Published as

Al-Tawalbeh, M., Jaradat, R., Al-Bashaireh, K., Al-Rawabdeh, A., Gharaibeh, A., Khrisat, B., and Kazmer, M. (2020): Two inferred Antique earthquake phases recorded in the Roman theater of Beit Ras / Capitolias (Jordan). – **Seismological Research Letters** 92(1), 564-582. https://doi.org/10.1785/0220200238 [online] [pdf]

Two Inferred Antique earthquakes recorded in the Roman theater of Beit-Ras / Capitolias (Jordan)

Mohammad Al-Tawalbeh[1], Rasheed Jaradat[2], Khaled al-Bashaireh[3], Abdulla Al-Rawabdeh[4], Anne Gharaibeh[5], Bilal Khrisat[6], Miklós Kázmér[1,7]

1- Department of Paleontology, Eötvös University, Budapest Hungary.
2- Department of Earth and Environmental Sciences, Yarmouk University, Irbid 21163 Jordan.
3- Department of Archaeology, Yarmouk University, Irbid 21163 Jordan.
4- Department of Earth and Environmental Sciences & Applied Geoinformatics Laboratory, Yarmouk University, Irbid 21163 Jordan.
5- Department of City Planning and Design, College of Architecture and Design, Jordan University of Science and Technology, Irbid 22110, Jordan.
6- Department of Conservation Science, Queen Rania Faculty of Tourism and Heritage, The Hashemite University, P. O. Box 330127, Al-Zarqa.
7- MTA-ELTE Geological, Geophysical and Space Science Research Group, Budapest, Hungary.

Abstract

A Roman theater is recently being excavated at Beit-Ras/Capitolias in Jordan, which is one of the Decapolis cities, founded before 97/98 AD. This is an archaeoseismological study that aims to investigate temporal and intensity impacts on the existing structures. A rich set of Earthquake Archaeological Effects (EAEs) are identified, including deformed arches, tilted and collapsed walls, chipped corners of masonry blocks, and extensional gaps indicating a seismic intensity of VIII-IX.

Contrary to the long lasting belief that the 749 AD event is the main candidate earthquake damaging most of the Decapolis cities, the study found that at least two major older earthquakes damaged the site and may have led to the abandonment of its major use as a theater at different periods. This is based on field observations of construction stratigraphy and damage features and on the assessment the observed destruction and on reports in literature. The date of the first event is bracketed between the establishment of the city (before 97/98 AD) and an inscription in the walled-up orchestra gate in 261 AD. This earthquake destroyed the external wall of the theater's external annular passageway (*ambulatorium*), the *scaena*, and its staircases. The most likely candidate earthquake is 233 AD or other event which is not mentioned in any catalogue. After restoration, another earthquake occurred between 261 AD and Late Roman-Early Byzantine times, when the *scaena* wall tilted and collapsed, rendering the building useless and beyond repair. It is probably 363 AD earthquake. Filled up with debris, the theater went out of use. The paper provides a rich discussion of potential causative earthquakes based on archaeoseismological, construction stratigraphy observations, and calibrated intensity of historical earthquake-based

attenuation modelling. It identifies the potential phases and types of destruction and reuse. It is setting the grounds for future archaeological and seismological research on this site.

Keywords: Archaeoseismology, Roman theater, Capitolias, Jordan, Antiquity, Middle Ages, earthquake, construction stratigraphy, attenuation equation.

Introduction

The Dead Sea Transform Fault (DST) is the main tectonic element in the Middle East. It is a left-lateral transform fault, defining the boundary between Sinai and the Arabia sub-plates (Garfunkel and Ben-Avraham, 1996) (Fig. 1). Several instrumental and historical catalogues describe the seismicity of the region in detail (Guidoboni et al., 1994; Guidoboni and Comastri, 2005; Ambraseys, 2009; Zohar et al., 2016). However, both documentary and archaeological records of historical earthquakes (see Marco, 2008 and Schweppe et al., 2017, with abundant references) are mainly concentrated on events that are located between the Dead Sea Transform and the Mediterranean Sea, while there is very little information available on historical seismicity effects east of the DST fault, especially across Jordan. This is either due to the lack of earthquakes, which is not plausible, or to the paucity of historical sources (Niemi, 2007). Seismic hazard assessment studies require accurate and complete information about historical seismicity. Thus, it is imperative to increase the number of archaeoseismologically investigated archaeological sites east of the Dead Sea Transform Fault.

Archaeoseismology is the study of historical earthquakes based on understanding the physical, social and cultural effects and changes of ancient places (Stiros, 1996). It contributes to close gaps in the historical earthquake record (Kazmer, 2020), enriches the knowledge of the temporal and spatial distribution of earthquake damage (Marco, 2008), and presents data of more than a thousand years into the past (Kázmér and Major, 2015). Within the Middle East, there are a multitude of well-preserved masonry buildings that are ideal for archaeoseismological studies (e.g. Harding, 1959; Segal, 1981; Retzleff, 2003; Kázmér, 2015), along the DST (Marco et al., 1997; Ellenblum et al., 1998; Meghraoui et al., 2003; Haynes et al., 2006; Ellenblum et al., 2015), and in the vicinity of the DST fault (Marco et al., 2003; Korjenkov and Erickson-Gini, 2003; Thomas et al., 2007; Al-Tarazi and Korjenkov, 2007; Marco, 2008; Wechsler et al, 2009; AL-Azzam, 2012; Alfonsi et al., 2013; Kázmér and Major, 2010, 2015; Korjenkov and Mazor, 2014; Hinzen et al., 2016; Schweppe et al., 2017, Al-Tawalbeh et al., 2019, and Jaradat et. al., 2019). These studies indicate a rising interest in archaeoseismology as a research topic around the DST.

This research presents the results of a detailed archaeoseismological study of a recently excavated theater at Beit-Ras / Capitolias, located 23 km east of the DST in northern Jordan. The study is based on understanding construction stratigraphy from the time of theater's construction until its abandonment, and the correlation of existing observations against direct and indirect existing earthquake evidences. This correlation allows clarification of potential earthquake damage scenarios within the site and the surrounding area, with an emphasis on the Roman and Byzantine era.

Capitolias/Beit-Ras Theater

Capitolias (Beit-Ras) was one of the Decapolis cities of the Levant, extending from Damascus in the north to Philadelphia (today Amman) in the south. It is located 70 km north of Amman (Fig. 1), at an elevation of about 600 m above sea level. It was founded before 97/98 AD and the city flourished during the Roman and Byzantine time until the Early Islamic (Umayyad) period (Lenzen and Knauf, 1987). Descriptions of 19th century travelers

(Seetzen, 1810; Buckingham, 1821; Schumacher, 1890), and 20th century archaeological excavations (Glueck, 1951; Mittmann, 1970; Al-Shami, 2005, Młynarczyk, 2017, 2018) yielded sufficient information for understanding the history and the general plan of the city (Fig. 2).

A medium size theater was found buried underneath rubble landfill. It was localized and excavated in the years since 1999 (Al-Shami, 2003, 2004, 2005; Fayyad and Karasneh, 2004; Karasneh and Fayyad, 2005; Lucke et al., 2012). It is located north of the city of Capitolias/Beit-Ras hill (Fig. 2 and 3) (32° 35' 56.4" N, 35° 51' 32.2" E). The foundations of the theater are erected on hill slope outcrops of the Umm Rijam Chert Formation, that was described by Powell (1989) as light-colored limestone (Eocene), bearing chert nodules, and of deep marine origin.

Roman theaters–developed from the Greek theaters–usually have recognizable and well-defined architecture built after the traditions as described by Vitruvius (Dodge, 2009). In the same notion, Beit-Ras theater is found very similar in the overall structure and in the small details to other Greek and Roman theaters.

Greek and Roman theaters have developed names for their structural parts. Likewise, if we follow the Roman naming of the theater parts, this theater's major parts are: the *cavea* (the semi-circular rows of seats for the audience of common people). the *orchestra* (where high-ranking citizens were seated), the *stage* (where actors performed), the *aditus maximus* (the main side passageways into the *orchestra*), and the *scaena* (a high, decorated backstage wall, which provided the acoustic quality for everyone in the theater), *ambulatorium*, an external annular passageway surrounding the upper seat rows. Common people used to enter the *cavea* from this annular passage via six radial corridors, called *vomitoria*, with horizontal floors and inclined barrel vaults. These radial *vomitoria* passages lead people to the *praecinctio*, a semi-circular narrow floor all around the *cavea* about halfway in elevation between the lowest and highest seat rows (Fig. 4) (Sear, 2006).

Methodology

The adopted methodology is based on the following main steps:

1- Identifying and documenting various damage anomalies within the building that can be described as earthquake features. Each feature was measured and described, based on careful field work (Spring 2019 - Fall 2020). The observed features were documented through drawings and photographs using single shots and structure-from-motion techniques. Dimensions, orientation, and tilted angles were measured using a geological compass, laser range finder, measuring tape, and clinometer.

2- Describing the original shape of the theater at the time of construction and comparing it with its present shape. The functional parts of the theater of Capitolias, based on our observations during field work (Spring 2019 - Fall 2020), were described based on careful reading of the reports of the archaeological investigations (Fayyad and Karasneh, 2004; Karasneh and Fayyad, 2005) as well as the Sears' (2006) monumental handbook on Roman theaters. Through understanding the role of each constructional element, existing deviations from the norm can be recognized and identified in terms of construction, destruction, and restoration features.

3- Characterizing the stratigraphic sequence of construction and phases formed the basis for understanding the chronological succession of construction, destruction, restoration, and repairs (Anastasio et al., 2016). Elements of stratigraphy are dated using published literature, available inscriptions, and the interpretation of radiocarbon data.

4- Correlating the stratigraphy sequences of the theater and phases against identified damage evidences to constrain damage to a given interval/s.

5- Defining potential seismic intensities based on the Earthquake Archaeological Effect (EAE) scale (Rodríguez-Pascua et al., 2013).

6- Discussing and proposing the most probable sequences of historical event/s, which could produce the observed damages and those which could not. This is based on historical documentation and the main historical earthquake catalogues of the DST region, and estimating plausible seismic intensities (MMI). For these events, seismic intensities (MMI) were estimated based on a new attenuation equation developed for the Dead Sea region (Hough and Avni, 2009), taking into consideration site amplification conditions (Darvasi and Agnon, 2019).

Results

Earthquake-Related Damage Features

Careful investigation indicated several observed damage features across the theater structure that can be attributed to seismic origin, including: displaced arches, chipped corners and edges of masonry blocks, tilted and collapsed *scaena,* extensional gaps and broken stairs (Fig. 5).

Displaced Arches

Three different styles of arches are seen in the theater: semicircular or arcuated, segmental and flat. They were built out of wedge-shaped stones arranged in various shapes of an arch. Two arcuate arches are seen above the eastern gates (*aditus maximus*) while the adjoining vault is damaged and partly collapsed. The flat arches are seen as the lintel arches above stage gates (Fig. 6a). The eastern stage-gate (*versurae*) (trending N-S) has a flat arch and a stress-releasing segmental arch above, where two stones of the flat arch dropped down almost 3 cm (Fig. 6b). The keystone of the segmental arch above is also dropped down ~4 cm (Fig. 6d). The flat arches of most *vomitoria* to the *cavea* also are dropped down (Fig. 6c).

Masonry arches are common above openings in walls, spanning wall openings by diverting vertical loads from above to compressive stress laterally (Dym and Williams, 2010). Dropped arches in a masonry building indicate an Earthquake Archaeological Effect (EAE) having an earthquake intensity of VII or more (Rodrigue-Pascua et al., 2013).

Chipped Corners and Edges of Ashlars

Chipping of stone corners can occur during ground motion at any structure, especially the ones with well-cut/sharp-edged blocks. This is because a large pressure is applied more on the corners than other parts (Marco, 2008). The orchestra gates display spectacular examples (Fig. 7), suggesting seismic intensity of VII or more (Rodrigue-Pascua et al., 2013).

Tilted and collapsed walls

Figure (8) shows a deviation of the *scaena* wall from the vertical towards the north by 8°. Also, a vertical buttress wall (portion of the city wall) was erected behind the tilted *scaena* wall (Fig. 5 and 8). The normal elevation of the *scaena* is presumed to be the same as the colonnade on top of the *cavea* or even higher (i.e almost 13 m). Today, only the lower 5.2 m of the *scaena* is preserved. Tilted and collapsed archaeological walls suggested an EAE seismic intensity range of IX and higher (Rodrigue-Pascua et al., 2013).

Shifted Blocks and Extensional Gaps

A number of out-of-plane extruded and shifted blocks are observed and developed across single or multiple masonry courses (Fig. 8b+c). Such features are typically associated with intervening gaps produced due to shaking directed at high angle to the wall (Kázmér, 2014), suggesting an intensity range of IX and higher (Rodrigue-Pascua et al., 2013).

Discussion

Relative Succession of Events and Phases

The Foundation of Capitolias and the Construction of the Theater

The Roman domination over the region extended from 63 BC until 324 AD (Stager et al., 2000). According to Lenzen and Knauf (1987), based on numismatic and epigraphic evidence, the city reached its peak of prosperity in the latter half of the second century and the first half of the third century AD, and the evidence of the coins suggests that the city certainly existed when coins were minted at Capitolias in 97/98 AD (Spijkerman, 1978).

The good financial/economic position of the city promoted the construction of a theater—usually a project of decadal duration—possibly as early as the coins were minted (i.e. at the end of the first century AD). The theater was built against a hill slope, a typical engineering solution until the end of the 2nd century AD (Sear, 2006). According to Frézouls (1959), many theaters were built in the region throughout the 1st to 3rd centuries.

The First Damage and Reconstruction Phase

In-situ observations indicate that the eastern orchestra gate displays a complex construction and reconstruction history. This is concluded based on existing differences in construction material, practice and observed masonry structures (Fig. 9). The eastern arched gate (*aditus maximus*) was made of well-cut and good-quality compact phosphatic limestone courses. Normally, it is open for its entire height and opens into the *ambulacrum*, the perimeter corridor connecting all entrances (*vomitoria*) to the theater (Sear, 2006). This corridor is now missing, as can be seen right above the gate where the lower two rows of the ashlars forming the barrel vault are preserved right above the gate (Fig. 5a). The gate is walled up to the top by locally extracted marly to chalky limestone ashlars, which is a lower quality material (i.e. highly weathered and soft) compared to the phosphatic limestone ashlars of the original wall and arch. The infill wall contains a significant inscribed stone, bearing the year 261 AD (Fig. 9c).

The inscription is Greek written in seven lines, and is now in a vandalized state. It translates as follows: <u>*In honour of the victory of our lord, Gallienus Augustus, at a time when Numerius Severus was governor and Aurelius Andromachos, excellent man and administrator was responsible for the works of this building in the year of 163*</u> (translated from the French manuscript of Bader and Yon, 2018). The year 163 of the Greek calendar corresponds to a date between 259 AD and 261 AD of the Julian calendar. The sole rule of Emperor Gallienus (without co-emperor Valerius) started in 260 AD. Therefore, the inscription was erected in 260 AD or 261 AD. It marks the completion of a restoration process after at least one pronounced damaging event, probably an earthquake, which included the rebuilding of the *scaena* with staircases and of the stage gate. The *ambulacrum* was not rebuilt; instead, the *orchestra* gate and four of six *vomitoria* were walled up. Another case is where the marly to chalky limestone of poorer quality was used to build the wall, to the right of the eastern gate, where the original wall is joined by irregular suture (Fig. 9d). However, the edges of some blocks of the original arch are cracked and spalled off (Fig. 7d). Spalled-off edges are held in place by blocks of the infill wall, indicating that spalling occurred after its construction. According to these observations, it is strongly believed that the theater was originally built of a well-cut and good-quality compact phosphatic limestone that was probably derived from distant quarries, while for an unknown reason subsequent reconstruction and restoration were carried out using marly-chalky limestone that was extracted locally from strata outcropping within the theater and its vicinity.

The basalt masonry in the upper left (Fig. 9f) suggests a later local collapse and repair phase, where the basalt courses are overlaying the marly-chalky limestone to the left of the walled arched eastern gate.

It can be understood that the original theater was heavily damaged by an earthquake, where the perimeter corridor, the *ambulacrum*, the staircases and the *scaena* were damaged beyond repair, while the lateral portions of the *cavea* survived, including the eastern arched gate of the *aditus maximus*. Subsequent restoration was made using stones of inferior quality for the *scaena*. The staircases and the eastern stage gate were re-built (still visible today), while the *ambulacrum* was not. Instead, the gate to the *aditus maximus* was walled up and marked with a dedicatory inscription. All these were built before 261 AD, the date of the inscription. A subsequent earthquake cracked the ashlars of the gate, causing stone spalling and breaking off. Finally, the basalt stone portion of the wall is evidence for a later local damage and repair at an unknown time (Fig. 9f).

As mentioned by Russell (1980), during reconstruction the archaeological evidence of earthquake destruction may consist solely of extensive rebuilding features postdating the time of the collapse. The evidence of which event (or events) caused the damage to the theater structure is not exactly clear, but it caused a substantial reconstruction that is still present. It is important to note that the *scaena* and the staircases are the most vulnerable parts of any theater, and are built of relatively thin walls, bordered by vertical planes inside and outside. The lack of a postscaenium (the dressing-rooms for actors) in Capitolias adds to the structural vulnerability. The *cavea*, however, is a robust structure, bordered by an external vertical wall, and internal slope: it provides stability like that of a pyramid. The *ambulacrum* was again a wall like the *scaena* vulnerable to seismic shaking. As one thin-walled structural element, the *ambulacrum*, is lacking, while another one, the *scaena* wall, was rebuilt from the foundations; it is a well-founded hypothesis that an earthquake destroyed these walls beyond repair. The idea that the previously collapsed *ambulacrum* is further evidenced by the walling up with chalk limestone masonry on four of the six *vomitoria*This was probably done at the same time as when the eastern gate was walled up.

The Conversion of Use Phase (i.e. Conversion into an Amphitheater)

Observations strongly indicate that after the first collapse and subsequent reconstruction as a theater, the building was transformed into an amphitheater. As different forms of theater entertainment vanished, gladiatorial games and animal displays became the norm in the Eastern Mediterranean (Segal, 1981; Retzleff, 2003; Sear, 2006; and Dodge, 2009). These changes rendered the *proscaenium*, the stage, and the *scaena* obsolete. In Capitolias theater, the orchestra's floor was then deepened to 3m below the level of the former stage to contain the danger of the wild animals. Additionally, the diameter of the orchestra semi-circle was increased at the expense the lowest rows of seats. Three refuges were carved into the face of the new wall of raw rock, which was plastered and color painted. The *proscaenium*, the frontal side of the stage, was removed as was the stage, and the remaining space was outlined by a wall of recycled stones arranged to form an oval *arena* (the orchestra foreground) (Fig. 10). The relative age of this substantial conversion is established by the deepening of the floor of the eastern *aditus maximus* by about 1.5 meters, as far as the 261 AD walled-up gate, making it essentially useless. A canal was carved into the floor of the *arena*, possibly to allow the introduction of caged animals (Fig. 10).

Converting an existing theater into an amphitheater was quite common. For example, the Myrtusa Theater in Cyrene (Libya) has seen the removal of some rows of seats. The *scaena* was demolished to give place to rows of seats, essentially creating a pseudo-amphitheater. At Stobi, Macedonia, the *scaenae frons* was preserved during transformation into a pseudo-amphitheater at the end of the 3^{rd} century AD. Instead of deepening the orchestra, a thick masonry wall was added to the *podium* to increase its height to 3.60 m (Sear 2006). Similar modifications were frequent in the Eastern Mediterranean, as seen at the theaters of Ephesus, Pergamum in Anatolia, Corinth, Dodona, Philippi and Athens in Greece (Dodge, 2009).

The Second Collapse and Abandonment Phase

It is likely that after the conversion into an amphitheater, at least one other earthquake was responsible for deformation seen in the *scaena* wall (i.e. tilting, shifted stones, dropped keystones, stones rotations). The *scaena* itself is strongly tilted towards the north, so much so that 2/3 of the original height collapsed and is missing, and leaving behind only a 3-5 m high truncated wall. This seismic event definitely contributed to the theater's abandonment, when all damage remained unrepaired (Karasneh et al., 2002). Later, a buttress wall was built to support the tilted *scaena*, making it a part of the city wall.

The second collapse of the theater certainly occurred after the conversion into an amphitheater and before buttressing the *scaena* wall system. This succession of events is proven by the severely damaged *vomitoria* arches, which were left unrepaired. It can be suggested that this final collapse led to a final abandonment of the theater / amphitheater.

Retzleff (2003, her footnotes 34, 35) mentioned that while some theaters (Antipatis and Diacaes on the Mediterranean coast and Philadelphia, today Amman) were abandoned after the 363 AD earthquake, and others were restored and used up to the 5^{th} and 6^{th} centuries: Caesarea, Daphne, Neapolis, Scythopolis, and Shuni. The Capitolias theater fits in this range and suffered catastrophic damages in a 4^{th} century earthquake.

The Second Restoration Phase (i.e. Conversion into a Fortification)

The unused theater structure was kept standing by a buttress wall, 1.5 m thick joining the 1 m thick tilted *scaena*. This wall encircled both staircases, providing support to the damaged northern facade. Also, there are two walls (part of the city wall) adjacent to the eastern side of the theater (trend NW-SE) (Fig. 3 and 5).

According to Lenzen (1990) the city wall was constructed during Roman times. It was found that it connects with the buttress wall all around the *scaena* and the two staircases and blocks all doors (Fayyad and Karasneh, 2004). This part of the city wall (buttress wall) includes stones from parts of the theater. It could have been constructed during Late Roman-Early Byzantine time to strengthen the defense of the northern part of the city (Fayyad and Karasneh, 2004).

Mlynarczyk (2017) dated a portion of the city wall that has a width of 2.5 m and is located 140 m west of the theater to not later than 2^{nd} century AD, based on ceramics embedded in abutting floor levels. We think that this dating is not valid for the portion of the city walls adjacent to the theater, where the buttress wall is 1.5 m thick. At this time, the building was still functioning as designed, as a theater or amphitheater, as proven by the inscription dated 261 AD (Bader and Yon, 2019). The original city wall was probably somewhere to the south of the theater at that time. The city wall, which blocks most entrances of the theater, was built later, most likely after the 2^{nd} damaging earthquake. Mlynarczyk's doubts can be accepted on 'tentatively dated' and 'not easy to be dated' ceramics from the lower two phases levels abutting the wall. However, we agree with her assignment of the upper phase (fifth phase) of the wall as late Roman ($4\text{-}5^{th}$ century), and consider this period as *terminus ante quem* when the wall was constructed.

The Landfill/Burying Phase

Following the final abandonment, the empty space above the *cavea*, *orchestra* and stage was filled up naturally and/or deliberately with sand and debris (Fig. 11), composed of sand-sized to boulder-sized clasts and containing fragments of ceramics and thin charcoal layers. It was interpreted by Lucke et al. (2012) as fluvial sediment, indicating an Early Medieval wet period. The lack of any sizeable natural drainage in the city makes this suggestion untenable. Several meters of thickly packaged and steeply dipping, parallel, decimeter-thick layers makes the succession similar to a man-made landfill used as a dump of quarry and construction garbage, where materials were dumped up to the entire volume contained by the theater walls, and they even buried the retaining wall in the north. However, the idea that the theater was used as water cistern cannot be overlooked, a suggestion that was mentioned by Karasneh and Fayyad (2004).

It is most likely that the sediment burying the theater can roughly be dated as Late Roman, Byzantine, and Umayyad, since it contained a chaotic mixture of ceramics from these ages, including stamped Late Roman pottery. Four ash bands were identified across the fill material. C^{14} dating indicated that the major part of the sediment was deposited approximately between 521 and 667 AD (Lucke et al., 2012). This is the period before and during the early years of the Umayyad caliphate (661-750 AD). Considering the error of radiocarbon dates measured on old timber (Schiffer, 1986), it is difficult to know exactly how old the living tree and age of dead wood was when carbonized. This is a *terminus post quem* for the deposition of the landfill.

How Many Earthquakes?

Most archaeoseismological studies provide documentation of observed damage features, attempting to attribute these to a known earthquake based on historical data and architectural styles. There are very few studies where a site allows the distinguishing of more than one earthquake event, e.g. Selinunte in Sicily (Guidoboni et al., 2002), Al-Marqab (Kázmér and Major, 2010), Avdat (Korjenkov and Mazor, 1998), Mamshit (Korjeknov and Mazor, 2003), Haluza (Korjenkov and Mazor, 2005), Rehovot (four events: Korjenkov and Mazor, 2014), and Beit-Ras / Capitolias (this paper) in the Levant.

The theater in Beit-Ras displays at least two phases of damage or earthquake activitiy separated by a reconstruction event/phase, as postulated by an inscription dated 261 AD, and reconstruction approaches.

The first major proposed earthquake responsible for the destruction of the annular passageway*(ambulatorium*) was followed by a reconstruction that was marked by a 261 AD inscription. However, a definitive judgment on the time separating the first earthquake occurrence from its subsequent reconstruction, that was evidently concluded in a documentary or celebrational activity, is difficult to support.

The second earthquake activity resulted in tilting of the rebuilt *scaena* wall. As a result, the upper two-thirds collapsed, and the vaulted corridors were totally demolished, which were never to be restored again.

Attribution to Causative Earthquakes

The DST has been the source of several large historical earthquakes (Ambraseys and Jackson, 1998; Guidoboni and Comastri, 2005; Ambraseys, 2009), which are capable of producing large earthquakes with magnitudes of up to 7.5. According to Zohar et al. (2016), there were 71 known historical earthquakes along the DST fault during the period from 2000 BC until 1927. The Levant was hit 32 times during this time of which 21 earthquakes occurred after the first millennium and into the second. The last major earthquake was in 1995 with M_w 7.2, located about 80km to the south of Aqaba (Ambraseys and Jackson, 1998; Al-Tarazi, 2000), and was too far from Bait-Ras to cause any significant damage.

Several Middle East historical earthquake catalogues were consulted to identify the major damaging earthquakes (i.e. Russell, 1985, Guidoboni et al., 1994, Ambraseys, 2009, Abu Karaki,1987; Sbeinati et al., 2005; Ben-Menahem, 1979, 1991). The major damaging earthquakes belonging to the period between the 1st and 8th centuries are listed in table (1) and the towns affected by these earthquakes are marked in figure (1).

During the lifetime of Capitolias theater, there were at least 13 events (Table 1). Five were probably coastal earthquakes (233 AD, 303/6 AD, 347 AD, 502 AD and 551 AD), while eight were produced by displacement along the DST (110/114 AD, 127/130 AD, 245 AD, 363 AD, 419 AD, 634 AD, 657 AD and 749 AD). Two of these were too weak, poorly documented, and too low in magnitude to cause any damage (127/130 AD and 347 AD). We are aware that even major damaging earthquakes might not be listed by existing catalogues. Further in-depth historical studies are needed to recover information about them.

In order to discuss potential causative relationships to candidate earthquakes, where observed earthquake archaeological effects (EAEs) produced a minimum seismic intensity of VIII-IX in the theater, an attempt was made to constrain the candidate events based on expected earthquake MMI intensities using a calibrated intensity-based attenuation model of the Dead Sea as proposed by (Hough and Avni, 2009) and developed by Darvasi and Agnon (2019) to incorporate site specific conditions (equation 1). The model incorporated site specific conditions (i.e. shear-wave velocity), local magnitude, and epicentral distances:

$$MMI = -0.64 + 1.7Ml - 0.00448d - 1.67\log(d) - 2.1\ln Vs30/655 \qquad (1)$$

where **MMI** is the Modified Mercalli Intensity, **Ml** is the local magnitude, **d** is the distance from the epicenter, and **Vs30** represents the average shear wave velocity from the surface to a depth of 30 m.

In this study, we reported a range of intensities assuming a Vs30 0f 360 and 800 m/s assuming soft rock and very dense soil material (according to the Eurocode 8 standard). Reported earthquake magnitudes were transformed into local magnitude Ml based on the model proposed by Al-Tarazi (2005). The results of the investigation are given in table (2) and Figure (13) shows the epicentral locations based on table (2).

The earthquakes considered as potential sources of damage to the theater of Beit-Ras / Capitolias are likely not all the earthquakes which have occurred there. Reading Zohar's catalogue (2017: his fig 5), there are 10 earthquakes known with some reliability in the first millennium, and 21 in the second millennium. Therefore, one can safely assume that as many major damaging earthquakes occurred in the first millennium as in the second.

The review of the causative earthquakes can be divided to two events. The first event that destructed the theater was between establishment of the city in 97/98 to 261 AD and the second candidate events, which caused the collapse and tilting of the *Scaena* followed by the abandonment of the theater (303-6 AD, 347 AD, 363 AD and 419 AD). The later earthquakes occurred post the abandonment and are also covered in this discussion.

Events Post the Establishment of the city

According to the first candidate events in this study, three events occurred within this period which are 110-114 AD, 130 AD, and 233 AD.

110-114 AD Earthquake

The 110 -114 AD earthquake is not the responsible event which caused considerable damage in the theater leading to the construction in 261 AD. The reason is that the rich citizens of Capitolias certainly did not wait so long, from 114-261 AD, to put their favorite theater—the place for public entertainment, social life, and display of wealth and power–to good use again.

130 AD Earthquake

About earthquake 130 AD, Ambraseys (2009) doubted the certainty of the sources of the 130 AD event. It is not certain whether they refer to the damage of Neocaesarea and Nicopolis in the Pontus (Niksar and Enderes, respectively) or Caesarea Maritima and Nicopolis (Emmaus) in Palestine, whilst the former position is more likely. His doubts have arisen because there were at least three towns in the Roman Empire called Nicopolis, and many called Caesarea. He mentioned that Nicopolis is very close to Jerusalem and he asked why was it that no damage was mentioned from Jerusalem, while a less significant Nicopolis was expressly mentioned? ~~Nicopolis~~ Besides, there is another pair of cities called Caesarea and Nicopolis, 110 km apart along the North Anatolian Fault. Accordingly, our suggestion is that the event 130 AD cannot be considered as a potential earthquake causing any damages to Capitolias**.**

233 AD Earthquake

The earthquake 233 AD has few resources, but its epicenter was identified along Tripoli-Beirut-Thrust Fault by El-Isa et al (2015) and its magnitude approximated to 6.2. According to attenuation equation (table 2), the intensity of this earthquake in Bait Ras ranged between V-VI. This intensity is very low to produce the high damage in the theater, it caused most of the damage farther to the north especially in Damascus (Ben-Menahem, 1979). It seems that it was a strong event that affected the area south of Lebanon and Syria. The discussion about these three candidate event suggest that there is not enough data in existing catalogue about the events which damaged the theater before 261 AD, although the event 233 AD is the most likely responsible earthquake.

***Scaena* collapse and tilting preceding the abandonment of the theater**

The second group of candidate events (303-6 AD, 347 AD, 363 AD, and 419 AD) may have caused *scaena* collapse and tilting preceding the abandonment of the theater. In the followings we discuss these events.

303-6 AD Earthquake

Most of the investigated catalogues reported that the severe earthquake damaging the cities of Sidon and Tyre was felt in Caesarea, possibly referring to the earthquake 303-6 AD. A record of a seismic sea wave indicated that this was rather a coastal earthquake, which probably had minimal impact east of the Jordan River (Guidoboni et al., 1994: 247; Ambraseys, 2009: 140). The location of the epicenter was reported by Ambraseys (2009) along the Roum Fault (South of Lebanon), meanwhile, Abu Karaki (1987) and Sbeinati et al. (2005) reported the epicentral location further to the west within the eastern Mediterranean. This event largely destructed many ancient towns in the southern part of Lebanon (Table 1 and Fig. 1). According to earthquake observations and attenuation modelling (Table 2), the intensity in Beit-Ras was V-VIII. Thus, this event cannot be excluded as is most likely the one causing damage in Capitolias.

347 AD Earthquake

There is a single historical source that mentions a catastrophic destruction only restricted to the city of Berytus (Beirut) that took place in 347 AD (Guidoboni et al., 1994: 254; Ambraseys, 2009: 144). However, there is nothing in Russell (1985) on this event. The epicenter location is mentioned only by Abu Karaki (1987).

363 AD Earthquake

It is given by Guidoboni et al. (1994: 264-265) and Ambraseys (2009: 148-151) that multiple historical sources report the 363 AD event, giving the exact date: 19 May, 363 AD. This might mean that both a northern and a southern segment of the Dead Sea Transform slipped, one after the other. Levenson (2013) provided names of 21 to 23 destroyed cities. Russell (1985) briefly described archaeological sites within the area of destruction. Several contemporary inscriptions are mentioning the earthquake or the succeeding reconstruction. The area of destruction extended from Baniyas in the north of Syria to Ayla in the south of Jordan; and from the coastal littoral of the Mediterranean through the Jordan Valley and beyond, i.e. Capitolias was certainly heavily damaged. According to earthquake observations and attenuation modelling (Table 2), the intensity in Beit-Ras reached to an intensity of VIII. One of these candidate earthquake caused the abandonment of the site followed by the conversion of the theater body to a fortification. This conversion was by connecting the city wall with the theater's body adding the buttressing wall in front of the tilted *s* Another evidence for more than one earthquakes is the variation of damage seen within the dropped arch stones. Usually, an arch stone drop occurs when ground motion is parallel to the trend of the arches (Hinzen et al., 2016; Martín-González, 2018) or if it is ±45° to their strike (Rodriguez-Pascua et al., 2011). Evidently, the arches in the theater have different trends and their stones are dropped down (Fig. 5), so this indicates that Capitolias was hit by more than one earthquake. Fig. 12 illustrates a timeline of the successions and major phases of the theaters and two major collapse events at the theater.

caena. So, the date of the earthquake is very close to the date of building the buttress wall. This is an excellent occasion to attempt radiocarbon dating of mortar (Al-Bashaireh, 2016) to estimate constraints of the date of potential seismic events. This can be done in future researches. According to the above discussion of the damage, the responsible event should have been very intense to cause considerable damage and abandonment.

The available data does not give a fit location for the earthquake 303-6 AD earthquake epicenter which occurred 45 years after before the reconstruction. It can be suggested that this earthquake could cause damage at the theatre, but it did not cause the abandonment. It It may suggest that this earthquake caused damage at the theater, but it certainly did not cause the abandonment. Evidently, it may have been responsible for the destruction in the western part of the theater which has been followed by the reconstruction in basalt stones (Fig. 9f). The event 363 AD is the most likely earthquake, because it was proved by many resources and it was a powerful event in the area which had the capability to produce damage at the theater up to VIII.

419 AD Earthquake

It was an event felt and recorded in Jerusalem only Russell (1985); Ambraseys (2009); Guidoboni et al (1994), without evidence for any major damage anywhere.

Post abandonment

The later earthquakes (i.e. 502, 551, 634, 659 and 749 AD) have occurred after the site was abandoned, during and after filling up the *cavea* and *orchestra* of the theater by debris, where most the theater body became buried underneath the rubble. While any damage may result from more than one earthquake, which may have even occurred much later after the structure was abandoned (Ambraseys, 2006: 1014), this is fortunately not the case in the theater of Beit-Ras. We believe that filling up the *cavea* and *orchestra* of the theater happened parallel with the construction of the enclosing wall, that essentially put all of the remaining building underground. Underground facilities are significantly less vulnerable to seismic excitation than that above-ground buildings (Hashash et al., 2001). Understandably, when each wall and arch are supported by embedding sediment (dump in Beit-Ras), the deformations observed on the excavated theater (Al-Shami, 2002; 2004) mostly cannot be developed unless unsupported. Therefore, evidence of these subsequent events, such as 551, 634, 659 and 749 AD, cannot be observed since the possibility of collapse of buried structures can be excluded. However, potential collapse to other structures with the site cannot be ignored or it could affect the upper part of the theater body, which was still exposed during filling the theater by the debris, that might be collapsed by these later earthquakes. The collapsed parts mixed with the debris which was documented by the Department of Antiquity excavations (Al-Shami, 2003, 2004). Another example affecting the later events is in 749 AD where Mlynarczyk (2017) attributed the collapse of some sections of the city wall of Beit-Ras based on the concentration of collapsed ashlars and the results of collected pottery from two trenches excavated to the west of the theater structure.

Conclusion

This research studied the archaeological stratigraphy of the Beit-Ras/Capitolias theater and the existing archaeoseismic damage features aiming to outline the relative chronological succession of the various phases of construction, destruction, and subsequent repairs. Parts of the theater vary in construction techniques and/or materials, which suggests possible temporal differences in the time/age of construction. The stratigraphy of the building was correlated with earthquake indicators and it was found that at least two severe earthquakes have damaged the building. Also, attenuation modeling was conducted to estimate the probable candidates for historical earthquake event/s. It is most likely that the first event occurred sometime between 98/97 AD to 261 AD, which resulted in the collapse of the external perimeter corridor (*ambulacrum*) and the eastern c*avea*. The second event occurred between 261 AD and the Late Roman-Early Byzantine times, which resulted in tilting of *the scaena* wall and collapses. Reviewing the seismicity of the Levant area of the 1st millennium indicates that the documentation of the main events were poor, so the first damage could have been caused by unknown event, but we suggest that 233 AD is potential causative event responsible for the destruction that preceded the major reconstruction prior to 261 AD. The

303-6, 363, and 419 events are candidates that severely damaged the theater of Capitolias ,but the event 363 AD is the most likely which caused the abandonment and subsequent burial. The later events such as 551, 634, 659, and 749 AD occurred when the theater was beneath the rubble. It cannot be excluded that other events, not mentioned in historical catalogues, contributed to the destruction of the theater. According to EAEs, the size of the earthquake damage was at least VIII-IX for both events.

Data and Resources

Archaeoseismological and archaeological stratigraphy data were collected in-situ from fieldwork at the theater, and from publications of Department of Antiquity reports, Jordan. APAAME: Aerial Photographic Archive of Archaeology in the Middle East (APAAME), archive accessible from: www.humanities.uwa.edu.au/research/cah/aerial, the last access was 8/7/2020.

Acknowledgements

This study is part of the "Mapping Archaeoseismic Damages across Jordan (MADAJ)" research project, conducted under the approval of the Department of Antiquities of Jordan. The project is led by Yarmouk University and in collaboration with Hashemite University and the Jordan University of Science and Technology. Mohammad Al-Tawalbeh enjoyed a Stipendium Hungaricum PhD scholarship while preparing this study. The American Center for Oriental Research (ACOR) in Amman provided access to its excellent library. Krzysztof Gaidzik (Sosnowiec, Poland), Balázs Székely (Budapest, Hungary), Yacine Benjelloun (Paris, France) provided advice and shared their ideas. The Department of Antiquities of Jordan kindly permitted the publication of this study. We are indebted and grateful to all of them.

References

Abu Karaki, N. (1987). Synthese et carte sismotectonique des pays de la bordure orientale la mediterranee: Sismicite du systeme de failles du Jourdain-Mer Morte, Ph. D. thesis, University of Strasbourg, in French.

Al-Azzam, N. (2012). Investigating earthquake damages of the ancient city of Gadara (Umm Qais): an archaeoseismological approach. MSc thesis, Yarmouk University, Irbid, Jordan.

Al-Bashaireh, K. (2016): Use of lightweight lime mortar in the construction of the West Church of Umm el-Jimal, Jordan: radiocarbon dating and characterization. *Radiocarbon* **58/3**, 583-598.

Alfonsi, L., F. R. Cinti, and G. Ventura (2013). The Kinematics of the 1033 AD Earthquake Revealed by the Damage at Hisham Palace (Jordan Valley, Dead Sea Transform Zone), *Seismological Research Letters* ***84*****(6)**, 997-1003.

Al-Shami, A. (2003). Beit Ras Irbid Archeological Project 2002, *Annual of the Department of Antiquities of Jordan* **47**, 93-104 (in Arabic).

Al-Shami, A. (2004). Bayt Ras Irbid Archaeological Project 2002, *Annual of the Department of Antiquities of Jordan* **48**, 11-22 (in Arabic).

Al-Shami, A. (2005). Anew discovery at Bayt-Ras /Capitolias – Irbid, *Annual of the Department of Antiquities of Jordan* **49**, 509-519 (in Arabic).

Al-Tarazi, E. (2000). The Major Gulf of the Aqaba Earthquake, 22 November 1995 – Maximum Intensity Distribution, *Natural Hazards* ***22*****(1)**,17-27.

Al-Tarazi, E. (2005). Investigation of the Effects of Earthquake Swarms in the Seismic Hazard in the Gulf of Aqaba, Northern Red Sea, *Dirasat, Pure Sciences* **32(1)**, 55-68.

Al-Tarazi, E., and A. Korjenkov (2007). Archaeoseismological investigation of the ancient Ayla site in the city of Aqaba, Jordan, *Natural Hazards* ***42*****(1)**, 47-66.

Al-Tawalbeh, M., M. Kázmér, R. Jaradat, K. Al-Bashaireh, A. Gharaibeh, B. Khrisat, and A. Al-Rawabdeh (2019). Archaeoseismic analysis of the Roman-Early Byzantine earthquakes in Capitolias (Beit-Ras) theater of Jordan. 7th International Colloquium on Historical Earthquakes and Paleoseismology Studies, 4-6 November 2019, Barcelona, (p. 19.).

Ambraseys, N. (2009). Earthquakes in the Mediterranean and Middle East: a multidisciplinary study of seismicity up to 1900, *Cambridge University Press*, Cambridge.

Ambraseys, N., and J. A. Jackson (1998). Faulting associated with historical and recent earthquakes in the Eastern Mediterranean region, *Geophysical Journal International* ***133*(2)**, 390-406.

Amiran, D. H., E. Arieh, and T. Turcotte (1994). Earthquakes in Israel and adjacent areas: Macroseismic observations since 100 BCE, *Israel Exploration Journal*, 260-305.

Anastasio, S., P. Gilento, and R. Parenti (2016). Ancient Buildings and Masonry Techniques in the Southern Hauran, Jordan, *Journal of Eastern Mediterranean Archaeology and Heritage Studies* ***4*(4)**, 299-320.

Bader, N., and J.B. Yon (2018). Une inscription du theater de Bayt Ras / Capitolias, *Syria* **95**, 155-168.

Ben-Menahem, A. (1979). Earthquake catalogue for the Middle East (92 B.C.-1980 A.D.), *Boll, Geofis. Teor. Appl* **21(84)**, 245-310.

Ben-Menahem, A. (1991). Four thousand years of seismicity along the Dead Sea Rift, *J. Geophys. Res* **96(B12)**, 20195-20216.

Buckingham, J.S. (1821) Travels in Palestine through the countries of Bashan and Gilead, east of the River Jordan, including a visit to the cities of Geraza and Gamala in the Decapolis. Longman, London, 553 p.

Darvasi, Y., and A. Agnon (2019). Calibrating a new attenuation curve for the Dead Sea region using surface wave dispersion surveys in sites damaged by the 1927 Jericho earthquake, *Solid Earth* ***10*(2)**, 379-390.

Dodge, H. (2009). Amphitheaters in the Roman East. In: Wilmott, T. (ed.): Roman Amphitheaters and Spectacula: a 21st-Century perspective. Papers from an internationalconference held at Chester, 16th-18th February, 2007, *BAR International Series*, 29-46.

Dym, C. L., and H. E. Williams (2010). Stress and displacement estimates for arches, *Journal of Structural Engineering* ***137*(1)**, 49-58.

El-Isa, Z., S. McKnight, and D. Eaton (2015). Historical seismicity of the Jordan Dead Sea Transform region and seismotectonic implications, *Arabian Journal of Geosciences* **8(6)**, 4039-4055.

Ellenblum, R., S. Marco, A. Agnon, T. Rockwell, and A. Boas (1998). Crusader castle torn apart by earthquake at dawn, 20 May 1202, *Geology* ***26*(4)**, 303-306.

Ellenblum, R., S. Marco, R. Kool, U. Davidovitch, R. Porat, and A. Agnon (2015). Archaeological record of earthquake ruptures in Tell Ateret, the Dead Sea Fault, *Tectonics* ***34*(10)**, 2105-2117.

Frézouls, E. (1959). Recherches sur les théatres de l'Orient syrien: Problèmes chronologiques, *Syria* **36(3-4)**, 202-228.

Fayyad, S., and W. Karasneh (2004). Archaeological excavation in Beit Ras theater, from first season to fifth season, *Annual of the Department of Antiquities of Jordan* **48**, 67-75 (in Arabic).

Glueck, N. (1951). Explorations in Eastern Palestine IV, *Annual of the American Schools of Oriental Research, 25-28.*

Guidoboni, E., A. Comastri, and G. Traina (1994). Catalogue of Ancient Earthquakes in the Mediterranean Area up to the 10th Century, *Istituto Nazionale di Geofisic*a, Bologna.

Guidoboni, E., and A. Comastri (2005). Catalogue of Earthquakes and Tsunamis in the Mediterranean Area from the 11th to the 15th Century, *Istituto Nazionale di Geofisica*, Bologna, 1037 p.

Guidoboni, E., A. Muggia, C. Marconi, and E. Boschi (2002). A case study in archaeoseismology. The collapses of the Selinunte temples (Southwestern Sicily): two earthquakes identified, *Bulletin of the Seismological Society of America* ***92*(8)**, 2961-2982.

Garfunkel, Z., and Z. Ben-Avraham (1996). The structure of the Dead Sea basin, *Tectonophysics* ***266*(1-4)**, 155-176.

Harding, G.L. (1959). The Antiquities of Jordan, Lutterworth Press, London, 223 p.

Hashash, Y.M., J. Hook, B. Schmidt, I. John, C. Yao (2001). Seismic design and analysis of underground structures, *Tunnelling and Underground Space Technology* **16**, 247-293.

Haynes, J. M., T. M. Niemi, and M. Atallah (2006). Evidence for ground-rupturing earthquakes on the Northern Wadi Araba fault at the archaeological site of Qasr Tilah, Dead Sea Transform fault system, Jordan, *Journal of Seismology* ***10*(4)**, 415-430.

Hinzen, K. G., I. Schwellenbach, G. Schweppe, and S. Marco (2016). Quantifying Earthquake Effects on Ancient Arches, Example: The Kalat Nimrod Fortress, Dead Sea Fault Zone, *Seismological Research Letters* ***87*(3)**, 751-764.

Hough, S. E., and R. Avni (2009). The 1170 and 1202 CE Dead Sea Rift earthquakes and long-term magnitude distribution of the Dead Sea Fault Zone, *Israel Journal of Earth Sciences* ***58***.

Jaradat, R., Kh. Al-Bashaireh, A. Al-Rawabdeh, A. Gharaibeh, and B. Khrisat (2019). Mapping Archaeoseismic Damages across Jordan (MADAJ). 2nd International Congress on Archaeological Sciences in the Eastern Mediterranean and the Middle East, 12-14 November 2019, The Cyprus Institute, Nicosia, Cyprus.

Karasneh, W., and S. Fayyad (2004). Archaeological excavations at Beit Ras Theater, working stages from the first season to the fifth season, *Annual of the Department of Antiquities of Jordan* **48**, 67-75 (In Arabic).

Karasneh, W., and S. Fayyad (2005). Beit Ras theater, *Annual of the Department of Antiquities of Jordan* **59**, 39-45 (In Arabic).

Karasneh, W., K. al-Rousan, and J. Telfah (2002). New discovery in Jordan at Beit-Ras region, (ancient Capitolias), *Occident and Orient* **7(1)**, 9-10.

Kázmér, M. (2014). Damage to ancient buildings from earthquakes. In: Beer, M., Patelli, E., Kouigioumtzoglou, I., Au, I. S.-K. (eds): Encyclopedia of Earthquake Engineering, Springer, Berlin, pp. 500-506.

Kázmér M, and E. Győri (2020) Millennial record of earthquakes in the Carpathian-Pannonian region – historical and archeoseismology. Hungarian Historical Review (in press).

Kázmér, M., and B. Major (2010). Distinguishing damages from two earthquakes Archaeoseismology of a Crusader castle (Al-Marqab citadel, Syria), *Geological Society of America Special Paper **471***, 185-198.

Kázmér, M., and B. Major (2015). Sāfitā castle and rockfalls in the 'dead villages' of coastal Syria–an archaeoseismological study, *Comptes Rendus Geoscience **347***(**4**), 181-190.

Korjenkov, A. M., and T. Erickson-Gini (2003). The seismic origin of the destruction of the Nabataean forts of Ein Erga and Ein Rahel, Arava valley, Israel, *Archäologischer Anzeiger* **2003/2**, 39-50.

Korjenkov, A. M., and E. Mazor (1998). Seismogenic origin of the ancient Avdat ruins, Negev Desert, Israel, *Natural Hazards **18***(**3**), 193-226.

Korjenkov, A. M., and E. Mazor (2003). Archeoseismology in Mamshit (southern Israel): Cracking amillennia-old code of earthquakes preserved in ancient ruins, *Archaeologischer Anzeiger* **(2)**, 51-82.

Korjenkov, A.M., and E. Mazor (2005). Diversity of earthquake destruction patterns: The Roman-Byzantine ruins of Haluza, Negev desert, journal name in full *Israel, Archaol. Anz* **(2)**, 1–15.

Korjenkov, A.M., E. Mazor (2014). Archaeoseismological damage patterns at the ancient ruins at Rehovot-ba-Negev, Israel, *Archäologischer Anzeiger* **2014/1**, 75-92.

Lenzen, C. J., and E. A. Knauf (1987). Beit Ras/Capitolias. A preliminary evaluation of the archaeological and textual evidence, *Syria* **64(1/2)**, 21-46.

Lenzen, C. J. (1990). Beit Ras excavations: 1988 and 1989, *Syria **67***(**2**), 474-476.

Lucke, B., M. Shunnaq, B. Walker, A. Shiyab, Z. al-Muheisen, H. al-Sababha, and M. Schmidt (2012). Questioning Transjordan's historic desertification: a critical review of the paradigm of 'Empty Lands', *The Levant **44***(**1**), 101-126.

Marco, S. (2008). Recognition of earthquake-related damage in archaeological sites: Examples fromthe Dead Sea fault zone, *Tectonophysics **453***(**1-4**), 148-156.

Marco, S., M. Hartal, N. Hazan, L. Lev, and M. Stein (2003). Archaeology, history, and geology ofthe AD 749 earthquake, Dead Sea transform, *Geology **31***(**8**), 665-668.

Marco, S., A. Agnon, R. Ellenblum, A. Eidelman, U. Basson, and A. Boas (1997). 817-year-old walls offset sinistrally 2.1 m by the Dead Sea Transform, Israel, *Journal of Geodynamics **24***(**1-4**), 11-20.

Martín-González, F. (2018). Earthquake damage orientation to infer seismic parameters in archaeological sites and historical earthquakes, *Tectonophysics **724***, 137-145.

Meghraoui, M., F. Gomez, R. Sbeinati, J. Van der Woerd, M. Mouty, A. N. Darkal, …and F. Hijazi (2003). Evidence for 830 years of seismic quiescence from palaeoseismology, archaeoseismology and historical seismicity along the Dead Sea fault in Syria, *Earth and Planetary Science Letters **210***(**1-2**), 35-52.

Mittmann, S. (1970). *Beiträge zur Siedlungs-und Territorialgeschichte des nördlichen Ostjordanlandes* **(2)**, Otto Harrassowitz Verlag.

Młynarczyk, J. (2017). Beit Ras/Capitolias: an archaeological project 2014–2016, *Polish Archaeology in the Mediterranean* **26/1**, 475-506.

Mlynarczyk, J. (2018). Archaeological investigations in Bayt Ras, ancient Capitolias, 2015: preliminary report, *Annual of the Department of Antiquities of Jordan* **59**, 175-192.

Niemi, T.M. (2007). Paucity of historical earthquakes south of the Dead Sea: Is it real? *American Geophysical Union Meeting*, San Francisco, California, Dec, 10-14.

Powell, J. (1989). Stratigraphy and sedimentation of the phanerozoic rocks in Central and Southern Jordan, Part B, Kurnub, Ajlun and Belqa Groups, *Natural Resources Authority*, Jordan, Amman. Bulletin 11B, p. 161.

Retzleff, A. (2003). New eastern theaters in Late Antiquity, *Phoenix* **57/1-2**, 115-138.

Rodríguez-Pascua, M., R. Pérez-López, J. L. Giner-Robles, P. G. Silva, V. H. Garduño Monroy, and K. Reicherter (2011). A comprehensive classification of Earthquake Archaeological Effects(EAE) in archaeoseismology: Application to ancient remains of Roman and Mesoamerican cultures, *Quaternary International **242***(**1**), 20-30.

Rodríguez-Pascua M., P.G. Silva, R. Pérez-López, J. Giner-Robles, F. Martín-González, M.A. Perucha (2013). Preliminary intensity correlation between macroseismic scales (ESI07 and EMS98) andEarthquake Archaeological Effects (EAEs). In: Grützner C, Rudersdorf A, Pérez-López R, Reicherter, K (Eds.), Seismic Hazard, Critical facilities and Slow Active Faults. PATA Days. Proceedings of the4th

International INQUA Meeting on Paleoseismology, Active Tectonics and Archaeoseismology(PATA), 9–14 October 2013, Aachen, Germany, pp. 221–224.
Russell, K. W. (1980). The earthquake of May 19. A. D. 363, *Bulletin of the American Schools of Oriental Research* **238**, 37-59.
Russell, K. W. (1985). The earthquake chronology of Palestine and northwest Arabia from the 2nd through the mid-8th century AD, *Bulletin of the American Schools of Oriental Research*, 37-59.
Sbeinati, M. R., R. Darawcheh, and M. Mouty (2005). The historical earthquakes of Syria: an analysis of large and moderate earthquakes from 1365 BC to 1900 AD, *Annals of Geophysics* **47**, 733-758.
Segal, A. (1981). Roman cities in the province of Arabia, J*ournal of the Society of Architectural Historians* **40/2**, 108-121.
Sear, F. (2006). Roman theaters: an architectural study. Oxford University Press.
Schweppe, G., K. G. Hinzen, S. K. Reamer, M. Fischer, and S. Marco (2017). The ruin of the Roman Temple of Kedesh, Israel; example of a precariously balanced archaeological structure used as a seismoscope, *Annals of Geophysics* ***60*****(4)**, 1-17.
Schiffer, M.B. (1986). Radiocarbon dating and the “old wood” problem: The case of the Hohokam chronology, *Journal of Archaeological Science* **13**, 13-30.
Schumacher (1890). Northern 'Ajlun "Within the Decapolis", *Palestine Exploration Fund*, London, 207 p.
Seetzen, U.J. (1810). Brief Account of the Countries Adjoining the Lake of Tiberias, the Jordan and the Dead Sea, *Meyler ad Son*, London.
Spijkerman, A. (1978). The coins of the Decapolis and Provincia Arabia. Edited by M. Piccirillo. Jerusalem, Franciscan Printing Press, Jerusalem, 322 p.
Stiros, S. C. (1996). Identification of earthquakes from archaeological data: methodology, criteria and limitations. editors, *Archaeoseismology* 7, 129-152.
Stager L.E., J. Greene, and M.D. Coogan (2000). The archaeology of Jordan and beyond: essays in honor of James A. Sauer, *J. Am. Orient. Soc* **121(4)**, 690–691.
Thomas, R., S. T.Parker, and T. M. Niemi (2007). Structural damage from earthquakes in the second: ninth centuries at the archaeological site of Aila in Aqaba, Jordan, *Bulletin of the American Schools of Oriental Research* **346(1)**, 59-77.
Wechsler, N., O. Katz, Y. Dray, I. Gonen, and S. Marco (2009). Estimating location and size of historical earthquake by combining archaeology and geology in Umm-El-Qanatir, Dead Sea Transform, *Natural hazards* ***50*****(1)**, 27-43.
Zohar, M. (2017). Earthquake damage history in Israel and its close surrounding evaluation of spatial and temporal patterns, *Tectonophysics* **696**, 1-13.
Zohar, M., A. Salamon, R. Rubin (2016). Reappraised list of historical earthquakes in Israel and its close surroundings, *Journal of Seismology* **20**, 971-985.

Full mailing addresses of each author

Mohammad Al-Tawalbeh: moh_tawalbeh89@yahoo.com
Rasheed Jaradat: rjaradat@yu.edu.jo
Khaled al-Bashaireh: kshanwan@yu.edu.jo
Abdulla Al-Rawabdeh: abd_rawabdeh@yu.edu.jo
Anne Gharaibeh: dr-anne@just.edu.jo
Bilal Khrisat: bilal@hu.edu.jo
Miklós Kázmér: mkazmer@gmail.com

Tables

Table (1): -A list of the major earthquakes of the DST from Roman to late Byzantine time.

Date	Sites that were damaged by or felt the earthquake	References
110-114 AD	- Caesarea, Hesban, Jerash and Petra, Advat (Partly Damage)	- Russell (1985); Ambraseys (2009)
127/130 AD*	- Caesarea (Severe damage)	- Amiran et al. (1994); Ambraseys (2009)

	- Lod (Strong earthquake) - Nicopolis (Emmaus) (Strong earthquake)	- Amiran et al. (1994) - Amiran et al. (1994) Ambraseys (2009)
233 AD	- Damascus (Destructive)	- Ben-Menahem (1979)
245 AD	- Occurred near Antioch Ml= 7.5	- Sbeinati et al. (2005)
303/306 AD	- Tyre and Sidon (Destructive) - Gush Halav (Destructive) - Byblus (May have affected) Caesarea (Felt)	- Russell (1985) ; Amiran et al. (1994) ; Ambraseys (2009) - Amiran et al. (1994) - Ambraseys (2009)
347 AD*	- Beirut (affected)	- Guidoboni et al. (1994); Ambraseys (2009)
363 May 19 AD	- Sebastia, Japho, Caesarea, Tiberias, Beit-Gubrin, Jerusalem and Petra (Severe damage) - Haifa, Gerasa and Lod(Severe damage)	- Amiran et al. (1994); Guidoboni et al. (1994) Ambraseys (2009) - Ambraseys (2009)
419 AD	- Jerusalem (Felt)	- Russell (1985); Ambraseys (2009); Guidoboni et al (1994)
502 AD	- Akko, Tyre and Sidon (Sever damage), Beirut (less damage)	- Guidoboni et al. (1994); Ambraseys (2009)
551 AD	- Tyer. Beirut, Sidon and Tripoli (worse damage) - Jerash (much damage) - Sarafand, Galiee and Samaria (some damage)	- Russell (1985); Amiran (1994); Ambraseys (2009) - Amiran (1994) - Ambraseys (2009)
634 AD	- Beit-She'an, Pella (affected) - Advat	- Guidoboni et al. (1994); Ambraseys (2009) - Korjenkov and Mazor (1998)
659 AD	- Jericho (Grate damage) - Jordan Valley, Beth Shean and Khan el Ahmer (Strong effect)	- Russel (1985); Guidoboni et al. (1994); Ambraseys (2009); Russell (1985) - Amiran (1994)
749 AD	- Powerful event in Palestine - Intensity X and epicenter along Jordan Valley Fault (Marco, 2003)	- Guidoboni et al. (1994); Ambraseys (2009) and Zohar (2017)
*: Poorly constrained.		

Table (2): A list of the major earthquakes of the DST from the Roman to late Byzantine time and estimated potential intensities. All Ms values converted to Ml by the model proposed by Al-Tarazi (2005). The corresponding location of epicenter marked in Figure (13).

Date		**Epicenter Location (°)**		**Reference**	**Reported Magnitude**	**Distance (Km)**	**Estimated Intensity (Darvasi and Agnon, 2019)**	**Intensity**
110-114 AD		30.70	35.30	Ambraseys (2009)	Ms=6 Ml= 6	217.63	4.26[a]* 5.93[b]*	IV [a]* VI [b]*
127/130 AD		Poorly documented.						
233 AD		34.4	35.5	El-Isa et al (2015)	Ml=6.2	200	6.4 4.7	VI V
303/306 AD	a	33.20	35.50	Ambraseys (2009)	Ms=6 Ml=6	74.78	5.67 7.35	VI VII
	b	33.50	35.00	Abu Karaki (1987)	Ms = 6.5 ± 0.5 Ml=6.3±0.4	128.25	5.55-6.23 7.23-7.91	V-VI VII-VIII
	c	33.80	34.30	Sbeinati et al, (2005)	Ms = 7.1 Ml=6.7	197.16	5.61 7.2	VI VII
347 AD		34.00	35.50	Abu Karaki (1987)	MS = 6.5 ± 0.5 Ml=6.3±0.4	159.35	5.25-5.93 6.93-7.61	V-VI VI-VIII
363 May 19 AD	a	31.30	35.60	Ben-Menahem, (1979, 1991)	ML = 6.4	146.44	4.87-6.57 6.54-8.24	V-VII VII-VIII
	b	31.30	35.4	Ambraseys (2009)	Ms = 7.1 Ml=6.7	150.73	6.01 7.69	VI VIII
	c	31.50	35.40			129.57	6.22 7.89	VI VIII
419 AD	a	33.00	35.50	Ben-Menahem, (1979)	ML = 6.2	91.81	5.79 7.47	VI VII
	b	33.00	35.50	Abu Karaki (1987)	Ms = 6.0 ± 0.5. Ml=6±0.3	55.81	5.97-6.48 7.64-8.15	VI VII-VIII
502 AD	a	33.00	35.00	Abu Karaki (1987)	Ms = 6.5 Ml=6.3	91.81	5.96 7.63	VI VIII
	b	33.00	34.80	Sbeinati et al., (2005)	Ms = 7.2 Ml=6.8	108.53	6.61 8.29	VII VIII
	c	32.90	35.10	Ambraseys (2009)	Ms = 6 Ml=6	78.45	5.62 7.35	VI VII
551 AD	a	34.00	35.50	Sbeinati et al., (2005)	Ms = 7.2 Ml=6.8	159.35	6.1 7.78	VI VIII
	b	33.70	35.20	Ambraseys (2009)	Ms=7 Ml=6.7	136.96	6.14 7.82	VI VIII
634 AD		32.50	35.50	Abu Karaki (1987)	Ms = 6.0 ± 0.5 Ml=6±0.3	35.34	6.39-6.9 8.07-8.58	VI-VII VIII
659 AD	a	32.00	35.50	Ambraseys (2009)	Ms=5 Ml= 5.3	74.60	4.48 6.16	IV VI
	b	32.50	35.50	Ben-Menahem,	ML = 6.6	35.34	7.42 9.09	VII IX

				(1979)				
746-749 AD	a	32.00	35.50	Ben-Menahem, (1979,1991)	ML = 7.3	74.60	7.89 9.57	VIII X
	b	32°.50	35.60	Sbeinati et al., (2005)	Ms = 7.2 Ml=6.8	26.58	8 9.67	VIII X
a*: assuming Vs30=360 m/s. b*: assuming Vs30=800 m/s.								

List of Figure Captions

Fig. 1. Location of Beit-Ras/ Capitolias,the southern part of the Dead Sea Transform (DST) and associated segments: Wadi Araba Fault (WAF), Jordan Valley Fault (JVF), Hula fault (HF), Roum Fault (RF), Yammouneh Fault (YF), Rachaya Fault (RAF), Serghaya Fault (SF) (after Zohar et al., 2016, modified). Historical cities affected by earthquakes from Early Roman to Late Byzantine times which are mentioned Table (1).

Fig. 2. City Plan of Capitolias/ Beit-Ras (modified after Al-Shami, 2005).

Fig. 3. An aerial photograph of the excavated Beit-Ras theater, taken on October 1st, 2015 and photographed by Rebecca Elizabeth Banks. Courtesy of APAAME, photo. APAAME_20151001_REB-0193. Creative Commons Licence CC BY-NC-ND 3.3. East-west length 57 m. Main parts of the theater are indicated The city wall serves as a buttress in front of the scaena walls and the towers with staircases. The city wall connected with the eastern the stage gate and vomitoria gate.

Fig. 4. Major parts of a Roman theater. It is mostly the shape of Beit-Ras theater at the time of construction. Modified after Fayyad and Karasneh (2004), Karasneh and Fayyad (2005) and Sears (2006) and our field observation.

Fig.5. Theater plan and the position of the observed damage features. Most of the locations damage features are marked in the drawing.

Fig. 6. Damage features within displaced arches: **a)** dropped blocks of the flat arch, east door in *scaena,* **b)** dropped blocks of the flat arch of the eastern stage gate(*versura*), **c)** dropped blocks of the flat arch of *vomitorium*, small spaces between the stones formed due to the ground shaking **d)** dropped keystone of the stress-releasing segmental arch above eastern stage gate (*versura*). Figure (5) shows positions of the damaged element.

Fig. 7. Chipped corners and edges of stones: **a+ b)** Back part of the western orchestra gate, **c)** Front part of the western orchestra gate, **d)** Some parts of the eastern orchestra gate. The edges of blocks cracked and spalled off. Figure (5) shows positions of the damaged elements.

Fig. 8. Deformation of *scaena*: **a)** *Scaena* tilted towards the viewer and is supported by the buttress vertical wall (city wall), **b**) Out-of-plane shift of blocks of *scaena*, **c)** Blocks sequentially shifted to the right, in direction of tilting, **d)** Extreme tilt of *scaena,* segment supported by buttress vertical wall (city wall). Figure (5) shows position of photos.

Fig. 9. External view of the eastern orchestra gate leading from the outside into the *aditus maximus*. Above the gate arch, there are two rows of ashlars of the former vault of the *ambulatorium* **(a).** Upon the collapse of the passage, the gate was walled up **(b)**, allowing access to the theater via a smaller stone door below (in the lower part). A carved inscription from 261 AD dates the walling up event **(c)**. About a meter to the right, there is a different wall, made of chalky limestone of lighter color and has irregular contact with the original

wall **(d)**. The wall suture clearly indicates that the lighter chalk wall was attached to the darker limestone wall later, as a repair structure **(e).** Repair on the left by basalt cubes was carried out after the wall with the inscription was built **(f)**.

Fig. 10. a) Photo of the orchestra from south shows the removed front part of the stage *proscaenium*, remnants of the two curved walls and a median N-S canal (L-shape) across the orchestra floor. **b)** Photo from north, orchestra's depth is 3 m with three refuges. **c)** Plaster and paint remains between refugia.

Fig. 11. Sand and debris found at the theater during the excavation (after Lucke et al 2012, modified).

Fig. 12. Timeline of the main phases, the two main phases of major destruction which could be earthquake events and the candidate earthquakes that affected Beit-Ras and surrounding region.

Fig. 13. Location map of suspected earthquake events (Table 2), likely to have caused the observed damage to the theater of Beit-Ras.

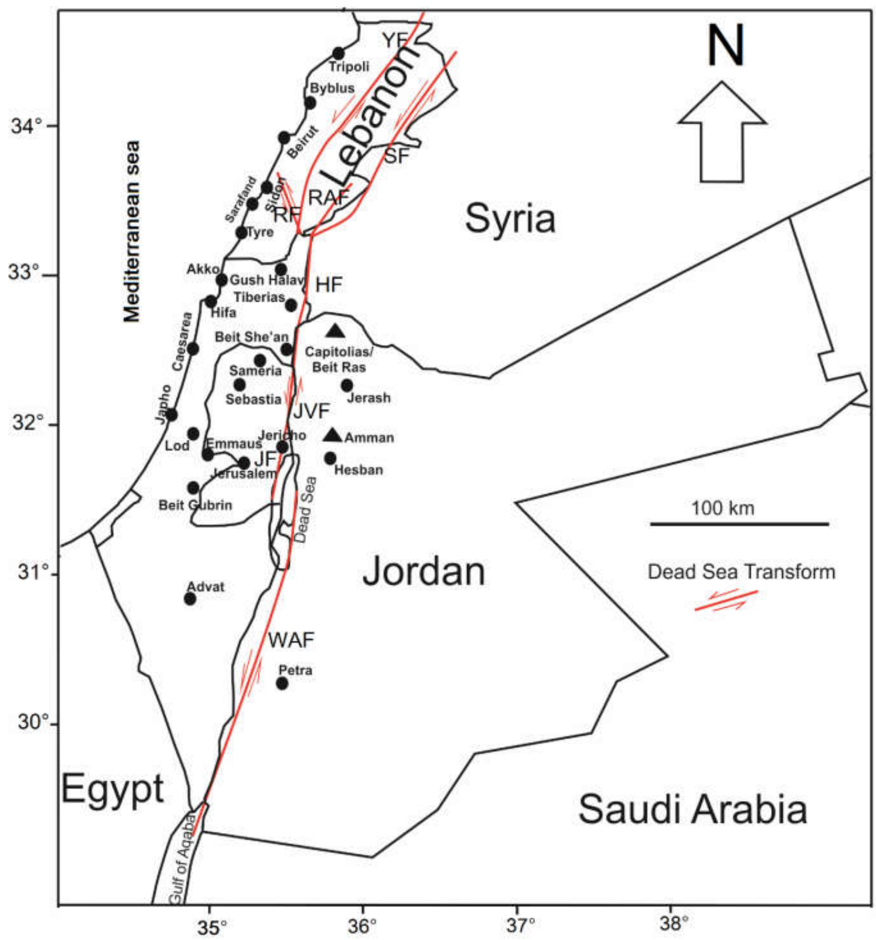

Fig. 1. Location of Beit-Ras/ Capitolias,the southern part of the Dead Sea Transform (DST) and associated segments: Wadi Araba Fault (WAF), Jordan Valley Fault (JVF), Hula fault (HF), Roum Fault (RF), Yammouneh Fault (YF), Rachaya Fault (RAF), Serghaya Fault (SF) (after Zohar et al., 2016, modified). Historical cities affected by earthquakes from Early Roman to Late Byzantine times which are mentioned Table (1).

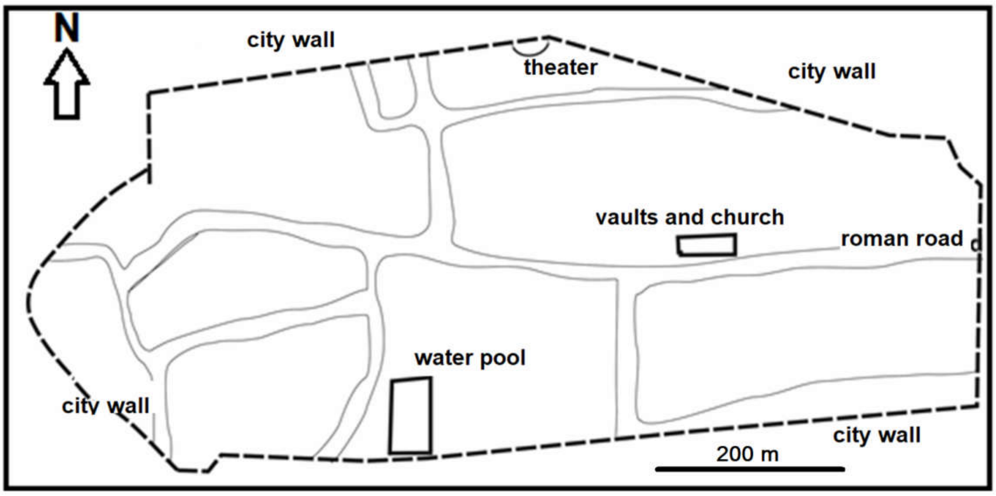

Fig. 2. City Plan of Capitolias/ Beit-Ras (modified after Al-Shami, 2005).

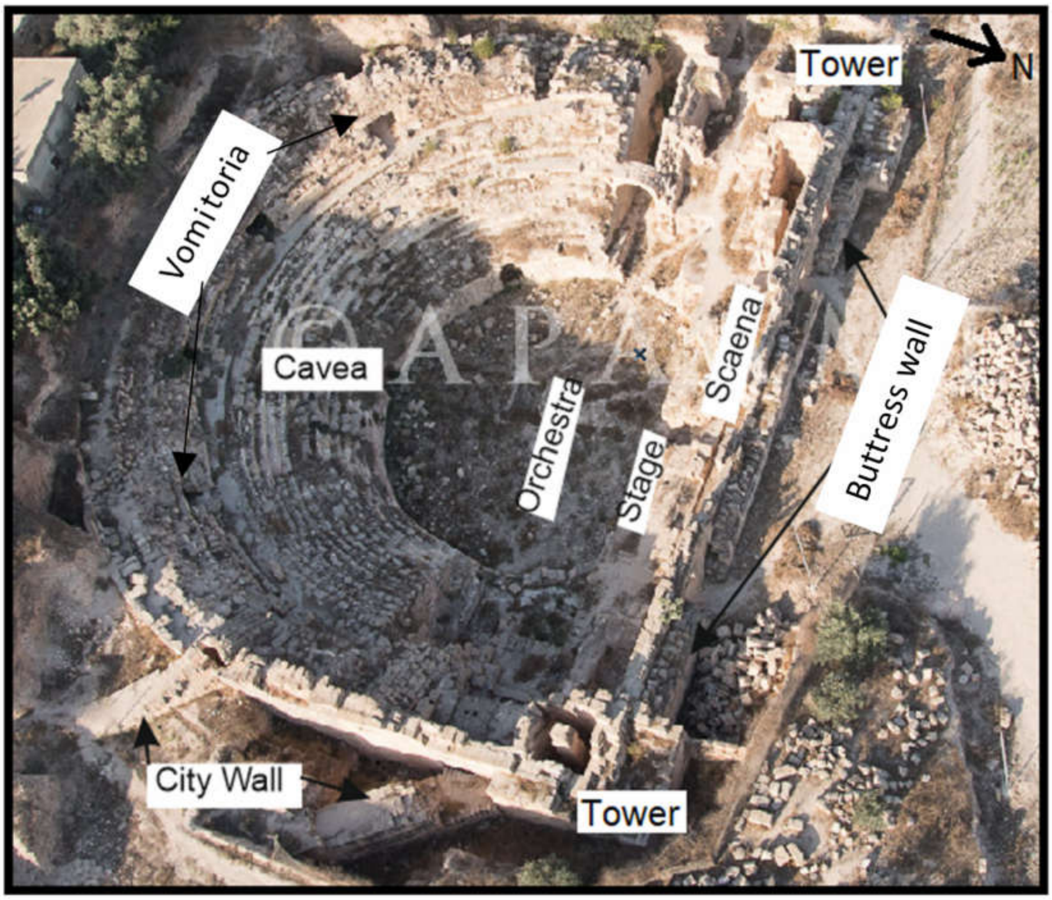

Fig.3. An aerial photograph of the excavated Beit-Ras theater, taken on October 1st, 2015 and photographed by Rebecca Elizabeth Banks. Courtesy of APAAME, photo. APAAME_20151001_REB-0193. Creative Commons Licence CC BY-NC-ND 3.3. East-west length 57 m. Main parts of the theater are indicated The city wall serves as a buttress in front of the scaena walls and the towers with staircases. The city wall connected with the eastern the stage gate and vomitoria gate.

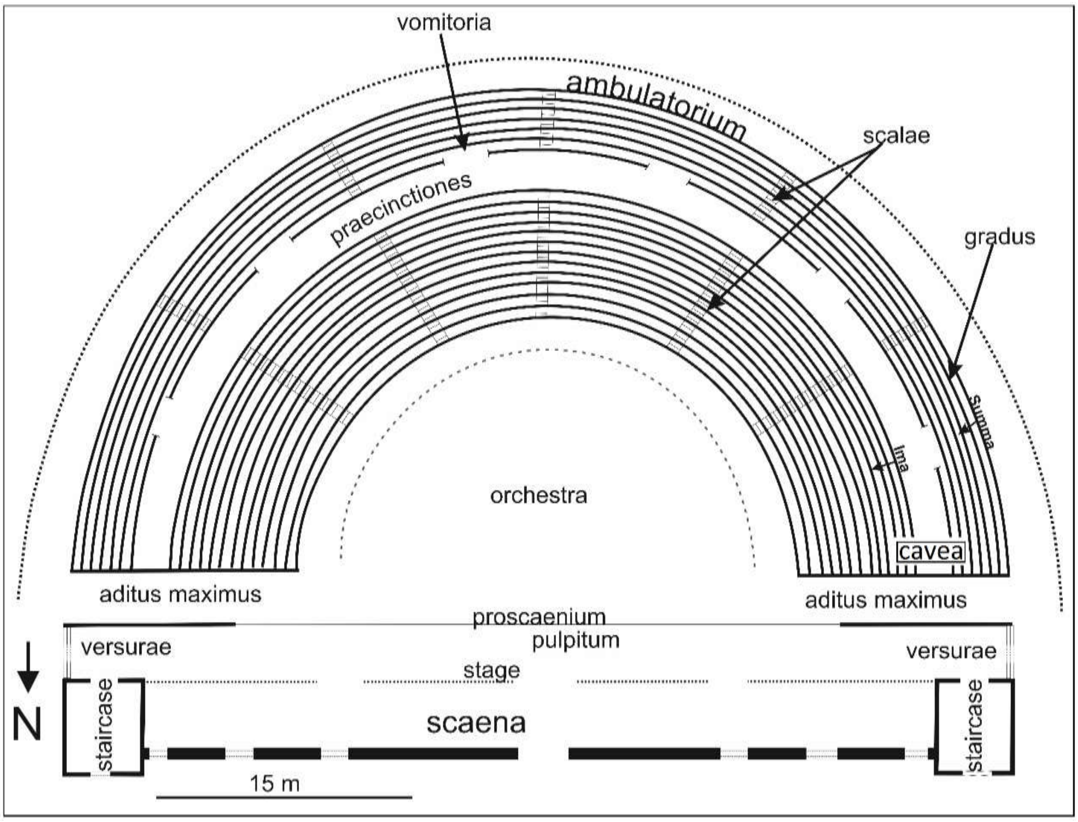

Fig. 4. Major parts of a Roman theater. It is mostly the shape of Beit-Ras theater at the time of construction. Modified after Fayyad and Karasneh (2004), Karasneh and Fayyad (2005) and Sears (2006) and our field observation.

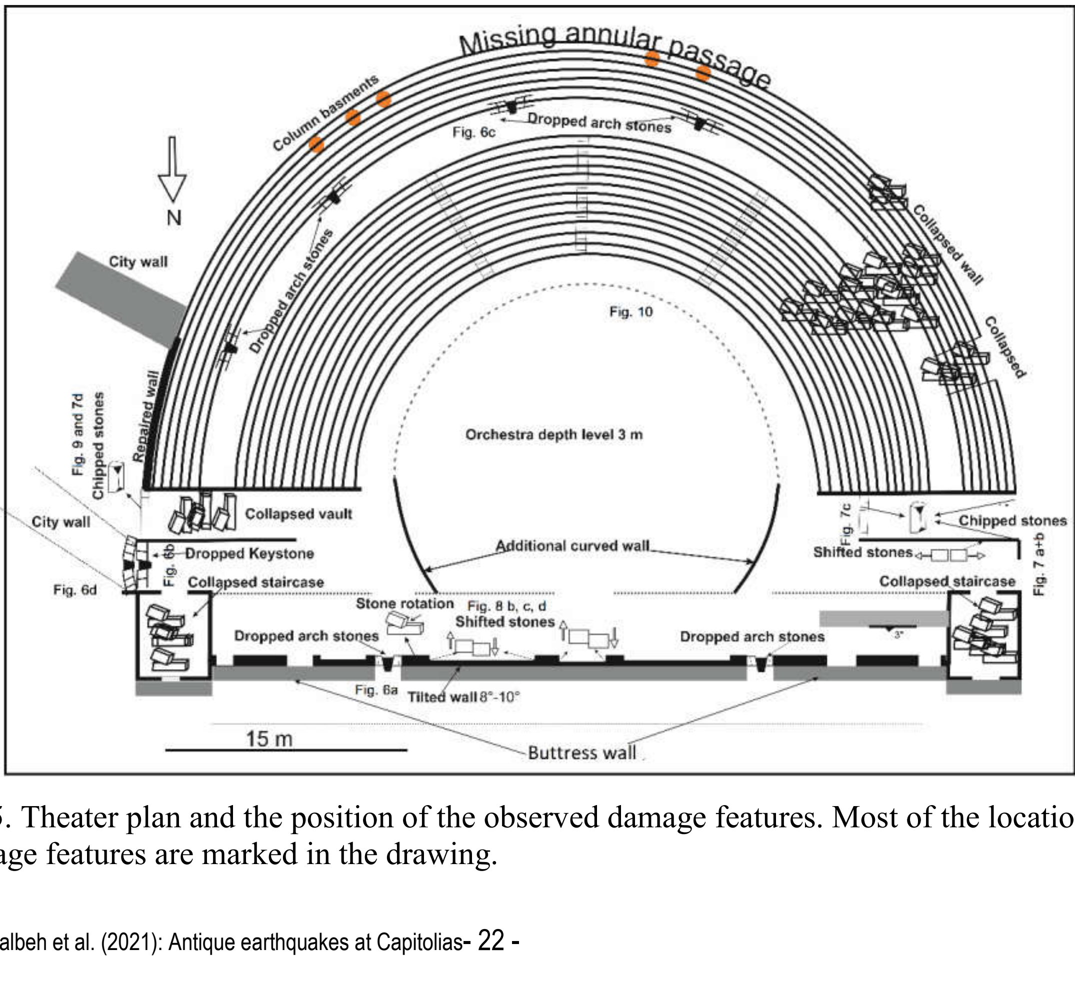

Fig.5. Theater plan and the position of the observed damage features. Most of the locations damage features are marked in the drawing.

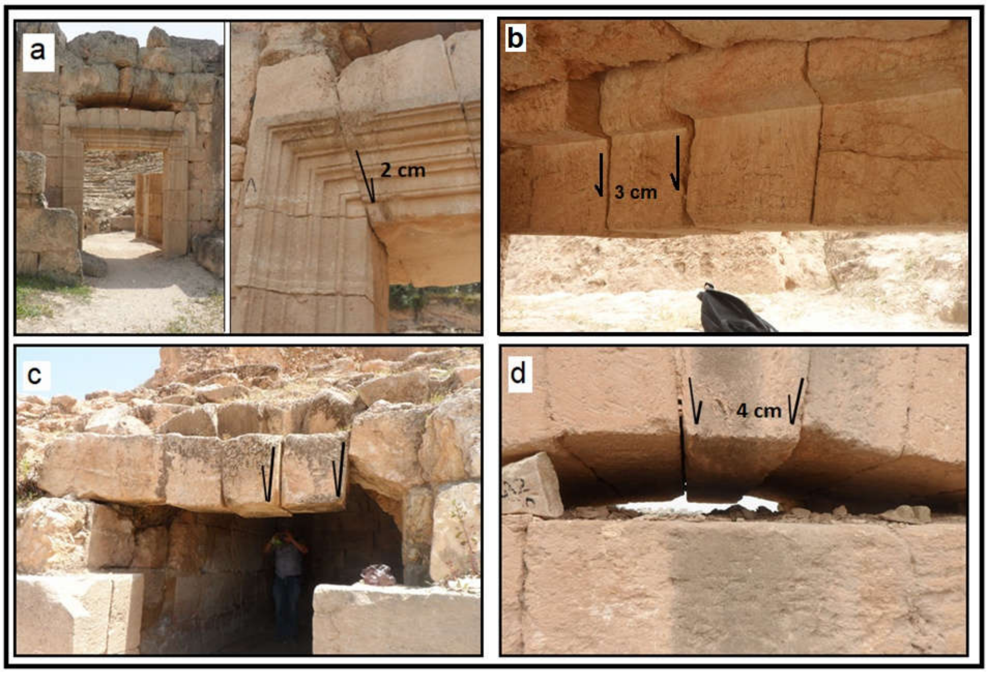

Fig. 6. Damage features within displaced arches: **a)** dropped blocks of the flat arch, east door in *scaena,* **b)** dropped blocks of the flat arch of the eastern stage gate (*versura*), **c)** dropped blocks of the flat arch of *vomitorium*, small spaces between the stones formed due to the ground shaking **d)** dropped keystone of the stress-releasing segmental arch above eastern stage gate (*versura*). Figure (5) shows positions of the damaged elements.

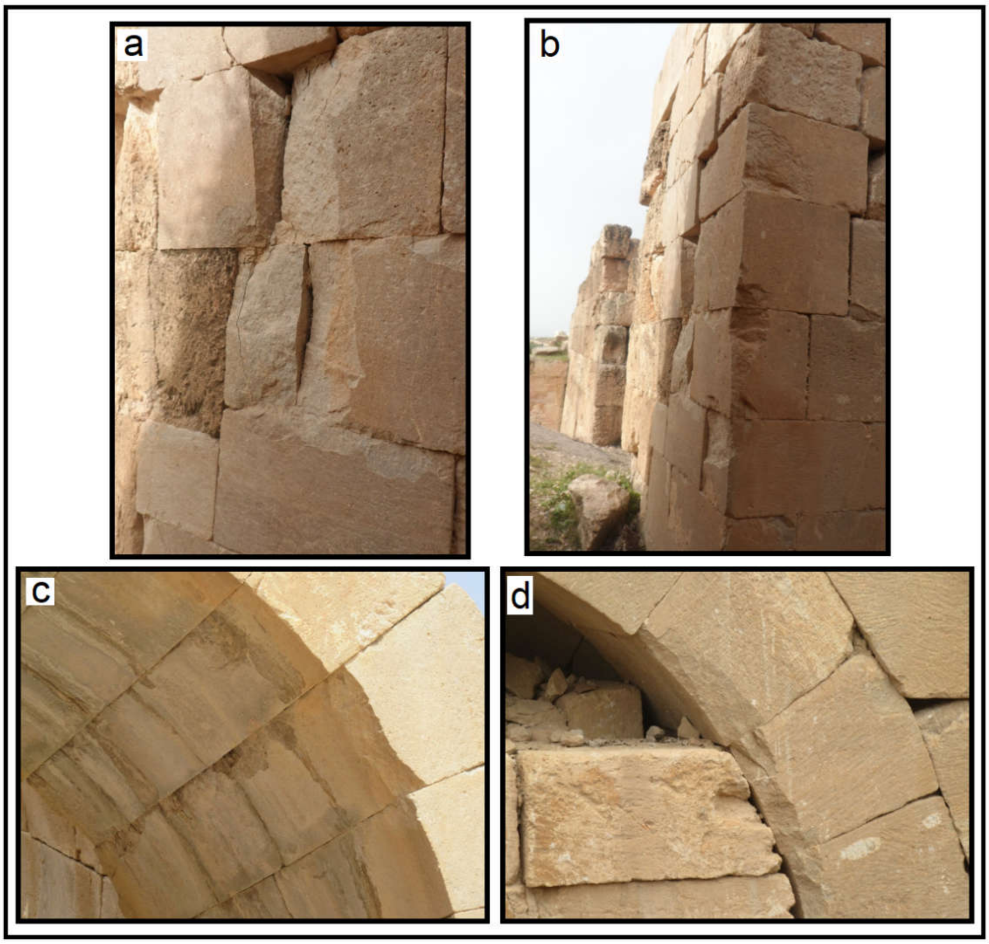

Fig. 7. Chipped corners and edges of stones: **a+ b)** Back part of the western orchestra gate, **c)** Front part of the western orchestra gate, **d)** Some parts of the eastern orchestra gate. The edges of blocks cracked and spalled off. Figure (5) shows positions of the damaged elements.

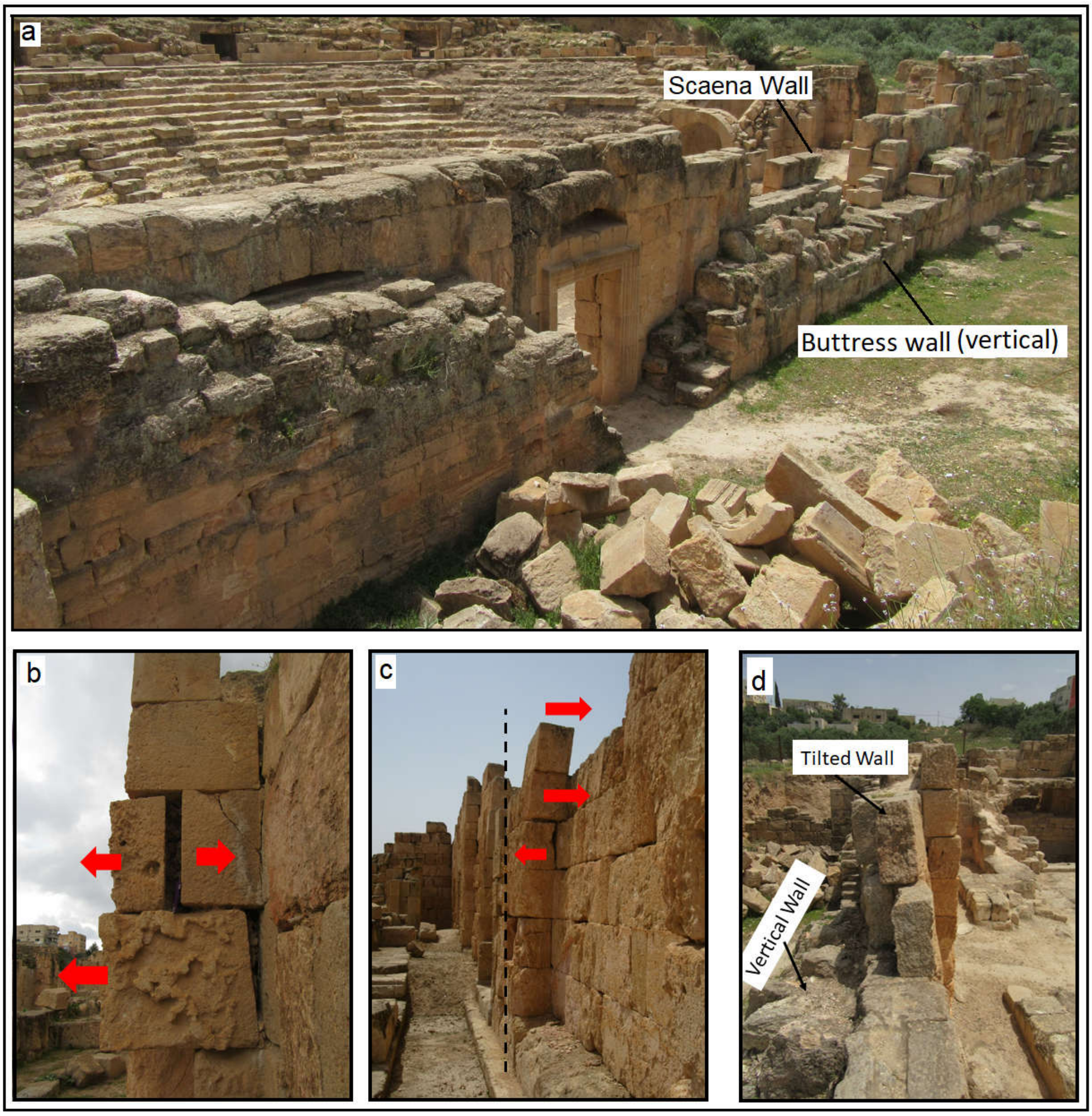

Fig. 8. Deformation of *scaena*: **a)** *Scaena* is tilted towards the viewer and is supported by the buttress vertical wall (city wall), **b**) Out-of-plane shift of blocks of *scaena*, **c)** Blocks sequentially shifted to the right, in direction of tilting, **d)** Extreme tilt of *scaena,* segment supported by buttress vertical wall (city wall). Figure (5) shows positions of photos.

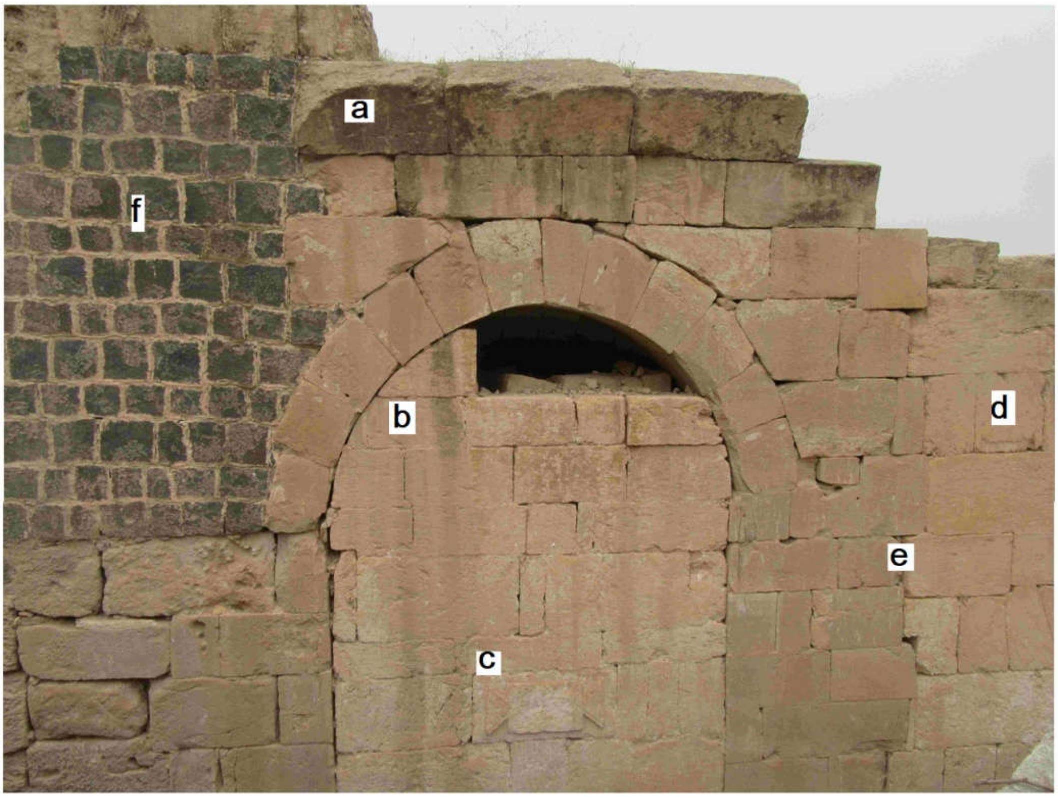

Fig. 9. External view of the eastern orchestra gate leading from the outside into the *aditus maximus*. Above the gate arch, there are two rows of ashlars of the former vault of the *ambulatorium* **(a).** Upon the collapse of the passage, the gate was walled up **(b)**, allowing access to the theater via a smaller stone door below (in the lower part). A carved inscription from 261 AD dates the walling up event **(c).** About a meter to the right, there is a different wall, made of chalky limestone of lighter color and has irregular contact with the original wall **(d).** The wall suture clearly indicates that the lighter chalk wall was attached to the darker limestone wall later, as a repair structure **(e).** Repair on the left by basalt cubes was carried out after the wall with the inscription was built **(f)**.

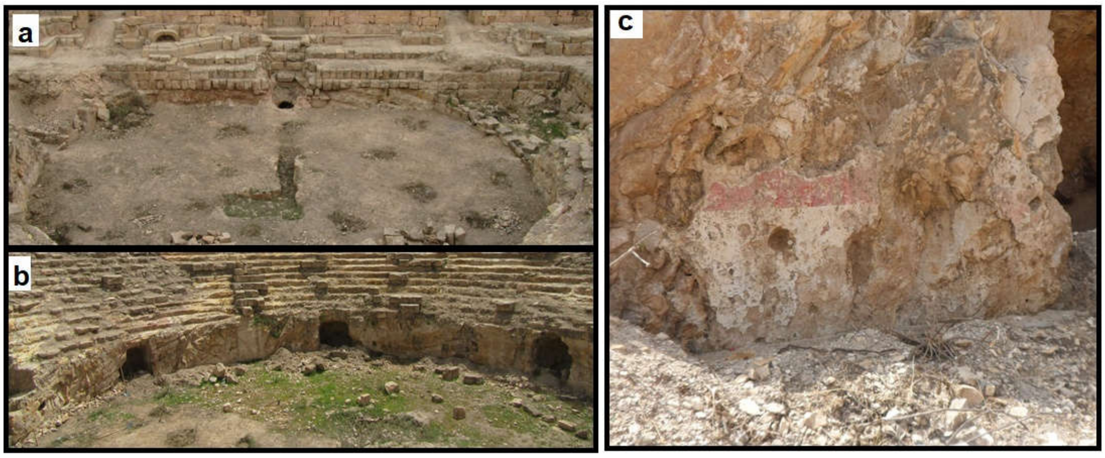

Fig. 10. **a)** Photo of the orchestra from south shows the removed front part of the stage *proscaenium*, remnants of the two curved walls outlining the arena of the amphitheatre and a median N-S canal (L-shape) across the floor. **b)** Photo from north, orchestra's depth is 3 m with three refuges. **c)** Plaster and paint remains between refugia.

Fig. 11. Sand and debris found at the theater during the excavation (after Lucke et al. 2012, modified).

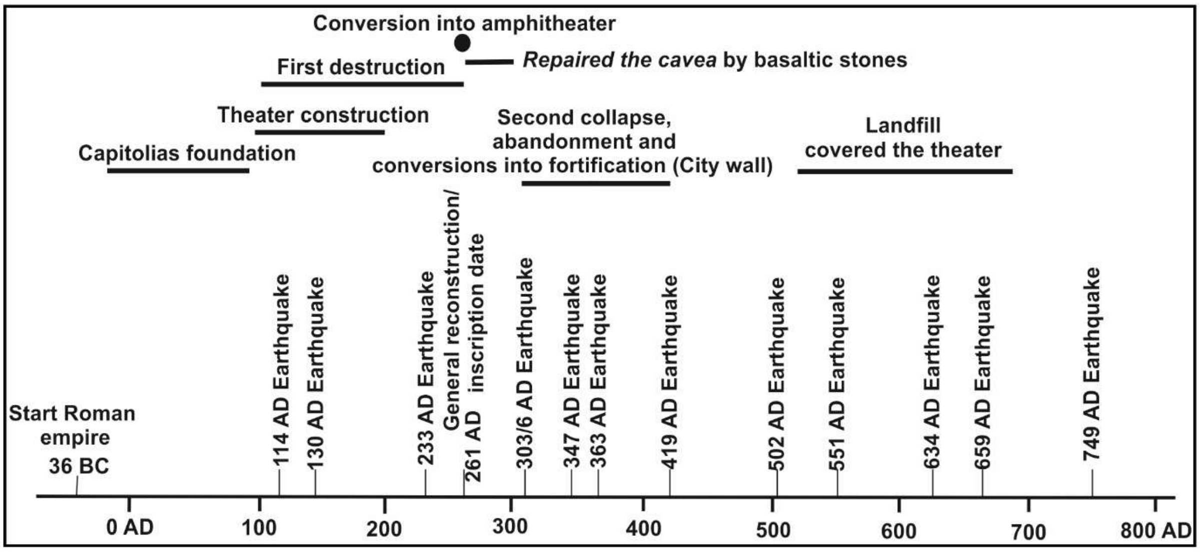

Fig. 12. Timeline of the main phases, the two main phases of major destruction which could be earthquake events and the candidate earthquakes that affected Beit-Ras and surrounding region.

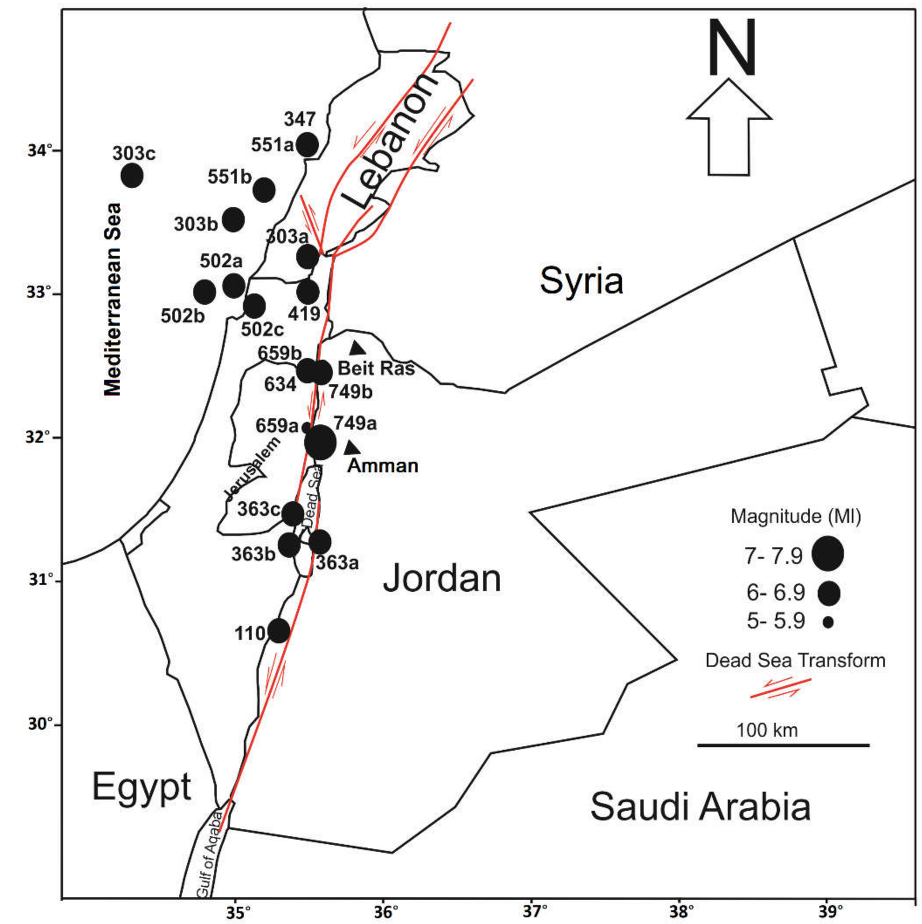

Fig. 13. Location map of suspected earthquake events (Table 2), likely to cause observed damages to the theater of Beit-Ras.