Earthquake-Related Damage at Two Sites East of the Dead Sea Transform: An Archaeoseismological Study (Beit-Ras and Umm el-Jimal, Jordan)

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Abstract

Earthquake-related damages were studied in two ancient buildings in Jordan, the Roman theater in Capitolias/Beit Ras, and Barracks in Umm el-Jimal, depending on archaeoseismolog method. The study aims to find the causative earthquakes that have damaged the buildings, investigating their parameters (i.e. date, intensity and source), in order to partially update and fill the significant gaps existed in the seismic catalogue.

Intensity maps for the main historical events that occurred and affected the area north of Jordan, from 1 AD to the 19th century, were created. The maps suggest that the earthquake catalogue needs to be updated, where the available data is lacking, especially records about the periods Roman and Byzantine, and, the records about the eastern part of the DSTF.

In Capitolias/Beit Ras theater, a rich set of earthquake archaeological effects were identified, including deformed arches, tilted and collapsed walls, chipped corners of masonry blocks, and extensional gaps, indicating a seismic intensity of VIII–IX, depending on EAEs. Stratigraphy reading of the theater (describing the construction, destruction, and repair successions) and attenuation model were used to investigate candidate earthquakes. The study identified at least two significant destruction phases that took part in the damage of the theater, which may have contributed 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, the assessment of the observed destruction, and literature reports. The date of the first phase is bracketed between the establishment of the city (before A.D. 97/98) and the date of an inscription found in the walled-up orchestra gate (261 AD). The most likely candidate earthquake(s) for this immense destruction are the 233 AD and/or 245 AD events. Other moderate and less damaging events may have also occurred within the region but are not mentioned in available catalogs. After a major restoration, another earthquake phase occurred between 261 AD and Late Roman–Early Byzantine times, when the scaena wall tilted and collapsed, rendering the building useless and beyond repair. Subsequently, the theater was then filled with debris and was abandoned. The most probable causative earthquake of the second phase of destruction is an event in 363 AD.

In the Barrack in Umm el-Jimal, the stratigraphy reading suggests that the building has six different phases, distinguished by masonry pattern. Many earthquake features were identified,
such as tilted, bulged, and U-shaped collapsed walls. These deformations indicate that the size of damage and intensity reached IX-X based on EAEs. The building was damaged at least by two earthquakes. The first earthquake occurred in late Byzantine time (491 AD-636 AD), causing two large U-shape collapses of the northern wall and failure of the upper part of the western wall. The damage was mainly reconstructed through an approach attributed to phase 4. The second earthquake occurred at the end of the Umayyad Caliphate (661 AD-750 AD), causing U-shape collapses and bulging walls, that was followed by a general abandonment of the site. According to attenuation model made in the site, the known historical major events generated by the DSTF are not capable for causing the observed damages. The local faults, north-eastern faults like Azraq-Sirhan and Fuluq faults are most likely reactivated faults, having capability to produce strong earthquakes to cause damage in Umm el Jimal and southern Huran. One focal mechanism for an earthquake, with 3.5 ML within the Azraq-Sirhan Fault indicates to a right-lateral strike-slip fault, suggesting its reactivation with the DSTF stress field.

Archaeoseismology method helps in updating the earthquake catalogue by: (1) filling the gaps of the catalogue, (2) enrich the knowledge about poorly documented events, (3) present accurate dating to the earthquake evidence, (3) uncover new events which are not mentioned in the catalogues.
Chapter 1: Introduction

1.1 Introduction

Historical earthquakes can be studied by different methods, such as historical seismology (macroseismology), paleoseismology, and archaeoseismology. Historical seismology is based on historical documentation that includes earthquake reports written by historians. Paleoseismology is based on excavating trenches dug along surface ruptures generated by active faults. Archaeoseismology is based on investigating earthquake-related damages of archaeological buildings (Stiros, 1996; Galadini, 2006; Silva et al., 2011; Kazmer, 2014).

Since few decades, archaeoseismology studies have played an important role, beside other methods, in updating seismic catalogues of many regions around the world, especially the regions that have a long seismic history (Caputo and Helly, 2008). Any single archaeological building deformed by historical earthquakes bears wealthy data related to the earthquake parameters (i.e. intensity and date). The archaeological buildings can be called stone-seismographs (Hinzen, 2005; Schweppe et al., 2017). So, applying the archaeoseismology method across a large area encompassing several buildings can present the spatial distribution of the intensity values of an earthquake (Galadini et al., 2006; Marco, 2008). This contributes in improving the accuracy of Intensity map for any event (Hinzen, 2005; Caputo and Helly, 2008).

Many previous studies have investigated archaeological sites in order to reconstruct the seismic history of a targeted area, such as in Pakistan (Bilham and Lodi, 2010), Venezuela (Laffaille et al., 2010; Altez, 2010), Japan (Barnes, 2010), Spain (Silva et al., 2005; Grützner et al., 2010; Rodríguez-Pascua et al., 2011), Greece (Tendürtüs et al., 2010), Turkey (Hancock and Altunel, 1997; Altunel et al., 2009; Yerli et al., 2010; Yönlü et al., 2010; Benjelloun et al., 2018), Egypt (Karakhanyan et al., 2010), Italy (Galadini and Galli, 2001; Guidoboni et al., 2002; Barreca et al., 2010), United States (Tuttle and Schweig, 1995), etc.

The Levant region is considered a favorable region for applying historical earthquake methods because region has wealthy historical records and cultural diversity dated back more than 3000 thousand years (Marco et al., 2003; Sbeinati et al., 2005; Marco, 2008), which is dominated mainly by the tectonics of the Dead Sea Transform Fault (DSTF). The DSTF is a major active left-lateral transform fault tectonic boundary.
Since the operation of the first instrumental earthquake station in 1898; recorded earthquakes along the DSTF are typically of low to moderate magnitude values (Hofstetter et al., 2014; Ferry et al., 2011). The historical earthquakes of the region have been extensively studied by many scholars and revised in several earthquake catalogues (i.e. Russell (1985), Amiran (1994), Sbeinati et al. (2005), Guidoboni et al. (1994), Guidoboni and Comastri (2005), and Ambraseys (2009)). Also, they have been evaluated in several published articles (i.e. Zohar et al. (2017), Zohar (2020), and Grigoratos et al. (2020)), suggesting that the seismic catalogue of the Levant region is still incomplete, bearing many gaps that need to be filled (Salamon, 2010; Zohar et al., 2016; Zohar et al., 2017). The historical reports and writings citing details about earthquake dates and their affected regions are scarce, especially during the Roman-Byzantine period, probably because of the lack of preservation of these historical sources (Zohar et al., 2016). In general, available catalogues of historical earthquakes and associated historical seismic studies have only focused on the western part of the DSTF, where the eastern part, like Jordan and south of Syria, are not thoroughly investigated (Al-Tawalbeh et al., 2021), despite the existence of hundreds of damaged archaeological settlements that indicate earthquakes activity in the past (Al-Azzam, 2012; Fandi, 2018; Jaradat et al., 2019; Al-Tawalbeh et al., 2021).

Farther to the east, in Hauran area, the region has been largely neglected to date. It is a well-known archeological region in the Levant, especially from an architectural point of view, as it encompasses several archaeological centers of characteristic Nabataean, Roman, Byzantine, and Umayyad buildings of considerable structures, strength and durability (Butler, 1913; Brown, 2009). Although most of these buildings are solid-wall structures, they have incurred significant damages and have distinguishable indications of reconstruction. Most archeological studies have suggested that observed damages are caused by vast incidents beyond human ability, indicating historical natural disasters such as earthquakes (De Vries, 1993; Al-Bashaireh, 2017).

This project aims to document and assess earthquake-related damages in two archeological buildings east of DSTF north of Jordan, using archaeoseismology method, which are Capitolias/Bait Ras theater, located 30 km from Jordan valley, and Barracks building in Umm el-Jimal, located 80 km east of Jordan Valley, south of Huran area and south of Busra (Fig. 1). It tries to find out the earthquakes that have caused the damages, estimates the size of the damage (intensity) in the sites and earthquakes source.
Fig. (1): Location map of the two study areas: Capitolias/Bait Ras and Umm el-Jimal.

**1.2 Study Areas**

**1.2.1 Capitolias/Beit Ras Theater**

Capitolias (Beit-Ras) is one of the major Decapolis cities of the Levant, that extended 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-sized theater was discovered buried beneath 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 on a hill north of the city of Beit-Ras/Capitolias (Fig. 1 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 a 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). The Beit-Ras/Capitolias theater is 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, the major parts of this theater 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), the scaena (a high, decorated backstage wall, which provided the acoustic quality for everyone in the theater), and the ambulatorium, an external annular passageway surrounding the upper seat rows. Common people used to enter the cavea
from the 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).

Fig. (3): An aerial photograph of the excavated Beit-Ras/Capitoliias theater, taken on October 1\textsuperscript{st}, 2015 and photographed by Rebecca Elizabeth Banks. Courtesy of APAAME, photo. APAAME_20151001_REB-0193. Creative Commons License 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 (After Al-Tawalbeh et al., 2021). The city wall connected with the eastern the stage gate and vomitoria gate.
1.2.2 The Barracks building of Umm el-Jimal
1.2.2.1 The History of Umm el-Jimal

Umm el-Jimal is one of the oldest cities in the Hauran region. It is situated at the southern boundary of the Hauran plains south of Busra (Fig. 1) and it includes well-preserved multi-storied constructions, that have remained standing even after hundreds of years after the city’s abandonment. The town consists of 150 different masonry structures constructed from split or carved basaltic blocks and long basaltic beams. It includes several impressive public buildings such as a praetorium, a castellum, a Barracks, several domestic buildings, several churches (the western church; the cathedral; and the church of Julianos), and other features (Butler, 1913; De Vries, 1990; Brown, 2009) (Fig. 5a). By the end of the Umayyad period in the middle of the eighth century AD., the population had dramatically decreased. The lack of any post-Umayyad pottery in any of the probes excavated in 1974 suggests that the site has been abandoned until the
modern period (De Vries, 1982). According to De Vries (1993), the population decline occurred primarily after the 749AD earthquake (i.e., herein he refers to as the 747 AD earthquake), where the site was never rebuilt again and eventually become under the control of the Abbasid Caliphate in Baghdad (De Vries, 1981). As there was no manpower or resources for its rehabilitation (De Vries, 1990), nearly a thousand years later, the settlement of Umm el-Jimal – as we see it today – has remained virtually intact since the time of its abandonment. The strength of the basalt rocks, its primary construction material, and the high quality of the construction has frozen it in a state of protection (De Vries, 1990). Although various structures are in excellent state of preservation, some are more or less in complete rubble, and nearly all tall structures are heavily damaged (Butler, 1913).

1.2.2.2 The Barracks Structure

The Barracks building is placed in the southern part of Umm el-Jimal city (Fig. 5a). The structure is of trapezoidal plan (33.75m x 55m), joined by rectangular chapel (Butler, 1913) (Fig. 5b+c). It is surrounded by high walls. It has several rooms as well as two distinguishable towers: the southern and the western towers. The square southern tower still stands in its entirety (4.40x 4.40 m wide and nearly 15 m high) (Butler, 1913). Butler (1913) dated the building based on a 412 AD inscription that was found within the rubbles around, that was built for military purposes. However, the building lost its military use in the 6th century, and the chapel and the southern corner tower was added (De Vries, 1993 and 2000). In the 7th century, the Barracks building was owned by the Umayyad (De Vries, 2000).
1.3 Objectives of the Study

The main objectives of the study are:

1- Identifying and documenting various damage anomalies, in Beit Ras theater and the Barracks in Umm el-Jimal, which can be described as damage earthquake features.

2- Overviewing the historical earthquakes and highlighting the significant gaps in the earthquake catalogue.
3- Analyzing the collected data to determine the known historical events that caused the damages to the locations, as well as investigate the likelihood of unreported historical earthquakes and undiscovered active faults that caused the deformations.

1.4 Significant of the Study

Historical earthquake researches are important for understanding the seismic condition, especially for the region that has major gaps in its seismic catalogue. An example of these regions is the Levant, as previously indicated. The Levant area is considered as the desired laboratory because of its tectonic setting and well-known long history. Therefore, employing archaeoseismology at archaeological sites, like Capitoliias Theater and Barracks in Umm el-Jimal, may help to update the seismic catalogues and fill in certain gaps, particularly during the Roman-Byzantine time.

1.5 Methods and Materials

The following adopted methods used in the research are described. Figure (6) shows a flow chart of the main steps of these methods.

1.5.1 Collecting the Earthquake-Related Damages

Various damage anomalies, including deformations and restorations, which can be regarded as earthquake indicators, were identified and documented in both locations during the fieldwork (from spring 2019 to summer 2020). Also the published literatures and reports related to the site were used. The documentation was through detailed drawings and photographs, using single shots and structure-from-motion techniques. Damage-related attributes, such as dimensions, orientations, and tilted angles, were measured using a geological compass, laser range finder, measuring tape, and a clinometer.
Fig. (6): Flow chart showing the main adopted methods used in the research.

- Collect earthquake-related damages:
  - Deformation features
  - Restoration features

- Using:
  - Fieldwork observations
  - Drawing (CorelDRAW x5) and photographs
  - Published reports, papers and books
  - Geological compass
  - Laser range finder
  - Measuring tape
  - Clinometer

- Stratigraphy reading of the buildings:
  - Construction phases
  - Destruction phases
  - Reconstruction phases

- Using:
  - Describe building technique
  - Identify building materials
  - Stones/blocks characteristics
  - Published reports, papers and books

- Dating each phase by using:
  - Published literatures
  - Available inscriptions
  - Published radiocarbon data

- Earthquake intensity maps
  - Data type included in the maps:
    - Affected locations
    - Size of the damage (intensity) for each location
    - Faults
    - Estimated magnitudes
    - Previous studies locations
    - Interval time given to the events from the previous studies

- Data sources:
  - Earthquake catalogues
  - Major events
  - Poorly documented events
  - Previous literatures and reports

- Intensity values in the map were measured by using:
  - Mercalli Intensity Scale (MMI)
  - Used software to create the maps:
    - ArcMap10.4
    - CorelDRAW x5

- Geophysical survey:
  - Resistivity (ERT)
  - Used device: ARES
  - Used software: RES2DINV (ver. 4.9.18) (Geotomo)
  - Seismic (MASW)
  - Used software: SeisIMAGER/SW

- Instrumental earthquakes map
  - Data Source:
    - USGS website
    - ds.iris.edu website
    - Jordanian earthquake observatory

- Attenuation model using Darvazi and Agnon. (2019) equation
  - Used data:
    - Epicenter distance from the site
    - Estimated magnitude
    - Vs30
    - P-Wave average velocity

- Focal mechanism analysis
  - Used data:
    - P-wave arrivals of the event 5th of January 2008
    - Seisan 1.11
    - FOCM/ECD
    - FPSIT

- Potential intensity MMI for each event in the sites
  - Estimated zone of the affected area
  - Candidate events
  - Candidate faults

- For Capotilas theater and barracks case studies

- For Umm el-Jomai case study
1.5.2 Stratigraphy Reading of the Building

The next step of the research is to study the stratigraphy of the standing structures in both sites and identify the various phases of the building (i.e., construction, destruction, and restoration phases). The method is mainly depending on carefully identifying the building’s techniques and materials used in each part of the structure, in order to determine the number of phases of the building (Anastasio et al., 2016). By correlation, the building phases with the collected damage features, the number of the earthquakes that occurred were estimated. Also, the earthquakes were constrained to a given interval time. In the following, the stratigraphy reading methods applied in Capitolias/Bait theaterRas and Umm el-Jimal Barracks are described:

a- Capitolias/Beit Ras Theater

The functional parts of the theater of Capitolias, based on the observations during fieldwork (spring 2019 to summer 2020) were described, in comparison with available succinct archaeological reports (Fayyad and Karasneh, 2004; Karasneh and Fayyad, 2005) as well as Sear’s (2006) monumental handbook on Roman theaters.

Describing the original shape of each building at the time of construction and comparing it with its present shape, 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. Then after, characterizing the stratigraphic sequence of construction and phases formed the basis for understanding the chronological succession of construction, destruction, restoration, and repairs. Elements of stratigraphy are dated using published literature, available inscriptions, and the interpretation of published radiocarbon data.

b- The Barracks in Umm el-Jimal

The stratigraphy reading was employed extensively at only the remains of the standing building to discern major variations in the construction and reconstruction techniques in the Barracks. The fieldwork was carried out in spring 2019 to summer 2020. The aim was to identify reconstruction events/phases in a chronological sequence. This methodology has been previously applied at other ancient Hauran towns, including Umm el-Surab by Anastasio et al (2016) who developed an atlas of local construction techniques, as seen on external and internal surfaces of the walls. Generally, the reading focused on material types, masonry texture (regular or irregular
arrangement), quality of the blocks (very good, good or bad), dimensions of the masonry, joint arrangements (very good, good or bad), traces of construction tools like chisel marks, connection points between the walls (interlocking vs. not interlocking), ceiling type, reconstructed parts, recycling and reuse of stone, reconstruction technique and the shape of the windows and doors.

1.5.3 Estimated Potential Seismic Intensity in the Sites

The potential seismic intensity was assessed in both sites using the earthquake archaeological effect (EAE) scale (Rodriguez-Pascua et al., 2013) (Fig. 7) after determining the number of earthquakes occurred in the sites. After determining the minimum and maximum potential intensity for each deformation individually, depending on the scale, the estimated intensity values were measured. Then, the average values of the intensity were estimated for each identified event. In the following, these values will help to identify the candidate earthquakes from the earthquake catalogues.

1.5.4 Intensity Maps

Intensity intensity maps for each major historical event of the Levant region were developed. The maps were used in showing the significant gaps in the seismic catalogues. Also, they were helped in identifying the candidate earthquakes.

ArcMap 10.4 and CorelDRAw x5 were used to create the maps. The size of the damage of the affected towns was identified in the maps based on Mercalli Intensity Scale (MMI) using historical data from common catalogues, such as Russell (1985), Amiran (1994), Sbeinati et al (2005), Guidoboni et al. (1994), Guidoboni and Comastri (2005), and Ambraseys (2009). Typically, the methods proposed by Marco et al. (2003) and Guidoboni and Comastri (2005) were followed in estimating the intensity for each location. The related data from the common earthquake catalogues were collected, and the damage size was converted into numbers (Roman numerals) (Table 1).

In addition, the data of the previous paleoseismology and archaeoseismology studies were included in the maps, such as study areas locations, the given time intervals constrained the event, and the estimated intensities. Many events were not reviewed as an intensity map, because there do not have enough data to create a convincing map for them. These events were named poorly documented events, and they were summarized in a separate table, which includes the event’s data and the affected locations.
Fig. (7): Earthquake Archaeological Effects (EAEs) classification (after Rodríguez-Pascua et al., 2013).

Table (1): Modified Mercalli Intensity Scale (MMI) comparing with the expressions in this research that indicate for the earthquake size.

<table>
<thead>
<tr>
<th>Intensity (MMI)</th>
<th>The expression that indicates earthquake size</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV-V</td>
<td>Felt widely or strongly</td>
</tr>
<tr>
<td>VI-VII</td>
<td>Some houses collapsed, suffered little, few parts of some building or light damage.</td>
</tr>
</tbody>
</table>
Severe, destroyed, strong earthquake, half/more than half damaged or ruined

| VIII-IX | All houses collapsed, whole site damaged, nothing left stand, devastated or thousand people died or loss of whole population. |

1.5.5 Geophysical Survey

Two geophysical methods were used in both sites, which are electrical tomography (ERT) and multichannel analysis of surface wave (MASW). The main aim of using these methods is to investigate site-specific conditions control on potential amplification of ground motion in order to estimate the intensity of the candidate event in the sites and identify earthquake sources. In the following, both methods processes are described:

1.5.5.1 Electrical Resistivity Tomography (ERT)

The electrical resistivity methods are one of the most commonly used geophysical surveying tools to investigate subsurface conditions in a targeted area (Sharma, 1997). The electrical current pass through the ground to calculate the resistance ($R$) of the layer’s materials by ohm’s law: $R = \frac{\Delta V}{I}$ where ($\Delta V$) is the voltage drop and (I) is the intensity of the passing current. However, the electrical resistance (given in ohm’s) of a conductor is a function of its Area (A) and length (L). The constant of proportionality between $R$, A, and L, is known as the electrical resistivity ($\rho$). It is a constant physical property of a material, calculated in (ohmm) by the equation $\rho = R(A/L)$, where A is the area and L is the length of the measured block.

Electrical Resistivity Tomography (ERT) is a technique used to calculate the vertical and horizontal resistivity variation of the subsurface layers. The technique is commonly referred to as a multichannel technique depending on collecting a large number of values along the installed profile (Reynolds, 2005).

The ERT survey was used at Umm el-Jimal, around the Barracks, using the Wenner array aiming, effectively using ARES imagining resistivity meter (Fig. 8). Two resistivity profiles were designed and lain down around the building. In each profile, forty-eight electrodes were planted and connected to the automatic resistivity system, by a multichannel cable. The resistivity values ($\rho$) were collected, saved and exported as a notepad file. The data files were processed by RES2DINV (ver. 4.9.18) software of Geotomo Software. The noisy data was removed and filtered. A smoothness-constrained least-squares method based on a Robust model inversion was
used to clearly image the interface between the values then the final 2D pseudo-sections of the true resistivity were produced.

![Multichannel Resistivity meter (ARES) used for Electrical Resistivity Tomography (ERT) survey.](image)

Fig. (8): The Multichannel Resistivity meter (ARES) used for Electrical Resistivity Tomography (ERT) survey.

### 1.5.5.2 Multichannel Analysis of Surface Waves (MASW)

Site effect analysis aims to measure local soil conditions and seismic wave amplification of an incoming ground motion field, by calculating the average of shear wave velocity for the upper 30 m soil column (Anbazhagan et al., 2011; Anderson et al., 1996).

In Beit Ras and in Umm el-Jimal, 24 vertical geophones arranged as linear array, 4.5 Hz natural frequency, were used to collect the surface wave records. The enter-geophone intervals are 3 m in Umm el-Jimal and 2 m in Beit Ras. 10 kg sledgehammer was used. The overall setup MASW is illustrated in figure (9 and 10). The software Seismager/SW designed to perform the dispersion analysis and the inversion analysis. dispersion curve of Rayleigh wave, one-dimension shear wave line and 2D shear wave profile were created. The 2D profile was extracted by kriging interpolation for all measured profiles.
Fig. (9): Multichannel Analysis of surface waves (MASW) survey at Umm el-Jimal.

Based on historical documentation and the main earthquake catalogues of the DSTF region, plausible seismic intensities (modified Mercalli intensity [MMI]), were estimated, for both location, to define potential causative earthquake candidates. The 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), that take into account the average shear wave value (Vs30).

In order to identify the causative faults that caused the damages in Umm el-Jimal, the amplification equation was used (Darvasi and Agnon, 2019). The potential intensity measured from the site and Vs30 were used in the equation to find out the maximum distance of the large events with 7.5 local magnitudes that caused the maximum size damage observed in the site. This allows to show the candidate faults in the region, epically, north-eastern fault.
1.5.6 Instrumental Earthquakes Analysis

One map for the instrumental earthquakes for the region was made. It includes instrumental earthquakes occurred from 1900 till present. The source of the data is from USGS and IRIS website, and Jordanian earthquake observatory. The main aim of the map is to show the instrumental events along the faults nearby both locations. Such as north-eastern faults and Dead Sea Transform faults.

One event along the north-eastern faults were analyzed for focal mechanism. The event was in 5th of January in 2008. The Focal mechanism analysis was used to assess seismicity of nearby instrumental events, that occurred along the north-eastern faults in Jordan, aiming to understand current state of stress field of the local faults nearby Umm el-Jimal and their potential reactivation. Analysis of some instrumental events that took place along the north-eastern faults was carried out using Seisan V.11 and FOCMEC (Snoke et al., 1984) and FPFIT (Reasenberg and Oppenheimer, 1985) software. Investigated events are usually relocated to their proper epicentral position and their focal mechanism solutions are created aiming to understand the field stress state in the area.
Chapter 2: Geographical and Geological Overview of Jordan

2.1 Geographical Overview of Jordan

Jordan is located in the Middle East, between latitudes 29° 11´ and 33° 22´ and longitudes 34° 59´ and 39° 12´. The surface area of the country is 89.320 km². It is divided into seven morphological zones: Wadi Araba-Dead Sea-Jordan Valley Depression (Dead Sea Rift), the Highlands located at the eastern rim of the Dead Sea Rift, the Southern Mountain Desert, the Central Desert east of Jordan, the Azraq-Sirhan Depression, the Northern Jordanian Basalt Plateau, and the Northeast Jordanian Limestone Plateau (Ababsa, 2013) (Fig. 11).

The Dead Sea Rift, in Jordan, is 360 km long, from Lake Tiberias to the Gulf of Aqaba. The Highlands at the eastern rim of the Dead Sea Rift has a sharp slope towards to the rift, and there are many large watersheds that drainage towards to the rift, such as, Wadi Yarmouk, Wadi Rajeb, Zarqa River, Wadi Kafrin, Wadi Mujib and Wadi Hasa. The northeastern area belongs to the desert of Arabia. It is divided into two parts: The Basalt Plateau and the Limestone Plateau regions. The Basalt Plateau region is 11,000 km² and its elevation ranges between 600-900 m, including many small hills and long rows of volcanoes. The Azraq-Wadi Sirhan Depression trends NW-SE, and its elevation ranges between 500-700 m. It gathers water from neighboring canyons that drainage toward a small lake called Azraq Lake (Ababsa, 2013).

2.2 Geological Overview

The Precambrian in Jordan consists of a crystalline shield belonging to the Nubo-Arabian shield, which was formed during the Pan–African orogeny stage. The Precambrian outcrops are divided into two parts: a part consists of metamorphic and Plutonic rocks, and another part comprises of unmetamorphed deposits, intrusions, and volcanic rocks, formed as a result of uplifting and erosion in the late orogeny stage.

During the Paleozoic, the orogeny stage and beginning of the platform stage, the platform stage began with uplifting and heavy erosion processes. The sediments, 1800 m thick, mainly comprises of sandstone and shale deposits (Bandel and Salameh, 2013).

In the Early Triassic of the Mesozoic era, the northern and western areas in Jordan were covered by marine sediment because of a regional marine transgression.
In the end of the Triassic, the area was subjected to erosion, due to marine regression. The average thickness of the Triassic deposit is almost 1000 m (Bandel and Salameh, 2013). In the middle of Jurassic, the sea transgressed again and covered half of the country, and the erosion was dominant across the southern and eastern parts. Later at the beginning of Late Cretaceous, a regional transgression covered the region, that mostly resulted in the sedimentation of limestone and dolomite (Bandel and Salameh, 2013).
In the Cenozoic (Paleocene-Eocene), the marine deposits dominated and filled the gentle swells and basin system, while in the Oligocene, coarse clastic sedimentation took place as a result of uplifting of the area. The accumulation of these sediments was mostly in the western part of the country. Later in Neogene, a new significant change in tectonics activity, as a result of breaking up of the African and Arabian plates which lead to Read Sea Opening (in the M. Miocene). This new tectonic activity caused uplifting for large areas and a widespread of magmatic activity, especially east of the Dead Sea Transform (Bandel and Salameh, 2013).

In Pliocene, a volcanic activity of basaltic flow covered the northern parts of Jordan and the southern Galilee and Golan mountains. The Jordanian Basaltic Plateau was formed by these volcanic activities (Fig. 12) (Bender, 1975; Bandel and Salameh, 2013). It has two main formations, up to 20 m thick: The Abed Olivine Basalt Formation, and the Fahda Vesicular Basaltic Formation (Pleistocene) (Gharaibeh, 2003).

During the Quaternary, large detritus was transported into Dead Sea Rift Valley in the west and the depressions in the eastern part such as Azraq-Sirhan and Al-Jafr depressions (Bandel and Salameh, 2013).

In Pleistocene, fresh and brackish water covered some parts of the depressions while fluvial conglomerate deposits dominated along the mountains bordering the Wadi Araba-Jordan Rift (Bandel and Salameh, 2013). Figure (12) presents the geological map of Jordan (Bender, 1975).

### 2.3 Tectonic Setting

In this section, the tectonic setting of the Levant area is described, covering the Dead Sea Transform Fault (DSTF) and the main north-eastern fault system, like Azraq-Sirhan Fault (ASF) and Fuluq Fault (FF) (Fig. 14 and 15).

#### 2.3.1 Dead Sea Transform Fault (DSTF)

The Dead Sea Transform is one of the world's most famous strike-slip faults in the Middle East. It was formed as a result of the opening of the Red Sea in Oligocene-Early Miocene due to the divergence between the Arabian and African Plates (Freund et al., 1970; Garfunkel, 1981). It stretches from the southern Gulf of Aqaba to Taurus-Zagros collision zones in the southern of turkey, with long almost 1100 km (Fig. 13). The movement of the fault began between 14 and 20 Ma ago (Freund et al., 1970; Garfunkel, 1981), and it is still active till now, with slip rate ranges.
between 4 to 7.5 mm/year (Garfunkel, 1981; Al-Taj, 2000; Klinger et al., 2000; Niemi et al., 2001; Marco and Klinger, 2014). It comprises of several segments, creating the present topography. In the following, the characteristics of each segment are described (Fig. 14):

![Geological map of Jordan](image.png)

**Fig. (12):** Geological map of Jordan (After Bender, 1975), and location Capitolias/Beit Ras and Umm el-Jimal.

1. **Gulf of Aqaba**

Gulf of Aqaba is the southern termination of the DSTF and the northeastern portion of the Red Sea, trending 20°N (Fig. 14). It consists of three pull-apart basins, striking 20°N-25°E. Elat, Aragonese, Dakar basins, with four main faults: Evrona Fault, Elat Fault, Aragonese Fault, and Darker.
Fig. (13): Major tectonics map of the Middle East (After Garfunkel, 1989; Ilani et al., 2001; Wald et al., 2019).

2- Wadi Araba Fault

Wadi Araba fault stretches almost 160 km from the Gulf of Aqaba to the Dead Sea Basin. It strikes NNE-SSW. Its slip rate is approximately 4.9 mm/y (Sadeh et al., 2012) (Fig. 14).
Fig. (14): Structural map of the Levant area. It includes the main structures (Modified after Ibrahim (1996), Ababsa (2013) and Zohar et al (2016)).
Fig. (15): Structural map of Jordan (after Ababsa, 2013).

3- Dead Sea Basin

The Dead Sea is a pull-apart basin, and it is almost 430 m below sea level, the lowest place in the world on land. It was generated as a result of left-stepping of the DSTF. The basin is 150 km long, and 17-20 km wide, consisting of various sub-basins separated by transverse Faults (ten Brink and Flores, 2012) (Fig. 14 and 15).
4- Jordan Valley Fault (JVF)

Jordan Valley fault extends almost 100 km from the northwestern edge of the Dead Sea Basin to Lake Tiberias (Galilee). The slip rate of the southern part is 4.9 mm/yr while the northern part is 3.8 mm/yr (Sadeh et al., 2012) (Fig. 14 and 15).

5- Carmel-Triza Fault

Carmel-Triza fault is a branch of Jordan Valley fault, trending NW-SE. It stretches almost 130 km from Jordan Valley to Mediterranean Sea, crossing Haifa town. It is oblique fault, with 0.7 mm left-lateral slip rate and 0.6 mm tension rate (Sadeh et al., 2012) (Fig. 14).

6- Sea of Galilee (Tiberias Lake)

Sea of Galilee is a pull apart basin, 20 km long and 8-12 km wide, located between the termination of the Jordan Valley fault and Hula fault. It was formed as a result of left-stepping of the Jordan Valley fault (Hurwitz et al., 2002) (Fig. 14 and 15).

7- Gorge/Hula Fault (HF)

Gorge/Hula fault extends from north of Tiberias Lake (Galilee) to Hula Valley (Marco et al, 2005), striking NNE with slip rate almost 3.7 mm/yr (Sadeh et al., 2012) (Fig. 14).

8- Yammouneh Fault (YF)

Yammouneh fault extends 170 km from the northern part of Hula Basin to north of Lebanon. It is part of Lebanon restraining bend, trending SSW-NNE strike. Its slip rate ranges between almost 4.0 to 5.5 mm/yr (Nemer et al., 2008) (Fig. 14).

9- Roum Fault (RF)

Roum fault is branch of the Yammouneh fault, striking NW from Hula Basin. The slip rate ranges between 0.86 to 1.05 mm/yr (Nemer and Meghraoui, 2006) (Fig. 14).

10- Rachaya and Serghaya Faults (RF and SF)

The Serghaya fault extends from NE of Hula Basin and runs through Hermon Mountain to the Anti Lebanon range (Gomez et al., 2007). The slip rate of the fault is almost 1.4 mm/yr (Nemer et
The Rachaya fault also extends from the NE of the Hula Basin to the northern part of the Mount Hermon, striking SSW-NNE (Gomez et al., 2007) (Fig. 14).

11- Missyaf Fault (MF)

Missyaf fault is the northern most part of the DSTF, trending NNE-SSW. It extends 80 km from Al-Boqueaa, the termination of Yammouned fault, to Ghab pull a part basin (Sbeinati et al., 2010). The fault slip rate is 6.9 mm/yr (Meghraoui et al., 2003) (Fig. 14).

2.3.2 Azraq-Sirhan Fault (ASF)

Azraq-Sirhan fault System was formed in the Senonian (Segev and Rybakov, 2010). It consists of several deep grabens extending from northeast Jordan to northwest of Saudi Arabia (NW-SE) (Segev et al., 2014) (Fig. 11 and 12). In Late Eocene, the fault was reactivated (Segev et al., 2006). In the Cenozoic, it was covered by Neogene-Quaternary deposits and volcanic rocks cover (Harrat Ash-Sham). The tectonics setting of the fault is not well studied, as well as the geomorphology (Segev et al., 2014) (Fig. 14 and 15).

2.3.3 Fuluq Fault (FF)

Fuluq fault, striking NW/SE, is part of an Azraq Basin (Fig. 12), that was formed in Late Cretaceous. It is bounded by Fuluq fault from the north and east. The deepest part in Azraq Basin is the east and northern east (Ibrahim, 1996), because of the long downthrown of the Fuluq fault, which reach to 2500 m to the southwest (MGEF website) (Fig. 14 and 15).

2.3.4 Zarqa River Fault (ZRF)

It is a Right lateral fault. It trends E-W and extends from Jordan valley to 80 km to the east (Mohammad and Muneizel, 1998) (Fig. 14 and 15).
Chapter 3: Instrumental Seismicity

Recording of the instrumental earthquakes in the Levant started in 1898 when the Helwan station HL was built in Cairo, Egypt. The second station was operated in 1912 in Lebanon, called the Kasara Station. In 1953, Hebrew University of Jerusalem (JER) built another station in Jerusalem. After that many stations were built across the region, covering large zone in the Levant area. In 1983, Jordan Seismological Observatory operated a regional seismic network, including several stations. They were recently upgraded to the broadband system (Hofstetter et al., 2014).

In the Levant, four large earthquakes, with magnitudes of more than 5, were recorded. The first one was in 1927, the Jericho earthquake, with Ms 6.2, located along the western shore of the Dead Sea (Zohar and Marco, 2012; Hofstetter et al., 2014). The second earthquake occurred in 1956, with Ms 5, along the Mediterranean coastline near Beirut. The third one, the strongest event, was occurred in Gulf of Aqaba in 1995 about 80 km south of Aqaba city, with 7.2 Mw (Nemer and Meghraoui, 2006). The last recorded event was in 2004, with 5.1 Mw, north of the Dead Sea (Hofstetter et al., 2008).

The data of the instrumental earthquakes has been analyzed by several researchers as part of several earthquake hazard assessment studies, using different methods such as focal mechanism analysis, Gutenberg-Richter relation, attenuation relation, earthquake kernel density, and others.

Figure (16) shows the recorded instrumental earthquakes in the Levant and surrounded area from 1900-2012, and the epicenter's locations of the major historical earthquakes from (1365 B.C.–1900) (Meghraoui, 2015).

The Focal mechanism analysis, as can be seen in figure (16), reveals the stress field along DSTF. (Meghraoui, 2015).

Several seismic attenuation relationships were developed that express the relation between the Peak Ground Acceleration (PGA) value and distance from epicenter. Ambraseys et al (1996), Boore-Joyner-Fumal (1994 and 1997) attenuation equations can be applied in the Levant area. As can be seen in figure (17a), the curves that show the attenuation of the earthquakes which have 6 and 7 Mw, including the recorded PGA values of the stations in Jordan (Jaradat et al., 2008). Al-
Qaryouti (2008) also developed an attenuation relation assuming a local magnitude (ML), using 57 recordings of 30 earthquakes from 1979-2001, in Jordan, as can be seen in figure (17b).

Fig. (16): Last-century instrumental seismicity (1900–2012, yellow circle), historical seismicity (1365 B.C.–1900, red box) along the DSTF and surrounded areas, and focal mechanism (Meghraoui, 2015).
Fig. (17): (a) Attenuation curves of the DSTF (after Jaradat et al., 2008). (b) Attenuation relation, using 57 recordings of 30 earthquakes from 1979-2001 (after Al-Qaryouti, 2008).

The Gutenberg-Richter relation reflects the relation between the magnitude and the total number of earthquakes in a certain period of time in any given location, using the equation: Log10 N = a-b M, where N is the number of events having magnitude >=M; a and b are constant. The b-value indicates to the seismic activity of the seismic source. If it is close to 1, it indicates high seismic activity (Gutenberg and Richter, 1956). As can be seen in table (2) the calculated b-value and annual rate of M>=4 earthquakes for different seismic sources in the Levant and surrounded area (Jimenez et al., 2008).
Table (2): Seismogenic source zones (DSTF and around sources) and seismic parameters b-value (b-constant of Gutenberg-Richter relationship, Mmax (upper bound magnitude), \(\lambda_4\) (annual rate of M\(\geq\)4.0 earthquakes).

<table>
<thead>
<tr>
<th>N°</th>
<th>Source</th>
<th>b-value</th>
<th>(M_{\text{max}})</th>
<th>(\lambda_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dead Sea-Jordan River</td>
<td>0.75</td>
<td>7.5</td>
<td>0.330</td>
</tr>
<tr>
<td>2</td>
<td>Wadi Araba</td>
<td>0.82</td>
<td>6.6</td>
<td>0.110</td>
</tr>
<tr>
<td>3</td>
<td>Yammouneh-Roum</td>
<td>0.92</td>
<td>8.0</td>
<td>1.470</td>
</tr>
<tr>
<td>4</td>
<td>Palmira</td>
<td>0.96</td>
<td>6.0</td>
<td>0.120</td>
</tr>
<tr>
<td>5</td>
<td>Gulf of Aqaba</td>
<td>0.85</td>
<td>6.5</td>
<td>1.510</td>
</tr>
<tr>
<td>6</td>
<td>Gulf of Suez-South</td>
<td>1.07</td>
<td>7.0</td>
<td>0.540</td>
</tr>
<tr>
<td>7</td>
<td>Gulf of Suez-North</td>
<td>0.80</td>
<td>7.0</td>
<td>0.190</td>
</tr>
<tr>
<td>8</td>
<td>Sirhan Faults</td>
<td>0.71</td>
<td>7.0</td>
<td>0.050</td>
</tr>
<tr>
<td>9</td>
<td>Fara' Haifa</td>
<td>0.86</td>
<td>5.8</td>
<td>0.090</td>
</tr>
<tr>
<td>10</td>
<td>SE Mediterranean 1</td>
<td>0.80</td>
<td>5.8</td>
<td>1.750</td>
</tr>
<tr>
<td>11</td>
<td>SE Mediterranean 2</td>
<td>1.05</td>
<td>5.8</td>
<td>0.490</td>
</tr>
<tr>
<td>12</td>
<td>SE Mediterranean 3</td>
<td>0.92</td>
<td>7.5</td>
<td>0.090</td>
</tr>
<tr>
<td>13</td>
<td>Cyprus</td>
<td>0.98</td>
<td>8.0</td>
<td>2.740</td>
</tr>
<tr>
<td>14</td>
<td>Wadi Karak</td>
<td>0.44</td>
<td>4.7</td>
<td>0.023</td>
</tr>
<tr>
<td>15</td>
<td>SE Maan</td>
<td>0.29</td>
<td>4.6</td>
<td>0.029</td>
</tr>
<tr>
<td>16</td>
<td>East of Gulf of Aqaba</td>
<td>0.40</td>
<td>5.9</td>
<td>0.054</td>
</tr>
<tr>
<td>17</td>
<td>Central Sinai</td>
<td>0.30</td>
<td>4.0</td>
<td>0.010</td>
</tr>
<tr>
<td>18</td>
<td>North East Gaza</td>
<td>0.34</td>
<td>4.5</td>
<td>0.022</td>
</tr>
</tbody>
</table>

Earthquake Kernel Density \((\rho Nk)\) is a spatial distribution analysis of the seismic events. The analysis provides the seismic pattern of a targeted area and the characteristics of the seismic source. \(\rho Nk\) is calculated by counting all the weighted events from each grid point within a 6-km radius, dividing their number by the area of the sampler \((\pi r^2)\) and normalizing the duration of the catalogues of the earthquake. The equation of this relationship is in the following (Sharon et al., 2019).

\[
\rho_{Nk} = \frac{\sum_{n=1}^{N} e^{-\frac{d(n)^2}{2\sigma^2}}}{T\pi r^2}
\]

Where \(N\) is the total number of events within the radius \(r\), \(d(n)\) is the distance between an event \(n\) and the circle center. \(\sigma\) is the standard deviation of the Gaussian function. \(T\) is the duration of the earthquake catalogue. The Unit is \([\text{events/km}^2/\text{yr}]\).

Sharon et al. (2019) modified the Earthquake Kernel Density parameter along the segments of the DSTF, using relocated 16,700 seismic events, with magnitude 0.1\(\leq\)M\(\leq\)7.2 from 1983-2017. As shown in the figure (19) which is the map of the kernel density parameter \((\rho Nk)\) along the DSTF.
It can be noticed that the highest values, which indicate to highest activity, are concentrated northwest of the Gulf of Elat, then along the Araba Valley, Jordan Valley, Dead Sea, Hula Valley, and Roum fault (Sharon et al., 2019).

Fig. (18): Earthquake Kernel density distribution, according to the relocated catalogue Colors and corresponding numbers indicate the value in [events/km2/yr]. The highest values, which indicate to highest activity, are concentrated northwest of the Gulf of Elat, then along the Araba Valley, Jordan Valley, Dead Sea, Hula Valley, and Roum fault.
Chapter 4: Literature Review

In the following, the previous studies concerning the historical earthquakes in the Levant area were summarized, covering paleoseismology, archaeo-paleoseismology, historical seismology and archaeoseismology studies.

4.1 Paleoseismology Studies

Reches & Hoexter (1981) excavated a trench along Jericho fault, which is the southern part of the Jordan Valley fault. They discovered evidence of displaced Holocene deposits caused by the fault. They suggested that the displacement of the fault was responsible for at least two major earthquakes in the last 2000 years, which are the 31 BC and 748/9 AD earthquakes.

Ken-Tor et al. (2001) excavated a Holocene outcrop in Ze'elim terrace, located west of the Dead Sea. They identified evidence of sediment deformations (seismites) in the outcrop. They suggested that these deformations were formed as a result of earthquakes 31 BC and 33 AD, 363 AD, 1212 AD, 1293 AD, 1834 AD, and 1927 A.D.

Gomez et al. (2003) excavated a trench along the Serghaya fault. They identified five surface-ruptures, and suggested that the youngest rupture was responsible for causing the 1759 AD earthquake.

Marco et al. (2005) excavated a trench in Bet-Zayda Valley along the Jordan Gorge fault. They found that a paleo river channel is displaced left latterly by the fault. They suggested that the fault caused the October 1759 AD earthquake and/or the 1202 AD earthquake.

Nemer and Meghraoui (2006) studied a trench along the Roum fault. They identified evidences of four displacements. They suggested that the last displacement caused the 1837 AD earthquake, with a magnitude of 7 (Ms).

Daëron et al. (2005 and 2007) studied a trench along the Yammouneh fault. They identified around 13 events dated back for more than 12 ka. They suggested that the youngest one caused the 1202 AD earthquake.

Nemer et al. (2008) investigated a trench along a stream channel truncated by the Rachaya and Serghaya faults. They suggested that the fault was the source of 30 October–25 November 1759 AD earthquakes, with a magnitude ranges between 6.6 - 7.4.
Kagan et al. (2011) studied two Holocene outcrops, located west of the Dead Sea in Ein Feshkha and Ze'elim Gully. They described many types of seismities resulted by historical earthquakes. They suggested that these deformations were caused by 1927 AD, 1458 AD, 1293 AD, 1202 AD, 1212 AD, 1033 AD, 749 AD, 659 AD, 551 AD, 419 AD, 502 AD, 363 AD, and 33 AD.

Wechsler et al. (2014) excavated a trench along Gorge fault-Hula fault. They identified evidence of displaced Holocene deposits. They suggested that the displacements produced 303 AD, 363 AD, 551 AD, and 659 AD earthquakes.

### 4.2 Archaeo-Paleoseismology Studies

In this section, the previous literature that studied the truncated archaeological structures by active faults were summarized as in the following:

Marco et al. (1997) identified evidence of displaced water channels and walls by Gorge fault in a Crusader fortress (Vodum Jacob Castle) in Ateret. They found that the displacement date backs to the time after the 1178 AD, and it caused the 1202 AD earthquake.

Ellenblum et al. (1998) investigated the Vodum Jacob Castle (Ateret). They found that some parts of the castle have been displaced two times by the Gorge fault. A wall is displaced almost 1.6 m and another wall is displaced almost 0.5 m. They suggested that the first displacement caused the 1202 AD earthquake and the second one caused the 1759 AD or/and the 1837 AD.

Meghraoui et al. (2003) studied a Roman aqueduct in Syria displaced almost 13.6 m by Missyaf fault. They suggested that the displacement caused almost three earthquakes constrained between 100 AD-750 AD, 700 AD-1030 AD and 990-1210 AD.

Haynes et al. (2006) studied an aqueduct in Qasr Tilah in Wadi Araba, Jordan, displaced 0.75 m by Wadi Araba fault. They suggested that the displacements caused 634 AD or 659/660 AD, 873 AD, 1068 AD, and 1546 AD earthquakes.

Thomas et al. (2007) excavated remains of the antique Aqaba city (Alia), Jordan. They investigated the Late Roman-Byzantine to Early Islamic deposits displaced by an active fault.

Sbeinati et al. (2010) excavated Al-Harifa Roman aqueduct in Syria displaced 13.6 m by the Missyaf fault. They suggested that the displacement caused four events constrained between 160-
510 AD, 625-690 AD, 1010-1210 AD, and they suggested that the last event caused the 1170 AD earthquake.

4.3 Historical Seismology (Macroseismology) Studies
Ambraseys and Barazangi (1989) studied historical documents, aiming to study the historical earthquake events between 1100 AD-1988 AD in the Levant. They concluded that 1759 was one of the greatest earthquake occurred, and produced considerable damage in the area.

Ambraseys and Karcz (1992) reviewed historical documents that include reports about the 1546 AD earthquake. They stated that the earthquake caused large damage in the area, with 6 Ms.

Ambraseys (1997) reviewed historical documents that include reports about the 1837 AD earthquake. He stated that the earthquake damaged many towns north of Palestine and south of Lebanon with 7 Ms.

Darawcheh et al. (2000) studied historical documents that have recorded the 551 AD earthquake. They concluded that the greatest damage was in Beirut, with intensity IX-X. They suggested that the causative fault is the Roum fault.

4.4 Archaeoseismology Studies
Karcz et al. (1977) mentioned that the archaeoseismology excavation in the Levant helps in updating the earthquake catalogues, as well as enriching the result of earthquake hazard assessment.

Korjenkov and Gini (2003) studied Ein Erga and Ein Rahel, located in Wadi Araba. They found traces of two historical earthquakes, with intensity ranging between IX-X. They dated the first event to the 3rd century BC and the second earthquake to the early 2nd century AD.

Al-Tarazi and Korjenkov (2007) excavated the ancient city of Ayla, Jordan. They described traces of damages caused by two earthquakes, with intensity IX, and epicenters location along the Wadi Araba fault, during the Rashidun (644-656 AD) and Fatimid periods (1050-1116 AD).

Wechsler et al. (2009) studied Umm El Qanatir's ancient city aged back to Byzantine-Umayyad time. They suggested that the 749 AD earthquake damaged the city, and caused many damage features, like fallen columns, fallen walls, and shifted stones.
Kázmer and Major (2010) studied Al-Marqab Castle in Syria. They recorded traces of damages of two earthquakes. The first one is the 1202 AD earthquake and the second backs to the time after 1285 AD.

Al-Azzam (2012) documented earthquake features in the ancient city of Gadara/Um Qais, Jordan. She suggested that the 749 AD earthquake was the main event which caused most of the observed damages in the site.

Alfonsi et al. (2013) studied earthquake damage in Hisham Palace in Khirbet Al-Mafjar. They suggested that the 1033 AD earthquake caused the damages, with IX-X intensity.

Kazmer and Major (2015) studied earthquake features in a crusader castle located in Syria in Tartus, called Safita. They suggested that the 1202 AD earthquake was the responsible for the main damages, with intensity almost VIII-IX.

Ward (2016) stated that the 363 AD earthquake caused severe damages to the pagan structures in Petra, such as the Qasr al-Bint, the "Great" Temple, the Small Temple, the Temple of the Winged Lions, and temples at Khirbet et-Tannur and Khirbet edh-Dharih.

Khamisy (2017) investigated a Frankish village, called Tarphile. He found that some walls have been destructed by an earthquake, and they suggested that the 1202 AD earthquake was the responsible event.
Chapter 5: Results

5.1 Pre-instrumental Seismicity

In this section, the documented historical earthquakes, which have been mentioned in the earthquake catalogues, are summarized, covering the events that affected the north of Jordan and occurred from the Early Roman to the end of the nineteenth century. The events are divided into two types; the first type is major events, which have data that can create intensity maps, and poorly documented events, which do not have enough data to create intensity maps. In the following are the maps and tables related to the events.

5.1.1 Intensity Maps of the Major Earthquakes

1- Earthquake 2/4/303 AD

The affected regions from this event extended from the north Byblus to the south Caesarea. The worst damaged zone was from Sidon to Gush Halav, with an intensity of IX-X. The epicentral location was identified by many researchers such as Ambraseys (2009) with ML= 6, Abou Karaki (1987) with ML= 6.3, Sbeinati et al. (2005) and Grigoratos et al. (2020) with Mw= 6.7 (ML= 6.5) (Table. 3 and Fig. 19).

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Tyre</td>
<td>Terrible earthquake and many buildings were collapsed</td>
<td>Destructive</td>
<td>Houses collapsed with loss of life</td>
<td>Serious damage (Average magnitude = 7.1)</td>
<td>IX-X</td>
</tr>
<tr>
<td>Sidon</td>
<td>Terrible earthquake and many buildings were collapsed</td>
<td>Destructive</td>
<td>Houses collapsed with loss of life</td>
<td>-</td>
<td>IX-X</td>
</tr>
<tr>
<td>Gush Halav</td>
<td>-</td>
<td>Destructive</td>
<td>-</td>
<td>-</td>
<td>IX-X</td>
</tr>
<tr>
<td>Byblus</td>
<td>-</td>
<td>-</td>
<td>May have affected</td>
<td>-</td>
<td>V-VI?</td>
</tr>
<tr>
<td>Caesarea</td>
<td>-</td>
<td>Tsunami</td>
<td>Felt</td>
<td>-</td>
<td>V-VI</td>
</tr>
<tr>
<td>Beit Ras</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>VI-VIII (Al-Tawalbeh et al., 2021)</td>
</tr>
</tbody>
</table>

Table (3): Earthquake's size damage of the event 303/306 AD.
2- Earthquake 19/5/363 AD: -

The affected area of this event extended from Banyas in Syria to Petra in Jordan. The maximum intensity reached IX. The epicenter location was identified by many researchers such as Ben-Menahem (1979, 1991) with ML= 6.4 and Ambraseys (2009) with ML= 6.7. (Table. 4 and Fig. 20).
Table (4): Earthquake's size damage of the event 363 AD.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Sebastia</td>
<td>Severe damage</td>
<td>Destroyed</td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Haifa</td>
<td>-</td>
<td>Destroyed</td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Japho</td>
<td>Severe damage</td>
<td>Destroyed</td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Beit Gubrin</td>
<td>Severe damage</td>
<td>More than half of the town was ruined</td>
<td>IX</td>
</tr>
<tr>
<td>Jerusalem</td>
<td>Damage in the Temple area, and some workmen were killed</td>
<td>More than half of the town was ruined</td>
<td>IX</td>
</tr>
<tr>
<td>Lydda</td>
<td>-</td>
<td>More than half of the town was ruined</td>
<td>IX</td>
</tr>
<tr>
<td>Petra</td>
<td>Severe damage</td>
<td>More than half of the town was ruined</td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Caesarea</td>
<td>Severe damage</td>
<td>Destroyed</td>
<td>VIII</td>
</tr>
<tr>
<td>Tiberias</td>
<td>Severe damage</td>
<td>Destroyed</td>
<td>VIII</td>
</tr>
<tr>
<td>Gerasa (Jerash).</td>
<td>-</td>
<td>The cathedral and staircase in the ‘Fountain Court’ were damaged</td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Banyas</td>
<td>Affected</td>
<td></td>
<td>V-VII</td>
</tr>
<tr>
<td>Beit Ras</td>
<td></td>
<td></td>
<td>VIII-IX (Al-Tawalbeh et al., 2021).</td>
</tr>
</tbody>
</table>

3- Earthquake 22/8/502 AD

The affected area of this event extended from Beirut to Akko. The worst damage was in Akko, with intensity X. The epicenter was identified by many researchers such as Abou Karaki (1987) with ML= 6.5, Sbeinati et al. (2005) with ML= 6.8 and Ambraseys (2009) ML= 6. (Table. 5 and Fig. 21).

Table (5): Earthquake's size damage of the event 502 AD.

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Ptolemais &quot;Akko&quot;</td>
<td>Overturned, and nothing left stand</td>
<td>Destructive</td>
<td>Devastated</td>
<td>Serious damage (M = 7)</td>
<td>X</td>
</tr>
<tr>
<td>Tyre</td>
<td>Half of the site was damaged</td>
<td>Sever damage</td>
<td>Half of the towns collapsed</td>
<td>-</td>
<td>IX</td>
</tr>
<tr>
<td>Sidon</td>
<td>Half of the site was damaged</td>
<td>Sever damage</td>
<td>Half of the town was collapsed</td>
<td>-</td>
<td>IX</td>
</tr>
</tbody>
</table>
Some houses were collapsed - VII

Beirut

Beit Ras VI-VIII (Al-Tawalbeh et al., 2021)

4- Earthquake 9/7/551 AD

The affected zone of this event extended from Tripoli to Jerash. The worse damage zone was from Tripoli to Tyre in the south. The maximum intensity ranged between IX-X. The epicenter was identified by Sbeinati et al. (2005) with ML= 6.8, Ambraseys (2009) with ML= 6.7 (Table. 6 and Fig. 22).

Table (6): Earthquake's size damage of the event 551 AD.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Tyre</td>
<td>Great damage, and many thousands of people were died</td>
<td>Much damage</td>
<td>Damaged</td>
<td>Serious damage (M = 7.5)</td>
<td>IX-X</td>
</tr>
<tr>
<td>Sidon</td>
<td>Great damage, and many thousands of people was died</td>
<td>Much damage</td>
<td>Damaged</td>
<td>-</td>
<td>IX-X</td>
</tr>
<tr>
<td>Beirut</td>
<td>Great damage, and many thousands of people were died</td>
<td>Much damage</td>
<td>Worst hit</td>
<td>-</td>
<td>IX-X</td>
</tr>
<tr>
<td>Tripoli</td>
<td>Great damage, and many thousands of people were died</td>
<td>Much damage</td>
<td>Damaged</td>
<td>-</td>
<td>IX-X</td>
</tr>
<tr>
<td>Jerash</td>
<td>-</td>
<td>Much damage</td>
<td>-</td>
<td>-</td>
<td>VIII</td>
</tr>
<tr>
<td>Sarfand</td>
<td>-</td>
<td>-</td>
<td>Damaged</td>
<td>Serious damage (M = 7.5)</td>
<td>IX-X</td>
</tr>
<tr>
<td>Galilee</td>
<td>-</td>
<td>Some damages</td>
<td>-</td>
<td>-</td>
<td>VIII</td>
</tr>
<tr>
<td>Samaria</td>
<td>-</td>
<td>Some damages</td>
<td>-</td>
<td>-</td>
<td>VIII</td>
</tr>
<tr>
<td>Beit Ras</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>VIII (AL-Tawalbeh, 2021)</td>
<td></td>
</tr>
</tbody>
</table>

5- Earthquake 659 AD

The affected area of this event extended from Jericho to Rehav. The maximum intensity reached to VIII-IX. The epicenters were identified by Ambraseys (2009) with ML= 5.3, Ben-Menahem (1979) with ML= 6.6 and estimated in Grigoratos et al. (2020) with Mw= 6 (ML= 5.9). (Table. 7 and fig. 23).
Table (7): Earthquake's size damage of the earthquake 659 AD.

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jericho</td>
<td>Overthrow the greater part of the site and all churches such as St. John were damaged</td>
<td>Large part of Jericho was destroyed</td>
<td>May cause a lot of damage in very populated area (M= 6.6)</td>
<td></td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Jordan Valley</td>
<td>Strong effect</td>
<td>-</td>
<td>-</td>
<td></td>
<td>VIII-IX</td>
</tr>
<tr>
<td>khan el-Ahmar</td>
<td>Monastery of St. Euthymius was destroyed</td>
<td>-</td>
<td>-</td>
<td></td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Rehov in Beth Shean basin</td>
<td>Strong effect</td>
<td>-</td>
<td>-</td>
<td></td>
<td>VIII-IX</td>
</tr>
</tbody>
</table>

6- Earthquake 18/1/749 AD

The affected area of this event extended from Damascus to Jerusalem. The worse damage extended from Galile to Beth Shean and to Dera'a. The maximum intensity reached to X. The epicenter was identified by Ben-Menahem (1979, 1991) with ML= 7.3 and Sbeinati et al. (2005) with ML= 6.8 (Table. 8 and Fig. 24).

Table (8): Earthquake's size damage of the event 749 AD.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Amman</td>
<td>-</td>
<td>Disastrous, severe loss of life</td>
<td>-</td>
<td>-</td>
<td>IX</td>
</tr>
<tr>
<td>Moab (Balqa)</td>
<td>Severe earthquake</td>
<td>-</td>
<td>A fortress was collapsed totally</td>
<td>-</td>
<td>IX</td>
</tr>
<tr>
<td>Galileee</td>
<td>Severe earthquake</td>
<td>30 houses were destroyed</td>
<td>Destroyed, more than 100,000 persons were died</td>
<td>Serious damage (M = 7.2)</td>
<td>IX-X</td>
</tr>
<tr>
<td>Dera'a</td>
<td>Severe earthquake</td>
<td>-</td>
<td>Completely damaged</td>
<td>-</td>
<td>IX-X</td>
</tr>
<tr>
<td>Damascus</td>
<td>Severe earthquake</td>
<td>-</td>
<td>Severe damage</td>
<td>VII</td>
<td></td>
</tr>
<tr>
<td>Um Al Jimal</td>
<td>Suffered</td>
<td>Affected</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Hlammat Gader</td>
<td>-</td>
<td>Totally destroyed</td>
<td>-</td>
<td>-</td>
<td>IX</td>
</tr>
<tr>
<td>Pella</td>
<td>Effected</td>
<td>Severe damage</td>
<td>-</td>
<td>-</td>
<td>IX</td>
</tr>
<tr>
<td>Beth Shean</td>
<td>-</td>
<td>Severe damage</td>
<td>-</td>
<td>Serious damage (M = 7.2)</td>
<td>IX-X</td>
</tr>
<tr>
<td>Jerusalem</td>
<td>-</td>
<td>Severe damage</td>
<td>-</td>
<td>Worst damage</td>
<td>IX</td>
</tr>
<tr>
<td>Jericho (Hishe Palace)</td>
<td>-</td>
<td>Destroyed</td>
<td>-</td>
<td></td>
<td>IX</td>
</tr>
<tr>
<td>Jerash</td>
<td>-</td>
<td>Many of its greatest buildings were destroyed</td>
<td>-</td>
<td></td>
<td>IX</td>
</tr>
<tr>
<td>Beit Ras</td>
<td></td>
<td></td>
<td></td>
<td>VIII-X Al-Tawalbeh et al. (2021)</td>
<td></td>
</tr>
</tbody>
</table>

7- Earthquake 5/12/1033 AD

The affected area of this event extended from Akko to the Negev. The worse damage was in Jericho. The maximum intensity reached X. The epicenter was identified by Grigoratos et al. (2020) with Mw= 7.3 (Table. 9 and Fig. 25).

Table (9): Earthquake size damage for the earthquake 1033 AD.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Akko (Acre)</td>
<td>M= VIII, much damage to buildings and loss of life</td>
<td>The sea flowed out several kilometers, and some houses of the town collapsed</td>
<td>VIII-IX</td>
</tr>
</tbody>
</table>
Tiberias | Many buildings were collapsed | Serve damage | VII-VIII
---|---|---|---
Nablus | Half of the city was damaged | Much damage, half of the buildings collapsed, and 300 persons were died. | IX
Ramla | Third of the city was collapsed | Much damage and great panic, also third to a half of its houses were damaged | IX
Jerusalem | Serve damage | damage was widespread | VIII-IX
Hebron | Many buildings were collapsed | A part of the mosque of Abraham (Masjid Ibrahim) was destroyed | VIII
Jericho | Destroyed | Much damage | IX-X
Askelon | Some damage | Collapse of the minaret of the Friday Mosque | VII-VIII
Negev | Felt | Felt | V

8- Earthquake 1202 AD

The affected area of this event extended from Margat to Jerusalem. The maximum intensity reached to IX. The epicenter was identified by Ambraseys (2009) with M 7.6 (Table. 10 and Fig. 26).

Table (10): Earthquake’s size damage for the event 1202 AD.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Baalbek</td>
<td>VIII</td>
<td>-</td>
<td>IX</td>
<td>IX</td>
</tr>
<tr>
<td>Tibnin</td>
<td>VII</td>
<td>-</td>
<td>IX</td>
<td>IX</td>
</tr>
<tr>
<td>Tyre</td>
<td>VIII</td>
<td>Towers and some outlying fortifications were destroyed</td>
<td>IX</td>
<td>IX</td>
</tr>
<tr>
<td>Beit Jann</td>
<td>IX</td>
<td>Many walls were collapsed</td>
<td>IX</td>
<td>IX</td>
</tr>
<tr>
<td>Akko</td>
<td>VIII</td>
<td>It was probably destroyed, with considerable damage to the royal palace and the walls</td>
<td>-</td>
<td>VIII</td>
</tr>
<tr>
<td>Tiberias</td>
<td>IX</td>
<td>It was loss of life</td>
<td>-</td>
<td>IX</td>
</tr>
<tr>
<td>Nablus</td>
<td>VII-VIII</td>
<td>-</td>
<td>-</td>
<td>VIII</td>
</tr>
<tr>
<td>Jerusalem</td>
<td>V</td>
<td>Suffered relatively little</td>
<td>VI</td>
<td>VI</td>
</tr>
<tr>
<td>Safitha</td>
<td>-</td>
<td>Badly weakened</td>
<td>VIII-IX</td>
<td>VIII-IX</td>
</tr>
</tbody>
</table>
VII

VII

Some damages - Margap

The castle watchtower had some collapses - Hims

VIII

VIII

Felt - Aleppo

9- Earthquake 1293 AD

The affected area of this event extended from Qaun to Gaza in the west and to Al-Karak in the east. The maximum intensity reached to IX in Al-Karak. The epicenter was identified Ambraseys (2009) with Ms = 6 (Table. 11 and Fig. 27).

Table (11): Earthquake’s size damage for the event 1293 AD.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Karak</td>
<td>The citadel and many houses were destroyed</td>
<td>Caused a lot of damage in very populated area (M= 6.6)</td>
<td>IX</td>
</tr>
<tr>
<td>Al-Ramla</td>
<td>The minaret of the main mosque were fissured and some its parts were collapsed.</td>
<td>Caused a lot of damage in very populated area (M= 6.6)</td>
<td>VIII</td>
</tr>
<tr>
<td>Gaza</td>
<td>A minaret was collapsed</td>
<td>Caused a lot of damage in very populated area (M= 6.6)</td>
<td>VIII</td>
</tr>
<tr>
<td>Qaun</td>
<td>The castle was suffered</td>
<td>Caused a lot of damage in very populated area (M= 6.6)</td>
<td>VII</td>
</tr>
<tr>
<td>Ludd</td>
<td>Some houses were effected</td>
<td>Caused a lot of damage in very populated area (M= 6.6)</td>
<td>VIII</td>
</tr>
</tbody>
</table>

10- Earthquake 16/11/1458

The affected area of this event extended from Ludd in the north to Al-Karak in the southeast. The maximum intensity reached to IX in Al-Karak. The epicenter was identified by Ambraseys (2006) with Ms= 7.1 (Table. 12 and Fig. 28).

Table (12): Earthquake’s size damage for the event 1458 AD.

|----------------|------------------|-----------------------------------|
Some towers and walls were destroyed

Many minarets were destroyed

Few parts of some buildings were torn

---

**AL-Karak**

**Al-Ramla, AL-Ludd, Hebron**

**Jerusalem**

---

Fig. (25): Intensity map of the 1033 AD earthquake. Kag2011: Kagan et al. (2011), Kling2015: Klinger et al. (2015), Ferry2011: Ferry et al. (2011), Alf2013: Alfonsi et al. (2013). The epicenters were identified by Grigoratos et al. (2020) with Mw= 7.3.

11- Earthquake 14/1/1546 AD

The affected area of this event extended from Nablus to Hebron. The maximum intensity reached to X in Jericho. The epicenter was identified by Ambraseys (2009) with Ms= 6 (Table. 13 and Fig. 29).
Table (13): Earthquake’s size damage for the event 1546 AD.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nablus</td>
<td>300-500 were died, and 500 persons were buried under the ruins</td>
<td>The earthquake was stronger than elsewhere</td>
<td>IX</td>
</tr>
<tr>
<td>Hebron</td>
<td>Severely damage, 17 persons were killed.</td>
<td>-</td>
<td>VIII</td>
</tr>
<tr>
<td>Jerusalem</td>
<td></td>
<td>Holy Tomb was damaged and the walls and tower of the Temple was collapsed</td>
<td>IX</td>
</tr>
<tr>
<td>Olivet mount</td>
<td></td>
<td>A church was damaged</td>
<td>IX</td>
</tr>
<tr>
<td>Bethlehem</td>
<td></td>
<td>A chapel was totally collapsed.</td>
<td>IX</td>
</tr>
<tr>
<td>Jericho</td>
<td></td>
<td>Sever damage</td>
<td>IX-X</td>
</tr>
</tbody>
</table>

Fig. (29): Intensity map of the 1546 AD earthquake. Hay 2006: Haynes et al. (2006). The epicenter was identified by Ambraseys (2009) with $M_s = 6$.

12- Earthquake 30/10/1759

The worst damage zone of this event extended from Tiberias to Gaza. The moderate damage zone extended from Damascus to Tripoli while from the south it extended from Nazaret to Nablus. The felt zone extended from Jerusalem to Gaza. The maximum intensity reached to X. The epicenter was identified by Ambraseys and Barazangi (1989) with $M_w = 6.8$ (Table. 14 and Fig. 30).
Table (14): Earthquake’s size damage for the event 1759 October AD.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Ambraseys (2009)</th>
<th>Intensity (MMI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safad</td>
<td>Almost totally destroyed</td>
<td>X</td>
</tr>
<tr>
<td>Jisr Bant Yaqub</td>
<td>Almost totally destroyed</td>
<td>IX-X</td>
</tr>
<tr>
<td>Qunaitra</td>
<td>Almost totally destroyed</td>
<td>IX-X</td>
</tr>
<tr>
<td>Saida</td>
<td>few houses were collapsed</td>
<td>VII-VIII</td>
</tr>
<tr>
<td>Nablus</td>
<td>The damage was probably due to ground failures rather than to severe shaking</td>
<td>VIII</td>
</tr>
<tr>
<td>Tiberias</td>
<td>many houses was sank into their foundations</td>
<td>IX-X</td>
</tr>
<tr>
<td>Damascus</td>
<td>one or two houses were completely collapsed, a few were damaged and many were badly cracked</td>
<td>VII</td>
</tr>
<tr>
<td>Tripoli</td>
<td>The shock caused some concern but apparently no damage</td>
<td>VI</td>
</tr>
<tr>
<td>Jerusalem</td>
<td>Widely felt</td>
<td>V</td>
</tr>
<tr>
<td>Gaza</td>
<td>Felt</td>
<td>V</td>
</tr>
</tbody>
</table>

13- Earthquake 25/11/759 AD

The earthquake caused strong destructions in the area. The damages extended from Homs to Jerusalem. The worse damage zone extended from Ras Baalbak in the north to Zebdin and Beit Jann in the south, with intensity X. The moderate zone extended along the shoreline from Hifa to Tripoli. The felt zone was in the south in Gaza. The epicenter was identified by Ambraseys and Barazangi (1989) with Mw=7.5 (Table. 15 and Fig. 31).

Table (15): Earthquake’s size damage for the event 1759 November AD.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Ambraseys (2009)</th>
<th>Intensity (MMI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Villages in the northern part of al-Hulah</td>
<td>Totally destroyed</td>
<td>X</td>
</tr>
<tr>
<td>mountainous Metwali settlements</td>
<td>Heavy damage and loss of life</td>
<td>X</td>
</tr>
<tr>
<td>Marjuyun</td>
<td>Collapsed</td>
<td>X</td>
</tr>
<tr>
<td>Kaukaba</td>
<td>Collapsed</td>
<td>X</td>
</tr>
<tr>
<td>Zebdin</td>
<td>Collapsed</td>
<td>X</td>
</tr>
<tr>
<td>Caravanserai of Nabatiya</td>
<td>Collapsed</td>
<td>X</td>
</tr>
<tr>
<td>Hasbaiya</td>
<td>Almost totally destroyed, many people were killed</td>
<td>X</td>
</tr>
<tr>
<td>Location</td>
<td>Condition</td>
<td>Magnitude</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Kafr Hatta</td>
<td>Totally destroyed</td>
<td>X</td>
</tr>
<tr>
<td>Mukhtara</td>
<td>Collapsed</td>
<td>X</td>
</tr>
<tr>
<td>Dair Qamar</td>
<td>Almost its churches totally ruined</td>
<td>X</td>
</tr>
<tr>
<td>Kesrawan</td>
<td>Many churches and houses were collapsed</td>
<td>IX</td>
</tr>
<tr>
<td>Tannurin</td>
<td>Many churches and houses were collapsed</td>
<td>IX</td>
</tr>
<tr>
<td>Afka</td>
<td>Many churches and houses were collapsed</td>
<td>IX</td>
</tr>
<tr>
<td>Ras Baalbek</td>
<td>Totally destroyed with loss of life</td>
<td>X</td>
</tr>
<tr>
<td>Baalbek</td>
<td>Its castle were ruined, with the loss of the whole population</td>
<td>X</td>
</tr>
<tr>
<td>Sergaya, Zebedani, Hasaya and other smaller villages in the hills on either side of the Barada valley</td>
<td>Damaged, and 500 people and many animals were killed</td>
<td>X</td>
</tr>
<tr>
<td>Saasaa</td>
<td>Completely destroyed</td>
<td>X</td>
</tr>
<tr>
<td>Qatana</td>
<td>Completely destroyed</td>
<td>X</td>
</tr>
<tr>
<td>Beit Jann</td>
<td>Completely destroyed, many people perished, and the town had many landslides</td>
<td>X</td>
</tr>
<tr>
<td>Villages between Daraiya and Dair al-Ashair</td>
<td>Were ruined</td>
<td>X</td>
</tr>
<tr>
<td>Jabal Niha</td>
<td>largest rockslides</td>
<td>X</td>
</tr>
<tr>
<td>Acre</td>
<td>Scarcely a house escaped without cracks in its walls and only a few dwellings, including part of the fortification towers, fell into the sea, without casualties</td>
<td>VII-VIII</td>
</tr>
<tr>
<td>Saida</td>
<td>Some damage</td>
<td>VII</td>
</tr>
<tr>
<td>Tripoli</td>
<td>A few dwellings and three minarets were collapsed</td>
<td>VII</td>
</tr>
<tr>
<td>Qusair</td>
<td>A few dwellings were collapsed without loss of life</td>
<td>VII</td>
</tr>
<tr>
<td>Saidnaya</td>
<td>A few walls fell over and some houses were shattered without loss of life</td>
<td>VII</td>
</tr>
<tr>
<td>Halboun and Mnin</td>
<td>No one was killed but many houses were ruined, mosques were damaged and bath houses destroyed</td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Arbin</td>
<td>The baths were collapsed and the walls of the mosque was badly cracked</td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Harasta</td>
<td>Most of the houses were damaged</td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Hamat, Dair Hanna, Caesarea and Haifa</td>
<td>Were no casualties and relatively few houses needed repairing</td>
<td>VII</td>
</tr>
<tr>
<td>A part of the citadel of Tiberias</td>
<td>Was ruined</td>
<td>VIII-IX</td>
</tr>
</tbody>
</table>

54
<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homs, Hama and Shaizar</td>
<td>Walls of houses were cracked, and the earthquake caused considerable concern but no other damage</td>
<td>VIII</td>
</tr>
<tr>
<td>al-Arish, Gaza, Jerusalem and Jafa</td>
<td>Felt strongly</td>
<td>V</td>
</tr>
</tbody>
</table>

Fig. (30): Intensity map of 1759 October AD earthquake. Marco2005: Marco et al. (2005), Marco97: Marco et al. (1997), Gom2003: Gomez et al. (2003), Nem2008: Nemer et al. (2008). The epicenter was identified by Ambraseys and Barazangi (1989) with Mw= 6.8.
Fig. (31): Intensity map of the 1759 November AD earthquake. Gom2003: Gomez et al. (2003), Nem2008: Nemer et al. (2008). The epicenter was identified by Ambraseys and Barazangi (1989) with Mw=7.5.

14- Earthquake 26/5/1834

The affected area of this event extended from Acre to Gaza in the south and Jerusalem in the east. The maximum intensity reached to VII-VIII while the felt zone extended along the coastline from Gaza to Acre. The epicenter was identified by Ben-Menahem, (1979) with Mw= 6.3 (Table 16 and Fig. 32).
Table (16): Earthquake’s size damage for the event 1834 AD.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Ambraseys (2009)</th>
<th>Intensity (MMI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jerusalem</td>
<td>Some houses and tops of minarets fell</td>
<td>VII-VIII</td>
</tr>
<tr>
<td>Bethlehem</td>
<td>The Church of the Nativity had some damages, and the church of the monastery of Deir Mar Saba was cracked in two places and two of its belfries were thrown down</td>
<td>VII-VIII</td>
</tr>
<tr>
<td>Dead Sea</td>
<td>The earthquake toppled the Moabite monolith of Meisha at Dhiban and damaged historical remains at Madaba.</td>
<td>VII-VIII</td>
</tr>
<tr>
<td>Gaza and Ascalon, Caesareaea to Acre</td>
<td>Felt</td>
<td>V</td>
</tr>
</tbody>
</table>

Fig. (32): Intensity map of the 1834 AD earthquake. KenT 2001: Ken-Tor et al. (2001). The epicenter was identified by Ben-Menahem, (1979) with Mw= 6.3.
15- Earthquake 1/1837 AD

The worst damage zone of this event extended from Nabatiya in the north to Irbid in the south. The maximum intensity reached to X. The moderate damage zone extended from Akko to Nablus while the felt zone was in Gaza and Tripoli. From the north the felt zone was in Tripoli. The epicenter along Roum fault according to Ambraseys (2009, 2006) with Mw= 7 (Ambraseys, 1997) (Table 17 and Fig. 33).

Table (17): Earthquake’s size damage for the event 1837 AD.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Safed</td>
<td>Severest damage</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Tiberias</td>
<td>Severest damage</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Beirut</td>
<td>Some damages to buildings</td>
<td>Caused panic but no serious damage. About eight houses, which had been built outside its walls on alluvium by the sea, collapsed, killing two people</td>
<td>VII</td>
</tr>
<tr>
<td>Sidon</td>
<td>-</td>
<td>Almost totally ruined, 1800 houses, 580 were demolished and 630 ruined, with the loss of life.</td>
<td>IX-X</td>
</tr>
<tr>
<td>el-Jish</td>
<td>Destructive</td>
<td>It was completely destroyed, and 235 persons were died.</td>
<td>X</td>
</tr>
<tr>
<td>Ein Zeitun</td>
<td>Destructive</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Kafr Kenna</td>
<td>Light damage</td>
<td>-</td>
<td>VII</td>
</tr>
<tr>
<td>Akko</td>
<td>Part of the fortifications overturned, several persons killed and injured (90).</td>
<td>-</td>
<td>VIII</td>
</tr>
<tr>
<td>Nablus</td>
<td>several persons killed (88).</td>
<td>-</td>
<td>VIII</td>
</tr>
<tr>
<td>Hebron</td>
<td>Moderate</td>
<td>-</td>
<td>VII-VIII</td>
</tr>
<tr>
<td>Qaquin, Jaffa, Ramie, Gaza</td>
<td>No damage but tremor felt</td>
<td>-</td>
<td>V</td>
</tr>
<tr>
<td>Al-Kufur, Dibbin Nabatiya al-Tahta and Jibshit</td>
<td>-</td>
<td>Collapsed and 72 persons were died</td>
<td>IX-X</td>
</tr>
<tr>
<td>Deir Mimas</td>
<td>-</td>
<td>Totally ruined</td>
<td>X</td>
</tr>
<tr>
<td>Deir Qufa</td>
<td>-</td>
<td>Totally ruined</td>
<td>X</td>
</tr>
<tr>
<td>Sur</td>
<td>-</td>
<td>Suffered considerable damage, and 40 houses, killing 16 and injuring 36 people</td>
<td>VIII-IX</td>
</tr>
<tr>
<td>Beit Yahun</td>
<td>-</td>
<td>Totally ruined</td>
<td>X</td>
</tr>
<tr>
<td>Bint Jubayl</td>
<td>-</td>
<td>It was totally ruined, with the loss of eight lives</td>
<td>X</td>
</tr>
</tbody>
</table>

58
<table>
<thead>
<tr>
<th>Location</th>
<th>Effect</th>
<th>Damage/Death Details</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dibil</td>
<td>Totally destroyed</td>
<td>12 people lost their lives</td>
<td>X</td>
</tr>
<tr>
<td>Alma</td>
<td>Totally destroyed</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rama</td>
<td>Totally destroyed, and 180 people were died</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Shezor and in Jabal</td>
<td>245 houses were destroyed and 563 damaged, 141 people killed</td>
<td>IX-X</td>
<td></td>
</tr>
<tr>
<td>Irbid</td>
<td>Totally ruined</td>
<td></td>
<td>IX-X</td>
</tr>
<tr>
<td>Haifa</td>
<td>3 houses were ruined</td>
<td></td>
<td>VII</td>
</tr>
<tr>
<td>Attil</td>
<td>2 houses were collapsed</td>
<td></td>
<td>VII</td>
</tr>
<tr>
<td>Qaquin</td>
<td>There was little damage and only a portion of the citadel was collapsed</td>
<td>VII</td>
<td></td>
</tr>
<tr>
<td>Burqa</td>
<td>slight damage</td>
<td></td>
<td>VII</td>
</tr>
<tr>
<td>Ajlun and Jerash</td>
<td>Some damages, During the earthquake free-standing columns in the ancient city of Jerash were seen chattering on their bases but they did not collapse</td>
<td>VII</td>
<td></td>
</tr>
<tr>
<td>Nablus</td>
<td>One quarter of the houses and a number of shops were ruined. 48 persons were died. The rest of the town suffered only light damage.</td>
<td>VII</td>
<td></td>
</tr>
<tr>
<td>Jit</td>
<td>Suffered very little</td>
<td></td>
<td>VI-VII</td>
</tr>
<tr>
<td>Zeita</td>
<td>×One house collapsed</td>
<td></td>
<td>VII</td>
</tr>
<tr>
<td>Tripoli</td>
<td>Felt, caused considerable concern, though no damage</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Jerusalem</td>
<td>Not very strong and caused only limited damage, It is alleged that the minarets of the mosque at Kafr al-Tur, east of the city, were shaken down</td>
<td>V-VII</td>
<td></td>
</tr>
<tr>
<td>Hebron</td>
<td>Slight damage</td>
<td></td>
<td>V-VI</td>
</tr>
</tbody>
</table>
5.1.2 Poorly Documented Earthquakes

The poorly documented earthquakes which are the events that have few data, that cannot be used effectively to create an understandable Intensity map. Most of these events are listed in table (18).

Table (18): Poorly documented earthquakes in Levant area.

<table>
<thead>
<tr>
<th>Date</th>
<th>Sites</th>
<th>Earthquake size</th>
<th>damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>Advat and Petra (Ambraseys, 2009)</td>
<td></td>
<td>Partly damaged</td>
</tr>
<tr>
<td>113/114 AD</td>
<td>Caesarea, Hesban, Jerash and Petra (Russell, 1985)</td>
<td></td>
<td>Partly damaged</td>
</tr>
<tr>
<td>127/130 AD</td>
<td>Caesarea and Nicopolis (Amiran et al., 1994; Ambraseys, 2009)</td>
<td>Severe damage</td>
<td></td>
</tr>
<tr>
<td>233 AD</td>
<td>Damascus (Ben-Menahem, 1979)</td>
<td></td>
<td>Destructive</td>
</tr>
<tr>
<td>245 AD</td>
<td>Antioch (Öztemir et al., 2000)</td>
<td></td>
<td>Destructed</td>
</tr>
<tr>
<td>347 AD</td>
<td>Beirut (Ambraseys, 2009)</td>
<td></td>
<td>Destructed</td>
</tr>
<tr>
<td>418-19 AD</td>
<td>Jerusalem (Russell, 1985; Amiran, 1994; Ambraseys, 2009)</td>
<td></td>
<td>Felt</td>
</tr>
<tr>
<td>447 AD</td>
<td>Hammat Gader thermal baths (Amiran, 1994)</td>
<td></td>
<td>Partly damaged</td>
</tr>
<tr>
<td>498 AD</td>
<td>Palestine (Russell, 1985)</td>
<td></td>
<td>Felt</td>
</tr>
<tr>
<td>580 AD</td>
<td>Palestine (Russell, 1985)</td>
<td></td>
<td>Felt</td>
</tr>
<tr>
<td>632 AD</td>
<td>Beth Shean (Ambraseys, 2009)</td>
<td></td>
<td>Felt</td>
</tr>
<tr>
<td>633 AD</td>
<td>Palestine (Russell, 1985)</td>
<td></td>
<td>Felt</td>
</tr>
<tr>
<td>634 AD</td>
<td>Jerusalem (Ambraseys, 2009)</td>
<td></td>
<td>Felt</td>
</tr>
<tr>
<td>637 AD, 641 AD</td>
<td>Syria and Judaea (Amiran, 1994)</td>
<td></td>
<td>Felt</td>
</tr>
<tr>
<td>672 AD</td>
<td>Ashkelon and Gaza (Amiran, 1994)</td>
<td></td>
<td>Partly damaged</td>
</tr>
<tr>
<td>710 AD</td>
<td>Jerusalem (Amiran, 1994)</td>
<td></td>
<td>Partly damaged</td>
</tr>
<tr>
<td>756 AD</td>
<td>Jerusalem (Russell, 1985; Amiran, 1994; Ambraseys, 2009)</td>
<td>Partly damaged</td>
<td></td>
</tr>
<tr>
<td>808 AD</td>
<td>Jerusalem (Amiran, 1994)</td>
<td></td>
<td>Partly damaged</td>
</tr>
<tr>
<td>850–854 AD</td>
<td>Tiberias (Landslide) (Ambraseys, 2009)</td>
<td></td>
<td>Partly damaged</td>
</tr>
<tr>
<td>881/2 AD</td>
<td>Akko (Tsunami) (Amiran, 1994)</td>
<td></td>
<td>Partly damaged</td>
</tr>
<tr>
<td>Year</td>
<td>Location</td>
<td>Damage</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>1002 AD</td>
<td>Palestine and Jordan Valley</td>
<td>Partly damaged</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Amiran, 1994; Guidoboni and Comastri, 2005)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1016 AD</td>
<td>Jerusalem</td>
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<tr>
<td></td>
<td>(Amiran, 1994; Ambraseys, 2009)</td>
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<tr>
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<td>Jerusalem, Ashkelon, Gaza and Negev</td>
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<tr>
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<tr>
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<td>Ramla</td>
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<td></td>
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<td></td>
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<tr>
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<td></td>
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<tr>
<td>1068 AD</td>
<td>Ramla</td>
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<tr>
<td></td>
<td>(Amiran, 1994; Ambraseys, 2009)</td>
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<td>1151 AD</td>
<td>Hauran</td>
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<td></td>
<td>(Ambraseys, 2009)</td>
<td></td>
<td></td>
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<tr>
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<td>Lejja and Bosra (Guidoboni and Comastri, 2005)</td>
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<tr>
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<td>Felt</td>
<td></td>
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<td>(Ambraseys, 2009)</td>
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<td>1504 AD</td>
<td>Jerusalem</td>
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<td>(Ambraseys, 2009)</td>
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<td>Judea</td>
<td>Felt</td>
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<tr>
<td>1712 AD</td>
<td>Palastine</td>
<td>Felt</td>
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<td>(Amiran, 1994)</td>
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<td>1643, 1644, 1753, 1817 AD</td>
<td>Jerusalem (Ambraseys, 2009)</td>
<td>Felt</td>
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</table>

The following results regarded to Beit Ras site is based on the published paper of Al-Tawalbeh et al. (2021). All careful field investigation indicated several observed damage features across the theater structure that can be attributed to a seismic origin, including: displaced arches, chipped...
corners and edges of masonry blocks, tilted and collapsed *scaena*, extensional gaps and broken stairs (Fig. 34).

![Diagram of theater plan and damage features]

**Fig. (34):** Theater plan and the position of the observed damage features. Most of the locations damage features are marked in the drawing. The location of the executed seismic profile is marked front of the theater is shown in red (modified After Al-Tawalbeh et al., 2021).

### 5.2.1 Displaced Arches

Three different styles of arches are seen in the theater: semicircular or arcuate, segmental and flat. They were built out of wedge-shaped stones arranged in the 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. 35a). 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. 35b). The keystone of the segmental arch above is also dropped down ~4 cm (Fig. 35d). The flat arches of most *vomitoria* to the *cavea* also are dropped down (Fig. 35c).
Masonry arches are common above openings in walls, spanning wall openings by diverting vertical loads from above to compressive stress laterally (Dym and Williams, 2011). Dropped arches in a masonry building indicate an Earthquake Archaeological Effect (EAE) having an earthquake intensity of VII or higher (Rodriguez-Pascua et al., 2013).

Fig. (35): 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) (after Al-Tawalbeh et al., 2021). Figure (34) shows positions of the damaged element.

5.2.2 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. 36), suggesting seismic intensity of VII or more (Rodrigue-Pascua et al., 2013).
Fig. (36): 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 (After Al-Tawalbeh et al., 2021). Figure (34) shows positions of the damaged elements.

### 5.2.3 Tilted and Collapsed Walls

Figure (37) 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. 37). 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 (Rodrique-Pascua et al., 2013).
Fig. (37): 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 scena, segment supported by buttress vertical wall (city wall) (After Al-Tawalbeh et al., 2021). Figure (34) shows position of photos.

### 5.2.4 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. 37b+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-XII (Rodriguez-Pascua et al., 2013).
5.3 Construction Stratigraphy of the Barracks

Careful field observations of the stratigraphy of the building indicated the existence of six main phases (Figs 38 and 39), which vary in construction techniques, craftsmanship, and material.

**Phase 1:** The outer perimeter walls of the Barracks was built during this phase. The construction technique is characterized by a double-surfaced wall with supporting bond stones (i.e. a stone beam tying the inner and the outer wall), where the inner space is filled with rubble. The exterior surface texture is distinguished by stones with a regular arrangement of high-quality shaped surface basalt stones (carved stones). The stones used are of two different sizes: large (0.63m x 0.33m) and small (0.40m x 33m). The surface of the stones is decorated with clear chisel marks. According to Anastasio et al. (2016), the block surface was roughed out and then marked with a chisel, while the bond stones were incorporated within the walls without any arranged pattern. It is clearly noticeable that the majority of the building walls were built during this phase (Figs. 38 and 39).

**Phase 2:** The western tower was built during this phase. The exterior surface is distinguished by a very regular arrangement of very precisely cut stones (carved stones), where the surface of the stones has faint chisel marks. The average measures of the used stone are 1.25m x 0.35m, with smaller infill of an average of 0.60m x 0.33m (Figs. 38 and 39).

**Phase 3:** The stones of this phase dominate the south-western corner of the building which contains the remains of some rooms with low ceilings. Similarly, it reflects a rubble filled double surfaced wall with bond stones. In comparison to Phase 1, the exterior surface texture reflects a less regular arrangement, yet the quality or the finishing of the carved basaltic stones remains good. It is made up of a mixture of smooth and rough stones of varying sizes (Figs. 38 and 39).

**Phase 4:** The general style of this phase is similar to that observed by Anastasio et al. (2016) at Umm el Surab, located 15 km northwest of Umm el-Jimal. It consists of a double-surfaced wall with bond stones arranged in multiple rows, which are separated and alternated by three successive rows of larger blocks (Figs. 38 and 39). Field observations show that this phase is distinguished by a very regular arrangement stones and joints. It consists of three rows of large stones (nearly 0.63m x 0.33m) of a rough surface split blocks, followed by a single row of small bond stones (almost 0.20m x 0.30m). This phase can be seen at the north-eastern corner above Phase 1, across the northern wall above Phase 1, and across the western wall above Phase 1 and 2, suggesting a phase of reconstruction.
**Phase 5:** Two sections of the Barracks building belong to this phase; the southern tower and the chapel. As for the southern tower, the construction technique is distinguished by an extremely regular arrangement of stones and joints. The stones are very well cut (carved stones), and the surfaces are of high quality, with chisel marks. The stones are nearly 0.25m x 0.20 m in size, with long stones measuring 0.90m x 0.20m (Figs. 38 and 39).

**Phase 6:** A small section of the southern wall next to the southern tower belongs to this phase. It is characterized by a double surface with bond stones, filled with rubble (Figs. 38 and 39). It shows a regular arrangement of stones and a rough stone surface (split blocks), presenting five courses of large stones (nearly 0.45mx 0.30m) followed by one course of small stones (nearly 0.20m x 0.15m).

Fig. (38): Construction and reconstruction phases of the Barracks, six phases.
Fig. (39): Photos and drawing of the wall’s construction techniques assigned to different phases (1-6).
5.4 Observed Earthquake Deformation Feature in the Barracks

The Barracks building includes many earthquake-induced deformation features. They are summarized in figure (40). The deformations are explained in detail below:

![Barracks floor plan illustrating the location of the main earthquake damage and their typologies. The original plan was modified after De Vries (1990). The trend of the executed seismic and resistivity profiles are marked on the plan.](image)

Fig. (40): Barracks floor plan illustrating the location of the main earthquake damage and their typologies. The original plan was modified after De Vries (1990). The trend of the executed seismic and resistivity profiles are marked on the plan.
5.4.1 U-Shaped Collapsed Walls

The Barracks building has several obvious U-shaped wall deformations that can still be readily recognized even after restoration activities (Fig. 41). These features were observed mainly across several sections of eastern and western outer walls of the building, in addition to those seen across the northern wall and the western tower. Similar U-shape collapsing was observed at the Al-Marqab Castle in Syria, which was attributed to earthquake damages by Kazmer and Major (2010). According to Korjenkov and Mazor (1998), these U-shaped collapse features result from extreme oscillating ground motion due to horizontal stresses taking place at the wall’s center and decreases towards adjoining perpendicular walls (Fig. 42).

Alexandris et al. (2004) simulated the mechanism of U-shaped collapsed walls based on an earthquake excitation of 0.8g, indicating that U-shaped collapses are usually occurring on walls located between supporting perpendicular walls of the collapse mechanism based on excitation model, and a U-shape resulted at PGA 0.8g (Fig. 42b). The Earthquake Archeology Effect Scale (EAEs) suggests a typical intensity for U-shaped wall damages to a seismic intensity of IX-XII (Rodríguez-Pascua et al., 2011).

![Fig (41): a) U-shape deformation (7m length) of the eastern wall (height 9 m). b) U-shape deformation of the western tower from inside (height 9 m). c) U-shaped deformation in the northern wall, reconstructed by Phase 4. All photos positions are marked on the floor plan shown in figure 40.](image)
Fig. (42): (a) Schema of U-shaped deformation under horizontal load. The maximum oscillation is in the center, decreasing towards the perpendicular, terminal walls, after Korjenkov and Schmidt (2009). (b) A model was made by Alexandris et al (2004).

5.4.2 Bulging Walls

Several wall sections suffered pronounced bulges within the Barracks building, particularly along the western wall (Fig. 43). Several researches have attributed the wall bulging of historical buildings to seismic origins (Korjenkov and Mazor, 2003; Alexandris et al., 2004; Gautam and Rodrigues, 2018). Quelhas et al. (2014) mentioned that the seismic action can cause bulging for whole wall or some parts, such an out of plan bending shape. Similar to U-shaped collapse features, they noticed that the deformation can occur if the direction of seismic motion is perpendicular to the wall, and that the connection between the wall with orthogonal walls and the floor is poor.

Along the western wall (9 m height and 45 m length), three large bulges are noticed, bulging inwards almost 0.25 m in the middle of the wall, two outward bulges are in the northern (lower part almost 0.20 m and upper part almost 0.15 m) and southern side (almost 0.30 m). Figure (44) shows vertical cross sections for these three bulged walls, from north to south and left to right. The ground motion intensity that caused this amount of damage ranges between IX-XII, according to the EAEs (Rodríguez-Pascua et al., 2011).
Fig. (43): Three bulges along the western wall. Two of them are outwards (+ve) and one of them is inwards (-ve). Black dots indicate outward extruded stones while crosses indicate inward movement. The locations of the photos are marked in the plan (Fig. 40).

Fig. (44): Three vertical cross sections (a, b, c) showing the bulging of the western wall, see figure (40). (a, b, and c are marked on the enclosed floor plan).

5.4.3 Other earthquake Deformation Features

There are other damage features that can be attributed to a seismic origin in the Barracks may include: shifted stones of the southern tower, cracked stones (in western tower), outward and inward displaced stones of both towers (Figs. 40 and 45), rotated stones and chipped stones
corners (in the western tower), as can be seen in figures 40 and 45. According to EAEs scale the size of the damage ranges between VII-IX.

Figure 45 (a) Shifted stones (marked by arrows) and inward/outward displacement of the stones of the southern tower (marked by dots and crosses). (b) chipped stones of an arch in the western tower. (c) cracked stones of the front face of the western tower form inside of the building. (d) rotated stones of the western tower from inside. All these deformations are marked in figure (40).

5.5 Geophysical Survey

Two geophysical surveys were applied in both sites, which are seismic methods by using Multichannel Analysis of surface waves (MASW), and resistivity by using Electrical Resistivity Tomography (ERT).

In the field, one seismic profile front of the theater in Capitoli/Assat Ras, in the northern side, was made. 1D and 2D profiles presenting the velocity of the shear wave to 30 m depth (Vs30) were created. The Vs30 average is almost 470.8 m/s in the theater depending on the profiles (Fig 46). Another profile was made in the Barracks in the western side of the building. 1D and 2D profiles to the velocity of the P wave, for 30 m depth, were created (Fig. 47). The profiles show that the velocity average of the P wave is 1734 m/s and the velocity of the shear wave is 867 m/s.

Two resistivity profiles were made around the Barracks (Fig. 40). The Profile shows that the thickness of the accumulated soil above the bedrock, the zone which has the lowest resistivity, ranges between 1.5-2 m depth from the surface.
Fig. (46): Shear wave profile made front of the theater, (a) 1D and (b) 2D. The velocity average of the shear wave Vs30 is 470.8 m/s. The profile is marked in figure (34).
Fig. (47): - (a) 1D P-wave profile to a profile made in the western side of the Barracks. (b) 2D P-wave profile to the profile made in the western side of the Barracks. The P-wave average value is 1734 m/s, with average error 1.44 m/s. The S-wave average value is 867 m/s. The profile marked in figure 40.

Fig. (47c): Resistivity profile, Electrical Resistivity Tomography ERT, made in the western side of the Barracks. The profiles are marked in figure 40.
Fig (47): Resistivity profiles, Electrical Resistivity Tomography ERT, in the northern side of the Barracks, The profiles are marked in figure 40.

### 5.6 Focal Mechanism Analysis

One event occurred on 5\textsuperscript{th} of January 2008 along ASF (the data taken from Jordanian earthquake observatory data base). The event was relocated by SEISAN Earthquake Analysis Software (V. 11) to new location 31.910° N and 36.376° E and the magnitude and the depth were found which are 3.5 ML, 8 km respectively. The data was analysis from almost 17 stations (Table. 19). Focal mechanism analysis was made to the event (Fig. 48), where it indicates to a NW-SE right lateral strike slip with normal slip component.

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<td>MASJ</td>
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Fig. (48): Focal mechanism solution analysis of wave form of earthquake 5th of January 2008 along Azqaq-Sirhan fault, recorded by seismograph station of Jordan.
Chapter 6: Discussion

6.1 Relative Succession of Events and Phases in Capitoliyas/Beit Ras Theater

6.1.1 The Foundation of Capitoliyas and the Construction of the Theater

The following discussion regarded to Beit Ras site is based on the published paper of Al-Tawalbeh et al. (2021). 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 2nd century and the 1st half of the 3rd century AD, and the evidence of the coins suggests that the city certainly existed when the coins were minted at Capitoliyas in 97/98 AD (Spijkerman and Piccirillo, 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 1st 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.

6.1.2 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. 49). 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 (Fig. 49a). 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 contained a significant inscribed stone, bearing the year 261 AD (Fig. 49c). The inscription is Greek written in seven lines and is now in a vandalized state. It translates as follows: *In honor 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* (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 indicates that the infill wall 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. Observation indicated that the *ambulacrum* was not rebuilt; instead, the *orchestra* gate and four of six *vomitoria* were walled up.

Another case where the marly to chalky limestone of poorer quality was used to build the wall, can be seen to the right of the eastern gate, where the original wall is joined by irregular suture (Fig. 49d). However, the edges of some blocks of the original arch are cracked and spalled off (Fig. 36d). 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. However, it is reasonable to assume that the purpose is to expedite the construction process or to cut expenses.

The basalt masonry in the upper left (Fig. 49f) 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. 49f).

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 *ambulacrum* collapsed previously 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.
Fig. (49): 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) (After Al-Tawalbeh et al., 2021).

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

Observations strongly indicate that after the 1st 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 Beit Ras/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 (figs. 50a and b). 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. 50a). 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. 50a).

Converting an existing theater into an amphitheater was quite common practice due to changes in the norms of use and activities. 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 scaenaefrons was preserved during transformation into a pseudo-amphitheater at the end of the 3rd 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).

Fig. (50): 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 amphitheater 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 (After Al-Tawalbeh et al., 2021).

6.1.4 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, in Late Roman-Early Byzantine.

The 2nd collapse of the theater certainly occurred after the conversion into an amphitheater and just 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.

**6.1.5 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 1m 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 34).

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 2nd 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, 2018). 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 2nd damaging earthquake. Mlynarczyk’s doubts can be accepted on 'tentatively dated' and 'not easy to be dated' ceramics from the lower two stratigraphic levels (i.e. phases) abutting the wall. However, we agree with her assignment of the upper phase (fifth phase) of the wall as late
Roman (4th -5th century), and consider this period as *terminus ante quem* when the wall was constructed.

### 6.1.6 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. 51), 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 (Karasneh and Fayyad, 2004). According to Lucke et al. (2012) four ash bands were identified across the fill material. The C14 dating of these bands 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.
6. 2 Candidate Earthquakes and Estimated Intensities in The Theater?

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 to distinguish damage feature 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).

The theater in Beit-Ras displays at least two phases of damage or earthquake activity separated by a reconstruction event/phase, as indicated by an inscription dated 261 AD and by the methods used for reconstruction. 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). The arches in the theater have different trends and the fact that their stones were dropped down along these arches (Fig. 34), suggests that
Capitolias was hit by more than one earthquake. Fig. 52 illustrates a timeline of the successions and major phases of the theaters and two major collapse events at the theater.

The 1<sup>st</sup> major proposed earthquake may be responsible for the destruction of the annular passageway (*ambulatorium*) which was followed by a reconstruction that was marked by a 261 AD inscription. However, a definitive judgment on the time separating the 1<sup>st</sup> earthquake occurrence from its subsequent reconstruction, that was evidently concluded in a documentary or celebrational activity, is difficult to support.

The 2<sup>nd</sup> 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.

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 DSTF during the period from 2000 BC until 1927. The Levant was hit 32 times during this time, of which 21 earthquakes occurred after the 1<sup>st</sup> and into the 2<sup>nd</sup>
millennium. 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 Beit-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, Abou 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 mentioned in chapter 5 in pre-instrumental seismicity section.

During the lifetime of Beit Ras/Capitoliias theater, there were at least 13 significant events. 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). However, the possibility of the existence of other major or moderately damaging earthquakes, that may be listed in existing catalogues of historical earthquakes of the region, cannot be ignored. 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 recently developed by Darvasi and Agnon (2019) to incorporate site-specific conditions (equation 1). The model includes information related to site specific conditions (i.e. shear-wave velocity), local magnitude, and epicentral distances:

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

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

In this study, average shear wave velocity ($\text{Vs30}$) using a Multichannel analysis of surface waves (MASW) was carried out, as can be seen in figure 46. The Vs30 average is 470.8m/sec. The reported earthquake magnitudes were transformed into local magnitude Ml based on the model
The results of the investigation are given in table 20 and figure 53, show the epicentral locations of the candidate events. The earthquakes considered as potential sources of damage to the theater of Beit-Ras / Capitolias are most likely not the only ones that have occurred there. Reading Zohar's catalogue (2017: his fig. 5), there are 10 earthquakes known with some reliability in the 1st millennium, and other 21 event in the 2nd millennium. As a result, one can fairly assume that there were just as many significant damaging earthquakes in the first millennium as there were in the second.

The review of the causative earthquakes can be divided to two phases. The 1st potential event, which belongs to the 1st phase of destruction of the theater, that can be bracketed between the establishment of the city in 97/98 and 261 AD. The 2nd potential candidate event(s) belongs to the 2nd phase of destruction that caused the collapse and tilting of the Scaena, followed by the abandonment of the theater, can be traced to the events of 303-6 AD, 347 AD, 363 AD and 419 AD. In the same notion, other later earthquakes that occurred post the abandonment cannot be ignored and are also covered in the discussion.

Table (20): 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 MI by the model proposed by Al-Tarazi (2005). The corresponding location of epicenter marked in figure 53 and in chapter 5 in pre-instrumental seismicity section.

<table>
<thead>
<tr>
<th>Date</th>
<th>Epicenter Location</th>
<th>Reference</th>
<th>Reported Magnitude</th>
<th>Distance (Km)</th>
<th>Potential intensity, with Vs30= 470.8 m/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>110-114 AD</td>
<td>30.70 35.30</td>
<td>Ambraseys (2009)</td>
<td>Ms=6 Ml= 6</td>
<td>217.63</td>
<td>5.3 (V)</td>
</tr>
<tr>
<td>127/130 AD</td>
<td></td>
<td>Poorly documented.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>233 AD</td>
<td>34.4 35.5</td>
<td>El-Isa et al. (2015)</td>
<td>Ml=6.2</td>
<td>200</td>
<td>5.8 VI</td>
</tr>
<tr>
<td>245 AD</td>
<td>36.25 36.10</td>
<td>Öztemir et al. (2000)</td>
<td>Ml=7.5</td>
<td>405</td>
<td>6.6 VII</td>
</tr>
<tr>
<td>303/30 6 AD</td>
<td>a 33.20 35.50</td>
<td>Ambraseys (2009)</td>
<td>Ms=6 Ml= 6</td>
<td>74.78</td>
<td>6.7 VII</td>
</tr>
<tr>
<td></td>
<td>b 33.50 35.00</td>
<td>Abou Karaki (1987)</td>
<td>Ms = 6.5 ± 0.5</td>
<td>128.25</td>
<td>6.6-7.3 VII</td>
</tr>
<tr>
<td>Year</td>
<td>Magnitude</td>
<td>Source</td>
<td>Event Description</td>
<td></td>
<td></td>
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<tr>
<td>------</td>
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<td>--------</td>
<td>-------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>347 AD</td>
<td>34.00 - 35.50</td>
<td>Abou Karaki (1987)</td>
<td>Ms = 6.5 ± 0.5, Ml=6.3 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>363 May 19 AD</td>
<td>31.30 - 35.60</td>
<td>Ben-Menahem, (1979, 1991)</td>
<td>ML = 6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>419 AD</td>
<td>33.00 - 35.00</td>
<td>Ben-Menahem, (1979)</td>
<td>Ms = 6.0 ± 0.5, Ml=6.0 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>502 AD</td>
<td>33.00 - 34.80</td>
<td>Sbeinati et al. (2005)</td>
<td>Ms = 7.2, Ml=6.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>551 AD</td>
<td>34.00 - 35.50</td>
<td>Sbeinati et al. (2005)</td>
<td>Ms = 7.2, Ml=6.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>634 AD</td>
<td>32.50 - 35.50</td>
<td>Abou Karaki (1987)</td>
<td>Ms = 6.0 ± 0.5, Ml=6.0 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>659 AD</td>
<td>32.00 - 35.50</td>
<td>Ambraseys (2009)</td>
<td>Ms=5, Ml=5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>746-749 AD</td>
<td>32.00 - 35.50</td>
<td>Ben-Menahem, (1979, 1991)</td>
<td>ML = 7.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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6.2.1 Post the Establishment of the City Events

Four candidate events occurred in association with the 1\textsuperscript{st} phase of destruction, which are 110-114 AD, 130 AD, 233 AD and 245 AD.
a- The 110-114 AD Earthquake
Due to the wide time span between the occurrence of this event and the date of subsequent reconstruction, we strongly believe that the 110 -114 AD earthquake is not the responsible event that caused the considerable damage in the theater resulted in the major reconstruction of 261 AD. Definitely it is not conceivable that the wealthy society of Capitolias would wait so long, from 114-261 AD, to put their favorite and only theater (i.e. excavated so far)—the place for public entertainment, social life, and display of wealth and power—to good use again.

b- The 130 AD Earthquake
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, at North-eastern Anatolia, is most 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 questioned the integrity of this event, asking why no damage was reported from Jerusalem, while a less significant Nicopolis was expressly mentioned? 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 130 AD event cannot be considered as a potential earthquake causing any damages to Capitolias.

c- The 233 AD Earthquake
The earthquake 233 AD has few historical source references (Sieberg, 1932; Ben-Menahem, 1979; Sbeinati et al., 2005), but its epicenter was reported along the Tripoli-Beirut-Thrust (to the west) by El-Isa et al. (2015) and a magnitude approximated to 6.2 (MI). According to attenuation equation modeling results (Table. 20), the intensity of this earthquake in Beit-Ras is VI. This intensity is very low to produce the high damage in the theater, while 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.

d- The 245 AD Earthquake
The epicenter of the 245 AD earthquake (MI=7.2) was reported by ÖZtemir et al. (2000). It is located far from the study area (about 405 km), where its epicenter was near Antioch (Ben-Menahem,1979; Sbeinati et al., 2005). Attenuation equation modeling results indicates an
Sieberg (1932) stated that the 242-245AD earthquake taking place at Antioch affected all of Syria and it was also felt in Egypt and Iran. According to Sbeinati et al. (2005) this event produced intensities of VI-VII at Antioch and Syria, III and at Egypt and Iran. Therefore, this event can be considered as a potential candidate to have caused damage to the Capitolias theatre.

The discussion about these candidate events suggest that there is not enough data in existing catalogues supporting the exact capable event(s) which could have damaged the theater before 261 AD, although the events of 233 AD and/or 245 AD are the most likely responsible earthquake, resulting in the collapse of the eastern cavea and the external perimeter corridor (ambulacrum).

6.1.2 Scaena Collapse and Tilting Preceding the Abandonment of the Theater

The 2nd 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.

a- The 303-6 AD Earthquake

As can be seen in table 3 and figure 19. 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, Abou Karaki (1987) and Sbeinati et al. (2005) reported the epicentral location further to the west within the eastern Mediterranean (Fig. 19 and 53). This event largely destroyed many ancient towns in the southern part of Lebanon. According to earthquake observations and attenuation modeling (Table. 20), the intensity in Beit-Ras was VII. Thus, this event cannot be excluded as the one causing damage in Capitolias.

b- 347 AD Earthquake

There is a single historical source that mentioned a catastrophic destruction only restricted to the city of Berytus (Beirut) that took place in 347 AD, as reported by Guidoboni et al. (1994) and
Ambraseys, (2009). It is worth mentioning that this event was not reported Russell (1985), and the location of the epicenter is only mentioned by Abou Karaki (1987). However, attenuation modeling of this event indicated an intensity of VI-VII (Table. 20).

c- 363 AD earthquake

It is from 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 (Table. 4 and Fig. 20), i.e. Capitolias was certainly heavily damaged. According to earthquake observations and attenuation modeling (Table. 20), the intensity in Beit-Ras reached to an intensity of VIII.

d- 419 AD Earthquake

In 419 AD there was a felt and recorded earthquake in Jerusalem (Russell, 1985); Ambraseys, 2009); Guidoboni et al., 1994). Its epicenter was identified close to Safad with a magnitude (MI) of 6.2-6.5 (Ben-Menahem, 1979; Abou Karaki, 1987). Based on attenuation modeling results (Table. 20), this event was capable of causing a seismic intensity of VII-VIII.

Although available historical catalogues did not report the exact location for the epicenter of the 303-6 AD event, this event was evidently documented as a causative earthquake across the Levant. However, the fact that it only occurred 45 years after the inscribed date of reconstruction (261 AD), may suggest that this earthquake could have caused some damage to the theater, but it certainly did not cause a total abandonment. Evidently, it may have been responsible for some localized destruction, such as the observed damage across the eastern upper part of the theater that was repaired with basaltic stones (Fig. 49f). On the other hand, the 363 AD event can be suggested as the most likely damaging earthquake, as it was documented by many resources and it was a significant major event that had the capability of producing damage up to intensity VII-VIII (Table. 20). Within the same notion, Retzleff (2003, her footnotes 34, 35) stated that other
theaters (i.e. Antipatis and Diacaes on the Mediterranean coast and Amman today) had also been abandoned after the earthquake of 363 AD. The 419 AD event just occurred 56 years after a major earthquake (i.e. 363 AD) that caused immense damage to the region, where the theater was already abandoned.

According to the previous discussion, one of these earthquakes could have caused damage that was significant enough to lead to the abandonment of the site, which was followed by the conversion of the theater body to a fortification. This conversion was carried out by connecting the city wall to the main structure of the theater, and by adding the buttressing wall in front of the tilted scaena. It is inferred that the date of the earthquake was very close to the date of construction of the buttress wall. Accordingly, the responsible event should have been very intense and was capable of causing considerable damage and subsequent abandonment of the theater. Therefore, we strongly believe that the 363 AD earthquake is the most likely event which caused severe damage (i.e. tilting and collapse of the scaena wall) that led to the abandonment and subsequent burial of the theater.

6.1.3 Post Abandonment Events

Other later earthquakes, 502, 551, 634, 659 and 749 AD, occurred after the site was abandoned, during and after filling of the cavea and orchestra of the theater with debris, when most the theater body became buried beneath the rubble. According to table 20 these events were all capable of causing significant damages (i.e. VI to X). While some damage may have resulted from more than one earthquake, which may have 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 observed deformations of the excavated theater mostly cannot develop unless unsupported. Therefore, evidence of damage due to any subsequent events, such as 551, 634, 659 and 749 AD, cannot be observed since the possibility of collapse of buried structures is not plausible. However, potential collapse of other above-ground structures within the site of Beit-Ras cannot be ignored, such as the upper elements of the theater’s
structures, which were still exposed after the filling of the theater with debris. Several observations indicated that many collapsed elements of the upper parts of the theatre were mixed with the debris, as documented in excavation reports by Al-Shami (2003 and 2004). Another example suggesting the effect of the later events, such as that of 749 AD. Mlynarczyk (2017) attributed the collapse of some sections of the city wall of Beit-Ras to this event, based on the concentration of collapsed ashlars and the age of collected pottery from two trenches excavated to the west of the theater structure.

6.3 Barracks Umm el-Jimal Discussion

6.3.1 Succession Events and Phases in Barracks

6.3.1.1 Barracks Construction (Early Byzantine)

The Barracks is the largest single building in Umm el-Jimal ancient city, founded in 412 AD (De Vries, 1981). It was originally built as a fortification linked with the city wall, including houses for soldiers (Butler, 1913). The building, at the beginning, comprised of the perimeter walls and several internal rooms, in addition to the western tower. Depending on the stratigraphic reading in this study, these parts have been built by the phases 1 and 2. Depends on Anastasio et al. (2016) they were built during the early Byzantine (324 AD-491 AD). Anastasio et al. (2016) described both phases in the atlas and dated them to the early Byzantine period (Fig. 16 in Anastasio et al. (2016): page 317, Jimal Barracks 1 and 2). Moreover, Gilento (2015) studied the building’s techniques in another ancient site in Hauran, called Umm el Surab, located 15 km northwest of Umm el-Jimal, and he noticed that Saint Sergius Church, located in the site, is built by the same technique of phase 1 and 2 of the Barracks building. According to an inscription in Saint Sergius Church, it was built in 489 AD (Gilento, 2015). Therefore, the age of Phase 1 and 2 can be dated no later than the end of the early Byzantine period (324-491 AD).

Some modification can be noticed in the Barracks that occurred during this period, for example the observed stone course interlocking between the western tower and the perimeter walls that was part of phase 1. Alterations within the lower course of the tower suggest that this phase is a separate and followed the previous phase, or at least a renovation of the façade of the tower that took place (i.e. the external stairs leading to the upper floors were blocked up by a newer cantilever and the lower steps were removed) (Fig. 41b). Another example, some parts were
constructed as additional rooms. These can be seen in the south-western corner. According to the plan (Fig. 40), they are designated to phase 3.

6.3.1.2 First Damage and Reconstruction

The Barracks walls have indicators of reconstruction, especially after phase 3. This can be seen in some parts of the building, especially in the northern wall, where the wall is repaired as U-shape using different techniques, by phase 4 (Fig. 41c). The reconstructed parts might have been built after a strong damage, forming large open U-shape. Other reconstructed parts can be seen in the western side, where also the upper parts, above phase 2 and 3, of the walls are reconstructed by phase 4 (Fig. 54b). It appears that the Barracks has been strongly damaged and then reconstructed by phase 4. Anastasio et al. (2016) dated the phase to the Late Byzantine period (491 AD- 636 AD) (page 317; Fig. 16, Jimal Barracks 3). The same technique of phase 4 was found in various places throughout the ancient Hauran cities, as part of the reconstruction effort for large buildings, for instance: the apse of the Julianos Church in Umm el-Jimal (Corbett et al., 1957), and the closure of the apse in the Church of Saint George at Sama as-Sirhan, located 20 km north-east of Umm el-Jimal, (Anastasio et al., 2016). It appears that there was a catastrophic earthquake followed by regional reconstruction, using technique of phase 4, during the Late Byzantine period in the Huran area. De Vries (1981) excavations and trenches opened around the Barracks (1972-1977) indicated that the building was modified during Late Byzantine.

![Fig. (54): (a) southern part of the Barracks where phase 5 and 6 are built above phase 1. (b) phase 4 is built above phase 2 and 3 as repairing the upper part of the western wall.](image-url)
6.3.1.3 Additional Buildings (Conversion into Monastery)

The Barracks originally was built as fortress, but it has been converted to a monastery (De Vries, 1993 and 2000). The chapel was added, linked to the eastern side, and the tower was built in the southeast corner, above Phase 1 (Fig. 54a). According to the plan (Fig. 40), the tower belongs to Phase 5 (Fig. 38 and 39). It has a religious Christian inscription related to the Byzantine period. De Vries (1993 and 2000) suggested that it was built in the 6th century for the purpose of defense and control against the locals (i.e. the Ghassanids).

6.3.1.4 Construction of Phase 6

Phase 6 can be seen above Phase 1, and is adjacent to the southern tower, but their stones are not interlocked (Fig. 54a). It appears that it was constructed after the tower, after Phase 5. This was most likely after the Byzantine time (after 636 AD) since it covers the Christian inscription written at the tower and prevents its appearance.

6.3.1.5 Abandonment and Last Damage

Following Phase 6, the Barracks has been strongly damaged and went out of use, where no other construction or maintenance activities were occurred. It was most likely affected by a major or several earthquakes that led to abandonment. The collapsed materials that found during previous and recent excavation included Byzantine and Umayyad remains (De Vries, 2000). Therefore, the abandonment time was most likely during or after the Umayyad period (661 AD–750 AD), that led to a general abandonment of the site.

6.3.2 How Many Earthquakes and Estimated Intensities in Barracks

Archaeoseismology as a method allows clarifying potential historical earthquake scenarios, especially when we understand the stratigraphy of the standing buildings. If there is an appropriate model that represents the consequences of the destruction and phases of construction, it allows to interpret the number of earthquakes that have produced the damage at any site and attributing them to historical events or periods, which have been mentioned in historical documents and in historical earthquake catalogues (Al-Tawalbeh et al., 2021). Moreover, tracing the directions of the ground motion can indicate to the number and the source of the earthquakes damaged the site (Korjenkov and Mazor1998; Alfonsi et al., 2013; Hinzen et al., 2016; Martín-González, 2018 Al-Tawalbeh et al., 2021).
Based on the observed damage features and interpreted phases of construction and reconstruction activities, it can be concluded that the Barracks building might have suffered at least two earthquakes.

Depending on tracing the direction of the arrived ground motion caused the damages, the direction of the arrived ground motion produced the U-shape collapsing of the northern wall, which trends NW-SE, is NE-SW. The walls trends SW-NE, described above suggest ground motion direction to NW-SE. The bulging of the walls trend SW-NE indicates to a ground motion NW-SE as well. So, the Barracks has been effected by two ground motions, that differ in direction and perpendicular to each other: the first one NE-SW and the second NW-SE.

Two events were recognized in this research. The first event followed by reconstruction in Late Byzantine times (491 AD- 636 AD) while the second one caused strong destructions and lead eventually to the abandonment of the site at the end of Ummayad Caliphate (750 AD).

According to the EAEs scale (Rodríguez-Pascua et al., 2013), the damage features for both events, such as the collapsed walls and the bulging (extruded blocks), suggest an intensity of almost IX-X.

**6.3.3 Attribution to Causative Earthquakes**

The most significant active fault element in the area is the DSTF, trending NNE-SSW. It is one of the world's most famous strike-slip faults. It is an active fault and has the capability to produce large earthquakes (Ambraseys and Jackson, 1998) with a magnitude of up to 7.5 (Begin et al., 2005).

Several historical earthquakes have been described in the catalogues (i.e. Ben-Menahem, 1979, 1991 and Russell,1985, Amiran, 1994, Ambraseys, 2009, Zohar et al. (2016), and Guidoboni and Comastri, (2005). Most of their epicenters have been identified along the Dead Sea Transform (i.e. see chapter 5 in section pre-instrumental seismicity).

The major events were summarized in chapter 5 in pre-instrumental section and the candidate events that might have affected the Barracks were described in the following, providing their affected zones (worst, moderately and felt zones) within the region and their estimated magnitudes. Figure (55) shows the Intensity maps of these events, remodified from chapter 5 in pre-instrumental seismicity section.
Accordingly, the first event occurred in the late Byzantine period (491 AD to 636 AD), three major earthquakes occurred during this period, which are 502 AD, 551 AD, and 634 AD (Fig. 55).

**a- The 502 AD Earthquake**

The epicenter location of this event was located along the offshore in Akko (Ptolemais), and the chronicles mentioned that the town was overturned and totally damaged, and nothing left standing. To the north, the ancient cities of Tyre and Sidon were badly damaged. In Beirut, 40 km form Sidon, one building, a synagogue was suffered and collapsed (Russel, 1985; Ambraseys, 2009) (Fig. 55).

**b- The 551 AD Earthquake**

The earthquake epicenter of this event was identified along Roum fault (Fig. 55), having a magnitude of 7.2 Ms, with shallow focus depth (Darawcheh et al., 2000). The event effect reached to widespread area, including Palestine, Arabia, Mesopotamia and Syria and felt in Alexandria (Russal, 1985), and Antioch (Ambraseys, 2009). In Botryos, a coastal city located northern Lebanon, some parts of the mountains were separated and collapsed toward the sea (Russal, 1985), as a result of landslide.

To the south in Jordan, it was reported that Jerash, Nebo and Petra suffered (Russal, 1985), but Ambraseys (2009) mentioned that the earthquake effect was impossible to reach Petra, because he did not find any damage evidence in Jerusalem, which is closer to the epicenter than Petra. He suggested that another earthquake has been generated by local fault around Petra in the same period.

It was reported that many events after the 551 AD earthquake occurred in the area. Russell (1985) suggested that these events were most probably aftershock events. It seems that the 551 AD earthquake effected at widespread area, and followed by strong earthquakes as aftershock. It is most probably that Petra was suffered by one of them.

**c- The 659 AD Earthquake**
According to Ambraseys (2009), the 659AD event resulted in damaging Jericho, and all churches were collapsed. However, there was no destruction evidence in Jerusalem. The epicenter was identified along Jordan Valley fault. The estimated magnitude values are not higher than 6.6 ML. Based on the Intensity maps (Fig. 5), it is not clear if Umm el-Jimal was within the worse damaged zones. Apparently, the reason is that the available historical data is not enough to present an appropriate map that gives a continuous spatial distribution of damage the intensities zones further to the east from the DSTF to the Hauran area. This can be attributed to the lack of written documentation of historical events causing damages to the eastern region of the Dead Sea, although, the northern part of Jordan is rich with many archaeological centers.

6.3.4 The Candidate Events Caused the Abandonment

The second candidate event that may cause considerable damage, like the large U-shape collapse and bulging features, resulting in the state that the Barracks went out of use till the present day. According to the discussion above, the second damage may occur at the end of Umayyad Caliphate. Accordingly, the major potential event that cause the regional abandonment of the site can be attributed to the 749 AD earthquake.

The affected area of this event extended from Damascus in the north to Jerusalem in the south. The worse damage extended from Galilee in the north to Beth Shean in the south and to Dera'a in the east, with a maximum intensity of X (Fig. 55).

Figure (55) shows the Intensity map of the 749 AD earthquake. Umm el-Jimal had an intensity VII, thus rendering little damage, depending on existing earthquake catalogues. The city was under the Umayyad Caliphate when the earthquake occurred. It caused the abandonment of the region and end of the rule of the Umayyad Caliphate there.

According to the historical documentations, the event effect extended over a large area, almost with a radius of 500 km. Many chronicles have reported the event to a different date, sometime between 746 to 749 AD, making considerable confusion around the exact date of the event. Ambraseys (2009) put a question; whether if it is feasible that one event was solely responsible for all damages described in the historical text, or whether there was more than one earthquake with different epicenter locations.
Fig. (55): Intensity maps for the earthquakes 502 AD, 551 AD, interpreted from (Russell, 1985, Amiran, 1994, Ambraseys, 2009 and Zohar et al., 2016), re-modified from chapter 5 in section pre-instrumental seismicity.
Continued to figure 55. Intensity maps for the earthquakes 659 AD, and 749 AD, re-modified from chapter 5 in section pre-instrumental seismicity.
According to Theophanes the Confessor, there were at least three strong events in Syria, Palestine, and Jordan, between 746-757 AD (Ambraseys, 2005). Two Syrian chronicles mentioned that there were two earthquakes: one between September 747 to August 748, and another one was on the 3rd of March 756. Arabic chronicles wrote about an event that damaged Jerusalem and felt in Damascus on the second of June 748 AD (Ambraseys, 2009).

After this event Umm el-Jimal was abandoned. It can be suggested that the earthquake affected at the buildings of Umm el-Jimal, making its strength and durability very low and vulnerable to future earthquake activities.

6.3.5 The Later Events (After Abandonment)

The Levant area has been affected by many events after the 749 AD earthquake, which caused considerable damages in the region, such as 1033, 1202, 1293, 1458, 1546, 1759, 1834, and 1837. The possibility that these events have contributed to subsequent damages in the Barracks cannot be avoided, where their accumulated damages and stones collapsing is still observed until now. Their effect is most likely related to the continued weakening of the building as it was already of low durability since the earthquake 749 AD. So, the accumulation of stones, which are noticed in the site, might have been formed as a result of these earthquakes after the abandonment.

6.3.6 Attenuation of the Ground Motions

According to review of all candidate earthquakes during the life time of the Barracks, the probability of effect the events in causing the observed damage is not clear. It is most probably because of the large distance from the identified epicenter along the DSTF and the Umm el-Jimal, where the ground motion generated from DSTF may drastically be attenuated when arriving to the site. Depending on previous studies, peak ground acceleration (PGA) curves of the DSTF suggest that the area located 80 km away from the DSTF is within a low PGA values (almost 0.08-0.2 g) for the events with magnitude 5-7 (i.e., Ambraseyes et al., 1996; Boor et al., 1997; Al-Qaryouti, 2008; Jaradat et al., 2008; Hough and Avni, 2009) (Fig. 17).

The city of Umm el-Jimal is built on basalt rocks, almost 20 m thick related to Abed Olivine Basalt Formation, and Fahda Vesicular Basaltic Formation (Pleistocene) (Gharaibeh, 2003), which is part of north east Jordanian Basaltic Plateau (Harrat Al-Sham). The Barracks is also built on the basalt as seen in excavation pits and trenches made by De Vries (1981).
Around the Barracks in this study, two resistivity profiles were made, in the western side and the northern side, where they show that 1.5-2 m thick soil accumulated above the basalt, as can be seen in the profiles (Fig. 47 c and d), the low resistivity values in the top, which does not influence negatively the stability of the building.

To examine the existence of the site amplification, Multichannel analysis of surface waves (MASW) was applied to measure the average of shear wave velocity for 30 m subsoil (Vs30). The Vs30 value was used in the attenuation equation (No. 1) to derive the possible intensity value at the site.

The survey was made around the Barracks in the western side. The dispersion curve of the profiles was created, but unfortunately it includes noise where the software couldn’t precisely build the S-wave profile. For this reason, alternately, we calculated the S-wave average from the average value of P-wave, where the P-wave first arrivals were very clear. Figure 47 represents profiles of P-wave. The P-wave average is 1734 m/s for almost 13 m depth. Using a conservative assumption that Vs almost equal to 50% f Vp, the S-wave average is 867 m/s.

The parameters data (epicenter location, magnitudes) of the candidate earthquakes mentioned above were used to measure the potential intensity at Umm el-Jimal (Table. 21).

Table (21): A list of Major Earthquakes of the DST Fault during the lifetime of the Barracks and Estimated Potential intensities.

<table>
<thead>
<tr>
<th>Date</th>
<th>Epicenter Location</th>
<th>Reference</th>
<th>Reported Magnitude</th>
<th>Distance (Km)</th>
<th>Potential intensity when Vs30= 867 m/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lat. (°)</td>
<td>Long. (°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>502 AD</td>
<td>a</td>
<td>33.00</td>
<td>35.00</td>
<td>Abou Karaki (1987)</td>
<td>Ms = 6.5</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>33.00</td>
<td>34.80</td>
<td>Sbeinati et al (2005)</td>
<td>Ms = 7.2</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>32.90</td>
<td>35.10</td>
<td>Ambraseys (2009)</td>
<td>Ms = 6</td>
</tr>
</tbody>
</table>
### Earthquakes in the DSTF Region

<table>
<thead>
<tr>
<th>Year</th>
<th>Magnitude</th>
<th>Depth</th>
<th>Source</th>
<th>Ms</th>
<th>Ml</th>
<th>Date</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>551 AD</td>
<td>7.2</td>
<td>34.00</td>
<td>Sbeinati et al. (2005)</td>
<td>35.50</td>
<td>204</td>
<td>5.5 ~ VI</td>
<td></td>
</tr>
<tr>
<td>659 AD</td>
<td>5.3</td>
<td>32.00</td>
<td>Ambraseys (2009)</td>
<td>35.50</td>
<td>90</td>
<td>4 ~ IV</td>
<td></td>
</tr>
<tr>
<td>746-749 AD</td>
<td>7.3</td>
<td>32.00</td>
<td>Ben-Menahem, (1979)</td>
<td>35.50</td>
<td>88.5</td>
<td>7.5 ~ VIII</td>
<td></td>
</tr>
<tr>
<td>746-749 AD</td>
<td>7.2</td>
<td>32.50</td>
<td>Sbeinati et al. (2005)</td>
<td>35.60</td>
<td>74.5</td>
<td>6.7 ~ VII</td>
<td></td>
</tr>
</tbody>
</table>

According to the intensity values in table (21), there is no indication for the site effect and all values are lower than the calculated intensity that measured from the observed damages in the site. So, this leads to considering that there were other strong events that occurred along the DSTF, maybe more than 7.5 M, however, historical reports did not support the occurrence of such event. Another probability can be adopted which is that there are another faults closer than the DSTF from Umm el-Jimal, probably the local faults such as north-eastern faults.

The value of the S-wave was used to estimate the zones of distance of large estimated events, by the attenuation equation of with ML 7.5 that can cause damaging in Umm el-Jimal, with intensity IX-X. According to this calculation, the earthquake’s epicenter with 7.5 ML is located no more than 40 km away from Umm el-Jimal. Within this zone, three main faults are intersected, which are Zarqa River Fault (ZRF), which is a Right lateral fault trending E-W and extends from Jordan.
valley to 80 km to the east (Fig. 15), ASF and FF. As can be seen the zone does not reach the DSTF (Fig. 16).

Fig. (56): Estimated circles zone of an event, with ML 7.5, caused damage intensity IX-X in Umm el-Jimal, depending on attenuation equation no. 1 (Darvasi and Agnon, 2019). The map includes the main faults in the area DSTF, Azraq Sirhan Fault (ASF), Zarqa River Fault (ZRF) Fuluq Fault (FF).

6.3.7 Candidate Faults Caused the Damage in Umm el-Jimal

The main reasons for considering the north-eastern faults, such ASF and FF, and ZRF as probable candidates for earthquake sources, is that the Barracks in Umm el-Jimal has been affected by large earthquakes, with size of damage over IX-X intensity, and the potential intensity values measured by the attenuation equation of Darvasi and Agnon (2019) for the candidate events are lower than the size of the damages existed in the Barracks.

It can be suggested that the site might have been damaged by other strong earthquakes which are not reported in the catalogues. As indicated in previous study by Al-Tawalbeh et al. (2021), there are many gaps in the existing catalogues where the Levant area have been affected by unknown events, especially during Roman and Byzantine period. So, it is most likely that the unknown earthquakes might have occurred and caused considerable destruction in the Hauran area.
6.3.8 Azraq-Sirhan Fault (ASF) and Fuluq Faults (FF) Seismicity

The ASF trends NW-SE (Fig. 55 and 56). It is cross cut by DSTF. The seismicity of the ASF is not well known because of the lack of instrumental and pre-instrumental earthquake data (Al-Tarazi, 1994). Along the system there are few events range between 2.5-3.5 ML which were instrumentally recorded after 1983 (Fig. 56).

The Fuluq fault, strike NW/SE, is part of Azraq Basin (Fig. 16), which was formed in Late Cretaceous. It is bounded by Fuluq fault from the north and east. The deepest parts in the basin is the eastern and northern eastern parts (Ibrahim, 1996), because of the highest downthrown of the Fuluq fault, which reaches to 2500 m to the southwest (MGEF website). Along the fault, few instrumental events, ranging between 2.5-3.5 M, were recorded (Fig. 17).

To the east of the Fuluq fault, almost 15 km, there was a moderate event, with 4.6 Mb, was recorded in 31/3/1989, with depth 33.5 km (IRIS website) (Fig. 17). The seismicity and the tectonic setting of the area are still not well studied, because of the lack of instrumental and pre-instrumental earthquake data (Al-Tarazi, 1994) and the region is covered by the basalt of Harrat Al-Sham, making the recognition of the faults too difficult.

These eastern faults are older than the DSTF and they are still considered inactive. In this study probability of reactivation of these faults are examined, like ASF.
6.3.9 Probability of Reactivation of ASF

A hypothesis hypothesis is put forward that of the reactivation the ASF caused the earthquake damage foreseen at the Umm el-Jimal area. Fault reactivation has been proved in different case studies in the world (Lyon Caen et al., 2004; Park et al., 2007; Irmak, 2013). The theory of the reactivation and fault interactions was investigated by Scholz and Gupta (2000), where they stated that fault exist within a population of faults, thus it is possible that stress fields from a population of faults can influence each other where a likelihood of a future earthquake will jump to adjacent faults resulting in a larger earthquake. Accordingly, fault interactions can trigger an earthquake event on another, nearby, fault elements. The level of fault interaction can be
attributed to the degree of overlap or separation between any inactive fault with an active fault that can activate a previously inactive fault element. The ASF is intersected with DSTF and shifted almost 100 km (Segev et al., 2014). Therefore, it might have been reactivated and have triggered a catastrophic earthquake that damaged the surrounded region like Umm el-Jimal and Huran area.

6.3.10 Focal Mechanism Analysis in the North-Eastern Faults

In attempt for proving the potential reactivation of the ASF, one instrumental event along the fault, which occurred on 5 January 2008, 3.5 magnitude, 8 km of depth, was analyzed in order to understand the field stress of the System, according the wave data of different stations in Jordan (Table. 19). The data was collected from Jordanian earthquakes observatory. It was relocated to a new location 31.910° N and 36.376° E, using SEISAN Earthquake Analysis Software (V. 11). A focal mechanism for the event was made, indicating a NW-SE right lateral strike slip with normal slip component (Fig. 17 and 18).

This fault type is a typical form of the Riedel shear structures of the transform fault system. The analyzed trend suggests that the fault source could be associated with the antithetic right-lateral strike-slip fault (R′) produced due to reactivation of the current stress state of the DSTF. Therefore, the analysis of the event suggests that the reactivation of the ASF was caused by interaction with the stress field of DSTF. So, a large earthquake might have occurred along much older fault elements which were capable of damaging many places of the Huran area as a result of earthquakes occurred because of its antithetic (R′) Riedel shear components, as part of the ASF. So, the earthquakes that might have occurred and damaged the Barracks were from reactivated faults within the ASF.

The analyzed focal mechanism indicates that the fault is parallel and the same movement of R′ radial, but it is not fit with the trend of the traced Azraq Sirhan faults, differing almost 20 degrees. It is most probably not all fault traces within Azraq-Sirhan Depression are not well identified. So, another focal mechanism for the recorded events should be analyzed, and the tectonic setting and the evolution of the faults within the graben should be well studied where might be there are faults fit with the R′ within the ASF generated as a result of DSTF stress filed.
6.3.11 Aftershock Events effected at the Barracks

Few major earthquakes along the DSTF were instrumentally recorded such as the 1927 Jericho with Ms 6.2, the 1995 Gulf of Aqaba with Mw 7.1, the 2004 in the north of the Dead Sea with ML 5.2 and the 2008 in Lebanon with Ms 5. Most of these events were followed by a number of aftershock events (Hofstetter et al., 2003; Al-Tarazi et al., 2006; Mohamad et al., 2000).

The largest event that caused a series of aftershock events along a regional scale is the 1995 earthquake, where many events were routinely recorded around the DSTF for one year after. The local seismicity networks recorded earthquake swarms, extending from the boundaries of the ASF to the southern part of Lebanon. It is most likely that the stress jumped to the other faults nearby the DSTF (Mohamad et al., 2000) and caused earthquake activates in the area.

Historically, it is most likely that the north-eastern faults have generated strong earthquakes as aftershock events, especially after the events 551 AD and 749 AD of the DSTF.

A historical events epicenter was identified in the Huran area, in Busra 45 km north of Umm el-Jimal, which is 1151 AD earthquake. The event caused severe damage in the Busra area, where it was mentioned that many walls were collapsed. The earthquake was felt in Palestine and Damascus (Sieberg, 1932; Ben-Menahem, 1979). It was reported by Ibn al-Qalanisi, and he recorded that the earthquake occurred during the night of 546, 13 latter Jumada, Hijri Calendar, (27 September 1151) (Sbeinati et al., 2005). Ben-Menahem (1979) identified its epicenter at 32.6N, 36.7E, close to Jabal Al-Arab Hauran with 6.2 ML (Fig. 17).

This earthquake might be an aftershock event generated from a fault around Busra. It is most likely that affected at the Barracks. Busra was mentioned in the historical texts many times where it was reported that it was horribly effected by strong earthquakes continued for more than 3 months in 1170 AD, and the damage extended to Acre, and many castles in Jordan and Palestine (Ghawanmeh, 1992).
6.4 Contributing the Historical Seismic Catalogue of the Levant Area

Intensity maps, in pre-instrumental seismicity section (chapter five), for the major earthquakes were developed for the period from 1 AD to the end of the 19th century. The maps can be divided into three groups. The first group which includes the maps that do not have enough data, and do not represent convinced estimation for the epicenter locations and the causative faults, for examples 303 AD, 659 AD, 1293 AD, 1458 AD, and 1834 AD earthquakes. Therefore, the historical earthquake methods ought to be applied on the area aiming to enhance the data of this group. The second group which includes the maps that have few data, but they almost reveal convinced estimation of the epicenter locations and the causative faults, for example 363 AD, 502 AD, 551 AD, 1033 AD, 1202 AD, 1546 AD 1759 October, and 1834 AD. However, more researches aiming to enhance the data of this group are needed to increase the certainty of the estimations, especially on the areas east of the DSTF. The third group which includes the maps that have wealthy data and they can represent highly convinced estimation of the epicenter locations and the causative faults, for example, 749 AD, 1759 November AD, and 1837 AD earthquakes.

Many events were considered as poorly documented events (Table. 18), because there is no enough data in the historical records that can be converted into an intensity map. The available catalogues include reports about theses event with mentioning one or two affected towns. It can be suggested that these events are related to large earthquakes occurred somewhere, but very few affected locations have been recorded in the catalogues. The data of these events can be enhanced by re-review more historical documentations that might have information about them. Also, other methods related to historical earthquake studies ought to be applied in the area.

Depending on the mentioned above the seismic catalogue of the Levant has significant gaps that ought to be filled. Many previous archaeoseismology have contributed in partly filling the gaps by many ways, for instance by uncovering new events which are not existing in the catalogues (Caputo and Helly, 2008; Zohar, 2019), improving the knowledge of the poorly documented events (Galadini et al., 2006), and enriching the information of the major events (Martín-González, 2018).

Examples of previous studies that have contributed in enhancing the seismic catalogue, Alfonso et al. (2013) estimated the intensity IX-X for the event 1033 AD in Hisham Palace, which is located...
close to the causative fault, JVF. The estimated intensity indicated that the damage size in the Palace was large. The intensity value supports the map (Fig. 24), which shows the high intensities of the surrounding towns. So, the contribution of this study is by supporting the occurring large earthquake in 1033 AD with epicenter close to Hisham Palace and along JVF. Another example, Kazmer and Major (2010) estimated the intensity VIII-IX for the event 1202 AD in Margat castle, which is located 120 km north of the estimated epicenter, and then Kazmer and Major (2015) estimated the intensity VIII-IX for the same event, 1202 AD, in Safita tower which is located 70 km north of the estimated epicenter, along Yammouneh Fault. Both studies enhanced the seismic catalogue by updating the shape of the intensity map of the earthquake 1202 AD, especially the northern part from the epicenter (Fig. 25).

In this research, the earthquake catalogue was enhanced and the gaps were partly filled. There are two main contributions by studying case study Beit Ras. The first one is that the measured potential estimated intensity values updated the maps of the earthquakes 749 AD, 659 AD, 551 AD. Whereas, they represent plausible values related to the values of the surrounding affected towns, location and the magnitude of the epicenters. The second contribution is the updating of late Roman- Byzantine period, by uncovering new earthquakes, occurred between 98 AD- 261 AD, that have never been mentioned in the available catalogues.

Moreover, two main contributions by studying the Barracks in Umm el-Jimal. The first contribution is that the measured potential estimated intensities for the candidate earthquakes indicated that the site has not been damaged by known earthquakes and known active faults, where the study presents suggestion that the north-eastern faults might have reactivated and caused large earthquakes and damaged Umm el Jimal. The second contribution is the updating the seismic catalogues during the Byzantine period.

On the other hand, many gaps, in the earthquake catalogue, have been filled by previous paleoseismology studies. Their results have presented wealthy data helped in estimation the epicenter location, causative fault and magnitude, for examples, Reches & Hoexter (1981) for the events 749 AD, Daëron et al. (2005 and 2007) for the event 1202 AD, Marco (1997, 2005) for the event 1759 AD October, Gomez et al. (2003) and Nemer et al. (2008) for the event 1759 AD November, Nemer and Meghraoui (2006) for the event 1837 AD (Nemeg 2006), Kagan et al (2011) for the events 502 AD, 551 AD.
The previous studies results, which were mentioned in the literature review and the pre-instrumental seismicity sections, are reviewed in a time line (Fig. 58). It includes the major events and the poorly documented events, given interval time and the candidate events of the previous studies. From the figure 58, it can be notice that the archaeoseismology studies present short intervals time constrained the candidate events, similar to paleoseismology studies. This means that the archaeoseismology can present accurate dating to the candidate earthquakes like paleoseismology method, although both methods are different in data processing and used materials. Another notice in the figure 58 is that the intervals time crosses the other events, which are not considered as candidates in the studies. This means that other events which are not mentioned in the previous studies also can be candidates in producing the damages in the sites. They can be considered such alternative events to these studies. Grigoratos et al. (2020) reviewed several historical studies and presented alternative events, updating the seismic catalogue.

Additional notice from the figure 58c about the results of this study, where the given intervals time bracketed the candidate events are plotted in the timeline, that the interval time of the first damage phase in Capitolias/Beit Ras does not cross any major events, but it crosses some few poorly documented events, including 233 AD and 245 AD earthquakes, which are the candidate events in this study. Also. In the Barracks, the intervals time cross major events and poorly documented events, but the study does not indicate to any of them as a candidate, but indicates to unknown events are not mentioned in the catalogues. So, more studies in the area like this type of archaeoseismology can present a contribution in converting the poorly documented events to major events and adding new events which are not mentioned in the earthquake catalogues.
Fig. (58a): Timeline chart includes the major and poorly documented earthquakes, the given interval time for the candidate events from the previous studies in the Levant area.
<table>
<thead>
<tr>
<th>Fault</th>
<th>Paleoseismology Studies</th>
<th>1759 AD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rachaya Fault</td>
<td>Wech2014 363 AD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wech2014 551 AD</td>
<td></td>
</tr>
<tr>
<td>Hula Fault</td>
<td>Marco2005 1202 AD</td>
<td>1759/10 AD</td>
</tr>
<tr>
<td></td>
<td>Marco97&amp;Elle98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1202 AD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1759/10 AD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1837 AD</td>
<td></td>
</tr>
<tr>
<td>Jordan Valley Fault</td>
<td>Ferry2011 749 AD</td>
<td>Fer2011</td>
</tr>
<tr>
<td></td>
<td>Ferry2011 1033 AD</td>
<td></td>
</tr>
<tr>
<td>Jericho Fault</td>
<td>Ro&amp;Ho1981 749 AD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>749 AD</td>
<td></td>
</tr>
</tbody>
</table>

**Main Earthquakes**
- 363 AD
- 363 AD
- 551 AD
- 651 AD
- 659 AD
- 749 AD
- 1033 AD
- 1202 AD
- 1229 AD
- 1458 AD
- 1546 AD
- 1759 AD
- 1834 AD
- 1837 AD

**Poorly Documented Earthquakes**
- 0 AD
- 100 AD
- 200 AD
- 300 AD
- 400 AD
- 500 AD
- 600 AD
- 700 AD
- 800 AD
- 900 AD
- 1000 AD
- 1100 AD
- 1200 AD
- 1300 AD
- 1400 AD
- 1500 AD
- 1600 AD
- 1700 AD
- 1800 AD
- 1900 AD

Fig. (S8b)
Fig. (58):

Chapter 7: Conclusions

Two archaeological buildings were studied in Jordan, depending on archaeoseismology method, in Capitoliyas/Beit Ras theater and Barracks in Umm el-Jimal, in order to document and assess earthquake related damages, and estimate the causative earthquake parameters (i.e. date, intensity and source). The study contributed in filling the significant gaps existing in the earthquake catalogues.

Intensity maps for the Major events effected at north of Jordan, from 1 AD- 19th century, were made, depending on the data existing in the available earthquake catalogues and previous literatures. The created maps were categorized into three groups; the first group which don’t have enough data to identify convinced estimation to the epicenter locations and needs more studies in the area. These events are 303 AD, 659 AD, 1293 AD, 1458 AD, and 1834 AD earthquakes. The second group which have few data, but represent almost convinced estimation for the epicenter locations. These events are 363 AD, 502 AD, 551 AD, 1033 AD, 1202 AD, 1546 AD 1759 October, and 1834 AD. However, they need to be updated by increasing the studies in the areas located in the east of DSTF. The third group which have lots of data and present convinced locations for the epicenters and the faults. These events are 749 AD, 1759 November AD, and 1837 AD earthquakes. On the other hand, another group was considered as poorly documented events, because the catalogues do not represent the affected locations in wide zone by these events, where just give damage information about one or two towns. All these mentioned gaps in these groups ought to be filled in the future for enhancing the earthquake catalogue and earthquake hazard assessment.

In Capitoliyas/Beit Ras theater, the research studied the archaeological stratigraphy and the existing archaeoseismic damage features of the Roman theater with the aim of defining 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. Contrary to the long-lasting belief that the 749 AD event is the main candidate earthquake damaging most of the Decapolis cities, the correlation of the stratigraphy of the theater with earthquake indicators revealed that at least two severe earthquake phases have damaged the theatre. It is most likely that the 1st phase occurred sometime between 98/97 AD and 261 AD, which resulted in the
collapse of the external perimeter corridor \textit{(ambulacrum)} and the eastern \textit{cavea}. The 2\textsuperscript{nd} phase occurred between 261 AD and the Late Roman-Early Byzantine times, which resulted in the tilting and collapse of the \textit{scaena} wall. We suggest that the 233 AD and/or 245 AD are the potential causative event(s) responsible for the destruction of the theater that preceded its major reconstruction before 261 AD.

The 303-6, 363, and 419 AD are probable candidate earthquakes for the 2\textsuperscript{nd} instance of severe damage to the theater during the 2\textsuperscript{nd} phase. The 363 AD earthquake is the most likely event which caused the abandonment and subsequent burial of the theater. Other subsequent events such as 551, 634, 659, and 749 AD occurred after the theater was filled up with the rubble. However, it cannot be excluded that other events, not mentioned in historical catalogues, contributed to the destruction of the theater. Observed Earthquake Archaeological Effects (EAEs) suggest the size of the earthquake damage was at least VIII-IX for both phases.

The attenuation model made to the theater and the historical documentation recorded the candidate events supports the certainty of the suggested events for the both phases.

Further to the east, 80 km from the Jordan Valley Fault, Barracks building in the ancient city of Umm el-Jimal, the traces of the earthquakes were studied. Six main phases were identified, constructed as repairing or modified parts. Several earthquake damage features, indicating for strong ground motion, were recognized, such as large U-shape collapsed walls, repaired U-shape collapsed walls, tiled walls, and large bulged walls. According to the EAEs scale, these features suggest an intensity of almost IX-X. At least two large earthquakes have damaged the Barracks. The first event occurred in Late Byzantine time (between 491 AD- 636 AD), causing a large U-shape collapse of the northern wall and falling the upper parts of the western wall. After this event, the Barracks was constructed by the technique of Phase 4. The second event occurred at the end of the rule of the Umayyad Caliphate followed by abandonment of the site.

According to the Intensity maps, the available data in the historical records suggest that the DSTF and known earthquakes, especially the major events, are not the candidates that caused the observed damages in the site. To support the suggestion, attenuation model was made and the intensities of the major earthquakes, along the DST, were measured. The model revealed that the measured intensities are lower than the intensity of the observed damage in the site, also there is no site-effect for amplification of the seismic waves. The model also suggests that strong events,
with 7.5 ML, generating from local north-eastern faults, within circle zone radius almost 40 km, such as ASF, FF, and ZRF, can produce the observed damages in the site. Whereas the earthquakes with 7.5 ML generated from DSTF can’t cause the observed damages.

ASF is the larger system in the eastern part of Jordan, consisting of several grabens striking NW-SE, intersecting with DSTF, and having many recorded instrumental earthquakes since 1983. It can be the best candidate fault that has been reactivated by DSTF, to cause earthquakes that might have been responsible in causing the damage to the Barracks. To study this proposal, a focal mechanism for one earthquake occurred in 5th of January 2008, along with the ASF, having magnitude ML 3.5, was analyzed. The focal mechanism indicates that the earthquake occurred along a right-lateral strike-slip fault with a normal component, parallel to R’ radial of the Riedel shear model of the DSTF. Thus, it is most likely that the fault has been reactivated as R’ related to the DSTF stress field, and the Barracks has been damaged by a historical earthquake generated along ASF.

The reactivation of the north-eastern fault was supported by many consideration, in addition to focal mechanism analysis: (1) occurrence instrumental earthquakes along north-eastern faults, with moderate magnitude 3.5 ML-4.6 Mb, as mainshocks or aftershocks, (2) identified epicenters of some large historical events in Bursa, (3) occurred large historical earthquakes along secondary faults after main events occurred along DSTF, like 551 AD and 749 AD.

For more support the certainty of this results, it is necessary to analyze the other instrumental earthquakes along with the faults and study the tectonic setting, as well as geomorphology and paleoseismology.

By reviewing the main data of all historical earthquake studies, in addition to the result of this research, four main points can be summarized: (1) the archaeoseismology studies present accurate and short interval time to the candidate earthquakes, the same as paleoseismology studies, however, both of them are different methods, (2) this study present updating to the earthquake catalogue, especially to the Roman and Byzantine period, (3) the study contributed to enhance the knowledge about poorly documented events, like 233 AD, which means more studies in the future can convert the poorly documented events into main events, (4) the study presents evidence about exist several unknown earthquakes, which are not mentioned the
available catalogues. All these can help in updating the earthquake catalogues and support the assessment of earthquake hazard.
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