3rd INTERNATIONAL NEPTUNE WORKSHOP

BOOK OF ABSTRACTS

Reconstructing Coastal paleo-landscapes: shelf to shore, data to model

Naples, 27 and 28 September 2022

Parthenope University of Naples, Centro Direzionale

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INDEX

SESSION 1- Coastal landscape and sea-level reconstruction

SESSION 2 - Methodological approach to coastal studies

p.20 Francesco Giuseppe Figliomeni (Parthenope University of Naples, IT), *Interpolating Electronic Navigational Chart depth data to model the North-East sector of the Gulf of Naples bathymetry – E. Alcaras, P.P. Amoroso, F. Giuseppe Figliomeni, C. Parente, A. Vallario*

p.22 Marta Pappalardo (University of Pisa, IT), *Applications of seismic reflection method support the reconstruction of a coastal landscape associated to outstanding Palaeolithic settlements – M. Pappalardo, F. Fiera, M. Perini, D.D. Ryan, E. Starnini, F. Negrino, S. Grimaldi, A. Zerboni*

p.24 Valeria Vaccher (University of Trieste, IT), *Present-day tidal notch elevation: the water level bias – V. Vaccher, F. Antonioli, E. de Sabata, M. Agate, G. Visconti, S. Furlani*

POSTER SESSION

p.26 Víctor Cartelle (Flanders Marine Institute, BE), *Palaeo-landscapes offshore Belgium: the search for the former Testerep peninsula – V. Cartelle, R. Plets, T. Mestdagh, T. Missiaen, Z. Vanbiervliet, S. Vervust, P. Deckers*

p.28 Ciro Cerrone (University of Naples Federico II, IT), *Morpho-structural analysis of Capo Faro Promontory cliff (Salina Island, Italy) – C. Cerrone, M. Bonasera, F. Caso, S. Lanza, G. Fubelli, G. Randazzo*

p.30 Martina Conti (University of York, UK), *Amino acid geochronology of bivalve shells – M. Conti, P.Butler, D. Reynolds, H. Robson, N. Milner, J. Scourse, K. Penkman*

p.32 Giuseppe Corrado (University of Basilicata, IT), *Middle to Late Pleistocene sea-level changes and vertical movements along the coastal belt between Formia and Minturno, central Italy – M. Schiattarella, M.L. Putignano, G. Corrado, P.E. Orrù, M. Voltaggio*

p.34 Gianluigi Di Paola and Grazia Dilauro (University of Molise, IT), *Influence of wave conditions and defense structures on the evolution of the Molise coastline (southern Italy) – G. Di Paola, G. Dilauro, M.C. Ciccaglione, V. Scorpio, C.M. Rosskopf*

p.36 Pier Paolo Amoroso (Parthenope University of Naples, IT), *Application of Machine Learning algorithms on Sentinel-2 images for coastline extraction – E. Alcaras, P.P. Amoroso, F. Giuseppe Figliomeni, C. Parente, A. Vallario*

p.38 Andrea Gionta (Parthenope University of Naples, IT), *First results on coastal paleolandscape and position of relative sea level of Gaeta Bay (Southern Italy) during the Roman period by archaeological and geomorphological data – A. Gionta, G. Mattei, C. Caporizzo, P.P.C. Aucelli*

p.40 Gennaro Mellone (Parthenope University of Naples, IT), *Deep learning techniques for seafloor classification and mapping – G. Mellone, A. Ciaramella, G. Pappone, G. Mattei, F. Peluso, P.P.C. Aucelli*

p.42 Angela Rizzo (University of Bari Aldo Moro, IT), *The analysis of past experience in Taranto (Southern Italy) as a key for defining guidelines for the geo-environmental characterisation of contaminated coastal sites – A. Rizzo, F. De Giosa, A. Di Leo, S. Lisco, M. Moretti, G. Scardino, G. Scicchitano, G. Mastronuzzi*

p.44 Alessia Sorrentino (Parthenope University of Naples, IT), *Geoarchaeological study of the south-western coastal sector of Campi Flegrei and its periphery – A. Sorrentino, C. Caporizzo, G. Mattei, G. Pappone, P. Stocchi, E. Tedesco, S. Troisi, P.P.C. Aucelli*

Paleomorphology and paleoenvironmental conditions during Late Mesolithic occupation of the Sado estuary, Portugal

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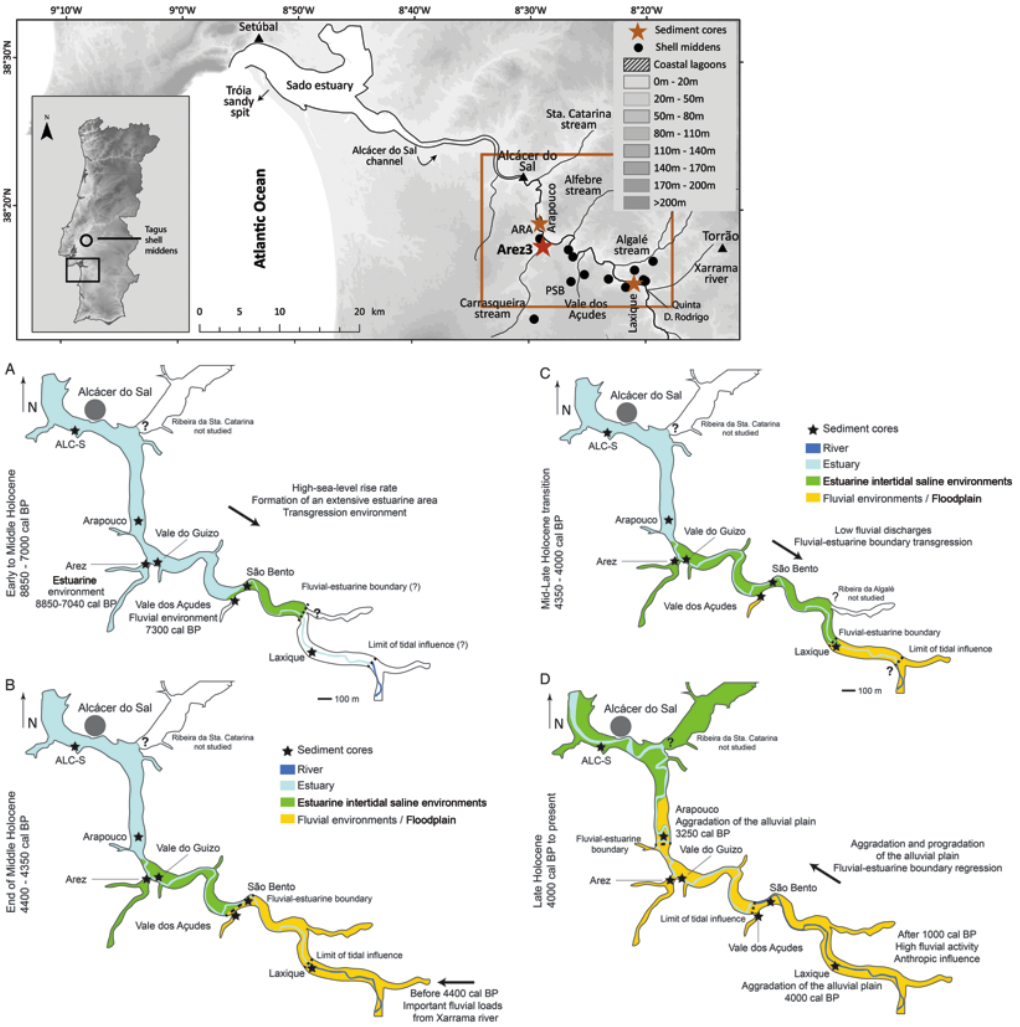

Schematic representation of the paleoenvironmental evolution of the Sado estuary through the Holocene.

The Sado valley was intensively occupied by Late Mesolithic communities between 8400 and 7000 cal BP. By then, the estuary had a different morphology: the area that today corresponds to the central estuarine basin was an open bay that started to enclose 6500 cal BP with the aggradation and progradation of a sandy barrier, the Tróia spit; the estuarine area developed through the channels that today feed the estuary, particularly the deep and narrow Sado channel and its tributaries, near where Late Mesolithic sites were identified.

This works aims to characterize the environmental context of Late Mesolithic communities by analysing sediment cores collected in the Sado and tributaries alluvial plains for several environmental and ecological proxies. The data was combined with 14C datings to establish a chronology and age-model. In addition, the paleoenvironmental evolution of the area during the Holocene was also reconstructed.

According to the multiproxy analysis, the deeper areas of the Sado channel, at least until 57 km upstream the present estuarine inlet, and the lowermost area of downstream tributaries, such as the Carrasqueira and the Alfebre rivulets, were flooded by brackish water since 8850 cal BP. Tidal flats and salt marshes developed in the channels shallower margins. Tidal flats had suitable conditions for the development of molluscs banks and for its exploitation by the Mesolithic communitites.

Marine influence prevailed until 4000 cal BP at Laxique (65 km upstream the present-day estuary mouth), from when the aggradation and progradation of the alluvial plain started. The aggradation of the alluvial plain began later (3250 cal BP) at Arapouco (50 km upstream the present-day estuarine inlet).

Work funded by the Portuguese Fundação para a Ciência e a Tecnologia (FCT) I.P./MCTES through national funds (PIDDAC) – UIDB/50019/2020 and by the Spanish Ministry of Science and Innovation through the project SimTIC (HAR2017-82557-P).

The harbour of Sozopol: evidence for prehistoric sea-level fluctuations

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Modern-day aerial panoramic photo of the Sozopol harbour, view south to north (photo: M. Damyanov).

The historical town of Sozopol, ancient Apollonia Pontica, is located on the south coast of the Burgas Bay on a rocky peninsula, connected with the mainland by a narrow sandy isthmus. Due to construction works in the town's harbour as early as the 1920s we have one of the first archaeological materials collected from the Black Sea in Bulgaria. Underwater excavations have documented two prehistoric settlements one from the Late Chalcolithic period and one from the Early Bronze Age as well as artefacts from the periods when the bay was used as an ancient harbour as early as the 6th century BC.

Detailed stratigraphic recording and the involvement of interdisciplinary methods have allowed for a recent reconstruction of the palaeo-terrain. It has revealed that the Late Chalcolithic dwelling was originally located on a flat terrace on the south shore of a small bay, or a fresh- or brackish water lake located in the northern part of today's harbour, in between the Sozopol peninsula and the St. Kirik island. The end of the settlement is marked by a flood event, caused by either a water level rise or tectonic subsidence.

After 3 200 BC, the water level would drop and the bay would have become habitable again for the Early Bronze age people to establish a settlement nearby (Dimitrov et al., 2020). This prolonged human activity in today's harbour of Sozopol gives us evidence for the fluctuations of the Black Sea and the human adaptation to changes in their environment.

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Modeling Last Interglacial notch formation in Orosei, Sardinia

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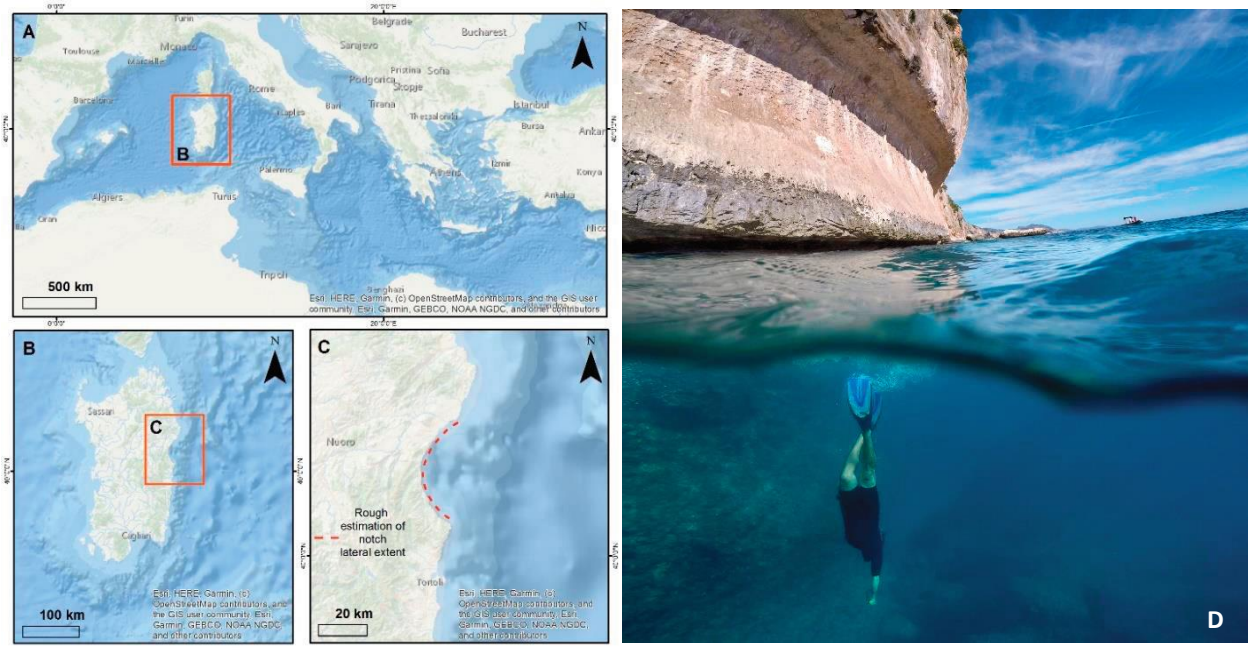

Picture of the Orosei notch and the subaqueous environment (diver: Paolo Stocchi, credits: Nikos Georgiou).

Imprints of the Last Interglacial (127-116ka BP) are carved on the Orosei Gulf limestones in Sardinia in a lateral extent of 60 km, under the form of a “fossil” tidal notch (Antonioli et al. 2018, Ferranti et al. 2006, Rovere et al. 2016). The best preserved part of the notch was mapped in detail using the Structure from Motion - Multi-View Stereo (SfM-MVS) reconstruction method, showing the “double notch” geometry and a maximum height of 10.5m. Although its geometry is laterally constant, the notch depth differs due to local factors. Different approaches, including a geometric (based on Schneiderwind et al. 2017) and a numerical model were used to simulate the Orosei notch formation. Data derived by photogrammetry together with local parameters, were used as input in the models that simulate the notch shape, based on randomly sampled relative sea-level (RSL) curves using the Monte Carlo simulation (Eckhardt, 1987). The modeled RSL curves that best simulated the measured notch were those characterized by a bimodal geometry. The study of this Last Interglacial notch is considered crucial to better understand past changes in sea level, which are in turn significant to better gauge and track the sea-level variations in future slightly warmer climate conditions.

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A submerged river channel in coastal zone of the Pärnu Bay, Baltic Sea record low relative sea levels in Holocene

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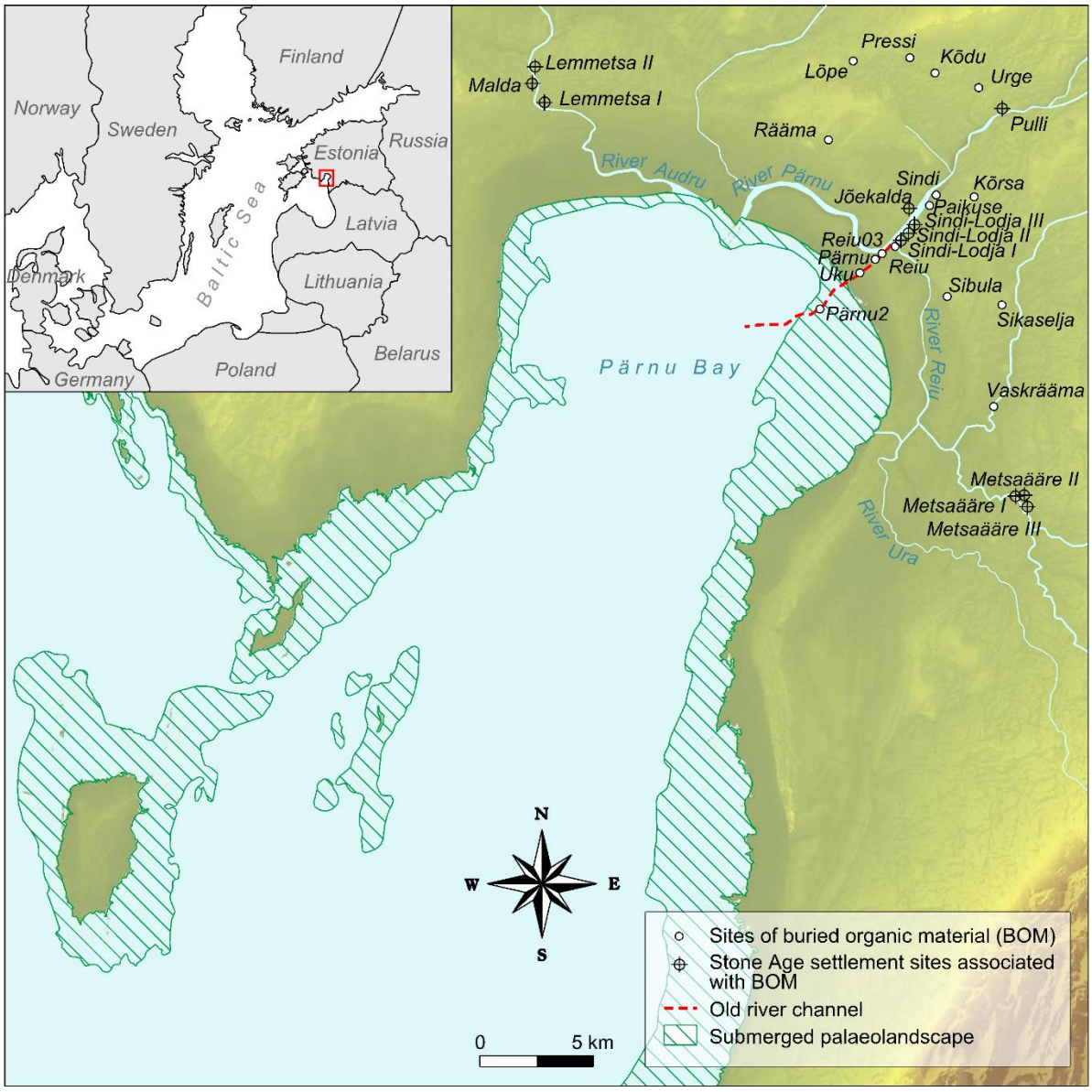

Location and topography of the study area with the locations of the Stone Age settlement sites and sites with buried organic matter (Nirgi et al. 2020). The hatched area was potentially exposed before the Litorina Sea transgression, i.e. this is the area where it is possible to locate submerged landscapes.

The Baltic Sea underwent significant changes during Holocene due to the melting of the continental ice sheet, the up-damming and drainage of the basin, and glacial isostatic land uplift. As a result of uneven glacial rebound, the prehistoric coastal landscapes in the southern Baltic Sea are submerged, while in the north, they are uplifted. Between these extremes, the competition between glacial isostatic land uplift and eustatic sea-level rise caused the altering of transgressions and regressions. As a result, the terrestrial landscapes with associated coastal settlements were inundated by the Ancylus Lake (*ca* 11–10.2 cal. ka BP) and the Litorina Sea (*ca* 9–7.5 cal. ka BP) transgressive waters and occur above or below present-day sea level.

A buried river channel with organic-rich infill was discovered in SW Estonia (Figure 1; Nirgi *et al.* 2020). It was mapped and studied on the coastal lowland and the shallow seabed of Pärnu Bay (up to 5 km offshore) to complement the Holocene RSL curve and reconstruct the local environment at the time of the infill deposition. According to the RSL data from the Pärnu area, the water level dropped at least down to –5.5 m a.s.l. before the Ancylus Lake transgression and then rose about 18 m during the transgression (10.7–10.2 cal. ka BP), with the average rate of rise about 35 mm/yr. Before the Litorina Sea transgression, the RSL was at least –4 m a.s.l. and then rose *ca* 14 m during the transgression (8.5–7.3 cal. ka BP), with the average rate of rise about 12 mm/yr. The palaeogeographic reconstructions show the settlement patterns of the coastal landscape since the Mesolithic and provide a new perspective for looking for Mesolithic hunter-fisher-gatherer settlement sites on the banks of the submerged river channel at the bottom of the present-day Pärnu Bay.

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Postglacial Relative Sea-Level databases from polar and sub-polar regions. A key tool to quantify the on-going isostatic signal along global coastlines

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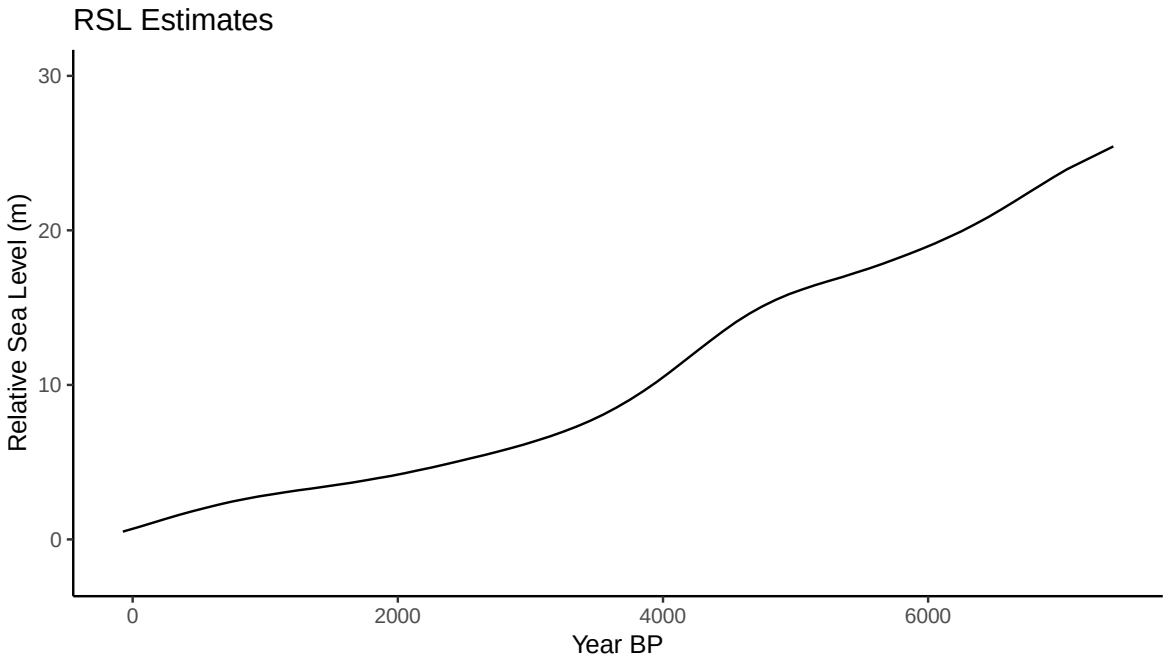
Reconstructions of relative sea level (RSL) since the last glacial maximum (~21 ka BP) have implications for investigation of crustal movements, calibration of earth rheology models, and the reconstruction of ice sheet extent, thickness, and deglacial chronology. These data provide a framework for developing our understanding of the primary mechanisms of RSL change during the last millennia and a long-term baseline against which to gauge the changes in sea level observed during the 20th century. Here, we present the results of recently compiled databases from polar and sub-polar regions (e.g., near field sites) and, in particular, the northeastern Canada and the Ross Sea area in Antarctica.



Statistical analysis of the post-glacial RSL evolution in the Ross Sea

Our re-evaluation of sea-level indicators from geological and archaeological investigations have yielded more than 700 RSL data points, comprised of sea-level index points and marine/terrestrial limiting data. The indicators are derived mainly from salt and freshwater marshes or adjacent estuarine sediment, isolation basins, marine terraces and beach ridges. We outline some of the common difficulties and provide potential solutions to analyse sea-level data in such different depositional environments.

In particular, we emphasize problems related to the definition of standardized indicative meaning (i.e., the relationship between the indicator and paleo mean sea level) and to the re-evaluation of old radiocarbon samples.

We further applied an innovative empirical Bayesian spatio-temporal statistical models to this large dataset. The application of the model to RSL index points with wide spatial and temporal coverage enables calculating rates of RSL change through time and space (averaged 1 ka time-steps).These results provided new insights into the pattern of on-going GIA processes in these key near field regions.

Introducing the TESTEREP project: the evolution of a former peninsula along the Belgian coast as a case study in the development and sustainable management of the coastal landscape

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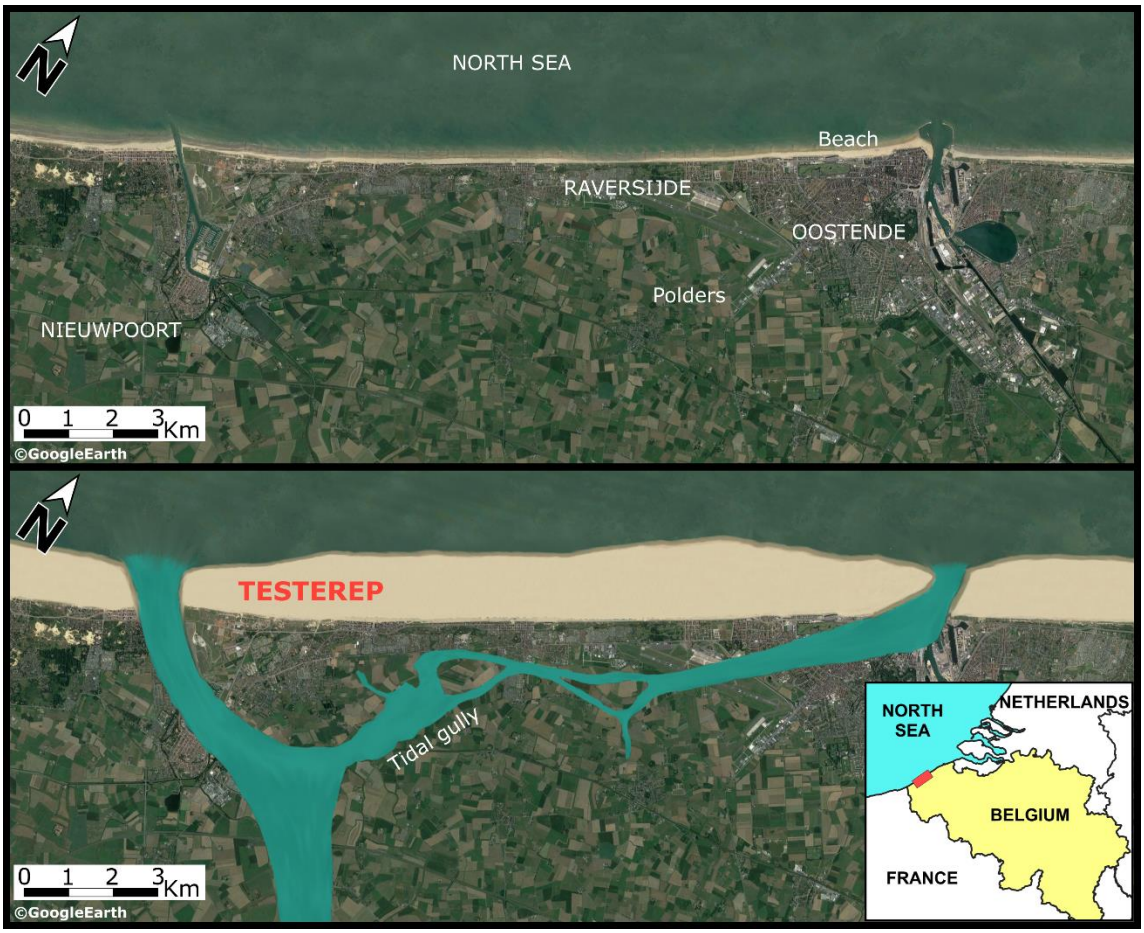

Hypothetical reconstruction of the Testerep peninsula superimposed on the present-day situation showing the location of the polders, beach and sea.

This presentation will give a general overview of the TESTEREP project, studying 5000 years of Belgian coastal evolution. Geological, sedimentological, and paleoecological research as well as historical and archaeological studies have led to a general understanding of the Holocene evolution of the Belgian coastal plain and the way people have interacted with this changing landscape.

However, existing research usually concentrates on either the onshore or the offshore. Questions about the interaction between on- and offshore geomorphological changes and the human impact on the landscape remain unanswered both on short- and long-term scales. With the TESTEREP project, we aim to address these shortcomings through novel interdisciplinary research across the land-sea border. Testerep was once a peninsula located off the middle part of the Belgian coast, separated from the mainland by a broad tidal gully from the Iron Age until the embankment in the Middle Ages. Today, this tidal gully is silted up and the landward part of the peninsula has become part of the polders and beach, while the seaward side is submerged. In order to study the evolution and eventual demise of Testerep over the past 5000 years, existing data on historic natural (e.g. palaeo-gullies) and artificial (e.g. embankments) features will be supplemented with new on- and offshore data, including LiDAR, geophysical surveys, coring and excavations. All information will be integrated through GIS analyses and will form the basis for morphological and hydrodynamic modelling. This will result in palaeogeographic maps and give insight into the driving factors behind landscape change. The project includes a large outreach component, leveraging the multidisciplinary knowledge to raise public awareness about coastal dynamics and current threats through innovative virtual landscape reconstructions, to stimulate blue tourism, support heritage management, and inspire sustainable coastal management strategies for the future.

Coastal Valleys From The North-West Black Sea Bring New Data On The Upper Pleistocene Highstands Of The World Ocean

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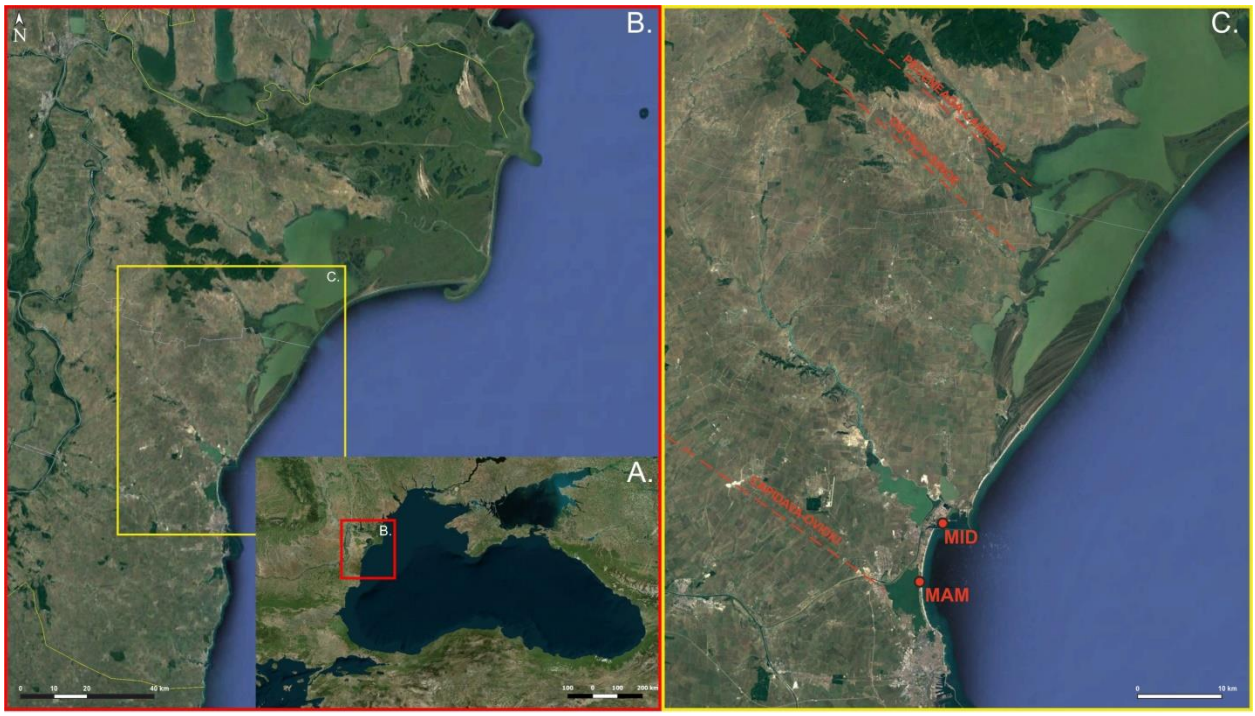

Study Area – Drill position (MID & MAM) on the western Black Sea coastal barriers

This study presents the multi-proxy results obtained on a 50-m drill from the Midia (MID) coastal barrier closing the Casimcea river valley (Tașaul Lake), one of the oldest Black Sea tributaries, draining the Paleozoic Casimcea plateau. We used a multi-proxy methodology combining sedimentology (texture, LOI, MS), geomorphology (morphometric analysis for identifying terraces), geochemistry (XRF, ^{18}O) and paleo-ecology (meiofauna, pollen) to identify and describe the facies associations. The new data were compared with another regional deep drill (MAM drill, 52 m) positioned 8 km south of the Mamaia barrier (Caraivan et al., 2012). The two stratigraphies reveal a longshore sequence that captured most of the paleoenvironmental changes which affected the western Black Sea coast during the Upper Pleistocene – Holocene; MID core stratigraphy shows a deep-incised valley cut under the stress of major sea-level oscillations.

Here, we present new data on the Black Sea level evolution during the MIS 5 – Holocene (especially on MIS5e, 5a highstands) and discuss the MIS 3 interval (60-29 ka), which was characterized by fast and intense climatic and eustatic changes that affected the environment and the human dispersal in Europe and Asia. One of the major controversies concerns the sea-level reconstruction during MIS3 where most of the direct (sedimentary) evidence of the paleo-coastline did not fit the sea-level reconstructions based on ^{18}O data from deep-sea cores, the latter ones generally producing sea levels no higher than 75-40 m below the current level. Both coastal barriers (MID and MAM drills) show two marine (transgressive) horizons at depths of 20-25 m and 40-46 m b.s.l.. The upper one presents an increased salinity and Meditteranean meiofauna corresponding to the last Pleistocene reconnection with the World Ocean. It is still uncertain if this layer formed during MIS5a or MIS3 highstands and new absolute ages (OSL) are in progress to compare with the preliminary AMS measurements. Considering the two drills belong to the stable old Casimcea Plateau (as proved by the morphometric analysis of the terraces), the present results might elucidate the maximum level recorded globally during MIS 3 and MIS5a highstands.

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Geodiversity hotspots and Geoconservation on coastline environments: Mapping and Quantitative Assessment in Cilento (Italy)

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Cilento, Vallo di Diano and Alburni UNESCO Global Geopark coast.

Geoconservation concerns the protection of those elements of geodiversity having geoheritage value for scientific reasons, but also as educational, cultural and ecological resource (Gordon, 2019). The International Union for Conservation of Nature (IUCN) recognizes geodiversity as an important paramenter in nature conservation (Crofts et al., 2020). The areas of high geodiversity have a key role to preserve high biodiversity under future environmental alteration due to ongoing climate change. In this frame, the coastal geodiversity hotspots typifying part of the Vallo di Diano and Alburni UNESCO Global Geopark (Southern Italy) (Valente et al., 2021) were mapped. Threats related to natural and man-made hazards were also analyzed after the method proposed by Bétard & Peulvast (2019) adapted to the coastal environment.

Two numerical indices were calculated using Geographical Information System approach: the geodiversity index (GI) and threat index (TI). The GI is the sum of four sub-indexes: geological diversity (rocks, minerals, fossils), geomorphodiversity (topography and landscape), pedodiversity (soils) and hydrodiversity (surface and underground waters). The TI is calculated as the sum of three sub-indexes regarding the level of environmental protection, the coastal erosion and subsidence (Di Paola et al., 2021). They were summarized in a geodiversity sensitivity index (SI) that allow to draw attention to the most geodiverse areas under the higher threat. Finding geodiversity hotspots could help to direct conservation efforts, allowing to identify the most threatened coastal areas and exposed to the impact of climate change. The geodiversity conservation is fundamental goal to promote a proper management and conservation of nature on a long-term prospective.

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A new approach for studying past sea-level changes using molecular fossils

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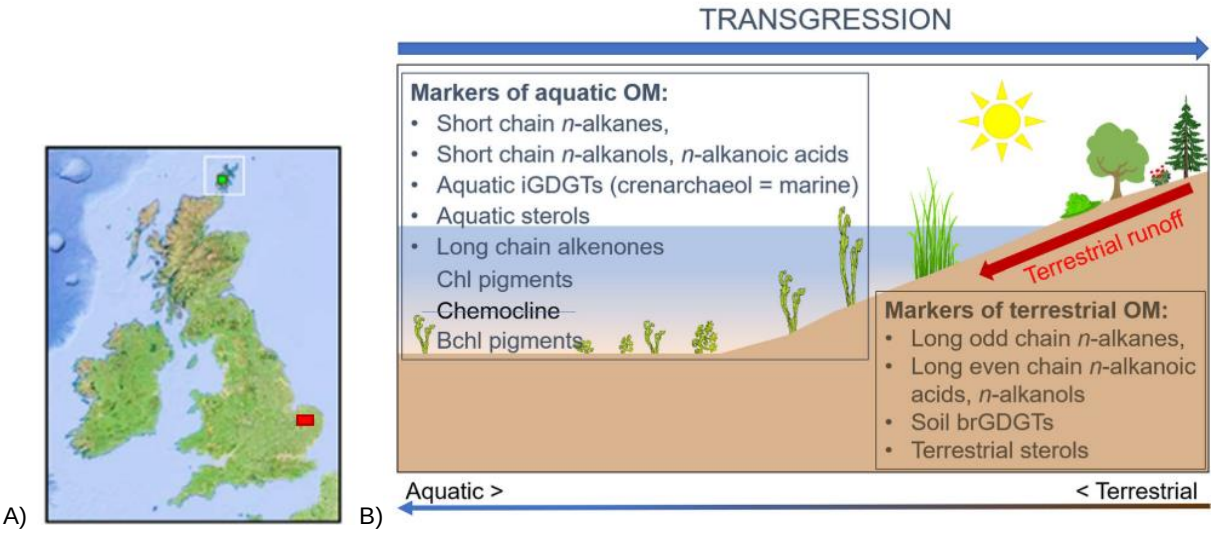

A) Map of the British Isles showing the Loch of Stenness (green square, Holocene) and Nar Valley (red rectangle; Middle Pleistocene) sediments analysed in this study; B) Summary of key biological markers used in this study and their association with particular organic matter sources. Abbreviations: OM=organic matter; iGDGTs = isoprenoid glycerol dialkyl glycerol tetraethers; Chl = chlorophyll pigments; Bchl = bacteriochlorophyll pigments; brGDGTs = branched glycerol dialkyl glycerol tetraethers (from Conti et al., 2020).

Targeted analysis of organic matter in soils and sediments is useful for evaluating past environmental conditions, as specific compounds may be directly linked to organisms and hence to the conditions in which they inhabited the environment. Variations in molecular fossil distributions have become a powerful tool for understanding changes in palaeoclimate conditionsv (Killops and Killops, 1993). This work uses molecular fossils to give an insight into the impact of transgressive events on primary producers inhabiting the studied basin, and hence a more detailed record of sea-level change.

The cores studied consisted of unconsolidated immature sediments from the mid-late Pleistocene (< 500,000 years) and the Holocene (Barlow et al., 2017; Conti et al., 2020). Molecular fossils, such as chlorophyll pigments and lipids, exhibit fluctuations as a response to changes in palaeoenvironmental conditions, providing a useful marker for sea-level changes. Fluctuations in the pigment (Keely, 2006) and *n*-alkane (Cranwell, 1973) distribution reflect changes in primary producer activity, while the GDGT-based index of branched and isoprenoid tetraether lipids (BIT) differentiates between terrigenous and marine organic matter inputs (Hopmans et al., 2004).

Lipids were analysed by gas chromatography-flame ionisation detection (GC-FID) and high-performance liquid chromatography-mass spectrometry (HPLC-MS) while analysis of chlorophyll pigments was carried out using a new ultra-high performance liquid chromatography-diode arrary detection (UHPLC-DAD) method.

The results from biomarker analyses show excellent time-resolved agreement with previous lithological and ecological studies, but enabled a more sensitive response of different primary producers to changing conditions to be observed. The molecular fossils were able to detect the onset and cessation of the studied transgressions earlier than it was possible with microfossil evidence. Linking the pigment and lipid record with more secure dating will enable a more accurate record of Quaternary relative sea-level change.

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Underwater 3D modeling using an array of multicameras in shallow waters

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The study of underwater environments involves several scientific fields such as marine-biology, hydrography, geology, and cultural heritage (Menna et al., 2018). All these disciplines need to know and then to represent the morphology of the environment with a specific level of detail. Numerous instrumentations and methods have been developed for surveying the seabed and for modelling the underwater environments. All these methodologies are basically based on sonar and optical measurements. In recent years this latter type of measurements has been widely employed for surveying small underwater areas, providing a three-dimensional model with a high level of detail (Figueira et al., 2015). Since the 3D model is obtained acquiring several images from different poses the final level of detail is related to the image quality and the footprint of the pixel on the scene. Moreover, this methodology can be carried out using consumer cameras, calibrated appropriately (Shortis, 2015). Generally, in order to define and to check the correct scale of the 3D model, calibrated scale bars or objects with known dimensions are positioned in the scene (Troisi et al., 2015). Unfortunately, this procedure cannot be easily performed everywhere, as for example on vertical wall or when the operations involve an archaeological site. In this work, to overcome such problem, an alternative procedure is illustrated using an array of synchronized cameras. The array it was designed by attaching four action cameras at four vertices of a rectangular aluminium frame. Such frame is calibrated in laboratory to find the relative distances as well as the relative pose orientation among cameras station using a specific calibration test field. During the survey, the synchronization ensures that in the same moment each camera acquire an image, thus the scale constrain is generated by the relative cameras' distances. Furthermore, such approach can be performed for surveying floating objects and/or half submerged areas with a non-invasive technique (Menna et al., 2011).

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Interpolating Electronic Navigational Chart depth data to model the North-East sector of the Gulf of Naples bathymetry.

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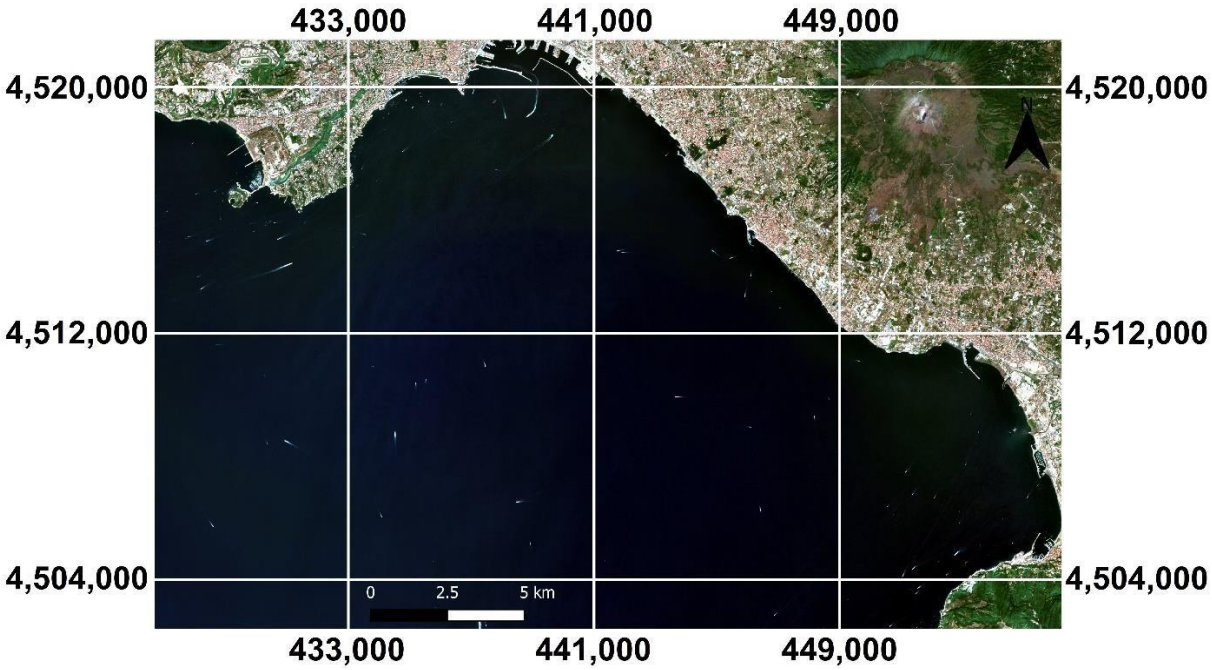

Sentinel-2 true color composition of the study area (Gulf of Naples, North-East sector) referred to UTM-WGS84 (Zone 33N) plane coordinates.

The knowledge of the sea depths is of fundamental importance for various reasons such as monitoring of natural disaster effects, geophysical purposes, safety of navigation, etc.

The maps used for navigation, i.e., the Electronic Navigational Chart (ENC), make available important distinctive elements for knowledge of the seabed. However, they do not provide a continuous sea-floor model.

Those elements are depth points and contours lines both supplied in vector format. These data comply with the standard specifications dictated by the International Hydrographic Organization (IHO).

A continuous 3D model of the seabed can be generated from these data, by performing interpolations. In this way we can generate a Digital Bathymetric Model (DBM) structured as a grid where the depth value is present in each node (Parente and Vallario, 2019).

In literature, interpolation methods are essentially divided into deterministic and stochastic. The choice of the best one cannot be made a priori but must be evaluated each time.

The aim of this work is to compare deterministic as well as stochastic methods, all applied on the same dataset obtained from an ENC produced by Hydrographic Institute of the Italian Navy, with a scale of 1: 30,000 in the north-east area of the Gulf of Naples (Figure reported above).

We utilize two deterministic methods, namely Inverse Distance Weighting (IDW) and Radial Basis Function (RBF), and two stochastic methods, Universal Kriging (UK) and Ordinary Kriging (OK) (Alcaras et al., 2021). The experiments are carried out using Geographic Information System (GIS) software, obtaining 4 models.

The accuracy evaluation is performed using the leave-one-out cross-validation method, where each known point is dismissed from the dataset and the other known points are used to interpolate the depth value at its location; the residual is calculated between measured and interpolated values before moving to the next point (Alcaras et al., 2022). In this way, we provide the statistical values (Table reported below).

The experiments confirm that the best performance is supplied by stochastic methods, particularly the Universal Kriging provides more accurate results.

	Min (m)	Max (m)	Mean (m)	St. Dev. (m)	RMSE (m)
IDW	-77.183	56.279	-0.260	3.237	3.248
RBF	-69.378	38.063	-0.091	2.607	2.608
OK	-49.000	33.991	-0.017	2.305	2.306
UK	-48.670	41.671	-0.001	2.298	2.298

Statistical values of the residuals produced by interpolation methods.

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Applications of seismic reflection method support the reconstruction of a coastal landscape associated to outstanding Palaeolithic settlements

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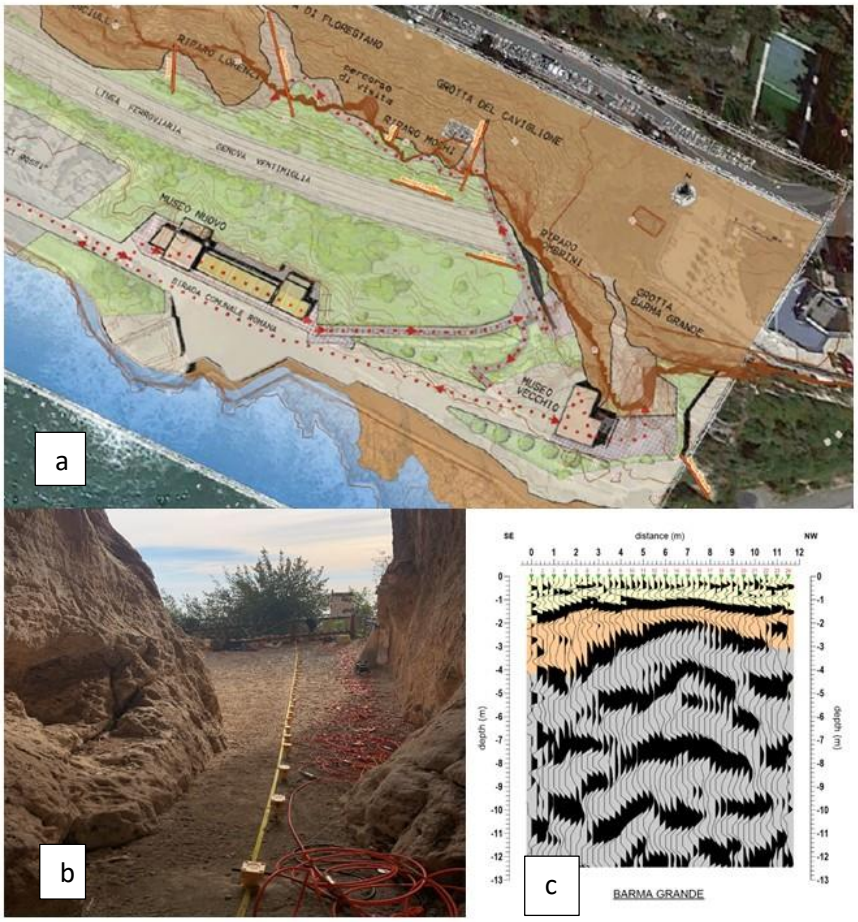

a) *Plan view of the seismic lines; b) the seismic line inside the Caviglione cave; c) interpreted section resulting from the Barma Grande cave survey (in grey the bedrock).*

Palaeolandscape reconstructions associated to the main phases of Palaeolithic human attendace of coastal regions are ongoing in the Balzi Rossi archaeological site, along the NW coast of the Mediterranean (Liguro-Provençal coast), in the framework of the SPHeritage project (Pappalardo et al., 2022). Within this site a number of sea-facing caves and rock shelters preserve geomorphological evidence of past interglacials and witness traces of human exploitation occurred during Mid-Upper Pleistocene intervening temperate and cold climate phases. In spite of 150 years of archaeological investigation in the area, a comprehensive overview of sites stratigraphy is still missing. Particularly, correlation between the stratigraphy of each cave-site has been hampered by numerous excavation leaders and strategies overtime and a loss of knowledge regarding the actual position and shape of the bedrock beneath the archaeological deposit. This problem was overcome through the execution of seven ultra-shallow seismic reflection surveys. Seismic reflection is a geophisical exploration method succesfully used in shallow applications with good resolution and cost effective results. This technique has been previously employed in paleosismological studies to recognize the fault plane at depth, and to characterize the attitude of the bedrock surface and the internal architecture of the overlying clastic deposits (*Nirta et al., 2021)*. However, its use in archaeological contexts is rare. Critical to the method success is that the type of energy source, receiver spacing and data acquisition parameters are appropriately selected. Generally reflections occur at boundaries between geologic layers with high density contrast. In this study, a control run over a 4.20 m long vertical section exposing the archaeological deposit, enabled us to directly calculate the velocity parameter of the debris to underlying bedrock. We were then able to calculate bedrock depth for additional sections using this value. At some sections, major discontinuities were identified within the deposit. Our results, for the first time, suggest the actual thickness of archaeological deposits in the area.

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Present-day tidal notch elevation: the water level bias

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Measuring of current tidal notch along the coast of Lampedusa Island.

Tidal notches are thought to form at the sea level, with well-defined morphometric features with respect to the sea level reference. Antonioli et al. (2015) described the morphometric parameters of more than 70 tidal notches in the Mediterranean area. Anyway, some variations can occur. In particular, at the southern coast of Lampedusa (Pelagie Islands, Sicily Channel), the southernmost island in Italy, the tidal notch occur along the entire limestone and calcarenite coastline. During geomorphological surveys within the Geoswim programme (Furlani, 2020), at two small bays (Cala Madonna and Cala Croce), the tidal notch shows the typical morphology outside the bay, while inside it deepens occurring at a semi-submerged to submerged position, about 10-30 cm below mean sea level. Antonioli et al. (2017) described the same phenomenon at Sormiou and Cassis (France), with very similar bathymetric values and tidal notch morphology evolution and amplitude. In fact, the tidal notch also tends to narrow from a width of 70-50 cm to 30-40 cm inward.

We can hypothesize two different factors that cause these morphological anomalies: 1) uknown hydrodynamic phenomena that are very frequently established to allow the formation of the notch under certain conditions of fetch, wind, waves, tide, pressure and shoreline morphology; 2) chemical dissolution phenomena due to the presence of conspicuous freshwater springs from the most distal part of the canyon floating on the water surface and eroding the notch. In the future, the installation of a tide gauge that would measure tidal fluctuations, currents, and wind over time over the course of at least a year might be the way to obtain a more thorough understanding of the strange and mysterious mechanisms that influence tidal notch elevations at Lampedusa.

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Palaeo-landscapes offshore Belgium: the search for the former Testerep peninsula

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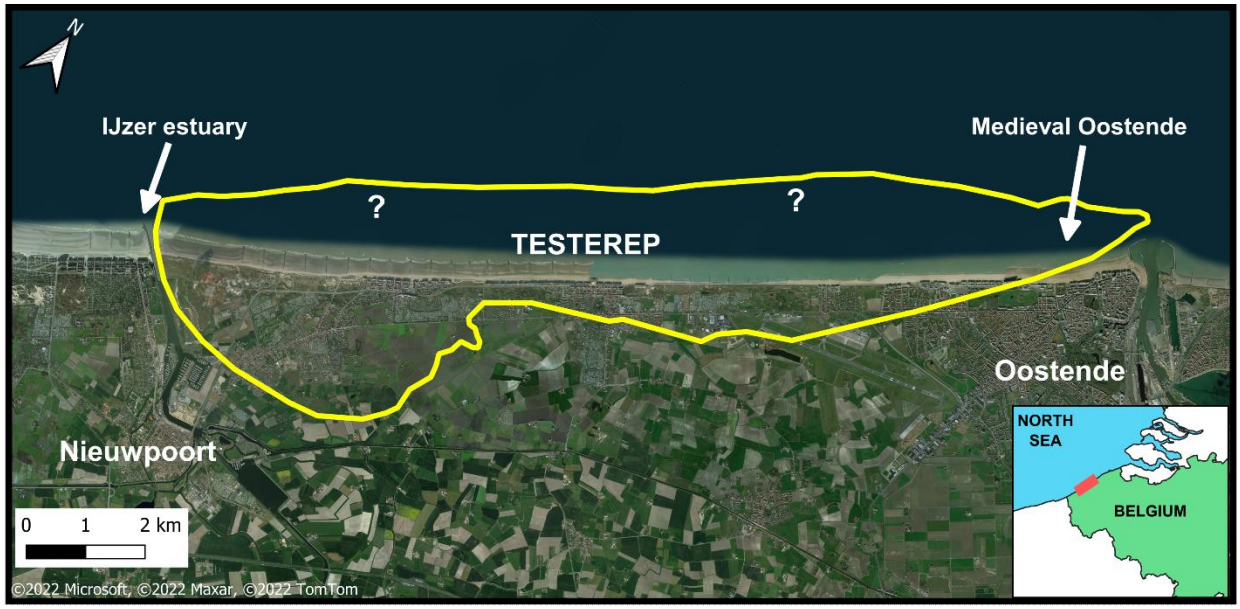

Hypothetical reconstruction of the Testerep peninsula on the coastal plain of Belgium.

Understanding coastal response to relative sea-level rise is key to planning for future changes and developing a suitable management strategy. Sedimentary records of the Holocene transgression provide a natural laboratory to study long-term changes in coastal landscapes. This is one of the aims of TESTEREP, an interdisciplinary research project focusing on the evolution of the Belgian Middle Coast during the past 5000 years. A large peninsula, known as Testerep, was once located between the coastal cities of Nieuwpoort and Oostende, bordered by the IJzer estuary and a tidal gully. As a relic of the former tidal environment, it is an ideal test case because many aspects of the coastal evolution have left traces in the landscape. However, many questions remain, for example, the exact location of Testerep's former coastline remains unclear because a large part of the peninsula was swallowed by the sea, including the medieval city of Oostende The combined analysis of high-resolution seismic profiles and sediment cores, complemented with radiocarbon dating, has been used to investigate the submerged extent of the former peninsula. Preliminary results point to complex landscapes buried beneath the seabed. Large-scale channels and bars are preserved offshore of the IJzer estuary, revealing the location of the palaeo-valley. Broad prograding bodies are found parallel to the present-day coastline overlying a flat sub-horizontal surface, probably corresponding to old coastal barriers. A dynamic tidal environment is preserved at their back, dissected by small tidal creeks.

Here, acoustic anomalies recognised in the seismic records allowed the identification of three levels of peat deposits, which represent former land surfaces subsequently drowned by the sea, the lower one dating to 8 ka cal BP. The reconstruction of the evolutionary phases of these paleo-landscapes will allow investigation of the potential preservation of archaeological features offshore and the patterns of erosion and deposition that drove the retreat of the coastline.

Morpho-structural analysis of Capo Faro Promontory cliff (Salina island Italy)

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Rock fall along the Capo Faro Promontory cliff.

In the study hereafter presented (Bonasera et al., 2022), a morphostratigraphic and structural analysis along the Capo Faro Promontory cliff was carried out. The studied cliff is located in the NE sector of Salina, Aeolian Islands (Italy), which is visited by thousands of tourists every year. The area is characterised by a flat surface right on the scarp edge of the coastal cliff. Such a cliff is affected by a rapid cliff retreat due to frequent landslides. The aim of the work is to investigate the hazard affecting the cliff and define the structural characteristics (e.g., rock mass discontinuities) which influence the stability of the rock wall. Remote sensing analysis by UAV flights have been integrated to support the field activities producing high-resolution Digital Elevation Model and bathymetric-topographic profiles along the coastline facing the cliff. In addition, a detailed reconstruction of the volcanic deposits thickness allows to create a geological model of the cliff. The results will contribute to planning risk mitigation measures.

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Amino acid geochronology of bivalve shells

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A) 

B) 

A) Map showing the location of collection of Arctica islandica *in the North Sea off the coast of Scotland; B) photo of a sample of* A. islandica *used for amino acid geochronology.*

The SEACHANGE project is a multidisciplinary project that aims to reconstruct marine ecosystems prior to and after significant cultural transitions. These transitions represent prehistoric and more recent changes, such as the transition from hunting and gathering (Mesolithic) to farming (Neolithic) in the North Sea basin, or changes in marine biodiversity/ecosystem caused by shifts in aboriginal culture prior to and after western influence in Queensland (Australia) after AD 1770. For robust geochronology, radiocarbon dating of organic material, cross-matched and cross-dated sclerochronology (dating of hard tissues of shells) are employed.

Cross-matched floating sclerochronologies (not precisely calendar-dated) can provide annual resolution records spanning decades to as much as 500 years for the longest-lived shells (Scourse et al., 2006; Butler et al., 2009). Developing such record requires visually and statistically comparing growth ring width patterns (cross-matching) across numerous shell samples. Such an endeavour is hugely time consuming given the unknown antiquity of dead-collected samples. Here we explore the potential for range-finding age estimates of individual dead shells by amino acid (AA) geochronology. AA dating is a relatively fast and cheap technique, which could be used to constrain the time period for any floating sclerochronologies. Through the study of AA, we can examine the endogeneity of protein within the shells. Previous work on calcareous biominerals has resulted in a robust dating method for the Quaternary period (Penkman et al., 2008; 2011). In SEACHANGE, aragonitic *Arctica islandica* and calcitic *Ostrea edulis* are targeted in the first instance to constrain Mesolithic-Neolithic and Medieval shell middens.

A method to effectively sample these shells has shown variation in amino acid concentration and composition between the two species. Further analysis of the different microstructures within these shells has also shown variation in AA composition. These preliminary results indicate that targeted sampling is necessary to establish a robust and reproducible method for dating *A. islandica, O. edulis* and possibly other bivalve shells.

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Middle to Late Pleistocene sea-level changes and vertical movements along the coastal belt between Formia and Minturno, central Italy

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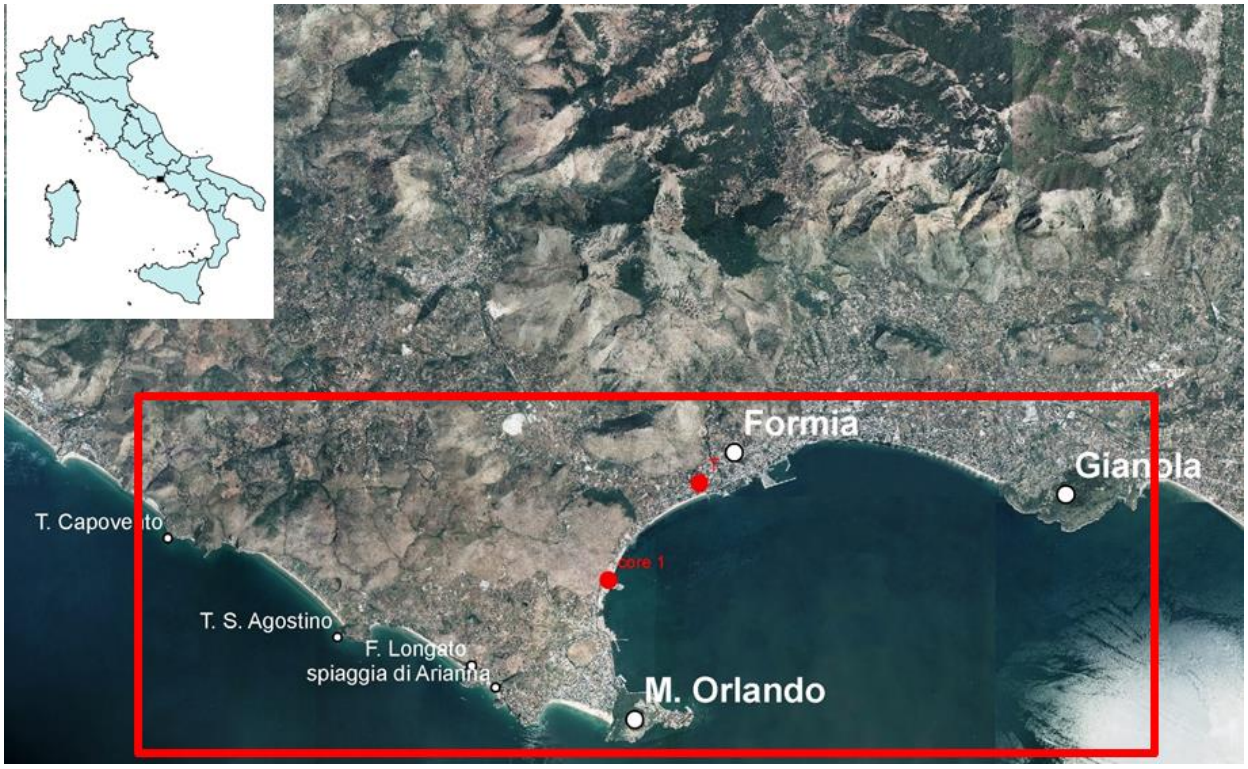

Study area in the southern coastal belt of Latium, Italy.

The southernmost coastal belt of Latium, central Italy (largely corresponding to the so-called “Riviera di Ulisse”), shows many morphotectonic features that may help in recostructing the evolutionary history of this segment of orogenic chain. Here, in fact, many markers of Quaternary sea-level changes are largely exposed. It is an about 30 km-long coastal belt facing to the south and including, from east to west-north-west, the Monte di Scauri promontory, the Gaeta Bay with the Formia-Vindicio plain crossed by several streams, the Monte Orlando promontory, the beach system of Ariana, Arenauta, and S. Agostino shores, separated by minor headlands (Torre Viola, Torre Scissura, San Vito, and Torre Capovento). New data came from the portion comprised between Gianola to the east and Vindicio to the west (Formia town). The coastal belt ranges from the sea level to about 30 m a.s.l. and is geologically constituted of several Quaternary (pre-Holocene) units, partly cropping out in the inner portion of the study area, and by a Holocene sequence known only by well logs.

The whole south-facing arched coastal plain of Formia is relatively narrow being immediately bordered at its back by an impressive mountain ridge (Aurunci Mts) made of Mesozoic-Cenozoic carbonate rocks and terrigenous units. A new geological survey associated to detailed measures of sea-level markers has been carried out along the Gaeta Bay coastline, from Vindicio plain to Monte di Scauri promontory (respectively to the west and the east of Formia town) and at Monte d'Argento in the Minturno plain. In the Vindicio area, a carbonate clastic deposit, never reported before in the maps of this sector, has been found at about 17 m a.s.l.: petrographic analysis of thin sections of these sediments suggests a deposition in an intertidal littoral environment as beachrock deposits. Different cementation facies indicate an early cementation in a littoral environment followed by supratidal main cementation. Altough this formation is similar to the marine carbonate-bioclastic deposit often morphologically hung along the coasts of southern Italy (the so-called "panchina carbonatica" Auctt.), the 230Th/234U isotopic analysis has revealed a Late Pleistocene (pre-Tyrrhenian) age for it. Such a deposit may be attributed to the Late Pleistocene (MIS 7.5), so testifying a recent and intense tectonic activity. As a matter of fact, the brittle deformation of this rock body produced a faulted staircase affecting also the weathered horizon of the calcarenite developed at least during or after the warm climate conditions of MIS 5. Therefore, it can be assumed that the area of Vindicio underwent a significant tectonic stage in Quaternary times, with an average uplift rate of 0.2 mm/yr. At Monte di Scauri and Monte d'Argento sites fossil notches, lithodome holes, beach deposits, and other geomorphological markers are well-exposed along the rocky cliffs and locally displaced by faults. Also between Gaeta and the Circeo promontory, at an elevation ranging from 5 to 10 m a.s.l., other sedimentary and morphological markers are largely present (Ozer et al., 1987; Antonioli, 1991; De Pippo et al., 2007; Schiattarella et al., 2016; Corrado et al., 2022). All these data allowed us to complete the framework of the morphotectonic evolution followed to the uplift occurred in the Middle to Late Pleistocene and indicate that the area was subject to a remarkable tectonic activity also during the Tyrrhenian up to the MIS 5.1.

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Influence of wave conditions and defence structures on the evolution of the Molise coastline (southern Italy)

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Coastal erosion has complex reasons and is often linked to both natural and anthropogenic factors. Sea level changes due to ongoing global climate change and/or soil subsidence are among the most studied natural controlling factors. Nevertheless, anthropogenic causes are probably the most common ones. In fact, the coastal equilibrium is conditioned by the reduction of sediment supply, whose distribution and availability is mainly controlled by the channel evolution of major watercourses feeding the coast, the presence of coastal defence and maritime structures, and the local marine climate.

This study aims to compare data acquired about erosion susceptibility, local erosion rates, and coastal defence works implemented over time, to better understand their role in coastal erosion of a section of the Molise Region coastline.

The 36 km long Molise coast (central Adriatic, Italy) is part of the physiographic unit Punta Penna–Punta Pietra Nere, and is limited northwards by the Formale del Molino channel and southwards by the Saccione Stream. Beaches are present almost along the entire coastline and made of moderately sorted sands. This coast has undergone, starting from the 1950s, significant shoreline erosion that was strongly triggered by the progressive decrease of fluvial sediment delivery to the coast, and prevailingly affected the sectors including the Trigno and Biferno river mouths. To cope with the ongoing erosion along the Molise coast, the regional government realized several engineering interventions over time. Starting from the 1980s, numerous hard protection structures were built along the coast, primarily adherent and detached (emerged and submerged) breakwaters, and secondarily groins and jetties. In 2014, which quiet well represents the situation today, due to progressive engineering, hard defences cover approximately 62% of the Molise shoreline. Moreover, three harbour structures are present along the Molise coastline, the Marina Sveva, Campomarino and Termoli harbors.

This study illustrates how coastal defence and maritime structures along with local marine climate conditions may have further controlled shoreline evolution. Direct observations of shoreline variations over time and numerical simulations through the model GENESIS, showed that the coast was governed by the wave component 10°N. In fact, the consequent equivalent direction of solid transport, coupled with a net decrease in sediment inputs from the main rivers, and the interference of longshore drift with coastal defences has contributed to increase coastal erosion rates, recorded in particular around the Biferno mouth. Moreover, obtained results show that the bimodality of the wave climate may has significantly influenced the recent beach dynamics, with the more inclined wave components that would be responsible for the genesis of coastal instability that amplifies the erosion phenomena.

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Application of Machine Learning algorithms on Sentinel-2 images for coastline extraction

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Sentinel-2 true color composition of the study area (coastal zone between Campania and Calabria) referred to UTM-WGS84 (Zone 33N) plane coordinates.

In the last decades, machine learning techniques have increasingly spread to many application fields of remote sensing and, more recently, have also involved the extraction of the coastline from satellite images.

This article aims to compare two methodological approaches of machine learning, one unsupervised, the other supervised, represented respectively by the K-Means (KM) and KNearest Neighbour (KNN) algorithms. The KM is a numerical, unsupervised, non-deterministic, iterative method usable for image classification (Alcaras et al., 2021). It attempts to group similar items in the form of clusters; the number of groups is represented by K. The KNN is the simplest supervised machine learning algorithm that can be used to resolve classification problems (Zhang, 2016). It assigns a category to unlabelled observations in the dataset by comparing them to the observations in the labelled samples that absolve to the function of training dataset.

The experiments are conducted on Sentinel-2 satellite images, limited to the bands with the highest geometric resolution (10 meters). The dataset includes also the image resulting from the application of the Normalized Different Water Index (NDWI), which is particularly effective for distinguishing water/non-water. The study area analysed extends from the coastline of Acciaroli (Campania, Italy) to Diamante (Calabria, Italy).

The coastline obtained by manual vectorization on the Sentinel-2 RGB composition is the term of comparison for evaluating the result accuracy. The Distributed Ratio Index (DRI) (Alcaras et al., 2022) is applied for this purpose. It represents the deviation between the reference coastline and the extracted one: the lower the value, the higher the accuracy.

The results show a better performance of the KNN compared to the KM when using the visible and infrared bands (RGBNIR), confirming the effectiveness of the training sites. KM and KNN provide the best results when applied to the NDWI layer alone. DRI values are expressed in meters as that they can be compared with the spatial unit of the pixel, i.e. 10 m, to establish the accuracy of the extracted coastline. The unsupervised approach on NDWI provides more accurate results.

Method	Mean (m)	St.Dev. (m)	RMSE (m)	Min (m)	Max (m)
KM(NDWI)	2.295	1.542	2.764	0.000	14.610
KM(RGBNIR)	4.106	4.660	6.210	0.000	64.278
KM(RGBNIR+NDWI)	4.013	3.967	5.643	0.000	44.536
KNN(NDWI)	2.576	2.082	3.312	0.000	22.332
KNN(RGBNIR)	3.453	4.014	5.295	0.000	41.229
KNN(RGBNIR+NDWI)	2.938	2.917	4.140	0.000	34.425

Statistical values of DRI for the extracted coastlines.

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First results on coastal paleolandscape and position of relative sea level of Gaeta Bay (Southern Italy) during the Roman period by geoarchaeological and geomorphological data

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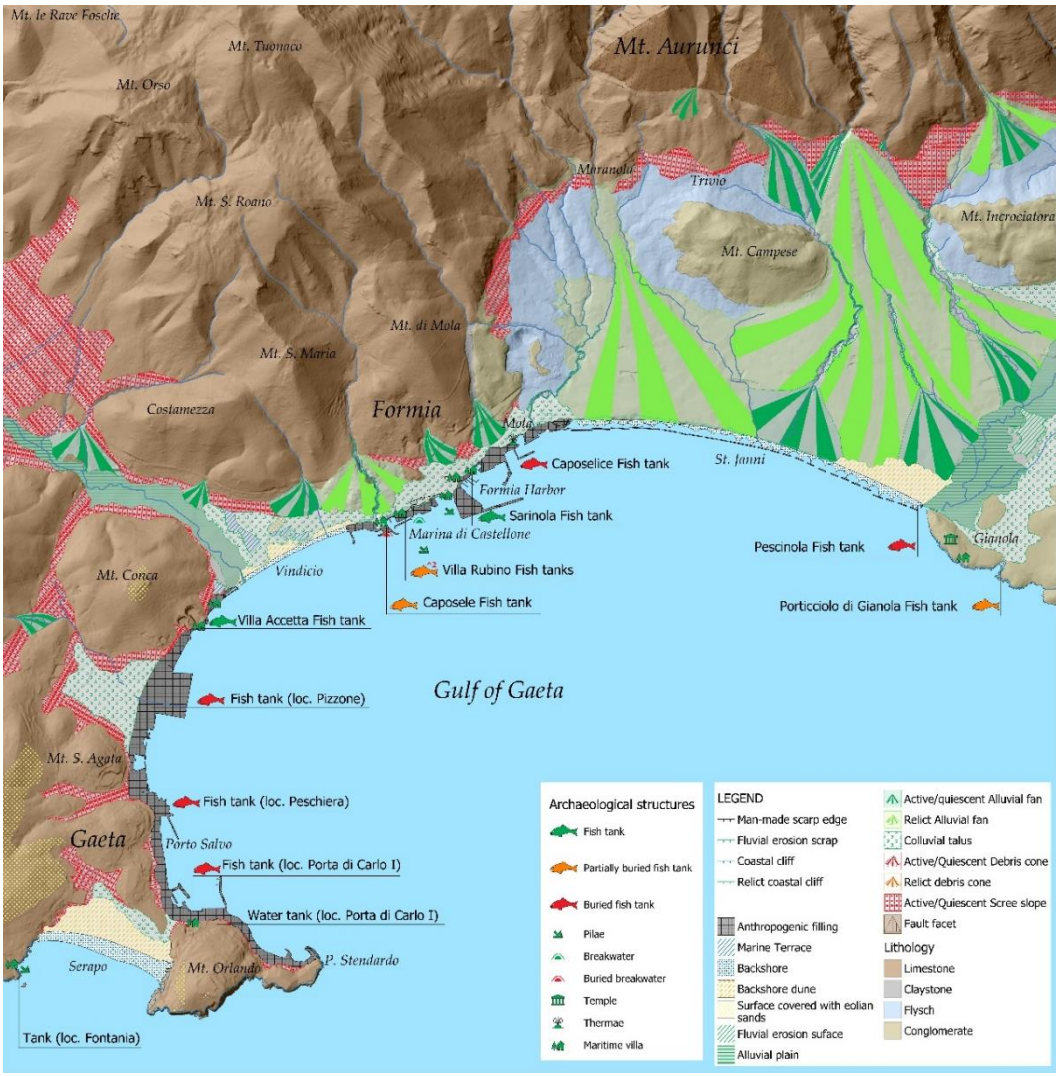

The figure shows geomorphological map based on LiDAR (2 m resolution) which include the main archaeological structures identified in the study area

This research aims to present first data regarding the relative sea level variations and related morpho-evolutive trends of the Formia coastal sector in the Gaeta Bay, southern Latinum (Italy), since Roman times, through a multi-technique approach using several geomorphological and archaeological elements.

The study area is located along the eastern sector of the Aurunci Mts, that represent the southernmost portion of the Volsci Range (Cardello et al., 2020). The Aurunci Mts. are bounded to the SE by a set of N-S and E-W, and NE-SW striking extensional faults, defining a S- to SE-dipping system that has in its hanging wall a basin formed by the Formia plain (Tavani et al., 2021).

The coastal landscape of the Gaeta Bay is the result of a significant tectonic control and the structural features derived from this activity are overlain by slope and littoral morphogenetic processes. In the narrow coastal plain of Formia in few kilometres there are the accumulation forms developed along valleys deeply cut in the carbonate slopes (Corrado et al. 2022).

The Formia costal area hosts several roman archaeological structures, also underwater, dated mostly from the 1st century BC, so several direct archaeological measurements were carried out both on the coastline and in the underwater portion. Several different fish tanks were identified, dated around 1st century B.C.: marina of Gianola (Formia), Sarinola (harbour Formia), Villa Rubino (Caposele harbour), Villa Accetta (Gaeta), and Roman MSL is estimated to be −0.55 ± 0.29 m modern MSL.

The geoarchaeological interpretation of these remains integrated in a GIS software with a historical sources, ancient pictures and maps and high-resolution geomorphological analysis from Lidar, allowed detecting and dating of ancient position of relative sea level (RSL), reconstructing some sectors of paleo shoreline, during roman age (1st century B.C.).

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Deep learning techniques for seafloor classification and mapping using marine ARGO drone.

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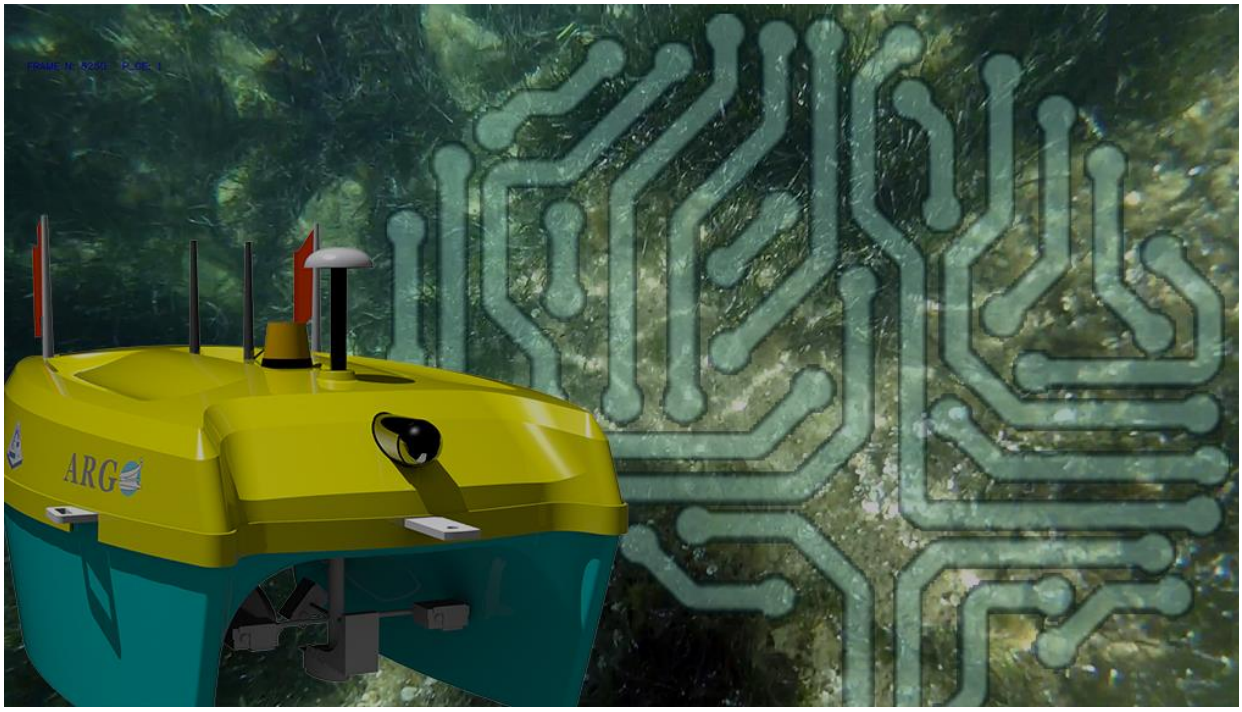

Deep learning techniques using marine ARGO-USV.

This research falls in the framework of ARGO-USV technological project aimed at testing innovative methodologies for integrated marine investigations in shallow water sectors usually considered critical areas to be investigated by using traditional survey boats.

The study aims to integrate the marine geomorphological and environmental data collected through the ARGO-USV (Unmanned Surface Vehicle for ARchaeological GeO-application), with those deriving from the use of AI (Artificial Intelligence) and Deep Learning techniques applied to video analysis and aimed to characterize the submerged sectors of wide coastal areas minimizing the impact on these environments.

The first case study here presented is finalized to characterize some benthic marine habitats, such as Posidonia Oceanica meadows.

The main classification models used in this work are based on One-Class Classifier (OCC) and Convolutional Neural Network (CNN), the latter, as verified in the testing phase, are better suited for image classification.

Embedded devices based on ARM processors were used as hardware to run classification algorithms. The starting point, on which this work walks, is to create a cluster of devices installed on board the USV to distribute the computational load to the individual devices, in charge of performing elementary operations, such as the classification of a single class, that in the case study here presented it is Posidonia Oceanica.

The final purpose is to obtain an extensive and integrated mapping of coastal areas. In this context, the class – detection of Posidonia Oceanica is a first example of a real-time classifier that will later be part of a broader classifier structure, in order to allow the classification of different types of environments and submerged landforms or anthropic features.

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The analysis of past experience in Taranto (Southern Italy) as a key for defining guidelines for the geo-environmental characterisation of contaminated coastal sites

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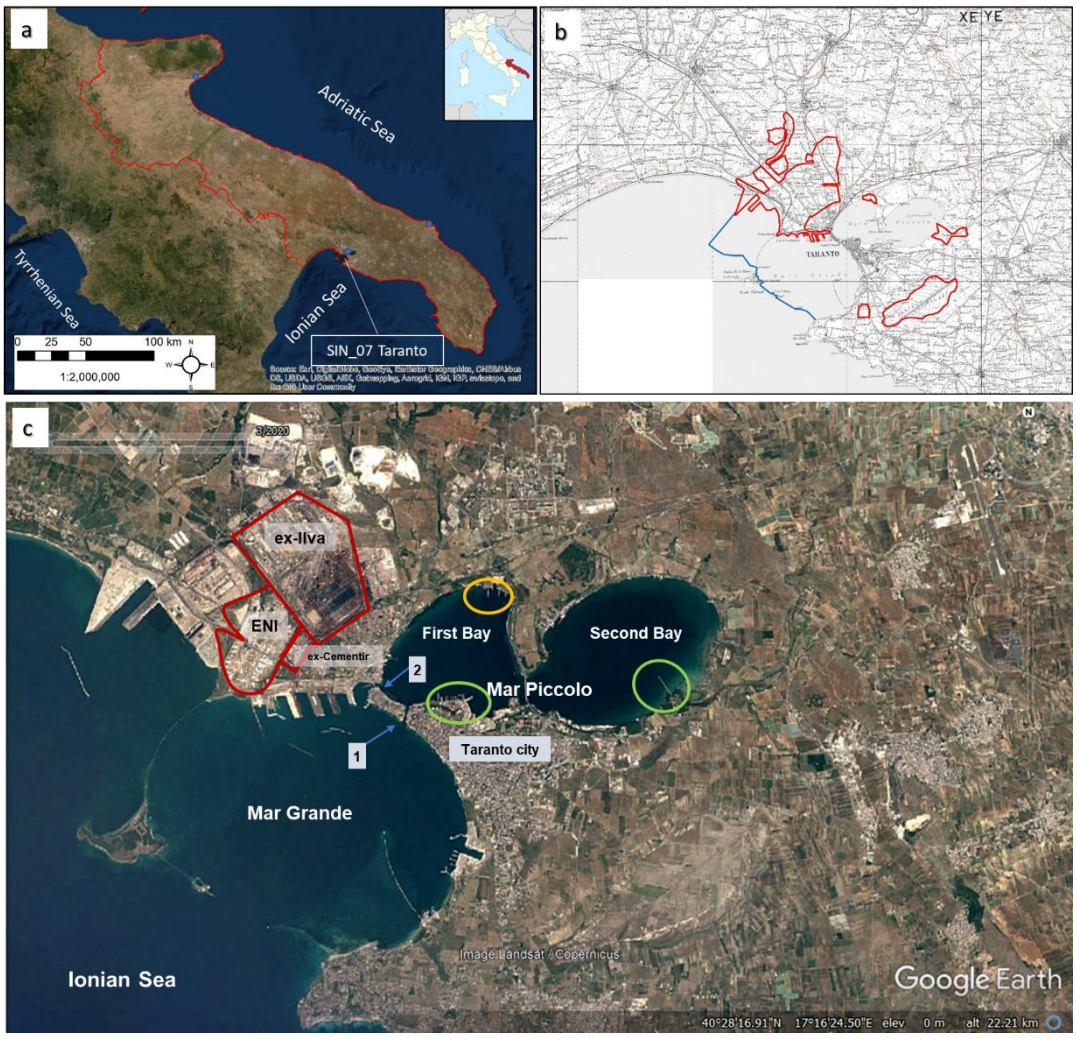

a) Study area location. b) Perimeter of SIN_07 "Taranto". The red line identifies the inland perimeter while the blue line identifies the seaward the main anthropogenic activities located in the study area. The seaward perimeter of SIN_07 "Taranto" is indicated as a blue line.

Despite its remarkable geomorphological, ecological, and touristic value, the coastal sector of the Apulia region (Southern Italy) hosts three of the main contaminated Italian sites (Sites of National Interest, or SINs), for which urgent environmental remediation and reclamation actions are required. These sites are affected by intense coastal modification and diffuse environmental pollution due to the strong industrialisation and urbanisation processes that have been taking place since the second half of the XIX century. The Apulian coastal SINs, established by the National Law 426/1998 and delimited by the Ministerial Decree of 10 January 2000, include large coastal sectors and marine areas, which have been deeply investigated by the National Institution for the Environmental Research and Protection (ISPRA) and the Regional Agency for the Prevention and Protection of the Environment (ARPA) with the aim of obtaining a deep environmental characterisation of the marine matrices (sediments, water, and biota). More recently, high-resolution and multidisciplinary investigations focused on the geo-environmental characterisation of the coastal basins in the SIN Taranto site have been funded by the “Special Commissioner for the urgent measures of reclamation, environmental improvements, and redevelopment of Taranto”. In this review, we propose an overview of the investigations carried out in the Apulian SINs for the environmental characterisation of the marine matrices, with special reference to the sea bottom and sediments. Based on the experience gained in the previous characterisation activities, further research is aimed at defying a specific protocol of analysis for supporting the identification of priority actions for an effective and efficient geomorphodynamic and environmental characterisation of the contaminated coastal areas, with special reference to geomorphological, sedimentological, and geo-dynamic features for which innovative and high-resolution investigations are required.

Geoarchaeological study of the south-western coastal sector of Campi Flegrei and its periphery.

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Photos taken during our indirect and direct surveys at Punta Pennata islet, with archaeological remains clearly visible.

Campi Flegrei, located within the Gulf of Pozzuoli (SW Italy), is one of the most active volcanic districts of the Mediterranean basin and is characterized by sudden vertical ground movements that have locally exacerbated the glacial-hydro-isostatic sea-level rise since the late Pleistocene.

In this research, a geoarchaeological study of the coastal sector between Torregaveta Promontory and the western margin of Miseno Cape, located in the peripherical area of Campi Flegrei caldera, was carried out through a multi-technique approach.

Along this coastal sector, several archaeological remains, witnessing the past Roman occupation, were deeply studied to investigate the ancient sea levels. In particular, at the foot of Torregaveta Promontory, the ruins of an ancient Roman maritime villa, dated back to the second half of the first century BC, are still visible. Among these, the fish tank and the nymphaeum were surveyed by specialized scuba divers in order to interpret them as archaeological sea-level markers.

At Miseno Cape, a direct and indierct survey were carried out between Dragonara cave and Punta Pennata islet, where the remains of several fish tanks are located and interpreted as sea-level index points. For thi scope, prototype of a marine drone (ARGO engineered in the Parthenope University laboratories) equipped with acoustic and optical sensors was used in order to obtain a multi-scale high-resolution mapping of both the underwater landscape and archaeological structures.

This data was crucial to reconstuct the morpho-evolutive model of the south-western sector of CF caldera never studied before as well as to interpret the relative sea-level variations and related coastal changes during the Late-Holocene. The comparison with the GIA models available for the study area, allowed assessing a differential overall subisdence between the inner and outer coastal sectors of CF occurred in the last 2100 years. Finally, all the data were crossed with bibliographic studies on low coast sectors in order to reconstruct the paleo-geographic scenario of this complex coastal sector during the Roman Age.

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