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# 34. Effects of Earthquakes on the Development of the Construction Techniques in a Rural Community in Northern Jordan between the Byzantine and the Mamluk Periods

## Effetti dei terremoti sullo sviluppo delle tecniche costruttive in una comunità rurale nel nord della Giordania tra il periodo bizantino e quello mamelucco

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### Abstract

The Near East is a highly seismic area characterised by a sequence of catastrophic events that strongly influenced the history of the whole region. Between antiquity and the Middle Ages this region was hit by a series of extremely violent earthquakes recorded both, in the written and in the material sources. The former are of particular importance for the urban contexts since are rich in details and more comprehensive. The latter are essential in rural contexts often characterised by a lack of valid references useful to understand how these events have impacted on villages. This contribution aims at identifying the effects of catastrophic events that affected the site of Umm as-Surab (northern Jordan), by analysing the traces left on its architecture and ground. Furthermore, the paper aims to highlight the solutions used by the local population to overcome the immediate effects of these events on the buildings and, in the long term, to limit the effects of further similar catastrophes. To achieve these objectives, the research approach is based on a *longue durée* vision that takes into consideration a wide chronological time frame, from the Byzantine period to the beginning of the Mamluk sultanate (4th-13th centuries AD). The good conservation condition of the village allows analysing the changes induced over time to the buildings, using the approach of the Buildings Archaeology. At the same time, the analysis of construction cycles gives the opportunity to better understand some of the phenomena that underlay the development of the building techniques. Our observations on the architecture are enriched with data from a stratigraphic excavation, laboratory analyses, and dating of mortars and plasters. Overall, from this study emerges a picture which, although characterised by the slow transmission of empirical knowledge, demonstrates how small technical changes can lead to important and lasting innovations.

KEYWORDS: TRANSMISSION, BASALT, ḤAWRĀN, TECHNOLOGY

### Riassunto

Il Vicino Oriente è un'area altamente sismica caratterizzata da una sequenza di eventi catastrofici che hanno fortemente influenzato la storia dell'intera regione. Tra l'Antichità e il Medioevo questa regione ha sperimentato una serie di violentissimi terremoti registrati sia nelle fonti scritte che in quelle materiali. Le prime sono di particolare importanza soprattutto per i contesti urbani in quanto ricche di dettagli e più esaustive, mentre i contesti rurali spesso mancano di riferimenti validi utili a comprendere come i terremoti abbiano avuto un impatto sui villaggi. Questo contributo si concentra sul sito di Umm as-Surab (attuale Giordania settentrionale) e cerca di identificare gli effetti di questi eventi catastrofici attraverso l'analisi delle loro tracce lasciate sull'architettura e nel terreno. Inoltre, il contributo si propone di evidenziare le soluzioni costruttive utilizzate dalla popolazione locale per superare gli effetti immediati di questi eventi e, nel lungo periodo, per superare gli effetti di ulteriori simili catastrofi. Per raggiungere questo obiettivo, il nostro approccio si basa su una visione di *longue durée* che prende in considerazione un arco temporale alquanto ampio che va dal periodo bizantino fino all'inizio del sultanato mamelucco (IV-XIV secolo d.C.). Il relativo buono stato di conservazione del sito permette di analizzare le modifiche che gli edifici hanno subito nel tempo applicando i metodi dell'Archeologia dell'Architettura. Allo stesso tempo, l'analisi dei cicli produttivi ci offre l'opportunità di comprendere meglio alcuni dei fenomeni che stanno alla base dello sviluppo delle tecniche costruttive. Le nostre osservazioni sull'architettura si arricchiscono grazie ai dati provenienti da scavi stratigrafici, alle analisi di laboratorio e alle datazioni di malte e intonaci. Nel complesso, da questo studio emerge un quadro che, pur caratterizzato dalla lenta trasmissione delle conoscenze empiriche, dimostra come piccole modifiche tecniche possano portare a innovazioni importanti e durature.

PAROLE CHIAVE: TRASMISSIONE, BASALTO, ḤAWRĀN, TECNOLOGIA

## Introduction

The eastern Mediterranean regions have an extremely rich seismic history with disastrous events that have occurred over centuries. In this paper we reflect on how these natural events could have influenced the construction history of the village of Umm as-Surab (today, northern Jordan) through the study of its building techniques. We will focus on the analysis of supporting systems (arches) and masonry techniques. Data from buildings will be complemented with data derived from archaeological excavation and archaeometric analysis of mortars and plasters. The analysis of construction techniques allows recording technological changes that can sometimes be explained only through radical events in the history of a place. These may be due to changes in the social, political and economic organization, or due to natural events. If the first three can be investigated through specific sources, such as the written or materials ones (such as pottery), the natural events, such as earthquakes, are more challenging to investigate since it is difficult to identify their traces and, therefore, to analyse their effects. In fact, although written sources can describe earthquakes and their effects on people and buildings, it is difficult to relate these events to specific evidence, because earthquakes can produce different effects depending on the places where they occur, their intensity, extension, and the construction culture of the area affected. For this reason, attention must be paid to the analysis of the material data available and its results always need to be cross-checked with results from different sources. This paper suggests the idea that an earthquake can cause changes in construction culture that can only be understood by analysing their *production cycle*. This entails dealing with aspects of the construction that includes the acquisition or development of new technical procedures (e.g. those related to stone quarrying), tools, as well as the development or acquisition of new geometric and mathematical knowledge (e.g. the knowledge necessary to produce squared-off blocks for arches), and the knowledge related to the physic-chemical characteristics of materials (e.g. for the production of mortars). The development of procedures, tools and knowledge is based on continuous testing that requires time and that eventually leads to the development of a new culture (the so-called 'local seismic culture'). In such a context, an earthquake can be the cause of the abandonment of a site or the beginning of new experiences for the community that decides to remain on it. In both cases, social effects of earthquakes can be recorded in the architecture although its traces may be more or less visible depending on the relevance of the changes that can be limited or not easily detectable. It is also interesting to understand how the most ancient building solutions can be maintained after earthquakes

because considered effective. Similarly it is interesting to understand how these solutions can be improved or replaced.

The time frame for such kind of research can only be long, since this is the only way to understand complex phenomena such as technological and typological changes in construction techniques. Because of this, this research extends from the Byzantine period to the beginning of the Mamluk sultanate. Furthermore, within such a context, written sources and information on the material culture are more abundant, which allows using better qualitatively and quantitatively data to draw at solid conclusions.

## Earthquakes in the eastern Mediterranean region from antiquity to the Middle Ages: an overview

The seismic history of the eastern Mediterranean consists of numerous earthquakes documented thanks to written sources and material traces present in both, archaeological contexts and geological deposits. The comparison of these data has already led to the production of a reliable list of historical earthquakes with their epicentres, magnitude and intensity.<sup>1</sup> However, research constantly produces new data that improve and enrich these lists. Below we present a series of seismic events that occurred between 3rd-4th century AD and 14th century AD whose effects were recorded in an area between present-day Syria and Jordan. Therefore, these events can be contextualise within the ongoing research at Umm as-Surab.

Earthquakes have repeatedly been responsible for the destruction of some important urban centres in Palestine and Arabia, such as Petra (AD 363 and AD 551) or Jerash (AD 749). As for the documented earthquakes between Palestine and Arabia, according to the study carried out by K.W. Russell, and a more recent study by N. Ambraseys that re-discusses the dating and identification and classification criteria of the ancient earthquakes that occurred in the Mediterranean and the Near East, there is the possibility of identifying, through reliable documentary sources, approximately ten destructive seismic events between 2nd and 8th centuries AD. The most extensive and disastrous seem to have been those of AD 551 and 749. The event of AD 363 seems to have been equally disastrous but in a relatively limited area.<sup>2</sup> Information related to it describe two earthquakes that occurred six hours apart and caused the destruction of 22 cities between Syria and Palestine, and the loss of a large number of human lives.<sup>3</sup> The earthquake of 9th July 551 (intensity of X on the Mercalli-Cancani-Sieberg scale, hereafter MCS),

<sup>1</sup> Russell 1985; Guidoboni, Comastri and Traina 1999; Sbeinati, Darawchech and Mouty 2005: 347-435; Ambraseys 2009.

<sup>2</sup> Russell 1980: 47-64.

<sup>3</sup> Ambraseys 2009: 148-151.

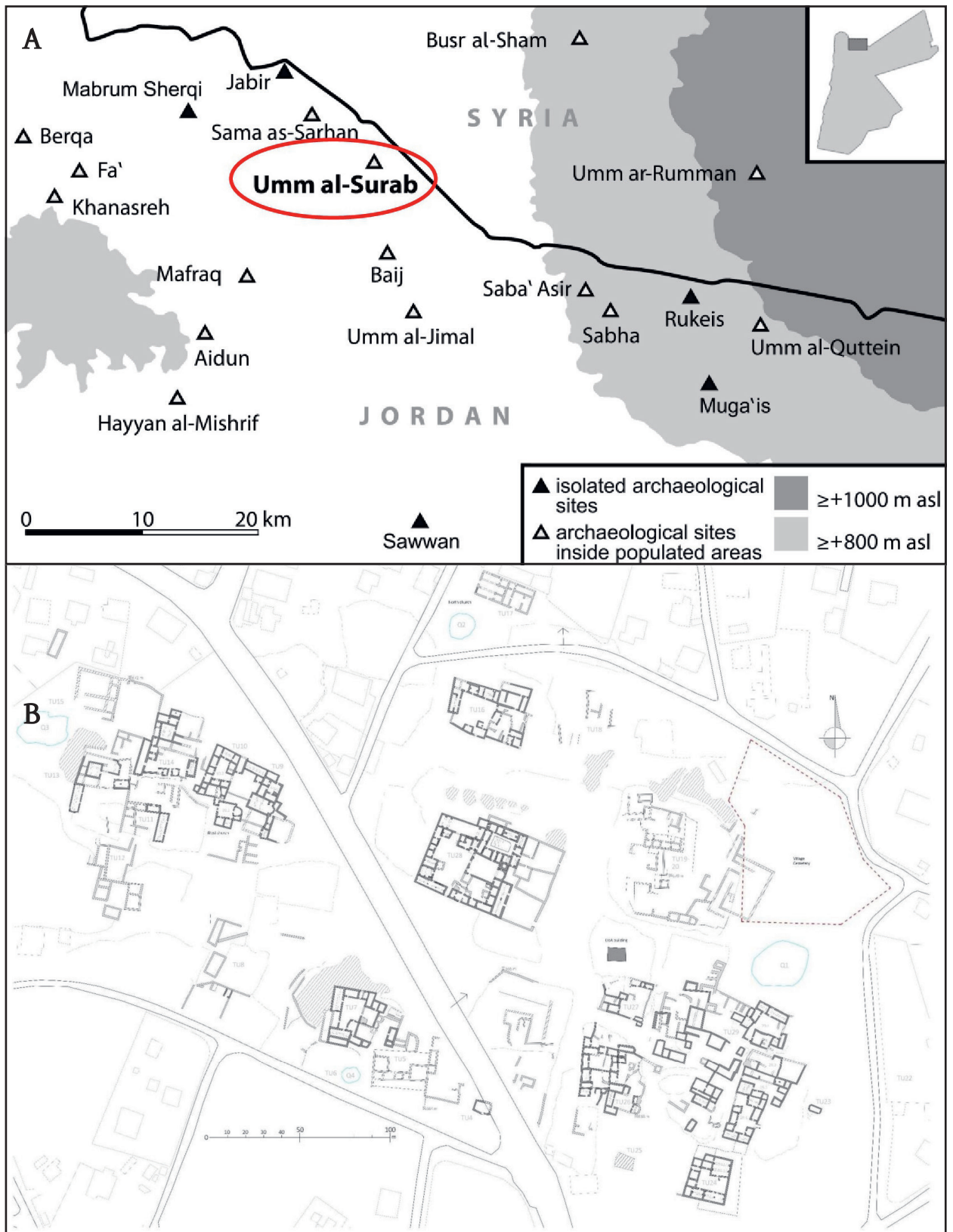


Figure 1. A: Location of Umm as-Surab (by Stefano Anastasio); B: Plan of Umm as-Surab (by Piero Gilento and Gourguen Davtian).

probably with its epicentre on the Lebanese coast, caused disasters over 100km from the coast, damaging numerous cities and villages.<sup>4</sup> The 8th century AD is a period of intense seismic activity. A significant series of earthquakes affected the entire area of the Eastern Mediterranean. The earthquake of 18th January 749 is a powerful event that struck Palestine with an intensity of IX-X on the MCS, of which we have information from different Arab, Byzantine and Syriac sources. Its dating was debated for a long time (*i.e.* if occurred in 746 or 749), and, after several studies, researchers agreed on the 749.<sup>5</sup> Its effects were felt in a huge area ranging from Egypt to Turkey and from the eastern coasts of the Mediterranean Sea to the shores of the Euphrates. For the Middle Ages, two important seismic sequences have recently been defined in detail and studied: the sequence of AD 1138-39 and the sequence of AD 1156 and 1159 which affected Syria, south-eastern Turkey and northern Lebanon.<sup>6</sup> Two other highly intense earthquakes that affected the eastern Mediterranean, and in particular the area of interest of this research, are those of AD 1182 and 1202. The first had Bosra and southern Syria as its epicentre with an intensity of IX on the MCS, while the second is a much larger earthquake (X on the MCS), the effects of which have been recorded from Iraq to Sicily, with the most significant damages are located between the Lebanese coast and central-southern Syria. The list of earthquakes between the 13th and 15th centuries AD encompasses many more events but the analysis of their epicentres, intensities and magnitudes do not allow inferring that their effects have significantly affected the area of interest of this study.

### Research context

The site of Umm as-Surab is located in northern Jordan, Mafrāq governorate, at only two kilometres from the Syrian borders (*Figure 1*). This area is characterised by a basalt plateau that from northern Jordan extends in larger part towards current Syrian territories and it is also named Ḥawrān. During the Roman period it was part of the province of Arabia, subsequently part of the *Diocesis Orientis* and then of the *al-Urdunn* district after the Islamic conquest. Historic and social events, combined with the use of basalt, have created the conditions for the good conservation of the village's ancient habitat. The basalt is a strong and durable building material, characterised by an extremely high density (approx. 2800kg/m<sup>3</sup>). Its characteristics require some level of complexity for both, the extraction and transport of blocks. Its transformation in building material is also related to the availability and use of

cutting and finishing tools with high dynamic hardness, and on the artisans' ability to use them. Despite all these technical restrictions, basalt has been used in the region as a building material since at least the Bronze Age.<sup>7</sup> This historical and geographical context made possible the preservation of numerous standing ancient structures, in some cases even exceeding 5m in height. This makes Umm as-Surab an optimal working area for investigating the traditional construction practices used to limit the effects of earthquakes.

The site covers a surface of about 17ha. and has been divided into 29 Topographic Units (TU) comprising four churches, some likely public buildings, and 26 housing blocks. The most well-preserved building of the site is the church of Sts. Sergius and Bacchus that has been the object of three main international research projects<sup>8</sup> and restorations activities by the Department of Antiquities of Jordan. The church is a building composed of three-*naves* and, on the north side of it, lies a monastic complex. An inscription on the lintel of the church main door (no longer *in situ*) dates its foundation to the AD 489, but various occupation phases are documented for the building. In particular, above the ruins of the room built to the north of the semi-circular apse was erected a 9m high tower that was used as a minaret when the building was probably re-used as a mosque. The whole site was subject to a surface survey, and two archaeological excavation (years 2018 and 2019) were carried out in the so-called AREA A, located in the south-eastern sector. The latter activities have brought to light a stratigraphic sequence that spans from the Late-Roman period (3rd-4th century AD) to the late Umayyad-early Abbasid period (8th-9th century AD), to the re-occupation of the area that occurred from the beginning of the 13th century AD to the 15th century AD.

### Research Methodology

The observations reported in this paper on the buildings of Umm as-Surab are the product of an extensive autoptic analysis of all of the structures described using the methods of Buildings Archaeology (*i.e.* the application of theoretical principles of archaeological stratigraphy to the study of still-standing buildings). Stratigraphy thus becomes an analytical methodology that can give useful information and help delineate the history of a building. In most of the cases, buildings were also recorded through a digital photogrammetric survey for generating a three-dimensional model with geometrically corrected photographs (orthophotos). The model was verified and its accuracy was assessed during various stages of data acquisition through direct measurements of some portions of the buildings. The

<sup>4</sup>Russell 1985: 44-46; Ambraseys 2009: 199-203.

<sup>5</sup>Guidoboni, Comastri and Traina 1999: 366.

<sup>6</sup>Guidoboni, Bernardini and Comastri 2004: 105-127.

<sup>7</sup>Braemer, Échallier and Taraqqi 2004.

<sup>8</sup>King 1983; Parenti 2012; Gilento 2014; Gilento 2015.

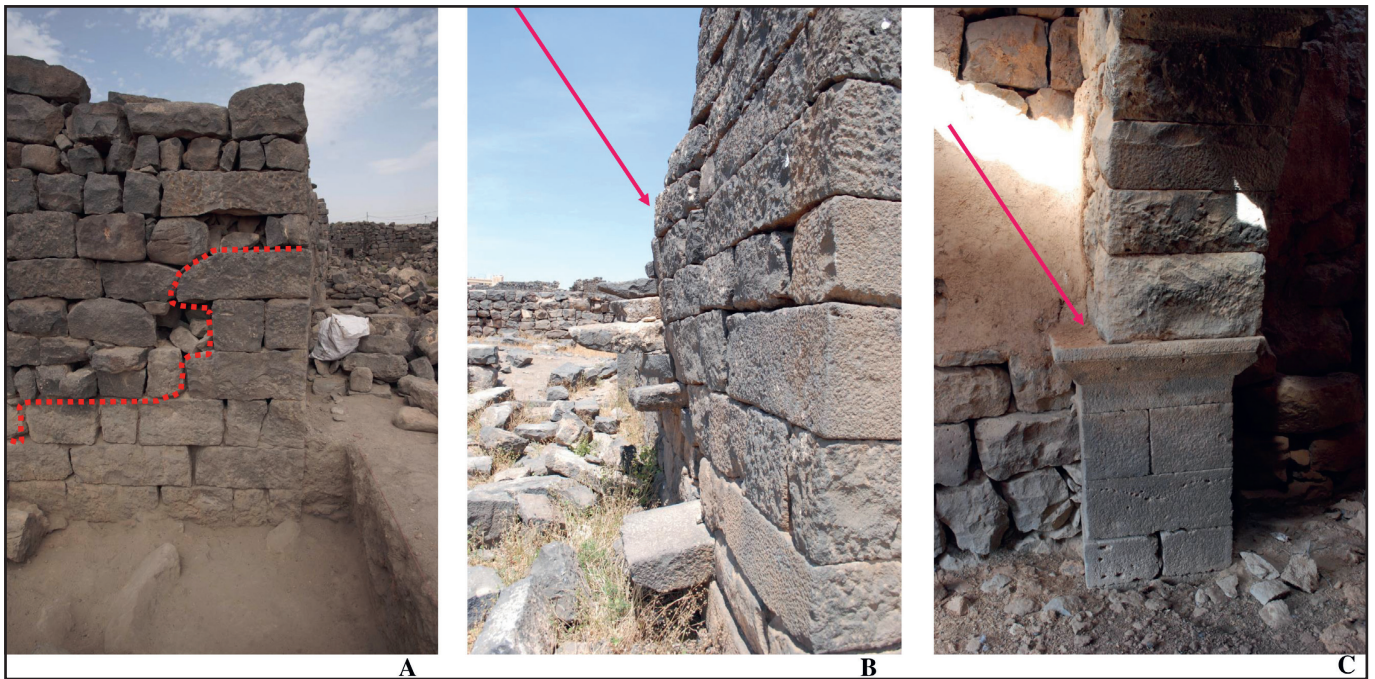


Figure 2. A: Collapse interface of the southern perimeter wall of TU 29.1; B: Bulging of a wall in TU28. C: Voussoirs that have been reset on the piers of an older arch (photos by Piero Gilento).

detailed description of all features of each masonry type was based on the observations carried out on areas of 2x2m of masonry. The section and core of a wall were also described where possible. Analysis of the arches also included consideration on the deformations caused by the numerous stresses (some of them due to earthquakes). The survey of these building systems was therefore performed in such a way that both the current state of a structure and the geometric reconstruction of its likely original shape could be visualised. For some pillars, precise measurements of the full height could not be obtained due to the considerable amount of material filling the rooms. All the arches were documented photographically except for one located in the western sector of the site (TU10), which was beyond reach due to the collapse of the entrance. Furthermore, archaeometric analyses were performed on samples of mortars and plasters<sup>9</sup> taken from stratigraphically-defined pieces of wall, and initial dates were obtained by the application of the <sup>14</sup>C method to charcoal fragments from both, the mortar and plaster. These results were complemented by the <sup>14</sup>C results from charcoal samples from excavated strata.

#### Effects of earthquakes on the construction techniques at Umm as-Surab

The stratigraphic analysis of the still-standing structures of Umm as-Surab allowed us to identify and define massive phases of reconstruction. Collapse interfaces and particular deformations of the walls were identified, such as bulging phenomena or the dislocation of the ashlar (Figure 2). These have been classified as possible effects caused by earthquakes. To try to better define these phenomena, we focused on the study of arches and walls, which we present in detail below, and then we discuss the results achieved by crossing them with the data from the archaeological excavation of AREA A and from archaeometric analyses on mortars and plasters.

#### Arches

In the past centuries, the main support system for the roofs at Umm as-Surab was the arch. Our extensive

<sup>9</sup> The mortars were studied by Giovanni Pesce and Cecilia Pesce of Northumbria University, Newcastle, in the framework of a collaboration during the EU – Horizon 2020 funded project ACTECH (P.I. Piero Gilento).

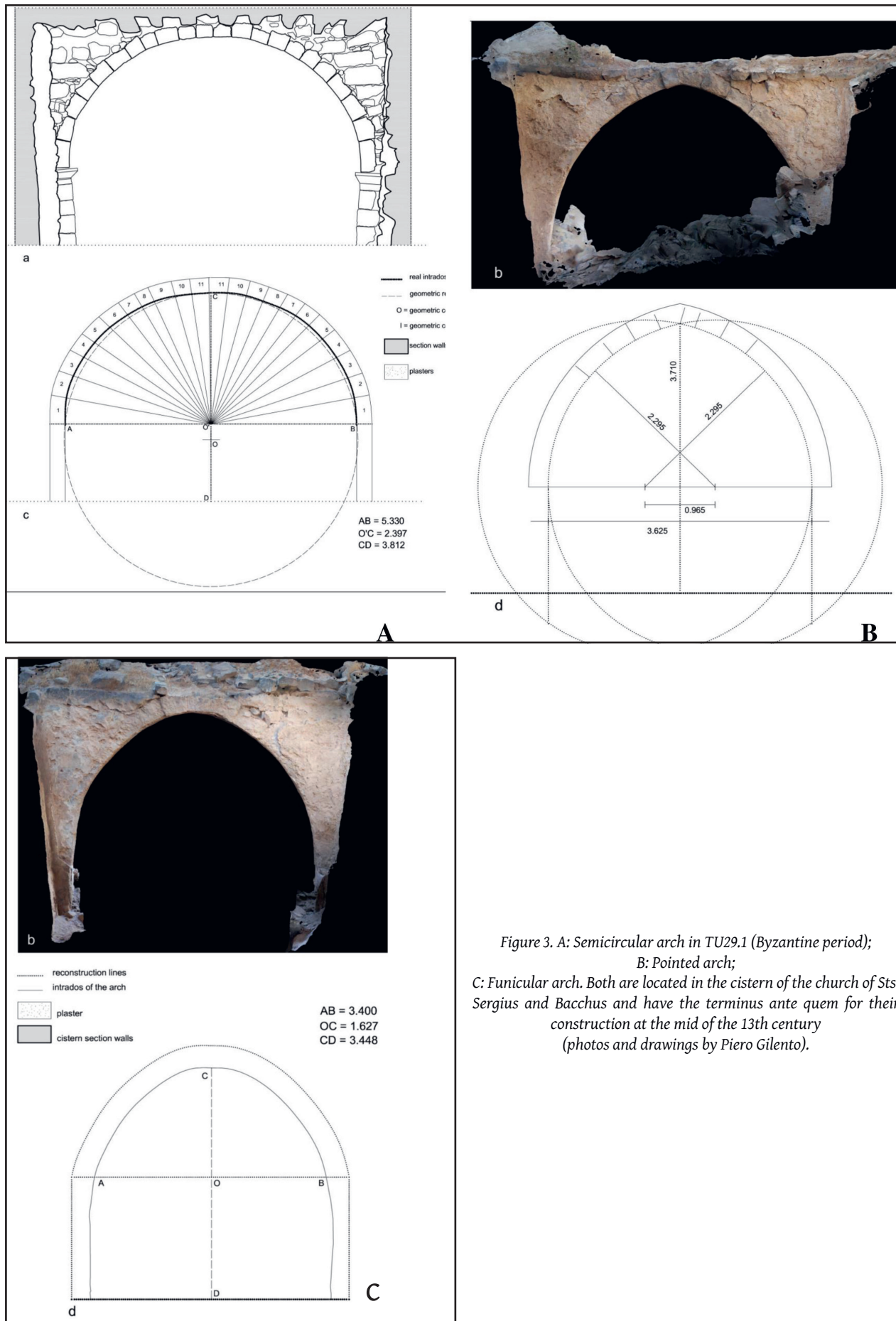


Figure 3. A: Semicircular arch in TU29.1 (Byzantine period);  
 B: Pointed arch;  
 C: Funicular arch. Both are located in the cistern of the church of Sts. Sergius and Bacchus and have the terminus ante quem for their construction at the mid of the 13th century (photos and drawings by Piero Gilento).

survey allowed documenting a total of 67 intact arches<sup>10</sup> organised in three groups and subdivided into seven main types related to four main shapes: semi-circular (round), surbased, pointed, and funicular (catenary) (Figure 3). The intense seismic history of the region is clearly readable on these structures which, in Umm as-Surab as well as in the rest of the Ḥawrān, have been reconstructed using older piers and capitals: the only parts of the structure that did not collapse during the paroxysmal event. In the Byzantine period, the semi-circular arch was used in the main room of houses, that is a relatively high (between 2.50 and 3.00m) and wide room of about 4.50x5.50m. Almost certainly this room was used as a living and reception space in the Byzantine period and probably it maintained the same function in other periods with only small changes. Evidence of Byzantine arches have been recorded for a total of 26 architectural elements. Currently only three of them are still standing: two inside houses and one inside the presbytery of the church of Sts. Sergius and Bacchus. Of the three, only the latter is in a good state of conservation thanks to the use of very well cut and laid ashlar. These are likely to have allowed for a good resistance to movements. The other two, on the other hand, show some deformations that could be due to both, the loads of the roofs and (probably) to earthquakes, which may have also caused the collapse of all the other arches of the village. The fact that the arches were reconstructed is clearly proved by the fact that the reused voussoirs are not aligned with the central axis of the piers, and by the fact that are not well re-positioned either without further reworking or with some reworking. Unfortunately, it is currently impossible to accurately date the reconstructions of the arches since no archaeological excavations have yet been conducted inside the houses. In any case, from the stratigraphic analysis of the walls and the typology of the arches, it is possible to suggest that some of these may be of medieval origin, while others may have been

<sup>10</sup> From this quantity must be subtracted nine arches which were certainly rebuilt between 1918 and 1978. These two chronological end points were derived from the analysis of two aerial images of the site of Umm as-Surab. The 1918 photograph, made by the German Air Force, clearly shows that several buildings did not exist or had collapsed roofs. The 1978 photograph, on the contrary, taken by the Spanish Air Force, clearly demonstrates the presence of new structures and, in other cases, the reconstruction of roofs. Thus, the analysis of the photographs provided an extremely important source of information for determining several modern building phases of the village that are otherwise difficult to detect and document. The authors wish to thank Bernard Lucke for kindly arranging consultation of the 1918 photograph, as well as the Packard Institute, which owns it. We also wish to thank Antonio Almagro for making available the photographic archive of the Spanish archaeological mission in Jordan, which includes the 1978 photograph, currently housed in the *Escuela de Estudios Árabes* (CSIC) in Granada.

reconstructed at the end of the Ottoman occupation of the region. Others again might be reconstructed in recent years. Currently, the only dating that it is possible to link to the construction of arches and that can be related to seismic events, are those of the northern courtyard of the church of Sts. Sergius and Bacchus. In this case, the dating at the second half of the 13th century (1241-96: probability of 95%)<sup>11</sup> of a fragment of charcoal embedded in the plaster that covers the walls and the arches of a cistern in the courtyard provides a *terminus ante quem* for their dating. In addition to this chronological information, the cistern also contains extremely important typological information. The arches supporting the cistern roof have, in fact, two different geometric shapes: catenary (or funicular) and pointed. These shapes, although existing in the region, are extremely rare in rural contexts. Besides, they are quite different from those in the architectural lexicon of the Byzantine era, whereas seems to be more common to the construction culture of the Early and Middle Islamic periods. The second <sup>14</sup>C dating, obtained from a piece of charcoal found in the bedding mortar of the joints of a door in the courtyard of the church, has approximately the same dating as the one seen before (i.e. the second half of the 13th century) confirming the existence of an important building site in this period.

#### Walls

Six groups of wall techniques, comprising 14 types, were identified in Umm as-Surab and some parallels have been found in other villages of the region (Figure 4). GROUP I: Walls with large polygonal stone blocks collected or extracted from the surface of the basalt rock, laid with the use of wedges and arranged in irregular layers.

GROUP II: Walls with large and small split or slightly rough-hewn blocks arranged in irregular layers.

GROUP III: Walls with rough-hewn and reworked rectangular elements, arranged in regular layers and containing irregularly-arranged headers in section.

GROUP IV: Walls with squared-off and 'L'-shaped blocks.

GROUP V: Walls with rectangular elements arranged in regular layers alternated with regular layers of headers.

GROUP VI: Walls made with elements recovered from other buildings and reworked, distributed in horizontal and quasi-horizontal layers; the section has headers arranged in regular layers or positioned irregularly.

In this contribution we will focus on the wall types in GROUPS IV, V and VI which correspond to the historical period considered in the research. The types of GROUPS IV and V were built during the Byzantine period and are characterised by the fact that all the elements

<sup>11</sup>The dating was performed by the CNA-Centro Nacional de Aceleradores of the University of Seville. The authors wish to thank its director Francisco Javier Santos Arévalo for the collaboration.



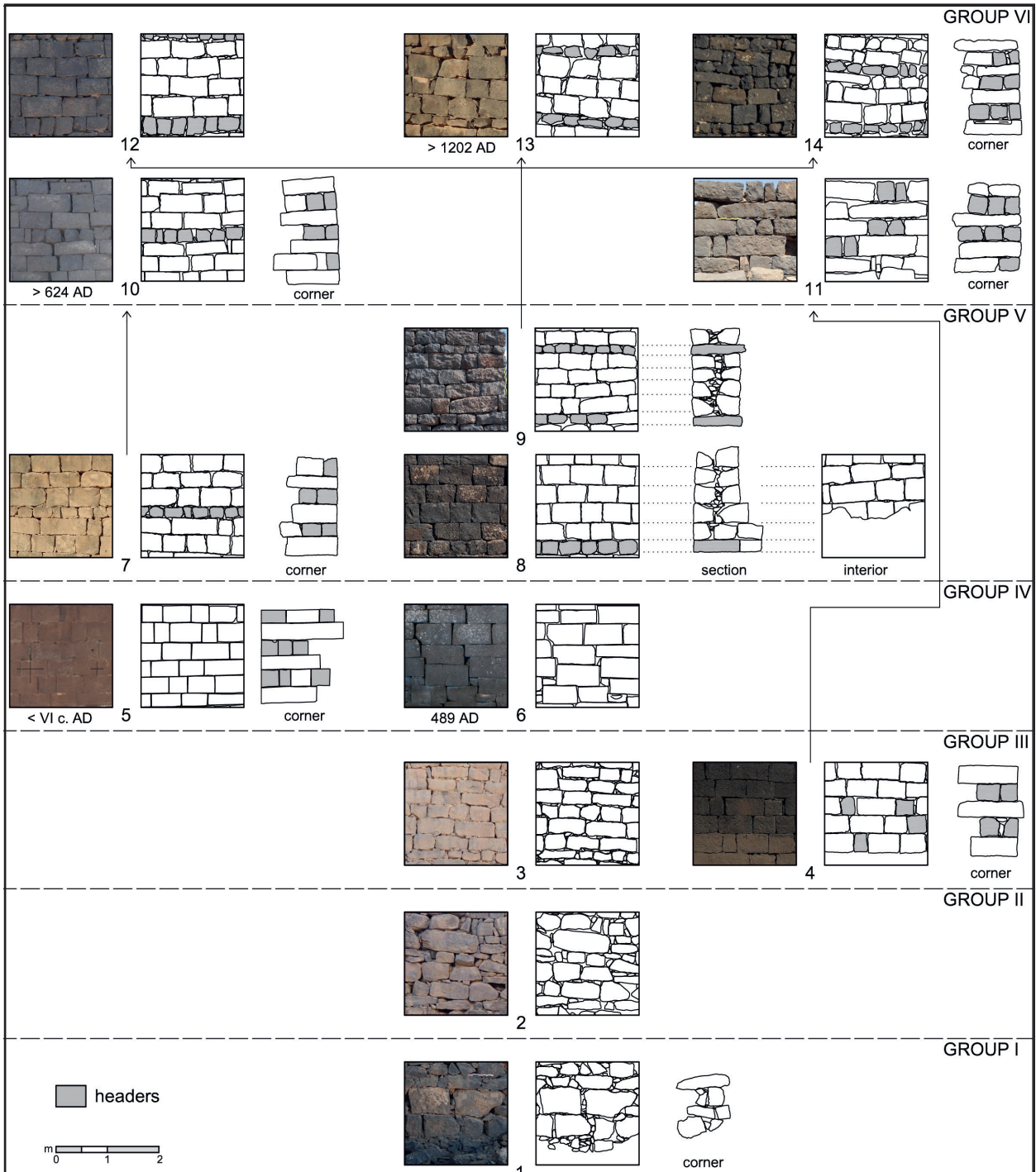


Figure 4. Chrono-typological table of the masonry techniques of Umm as-Surab (by Piero Gilento).

come from quarries and have specific installation systems, such as L-shaped elements (GROUP IV), and by the presence in the section of headers arranged in ordered layers (GROUP V). The headers have particular features: the visible short end of the blocks is worked (rough-hewn or smoothed) and has standard dimensions of about 0.60m, which is also the width of the section. These are masonry types put in place by highly specialised craftsmen with specific technical knowledge and availability of cutting tools and stone

processing that allow their realization. If both of these construction solutions give greater stability to the masonry, the first seems to be a stone cutting system that has a mainly decorative purpose. The use of headers, on the other hand, has an important static role because it allows the two faces of the walls to remain connected despite the stresses caused by earthquakes. In fact, the wall portions that use this construction technique are those more frequently preserved in the village. The masonry techniques described in Group



Figure 5. A: Southern perimeter wall of TU 29.1. In red is marked the collapse interface (photo by Piero Gilento); B: Orthophoto of the archaeological excavation with the collapse layer marked in red (elaboration by Gourguen Davtian); C: Particular of the collapse layer (photo by the Yarmouk University).

VI appear to be the result of the transmission of technical knowledge that, after a long period of use and experimentation, was absorbed into the local building knowledge, probably because of its great stability. One of the greatest differences between Groups V and VI is the height of the courses: in Group VI it is slightly reduced compared to Group V because of the reworking of the surfaces of individual elements before being re-laid. Similarly, the corners demonstrate persistence of the types documented in the previous groups, re-using solutions in which headers and stretchers alternate regularly, contributing to the creation of a particularly solid and stable masonries at the corner of the building. The types described in this group can be attributed to specialised masons, almost certainly local despite the presence of labour from nearby villages cannot be excluded. The analysed types in fact demonstrate technical characteristics that can be attributed only to expert artisans who have the related knowledge and skills. Several chronological indicators allow to narrow the chronology of these masonry types. Type 10 was used in the western façade of the tower of the church of St. George at Samah as-Sarhan and it is dated after AD 624. Type 13, instead, was used in the reconstruction of

the southern edge-wall of TU29.1, in the south-eastern area of the village. The archaeological excavation conducted immediately behind the structure revealed the collapse levels of a wall whose first phase can be dated by stratigraphy and typological comparison to the late Roman/early Byzantine period. The data from the archaeological excavation suggests that the wall collapsed during the Mamluk sultanate (see below for more data). The reconstruction of the wall (i.e. Type 13) is therefore later than this date. The stratigraphy and the typology confirm a similar chronology for the remaining types, which belong to the reconstruction phases of religious or domestic structures. Type 11 was widely employed in the reconstruction of the walls of the so-called ‘Two Arches Church’; Type 12, instead, comes from the blocking of the apse of the church of St. George at Samah as-Sarhan and could be contemporary to Type 10. Finally, Type 14 was used in the western elevation of the tower rebuilt on the collapsed portion of the apse of the church of Sts. Sergius and Bacchus at Umm as-Surab. All these types have important building phases in the Islamic era. The most reliable chronological indicator for this group is currently the stratigraphy, that provides the first chronological

clues for dating this wall techniques to the Islamic period. It is possible to assume that the earthquake of AD 749 could have caused an important break in the building history of the village, further increased by the subsequent political and cultural changes. A new moment of building vitality seems to affect Umm as-Surab in the mid of the 13th century AD, which can be considered as a *terminus post quem* for most of the types of Group VI. Analysis of these masonry types reveals a radical technological change, compared to the types of Groups IV and V, characterised by much more common practice of the reuse. The five types (i.e. 10, 11, 12, 13 and 14) of Group VI, in fact, show only reused elements organised in slightly irregular layers with reduced height compared to Groups IV and V. For Group VI it is possible to suppose a labour organisation divided into discrete building project sites concentrated in several parts of the village, especially in the central and eastern parts. This group is no longer based on the presence of specialised craftsmen, but on the presence of good shapers and masons capable to recover the abundant old material and build dwellings with different spatial organisation compared to the Byzantine period, where long and narrow spaces appear to predominate.

#### *Archaeological Excavation*

In the 2018 and 2019, archaeological excavations were carried out in Umm as-Surab. These activities took place in the south-eastern part of the site and involved a large area of about 25m<sup>2</sup> that extends between two housing units: the TU29.1 and TU24. Although the excavations have not yet been completed, the stratigraphic sequence defined so far thanks to a preliminary analysis of the pottery,<sup>12</sup> has allowed identifying four main periods of occupation: Late Roman-Byzantine; Umayyad; Post-earthquake (749) – early Abbasid and Mamluk. Among the main layers unearthed during the excavation, one of the most evident is a vast collapse of basalt stones coming from the wall that still limit the excavation area to the north and that it is the southern perimetral wall of the house 29.1. The analysis of this wall has revealed a collapse interface that marks the boundary between two typologically and technically different masonry techniques. The type of collapse interface and the related layer of stones documented in the excavation leave little doubt about the cause of their formation which is due to an earthquake (*Figure 5*). By cross-referencing the data from the archaeological excavation and the analysis of the wall it is possible to suggest that the earthquake occurred in medieval times. The collapse of the stones lays in fact on a stratigraphic unit (SU 1469) which has returned pottery from the Mamluk period (c. 13th-14th AD). In turn, the collapse of the

stones is covered by a level (SU 1460) whose material culture belongs to the same chronological framework. This suggest that sometime after the seismic event, the area was reoccupied. However, despite the fact that the list of medieval earthquakes that struck in the eastern Mediterranean is quite rich, the dating of the event that could have cause the collapse of the wall is still problematic. Two earthquakes that closely affected the area of this research with an intensity greater than VII of the Mercalli scale are known: that of 1182 (I: VII), which is documented nearby Bosra and its effects could have also affected Umm as-Surab (only 12km away), and the earthquake of 1202 (I: IX, M: 7.6), which is remembered by old sources as one of the most destructive earthquakes of the Middle Ages in the Eastern Mediterranean. However, the dating of these two earthquakes differs from the material culture found in the excavated level (SU 1469) just below the collapse. The collapse of the wall should therefore be attributed to a later event for which it is currently impossible to provide more reliable information. In fact, in the list of earthquakes that occurred in Syria, between the 13th and 14th century AD, it emerges a sequence of numerous seismic events including those of AD 1303, 1339, 1344 and 1404.<sup>13</sup> However, from the analysis of the geographical location, intensity and magnitude it seems that none of them could have been the cause of the collapse of the perimeter wall of house 29.1. In this regard, the research will have to continue to try to better understand which seismic event can be linked to the material traces found in the wall stratigraphy and in the archaeological excavation. An important fact that emerges from the reading of these data is certainly that relating to the change in the masonry construction technique on the southern perimeter wall of the TU29.1 that has already been discussed in the previous paragraph.

#### *Construction materials and Archaeometry*

Although basalt plays a prominent role in Ḥawrān built environment, analysis of the architecture demonstrated that different materials were used at different time. Therefore, the study of these materials can improve our understanding of the production cycle of different masonries and suggests the presence (or absence) of specific knowledge and skills and, consequently, of specific craftsmen. For example, in Umm as-Surab the core of a wall usually filled with a mortar containing basalt chips, but in the Roman and Byzantine times core mortars also contained earth and ceramic fragments, glass and stone flakes probably intended to make the cores more compact. Chemical and physical analyses of mortars and plasters have provided indicators for the production technology used in different periods.

<sup>12</sup> This research, still in progress, has been carried out by Dr. Raffaella Pappalardo, whom the authors thank for her contribution.

<sup>13</sup> Sbeinati, Darawchech and Mouty 2005: 347-435.

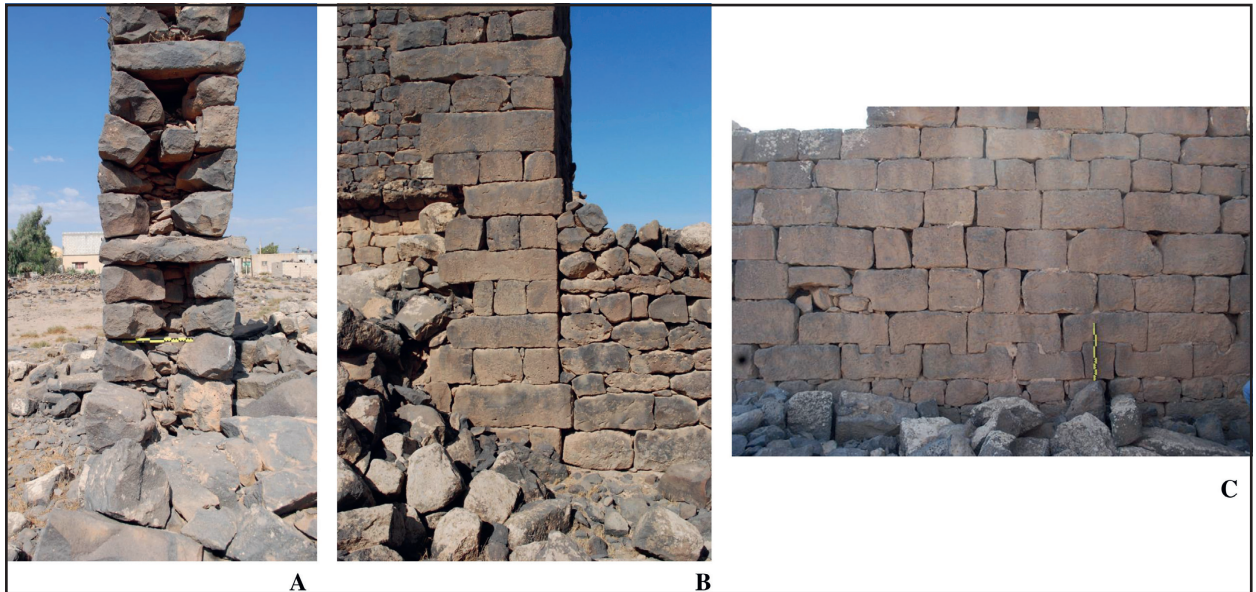


Figure 6. A: Section wall with headers, Umm as-Surab; B: Still-standing corner, Umm al-Jimāl; C: Lower part of the tower of house XVII at Umm al-Jimāl: mortise and tenon technique (photos by Piero Gilento).

Results demonstrated that mortars were exclusively made of lime in the Byzantine period, whereas in the Islamic period mortars were based on a mixture of lime and gypsum.<sup>14</sup> Mortar analysis has also facilitated identification and extraction of charcoal fragments originally mixed (intentionally or unintentionally) into the mortars whose radiocarbon dating has provided some of the first absolute chronologies for the whole site (see above) that are of fundamental importance in such context where chronological indicators are extremely difficult to find. Although in smaller quantities, mortars were used also in the joints of walls and arches, and its abundant use in certain types of arches has been demonstrated not only between the voussoirs but also to bind the elements laid above the arch extrados. Therefore, the mortar can be used to discriminate groups of construction systems. Another very common practice in Ḥawrān is the pointing of the mortar joints, probably to prevent the leakage of mortars from the core of the wall. Such a practical function may have been accompanied by an aesthetic value as well, suggested by the arrangement of small basalt fragments either at the juncture between vertical and horizontal seams or along the entire line of a joint. Depending on the stone shape and organization, mortars may not be essential to the stability of the walls in Ḥawrān (*e.g.* when walls are made of perfectly squared-off blocks with very thin mortar joints), however studying these materials and their physico-chemical characteristics is essential for the study of the craftsmanship that produced them and that, in turn, can highlight changes in the building culture, potentially sprout even by the effects of

earthquakes.

#### Use and improvement of anti-seismic technical solutions

One main point emerges from the study of earthquakes and construction techniques at Umm as-Surab. It concerns the long-term use and improvement of specific technical solutions, such as the use of headers and wall-corners. The use of prismatic elements with length perpendicular to the face of the wall that can join its two side (*i.e.* headers) is evidence of the attention paid by the builders to deploy solutions that can greatly improve the stability of the walls. This detail was certainly already in use in the Hellenistic and Roman times in the region, especially in important structures, and it spread as a common practice also in the Byzantine period. This research has shown that even in the medieval period the headers continue to be a common solution in the masonry techniques which, on the other hand, are characterised by less refined faces compared to the Byzantine period (due to the practice of the reuse of the stones). Further evidence of the continuous use of construction techniques is in the wall-corners. Sometimes the corners are the only preserved parts of historic structures, demonstrating their particular resilience. In Umm as-Surab the functionality and resistance of the corners were exploited, for example, to build (probably in the 13th-14th centuries AD) the tower on the remains of the church of Sts. Sergius and Bacchus. Although the stone blocks used in the tower are all re-employed, the corners are well connected, making the whole structure extremely stable and demonstrating the

<sup>14</sup> Gilento, Pesce and Pesce 2019.

particular attention paid in the construction of the building. In this specific case, the stability of the tower is also improved by the construction of the stairs that develops around a central axis forming a sort of quadrangular-based pillar connected to the tower perimeter wall, making the structure even more stable. A third technical solution that could have been used for anti-seismic purposes in the region, is a particular type of anchoring solution of the blocks that allows a stronger connection: the creation of a so-called mortise and tenon join. According to the literature, this is a widespread system especially used in prestige architecture of the Roman and Byzantine eras.<sup>15</sup> This could be positioned in specific points of the structures as well as in the façades and the upper and lower sections of high-rise buildings, such as the tower of the house XVII at Umm al-Jimāl (*Figure 6*). According to the literature and field surveys, no traces of such a technical solution have been found dated to the medieval period. This lack of evidence could demonstrate the loss of some construction traditions due to technical, cultural and economic factors. According to Jean-Claude Bessac, the oldest examples of use of this reinforcement technique in the territories of present-day Syria were identified in the walls of Sharah. Here, this technique evolved even further with the creation of a double hook blocks such as those used in Shahba, dated to the 3rd century AD and then spread throughout the Byzantine period (well documented always in Sharah on the Byzantine tower and in Bosra in the church of Sts. Sergius, Bacchus and Leontius, dated to the beginning of the 6th century). The use of double hook mortice and tenon locking systems would have been particularly effective with the use of basalt, which can more easily withstand the tensile forces caused by earthquakes (compared to other stone types) and, in fact, this solution is unknown in limestone constructions of the Near East. From a chronological point of view, another observation made by Bessac,<sup>16</sup> concerns the spread of this technical solution from the 2nd century and its systematization in the Byzantine period, almost certainly caused by a strong seismic activity. In fact, such a technique entails a considerably lengthily production (with high costs) that can only be justified by its effectiveness in solving specific problems. This entails the fact that there must have been a specific reason for using it (and for having developed it over four centuries). Unfortunately, traces of this solution were lost at the end of Antiquity. The mortise and tenon technique is also cited as an anti-seismic device by Arce, who indicates the example in the tower of the XVII house of Umm al-Jimāl<sup>17</sup> and by Clauss-Balty, that records it in the tower added to

Kafr Shams' house 1.<sup>18</sup>

## Discussion

The cases discussed above (walls, arches and mortars) clearly demonstrate that there has been a clear change in the production cycle between the Byzantine and medieval periods. However, this change did not influence the choice of technical solutions (corners and headers) that become essential components of the constructive culture of the region: the effect of a continuous adaptation to natural events and environmental needs and the technical success of these solutions in the long term. The mortises and tenons technique, on the other hand, could be a case in which an anti-seismic solution has either, not been incorporated into the local building culture, or lost because of the loss of the necessary technical skills, knowledge or craftsmen.

The rebuilding phases after an earthquake can be a moment to introduce new architectural forms, materials and solutions that mark a discontinuity in the construction tradition of the local culture. The arches of the cistern in the monastery of the church of Sts. Sergius and Bacchus could be considered as an example of this typological and technical discontinuity in Umm as-Surab. The cistern was in fact built at the end of the 5th century AD together with the monastery and it is possible to hypothesize that the arches that supported its roof in this phase were semi-circular, following the practices and construction forms of the time. A disastrous earthquake could have caused their destruction, which then gave rise to the need for a reconstruction of the arches for a new use of the cistern, whose plastering dates back to the second half of the 13th century (see above). Two destructive earthquakes can be associated with the collapse of the arches of the cistern: that of 749 and that of 1202. Currently, there is no data suggesting a date or the another. In any case, one of the two events created the opportunity to build new arches, typologically and technically very different from the previous ones. The new arches were built by specialised masons who had the technical and geometrical knowledge necessary, probably acquired in other areas of the region (Bosra?). This introduction of new craftsmanship was, perhaps, sponsored by the new political and social élite (the Mamluks) that had the necessary economic resources and interests to promote a broad project of improving water infrastructure and territorial reorganisation. The rise of the Mamluk sultanate in the mid of the 13th century could, therefore, have created the conditions for external elements to bring innovations that have entered the constructive culture of the village, as demonstrated by the presence of other catenary or pointed arches in the site which completely replaced the semi-circular ones from the

<sup>15</sup> Arce 1996; Bessac 2010.

<sup>16</sup> Bessac 2010: 419.

<sup>17</sup> Arce 1996: 44-45.

<sup>18</sup> Clauss-Balty 2008: 54.

Byzantine period (likely almost all of them collapsed due to one or more seismic events). These changes are also found in the mortars studied in Umm as-Surab, showing important technological innovations, such as the use of gypsum, found in a sample of mortar used in a construction phase subsequent to the Byzantine period and technologically very different from it.

### Conclusion

Earthquakes occur in specific areas of the Earth that are also unique social and cultural contexts. Earthquakes can trigger changes in various aspects of the communities experiencing such paroxysmal events, although these are not sufficient and require the contemporary actions of other forces pushing for changes already present *in nuce* in a community. These changes can also be found in construction techniques and become part of a much longer and more complex evolutionary process that can only be appreciated by looking at a longer time perspective. This is what we have tried to demonstrate in Umm as-Surab, where the daily life of a small community can be intertwined with big natural, social and cultural events leaving their traces and effects on its common practices, including those related to the constructions. The local seismic culture developed in Umm as-Surab is the result of a long adaptation to the limits imposed by the construction materials which, for example, did not allow the use of lighter materials for roofing (e.g. timber). Despite this, the continuous experiments, and the timely external influences, have led to the development and use of technical solutions which, while not capable to completely prevent the collapse of the structures, have been able to, at least, mitigate the damage. The result of this long adaptation and evolution of the construction techniques is represented by the chronotypological table of the masonry techniques of Umm as-Surab which demonstrates how the most recent techniques have almost always incorporated past experiences, adapting them to the historical, economic and social context of the time. This does not mean that in the construction history of Umm as-Surab there has been only continuity, but on the contrary, there are also important technical-formal breaks that led to innovations.

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### Author Contributions

The text was conceived and written by Piero Gilento whereas Giovanni Pesce reviewed it. The other authors have contributed in various capacities through the field research and the discussion of the results: Gourguen Davtian-GIS and GPS survey; Pierre-Marie Blanc-archaeological excavation and pottery studies; Khaled al Bashaireh-archaeological excavation and pottery archaeometric studies; Apolline Vernet-archaeological excavation; Maen Omoush-archaeological excavation and pottery studies.

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