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Geoarchaeological investigations of the river harbours of Noviodunum – The headquarters of the Roman Imperial fleet (Lower Danube, Romania)

Alexandra Bivolaru [a,*], Christophe Morhange [b,c], Aurel Daniel Stănică [d], Tiberiu Sava [e], Daniela Pascal [e,f], Marian Mocanu [d]

[a] Department of Humanities, Ca'Foscari University, Malcanton Marcorà - Dorsoduro 3484/D, Calle Contarini, 30123, Venice, Italy
[b] CEREGE, IMBE, Aix Marseille Université, CNRS, IRD, INRA, Collège de France, CEREGE, Aix-en-Provence, France
[c] EPHE-Section des Sciences Historiques et Philologiques, AOROC, UMR 8546 - Archéologie et Philologie d'Orient et d'Occident, CNRS/PSL, École normale supérieure, 45 rue d'Ulm, Paris, France
[d] ICEM Tulcea, Strada Progresului 32, Tulcea 820009, Romania
[e] Horia Hulubei National Institute for Physics and Nuclear Engineering, Turnu Magurele, Romania
[f] University of Bucharest, Faculty of Geography, Romania

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ABSTRACT

Noviodunum was the headquarters of the Roman Imperial fleet *Classis Flavia Moesica* from the 1st c. AD. Its importance as a river port is shown by its description in various ancient sources and *itineraria*. The settlement is located on a limestone promontory on the right bank of the River Danube (Romania). Its location is highly strategic, as it is the last narrow crossing of the river before entering the Danube Delta and thereafter the Black Sea. Despite its advantageous position, the settlement location was geomorphologically challenging; issues of flooding, rising groundwater tables, drainage problems, mobility and erosion of the concave banks and sedimentary budget have all played a role in the evolution of the site, and in turn, the location and preservation of archaeological remains. Understanding the processes operating in this dynamic environment has required an interdisciplinary research study. Here we present the results of a multi-proxy approach combining bio-sedimentology, granulometry, statistical analysis and archaeology. Our geoarchaeological research aimed to (1) understand the Danube's palaeodynamics in order to (2) locate and characterise the harbours.

Our findings suggest the existence of two possible harbour basins, upstream and downstream of the fortress, that functioned until at least the 5th c. AD.

1. Introduction

Throughout the Roman Empire, rivers were integral to its function, socially, economically and politically, even forming parts of its European land borders (*ripa*). River valleys served as natural route ways for contact, trade and communication axis with steppe lands, coastal zones and wider frontiers (Franconi, 2017). As a result, the banks of rivers such as the Danube, Rhône, and Rhine were densely populated, with military and civilian settlements and ports built along them (Campbell, 2012; Franconi, 2017; Werther and Kröger, 2017). The Lower Danube and its delta came under Roman control sometime during the 1st Century CE (Suceveanu and Barnea, 1991; Zahariade and Gudea, 1997; Matei-Popescu, 2010). Roman fortifications were erected along the Danube in order to control the border and in areas where the Danube can be easily crossed: Arrubium, Dinogetia and Noviodunum (Alexandrescu and Gugl, 2016) (Fig. 1).

The last segment of *limes*, where the fortress of Noviodunum is located, was particularly significant because it represented the corridor connecting the Danube with the Black Sea via the Danube delta. Noviodunum was strategically positioned, located at the last ford before the Danube delta. Therefore, the fortress allowed the control of roads leading into the Thracian lands north of the river and the Greek cities of the North-Western Pontic area. Given its strategic importance, the port of Noviodunum served as a military and economic hub, and it has played an important role in local and regional history (Fig. 1) (Vulpe and Barnea, 1968; Aricescu, 1975; Suceveanu and Barnea, 1991; Baumann,

* Corresponding author.
E-mail addresses: alexandra.bivolaru@unive.it (A. Bivolaru), morhange@cerege.fr, christophe.morhange@ephe.psl.eu (C. Morhange), aurelstanica@gmail.com (A. Daniel Stănică), tiberiu.sava@nipne.ro (T. Sava), daniela.pascal@nipne.ro (D. Pascal), marian1054@yahoo.com (M. Mocanu).

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2010; Panaite, 2012; Matei-Popescu, 2016; Țentea et al., 2019). However, identifying the location of its harbours has been hindered by the complexity of the archaeological sequences and its geomorphological evolution. Thus, the research described in this paper aims to (1) understand the Danube's geomorphological processes and palaeodynamics since the 1st c. AD at Noviodunum and (2) to locate, characterize, and date the harbour (s).

1.1. Geographical context

Noviodunum is located on the eastern bank of the Danube, at the border with Ukraine, approximately 3 km eastward of the modern city of Isaccea (Fig. 2). The site is located approximately 55 miles from the Black Sea, where the Danube valley floor narrows between limestone cliffs, causing the alluvial plain to almost entirely reduce (to approximately 0.6 km). The Danube plain widens again downstream of Noviodunum, with an average width of approximately 5 km in this reach. There are several shallow natural lakes, marshy areas, and a network of meanders and canals that give the plain a deltaic appearance. The flow of the Danube is significantly reduced downstream of Noviodunum, with an important volume of water retained in these wetlands; flow decreases from approximately 6500 m^3/s at Noviodunum to approximately 3000 m^3/s at Ceatal St. George-Tulcea (Strechie-Sliwinski et al., 2008). A remnant pond is situated upstream of the promontory, near to the promontory where the site is located (Fig. 10).

The current climate is temperate-continental, with hot, dry summers and cold, windy winters (Ciulache and Ionac, 2004). The Crivăț, a strong, south-westerly wind blowing from north-east Russia, produces mist and very low temperatures, resulting in frosts that last 30–40 days on average and up to 90 days per year. Between 1932 and 1982, ice bridges over the Danube appeared 40–55 percent of the time, lasting an average of 15 to 20 days (and up to 80–85 days in very cold winters). River ice jams can impede navigation in winter months where the Danube is constrained within its valley floor, as at Noviodunum.

Fig. 1. Late Roman fortresses along the Lower Danube and Danube delta limes sectors (red dotted line) (modified after Gudea 2005; Alexandrescu and Gugl 2016). Top left panel – Map of the Roman provinces and the Danubian limes in the 2nd c. AD (Credit: C. Raddato, https://www.followinghadrian.com). Top right panel - Danube watershed (Revenga et al., 1998) and Noviodunum location (yellow square).

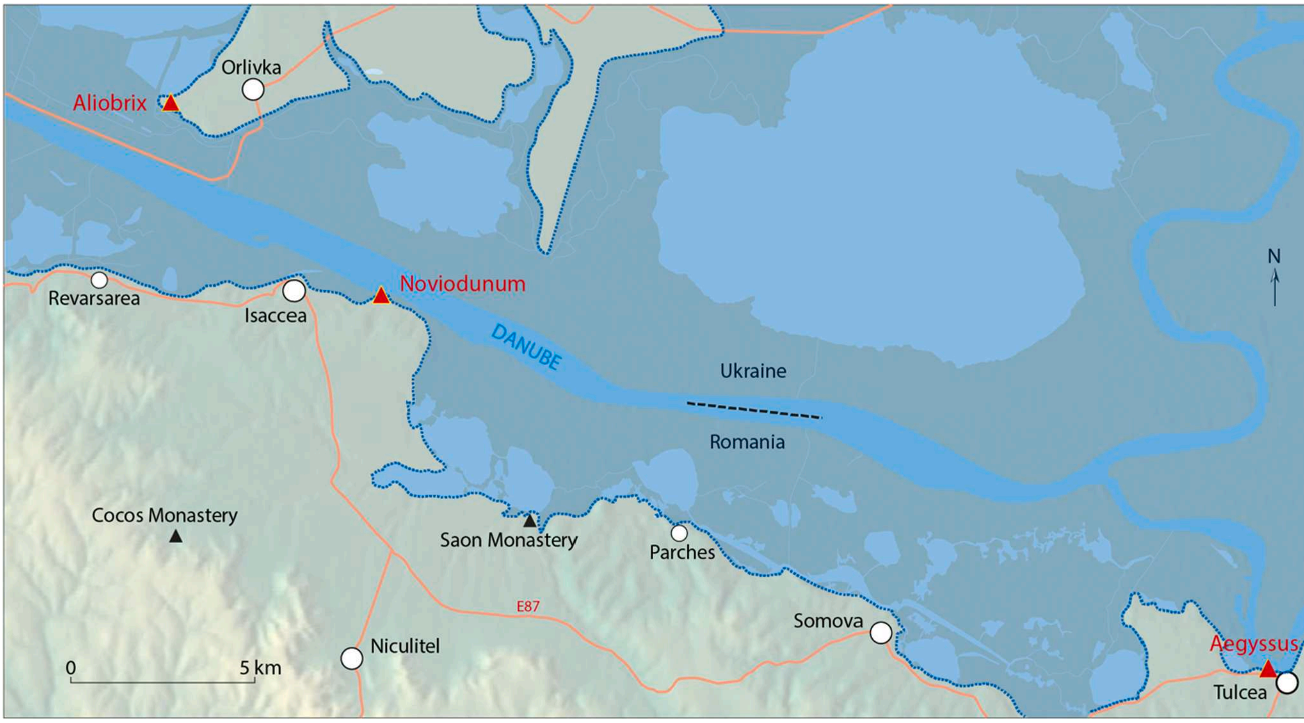


Fig. 2. Location of Noviodunum and its complementary site, Aliobrix (Ukraine). (Credits: P. Pentsch).

1.2. Historical evolution of Noviodunum: From military strategic point to the headquarters of Classis Flavia Moesica

The political and military importance of Noviodunum is demonstrated by the long history of occupation. The settlement is mentioned in the most important cartographic, hagiographic and historical sources from the Roman and Byzantine periods (Iliescu et al., 1964; Mihăescu et al., 1970): Ptolemy (III, 10, 2, 5), *Antonine Itinerary* (226, 1), *Notitia Dignitatum Orientiis* (XXXIX, 25, 32, 33) Ammianus Marcellinus (XXVII, 5, 6), Procopius of Caesareea (*De ed.*, IV, 11) the Geographer of Ravenna (IV, 5, 16), Jordanes (*Getica*, 35) and in *Notitia Episcopatum* (532). One last mention of the fortress is made by the Emperor Constantine VII Porphyrogennetos in the 10th Century CE (*De Thematibus*, II, 47, 15).

According to Brătianu (1999), the toponym Noviodunum is of Celtic origin and refers to the Celts' passage in the 3rd c. BC. The Celts may have come across a fortified Getae settlement established during the Iron Age as they crossed the Isaccea ford (Barnea and Barnea, 1984). Noviodunum faces another Roman fort with a Celtic toponymy, Aliobrix (*codex Vaticanus Graecus* 191, X, Gostar, 1976) across the river, in the modern town of Orlovka (Ukraine). Archaeological discoveries, especially local and Hellenistic pottery as well as coins from the 4th – 1st centuries BC, point to a military and commercial settlement here prior to the arrival of the Romans (Baumann, 2008; Topoleanu and Chrzanovski, 2016).

Noviodunum is generally known as the headquarters of the Imperial Fleet *Classis (Flavia) Moesica*. The fleet was founded between 20 BC and 10 AD and played an important role in the political and military events that shaped the history of the Middle and Lower Danube prior to the Roman conquest (Bounegru and Zahariade, 1996). Noviodunum most likely became the headquarters of Classis Flavia Moesica after Legio V Macedonica was relocated to Troesmis sometime between 103 and 105 CE, during Trajan's reign (Bounegru and Zahariade, 1996; Gudea, 2005; Matei-Popescu, 2010). Prior to Trajan, there is only one epigraphic source (CIL III 6221 = ISM V 286) that records the presence of the Roman army in the area, discovered at Aegyssus (nowadays Tulcea) (Matei-Popescu, 2010; Ţentea, 2016).

The honorary title *Flavia* is likely to have been received during a reorganization under Vespasian around 75 AD. The fleet's responsibilities extended into the western Black Sea and the trade routes between the Danube and the Bosporus (Fig. 3). With increasing Roman power and influence in the Black Sea area, the fleet was used to secure its interests in the western half of the Black Sea; this included the Hellenistic cities along its northern shore and with the Bosporan kingdom of the Crimea and adjacent lands, an important producer of grain (Gudea, 2005; Pitassi, 2012). The fleet later established a naval base at Chersonesos (Matei-Popescu, 2010).

The primary duties of the Moesian fleet on the Danube were military. The squadron could not prevent sudden raids on its own because most barbarian invasions recorded in written sources occurred during the winter months, when the Danube was frozen and the Roman fleet was impotent (Starr, 1960). In addition to assisting in transportation along and across the Danube, the squadron may have performed fiscal duties similar to those of the Egyptian *potamiphylacia*, as *portorium Illyrici* was exacted at various toll stations along the Danube (Starr, 1960).

The military importance of Noviodunum is reflected in the epigraphic sources (Doruţiu-Boilă, 1980). Here were stationed vexillations of the *Legio V Macedonica* (RE XII, 2; ISM 5, 284), the *Legio XI Claudia* during the 2nd century, the *Legio I Italica* starting in 167 CE (RE XII, 2; ISM 5, 271) and finally, during Late Antiquity, the *Legio I Iovia Scythica* (AE 1974, 568).

As a result, ships from these legions may have been stationed at Noviodunum alongside those from the *Classis Flavia Moesica*. This is especially true for the *Legio I Italica*, which is recorded far from its main base on the Danube at Novae (Bulgaria) after 167–168 CE, namely at Noviodunum, Capidava, and Dinogetia (Press and Sarnowski, 1990; Matei-Popescu, 2010). During the 2nd century CE, the *Legio I Italica* was producing bricks with its name set in a ship-shaped frame (Type 4 + variations, Gudea, 2005). This type of vessel is a warship with the typical bow and stern decoration similar to the *liburnas* on Trajan's column. This uncommon brick stamp suggests that the *Legio I Italica* had both warships and commercial ships (Press and Sarnowski, 1990; Gudea, 2005). The *Legio I Italica* fleet, along with the *Classis Flavia Moesica*, were most likely supervising the Danube sector corresponding to the province of Lower Moesia (Sarnowski and Trynkowski, 1986).

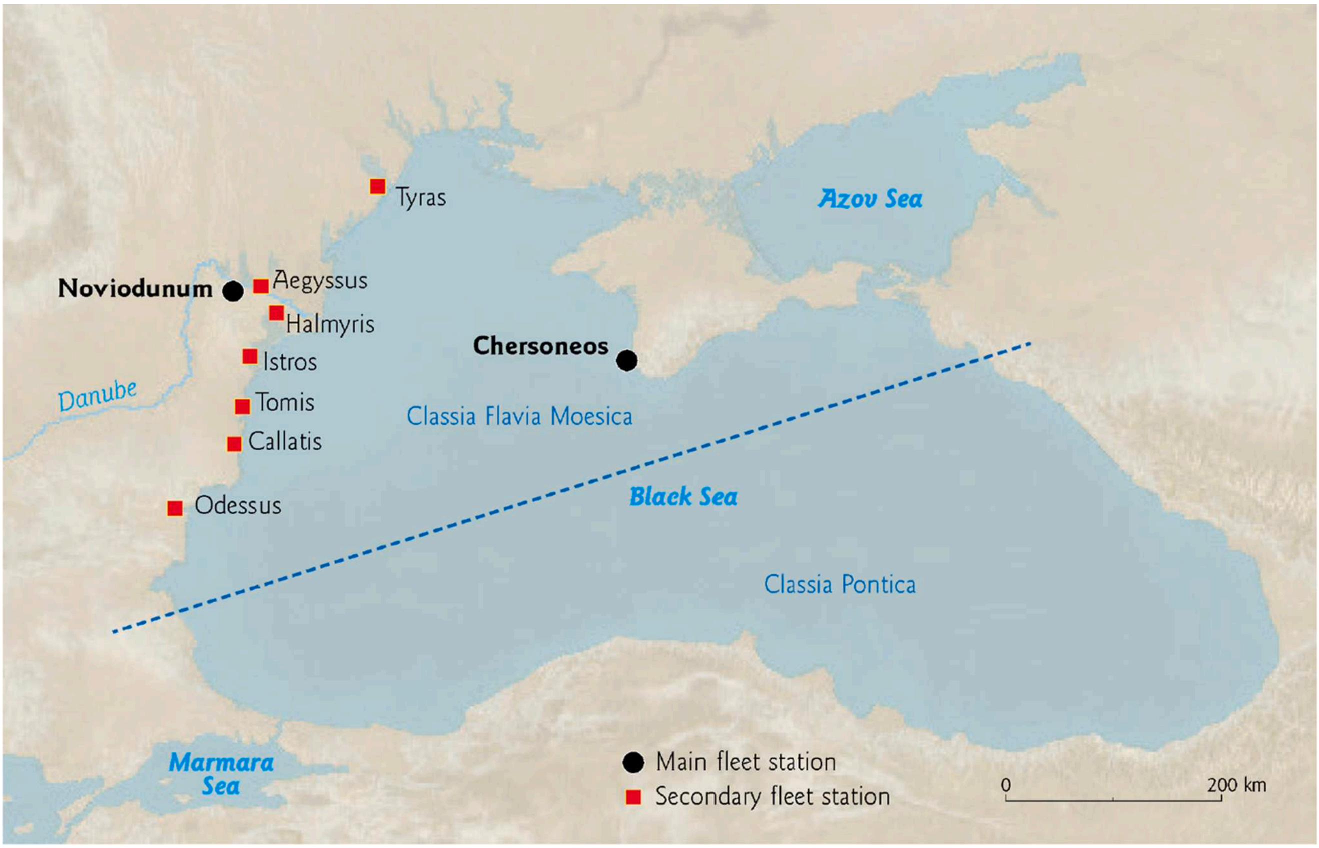


Fig. 3. The main and secondary stations of the Classis Flavia Moesica. The dotted line separates the postulated surveillance areas of the Classis Flavia Moesica and Classis Pontica. Modified after Gudea 2005 by P. Pentsch.

Beside the military occupation, a civilian settlement developed around Noviodunum, south and east of the promontory. Sometime during the 2nd – 3rd centuries AD, during the Severan Dynasty, historical sources indicate that Noviodunum became a *municipium* (Suceveanu and Barnea, 1991; Matei-Popescu, 2016).

Noviodunum was included in the border fortification network between the 4th and 6th centuries AD, forming a triangle with Troesmis and Dinogetia. The fortification system included intermediate citadels (Arrubium, Luncavița, and Rachelu), a secondary fortified line (Traian, Cerna, Nifon, and Niculițel), and, behind this, the largest Late Roman fortification, Ibida (Scorpan, 1988) (Fig. 1).

The *Classis Flavia Moesica* became the *Classis Ripae Scythicae* in Late Antiquity. According to the *Notitia Dignitatum*, the *Praefectus legionis primae Ioviae and the Praefectus ripae legionis primae Ioviae cohortis quintae Pedaturae superioris* were stationed in Noviodunum under the high command of the *Dux Scythiae* (Zahariade, 1988). As a consequence, the port was still active and had a military function during the Late Roman period.

Recent archaeological research has revealed intensive occupation during the Byzantine and Medieval periods, with numerous ceramics and coins, jewellery, cult objects, tools, and building materials dating from the 10th to the 14th centuries (Stănică and Dinu, 2017). Such significant occupation would imply that a port was still active at Noviodunum in Byzantine times, and that it served as a stopping point on the way to Durostorum, as Carsium did for a shorter period of time (Madgearu, 2013). The occupation of Noviodunum came to an end in the 14th century, with power shifting to the nearby city of Isaccea, where a new settlement began to develop in the 13th century (Baumann, 2010).

1.3. State of the art

Despite the historical significance of Noviodunum as a port, no harbour structures have been discovered to date. This is due, in part, to a lack of detailed research focus on this particular aspect of the site's history during previous multidisciplinary investigations (Lockyear et al., 2006; Lockyear et al., 2008). Lockyear and his team conducted a topographic survey, resistivity and magnetometry investigations, and hand auger drillings (Lockyear et al., 2006; Lockyear et al., 2008). Their findings improved our understanding of the site by providing a more accurate topography of the spatial distributions of the remains. Based on the surveys, the team proposed a new interpretation of the three defence lines identified by Ştefan (1973), as being natural features (old water channels, Lockyear et al., 2006) rather than artificial. However, both Ştefan (1973) and Lockyear et al. (2006, 2008), based their interpretations without any archaeological investigation. Furthermore, the geophysical survey was problematic due to the nature of the subsoil and modern pollution; additionally, the used methods penetrated only 1 m below the surface, limiting the results (Lockyear et al., 2006, 2008). The geophysical survey and hand-coring, on the other hand, were focused on the civil settlement and the fortress itself, rather than the harbours. The auger drillings (Fig. 4) in the lowland SW of the fortress (in the so-called "putative harbour") indicate deep colluvium deposits, which the authors interpret as silting-up of the area. However, the interpretation of these deposits is impossible in the absence of a chronological framework. Fiederling et al. (2017) conducted additional remote investigations (sonar) in the Danube, in front of the fortress. The team discovered an eroded channel up to 19 m deep with an almost vertical submerged slope directly in front of the Late Roman fortress, as well as a "ridge" to the north, parallel to the river bank, towards the middle of the Danube, at a water depth of 6–7 m. It is difficult to

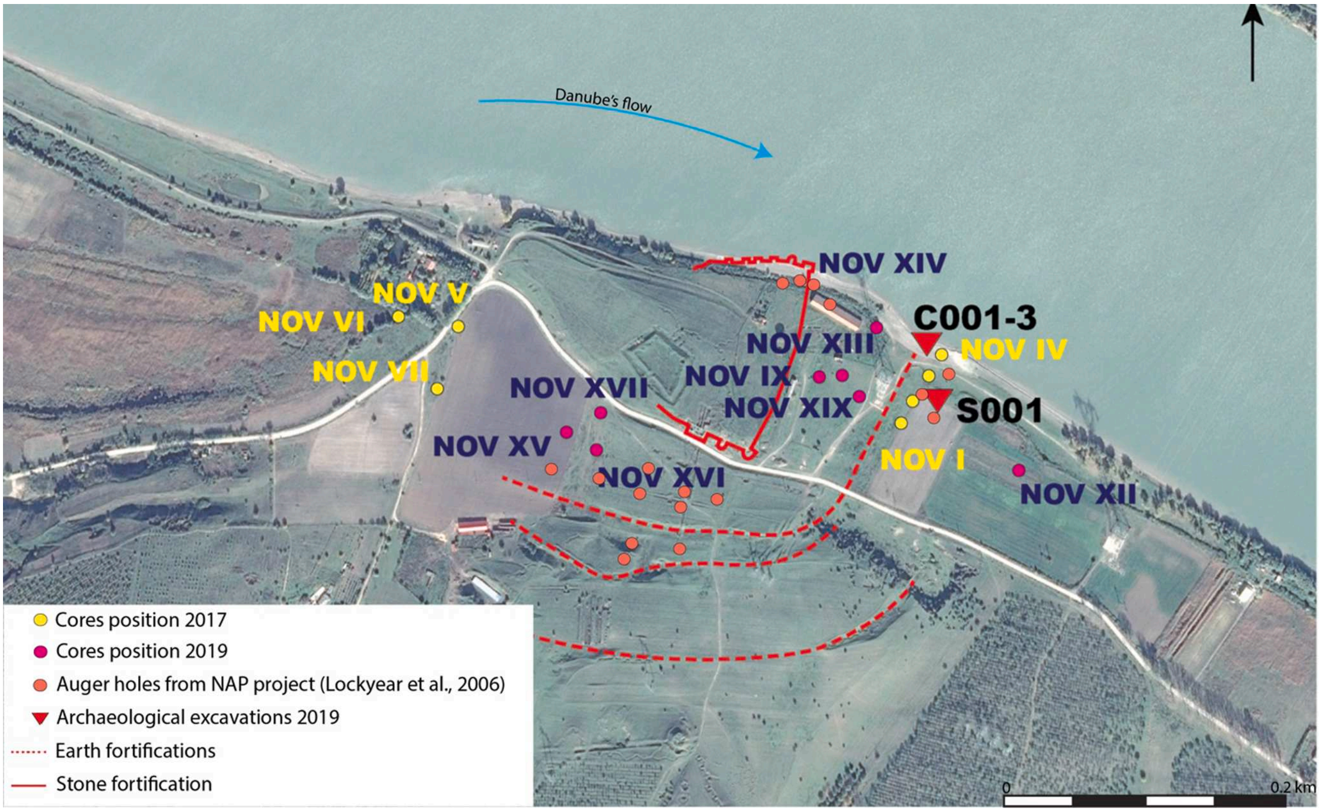


Fig. 4. Locations of the cores used in this study (yellow dots) in relation to the three earth fortifications (red dotted line) and stone fortifications (red line). Archaeological excavations are indicated by red triangles. Source of the base image – Google Earth.

interpret and link this fluvial formation to the Roman harbours because neither its nature nor its age is known. In this context, our research project is the first interdisciplinary study dedicated entirely to the investigation of Noviodunum's harbours, as well as the impact of past river dynamics on their location and character. We delivered the first integrated study of Noviodunum's harbours and paleo-environmental dynamics, as well as a new ground for future work, by using coring, bio-sedimentological analysis, radiocarbon dating, typo-chronology, archaeological investigations, and historical sources.

2. Materials and methods

Our research is based on a multidisciplinary approach, combining geomorphology, sedimentology, the analysis of biological proxies and archaeology. In 2017, nine sediment cores were extracted, both downstream and upstream of the promontory on which the fortress is located, as well as to the south of it, in the civil settlement (Fig. 4). Coring was undertaken using a Cobra corer and the tubes had a diameter of 5 cm.

The cores locations were mapped (latitude, longitude, WGS 84 system) using a Garmin GPS-12 with an accuracy of approximatively 3 m, and described for colour, texture, homogeneity/heterogeneity and compaction. Cores were sampled on site (using sampling intervals of between 5 and 10 cm, depending on the core material). In total, 187 samples were collected and analysed after the methodology proposed by Marriner and Morhange (2007). Geoarchaeological fieldwork was augmented by archaeological excavations in 2019 (Figs. 4, 8).

2.1. Chronology

The chronology of the cores was established using AMS radiocarbon dating at RoAMS Radiocarbon Laboratory in Bucharest. In total, 12 radiocarbon age estimates were obtained (Table 1). The dated material consisted of charcoal and plant remains. The obtained ages were calibrated using Calib 8.20 with the IntCal20 atmospheric curve (Reimer et al., 2013), Marine20 (Reimer et al., 2013) and the post-bomb atmospheric NH1 curve (Hua et al., 2013). Before calibration, the marine age

Table 1
Radiocarbon ages obtained at Noviodunum. Depth of the samples is given below surface.

Core	Lat-Long	Depth b.s. (cm)	Material	Lab code	Age BP & error	cal 2σ	Remark
NOV I	45.269713; 28.496166	180–190	charcoal	RoAMS 1139.90	1248(40)	672–776 CE	Accepted
NOV III	45.270335; 28.496890	308–309	charcoal	RoAMS 1114.90	1111(54)	820–1026 CE	Rejected
NOV IV	45.270467; 28.497221	70–80	charcoal	RoAMS 1115.90	1886(42)	59–241 CE	Rejected
		290–300	charcoal	RoAMS 1116.90	1753(38)	237–403 CE	Accepted
NOV V	45.271044; 28.487793	160–170	charcoal	RoAMS 1117.90	1680(35)	323–435 CE	Accepted
		490–500	charcoal	RoAMS 1119.90	2274(39)	314–205 BCE	Rejected
		580–585	charcoal	RoAMS 1120.90	2144(39)	231–49 BC	Accepted
NOV VI	45.271150; 28.486454	110–120	plant remains	RoAMS 1121.90	436(75)	1395–1640 CE	Accepted
		280–290	plant remains	RoAMS 1122.90	933(78)	992–1264 CE	Accepted
NOV VII	45.269579; 28.487264	205–215	charcoal	RoAMS 1126.90	1179(45)	773–979 CE	Accepted
		330–340	charcoal	RoAMS 1140.90	2000(51)	125 BCE-129 CE	Accepted
		489–490	charcoal	RoAMS 1124.90	2026(38)	116 BCE- 81 AD	Rejected

reservoir calculated for the Danube delta (498 41, Siani et al., 2000) was extracted.

Ceramic typological data recovered from selected cores were used to supplement the radiocarbon chronology (Table 2).

2.1.1. Age-depth models

The chronology of the facies was determined by combining radiocarbon ages and age-depth models with typo-chronology. Age-depth models were obtained for all cores using XL-STAT19 (Fig. 5). The age-depth models for core NOV V showed younger ages than the radiocarbon ages and the typo-chronology, thus it was rejected. We used relative chronology (before/after) when no absolute chronology was available (e.g., radiocarbon ages or typo-chronology).

Obtaining a strong chronological framework and robust age-models in a fluvial context is difficult due to material recycling processes, particularly of charcoal (Carol et al., 2012; Long et al., 2016; McLaughlin et al., 2020), and the mixing of archaeological material due to natural (floods, erosion) and anthropogenic (dredging works, modern levelling, dam construction) processes. The obtained chronology is a limitation of this study and further determinations will be done to improve it.

2.2. Grain size analysis

Each sample was dried, weighed and wet-sieved using a sieve with a 2 mm aperture and one with a 50 µm. As such, we determined the granulometry, represented by (1) gravels (>2 mm, mainly pebbles, plant remains and mollusc shells), (2) sand (<2mm and > 50 µm) and (3) silts and clays (<50 µm). The sand texture was obtained by dry-sieving using two sieves with 500 µm and 160 µm apertures. Statistical analysis was performed using GRADISTAT (Blott 2010) and following the method proposed by Folk and Ward (1957). For the grain size distribution, we calculated the following parameters: mean grain size, sorting, and skewness.

Sediment texture was determined by using Shepard's classification (1954), which divides a ternary diagram into ten classes. This scheme shows the relative proportions of sand, silt, and clay within a sample based on the specific grain-size composition of each sample. Each sample plots as a point within or along the sides of the diagram (Fig. 9).

2.3. The Passega diagram (CM image)

As our samples are exclusively from a fluvial environment, a CM image was plotted using the methodology proposed by Passega (1957).

CM images are widely used to characterise sedimentary environments and the different modes of transport within river environments. Bravard (1983, 1986) identified deposits linked to various aqueous (active channel, banks, secondary arms) and terrestrial (banks, floodplain) environments. The technique has been used widely in addition to the Mississippi where it was first tested (Passega, 1957). In Europe, it has been used in the Rhône basin (Péiry, 1994; Bravard and Peiry, 1999; Arnaud–Fassetta, 2003; Salvador et al., 2005), the Garonne (Lescure et al., 2015); on the Danube, it has been used previously by Opreanu (2008) and Tiron (2010).

The method is based on the principle that two parameters are sufficient to identify and describe the hydro-sedimentary dynamics, and thus characterize the sedimentary environments. These parameters are the 90 percentile (C) and the 50 percentile (M), calculated on the total fraction of sediment. C represents the coarse fraction of the sediment and varies depending on the competence of current and / or river load availability. It measures the maximum competence of the current. M is the value that divides the distribution in two equal subsets and describes the average coarseness of the deposit. It best represents the characteristics (texture) of the sediment and the depositional environment (hydrodynamic energy). The values of C and M for each sample are plotted on a diagram with logarithmic scales. he values of M are reported on the X axis, while the values of C are reported on the Y axis. The CM image is formed by plotting all of the points into a cloud. They are divided into segments that correspond to specific modes of transportation and deposition:

- NO, OP and PQ segments characterise deposits related more or less to rolling;
- The QR segment defines the deposits resulting from traction currents influenced by bottom turbulence;
- The RS segment defines the deposits of uniform suspension;
- The T zone is linked to decantation in calm water (very fine suspension).

Bravard and Péiry (1999) and Arnaud-Fassetta (1998, 2003) emphasize that the position of the RS segment on the CM image depends on the turbulence of the sector: this segment can be located at different levels, on the vertical axis, depending on the variation in river power. Arnaud–Fassetta (1998) proposes dividing the RS segment, which defines the deposits of uniform suspension, into three competence levels (RS, R'S'and R''S''). On either side of the RS segment, the R'S' and R''S'' segments represent uniform suspension corresponding to the different energy levels of the flow. This subdivision was used in this paper to describe the results.

2.4. Paleoecology

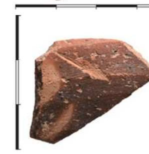
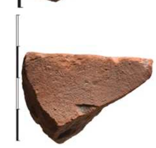
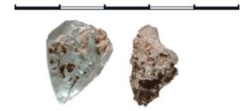
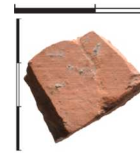
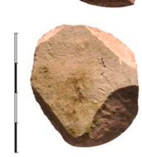
n this study, two biological proxies were used: ostracods and molluscs. Ostracods were picked from the > 160 µm fraction and identified to species level when possible, using reference manuals (Atersuch et al., 1990; Meisch, 2000) and scientific papers (Opreanu, 2005; Salel et al., 2016). Each valve was determined in most of the cases at species level, and counted. When not identified at species level, we identified the genus. When a species could not be identified, we identified the genus. For our paleoenvironmental reconstruction, we counted and used only transparent and translucid valves. The relative abundance was calculated per 10 g of sediment. Mollusks>1 mm in length were also identified and assigned to assemblages in accordance with Pope and Goto (1991), Grossu (1993), and Wesselingh et al (2019). Molluscs, which were statistically underrepresented, were used to supplement the paleoecological data derived from the ostracod analysis.

Some of the environmental parameters influencing the distribution of ostracods are salinity, depth, distance from the shoreline, vegetation and hydraulic conditions. However, ostracod distribution in rivers is strongly influenced by hydraulic and sedimentary conditions, as ostracods generally avoid high water velocities by moving inside sediments or vegetation (Rempel et al., 2000; Ruiz et al., 2013; Szlauer-Łukaszewska and Pešic, 2020). Because of its very fast flow (mean velocity at Isaccea 6400 m^3/s, https://www.ingha.ro), the Danube river at Noviodunum is not a favourbale environment for ostracod community development. In a study of the Danube valley by Kiss and Schöll (2009), an intensive growth in the ostracod population was observed in the river channel itself, while the water bodies of the floodplain offered greater species richness.

2.5. Archaeological excavation

Archaeological excavations were conducted in July 2019 to confirm the hypothesis of a harbour basin downstream. The hypothesis was developed following the bio-sedimentological analysis of the cores NOV I, III, and IV. As a result, we opened three square trenches (C001-002–003, each 4 m by 4 m by 0.50 m deep) and a section (S001, 15 m long by 2 m wide by 2.45 m deep) (Fig. 5). Section S001 is located on a terrace edge, in a floodplain depression, between cores NOV I and NOV III. The three trenches C001-3 are located on the actual beach, near core NOV IV. The MoLAS record sheets (Westman 1994) were used to document the stratigraphy and identified archaeological structures.

Table 2
Archaeological finds from the cores, used to build up the chronology together with radiocarbon ages.

Location/Core	Depth below surface (cm)	Archaeological find	Dating	Photos
Downstream/NOV I	200–210	Ceramic fragment	Roman, probably 3rd – 4th c. AD	
	250–260	Amphora handle	Roman, probably 3rd – 4th c. AD	
	250–260	Ceramics fragments	Late Roman, 4th – 6th c. AD	
Downstream/NOV III	230–240	Ceramic fragment	Roman, 2nd – 4th c. AD	
	250–260	Brick fragment	Roman, 2nd – 4th c. AD	
Downstream/NOV IV	260–270	Ceramics fragments	Roman, 2nd – 3rd c. AD	
	270–280	Ceramics fragments	Roman, 2nd – 4th c. AD	
	290–300	Glass fragments	Roman, 2nd – 3rd c. AD	
Upstream/NOV V	230–240	Amphora fragment	Late Roman, 4th – 6th c. AD	
	280–290	Amphora fragment	Late Roman, 4th – 6th c. AD	
	290–300	Amphora fragment	Late Roman, 4th – 6th c. AD	
	410–420	Amphora fragment (possible Dressel 24)	Roman, 2nd – 3rd c. AD	

(*continued on next page*)

Table 2 (*continued*)

Location/Core	Depth below surface (cm)	Archaeological find	Dating	Photos
Upstream/NOV VII	320–330	Ceramics fragments	Roman, 2nd – 4th c. AD	

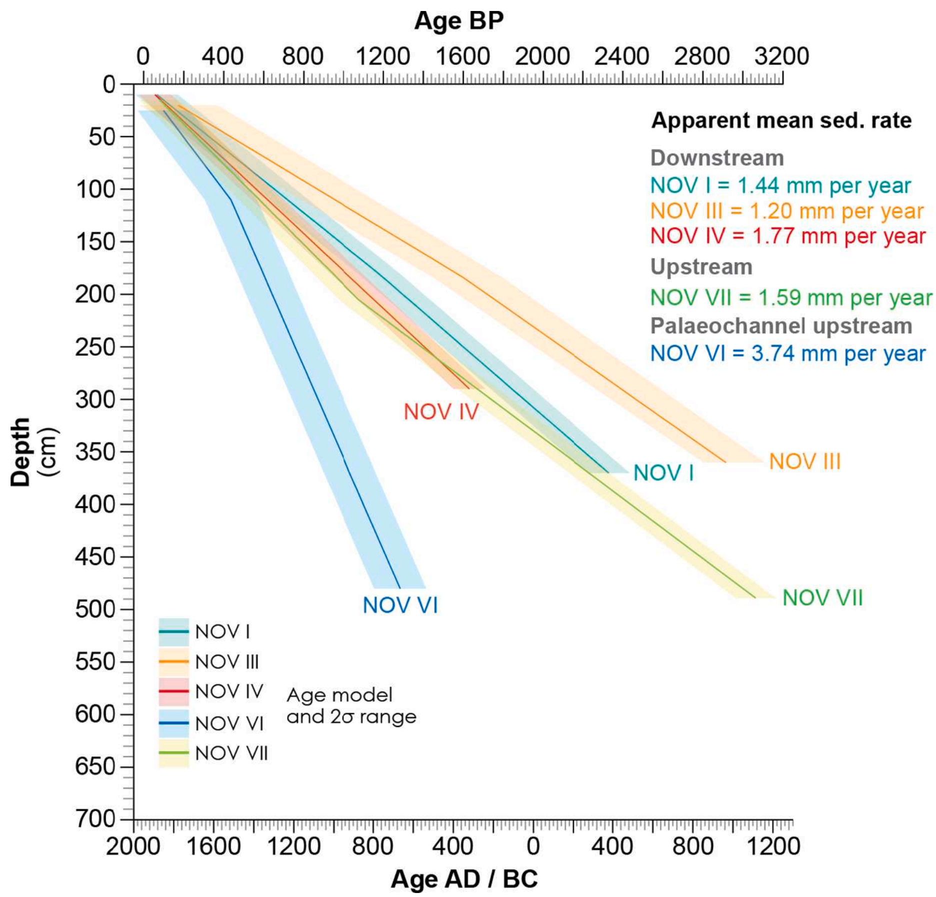


Fig. 5. Age-depth models and mean sedimentation rates of the cores. The age-depth models were obtained by using radiocarbon ages with typo-chronology.

3. Results

3.1. Chrono-stratigraphy

The upstream cores (NOV V, VI and VII) were located south-west of the promontory (Fig. 4). The substratum was not reached in any core, the deepest drilling reaching 700 cm below ground level. Compared with those cores downstream, much less archaeological material was recorded in the upstream cores. Core NOV V was located east of the actual road going to the archaeological site, on an agricultural terrace, and was 700 cm long. Core NOV VI was located in a swampy area, 130 m west of core NOV V and was 500 cm long. Core NOV VII was located 100 m south of core NOV V and was 500 cm long. The 3 downstream cores were located on an agricultural field eastward of the road going to the modern river beach (Fig. 4). This is a reclaimed land, protected by a man-made levee, as the area was flooded by the Danube. The limestone substratum was reached about 320 cm below ground level in all four cores drilled in that area. he cores form a north–south transect covering 120 m. Core NOV I is located furthest away from the contemporary channel and was 400 cm long. Core NOV III was located 90 m north of NOV I and was 400 cm long. Core NOV IV was located around 30 m north of core NOV III, on the bank of the Danube, around 100 m east of the archaeological excavations C001-C003; it was 400 cm long. The ostracods assemblages of these cores correspond to floodplain water bodies and (artificially) protected environments in connection with the main arm. In summary, the following facies were identified in the cores (Figs. 6-9, Tables 3-4):

3.2. Archaeological investigations

As a result of the coring campaign, paleoenvironmental and geoarchaeological analyses, and LiDAR imagery (Fig. 10), we proposed the hypothesis of two harbour basins, one to the east (downstream) and one to the southwest (upstream). Our hypothesis is based on a three-phase sequence that shows a natural fluvial environment being anthropologically altered, followed by the reoccurrence of a natural environment. The chrono-stratigraphy and sedimentation pattern of ancient harbours have been extensively discussed by Marriner and Morhange (2006, 2007), Marriner et al., (2015), and Morhange et al., (2016). (2015, 2016).

With the exception of core NOV VI, which registers an entirely natural sequence, we identified three phases in the other five cores: (1) fine

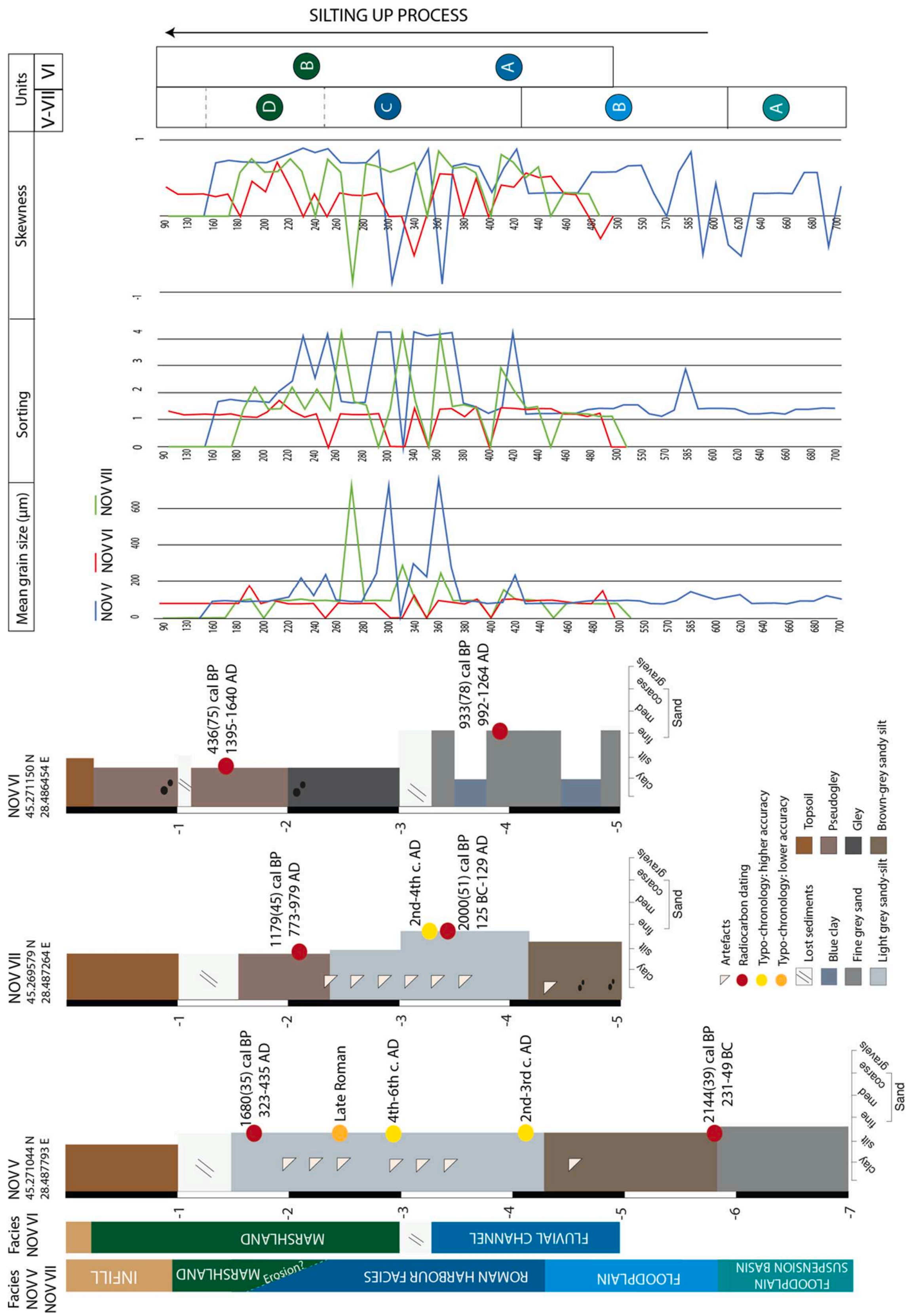


Fig. 6. Stratigraphy and interpretation of the downstream cores (NOV V, NOV VI and NOV VII).

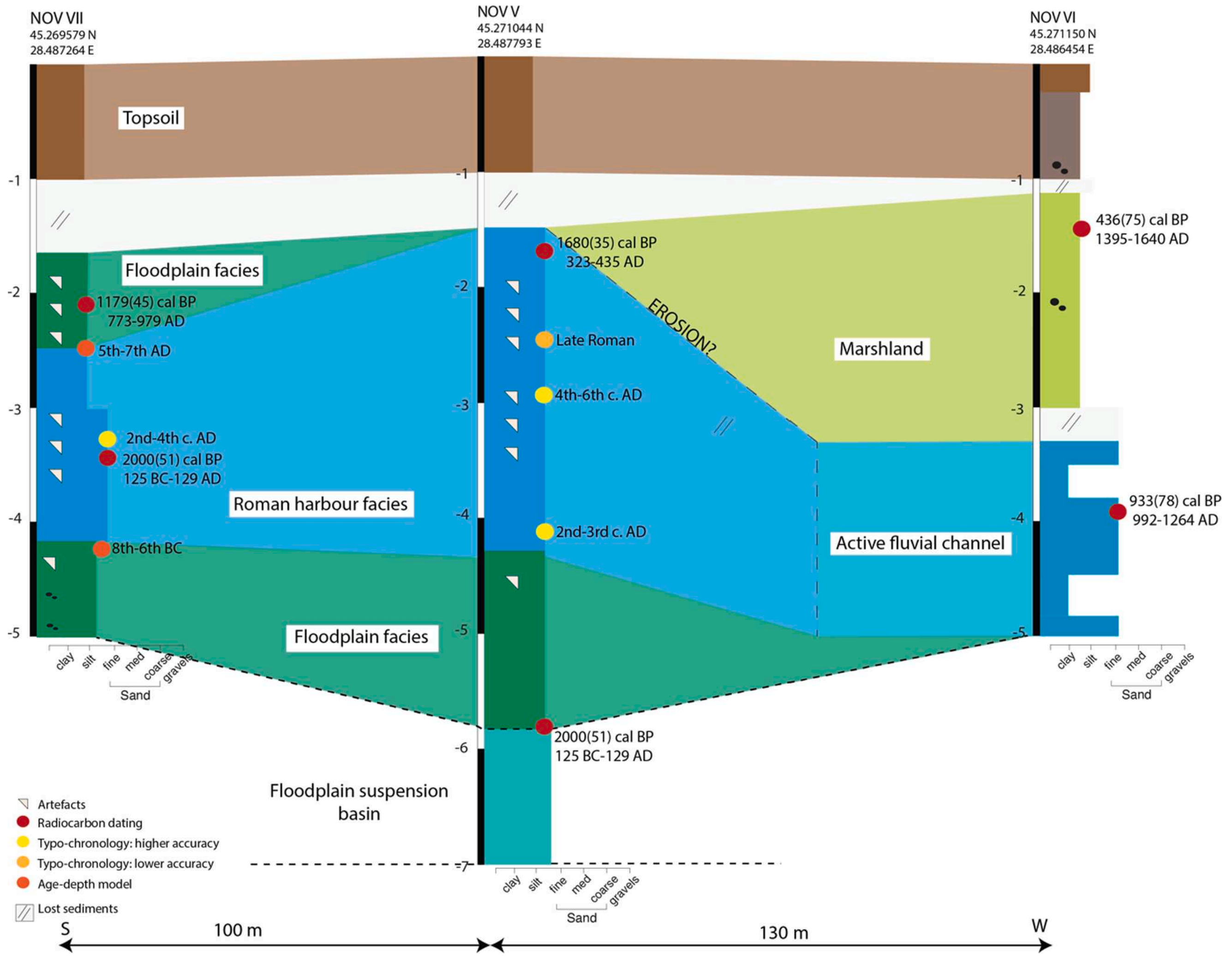


Fig. 7. Chrono-stratigraphic cross-section of the upstream area, showing sedimentary facies of cores NOV V, VI and VII, and their interpretation.

sediments, corresponding to the natural sedimentation pattern of the river or to the river-bed (pre-harbour facies); (2) anthropogenically-modified sequence, characterized by heterometric granulometry, due to the high anthropogenic input embodied by the archaeological artefacts (harbour facies) (3) terrestrial sediments (post-harbour facies).

Considering the data from the cores and the observations from a field survey (artefacts distribution on surface, traces of building structures), review of the literature, as well as the available funding and time, our research was focused on two points downstream (Fig. 11):

3.2.1. *Section S001 (Fig. 12)*

Section S001 aimed to verify the hypothesis of a port basin, which could represent the eastern limit of the extra-mural civilian settlement. It was excavated north–south between boreholes NOV I and NOV III. The section was 15 m long and × 2 m wide. It was divided into 1 × 1 m squares, numbered A-B in width (W-E) and from 1 to 15 in length (N—S). The maximum depth reached was 2.46 m below ground surface. Within the section, we delimitated 6 stratigraphic units (US) (Table 5). The first 3 units show a high disturbance of the area by contemporary and modern interventions, with a mix of artefacts from different periods (contemporary, Modern, Medieval, Byzantine, Roman). The ceramic material found in US 1004, 1005 and 1006 corresponds to three phases: 2nd – 3rd c. AD, 5th-6th c. AD and 11th-13th c. AD. The ceramic material dated 5th-6th c. AD is rarely represented, whereas material from the 2nd-3rd c. AD and 11th-13th c. AD is present in relatively equal proportion. We note the absence of ceramic material from 7th to 10th c. AD. The abundant quantity of pottery suggests an important and long-lasting activity that can be dated from 11th to 13th c. AD (Byzantine-Early Medieval). The mixing of two chronological phases and a chronological hiatus (absence of material from 7th to 10th c. AD) in this large chrono-stratigraphic level may suggest dredging works. The majority of the recovered material is pottery. Other discoveries consist in 9 coins, various metal objects (iron and bronze), fragments of Medieval glass bracelets, and three ceramic cannonballs.

3.2.2. *Section C001-3: An Early Roman edifice (Fig. 13)*

The second research location was on the present-day river bank and positioned in order to determine the functionality and chronology of a building exposed by low river levels. The investigation was carried out by opening 3 square trenches (C001-002–003). Each square trench was 4 m × 4 m. The exposures provided evidence for 18 US and four walls (Fig. 13). The walls are built of limestone, bound with earth. Traces of mortar have been also discovered. It is unclear whether the discovered walls are part of the same structure. While the walls in C002 and C003 are linked together, a clear relationship could not be established with those in C001 and from the C001 / C002 berm. Furthermore, the walls in C002 and C003 appear to have been built in a much more robust manner, with large and medium-sized stones, as opposed to those in C001, which feature smaller stones. As with S001, the majority of the recovered material is ceramic. Following a preliminary examination, we observed that all specific functional categories are present (transport containers, table ware and kitchen ware). Among the types of amphorae,

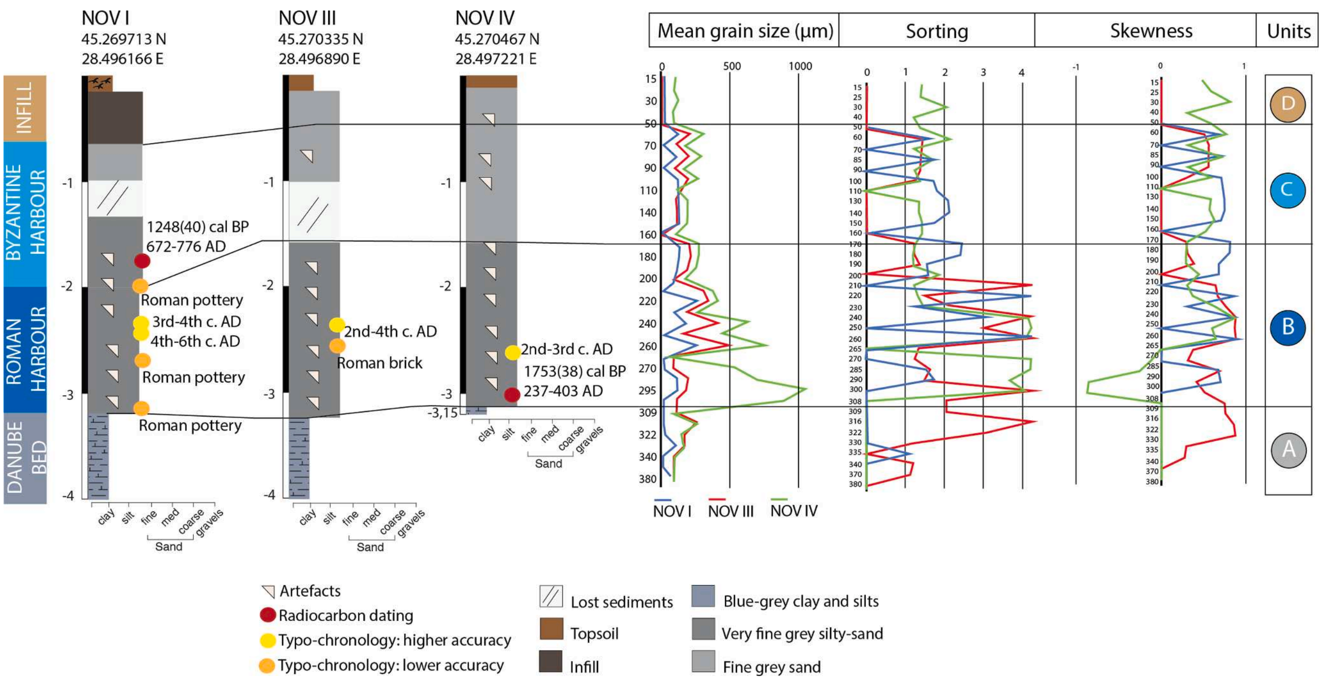


Fig. 8. Stratigraphy and interpretation of downstream cores (NOV I, NOV III and NOV IV).

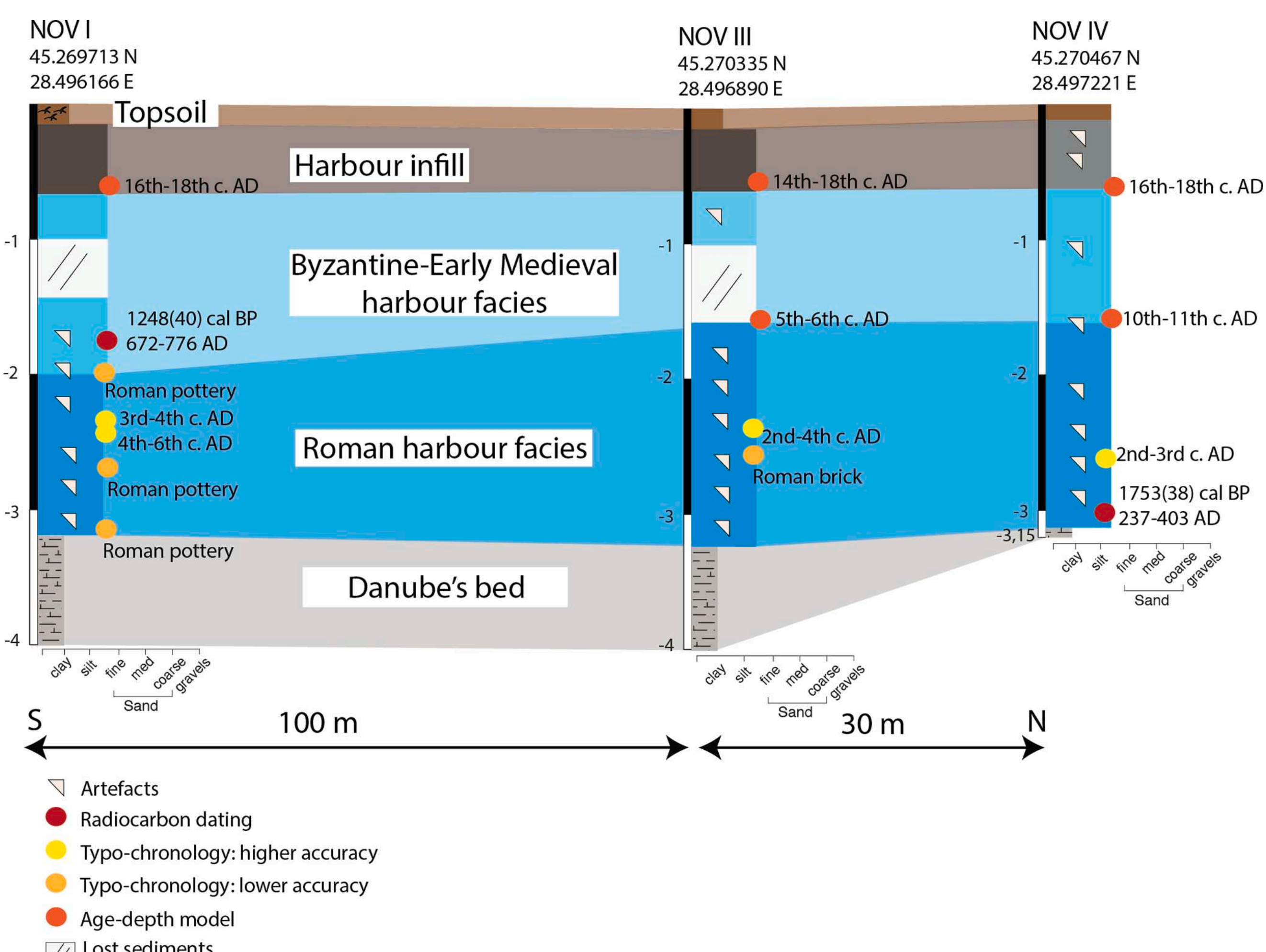


Fig. 9. Chrono-stratigraphic cross-section of the downstream area, showing sedimentary facies of cores NOV I, II and III, and their interpretation.

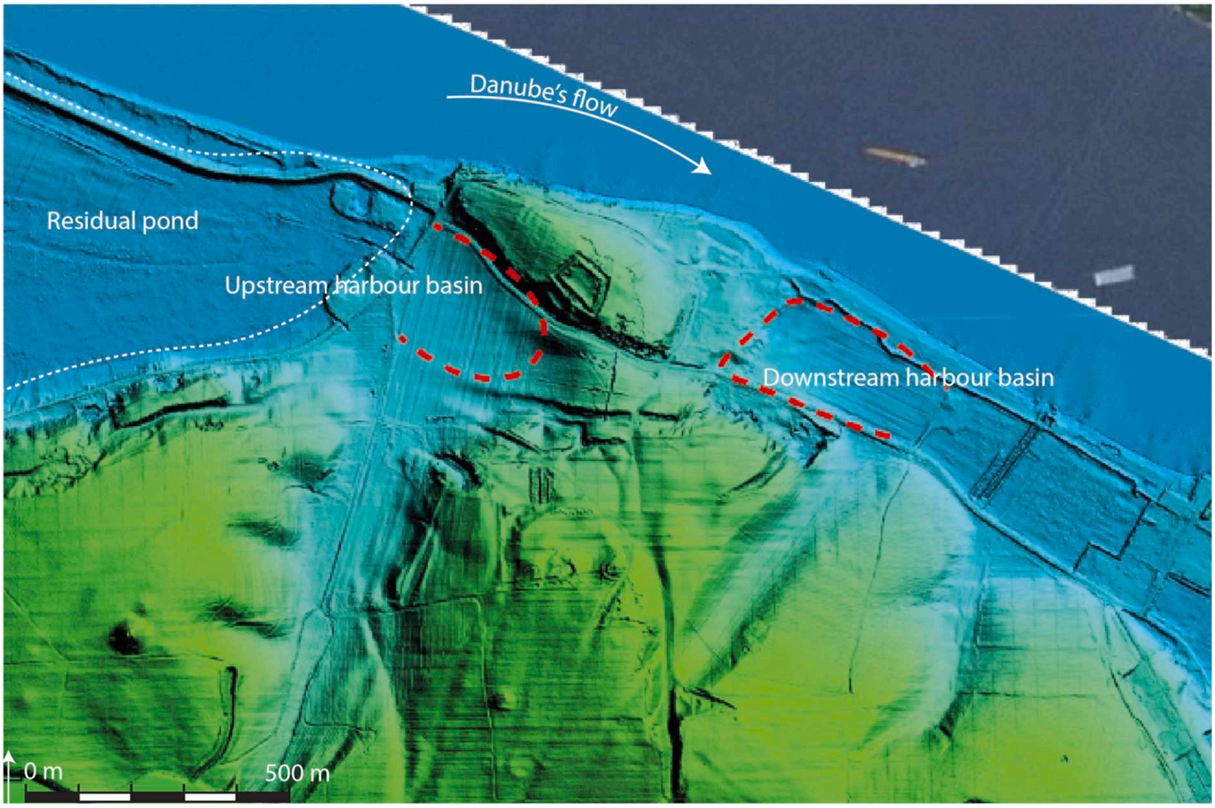


Fig. 10. LiDAR image showing two natural depressions SW and E corresponding to the two harbour basins identified through coring and palaeoenvironmental analysis. (Source of the LiDAR: https://www.ddni.ro).

the presence of the Šelov C shape is noticeable, and for table ceramics, the shapes imported from the micro-Asian space (ESC and BSE) predominate, doubled by numerous ceramic fragments specific to the Pontic space. We note, however, the presence in large numbers of so-called censers (*thuribula*), ceramic category related to the presence of Roman troops (Radu 2014). From a chronological point of view, the ceramic material can be dated between the second half of the 1st century CE and the middle of the 3rd century.

At least two occupational moments were observed: (1) one of abandonment / fire, corresponding to the level of burnt mortar, ashes, collapsed stones, and bricks fallen on the edge (C001), and (2) one of levelling, characterised by a yellow, compact clay covering this level of debris.

At this point in the investigation, the relationship between the building(s) and the harbour basin is unclear. It does, however, provide an important indication regarding the shoreline position between the second half of the 1st c. AD and the middle of the 3rd c. AD.

4. Discussion

4.1. Past fluvial dynamics

Understanding fluvial dynamics is critical to developing models of valley floor evolution and the nature of archaeological activity and preservation. These dynamic and physiochemical processes affect the taphonomy of the biological remains (here ostracod assemblages, Kaandorp et al., 2005; Higuti et al., 2007; Gross et al., 2013) and sedimentological characteristics (mean grain size, sorting, skewness, CM image). The distinction between river and fluvial harbour sediments is less clear than the distinction between sea and marine harbour sediments (Tronchère et al., 2012). However, the alteration of the natural environment through the building of basins and other works (e.g. dredging) results in a slowing down and reworking of the deposits (Skafel and Krishnappan, 1998). The apparent mean sedimentation rates at Noviodunum are a good example of anthropogenic alteration of the fluvial environment. An apparent mean sedimentation rate of 1.20 mm/yr-1.77 mm/yr was calculated for the downstream basin and of 1.59 mm/yr for the upstream basin, while the sedimentation rate in the upstream paleo-channel is 3.74 mm/yr (Fig. 5). This paradox of apparent mean sedimentation rates of low accumulation in a protected environment most likely indicates dredging operations.

The mean grain size (M_G) indicates the average competence of aqueous flux – the level of energy. When measuring grain size and calculating data, the archaeological material was not excluded. Because artefact fragments were observed at a micro-level, we consider them to be a component part of the sediment sample, despite the fact that they are anthropogenic. The samples which show an elevated value of M_G (>1000 μm) contain in fact archaeological remains and their positioning on the CM image on the NO segment ($D_{99} > 1000$ μm) is not an indicator for a rolling current corresponding to a channel bedload deposit (i.e. primarily gravels, Tiron 2010).

Furthermore, in accordance with Tiron's granulometric results on the present-day base of the cut-banks of the Saint-George arm (Tiron 2010), the sole core where we did not record artefact fragments (NOV VI) does not indicate a value higher than 200 μm of M_G. As such, the CM image indicates that the site was positioned on a cut-bank also in the past. In our investigation, the CM image illustrates the intensity of anthropogenic influences (Fig. 14).

As can be seen in the Figs. 5-6, the smallest registered M_G is 75 μm. The samples, when plotted on a Shepard ternary diagram, fall into two granulometric categories: silt and sandy silt. These are generally associated with low to medium energy levels. The amount of fine sand in our cores is associated with an increase in fluvial energy and/or flood conditions. for the majority of its length, the riverbed of the Danube is characterized by coarse sand and gravel that transition laterally into finer sediments consisting of silty sand or sandy silt. Finer sediments

Table 3
The main chrono-stratigraphic units identified in the upstream cores, as well as their interpretation. The chronology is based on radiocarbon dating (Table 1), typo-chronology (Table 2) and the age-depth model (Fig. 5).

Facies	Unit/ Core	Depth (cm b.s.)	Chronology	Sediment description	Biotic components	Archaeological finds	Interpretation
1	A/ NOV V	585–700	Before 2144 ± 39 cal BP (231–49 BC)	Fine grey sand interbedded with silty-sand, (76 μm < M_G < 120 μm), moderately sorted (σ_1 = 1), positive skewness (Sk_1 = 0,11).	Molluscs (*Litoglyphus naticoides*). Ostracods (*Candona neglecta, Candona neglecta* juvenile, *Pseudocandona* cf. *albicans, Ilyocypris* spp, *Heterocypris salina, Physocypria kraepellini, Potamocypris* sp.)	N/A	Floodplain suspension basin.
2	A/ NOV VI	280–500	Before 933 ± 78 cal BP (992–1264 CE)	Fine grey sand interbedded with blue clay laminae, (75 μm < M_G < 145 μm) moderately sorted (σ_1 = 1), positive skewness (Sk_1 = 0,25).	N/A	N/A	Active fluvial channel.
3	B/ NOV V; A/ NOV VII	420–585; 420–500	Base dated 2144 ± 39 cal BP (231–49 BC), top dated 2nd – 3rd c. AD (amphora fragment)	Brown-grey sandy-silt (75 μm < MG < 90 μm), well to moderately sorted (σ1 = 1 to 1.9), very positive to positive skewness (Sk1 = 0,513 to 0,291)	N/A	N/A	Floodplain
4	C/ NOV V; B/ NOV VII	150–420; 250–420	Lower part dated 2000 ± 51 cal BP (125 BCE-129 CE), top dated 1680 ± 35 cal BP (323–435 CE), throughout its extension 2nd- 6th c. AD (ceramic material)	Light grey heterogenous sandy silt (77 μm < MG < 759 μm), poorly sorted (σ1 = 2), very positive skewness (Sk1 = 0,681).	N/A	Ceramics and bones fragments.	Roman harbour facies.
5	C/ NOV VII	165–250	Lower part dated 1179 ± 45 cal BP (773–979 CE)	Pseudogley, followed by a 50 cm thick dark grey clayey silt sequence, succeeded by a brown silt (88 μm < MG < 100 μm), moderately well-sorted (σ1 = 1,9), high positive skewness (Sk1 = 0,513).	N/A	Few ceramics and bones fragments, probably a mortar fragment and an unidentified lead object.	Floodplain facies after harbour abandonment.
6	B/ NOV VI	30–280	Base dated 933 ± 78 cal BP (992–1264 CE), 436 ± 75 (1395–1640 CE) at 110–120 cm.	Grey gley and pseudogley (MG = 77 μm), very moderately sorted (σ1 = 1), positively skewed (Sk1 = 0,298).	Molluscs (*Litoglyphus naticoides, Esperiana daudebardii Theodoxius danubialis*). Ostracods (*Candona neglecta, Candona* sp., *Pseudocandona* cf. *albicans, Ilyocypris* spp, *Cyprideis torosa, Limnocythere inopinata, Heterocypris salina*). This sequence recorded the most abundant ostracod fauna from all cores, with a maximum of 100.000 valves/10 g	N/A	Marshland. The gley formation is related to groundwater fluctuations, while the strong mottling (pseudogley) is associated with stagnating waters (PiPujol and Buurman, 1994).

richer in silt and clay crop out along the lateral banks (Opreanu 2008). After the 167 km point downstream to its confluence with the Black Sea the riverbed is characterised by medium and fine sands that replace the gravel fraction (Oaie et al., 2005; Opreanu 2008). This sedimentary composition characterises the riverbed at Noviodunum.

Except for some samples from core NOV VI, most of the samples plot on the CM image on the R'S' segment. This segment corresponds to the uniform suspension under energetic conditions (Arnaud-Fassetta, 1998), with grains transported in graduated suspension during flood events. The samples from NOV VI regrouped around the QR segment correspond to gradual suspension. This indicates a decrease in energy corresponding to a depositional environment indicative of a slow-flowing secondary channel and low dynamics. The lack of archaeological material from this core suggest a distal position of the harbour basin.

The sorting index provides us with indications of energy and transportation mode. Good sorting is generally associated with regular flows whereas poor sorting indicates more irregular flow and the bulk deposition of sediment particles (Folk and Ward, 1954; Friedman 1967; Gasparini et al., 1999).

The poor sorting shows the predominance of moderate to low dynamics (Opreanu et al., 2007; Tiron 2010). The poor sorting of the sediments at Noviodunum can also be attributed to the mixture of different sediment sources as well as the presence of artefact fragments. The poorly sorted sediments were deposited relatively close to the source area. The moderately sorted sequences at Noviodunum correspond to flow within active channels.

Only positive and very positive skewness was observed in our samples, which is typical of fluvial environments (Aranud-Fasseta 1998; Opreanu 2008; Tiron 2010). The very positive skewness suggests lower water velocity and the positive skewness low to medium energy. These characteristics are typical for the zone near river banks or secondary channels (Arnaud-Fasseta 1998; Opreanu 2008; Tiron 2010). The cores from Noviodunum show rather a protected environment, with low energy allowing for the accumulation of fine particles. The basal units

Table 4
The main chrono-stratigraphic units identified in the downstream cores, as well as their interpretation. The chronology is based on radiocarbon dating (Table 1), typo-chronology (Table 2) and the age-depth model (Fig. 5).

Facies	Unit/ Core	Depth (cm b.s.)	Chronology	Sediment description	Biotic components	Archaeological finds	Interpretation
1	A/ NOV I; A/ NOV III; A/ NOV IV	325–400; 322–400; 300–320	Pliocene	Very fine blue-grey clay and silts	N/A	N/A	Pliocene substratum (Danube bed)
2	B/ NOV I; B/ NOV III; B/ NOV IV	200–325; 170–322; 170–300	Base dated at 1753 ± 38 cal BP (237–403 CE), top dated 1680 ± 35 cal BP (323–435 CE), throughout its extent 3rd – 6th c. AD (ceramics and glass fragments).	Very fine grey silty-sand with ceramic and charcoal fragments (77 μm < MG < 873 μm), poorly to very poorly sorted (σ1 = 3) and positively skewed (Sk1 = 0,4). Variations in MG are attributable to the archaeoclasts.	Molluscs (*Litoglyphus naticoides, Viviparus* sp., *Dreissena polymorpha, Theodoxius danubialis, Esperiana daudebardii*). Ostracods (*Candona* sp., *Pseudocandona* cf. *albicans, Pseudocandona* sp., *Ilyocypris* spp, *Limnocythere inopinata, Candona neglecta* juvenile,)	Ceramics, bones and glass fragments; one adobe/ brick fragment, a head of an iron nail, mortar and a bronze coin (poorly preserved)	Roman harbour facies.
3	C/ NOV I; C/ NOV III; C/ NOV IV	50–200; 50–170; 50–170	After 1248 ± 40 cal BP (672–776 CE), 5th-6th c. AD and 10th –11th c. AD based on the age-depth model.	Very fine grey sand (76 μm < MG < 309 μm), well to very poorly sorted (σ1 = 1,2 to 2,4), strongly positively skewed (Sk1 = 0,59). Variations in MG are attributable to the archaeoclasts.	Molluscs (*Lithoglyphus naticoides*). Ostracods (*Pseudocandona* cf. *albicans, Candona neglecta* juvenile, *Ilyocypris* spp, *Heterocypris salina*)	Ceramics and bones fragments, charcoal.	Byzantine-Early Medieval harbour facies.
4	D/ NOV I; D/ NOV III; D/ NOV IV	20–50	14th – 18th c. AD based on the age-depth model.	Brown-grey silty sand, with *Typha* roots and other plant remains.	N/A	N/A	Harbour infill (?)

exhibit good sorting and positive skewness, indicating that the substratum is the primary sediment source (Pliocene grey clay). The poorly sorted silty sands with a very positive skewness registered in the upstream area indicate a low energy environment which may indicate a sheltered environment, potentially a harbour basin.

4.2. The harbours location in the Roman period

The chronostratigraphic data allow us to draw some conclusions on river dynamics and on possible harbour basins locations. The limestone promontory on which Noviodunum lies has created localised disturbance of river flow, leading to increased turbulence and spatial variability of velocities and energy. Deciphering the palaeodynamics of the river and locating the harbours must be done through a comparative approach between the upstream and downstream depressions on both sides of the promontory. It is unlikely that a port facility would be located directly in front of the fortress, as proposed by Barnea et al. (1957). Firstly, Noviodunum is located on a cut-bank. The currents are stronger on a cut-bank and the rates of erosion higher, thus making the northern edge of the promontory an unstable and too energetic setting for a harbour. Strong river currents impacted Noviodunum throughout its history, as demonstrated by an increase in fluvial discharge during the late Holocene (Giosan et al., 2012). Most probably, the late Holocene hydrological regime of the Danube was similar to that of the present day, as seasonal precipitation patterns are similar to those of the Little Ice Age (McCarney-Castle et al., 2011).

4.2.1. Upstream (SW basin)

Core NOV VI shows that as late as the 13th century CE, a secondary channel was flowing west of the city. For comparison, the sediments deposited in the Holocene channels of the Tiber delta also show intercalations of clay and silt, associated with periods of relative hydrological calm (Salomon 2013). The ostracods are often absent in this type of dynamic environment (Claret et al., 2007; Salel 2018). The formation of a secondary channel might be related to the existence of a sand island upstream, as shown by present-day records and historical sources. A sand island is forming continuously in front of the modern town of Isaccea, but it is dredged to maintain the river navigable. Furthermore, a sand island appears on an accurate map created by Capitan Spratt in 1857, and even earlier, on a military map from 1783 describing the expeditions of General Weismann in 1771. This type of depositional feature can provide natural protection for a harbour basin (Fig. 15). The existence of a protective sandy island upstream supports our paleoenvironmental interpretation of a possible secondary channel flowing north-west of the fortress.

Based on the ostracod assemblage, the environment changed into marshland after the 13th c. AD. As the secondary canal silted up, the harbour would have been abandoned. A movement of population from Noviodunum to Isaccea is documented in historical and archaeological records during the 13th c. AD (Stănică 2016). Although the demise of the harbour cannot be the sole reason for such a movement, the contemporaneity of the events might indicate a correlation between the two.

A low-energy channel flowing upstream of the civilian settlement represented an opportunity to construct a harbour basin in the south-

Fig. 11. Aerial view of the site and the position of the archaeological excavations.

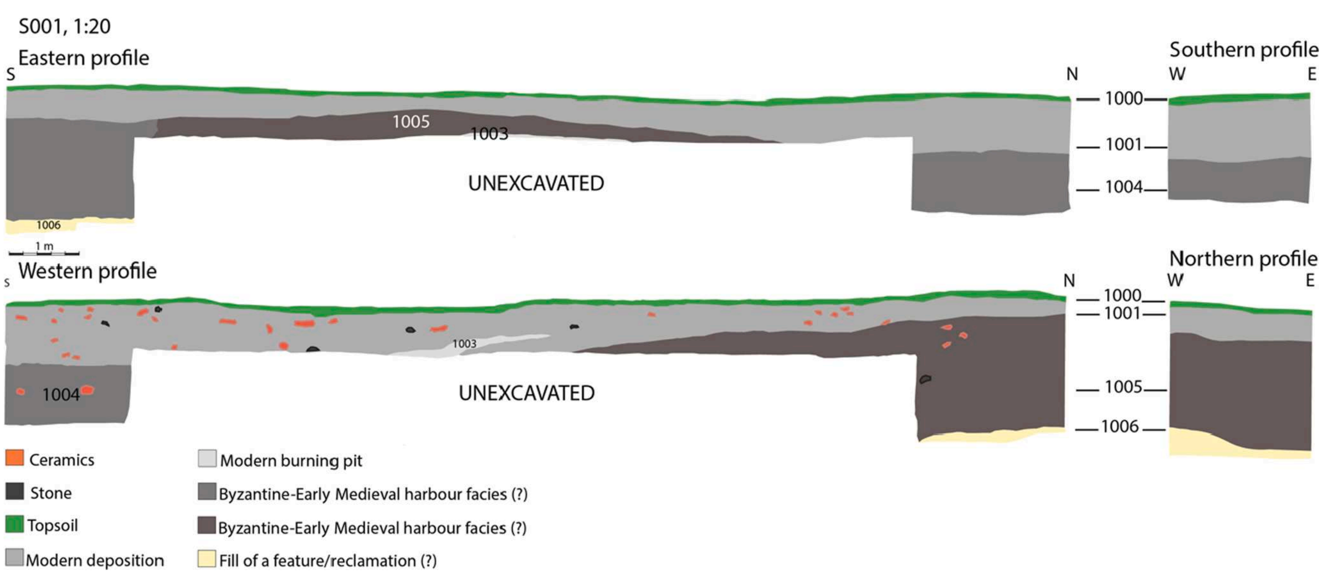


Fig. 12. Stratigraphic profiles of S001, excavated in the downstream harbour basin. The grey, compacted silty sand correspond to the post-Roman harbour facies of downstream cores.

west part of the promontory. Besides, the topographical depression observed on LiDAR image (Fig. 10) represents an advantage for positioning the harbour in this area. Furthermore, the cores NOV V and NOV VII are composed of a silty matrix containing a significant amount of archaeological material, which would seem to suggest a harbour basin facies. A typical harbour sequence was described in detail by Marriner and Morhange (2006, 2007) and Marriner et al., (2015), Morhange et al., (2015, 2016). Three poorly sorted fractions are characteristic of a harbour facies: 1. human waste products corresponding to a dump site; 2. poorly sorted sand; 3. an important fraction of silt indicating a protected environment (Marriner and Morhange, 2007; Marriner et al., 2015). Except for core NOV VI, all of these characteristics were observed in both cores upstream and downstream. We can thus presume the existence of two harbour basins, which correspond to the two low-lying features observed on the LiDAR image (Fig. 10). The existence of a harbour basin in the western area was already postulated by Lockyear et al., (2008) and Fiederling et al., (2017). This hypothesis may be strengthened by our findings. According to the radiocarbon age-depth

Table 5
Synthetic presentations of the 6 US excavated in the S001. The US were dated and interpreted based on the primary analysis of the archaeological material.

US	Depth/ Extension	SEDiment description	Dating	Interpretation
1000	−0.21 m/- 0.31 *m*	Brown topsoil with roots	Recent	Topsoil
1001	−0.31 m/- 0.75 *m*	Light grey heterogenous clayey silt	Recent	Modern deposition
1002	−0.75 m/- 0.86 *m*	Brown-grey heterogenous silty sand	Modern	Modern deposition
1003	−0.86 m/- 1.18 *m*	Ash, loose, grey-white	Modern	Burning pit
1004	−1.27 m/- 2.13 *m*	Homogenous greyish silty-sand	2nd – 3rd c. AD 5th-6th c. AD 11th-13th c. AD	Byzantine-Early Medieval harbour facies (?)
1005	−0.80 m/- 2.42 *m*	Homogenous greyish silty-sand	2nd – 3rd c. AD 5th-6th c. AD 11th-13th c. AD	Byzantine-Early Medieval harbour facies (?)
1006	−2.00 m/- 2.46 *m*	Compacted yellow sandy silt	2nd – 3rd c. AD 5th-6th c. AD 11th-13th c. AD	Fill of a feature/ reclamation?

model, the upstream harbour sequence appears during the 1st century CE, corresponding to the deployment of the imperial fleet at Noviodunum. A harbour basin located south-west of the promontory provides various strategic advantages. The military ships would have been the primary assets in need of defence at any harbour that would have served as the headquarters for the *Classis Flavia Moesica*. A south-west basin would have been protected to the north–north-east by the promontory and to the south by the first earth *vallum*. Because the Danube freezes over during the winter in general, barbarian populations could easily cross the river to mount an attack, therefore the ships had to be kept in an area where access could be easily controlled.

The harbour was only one point in the communication network, in direct connection with the terrestrial routes. Some roads were identified by Ştefan (1973) through the interpretation of aerial photographs. Their trajectory seems to articulate with the presumed position of the harbours (Fig. 16). First, a Roman road was identified running south-west, parallel to the shore of what was still a residual pond in the 1970 s. Another road enters the city through the south-west valley, where it can no longer be traced in the contemporary landscape. As the road has not been excavated, we don't know if it was preserved in this sector or if it stops intentionally due to the presence of a harbour basin. Supposedly, another road existed on the right bank of the pond located west of the site, and is overlain today by the modern one leading from the fortress to Isaccea.

4.2.2. Downstream (Eastern basin)

Downstream, the setting is naturally protected by the promontory. In a 120-meter-long north–south transect, the riverbed was reached at 312 cm / 315 cm in all three cores. The most recent radiocarbon measurements of the contact zone between the substratum and the units that overlap it show just 3 m of sediment deposit since roughly 200 CE. This indicate that strong erosional processes or dredging operations might have affected the downstream area.

A homogenous grey silt full of archaeological material (ceramics, metal, charcoal), mostly river-rolled, was identified in the core drilled on the river bank (NOV IV). This unit shows the poorest sorting from all cores, indicating a low-energy flow. The substantial amount of archaeological material is the footprint of important commercial and military activity in the area since 3rd c. AD. This unit may be interpreted as a harbour facies. The chronology of the Early Roman structures discovered in the excavation on the present-day riverbank corresponds to the radiocarbon dating of the unit B of the core NOV IV (located around 100 m west), which is interpreted as the Roman harbour sequence. As neither the extent of the basin nor of the building is known, we cannot establish a functional liaison yet between the harbour and the building, despite their proximity and their contemporaneity.

The two cores located more inland (NOV I and NOV III) show a sequence that suggests siltation in a harbour basin environment. The deposits are fine-grained (75 µm < M_G < 115 µm), poorly sorted, with a very positive skewness which indicates of low energy. Trench S001, excavated in the area between cores NOV I and NOV III, shows significant use of the area, since archaeological material is abundant and consistently found from surface to 2 m below the surface. The US are composed of a layer of compact grey sandy-silt that is rich in archaeological material (mostly pottery), has a low degree of fragmentation compared to the one recovered from the US above, and is

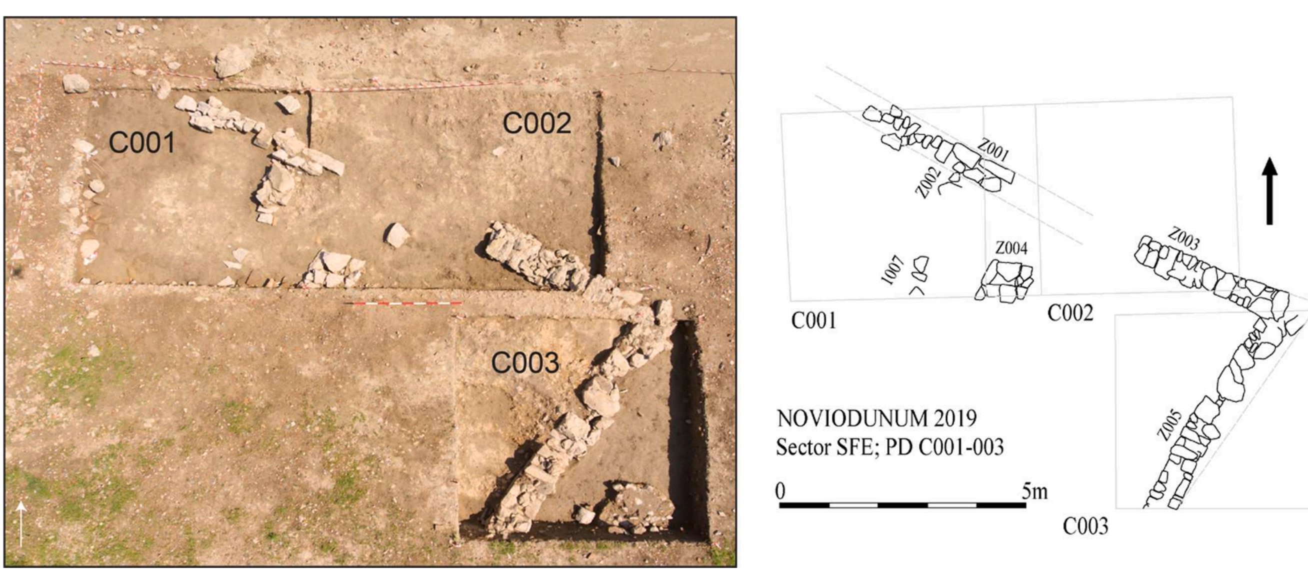


Fig. 13. Aerial view of C001-3 (left) and the detailed plan (right).

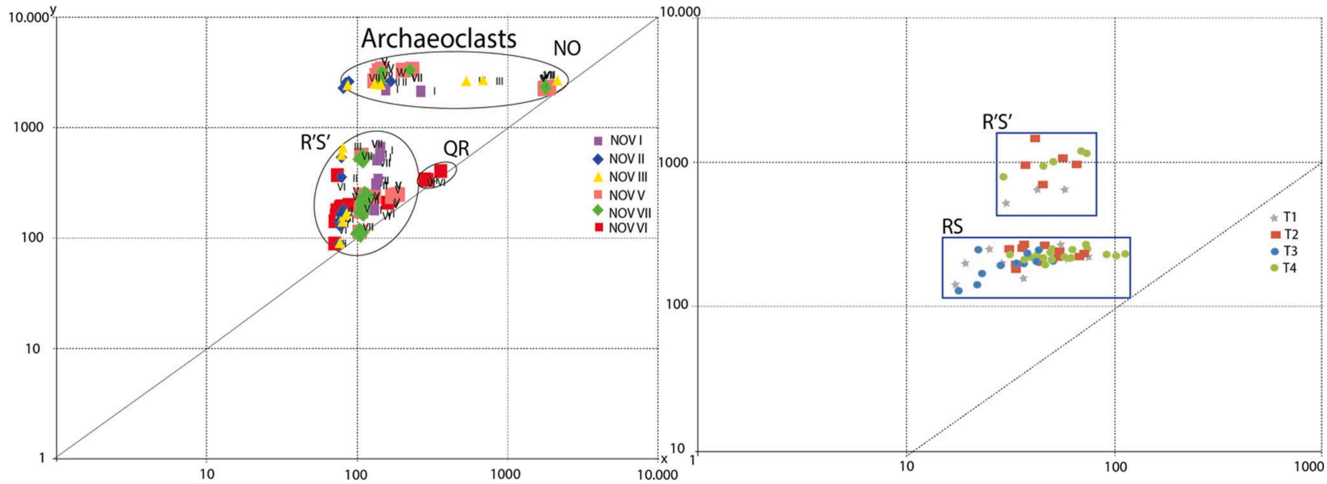


Fig. 14. Left – CM image for the all of the cores. The samples plotted on the NO segment are artefacts fragments. Core NOV VI plots only on the R'S' and QR segments, thereby indicating lower energy conditions. Right – CM image of present-day St. George' types (T) of banks: T1- rectilinear sector; T2 – confluence/ bifurcation and apex of meanders; T3 – meander cutoff and external side of banks; T4 –cut-banks meanders. (modified after Tiron 2010).

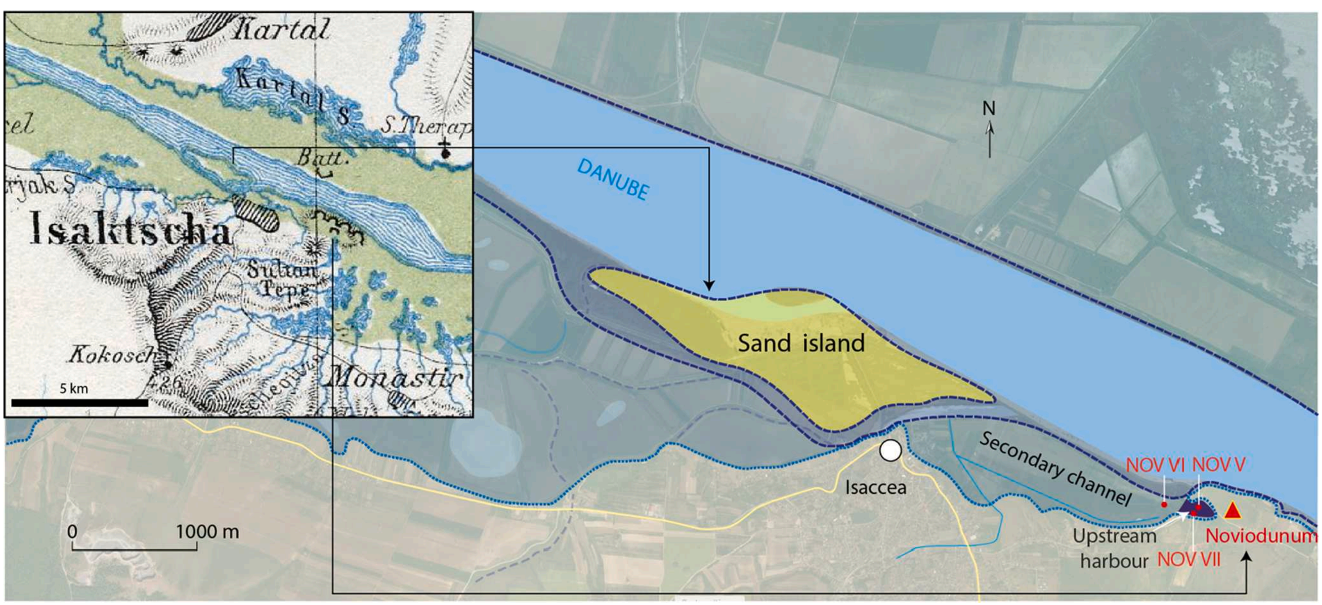


Fig. 15. The position of the sand island according to Spratt (1857), superposed over a Google Earth image. (Credit: P. Pentsch).

chronologically heterogeneous. Potshards from different periods (2nd – 3rd c. AD, 11th – 13th c. AD) were discovered in the same stratigraphic units (US 1004–1006), which could indicate that the space was used as a waste depocenter, as is common in harbour basins (Marriner et al., 2015; Morhange et al., 2015, 2016), or that erosion processes impacted the site during or after the 13th c AD. The excavated US 1004–1006 correspond to potential port facies identified in downstream cores, radiocarbon dated after 5th-7th c. AD and typo-chronologically in between 11th – 13th c. AD.

We hypothesize the existence of a harbour basin downstream with two functioning phases: from the 2nd to the 4th c. AD, in the Early Roman period, when the fleet is based at Noviodunum, and from the 11th to the 13th c. AD, in the Byzantine-Early Medieval period, contemporary with a flourishing period at Noviodunum, despite political turmoil caused by migratory populations (Baumann 2010). The absence of harbour basin sediments dated in the Late Roman period (after the 4th century CE) can be attributed to either Byzantine occupation (levelling, dredging?) or to strong erosional processes.

5. Conclusions

Our research may suggest that Noviodunum may have had one protected harbour basin upstream and another one downstream, in the eastern area, from the 1st century CE until at least the 5th century CE. Their suggested location seems to be integrated in the communication network and the defensive system of the fortress (Fig. 17).

The role of Noviodunum as headquarters of the imperial fleet *Classis Flavia Moesica* during the Roman period implies a major importance of the harbours in the life of the fortress. The integration of the harbours in the urban fabric reflects the political, military and commercial purposes and must be analysed in its fluvial context. Both downstream and upstream depressions may be suitable for harbour activities. The upstream harbour would have been sheltered by the promontory to the *N*-NE and by the first earth vallum to the south, making it less vulnerable in front of eventual attacks. A secondary channel running upstream, most likely formed by the appearance of a sandy island, remained active until at least the 10th – 13th c. AD. In the Byzantine period, the flowing channel converges with the hypothesis of an existent port and a squadron of the

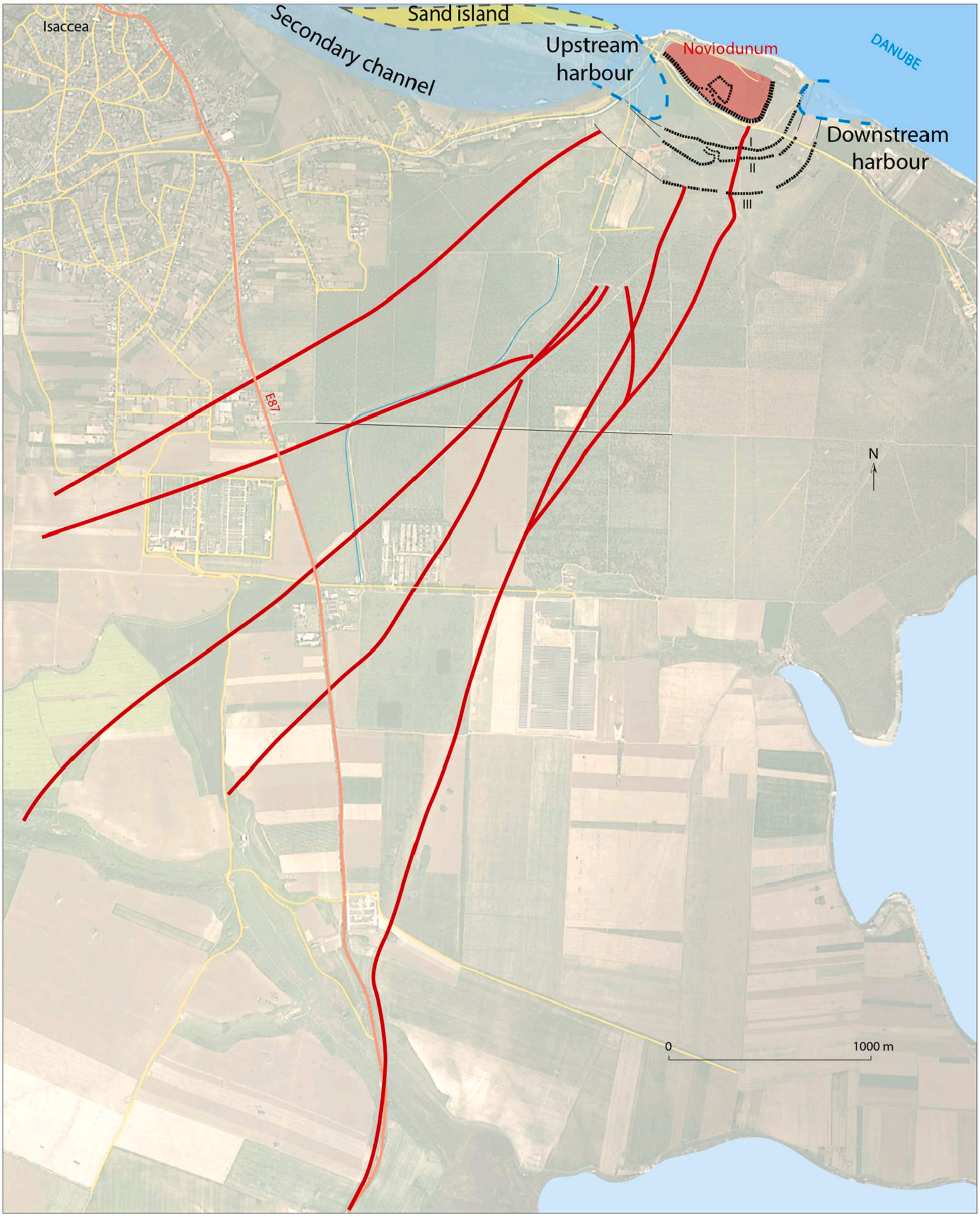


Fig. 16. The position of harbours and the presumed terrestrial routes (in red) identified on aerial photos coming from the territory (Ştefan, 1973). In black dotted lines, the Late Roman fortifications. (Credit: P. Pentsch).

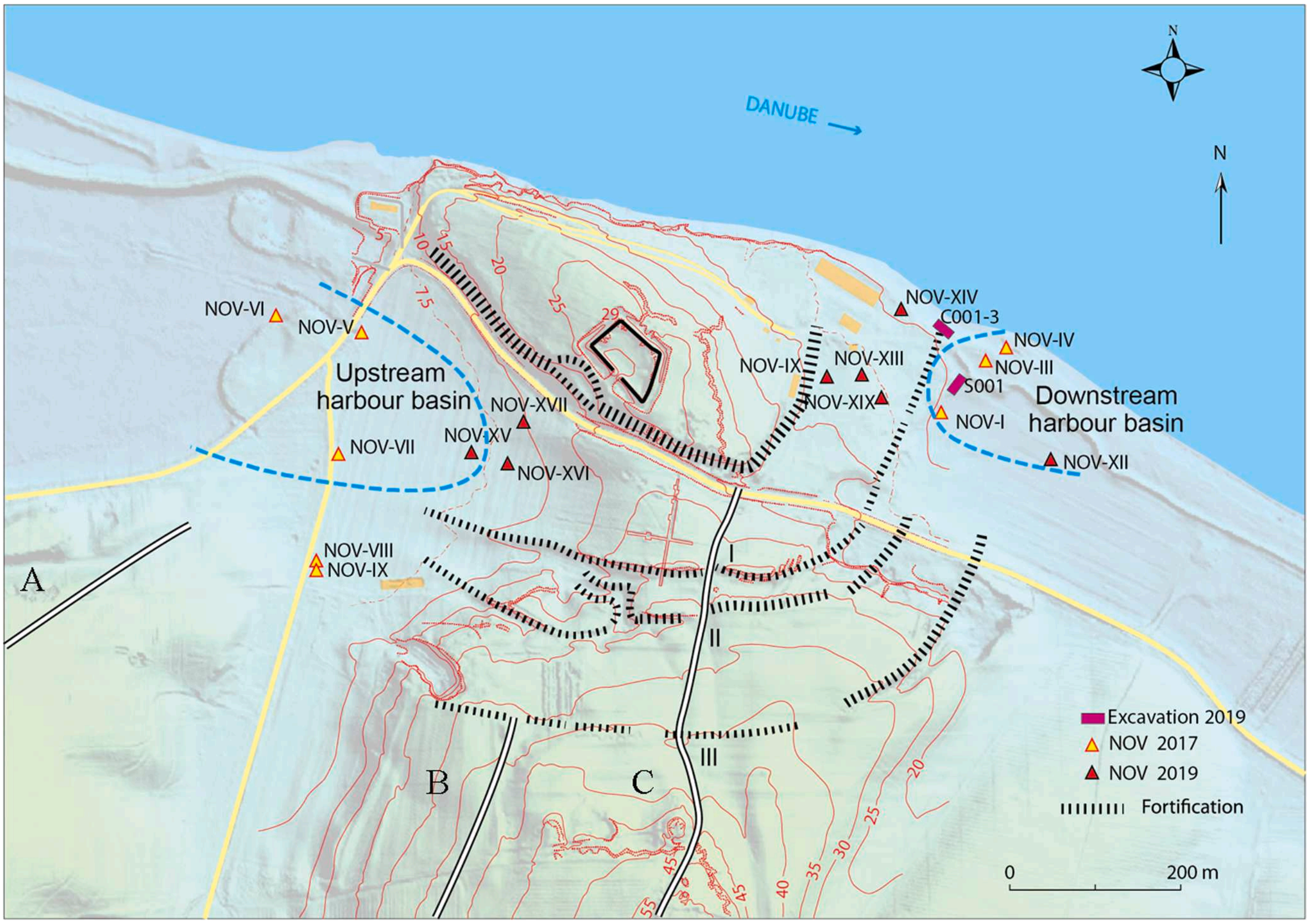


Fig. 17. Possible location of the harbours in the urban fabric. With blue dashed line, the possible extension of the basins; the three earth ramparts, in black dotted line; the routes (A-C) identified on aerial photos by Ştefan (1973), in white lines with black contour. In black line, the Turkish fortress (Credit: P. Pentsch).

Byzantine fleet in Noviodunum. Downstream, the harbour would have been protected by the promontory. The downstream sequences present the same chronological and sedimentological characteristics as upstream. During the Late Byzantine-Early Medieval period, the two probable harbour basins were completely silted up. The transfer of power sometime during the 14th century from Noviodunum to Isaccea was most probably the result of a concatenation of political, military and environmental events.

CRediT authorship contribution statement

Alexandra Bivolaru: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft. **Christophe Morhange:** Methodology, Validation, Supervision, Funding acquisition. **Aurel Daniel Stănică:** Investigation, Resources. **Tiberiu Sava:** Formal analysis, Resources. **Daniela Pascal:** Formal analysis, Investigation, Resources. **Marian Mocanu:** Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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