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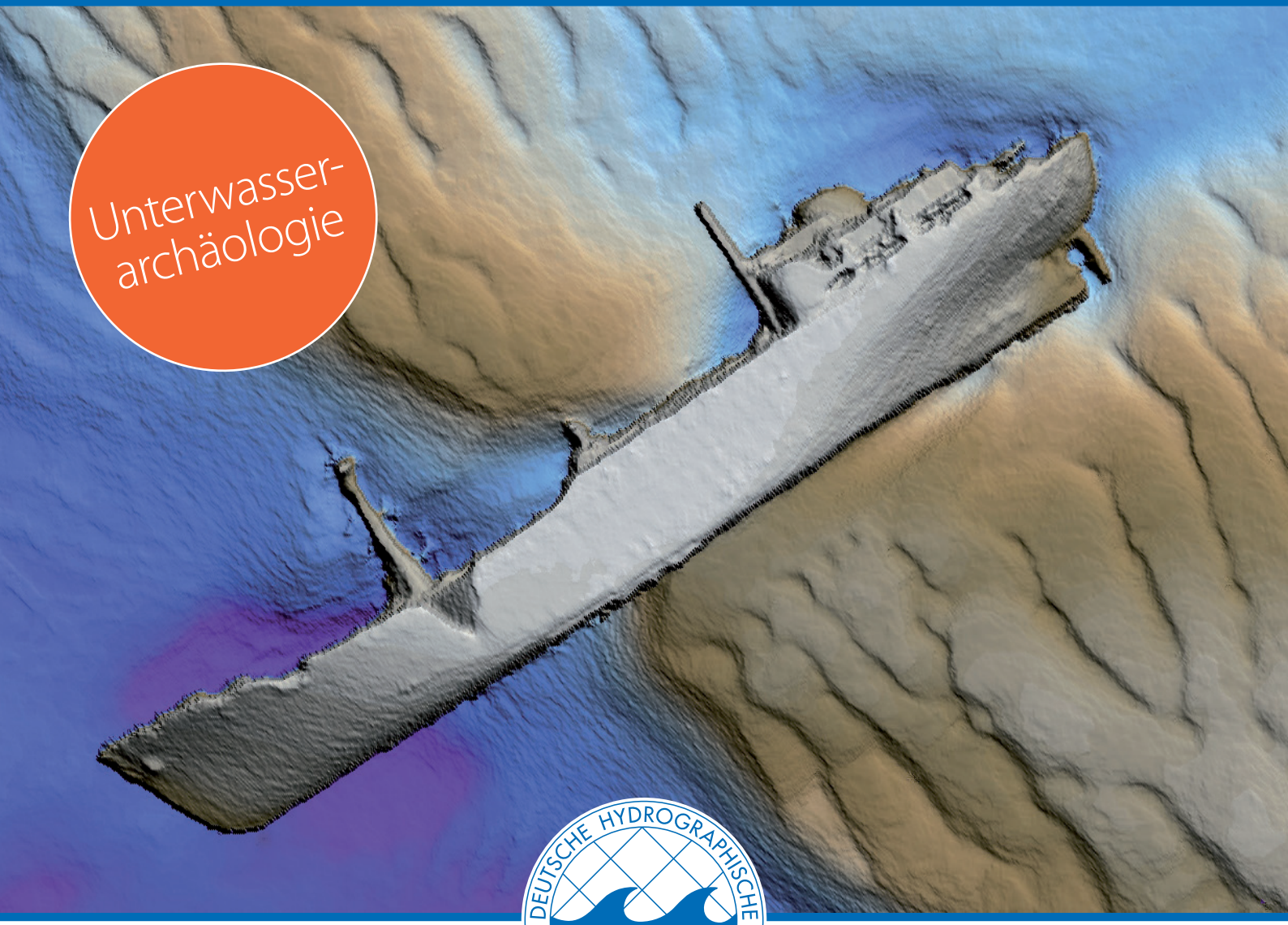


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# Sub-bottom profiler in underwater archaeology

## Study of the palaeolandscape and shipwreck alteration processes at Carthago Nova

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**The application of geophysical methods and underwater photogrammetry for palaeolandscape reconstruction and the determination of shipwreck alteration processes at the bay of Cartagena, Murcia, Spain is presented. Sub-bottom profiler data revealed a chronology of the palaeotopography from the Upper Palaeolithic to the transgressive maximum of the Holocene. Investigations of the site of the wreck *Cartagena 1* show sedimentary processes and dispersion of the remaining ship cargo exacerbated by consequences of extreme climatic events and contemporary garbage dumps. These results underscore the need for comprehensive documentation, with photogrammetry prioritised to achieve a complete and accurate record of the archaeological site.**

underwater archaeology | shipwreck | sub-bottom profiler | sedimentation
Unterwasserarchäologie | Wrack | Sedimentecholot | Sedimentation

Die Anwendung geophysikalischer Methoden und der Unterwasserphotogrammetrie zur Rekonstruktion der Paläolandschaft und zur Bestimmung der Änderungsprozesse von Schiffswracks in der Bucht von Cartagena, Murcia, Spanien, wird vorgestellt. Daten des Sedimentecholots enthüllten eine Chronologie der Paläotopographie vom Jungpaläolithikum bis zum transgressiven Maximum des Holozäns. Untersuchungen der Fundstelle des Schiffswracks *Cartagena 1* zeigen Sedimentationsprozesse und eine Ausbreitung der verbliebenen Schiffsladung, die durch die Folgen extremer Klimaereignisse und heutiger Müllablagerungen noch verstärkt wurden. Diese Ergebnisse unterstreichen die Notwendigkeit einer umfassenden Dokumentation, wobei der Photogrammetrie Vorrang eingeräumt werden sollte, um eine vollständige und genaue Erfassung der archäologischen Stätte zu erreichen.

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### 1 Introduction

Underwater archaeology faces the challenge of detecting and analysing cultural remains that remain hidden under the water column and often buried by marine sediments, which limits the effectiveness of conventional visual prospecting methods (Bailey and Flemming 2008). The integration of active acoustic remote sensing techniques, such as sub-bottom profilers (SBP), has established itself as a fundamental tool to overcome these limitations, allowing the characterisation of the geological and sedimentological structure of the seafloor (Rizzo et al. 2024), as well as locating anthropic elements trapped in these sediments (Li et al. 2023). These high-resolution reflection seismic instruments are essential for a less intrusive management approach for the preservation of submerged cultural heritage sites in situ. They provide the non-invasive data needed to understand site formation processes and plan effective protection strategies against accelerated degradation (Winton 2023). The ability of SBPs to penetrate sediments and generate detailed acoustic profiles allows not only the detection of anomalies associated with anthropogenic structures, but also the reconstruction of submerged palaeolandscapes that contextualise human settlements over time (Gusick et al. 2022; Winton 2023). The application of these remote sensing technologies in underwater archaeology encompasses two main approaches: the location and mapping of historic shipwrecks on the seabed or semi-buried, and the study of coastal palaeogeography to identify archaeological sites of submerged interest (Gusick et al. 2022; Plets et al. 2008). This palaeogeographical approach is essential to understand the evolution of coastlines and to locate prehistoric sites that, due to changes in sea level, are now situated underwater (Ghilardi and Pateau 2023). The Holocene maximum transgression, in particular, has

caused the disappearance of large coastal areas that were inhabited during the Pleistocene and Holocene, making the underwater sedimentary record a fundamental archive for the research of regional prehistory (Nieto Prieto 2019). The recent technological evolution of chirp and parametric systems, which incorporate multiple sensors and precision positioning, has made it possible to characterise not only the geometry of the buried materials, but also their state of conservation within the sedimentary column. Thus, based on accurate geophysical evidence, appropriate measures can be implemented to mitigate the aforementioned effects (Souza 2006).

This methodological approach is aligned with the principles of UNESCO's (2001) Convention on the Protection of the Underwater Cultural Heritage, which promotes in-situ preservation and the use of non-destructive techniques for the management of archaeological heritage.

The geoarchaeological study of the Bay of Cartagena (Fig. 1) was conducted within the framework of Cerezo Andreo's (2016) doctoral thesis and was supported by an Innomar student scholarship, which provided access to their sub-bottom profiler.

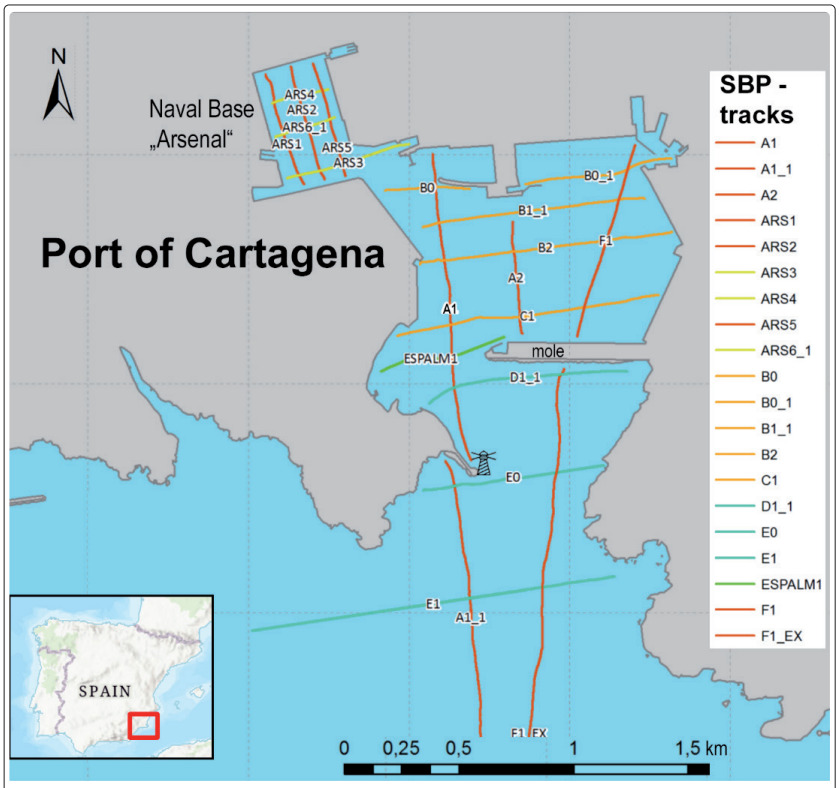


**Fig. 1:** Map of sub-bottom profiler survey lines from 2015 in the Bay of Cartagena

## 2 Objectives

The main objectives of the research presented are as follows:

1. To reconstruct the palaeogeographic and sedimentological evolution of the port area of Carthago Nova, to understand its configuration throughout the Holocene transgression.

2. To evaluate the effectiveness of high-resolution geophysical techniques, in particular sub-bottom profiling based on parametric echo sounding, in the detection and characterisation of seismic anomalies associated with potential underwater archaeological sites.

3. To analyse the processes of natural and anthropic alteration on underwater cultural heritage, illustrated by the *Cartagena 1* wreck case study. The focus here is to assess cargo dispersion, its sedimentary covering or uncovering, and the consequences of extreme climatic events such as DANA (»Depresión Aislada en Niveles Altos« – Isolated depression at high levels).

4. Establish a multidisciplinary methodological framework that integrates geophysical prospecting, analysis of past geotechnical data, absolute dating and photogrammetry for the documentation, monitoring and efficient non-intrusive management strategy for the preservation of underwater cultural heritage in dynamic marine environments.

## 3 Methodology

The methodology used is situated within underwater archaeology as a science of historical research and heritage documentation, with a priority on non-intrusive recording techniques. In 2008, a geophysical survey campaign using a Klein 3900 side-scan sonar was carried out by the National Museum of Underwater Archaeology of Spain and the non-governmental organisation Aurora trust. With these works, it was possible to obtain a sonography of the seabed, which allowed an updated image of the Bay of Cartagena and its accesses (Fernández Matallana 2008; Pinedo Reyes 2012). It was in these works that the *Cartagena 1* wreck was located.

The promising results of this work prompted us to propose a new prospecting campaign within the framework of the Archeotopes project (Ramallo Asension et al. 2015), which was carried out in 2015.

The SES-2000 series are parametric echo sounders that are based on the concept of non-linear generation of acoustic waves. During simultaneous transmission of two signals of slightly different high frequencies at high sound pressure, a new frequency arises, with a frequency equal to the difference between the two primary frequencies. The resulting low-frequency signal allows a better bottom penetration and a high vertical resolution. The SES-2000 device generates a low frequency between 4 kHz and 12 kHz based on primary frequencies of around 100 kHz. Thus, the system is able to achieve a resolution of about 5 cm, an accuracy of ±2 cm + 0.02 % of the water depth for the 100-kHz frequency, and about ±4 cm + 0.02 % of the water depth for the chosen low frequency

**Fig. 2:** Installation of the sub-bottom profiler on the vessel of the University of Murcia

of 10 kHz (Wunderlich et al. 2005; Heine et al. 2014). Frequencies of 6 kHz and 10 kHz were selected, achieving a penetration up to 15 metres The portable equipment was installed on the research vessel *Betsaida* of the University of Murcia (Fig. 2). 3D positioning and real-time, decimetre-level navigation accuracy were achieved using an Ashtech/Thales DG14 DGPS system. The Eye4Software Hydromagic hydrographic survey package was used to plan survey lines and to map the vessel's position relative to them.

Twenty intersecting profiles were defined (Fig. 1) based on analyses of existing terrestrial geological data. The survey lines were oriented north–south along the bay's main axis and perpendicular to it. The water depth in the bay ranges from 2 m to 78 m. The vessel's speed was maintained at 3.5 knots to optimise sub-bottom profiler performance in the port basin, where water depths ranged from 3 to 18 m (Cerezo Andreo 2016).

The subsequent data processing included filtering and analysis of sub-bottom profiler data and generation of profile section diagrams using Innomar's ISE software, ArcGIS for georeferencing of historic geotechnical boreholes and interpolation of sedimentological profiles and RockWorks for 2D and 3D modeling of the palaeo-seafloor.

To better constrain the area's lithology, the investigation incorporated results from previous analyses of onshore geotechnical borehole samples. Within the framework of the Archeotopes project 457 historical samples carried out between 1999 and 2015 were analysed alongside recent samples. The recent sediment samples were dated by C14 and validated by amino acid racemisation techniques, biomarker studies (gastropods, ostracods, foraminifera and algae) and archaeometric and geomorphological analyses, which allowed a diachronic restitution of the palaeotopography of the environment with a record of more than 12,000 years (Cerezo Andreo 2017; Torres et al. 2018).

Verification actions with an ROV and archaeologist dives were carried out on areas where anomalies in the sub-bottom structures were detected (Cerezo Andreo et al. 2022).

### Cartagena 1 wreck and Aladroque project

The study of the *Cartagena 1* wreck began with a 2008 geophysical survey using sub-bottom profiler and side-scan sonar, whose data served as a comparative basis (Fernández Matallana 2008).

The Aladroque project campaigns (2021 to 2022), focused on the impact of DANA-type climate events, incorporated previous data from 2008 and 2015 for specific objectives: to evaluate burial/disinterment processes, sedimentation and anthropic/climatic alterations through repeated geophysics, verification dives and photogrammetry (Cerezo Andreo et al. 2022).

Underwater photogrammetry using photo series obtained by ROVs of the Cartagena Oceanographic Research Institute, has made it possible to generate accurate and original 3D models of the wreck.

The value for the techniques applied in this project became evident in the face of the significant changes observed at the site resulting from time series analysis of the 2008 and 2021/2022 datasets.

## 4 Results

### 4.1 The results of the port of Cartagena

The parametric sub-bottom profiler data reconstruct a palaeotopographic chronology from the Upper Palaeolithic to the Holocene transgressive maximum. The analysis of the most representative SBP sections identifies three morpho-stratigraphic units (Fig. 3) The deepest, designated »unit 3« records a glacial palaeotalweg of the last

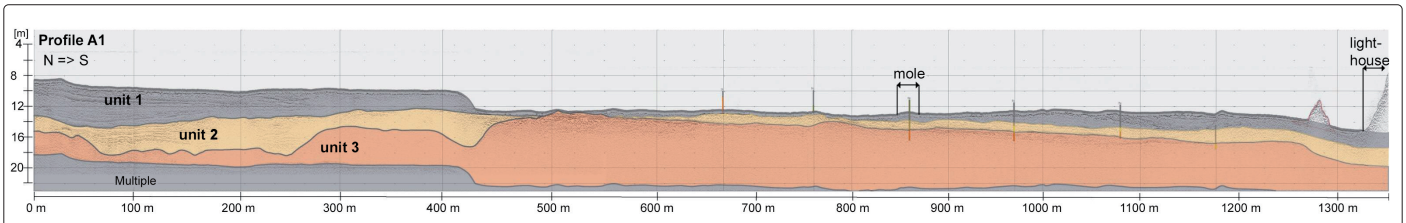


**Fig. 3:** SBP Profile A1 showing three morpho-stratigraphic units and gently inclined foresets towards the sea (south)

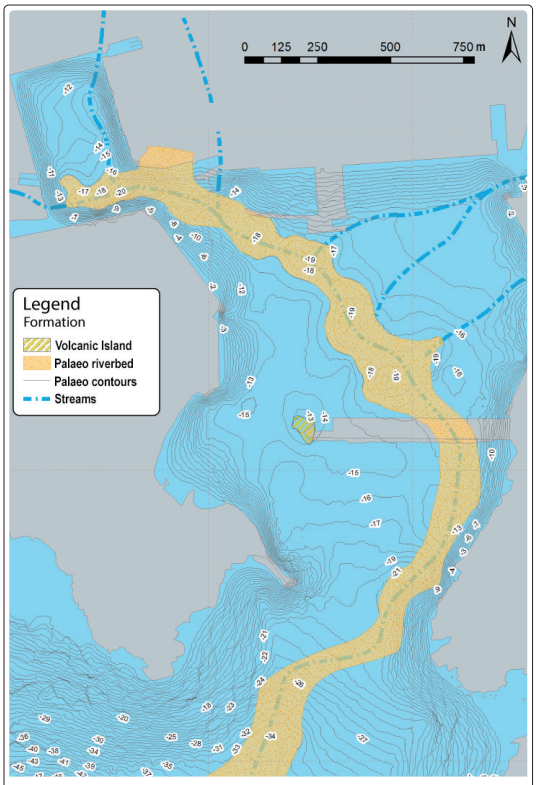


**Fig. 4:** Interpolation of the pre-transgressive landscape in Cartagena Bay

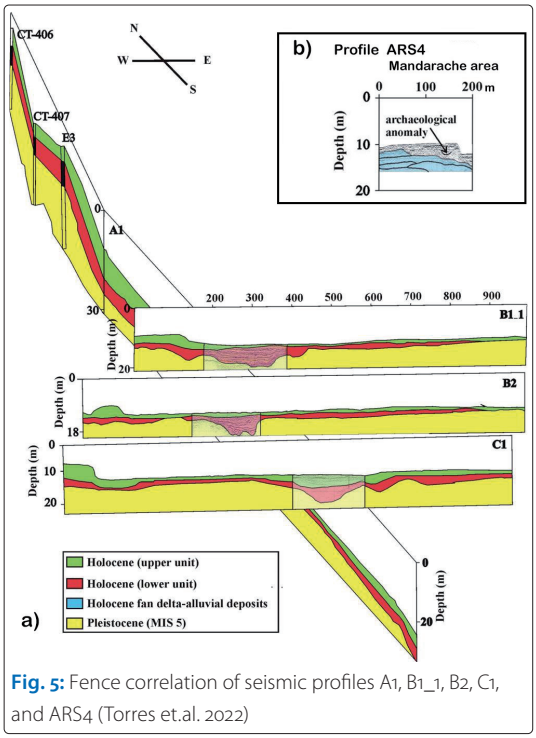


**Fig. 5:** Fence correlation of seismic profiles A1, B1_1, B2, C1, and ARS4 (Torres et.al. 2022)

glacial period. It crosses the port bay, with foresets gently inclined towards the sea and with morphological differences between the coastal zone and the outer basin, conditioning the configuration of the port during the Holocene transgression (Fig. 3).

This palaeochannel (Fig. 4), associated with the palaeochannel or Benipila wady, showed fan deltaic developments at its northern end (ARS4 profile, Mandarache area), with a stratified lower Holocene seismic unit covered by recent massive mud rich in organic matter and with anthropic influence (Fig. 5a). C14 dating at nearshore »unit 1« (Fig. 3) indicated ~8500 years BP at its base, with contemporary deposits at the top and original thicknesses of up to 12 m in the actual Arsenal area. From an archaeological perspective, the artefacts found in »unit 1« in the Arsenal area indicate a possible 6 × 21 m U-shaped shipwreck at a depth of 12 metres, which is consistent with other shipwrecks found at a similar depth (Fig. 5b).

### 4.2 Cartagena 1 wreck and Aladroque project

The time series analysis of the 2008 and 2021/2022 datasets of the *Cartagena 1* wreck revealed a removal of sediments covering the wreck of 70 to 80 cm compared to 2008, a dispersion of the cargo that has doubled the original extension. Beyond that, in some areas a doubling of sedimentation could be observed (Fig. 6 and Fig. 7).

Three-dimensional models of the wreck area and its cargo is crucial not only to visualise the reservoir in its current state, but also to facilitate detailed structural analyses and monitoring of changes over time (Fig. 7).

ROV dives at the wreck site documented contemporary trash (plastics, nylon lines, bottles and cans) causing erosion and the rupture of amphorae that protrude from the seabed. This accu-

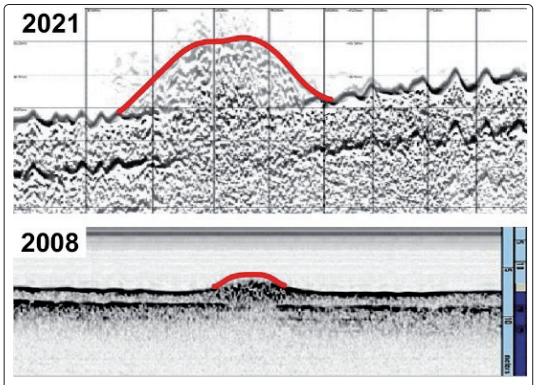


**Fig. 6:** Comparison of SBP image of the amphorae mound of the *Cartagena 1* shipwreck from 2008 and 2021



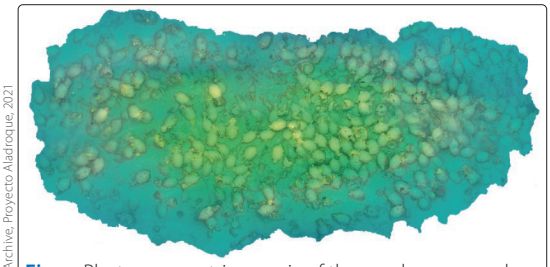

**Fig. 7:** Photogrammetric mosaic of the amphora mound (*Cartagena 1* shipwreck cargo from 2021)

mulation of harmful anthropogenic debris at the site has increased following high-impact rainfall events in recent years.

Photogrammetric documentation of the impacts of extreme weather events (DANAs), along with graphic records of the resulting damage, has been obtained and is vital for developing conservation proposals and monitoring subsequent alterations.

## 5 Discussion

The results obtained in this geoarchaeological research projects highlight the ability of high-resolution geophysical techniques, such as the SES-2000 parametric profiler, to reconstruct the palaeotopography of the bay of Cartagena and assess the environmental impact on underwater heritage. The identification of three morpho-stratigraphic units confirms the influence of a glacial palaeotalweg on the configuration of the port during the Holocene transgression, aligning with previous stratigraphic reinterpretations that integrate geophysical and chronological data.

The reinterpretation of previous seismic profiles, such as AR54 in Mandarache, reveals a fan delta at the mouth of the Rambla de Benipila, with a Holocene seismic unit stratified at the bottom and massive at the top, rich in organic matter and with anthropic influence. These units confirm a fluvial palaeotalweg that shaped the port during the Holocene transgression.

These sedimentary dynamics, with variable rates calculated by GIS and C14 dating, allow precise palaeobathymetries to be restored. It reveals underwater sand bars in key areas such as the actual Plaza del Ayuntamiento and Plaza del Rey. These features configure a coastal landscape affected not only by marine transgression initially, but also by a progressive coastal progradation. This progradation is due to high-energy events such as floods or floods that configured and built these sandy bar structures in the deltaic area of what is now the city's military arsenal.

From an archaeological perspective, the seismic anomalies in »unit 1«, such as the possible shipwreck in the Arsenal at 12 m below m.s.l., show the capacity to detect the status of preservation of remains in Holocene sediments and their alteration by anthropic processes. Unfortunately, research on the port of Cartagena is hampered by historical dredging to depths of 13 m, which removed portions of the Holocene seafloor record.

The investigations of the *Cartagena 1* wreck site show sedimentary uncovering and dispersion of the cargo exacerbated by DANA events and contemporary garbage dumps. The combination of photogrammetry with geophysical prospecting and sedimentation monitoring analyses has made it possible to assess the degree of burial and unearthing of the wreck, as well as the interaction between natural processes and human action in the conservation of this important Roman site from the second century BC.

The results of this study underscore the urgency of comprehensive documentation, with photogrammetry prioritised to obtain a complete and accurate record of the archaeological site.

## 6 Conclusion

The results of this geoarchaeological research in the bay of Cartagena demonstrate the effectiveness of high-resolution geophysical techniques, in particular parametric sub-bottom profilers, to reconstruct underwater palaeotopography and assess environmental impacts on underwater cultural heritage.

Archaeologically, anomalies can be detected preserved in lower Holocene sediments, which is particularly important when the seabed is affected by dredging or construction activities.

The geoarchaeological data, integrated with GIS and geotechnical soundings, allow us to reconstruct palaeolines, bathymetries and variable sedimentation rates. This enriches the understanding of Atlantic-Mediterranean port dynamics, with 14 shipwrecks documented since the eighteenth century.

Underwater photogrammetry using ROVs has proven to be an indispensable tool for assessing the state of conservation of the *Cartagena 1* wreck and accurately documenting the complex alteration processes to which they are subjected. //

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