History and influence of the Danube delta lobes on the evolution of the ancient harbour of Orgame (Dobrogea, Romania)

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A B S T R A C T

On the coast of Northern Dobrogea, south of the Danube delta, the Greek settlement of Orgame was founded in the mid 7th c. BC, probably by Milesian colonists. The ancient city was located on the Cape Dolojman which today overlooks a large lagoon complex. We undertook a chronostratigraphic study to: (i) understand coastal changes around Cape Dolojman since ca. 5000 years BP in connection with the construction of the Danube delta lobes, and (ii) identify potential sediment impacts related to human occupation of the site. Three cores were extracted from the lagoon area. Sedimentological and biological analyses were undertaken to reconstruct the evolution of the coastal palaeoenvironments. The results show a closure of the marine bay around 3500 cal. BP and its transformation into a lagoon environment. The first major environmental change was due to the construction of the lobe St. George I and the formation of the barrier Lupilor. Around 2000 cal. BP, the formation of an intra-lagoonal lobe, the Dunavatz, led to the gradual transformation of the lagoon into a fluvial-dominated system. Paradoxically, lagoon waters today still wash the ancient Greek harbour environment, which has not been totally infilled by alluvial sediments. To understand this paradox, in a context of coastal progradation, we compared and contrasted the geomorphological data with the nearby city of Istros/Histria, which was already land-locked at this time. The location of these two Greek colonies relative to the coastal sediment cell and barriers partly explains their contrasting palaeoenvironmental evolution. Until 2650 cal. BP, the increase in charcoal and organic matter in sedimentary archives is interpreted as an anthropogenic signal for a more extensive use of the vegetation cover following the foundation of the city of Orgame (e.g. for domestic use and funeral rites).

1. Introduction

Orgame constitutes one of the four earliest Greek settlements in the Black Sea area. Founded in the mid-7th c. BC, on the coast of Northern Dobrogea, the remains of the ancient city occupy the Cape of Dolojman, today overlooking a large lagoon complex located south of the mouths of the Danube (Fig. 1). Its location at the proximal margin of the delta complex partially explains the installation of Greek settlers in this very specific ecological area,

due to its rich wetland resources, while the latter in turn significantly influenced the historical trajectory of the city. The archaeological research on this site began in 1926 with the work of P. Nicorescu, before regular excavations were launched in 1965 and have continued up to present day. Like many of the world's deltas, human occupation of the Danube delta began during the Neolithic period (around ~6000 BC; Stanley and Warne, 1997; Kennett and Kennett, 2006; Giosan et al., 2012; Hu et al., 2013), when a slow-down in relative sea-level rise favoured the outbuilding of the deltaic plain and yielded a multiplicity of environmental resources that could be exploited by societies (Carozza et al., 2012; Dimitriu, 2012). Nonetheless, the earliest attested traces of human occupation on Cape Dolojman date to the First Iron Age (~700 BC).

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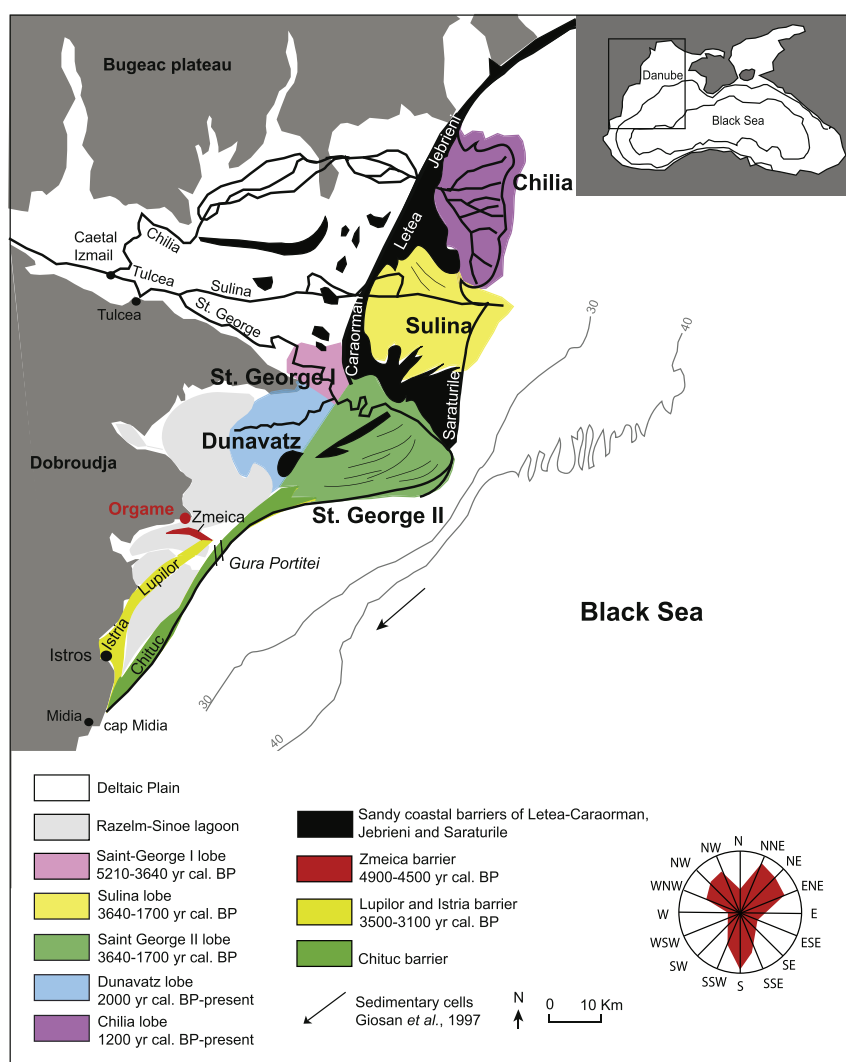
Fig. 1. Location of Orgame's ancient harbour in the present Razelm–Sinoe Lagoon, on the proximal margin of the Danube delta. The chronology of the deltaic lobes and barriers derives from Giosan et al. (2006).

Excavations conducted in 1972 by M. Coja on the southern areas of the peninsula have unearthed several levels dated to the earliest phases of the Babadag culture (8th–7th c. BC according to Coja (1972); 11th–9th c. BC according to Ailincăi et al. (2006)). More recently, the discovery of a collective burial, accommodating 13 individuals, has complemented these initial discoveries, testifying to the existence of a Getic settlement (Thracian tribes inhabiting the regions on either side of the Lower Danube and who could be in contact with the ancient Greeks) on this site before the arrival of the Greek settlers (Alincăi et al., 2006). However, its geography is still unclear, despite the recent identification of the two earth anomalies located west of the late Roman fortification as the possible remains of an Early Iron Age defensive system (Fig. 2). Although no epigraphic documents corroborate the name of the Greek city, which overlaps with the Getic levels on Cape Dolojman, it has been largely attributed to Orgame on the basis of two occurrences of the latter in textual sources, as well as in three inscriptions (Mănucu-Adameşteanu, 2003). Its history is characterized by two main periods of occupation. The first is related to the Greek colony. The exact date of its foundation is unclear, but the ceramic material found in the urban areas and at the necropolis'

oldest burial mound (Ta 95), suggests an installation of the Greek settlers in the mid-7th c. BC (Lungu, 2000). Because of its considerable size (42 m in diameter), this mound is a unique monument in the burial area. It hosted ritual offerings spanning a long period from the mid-7th c. BC to the 3rd c. BC, and has been interpreted as a heroon — the tomb of the colony's founder. This official burial clearly shows an autonomous political consciousness of the civic community during the Archaic period (7th–6th BC), underlining the high probability that Orgame was an independent city during this early period. Since 1988, extensive excavations carried out by V. Lungu on various areas of the necropolis have unearthed around 80 burial mounds covering a total area of more than 100 ha. The dominant ritual practice from the 7th to the mid-3rd c. BC, remained the cremation of the deceased followed by the deposition of their ashes in urns, a tradition that naturally consumed important amounts of wood, accentuating the human impacts related to the Greek city.

Moreover, the Greek harbour of Orgame is located south of the settlement, in a lagoon naturally sheltered from the north-south longshore drift by the Cape Dolojman (Fig. 2). This environment faced an important natural outlet named Gura Portiței (Fig. 1). A
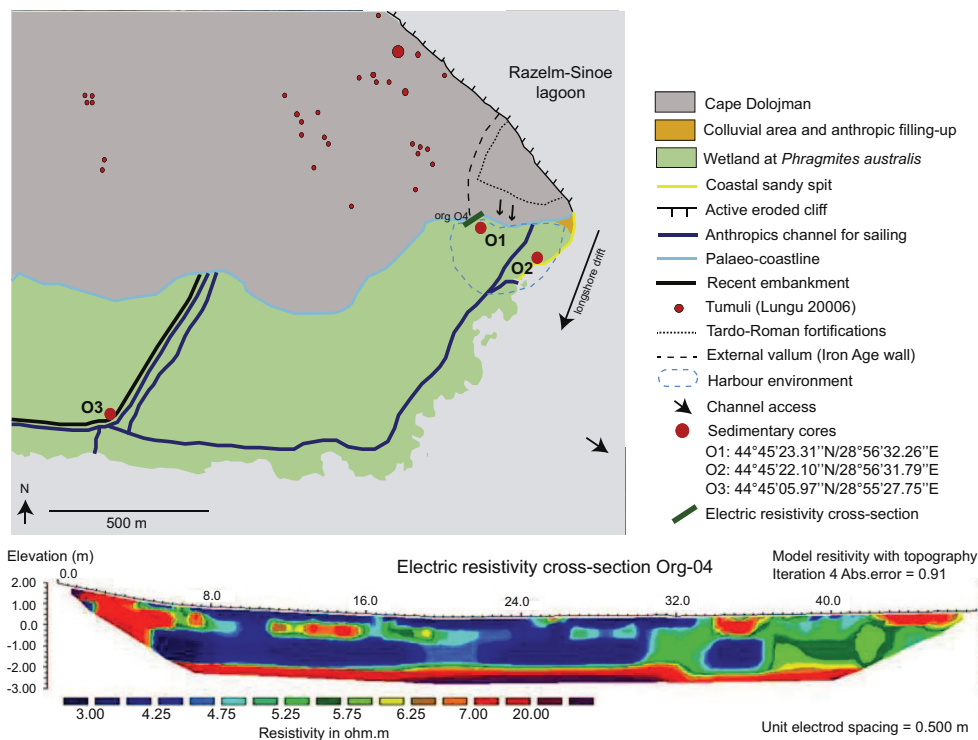
Fig. 2. Geomorphological map and location of archaeological remains and sedimentary cores. Geoelectric survey on the margin of the Razelm lagoon (Org 04).

geoelectric survey has revealed the presence of parallel structures that may correspond to harbour infrastructures (Fig. 2), including warehouses, but the exact chronology remains unclear (Baralis et al., 2010). The economic importance of Orgame declined, like most Greek settlements in the region, during the first half of the 3rd c. BC. This chronology appears similar to that found along the Western Black Sea. During the 3rd c. BC, the agricultural system of the ancient city of Apollonia Pontica (Bulgaria) also collapsed, as attested by the abandonment of the agricultural buildings located around the city (Baralis et al., 2012). A troubled period ensued, which saw the Celtic invasions and wars led by Lysimachus after the death of Alexander. It was not until the 2nd c. AD that Orgame regained importance. It was known in ancient sources by its Latinized name of Argamum. The military importance of the Northern borders of the Roman Empire explained the increasing attention of the authorities for the major settlements of Northern Dobrogea, leading to a new period of prosperity in the region. A new fortification wall was built to protect the city of Orgame/Argamum while the regional agricultural system adopted a new model characterized by the spread of individual farms along the main roads joining the two gates of the city (Baralis and Lungu, 2015). Nevertheless, the invasions of the early 7th c. AD affected the Roman administration of Dobrogea and also engulfed Orgame/Argamum. The harbour remained active until the 7th c. AD.

This papers looks to better understand 5000 years of human-–environment interactions at Orgame, located at the mouth of the Danube, using geoscience techniques developed and refined during the past 20 years (Reinhardt and Raban, 1999; Morhange, 2001; Marriner and Morhange, 2007). Today, the harbour of ancient Orgame/Argamum lies in Razelm–Sinoe lagoon. The shoreline is currently surrounded by a wetland dominated by *Phragmites australis*, that we suggest is broadly consistent with the ancient shoreline. The main objectives of the paper are: (1) to reconstruct coastal changes from ca. 5000 years BP onwards and to determine their impact on Orgame's development and abandonment; and (2)

to understand human impacts. A synthesis of these results is presented in Bony et al. (2013).

2. Geomorphological setting

The Danube delta is one of the world's major wave-dominated deltas. Its morphogenesis has taken place during the Late Pleistocene and Holocene (Panin, 1999, 2003; Panin et al., 2003; Olteanu, 2004; Giosan et al., 2006). Geologically, the Danube Delta is built upon the Dobroudja and the pre-Dobroudja formation. The weight of these sedimentary accumulations has led to some crustal mobility. The subsidence rate of the Danube delta is estimated to be between 1.2 and 2 mm y^{-1} (Giosan et al., 1997). The Razelm–Sinoe lagoon, composed of four lakes (Razelm, Golovita, Zmeica and Sinoe) which are delineated by sandy barriers and beach ridge plain, extends over two geotectonic units: i) the North Dobroudja, made of Cretaceous limestone and delineated to the North by the St. Geroges fault; ii) the Central Dobroudja caracterized by Precambrien green schists (Seghedi, 2012). The Cape Dolojman is formed by Mesozoic limestone corresponding to the North Dobroudja geotectonic units. The north-east side of the Cape of Dolojman shelters most of the archaeological remains of the city. At around 20 m in height, this active cliff is subject to intense erosion by north-east waves whereas the south-west side of the Cape is characterized by a gentle slope that dips into Sinoe–Razelm lagoon. This lagoonal shoreline, currently characterized by a wetland rich in organic matter, probably corresponds to the ancient coastline.

The development of the Danube delta took place in several phases shaped by the formation of successive lobes, driven by hydro-sedimentary changes in the Danube watershed. The delta plain is divided into two areas, consisting of an upper and lower part. The upper part is characterized by fluvial deposits and is considered to be linked to the bay behind the initial barrier Letea-Caraorman (Fig. 1), during the early development of the delta. The lower part of the plain is composed of fossil sandbars (Fig. 1) and

Table 1

Ecology of Ostracoda species, modified from Frenzel et al. (2010).

Taxon	Salinity	Latitudinal distribution; temperature	Water depth	Habitate and susbtrate	O2
Amnicythere longa	Oligohaline[f]	Black Sea, Caspian Sea[a]	Very shallow, 0–5 m[b]	Lagoons[c], estuarine systems of the rivers[g]	
Amnicythere quinquetuberculata	Up to 150 m[e]	Black Sea, Caspian Sea[a]	Very shallow[b]	Estuarine systems of the rivers[g]	
Amnicythere striatocosta	Oligo to mesohaline[c]	Black Sea, Caspian Sea[a]	Very shallow[b]	Lagoons[c], estuarine systems of the rivers[g]	
Amnicythere gracilloides	Oligohaline[c,d]	Black Sea, Caspian Sea[a]	Very shallow[b]	Lagoons[c], estuarine systems of the rivers[g]	
Amnicythere relicta	Oligohaline[c,d]	Black Sea, Caspian Sea[a]	Very shallow[b]	Lagoons[c], estuarine systems of the rivers[g]	
Amnicythere postbissinuata	Oligohaline[c,d]	Black Sea, Caspian Sea[a]	Very shallow[b]	Lagoons[c], estuarine systems of the rivers[g]	
Amnicythere volgensis	Oligohaline[c,d]	Black Sea, Caspian Sea[a]	Very shallow[b]	Lagoons[c], estuarine systems of the rivers[g]	
Candona angulata	Freshwater to mesohaline	Britannic to moroccan[i]; mesotherm[j]	Very shallow[k] and shallow[h]	Ponds and estuaries[i]; mud and sand[h]	Low oxygen[h]
Candona neglecta	Freshwater to mesohaline	Arctic[l] to moroccan[m]; oligotherm	Very shallow to deep[h,k]	(Coastal[i]) Lakes, lagoons estuaries[h] and open sea[i], mud[h,k]	Low oxygen[i]
Cyprideis torosa	Holeuryhaline[i]	Norwegian[l] to african[m]; polytherm[h]	Very shallow[k] to shallow[h]	Estuaries[h], ponds and lagoons[h,i]; salt marsh[n]; sediment[h], prefers mud[k]	Low oxygen[h]
Cypridopsis vidua	Freshwater to oligohaline	Artic to moroccan[m]; polytherm[o]	Very shallow[k] to shallow[h]	Lagoons[h] (coastal[i]); mud[h] and phytal[i]; nectobenthic[i]	
Darwinula stevensoni	Freshwater to oligohaline	Artic[p] to african[m]; eurytherm[o]	Very shallow[h,k] to shallow[h]	Ponds, lagoons[i] and estuaries[h]; sediment and phytal[h]	
Eucypris virens	Freshwater to oligohaline[i]	Norwegian to moroccan[i]; mesotherm[o]	Very shallow[h]	Ponds[q], temporary also[i]	
Euxinocythere bacuana	Stenohaline[e]	Black Sea, Caspian Sea[g]; mesotherm[r]	All depths[e]	Lagoons, estuaries; soft muddy substrates[r,a,b]	
Herpetocypris reptans	Freshwater to mesohaline	Arctic to african[i]; eurytherm[j,o]	Very shallow[i] to shallow[h]	Lakes, ponds and estuaries[i]; phytal and mud[h]; endobenthic	High oxygen[h]
Heterocyrpis salina	Oligohaline to mesohaline[j]	Cosmopolitan[s]; eurytherm[t]	Very shallow[k]	Permanent[i] and temporary[h] ponds; sediment and phytal[k]	Low oxygen[k]
Ilyocypris bradyi	Freshwater to oligohaline[u]	Norwegian[l] to moroccan[i]; polytherm[j]	Very shallow[m]	Springs, ponds, swamps and estuaries, temporary waters also[i,m]	High oxygen[h]
Ilyocypris gibba	Freshwater to oligohaline[k]	Norwegian[l] to african[i]	Very shallow[i,k]	Ponds and estuaries[i]	High oxygen[h]
Limnocythere inopinata	Freshwater to mesohaline[k]	Arctic to african[i]; polytherm[j]	Very shallow to shallow[h,k]	Lagoons and estuaries[h]; sediment and phytal[h,k]	Low oxygen[h]
Loxocaspia immodulata	Mesohalin[b]	Black Sea, Caspian Sea[a,g]	Shallow, >10 m[a,g]	Coastal, calm environment; soft muddy substrate[a,g]	
Loxoconcha elliptica	Oligohaline to polyhaline[j]	Norwegian to morrocan[m]; eurytherm	Very shallow[h,k]	Lagoons and esturaries[h], salt marsh[n]; sediment phytal[h]	Probably low oxygen[h]
Loxoconcha pontica Klie	Oligaohalin[s]	Black Sea, Azov Sea, Mediterranean Sea[s]		Inland sea, estuarie, lagoons[s]	
Pseudocandona albicans	Freshwater to mesohaline[k]	Norwegian to morrocan[l]; mesotherm	Very shallow[h,k]	Lagoons ans estuaries[h], swamps, ponds and lakes, temporary waters also[i]; phytal[h]	Low oxygen[k]
Pontocythere baceseoi	Oligo to mesohaline[v]	Black Sea, Azov Sea[s]		Lakes, lagoons[v]	
Potamocypris villosa	Freshwater[w]	Cosmopolitan[w]		Springs, ditches and small ponds. It seems to be rather rare in lakes[w]	
Semictyherura sulcata	Mesohaline to euhaline[x]	Mediterranean[x]	Shallow[x]	Marine littoral to sublittoral; sandy to silty or muddy substrates frequently with algae[x]	
Tyrrhenocythere amnicola	Oligohaline to mesohaline[y]	Black Sea, Azov Sea, Caspian Sea, Tyrrhenian Sea[y]		Flooding river valleys, lagoons, ponds; muddy bottom with aquatic vegetation[b]	
Tyrrhenocythere pseudoconvexa	Oligohaline[y]	Black Sea, Caspian Sea[y]	Shallow[y]	Flooding river valleys, lagoons, ponds; muddy bottom with aquatic vegetation[b]	

Table 1 (*continued*)

Taxon	Salinity	Latitudinal distribution; temperature	Water depth	Habitate and susbtrate	O2
Xestoleberis aurantia	Oligohaline to euhaline[j]	Britannic to lusitanian[y]	Very shallow to shallow[h]	Ponds, lagoons and open sea; phytal[h]	

[a] Opreanu (2008).
[b] Gliozzi and Grossi (2008).
[c] Olteanu (2004).
[d] Schornikov (2011a).
[e] Gofman (1966).
[f] Schornikov (1972).
[g] Schornikov (2011b).
[h] Frenzel et al. (2010).
[i] Meisch (2000).
[j] Vesper (1975).
[k] Jävekülg (1979).
[l] Löffer and Danielopol (1978).
[m] Klie (1938).
[n] Penney (1987).
[o] Hiller (1972).
[p] Delorme and Zoltai (1984).
[q] Sywula (1966).
[r] Chekhovskaya et al. (2014).
[s] Kiliç (2001).
[t] Mischke et al. (2012).
[u] Usskilat (1975).
[v] Altinsaçh et al. (2014).
[w] Meisch (1985).
[x] Cabral et al. (2006).
[y] Tunoglu and Gokçen (1997).

corresponds to the development of the delta lobes outside the estuary. It comprises the lobes of St. George I and II, Sulina lobe and lobes Chilia I, II and III (Fig. 1). The secondary arm of St. George, the Dunavatz, also formed a small lobe that developed in Sinoe lagoon−Razelm around 2000 years cal. BP (Giosan et al., 2005, 2006). Giosan et al. (2006) have demonstrated that this lagoon was formed by sand spit accretion fed by Danube sediment input and north-south longshore drift since 5000 years BP, in a context of relative sea-level stability (Porotov, 2007; Brückner et al., 2010). Three generations of coastal barriers (Zmeica, Istria-Lupilor and Chituc) characterize the Razelm−Sinoe lagoon. According to Giosan et al. (2006), the barrier system of Zmeica is either the remnant of the initial barrier that blocked the Danube bay (barrier-Letea Caraorman; Fig. 1) or a remnant sand spit linked to the development of the asymmetric lobe St. George I, from 4900 to 4500 years cal. BP (Fig. 1). The Lupilor barrier system stabilized between 3500 and 3100 years cal. BP, during the progradation of the St. George I lobe. It appears synchronously with the first generation of barriers of the strandplain of Istria, dated between 3700 and 3300 cal. BP. The recent barrier was built at Istria between 1500 and 600 cal. BP, followed by the barrier plain of Chituc. Finally, recent barriers (<450 cal. yr BP), located inside the lagoon Razelm−Sinoe are in discordance with the coastline and are the product of intra-lagoonal processes. Sediments brought into the lagoon by the Dranov (now channelized) and Dunavatz channels (secondary arms of St. Georges arms) and are redistributed to the south by the lagoon's longshore drift. The natural opening of Gura Portiței probably corresponding to a deep area, was artificially closed in 1969 for touristic reasons (Mihailescu, 2006). It was located in front of the ancient city. The Razelm−Sinoe lagoon, corresponding to a low-energy environment, is characterized by a sandy−silt sediment. Sediments brought into the lagoon by the Dunavatz and Dranov channels are redistributed to the south by the lagoon's longshore drift. Wave heights in the lagoon complex can reach 1.2 m during severe storms (Mihailescu, 2006). They can resuspend parts of the bedload, leading to bio-detritic accumulations on the shore. The lagoon system is characterized by mesohaline Ponto-Caspian fauna.

Since the 1970s, the lagoon has gradually infilled and is nowadays a polluted oligohaline system (Vadineanu et al., 1997; Alexetrov et al., 2004).

The city of Orgame is located 60 km southwest of St. George's arm, 20 Km Dunavatz arm, 14 km from Gura Portiței and 2.5 km from the island of Bisericuta with archaeological remains, vintage Late Roman and Proto-Byzantine (Manucu-Adamesteanu, 2003). This location makes it a strategic site of human occupation.

3. Methods

The Holocene palaeoenvironments in the region of Orgame have been reconstructed using sedimentological, palaeo-biological and chronostratgraphic methods on three stratigraphic cores. These cores have been extracted on the shoreline of Razelm lagoon, in front of the city of Orgame (Fig. 2). The coring campaign was undertaken in November 2009 using a Cobra TT percussion corer. Core descriptions (texture, Macrofauna, organic remains) and sampling were undertaken in the field. The sampling interval depends on the nature of the sediment but varied between 5 and 10 cm. In the laboratory, the sediment texture was determined by sieving and laser granulometry (Blott et al., 2004). Three granulometric indices were used in order to characterize the depositional sedimentary processes: mean grain size, the sorting index and skewness (Folk and Ward, 1957). Organic matter content has been quantified using the Loss of Ignition method (LOI; Bengtsson and Enell, 1986; Heiri et al., 2001; Sanisteban et al., 2004). Concerning palaeo-biological analyses, we paid particular attention to Macrofauna (present in the sedimentary fraction >2 mm) and Ostracoda (present in dry sand fraction >150 μm). 88 samples were been analysed. 729 specimens of Macrofauna covering 12 taxa were picked and identified using the following references: D'Angelo and Garguillo (1978); Poppe and Gotto (2000a,b). The autoecological groups were defined according to Péres and Picard (1964), a molluscan ecological classification system for Mediterranean species, and to the salinity gradient. Concerning Ostracoda, 5314 specimens covering 30 taxa were picked and determined. For each sample we

Table 2
Radiocarbon determinations and calibrations.

Lab code	Sample n°	Depth (cm)	Material	Age ^{14}C BP	σ	δ ^{13}C (‰)	Corrected Age ^{14}C BP	σ corrected	Calibrated Age BP (2σ)	Calibrated Age BC/AD (2σ)	Status
Poz-43347	O1 228	228	Organic sediment	3830	35	−28.5			4099−4407 cal BP	2458 cal BC−2150 cal BC	Accepted
Poz-43349	O1 277	277	Marine shell *Donax variegatus*	5165	35	−3.2	4667	54	5303−5580 cal BP	3631 cal BC−3354cal BC	Accepted
Lyon-8279	O1 330	330	Organic matter	5630	35	−27.18			6317−6482 cal BP	4533 cal BC − 4368 cal BC	Accepted
Lyon-8289	O1 385	385	Organic matter	6050	35	−27			6795−6991 cal BP	5042 cal BC−4846 cal BC	Refused
Lyon-8281	O1 395	395	Organic matter	5835	35	−26.64			6545−6991 cal BP	4791 cal BC−4596 cal BC	Accepted
Poz-43348	O1 420	420	Wood	4685	35	−29.5			5318−5576 cal BP	3627 cal BC−3369 cal BC	Refusée
Lyon-8282	O2 86	86	Plants (monocotyledon)	−29.06		−29.06				moderne	Refused
Poz-51363	IRO2 35	92	Charcoal	295	30	v.n.d			291−459 cal BP	1491−1659 cal AD	Accepted
Lyon-9404	O2 150−160	145	Plants (monocotyledon)	180	30	v.n.d			74−297 cal BP	1653−1876 cal AD	Refused
Poz-43350	O2 202	202	Freshwater shell *Melanopsis praemorsa*	2060	60	−25.2			1881−2294 cal BP	345 cal BC−69 cal AD	Accepted
Poz-51364	IRO2 67	210	Charcoal	2575	30	v.n.d			2518−2759 cal BP	810−519 cal BC	Refused
Beta-325708	IRO2 73	222	Charcoal	2310	30	−22.5			2183−2358 cal BP	409−234 cal BC	Accepted
Poz-51362	IRO2 100	282	Charcoal	2560	30	v.n.d			2503−2753 cal BP	804−554 cal BC	Accepted
Lyon-8276	O2 382	382	Wood	2900	30	v.n.d			2950−3160 cal BP	1211 cal BC−1001 cal BC	Accepted
Lyon-9405	O2 420−430	425	Organic matter	3655	30	v.n.d			3894−4084 cal BP	2135−1495 cal BC	Accepted
Beta-325709	IRO2 153	460	Charcoal	4790	30	−24.6			5470−5593 cal BP	3644−3521 cal BC	Refused
Lyon-8277	O2 528	528	Organic matter	6010	35	v.n.d			6749−6945 cal BP	4996 cal BC−4800 cal BC	Refused
Poz-43351	O2 610−620	615	Marine shell *Donax variegatus*	5160	35	−6	4662	54	5299−5580 cal BP	3631 cal BC−3350 cal BC	Accepted
Poz-43353	O2 850−860	855	Marine shell *Donax variegatus*	5630	40	−3.6	5132	57	5739−5993 cal BP	4044 cal BC−3790 cal BC	Accepted
Poz-51366	O3 140−150	145	Charcoal	770	30				669−733 cal BP	1217−1281 cal AD	Refused
Lyon-8283	O3 200	200	Plants (monocotyledon)	715	30	−25.16			566−720 cal BP	1230 cal AD−1384 cal AD	Accepted
Lyon-9402	O3 250−260	255	Plants (monocotyledon)	182.9		v.n.d				moderne	Refused
Lyon-8284	O3 288	288	Wood	720	30	v.n.d			568−722 cal BP	1228 cal AD−1382 cal AD	Refused
Lyon-9401	O3 290−300	295	Plants (monocotyledon)	730	30	v.n.d			654−726 cal BP	1234−1296 cal AD	Refused
Lyon 8275	O3 358	358	Organic matter	−26.33		−26.33				moderne	Refused
Poz-43354	O3 479	479	Organic matter	6190	40	−27			6974−7241 cal BP	5292 cal BC−5025 cal BC	Refused
Lyon-9403	O3 490−500	495	Marine shell *Abra alba*	5225	30	v.n.d	4727	50	5323−5585 cal BP	3636−3574 cal BC	Refused
Poz-43355	O3 630−650	640	Marine shell *Donax variegatus*	5275	35	−1.2	4777	54	5326−5603 cal BP	3654 cal BC−3377 cal BC	Accepted

Radiocarbon Calibration Curve IntCal09 (Reimer et al., 2009). Marine reservoir Age 498 ± 41 ^{14}C BP (Siani et al., 2000). Corrected Age = Age adjusted for marine Reservoir Age.

normalised the ostracod density to a standard dry sample weight (40 g). The Danube delta region is characterised by its relatively low salinity and for the presence of Ponto-Caspian species. Therefore, species observed in these three cores have a similar ecology. They are eurythermal and live on sandy substrata in shallow, low salinity environments. A list of all Ostracoda species with references and the species ecology is given in Table 1. The ecological groups are based on the salinity gradient which separates oligaline species from oligo to mesohaline species to mesohaline species. The chronological framework is provided by radiocarbon dates performed at Poznan (Poland) and the Artemis laboratory (Saclay, France). All the radiocarbon dates have been corrected for atmospheric ^{14}C variations using the calibration curve IntCal09 (Reimer et al., 2009; Table 2). Concerning the dates obtained on marine shells, a marine reservoir age of 498 ± 41 ^{14}C years BP (Siani et al., 2000) has been subtracted from the radiocarbon dates before calibration with IntCal09 (Table 2). The age model was made using all accepted dates (Table 2) and a simple linear regression was applied. Principal components analysis (PCA) was performed to test the ordination of samples by assessing major changes in palaeo-biological proxies and sediment deposits. PCA ordination was selected because it is a nonparametric method of extracting relevant information from complex datasets (Kaniewski et al., 2008, 2011). Most of the variance is accounted for by the first PCA-Axis, with 72.59% of total inertia (Ostracoda), 57.7% (Macrofauna) and 64.22% (granulometry). The PCA-Axes1 (Ostracoda, Macrofauna and granulometry) have been plotted on a linear age-scale with the organic matter scores and the fire history. The numerical analyses were performed using the software PAST (Version 2.14 Paleontological statistic, Hammer et al., 2001).
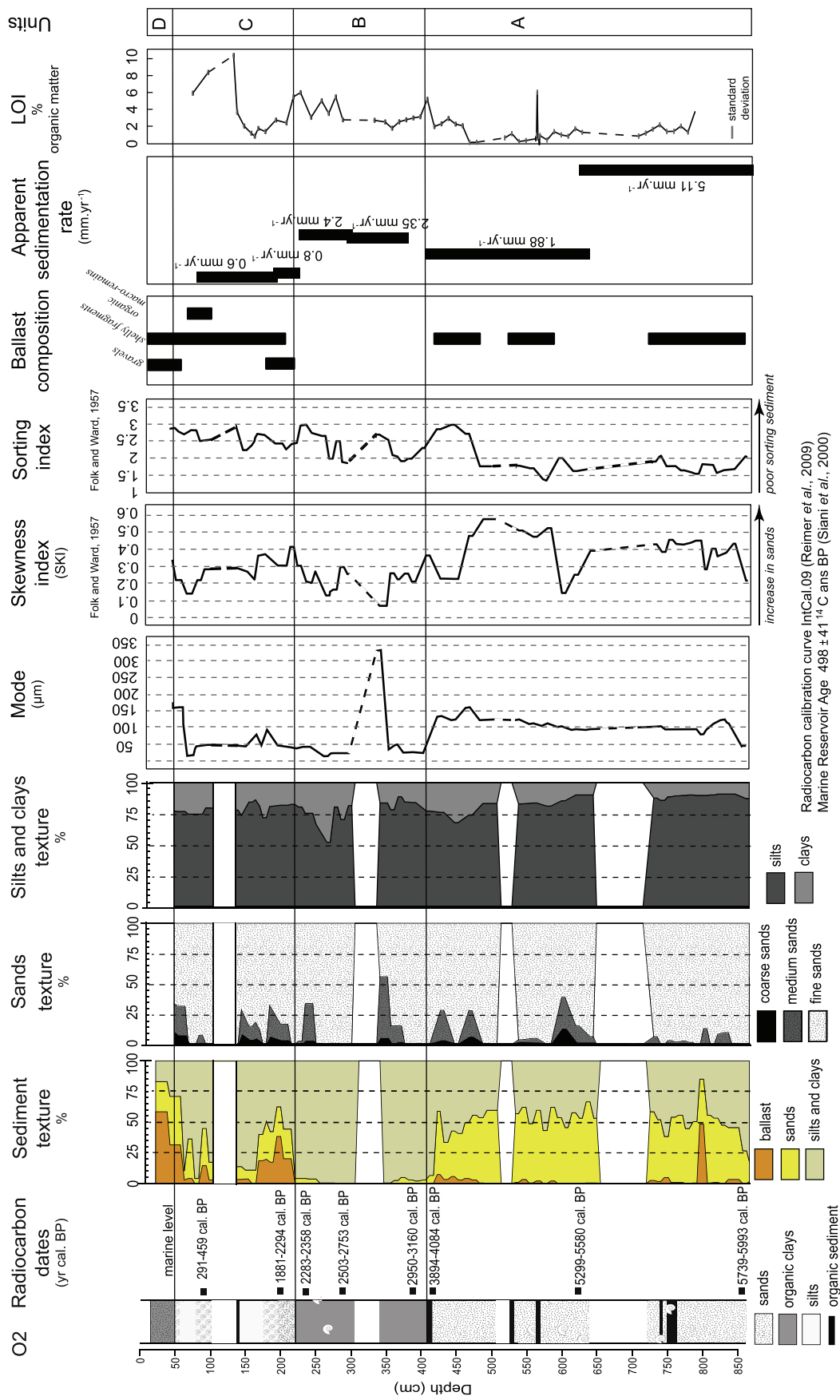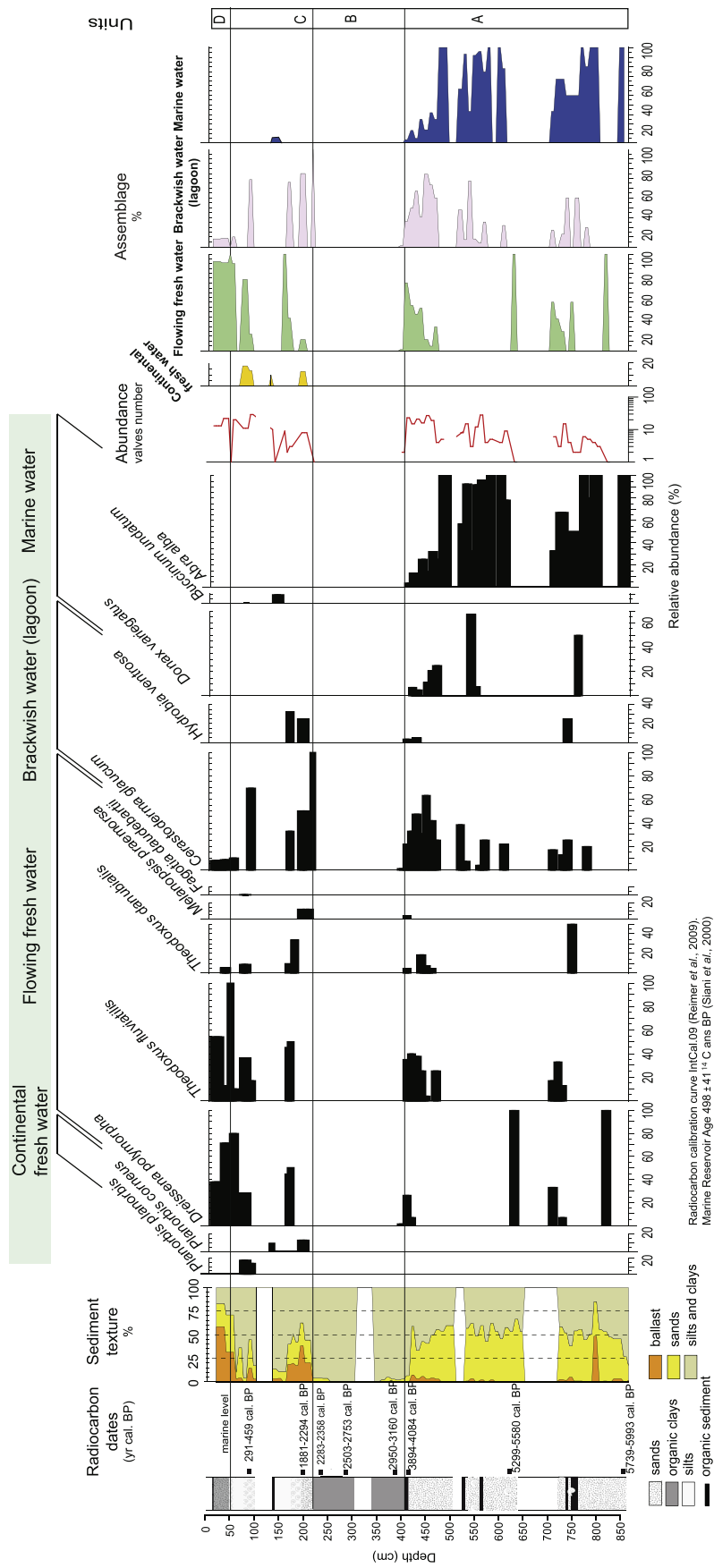
Fig. 3. Sedimentology of core O2.

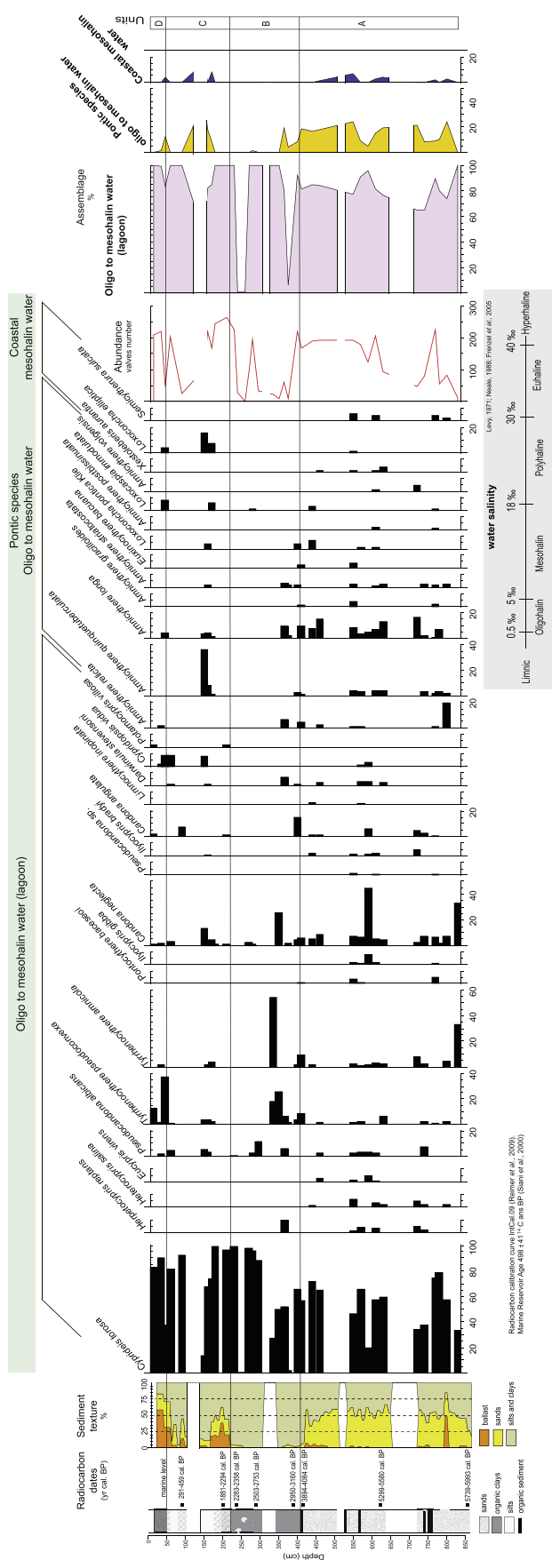**Fig. 4.** Molluscan Macrofauna species and assemblages from core O2.

Fig. 5. Ostracofauna species and assemblages of core O2.

The fire history of the lagoon was reconstructed by counting charcoal particles (50−200 μm) from the slides prepared for pollen analysis as well as from larger charcoal remains (>200 μm) (Gavin et al., 2006; Higuera et al., 2007). The 50 μm size criterion was chosen to avoid confusion of microscopic charcoal fragments with opaque minerals, which are typically <50 μm (Parshall and Foster, 2002; Pederson et al., 2005). Macroscopic charcoal, extracted with Na_2HPO_4, were sorted and counted under a binocular microscope (at ×36). Charcoal accumulation rates (CHAR) were subsequently estimated (number of particles g^{-1} y^{-1}).

4. Results

Sedimentary cores O1 and O2 were taken from inside the ancient harbour environment while core O3 is located southwest of the city, beyond its zone of influence (Fig. 2). They show a transformation of the Orgame coastline. This paper describes the bio-sedimentological results of core O2, which is the best-dated core (Figs. 3−5). These results are subsequently compared to cores O1 and O3 (Fig. 6).

4.1. Palaeoenvironmental evolution of Orgame bay and characterization of the ancient harbour environments

In the absence of a core that attained the bedrock, we suggest that the onset of marine sedimentation began with the reconnection of the Black Sea to the Mediterranean Sea ca. 9400 years cal. BP ago (Soulet et al., 2011).

4.1.1. Unit A: a marine bay at the distal margin of the Danube delta

The basal unit (Unit A) is located between 4.1 m and 8.5 m depth. It consists of an accumulation of shelly sandy-silt sediments, reflecting a dynamic depositional environment. Three samples were taken for radiocarbon dates; two on marine shells (*Donax variegatus*) situated at 8.5 m and 6.15 m depth, and one on organic sediment at 4.25 m depth (Table 2). The organic sediment was dated to 3894−4084 cal. yr BP (2135−1945 cal. yr BC). This sample is located at the transition between the sandy-silts facies (Unit A) and the overlying silty facies (Unit B). Marine shells have been dated to 5739−5993 cal. yr BP (4044−3790 cal. yr BC) and 5299−5580 cal. yr BP (3631−3350 cal. yr BC). This unit consists of 50% sands and 50% clayey silt. The gravels fraction is almost absent and comprises marine shell fragments. At 4.7 m, the sand fraction decreases slightly and drops abruptly at the transition with the overlying unit. The sand fraction comprises 90% fine sand which is confirmed by a mode of 100 microns. The importance of the sands fraction is translated by a skewness index between 0.3 and 0.6 and a sorting index between 1.5 and 2 (Fig. 3). The sedimentation rate at the base of the unit is relatively high (ca. 5 mm yr^{-1}; Fig. 3).

The Macrofauna analysis (Fig. 4) shows an ecological assemblage of autochtonous and allochthonous molluscan taxa. The assemblage of autochtonous molluscan taxa is delimited by lagoonal species and marine species from the infralittoral zone on sandy substrate (*Abra alba*, *D. variegatus*). *A. alba* lives in fine sediments having a mode between 50 and 250 microns (Huber and Gofas, 2012). Some of the optimal development conditions for this species are identical to the particle size data for this unit. The lagoonal assemblage comprises *Hydrobia ventrosa* and *Cerastoderma glaucum*. *C. glaucum* is a brackish species living in lagoonal environments but that is also typical of coastal environments close to river mouths (Peres and Picard, 1964). The mixing of these two assemblages is entirely consistent with coastal environments. Allochthonous molluscan taxa consist of Macrofauna common to the Danube River (*Theodoxus danubialis*, *Theodoxus fluviatilis* and *Dreissena polymorpha*; Murphy, 2012). This assemblage of common
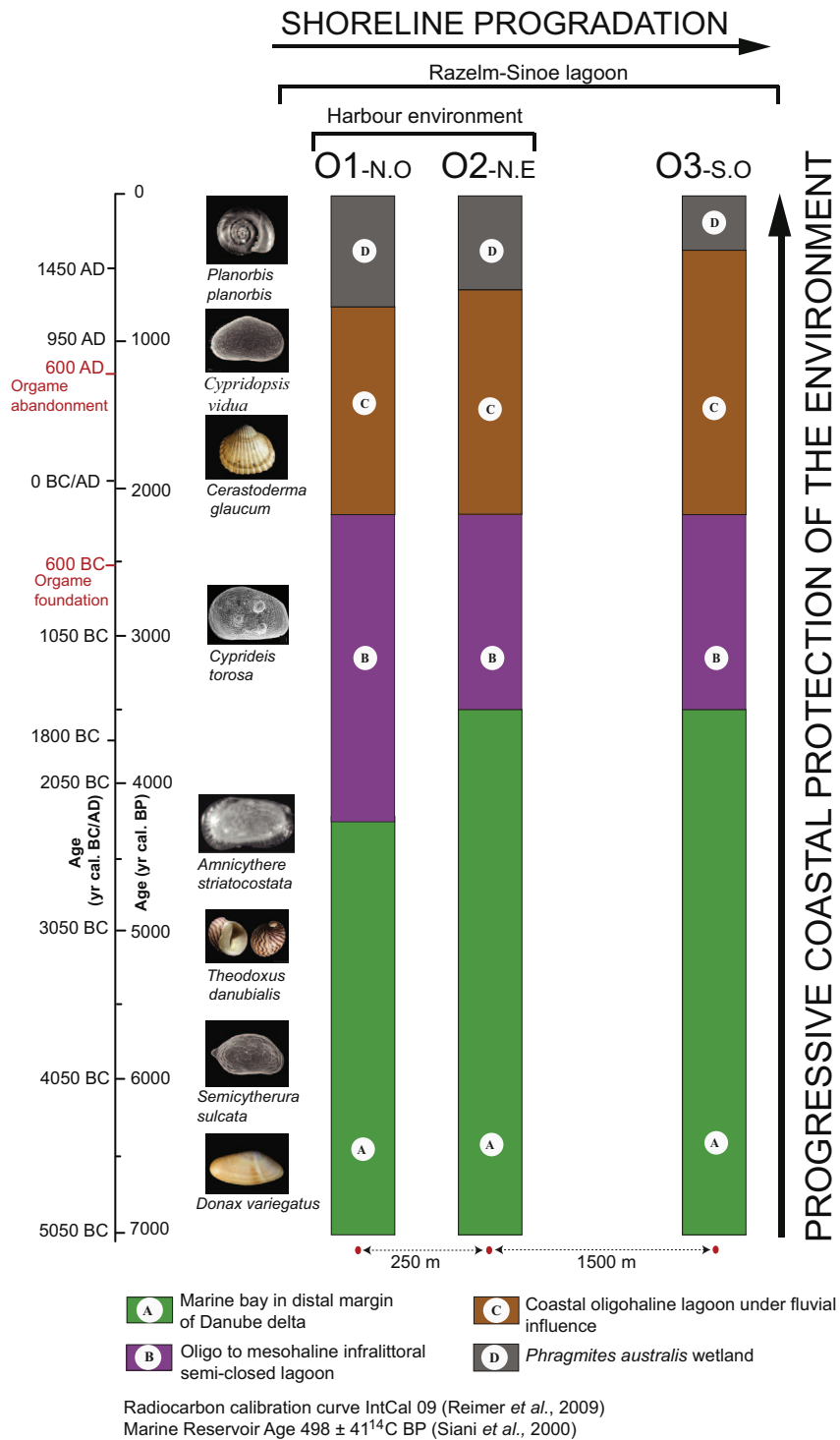
Fig. 6. Stratigraphy of the three cores based on litho- and biostratigraphic data.

freshwater species can only be explained by the proximity of the Danube flows to this environment. From 4.70 m deep, infralittoral marine species decline in favour of *T. fluviatilis* and *C. glaucum* species. The environment becomes more oligohaline.

Concerning the microfauna, we observed a mixture of oligo to mesohaline lagoon taxa, coastal and Pontic species (Fig. 5). The Pontic ostracods are characteristic of oligo to mesohaline environments and marginal environments such as lagoons. They have good affinity with Mediterranean coastal mesohaline species and oligo to mesohaline Mediterranean species (*Candona* spp, *Cypridopsis* spp, *Darwinula* spp and the species *Cyprideis torosa*). The ecological assemblages that we observed in the sediments of unit A are consistent with the ostracodological data of the Black Sea coast. For the ostracod *C. torosa*, most shells have nodules. The nodules develop when the species evolves in lacustrine to brackish environments of low salinity (Carbonel, 1980; Bordegat et al., 1991; Gliozzi and Mazzini, 1998; Frenzel and Boomer, 2005; Cabra et al., 2006). According to the literature, the salinity thresholds at

which these nodules appear varies between 5‰ (Keyser and Aladin, 2004) and 8‰ (Carbonel, 1980; Gliozzi and Mazzini, 1998). We infer that the salinity recorded for this sedimentary unit is less than 10‰. The salinity of the Black Sea is not very high (18‰) and is lower at the coast (Schokalsy and Nikitin, 1927). This is consistent with the ostracod assemblages that we observed.

Unit A corresponds to an open coastal environment of low salinity (oligo mesohaline) typical of Black Sea coastal environments and the Danubian area. However, the decrease in grain size observed after 4.7 m is paradoxical. Indeed, the sedimentary characteristics of the sandy bottom deposit is a rise of coarse particles towards the coastline and the wave breaking zone. In this case, it could mark the beginning of a naturally protected environment. Deltaic progradation of the Danube delta (started around 5200 yr BP; Giosan et al., 2006) has led to a natural protection of the environment by building coastal barriers opposite the Cape Dolojman (Fig. 1).

4.1.2. Unit B: semi-enclosed lagoon

Unit B, located between 2.2 m and 4.1 m depth, is characterized by silt accumulation (mode <50 microns; Fig. 3), which contrasts with the sandy texture of the underlying unit (5% of the sands fraction versus 50% for unit A). The sediment is poorly sorted but is enriched in fine particles (0.1 > SKI > 0.3; Fig. 3), confirming a low-energy context. The transition between unit A and unit B is relatively abrupt indicating a rapid transformation of the dynamic marine environment into a protected and calm environment. The top of the unit (2.22 m depth) is dated to 2183−2358 cal. yr BP (409−234 cal. yr BC; Table 2). A piece of wood located at 3.82 m depth and a charcoal located at 2.82 m depth has been dated respectively to 2950−3160 cal. yr BP (1211−1001 cal. yr BC) and 2503−2753 cal. yr BP (804−554 cal. yr BC; Table 2). The sedimentation rate is about 2 mm yr^{-1} (Fig. 3).

The unit is devoid of Macrofauna and shell debris (Fig. 4). Concerning the microfauna, coastal assemblages are completely absent (Fig. 5), only a few oligo to mesohalines lagoon species (Candona neglecta, Tyrrenocythere pseudoconvexa, Darwinula stevensoni, Pseudocandona albicans…) and some Pontic species are present (Amnicythere longa and Amnicythere striatocosta). At 3.5 m depth, the ostracofauna is dominated by the species C. torosa (Fig. 5). According to Carbonel (1980), protected environments (like lagoons) are generally marked by a monospecific population and the dominance of euryhaline species such as C. torosa. The transformation of the environment into a monospecific environment is consistent with a rise in organic matter content (Fig. 3). A protected turbid environment like a lagoon, rich in organic matter, can often lead to a decrease in photosynthetic activity and thus a decrease in Macrofauna and a monospecific population (Guelorget, and Perthuisot, 1983; Akouminanki and Nicolaidou, 2007).

This stratigraphic unit records a changing environment marked by the transition from a marine-protected bay to a semi-closed mesohaline lagoon between ca. 3000 and 2000 cal. yr BP.

4.1.3. Unit C: fluvial oligohaline lagoon

Unit C is located between 2.4 m and 0.5 m depth. Its deposit is contemporary of 1881−2294 cal. yr BP (345−69 cal. yr BC). At 0.92 m depth a charcoal has been dated to 291−459 cal. yr BP (1491−1659 cal. yr BC; Table 2). The grain-size analyses indicate a sedimentary texture similar to unit B but composed of 15% sands made-up of shelly fragments (Fig. 3).

Marine Macrofauna are absent from this unit. Other molluscan taxa are similar to unit A but in higher abundance indicating an oligo to mesohaline lagoon disconnected from marine flows (Fig. 4). The presence of species common to the Danube river attests to Danube flows into this lagoonal environment. The occurrence of

Planorbis corneus (a gastropod living in vegetated areas with <4‰ salinity), reflects the input of continentally-derived freshwater and suggests a progradation and continentalisation of the lagoon margins. At a depth of 1.60 m, Buccinum undatum shells suggest marine water input (Fig. 4). Currently, on the Chituc barrier at the ancient pass of Gura Portiţei, present Black Sea storm deposits constitute accumulations of B. undatum. Therefore, the presence of this species suggests a sedimentary record of a storm. Concerning microfauna, the assemblage is characterised by abundant C. torosa, coastal and pontic species, whereas the underlying interval B was dominated by lagoonal species (Fig. 5). The presence of marine adults species confirms marine water flow from storms into the lagoonal environment. The decrease in organic matter, between 2.1 and 1.5 m depth, can be explained by the sedimentation of lagoonal and fluvial shells on the shore due to the reopening of the environment to fluvial inputs in the lagoon.

4.1.4. Unit D: Phragmites australis wetland

Unit D corresponds to the uppermost unit. The sediment is an organic black mud (with high gravels content) rich in leaves and stems of Phragmites australis (Fig. 3). This grass thrives in freshwater to lightly brackish environments (salinity of around 5‰) and on sandy loam soils. These are concomitant with the freshwater species, D. polymorpha and T. pseudoconvexa (Figs. 4 and 5). This unit corresponds to the onset of the Phragmites australis wetland, observed on the current margins of the Razelm−Sinoe lagoon complex. It corresponds to the final stage in the infilling of the lagoon margins.

5. Discussion

5.1. Reconstruction of the palaeoenvironmental changes around Orgame lagoon

The stratigraphy of these three cores is similar and indicates a classic environmental transformation (Fig. 6). The reduction in accommodation space gradually led to the transition from a marine environment to a quasi-closed lagoon (3660 cal. yr BP) to an oligohaline lagoon (2300 cal. yr BP) whose margins were progressively transformed into a coastal wetland dominated by Phragmites australis (1000 cal. yr BP). Seaward development is, however, recent (Fig. 3). On the shoreline (core O1), the transition from a marine bay to a lagoon environment occurred at 4300 cal. yr BP due to the progradation of the coastline (Fig. 6).

Units A and A′ correspond to subtidal sand deposits related to relative sea-level rise. The high sedimentation rates recorded at the bottom of the core O2 (ca. 5 mm yr^{-1}; Fig. 3) could be explained by an increase in the discharge of the Danube river around 5000 cal. yr BP, when sea level stabilized (Giosan et al., 2006). At the top of unit A core O2 (4.7 m depth), the environment records an increase in silty particles in concordance with a rise in lagoonal Macrofauna to the detriment of coastal Macrofauna (Fig. 4). This unit is characterized by organic deposits which are older than the sediments they overlie (Fig. 3). For example, the organic deposit located at a depth of 5.3 m is dated to 6010 ± 35 ^{14}C yr BP (6749−6945 cal. yr BP; 4996−4800 cal. yr BC; Table 2) and is not compatible with sea shell dates located below (Table 2, Fig. 3). We observed the same deposit in core O1 and O3 (Fig. 6). The organic matter located at approximately the same depth is of the same age and is also not compatible with dates located below. These organic-rich deposits suggest a homogenous sedimentary event possibly linked to the high sedimentation rate around 5000 cal. yr BP. Stanley (2001) has suggested that on delta margins like the Nile Delta which is similar to the Danube delta in terms of processes, old carbon can be reworked in the watershed by fluvial action and
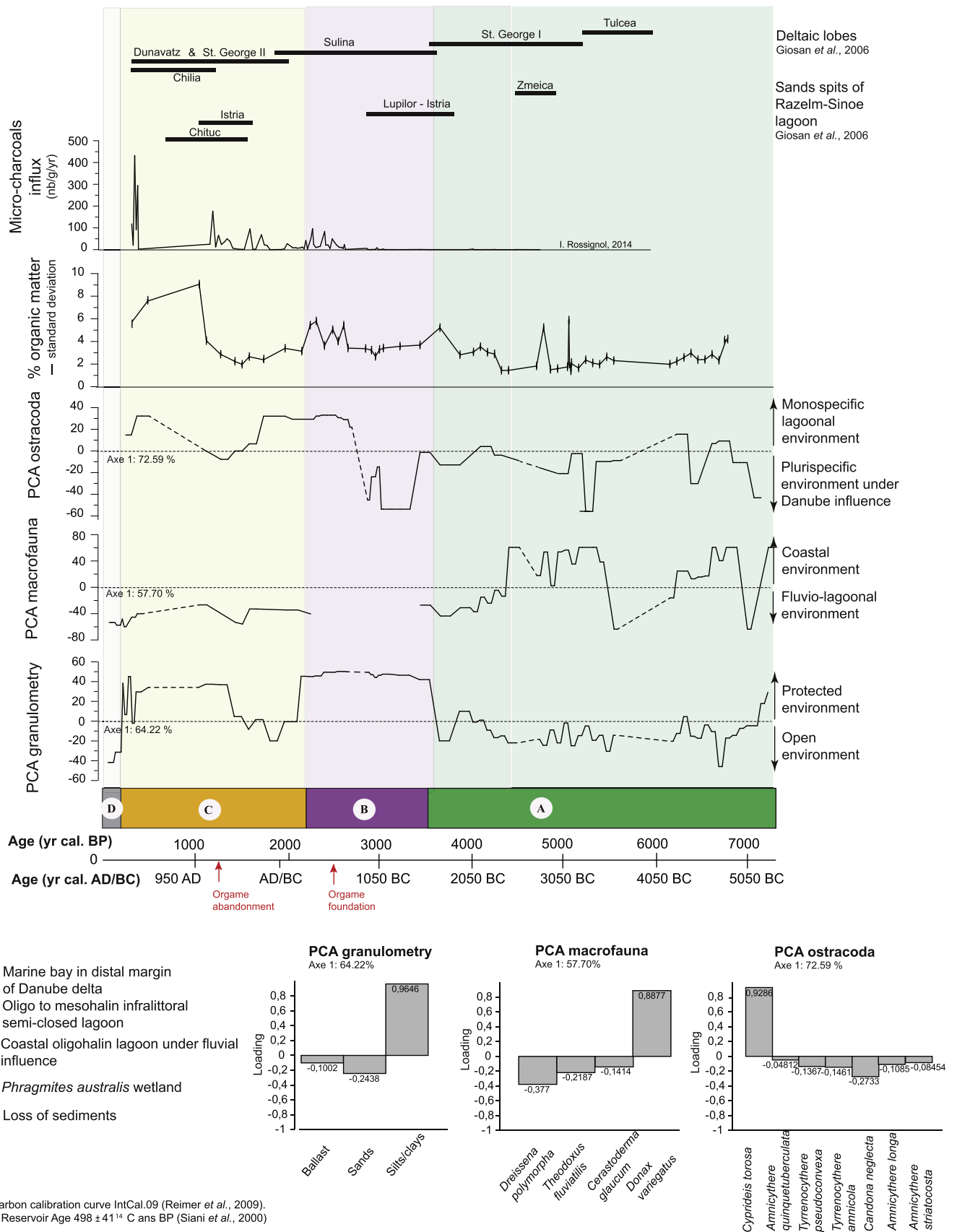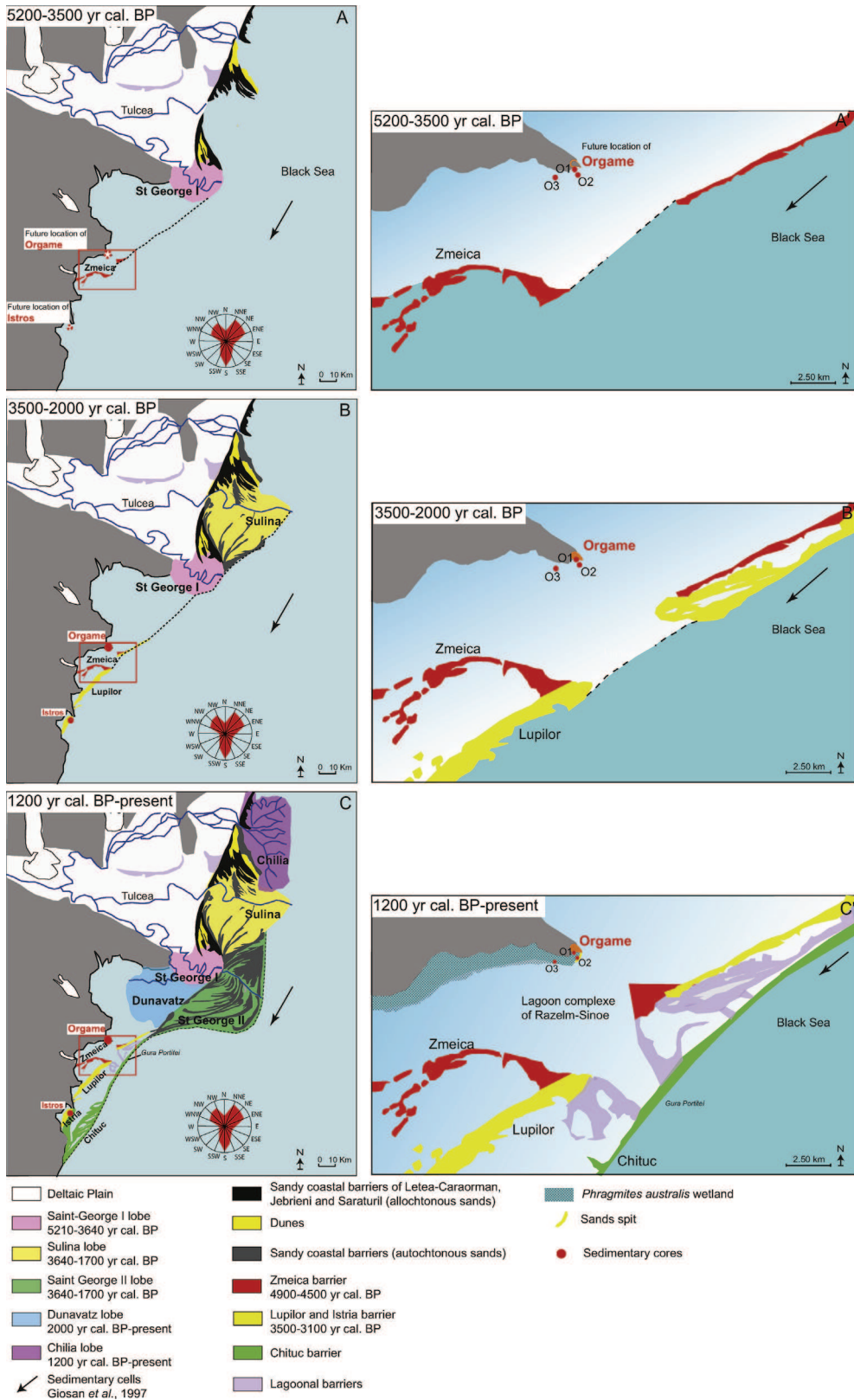
Fig. 7. Statistical analysis using Principal Components Analysis (PCA) on bio-sedimentological results from core O2.

Fig. 8. Palaeo-geographical reconstruction of Orgame's coastal landscapes at the Danube delta scale (A, B, C) and at the Razelm lagoon scale (A′, B′, C′) around 5200–3500 yr cal. BP (A, A′); 3500–2000 yr cal. BP (B, B′); 1200 yr cal. BP and present day (C, C′).

deposited in coastal depocentres. Based on the facies model for wave-dominated deltas, shoreline sediments derive directly from the associated river (Bhattacharya and Giosan, 2003). In a context of radiocarbon dating, sedimentary processes at work in the Danube Delta (wave action opposed to fluvial processes) have a stratigraphic impact. Although, in the absence of stable isotope analyzes of the organic matter, however, we can suggest that the organic material comes from the Danube and is an indicator of the Danube flows.

Units B, C and D correspond to aggradation dynamics (Fig. 6). The gradual closure of the marine embayment occurred well before the foundation of the city of Orgame on the Cape. We did not observe any bio-sedimentological differences between cores located inside and outside the harbour environment. Therefore, this environmental change cannot be ascribed to a human modification of the environment, as in the case of many ancient coastal harbours (e.g. Bony et al., 2011). The Greek harbour of Orgame comprised a natural lagoon environment which was not artificially modified to accommodate shipping vessels. From a geomorphological point of view, this location is calm, protected by the Cape and in front of the natural inlet (Fig. 1). Possible warehouses, identified by the resistivity profiles, are located in the coastal area (Baralis et al., 2010, Fig. 2). This naturally protected environment possessed the environmental endowments to host harbour activities.

After this first environmental change, the sedimentation rate doubled but remained low for a harbour environment in a deltaic context. For instance, at Fréjus, the rate of shoreline progradation outside the harbour environment was ca. 170 cm yr^{-1} during the 1st c. AD (Excoffon et al., 2010). Such coastal progradation processes are similar for all Mediterranean deltaic areas (Dubar, 2004; Brückner et al., 2005; Stefaniuck et al., 2005; Vött, 2007; Goiran et al., 2010, 2011).

5.2. Influence of the Danube Delta's morphogenesis on the palaeoenvironmental evolution of Orgame's coastline

Our results highlight chronological parallels between coastal changes at Orgame and the construction of various barriers that form the Razelm–Sinoe lagoon. The sedimentological and palaeoecological data have been analysed using PCA (Fig. 7). The age model is based on radiocarbon dates obtained and accepted for core O2. Loadings of the PCA-Axis 1 (Fig. 7) are used to determine the main environmental factors that generate the variance in the sedimentological and palaeo-ecological data. For the grain-size data, the negative PCA-Axis 1 scores correspond to sand particles (and ballast) and reflect the development of a dynamic depositional environment (Fig. 7). For the molluscan data, positive PCA-Axis 1 scores correspond to the development of coastal species, and for the ostracod data, to the euryhaline species C. torosa (Fig. 7). The organic matter content was compared to the CHAR influx observed in sediment samples from core O2. These data were compared with data from Giosan et al. (2006), focussing on the chronology of the Danube's deltaic fans and on the timing of spit formation in the Razelm–Sinoe lagoon.

Until ca. 1500 cal. yr BC (3500 cal. yr BP), statistical analyses reflect the establishment of a depositional environment characterized by a sandy sedimentation and a rich coastal fauna, with some fluvial species from the Danube river. According to Giosan et al. (2006), the Danube delta began forming around 3500 cal. yr BC (5000 cal. yr BP; Fig. 7). Thus, the environment corresponds to an open marine bay at the margins of the Danube Delta (Fig. 8). From 2500 cal. yr BC (4500 cal. yr BP), we observe a transition towards finer-grained sediments and the fauna becomes more lagoonal (Fig. 7). Progradation of the St. George I lobe leads to the

gradual growth of the Zmeica barrier resulting in a natural coastal protection of the Orgame coastline (Fig. 8). From 1500 years cal. BC (3500 cal. yr BP), the statistical analyses suggest a radical transformation of the depositional environment characterized by organic silty clay sedimentation and C. torosa, an Ostracoda species that is typical of lagoon environments (Carbonel, 1980; Fig. 7). The environment is very well protected. This landscape change was due to the construction of the Lupilor barrier leading to the progradation of the Sulina lobe (Fig. 8). After 2000 cal. yr BP, the growth of the Dunavatz lobe within the lagoon, led to an increase in freshwater inputs (Figs. 7 and 8). The numerical analyses underscore an increase in sediment particle size and the development of fluvial fauna from the river Danube. The margins of the lagoon gradually infilled and became a wetland. From 1000 cal. yr AD, the progradation of the lobe of St. George II led to the formation of Chituc barrier. However, this did not affect the shoreline of Orgame, which was already protected by Lupilor barrier. Environmental changes due to outgrowth of the Dunavatz lobe cannot be probed due to the absence of sedimentary archives for this period (Figs. 7 and 8). Giosan et al. (2006) linked the formation of its barriers to the construction of different Danubian lobes (in particular St. George I, Sulina, St. George II, Dunavatz). The chrono-stratigraphy of sediment cores translates the different stages of Danube delta growth according to Giosan et al. (2006). The hypothesis that the erosion of the Cosna-Sinoe lobe led to the formation of the Lupilor barrier (Panin, 1983; Vespremeanu et al., 2013) cannot be confirmed by our results given the absence of sedimentary archives for this period.

The environmental changes of Orgame's coastline are characteristic of coastal environments at the distal margin of deltaic areas. They are induced by bottom aggradation related to the infilling of the accommodation space by alluvial sediment from the River Danube and spit formation. This infilling is due to the progradation of the coastline and the environmental transition to an oligohaline wetland. The protection of the coast is due to the construction of offshore coastal barriers. This naturally protected environment was particularly conducive to the foundation of a harbour, open to the sea and linked to a major fluvial system and located inside a protected lagoon.

5.3. Human occupation of Cape Dolojman

Charcoal appears from 1500 cal. yr BC (3000 cal. yr BP) and an increase is clearly observed from 700 cal. yr BC (2650 cal. yr BP; Fig. 8). This increase in charcoal may explain the variations in organic matter content between 1500 and 300 cal. yr BC (3000–2250 cal. yr BP; Fig. 7).

The absence of dating inversions for the charcoal-derived radiocarbon dates of core O2 (Table 2, Fig. 3) showed no significant alterations and suggests a direct sedimentation in the lagoon, probably as a result of colluvial processes. This is consistent with an increase in sedimentation rates recorded for core O2 during this period (2.4 mm yr^{-1} for unit B compared to 1.3 mm yr^{-1} for unit A; Fig. 3). Micro-charcoal mainly reflects a local signal of vegetation cover. They display a vitreous texture but correspond to hardwood charcoals. Does the presence of charcoal at the end of the Iron Age reflect an increase in human impacts?. The new palynological results suggest the onset of a steppe vegetation on the coast (Rossignol, 2014). Giosan et al. (2012) date the installation of this land cover to around 2600 cal. BP and have attributed it to an increase in human occupation. Meanwhile, the archaeological data attest to a human occupation of the Cape since the end of the Iron Age (Ailincai et al., 2006). Part of the Cape Dolojman trees could be used for agricultural purposes (clearance by fire) or for domestic use (wood for heating). This would explain the presence of charcoal

particles from 1500 cal. yr BC onwards (3000 cal. yr BP). The installation of the Greek settlers along the Dobrogea shoreline during the foundation of the city of Orgame resulted in changes in the types of human occupation such as the introduction of cremation in funeral rites (Lungu, 2006). Domestic uses, land clearing by fire, the use of wood for cremations and more generally human pressures certainly played a significant role in the evolution of vegetation cover and soil erosion.

5.4. Influence of these environmental changes on the organization of Orgame

At ca. 650 cal. yr BC, the Greek city of Orgame followed on from the first occupation of the Iron Age. Orgame overlooked a huge lagoon, the Danube delta, the channel of Gura Portiței and was protected from the east and north-east, where cliffs act as natural barriers (Lungu, 2006). This location, a natural environment protected from river flooding and marine agents, made the site particularly attractive to human societies. This strategy is consistent with the location of Greek and Roman ports in the Mediterranean including, for example, Marseille's ancient harbour at the eastern margin of the Rhône delta (Morhange et al., 2003), Oiniadai's ancient harbour on the Acheloos delta (Vött, 2007), Olbia's ancient harbour on the Gapeau delta (Vella et al., 2000), the ancient harbour of Agde on the margins of the Herault delta (Falguéra et al., 2000; Sanchez et al., 2013), as well as the ancient harbour of Kition on the distal margin of the Thremitos delta (Bony, 2013).

Our data support a water depth of 3.3 m ± 1 at ca. 1000 cal. yr BC (3000 cal. yr BP; Fig. 3, Table 2) and 1.5 ± 1 m at ca. 50 cal. yr BC (2000 cal. yr BP; Fig. 3, Table 2), required for the circulation of ships (Pomey, 1995). No grain-size variations consistent with an artificial protection of the environment were observed in the sedimentary records. This suggests the absence of harbour protection such as moles. Orgame's ancient harbour was therefore a natural harbour, located in a naturally-protected lagoon environment. The city of Orgame was probably intentionally founded on the margins of this lagoonal environment to take advantage of the lagoon's natural resources and the transport possibilities offered by the River Danube (Baralis, 2007; Baralis et al., 2012). Formation of the Dunavatz lobe in the lagoon at ca. 2300−2000 cal. yr BP (Figs. 7 and 8) did not disrupt the organization of the harbour city but expanded its trading routes. Despite the gradual infilling of the shoreline, the harbour was still active until the 7th c. AD. Between the 5th and the 7th centuries AD, and in an unstable political setting, Orgame became a citadel, the island Bisericuţa acting as a navigation control (Mănucu-Adameşteanu, 2003). Although Orgame is located on the Danube delta, siltation has had little impact upon the coastline in this area. By contrast, the nearby Greek harbour of Istros/Histria, was completely infilled (Stefan, 1987; Fig. 8).

5.5. Environmental comparison with the ancient harbour of Istros/Histria

The Greek colonies of Istros and Orgame were founded at the same time. Istros is located on a low-lying coast at the southern extremity of the Razelm−Sinoe lagoon. In agreement with the chronology for the formation of the lagoon's coastal barrier, the city of Istros was founded on "the oldest barrier of the Istria strandplain" formed during the construction of the lobe St. George I (1750−1350 cal. yr BC; 3700−3300 years cal. BP; Giosan et al., 2006; Vespremeanu et al., 2013; Fig. 8). At the time of their foundation, Orgame and Istros were situated in different environmental contexts due to the Lupilor barrier which separated the lagoon where Orgame is located from the exposed shoreline where Istros was founded (Fig. 8). The harbour environments of Istros and Orgame are subject to completely different environmental changes. Although located on either side of the Lupilor barrier, and receiving freshwater inputs from the Dunavatz lobe since 2000 cal. yr BP, Orgame's shoreline has not undergone significant progradation since the maximum marine ingression (ca. 100 m) and the harbour environment is today still partially washed by the sea. By contrast, Istros's harbour has been completely infilled. Today it lies ca. 10 km from the sea. The infilling of Istros's harbour is due to the morphogenesis of the Chituc barrier (Vespremeanu-Stroe et al., 2013). With regards to Orgame's harbour, the apparent paradox of low progradation rates might be explained by its location perpendicular to the direction of prevailing winds in the middle of the Danube sediment cell. Furthermore, the longshore drift energy might be low at this location. Moreover, Orgame is situated in front of the Gura Portiței inlet which has remained open since it was artificially closed in 1969 (Mihailescu, 2006). The offshore bathymetry of the Cape Dolojman shoreline is deeply incised. This topography has probably kept the inlet open and has certainly contributed to the sedimentary cell's fall in energy.

5.5.1. Have the environmental contexts played a role in the development of Istros and Orgame?

At the time of their foundation, Istros was in direct contact with the Black Sea and was an important node of the maritime trade route. At Orgame, maritime communication was possible through the channel of Gura Portiței. Therefore, the maritime resources offered by the lagoon certainly played a role in the decision to found the city on Cape Dolojman. Numerous archaeological discoveries demonstrate that Istros was a rich, prosperous and democratic urban city with institutional development (construction of three aqueducts and the presence of many roads and tumuli and an important mound corresponding to a necropolis tumuli; Stefan, 1987; Bounegru, 1988). The maritime character of the city is attested since its foundation (Stefan, 1987). The harbour was located south of the city in a small bay open to the sea and sheltered from the north and north-east winds, and from the dominant longshore drift. Istros' harbour did not correspond to a lagoon harbour like Orgame but to a pocket beach harbour. The city of Istros was an important centre of fishing on the Danube delta until the Roman period (Giosan et al., 2006) and this may explain the poor development of the city of Orgame at that time. The construction of the lobe St. George II, after 2200 cal. yr BP (ca. 250 cal. yr BC), followed by the building of the second generation of Istrian barriers (Saele barrier; Vespremeanu-Stroe et al., 2013) and the Chituc barrier around 1500 cal. yr BP (ca. 450 cal. yr AD), may be due to the formation of the Cosna-Sinoe Lobes (Vespremeanu-Stroe et al., 2013), leading to a progressive land-locking of the Istros harbour (Giosan et al., 2006; Vespremeanu et al., 2013; Fig. 8). The city lost its maritime vocation during the 3rd and 4th centuries AD (Bounegru, 1988). Indeed, urban buildings are attested around the silted harbour area (Stefan, 1987). The city was completely abandoned in the 7th c. AD (1250 years cal. BP) and no subsequent trace of habitation has been identified. In contrast to Orgame, the city of Istros/Histria, located further from the mouths of the Danube, suffered from the impacts of high sediment supply. Nonetheless, it achieved greater socio-economic importance.

Sediment transport processes are complex on the Danube delta coast. In association with the ancient topography of the Danube deltaic system, these processes appear to constitute the main natural forcing in the palaeoenvironmental history of these two Greek cities. This study nonetheless underscores the need to integrate the socio-political context in any geoarchaeological study.

6. Conclusion

The results of this study fit closely with the primary model of coastal evolution in a deltaic context. From ca. 5000 years onwards, massive sediment supply from the Danube, on the southern coast of St. George's arm, engendered a two-phase model of palaeoenvironmental change: (1) the closure of the bay at ca. 1500 cal. yr BC (3600 cal. yr BP) due to the formation of the Lupilor barrier; and (2) the evolution of a freshwater lagoon environment around ca. 300 cal. yr BC (ca. 2250 cal. yr BP) due to the formation of the Dunavatz arm inside the lagoon. However, a rapid infilling of the deltaic coast was not observed. The morphology of the underwater coastline and its orientation, perpendicular to the direction of the waves, has reduced the impacts of rapid coastal sedimentation. An interesting conclusion of this study is the differences in the environmental and urban development between Istros/Histria and Orgame/Argamum. During the final phase of the harbour the city, Istros/Histria was attacked by the Goths in the 4th c. AD (1600−1500 cal. yr BP). Although the foundation of Orgame is largely due to fishery resources offered by the lagoon, Istros/Histria became, during the troubled period of the third c. BC, the only stable Greek settlement in the region, probably due to its direct connection with the open sea. However, the historical trajectory of these two settlements appears to be independent of the paleo-environmental changes. The formation of Dunavatz lobe did not lead to significant environmental impacts on Orgame. Its abandonment in the 4th c. AD is due to the military environment and contemporary politics. Later, Istros/Histria thrived despite the silting up of its harbour and Orgame was overcome by the invasions of the 7th c. AD.

Acknowledgements

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