Routledge
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Environmental Archaeology

The Journal of Human Palaeoecology

ISSN: 1461-4103 (Print) 1749-6314 (Online) Journal homepage: www.tandfonline.com/journals/yenv20

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To cite this article: A. Bivolaru, C. Morhange, A. Baralis, V. Lungu, P. Poveda, T. Sava & M. Vacchi (18 Nov 2025): Reconstructing Late Holocene Environmental Changes in the Southern Danube Delta (Black Sea, Romania): Implications for Harbours and Navigation Potentialities in Antiquity, Environmental Archaeology, DOI: 10.1080/14614103.2025.2586268

To link to this article: https://doi.org/10.1080/14614103.2025.2586268

Published online: 18 Nov 2025.

ENVIRONMENTAL ARCHAEOLOGY
https://doi.org/10.1080/14614103.2025.2586268

Reconstructing Late Holocene Environmental Changes in the Southern Danube Delta (Black Sea, Romania): Implications for Harbours and Navigation Potentialities in Antiquity

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ABSTRACT
This paper presents a novel paleo-environmental reconstruction of the Razelm-Golovița lagoon system, focusing on the harbours and navigation conditions of the Greek Archaic settlements of Orgame and Caraburun-Acic Suat. By analyzing three new sedimentary cores, we examine the Late Holocene evolution of the lagoon system, shedding light on previously unexplored aspects of navigation and accessibility. Our findings show that the settlements were positioned along a naturally protected shallow lagoon, which effectively functioned as a natural anchorage, influenced by the flow of the Dunavăț branch, the main distributary of the Danube in Antiquity. While Orgame maintained access to the sea via inlets in the Periteașca littoral spit, Caraburun-Acic Suat remained isolated from the sea due to the Zmeica and Lupilor coastal ridges. Additionally, our reconstruction of the paleo-water column suggests that Bisericuța island may have served as a trans-shipment hub or outer harbour, facilitating the transfer of goods from river mouths or the open sea to smaller draft vessels suitable for navigating the lagoon's shallow waters.

ARTICLE HISTORY
Received 14 February 2025
Revised 22 October 2025
Accepted 1 November 2025

KEYWORDS
Geoarchaeology; Paleo-environment; RSL; Ancient harbours; Black Sea; Greek colonisation

Introduction

The Razelm-Golovița lagoon system, located in the southernmost part of the Danube delta (W Black Sea coast) has a history of long-term human occupation along its shores (Baralis and Lungu 2015; Micu et al. 2016, 2022). Several Greek Archaic settlements are found on its shores, including Orgame, Baia 2 and Caraburun-Acic Suat. These sites are located in a very dynamic deltaic waterscape, so their history of occupation is entangled with numerous environmental fluctuations. Prior investigations of the Danube delta have predominantly focused on its geomorphological evolution and have provided regional-scale paleo-environmental reconstructions (Bivolaru 2020; Giosan et al. 2006; Panin, Ion, and Ion 2005; Vespremeanu-Stroe et al. 2017), while some studies, such as those by Bony et al. (2013; 2015), have adopted a meso-scale approach by examining the evolution of Danube delta lobes and their impact on Orgame's harbour. Our paper aims to contribute to the field by presenting a comprehensive palaeo-environmental reconstruction of the Razelm-Golovița lagoons at site-level with a focus on the harbours of Orgame and Caraburun-Acic Suat and the navigation conditions in Antiquity in the southern Danube delta.

Study Area

The studied archaeological sites are located in the south-eastern maritime sector of the Danube delta (Figure 1). This region is characterised by fluvio-maritime spits and ridges and a complex of lagoons including Razelm, Golovița, Zmeica, and Sinoe (Figure 1). Internal divisions within the Razelm-Golovița lagoons are delineated by Zmeica and Lupilor beach-ridge plains, while Golovița and Zmeica lagoons are separated by the Zmeica barrier (Figures 1 and 2). These lagoons, relatively shallow with Razelm lagoon reaching a maximum depth of approximately 3.1 m and Sinoe lagoon around 2.2 m (R. Dimitriu et al. 2008), are separated from the Black Sea by the Periteașca littoral barrier. Historically, the lagoons were connected to the sea through the natural pass of Gura Portiței before its artificial closure in the 1970s (Figure 1). Presently, seawater ingress occurs only during storm events.

From Greek Colonies to Roman Settlements

The archaeological site of Orgame is located on a limestone cliff, Cape Dolojman, on the western shore of Razelm lagoon (Figure 2). The cape features a north-

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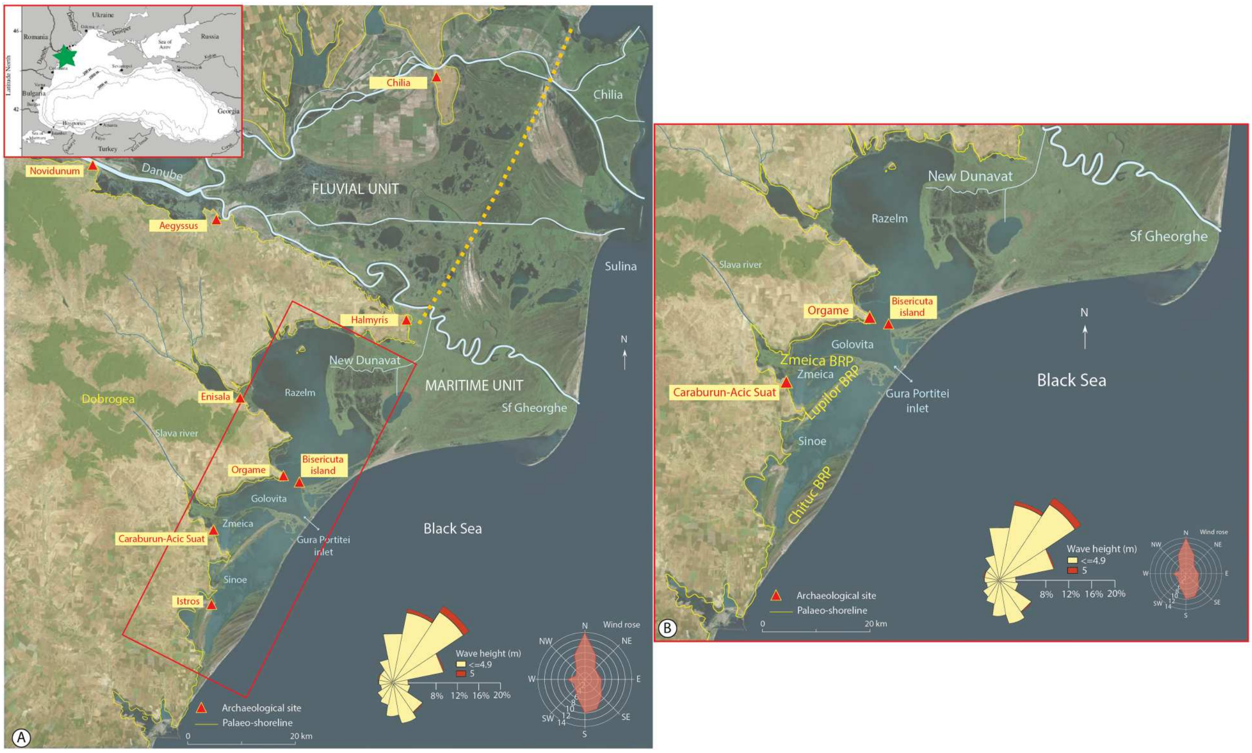

Figure 1. (A) Geomorphological map of the Danube delta with the two main units – fluvial (western) and maritime (south-eastern). (B) The main geomorphological units in the study area. In the vignette, the location of the Danube delta at Black Sea basin level.

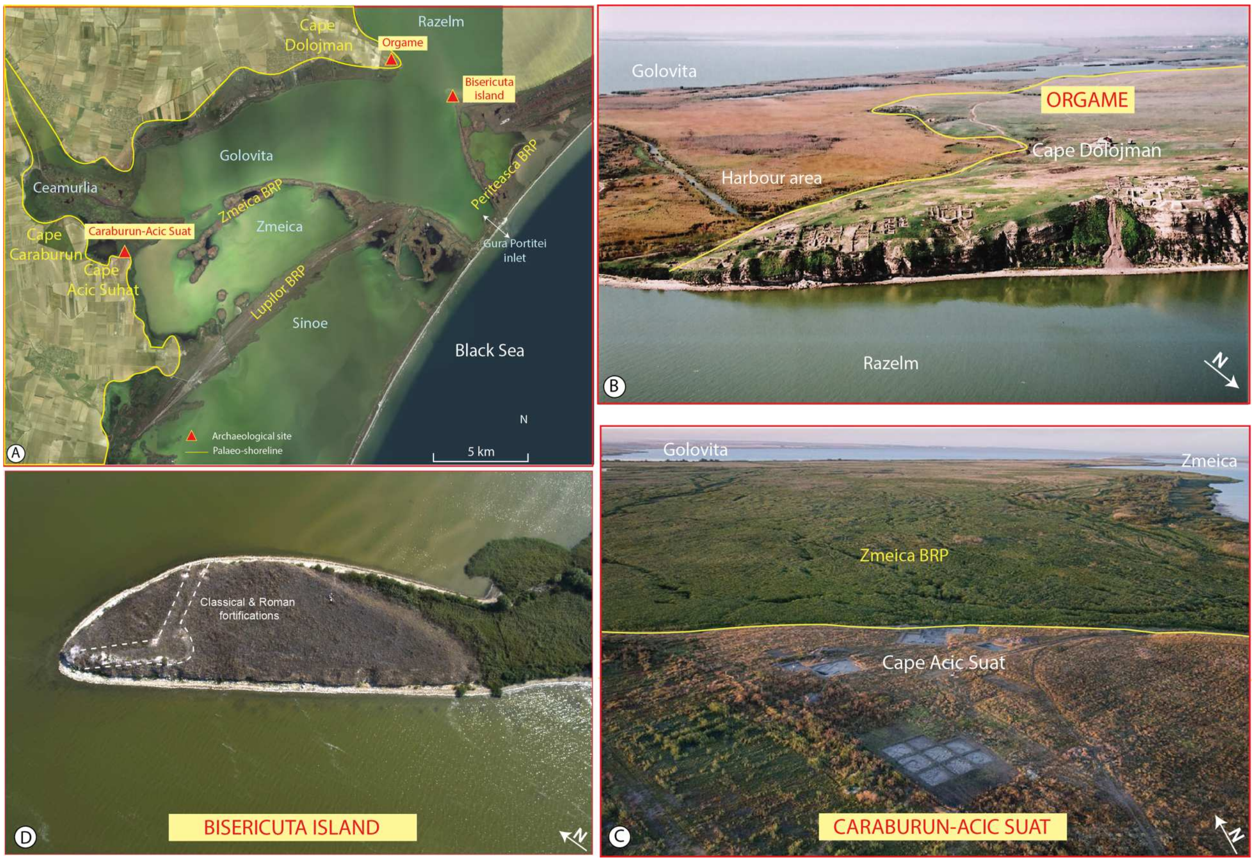

Figure 2. (A) Sites position and the main geomorphological units of the Southern Danube delta. (B) Aerial view of Orgame and Cape Dolojman. (C) Aerial view of Caraburun-Acic Suat and Zmeica beach-ridge plain. (D) Aerial view of Bisericuta island. (Photo credits: www.limenproject.net, L. Damelet, CCJ, courtesy of Franco-Romanian archaeological mission to Orgame, Louvre Museum-IESEE, Mario Hölz).

to-south slope, descending from 55 to 5 metres. Founded in the mid-seventh century BC, Orgame is one of the oldest Greek colonies in the Black Sea. The site saw significant development during the late Classical and early Hellenistic periods (fourth–third century BC). In the second century AD, it was referred to as Argamum in the *horothesia* of Istros (ISM I 69), marking an Early Roman presence, though few structures from this time have been excavated (Coja 1972; Iacob 1999). The Late Roman and Proto-Byzantine periods (fifth–seventh century AD) saw expansion to about 2.5 hectares within fortified walls and a significant suburb. Decline set in by the mid-seventh century AD due to geopolitical instability and Slavic migrations (Suceveanu and Barnea 1991) (Figure 3).

The Caraburun-Acic Suat settlement, situated on the Acic-Suat promontory between Istros and Orgame, is flanked by three lagoons: Ceamurlia, Golovița, and Zmeica (Figure 2). The promontory is surrounded by the Zmeica barrier system, a marshy plain with reeds. Founded in the mid-sixth century BC, the Archaic settlement lasted until the early fifth century BC, followed by a period of abandonment (Baralis et al. 2011; 2017). It was reoccupied in the late fourth century BC and continued until the early third century BC (Lungu 2019). During this period, the area was sparsely populated, lacking urban planning and primarily featured terraced dwellings (Baralis et al. 2017; Baralis and Lungu 2015). The settlement was destroyed around 270 BC during a conflict, evidenced by found arrowheads and fire traces (Baralis et al. 2017). The site was abandoned for about four centuries until a Roman settlement, probably a *vicus*, emerged in the second century AD. Roman habitation was more structured, with buildings arranged around key structures, showing an expansion southward and a more organised layout compared to earlier periods (Baralis et al. 2017). This Roman phase marked the last significant occupation, with the site abandoned by the third century AD (Figure 3).

Bisericuța island, a rocky limestone islet situated in the Razelm lagoon approximately 2.5 km in front of Orgame (Figure 2), spans approximately 2 hectares and is oriented on a north-northwest to south-south-east axis. The southern portion of the island is flat and covered with reeds, while the northern segment rises to approximately 9 metres, featuring steep edges on three sides, with a gentler slope only towards the south-southeast. Two fortifications were identified on the northern part of the island, one dated back to the Classical Greek period (fifth–fourth century BC) and another from the second – sixth century AD. Additionally, evidence of High Medieval occupation, dating from the tenth – twelfth century AD, has been discovered. However, archaeological investigations on the island remain limited (Barnea 2000; Mănucu-Adameșteanu 2003).

Materials and Methods

Coring and Bio-Sedimentological Analysis

The palaeo-environmental reconstruction was based on the analysis of three long continuous sediment cores: one from Orgame and two from Caraburun-Acic Suat (Table 1, Figure 3). Coring was conducted using a Cobra TT percussion corer. The core lengths range from 400 to 700 cm. Each core was positioned

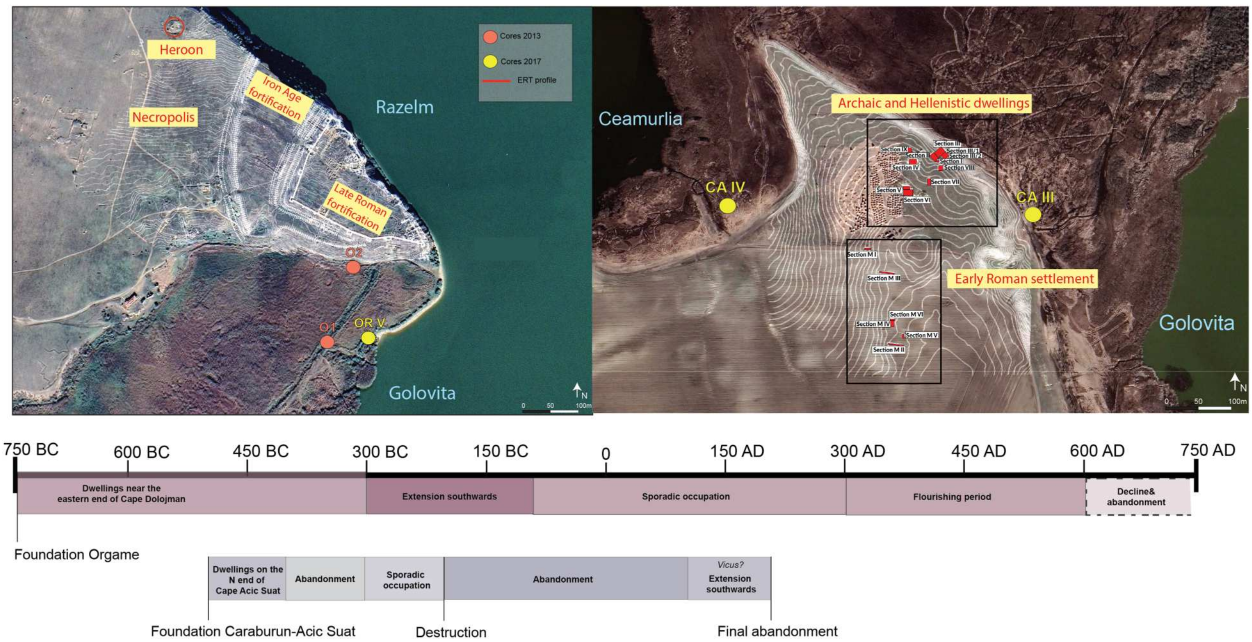

Figure 3. The spatial distribution of the main occupational phases and cores position at Orgame (left) and Caraburun Acic-Suat (right). Below, a comparative chronology of the sites' occupation.

Table 1. Position and length of the studied cores.

Site	Core	Position	Lat Long	Length (cm)
Orgame	OR V	Southern extremity of the beach, south of Cape Dolojman	44.755238; 28.940910	700
Caraburun-Acic Suat	CA III	Southeast side of Acic-Suat promontory in the marshy area	44.674082; 28.775943	410
	CA IV	Western side of Acic-Suhat hill in the marshy area	44.674516; 28.769684	500

using a GPS, and described in the field in terms of colour, texture, homogeneity/heterogeneity, and compaction. The cores were sampled on-site with a sampling interval of 5–10 cm, depending on the collected sediment. A total of 93 samples were collected from Orgame and 80 from Caraburun-Acic Suat. Each sample was dried, weighed, and wet sieved using apertures of 2 mm and 50 microns to determine the granulometry: gravel (>2 mm), sand (<2 mm and >50 µm), and silts/clays (<50 µm). The granulometry of the sandy fraction was obtained on dry sediment with the help of three sieves, with decreasing mesh from top to bottom: >500 µm, coarse sand; <500 µm and >125 µm, medium sand, <125 µm, fine sand. The grain-size distribution was statistically analyzed using GRADISTAT (Blott and Pye 2001). We calculated three granulometric indexes: mean grain size (M_G), sorting (σ_1) and skewness (Sk_G).

Sedimentation rates were determined by calculating the minimum, maximum, and average rates using sediment layer thickness and time intervals. Rates were calculated by dividing thickness by time, with the minimum rate from the lowest thickness-to-time ratio, the maximum from the highest, and the average as the mean of all measurements.

The biological proxies used in this study are ostracods, recovered from the medium sand fraction (125–500 µm), and molluscs, extracted from the gravel fraction (>2 mm). Ostracods were identified at the species level by referring to literature on the Black Sea (Boomer, Guichard, and Lericolais 2010; Olteanu 2003–2004; P. A. Opreanu 2003–2004, 2005, 2008; Schornikov 2011) and general references (Atersuch, Horne, and Whittaker 1990; Frenzel, Keyser, and Viehberg 2010; Gliozzi and Grossi 2008; Meisch 2000). Identification of molluscs was done using references by Grossu (1993) and Wesselingh et al. (2019). The Shannon Index (H') for the ostracod assemblages was calculated using the software PAST4.

Loss on Ignition (LOI)

Loss on ignition was used to determine the organic matter and carbonate content of the samples. To combust and ignite the organic matter, a muffle furnace was used. The samples were firstly dried at 105°C and weighed after cooling. Subsequently, organic matter (OM) was combusted at 550°C, resulting in the formation of ash and carbon dioxide. The difference in weight between the dry sediment and the residue after the 550°C ignition represents the organic matter content (Dean 1974; Heiri, Lotter, and Lemcke 2001; Maher 1998). Furthermore, the samples were ignited at 925°C to release carbon dioxide. The carbonate content was calculated by multiplying the quantity of carbon dioxide by 2.27, which represents the ratio between the molecular weight of $CaCO_3$ and CO_2 as described by Dean (1974).

Chronology

The chronology of the cores was established using AMS radiocarbon dating at Poznan Radiocarbon Laboratory and RoAMS Laboratory. In total, 18 ages have been obtained (Table 2). The samples used for dating consisted of various materials, including plant remains, charcoal, peat, and mollusc shells (*Abra* sp. and *Cerastoderma* sp.). The obtained ages, as well as the ages obtained by Bony et al. (2013) were calibrated using OxCal v8.2 with IntCal20 atmospheric curve (Reimer et al. 2020). The marine age reservoir calculated for the Danube delta (498 ± 41; Siani et al. 2000) was extracted before calibration. Subsequently, an age-depth model was developed for cores OR V and CA III using the statistical software R, bacon package (de Blaauw and Christen 2011).

Relative Sea-Level and Paleo-Water Depth

We produced a local sea-level curve by utilising biological proxies and radiocarbon ages. We used mollusc and ostracod assemblages to define the depositional environment. These data were then used to produce a new suite of sea-level data according to the procedure described in Vacchi et al. (2016, 2021). We calculated the paleo-water column by subtracting the paleo-elevation obtained by elevation-age model from the sea level curve obtained using the ICE-6 VM5a geophysical model (Peltier, Argus, and Drummond 2015; Vacchi et al. 2018) that was widely used to predict the sea-level evolution in different Mediterranean areas (Melis et al. 2017; Vacchi et al. 2020). Paleo-water depths were calculated by subtracting the modelled relative sea-level from the fixed core elevation of 0 m a.s.l. using the ICE-6G VM5a glacio-isostatic adjustment curve. To explore the influence of local subsidence, we added cumulative sinking for two constant rates: 0.4–0.6 mm yr^{-1} (Vespremeanu-Stroe et al. 2017) and 1.5–1.8 mm yr^{-1} (modern tide-gauge/leveling; Panin 1998). Subsidence was computed as rate × elapsed time and propagated as ± half-range uncertainties (Table 3). To evaluate the navigability of Razelm-Golovița lagoons in

Table 2. Radiocarbon ages obtained for sediment cores CA III, CA IV, OR V in this study, and previous ages from core O2 by Bony et al. (2013, 2015).

Core	Depth b.s. (cm)	Material	Lab code	Age BP and error	Marine age reservoir	cal 2σ	Remarks
CA III	120–125	Plant remains	Poz-101729	−220 (30)		1735-1806 AD	Accepted
	180–190	Plant remains	Poz-101730	1335 (30)		647-706 AD	Accepted
	220–230	Charcoal	Poz-101549	2275 (30)		296-208 BC	Accepted
	265–270	Charcoal + plant remains	Poz-101731	2460 (30)		598-454 BC	Accepted
	327–337	Charcoal + plant remains	Poz-101732	3990 (30)		2577-2460 BC	Rejected
	393–396	Plant remains	Poz-102508	3340 (30)		1690-1532 BC	Accepted
CA IV	80-90	Typha australis	Poz-100732	185 (30)		1724-1812 AD	Accepted
	120-130	Plant remains	Poz-100733	205 (30)		1728-1809 AD	Accepted
	180-190	Plant remains	Poz-100734	620 (30)		1298-1399 AD	Accepted
	270-280	Plant remains	Poz-100735	2135 (30)		206-50 BC	Accepted
	310-320	Typha australis	Poz-100736	−1195 (23)		1986-1995 AD	Rejected
OR_V	120-130	Plant remains	Poz-100793	385 (30)		1445-1505 AD	Accepted
	272-276	Peat	Poz-100794	5780 (40)		4723-4534 BC	Rejected
	330-340	Plant remains	Poz-100795	2790 (35)		1015-833 BC	Accepted
	370-380	Plant remains	Poz-100797	3150 (30)		1499-1384 BC	Accepted
	413-423a	Plant remains	Poz-100724	4640 (35)		3516-3391 BC	Accepted
	490-500	Plant remains	Poz-100725	5850 (35)		4797-4608 BC	Accepted
	680-690	Shell	Poz-101151	5240 (40)	498(41)	3637-3491 BC	Rejected
O2	145	Plant remains	Lyon-9404	180 (30)		1723-1813 AD	Accepted
	202	Freshwater shell	Poz-43350	2060 (60)		202 BC-83 AD	Accepted
	210	Charcoal	Poz-51364	2575 (30)		808-750 BC	Rejected
	222	Charcoal	Beta-325708	2310 (30)		412-354 BC	Accepted
	282	Charcoal	Poz-51362	2560 (30)		804-747 BC	Accepted
	382	Wood	Lyon-8276	2900 (30)		1210-1005 BC	Accepted
	425	Organic matter	Lyon-9405	3655 (30)		2072-1943 BC	Accepted
	460	Charcoal	Beta-325709	4790 (30)		3638-3525 BC	Accepted
	528	Organic matter	Lyon-8277	6010 (35)		4993-4832 BC	Accepted
	615	Marine shell	Poz-43351	5160 (35)	498(41)	3631-3350 BC	Rejected
	855	Marine shell	Poz-43353	5630 (40)	498(41)	4044-3790 BC	Rejected

Table 3. Paleowater depth estimates (m, mean ± half-range) at Orgame and Caraburun–Acic Suat under GIA-only and two local subsidence scenarios (0.4–0.6 mm yr^{-1}; 1.5–1.8 mm yr^{-1}).

Site	Age cal	GIA-only (m)	0.4–0.6 mm yr^{-1} (m)	1.5–1.8 mm yr^{-1} (m)
Orgame	1000–800 BC	2.90 ± 0.10	4.38 ± 0.30	7.76 ± 0.45
	50 BC	2.45 ± 0.10	3.49 ± 0.21	5.88 ± 0.32
	100 AD	2.25 ± 0.08	3.21 ± 0.19	5.43 ± 0.29
	600 AD	2.00 ± 0.08	2.72 ± 0.15	4.36 ± 0.22
Caraburun–Acic Suat	600–400 BC	2.20 ± 0.10	3.47 ± 0.26	6.37 ± 0.38
	300–200 BC	1.90 ± 0.10	3.04 ± 0.23	5.65 ± 0.34
	700 AD	1.70 ± 0.08	2.37 ± 0.14	3.89 ± 0.20
	1800 AD	1.20 ± 0.05	1.32 ± 0.03	1.58 ± 0.04

Antiquity, we analysed the paleo-water column, relative sedimentation rates, and paleo-environmental data utilising a paleo-environmental age-depth model (PADM) following the methodology developed by Salomon et al. (2016; 2020).

Chrono-Stratigraphic Characterisation of the Cores

Orgame (Figure 4)

Core OR V was subdivided into three chrono-stratigraphic units, with similarities observed between our findings and those of previous studies (Bony et al. 2013, 2015). Earlier research indicates the closure of the marine bay around 3600 cal BP, followed by its evolution into a lagoon environment around 2300 cal BP. The only notable discrepancy concerns the timing of the bay's closure, which our data suggest occurred approximately 300 years later.

Unit A – (700–380 cm, 6600 to 3300 cal BP): the unit is dated to 5850 ± 35 BP (4797-4612 cal BC) at 500 cm, 4640 ± 30 BP (3518-3394 cal BC) at 423-413 cm, and 3150 ± 30 BP (1500-1383 cal BC) at the A-B units boundary. It consists of fine grey micaceous sand (112 *μm* < M_G < 173 *μm*), moderately well sorted ($\sigma_1 = 1.5$), and coarse skewed ($Sk_G = -0.296$). OM (~5%) and $CaCO_3$ (~10%) levels are generally low, except for a bioclastic layer at 380-390 cm with $CaCO_3$ content reaching ~30%.

The ostracofauna is diverse (H' ≈ 2.07) and includes 33 species, with ostracod abundance ranging from 1300 to 9300 valves/10 g. Brackish (*Candona neglecta*, *Pseudocandona compressa*, *Loxoconcha elliptica)*, Ponto-Caspian (*Amnicythere quinquetuberculata*) and euryhaline (*Cyprideis torosa)* species dominate the unit. Molluscs are sparse, primarily represented by brackish *Abra segmentum* and *Cerastoderma glaucum*, with occasional riverine species (*Theodoxus fluviatilis*, *Theodoxus danubialis*, and *Dreissena polymorpha*).

Unit B – (380–140 cm, 3300 to 450 cal BP): the base of the unit is radiocarbon dated 3150 ± 30 BP (1500–1383 cal BC), 2790 ± 35 BP (1018–839 cal BC) at 340–330 cm, and 385 ± 30 BP (1442–1524 cal AD) at the top. The unit shows a fining-up sequence, consisting predominantly of sandy silts and fine sand (106 *μm* < M_G < 163 *μm*), moderately to poorly sorted (σ_1 = 1.9), and symmetrically skewed ($Sk_G = -0.05$). OM

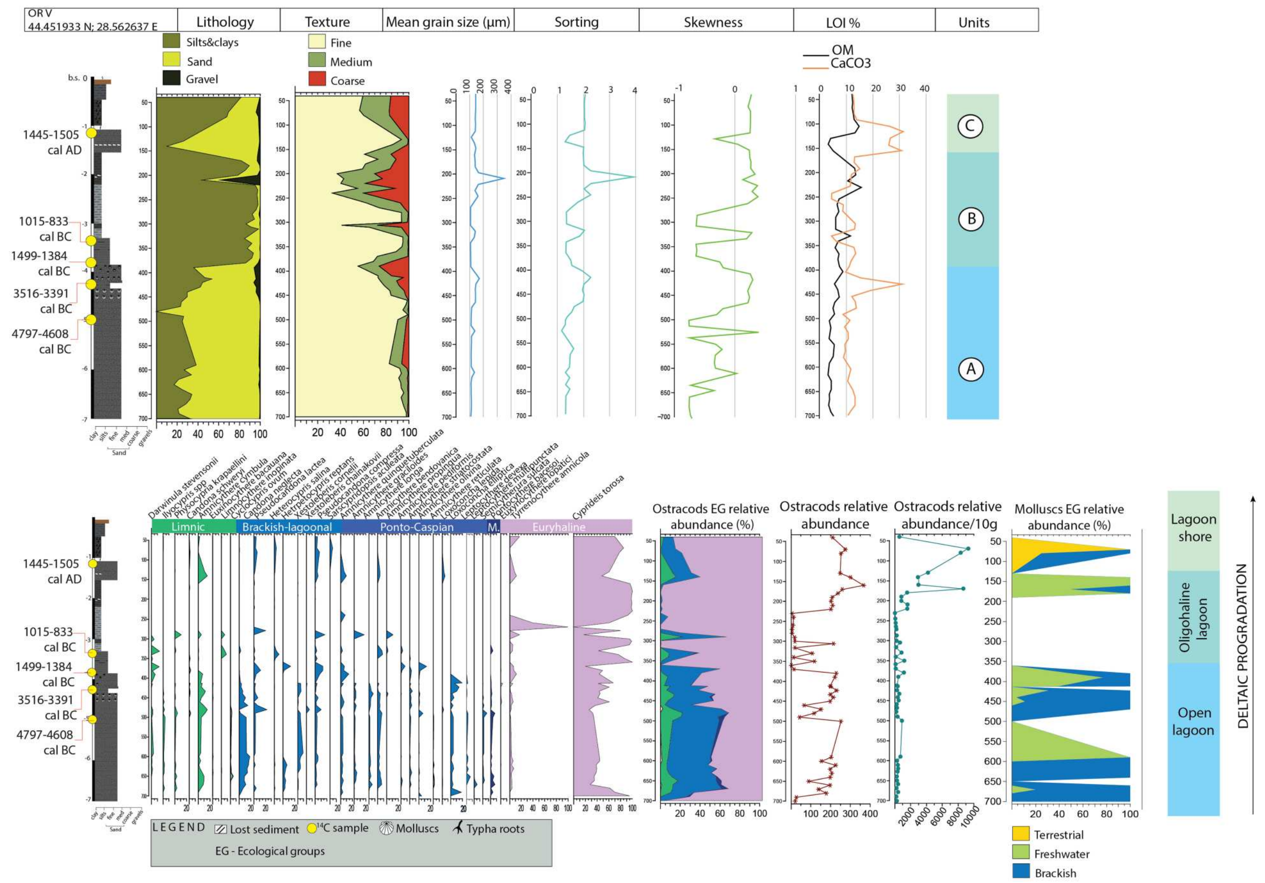

Figure 4. Chrono-stratigraphy and bio-sedimentological analysis and the main units of core OR V. Depths are given below surface (b.s.).

(~3-13%) and $CaCO_3$ (~4-30%) levels shows important fluctuation, corresponding to transitional environments influenced by both organic input and carbonate precipitation.

The ostracod assemblage fluctuates significantly in density (66–86.000 valves/10 g) and shows reduced diversity (H' ≈ 0.645), becoming nearly mono-specific with *Cyprideis torosa*. Sparse oligo- to mesohaline species (*Tyrrenocythere amnicola*, *Darwinula stevensonii* and juvenile *Candona neglecta*) and Ponto-Caspian species (*Amnicythere quinquetuberculata* and *Amnicythere bendovanica*) are present. Macrofauna is nearly absent, with only a few molluscs identified, including *Theodoxus fluviatilis*, *Dreissena polymorpha* and *Abra segmentum*.

Unit C – (380–0 cm, 450 cal BP to present): represents the uppermost unit, with a basal radiocarbon date of 385 ± 30 BP (1442–1524 cal AD). This unit is characterised by sandy-silt, with a fine texture (M_G = 142 μm), poor sorting ($\sigma_1 = 2.2$), and fine skewness ($Sk_G = 0.256$). OM (~3-15%) and $CaCO_3$ (~4-27%) levels show the same fluctuation as in the previous unit.

The ostracod assemblage also maintains a low to moderate diversity (H' ≈ 0.75). The Ponto-Caspian species are replaced by brackish-water taxa such as *Heterocypris salina* and *Sarscypridopsis aculeata*, *Pseudocandona compressa*, and juveniles of *Candona neglecta*, alongside euryhaline *Cyprideis torosa*. We observed the occurrence of *Planorbis planorbis* gastropod shells in the uppermost 40 cm of the core.

Caraburun-Acic Suat

Core CA III was divided into five chrono-stratigraphic units, and core CA IV in four.

Core CA III (Figure 5)

Unit A – (400–364 cm, 3500 to 3300 cal BP): lies directly above the limestone bedrock, with the contact being radiocarbon dated to 3340 ± 30 BP (1692–1531 cal BC). This unit consists primarily of coarse grey shelly sand, with medium texture (280 μm < M_G < 343 μm), poorly sorted ($\sigma_1 = 2.3$), and extremely coarse skewness ($Sk_G = -0.535$). The OM levels are low (3% to 7%), while $CaCO_3$ is present in high concentrations (40–70%), attributed to biogenic shell sedimentation and the proximity of the limestone bedrock. This unit contains the richest molluscan fauna in the core, with a maximum density of 760 shells/10 g. Dominant species include brackish-water taxa *Abra segmentum* and *Mytilaster lineatus*. Ostracod diversity is also highest in this unit (H' ≈ 1.91), with a density ranging from 15 valves/10 g at the base to 3700 valves/10 g at the top. The dominant autoecological group is brackish (*Candona neglecta*, *Xestoleberis*

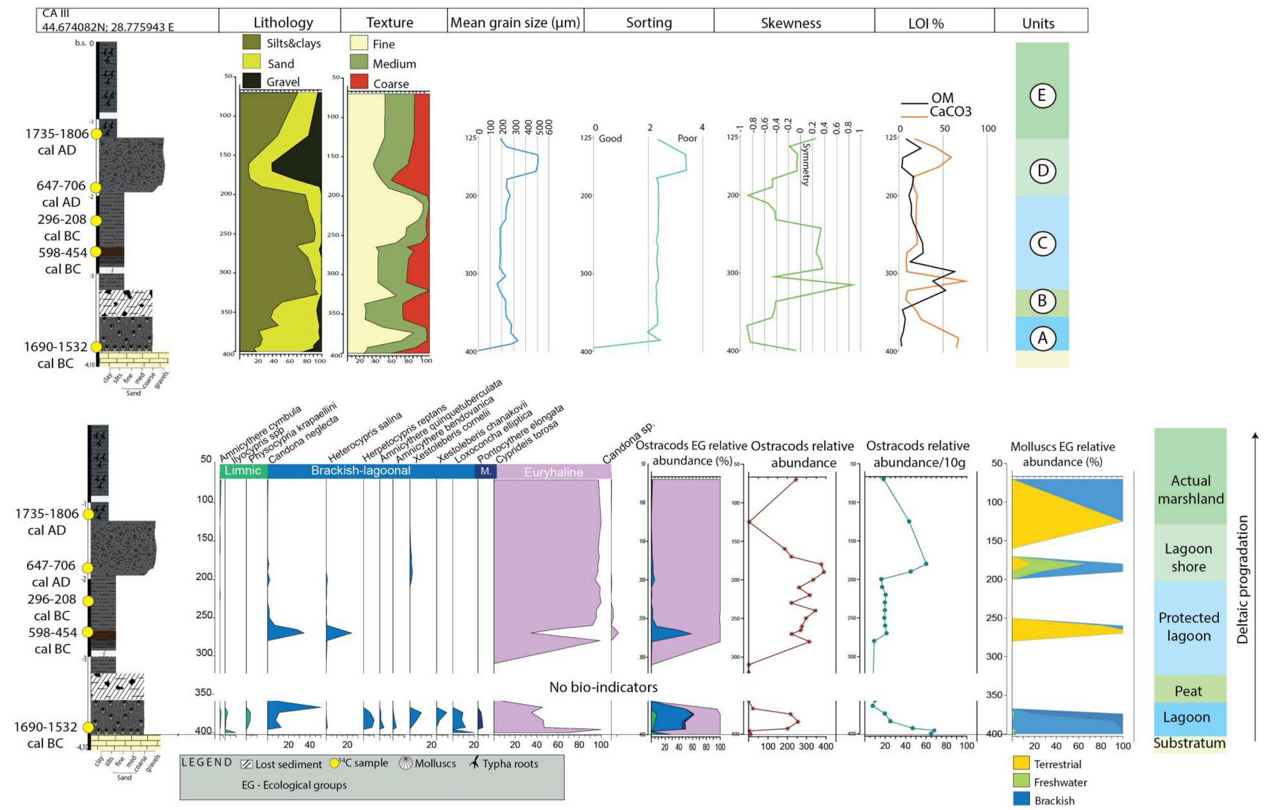

Figure 5. Chrono-stratigraphy and bio-sedimentological analysis and the main units of core CA III. Depths are given below surface (b.s.).

cornelii, and *Xestoleberis chanakovii*), followed by the euryhaline one (*Cyprideis torosa*). An assemblage of freshwater to low brackish species, (*Amnicythere cymbula*, *Illyocypris* spp, *Physocypria kraepellini*), along with the brackish–marine *Pontocythere elongata*, are present only in this unit. These freshwater and brackish–marine taxa are less abundant but consistent with the dominant groups.

Unit B – (364–327 cm, 3300 to 3000 cal BP): consists of a peat layer. While no direct radiocarbon dates were obtained for this unit, the age-depth model places its formation between 3361 cal BP and 3064 cal BP. Both OM (~30% to ~60%) and $CaCO_3$ (~30% to ~80%) levels exhibit high fluctuations. This unit lacks biological proxies.

Unit C – (327–190 cm, 3000 to 1300 cal BP): has the upper boundary radiocarbon-dated 1335 ± 30 BP (646–717 cal AD), 2275 ± 30 BP (401–351 cal BC) at 230 cm and 2460 ± 30 BP (672–429 cal BC) at 270 cm. According to the obtained age-depth model, the contact zone between this unit and the peat layer is dated 3031 BP. It is characterised by organic sandy silts and clays (70% to 90%), with a fine to medium texture (163 μm < M_G < 266 μm), poorly sorted ($\sigma_1 = 2{,}3$) and symmetrically skewed ($Sk_G = -0{,}027$). Both OM (~12% to ~16%) and $CaCO_3$ (~8% to ~16%) values are relatively low but peak at ~30% OM and ~20% $CaCO_3$ between 260–270 cm.

No biological proxies were identified between 327 cm – 280 cm. Above 280 cm, ostracods are extremely abundant (7.000 to 83.000 valves/10 g), predominantly featuring robust adult valves of *Cyprideis torosa* (H' ≈ 0.33). Only in a short passage corresponding with the sandy layer in between 250-270 cm, the ostracofauna diversifies, with the brackish species *Candona neglecta* and *Heterocypris salina* present in a considerable percentage (40-60%). In between the same interval, few specimens of *Planorbis planorbis* were identified. Otherwise, molluscs are absent.

Unit D – (190–125 cm, 1300 to 200 cal BP): is dated between 1335 ± 30 BP (646–717 cal AD) at the base and 220 ± 30 BP (1735–1806 cal AD) at the top. The unit is characterised by grey sand at its base (190 cm – 170 cm), overlay by a slope deposit consisting in limestone fragments in a sandy matrix (230 μm < M_G < 530 μm). The sediment is very poorly sorted ($\sigma_I = 3$) and coarsely skewed ($Sk_G = -0{,}162$). LOI indicates a high content in $CaCO_3$ (>40%, due to the limestone colluvium) and a very low OM (<4%). The ostracofauna is highly abundant up to 150 cm, followed by a sharp decline and total demise at 120 cm. Although highly abundant, the assemblage is nearly monospecific (H' ≈ 0.11), dominated by *Cyprideis torosa*, with a few brackish species such as *Candona neglecta* and *Xestoleberis cornelii* also present. Macrofauna is scarce in this unit, represented by only a few specimens of the gastropods *Planorbis planorbis* and *Theodoxus fluviatilis*.

Unit E – (125–0 cm, post 200 cal BP): is the uppermost unit of the core and it is characterised by organic black mud mixed with *Typha australis* and *Phragmites australis*.

CA IV (*Figure 6*)

Unit A – (500–345 cm, ante 2100 cal BP): the basal unit consists of light brownish with orange spots sandy-silt from 500 cm to 395 cm interdigitate with a fine sand passage at 395 cm – 380 cm, overlapped by a compact homogenous blue-grey silts from 380 cm – 345 cm. The texture is fine (94 μm < M_G < 170 μm), the sediment is moderately sorted (σ_1 = 1,9) and symmetrically skewed (Sk_G = 0,00). The LOI indicates a low content in OM (6%) and $CaCO_3$ (17%).

No radiocarbon determinations were obtained for this unit. The closest one, which dates the top of unit B and the base of unit C, dates this unit prior to 2135 ± 30 BP (211-55 cal BC). Unit A lacks almost completely biological indicators. Few valves of *Cyprides torosa* (max 400 valves/10 g) were collected from the upper part of the core (above 365 cm). No molluscs were found.

Unit B – (345–280 cm ante 2100 cal BP): is radiocarbon dated 2135 ± 30 BP (211-55 cal BC) at the top. The unit is defined by a coarse material in a sandy matrix, with gravel fraction representing between 30% to 60% of its composition. The texture is medium-to-coarse bioclastic sand (440 μm < M_G < 880 μm), very poorly sorted (σ_1 = 3,3) and symmetrically skewed (Sk_G = −0,024). OM values are consistently low (~3% to ~5.5%), while $CaCO_3$ values decrease from ~75% to ~40% up the unit.

Starting with 310 cm, the relative abundance of ostracofauna varies from 34 valves/10 g to 2400 valves/10 g, with very well-preserved adult valves. It exhibits a pattern similar to that observed in core CA III, Unit C, with a monospecific assemblage dominated exclusively by *Cyprideis torosa*. The molluscan fauna is nearly absent, represented by only two specimens of *Theodoxus fluviatilis*.

Unit C – (280–120 cm, 2100 to 185 cal BP): it is dated 2135 ± 30 BP (211-55 cal BC) at 270-280 cm and 205 ± 30 BP (1731-1809 cal AD) at 120-130 cm,

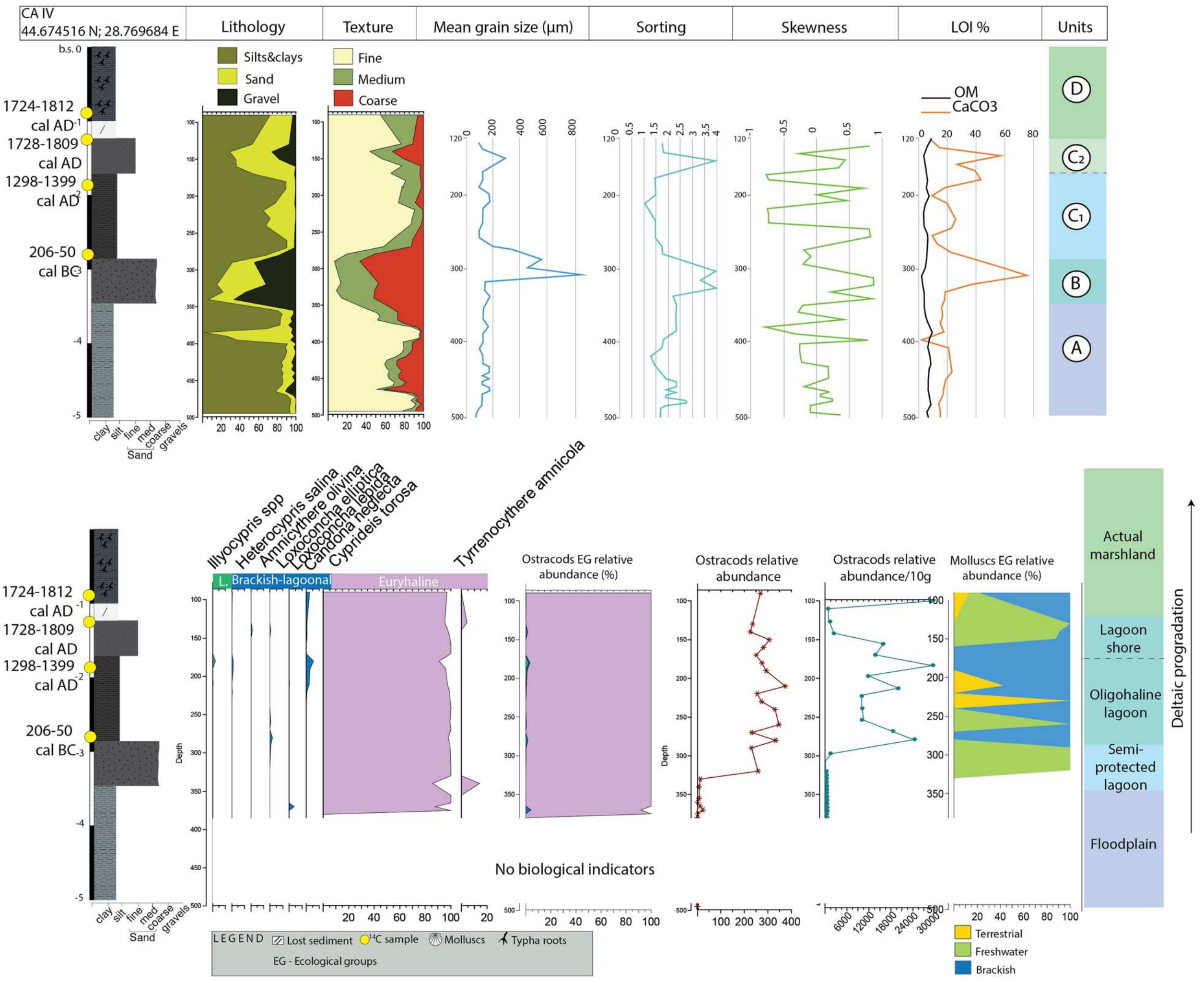

Figure 6. Chrono-stratigraphy and bio-sedimentological analysis and the main units of core CA IV. Depths are given below surface (b.s.).

and it can be divided into two sub-units. The first one, C1 (280 cm – 160 cm) is radiocarbon dated 2135 ± 30 BP (211-55 cal BC) at 270-280 cm and 620 ± 30 (1292-1401 cal AD) at 180–190 cm. The sub-unit's texture is defined by fine micaceous sands (94 µm < M_G < 188 µm), moderately sorted (σ_I = 1,5) and symmetrically skewed (Sk_G = 0,005). OM values are low (~3% to ~7%), while $CaCO_3$ values fluctuate (~9% to ~25%). A peak of $CaCO_3$ (~ 45%) is observed at the top of the sub-unit.

The ostracods of sub-unit C1 are highly abundant robust adults (min 16700 valves/10 g) with very low diversity (H' ≈ 0.061). The ostracod assemblage is dominated by the euryhaline *Cyprideis torosa*, followed by the brackish group (*Candona neglecta*, *Heterocypris salina* and *Loxoconcha elliptica*). A few specimens of freshwater to low-brackish *Ilyocypris spp* were also discovered. Although not enough quantitatively, the molluscan fauna is relatively diverse. Five species were collected, four brackish (*Cerastoderma glaucum*, *Abra segmentum*, *Ecrobia ventrosa*, *Hydrobia acuta*) and one freshwater to low-brackish (*Theodoxus fluviatilis*).

Sub-unit C2 (160 cm – 120 cm) is characterised by an increase in sands, with a fine texture (123 µm < M_G < 295 µm), poorly sorted (σ_I = 2,8) and fine skewed (Sk_G = 0,171). The OM shows significantly reduced values (~3%), while the presence of bioclasts and limestone fragments corresponds to a high $CaCO_3$ content (~50%).

Brackish mollusc species are replaced by the freshwater to low-brackish *Theodoxus fluviatilis*, while the ostracofauna becomes monospecific (*Cyprideis torosa*), in high numbers (up to 275,000 valves/10 g) and in a well-preserved state.

Unit D – (120–0 cm, post 185 cal BP): is radiocarbon dated 185 ± 30 BP (1726 -1814 AD) at its base. The unit is characterised by a rich-organic mud in a sandy matrix mixed with fibres of *Typha australis* and *Phragmites australis*.

The Relative Sea Level Since 6000 cal BP in the Danube Delta and the Water Column of Razelm-Golovița in Antiquity

From 6000–4000 cal BP, sea level rose ~3 m; from 4000–2000 cal BP it climbed more slowly to about −1 m, and from 2000 cal BP to today it has remained stable within roughly ±0.5 m of modern mean sea level (Figure 7). These changes may reflect long-term subsidence linked to sediment compaction. The Danube delta lies in a tectonically active zone with high sediment accumulation and subsidence. Estimates for subsidence rates in the delta vary between 0.4–0.6 mm yr^{-1} (Vespremeanu-Stroe et al. 2017) and 1.5–1.8 mm yr^{-1} (Panin 1998), suggesting that

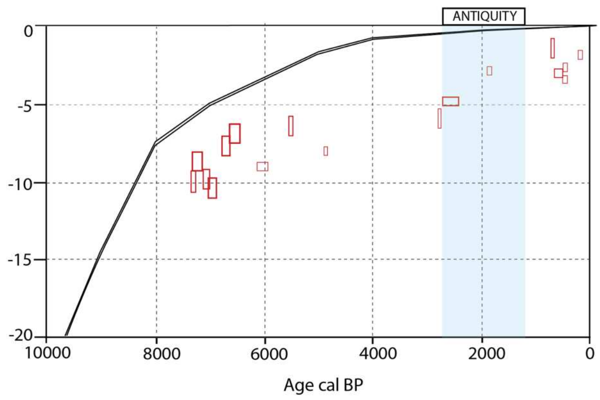

Figure 7. The local relative sea-level curve, showing a gradual rising trend of approximately 3 metres since 6000 BP in the region, which is attributed to the ongoing subsidence process associated with sediment compaction. Depths are given below surface.

subsidence and compaction could have contributed to the observed sea level trend.

Because sediment compaction and tectonic loading likely varied over the last 4000 years – and modern anthropogenic impacts have accelerated subsidence – a uniform back-extrapolation of high subsidence rates (1.5–1.8 mm yr^{-1}) yields probably unrealistically deep estimates (4–8 m) for the paleo-water column. The lower rate (0.4–0.6 mm yr^{-1}) produces more plausible mid-range corrections (3–5 m). Nonetheless, the GIA-only depths (2-3 m) remain the most robust baseline, and we recommend referring primarily to them while using the subsidence-corrected curves to bracket possible extremes. In the harbour area of Orgame, we observed a consistent decrease in water depth from approximately 290 ± 10 cm between 1000 - 800 cal BC, to 245 ± 10 cm in 50 cal BC, 225 ± 8 cm in 100 cal AD, and 200 ± 8 cm in 600 cal AD. This decline correlates with the southward extension of the Dunavăț pro-delta over time. Presently, water depth near Cape Dolojman is around 200 cm, gradually diminishing to 100 cm near the shoreline. Similarly, Golovița lagoon around Caraburun-Acic Suat exhibited a decrease in water depth from around 215-220 ± 10 cm in the Archaic-Classic period to 170-180 ± 8 cm in the Late Antiquity – Early Byzantine period, with historical records from the 1800s indicating a depth of approximately 120 cm (Lahovari, Brătianu, and Tocilescu 1898). Currently, Golovița lagoon around Cape Acic Suat has a depth of 100 cm (R. Dimitriu et al. 2008).

Discussion

Geomorphological Evolution of Razelm-Golovița Lagoons System

The observed environmental evolution of the Razelm-Golovița lagoon system follows a classical

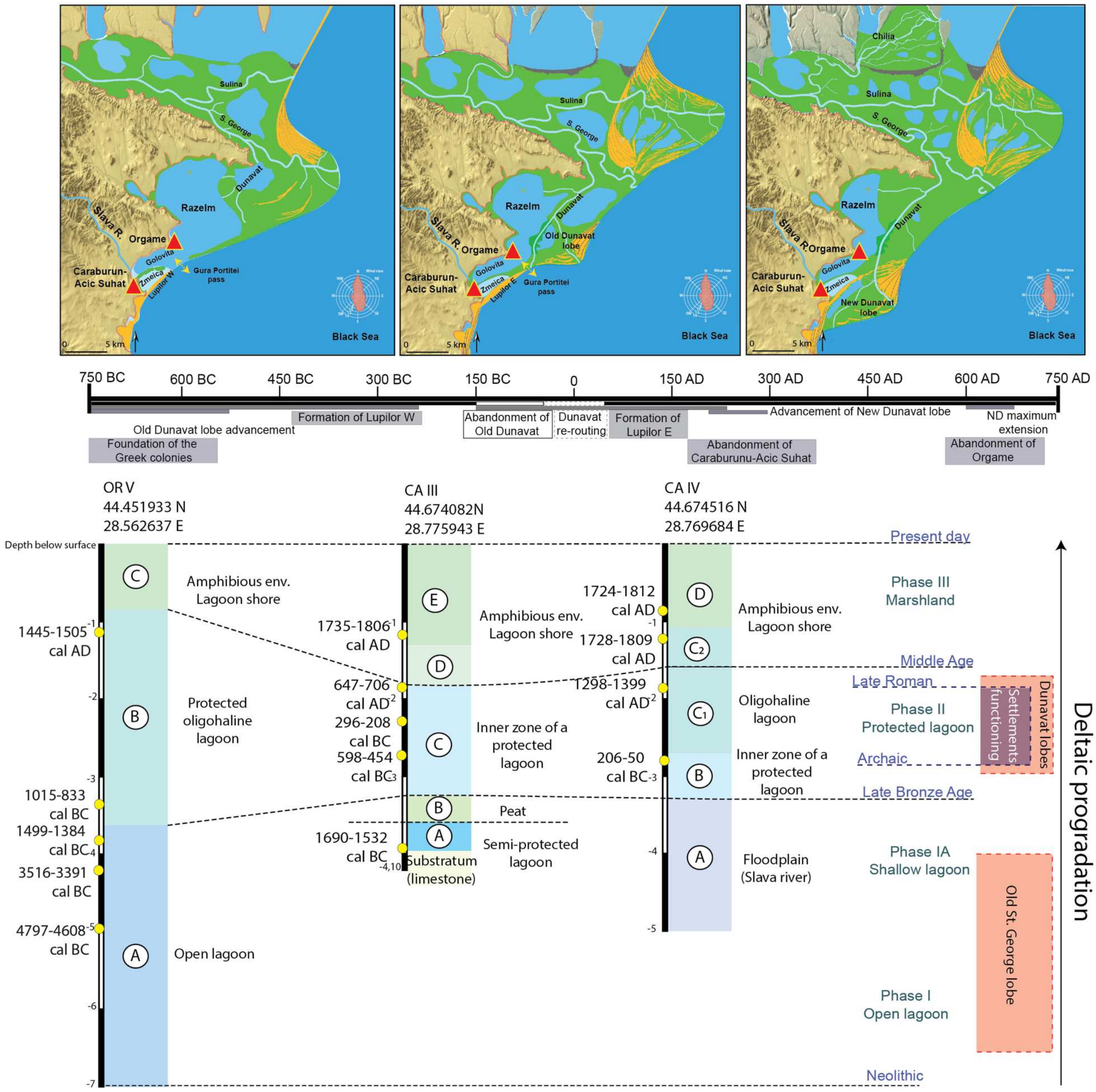

Figure 8. Paleo-environmental evolution of Razelm-Golovița distal lagoons in the general context of Danube delta evolution, correlated with the prehistorical and historical periods of human occupation in the study area. Depths are given below surface. Geomorphological sketch modified after Vespremeanu-Stroe et al. 2017.

progradational sequence within a deltaic context (Reineck and Singh 1980): an open marine bay gradually became separated from the sea due to the formation of a sandy barrier, thus altering the bay's configuration into a lagoon. The evolution of the lagoon system can be divided into 3 phases that cover a time span from Neolithic onwards (Figure 8).

Phase I: Gradually Closing Lagoon Under the Influence of Old St. George Lobe, from Neolithic to the Bronze Age

From the Neolithic to the Bronze Age (ca 4650–1150 cal BC), the regions of Orgame and Caraburun-Acic Suat were influenced by the growth and subsequent avulsion of the Old St.-George lobe, which reshaped regional hydro-sedimentary dynamics and contributed to the bay's progressive closure and to the emergence of a lagoon after 1150 cal BC.

At Orgame, the bay functioned as an open lagoon (Unit A, core OR V), progressively restricted by the progradation of the lobe. The fine micaceous sands deposits with moderate sorting, as well as the low but stable values of OM and $CaCO_3$, indicate a moderate to low-energy depositional setting. Periodic marine influence is reflected in the diverse ostracod assemblages, dominated by brackish (*Candona neglecta*, *Loxoconcha elliptica*) and euryhaline taxa (*Cyprideis torosa*), mixed with brackish–marine species. Sparse molluscan remains, including brackish *Abra segmentum* and riverine *Theodoxus fluviatilis*, further indicate a transitional open lagoon environment.

At Caraburun-Acic Suat, the depositional environment differed from that of Orgame and also varied between the western (core CA IV) and eastern (core CA III) facades of Acic Suat cape. The eastern bay of Caraburun-Acic Suat, between approximately 1550–1350 cal BC, was a semi-protected lagoonal environment with a rocky shoreline. The poor sorting and high gravel content may reflect episodic colluvial input from nearby slopes, while the high $CaCO_3$ concentrations (40–70%), presence of shell debris, and the known limestone bedrock point to a predominantly low-energy, shallow-water setting. The presence of *Mytilaster lineatus*, a species associated with rocky substrates (Fet and Popov 2007), supports the influence of the local limestone substratum, which likely created a patchy habitat with rocky and sediment-covered zones.

The presence of freshwater to low-brackish ostracoda, including *Amnicythere cymbula*, *Illyocypris* spp, and *Physocypria kraepellini*, suggests intermittent freshwater inflow.

Brackish and macrophytal ostracod species (Candona neglecta, Xestoleberis cornelii, and Xestoleberis chanakovii, Salel 2018; Zenina et al. 2017), together with the occasional presence of brackish–marine species such as *Pontocythere elongata* alongside the opportunistic *Cyprideis torosa*, suggests fluctuating salinity conditions likely driven by episodic marine connection through temporary inlets in Zmeica barrier, with its probable eastward fossil bars now submerged (R. Dimitriu et al. 2008). Their positioning, west of Lupilor ridge and further inland, suggests formation prior to the edification of the Lupilor W ridge between 750-250 cal BC.

On the western side of Caraburun-Acic Suat, (core CA IV, unit A), shows a markedly different depositional environment from its eastern counterpart. The western area corresponded to a floodplain environment likely associated with Slava river (Figure 9). The relatively high $CaCO_3$ content in the floodplain is primarily due to erosion of the limestone hills of Dobruja plateau. Fine sandy silts with moderate sorting and the absence of biological indicators suggest a calm, poorly oxygenated depositional setting with fluctuating hydrodynamic conditions. The lack of ostracods and molluscs, combined with colour changes from light brown to blue-grey, indicates fluctuating hydrodynamic conditions and periods of temporal anoxia, characteristic of floodplain deposition. This floodplain environment contrasts with the semi-protected lagoonal conditions identified in Unit A of core CA III. This divergence indicates that the Zmeica barrier was already established by at least 1550 cal BC, effectively separating the floodplain to the west (CA IV) from the lagoon to the east (CA III), supporting the hypothesis of Zmeica barrier as being a remnant of the asymmetric St. George lobe (Giosan et al. 2006; Vespremeanu-Stroe et al. 2016).

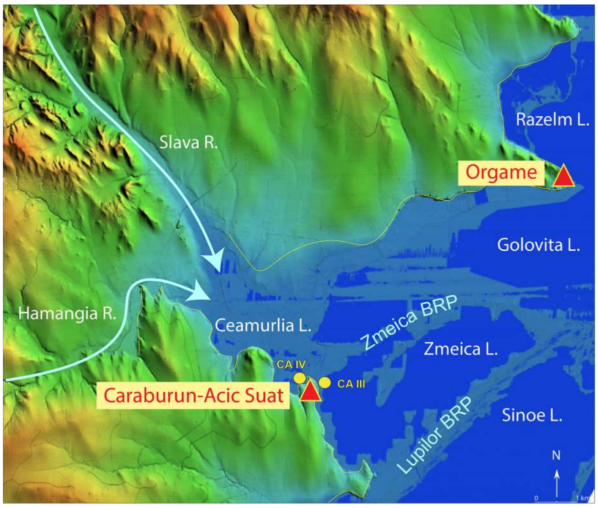

Figure 9. Lidar-based topographic map showing the course of the Slava and Hamangia Rivers as primary sediment transport pathways into Zmeica lagoon, with core locations CA III and CA IV. Source of the Lidar map: www.dddni.ro.

The transition from semi-protected lagoon (Unit A, core CA III) to peat formation (Unit B, core CA III), dated to approximately 1350–1050 cal BC, suggests an absence of fluvial input in the area. This shift corresponds with the abandonment of the Old St.-George lobe.

Phase II: Protected Lagoon Under the Influence of Dunavăț Lobes, from the Bronze Age to the Middle Ages

Following the erosion of the Old St. George lobe (Vespremeanu-Stroe et al. 2017), the Dunavăț branch became the primary driver of hydro-sedimentary dynamics in the Razelm-Golovița lagoon system from approximately 1050 cal BC to 1500/1700 cal AD. The formation of the Lupilor W ridge and the progradation of the Old Dunavăț lobe created localised hydrodynamic and sedimentary regimes, resulting in distinct depositional environments across Razelm-Golovița lagoon system.

At Orgame, the fine sands with moderate to poor sorting point to a moderate to low-energy depositional environment, consistent with the conditions of a protected lagoon (Unit B). The fluctuating OM and $CaCO_3$ levels suggest an environment subject to an episodic mix of freshwater and marine influences (floods, storms) or shifts in sediment input related to intra-lagoonal dynamics.

The ostracod assemblage became dominated by the typical lagoon species *Cyprideis torosa*. The overall diversity of ostracods declined, with only occasional occurrences of Ponto-Caspian taxa (*Amnicythere quinquetuberculata*, *Amnicythere bendovanica*) and oligo- to mesohaline species (*Darwinula stevensonii*). Molluscan fauna became sparse, reflecting more restrictive conditions.

The apparent consistency in sedimentation rate at Orgame (~0.66 mm/year) between 800 cal BC and 1500 cal AD, based on the available age model, suggests relatively stable depositional conditions. While the absence of dates within this interval limits chronological resolution, the stratigraphic continuity and dominance of euryhaline ostracods may reflect a low-energy, brackish environment with limited but recurrent freshwater input from the Dunavăț branch, and no clear evidence of major environmental disturbance despite continued human activity nearby. At eastern bay of Caraburun-Acic Suat, this phase corresponds to the inner margin of a protected lagoon (Unit C, core CA III), dated from 1050 cal BC–650 cal AD. The formation of the Lupilor W ridge-set during the period from 750–250 cal BC (Vespremeanu-Stroe et al. 2016) resulted in the isolation of Caraburun-Acic Suhat. The apparent sedimentary rate of 2.72 mm/yr observed in the area indicates a significant deposition related to the construction of the barrier. The sediments are dominated by organic sandy silts and clays (70–90%), with intermittent flood deposits reflected by coarser sands and poorly sorted layers.

The moderate to high levels of OM and $CaCO_3$ indicate substantial biological productivity and intermittent carbonate deposition, influenced by limited water exchange and a mix of biological activity and limestone dissolution from the surrounding watershed. Ostracod assemblage is dominated by *Cyprideis torosa*, while molluscs are nearly absent, underscoring the increasingly restricted conditions of this lagoonal basin.

Following the formation of the Lupilor W ridge, apparent mean sedimentation rates declined to approximately 0.37 mm/yr after 250 cal BC. While the absence of dated levels between 250 cal BC and 650 cal AD limits chronological precision, the sedimentary sequence appears continuous, which may reflect the progressive isolation of the eastern bay from Danubian sedimentary input and the shifting influence of the Dunavăț lobes. A slight increase in the mean sedimentation rate to 0.57 mm/yr after 650 cal AD may correspond to the erosion of the New Dunavăț lobe, which began sometime post-650 cal AD (Vespremeanu-Stroe et al. 2017).

In the western bay we observed a transition from a restricted floodplain (Unit A, core CA IV) to a semi-protected lagoon (Unit B, core CA IV) and further on to an oligohaline lagoon (Unit C, core CA IV), likely resulted from the erosion of the Zmeica barrier. This erosion, triggered after the abandonment of the Old St.-George lobe, would have allowed increased water circulation between the western and eastern basins of the Golovița-Zmeica lagoons. Unit B of core CA IV presents significant changes, with coarser materials, including limestone gravels and bioclastic sands, and higher $CaCO_3$ levels (~40%). The coarse fraction, likely colluvial material derived from the surrounding limestone-rich hills, indicates geomorphological instability associated with slope activity and enhanced runoff, probably related to the activity of Slava river (Figure 9). Organic matter remains low (<5%), and biological proxies are sparse but present, with *Cyprideis torosa* dominating the ostracod assemblage. The scarcity of molluscs, represented only by *Theodoxus fluviatilis*, underscores the limited establishment of benthic communities, likely due to fluctuating salinity and intermittent hydrodynamic activity. This suggests that Unit B represents an unstable shallow transitional phase as sediment influx increased and initial connections to the adjacent lagoonal systems began to form. Unit C reflects the establishment of an oligohaline lagoon around 200–50 cal BC. Sediment texture transition to finer micaceous sands with moderate sorting suggest an increase in hydrodynamics. The ostracod assemblage becomes more diverse and abundant, with *Cyprideis torosa* continuing to dominate but accompanied by brackish taxa (*Candona neglecta*, *Heterocypris salina*) and occasional freshwater to low-brackish species (*Ilyocypris spp*). Brackish molluscs species, (*Abra segmentum* and *Cerastoderma glaucum)*, appear sporadically, indicating improved, but still fluctuating, water circulation. The elevated $CaCO_3$ levels (~50%) could point to increased carbonate precipitation, possibly driven by biological activity.

Phase III: Silting-up Process After Dunavăț Avulsion, Post Middle Ages to Nowadays

The final phase of the Razelm-Golovița lagoon system marks its progressive siltation and eutrophication. This shift reflects a combination of natural processes and anthropogenic influences.

At Orgame, this phase is represented by Unit C (core OR V), dated post 1500 cal AD to the present. The sandy silts with poor sorting and fine skewness indicate a low-energy depositional setting. Organic matter levels increase significantly, with the presence of organic mud interspersed with plant remains, including *Typha australis* and *Phragmites australis*, indicating the establishment of a reed-dominated marshland. The ostracod assemblage shows a decline in diversity, with brackish taxa such as *Heterocypris salina* and *Sarscypridopsis aculeata*, alongside *Cyprideis torosa*, dominating the record. Both *Heterocypris salina* and *Sarscypridopsis aculeata* are halophilic species adapted to slightly brackish, small water bodies (Salel 2018). The presence of freshwater gastropods, including *Planorbis planorbis*, reflects the transition to increasingly oligohaline conditions and to a sedimentary infill.

At Caraburun-Acic Suat, the uppermost units of core CA III (Unit D) and core CA IV (Unit C) reflect similar transitions post 1700 cal AD. In Unit

D of CA III, the base consists of gravelly sand with limestone fragments, likely slope deposits originating from the surrounding hills. Poorly sorted sediments and minimal organic matter (<4%) suggest episodic inputs of colluvial material. Above this, organic-rich mud similar to that found at Orgame indicates the establishment of a marsh environment. The ostracod fauna, dominated by *Cyprideis torosa*, declines sharply towards the surface, coinciding with the appearance of freshwater gastropod taxa, such as *Theodoxus fluviatilis* and *Planorbis planorbis*. These trends indicate reduced water depth, limited salinity, and eventual vegetation colonisation.

The processes driving these transitions are linked to a combination of sediment accumulation and human interventions. The erosion of the New Dunavăț lobe after 750 cal AD, coupled with reduced hydrodynamic energy, led to extensive siltation. By the twentieth century, anthropogenic factors, such as reclamation projects and artificial fishery constructions, exacerbated eutrophication and habitat alteration, accelerating the marshland formation.

The Lagoon as a Harbour Basin

The settlements benefited from the natural protection provided by the lagoons (Figure 10), with capes extending into bays sheltered by sandy barriers, offering secure anchorage without the need for offshore structures like breakwaters. At Orgame, the harbour area was situated leeward, south of Dolojman Cape, sheltered from the main action of swells and waves (Bony et al. 2013, 2015; Mănucu-Adameşteanu 2003) (Figure 9). Geophysical investigations from 2011 revealed the presence of multiple buildings around the port area, although their specific functions require archaeological exploration (Bony et al. 2013, 2015) (Figure 9). At Caraburun-Acic Suat, the current state of archaeological research makes it difficult to discuss the presence of harbour structures. The western and

Figure 10. (Above) The harbour area of Orgame has been localised leeward, S of Cape Dolojman. (Below) At Caraburun-Acic Suat, both Western and Eastern sides are suitable anchorage areas.

eastern bays near Cape Acic Suat were both viable for small-scale harbour activities (Figure 9). The western bay's double barrier system limited its connectivity, making it less ideal for frequent harbour use. In contrast, the eastern bay featured better water circulation, enhancing its suitability for harbour activities and small-scale docking.

The Water Column of Razelm-Golovița in Antiquity

Without taking into account the subsidence rate, the water column calculated for the harbour areas of Orgame and Caraburun-Acic Suat indicate that the lagoon was a shallow waterbody, with depths ranging from approximately 280–290 ± 0.10 cm in the early first millennium BC to around 200 ± 0.075 cm by Late Antiquity at Orgame (Figure 11) and from approximatively from around 215–220 ± 0.10 cm to 170–180 ± 0.08 cm during the same time span at Caraburun-Acic Suat (Figure 12). Based strictly on the GIA-only paleo-water depths, the lagoon would have remained too shallow for large or medium-sized vessels (75–100 t dwt). Instead, smaller river and river-sea craft with broad, flat hulls – drafts under ∼2 m – would have been best suited to these restricted waters (Boetto 2010; Nantet 2020; Poveda 2012). For instance, the second century AD Gura Portiței shipwreck (R. G. Dimitriu et al. 2017) likely belonged to the category of small-tonnage boats, suggested by its cargo of 1000 amphorae identified as Vnukov IVc type, indicating a total weight not exceeding 20 tons. The shipwreck's mound dimensions, approximately 12 m in length and 5 m in width, imply a vessel length of no more than 15 m, further supporting its suitability for lagoon navigation and shallow waterways. However, if we allow for modest long-term subsidence (e.g. 0.4–0.6 mm yr^{-1}), the lagoon depths would increase by another ∼1 m (to ∼3–4 m), making it somewhat deeper yet still marginal for large ships. Considering these natural constraints for navigation, it is possible that Bisericuța island, located near the modern Gura Portiței pass, served as a trans-shipment hub or outer harbour (Figure 13). Its strategic position, at only 2.5 km from Orgame and in proximity to the Dunavăț mouth and Black Sea would have facilitated its role as an intermediary point. Goods arriving on larger vessels from river mouths or the open sea could have been offloaded here and transferred to smaller, shallow-draft boats capable of navigating the lagoon's sandy bars and shallow waters. Conversely, smaller vessels from the lagoon could have delivered cargo to the island for reloading onto larger ships for long-distance trade, highlighting the possible logistical role of this island.

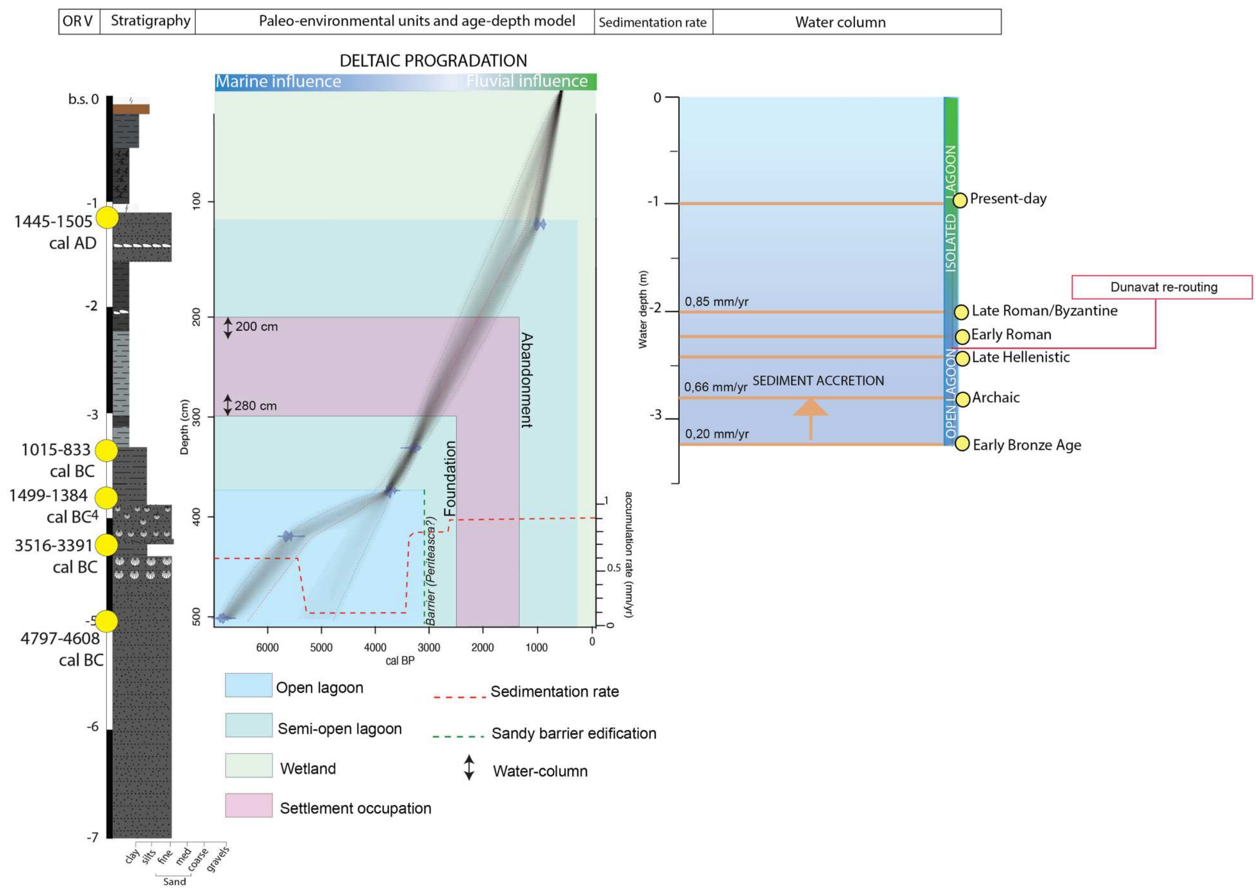

Figure 11. PADM chart of core OR V. The water depth in the harbour area has been suitable for accommodating small and medium-sized vessels since the Archaic period. Depths are given below surface (b.s.).

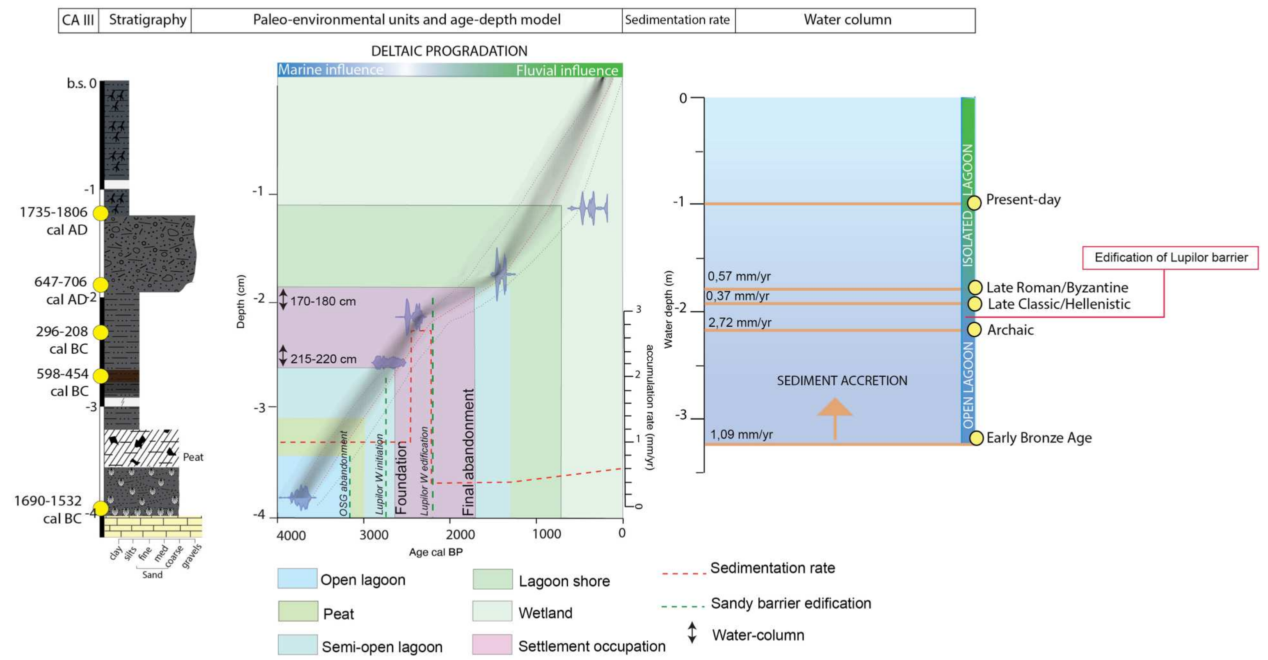

Figure 12. PADM chart of core CA III. As for Orgame, the water depth in the harbour area has been suitable for accommodating small and medium-sized vessels since the Archaic period. Depths are given below surface (b.s.).

The Question of Navigability

The navigational dynamics at Orgame were significantly influenced by the Dunavăț branch, which discharged into the lagoon, thereby linking it to the Danube river basin. This influx played a critical role in ancient maritime activities, as it could alter the hydro-sedimentary patterns within the lagoon, potentially affecting the accessibility and usability of ancient waterways crucial for navigation and trade connectivity between the lagoon and the broader Danube delta. Regarding maritime connectivity, Orgame connected to the open sea via inlets like Gura Portiței in the coastal spit, characterised by significant spatial and temporal variability (de Swart and Zimmerman 2009). Historical references to Gura Portiței pass in Ottoman sources from the thirteenth century AD (Giurescu and Giurescu 1974) suggest its longstanding significance in navigation, likely dating back to antiquity (Bony et al. 2013, 2015; Mănucu-Adameşteanu 2003). Nearby Bisericuța island, located close to the pass, probably served as a navigational reference within this dynamic waterscape, providing a stable and recognisable landmark that facilitated safe navigation for ancient seafarers (Figure 13).

The navigation conditions at Caraburun-Acic Suat were primarily influenced by distinct localised constraints that limited broader regional connectivity. The settlement was situated between the Golovița and Zmeica lagoons, separated between themselves and overall from the sea by a double-barrier system: Zmeica and Lupilor W. When the settlement was founded in the sixth century BC, the Lupilor W ridge was still forming, and the eastern bay of Cape Acic Suat had limited connectivity to the sea. By the third century BC, the completion of the Lupilor W ridge isolated the settlement entirely from direct maritime access. While the erosion of the Zmeica barrier allowed for improved water exchange between the eastern and western basins, this development likely supported localised connectivity rather than enabling broader regional trade.

Diachronic Settlement Trajectories in the Razelm–Golovița Lagoon (1050 BC – AD 1500/1700)

Throughout the long Phase II interval (ca. 1050 BC – 1500/1700 AD), Orgame, Caraburun–Acic Suat, and Bisericuța island trace a staggered yet interwoven sequence of occupation that reflects both shared regional dynamics and individual resilience. Orgame is the earliest Greek foundation (mid-7th c. BC), flourishing during the late Classical–early Hellenistic period (4th–3rd c. BC), reappearing as Argamum in the 2nd c. AD, and expanding within fortified walls in the 5th–7th c. AD before its mid-seventh-century decline. By contrast, Caraburun–Acic Suat's Archaic settlement (mid-6th–early 5th c. BC) persisted only briefly, was destroyed ca. 270 BC, and lay fallow for four centuries until it was founded as a Roman *vicus* (2nd–3rd c. AD). Bisericuța island punctuates both narratives: its first fort (5th–4th c. BC) overlaps Caraburun's final phase and Orgame's Hellenistic development; its second fort (2nd–6th c. AD) parallels the Roman revivals at both mainland sites; and its 10th–12th c. AD High Medieval reuse persists centuries

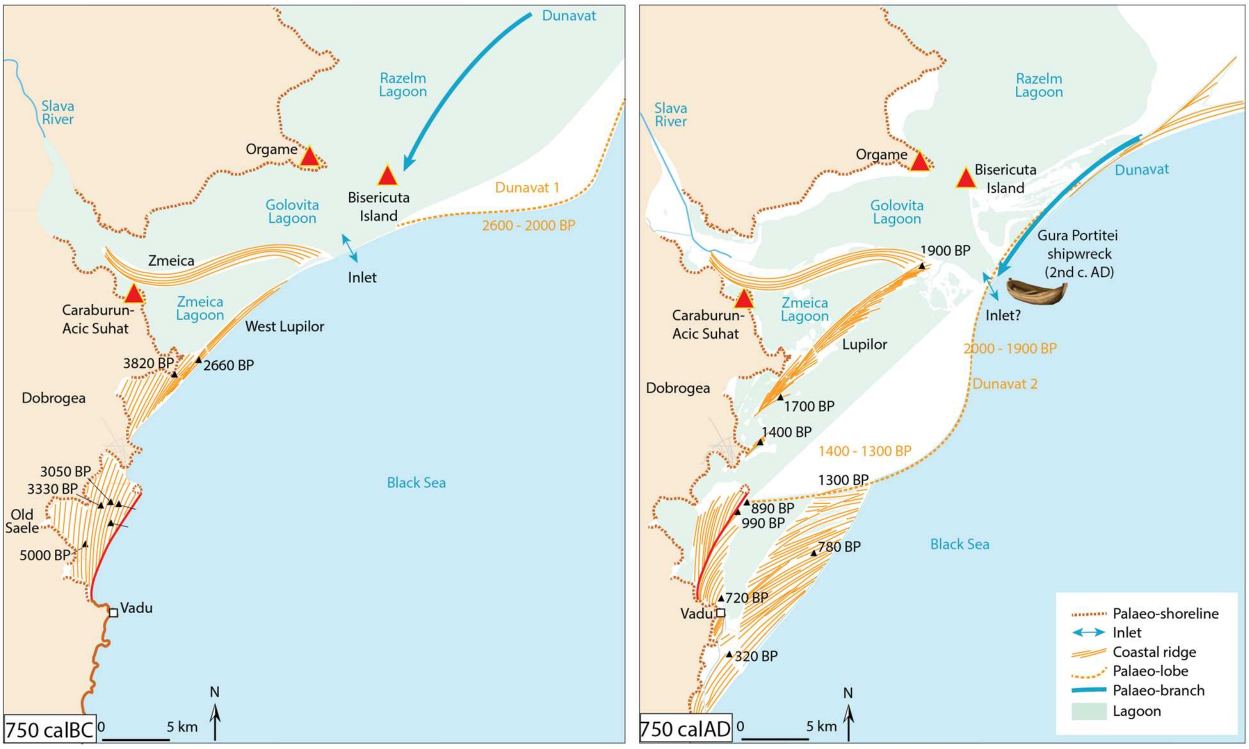

Figure 13. Razelm-Golovița lagoons reconstruction and Dunavăț I and II lobes presumed position at the moment of Greek colonisation (750 BC, left) and after the abandonment of the sites (750 AD, right). Geomorphological sketch modified after Vespremeanu-Stroe et al. 2017.

after the other two settlements had vanished. Although numerous smaller shoreline sites appear and disappear during the same span, and gaps in excavation and dating remain, this pattern of foundation, abandonment, revival, and final desertion reveals a coherent, if non-uniform, settlement sequence: each site rises and falls within the same lagoon-evolution framework, yet none follows an identical trajectory.

This staggered record suggests a complex dialogue between people and place rather than simple environmental causation. In the mid-seventh–sixth centuries BC, Greek settlers chose to found Orgame and Caraburun-Acic Suat when the lagoon's semi-enclosed form offered reliable small-boat access and a naturally protected harbour, but the decision to establish two complementary settlements reflects an occupational strategy rather than mere environmental happenstance. Their proximity implies a deliberate, polycentric strategy: two modest harbours, probably alongside neighbouring coastal communities, positioned to exploit distinct resources and access routes, rather than a straightforward duplication of sites or a clear subordination to nearby Istros, whose political reach at this date cannot be firmly established.

Caraburun-Acic Suat's destruction around 270 BC and its abandonment during four centuries reflect shifting political and economic priorities rather than environmental stress. The lagoon at Cape Acic Suat was already well protected, and the gradual avulsion of the Old Dunăvăț lobe had little practical impact on local harbour conditions. Reoccupation came only in the second century AD, when Roman administrative expansion created a need for small coastal *vici*; by contrast, the region's Hellenistic instability and the edification of the Lupilor W barrier, which resulted in the isolation of Caraburun-Acic Suat, offered scant incentive for earlier resettlement. Meanwhile, Bisericuța island most probably functioned as a lookout and trans-shipment point: its first fort (5th–4th c. BC) and second (2nd–6th c. AD) bracket the Hellenistic development of Orgame and the intensive Roman occupation of the whole Danube delta, while its lone medieval reuse (10th–12th c. AD) reveals opportunistic adaptation to lagoon openings during a period of political instability in the area. Thus, while the geomorphological phases provide temporal scaffolding, the actual patterns of foundation, abandonment, and revival reflect strategic human choices, driven by trade networks, political shifts, and opportunistic reuse of changing coastal waterscapes, within an incompletely documented regional web of settlements.

Conclusions

The settlements of Orgame and Caraburun-Acic Suat exemplify the challenges and potentialities for ancient navigation inherent in deltaic environments. The geomorphological configuration and mobility of the lagoon system, characterised by its separation from the Black Sea and internal division by beach-ridge plains, significantly influenced maritime accessibility and navigability. The hydro-sedimentary discharge of the Dunavăț branch into the lagoon added another layer of complexity to the navigation dynamics, as it can alter the depth and shape of the waterways, potentially leading to shallower channels and the creation of submerged bars, also mentioned in ancient sources (Polybius IV.41.1, 2; Strabo I.3.7). While Orgame had access to the sea through inlets in the littoral spit, Caraburun-Acic Suat was isolated by the Zmeica and Lupilor ridges. While the western bay of Caraburun-Acic Suat remained largely isolated and functionally limited as a harbour, the eastern bay offered modest opportunities for anchorage and connectivity.

Bisericuța island emerged as a potential trans-shipment outpost, facilitating the transfer of goods from river mouths or the open sea to smaller vessels suitable for navigating the lagoon's shallow waters. Additionally, its strategic location suggests it may have served as a reliable navigation landmark in a mutable waterscape.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Fondation IDEX-UNICA. This work was supported by the French government through the France 2030 investment plan managed by the National Research Agency (ANR), as part of the Initiative of Excellence under reference number ANR-15-IDEX-01.

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