Halmyris: geoarchaeology of a fluvial harbour on the Danube Delta (Dobrogea, Romania)

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Abstract

In Northern Dobrogea, north of the Dunavăț promontory, the Roman fortress of Halmyris was founded in the late 1st century AD on a Getic settlement dating to the middle of the 1st millennium BC, probably associated with a Greek emporium of the Classical and Hellenistic periods. At the time of the foundation of Halmyris, the Danube delta had already prograded several kilometres to the east leading to the progressive retreat of the sea and the formation of a deltaic plain characterised by numerous lakes and river channels. Here, we present the results of a multiproxy study combining sedimentology and palaeoecology to: (i) understand the evolution of fluvial landscapes around Halmyris since ca. 8000 years BP, (ii) identify the fluvial palaeoenvironments close to the city in Getic/Greek and Roman times, in order to locate and characterise the waterfront and the harbour. Our overriding objective was to improve understanding of human-environment relations in river delta settings. We demonstrate that Halmyris, protected by the Danubian floods due to its location on a palaeo-cliff top, had direct access to the river. A secondary channel of the Saint George, flowing north of the site, has been elucidated between the 7th century BC and the 7th century AD and could have been used as a natural harbour.

Keywords: geoarchaeology, geomorphology, fluvial harbour, Halmyris, Danube delta, Black Sea.

1. Introduction

In recent decades, deltaic environments have attracted interdisciplinary research interest, looking to understand human-environment interactions in these important waterfront areas (see Anthony et al., 2014). These lowlands at the land-sea interface were particularly attractive, since the stabilisation of sea-level around 6000 yrs BP, because they provided fertile lands for agriculture and a permanent freshwater supply, as well as access to the hinterland by fluvial routes. A multi-proxy approach allows to clearly identify the environmental pressures that affected deltaic harbour cities and to highlight the adaptation of populations, including for instance Alexandria (Nile delta: Goiran et al. 2005; Flaux et al., 2017), Miletos (Büyük Menderes delta: Bruckner et al., 2006, 2014), Ephesos (Küçük Menderes delta: Stock et al., 2013, 2016), Ainos (Hebros delta: Seeliger et al., 2018), Pisa (Arno and Serchio delta: Benvenutti et al., 2006; Allinne et al., 2016; Kaniewski et al., 2018), the Greek colonies of the Taman Peninsula (Kuban delta: Kelterbaum et al., 2011; Giaime et al., 2016); Aigues-Mortes (Rhône delta: Rey et al., 2016), Ostia (Tiber delta: Goiran et al., 2014; Salomon et al., 2017, 2018) or Utrecht (Rhine delta: van Dinter et al., 2017).

The Danube delta is one of the largest fluvial and wave-dominated delta's in the world and constitutes one of Europe's major wetland zones. It has been listed on the UNESCO World Heritage List since 1991. Occupied since the Neolithic (Micu et al., 2009; Carozza et al., 2012, 2013), the coast of the Danube delta has a long and rich history of human occupation. It was, at the end of the Archaic Period, coveted by the Black Sea's first Mediterranean colonists. The area offered favourable environmental conditions for thriving socio-economic activities (Avram et al., 2004). In recent years, geoarchaeological studies looking to understand environmental changes at several ancient sites located on the southern margin of the Danube delta have been undertaken (eg. Orgame, Bony et al., 2013, 2015; Histria, Vespremeanu-Stroe et al., 2013, Bivolaru et al., in press; Enisala and Babadag, Preoteasa et al., 2018, Bivolaru et al., in press; see Figure 1.A for location). These different studies have highlighted the interplay between environmental and anthropogenic changes, furnishing new data on the evolution of the ancient sites. In contrast, and despite the geoarchaeological importance of the Lower Danube, its ancient and medieval fluvial harbours are poorly known.

River delta sedimentary archives are particularly interesting because they can help to probe the interplay between river course evolution (fluvial geomorphology) and archaeological development. In this paper, we present a case study to highlight these human-fluvial landscape interactions during Antiquity. We focus on the archaeological site of Halmyris, located ca. 38 km from the present mouth of the Saint George arm of the Danube, on the northern side of the Dunavăţ promontory (**Figure 1.A**). Several authors have suggested the presence of a harbour connected to the Danube River directly north of the fortress in Roman times (Zahariade, 1991; Bounegru and Zahariade, 1996; Suceveanu et al., 2003). By coring on the delta plain, 100 m from the main northern gate of the fortress, we looked to better understand the evolution of the environment during the last 8000 years. Our investigations are based on multiproxy analyses of fluvial sedimentary archives (sedimentology, molluscs, ostracods and chironomids). The combination of such proxies is particularly useful in palaeohydrology (Petts et al., 1989). Ostracods and chironomids have proven to be helpful proxies in the study of palaeoenvironments in hypohaline river-delta settings (e.g. to reconstruct the past connectivity between alluvial waterbodies and the main channel; to estimate shifts in salinity; Gandouin et al., 2005, 2006). Our aim is to study the stratigraphic sequence in order: (i) to understand the long-term evolution of the sedimentary environments; and (ii) to elucidate the presence of a harbour sedimentary sequence corresponding to the occupation of the site by the Getic and Greeks (6th-1st centuries BC) and the Romans (1st-7th centuries AD).

2. Geomorphological context

The Danube river is the most important water and sediment supplier of the Black Sea, with a water discharge of 190 km^3/year and a sediment discharge of 25 to 35 million tons per year (4-6 million comprising sands) (Panin and Jipa, 2002; Panin et al., 2016). The delta constitutes a large coastal accumulation of sediments that has evolved continuously during the Holocene, under the combined effects of natural and human-induced pressures. The river started to build its delta in the Danube Bay around 8000 – 7500 cal. yr BP (6000 – 5500 BC; Vespremeanu-Stroe et al., 2017). The deltaic sediments fill the pre-Dobrogea depression that lies mainly on the Scythian platform (Burchfiel et al., 1974). This important accumulation of sediments (also supplied by important loess formations; Fitzsimmons and Hambach, 2014; Marcovic et al., 2015) has led to subsidence. Estimates for subsidence rates vary between 0.4 – 0.6 mm.yr^{-1} (Vespremeanu-Stroe et al., 2017) and 1.3 – 2 mm.yr^{-1} (Giosan et al., 1997).

According to Antipa (1914), Panin and Jipa (2002) and Vespremeanu-Stroe et al. (2017), the delta can be divided into two distinct geomorphological units: (i) the western fluvial delta; and (ii) the eastern and southern marine delta. In their recent study, Vespremeanu-Stroe et al. (2017) confirm that the limit between the two units is formed by a coastal spit that prograded southwards in the northern part of the delta after ca. 6700 – 6100 cal. yr BP (4700 – 4100 BC; **Figures 1.A and 1.B**). The formation of the fluvial delta can be divided into two main phases. Initially, north of the Dunavăţ promontory, the old Danube delta (mainly formed by the Saint George arm) started to build its first lobes around 8000 – 7500 cal. yr BP (6000 – 5500 BC). Reconstruction of the palaeo-delta front position shows that the area, north of ancient Halmyris, was washed by the sea until almost 7500 cal. yr BP (5500 cal. yr BC; Vespremeanu-Stroe et al., 2017; **Figure 1.B**). The important sedimentary input between 7500 and 6500 cal. yr BP (5000 – 4500 BC) gradually led to the progradation of the delta front (1.5 – 2 m.yr-1; Vespremeanu-Stroe et al., 2017). Formed from 6700 – 5800 cal. yr BP (4700 – 3800 BC), the spit did not influence the early stages of delta formation. In the mid-Holocene, the Danube delta was mainly formed by the Saint George arm, the oldest arm of the Danube and which has been continuously active for more than 8000 years. The second major phase in the evolution of the fluvial delta started around 5500 cal. yr BP (3500 BC) and was characterised by fluvial and peat aggradation in the shallow lakes spanning a large part of the amphibic delta plain. This transformation took place in a context of low relative sea-level rise (ca. 1m between 5500 and 3500 cal. yr BP (3500 – 1500 BC); Vespremeanu-Stroe et al., 2013) and low subsidence (0.4 – 0.6 mm.yr-1; Vespremeanu-Stroe et al., 2017).

[Insert Figure 1]

The formation of the "marine delta" started eastward and southward of the initial spit/barrier and is composed of five main open coast lobes that have contributed to the present coastal geography of the delta (Panin, 2003; Giosan et al., 2006; Vespremeanu-Stroe et al., 2017). The first phase of this "marine delta" was initiated by the first open coast lobe formation (Old Saint George; **Figure 1.A**) between 6500 and 5500 cal. yr BP (4500 – 3500 BC), characterized by increasing wave action on the coast (Vespremeanu-Stroe et al., 2017). The formation of the different deltaic lobes had no direct influence on the site of Halmyris because of its location on the old Danube delta plain ("fluvial delta"). In fact, the delta front has been situated downstream of Halmyris for around 6000 years. Nonetheless, the harbour environments of other ancient settlements, including those located in the southern part of the delta (Razelm-Sinoe lagoon), were directly impacted by the progradation of the various branches of the river and their erosion/reworking induced by longshore drift (Vespremeanu-Stroe et al., 2013; Bony et al., 2015, Preoteasa at al., 2018,).

3. Historical and archaeological contexts of Halmyris

The ancient history of Halmyris is divided into three main occupation phases (Zahariade et al., 1987; Zahariade and Phelps, 2002, Suceveanu et al., 2003).

(i) Between the 6th and the 1st centuries BC, the site was occupied by a Getic settlement. During this period, archaeologists have highlighted the presence of a possible Greek emporium associated with this settlement. The emporium was integrated into the *chora* of Histria, or, more likely into that of Orgame (Zahariade, 1991; Zahariade and Phelps, 2002; Suceveanu et al., 2003). The authors base their hypothesis on the toponymy (Halmyris is possibly a Greek name, related to the ancient homonymic gulf, which could mean salt water) and on the Greek pottery discovered (especially amphorae from Chios, Chersonessos and Thassos). Even though the hypothesis of a Greek foundation, where the Getic mixed with Greek elements is plausible, there is insufficient archaeological data to support this hypothesis.

(ii) Halmyris played an important strategic role during the Early Roman period (1st – 3rd centuries AD). Initially an earth-fortification (last quarter of the 1st century AD), Halmyris was rebuilt in stone during the 2nd century AD as a fort by the military groups of the *Legio I Italica* and the *Legio XI Claudia pia fidelis* (Zahariade, 1986). Halmyris *castrum* had the most important role on the last segment of the Danubian limes, controlling the territory between Aegysus (Tulcea) and the mouth of Saint George or Dunavăţ arm (Suceveanu et al., 2003). Discovery of 2nd – 3th century AD inscriptions on an altar dedicated to Hercules mention the existence of a settlement « *vicus classicorum* » (*classicorum* from *Classis Flavia Moesia*, the fleet organised by Emperor Vespasian). The dating of the epigraphic monuments (136 AD, 163 AD, 171 AD and 200 AD) suggests that during this period, a village founded by mariners from *Classis Flavia Moesia* was located near the fortress (Zahariade, 2012). This type of settlement is also known epigraphically from other provinces of the Roman Empire: vicus *navaliorum* (at Mainz, related to *classis Germanica*), vicus *Portensium* (at Nantes, related to *civitas Namnetum*) (Zahariade and Alexandrescu, 2011).

(iii) The Late Roman period of Halmyris spans an interval between the last quarter of the 3rd century AD and the 3rd or 4th decade of the 7th century AD (Suceveanu et al., 2003). At that time, the original rectangular shape of the fort was abandoned in favour of a triangular morphology (Zahariade and Phelps, 2002). The fort was composed of thick walls adjoined by numerous towers and three gates (**Supplementary Material 1**; Mărgineanu-Cârstoiu, 2015). The northern and the north-eastern gates were built towards the Danube. Civil constructions, such as *thermae*, suggest a change from primarily military to mixed civilian and military usage of the settlement in the 4th century AD. Roman provincial pottery intermixed with Slavic coarse wares, mark the presence of a non-Roman population in the fort during the second quarter of the 7th century AD and support the abandonment of the fortress by the Romans (Zahariade and Phelps, 2002).

4. Possible harbour location

Access to the city was possible from the sea by sailing back up the course of the Danube, which is believed to have flowed close to the Dunavăţ promontory in Late Antiquity (Zahariade and Phelps, 2002). Discovery of an inscription mentioning a « *vicus classicorum* » dated to the 2nd century AD suggests that during this period, close to the *castrum*, a civil settlement related to naval activities was founded by the discharged mariners of *Classis Flavia Moesia* (Zahariade and Alexandrescu, 2011). From the 4th century AD, the harbour may have been a disembarkation point for military material, from large maritime vessels to fluvial ones as indicated by the ancient writer Zosimos (first half of the 5th century AD; *Historia Nova*, IV, 10). In the context of successive barbarian's invasions during the 5th century AD archaeologists consider the fact that the military importance of Halmyris increased at that time (Suceveanu et al., 2003).

The presence of two natural decantation basins to the north of the site (Cruhlic Mic and Cruhlic Mare), are the relic of fluvial activity on this part of the floodplain (**Figure 2**). These palaeo-meanders are located at the southern limit of the inundation plain, at the foot of the Dunavăţ promontory in front of the major northern gate of the fort. According to Zahariade and Phelps (2002), this gate was mainly associated with harbour activities and it was probably blocked due to the abandonment of the harbour during the second half of the 6th century AD.

[Insert Figure 2]

5. Methods

Our work is based on the study of two sedimentary cores drilled on the Danube delta plain (HAI (335 cm in length): 45° 1'32"N; 29°11'48"E; ca. +1 m a.s.l.; and HAIII (577 cm in length):

45° 1'34"N; 29°11'56"E; ca. +0 m a.s.l.) immediately near Halmyris (**Figure 2 and Supplementary Material 1**). The cores, drilled using a percussion corer (Cobra TT), were attitudinally benchmarked relative to present mean sea level using a GPS. Core descriptions (texture, macrofauna content, organic remains) and sampling were undertaken during fieldwork.

Chironomid analyses of core HAI

Laboratory methods for the extraction and identification of subfossil remains are described in Gandouin et al. (2005) and consisted of deflocculation with KOH, rinsing with water over a 100-μm sieve, and paraffin flotation. We analysed 55 chironomid samples from core HAI (355 depth). A minimum of 50 head capsules per sample was chosen to provide statistically significant estimates of environmental conditions (Heiri and Lotter, 2001). The identification of head capsules was based on Brooks et al. (2007) and Klink and Moller Pillot (1999). Head capsules were identified under a stereomicroscope at 400X magnification. Chironomid diagrams were drawn using C2 version 1.7.2 (Juggins, 2007).

Statistical analyses have been performed with R Studio version 3.1.1: ade4, vegan and factoExtra were used for multivariate analyses (Chessel et al., 2004); rioja package for the constrained sum-of-squares cluster analysis (CONISS: in Juggins, 2015). Principal Component Analysis (PCA) was performed on the n (number of samples) by p (number of taxa) chironomid matrix of percentages. Data were square-root transformed to stabilize the variance. Rare taxa, i.e. those present in only one sample or in less than 5% of all samples, were removed from the analysis.

Subfossil samples have been projected as passive objects for comparison between fossil and modern assemblages from Gandouin et al. (2006), in order to characterize the type of contemporary habitats. This allowed us to obtain an ordination of subfossil samples along a gradient of connectivity (materialised by scores on an axis of a between-class Correspondence Analysis) between the main channel and other floodplain habitats such as secondary channels, oxbow lakes, ponds and marshy environments.

Ostracods analyses and sedimentary texture of core HAIII

Bio-sedimentological analyses were performed following the methodology detailed in Marriner and Morhange (2007) and Marriner (2009) on 90 samples taken from core HAIII (577 cm depth). The general sediment texture, including the gravel (larger than 2 mm), sand (50µm-2mm) and silty-clay fractions (smaller than 50µm), was determined by wet sieving. Ostracods were picked from the fraction >160 µm and identified to species level using reference manuals and papers for Ponto-Caspian species (Tunoglu and Gokçen, 1997; Meisch, 2000; Opreanu, 2008; Boomer et al., 2010; Frenzel et al., 2010). To obtain reliable statistical estimates, we have picked around 300 valves per samples when the amount of sediments was sufficient.

Statistical analyses have been performed on the percentage matrix using the paleontological statistics software PAST (Version 2.14, Hammer et al., 2001). Rare species that represent less than 2% of the total individuals identified in this study were removed from the PCA. Ostracods were grouped according to three main assemblages; defined as shallow-marine, lagoonal and fresh/mesohaline inland waters. In order to test the ordination of samples by assessing major changes in palaeoenvironmental proxies, Principal Component Analysis (PCA) was undertaken on the ostracods matrix.

Malacology of cores HAI and HAIII

Molluscss have been observed in both HAI and HAIII samples. Their identification was undertaken using Pfleger (1993). Due to the low number of individuals encountered in our study, the molluscan assemblage only permits to strengthen the information provided by the other biological proxies.

Dating of HAI and HAIII

The chronology is based on fifteen AMS radiocarbon determinations performed at the Poznan Radiocarbon Laboratory on short-lived samples (seeds and small leaves), charcoal remains and articulated mollusc shells (**Table I**). The dates obtained from articulated mollusc shells (*Dreissena polymorpha* and *Cerastoderma* sp.), have been corrected using a marine reservoir age. A marine reservoir age of 498 ± 41 (in Bony et al., 2015) has been subtracted from the radiocarbon age before calibration using the calibration curve IntCal13 (Reimer et al., 2013) in Clam (R Studio).

With the retained radiocarbon determinations, we constructed an age-depth model for each core using the dedicated R-code Clam (Blaauw, 2010), which uses repeated random sampling of the calibrated distributions to derive a robust age-depth model. Thanks to these age-depth models, we obtained reliable ages for each unit and level analysed (Figure presented in the section 6.3).

Table I: AMS-14C data expressed in calibrated years BP and BC at the 95% confidence level (2σ). b.s.: below surface, b.s.l.: below present mean sea level, a.s.l.: above present sea level. Calibration using R-code Clam (Blaauw, 2010) with the calibration curve IntCal13 (Reimer et al., 2013).

Sample	**Laboratory number**	**Material**	**δC13**	**Depth (cm b.s.)**	**Depth (cm b.s.l.)**	**Age ^{14}C**	**Age ^{14}C (corrected)**	**2 sigma BP min; max**	**2 sigma BC/AD min; max**	**Status**
HAI(55-60)	Poz-79628	Peat	-23.7	55-60	45-50 a.s.l.	110 ± 30 BP		12 ; 269	1681 ; 1938 AD	Accepted
HAI(157-163)	Poz-79629	Plan remains	-28.4	157-163	57-63	900 ± 30 BP		740 ; 911	1039 ; 1210 AD	Rejected
HAI(157-163)	Poz-79163	Marine shell (*Cerastoderma sp.*)	-2.5	157-163	57-63	2385 ± 30 BP	1785 ± 50	1569 ; 1823	127 ; 381 AD	Accepted
HAI(170-175)	Poz-79630	Peat	-24.3	170-175	70-75	2545 ± 30 BP		2498 ; 2749	800 ; 549 BC	Accepted
HAI(295-300)	Poz-79631	Peat	-26.6	295-300	195-200	4660 ± 30 BP		5315 ; 5467	3518 ; 3366 BC	Accepted
HAIII(60-63)	Poz-81693	Peat	-30.3	60-63	60-63	1230 ± 30 BP		1069 ; 1261	689 ; 802 AD	Rejected
HAIII(120-125)	Poz-79633	Plant remains	-26.3	120-125	120-125	830 ± 30 BP		688 ; 789	1161 ; 1262 AD	Accepted
HAIII(245-250)	Poz-81694	Organic sediment	-25.8	245-250	245-250	1930 ± 30 BP		1820 ; 1946	4 ; 130 AD	Rejected
HAIII(270-275)	Poz-79655	Charcoal	-29.1	270-275	270-275	1775 ± 30 BP		1611 ; 1812	138 ; 339 AD	Accepted
HAIII(275-280)	Poz-81695	Charcoal	-24.7	275-280	275-280	2585 ± 35 BP		1770 ; 2510	821 ; 561 BC	Accepted
HAIII(300-305)	Poz-79656	Charcoal	-32.9	300-305	300-305	3920 ± 35 BP		4242 ; 4496	2547 ; 2293 AD	Accepted

HAIII(355-360)	Poz-79657	Peat	-32.8	355-360	355-360	4425 ± 35 BP		4871 ; 5276	3327 ; 2922 BC	Accepted
HAIII(405-410)	Poz-81696	Peat	-30.2	405-410	405-410	5210 ± 40 BP		5903 ; 6174	4225 ; 3954 BC	Accepted
HAIII(470-480)	Poz-79659	Organic material	-30.6	470-480	470-480	5125 ± 35 BP		5749 ; 5939	3990 ; 3800 BC	Rejected
HAIII(530-540)	Poz-79164	Freshwater shell (*Dreissena polymorpha*)	-8	530-540	530-540	7170 ± 40 BP	6672 ± 57	7437 ; 7650	5701 ; 5488 BC	Accepted

6. Results

6.1. Faunal record and sedimentary texture of core HAIII

The ostracods identified are common in present-day ponds and lagoons of the Danube (Opreanu, 2003; **Figure 3.A**). According to the ecology of the species, we differentiated three groups.

(1) The first group includes endemic species of the Ponto-Caspian region (e.g. *T. Amnicola*, *A. Bendovanica*) associated with euryhaline marine environments. (Boomer et al., 1996; 2010). Due to the stratification of Black Sea waters (Neretin et al., 2001), the surface waters are less saline (15-17‰) than the deep waters (23‰). Marine Mediterranean species are found at depths >20 m on the continental platform and Ponto-Caspian species are present in surface waters (Opreanu, 2005).

(2) The ostracod *Cyprideis torosa* is an opportunistic species that can support holeuryhaline conditions (Boomer and Frenzel, 2011; Pint et al., 2012); it is the only species that constitutes the lagoonal assemblage.

(3) The third assemblage comprises ostracods living in fresh to mesohaline inland water environments. *Darwinula stevensoni* (presented alone in **Figure 3.A**) is associated with permanent and clear-waters. The other species are characteristic of stagnant waters (*Candona neglecta*, *Cypria ophtalmica*, *Pseudocandona albicans*).

The macrofauna assemblage is composed of brackish or lagoonal waters (*Dreissena polymorpha*) and freshwater species common to the Danube such as, *Lithoglyphus naticoides*, *Theodoxus danubialis*, *Viviparus* sp. (**Supplementary Material 2**).

By means of a Principal Component Analysis (PCA) undertaken on the ostracod matrix, the different samples were reduced to two PCs that account for 78.8 % of the total variability depending on their faunal contents. PC1 (64.3%) has high positive scores for samples composed of freshwater species and negative ones for those comprising marine species. PC2 (14.5%) allows us to categorise the freshwater species into two distinctive groups; samples with lotic species present negative scores and those containing freshwater species living in stagnant water bodies present positive scores (**Figure 3.B**).

[Insert Figure 3]

The sedimentary sequence of core HAIII is typical of a regressive deltaic sequence with fluvial sediments overlying marine sediments. The sequence broadly displays three main textures; from fine-to-medium sands between -563 and -410 cm, silty-clay between -300 and -63 cm and then between -40 and the top of the core. Two organic-rich peat layers are intercalated in the sequence (between -410 and -300 cm and between -63 and -40 cm).

6.2. Faunal record of core HAI

Fifty-five chironomid samples were analyzed. Twenty-six samples, mainly peat sediments, were devoid of headcapsules (hc) or under the limit of 50 hc (Heiri et al., 2001). Twenty-nine samples yielded 2080 identifiable hc (74 identified taxa). Amongst these samples, four stratigraphic levels were pooled (cf., 157-163, 180-190, 260-270 and 280-290 cm) in order to yield a significant number of hc. The cluster analysis allowed us to identify six chironomid zones: Hach-1 to Hach-6 (**Figure 4.A**). Based on the typology of Gandouin et al. (2006), we differentiated three ecological groups: lentic, ubiquitous and lotic taxa. The main chironomid taxa and their dynamics are summarized in table II.

Table II: main chironomid taxa and their dynamics over the HAI record.

Faunal zones	**Main assemblage dynamics**	**Lithology**
Hach-6 (50-35 cm)	Increasing percentages of *Glyptotendipes* and *Dicrotendipes nervosus*.	Peaty sediments
Hach-5 (95-50 cm)	Dominance of *Polypedilum*. Increase in *Procladius* percentages.	Clayey sediment
Hach-4 (145-95 cm)	Dominance of *Cricotopus* and *Dicrotendipes notatus*. First appearance of *Eukiefferiella / Tvetenia*, *Rheotanytarsus*, *Micropsectra* and *Neozavrelia*.	Sandy silt sediment
Hach-3 (163-145 cm)	First appearance of *Psectrocladius*, *Halocladius*, *Microchironomus* and *Acricotopus*.	
Hach-2 (300-163 cm)	Dominance of *Chironomus*, *Dicrotendipes notatus*, *Glyptotendipes*. Significant abundances of *Endochironomus* and *Einfeldia*.	Peaty sediments
Hach-1 (335-300 cm)	Dominance of *Dicrotendipes nervosus and Polypedilum*. Highest abundance over the record of *Procladius*, *Cryptochironomus* and *Harnischia*.	Sandy silt sediments

The PCA axis 1 explains 17.9% of the total variance of the data set (Figure 4.B), 15.5% for PCA axis 2. The first axis shows a clear contrast between two groups of taxa. The first group (positive scores) is mainly characterized by *Chironomus*, *Dicrotendipes*, *Polydedilum* and *Phaenopsectra*. The second group (negative scores) is characterized by *Psectrocladius*, *Cladotanytarsus* and *Cricotopus*. *Procladius* strongly contributes to the positive side of the PCA axis 2. The positive PCA scores comprise mostly peaty sediments (particularly samples 273 and 285 cm), while the negative scores constitute sandy sediments (155 cm in particular). Clayey (73, 78 and 83 cm) and silty sediments (323, 328 and 333 cm) comprise positive PCA axis 2 scores. PCA analysis demonstrates a strong opposition between lotic or ubiquitous assemblages such as (e.g, *Cricotopus*, *Cladotanytarsus*, *Neozavrelia*) and lentic ones (e.g., *Dicrotendipes notatus*, *Glyptotendipes*, *Limnophyes* and *Phaenopsectra*), which is probably induced by the transversal connectivity gradient between the main fluvial channel and other floodplain waterbodies.

The passive projection of subfossil samples into the ordination of the between-class Correspondence Analysis (**Supplementary Material 3**) performed by Gandouin et al. (2006) shows that the fossil data set are close to lotic stations such as connected side arms (SA1 et SA2) and the main channel (MCRh). Two groups of samples can be identified. The more organic samples are close to the station SA2, a temporarily connected side arm (Garcia and Laville, 2001), while minerogenic samples (sand, silt and clay) are close to a permanently connected side arm (SA1) and the main channel (MCRh).

Two hundred and thirty-five mollusc shells have been identified in core HAI (**Supplementary Material 2.B**). In silty-dominated samples, between 280 and 320 cm, a large number of freshwater and stagnant gastropods (such as *Planorbis planorbis*, *Planorbis corneus* and *Bithynia tentaculata*) were found. Sandy silts from 145 to 165 cm were characterised by an abundance of halotolerant (*Dreissena polymorpha*) and lagoonal (*Cerastoderma glaucum*) bivalves. In sandy peat from 95 to 145 cm deep, a majority of *Dreissena polymorpha* was found. Finally, the more clayey samples (between 70 and 95 cm) were marked by the presence of *Lithoglyphus naticoides*, a taxon inhabiting slow-flowing and muddy environments.

[Insert Figure 4]

6.3. Cores chronology

Fifteen radiocarbon-dated samples were taken from various depths, providing a chronological framework from 7170 to 110 uncalibrated years BP (**Table I**). Among them, we identified some age reversals. In core HAI we removed the date, Poz-79629 (900 ± 30 BP; 1039-1210 cal. yr AD) from the age-depth model because of the presence of roots in the plant remains observed during the sampling preparation. In core HAIII, at the bottom of the core (470-480 cm depth), the date Poz-79659 (5125 ± 35 BP; 3990-3800 cal. yr BC) was rejected due to possible reworking. This date was obtained from organic material collected in the unit identified as the channel/river mouth deposits and was possibly eroded from upstream and transported by the river. Above the first peat layer, we chose to reject the date Poz-81694 (1930 ± 30 BP; 4-130 cal. yr AD; 245-250 cm depth) because we dated the bulk sediment. We have chosen to use the dates performed on organic remains taken from the same unit. At the top of the core (60-63), the bottom of the second peat layer (Poz-81693) seems to be too old (1230 ± 30 BP; 689-802 cal. yr AD) compared to the dating of the peat layer of core HAI, dated to 110 ± 30 BP (1681-1938 cal. yr AD; Poz-79628; 55-60 cm depth).

Mean sedimentation rates calculated for the cores HAI and HAIII are summarized in table III. The age-depth models (**Supplementary Material 4**) reveal a possible sedimentary hiatus at the top of the peat layer (between units Hach-2 and Hach-3 in HAI and units D and E in HAIII).

Table III: mean sedimentation rates calculated for cores HAI and HAIII

Core	**Cores section in cm from core top**	**Calculated mean sedimentation rates**
HAI	57.5-160	0.61 $mm.yr^{-1}$
HAI	160-172.5	0.12 $mm.yr^{-1}$
HAI	172.5-297.5	0.43 $mm.yr^{-1}$
HAIII	122.5-272.5	1.34 $mm.yr^{-1}$
HAIII	272.5-277.5	0.18 $mm.yr^{-1}$
HAIII	277.5-302.5	0.09 $mm.yr^{-1}$
HAIII	302.5-357.5	0.63 $mm.yr^{-1}$
HAIII	357.5-407.5	0.43 $mm.yr^{-1}$
HAIII	407.5-535	0.78 $mm.yr^{-1}$

7. Discussion

In the previous section, the results of the two cores were presented using a metric scale. Here, in order to compare the results of the two cores, we have chosen to represent the main bio-sedimentological units on a chronological scale in order to place the two cores in a broader palaeoenvironmental context (**Figure 5**). Because core HAIII represents a more complete sedimentary sequence than HAI, we decided to discuss the palaeoenvironmental evolution of Halmyris based on the main bio-sedimentological units identified in HAIII. The chironomid data from core HAI are used to reinforce our interpretations.

[Insert Figure 5]

7.1. Palaeoenvironmental phases recorded in cores HAI and HAIII

7.1.1. Unit A: marine bay before ca. 7550 cal. yr BP (ca. 5600 cal. yr BC)

The top of this unit is dated to ca. 7550 cal. yr BP (ca. 5600 cal. yr BC). It is composed of medium to fine yellow/orange sands. Macrofauna is represented by the species *Dreissena polymorpha* and *Theodoxus danubialis*, which are fluvial species endemic to the Pontic region and very frequently encountered in the Danube riverbed. The samples are dominated by lagoonal and euryhaline marine ostracods and reflect negatives values of the PCA Axis-1 (**Figure 3**). The combination of marine ostracods endemic to the Black Sea (e.g. *Tyrenocythere amnicola*) with the opportunistic species *Cyprideis torosa* mark the presence of the sea after the reconnection of the Black Sea to the global ocean ca. 9400 cal. yr BP (Soulet et al., 2011). This unit presents a marine (coastal) sedimentation in a context of high freshwater supply, in front of the mouth of the Danube.

7.1.2. Unit B: delta-front deposits between ca. 7550 cal. yr BP (ca. 5600 cal. yr BC) and ca. 6680 cal. yr BP (ca. 4730 cal. yr BC)

The rapid progradation of the Old Danube lobe led to the deposition of medium grey sands. Only two freshwater species were identified for the macrofauna (*Dreissena polymorpha* and *Viviparus* sp.). The absence of ostracods in the sand could be linked to high sedimentation rates and/or high fluvial energy, evoking the position of the delta front as proposed by Vespremeanu-Stroe et al. (2017) (**Figure 1.B**).

7.1.3. Unit C: lower delta plain environment between ca. 6680 cal. yr BP (ca. 4730 cal. yr BC) and ca. 6040 cal. yr BP (4225-3954 cal. yr BC)

We observe a decrease in the grain-size probably linked to a decrease in river flow energy. Ostracod fauna is present in two samples and comprises a mixture of fresh to euryhaline species commonly found in deltaic environments (e.g. *Candona neglecta*, *Heterocypris salina*). The end of this unit corresponds to the first chironomid zone Hach1, from ca. 6200 cal. yr BP to ca. 5390 cal. yr BP. The abundance of *Dicrotendipes nervosus* suggests a developed macrophytic vegetation (Brodersen et al. 2001). Abundances of *Polypedilum* indicate eutrophic waters (Klink, 2002). The presence of *Harnishia*, which is nowadays associated with large waterbodies with stagnant or slow-flowing water on a mineral bottom (Moller Pillot and Buskens, 1990), coupled with the presence of *Cryptochironomus*, indicate a sandy substrate mixed with fine organic matter (Vallenduuk and Morozova, 2005). These data are in agreement with the stratigraphy. Some species of *Cryptochironomus* are strictly predatory (Armitage et al., 1995), which is also the case for *Procladius*. This latter is also an oxy-regulator taxa and it is tolerant to daily water-oxygen fluctuations, due to intense photosynthetic activities (Brodersen et al, 2004). The passive projection of Halmyris fossil data on the modern dataset ordination (Gandouin et al., 2006) suggests a permanently connected side arm. Freshwater molluscs (e.g. *Anisus vortex*, *Planorbis planorbis* and Lymnae) from core HAI are in agreement with chironomids and ostracods (**Supplementary Material 3**) and the prevalence of slow flowing freshwater conditions. The decrease in the grain size in comparison to the previous unit could be explained by the displacement of the channel from the palaeo-cliff, possibly translating a fluvial avulsion. Channel avulsions are common on fluvial-dominated deltas and play an important role in their morphogenesis (Jones and Schumm, 1999; Stouthamer et al., 2001).

7.1.4. Unit D: peat layer between 5210 ± 40 BP (4225 – 3954 cal. yr BC) and 3920 ± 35 BP (2547 – 2293 cal. yr BC)

This organic-rich peat layer formed between 5210 ± 40 BP (4225 – 3954 cal. yr BC) and 3920 ± 35 BP (2547 – 2293 cal. yr BC). Vespremeanu-Stroe et al. (2017) have demonstrated that the formation of peat is common in this area (between the Saint George arm and the Razelm-Sinoe lagoon). Formation of such peat layers reflects the very low sedimentary inputs into the inner delta at this time, due to the important progradation of the Saint-George lobe and the export of the sediment to the eastern delta and the Black Sea shoreline.

This unit corresponds to the second chironomid zone Hach-2 from 4660 ± 30 BP (3620 - 3363 cal. yr BC) and 2545 ± 30 BP (800 - 550 cal. yr BC), with the sporadic presence of chironomid and mollusc subfossils that reveal a probable disconnection of the site from the fluvial system, possibly leading to conservation problems. Projection of these results on the modern data set (Gandouin et al., 2006) evokes a temporarily connected side channel with vegetated and eutrophic waters as suggested by *Chironomus, Dicrotendipes notatus*, *D. nervosus* and *Glyptotendipes (*probably *G. pallens). Dicrotendipes notatus* is presently associated with a very slow flowing channel from the Danube River with numerous dead-leaves on the river bottom (Moller Pillot and Buskens, 1990). Nowadays, *G. pallens* larva thrive in submerged woods and plants or build transportable cases on solid substrates. Occasionally, they are found in slightly brackish waters (Vallenduuk, 1999). Throughout the zone, both PCA axis 1 and between-class CA scores show an increasing trend towards higher connectivity of the site with the main channel. Particularly from ca. 2800 cal. yr BP (180 cm), which is contemporaneous with the foundation of *Halmyris* (about 650 cal. yr BC).

7.1.5. Unit E: distributary channel in Getic and Roman times (ca. 6th century BC to ca. 7th century AD)

In the two cores, this unit is located above the peat layer and it is composed of silty-sand that incorporate significant freshwater shell debris. In HAIII, this unit is dated to after 3920 ± 35 BP (2547 – 2293 cal. yr BC; date obtained on the top of the peat layer). The three ages obtained in this unit highlight an important chronological gap (**Table I and Supplementary Material 4**). This chronological gap may be due to the erosion of the peat layer as a result of fluvial activity (or anthropogenic dredging).

The macrofauna is composed of *Dreissena polymorpha* living in rivers and *Lithoglyphus naticoides* and *Viviparus* sp., living on the riverbanks of low-energy rivers (Pfleger, 1993). The ostracods are composed of a mixture of species that have a wide ecological range including lagoons, springs, ponds and lakes (Opreanu, 2003; Frenzel et al., 2010; Salel et al., 2016). The presence of *Darwinula stevensoni*, which does not tolerate drying up of the water body, testifies to permanent submerged conditions. Furthermore, this species is a lotic ostracod associated with fluvial interstitial sands (Dole-Olivier et al., 2000). At the base of the unit, samples are dominated by *Darwinula stevensoni* and reflect negatives values of the PCA Axis-2, consistent with ostracods living in permanent waters (**Figure 3.B**). This facies could be identified as a secondary channel dating from the Getic/Greek (2585 ± 35 BP; 820-566 cal. yr BC; 275-280 cm depth) and the Roman periods (1775 ± 30 BP; 138-339 cal. yr AD; 270-275 cm depth), with moderate (?) flowing waters, allowing the development of a large population of ostracods (ca. 500 valves for 20 grams of sediment). This channel may have formed after an avulsion of the main course of the Danube, which can occur rapidly in deltaic environments (Jones and Schumm, 1999). Progressively, the connection with the main fluvial channel decreases and the samples are dominated by the ostracod *Candona neglecta* that is characteristic of stagnant water bodies (positive PCA Axis-2 scores; Fuhrmann, 2012). Furthermore, the proportion of *Darwinula stevensoni* is still >5% up to 220 cm depth and shows that the secondary channel remains connected to the main channel (**Figure 3.A**).

Chironomids confirm this hypothesis, with high scores of both PCA axis 1 and between-class CA, characteristic of a permanently connected side-arm (during Hach-3 and 4). In the sandy zone Hach-3 (163-145 cm depth) dated between ca. 210 cal. yr BC and ca. 202 cal. yr AD, we found high percentages of *Chironomus* and *Glyptotendipes* suggesting the persistence of eutrophic waters. These taxa, in association with halotolerant species, such as *Halocladius* and *Psectrocladius sordidellus* (Klink and Moller Pillot, 1999), as well as the presence of numerous shells of halotolerant (*Dreissena polymorpha*) and lagoonal (*Cerastoderma glaucum*) bivalves, point to increasing salinity at the site.

In zone Hach-4, (145-95 cm), the dominance of *Cricotopus* and the appearance of several lotic taxa such as *Eukiefferiella/Tvetenia*, *Rheotanytarsus* and *Micropsectra*, suggest that the site was always connected to the main channel. *Neozavrelia* has always been found in association with *Nuphar luteola* (Thienemann, 1942) and other bryophytes in artificial riffles from the lower part of the Rhine river (Klink, 2002).

7.1.6. Unit F: residual channel during the 6-7th centuries AD

In HAIII, the unit is dated between ca. 1360 cal. yr BP (ca. 590 cal. yr AD) and 1230 cal. yr BP (ca. 720 cal. yr AD). It is composed of fine sediments (silts and clay >98 %), as is generally the case for residual channels (Toonen et al., 2012). In the absence of direct dating of this unit, the proposed chronology is based on the age-depth model. The change in the dominant ostracod species (from *Darwinula stevensoni* to *Candona* sp.) underscores the shift from a connected-fluvial channel to a probable stagnant water body. In HAI, scores show an abrupt decrease around 140-130 cm, corresponding to 1400 - 1245 cal. yr BP (550-700 cal. yr AD), highlighting a probable temporary disconnection towards the end of the Roman occupation of Halmyris, which is contemporaneous with the disconnection recorded in core HAIII (**Figure 5**).

7.1.7. Unit G: upper delta plain between 1230 cal. yr BP (ca. 720 cal. yr AD) and 110 ± 30 BP (1681-1938 cal. yr AD).

This unit, located between 63 and 200 cm depth, started to accrete after 1230 cal. yr BP (ca. 720 cal. yr AD) in core HAIII and is dated at its centre to 830 ± 30 BP (1160 – 1260 cal. yr AD). In core HAI, this unit corresponds to the chironomid zone Hach-5 dated between ca. 1300 cal. yr AD and 110 ± 30 BP (1681-1938 cal. yr AD). It is mostly composed of silts and clay (85-98%) and the sedimentation is very homogeneous. The absence of aquatic fauna on HAIII could demonstrate the transformation of the area into a dried-out floodplain because of the migration of the river. The sediment deposition may translate a succession of overbank flooding. The chironomid data in

HAI show a trend towards a fluvial-disconnection as suggested by a progressive decrease in PCA axis1 values and between-class CA scores over Hach-5, which is due to the increase of lentic taxa such as *Chironomus*, *Dicrotendipes* and *Glyptotendipes* (Gandouin et al., 2006). The presence of *Lithoglyphus natocoides*, indicative of stagnant or slow-flowing freshwater, meshes with this hypothesis.

7.1.8. Unit H: organic-rich peat layer

The development of a second organic-rich peat layer attests to the presence of freshwater inputs that favoured peat growth during the 19th century. These inputs of freshwater could be linked to a rise in the water table in this area (groundwater flows). The chironomid content in the peat layer of core HAI demonstrates that the level of connection to the main river was poor, with the disappearance of lotic taxa. The development of this peat layer, during the Little Ice Age, seems to underscore a reduction in sediment inputs near Halmyris in the period of generally high fluvial activity due to secular climatic degradation (McCarney-Castle et al., 2012). This reduction could be because the main flow of the delta was concentrated in the Chilia lobe (northern part of the delta; Filip and Giosan, 2014; Vespremeanu-Stroe et al., 2017). This disconnection could also be due to the containment of the Danube River, which became widespread in the mid-nineteenth century in the Danube area (Gupta, 2007) and elsewhere in Europe (Tockner et al. 2009).

7.2. *Geoarchaeological implications and characterisation of the anchorage*

The comparison of cores HAI and HAIII reveals the presence of a fluvial channel north of the settlement of Halmyris, attested by the presence of lotic ostracods and chironomid species (**Figures 3, 4 and 5)**. We have demonstrated that it was active during the occupation of Halmyris (6th c. BC – 7th c. AD). The presence of the channel from the middle of the second millennium BC could explain the choice of this emplacement for the location of the Getic settlement and the possible Greek *emporium* in place for the later fortress in the 6th century BC.

7.2.1. Navigation in the channel – water depth

To ascertain if this channel was navigable, we need to know its nautical dimensions. In particular, the depth of the channel will help us to elucidate the maximum draught of the ships (Boetto, 2010; Salomon et al., 2016). For this purpose, we based the reconstruction on the core HAIII because the core HAI was drilled close to the palaeo-bank of the channel and, as a result, the water depth in this area was much lower. Because the ancient harbour of Halmyris was situated on the deltaic plain of the Danube, ca. 38 km from the present shoreline (but closer to the river mouth during Antiquity), the water level of the channel is linked to the elevation of the sea level. It is largely assumed that the post-glacial sea-level rise in the Black Sea is comparable to that of the Mediterranean, comprising a rapid glacio-eustatic rise until 6000 BP, followed by an important deceleration in sea-level rise that reached its present position around 2000 years ago (Giosan et al., 2006; Brückner et al., 2010). Nevertheless, we have no data precisely constraining the level of the Black Sea around 2000 years ago for the Danube delta. Using the ICE-5G (VM2) GIA model (Peltier, 2004), we have constrained the RSL position of the Black Sea for the two periods of human occupation at Halmyris. We propose the related water depth of the channel (**Table IV and Figure 6**). In the 6th century BC (Getic/Greek occupation of *Halmyris*), the level of the Black Sea was between 76 and 44 cm below the present MSL and the water column of the channel was at least 165 ± 9 cm deep (mean 246 ± 9 cm). At the end of the occupation of Halmyris, the level of the Black Sea was between 29 and 22 cm below the present MSL and the water column of the channel was at least 155 ± 9 cm deep (mean 246 ± 9 cm).

Table IV: estimate of the water depth of the channel at different times. The modern tidal range is from Medvedev et al., 2016. Maximum and minimum water depth at Sulina mouth from Bondar and Iordache (2016). Mean water depth = (A + (B+C)); Minimum water depth = (A + (B+D)); where A = Depth of the sample; B = Minimum sea-level position; C = Average level Sulina mouth (1840-2011); D = Minimum level Sulina mouth 1921.

Dating of the	Dating	Depth of the	Minimal sea-level	Mean sea-level	Modern tidal	Maximum level	Average level	Minimum level	**Mean water**	**Minimum water**

channel (14C)	of the channel (cal. BC/AD)	sample (cm b.s.l.)	position (modelled)	position (modelled)	range (cm)	Sulina mouth (May 2006)	Sulina mouth (1840-2011)	Sulina mouth (January 1921)	**depth of the channel (cm)**	**depth of the channel (cm)**
(age depth model)	600-650 AD	220	-29 cm	-22 cm	18	+137 cm	+45 cm	-36 cm	**236 ± 18**	**155 ± 18**
1775 ± 30	140-340 AD	270-275	-44 cm	-27 cm	18	+137 cm	+45 cm	-36 cm	**290 ± 18**	**192 ± 18**
2585 ± 35	820-565 BC	275-280	-76 cm	-44 cm	18	+137 cm	+45 cm	-36 cm	**246 ± 18**	**165 ± 18**

[Insert Figure 6]

The channel was more than deep enough for the circulation of flat-bottomed vessels typically used on rivers during Antiquity. In Roman times, the harbour of Halmyris was mainly used for military purposes. Bounegru and Zahariade (1996) present different types of fluvial boats used between the 1st and the 6th centuries AD on the Lower Danube. Although they provide little information regarding the draught of boats used between the 1st and the 3rd centuries AD, they do state that they were flat-bottomed boats adapted to fluvial navigation such as *liburnae* (a *liburna* has been identified in a text from the 2nd c. AD in *Noviodunum*, another fortress of the Danubian limes, situated ca. 60 km upriver from Halmyris; Bounegru and Zahariade, 1996). The fleet of the Lower Danube was particularly important at the beginning of the 5th century AD and comprised, according to the Theodosian code (7.17.1. January 412), 225 *lusoriae* (Syvanne, 2015). *Navis lusoriae* were war-ships intended for fluvial navigation on the Frontier Rivers of the Roman Empire (Torr, 1894; Pitassi, 2011). The use of these ships is attested by a 4th-century Roman author, *Vegetius* (*Epitoma Rei Militaris*, 4.34, 4.46) that mentions small vessels, including *navis lusoriae*, that were used on the Danube River (Syvanne, 2015). Such boats, intended to protect the borders of the Empire, were also used on the Rhine River. Archaeological excavations undertaken in Mainz (*Mogontiacum*) have provided important information about river vessels used in the Late Roman period. In the ancient harbour basin of *Mogontiacum*, archaeologists have discovered several shipwrecks dated to the 3rd and the 4th centuries AD (Höckmann, 1993). Two different types of boats have been identified, *navis lusoriae* (Mainz 1 and 5) and a smaller vessel used as a patrol ship for the surveillance of the Rhine border during the 4th century (NAVIS Project, Römisch-Germanisches Zentralmuseum, Mainz). According to reconstructions of the boats by archaeologists at the "Museum of Ancient Shipping" in Mainz (**Supplementary Material 5**), it is noted that such fluvial military vessels had a small draught (around 1m) and may have been used at Halmyris.

7.2.3. Relationship between settlements and rivers in ancient times

Our study shows that Halmyris' inhabitants exploited a natural fluvial channel to host their harbour in Getic/Greek and Roman times. In Antiquity, settlements located along river channels used riverine flow which explains why several of them have densely artificialized riverbanks, particularly in urban areas (Allinne, 2007). Numerous rural settlements were founded along the palaeo-channels of the Rhone delta (France), particularly between the 3rd century BC and the 7th century AD. Arnaud-Fassetta and Landuré (2014) have demonstrated that these settlements were mostly located along the main channels of the river and that human iccupation was coeval with the period of activity of the channels. This link is also visible on the Nile delta, where the ancient city of Pelusium, originally located at the mouth of the Pelusiac branch of the Nile, seems to have been abandoned following the shift of the river channel to the east and the infilling of the initial river-mouth due to the progradation of the coastline (Goodfriend and Stanley, 1999; Stanley et al., 2008). The same phenomenon occurred in the Rhine delta, where van Dinter et al. (2017) have highlighted a strong relationship between settlement history and river activity, furthering addition to other socio-economic and political factors. Halmyris was an important Roman fortress installed along the *limes* of the Lower Danube. The identification of a natural harbour of the banks of a secondary channel leads us to draw comparisons with other fluvial harbours present in the region. Upstream, still on the southern bank of the Danube, the fortress of Capidava has furnished interesting information regarding harbour infrastructure (Munteanu, 2012). Archaeological investigations have unearthed an artificial quay 2.5 meters wide and 64 meters long to the southwest of the fortress

(**Supplementary Material 6**; Dobrinescu and Bodolică, 2016). This harbour was used from the 2nd to the 4th centuries AD. The structure, in a perfectly upright position, is fixed on the rocky substratum. At Halmyris, no archaeological surveys in the supposed harbour area have been undertaken. The ancient harbour could have been managed as the harbour of Capidava because the channel, in front of the main gate, is conducive harbour activity.

8. Conclusion

The Roman limes of the lower Danube was protected by a series of fortresses and harbours. Our study demonstrates the presence of a channel to the north of the fortress of Halmyris which confirms the previous archaeological hypotheses regarding harbour activities in this area. Furthermore, it provides useful information to understand the interplay between the natural environment and the organisation of ancient harbours in deltaic contexts. The Roman harbour of Halmyris was probably located in the reconstructed channel that flowed in close proximity to the site until the 7th century AD. The fortress enjoyed an easy access to the river while being protected from the floods of the Danube due to its position on the promontory (palaeo-cliff). We have demonstrated that this channel was navigable throughout the period when the site was occupied (Getic/Greek and Roman Periods). At the time of the abandonment of Halmyris in the 7th century AD, the depth of the channel was >155 cm, allowing the circulation of fluvial-military boats. Zahariade and Phelps (2002) have arbitrarily attributed the complete obstruction of the northern gateway to the fortress during the second half of the 6th century to the navigation difficulties encountered to reach *Halmyris*. Our core reveals that the disconnection of the channel of Halmyris from the main channel was contemporaneous with the abandonment of the site. However, we cannot determine whether the abandonment of the site resulted in a natural disconnection between the secondary channel of *Halmyris* and the main channel. A fall in population, associated with the general geopolitical situation of the Late Roman Empire, could also have resulted in poor maintenance of the connection between the main channel and the secondary channel.

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