ISSN 2039-6651
Anno 2015_Numero 27

Miscellanea INGV

Abstracts Volume 6th International INQUA Meeting on

Paleoseismology, Active Tectonics and Archaeoseismology

19 | 24 April 2015, Pescina, Fucino Basin, Italy

27

Istituto Nazionale di
Geofisica e Vulcanologia

INQUA Focus Group on Paleoseismology and Active Tectonics

New insights on the occurrence of ancient earthquakes in Central Spain: Archaeoseismology of the Complutum area (4th century AD, Madrid)

Rodríguez-Pascua, M.A. (1), Heras, C. (2), Bastida, A.B. (2), Giner-Robles, J.L. (3), Silva, P.G. (4), Perucha, M.A. (1), Roquero, E. (5), Carrasco, P. (4), Pérez-López, R. (1), Lario, J. (6), Bardaji, T. (7)

(1) Instituto Geológico y Minero de España, Madrid, Spain. Email: ma.rodriguez@igme.es
(2) Trébede, Patrimonio Cultural, S.L. Torres de la Alameda, Madrid, Spain
(3) Facultad de Ciencias, Universidad Autónoma de Madrid, Madrid, Spain
(4) Dpto. Geología, Escuela Politécnica Superior de Ávila, Universidad Salamanca, Ávila, Spain
(5) Dpto. Edafología, E.T.S.I. Agrónomos, Universidad Politécnica de Madrid, Madrid, Spain
(6) Facultad de Ciencias. UNED, Madrid, Spain
(7) Dpto. Geología. Fac. Ciencias, Universidad de Alcalá de Henares, Madrid, Spain

Abstract: *The ancient Roman city of Complutum (Alcalá de Henares, Madrid) was founded in the first century AD and it was one of the most important cities of Hispania. The old Roman city was destroyed, abruptly abandoned, relocated in a close place and rebuilt in the 4th century AD. The destruction of the city and its new location is not still explained by the archaeology. In this paper we show different earthquake archaeological effects (EAEs) affecting the La Magdalena site (an agricultural holding located 4 km away from the core of Complutum). We used a multidisciplinary approach in order to identify and characterize apparent EAEs affecting the archaeological site. The most important earthquake geological effect identified in the site is the occurrence of liquefaction (sand dikes and ground settlement) affecting roman structures, such as water tanks, houses and graves. Ground liquefaction generated significant ground cracks and folds in the foundations of the buildings. Several Roman sites along the valley were also abruptly abandoned during the 4th century AD, in some cases with EAEs of similar origin. This suggests the occurrence of a 5.5 – 6.0 Mw seismic event in the zone according the empirical limit of seismically-induced liquefaction.*

Key words: *Complutum, earthquake, Earthquake Archaeological Effects (EAEs), Liquefaction, 4th century AD.*

INTRODUCTION

The archaeological site of "La Magdalena" is located in the Henares Valley (Madrid, Central Spain; Fig. 1) adjacent to the present town of Alcala de Henares, the old Roman City of "*Complutum*" (II-IV Century AD). This site has six occupational phases, from the Chalcolithic period (Campanian pottery; c. BC 2500), two roman industrial stages during the Early Imperial period (1st BC – 2nd centuries AD) finally transformed in a necropolis during the Late Imperial period (3rd to 5th centuries AD). Eventually the site record several post-roman periods of occupation during the centuries VI, VII and VIII, mainly corresponding to Visigoth graveyards. During the middle 4th century AD an earthquake affected the site as evidenced by ground disruptions and clear anomalies in the archaeological record. Several sites along the valley, including the main city of Complutum were abruptly abandoned or relocated during the same period, most of them also displaying apparent earthquake archaeological effects (EAEs).

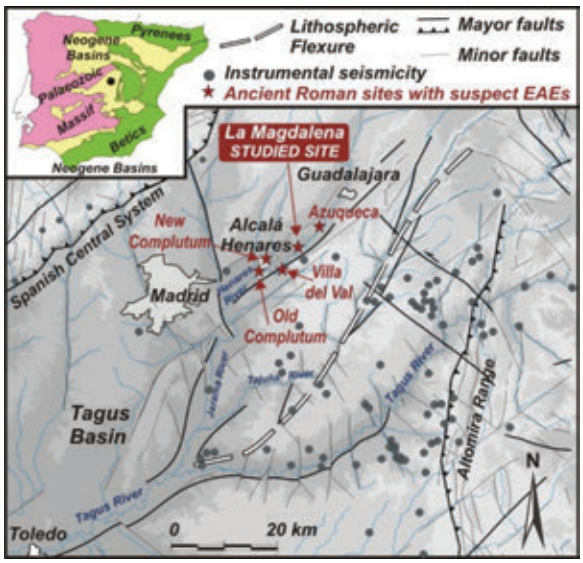

Figure 1: Geographical location of the archaeological Site of La Magdalena, ancient roman city of Complutum (Alcalá de Henares, Madrid).

GEOLOGICAL SETTING

The archaeological site of La Magdalena is located in the Madrid Basin, founded on the floodplain of the Henares River 5 m above the present river thalweg (Fig. 1). In detail, the site is placed in the internal edge of a large meander and the sedimentary record display the occurrence of offlaped sand-gravel point bars and channels, topped by fine-grained (clayey - silts) floodplain deposits. This fluvial stack (5 - 10 m thick) has an Holocene age probably older than 4,900-4,500 years according to the Calcolithic findings in the archaeological site. The fluvial sediments overlay the thick clayey Miocene substratum of this area of the Neogene Basin. This zone of the Henares valley is featured by the occurrence of a nearly-linear scarp (40-

60 m high) along the southern margin of the river, probably developed along a NE-SW km-scale normal fault as proposed by several authors (i.e. Pérez-González & Portero, 2004; Giner et al., 2012). This fault will work as northern boundary of a lithospheric-scale flexure, parallel to the Spanish Central System, responsible for the historical and instrumental seismicity recorded in the area (Fig. 1; Giner et al., 2012).

Figure 2: Fractured Cistern, ground cracks affecting the floor and impact block marks.

EARTHQUAKE ARCHAEOLOGICAL EFFECTS

The remains of the Late Imperial Roman period excavated at the site show evidences of EAEs in both factory buildings and in the necropolis remains. Below are listed and briefly described the different type of deformations recorded in the site:

Open Ground cracks and related liquefaction

Ground cracks are metric in length with openings up to 30 cm. In one of the cases, the ground cracks directly affect a cistern built in 1 m thick hydraulic "*opus caementicium*" (Fig. 2) generating fractures and displacements in the archaeological remains. The ground cracks propagated from the foundations cutting the thick floor of the cistern and displaying a clear continuity with the ground cracks affecting the substratum (presently filled by sands). Consequently, the fracturing of such type of resistant roman hydraulic concrete can be clearly linked to ground failure, and destruction due to building ruin and degradation can be rejected. The cracked floor of the cistern displays two significant impact marks overprinted to the cracks, which can be interpreted as local collapses of the side walls or roof materials soon after or during the abrupt destruction of the cistern.

In order to check the relationship between ground cracks and the fractures affecting the cistern, a prospective trench (1.5 m deep) was open at the base of the cistern. This water-facility is directly founded on a 50 cm thick clayey anthrophic level with archaeological remains overlying a 20 cm thick clayey silt level. The underlying sediments are constituted by gravelly sands (50 cm) and at least a 40 cm thick gravel bed of quartzite pebbles embedded in medium-coarse sized sand (Fig. 3). The contacts between the different units are wavy and irregular displaying cm-scale vertical sand dikes of the lower sandy units intruded in the overlying confining layer of finer sediments (Fig. 3). In detail, the basal gravel bed is intruded in the whole overlying sedimentary sequence, with the apparent vertical mobilization of smaller gravels (3-5 cm), which prove the occurrence of significant liquefaction processes around the destroyed building. In fact, the sand dikes extruded at surface through the ground cracks and open fractures affecting the floor of the cistern, since during the archaeological excavation of the building, the remains were nearly filled by sands.

The liquefaction processes involved in the destruction of the cistern triggered differential ground settlement and "lateral spreading" resulting in the severe rotation, tilting and collapse of one of the sides of the cistern structure (Fig. 2). The liquefaction of near-surface (< 1m) sand and gravel levels underlying the site generate apparent NE-SW ground folding all over the entire site affecting different types of structures (Fig. 4). The foundations of some buildings (made by rows of fluvial quartzite pebbles) display a clear bending coherent with surface folding. The foundations of basilica-pattern build adjacent to the damaged cistern display a monoclonal folding and height differences between its eastern and western zone (c. 50 m apart) is about 1 m. Foundations in the SW corner of this building are missed, suspect of local sagging as a consequence of surface liquefaction. In this sense, the unique structure of the site built with heavy masonry blocks (NE sector) sunken about 3 m down the average level of the archaeological site (Fig. 4). Exploratory trenches in one of the sides of the sunk building exposed a N055E vertical sand dike 1 m wide sub parallel to the main folds affecting the site.

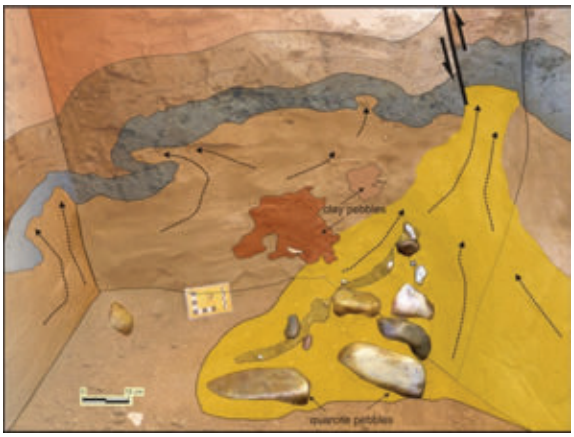

Figure 3: Photography and interpretational sketch of the liquefaction structures located under the cistern made of hydraulic mortar.

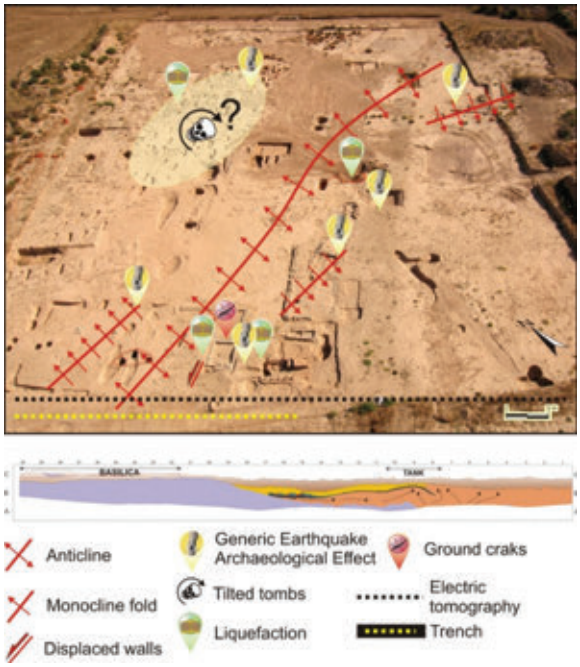

Figure 4: Aerial view of the La Magdalena archaeological site displaying ground surface deformations and recorded EAEs (up). Simplified stratigraphic-log of the exploratory trench showing paleo-liquefaction features associated to the recorded EAEs and surface ground deformations of the site(up).

Anomalies in the Necropolis (Forensic EAEs):

The main area of the necropolis located in the northern part of the site is altered (Fig. 4) containing several phases of burials. The early phase belongs to the early imperial period (≤ 3rd century AD) and the second one to the late one (4th centuries AD). In this last burial level, deceased persons were buried in wood coffins. Wood remains and iron spikes of the coffins were found in many of the graves. In most of these cases skeletons were found tilted and disturbed, with the pelvis displaced towards the thorax position, crania displaced from the necks, or a mixture of jumbled bones. It is interpreted that this particular burial level suffered the effects of ground shaking and liquefaction, stirring and tumbling the skeletons (after the lost of muscular bone cohesion) within the coffins. It is to note that previous (without coffins) and subsequent burials (Visigoth graves) in the zone do not display such post-mortem disturbances. Common cases of severe disturbance of burials are documented for seismically-induced landslides and liquefaction in historical earthquakes in Spain from intensity levels up to VIII MSK (i.e. 1884 AD Arenas del Rey event), even triggering the ejection of burial coffins. This particular *post-mortem* forensic EAE will be subject of further detailed analyses in order to identify bone-displacement vectors for reconstructs dominant directions of ground movement.

GEOPHYSICAL PROSPECTING & TRENCHING

Electric resistivity tomography profiles (ERT Schlumberger array) were done parallel to the southern wall of the basilica building and the cistern (N150ºE; Fig 4). The preliminary interpretation indicates the presence of an important deformed and sunken paleochannel replaced by a new smaller one by avulsion processes. The main zone of deformation is located beneath the western zone of the basilica and the cistern, where the ancient channel is apparently busted upwards as shown by the ERT profile (Fig. 5). Additionally a 30 m length exploratory trench (2.5 m deep) was open to explore the suspect deformation displayed by the ERT profile (Fig. 4). Data from the trench indicate that the deformed fluvial deposits are buried by a clayey floodplain level, on which the first settlements in the site occur (Calcolithic silos and graves, BC 2900 - 2500) and on which are founded the deformed buildings explored in this work. Underlying this top level a sandy channel (c. 10 x 1.2 m) display an anticline-like upwards bending just under the destroyed cistern. The orientation of the anticline observed at both walls of the trench is congruent with the main directions of ground flexures recorded at the surface. The deformation of the fluvial sediments is triggered by the complete liquefaction of an underlying thick sandy level (c. 1.5-2.8 m thick) in which the sedimentary structures (nicely preserved in adjacent units) were completely blurred by the full fluidization of the sands, which extruded over the deformed channel. The fluidization process also affected sandy gravels outcropping at the base of the trench, which record

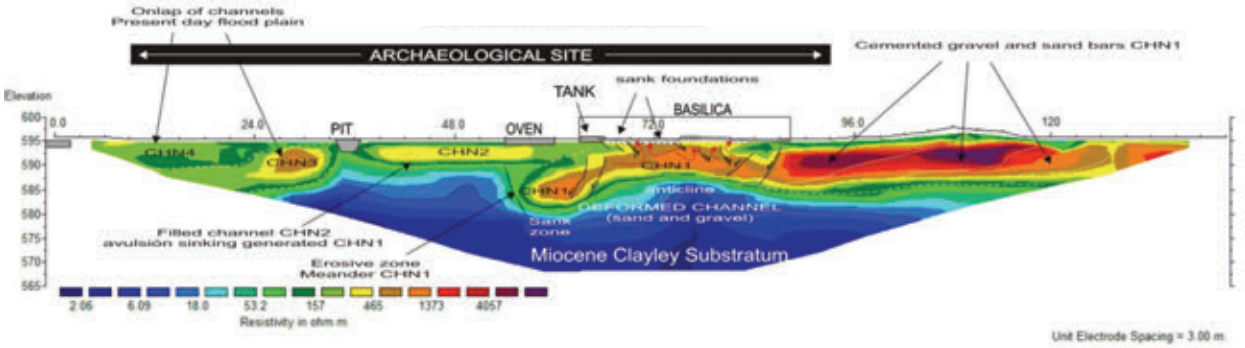

Figure 5: ERT 2D Pseudosection displaying deep deformations printed in the point bar- channel sequence underlying the archaeological site.

apparent injection features. In any case, the large deformations observed in the ERT profiles seems to be previous to the Calcolithic period, but the near-surface paleo-liquefaction features recorded in the exploratory trench can be linked to the deformations recorded in the roman remains. Therefore, these latter processes seems to be a discrete reactivation of large deformation structures acting in the zone before c. 5,000 yr BP.

DISCUSSION AND CONCLUSIONS

The deformation structures affecting the archaeolo-gical site of "La Magdalena" can be categorized according the EAE classification of Rodriguez-Pascua et al. (2011). There are two outstanding geological coseismic effects: (1) Sand ejections affecting the buildings and the necropolis; (2) Open ground cracks and folded substratum. Both are caused by ground liquefaction and differential settlement, and also considered in the ESI-07 scale (Michetti et al., 2007) from intensity levels ≥VIII according to the observed dimensions.

The archaeological remains record three noticeable primary coseismic effects in the building fabric: (1) Tilted and folded walls throughout the entire site; (2) Broken and displaced walls (cistern); and (3) Impact block marks (cistern). To these common archaeological effects the necropolis records a new type of forensic EAE witnessed by the disturbed skeletons in the burials of the 4th century AD.

During the 4th Century the industrial buildings of the site are abandoned and the zone is only used as a graveyard during late-Roman and Visigoth times (≤ 8th Century AD). In spite of no clear signals of abrupt abandonment being present at the investigated site, many Roman settlements around the area record sudden abandonments or related-anomalies during the 4th century AD (Fig. 1; Gómez-Pantoja, 2013). Fires and subsequent abandonements, unexpected changes in building patterns and land-use are recorded in the in the houses of *"Hippolytus"* and *"Los Grifos"* located in *Complutum* 7 km SE from the site (Rascón Marqués, 2007), *"Villa de El Val"* rural settlement of the Henares Valley about 4 km away (Rascón Marqués et al., 1991), and Azuqueca de Henares 8 km NE (Cardín y Cuadrado, 2013). Additionally the zone records the abrupt abandonment of the main city of *Complutum* soon after (c. 350 AD) its main period of Monumental development (275 - 300 AD). The city was abandoned and re-located about 2 km away in the present-day location of Alcalá de Henares (Gómez-Pantoja, 2013). At least an area of about 50 km^2 along the Henares Valley shows archaeological anomalies during the middle 4th century AD closely related to the deformation period identified in La Magdalena archaeological site.

The observed deformations can be certainly related to abrupt extensive liquefaction of near-surface sandy levels triggering ground differential settlement damaging roman buildings, disturbing burial sites and leaving permanent deformations in the ancient ground surface. Such extensive liquefaction, in sand-grain size materials, needs of at least an earthquake 5.5 - 6.0 Mw according to empirical approaches for seismically-induced liquefaction by near-field seismic sources (i.e. Obermeier, 1996). If this is the case, this recovered ancient earthquake exceeds the intensity and magnitude levels of the instrumental and historical records for central Spain. In fact, this densely populated zone (2.800 habitant/km^2), close to the Madrid urban area (30 km away), is actually outside the area of application of the Spanish Seismic Building Code (IGN, 2013). Therefore the unearthing of such "lost earthquakes" in these populated areas is critical to update seismic hazard assessments in Central Spain.

Acknowledgements: This work is a contribution of the Spanish projects CATESI-07 (IGME-MINECO), CGL2012-37281-C02.01 (QTECTBETICA-USAL), CGL2013-47412-C2-2-P (SISMOSIMA-IGME).

References

Cardín, I., M.A Cuadrado, (2013). Yacimiento del Polígono UG XVI de Azuqueca de Henares. En: *La romanización en Guadalajara, arqueología e historia.* (Cerdeño, M.L., Gamo, E. y Sagardoy, T., eds.). Ed. La Ergástula. Madrid. España. 137-144.

Giner-Robles, J.L., R. Perez-Lopez, P.G. Silva, A. Jiménez Díaz, M.A. Rodriguez-Pascua, (2012). Recent tectonic model for the Upper Tagus Basin (central Spain). *Journal of Iberian Geology*. 38, 113-126.

Gómez-Pantoja, J., (2013). Complutum y su territorio. En: *La romanización en Guadalajara, arqueología e historia.* (Cerdeño, M.L., Gamo, E. y Sagardoy, T., eds.). Ed. La Ergástula. Madrid. España. 63-72.

IGN (2013). *Actualización de Mapas de Peligrosidad Sísmica en España 2012*. IGN. Madrid. 267 pp.

Michetti, A.M., E. Esposito, L. Guerrieri, et al., (2007). Environmental Seismic Intensity scale – ESI 2007. Intensity Scale ESI-07 (Guerrieri, L., Vittori, E. Eds.). *Mem. Descr. Carta Geologica d'Italia 74*. APAT. Rome. Italy. 41 pp.

Obermeier, S.F., (1996). Use of liquefaction - induced features for paleoseismic analysis. *Engineering Geology*. 44, 1 - 76.

Pérez-González, A., J.M. Portero, (2004). *Mapa Geológico de España 1.50.000*. Alcalá de Henares (560). MAGNA 2ª Serie. IGME. Madrid. 52 pp.

Rascón Marqués, S., A. Méndez Madariaga y P.D. del Río Español, (1991). La Reocupación del mosaico del Auriga Victorioso en la villa romana del Val (Alcalá de Henares). Un estudio de microespacio. *Arqueología, paleontología y etnografía*. 1, 181-200.

Rascón Marqués, S., (2007). La así llamada casa de Hippolytus: la fundación de los anios y la schola de una agrupación colegial de la ciudad romana de Complutum. *Archivo Español de Arqueología*. 80, 119-152.

Rodríguez-Pascua, M.A., R. Pérez-López, P.G. Silva, J.L. Giner-Robles, V.H., Garduño-Monroy y K. Reicherter, (2011). A Comprehensive Classification of Earthquake Archaeological Effects (EAE) for Archaeoseismology. *Quaternary International*. 242, 20-30.