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The 4th century Siscia (Croatia) earthquake – archaeoseismological evidence

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Abstract

Proximity of the active faults in Croatia is being studied for evidence of past earthquakes by archaeoseismology. Excavations of the Roman city of Siscia (Sisak, Croatia) yielded large chunks of thick brick walls (considered to be the city wall), 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. Much of the collapsed portion is entire, there are not even joints between adjacent bricks. Wall chunks are found in various orientation: the original horizontal layering of masonry is now mostly vertical, even overturned. The remaining foundation displays features of twisting and shearing. The construction level is underlain by sandy clay. Significant recycling of construction material occurred in later centuries, so original dimensions are estimates only. 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 distance 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 are missing from historical catalogues. We suggest that fault activity in Croatia is more widespread than previously considered. Archeoseismological features – even if lacking proper dates – must be added to the catalogues of historical earthquakes of the region.

Key words: earthquake, Petrinja, Siscia, Croatia, archeoseismology

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1 Introduction

In Late December 2020 and January of 2021 severe earthqukes hit the town of Petrinja in Croatia, culminating in a M 6.4 event on 29 December. This was the largest earthquake in mainland Croatia since the 1880 Zagreb earthquake (M 6.3). The old town was severely damaged and there were casualties, too. Neigbouring settlements, indcluding the city of Sisak, suffered damage. A long series of aftershocks followed, still lasting while we are writing this paper.

While most parts of Croatia are known to be seismically active [1, 2], the Sava valley is moderate in this respect. Historical catalogues, e.g. [3-5] are probably complete for the 20th century, while an increasing number of events remain unknown as we go back in time. Altogether, about 90 % of destructive events (M 5 and above) remain unknown [6]. Following preliminary attempts in archaeoseismology in Poreč, Istria ([7] and in the Kvarner islands [8], here we provide an archaeoseismological study of a major earthquake which hit Siscia (modern Sisak) in Roman times (Fig. 1).

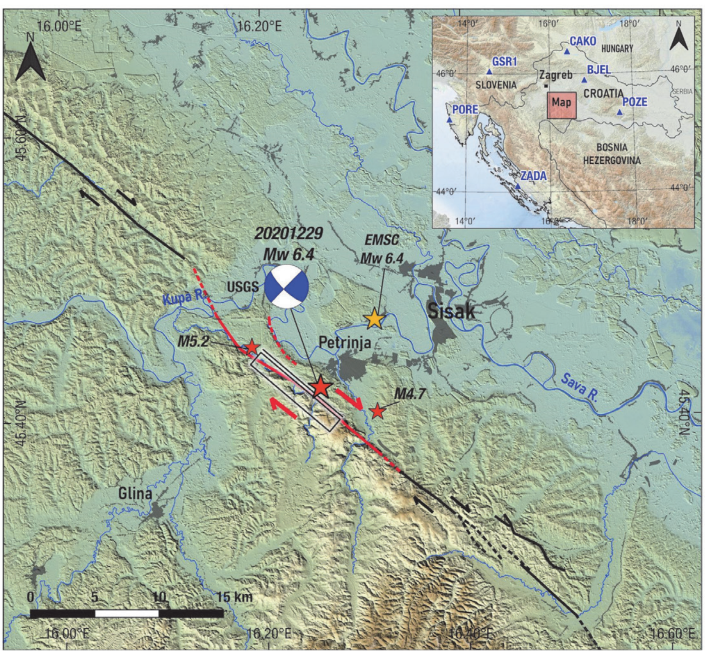

Figure 1. Location and parameters of the 2020 AD Petrinja earthquake in Croatia (after [9], modified). Location map showing shaded topography, the seismic fault (black rectangle & red line; this study), the USGS focal mechanism and the epicenter of the Petrinja December 29, 2020, earthquake (Mw=6.4). Red arrows indicate sense of relative motion across fault. Inset box indicates location of earthquake area within Croatia together with the location of EUREF/EPN/CROPOS seismic stations (blue triangles). Accessed 15 February 2021

2 Sisak

Sisak is a city in Croatia located on the fringe of the Pannonian plain, 50 km SW from Zagreb [10, 11]. During the Iron Ages, a large trade and production center developed, Segesta or Segestica. It was destroyed by the Romans in 35 BC. From then until the Middle Ages, the whole area was a part of the Roman state. After the conquest, the Romans had established a military base at this position that served as a basis for further military operations [12-15]. Siscia belonged to the Roman province of Pannonia and was one of the provincial capitals. It had all the elements of a typical Roman town: paved roads and streets, sewers, aqueducts, public spaces and buildings (fora, basilica), administrative and religious buildings. The city was fortified by a high surrounding wall. Here we provide archaeological data on a collapsed portion of the Roman city wall of Siscia, which suffered severe deformation and collapse. Deformation features are described, their protential cause is outlined. Parameters of the earthquake (date, intensity, causative fault) are suggested.

2.1 The city wall of Siscia

The city wall of Siscia was most probably built during the Severan dynasty. The dating is based on the stratigraphy, analyses of the finds, and the historical circumstances [11, 16]. Its total length was 3,5 km. It was built mainly out of whole bricks (the first phase) and stone blocks, bound with mortar. The width varies between 1,20 and 2 m. Mostly only the foundations are preserved. We do not know the original height, but when Marsigli visited Sisak, the eastern section was at places 6 m high ([11, 16, 17]. We can take that that was the minimum height. The special sections, e.g. entrances and towers, would have been higher.

2.2 St. Quirinus Site

Since 2003 excavations have been conducted at the site next to the 18th century St. Quirinus church (45° 30′ 07″ N, 16° 22′ 18″ E) [11, 18-28]. The stratigraphic sequence is 3–5 m thick. The geological basis is an alluvial deposit [16, 25], upon which there are Roman-age leveling and cultural layers. The Roman building at the site had several construction phases between the first half of the 1st century to the 4th century, dated by the radiocarbon and by the analyses of finds. The remains of the city wall and the northern entrance are dated to the Severan period (3rd century AD) [16]. The entrance consists of two strong parallel walls (N-S). On the walls, the St. Quirinus church was built in the 18th century. The walls are built with brick masonry laid horizontally, except at the bottom, where they are laid transversely. The western entrance wall is 1.60 m wide, and the eastern 2.00 (with the later addition of a portico) [16, 18].

3 Methods

Istrumental and historical methods of paleoseismology are increasingly complemented by studying earthquake-damaged buildings and archaeological locations [29]. Buildings with upright walls above surface are the preferred objects of studies [30-33], although buried walls, foundations, [34] and floors [35] are shown to be useful in recognizing and parametrizing past earthquakes: site location, date, intensity and magnitude of past seismic events can be assessed. Quantitative methods are gaining acceptance recently [36].

4 Results

During the first season of the excavations, a part of a wall was found, some 10 m to the south of the confirmed position of the city wall. It is 10 m long, up to 2 m wide, and the building technique corresponds to the entrance. It continues, after a hiatus, into the western profile. When discovered, it was considered that it had fallen from the entrance wall. Later excavations revealed that a large segment of the corresponding wall collapsed into the defense ditch, along with segments of smaller walls.

Figure 2. 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

Figure 3. Overturned wall in the moat. The viewer is looking at a mortar layer between rows of bricks, a seen from below(!). Note that in-plane deformation caused a wide gap to appear, marking extension of the wall during shaking or during collapse [37]

Figure 4. Two portions of a collapsed wall, arranged in different positions. Left block tilted towards the viewer, right block tilted towards west

Figure 5. View of the church apse. A tilted wall, next to the early 3th century vertical walls of theRoman entrance complex, on top of which is the 18th century church [19]

Figure 6. Brick masonry walls collapsed in various directions [37]

5 Discussion

5.1 Earthquake caused collapse

Walls, thick or thin, can collapse for various reasons: storm, military attack, earthquake, and – most –often – from neglect. However, the features caused by these factors differ significantly. While Romans had warfare machinery, their barbarian enemies enemies certainly lacked sophisticated equipment and technique to cause destruction to strong walls and fortresses in the way observed in Siscia. Storms can destruct buildings and walls, but probably cannot remove a 2 m thick masonry wall in its entirety. Neglect and abandonment mostly causes destruction in a more-or-less symmetrical ways: bricks and building fragments accumulate on both sides of the walls. The uni-lateral directivity of the collapse, the fall of the wall as a whole is a strong argument for seismic origin of the damage.

5.2 Similar collapse fetures

Coherent toppled walls are well-known in earthquake-damaged sites in the Mediterranean. A spectacularly similar find is illustrated in [38]: the city wall of Roman Carnuntum, capital of Pannonia Superior province, fell into the city moat. It was a tens of metres long segment, collapsing in a coherent way. Further examples can be seen in Gadara in Jordan [39], in Baeolo Claudia in Spain [40], in El-Lejjun in Jordan [41], or in Oberndorf-Bochingen in Germany [42]. In-plane extension and shift are well documented, among others, extensively in Carnuntum [38, 43, 44].

5.3 Dating

The hypothesis is that the original city wall at this position collapsed sometime between 2nd half of the third and the beginning of the 5th century AD. The fact that the new wall had to be built is the evidence that something happened to the old one. The dating is supported by the movable finds. The evidence that supports that dating is the following: the coins found between "new" and "old" wall segment are from the 2nd to 4th century. Before the building of the new wall, the area was within the city, and people were losing money in that area during 2nd, 3rd and 4th centuries. After the second wall was built, there were fewer everyday activities in that area. Only 2 coins, and both near to the ditch, can be dated to the 5th century. Pottery fragments point to that time-frame too. Other finds are not suitable for dating, for they had the same shape during the whole Roman period (bone needles, metal fragments) [18-19, 21, 24-28].

5.4 Intensity

The EAE13 archaeoseismological intensity scale correlates seismic destruction features to the EMS98 macroseismic scale [45]. Environmental consequences of seismic shaking (e.g. liquefaction) are classified the same way [46].

Shifted wall (in-plane, out-of-plane)	IX
Rotated wall sheared off the foundation	VIII
Tilted wall	VII
Collapsed wall	IX
Twisted/folded wall	VIII
Uneven subsidence / liquefaction	VIII

Intensity of the Roman-time Siscia earthquake was probably IX.

5.5 The fault

There is a right-lateral strike slip fault, which caused the 29 December 2021 to the south both from Siscia and Petrinja (Fig. 1). Intensity I = IX is suggested for both earthquakes. As Petrinja is only 3 km from the fault, while Siscia is 12 km away, a similar intensity value for the farther city suggests higher magnitude for the Siscia earthquake, higher than M 6.4. Modeling is needed to address this problem.

6 Conclusions

Walls of the Roman town Siscia (now Sisak, Croatia) were excavated: spectacular features of collapse were documented: out-of-plane toppling of an entire, 2 m thick, more than 3 m high wall into the moat, and in-plane extensional fissures. We bring forward evidence that collapse was caused by an earthquake between the 3rd and 5th century AD. It was an intensity IX event on the EAE13 archaeoseismological scale. Siscia being farther from the active strike-slip fault than Petrinja, which suffered a M 6.4 earthquake on 29 December 2020, we suggest that the Siscia earthquake in Antiquity was stronger than the contemporary event.

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