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New insights about the consolidation of archaeological mortars located in underwater environment: the case study of the apsidal fishpond of Castrum Novum (Santa Marinella, Rome, Italy)

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***Abstract* – This work is part of a research project titled MaTaCoS (Advanced materials and technologies applied to the conservation of underwater cultural heritage) funded by the Italian Ministry of Economic Development (MISE), concerning development of innovative tools and methods for the protection of Underwater Cultural Heritage, with particular regard to cleaning and consolidating procedures to be carry out directly in situ. The fishpond of the archaeological site of Castrum Novum (Santa Marinella, Rome, Italy) was chosen as a pilot site for experimentation. Castrum Novum was a Roman colony whose ruins are located between Torre Chiaruccia and Casale Alibrandi. The archaeological site lies on a wide area facing the sea, at the 64.4 km of the Aurelia State Road, in the Province of Rome, in a territory corresponding to today's Santa Marinella, which, during the Roman ages, belonged to Caere, now Cerveteri [1]. During the first half of the third century BC, it was one of the most important cities found along the ancient Etruscan coast as Alsium (now Palo Laziale) and Pyrgi (Santa Severa). Other significant remains, concerning the ancient city and the ancient harbour, lie close to the beach where now some modern stilts stand. The apsidal fishpond is one of these structures on the coastline. It is composed of only one tank, with an average immersion of 0.37 m below the sea level, and it develops with an NE/SW orientation. The masonry structures reach the maximum thickness at the apex of the fishpond (4.70 m) and consist of a concrete conglomerate composed of slightly rough stones of medium size bound with non-hydraulic mortar. After sampling, for a complete characterization of selected archaeological fragments, different and complementary techniques (stereomicroscopy, polarising optical microscopy and X-ray powder diffraction analysis) were carried out in order to: a) define the minero-petrographic features; b) investigate their state of conservation. The obtained data allow defining the main constituents of mortars from a compositional point of view. The raw materials, in fact, are quite homogeneous, as well as the ratio in which they were mixed, confirming the typical "recipe" used in Roman times to manufacture hydraulic-type mortars by adding pozzolana. At the same time, it was possible to identify the various degradation processes they are interested in, mainly, biological colonization (bio-fouling) that develops differently according to environmental conditions. From the applicative point of view, the textural, mineralogical and chemical information might represent the first step both for the definition of restoration interventions and for the planning of maintenance protocols.**

I. INTRODUCTION

In recent decades, interest in the study of degradation phenomena affecting archaeological sites located in

submarine environments has increased significantly. This study is part of the MaTACoS Project (Materiali e Tecnologie avanzate applicate alla conservazione subacquea—Advanced materials and techniques for underwater conservation), funded by the Italian Ministry of Economic Development (MISE). Partners of the project are the University of Calabria, Tech4sea and AppliCon.

It concerns the development of innovative tools and methods for the protection of Underwater Cultural Heritage, with particular regard to cleaning and consolidating procedures to be carry out directly in situ.

In particular, MaTACoS project aims improving the conservation of underwater cultural heritage by new methods, technologies and tools suitable for the underwater environment by means of four main steps:

1. Characterization of archaeological materials and evaluation of decay forms [2];
2. Cleaning procedures by new tools suitable for underwater;
3. Consolidation of underwater structures by innovative mortars;
4. Monitoring of environmental parameters by in situ probes and tools.

II. MATERIALS AND METHODS

Seventeen samples were collected directly on site for petrographic, mineralogical, and microchemical investigations (Table 1, Figure 1).

Table 1. Samples list and typology

	Sample Code	Typology
1	CN-1	coarse aggregate fragment + mortar
2	CN-1M	mortar
3	CN-2	mortar
4	CN-2M	mortar
5	CN-4	mortar
6	CN-7	mortar
7	CN-8	mortar
8	CN-9	mortar
9	CN-10	mortar
10	CN-12	mortar
11	CN-13	mortar
12	CN-14	mortar
13	CN-15	mortar
14	CN-16	mortar
15	CN-17	mortar
16	CN-18	ceramic fragment + mortar
17	CN-19	mortar

III. RESULTS AND DISCUSSION

A. Stereomicroscopy observations

Mortar's surfaces were colonized by different groups of encrusted organisms such us barnacles, tubeworms, bryozoans, molluscs and coralline algae. Barnacles and tubeworms were, apparently, the most abundant (Fig. 1).

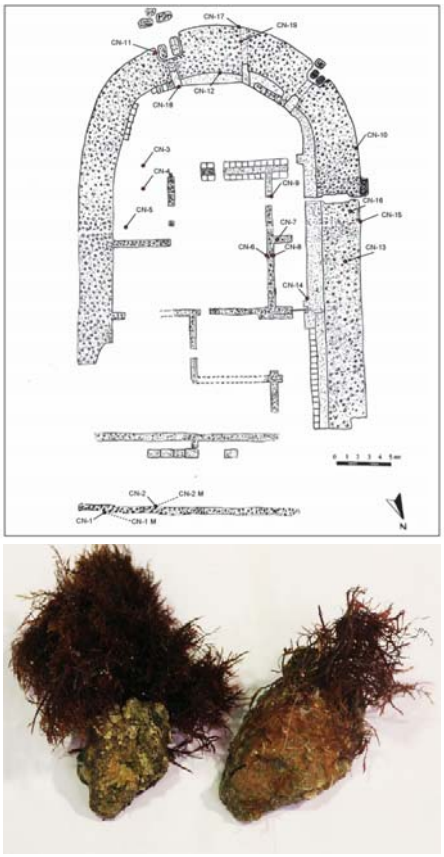

Fig. 1. Sketch of the apsidal fishpond composed of only one tank. Representative fragments of mortar from underwater archaeological site.

B. Thin section petrography and EMPA analysis

Mortars samples show as distinctive 'marker' the presence of trachyte, pumice and glassy scoriae fragments (with a variable relative abundance ratio), apparently predominating over all the other constituents.

The mortars can be thus considered of hydraulic type after the addition of natural volcanic material and cocciopesto, as confirmed by EMPA-EDS results on the binder.

C. Biological characterization

To simulate the submarine degradation conditions, mortars samples both treated with biocides and untreated

(control group), were immersed in an aquarium containing seawater, for about 3 months. During this time, physical and chemical parameters (temperature, pH, oxygen level, salinity, resistivity, etc) were constantly monitored at regular intervals (daily).

After 3 months, mortars samples have been "scraped" with sterile little pests (using both non-invasive or minimally invasive sampling methods for substrates and non-destructive for the biofilm) and then crawled on solid culture medium (agar) or immersed in liquid culture medium (broth). Bacterial cultures were incubated for a maximum of 72 hours at 23 °C (to simulate the aquarium temperature). The bacterial growth (agar) was constantly monitored by optical microscopy observation. On the culture broths two microbiological parameters were detected: the pH value and the turbidity measured respectively by using a pH-meter and a spectrophotometer. At the end of the 72h, broth aliquots were centrifuged at 2000 g for 5 minutes at 4°C in order to obtain a cellular pellet, which was subsequently fixed in paraformaldehyde for electron microscopy observation.

IV. CONCLUSIONS

This archaeometric study provided interesting information both on the mortars used in the archaeological site of Santa Marinella and on their production technology.

The data obtained allowed us to define the main constituents of historic mortars i.e. trachyte, pumice, and glassy scoriae fragments composing the sandy aggregate together with monomineralic grains of alkali feldspar, clinopyroxene, and biotite. With regard to the binder composition, the analyzed mortars can be all classified as lime mortar with hydraulic character obtained by mixing lime with natural pozzolana and/or by mixing lime with man-made materials (cocciopesto).

This dataset will be used for the development of new restoration mortars that will be applied and tested in situ to consolidate the wall structures.

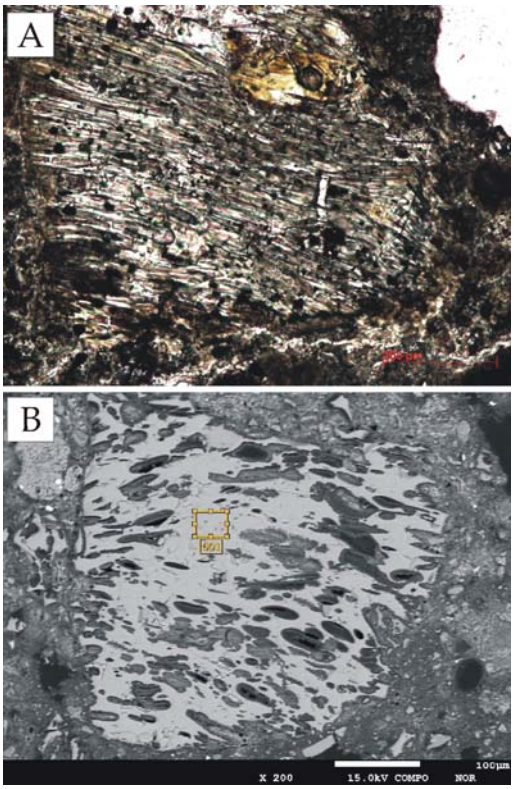

Fig. 2. A) Glassy scoriae constituting the aggregate (clinopyroxene crystals are also evident); B) Glassy scoriae EMPA microphotograph.

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