

## Seismically induced liquefaction structures in La Magdalena archaeological site, the 4th century AD Roman Complutum (Madrid, Spain)



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### ABSTRACT

The ancient Roman city of Complutum (Alcalá de Henares, Madrid), founded in the 1st century AD, was one of the most important cities of Hispania. The old Roman city was destroyed, abruptly abandoned, relocated close by and rebuilt during the late 4th century AD. Destruction of the city and its relocation has not yet been explained by archaeologists. In this paper, with our multidisciplinary approach, we identify and characterize earthquake archaeological effects (EAEs) affecting the archaeological site, the La Magdalena, an agricultural holding 4 km from the core of Complutum. The most important EAEs in the site are liquefactions (sand dikes and explosive sand-gravel craters) affecting Roman structures, such as water tanks (cisterns), houses and graves. Ground liquefaction generated significant ground cracks, explosive craters and folds in foundations of buildings. Several other Roman sites throughout the valley were also abandoned abruptly during the 4th century AD, in some cases with EAEs of similar origin. This suggests the occurrence of a 5.0–6.6 Mw seismic event in the zone, in accordance with the minimum empirical limit of seismically-induced liquefaction and the maximum surface rupture length of the Henares fault.

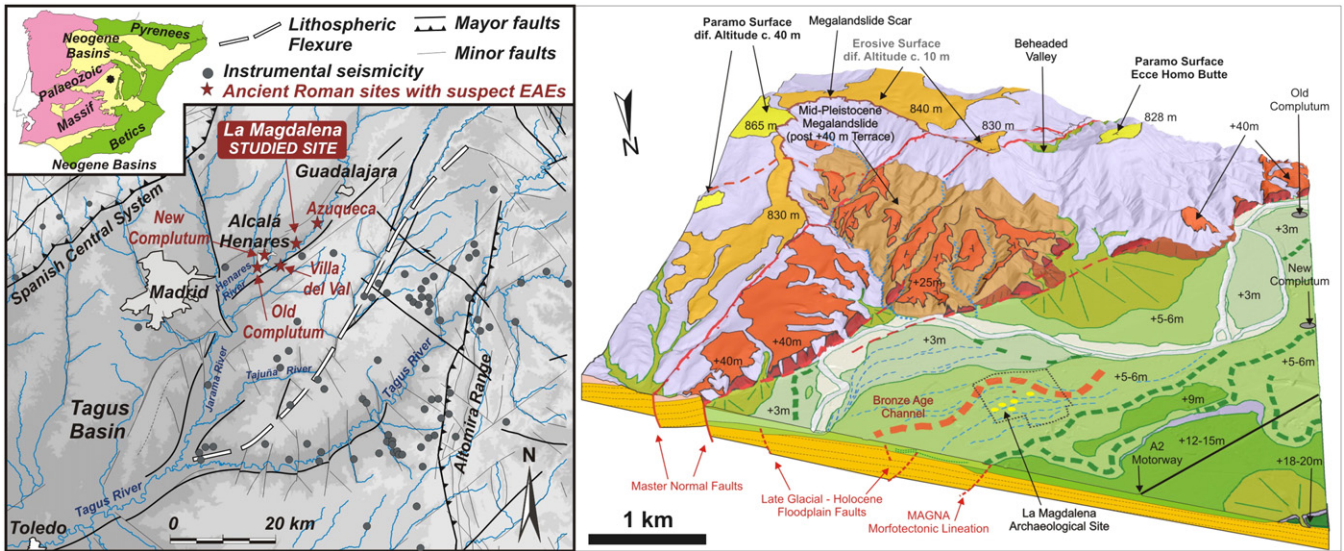
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### 1. Introduction

The archaeological site “La Magdalena”, site of the old Roman City of “Complutum” (II–IV Century AD), is located in the Henares Valley adjacent to Alcalá de Henares (Madrid, Central Spain; Fig. 1). In this site remains have been found: of six occupation phases from the Chalcolithic period (Campanian pottery; c. BC 2500); of two Roman industrial stages, from the Early Imperial period (1st BC – 2nd centuries AD); and of its transformation into a necropolis during the Late Imperial period (3rd to 5th centuries AD). The site also records several later, post-Roman periods of occupation, from 6th to 8th centuries (Visigoth graveyards). During the middle 4th century AD an earthquake shook

the site, leaving such evidence as notable ground disruptions, sand ejections, gravel injections and metre-size open craters and ground cracks, affecting Roman industrial buildings and tombs (Rodríguez-Pascua et al., 2015a). Clear anomalies in the Late Roman archaeological record also point to seismic shaking as the main factor influencing the abandoning of the Roman industrial site. In addition to the main city of Complutum, several other sites throughout the valley, most also displaying apparent earthquake archaeological effects (EAEs; Rodríguez-Pascua et al., 2015a), were abruptly abandoned or relocated during the same period. This paper is focused on analysis of the large set of soft-sediment deformation structures (SSDS) found in the archaeological site, as well as on their probable seismic origin. Sand-blown craters affecting pebbles, sand dikes and collapsed terrain, associated with oriented building damage, were also systematically described and mapped. Moreover earthquake environmental effects (EEE) such as ground cracks, mass movement and lateral spreading of river banks were recognized, in agreement with liquefaction features. In light of the foregoing, as the potential seismic source for this historical earthquake we propose an earthquake greater than M5–5.5, and most

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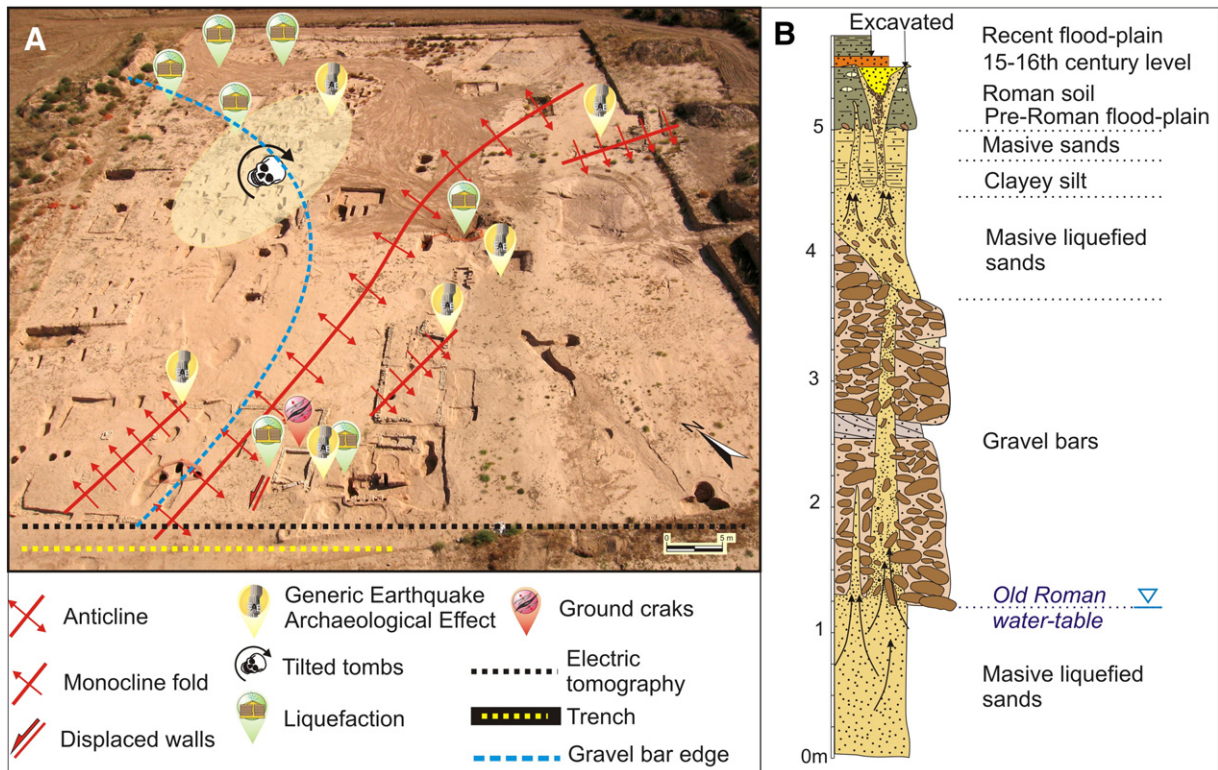
**Fig. 1.** A) Geographical location and regional geodynamic context of the archaeological Site of La Magdalena, ancient Roman city of Complutum (Alcalá de Henares) and other Late Roman sites in the zone. In the figure are displayed the main recent tectonic features and instrumental seismicity in the whole Neogene Basin. B) Geomorphological sketch of the Henares valley around the studied archaeological site illustrating the most outstanding fluvial and erosive landforms and tectonic features.

probably close to M6, generated by the fault segment of Henares (NE–SW trending) that reached an intensity of ESI 07 on macro-seismic scale IX.

**2. Geological and geomorphological setting**

The archaeological site of La Magdalena, founded on the Henares River floodplain, +5 m above the present river thalweg, is located in

the Tagus Basin (Fig. 1). The site, on the internal edge of a large meander, contains a morpho-sedimentary record of off-lapped sand-gravel point bars and channels, topped by fine-grained (clayey-silts) floodplain deposits (Fig. 2). This fluvial stack (5–10 m thick) of Holocene age is probably older than 4900–4500 years, according to Chalcolithic findings in the archaeological site (Rodríguez-Pascua et al., 2015a). Alluvial sediments overlay thick clayey Miocene materials featured in the sedimentary filling of this area of the Neogene Basin. This implies that



**Fig. 2.** A) Aerial view of the La Magdalena archaeological site displaying ground surface deformations and recorded EAEs (up), the structure at the bottom of the image corresponds to the Roman tank, surrounded by the labels of the EAEs. B) Simplified stratigraphic-log of the floodplain of the Henares River in the archaeological site of La Magdalena.

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