Archaeoseismology in Algeria: Observed Damages Related to Probable Past Earthquakes on Archaeological Remains on Roman Sites (Tel Atlas of Algeria)

K. Roumane and A. Ayadi

Abstract For the period before 1365, the catalogue of historical earthquakes in Algeria remains sparse. A number of earthquakes have been identified in archived documents, and yet others can be inferred from their damage to archaeological structures. In this study, we focus on the Roman period (BC 146–429), the Vandal and Byzantine period (AD 429–533) in the region of the seismically active Tell Atlas. The Tell Atlas of Algeria retains numerous archaeological records of former earthquakes. At the Roman sites of Lambaesis (Lambèse), Thamugadi (Timgad) Thibilis (Salaoua Announa) or Thevest (Tebessa), we interpret damage to monuments as having been caused by strong shaking, ground subsidence, and landslides effects. In this study, we aim at contributing towards archaeoseismology in Algeria by presenting examples of observed damage and disorders on several Roman sites.

Keywords Archaeoseismology · Ancient earthquakes · Antiquity
Roman sites · Thamugadi · Lambaesis · Cuicul · Theveste · Tipasa

1 Introduction

The seismicity of Algeria is attributed to its location within the Africa-Eurasia plate boundary. The Tell Atlas of Algeria has experienced numerous strong and devastating shallow earthquakes, 5–20 km depth (Ayadi and Bezzeghoud 2015). The goal of this paper is to analyze the various Algerian archaeological sites, located on seismogenic zones through the identification and examination of the features observed on structures that are probably related to the effects of earthquake. The selected sites (Fig. 1) were chosen based on their proximity to seismogenic areas

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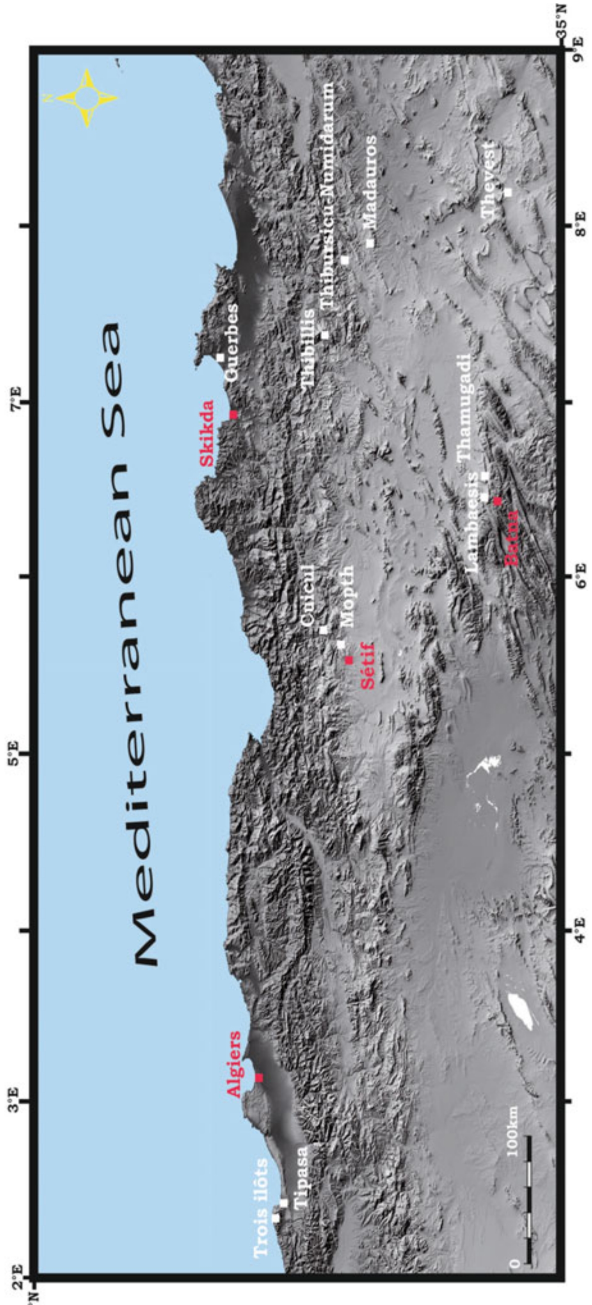

Fig. 1 Location of the Roman sites along the eastern part of the Tell Atlas (Northern Algeria)

that experienced strong seismic events and frequently guided by ancient texts that reported destruction and extensive damage following an earthquake in these sites (Ferdi and Harbi 2013; Roumane 2016). For this, we studied several cases and we attempted to compare them to other studies such that of Sintubin and Stewart (2008), Stiros (1996) and Rodriguez-Pascua et al. (2011), that reported typological identification of disorders on archaeological sites.

2 The Algerian Archaeological Sites Located in Earthquake Prone Areas

The Tell Atlas in Northern Algeria is a wide zone of tectonic deformation induced by the convergence between the Africa and Eurasia plates. Most of the seismicity is located in this extended zone bounded to the south by the south Atlasic faults system and to the north by the Mediterranean Sea. This area experienced several strong earthquakes (Ayadi and Bezzeghoud 2015). Roman archaeological sites in the Tellian Atlas (Fig. 1) are numerous and most of them are located near seismogenic zones regarding the distribution of the seismicity along the Tell Atlas (Fig. 2). In this paper, we investigated the following sites:

- Tipasa (Tipasa) is located on the Algerian coast west of Algiers Capital city. According to Lancel (2005), its location was strategic and considered as a

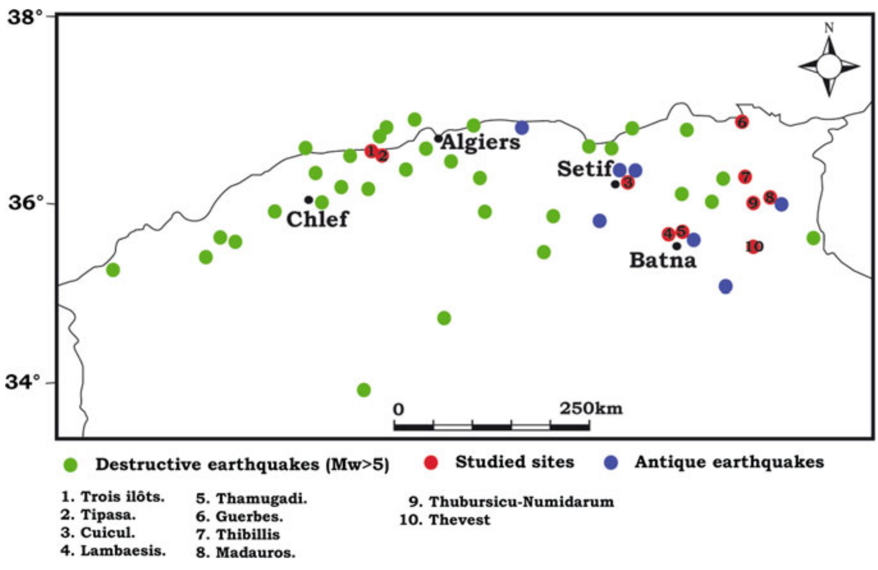

Fig. 2 Significant earthquakes in the Tell Atlas of Algeria from Maouche et al. (2010). Green circles: significant earthquakes with magnitude > 5.0, Red circles: Archaeological sites in this study. Blue circles: other archaeological sites during the Antic period

trading center and a stopover for Phoenician sailors on their route to the west (Gsell 1894). Baradez (1952) specified that the city was built in the fifth century BC (Phoenician counter) and became a Roman city in AD 39. Tipasa comprises several archaeological complexes and many of them were not restored.

- Cuicul (Djemila), an ancient Roman city which was built far from the coastline on the high plateau in a mountainous area on a rocky site at about 900 m elevation, 40 km east of Setif (known as Sitifis during the Roman empire). According to Février (1978), who referred to Cagnat (1923), the city was founded between AD 96 and 97 during the reign of Nerva. Other authors, such as Gascou (1972), proposed the beginning of the reign of Trajan (AD 98) as a period during which Cuicul was created. The remains of the archaeological structures of Cuicul have been restored in the beginning of the twentieth century.
- Thamugadi (Timgad) is located in the Aurès region. Its original name was Colonia Marciana Trajana Thamugadi (Courtois 1951) and it was built during the reign of Trajan (AD 100) as a Roman veteran's city by the legate Lucius Munatius Gallus. Thamugadi was believed to be a fortification defending the occupied area from southern threats.
- Lambaesis (Tazoult) is a military camp which was built in AD 81 by the Third Augustus legion. An independent source reports it to have attained City status during a period of enlargement by the emperor Trajan in AD 100, and its military camp to have been inspected by Emperor Hadrian in AD 128.
- Thibilis (Sellaoua-Announa) is a Numidian city which became an important Roman settlement. Administratively, the town was ruled by the Roman colony of Cirta, 57 km to the northwest. Thibilis became an autonomous municipality, probably between AD 260 and 268.
- Madauros (M'Daourouch) was the home of the famous writer *Lucius Apuleius* who reported that the city was located in the border of Numidia and Getulia (Gsell 1901, 1914, 1922). Madauros was built during the Flavian dynasty between AD 69 and 96.
- Thubursicu-Numidarum (Khemissa) in Guelma province, northeastern Algeria is one of the important Roman cities in Africa as suggested by its extensive ruins. According to Gsell (1914), about 600 epitaphs were found reporting the importance of the city which was founded during the reign of Trajan (AD 100) when it became a Municipium (Municipium Ulpium Traianum Augustum Thubursicu) and Colonia (Roman colony) around AD 270.
- Thevest (Tébessa) was founded during the reign of Vespasian at the end of the first century (AD 69–79) and became the principal residence of the Third legion of Augustus. Subsequently, Theveste became the richest city in Africa after Carthage (Ballu 1893).
- Mons (Mopth) in eastern Algeria between Cuicul and Sitifis is a Roman settlement built on a rock hill founded under the reign of Nerva (AD 96–98) (Gsell 1901).

- Guerbes is a town in eastern Algeria on the coastline which consists of a large rectangular enclosure, typical of many sites that served as overnight shelters for passing travelers (Gsell 1901).

3 Seismicity of Algeria and Earthquakes of the Ancient Times

In earlier earthquake catalogues, Ayadi and Bezzeghoud (2015) and Harbi et al. (2015) identified several damaging earthquakes in the Tell Atlas (Algeria), over a period starting from the fourteenth century to the present (Table 1). The most important ones are those of Algiers (1365, I_0 X, 1716, I_0 IX), Blida (1825) and the El Asnam of October 10th 1980 with Ms7.3. Testimonials in ancient documents and epigraphs prior to 1365 are scarce (Ferdi and Harbi 2013). This is probably due to the destruction of historical records during numerous invasions. According to an epighraphic inscription, Ad Maiores (Henchir Besseriani now, South of Tébessa) (Lepelley 1981; Laporte and Dupuis 2009; Laporte 2016) (Table 2) experienced in

Table 1 Table of significant earthquake that have occurred in Algeria since 1365 (Ayadi and Bezzeghoud 2015)

Locality	Date	Intensity	Magnitude	Observations
Algiers	3/01/1365	Strong	Strong	Algiers completely destroyed
Algiers	10/03/1673	Strong	Strong	71 aftershocks
Mediterranean	3/02/1716	X	7.5	Several houses destroyed
Algiers	29/11/1722	Strong	Strong	Damage 75 km SW Algiers
Oran	9/10/1790	IX–X	6.5–7.5	Felt in Malta
Mascara	–03/1819	IX	6.5	Little damage to Oran
Blida	02/03/1825	X–XI	7.5	Destruction of Blida
Jijel	22/08/1856	X	7.5	Generated a tsunami
Kherba	09/03/1858	IX	6.5	Damage in the plain of Mitidja
Mitidja	02/01/1867	X–XI	7.5	Mouzaïa destroyed
Biskra	16/11/1869	IX	6.5	
Gouraya	15/01/1891	X	7.5	Damage in Algiers. Felt in Saida and Djelfa
Sour El Ghozlane	24/06/1910	X	6.4	
A. El Hassan	25/08/1922	IX–X	5.1	Damage reported in Cherchell
El Attaf	07/09/1934	IX	5.0	Landslides triggered
Bejaia	12/02/1946	VIII–IX	5.6	
Chlef	09/09/1954	X–XI	6.7	
M'Sila	21/02/1960	VIII	5.6	
M'Sila	01/01/1965	VIII	5.6	

(continued)

Table 1 (continued)

Mansourah	24/11/1973	VII	5.1	
Chlef	10/10/1980	IX	7.3	
Constantine	27/10/1985	VIII	5.9	
El Affroun	31/10/1988	VII	5.4	
Djebel Chenoua	29/10/1989	VIII	6.0	

Table 2 Table of the major earthquakes in Algeria during the Antiquity period according to ancient texts

Date	Locality	References
Antic period	Rusucurru	Robert (1891), Laporte (2016)
267 AD	Lambaesis (Praetorium)	Bull. Soc. Archéologique du midi de la France (24 June 1902); Lepelley (1981)
267 AD	Lambaesis	Ballu (1893), Ferdi and Harbi (2013)
267 AD	Ad Maiores and Thamugadi	Ballu (1897), Lepelley (1981, 1984), Laporte and Dupuis (2009)
355 AD	Thubursicu Numidarum	Lepelley (1981, 1984), Ferdi and Harbi (2013)
365 AD	Cuicul	Albertini (1949), Rebuffat (1980)
419 AD	Sitifis	Guidoboni (1994); Augustin Sermon 19.6 in Ferdi and Harbi (2013)

AD 267 an earthquake which caused damage and was responsible of the collapse of an arch at night. In his book on the ruins of antique Thamugadi, Ballu (1897) related damaging earthquake which was felt in Thamugadi in AD 267. Finally, the earthquake that occurred on 21 July 365 affected much of the Mediterranean, including the Roman city of Cuicul (Djemila) (Rebuffat 1980; Di Vita 1990) (Table 2). Lepelley (1984), by reading several epigraphic texts, has drawn up a picture in which the term “ruina” (in Latin), which most often means falls of rubble, is highlighted in Table 3. This table describes various damage observed in some archaeological sites of Algeria. The AD 365 earthquake was recently studied by Stiros (2001, 2010) and conclude that the earthquake was not related to a single event but a series of at least three earthquakes in Cyprus, Crete, and Sicily/Libya giving the impression of a “universal” earthquake.

4 Damage Identification on Archaeological Sites

Deformation associated with earthquakes in the vicinity of an archaeological site can be classified into two categories according to the effects they induced. We can have direct and indirect effects. The study of damage on archaeological sites related

Table 3 Inventory of destructions observed on sites in North Africa (after Lepelley 1984)

	Date	Cities name (in Latin)	Place	Type of damage (in Latin)	Type of damage (in English)
1	Before AD 305	Thubursicu Bure (Proc.) – *C.* 25998	Square	ruinam manans	Risk of collapse
2	AD 324–326	Lepcis Magna (Tr.) *I.R.T.* 467	Basilica	ruina … deformata … [cum] diunio ictu confla-Graret incendio	Collapse… degradation as well as destruction by fire
3	AD 324–326	Lepcis Magna (Tr.) *I.R.T.* 468	Gantry	in ruinam [la] bemque conuersa	Removal of trace of destruction
4	AD 361–362	Thubursicu Numidarum (Proc.) – *I.L. Alg.*, I, 1247 et 1274	Statues transferred from a place in ruins	signum Traiani de ruinis ablatum; de ruinis asigno titulisque translatis	Removal of stigmas by cleaning and transferring statues to another location
5	AD 364	Madauros (Proc.) *I.L. Alg.*, I, 2101	Baths	[tot re] tro annis ruinarum labe deformes	A few years ago, the bath was cleared of any sign of destruction
6	AD 364–367	Lambaesis (Num.) *C.* 2656	Fountain	r[u]inis [obrutam ?]	Cover the ruins
7	AD 364–467	Mascula (Num.) *A.E.* 1911, 217	Baths	ruinarum deformitas	The ugliness of the ruins
8	AD 368–370	Abbir Maius (Proc.) *A.E.* 1975, 873	Baths	soliaris ruina conlapsus	Became ruin
9	AD 378	Sabrtha (Tr.) *I.R.T.* 103	Baths	post ruinam	After ruin
10	AD 383–392	Sitifis (Maur. S.) *C.* 8480 (*I.L. S.*, 5596)	Public Bakery	ruinis imminentibus destitutis	The ruins were left
11	Lower-Empire (AD 284–533)	Thamugadi (Num.) *B.C.T.H.*, 1907, p. 262	House	ruinis tamdiu informibus tristem, felicius quam condita est restituit	As long as these ruins are in desolation, glory to who will restore them.
12	Lower-Empire (AD 284–533)	Thibilis (Num.) *A.E.*, 1969-70, 691; *I.L. Alg.*, II, 2, 4724	Fountain	inca(s)um funditus superante ruina	Weak foundations, defeated by the ruins

to earthquakes is a recent approach, several studies such those of Stiros (1995, 1996), Stiros and Pytharouli (2014), Monaco and Tortorici (2004), and Stiros et al. (2006), highlighted the importance of archaeological, geological, and seismological investigations to retrieve the impact of ancient earthquakes on archaeological structures.

Direct effects are directly observed on structures and the indirect effects are due to other geological phenomena such as landslides, folding, liquefaction, or subsidence. According to Schaub et al. (2009), it is necessary to determine, the type of material and its use by ancient civilizations on archaeological sites (masonry, type of mortar, type of column, etc.). Thus, knowledge of the local architectural framework allows good discrimination between buildings that potentially record the first effects, associated to the ground shaking from those due to the secondary effects related to other phenomena.

5 Seismic and Non-seismic Damage on Archaeological Structures

In archaeoseismological research, it is important to discuss some ambiguous cases when damage could not be identified whether related to tectonic activity or caused by other geological or anthropic origin. In this context, we met two significant cases. We observed the first on the site of Tipasa (70 km west of Algiers) at the base of the new temple where a displacement of blocks was not due to a seismic effect but to the development of the roots of tree, which generated a vertical displacement of about 12 cm (Fig. 3). The second case was noticed in Cuicul (Djemila), and consists of a large inclination that was observed on walls of the Septimius Severe (Septime Severe) Temple. This inclination was attributed to a poor restoration of the Temple. Old pictures show the original form of the ruins, and compared with its present form it is easy to attribute the deformation to bad restoration (Fig. 4). In the Oum El Kanatir site in Jordan, Marco (2008) observed a large break in an old basin that recent investigation concludes to the effect of the landslide. To avoid erroneous conclusions on the origin of the damage, care should be given to the various deformations observed on ruins especially those which have been subject to restoration.

6 Observed Damage on Archaeological Sites

To retrieve the cause of the damage on archaeological structures and identify its relation to a seismic action, we have been inspired by the approach used by several studies. We may mention as examples particular fractures, falls of columns,

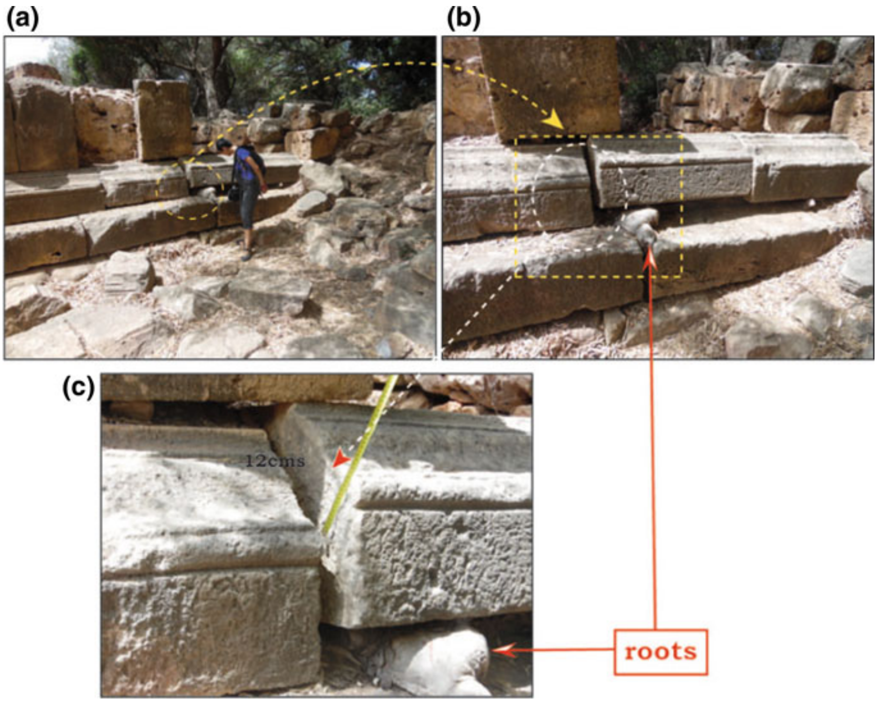

Fig. 3 Displacement of blocks of steps in a Roman Temple, Tipasa. **a** View of the Temple, **b** zoom on the tree roots, origin of the displacement of the block. **c** The block uplift was measured to about 12 cm

extrusions and intrusions of masonry blocks, as well as permanent ground deformation.

The damages caused by an earthquake on buildings are various. We can have disorders on walls, fractures, blocks, and keystones displacement and folded steps. All these observations were noted on structures in the sites we investigated.

a. Deformation on walls

In all the sites investigated, we observed folded walls. When walls are relatively subject to large distortion and displacements, they may indicate that these effects were caused by earthquakes. The best example of these deformations is located in the upper town of Tazoult (Lambaesis) where a distortion was observed in the propylaea of the Asclepieum (religious and prestigious complex, organized around the center of the city). A wall of the structure was rotated with a large tilt component. The investigated structure is of rectangular shape, but in its eastern part, the wall is no longer continuous and exhibit an outward rotation (Fig. 5a) which has been measured at more than 1 m (Fig. 5b). It should be noted that this rotation was made possible by the existence of an inflection point where the torsion of the wall begins (Fig. 5c). This torsion at the center (point of rotation) is measured at 8 cm

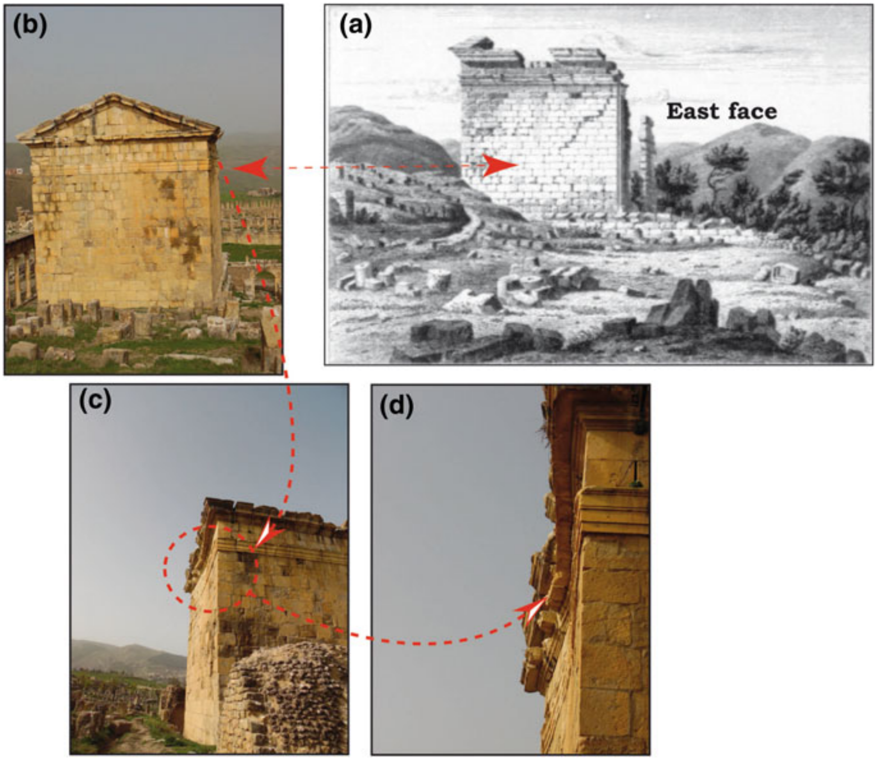

Fig. 4 Bad repairing of the Septime Severe Temple in Cuicul **a** old picture in black and white, before repairing, **b** recent picture after repairing, **c**, **d** view and zoom on the deformed wall

(Fig. 5d). This rotation induced a considerable inclination of the structure towards the interior of the building (Fig. 5e) visible, also from inside the structure (Fig. 5f). The resulting inclination and rotation (Fig. 5g) resulted in an extrusion blocks (13 cm) on a wall perpendicular to this structure (Fig. 5h). Even if they are of minor importance, inclined walls were observed in many Algerian archaeological sites, notably in Thubursicu Numidarum and Cuicul at the thermal baths with 10° inclination (Fig. 6). The walls under lateral seismic load could be tilted with various inclination and this is a good indicator of seismic action. Rodriguez-Pascua et al. (2011) indicate that in ancient cities, the inclination of walls, in general, may be a consequence of a significant horizontal movement. Moreover, Korjenkov and Kaiser (2003) and Korjenkov et al. (2003) specify that the types of deformation observed on walls are dependent on the orientation of the walls. We should note that these effects are better seen on the brick walls than on walls with large and heavy stones (opus quadratum) which relatively have more rigidity for being not tilted by earthquake shaking.

b. Fractures

Active faults could reach the surface (strong earthquakes) and generates traces on ground, damaging the constructions with different degrees. The ground shaking may also cause fractures on structures due to transient movements. But this is not always the case because in most cases, fractures could have other origin. The best examples were noticed in Thamugadi where several forms of fractures are observed. Fractures were observed on an oil roller mill near the Lambaesis gate with more than one meter in length (Fig. 7a, b), and with E-W orientation (Roumane 2016).

c. Displaced blocks

The displacement of large blocks in archaeological structures is attributed to damage due to seismic shaking according to many authors, such as Sintubin and Stewart (2008), Hinzen et al. (2010) and Hinzen and Yerli (2010). Yerli et al. (2010) links these displacements to the proximity of a fault. For Bilham et al. (2010), who worked on a Hindu temple, the displacement of large blocks is related to a seismic action (intensity VII to IX, MSK scale).

For this type of deformation, several observations were made on all sites. In the site of Thamugadi, in the lower part of the capitol (Fig. 8a), there is a movement of a block with a slight inward orientation (Fig. 8b, c), quite large of about 15 cm (Fig. 8d). Karakhanyan et al. (2010), described the same deformation at the level of a temple in Luxor in Egypt. In the site of Thibilis, the same disorder was recorded at the Christian basilica at the lower part of the eastern section. The investigation on this typical case shows block extrusion to outside (Fig. 9a, b), with an offset of about 14 cm (Roumane and Ayadi 2016). The same pathology was found at Thevest on the byzantine rampart, not far from the arc of Caracalla (symbol of the Metropolis). The observed deformation shows a masonry block extrusion (Fig. 10a), in the lower part of the rampart. The two extruded blocks do not exhibit any rotation, but the displacement is variable between 13 and 15 cm (Fig. 10b). The significant example was observed in the Lambaesis mausoleum. The observed deformation is represented by a lateral displacement of blocks and horizontal rotation also reported by Gsell (1893) (Fig. 11a) in the upper part of the structure (Fig. 11b, c) and in the lower part (Fig. 11d). Similox-Tohon et al. (2006) reported similar deformation in the upper part of a Roman mausoleum at Pinara (Southwest Turkey).

d. Dropped keystones and lintels

Keys stones of arches are common in old structures usually in doors, large windows, bridges, and other corridors. In many cases, the deformations recorded in keys and arches suggest a displacement of the vault key downwards, which may be according to Marco (2008), and Silva et al. (2009) an indicator of seismic origin. Kamai and Hatsor (2007) point out that the sliding of the lower lintels is also an earthquake shaking result. There is a relation between the vertical sliding of the key

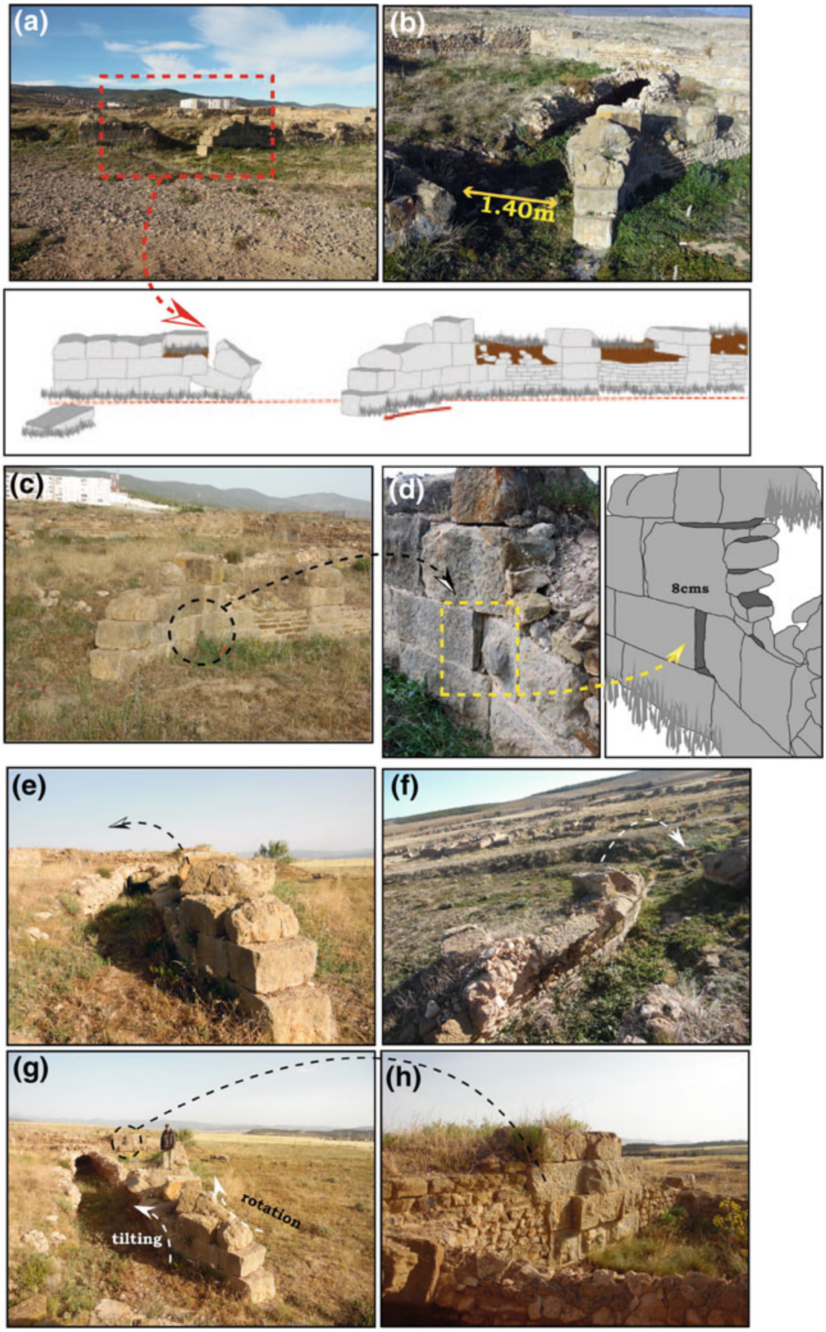

Fig. 5 Displaced and rotated wall at Lambaesis site. **a** Rotated wall. **b** Displacement of about 1.4 m. **c**, **d** Point of rotation. **e** Tilting of the wall towards the interior of the building. **f** Rear view of the tilting. **g**, **h** Rotation and tilting and extrusion of blocks in the background

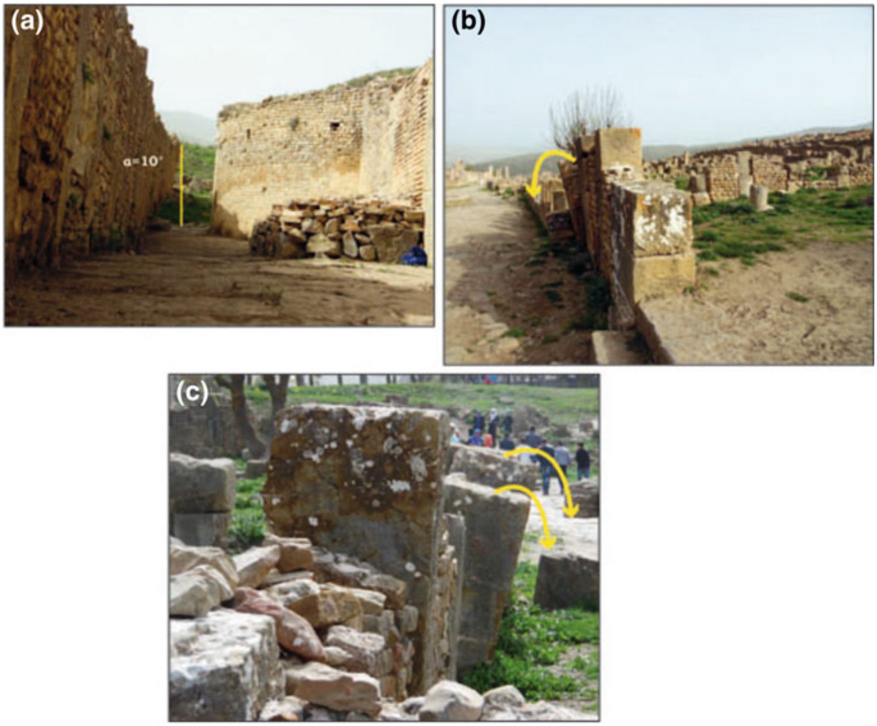

Fig. 6 Displaced and rotated wall at Cuicul site. **a** Thermal baths. **b**, **c** Main street

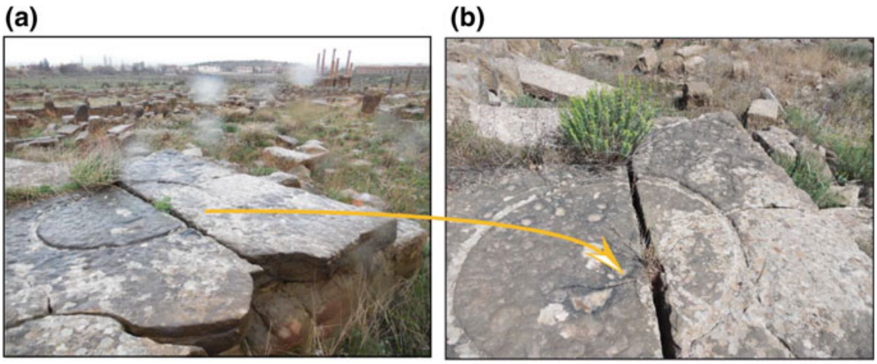

Fig. 7 Fractures observed at Thamugadi site. **a**, **b** Basis of oil mills

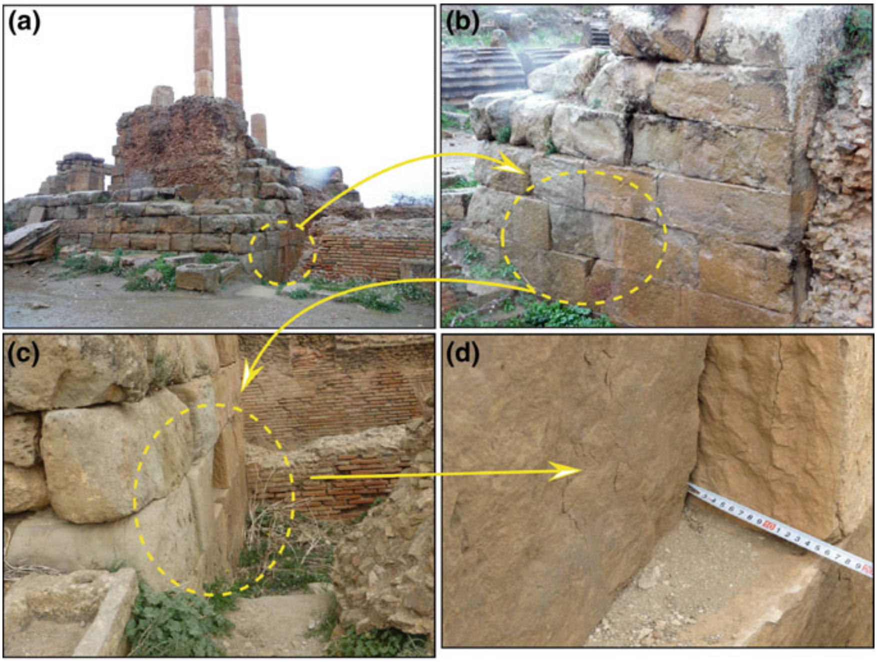

Fig. 8 Displaced blocks at Thamugadi site. **a** In the Capitole. **b** Zoom on the displacement measured at 15 cm

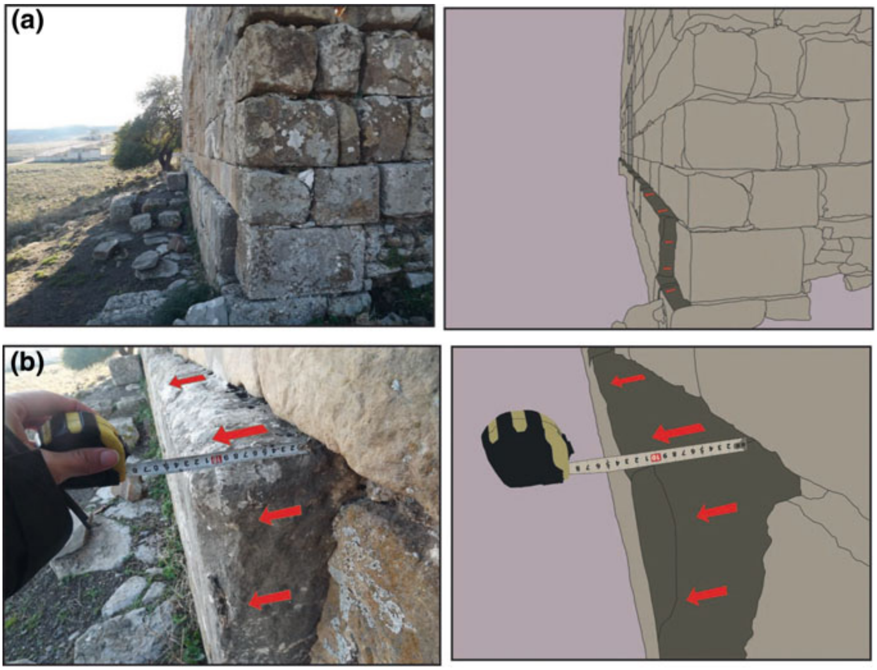

Fig. 9 Extrusion of blocks in the Christian basilica at Thibillis site

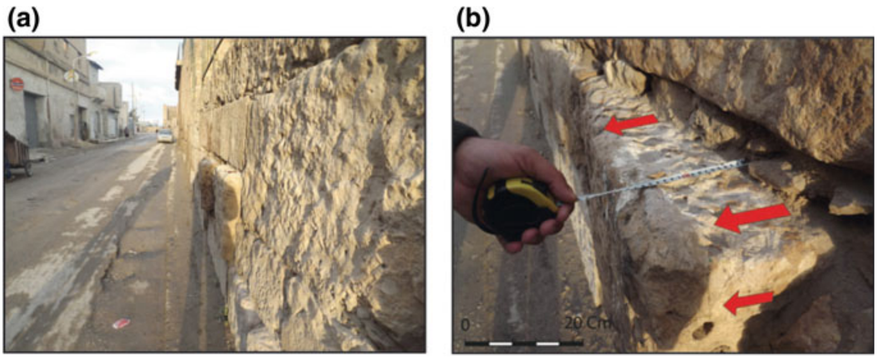

Fig. 10 Extrusion of blocks at Thevest **a** on a wall of Caracalla Temple, **b** zoom on the displacement observed

to the bottom and the direction of the seismic shaking. Thubursicu Numidarum city recorded an important example of this pathology. Three kilometers east of this site, we investigated an aqueduct in perfect conservation and its foundations have not suffered any deformation. The central part of the vault key of the Roman aqueduct moved down by about 10 cm (Fig. 12). On the site of Madauros, collapsed lintels were studied at the thermal baths on the entrance facing the slave tunnel. In the central part, attempts of restoration can be seen on the facade, allowing the building to remain in place (Fig. 13). These lintels are degraded in the left part, while in the right part, the offset is clearly visible when we measured it, to about 5 cm.

e. Folded steps

Soft sedimentary rocks, especially clays, react differently compared with other limestones and sandstones (competent rocks). The recording of the deformations and the reaction of these elements are different. The soft sedimentary rocks exhibit sort of plastic deformation, on the other hand, competent rocks will be displaced or fractured depending on the seismic loading. The deformations observed on the pavements and paving stones seem most often to be related to the local instability of the soil. Stairs are a good indicator of seismic disorder. Blocks of rock forming the steps could be folded or displaced. We observed such deformation on a western view of the arch of Trajan at Thamugadi, and the steps on the path to the arch of Trajan were deformed. This deformation is shown by large undulations of the different steps (Fig. 14). Slight deformation of the ground due to various non-seismic geotechnical effects can produce extension on arches and keystone drops or even collapse (Stiros 1996).

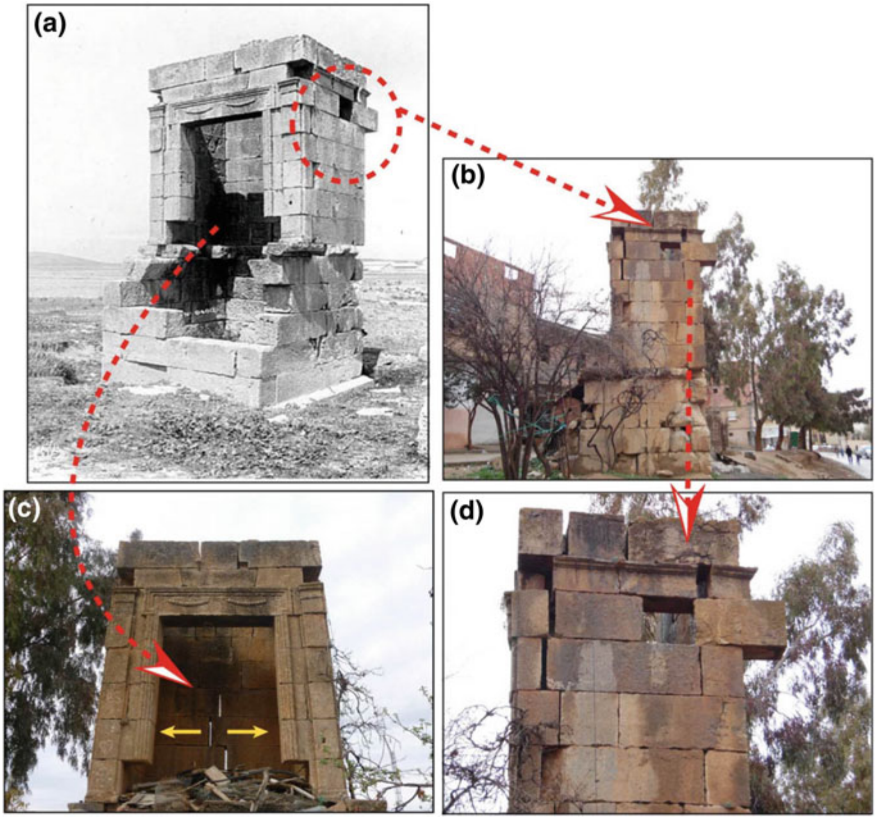

Fig. 11 Lateral displacement of blocks at Lambaesis site. **a** Observations made on picture from Gsell (1893). **b**, **c** Actual view of the upper level. **d** Lateral displacement in the basal part

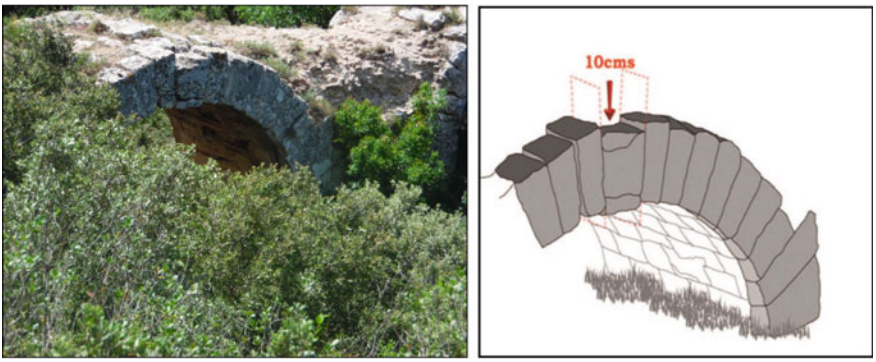

Fig. 12 Collapsed keystones at roman aqueduct in Thibursicu Numidarum site

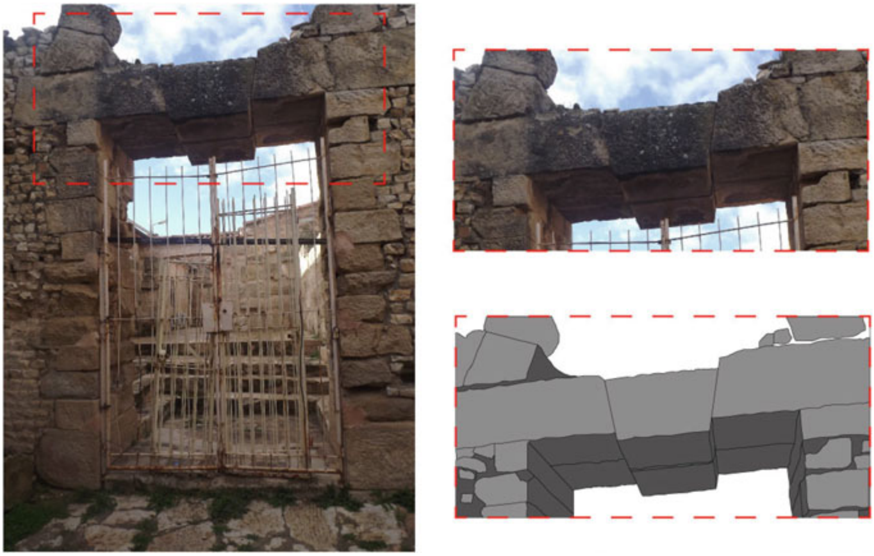

Fig. 13 Collapsed lintels near the thermal baths at Madauros site

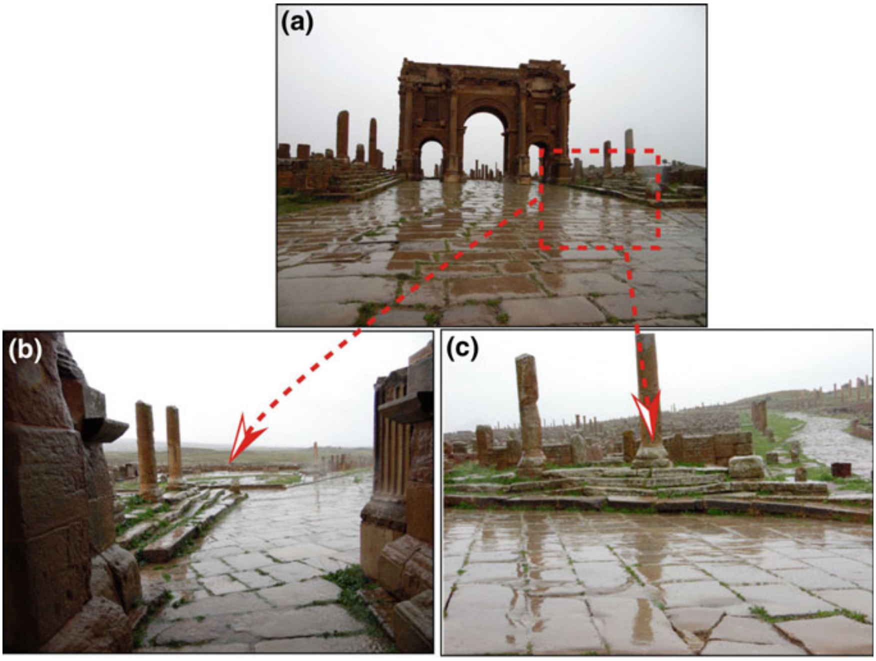

Fig. 14 Folded steps on stairs on the path to the Arche of Trajan at Thamugadi site

7 Conclusion

The aforementioned deformations and disorders in this study were carefully analyzed following observations that have been made by other authors on other sites. We have compared our results to that obtained by Stiros (1996), Sintubin and Stewart (2008) and Rodriguez-Pascua et al. (2011). During our study, we have visited ten sites of the Roman period in Algeria and most of them that are located within the Tell Atlas considered as a seismic active zone in northern Algeria. We tried to identify the action of probable past strong earthquakes considering the damage observed on archaeological structures. Attention was given to deformation that is not of seismic origin but of bad repairing procedures or other source of action. The bad repairing process was observed on several sites as on the Septime Severe Temple and Arch of Caracalla in Cuicul which are the best examples. The Septime Severe Temple was badly repaired as shown by the old and recent pictures of the structure, and the Arch of Caracalla was disassembled for transportation to France (during the French colonization in the beginning of the twentieth century) and reassembled on site, unfortunately with some deformation and disorders on it. We focused in this paper on damage and disorders that are related to probable earthquakes. This work should be completed by a detailed tectonic investigation in the archaeological sites and their surroundings to identify active faults. Much remains to be done on the dating of damage and the seismic events associated in relation with the tectonic context where the archaeological site is located. This will be useful and be the objective for seismologists dealing with historical seismology who need to assign dates on the observed damage. In Algeria, except for few seismic event retrieved from some epigraphic documents, the seismic catalogues seriously suffer of lacks for the period prior to 1365. The recognition of earthquake effects on archaeological sites should lead us to pay more attention to this heritage to better save them by engaging a serious policy of preservation of the archaeological heritage.

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