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Navigable canals in deltaic environments during the Roman period: deciphering location patterns

Ferréol Salomon, Corinne Rousse

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Ferréol Salomon, Corinne Rousse. Navigable canals in deltaic environments during the Roman period: deciphering location patterns. A. Lasheras; J. Ruiz de Arbulo; P. Terrado Ortuño. Ports Romans. Arqueologia dels sistemes portuaris. Actes V Congrés Internacional d'Arqueologia i Món Antic Tarraco Biennal, 24-27/11/2021, Institut Català d'Arqueologia Clàssica; Universitat Rovira i Virgili, pp.173-195, 2022, 978-84-125214-1-2. hal-03869453

HAL Id: hal-03869453

<https://hal.science/hal-03869453>

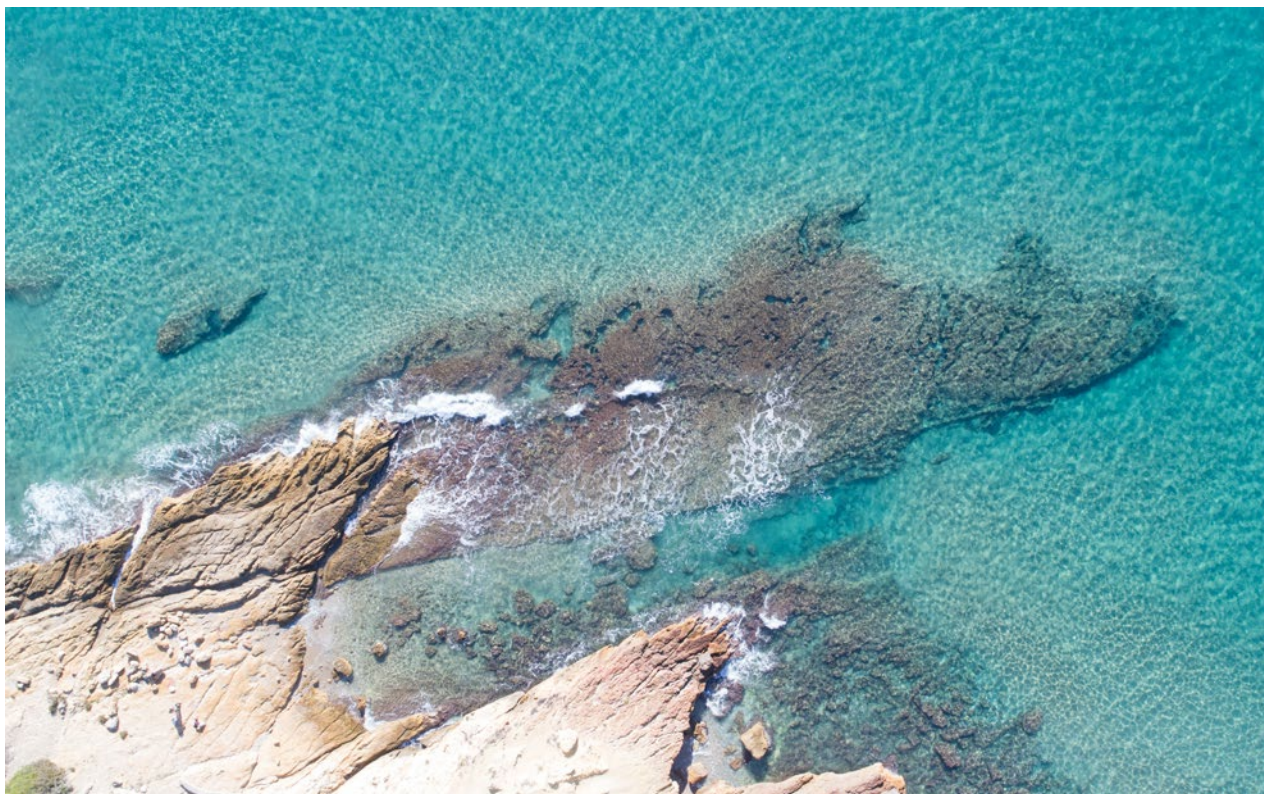
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TARRACO

B I E N N A L



ACTES

5^È CONGRÉS INTERNACIONAL
D'ARQUEOLOGIA I MÓN ANTIC

PORTS ROMANS.
ARQUEOLOGIA DELS SISTEMES PORTUARIS

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PORTS ROMANS. ARQUEOLOGIA DELS SISTEMES PORTUARIS

TARRAGONA, 24-27 DE NOVEMBRE DE 2021

DIRECCIÓ I EDICIÓ A CURA DE
ADA LASHERAS, JOAQUÍN RUIZ DE ARBULO
I PATRICIA TERRADO

TARRAGONA, 2022

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NAVIGABLE CANALS IN DELTAIC ENVIRONMENTS DURING THE ROMAN PERIOD: DECIPHERING LOCATION PATTERNS

Ferréol Salomon - Corinne Rouse

Navigable canals contribute to the improvement of connectivity between marine, coastal and inland waterways networks. This paper questions the location of active canals during the Roman period in relation to their archaeological and geographical contexts in which they were excavated. During the Roman period, literary and archaeological evidence reveal that most of the canals were dug in lowlands, coastal plains, and especially in river deltas. Locally, canals connected fluvial and/or coastal port-cities to inland waterways and maritime routes (e.g. Ostia-Portus, Ravenna, Aquileia, Alexandria). Additionally, some canals could have had a regional relevance in interconnecting fluvio-coastal port systems or possibly organising wider port systems. We identified three types of coastal settings that hosted regional projects of canals or actual constructed canals: (1) river deltas with the Nile delta as the archetype; (2) overlapping or contiguous deltaic plains similar to the Northern Adriatic coastal plain; and (3) separated coastal or deltaic plains, categories in which most of the Mediterranean port systems fit, especially the coastal port system of Rome. This paper explores the potential of these fluvio-coastal landscapes in which canals may have contributed in establishing interconnected port systems.

CANALES NAVEGABLES EN AMBIENTES DELTAICOS DURANTE LA ÉPOCA ROMANA: DESCIFRANDO PATRONES DE LOCALIZACIÓN

Ferréol Salomon - Corinne Rouse

Los canales navegables contribuyen a la mejora de la conectividad entre las redes marinas, costeras y las vías navegables interiores. Este artículo examina la ubicación de los canales activos durante la época romana en relación con los contextos arqueológicos y geográficos en que fueron excavados. Durante el período romano, las evidencias literaria y arqueológica revelan que la mayoría de los canales se excavaron en tierras bajas, llanuras costeras y especialmente en los deltas de los ríos. A nivel local, los canales conectaban ciudades portuarias fluviales y/o costeras con vías navegables interiores y rutas marítimas (Ostia-Portus, Ravenna, Aquileia, Alejandría...). Además, algunos canales podrían haber tenido una relevancia regional en la interconexión de sistemas portuarios fluvio-costeros o posiblemente en la organización de sistemas portuarios más amplios. Identificamos tres tipos de entornos costeros que albergaban proyectos regionales de canales o canales construidos: (1) deltas de ríos con el delta del Nilo como arquetipo; (2) llanuras deltaicas superpuestas o contiguas, similares a la llanura costera del norte del Adriático; y (3) llanuras costeras o deltaicas separadas. En una de estas tres categorías encajan la mayoría de los sistemas portuarios del Mediterráneo, especialmente el sistema portuario costero de Roma. Este artículo explora el potencial de estos paisajes fluvio-costeros en los que la construcción de canales pueden haber contribuido a establecer sistemas portuarios interconectados.

NAVIGABLE CANALS IN DELTAIC ENVIRONMENTS DURING THE ROMAN PERIOD: DECIPHERING LOCATION PATTERNS

Ferréol Salomon, *Université de Strasbourg / CNRS*
Corinne Rousse, *Aix Marseille Université / CNRS*

1. INTRODUCTION

During the reign of Emperor Trajan (98-117 CE), the Roman Empire reached its maximum size. It extended from England to the Near East, and along the shores of the Mediterranean. In such a far reaching empire, maritime routes were essential in connecting regional and long distance port systems (Arnaud 2005) (fig. 1). However, the Mediterranean Sea and the Roman Empire offer fragmented geographies. Mountain ranges and large peninsulas divide lands, coasts, and seas (Horden & Purcell 2000). In this landscape, the networks of roads (Grenier 1936; Laurence 1999; Quilici 2008) and inland waterways (Izarra 1993; Campbell 2012; Felici 2016) were crucial to complement the maritime route network.

River deltas are junctions between these three categories of networks. Consequently, natural settings offered by river deltas should provide ideal conditions to establish hubs including a continuum river-sea, many waterways through different channels tributaries, succession of lagoons, and fertile lands. However, advantages offered by river deltas are not straightforward. Inland navigation notably differs from maritime navigation, where sediments deposited at the river mouths limit the access to large maritime ships, while navigable water bodies are sprinkled throughout the deltaic plains, and road networks are fragmented by channels flowing into the sea. Floods regularly cover large areas and marshy areas offer difficult conditions in which to live. Considering these challenges, one of the main features of deltaic territorial management are canals which drain, irrigate, and allow navigation.

Many Roman canals were dug to improve inland navigation (Campbell 2012; *United Kingdom*: Ellis Jones 2012; *France*: Peter 2021). However, systematic use of canals are mainly observed in lowlands from coastal plains and deltaic areas (Uggeri 1997;

Vella *et al.* 1999; Keay *et al.* 2005; Rousse 2005; Rousse 2016; Wilson 2012; Campbell 2012; Salomon 2013; Peter 2021; Verhagen *et al.* 2022). Using literary, archaeological and geoarchaeological evidence, this paper will identify patterns in the location of navigable canals in deltaic and coastal areas from a geoarchaeological perspective, and characterise their role within territories and port systems from an archaeological/historical perspective. In alluvial and/or littoral contexts, geomorphologists examine issues related to canals within a comprehensive natural system such as a *fluvial system* (Schumm 1977) and/or a *littoral cell* (Inman 2005¹). In contrast, historians and archaeologists of the Roman period examine navigable canals in relation to urban planning, territorial management and port systems (Keay 2012; Wilson *et al.* 2012; Rousse, 2016). Both of these viewpoints will be considered here.

This study will be conducted at two different scales: (1) *Local* – deltaic environments where Roman canals were built or not built according to geoarchaeological case studies; (2) *Regional* – selected deltaic and coastal areas considering canals and territorial planning. This includes projected canals never realised and canals partly or actually built or even reused by the Romans.

2. DIGGING INLAND NAVIGABLE CANALS DURING THE ROMAN PERIOD: GEOMORPHOLOGICAL ADVANTAGES AND CONSTRAINTS

River networks and the role of inland waterway networks. – Today and in the past, inland waterway networks are mainly structured by existing river channel networks (Economic Commission for Europe 2017). Ancient authors such as Strabo and Pliny listed many navigable rivers across the Roman

1. “Compartment that contains a complete cycle of sedimentation including sources, transport paths, and sinks” (Inman, 2005).

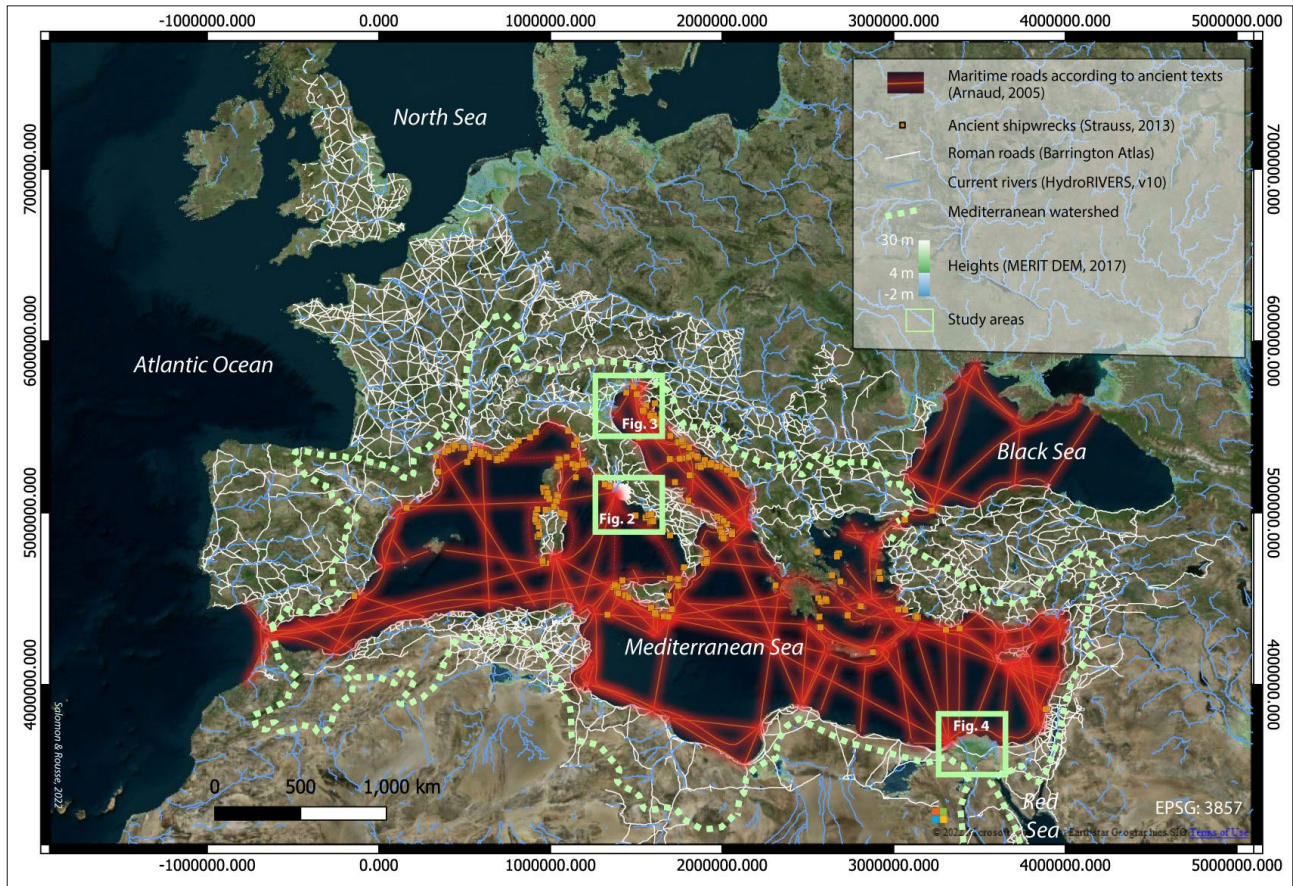


Figure 1. Main port systems in fluvio-coastal contexts during the Roman period. Sources: Talbert, 2000 (Barrington Atlas); Arnaud, 2005; Strauss, 2013; MERIT DEM 2017, HydroRIVERS v10.

Empire while describing hydrographic systems in the *Geography* and the *Natural History*, highlighting their importance for transportation. Inland waterways were a continuation of the maritime routes for the transport of bulk and large quantities of goods at low cost. They were especially advantageous over long distances, whereas road transports were favoured for short distances. According to the *Edict on maximum price* promulgated in 301 CE by the Emperor Diocletian, waterway transport was more expensive than maritime transport, but much more advantageous than land transport (Fulford 1984, 134; Polfer 2000; Arnaud 2007).

Limitation of navigable river networks and canals. – The natural configuration of river networks does not fit well with commercial networks which generally adopt a grid logic, which is where the road system responds more effectively. Hydrographic networks drain relatively limited areas and offer hierarchical networks (Strahler 1957), whether they are converging in watersheds or diverging in deltas. Canals have the capacity to better interconnect natural waterways in a grid logic. Here we consider a restrictive definition of navigable canals. They have the capacity to increase the connectiv-

ity of waterway networks in joining water bodies within a single watershed or between watersheds. This definition excludes channelisation of natural channels already existing or channel straightening.

Technical limitations and distribution of canals during the Roman period. – While canals are the solution to improve the connectivity of inland navigable networks, their construction can be challenging at different levels considering the socio-economic and technologic context in which they are planned. The construction of large, long and deep canals requires technical skills, hydro-geomorphological knowledge and intensive work. Locks are the most prominent technical skill limiting canal projects during the Roman period. Several studies suggest that Romans knew how to build single locks (e.g. Pliny 3.9.53 for the upper Tiber valley) but not locks with a fixed chamber and variation of the water level, or with a moving caisson (Moore 1950; Peter 2021). Consequently, Roman navigable canals were located within a single watershed connecting waterbodies in alluvial plains (Campbell, 2012; Ellis Jones, 2012; Peter 2021), as well as coastal plains and river deltas (Rousse *et al.* 2007; Salomon 2013; Peter 2021).

Advantages of digging canals in river deltas. – River deltas offer a large range of opportunities to dig navigable canals. Roman engineers only had to deal with low-slope gradients and the amount of work was reduced because the ground composition was soft material from Holocene sedimentation, rather than hard substratum. Additionally, many existing waterbodies can be found consisting of one to several tributaries, lagoons, and marshy areas. The establishment of a well-connected network of waterways in deltaic plains assists in creating canals between channels, lagoons and the sea. The largest deltas of the Roman Empire had navigable canals, e.g. the Nile (Strabo 17.1.4; Ptolemy 4.5.54 in Stükelberger and Graßhoff, 2006), the Rhine (Tacitus, *Annals*, 4.8 and 13.53; Suetonius, *Claudius*, 1.2), the Po (Pliny 3.119-121), the Rhone (Plutarch, *Marius*, 15; Strabo 2.5.183 and 4.1.8) and the Tiber (Pliny the Younger, *Epistulae*, 8.17.1-2).

Geomorphological contexts of the canals. – Many canals mentioned by ancient authors are not yet identified or confirmed on the field (e.g. Po delta – Medas 2013; Rousse 2016 ; Mosca 2020; Rhone delta – Vella *et al.* 1999; Rousse *et al.* 2019; Rhine delta – Verhagen *et al.* 2022; Nile delta – Redon, 2018; Schiestl 2021). Interdisciplinary research involving geophysical surveys, geoarchaeological investigations, and archaeological excavations are necessary to identify and study ancient navigable canals. The first integrated approach was conducted on the marine canal of Xerxes in Greece studied between 1991 and 2001 (Isserlin *et al.* 2003). Geomorphological, chrono-stratigraphical and paleo-environmental evidence contribute in differentiating a canal from a natural channel or from a channelized river (Sanderson *et al.* 2003; Salomon 2013; Kort & Raczynski-Henk 2014; Faisse *et al.* 2018) to better understand their characteristic and evolution through time (Salomon *et al.* 2014 for archaeological and historical data). Geomorphology also raises issues about the location of the canals and the natural opportunities offered to dig them (this paper). Unfortunately, the scarcity of Roman canals identified and fully studied through interdisciplinary studies provide few examples of the local environmental contexts in which the canals were dug.

In the Rhine delta, the *Fossa Corbulonis* was a canal dug in the mid-1st c. CE under the Roman general Gnaeus Domitius Corbulo (Kort & Raczynski-Henk 2014). It connected the river mouths of the Meuse and the Rhine. Archaeological and geoarchaeological studies revealed that the canal was dug into swales filled with peat between ridges and connected to tidal creeks related northwards to the Rhine and southwards to the Meuse. The canal was located along the coast inbetween longshore

dunes / beach ridges and the marshy area (Kort & Raczynski-Henk 2014). In the Rhone delta, a new hypothesis for the location of the canal of Marius is under investigation (Rousse 2019). However, the Vigueirat's Marshes on the eastern margin of the Rhone delta were probably partly used to navigate and connected to the *Fossae Marianae*, dug by the consul Caius Marius in 103-102 BCE (Leveau 1999; Vella *et al.* 1999; Rousse *et al.* 2019). These marshes were not located along the coast but along the Crau plain offering a natural corridor in which to build a waterway between the sea and the apex of the delta.

Geomorphological and historical context of the canals: the importance to avoid natural determinism. – It should be noted that these two Roman canals in the Rhine and the Rhone deltas were dug during military campaigns. The army was available and had to work within a very limited time. Consequently, they had to deal with natural advantages of the field to carry their work faster. In contrast, the canals built between Portus, the Imperial maritime port of Rome and the Tiber did not follow any pre-existing geomorphological features. The canals of Portus were located in the prograded plain perpendicularly to the beach ridges (Northern canal, *Canale Romano*, *Fossa Traiana* – Fiumicino) and when the canal is dug along the coast (Portus-Ostia Canal), it conforms to the orientation of the central district of Ostia and the structures of the harbour of Claudius rather than the beach ridges (Salomon *et al.* 2020; Salomon *et al.* Accepted). The role of preexisting geomorphological features in building navigable canals should be put in balance with the socio-economical and historical context.

3. THE CRUCIAL ROLE OF THE CANALS IN FLUVIO-COASTAL PORT SYSTEMS

We selected three case studies that hosted important fluvio-coastal port systems during the Roman period. These are the port systems of Latium and Campania along the Tyrrhenian coast, the port systems of the North Adriatic coastal plain, and the port systems of the Nile delta.

These case studies are more or less bordered by two major port-cities separated by comparable Euclidian distances: Rome and *Puteoli*/Pozzuoli on the Tyrrhenian coast are separated by ca. 240 km; Ravenna and Aquileia on the Adriatic coast are distant of ca. 250 km; and ca. 300 km separate Alexandria and Pelusium in the Eastern Mediterranean. The extent of the study areas was chosen based on navigable canal networks that either stayed at the stage of projects or might have been active during

the Roman period. The whole Nile delta and the whole Northern Adriatic coastal plain are included in the case studies. In contrast, no coherent geomorphological feature justifies the extent of the port system of Rome between the Tiber delta and the Bay of Naples (*Puteoli/Pozzuoli*). Instead, this port system is only determined by history and projects envisioned during the Roman period.

Very different temporal trajectories characterise the navigable canals of the study areas. The Nile delta experienced early large-scale hydraulic operations, way before the annexation of the Ptolemaic Kingdom by the Romans in 30 BC (see: Canal of the Pharaohs in Aubert 2004). Some navigable canals were possibly already dug by Etruscans in the Po delta before the Romans conquest (Pliny 3.119-121; Uggeri 1997; Medas 2013). The need of canals along the Latin and Campanian coasts did not start during the period of the Kings or most of the Republican period, it came much later in the 1st c. BCE according to ancient literary sources (Johannowsky 1994; Zevi 2001). The period between the 1st c. BCE – 2nd c. CE is actually crucial in the development of navigable canal networks in all of the study areas.

3.1. CONNECTING ROME TO THE SEA: SHORT SECTIONS OF CANALS DUG ALONG THE LATIN-CAMPANIAN COAST

Successive coastal plains and headlands. – The coasts of the Latium and Campania offer a wide range of coastal opportunities to build fluvio-coastal port systems (Schörle 2011). The coast is divided and characterised by a succession of coastal and deltaic plains of different sizes (Tiber delta, Pontine Plain, Fondi Plain, Garigliano delta, Volturno delta) and headlands (Antium, Circeii, Caieta) (fig. 2). In geology or geomorphology, there are very few papers comparing coastal plains along the Tyrrhenian coast (Bellotti 2000). Geomorphological or geological studies are usually focused only on one coastal plain/delta: Tiber delta (Bellotti *et al.* 2007; Milli *et al.* 2016; Salomon *et al.* 2020), Pontine plain (van Gorp *et al.* 2020; Sevink 2020), Garigliano delta (Bellotti *et al.* 2016), Volturno delta (Barra *et al.* 1996; Caiazza 2003; Amorosi *et al.* 2012), the area of Cumes (Stefaniuk *et al.* 2005), and the Bay of Pozzuoli (Milia & Giordano 2002; Morhange *et al.* 2006). Along the coast, small port systems can be related to different geomorphological units and different types of port systems. The example of Minturnae is particularly illustrative. Some archaeological and geoarchaeological studies integrate the port of Minturnae within the deltaic plain of the Garigliano delta (Bellotti *et al.* 2016) and its port system is reconstructed at the scale of a territory

organised around the mouth of the Garigliano, the lagoons, and a hinterland structured by the watershed of the Garigliano (Ferrari *et al.* 2013; Ferrari *et al.* 2014). From this point of view, the coastal plain plays an important role in the organisation of the local port system of Minturnae between the sea and inland territories. In contrast, some archaeological studies insist on the Bay of Gaeta with a hierarchy of harbours including Minturnae, Caieta, Formis, Gianola (Schörle, 2011; Wilson *et al.* 2012, fig 20.5), that is organised between the headland of Gaeta and the plain of the Garigliano River. Finally, these two local port systems (river/lagoon-centred or bay-centred) are integrated in the Rome-Ostia/Portus-Puteoli port system organised upon a succession of coastal plains and headlands occupied by different port-cities (fig. 2) (Zevi 2001).

Rome, the Tiber and Ostia. – The history of Rome is closely related to the Tiber since its origins (Le Gall 1953). During the reign of King Ancus Martius (640-616 BCE), Rome conquered territories towards the Tyrrhenian Sea, particularly on the left side of the Tiber until its delta (Livy 1.33.6-9). According to ancient literary sources, saltworks were installed in the southern lagoon and a settlement named Ostia was built at the mouth of the Tiber River (Cicero, *De Re Publica*, 2.3.5; Florus 1.4.2; Strabo 5.3.5). While ancient authors like Aurelius Victor (*De vir. Ill.*, 5.3) and Ennius (*Annals*, 2, Frag. 22) suggest that a harbour was already established at that time, historians consider that Ostia became a port much later (Zevi 2001). Additionally, archaeological data has not yet identified if this settlement ever existed (Zevi 2001; Salomon 2020). The oldest archaeological evidence at the mouth of the Tiber is a *castrum* built in the centre of the Late Republican-Imperial Roman city of Ostia, dated to the late 5th c. to the early 3rd c. BCE (Coarelli 1988; Martin 1996; Zevi 2001). First harbour activities are recorded in historical sources right before (278 BCE - Valerius Maximus 3.10) and during the First Punic War (264-241 BCE - Polybius 1.29; Florus, 2.2).

Colonisation of the southern coast of Rome and the port system Rome-Ostia-Puteoli. – During the reign of the last king of Rome, Tarquinius Superbus, and the early Republican period, Rome continued to expand its territory, especially towards the south along the Tyrrhenian coast (fig. 2) (Salmon 1955; Zevi 2001; Cazanove 2005). An early colony was built in Circeii (during Tarquinius Superbus – 534-509 BCE – after Livy 1.56, or ar. 390 BCE). Between the mid-4th and the early 3rd c. BCE, ten settlements became Roman *coloniae maritimae*, including several ones between the Tiber and northern Campania. These included Ostia, Antium, Terracina/Anxur, Minturnae, and Sinuessa. Later in 194 BCE,

the colonies of Puteoli, Liternum and Voltturnum were created after the Second Punic War (218-201 BCE) on the previous coastal territory of Capua. The function of these *coloniae maritimae* was the defense of the coast, but their economic potential was also developed. Puteoli/Pozzuoli offered a high potential to host a harbour because it had a large semi-protected bay and deep waters. According to F. Zevi, the system Puteoli-Ostia-Rome was established in 194-193 BCE based on two major points of evidence. First, Puteoli became a *coloniae maritimae* and secondly, the *porticus Aemilia*, a warehouse and distribution centre next to the *emporium*, was built in Rome (Zevi 2001a). Additionally, a public area was created between the Tiber and the *decumanus* in Ostia during the 2nd c. BCE in Ostia, possibly to deal with ships and goods (Zevi 2001). This area later hosted large warehouses (the *Magazzini repubblicani* and the *Grandi Horrea*) (Boetto *et al.* 2016). In this new system, the goods from large maritime ships were unloaded in Puteoli/Pozzuoli and transported on roads or by small ships along the Tyrrhenian coast until Ostia, then up to Rome on the Tiber river.

Development of the port system of Rome in the 1st c. BCE/CE: Harbours and canals. – We identify two distinct interrelated issues regarding the evolution of the Rome-Ostia-Puteoli port system. With the growth of Rome, the Rome-Ostia-Puteoli system became insufficient (docks, storage, connectivity, logistic) and unsure (Ostia is attacked by pirates in 68 BCE, floods affecting inland waterways and maritime routes, sediments accumulating in the river mouths). Two solutions were considered. First, the creation of new harbours and port infrastructures along the coast to offer more space to welcome and to unload ships, especially close to Rome. Second, the creation of easier and safer waterways to bring goods up to Rome along the whole coast (e.g. the canal of Nero) or only some sections (e.g. Tiber river mouth).

Julius Caesar's projects: a regional canal and improved port infrastructures. – With the growth of Rome, more infrastructure was necessary to bring goods to its population. Infrastructure projects were discussed since at least the middle of the 1st c. BCE (Quintilian, 2.21.18 and 3.8.16). In the mid-1st c. BCE, Caesar wanted to build a regional deep canal connecting the Tiber downstream of Rome to Terracina further south (Plutarch, *Caesar* 58.10). The aim was to create a more convenient and safer waterway to Rome. However, Ostia would not have been neglected. In the same text, Plutarch reports that Caesar also intended to build a harbour at the river mouth of the Tiber (Plutarch, *Caesar*, 58.10). At least during the late 1st c. BCE / 1st c. CE,

a navigable canal between Forum Apii and Terracina was active in the Pontine Marshes according to the literary sources (Strabo 5.3.6; Horace, *Satires*, I.5.1-26) (fig. 2).

The construction of Portus and its canals during the reign of Claudius. – In the mid-1st c. CE, the construction of Portus corresponded to a project offering a new harbour and port facilities near Ostia. In this project, the stress was on the harbour and its size on the coast close to Rome. Local canals were part of the project but mainly contributed to the harbour project. The navigable canals built around Portus intended to connect the new harbour to Ostia and the Tiber leading to Rome. Literary sources and epigraphy only mention their function as flood-relief canals rather than waterways (see synthesis in Keay *et al.* 2005 and Salomon 2013). In the inland waterway project of Claudius, the canals were dug over relatively short distances and built on the natural opportunities offered by the Tiber to connect Portus to Rome. This directly contrasts with Caesar's project.

The development of the port system with a coastal canal. – The project of a long regional canal was not completely abandoned. Nero and the architects Severus and Celer planned and initiated the construction of a 200 km canal between Puteoli/Pozzuoli and the Tiber (Johannowsky 1994; Arata 2014). Interestingly, both the projects of Claudius (Portus) and Nero (canal) were considered too big and too expensive (Johannowsky 1994; Zevi 2001). However, in contrast to Portus, which was actually built, the canal of Nero was quickly abandoned in 68 CE after having been started (Johannowsky, 1994). It should be noted that though Nero wanted to build this long canal, he also inaugurated the Claudian harbour and tried to reactivate Portus Iulius (Johannowsky 1994; Zevi 2001). Here again, the port solutions and the canal solutions are coupled in trying to reach the common objective to feed Rome with productions coming from the whole Rome Empire. In addition, F.P. Arata (2014) suggests that Nero's canal would not have been a bypass of the whole coast to convey wheat from Puteoli/Pozzuoli and the Tiber, but would have also contributed in draining coastal areas and increasing agricultural production closer to Rome. Following this hypothesis, it would have promoted local port systems along the coast.

More port infrastructure along the coast of Rome during the reign of Trajan. – In the beginning of the 2nd c. CE, Trajan built new ports along the coast and contributed to developing transports leading to Rome (construction of the port of Civitavecchia; cuts along the sea for the via Appia in Terracina – maybe initiated by Nero, after Johannowsky 1994).

During the reign of Trajan, projects mainly focused on Portus (Trajanic basin) and Civitavecchia (construction of the new harbour). Nevertheless, Puteoli (Keay 2010) and Ostia (Calza *et al.* 1953; Heinzlmann 2002) continued to have strong urban development in the 2nd and 3rd c. CE. This again suggests the complementarity of all the projects engaged along the coast to cope with the growth of Rome.

Port systems and diversity of networks. – Between the 1st c. BCE and the 2nd c. CE, the idea of a Rome-Ostia-Puteoli port system integrating new harbours infrastructure, canals, and roads was driven by a strong necessity. The need of space for ships and goods and also the need of facilities to transport most of those goods to Rome were not concurrent but complementary. The construction of the port system of Rome from its origin to the Imperial period was an increasing process closely related to the growth of Rome, its conquests, and its economy. In parallel to the expansion of the port system of Rome, safer roads and waterways between coastal ports and Rome became a necessity. Waterways and terrestrial routes themselves would often be mixed (Pison's route in Tacitus, *Annals*, 3.9). There were also parallel routes between different means of transport. In order to reach Rome from the Tiber delta, the *Via Portuensis*, the *Via Ostiensis* and the Tiber were all used mainly depending on the types of goods or the seasons.

Transregional canals: high needs, low natural advantages. – The Trajanic period was the peak of the extent of the Roman Empire, and it was also a period of important works on the port system of Rome along the coasts of the Latium and northern Campania. Later, no more reorganisation at such a scale was engaged (Zevi 2001). The succession of coastal plains and headlands stopped most of the projects of regional canal planning to connect *Puteoli/Pozzuoli* and Rome through waterways. Instead, the port system of Rome remained a combination of large and small harbours bordering the coast (Schörle 2011) with the construction of local canals (e.g. Portus) or channel straightening (e.g. Minturnae) when necessary. On one side, Puteoli was a natural good harbour far from Rome (Camodeca 1987), while on the other side, Portus was an engineered harbour located close to Rome that experienced several adjustments before fitting the requirement of a large and safe harbour (Keay *et al.* 2005; Goiran *et al.* 2010). Coastal plains between Puteoli and Rome were stopping stations but they were also developed original territorial management and productions. Finally, the river Tiber axis remained essential from the origin of Rome (Zevi 2001) to the end of the Roman Empire (Moreno

Escobar 2021). It is clear that the structure of the port system of Rome was driven by historical factors and largely influenced by the advantages and constraints offered by the geology and the geomorphology of the coast.

3.2. THE CASE OF THE NORTH ADRIATIC SYSTEM: POTENTIAL OF INTERCONNECTED FLUVIO-COASTAL PLAINS THROUGH CANALS

From the Po to the Isonzo: converging fluvio-coastal plains into the Adriatic Sea. – Compared to the Tyrrhenian coast, the northern Adriatic coast offered better opportunities to create an integrated network between maritime, coastal, and inland navigation and terrestrial transport. Lowlands lie between Rimini and Aquileia without salient headlands (see heights up to 30 m in fig. 3). While geoscientific studies of the coastal plains of the Tyrrhenian coast of the Latium and Campania are divided into many case studies (cf. *supra*), studies embrace larger areas in the northern Adriatic coast from Rimini to Aquileia. Three main coastal systems can be identified. First, the Po delta is the more important fluvio-coastal system of the area (Bondesan *et al.* 1995; Stefani & Vincenzi 2005; Amorosi *et al.* 2005; 2019). It gives access to a large alluvial plain (Padan Plain) and to a large watershed between the Alps to the west and the north and the Apennines to the south. Second, to the north, the Venetian-Friulian plain is a succession of smaller fluvio-coastal systems between the rivers of the Adige and the Isonzo (Fontana *et al.* 2008; 2014). The northern Po branches and the Adige channels successively occupied the area between the two fluvial systems (Piovan *et al.* 2012). Third, to the south, the influence of sediments from the Po and small rivers built a narrow coastal plain between the cities of Ravenna and Rimini. The reconstruction of the 1st c. CE coastline proposed in fig. 3 is not definitive (Stefani, 2005). It only gives an idea of the general morphology of the coast during the Roman period and it informs us about the areas that might have been affected by high geomorphological changes (sedimentation/erosion/subsidence). This reconstruction shows that main coastline changes affected the Po and the Isonzo deltas. Specifically, it should be noted that the active lobe of the Po delta is now located to the north of the Roman abandoned lobe that was active in the 1st millennium BCE / CE (fig. 3).

Roman domination and main chronology. – Historically, the first Roman port-city along the north Adriatic coast was Rimini / *Ariminum* (Ortalli 2006). Originally an Etruscan and then Celtic settlement, Romans founded the colony of *Ariminum* in 268 BCE. At the end of the 3rd c. BCE,



Figure 2. The Latium and Campanian coasts near Rome. A series of coastal plains and river deltas separated by headlands. Sources: Talbert, 2000 (Barrington Atlas); Keay *et al.* 2005, 2020; Salomon, 2013; SINAnet, ISPRA, 2012; MERT DEM 2017.

Ravenna became a Roman *municipium*. During the beginning of the 2nd c. BCE, Romans conquered the area of the Po and made an alliance with the Venets. In 181 BCE, Romans founded a Latin colony in Aquileia in Celtic territory. Later came the development of *municipia* like Altinum and Patavium (2nd – 1st c. BCE), and new colonies such as Iulia Concordia (42 BCE). All of these cities were settlements originating from the Late Bronze Age to the Early Iron Age and developed an original urban layout mixing local traditions and Roman urban standards after the conquest.

Original urban fabrics structured by roads and canals. – The urban fabric of Hatria, Vicetia, Opiertegum, and Aquileia (canals around the city) but especially Ravenna, Altinum, and Iulia Concordia (canals within the city) were structured by an intertwining of streets and canals (Rousse 2016). Developed earlier than the other Roman cities of the area, Aquileia was probably the model in which innovations were tested relating to cities and planning in fluvio-coastal environments (Vitruvius, 2.4.11; Pliny 3.120-121, Strazzula 1989; Carre 2004; Rousse 2013). These canals had several uses including

drainage, protection, and navigation. All of these north Adriatic cities are ideal for interdisciplinary studies between archaeology and geoarchaeology. Archaeological studies revealed the structure and the evolution of the cities and their territories. Many geomorphological and geoarchaeological studies reexamined these cities within the dynamics of the fluvio-coastal systems, including Hatria (Corrò & Mozzi 2017), Altinum (Mozzi *et al.* 2016), Iulia Concordia (Ronchi *et al.* 2021) and Aquileia (Arnaud-Fassetta *et al.* 2003; Siché 2008). Fewer geoarchaeological studies are available for the towns/cities in the Po delta to the south (Medieval town of Comacchio: Rucco, 2015, Rimini: Ugolini, 2015; Dall’Aglia *et al.* 2017).

Coastal to inland distribution of port-cities. – During the Roman period, no major city-port was located in the Po delta. According to Strabo (5.1.5), “the Po (...) is both a large river, and also continually swelled by the rains and snows. As it expands into numerous outlets, its mouth is not easily perceptible and is difficult to enter”. In this extract, Strabo insists on hydrological and geomorphological risks of the area of the Po delta. Strabo distinguishes the Po delta, with low territorial management, and the “district of the Heneti” (Venetian-Friulan plain), “full of rivers and marshes” with higher hydraulic engineering. He observes that “the inhabitants have dug canals and dikes so that part of the country is drained and cultivated, and the rest is navigable”. In terms of urbanisation, Strabo separates the fluvio-coastal plain and the fluvial plains: “Some of their cities stand in the midst of water like islands, others are only partially surrounded. Such as lie above the marshes in the interior are situated on rivers navigable for a surprising distance, the Po in particular”. These geographical observations from Strabo conform with current knowledge from archaeology and geomorphology.

The map in fig. 3 brings together information from literary sources as well as geomorphological and archaeological data. In the 1st c. BCE/CE, the main Roman cities of the Venetian-Friulan plain (Aquileia, Altinum, Iulia Concordia) are located right above the Holocene maximum landward migration of lagoonal-marsh environments (Amorosi *et al.* 2008; Fontana *et al.* 2010). Interestingly, the cities of Vicetia, Tarvisium, and Opitergum located further inland are located just below the upper limit of the spring belt, providing them a large amount of freshwater. The cities of Este and Opitergum in particular developed river engineering similar to the coastal cities. Respectively to the north and to the south of the Po delta, Hatria/Adria and Ravenna are located in the area affected by important Holocene fluvio-coastal changes. To the South, cities were dis-

tributed along the deltaic plain of the Po following the *via Emilia* until Rimini/Ariminum. Hydromodifications were also conducted on the rivers flowing from the Apennine in these cities (Ortalli 2010).

At this stage of the discussion, main Roman cities setting in or just above the fluvio-coastal deltaic plains occupied by lagoons were connected to lagoons and the sea with possible canals (e.g. *Canale Anfora* in Aquileia with a detailed study in Maggi *et al.* 2017; Bonetto *et al.* 2020). Some of these cities might have had outer harbour facilities better connecting at the interface between the sea and the fluvio-coastal plain (Uggeri 1997). They were also connected to hinterlands of different sizes, Ravenna being connected to the largest (e.g. Padan Plain). These port systems structured territories following upstream-downstream axes. However, further geophysical, geoarchaeological and archaeological investigations would be necessary to better understand this layout and chronologies of these local port systems.

Canals of regional significance. – Roman navigable canals of possible regional significance were hypothesised based on ancient sources and some archaeological evidence in the North Adriatic coast as demonstrated on fig. 3 (Pliny 3.120-121; Strabo 5.1.5). It should be noted that most of these regional canals have not yet been studied on the field. Apart from a section of the *fossa Augusta* near Ravenna to the south (Maioli 2001), few archaeological and geoarchaeological data are available (see synthesis in Rouse, 2007 reported in fig. 3). Hypotheses of the location of the canals are mainly based on textual, toponymic and topographic evidence, belonging to different chronologies (Uggeri 1978; Medas 2013). According to sources from the 1st c. CE to the Medieval period (e.g. Pliny 3.120-121, *Tabula Peutingeriana*, Procopius, 5.1.22, Cassiodorus, *Variae*, 12, 24 mainly) and their interpretations, canals were connecting different cities in the fluvio-deltaic plain. In addition, inland navigable canals were probably dug in the Padan Plain during the Roman period but, here again, reliable archaeological data are still lacking (Uggeri 1997; Strabo 5.1.2).

Most of the canals cited in ancient texts are also difficult to date. Chronologically, hypotheses suggest a close relationship between the regional importance of the local port systems and the development of the canals connecting the different fluvial and coastal ports. For example, earlier in the 1st millennium BCE, the coast of the Po delta was dominated by the Etruscan cities of Spina and Hadria (6th – 3rd c. BCE) (Gaucci 2015). Spina was abandoned around the 4th – 3rd c. BCE (Mistireki *et al.* 2019). Pliny, writing in the 1st c. CE, reports that

navigable canals already existed during the Etruscan period (Pliny 3.120-121). According to Modern scholars, the *fossa Flavia* located between Spina and Hatria could have been one of the original Etruscan canals (Uggeri 1997). Later, by the end of the 1st c. BCE, Ravenna, to the south-west, is the main hub of the area with Aquileia, to the north-east (Ugolini 2021). The Emperor Augustus decided the construction of the large harbour of Classe near Ravenna and stationed the military ships of Rome there to control the eastern Mediterranean (Cirelli 2013). In this last case, archaeological evidence confirmed the existence of this canal and its date (Maioli 2001)

Classic reconstructions from Modern scholars suggest that several sections of canals connecting river channels and lagoons created a continuous waterway between Ravenna and Altinum (fig. 3) (Uggeri 1997; Medas 2013). It is not known if canals were easily connecting to each other or if the waterway was adopting a more complex route within the fluvio-coastal plain. This waterway was by-passing the river mouths of the Po and their accumulation of sediment as well as protecting the ships from heavy seas (Strabo 5.1.5). Nevertheless, it also certainly had a role in the exploitation of the land (local trade and navigation, drainage). The most important canal would have remained the section of the *fossa Augusta* connecting Ravenna and the new port of Classe to the Po River and the large Padan Plain upstream (Maioli 2001). Canals connecting Altinum and Aquileia could have existed during the Roman period but more evidence would have to be provided from field data (Uggeri 1997; Medas 2013; hypothesis mainly based on later sources).

Regional canals: high natural advantages and different needs from place to place. – Due to their configurations, the coastal plains of the north Adriatic were particularly prone to be managed by Roman hydraulic engineering (Uggeri 1997; Rousse et al. 2007). At the scale of the cities and their surroundings, territorial managements displayed integrated systems including road networks, inland waterways, land division (centuriation), urban fabric, and possibly inner / outer harbour systems. The succession of lagoons and channels along the coast offered great opportunities to connect easily to these different coastal port systems. However, navigable canals constructed to connect these natural water bodies were mainly done so to bypass the mouths of the Po delta in the South-West, and to connect Ravenna to the Padan Plain. A strong complementarity between punctual artificial developments (i.e. canals) and the natural environments (lagoons, deltaic mouths and rivers) might have favoured navigation in the Po delta. A continuous

waterway between Ravenna and Aquileia would be possible but it is not yet based on archaeological evidence. It should also be hypothesised that the curvature of the coast would have made it faster to navigate between Ravenna and Aquileia by the sea (Arnaud 2005) rather than through series of canals along the coast

3.3. THE CASE OF THE NILE DELTA: ARCHETYPICAL DELTA AND ATYPICAL PORT SYSTEM?

The archetype of river deltas. – In its lower part, the Nile has the specificity to be a delta flanked by deserts to the east and to the west, which limits lateral extent of the settled territories and contains the development of the port systems within the valley and the deltaic plain (fig. 4). From upstream (south) to downstream (north), three geomorphological areas can be identified: the Nile valley, the alluvial deltaic plain, and the fluvio-coastal plain. In the context of the MEDIBA project, the fluvio-coastal area was studied as a whole and this program remains a reference for much deltaic research (Stanley et al. 1996). Nevertheless, Egypt is characterised by many other international studies in geology, geomorphology, geoarchaeology. Research included international studies at a regional scale (Flaux et al. 2013; Marriner et al. 2014; Pennington, 2018 amongst others) and at the scale of cities (Pelusium - Stanley et al. 2008; Tinnis - Gascoigne et al. 2019; Canopus-Heraklion - Stanley et al. 2004; Alexandria - Goiran, 2001). No major project with a systematic cores strategy was conducted at the scale of the fluvial plain of the Nile. The complexity of the fluvial system divided in many palaeochannels makes a coherent study harder to carry (Pennington et al. 2017). However, local studies were conducted around Buto (Wunderlich 1988), Naukratis (Pennington & Thomas 2016), Avaris-Pi-Ramses (Tronchère 2010), and Minshāt Abū ‘Umar (Brink 1992). Based on a synthesis of local and regional studies, Pennington et al. (2017) proposed a first model of evolution of the fluvial system in the Nile delta. Previously, topographical evidence, ancient texts (Toussoun 1922) and archaeological datasets (Bietak 1975) were used to reconstruct the evolution of the branches of the Nile through the Middle and Late Holocene. Lately, the use of satellite imagery and LiDAR data offers now new perspectives to observe distribution of palaeochannels in the Nile delta (El Bastawesy et al. 2016; Ginou et al. 2018), but still only few palaeochannels have been dated yet using geochronological techniques (Tronchère 2010).

In the Nile delta, the identification of canals is particularly difficult and no archaeological or geo-

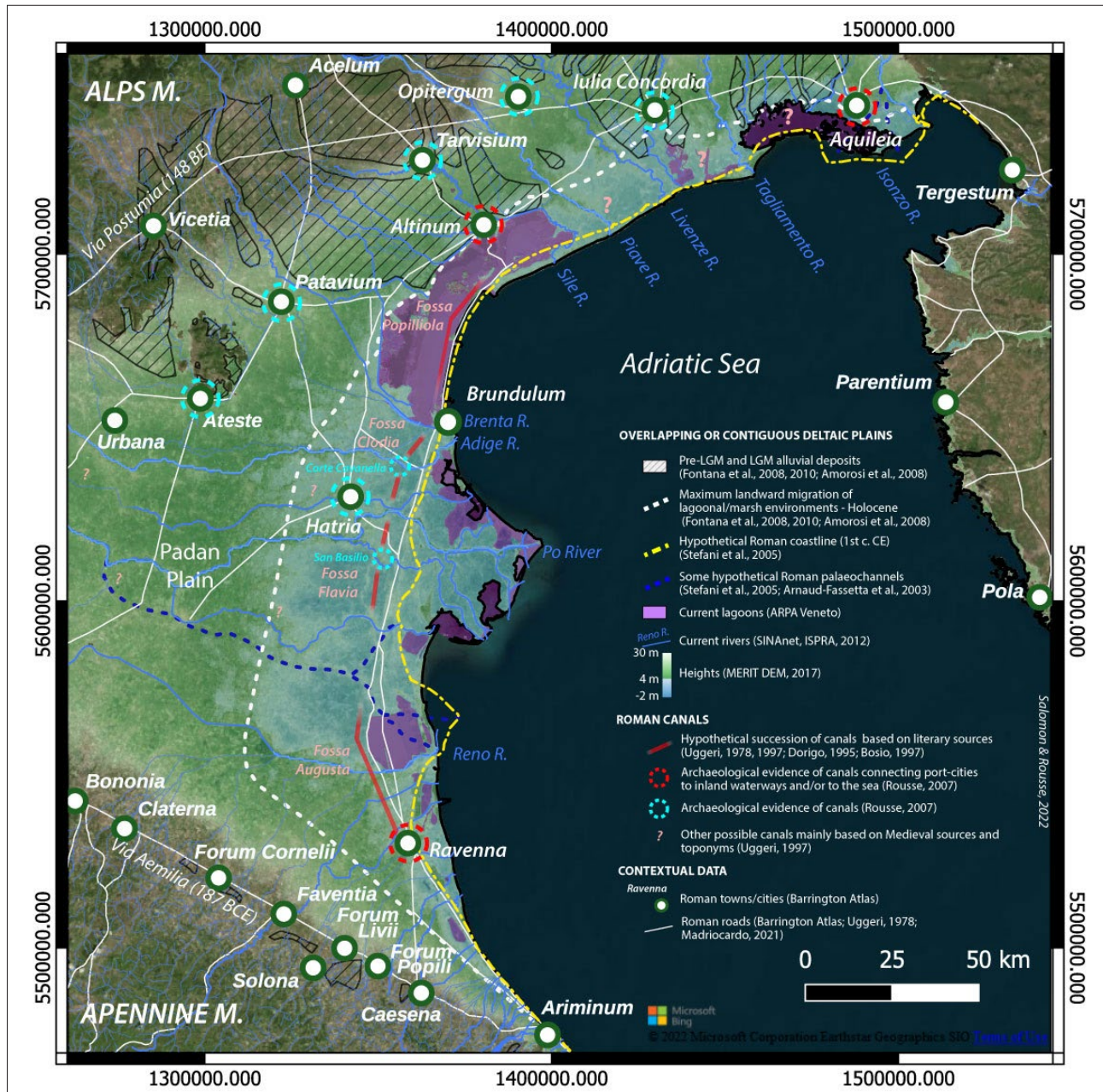


Figure 3. The Adriatic back coastal arc during the Roman period. Sources: Uggeri 1978; Dorigo 1995; Bosio 1997; Talbert 2000 (Barrington Atlas); Arnaud-Fassetta *et al.* 2003; Stefani & Vincenzi 2005; Rousse, 2007; Fontana *et al.* 2008, 2010; Amorosi *et al.* 2008; Madricardo *et al.* 2021; ARPA Veneto, SINAnet, ISPRA, 2012; MERT DEM 2017.

archaeological project has focused yet on this topic using joint geophysical, geoarchaeological and archaeological investigations. The eastern (Pelusium) and western margins (Alexandria) were primary axes of transports during the Ptolemaic and Roman periods (fig. 4). Consequently, the history and the archaeology of these margins are better known than the central part of the delta (Bietak 1975; Hairy & Sennoune 2006; Wilson 2012). Since early periods, navigable canals were dug and some became sections of branches or new branches. Strabo indicates that the Nile delta was cut by many canals (Strabo 17.1.4). According to Herodotus (2.17), two river

mouths of the Nile were actually outlets from canals.

Alexandrine port system: organisation of the western Nile delta through canals. – Since the annexation of Egypt in 30 BCE, Romans in the Nile delta both reaffirmed the preponderance of Alexandria (f. 323 BCE) initiated during the Ptolemaic period and pursued the reorganisation in the delta (Wilson 2012; Wilson 2016). During the Roman period, the administration and the productive system of Egypt was reorganised. Settlement patterns, water systems, and food production were affected (Wilson 2012). Waterways were essential to carry all kinds of goods

produced in Egypt to feed local cities, Alexandria, and Rome (Wilson 2012; for more complexity in the destination of the production of Egypt during the Roman period see Rossi 2015).

Alexandria was an area of high production (Wilson 2012; Kenawi 2014) associated to a dense inland navigable network during the Roman period (Khalil 2010). This network connected Alexandria, the Mareotis lake, and the Canopic branch. It included canals within the city of Alexandria (Hairy 2011; Hairy 2020), the Canopic Canal between Alexandria and the city of Canopus (Hairy 2011), and the Schedia Canal between Alexandria and the Canopic branch at Schedia (Bergmann & Heinzelmann 2015; Hairy & Sennoune 2006). Recently, Roman navigable canals were also identified in the western part of the Lake Mareotis linked to the city of Taposiris Magna (Crépy & Boussac 2021; Redon *et al.* 2021). All these canals created a navigable network around Alexandria and its marine harbour.

Crossing the Nile delta along an E-W axis: coasts, lagoons or river channels? – Three different kinds of environments offered the potential to navigate from one part of the delta to the other: the coast, the lagoonal belt (fluvio-deltaic area) and the fluvial deltaic plain.

The coastal area was considered dangerous during the Roman period, with high grounds especially in the central part of the delta (Strabo 17.1.18; probably related to the remnant lobe of the Sebenitic branch - Arbouille and Stanley 1991) Egypt is determined by petrological analysis of radiocarbon-dated sediment borings. Shallow marine, lagoonal and fluvial deposits accumulated during the late Pleistocene, and delta plain to coastal facies during the Holocene (since about 7500 yrs B.P., but not impossible to navigate (Dio Cassius 42.7.2).

Less is known about the fluvio-coastal area of the delta occupied by lagoons (Wilson 2016). This area excludes the lakes protected by the Pleistocene sandstone coastal ridges on the Western margin of the Nile delta that are better known regarding port, canals, and navigation (Mariut and Abu Qir Lakes) (Blue *et al.* 2011; Boussac 2007; Redon *et al.* 2021), but concerns the succession of lagoons from Canopus-Heraklion to Pelusium (Idku, Burullus, Manzala). It seems that no itineraries crossing the delta through the lagoons are mentioned by ancient authors from the Ptolemaic and Roman periods (Redon 2018). In addition, lagoonal navigation is still largely unknown (about lagoonal boats from the texts see Arnaud 2015, and from an archaeological perspective see Belov 2020; Robinson 2018).

Traditionally, in ancient Egypt, the easiest way to cross the Nile delta in an East-West axis was to

navigate upstream on branches of the Nile to the apex of the delta and then downstream on another branch (Redon 2018). However, navigable canals were also connecting the different branches before and during the Roman period (Strabo 17.1.4). Considering ancient itineraries crossing the delta, Redon (2018) observes that the routes were gradually moving to the north at least from the Ptolemaic period until Late Antiquity / Byzantine periods, using terrestrial and/or waterways. This was maybe related to new productive agricultural basins developed towards the north especially during the Roman period (Wilson 2016).

The Butic canal. – The longest canal across the Nile is known from Ptolemy (4.5.44 - Stückelberger and Graßhoff, 2006) writing in the 2nd c. CE: *Boutikos potamos*, the butic canal (fig. 4). Named after the city of Buto, it would have connected the Canopic branch to Pelusium. It is not clear if it was one or several canals parallel to the coast (Blouin 2014; Redon 2018), a sum of canals and channels segments (Redon 2018), or a unified canal (Carrez-Maratray 1999). Several hypotheses for its location were proposed locally and across the delta (Ball 1942; Talbert 2000; Blouin 2014; Redon 2018). A step further in the hypothesis was proposed recently in locating a small area using aerial photography possibly related to this canal (Schiestl 2021).

The role of this canal is unclear, whether for military, water management, and/or economic purposes (Ball 1942; Bietak 1975; Blouin 2014; Redon 2018; Schiestl 2021). If this canal is confirmed with an economic relevance to carry goods produced in the delta, the butic canal could have been a part of a shift from a 'natural' urban delta centred on the apex to an 'anthropic' urban delta initiated during the Ptolemaic period centred to the Alexandrian port system.

The canal of the Pharaohs. – Located to the East, the canal of the Pharaohs (or Canal of Trajan) is one of the most emblematic of the Nile delta (Toussoun 1922; Bourdon 1925; Posener 1938; Servin 1949; Redmount 1995; Holladay Jr 1999; Aubert 2004). It connected the Pelusiatic branch of the Nile or Heliopolis to the Red Sea through the Wadi Tumulat. The route of this canal is not known in detail. However, the historical data concerning it are numerous and very diversified. Inscriptions on steles, dated to the time of Darius (late 6th - early 5th century BCE), have been discovered along the route of the canal. Many ancient authors also mentioned this canal, from Herodotus (2.158) to St. Gregory of Tours (1.10). The Romans sought to reactivate the so-called Canal of the Pharaohs (at the time of Trajan according to Ptolemy 4.5.54), but this canal could date back to the first half of the 1st millen-

nium BCE (Herodotus, 2.158) or earlier (Aubert 2004). The purpose of this canal may have allowed continuous navigation between the Mediterranean area and the Red Sea via the deltaic Nile (Ptolemy 4.5.54). From the time of Trajan to the Arab period, information on the maintenance of the canal can also be found in *papyri* and *ostraca* (Aubert 2004). Despite some chronological difficulties, this canal reveals a history of several millennia, from the time of the Pharaohs to the Arab period.

4. MODELS OF FLUVIO-COASTAL PORT SYSTEMS ORGANISATION DURING THE ROMAN PERIOD

Romanisation, port systems and navigable canals. – Locally, major fluvio-coastal port-cities engaged in lots of work in their infrastructure. These include Rome, Aquileia, Ravenna, and Alexandria. These cities had supra-regional influence and contributed to reorganised wide fluvio-coastal territories. Rome had the specificity to be located more inland compared to the other cities that were clos-

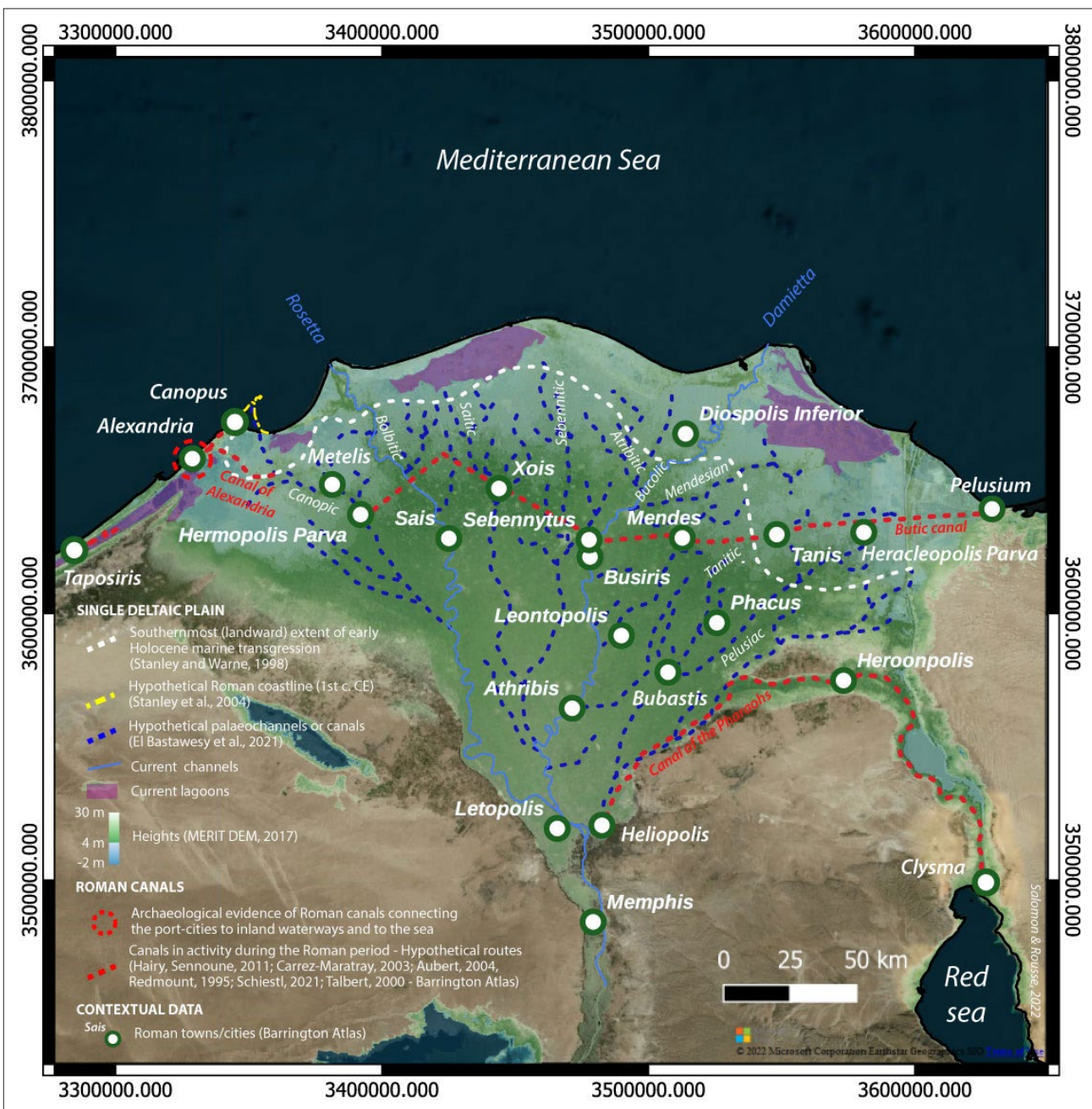


Figure 4. The Nile delta during the Roman period. Source: Redmount 1995; Stanley & Warne 1998; Talbert 2000 (Barrington Atlas); Carrez-Maratray 2003; Aubert 2004; Stanley *et al.* 2004; Hairy 2011; El Bastawesy *et al.* 2016; Schiestl 2021; SINAnet, ISPRA, 2012; MERT DEM 2017.

er to the coast, if not on the coast. The Nile and the Po deltas had more ancient fluvio-coastal hydraulic engineering skills. In these cases, Romans did build on local tradition and previous engineered structures to establish larger and more connected port systems. The conquest of Cisalpine was probably a technological leap for Roman engineering (Rousse 2016). Navigable canals became indicators of Romanisation in urban cities along the North Adriatic coast, and later became essential pieces in the structure of fluvio-coastal port systems in the Roman World, improving their connectivity. Due to the large amount of texts available for the case study of Rome, it was possible to demonstrate the interrelation between the development of large port systems (Rome-Ostia-Puteoli) and the construction of navigable canals (see *supra*).

Major fluvio-coastal port-cities connected to inland waterways with bypass canals. – In the three studied areas, the first role of the canals was to connect fluvio-coastal port-cities or harbour systems to large hydrosystems, as well as to avoid navigation in deltaic river mouths. Portus was built north of the natural mouth of the Tiber with a series of canals connected to the river. The *Fossa Augusta* connected Ravenna-Classe to the Po, and the canal of Alexandria connected the city to the Canopic branch. It was possibly the case for the Anfora Canal in Aquileia. Similar reasons were at the origin of the *Fossae Marianae* in the Rhone delta (Rousse *et al.* 2019) and the *Fossa Corbulonis* connecting the Meuse and the Rhine right upstream of their mouths (Kort & Raczynski-Henk 2014). The difference is that these last two canals were excavated for military purposes and not for their contribution to a first ranked port system. However, the *Fossae Marianae* eventually became a part of the port system related to the harbour of Fos later in the 1st c. BCE (Fontaine *et al.* 2021).

Paradigm shift. – The excavation of long regional navigable canals behind the shores is more subject to caution. In the 20th c., scholars projected ideas of large and unified navigable canal systems planned or actually realised along the coasts of Rome, the Northern Adriatic, and the Nile delta. This was the case in considering Nero's canal project (Johannowsky 1994), as well as the hypothetical canal between Ravenna and Aquileia attributed to Late Antiquity (Uggeri 1997), or the Butic canal (Carrez-Maratray 1999). An analogy with the 20th c. "highways" was also proposed for the Butic canal (Carrez-Maratray 1999). During the last two decades, the scarcity and the spread of the data available together with the few chronological constraints led the researchers to more complex interpretations. The canal of Nero was probably not planned to be

disconnected to the local economies settled along Latin and Campanian shores but included coastal drainage to promote agricultural productions locally (Arata 2014). Along the coast of the North Adriatic plain, questions were raised about the local or regional relevance of the canals (Rousse 2007). Finally, the Butic canal was suggested to be a sum of new and existing canals connecting channels (Redon 2018).

Coastal versus longshore navigation. – In each of the three studied areas, the importance of the longshore inland waterways can be estimated compared to coastal marine navigation.

Because the project of Nero failed to provide a second navigable route inland to transport goods between Puteoli and Rome, the port system of the coast of Rome was structured around coastal navigation between Puteoli and Ostia/Portus, with fluvial navigation between the Tiber delta and Rome. According to Johannowsky (1994), no ancient author indicates that the navigation along the coasts of the Latium and Campania was particularly risky, except during winter. The main risks were concentrated at the mouth of the Tiber River (bars, fluvio-coastal mobility), but Portus with its canals tried to provide local solutions (Salomon *et al.* Accepted).

The navigation along the coast of the North Adriatic plain was organised both in the maritime domain and in the fluvio-coastal plain. In the 1st c. BCE/CE, older and new canals connected Ravenna to Altinum in order to avoid the coastal navigation near the mouths of the Po delta considered particularly risky (Strabo 5.1.5). The realisation of canals could have continued until the end of Antiquity, along the lagoonal coast and perhaps as far as Aquileia, but no archaeological or geoarchaeological data are available to prove it. However, maritime routes were probably easier and faster (see *above*).

Finally, the Egyptian coast was particularly difficult to navigate (Diodorus of Sicily 1.31.2-5; Strabo 17.1.18). In contrast, a dense system of navigable canals existed at least in the fluvial deltaic plain of the Nile (Strabo 17.1.4). While not much is known about the fluvio-coastal area of the Nile delta (lagoonal fringe), the *Butic canal* mentioned by Ptolemy would have provided a kind of longshore waterway to avoid coastal navigation.

Roads were also essential to transport goods and provided alternative routes to coastal and inland navigation. In Italy, Roman road networks developed earlier than the development of waterways. For Egypt, no milestones were discovered that could have helped to reconstruct the precise location of the roads in Roman Egypt. It is often considered that roads followed canals and vice versa (Redon 2018).

Canal locations: geometry of the coast or type of coastal environments? - The convexity of the coast (Nile delta) or the concavity of the coast (Northern Adriatic plain), are genetically related to the size of the hydrosystem, their water and sediment discharge, and their history. The North Adriatic plain was initially a single hydrographic system during the Last Glacial Maximum (Amorosi *et al.* 2003), while the Nile remained a single system between the Pleistocene and the Holocene (Chen & Stanley 1993 interbedded with alluvial sands, are buried beneath Holocene deposits of the Nile delta in Egypt. The origin of the muds are interpreted on the basis of the petrology, stratigraphy and distribution of radiocarbon-dated sections recovered in cores across the northern delta. Four distinct stiff mud sequences, or subfacies, are defined on the basis of lithology, sand-sized composition and clay mineralogy. These sequences include (I). In terms of navigation, the maritime routes were facilitated between Ravenna and Aquileia and conditions were particularly difficult between Pelusium and Alexandria. It could have also had consequences on the location of the canals. In terms of optimal location, a shorter distance line is passing through the fluvial delta in Egypt (see *Butic canal* described by Ptolemy, not totally straight according to reconstructions). For a straight coast like the Latium with low sedimentary inputs compared to the coast of Egypt, the distance by sea or canal along the coast would have been similar.

Models of fluvio-coastal port systems - At this stage of the discussion we propose geoarchaeological models to characterise each of the three studied areas in terms of potential for inland waterway networks during the Roman period (fig. 5).

Model 1 is inspired by the Nile delta (fig. 5). It corresponds to a large deltaic system with a dense urban network. River tributaries splitting in the delta structure the urban network. However, humanmade tributaries can expand the hierarchical network of channels in the delta and open new river mouths (see Herodotus 2.17). Higher connectivity in the navigational network depends on canals connecting at least two natural tributaries (e.g. *Butic canal*). In the fluvio-coastal delta in particular, canals could potentially connect lagoons between them and with the sea or with the fluvial network (e.g. harbour system around Alexandria). In this model, navigable canals can potentially be built anywhere in the deltaic plain with the technological skills of the Roman engineers with relatively low efforts to excavate soft sediments rather than hard rock substratum. Model 1 can also be applied to smaller deltaic systems such as the Po delta, the Tiber delta, the Rhone delta, the Aude delta, and the Rhine delta.

The configuration may vary from one delta to another and modalities of territorial organisation may change due to environmental, historical, cultural and socio-economic factors. According to the data synthesised in this paper, the Nile delta is mostly structured by *navigation in the fluvial delta* during the Roman period. However, not much is known from the navigation and connectivity within the lagoonal fringe. Only the area around Alexandria provides a fully integrated navigational network connecting channels, lagoons, harbours, canals and the sea.

Model 2 is based on the example of the North Adriatic coastal plain (fig. 5). The Po delta or the Isonzo delta alone would fit into Model 1, but the overlapping or contiguous deltaic plains made the North Adriatic very specific. The succession of fluvio-coastal deltas along shore creates a succession of lagoonal areas separated by river mouths. No headland of hard substratum divides the different fluvio-coastal systems. Potentially, all hydrographic networks can be connected downstream by canals at the level of the lagoonal fringe. During the Imperial period, the port system of the North Adriatic is mainly structured by two ports: (1) Aquileia to the north is connected to the sea possibly through one or several natural channels and the Anfora canal, and plays an important role of redistribution towards the Danubian limes by crossing the Alps; and (2) Ravenna along the sea is connected by the *fossa Augusta* to the large Padan Plain inland. Between these two ports, many cities are located above the lagoonal fringe connected to the sea by channelised rivers or canals. During the Imperial period, some port-cities along the North Adriatic coast are connected to each other by a *mixed system* of coastal navigation and lagoonal-river-canal navigation, at least between Ravenna and Altinum.

Finally, Model 3 is characterised by a succession of coastal or deltaic plains separated by rocky headlands making it harder to construct waterways. However, canals are actually built in a single coastal or deltaic plain (e.g. Tiber delta, Pontine Marshes). The different coastal lowlands are interconnected mainly through *coastal navigation*. The port system of the Latin and Campanian coast is structured by a city inland (Rome), and towns/cities built along the coast are connected by marine navigation or small cabotage.

Balance between need and (natural) opportunities: the case of Rome. - The balance between opportunities and needs is essential regarding the three case studies (fig. 5). The coastal area of Rome along the Tyrrhenian sea does not provide ideal coastal settings to build canals during the Roman periods (presence of headlands). However, many projects

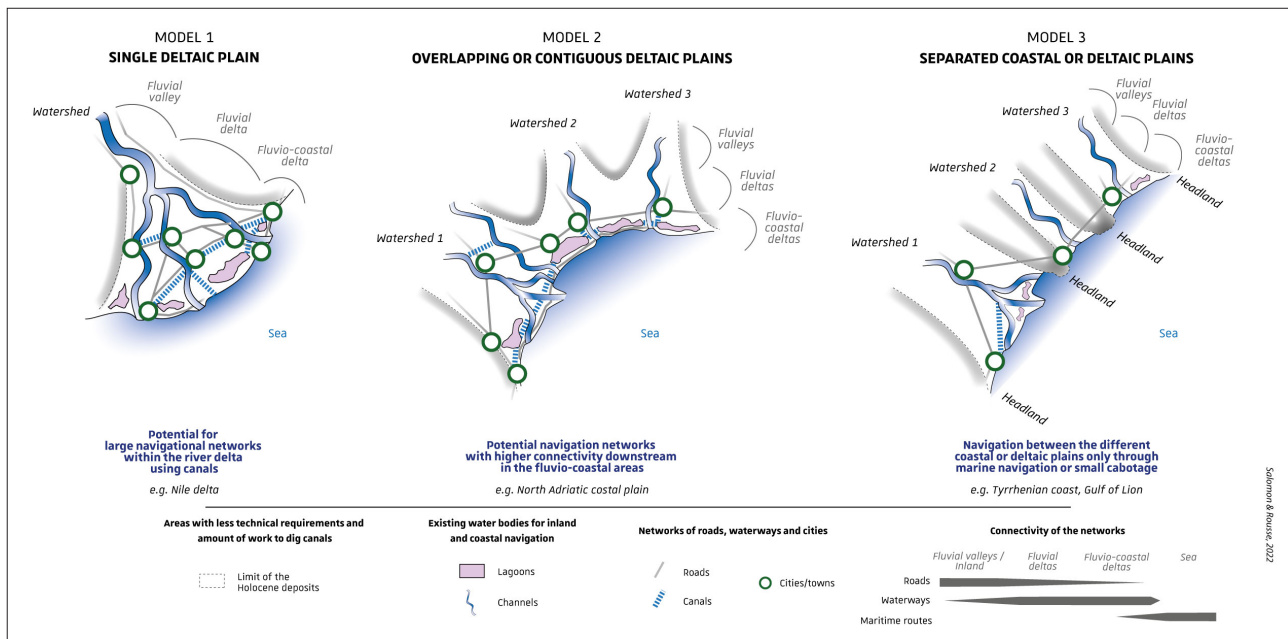


Figure 5. Advantages and constraints for interconnected port systems in fluvio-coastal environments in the Roman period. The limits of the fluvial and coastal lowlands and Holocene deposits are important settings guiding the development of port systems and their interconnection through canals.

were envisioned according to ancient authors. The proximity of Rome provided many comments from ancient authors while less are available for projects established in the Po and Nile delta. This might slightly twist our perception. However, needs were particularly important to carry the grain from Egypt to Rome during the Early Imperial period. Consequently, even projects that required a lot of resources and logistics were realised (Portus) or started (canal of Nero). However, if the canal of Nero was initiated, his successors abandoned the project probably due to the large amount of work required by the task (Model 3 in fig. 5). In contrast, many more opportunities to dig canals were offered in the Po and Nile delta.

5. CONCLUSION

The three models proposed are based on three coastal settings hosting original fluvio-coastal port systems in the Mediterranean area (fig. 5). Our knowledge about the ports, harbours and canals discussed in this paper are still fragmentary. Many hypotheses should still be confirmed on the field by geophysical, geoarchaeological and archaeological surveys, especially regarding the identification of the Roman canals. The three case studies are presenting similar elementary features such as deltaic areas, channels, lagoons, cities, harbours and canals that are combined according to natural evolution

of the different coastal landscapes, inherited or reorganised by Roman territorial planning. During their conquests, technological transfers in water engineering benefited Romans (Rousse 2016; from Etruscan but also from Venets, observed at Ateste, Padova or Altinum).

This proposal of three models is not restrictive but they are probably the most advanced development of port systems in deltaic and coastal plains combining port-cities, harbours and navigable canals during the Roman period. Model 1 regarding the “single deltaic plain” can actually be applied to deltaic areas of different scales (e.g. Rhône delta, Tiber delta). The Rhône delta already had a part of this system where a navigable canal connected a branch of the delta to a major coastal port-city (e.g. *Fossae Marianae*), similar to the role of the Canal of Alexandria. The Tiber delta with the port-city of Ostia and Portus, had all kind of canals interconnecting the two sites together along the shore (Portus-Ostia canal), linking the river to a major harbour (*Canale Romano*, *Fiumicino*, *Canale Traverso*), offering new mouths to the delta (*Fiumicino/Fossa Traiana*). With only the first pieces of the puzzle, the Rhine-Meuse delta could fit into Model 2 developed on “overlapping or contiguous deltaic plains”. The *Fossa Corbulonis* connected two tributaries of two hydrographic systems, the Rhine and the Meuse. Finally, Model 3 is referring to the most common configuration of Mediterranean shores with “separated coastal or deltaic plains” of small sizes. The coast of the Gulf of the Lion, in-

cluding the port system of Narbonne (*Narbo Martius*) on the delta of the Aude River, corresponds to a series of coastal lagoons and small river mouths separated by headlands (Cap d'Agde, Cap Leucate, Cap Béar).

6. ACKNOWLEDGEMENTS

A sincere thank you to Leah Holguin for her diligent proofreading of this paper.

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ISBN: 978-84-125214-1-2



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