2020 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Trento, Italy, October 22-24, 2020

# The role of geosciences and non destructive methods in the TECTONIC project

Michela Ricca[1], Marco Ricci[2], Stefano Laureti[2], Mauro Francesco La Russa[1]

[1] *University of Calabria, Department of Biology, Ecology and Earth Sciences (DiBEST), 87036 Arcavacata di Rende, CS (Italy)*
[2] *University of Calabria, Department of Informatics, Modeling, Electronics and System Engineering (DIMES), 87036 Arcavacata di Rende, CS (Italy)*

***Abstract*** **– TECTONIC project promotes a collaboration among several professionals (i.e. archaeologists, conservator, geologists, engineers, etc.) working on different topics related to the Underwater Cultural Heritage (UCH), to find solutions to the issues still existing in the field. One of the main aims of the project is the exchange of skills for the study and assessment of innovative materials for the conservation of the UCHs, sustainably. To achieve this goal, several activities, analytical investigations and laboratory tests have been planned to be carried out on archaeological and historical materials coming from three underwater pilot areas, selected in the Mediterranean and Atlantic sea. Specifically, in this work the main stages that will be conducted are: a) study and characterization of archaeological/historical materials; b) laboratory and in situ experimentation for developing a conservation strategy against the biofouling; c) development of marketable products. This paper show the detail of each of the abovementioned stages, with a close look also at non destructive testing methodologies.**

## I. INTRODUCTION

Nowadays the conservation of Underwater Cultural Heritage requires the implementation of sustainable and innovative solutions aimed primarily at preserving them and improving their knowledge. UCHs represent a key and success factor for fostering a crucially important topic such as the preservation and the safeguarding of tangible testimonies of human past related to assets lying underwater [1-6].

Europe and the rest of the world are rich in UCHs, due to sinking of ancient vessels, sea-level rise or geological phenomena causing gradual uplifts or descendants of the earth's surface.

Nevertheless, just a few countries are experienced at taking advantage of them as a further source of knowledge and tourist attraction, ensuring significant economic benefits related to the cultural and sustainable tourism [7-22].

Over recent decades, the main international Cultural Heritage (CH) protection organisms, agreed on promotion, protection and also the in situ preservation of underwater archaeological and historical heritage in order to enjoy and safeguard these valuable artefacts lying under the sea surface [23-25].

Particularly, the UNESCO 2001 Convention [23], ratified by 63 countries, provided a detailed states-cooperation system and defined some guidelines for the protection of Underwater Cultural Heritage. Also, one of the main principles of such Convention promotes the in situ preservation of UCH as the first option before engaging in the planning of any further activities.

Starting from these premises, this work wants to explain one of the main objectives that will be addressed within the TECTONIC project (Technological Consortium TO develop sustainability of underwater Cultural Heritage) [26], aimed at:

a) study different types of archaeological/historical materials from selected areas of the Mediterranean Sea and the Atlantic Ocean;
b) test, through different laboratory and in situ surveys, several and suitable protective and eco-sustainable products, against the action of biofouling [3-4,6,9].

The historical/archaeological stone materials will be taken at three different pilot sites, respectively located in Italy, Greece and Argentina.

The choice of the pilot sites, two of which in the Mediterranean area and one in the Atlantic Sea, was made in order to test the new protective products in different environmental conditions and on different materials, also making comparisons possible.

To this aim, non destructive testing (NDT) techniques are used to infer a plethora of information both in the laboratory and in situ. Details of NDT methods that will be employed within TECTONIC are shown in Sect. III.

The final aim is to find and prototype marketable antifouling products [4,9] for the protection of Underwater Cultural Heritage, responding to the issues still existing in this complex field, such as their applicability directly in situ [3-4,6,9].

## II. PILOT SITES

The analytical investigations and new protective materials will be tested in the three different scenarios, briefly described hereafter, chosen as pilot sites of TECTONIC project (Fig. 1).

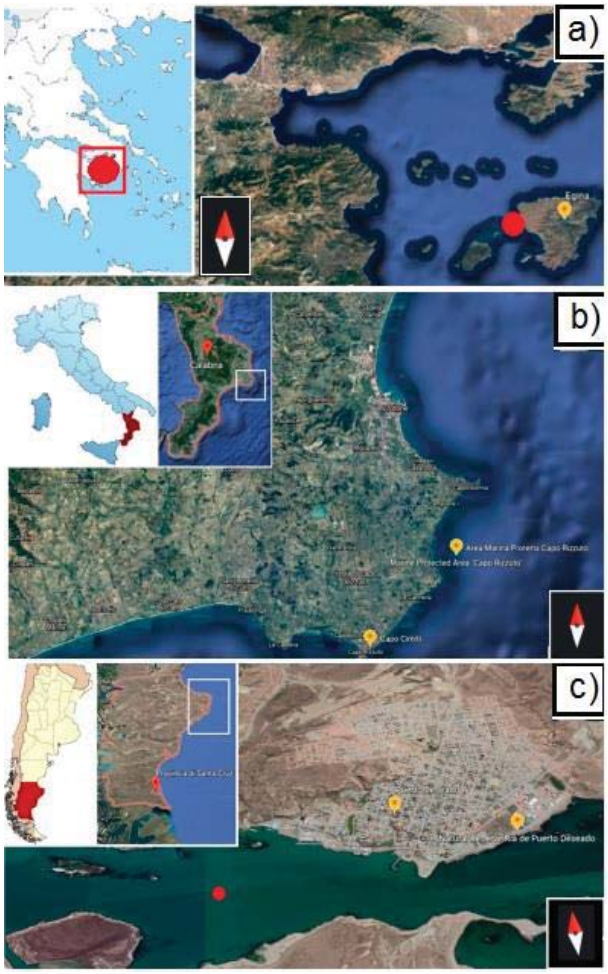


*Fig. 1. Aerial view by Google Earth of the three pilot sites: a) Greece; b) Italy; c) Argentina according to [4].*

In the following underwater areas, different types of materials (i.e. stones, metals, etc.), also belonging to different sites of interest, are present.

This work will focus only on the study of stone materials [4].

Specifically:

- *Greece, ancient Aegina harbour and Epidaurus*

The ancient Aegina harbour is one of the largest artificial harbours of Classical Antiquity [4,27-29], with a total length of 1600 m and an average width of 270 m, occupying an area of 500,000 $m^2$. It includes the north harbour, the commercial harbour to the south and a wide anchorage area between them.

Instead, the Ancient Epidaurus is an area famous for the presence of a submerged Villa, known as "Villa of the dolia", off the coast of the ancient city.

- *Italy, the shipwrecks of Capo Cimiti*

The Capo Cimiti wreck is located in Southern Italy within the Marine Protected Area "Capo Rizzuto" (Crotone). The underwater area is rich with historical remains such as Roman and Greek ruins, shipwrecks, and artifacts made of stone and other ancient materials. Specifically, the the shipwrecks of Capo Cimiti was a navis lapidaria carrying 5 smooth columns made in stone material and up to 9 m long [4,30-31]. It is located north of the namesake locality, about 70 m from the cliff and at 6–7 m depth.

- *Argentina, Puerto Deseado*

The remains located in the Ría Deseado (Deseado estuary), Santa Cruz Province, Argentina, a Provincial Natural Protected Area, mainly consist of a shipwreck site of a historic steamer. Although the steamer is made of metal, there are several artificial building materials in the area, such as bricks, which will be the subject of this study [4].

## III. ANALYTICAL METHODS

After sampling of stone material at pilot sites, analytical methods will be firstly addressed to the minero-petrographic characterization of archaeological and/or historical samples as well as to evaluate their degradation products mainly due to biological colonization.

Precisely, the investigations that will be performed include:

- Petrographic characterisation on thin and stratigraphic sections by using a polarised optical microscopy (POM);
- Mineralogical composition by X-ray powder diffraction analysis (XRPD), with the aim of identifying the constituent phases;
- Study of degradation products and identification of the biological species colonizing the samples by several microscopic techniques such as: polarised optical microscopy, stereomicroscope and EMPA-EDS;
- Study and characterisation of the degradation due to salts crystallisation by mean of ultrasonic NDT [10].

Secondly, after the characterization and the study of decay phenomena that affect materials in sea-water, non-polluting and eco-friendly products (e.g. innovative nanostructured materials) will be tested on quarry stone specimens, first in the laboratory through tank simulations of the marine environment, and then at sea, at

the pilot sites.

During the trials, the specimens will undergo several analytical investigations in order to evaluate the antifouling effectiveness and the state of preservation.

In particular, various microscopic techniques, commonly applied in earth sciences disciplines (i.e. SEM, POM, stereomicroscope, etc.), along with biological (i.e. for species recognition) and non destructive test will be performed.

Regarding non-destructive techniques, it is has been recently demonstrated that ultrasonic NDT show promises for studying salt-related degradation [32].

In fact, ultrasonic testing using an advanced combination of coded waveforms and pulse-compression techniques has been shown to be a reliable method to characterise the porosity, grain structure, and degradation in highly-attenuating materials such as stones and other highly heterogenous samples [33-34].

For instance, Figs. 2 and 3 depict the results obtained by extracting two different features, i.e. the frequency magnitude maxima and the signal-to-noise ratio (SNR) of the received signal, respectively, that allows the state of a given stone sample to be assessed.

In particular, eight different stone samples were threated to alter their original condition. The reported preliminary results show that info about the state of conservation can be inferred both as a change in the frequency spectra of the received signals and in the SNR [32].

Note that the ultrasonic NDT results were achieved using a handy Arbitrary Waveform Generator/Analog-to-Digital converter (TiePie HandyScope HS5) and a peak-to-peak input signal amplitude of 24 V.

The use of low voltages is of high importance for the feature *in situ* ultrasonic testing campaign in underwater environment, and it is solely due to the combined use of coded signals and pulse-compression technique [35].

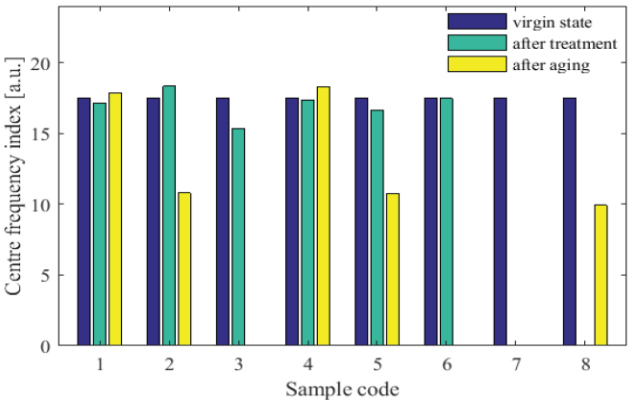


*Fig. 2. Extracted feature, i.e. maxima of the frequency spectra, from ultrasonic testing conducted over eight different threated stone samples (taken from Ref. [10]).*

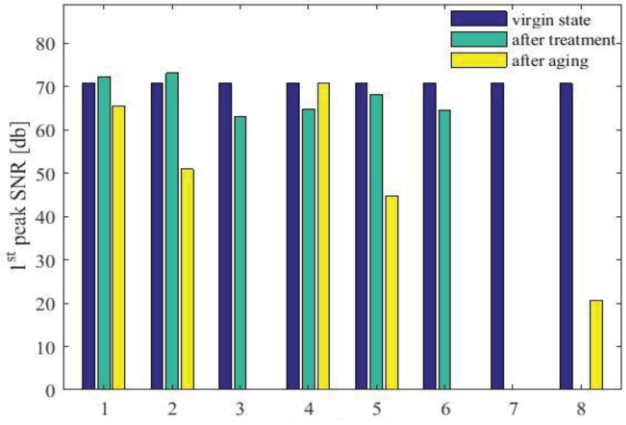


*Fig. 3. Extracted feature, i.e. SNR of the retrieved impulse response, from ultrasonic testing conducted over the same stone samples of Fig.2 (taken from Ref. [32]).*

## IV. EXPECTED RESULTS & CONCLUSIONS

This research focuses on a multidisciplinary study of archaeological/historical stone materials from different underwater environments, addressed to a deep comprehension of their degradation agents, particularly those related to biological colonization.

To this aim, both micro-destructive and non destructive testing (NDT) techniques will be used

In a second stage of the research, different eco-friendly products with antifouling properties will be tested, first in the laboratory and then *in situ*, in order to develop marketable products that can be used for the protection of Underwater Cultural Heritage in different exposure conditions and according to the different types of stone material recovered at pilot sites.

The results that will be achieved want to provide further milestones to already existing data in the complex field of the conservation of Underwater Cultural Heritage.

## V. ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under the Marie Skłodowska-Curie Grant Agreement No 873132.

## REFERENCES

[1] M. Ricca, M.F. La Russa, S.A. Ruffolo, B. Davidde, D. Barca, G.M. Crisci. Mosaic marble tesserae from the underwater archaeological site of Baia (Naples, Italy): Determination of the provenance. Eur. J. Mineral., vol.26, 2014, pp. 323–331.

[2] M.F. La Russa, M. Ricca, C.M. Belfiore, S.A. Ruffolo, M. Álvarez De Buergo Ballester, G.M. Crisci. The Contribution of Earth Sciences to the Preservation of Underwater Archaeological Stone Materials: An Analytical Approach. J.C.S., vol.6, 2015, pp. 335–348.

[3] L. Randazzo, M. Ricca, D. Pellegrino, D. La Russa, A. Marrone, A. Macchia, L. Rivaroli, F. Enei, M.F. La Russa.

Antifouling additives for the consolidation of archaeological mortars in underwater environment: efficacy tests performed on the apsidal fishpond of Castrum Novum (Rome, Italy). IJCS., vol.11, 2020, pp. 243-250.

[4] M. Ricca, G. Alexandrakis, A. Bonazza, F. Bruno, B. Davidde Petriaggi, D. Elkin, A. Lagudi, S. Nicolas, M. Novák, G. Papatheodorou, J. Prieto, M. Ricci, A. Vasilijevic, M.F. La Russa. A Sustainable Approach for the Management and Valorization of Underwater Cultural Heritage: New Perspectives from the TECTONIC Project. Sustainability, vol.12, 2020, 5000; doi:10.3390/su12125000.

[5] L. Randazzo, M. Ricca, S.A. Ruffolo, M. Aquino, B. Davidde Petriaggi, F. Enei, M.F. La Russa. An Integrated Analytical Approach to Define the Compositional and Textural Features of Mortars Used in the Underwater Archaeological Site of Castrum Novum (Santa Marinella, Rome, Italy). Minerals, vol.9, 2019, 268; https://doi.org/10.3390/min9050268.

[6] M. Ricca, M.F. La Russa. Challenges for the Protection of Underwater Cultural Heritage (UCH), from Waterlogged and Weathered Stone Materials to Conservation Strategies: An Overview. Heritage, vol.3, 2020, DOI10.3390/heritage3020024.

[7] L. Randazzo, M. Ricca, D. Barca, F. Enei, B. Davidde Petriaggi, M.F. La Russa. New data on the exploitation of obsidian in the mediterranean basin: The harbour of Pyrgi and the trade in neolithic age IJCS, vol.11, 2020, pp. 305-318.

[8] B. Cámara, M. Álvarez de Buergo, M. Bethencourt, T. Fernández-Montblanc, M.F. La Russa, M. Ricca, R. Fort. Biodeterioration of marble in an underwater environment. Sci. Tot. Environ., vol.609, 2017, pp. 109–122.

[9] S.A. Ruffolo, M. Ricca, A. Macchia, M.F. La Russa. Antifouling coatings for underwater archaeological stone materials. Prog. Org. Coat., vol.104, 2017, pp. 64–71.

[10] A. Macchia, F. Mangini, S.A. Ruffolo, M. Muzi, L. Rivaroli, M. Ricca, M.F. La Russa, F. Frezza. A novel model to detect the content of inorganic nanoparticles in coatings used for stone protection. Prog. Org. Coat., vol.106, 2017, pp. 177-185. doi.org/10.1016/j.porgcoat.2016.11.004.

[11] F. Bruno, A. Gallo, L. Barbieri, M. Muzzupappa, G. Ritacco, A. Lagudi, M.F. La Russ,a S.A. Ruffolo, G.M. Crisci, M. Ricca, V. Comite, B. Davidde, G. Di Stefano, R. Guida. The CoMAS project: new materials and tools for improving the in-situ documentation restoration and conservation of underwater archaeological remains. MTSJ, vol.50, 2016, pp. 108-118.

[12] M. Ricca, V. Comite, M. F. La Russa & D. Barca. Diagnostic analysis of bricks from the underwater archaeological site of Baia (Naples, Italy): preliminary results. Rend. Online Soc. Geol. It., vol.38, 2016, pp. 85-88, doi: 10.3301/ROL.2016.24.

[13] M. Ricca, C.M. Belfiore, S.A. Ruffolo, D. Barca, M. Alvarez De Buergo, G.M. Crisci and M.F. La Russa. Multi-analytical approach applied to the provenance study of marbles used as covering slabs in the archaeological submerged site of Baia (Naples, Italy): the Case of the “Villa con ingresso a protiro”. App. Surf. Sci., vol.357 2015, pp. 1369–1379, doi:10.1016/j.apsusc.2015.10.002.

[14] M.F. La Russa, S.A. Ruffolo, M. Ricca, N. Rovella, V. Comite, D. Barca, Archaeometric approach for the study of mortars from the underwater archaeological site of Baia (Naples) Italy: Preliminary results. Per. Mineral., vol.84, 2015, pp. 1-16.

[15] M. Ricca, M.F. La Russa, Ruffolo S. A., Davidde B., Barca D., Crisci G. M., "Mosaic marble tesserae from the underwater archaeological site of Baia (Naples, Italy): determination of the provenance". Eur. J. Mineral., vol.26, 2014, pp. 323-331.

[16] P. Aloise, M. Ricca, M.F. La Russa, S.A. Ruffolo, C.M. Belfiore, G. Padeletti, G.M. Crisci. Diagnostic analysis of stone materials from underwater excavations: the case study of the Roman archaeological site of Baia (Naples, Italy). Appl. Phys. A., vol.114, 2014, pp. 655-662, DOI 10.1007/s00339-013-7890-1-.

[17] M.F. La Russa, S. A. Ruffolo, M. Ricca, S. Ricci, B. Davidde, D. Barca, V. Capristo. A multidisciplinary approach to the study of underwater artefacts: the case of a Tritone Barbato marble statue (Grotta Azzurra, Island of Capri, Naples). Per. Mineral., vol. 82, 2013, pp. 101-111.

[18] D.J. Gregory, M. Manders. Best practices for locating, surveying, assessing, monitoring and preserving underwater archaeological sites. In SASMAP Guideline Manual 2; SASMAP Project: Amersfoort, The Netherlands, 2015.

[19] D. Gregory, H. Matthiesen. Conservation and management of archaeological site. Preserving Archaeological Remains in Situ. In Proceedings of the 4th International Conference, National Meuseum of Copenhagen, Copenhagen, Denmark, 8–10 April 2012; vol. 14, p. 489.

[20] A. Trakadas, A. Firth, D. Gregory, D. Elkin, U. Guerin, J. Henderson, J. Kimura, D. Scott-Ireton, Y. Shashoua, · C. Underwood, et al. The Ocean Decade Heritage Network: Integrating Cultural Heritage within the UN Decade of Ocean Science 2021–2030. J. Marit. Archaeol., vol.14, 2019, pp. 153–165.

[21] B. Davidde, Methods and strategies for the conservation and museum display in situ of underwater cultural heritage. Archaeol. Maritima Mediterr., vol.1, 2004, pp. 137–150.

[22] B. Davidde, Underwater archaeological parks: A new perspective and a challenge for conservation-the Italian panorama. Int. J. Naut. Archaeol., vol.31, 2002, pp. 83–88.

[23] UNESCO, Convention on the protection of the underwater cultural heritage, 2001, Paris.

[24] J.A. Gifford, M. Redknap, N.C Flemming. The UNESCO International Survey of Underwater Cultural Heritage. World Archaeol., vol.16, 1985,pp. 373–376.

[25] T. Treaty. Convention for the Protection of the Archaeological Heritage of Europe (Valletta, 1992); Council of Europe: Strasbourg CEDEX, France, 1992.

[26] TECTONIC Project Website. Available online: https://www.tectonicproject.eu/ (accessed on 1 February 2020).

[27] G. Papatheodorou, M. Geraga, D. Christodoulou, M. Iatrou, E. Fakiris, S. Heath, K. Baika. A marine geoarchaeological survey, Cape Sounion, Greece: Preliminary results. Mediterr. Archaeol. Archaeom., vol.14, 2014, pp. 357-371.

[28] G. Papatheodorou, M. Geraga, N. Georgiou, D. Christodoulou, X. Dimas, E. Fakiris, G. Ferentinos.

Marine Geo-archaeological survey in the Straits of Salamina and in Ampelakia Bay. Hellenic Maritime Museum. 2020, in press.

[29] B. Davidde Petriaggi, P. Galiatsatou, S. Medaglia. The submerged “Villa of the Dolia” near ancient Epidaurus. The preliminary results of the first excavation and conservation campaign. In Annuario Della Scuola Archeologica di Atene e delle Missioni Italiane in Oriente; Scuola Archeologica Italiana di Atene: Atene, Italy, vol. 97, 2019.

[30] S. Medaglia. Carta Archeologica della provincia di Crotone, paesaggi storici e insediamenti nella Calabria centro-orientale dalla Preistoria all’Altomedioevo. In Ricerche, Collana del Dipartimento di Archeologia e Storia delle Arti, IV; Università della Calabria: Rende, Italy, 2010.

[31] S. Medaglia, Ricerche Storiche in Calabria: Modelli e prospettive (edited by Lena G.) In Per un Censimento Dei Relitti Antichi Lungo la Costa Crotonese; Nota Preliminare: Cosenza, Italy, 2008.

[32] R. Arcidiacono, P. Burrascano, M.F. La Russa, S. Laureti, L. Randazzo, M. Ricci. Ultrasonic Non-destructive Testing of Building Materials for the Diagnosis and Characterization of the decay due to Salts Crystallization. IJCS, vol.11, 2020, pp.271-276.

[33] S. Laureti, M. Ricci, M. N. I. B. Mohamed, L. Senni, L. A. J. Davis, D.A. Hutchins. “Detection of rebars in concrete using advanced ultrasonic pulse compression techniques”. Ultrasonics, vol.85, 2018, pp. 31-38.

[34] D.A. Hutchins, R. L. Watson, L. A. Davis, L. Akanji, D.R. Billson, P. Burrascano, S. Laureti, M. Ricci. Ultrasonic Propagation in Highly Attenuating Insulation Materials. Sensors, vol.20, 2020, 2285, doi: 10.3390/s20082285.

[35] M.K. Rizwan, L. Senni, P. Burrascano. S. Laureti, M. Goldammer, H. Mooshofer, R. Borgna, S. Neri. Contextual Application of Pulse-Compression and Multi-frequency Distance-Gain Size Analysis in Ultrasonic Inspection of Forging. J. Nondestruct. Eval., vol.38, 2019.