



# Hydraulic structures of the Roman *Mithraeum* house in *Augusta emerita*, Spain

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## ABSTRACT

This paper deals with some of the hydraulic structures of *Augusta Emerita* (Mérida, Spain), specifically those found in the *Mithraeum* House. In particular, we describe and characterise the hydraulic mortars and coatings of the *viridarium* water channel. The recipient of the channel was covered with two hydraulic mortars and a finishing coating. Hydrated lime was used as binder. Calcite grains with different morphology have been observed in the mortars studied. The siliceous aggregate was composed of quartz, mica and feldspars. Ceramic fragments, which were added to the mortar to improve its hydraulic properties, were composed of quartz, mica, iron oxides, anorthite and an amorphous phase; aluminium-iron silicates were used as raw materials for their manufacture. We discuss the interactions between the hydrated lime and the surface of the ceramics in the mortars.

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## 1. Introduction

Roman engineers applied considerable technical knowledge in the field of hydraulic engineering throughout the Roman Empire. Books 8, 9 and 10 from *De Architectura* by Vitruvius describe key details about the aqueducts and hydraulic structures especially for the way they were surveyed, and the careful choice of materials needed (Rowland and Howe, 2001). Vestiges of the Roman hydraulic structures still survive across the extent of the former empire (Buonora, 2004; Rafford et al., 2001; Rowland and Howe, 2001). The major hydraulic works found in one of the most important Roman centres, *Augusta Emerita* (Mérida, Spain), include structures designed for water capture and transportation, a containing wall on the Guadiana River, bridges over the Anas and Alberregas rivers, and a sewer network. These structures constitute a major archaeological complex that provides information about the materials and techniques used for Roman hydraulic structures (De la Torre, 2006; Rafford et al., 2001).

The Roman *Mithraeum* House, which was located outside the Roman city walls, was probably built between about 110 and 90 BC. The importance of this *domus* lies in the almost complete preservation of its ground plan and a great part of its internal

organisation. Thus, this structure provides a close approximation of the typical *domus italica*, with a series of spaces connected by the *atrium* (open area in the center), the *peristilum* (small garden often surrounded by columns) and the *viridarium* (pleasure garden). There, the private and social activities of the inhabitants of the house were concentrated, with large dwelling spaces derived from Hellenistic prototypes such as *triclinia* (formal dining room), *oeci* (principal hall) and *exedrae* (semicircular recess usually set into building's facades). The water channels of the *viridarium*, discovered during excavation, survive; they present a good opportunity to study the technology and materials used for their construction.

The characterisation of ancient mortars can provide useful information about past technological knowledge and help to elucidate how complex architectural structures were built and what construction phases were involved in their manufacture (Crisci et al., 2001; Duran et al., 2008, 2010a, 2010b; Franzini et al., 2000; Jackson et al., 2009; Meir et al., 2005; Mertens et al., 2009; Moropoulou et al., 2000; Velosa et al., 2007). Hydrated lime has been used since antiquity as a binder material. Limestone can contain aluminosilicates, which provide hydraulic character to the mortar. However, pure lime is a non-hydraulic compound that hydrates in contact with water, forming the hydrated compound (hydrated lime,  $\text{Ca}(\text{OH})_2$ ), which can be mixed with natural or artificial pozzolans to make duct drains, cisterns, swimming pools and other hydraulic structures (Dondi et al., 2003; Harries, 1995).

In reference to the characteristics of mortars, the term “hydraulic” refers to two specific properties: the property of hardening when water is added to the dry binder and the capacity

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to harden under water. Hydraulic compounds are obtained from reactions of hydrated lime [ $\text{Ca}(\text{OH})_2$ ] with natural pozzolans (natural earth from volcanic sources) or artificial pozzolans (such as ground fired bricks and tiles or ceramic shards). These materials contain silicon dioxide and aluminium and iron oxides. An amorphous, highly reactive aluminium silicate is present in ceramics obtained from kaolinite materials (Alvarez et al., 2000; Duran et al., 2008; Franquelo et al., 2008; Kakolas et al., 1995; Maravelaki-Kalaitzaki et al., 2003; Moropoulou et al., 1995, 2004; Paama et al., 1998).

The main objective of this study is to describe and characterise the hydraulic mortars used in the construction of the *viridarium* water channel in the *Mithraeum* House in *Augusta Emerita*. We also characterise the interactions between the different compounds within the mortar that determine the hydraulic properties of the material.

## 2. Materials and methods

### 2.1. Site description and materials

The Roman *Mithraeum* House (Fig. 1) is organised around three patios that serve as articulations of the structure of the house. The first patio (*atrium tetrastilo*) is accessed through the entrance passage. This patio has an overhead opening, and its roof slopes toward the interior. Through the opening in the roof, rainwater falls into the *impluvium* and light reaches the interior space. The presence of an *atrium* indicates high social standing and prestige; this space serves as an elegant reception area and connects the exterior to the most private zone of the *domus*. The second patio, the *peristilum*, is situated on the same axis as the *atrium*. The third patio,

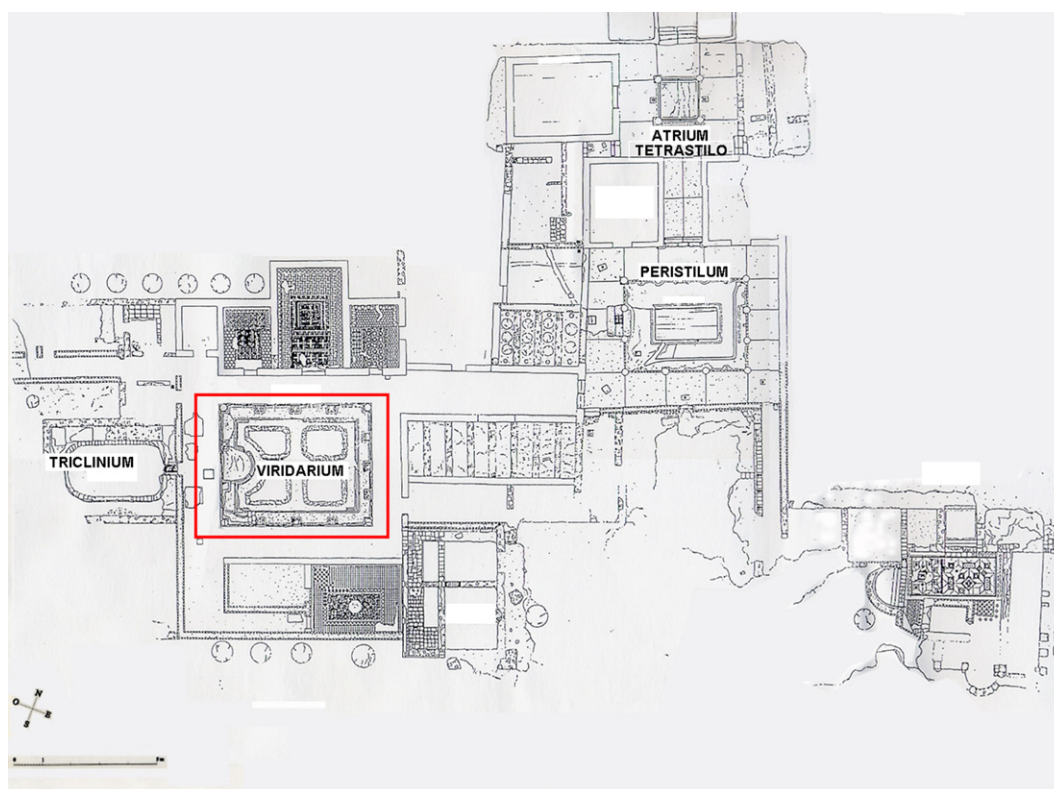
which is located on the axis perpendicular to that formed by the first two patios, contains the *viridarium* in its centre (Fig. 2a). Three sides of the patio are surrounded by five columns each one (Fig. 2b and c), except that which borders the west side (Fig. 2d). Water collected in the water channel of the *viridarium* (Fig. 2b) from the rainwater was conducted to a large cistern situated to the west (Fig. 2d), over which the *triclinium* was built. The dimensions of the patio which contain the *viridarium* are 12.5 m long and 12.5 m wide (Figs. 1, 2a and c). Fig. 2c–e shows the water channel with the cistern and a cross-section of the *viridarium*. The subterranean rooms of the house are found to the south of the third patio.

We collected several mortar samples from the hydraulic structures of the *viridarium* water channel using hammer and chisel.

### 2.2. Methods

Quantitative determination of  $\text{CaO}$ ,  $\text{SO}_3$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$  and  $\text{SiO}_2$  was carried out using X-ray fluorescence (XRF) with a Siemens SRS-3000 spectrometer. Fragments detached from the bulk of the outer and inner mortars, and also from the bulk of the ceramics and from the edges of the largest ceramic fragments were ground and analysed. Loss on ignition was determined by heating the sample at 1000 °C for two hours.

The proportions of calcite, ceramics and sand were determined in the mortars of the *viridarium* water channel. The weight of the detached mortar fragments was previously determined. The quantitative estimations of the amounts of calcite ( $\text{CaCO}_3$ ) was carried out by using the Bernard calcimeter classical method (Duran et al., 2008), which allows determine  $\text{CO}_2$  from the samples by attacking the samples with hydrochloric acid. After removing the calcium carbonate, the remaining samples are comprised of the



**Fig. 1.** Plan of the Roman *Mithraeum* house in *Emerita Augusta*. The location of the patio containing the *viridarium* is marked in red (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

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