Was Antiquity seismically more active than the Middle Ages? – Roman earthquakes in Pannonia and Dacia

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Abstract: There are only two earthquakes known from the first millennium AD in the Carpathian-Pannonian region: Carnuntum (Austria) and Savaria (Hungary). Archaeoseismological studies allowed us to add six more events to the list, which damaged six Roman towns: Brigetio and Salla (Hungary), Celeia (Slovenia), Siscia (Croatia), Virunum (Austria), and Napoca (Romania). Archaeoseismological analysis brings up sufficient evidence to prove the seismic origin of various destruction features, and allows to bracket the period when the earthquake happened.

Keywords: archaeoseismology, Antiquity, Carpathians, Pannonian Basin

1. Introduction

The length of time covered by modern instrumental seismology is negligibly short when compared with the geological time-scale involved in earthquake processes (Ambraseys, 1973). The historical and instrumental data-set for the Carpathian-Pannonian region (Zsíros, 2000) and the current catalogue of the Kövesligethy Radó Seismological Laboratory in Budapest (Fig. 1) is considered complete for M >= 5 for the 20th century. However, only less than 5% of destructive earthquakes of comparable magnitude are known from the preceding two millennia (Kázmér & Győri, 2020). The first millennium AD is critical: international seismic catalogues (AHEAD, SHEEC) start listing events in AD 1000 (Albini et al., 2013; Stucchi et al., 2013). The Zsíros catalogue lists only five events for the first millennium. Out of these the 1000 AD event in Slovenia was proven as fake (Alexandre, 1991). The 935 AD Salzburg event is out of the frame we are studying. What remains are three events: 456 AD in Savaria (Varga, 2019), 567 AD in Croatia (Herak et al., 1996, updated), and 984 AD, which could be anywhere within Fig. 1. (Réthly, 1952). We note that Alexandre (1990) omits this event from his Medieval catalogue, while listing Savaria). Therefore it is imperative to introduce new methods, e.g., archaeoseismology, to fill gaps left blank in historical catalogues and to improve seismic hazard assessment.

After the early start of archaeoseismology in the region (Kandler, 1989) both enthusiastic (Decker et al., 2006) and critical (Hammerl et al., 2014) opinions appeared. Recently an international conference on earthquakes in Carnuntum (Petronell, Austria) provided ample evidence for the seismic destruction of the city in Roman times (Konecny et al., 2019). Here we add six, Roman archaeological sites to the two (Carnuntum and Virunum) already known: Brigetio, Savaria, Salla, Celeia, Siscia, and Napoca. Previously these were not known as bearing evidence for past earthquakes. An approximate dating is provided for each destructive event.

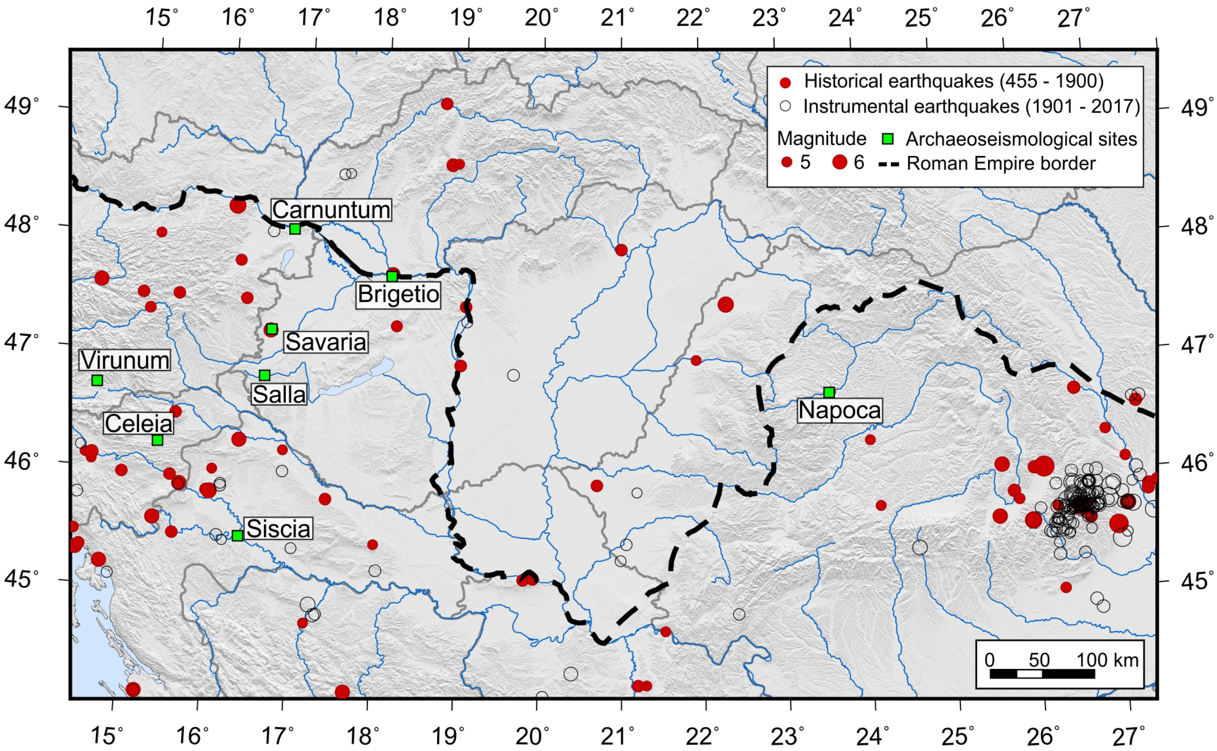

Fig. 1. Earthquakes measured using instruments and earthquakes to which there are references in historical sources equal to or larger than magnitude 5 in the Carpathian-Pannonian region and surroundings. A dotted line marks the largest northern extent of the Roman Empire in the 1 to 4th centuries. Source: *Earthquake Catalogue* (after Kázmér & Győri, 2020, modified).

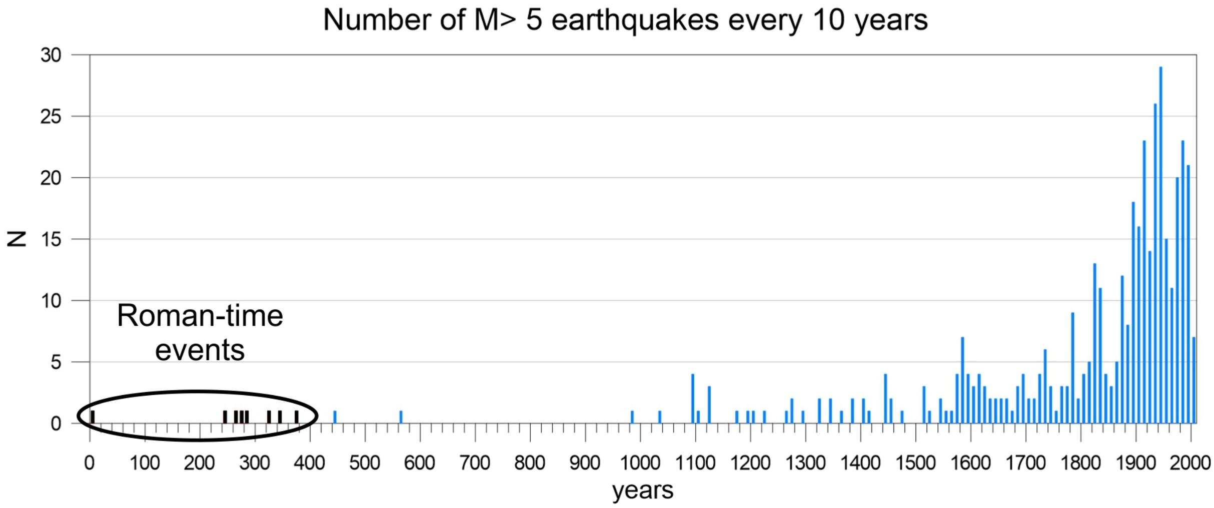

Fig. 2. Number of known earthquakes in the Carpathian-Pannonian region and surroundings in the past two millennia. Magnitude 5 and larger events are shown for each decade (After Kázmér & Győri, 2020, modified). See Table 1 for dating of individual events. Encircled: Roman events.

Table 1. Date of earthquakes which affected Roman settlements in the Carpathian-Pannonian region. Textual dates were converted to numerical ages as follows: second half of the 3rd century: 250-300; first quarter of 3rd century: 200-225; beginning of 3rd century: 200-210.

Settlement	Interval when earthquake happened (AD)	Value used in earthquake frequency plot of Fig. 2	References
Carnuntum	348–363	360	Gazdac (2019)
Brigetio	250–325	287	Dobosi & Kázmér (2022)
Savaria	337–346	342	Kázmér (2021) and here
Salla	230–310	270	Redő (2002)
Siscia	250–410	280	Kázmér & Škrgulja (2021)
Celeia	300–350	325	Kázmér et al. (2021) and here
Virunum / Magdalensberg	1–20	10	Dolenz (2007)
Napoca	201-300	250	Kázmér & Rusu (2022)

2. Evidence for Roman earthquakes in the Carpathian-Pannonian region

2.1. Carnuntum

The city of Carnuntum, former capital of Pannonian Superior is the most studied site in the region regarding past earthquakes (Konecny et al., 2019). Beyond the ubiquitous collapse features, there are broken and shifted walls of buildings, large portions of walls collapsed in their entirety (Fig. 3), sheared columns of hypocaust floors, etc. In the areas hit by collapse, there were major alterations in the street pattern and many new buildings were erected in the middle of the 4th century (Maschek, 2019). Coins date the earthquake to the interval between 348-363 AD, probably it happened right before the end of this period (Gazdac, 2019).

Fig. 3. Collapsed city wall of Carnuntum (Petronell, Austria): a wall section, tens of metres long, 3-4 m high collapsed in its entirety into the moat outside the city. The external layer of the wall is preserved, face down. All other stones have been robbed after the abandonment of the city. Archaeoseismological Database (ADB) photo #5496.

2.2. Brigetio

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. Seismic-induced soil liquefaction and uneven subsidence in the form of distorted floors and broken, tilted and toppled walls were identified (Fig. 4). 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 AD 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 (Dobosi & Kázmér, 2022).

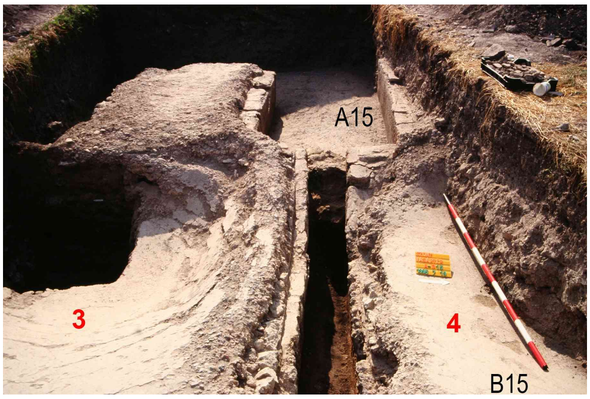

Fig. 4. Liquefaction-caused deformations in the terrazzo floor. Two depressions (4 and 3) are separated by the heating canal of the hypocaust. Depression (3) is 3 m in diameter (Dobosi & Kázmér, 2022).

2.3. Savaria

In-depth studies of historical sources testify to a major earthquake in Savaria in AD 455 or 456 (Tóth, 2014; Varga, 2019). However, the material evidence – if any – is under-studied as yet. The first results of an archaesoseismological pilot study are presented here. The Járdányi Paulovics István Garden of Ruins displays spectacular features, which can readily be assigned to a destructive seismic event. An inclined road surface (Fig. 5), 'steps' in the road cover, slabs on top of each other individually and collectively testify to liquefaction of the underlying alluvial soil. Seismic vibration caused the loss of cohesion of the subsoil, causing vertical subsidence and lateral displacement (floating, thrusting) of the slabs covering the road. A 40 cm wide fissure in the octagon was possibly caused by lateral spreading. The fractured wall of the canal was probably caused by the same effect. There is a possible drop of a slab in the arch of the canal, potentially the best marker of seismic shaking. The mosaic floor of the governor's palace displays liquefaction-caused differential subsidence. Other sites should be checked for any further evidence of past earthquakes. Heavy buttresses were built to support the damaged octagon, indicating that there were both need and sufficient resources for extensive repair after the earthquake (Kázmér, 2021).

Fig. 5. 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. ADB photo #2156 (Kázmér & Győri, 2020).

2.4. Salla

A Roman market town controlling the crossing of the lesser Salla (Zala) river yielded upright, undamaged walls and the main road, displaying uneven subsidence, caused by seismic-induced liquefaction.

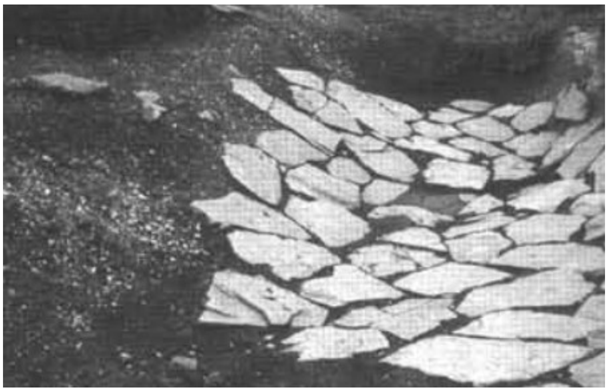

Fig. 6. Severe differential settlement of road paved by basalt slabs in the Roman town of Salla. (Redő, 2002)

2.5. Siscia

Excavations of the Roman city of Siscia (Sisak, Croatia) yielded large chunks of thick brick walls (considered to be the city wall) that collapsed in the adjacent ditch in their entirety. The wall is made of brick masonry on both sides and a thick concrete infill between them. Wall chunks are found in various orientations: the original layering of masonry is now mostly vertical or overturned. The remaining foundation displays features of twisting and shearing (Fig. 7). We suggest that a major earthquake damaged the city wall of Siscia. Excitated by site effects of loose soil, high peak ground acceleration caused the wall to be removed from its foundation, landing it ultimately in the ditch nearby.

Presumed intensity of the earthquake was IX. Fault activity within a couple of kilometres was responsible for this collapse. Rebuilding of the city wall in the late antique period suggests that the first wall collapsed between the beginning of the 3rd and the middle of the 4th century. This earthquake between ~200 AD and ~350 AD is missing from historical catalogues (Kázmér and Škrgulja, 2021; Kázmér et al., 2021).

Fig. 7. A collapsed segment of the city wall of Roman Siscia. There are still low parts of the wall in place on the right. Top of these walls displays clear sign of shearing to the left. Upper portion of the wall is in the city moat on the left: brick layers are bottom-up(!). North to the left (Kázmér & Škrgulja, 2021).

2.6. Celeia

The „Mesto pod mestom" museum in Celje exhibits a paved Roman road, which suffered severe deformation. Built on fine gravel and sand of the Savinja river the road displays >40 cm difference in elevation between centre and edges (Fig. 8). The city wall was built over the deformed road in Late Roman times. Foundation of the new structure contains statues and column plinths, suggesting that a surplus of decorative stones were available for construction. We hypothesize that a severe earthquake hit the town (intensity VIII-IX on the Environmental Seismic Intensity (ESI07 scale), causing widespread destruction, and seismic-induced liquefaction caused differential subsidence, deforming the road. Possibly the Sava Fault, running right next to the town, was the seismic source of this event (Kázmér et al., 2021).

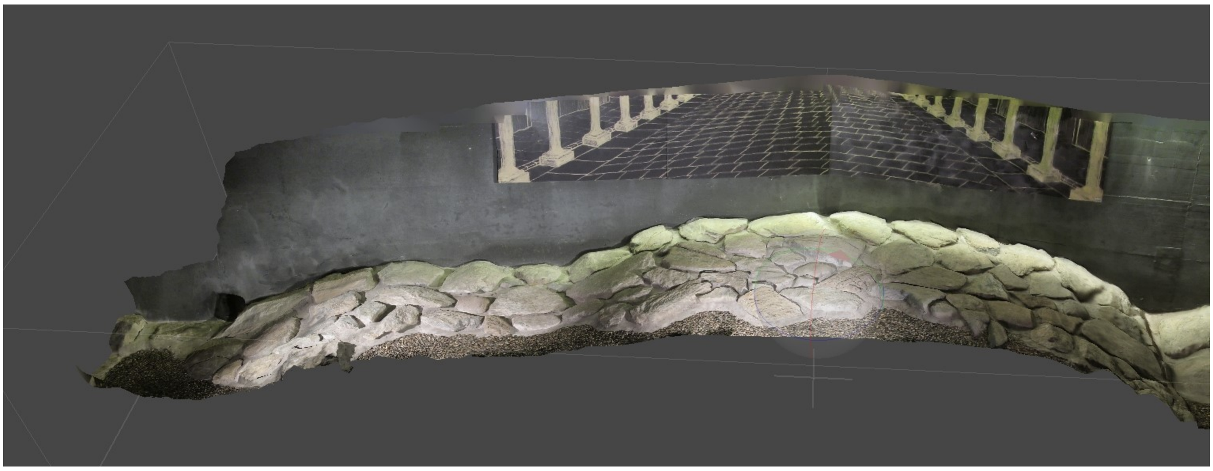

Fig. 8. 3D model of the paved Roman road as exhumed in the *Mesto pod mestom* exhibition in Celje, Slovenia) (Kázmér et al. 2022).

2.7. Virunum (Magdalensberg)

Magdalensberg in Carinthia, Austria, was a Roman hillside settlement, including a major temple (Fig. 9). The temple presents heterogeneous and irregularly distributed buttresses that support structurally damaged foundation walls being uncommon features in such Roman constructions. The Antique name is not known. Being ca. 5 km from Virunum, a larger town of known name, it is either mentioned as Alt-Virunum (Old Virunum) or by the modern name: Magdalensberg. Buildings on more than two-thirds of the excavated archaeological site (7000 m^2) have been destroyed and demolished, and subsequently rebuilt, often on top of the collapse level. There is a historical record of an earthquake somewhere in the Alps at about 9 AD, but the location is unknown. Archaeological data on destruction and the historical datum has not been correlated yet (Dolenz, 200).

Fig. 9. Foundations of Roman temple on the old site of Virunum on Magdalensberg, Carinthia, Austria. Irregularly arranged strong buttresses support structurally damaged walls. ADB photo #KRG_5021.

2.8. Napoca

Napoca (modern Cluj-Napoca, the ’capital’ of Transylvania, Romania) was the seat of a Roman colony after the second Roman-Dacian War (AD 105-106), inhabited at least until AD 249-251 (Gazdac & Cocis, 2020). Roman administration withdrew from Dacia AD 271. There is very little archaeological evidence of life within the city walls from the AD 280s or later. The latest coin found in the archaeological context was of Carinus (AD 285). More surprisingly, no artifacts referring to Christianity were found. Third-century pottery is generally poorly represented (Rusu-Bolindeţ 2007). On Piata Unirii the first level of constructions started at the depth of 3.2 m. The last Roman level was dated to the 3rd century by fibulas (Voişian et al., 2000, *fide* Rusu-Bolindeţ, 2007). This is the layer, which displays spectacular deformation features attributed to subsoil liquefaction. It is topped by layers with 4-6th century ceramics, right below the modern square (Fig. 10).

Fig. 10. Folded pavement with features of uneven settlement on Piata Unirii in Cluj-Napoca (Transylvania, Romania). Columns were restored and erected during excavations. The floor is undulating, slabs remained tightly fit (Kázmér & Rusu, 2022). Image source: https://actualdecluj.ro/tehnologie-nasa-pentru-studierea-patrimoniului-arheologic-din-judetul-cluj/ (Accessed 13 March 2022)

3. Discussion and conclusions

The long-term seismicity of the Carpathian-Pannonian region is unknown, at least on the millennial-scale. While 100% of destructive (M>5) earthquakes are known after 1900 AD, we have less and less information about their occurrence backwards in time. On average, only 4.6% of M>5 events are known in the past two millennia, i.e. more than 95% of them remain unknown! (Kázmér & Győri, 2020). Seismic catalogues offer information on two(!) events only from the period between 1 and 1000 AD.

Systematic research on archaeoseismology already yielded six new sites, which were not known before displaying evidence for earthquake-induced deformation. These events occurred between 1 AD and 410 AD, concentrated between 200 and 400 AD. Was there a real increase in seismic activity, or we are dealing with the case of the records being better than in other times?

It is well known that damaged buildings are mostly preserved from periods of economic, military, and cultural decline. Change of religion also adds chances for the survival of specific features of earthquake damage. A healthy, vigorous, rich society does not allow itself to live among damaged buildings: they either repair or demolish and rebuild the damaged edifice. The reason why we know many more Roman buildings than Medieval ones from the Middle Ages are threefold: (1) the Romans were capable of building good-quality edifices, which survived earthquakes; (2) although most damage was repaired during economically vibrant periods, political, military and economic decline halted restoration and rebuilding. This occurred at different times in each province: first in Napoca, last in Celeia, and Siscia.

We suggest that both Roman times and the Middle Ages were seismically as active as the 20th century. Archaeoseismology can reveal many more destructive earthquakes in Antiquity than in early Medieval times because the high Roman civilization left behind so many masonry buildings, which are suitable to record past seismic events.

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