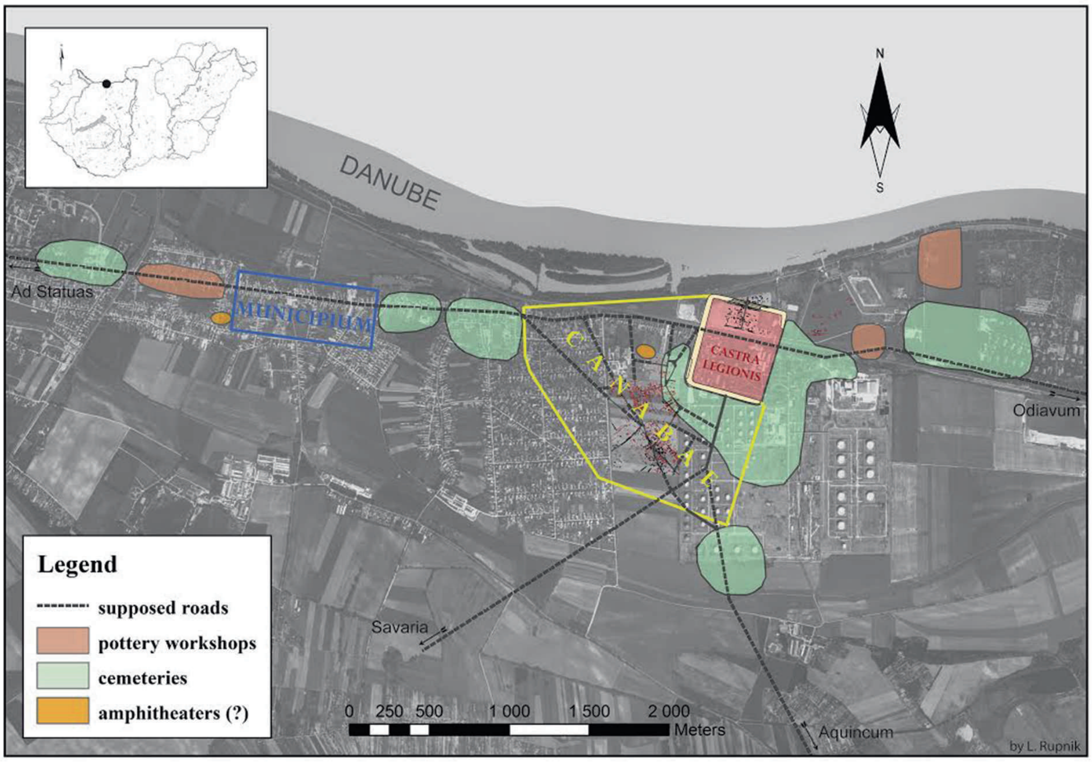

Fig. 5.
Location and topography of Roman Brigetio (drawing: L. Rupnik)

The essence of archaeoseismological studies is the search for anomalies: for deviations from the normal, everyday tear and wear of man-made constructions. Buildings are usually designed to bear static vertical loads of walls, floors, and roofs. Lateral, horizontal displacement of masonry blocks and walls, either in-plane or out-of-plane, raises the suspicion of lateral loading, caused by earthquake shaking. In-plane shaking also allows arch keystones to drop (vertical displacement). Vertical vibration causes masonry blocks to be fractured due to pounding by overlying blocks. Walls tend to be broken, torn, twisted, and finally collapsed following specific patterns.[41]

Earthquake-damaged buildings are rebuilt by society, if there is need, and sufficient funds and manpower available. This results in annihilation of traces of past seismic events. However, careful analysis of building stratigraphy[42] can yield spectacular evidence for destructive earthquakes, for example the Roman theatre of Capitolias in Jordan, which preserved evidence for two events.[43] Where stone masonry was robbed, one can still rely on deformed floors.

Beyond providing reliable evidence for past earthquakes damaging or destructing an archaeological site, archaeoseismology makes earthquake catalogues richer by inserting previously unknown events, gives numerical data on in-

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41 Rodríguez-Pascua et alii 2011.
42 Gilento 2020.
43 Al-Tawalbeh et alii 2021.

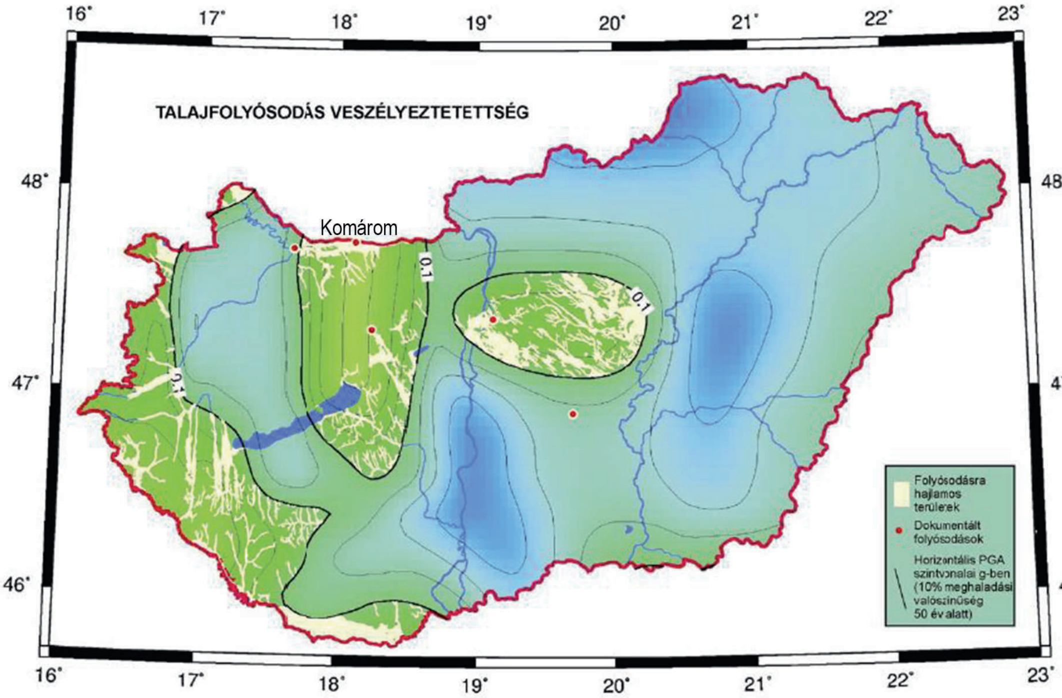

Fig. 6.
*High risk areas concerning soil liquefaction (*Győri et alii *2004, 7. ábra)*

tensity of shaking,[44] offers arguments to determine direction of main shock,[45] and to find the fault responsible for destruction.[46]

III. The case of Brigetio

Roman Brigetio lay along the Danube limes, under present-day Komárom, Hungary. The settlement complex consisted of three parts: the *castra legionis* (legionary fortress), the *canabae* (military town) and the *municipium* (civil town) ***(Fig. 5)***. Modern archaeological research concentrated on the area of the civil town between 1992–2016, where excavations were carried out at the so-called Komárom/Szőny-Vásártér site.[47] According to the results of the archaeological research, the civil town was founded at the turn of the 1st and 2nd centuries A.D. and was left by its inhabitants in the second half of the 3rd century A.D. for an unknown reason.[48] Roman age cultural layers at the site lie only about 0.2–0.5 m below the present-day ground level.

44 Rodríguez-Pascua et alii 2013.
45 Hinzen et alii 2016.
46 Kázmér – Major 2015.
47 Excavations were led by László Borhy (Member of the Hungarian Academy of Science, rector of Eötvös Loránd University) and Emese Számadó (director of the Klapka György Museum of Komárom).
48 For more about the civil town see Dobosi 2022 in this volume.

The detailed study of the documentation made during the excavations, such as maps, drawings, photographs, and field notes attracted our attention to deformed structures at the archaeological site. Their interpretation by comparing them to published archaeological sites damaged by known earthquakes allowed recognition of suspect seismic damage. The possibility of finding earthquake-induced damages at the Komárom/Szőny-Vásártér site came as no surprise, since the area of Brigetio, i.e. the modern settlement of Szőny or Ó-Szőny (today part of Komárom, Hungary) is known to be prone to earthquakes.[49] Substantial damage was reported from Szőny after the 28th June 1763, caused to ecclesiastical buildings, noble residences and taxpayer houses by the big Komárom earthquake.[50] Concerning the soil liquefaction effect of earthquakes, Komárom lies in a high risk area (*Fig. 6*).[51]

Located on the bank of the Danube and surrounded by water on three sides *(Fig. 7)*, the Roman town of Brigetio was built on the higher floodplain of the Danube River, on a Pleistocene gravel terrace. The settlement stood at 110–113 m altitude above sea level, while the average river flow was at about 105 m. Large floods of the river could raise the water level by several metres a few times per year. Because of this, Brigetio was naturally susceptible to the liquefaction of its subsoil.[52] The M 6.3 Komárom earthquake in 1763 produced fountains in the Danube and sand volcanoes on land north of the Danube.[53]

Brigetio has no surviving upright walls, therefore the classical archaeoseismological methods, based on the analysis of deformed masonry[54] cannot be applied. Fortunately, floors can preserve deformed features, as seen at various Mediterranean sites, which inform us on processes affecting the ground in the past millennia.[55]

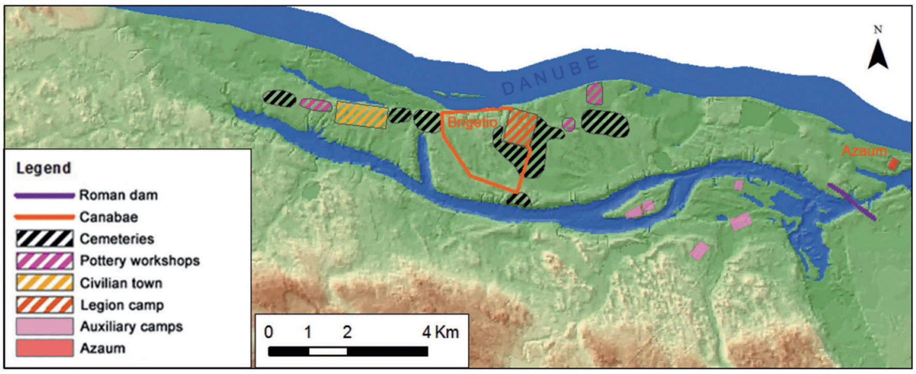

Fig. 7.
Environmental reconstruction of Roman Brigetio (VICZIÁN ET ALII 2013, Fig. 6)

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49 ZSÍROS 2004; VARGA ET ALII 2021.
50 VARGA ET ALII 2021, 8.
51 GYŐRI ET ALII 2004, 124.
52 VICZIÁN ET ALII 2013.
53 VARGA ET ALII 2021.
54 STIROS 1996; MARCO 2008; KÁZMÉR 2015.
55 For example: KARABACAK 2016; APOSTOLOPOULOS ET ALII 2015; FANDI 2018; BOTTARI ET ALII 2008; RODRÍGUEZ-PASCUA ET ALII 2016.

At the Komárom/Szőny-Vásártér site, in the Roman civil town of Brigetio, the following anomalous features were observed ***(Fig. 8)***: 1, liquefaction-caused depressions (nr. 1–4) 2, broken and displaced foundation wall (nr. 5) 3, toppled adobe walls (nr. 6–8) 4, diagonal fractures in wall painting (nr. 9) 5, flame-like features of liquefied sand (nr. 10) 6, wall collapsed and slid into cellar (nr. 11). Some of them are decisive evidence of a one-time earthquake in Brigetio, like the liquefaction-caused depressions, the broken foundation wall, or the flame-like structures in the subsoil (nr. 1–5 and 10), and some make weaker evidence, but fit in well in the overall image, like the toppled adobe walls (nr. 6–9 and 11).

III.1. Liquefaction-caused depressions (nr. 1–4)

A row of circular depressions was documented in the area of Street A, the bakery and the large, representative Room I/4 in House I/b ***(Fig. 9–12)***. One of the four depressions deformed the surface of Street A, while the other three distorted the terrazzo floor and the hypocaust heating channel of Room I/4.

The surface of the so-called Street A, which was subject to uneven subsidence, was paved with flagstones in the first half of the 3rd century A.D., when the bakery itself was built.[56] The lowest point of the depression was a little south of the bakery entrance ***(Fig. 9–10)***. Not only the road surface was affected, but the oven floor also slopes to the east. While some of the plaster remained in situ on the tilted wall of the bakery, most of it slid down onto the surface of the flagstones, painted side up. The average level of the flagstones was around 110.75–110.80 m above sea level, but it dropped to 110.32 m in the deepest point.

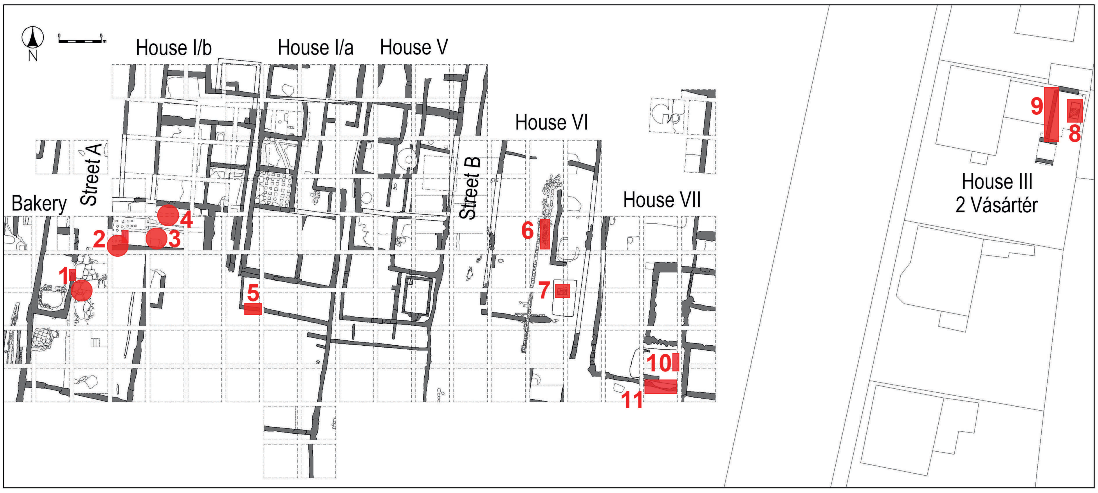

Fig. 8.

*Location of earthquake-induced damages: **1-4.** liquefaction-caused depressions, **5.** broken and displaced foundation wall, **6-8.** toppled adobe walls, **9.** diagonal fractures in wall painting, **10.** flame-like features of liquefied sand, **11.** wall collapsed and slid into cellar (drawing: L. Dobosi)*

56 For more about Street A, the bakery, and dating problems see Dobosi 2022 in this volume.

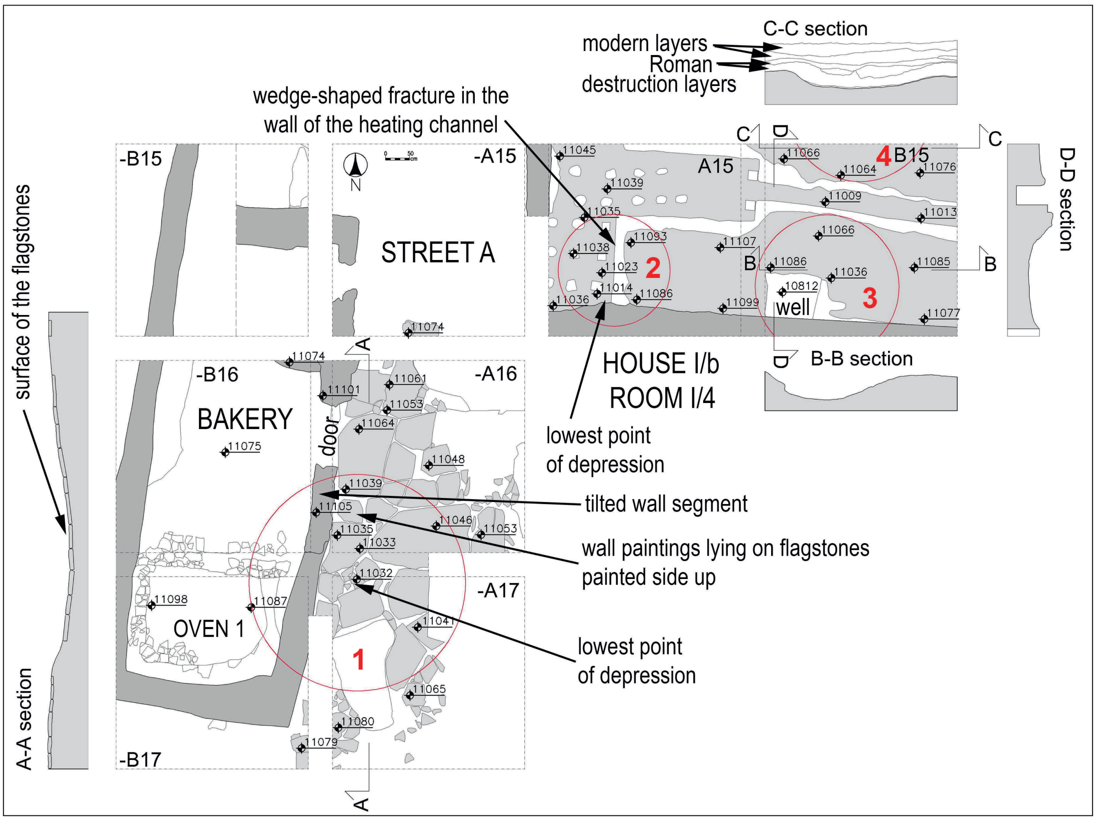

Fig. 9.
Location of the liquefaction-caused depressions (drawing: L. Dobosi)

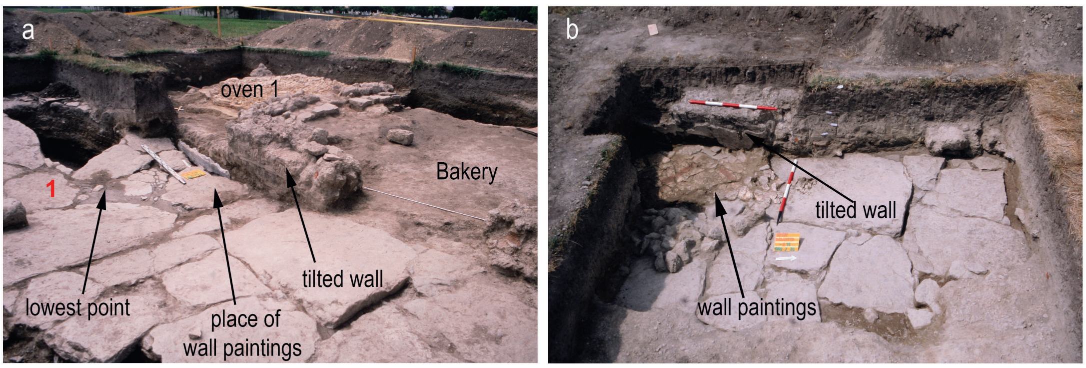

Fig. 10.
Liquefaction-caused depression in Street A (nr. 1). ***a,*** *There is about 40 cm difference in elevation between the highest and lowest points of this flagstone-covered road. There is a tilted wall adjacent to it.* ***b,*** *Depression on a flagstone-paved road. Large fragments of wall painting separated from tilted wall, and fell to the road surface painted side up. This is also an evidence for earthquake-induced shaking (Photos: L. Borhy)*

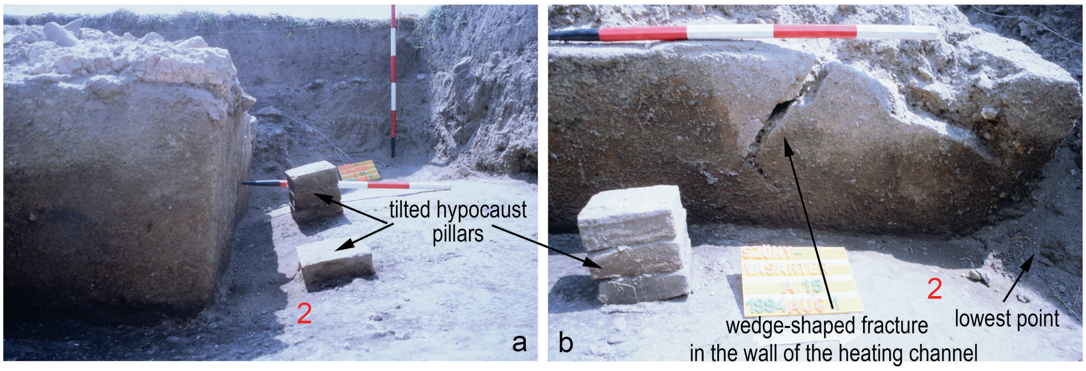

Fig. 11.

Liquefaction-caused depression in the terrazzo floor of the hypocaust heating channel in Room I/4 (nr. 2). ***a,*** *Deformed floor of hypocaust with the brick hypocaust pillars tilted to the left. The dimension rod marks the horizontal direction.* ***b,*** *The wedge-shaped fracture in the wall of the hypocaust heating channel marks uneven settlement (photos: L. Borhy)*

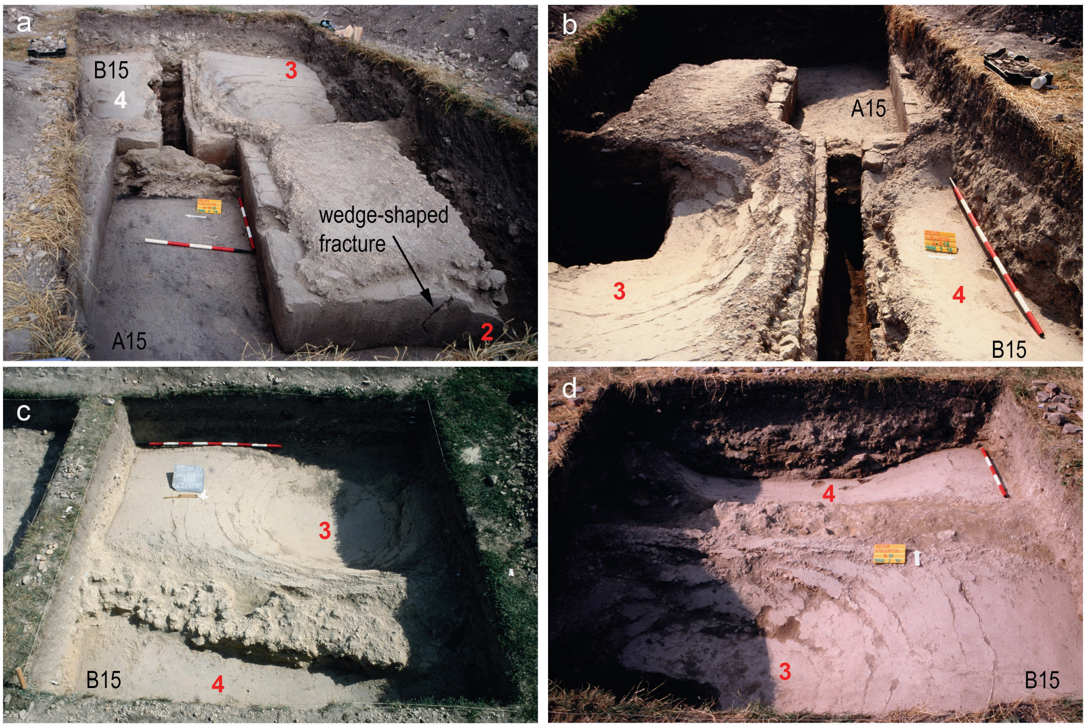

Fig. 12.

Two liquefaction-caused depressions in the terrazzo floor of Room I/4 (nr. 3–4), on either side of the hypocaust heating channel. ***a****, The wedge-shaped fracture in the forefront was caused by depression nr. 2 deforming the hypocaust floor.* ***b–d,*** *Depression nr. 3 measures 3.0 m in diameter and is 0.5 m deep. The concentric fractures formed during subsidence (photos: L. Borhy)*

Fig. 13.
Wall broken and displaced downwards by 0.2 m due to uneven settlement. ***a,*** *wall from the north* ***b,*** *wall from the south (photos: L. Borhy)*

A little to the north, three crater-like depressions were found in Room I/4 of House I/b ***(Fig. 9, 11–12)***. The most spectacular feature (nr. 3) is an oval depression with a diameter of roughly 3 m, and a depth of 0.5 m ***(Fig. 9, 12)***. Its volume measures appr. 1.2 m^3. The western side of its wall is almost vertical, while the eastern side is gently sloping towards the centre. The uppermost layer of the terrazzo is 0.15 m thick, dissected by a set of concentric fractures. Under the terrazzo floor the remains of an earlier wooden structure, a rectangular well was found, which was probably filled just before Room I/4 was built in the first half of the 3rd century AD.[57] On the other side of the heating canal, in the northeastern corner of the room, another, less regular depression can be seen (nr. 4, ***Fig. 9, 12***). Its depth measures about 0.3 m. The third depression in Room I/4 distorted the terrazzo floor of the hypocaust heating channel in the southwestern corner of the room (nr. 2, ***Fig. 9, 11***). The floor visibly slopes to the east and south, and the in situ hypocaust pillars made of brick are tilted. The eastern wall of the heating channel is cut by a wedge-shaped fracture, indicating that portions of the wall settled in an uneven way.

Depressions of similar geometry were recorded in abundance on the paved floor in the Lechaion basilica (Corinth, Greece),[58] on alluvial landfill in Kachchh (Gujarat, India),[59] etc.

III.2. Broken and displaced foundation wall (nr. 5)

A broken wall was found in the southwestern corner of House I/a (nr. 5, ***Fig. 8, 13***). The 0.45–0.5 m thick *opus incertum* foundation wall and plinth broke, and was displaced vertically by about 0.2 m, having yielded to uneven subsidence.

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57 For more about the dating of the well and terrazzo floor see Dobosi 2022 in this volume.
58 Apostolopoulos et alii 2015; Minos-Minopoulos et alii 2015.
59 Rajendran et alii 2001.

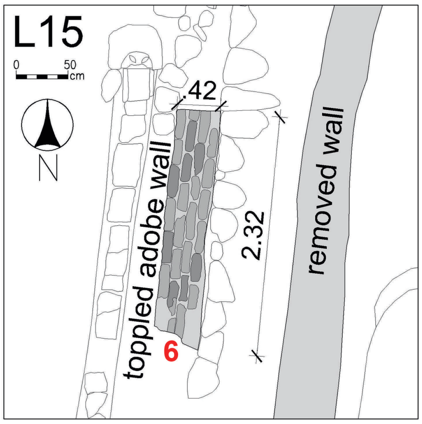

Fig. 14.
Toppled wall of adobe bricks fallen from the wall to the east (drawing: L. Dobosi, photo: D. Bartus)

III.3. Toppled adobe walls (nr. 6–8)

There is an unusually high number of well-preserved, toppled adobe walls at three different points of Vásártér.[60] In House VI, the 0.45 m thick wall of adobe bricks toppled to the west from its foundation (nr. 6, ***Fig. 8, 14***). The foundation of the wall was robbed of its stone material in modern times, which left only the removed wall, the foundation trench for us.

A few meters south, another toppled adobe wall was uncovered in Cellar 2 (nr. 7, ***Fig. 8, 15***). The wall segment fell onto the wooden ceiling of the cellar, which was also preserved in an exceptionally good condition. The cellar was still in use in the late 2nd century and its wooden ceiling collapsed at the end of the 2nd century A.D. at the earliest. The latest Samian ware shards in the infill of the cellar came from the Pfaffenhofen workshop and can be dated to the middle of the 3rd century A.D., indicating that the process of filling the cellar with rubbish ended only around or after the middle of the 3rd century.[61] The toppled wall could have fallen into the cellar after the end of the 2nd century A.D. and before the end of the 3rd century A.D.

The third toppled adobe wall at 2 Vásártér, in House III was also burnt (nr. 8, ***Fig. 8, 16***). It must have collapsed from the northern wall of Room III/1. The wall paintings covering the surrounding walls of Room III/1 can be dated to the middle of the 3rd century A.D.,[62] consequently, the adobe wall must have collapsed sometime in the second half of the 3rd century.

Toppled walls were documented in mounds in Bulgaria,[63] Hierapolis in Anatolia,[64] in the adobe city of Bam after the 2003 earthquake,[65] etc.

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60 Apart from these listed here, another toppled adobe wall was found in the canabae. It fell into another cellar. Bartus et alii 2020, 195–200.

61 Bartus – Borhy 2016, 102–103; Bartus et alii 2018, 63–68; Hajdu 2020, 155–158.

62 Borhy et alii 2010, 116.

63 Kabakchieva 2008.

64 Kumsar et alii 2016.

65 Maheri et alii 2005.

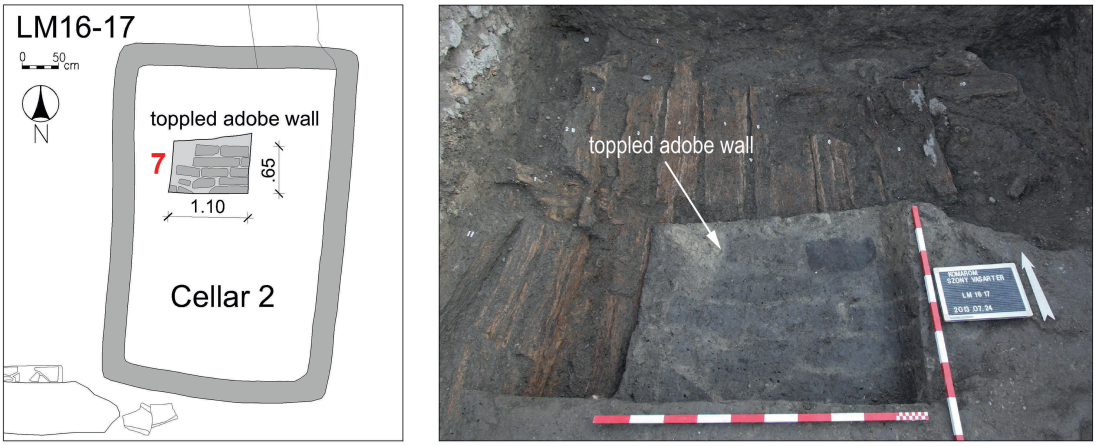

Fig. 15.
Toppled wall of adobe bricks fallen into Cellar 2 (drawing: L. Dobosi, photo: D. Bartus)

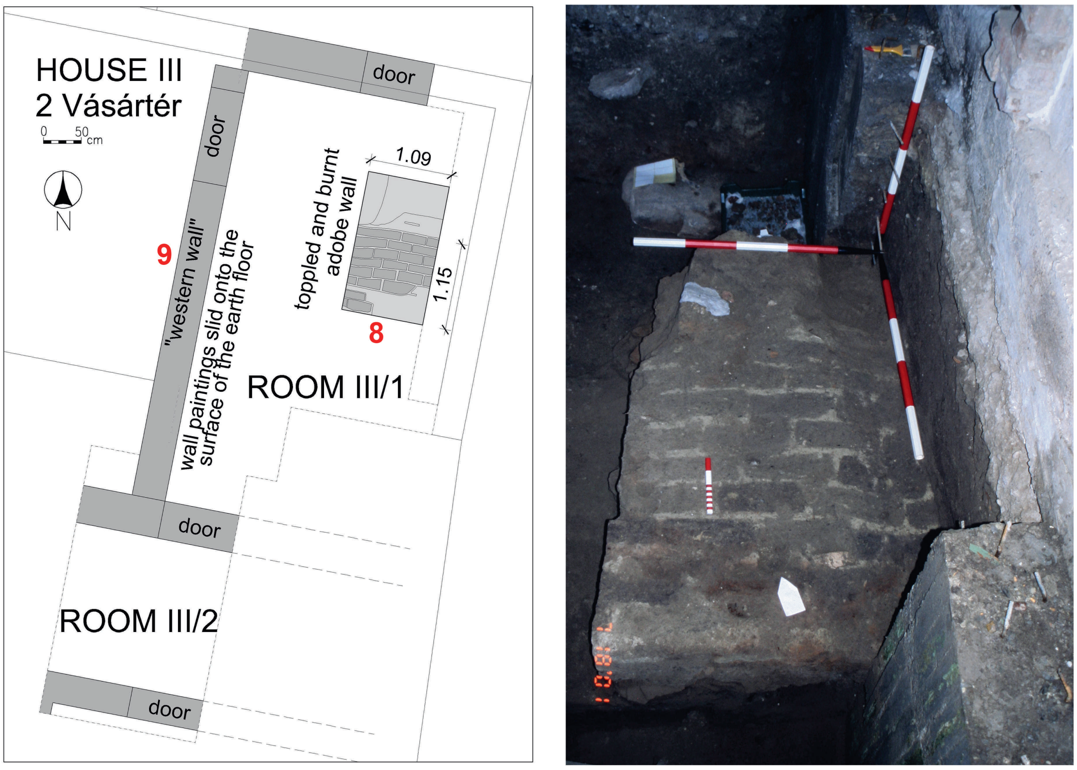

Fig. 16.
Toppled and burnt wall of adobe bricks fallen from the northern wall of Room III/1
(drawing: L. Dobosi, photo: L. Borhy)

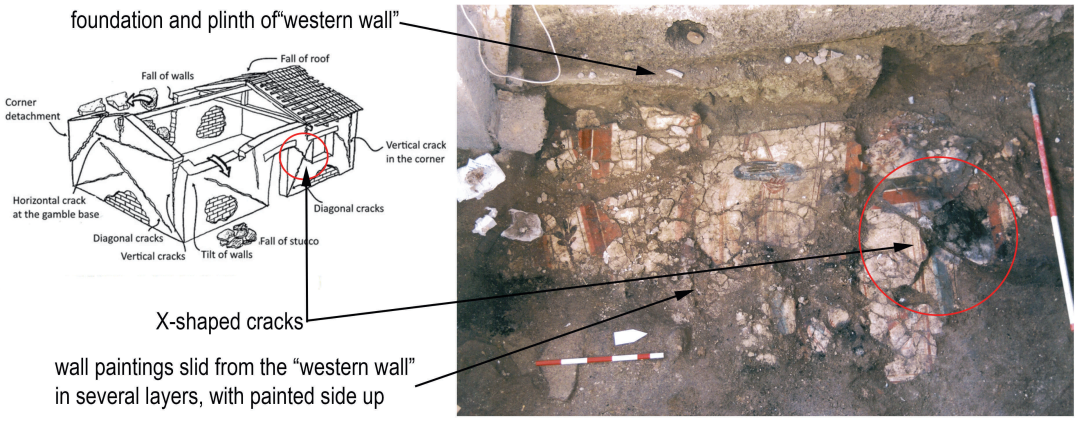

Fig. 17.
The wall paintings slid onto the floor of Room III/1. ***a,*** *Seismic damages on adobe buildings (Tarque 2021, Fig. 1)* ***b,*** *Wall paintings on the floor with a possible X-shaped crack*

III.4. Diagonal fractures in wall painting (nr. 9)

The wall paintings of the western, southern, and northern walls of Room III/1 slid down from the walls onto the floor of the room. They were partly burnt in the same fire that burnt the toppled adobe wall in the room (nr. 9, ***Fig. 8, 17***). The paintings so far restored covered an about 3.7 m high and 5.5 m wide surface on the western wall and further 2–2 m wide surfaces on the northern and southern walls.[66] Traces of oblique fractures can be observed on the restored wall painting, that look like diagonal or X-shaped cracking due to in-plane wall damage, before the wall paintings fell off the walls.

Conjugate fractures arranged in an X-pattern are common features on walls after a dominantly in-plane shaking, well documented after the 2011 Van (Turkey) event,[67] after the 1999 Athens earthquake,[68] and in Pompeii,[69] among many others.

III.5. Flame-like features of liquefied sand (nr. 10)

In Cellar 3, disturbed layers of the subsoil can be seen in the eastern wall of the excavation trench, more than 2 meters below the present-day walking level (nr. 10, ***Fig. 8, 18–19***). There are fine-grained sandy and loamy sediments alternating, separated by curly bedding planes, bearing flame-like structures. Thin layers of light-coloured sandy clay between darker strata look like intrusions (sills).

Similar features are commonly observed in both experimental[70] and natural settings.[71]

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66 The restauration of the wall paintings is the work of Eszter Harsányi and Zsófia Kurovszky.
67 Carydis et alii 2012.
68 Lekkas et alii 2011.
69 Martini et alii 1998.
70 Owen 1996.
71 Obermeier 1996.

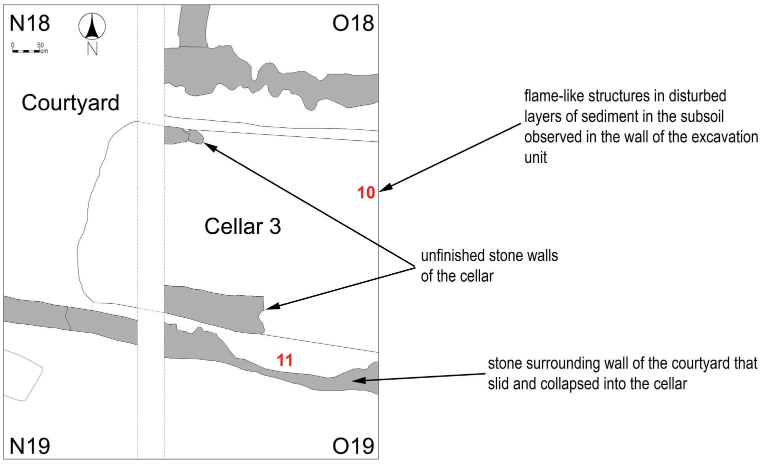

Fig. 18.
The unfinished Cellar 3 (drawing: L. Dobosi)

III.6. Wall collapsed and slid into cellar (nr. 11)

Still inside Cellar 3, a collapsed wall was found. As it seems, Cellar 3 was dug into a courtyard and it was still under construction, when the adjacent courtyard wall collapsed and slid into the cellar. The cellar was left in an unfinished state: its pit was dug out and they began with the building of its stone walls when the courtyard wall collapsed due to an unknown reason: a possible effect of the earthquake. The cellar was then filled with rubbish that can be dated to the middle of the 3rd century A.D.

IV. Evidence for earthquake

In the case of suspected seismic damages, it is important to consider other possible causes for the damages and carefully assess the evidence.

Uneven or differential settlement of floors and walls can occur slowly or rapidly. Slow subsidence is due to the loading of a building on the soil. Rapid subsidence is due to liquefaction. Liquefaction is the fluidization of sediments: water-saturated sediment, usually sand, behaves like fluid under extreme pressure created by earthquake shaking. Overpressurized sediment is pressed into overlying strata, forming vertical dykes and horizontal sills, producing fountains on the surface, leaving behind so-called sand volcanoes.[72] Additionally, when seismic or other shaking exerts repeated loading on a significant column of water-saturated soil, pressure of ground water increases, soil granules get separated from each other. Soil loses cohesion, behaving like liquid. Objects – as large as whole multi-floor houses – sink and topple in soil.

Distinguishing between slow and rapid differential settlement can be challenging. If there is a cross-section of a sand dyke, sill, or sand volcano preserved in

72 Tuttle et alii 2019.

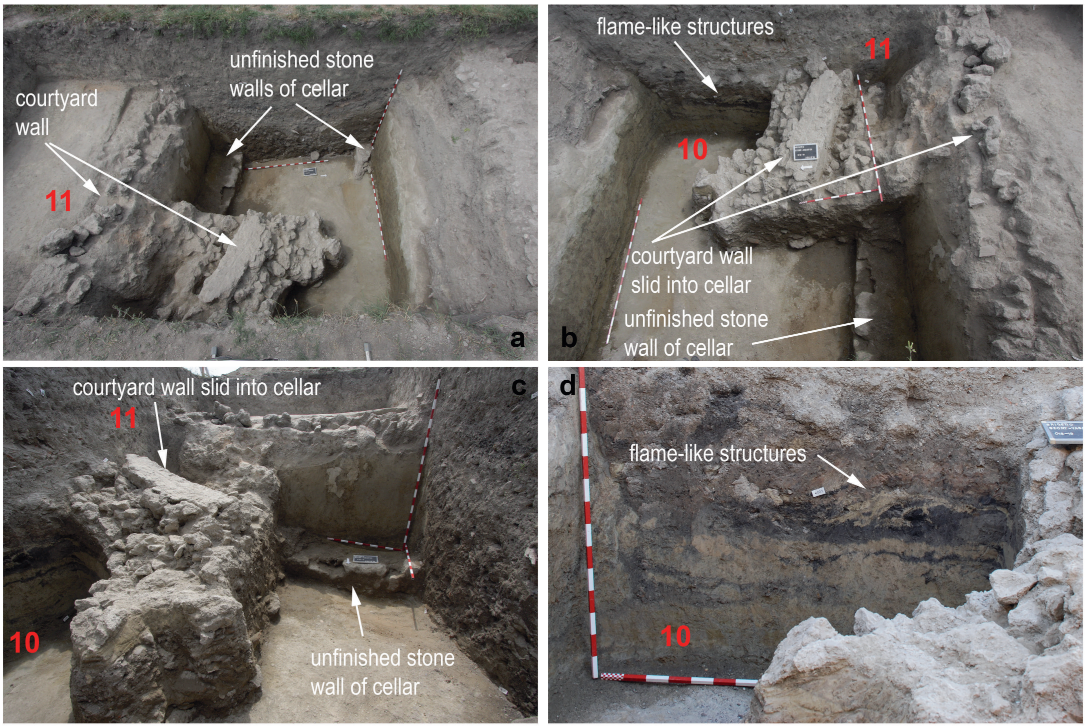

Fig. 19.

Collapsed wall and flame-like features of liquified sand. ***a-b-c***, *Courtyard wall collapsed into adjacent cellar (from east–west–north)* ***b-d***, *Flame-like features of liquefied sandy clay (light colour) intrudinginto clay (dark colour). This feature indicates a shaking event preceding the construction of the cellar and the collapse of the courtyard wall into the cellar (photos: L. Borhy and N. Sey)*

the excavation wall, then seismic action can be considered proven. In Brigetio the disturbed layers in the subsoil might indicate seismic-induced liquefaction (nr. 10, ***Fig. 19***).[73] Sand volcanoes can form a crater, when the extruded sediment is so much, that the remaining standing walls of the vent or dyke collapse. We attribute the oval-shaped depression in the terrazzo floor (nr. 3, ***Fig. 8–9, 12***) to collapse after sand volcano action. Sand-laden groundwater escaped through the concentric fractures.

Less regular subsidence pattern can be attributed to ejection of sediment-laden fluid or to other kind of seismic-related deformation. While liquefaction is a persistent engineering problem, therefore well studied,[74] other kinds of seismic soil deformations are less well known. However, there is an abundance of descriptions in archaeological and seismological literature of similar deformation features (see above). Recently these are complemented by the geophysical study of the subsoil to understand the ability of the soil to liquefaction.[75]

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73 A succession very similar to our Fig. 19 in Brigetio is illustrated in Mickelson et alii 2011, Fig. 8.
74 For a review see Tuttle et alii 2019.
75 Apostolopoulos et alii 2015; Minos-Minopoulos et alii 2015.

Uneven subsidence can affect terrazzo floors, flagstone-covered roads, even walls of any thickness. The 0.45–0.5 m thick *opus incertum* wall was broken and a portion of it subsided by about 20 cm (nr. 5, ***Fig. 8, 13***).

Intensity

The universally used EMS-98 intensity scale was designed to be used for standing buildings with upright walls. As Brigetio has no standing walls, we have to revert to the ESI-07 environmental seismic scale,[76] which uses not man-made but natural features to estimate the intensity of shaking. Uneven, crater-like settlement of 3 m diameter, 0.5 m depth indicates intensity IX (destructive). A further feature which can be assigned to this level of intensity are gas emissions, often sulphureous, which may cause burning nearby. P. Varga assigned the same intensity to the 1763 Komárom earthquake based on multiple historical documents.[77]

Questions of dating

Based on the findings at the Komárom/Szőny-Vásártér site, it seems conspicuous that the archaeological site was hit by an earthquake sometime during its history. Evidence points to an earthquake after the middle of the 3rd century A.D. or the early 4th century. The *terminus post quem* for the earthquake is provided by ample well dated evidence: most of the structures deformed in the earthquake were built during the first half or even at the middle of the 3rd century. None of the damages listed above were repaired, although the highly distorted terrazzo floor of Room I/4, for example, excludes any possibility of normal use of this richly decorated, large reception room in its preserved state. This means, that the earthquake hit the town at or shortly after the abandonment of the settlement in the second half of the 3rd century. The toppled adobe walls, and the fallen wall paintings of the tilted wall of the bakery indicate that the buildings of the town were still standing when the earthquake occurred. As an abandoned adobe building takes only a few years to decay, the earthquake must have hit the Brigetio civil town shortly after its inhabitants left, at the latest. The question may arise, whether the earthquake could have caused the abandonment of the Brigetio civil town in the second half of the 3rd century. The answer is, it could, but needn't have. After the middle of the 3rd century A.D., the barbarian invasions and the economic crisis caused the abandonment of many towns or settlement-parts along the *limes*, throughout the Pannonia and other parts of the Empire.[78]

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76 Michetti et alii 2007.
77 Varga 2014.
78 Láng 2018, 164–165; Juhász 2018, 18–19.

Conclusions

Archaeoseismological research is an effective way of enhancing our knowl-edge about past earthquakes unknown from historical sources, thus collecting data to help assess the earthquake hazard of a site. Although several earthquakes are known from Komárom, the here suggested late Roman earthquake in Brigetio was hitherto unrevealed. Different types of seismic damages were identified at the so-called Komárom/Szőny-Vásártér site, such as seismic-induced soil liquefaction and uneven subsidence in the form of distorted floors and broken, tilted and toppled walls. Based on archaeological evidence, a late Roman earthquake some time between the middle of the 3rd century A.D. and early 4th century is suspected. An intensity IX event is estimated using the ESI-07 environmental seismic scale. It is important to note that our research was limited to a single, although large site (Komárom/Szőny-Vásártér) in the Roman civil town of Brigetio, and further evidence needs to be collected from other parts of the settlement-complex, the legionary fortress and the *canabae* of Brigetio to confirm our results.

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