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A microclimate study on *hypogea* environments of ancient roman building

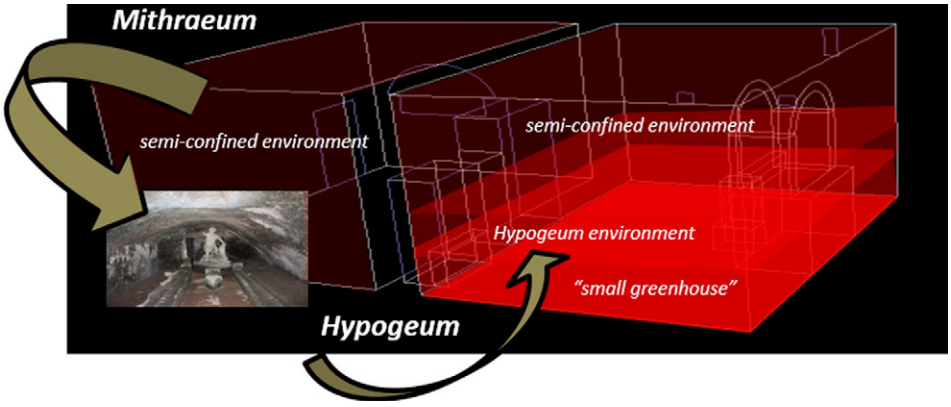
C. Scatigno [a,*], S. Gaudenzi [b], M.P. Sammartino [c], G. Visco [c]

[a] Department of Earth Science, University of Rome "La Sapienza", Piazzale Aldo Moro 5, 00185 Rome, Italy
[b] INAF/IAPS, Via Fosso del Cavaliere 100, 00133 Rome, Italy
[c] Department of Chemistry, University of Rome "La Sapienza", Piazzale Aldo Moro 5, 00185 Rome, Italy

HIGHLIGHTS

- A monitoring (T- RH) of a *Mithraeum* and *Hypogeum* was performed in Ostia Antica
- Multivariate statistical and PCA techniques were applied to evaluate the environments
- Study on semi-confined and underground environments in view of conservation

GRAPHICAL ABSTRACT



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ABSTRACT

Roman *hypogea*, vernacular settlements or crypts, are underground places characterised by specific and unique challenges (RH < 90% and almost constant temperature throughout the whole year) related to their relative isolation from the outdoor environment. These sites often require adequate monitoring tools providing complete environmental information in order to carry out appropriate strategies for scheduling routine maintenance and designing suitable layouts for their preservation.

In this work we present the results of a carefully planned thermo-hygrometric monitoring campaign conducted in a peculiar Roman building (130 CE), the "Casa di Diana" *Mithraeum*, sited in Ostia Antica (archaeological site, Rome-Italy), with the aim of characterising the indoor environment as the structure suffers of several conservation problems (biocolonisation, efflorescences, evaporating and condensing cycle for wall-building materials).

The campaign involving multipoint continuous measurement was carefully planned to better describe this micro-clime. In addition to underground environmental data available in literature, we have also performed, as a checkpoint control, a thermo-hygrometric monitoring campaign in the "Terme di Mitra" *Hypogeum*, a few meters from the "Casa di Diana".

The recorded data was analysed by multivariate statistical and chemometric analyses.

The results brought to light the presence of different microclimates (three areas) within a single *Mithraeum*: a room (*pre-Mithraeum*) and an area (*Mithraeum*: 2–4 m) present a thermo-hygrometric environmental behaviour

Abbreviations: T, temperature; RH, relative humidity; T_{dm}/RH_{dm}, average daily temperature/relative humidity; T_{min}/T_{max}, minimum and maximum temperature.

* Corresponding author.
E-mail address: claudia.scatigno@uniroma1.it (C. Scatigno).

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in accordance with a semi-confined environment, another area (*Mithraeum*: 1–2 m) behaves accordingly with underground environments (although it cannot be described as such), and the last area (*Mithraeum*: 0–1 m) where was recording RH values close to saturation (96–99%), associated with non-ventilated areas where the rising damp is "held" and not dispersed, describing an own micro-clime, comparable to a "small greenhouse". This study has allowed to identify some critical areas in view of planning future conservation solutions, without exporting the artefacts kept inside.

1. Introduction

Hypogea literally means "underground". It usually refers to an underground temple or tomb. The later Christians built underground shrines, crypts and tombs, which they called catacombs.

Thermo-hygrometric studies conducted in several *hypogea* (St. Calisto's and Priscilla's Catacombs and St. Marco, Marcelliano and Damaso, in Rome-Italy) recorded high values of relative humidity ≥95%, and temperature values typically range between 15 and 18 °C (Albertano and Urzi, 1999; Albertano and Bellezza, 2001; Cuzman et al., 2014). These studies were conducted focusing only on microbiological phenomena. In general, Roman *hypogea* are characterised by high relative humidity (≤90%), almost constant temperature throughout the year, and extremely low photon fluxes (Albertano and Urzi, 1999; Cardinale and Ruggiero, 2002; Compagnone et al., 1999; Cuzman et al., 2014). Roman *hypogea* are located in archaeological sites, where the preventive conservation is particularly complex due to the particular thermo-hygrometric features. Their conservative problems were concerned mainly the salt crystallization due to capillary rising (Casti, 2016) and biodeteriogenic presence caused by favourable microclimatic conditions (Cuzman et al., 2014). The preservation of *hypogea* is characterised by specific and unique challenges related to their relative isolation from the outdoor environment (Cardinale and Ruggiero, 2002; Cardinale et al., 2010; Visco et al., 2012a, 2012b).

Because of the extreme features of such environments, *hypogea* are not usually destined to worship or museum purposes. Additionally, the artefacts or decorations, such as wall paintings, organic-nature objects or funerary furnishings made of heterogeneous materials, are often removed from their original location and placed in museum environments, more suitable for their conservations (Mandrioli et al., 2003).

In the last years, in the context of closed or buried archaeological sites, a monitoring study of temperature and relative humidity was carried out in an Italian *hypogeum* by employing statistical tools for exploratory purposes, mainly focusing on the instrument validation and data treatment (Visco et al., 2012a).

In this work, a thermo-hygrometric monitoring and data analysis methodology (multivariate statistical and chemometric analyses based on principal component analysis (PCA)) was applied to the "Casa di Diana" *Mithraeum* (130 CE — 4th century), a Roman building located in the "Ostia Antica" archaeological site (Rome, Italy), with the aim of characterising the indoor environment where several damages are visible. The structure presents several problems: the building materials are affected by biological growth (Scatigno et al., 2016a, 2016b), along with the crystallization of soluble salts visible in the form of efflorescence (Scatigno et al., 2014, 2016b), compromising the durability of these ancient materials. Recent studies applied on this particular case reveal how the relative humidity close to saturation encourages phenomena of efflorescence, sub-efflorescence and biological proliferation (Scatigno et al., 2016b). This monitoring campaign involves multipoint continuous measurements carefully planned to better describe the indoor environment.

The "Terme di Mitra" *Hypogeum* monitoring (involving one sensor) was also conducted in order to serve as a checkpoint control, in addition to the data available in literature, which do not include multipoint continuous measurements.

2. Methodology

2.1. The "Casa di Diana" Mithraeum

Sixteen *Mithraea* (of which only one is set in a *hypogeum*: the "Terme di Mitra" *Hypogeum*) have been found in the archaeological complex of Ostia Antica. The "Casa di Diana" *Mithraeum* is situated in the north-eastern corner of the homonymous house (Fig. 1a). The "Casa di Diana" name is derived from a ceramic tile, found in the courtyard, representing the goddess Diana. The *Mithraeum* (a place dedicated to the cult of the Persian god Mithra during the Roman times) consists of two adjacent rooms, the "*Mithraeum*" and "*pre-Mithraeum*", each of which measures approximately 27 m^2 (Fig. 1b). The "Casa di Diana", Region I, Insula III, is set between the "Lucrezio Menandro" *Mithraeum*, to the north, and the "Molini" tenement, to the east. This structure is mainly composed of bricks and pozzolanic mortar aligned with the "*opus caementicium*" technique and was built in the central area of Ostia Antica approximately in 130 CE, remaining in use until the early fourth century. The house was originally made up of a ground floor and four upper floors; today, only the ground floor and traces of the projecting part of the continuous balcony of the first floor survive (Fig. 1c).

The *Mithraeum* has seven openings, five on the west side, facing the "triclinium" (one window and the entrance door are located in the *pre-Mithraeum*, while the remaining three openings are located in the *Mithraeum* at different heights on the west wall) and two passage areas between the two rooms (Fig. 1b). The podiums of the "*Mithraeum*" and the "*pre-Mithraeum*" are raised approximately 0.60 m above the central area of the communication trench (Fig. 1b).

2.2. Data-loggers' description

Taking into consideration that no funding was available, we utilized all the sensors momentarily available in the department laboratories, in spite of their difference always compatible with a coherent monitoring. Therefore, the monitoring survey involved nineteen data-loggers measuring temperature (Ta) and relative humidity (RH), specifically HOBO® (accuracy ±0.4 °C, ±2.5%) and EBI 20 (Ebro, accuracy ±0.5 °C, ±3%) data-loggers.

Regarding the thermo-hygrometric monitoring at "Terme di Mitra" *Hypogeum* (a few meters from the "Casa di Diana" *Mithraeum*), a Lascar EL-USB-2 (accuracy ±0.5 °C, ±3%) was utilized.

The sensors were calibrated before and after the measurement survey by placing the instruments in a "microclimatic chamber" producing thermo-hygrometric conditions coherent with those expected in the "Casa di Diana". In this way, before starting the measurement campaign, we checked the sensors' rising time, accuracy, hysteresis, and coherence. The obtained results, both for the temperature and relative humidity, are consistent with the standard deviation values (SD) declared by the manufacturer.

2.3. Continuous monitoring campaign: recorded data and positioning sensors

Continuous measurements at sampling interval of 5 min (HOBO®, accuracy ±0.4 °C, ±2.5%; EBI 20 — Ebro, accuracy ±0.5 °C, ±3%)