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Exploration of the maritime façade of Utica: The potential location of the Phoenician and Roman harbours

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ABSTRACT

According to ancient literary tradition, Utica is considered to be one of the first three Phoenician foundations in the Western Mediterranean, supposedly founded in 1101 BC by Levantines from Tyre. In the Phoenician and Roman periods, it was an important merchant coastal town, on a promontory facing the sea. Over the centuries Utica lost its access to the sea, and its ports silted up as a consequence of the activity of the wadi Medjerda, which flowed to the south of the city. Despite over a century of investigation by archaeologists and associated researchers, the location of the city's harbour structures from the Phoenician and Roman periods remains unknown, buried under sediments resulting from the progradation of the Medjerda. Based on the study of sedimentary cores, the research presented here highlights the existence of a long maritime façade to the north of the Utica promontory in Phoenician and Roman times. A deep-water marine environment is attested in the former bay from the 6th mill. BC and the depth of the water column along the northern façade was still 2 m around the 4th – 3rd c. BC. Another core to the east of the Kalaat El Andalous promontory showed the possibility that this sector was a sheltered harbour during the Phoenician and Roman periods. This paper illustrates the contribution of geoarchaeology to address this archaeological problem and to understand the relations of this important port city with the sea.

1. Introduction and state of the question

1.1. Historical background

Utica (Fig. 1) is considered as the largest city of “Libya” (i.e. Africa) after Carthage, according to Appian (*Roman History* V, II, 3). It lies in the lower Medjerda basin, at the eastern end of the Jebel Menzel Roul, in the former *Sinus Uticensis* (“Gulf of Utica”). It is mentioned for the first time in the 4th c. BC in the *Periplus* of Pseudo-Scylax (§111), which also mentions its port. According to later literary tradition, it was founded by Levantines from Tyre, three centuries before Carthage, at a date which can be calculated as 1101 BC (Pliny, *Natural History* XVI, 216; Pseudo-Aristotle, *de Mirabilibus Auscultationibus*, 134). Nevertheless, no archaeological remains date back beyond the 9th c. BC (Monchambert et al., 2013; López Castro et al., 2016).

Utica developed as an important city, second only among the western Phoenician, or Punic, cities to Carthage which established itself as the hegemonic leader of the Punic colonies in North Africa and the western Mediterranean. Over the centuries, the city expanded southwards from the end of the promontory on which the original nucleus of the site lay (Hay et al., 2010). It was besieged in the Second Punic War, and in the Third Punic War it opposed Carthage, and after the end of the war in 146 BC it was made the capital of the new Roman Province of Africa (Tissot, 1884). This change does not seem to have had an immediate effect on city organisation (Lézine, 1968), although by the end of the 2nd c. BC it had expanded to the south to cover over 80 ha, with an orthogonal street grid and a suburban area including pottery and lime kilns (Ben Jerbania et al., 2015). During the Civil Wars at the end of the Roman Republic, the city was besieged by Curio in 49 BC. After hearing the news of Caesar's victory at Thapsus (200 km south-east of

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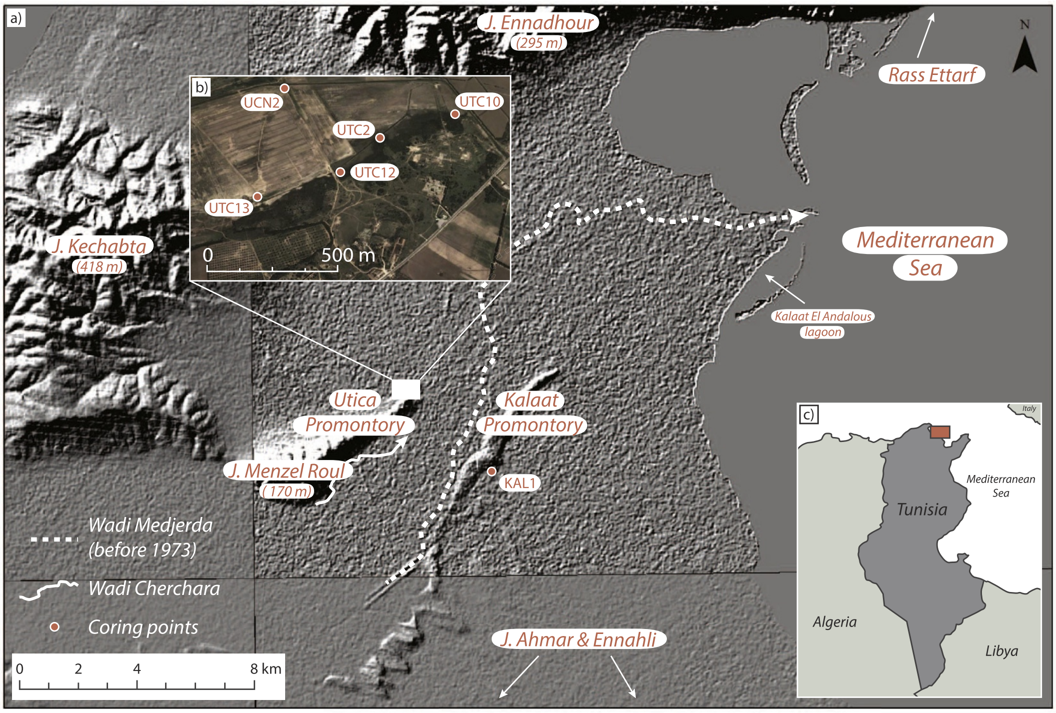

Fig. 1. Location map of the coring points; a) Hillshade from DEM: (Jarvis et al., 2008) (http://srtm. csi. cgiar. org); b) Google Earth image of the area of interest showing location of cores drilled to the north of the Utica promontory (Image © 2014 DigitalGlobe); c) Location of the study area on the northern coast of Tunisia.

Carthage), Cato the Younger committed suicide at Utica in 46 BC.

During the reign of Augustus (27 BC–AD 14), the government of the province was transferred to Carthage but Utica continued to prosper, first as a *municipium*, then as a *colonia* from the reign of Hadrian onwards. During the first two centuries of our era, major urban development projects were initiated (Lézine, 1968), and the city acquired all the public buildings expected in an important and prosperous Roman city; private houses of the period have lavish floors of mosaic and imported coloured marbles (Fentress et al., 2014). Pliny (*Natural History* XXXI, 39) mentions Utica as a centre for salt production by evaporating seawater, and archaeological research has shown that it was also producing (and probably exporting) salted fish in the Roman period (Fentress et al., 2013). The ruins currently cover an area of about 100 ha, suggesting that the population at its peak could have amounted to between 15,000 and 30,000 inhabitants (Delile et al., 2015b).

A marked decline in activity is observed in the late Roman period, although some private houses continued to flourish in the 4th c. AD. The civil basilica was destroyed in the late Roman period, and we have no trace of occupation on the site after the early 5th c., when an earthquake is recorded at the site (Fentress and Wilson, in press). The site was reoccupied in the 10th c., when an Islamic village developed on the remains of the city (Kallala et al., 2010; Fentress et al., 2014).

1.2. *Castra Cornelia*

Relevant to the wider regional setting and the question of Utica's port facilities is the site of *Castra Cornelia*, a military base established by Scipio some 4 km from Utica during the Second Punic War (218–202 BC) in order to interrupt communication between Carthage and Utica (Livy, *History of Rome* XXIX, 35, 13–14). It was also used by Curio during the Civil Wars (49 BC). Topographic details given by Caesar during his account of Curio's reconnaissance permit us to place this camp at the site of the present Kalaat El Andalous (Lézine, 1956). He also explains that the way between this promontory and Utica is rendered impracticable by the presence of marshes, and that it is necessary to circumvent the latter by making a detour, approaching Utica from the southwest (Caesar, *Civil Wars* II.24). Caesar talks about *Castra Cornelia* as “a straight ridge, projecting into the sea, steep and rough on both sides, but the ascent is gentler on that part which lies opposite Utica” (Caesar, *Civil Wars* II.24).

1.3. *The problem of the port(s)*

One of the supposed causes of the decline and then the abandonment of Utica is thought to have been the silting up of its harbour (Tissot, 1888; Bernard, 1911; Paskoff et al., 1991). This would have led the inhabitants of the city to modify their economic base, previously oriented towards maritime trade, in favour of the exploitation of the surrounding landscape (Lézine, 1968). The promontory of Utica, which possessed at least one maritime façade in the Phoenician and Roman periods, is at present 10 km from the shoreline, following the progradation of the Medjerda delta.

Several ancient texts mention the city's harbour, or harbours—Appian, writing in the 2nd c. AD but referring to events of the late 3rd c. BC, says that Utica had “harbours with good anchorage and numerous landing-places for disembarking armies” (*Roman History,* VIII 1.75). Yet their location has remained one of the major problems in the study of this archaeological site of primary importance for the investigation of the Phoenician expansion in the Mediterranean.

Since the 19th c., many authors have proposed hypotheses; most of these assume (1) that there was built infrastructure (docks, quays, moles, or a jetty) constituting a port; and (2) that this supposed port was located on the northern edge of the Utica promontory.

Beulé (1861), Daux (1868, 1869), Tissot (1884), and Reyniers (1952) saw in the ruins of what was later interpreted as the Roman Large Baths a monumental war port, in the center of which stood a “Palais de l'Amiral” (Fig. 2; n°1). To the east of the city, separated from it by a canal, they also supposed a second highly protected trading port (Fig. 2; n°2). These two ports would have been in operation during the Phoenician and Roman periods. They would have preceded the foundation of the ports of Carthage and might have served as an example for the latter (Daux, 1868). This hypothesis was subsequently refuted by

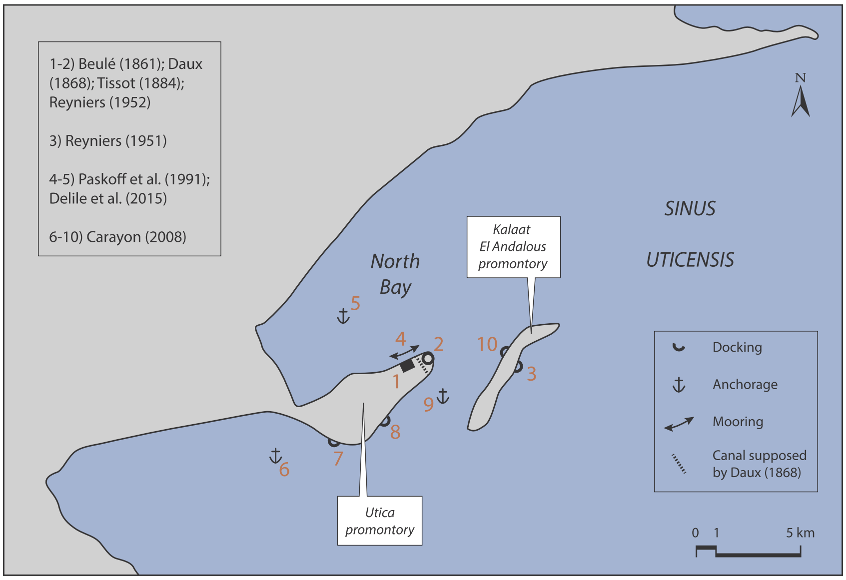

Fig. 2. Schematic map of Utica with the different hypotheses of the location of port structures according to different authors. The numbers are referred into the text.

Cintas (1951), Picard (1953), Lézine (1966), and then definitely excluded by Delile et al. (2015b). Indeed, the stratigraphy of a core taken in this area by Delile et al. (2015b) proves that the harbour cannot be located in the area of the Large Baths, since the bedrock lies above both modern and Roman sea level here.

Reyniers (1951) concluded that the corridor between the promontories of Utica and Kalaat El Andalous was filled early on, making Utica a sort of river port by the beginning of the Christian era, accessed from the west between the landings provided by the Medjerda and the Wadi Cherchara. This hypothesis is not so far from that proposed later by Delile et al. (2015b) of a maritime city accessed by an arm of the sea, bypassing alluvial bars caused by the progradation of the Medjerda delta. An “anchorage” on the eastern flank of the promontory of Kalaat El Andalous (Fig. 2; n°3) was also featured in a drawing by Reyniers evoking the situation in the 1st c. BC.

As Lézine (1966) has pointed out, according to the *Stadiasmus Maris Magni,* of the second half of the 3rd c. AD, there was no port at Utica, only a poor anchorage (*salos*) (*Stad.*, 126); but the same text mentions a harbour (*limen*) where large ships could over-winter at *Castra Cornelia*, modern Kalaat El Andalous (*Stad.*, 125) (Ghaddhab, 2016). Lézine also noted that Caesar's description of Utica during the Civil Wars suggests an anchorage: 200 merchant vessels were anchored in front of Utica and they left the besieged city without hindrance, so the harbour had to be an open bay and not a closed port (Caesar, *Civil Wars*, II, 25). Lézine deduced that the pre-Roman built structures which he supposed had existed were replaced in the 1st c. BC, or before, by a simple anchorage which was gradually suppressed by the sea swell. For him, the silting up of the port(s), and then of the anchorage, was not the result of a change of the course of the Medjerda, but was due solely to the action of the sea. During the imperial period, the port of Utica lay to the north-west, because by that time marshes (mentioned by Caesar) had developed to the south-east of the promontory (Lézine, 1966).

Another hypothesis proposed that the corridor between the promontories of Utica and Kalaat El Andalous could have been used as a port-channel, while the area situated to the southwest of Utica could have served as a natural harbour (Carayon, 2008) (Fig. 2; n°6–9). However, recent research proves that the wadi Medjerda began to influence the sedimentary accumulation in this corridor from 2600 BC, and that it was entirely silted up during the Roman Empire (Pleuger et al., in prep.).

According to the latest fieldwork, the most likely location of the ancient harbour would be on the north side of the Utica promontory to the east of the Large Baths (Fig. 2; n°4–5) (Paskoff et al., 1991; Paskoff and Trousset, 1992; Chelbi et al., 1995; Slim et al., 2004; Delile et al., 2015b).

This paper presents the results of analyses on sediment cores drilled on the northern façade of the Utica promontory and to the east of the promontory of Kalaat El Andalous, the most likely areas for the location of the Phoenician and Roman harbours. The aim of this research is to reconstruct the evolution of the coastal environment around Utica and Kalaat El Andalous to identify the potential location of the Phoenician and Roman harbours.

2. Geological and geographical background

The deltaic plain around the promontory of Utica is formed by Quaternary alluvium deposited by the Medjerda, the largest watercourse of Tunisia, and the only perennial river. The reliefs surrounding the plain are traversed by a dense network of wadis, adding to the water supply of the Medjerda in the plain. Anticlinal structures bound the plain on the south (Jebels Ahmar and Ennahli) and on the north (Jebels Ennadhour and Kechabta). These reliefs provide effective natural protection against prevailing winds from the northwest. The plain is divided into two parts by the anticline of the Jebel Menzel Roul to the west of Utica and the small horst of Kalaat (i.e., the substrate beneath the present city of Kalaat El Andalous). Upper Quaternary clay dunes compose the other hills (Fig. 1) (Paskoff and Trousset, 1992; Oueslati et al., 2006).

The dominant swell comes from the northwest and is deflected by the promontory of Rass Ettarf. It results in a weakened northeast swell, controlling the general orientation of the coast and the meanders of the river for centuries (Pimienta, 1959; Paskoff and Trousset, 1992; Oueslati et al., 2006; Delile et al., 2015a). The tidal range is low, 0.10 m during neap tides and 0.30 m during spring tides (Oueslati et al., 2006). Two phases of evolution of the Tunisian coast were highlighted by Oueslati (1995) and Paskoff and Oueslati (1988). First, an important progradation of the coast took place during the Punic/Roman period. A study of Anzidei et al. (2011) situates the Roman sea level (1.8 ka ± 0.05) at 0.58 ± 0.3 m below the local mean sea level (LMSL). This estimation is based on precise measures of presently submerged archaeological remains that are good indicators of ancient sea-level elevation. The second main phase is characterized by a sea level rise which began after the Roman occupation and continues to this day. The Medjerda delta is thus a special case, since the progradation continued after the Roman period and now stretches for 10 km (Delile et al., 2015b). It led to the isolation of Utica from the sea, leaving its harbour buried under several meters of alluvium.

3. Material and methods

3.1. Coring and radiocarbon dating

This study is based on the mechanical extraction of cores with a rotary corer, allowing us to probe several meters under the alluvium. This technique is a good compromise compared to conventional excavation methods to avoid the problems related to the water table in a delta area (Goiran and Morhange, 2003; Marriner et al., 2010; Brückner et al., 2013; Goiran et al., 2014). Indeed, the considerable thickness of sediment accumulation in this area makes it difficult to obtain interpretable geophysical results (Hay et al., 2010; Hay, 2015; Keay, 2015). The coring points were positioned in x, y, and z using a DGPS Trimble geoXT 6000, and a measurement was also taken in the Kalaat El Andalous lagoon (Fig. 1) to correct the elevation (z) of each core according to the current sea level. Two cores were taken: one along the northern façade of the Utica promontory (UTC12) in order to confirm or exclude the hypothesis that the harbour was located in this sector; the other along the eastern side of the Kalaat El Andalous promontory (KAL1) to see if the environment was suitable for an anchorage during the Punic and Roman periods. The AMS radiocarbon datings were calibrated with the OxCal 4.2.4 calibration program (Bronk Ramsey, 2009) using atmospheric IntCal13 or Marine13 curve (Reimer et al., 2013), and reported at the 95% confidence level or 2 sigma (Table 1). In this paper, a reservoir effect of 400 years was chosen in order to guarantee comparability between the Mediterranean sites (Siani et al., 2001; Jaouadi et al., 2016; Vött et al., 2018). The calibration curve used was decided according to the nature of the material dated and/or the delta 13C value.

3.2. Sampling and analyses

Based on the stratigraphic log, several samples were selected in each stratigraphic unit, and then analysed in the laboratory, using complementary approaches in order to reconstruct the palaeoenvironments and sedimentary processes (Marriner et al., 2010; Goiran et al., 2014; Pint et al., 2015).

Magnetic susceptibility was measured three times by a Bartington MS2E, in order to differentiate the stratigraphic units of the core. This signal allows to detect the variations in ferromagnetic mineral contents in the sediment, and in a deltaic context it reflects the detrital flux derived from fluvial processes (Delile et al., 2016). It is expressed in SI (Dearing, 1999).

Particle size analysis helps to determine depositional and transport processes. Texture analysis is carried out from a fraction of 30 g of dry sediment. The samples are sieved under water and the sieve residues are weighed to obtain the percentages of the different fractions (coarse fraction (> 2 mm), sands (2 mm–63 mm) and silts/clays (< 63 µm) (Salomon et al., 2014). For particles < 2 mm, laser granulometry was performed on bulk sediment, using a Malvern Mastersizer 2000 (ResearchUnit Inorganic and Structural Chemistry, Department of Chemistry, University of Liège). This technique allows one to obtain the granulometric distribution, the particle size histogram with its cumulative curve, and parameters like the median grain size (D50), which provides hydrodynamic information (Bertrand et al., 2005).

Loss-on-ignition (LOI) was performed to estimate the organic and carbonate content of the sediment. After oven-drying at 105 °C for 12 h, samples are placed in a muffle furnace at 550 °C for 4 h to determine the organic content, and then at 950 °C for 2 h to obtain the carbonate content (Heiri et al., 2001).

Mineralogical characterisation of the sediment is important in order to understand the genesis of the sediments, deciphering the transport mechanisms, and inferring past limnological, hydrological and climatic conditions (Last and Smol, 2002). Bulk mineralogy was carried out by X-ray diffraction (XRD), using a Bruker AXS D8 Advance diffractometer (Cu-Kα radiation, 40 kV and 25 mA), equipped with a linear detector (LINXEYE XE). Samples of non-oriented powder (Brindley and Brown, 1980) were passed through X-ray diffraction between 2 and 70° 2θ with a step size of 0.02° 2θ. Mineral characterisations were determined with the EVA 3.2 software and their abundance was calculated in a semi-quantitative way (± 5%) following (Cook et al., 1975).

Thin sections were made to visualize and identify the characteristics of grains and fossils constitutive of the sediment. After resin-impregnation, a block of sediment was glued to a glass microscope slide and polished to obtain a 35 µm-thick section which can be observed under microscope with normal light or crossed nicols (Last and Smol, 2002).

4. Results

The stratigraphic logs of the two cores UTC12 and KAL1 are described from bottom to top and the depths are expressed as metres below the surface of each core. Both raw and calibrated radiocarbon dates are given in Table 1; in the discussion below, the calibrated date range at 2σ (95.4% probability) is given.

4.1. UTC12 core

Core UTC12 was drilled in the marshy area north of Utica (Figs. 1 and 3). The depth of this core is 9 m and it can be divided into five major units.

The top of unit A (9–6.80 m) is dated to 373–201 BC at 6.87–6.93 m. This unit is composed of yellow to grey laminated fine sands, between 36 and 91% of the total sample weight. The organic matter rate is between 0.5 and 3%, while the carbonates are between 0.5 and 25%. Quartz represents the major part of the mineralogy (40–90%).

Unit B (6.80–6 m) is constituted by calcareous crusts interspersed with white clays. The coarse fraction represents up to 65% of the total sample weight around 6.04 m, but D50 is between 0.004 mm and 0.01 mm. Organic matter composes 2–3% of the sediment. The carbonate proportion is high (25–33%), corroborated by the calcite which reach ~65% of the total mineralogical composition. Pyrite is present, but in traces (< 1%).

Unit C (6–4.30 m) is dated to AD 117–252 at 5.51–5.64 m. It is composed of dark marine sands, containing a lot of rolled potsherds. A peak of magnetic susceptibility is observed at 5.14 m. Sands compose the major part of the texture, with 60–90% of the total sample weight. The proportion of organic matter is between 0.7 and 3.5%, and the percentage of carbonates is from 2 to 20%. Dolomite, gypsum and pyrite are present, but each of them accounts for less than 1% of the total mineralogical composition of the sediment.

Unit D (4.30–3.80 m) is a peat layer, whose base is dated to AD 663–778 (4.14–4.17 m). Organic matter comprises up to 35% of the sediment (at 3.91 m), and the carbonates are between 8 and 15%. Pyrite accounts for 5% of the mineralogical composition.

Unit E (3.80–0 m) is constituted by grey to beige silty clays, sometimes containing organic matter. Fraction < 63 µm composes 90–99.5% of the total sample weight, while D50 is between 0.003 and 0.011 mm. Total clays constitute 40–50% of the mineralogical composition. The proportion of organic matter is 8%, and of carbonates 15%.

4.2. KAL1 core

Core KAL 1 was drilled along the eastern side of the Kalaat El Andalous promontory, in order to check the possibility of an

Table 1

Radiocarbon datings. The AMS radiocarbon datings were calibrated with the OxCal 4.2.4 calibration program (Bronk Ramsey, 2009) using atmospheric IntCal13 or Marine13 curve (Reimer et al., 2013), and reported at the 95% confidence level (2 sigma).

Core	Depth below soil surface (m)	Depth below present MSL (m)	Laboratory code	Material	δ ^{13}C	^{14}C age (B.P.)	Atmospheric curve cal. date (Reimer et al., 2013; 2σ)	Marine curve cal. date (Reimer et al., 2013; 2σ)	Reference
KAL1	2.80–2.83	+ 0.22 to + 0.19	Lyon-13587	Charcoal		2025 ± 30	112 BC–AD 55		This study
KAL1	6.80–6.83	− 3.78 to − 3.81	Lyon-13588	Sea urchin		3385 ± 30		1396–1208 BC	This study
UTC2	4.13–4.16	+ 0.46 to + 0.43	OxA-28614	Peat	− 26.13	1362 ± 26	AD 619–758		Delile et al. (2015a),b
UTC2	4.13–4.16	+ 0.46 to + 0.43	Lyon-10289	Peat		1195 ± 30	AD 720–941		Delile et al. (2015a),b
UTC2	4.37–4.44	+ 0.22 to + 0.15	Lyon-10288	Peat		1295 ± 30	AD 662–770		Delile et al. (2015a),b
UTC2	4.44–4.47	+ 0.15 to + 0.12	Lyon-10291	Shell		1860 ± 35		AD 443–635	Delile et al. (2015a),b
UTC2	4.56–4.61	− 0.02 to − 0.03	Lyon-10290	Peat		1560 ± 30	AD 420–565		Delile et al. (2015a),b
UTC10	2.88–2.90	+ 1.70 to + 1.72	Lyon-12628	Peat	− 20.67	1460 ± 30	AD 553–648		Pleuger et al., in prep.
UTC10	4.98–5.01	− 0.38 to − 0.41	Lyon-13581	Vegetal matter		1600 ± 30	AD 399–539		Pleuger et al., in prep.
UTC10	6.00–6.03	− 1.40 to − 1.43	Lyon-13582	Vegetal matter		1725 ± 30	AD 245–389		Pleuger et al., in prep.
UTC10	7.39–7.42	− 2.79 to − 2.82	Lyon-12629	Wood	− 20.9	1640 ± 30	AD 336–535		Pleuger et al., in prep.
UTC10	8.60–8.65	− 4.00 to − 4.05	Lyon-13583	Vegetal matter		1940 ± 30	20 BC–AD 130		Pleuger et al., in prep.
UTC12	4.14–4.17	+ 0.19 to + 0.16	Lyon-13584	Vegetal matter		1270 ± 30	AD 663–859		This study
UTC12	5.51–5.64	− 1.18 to − 1.31	Lyon-13585	Vegetal matter		1830 ± 30	AD 81–311		This study
UTC12	6.87–6.93	− 2.54 to − 2.60	Lyon-13586	Seeds		2215 ± 30	373–201 BC		This study
UCN2	4.47	− 0.17	GdA-5017	Vegetal matter	− 25.8	1160 ± 25	AD 775–964		Pleuger et al., in prep.
UCN2	10.47–10.50	− 6.17 to − 6.20	GdA-5019	Vegetal matter	− 25.4	2090 ± 25	179–46 BC		Pleuger et al., in prep.
UCN2	16.70–16.74	− 12.40 to − 12.44	GdA-5018	Posidonia	− 13.0	2095 ± 25		AD 188–572	Pleuger et al., in prep.
UCN2	22.42–22.46	− 18.12 to − 18.16	GdA-5020	Vegetal matter	− 26.8	3525 ± 30	1936–1756 BC		Pleuger et al., in prep.

environment suitable for anchorage harbour during the Phoenician and/or Roman periods (Figs. 1 and 4). The depth reached is 11.5 m, and the core KAL 1 can be divided into three major units.

Unit A (11.5–6.20 m) is composed of a very compact layer of dark grey clays with oxide nodules. It can be divided into three subunits. In the first subunit (A1; 11.5–8 m), fraction < 63 μm constitutes up to > 99% of the total sample weight. Organic matter represents 10–11% and carbonates 13–14% of the sediment. Subunit A2 (8–6.80 m) contains a lot of fragmentary shells. The top of this subunit is dated to 1396–1208 BC (at 6.80–6.83 m). It contains 10 to > 30% of elements between 63 μm and 2 mm. The proportions of organic matter are between 7 and 11%, and the carbonates between 13 and 17%. The last subunit (A3; 6.80–6.20 m) is a layer of laminated grey clays, interspersed with fine sands. Fraction < 63 μm represents up to > 98% of the total sample weight. Organic matter is from 10 to 14% and the carbonates from 10 to 15%. Halite and pyrite are present in the whole unit (≤ 4% and 1%).

Unit B (6.20–2.36 m) is composed of fine ochre sands. The base is dated to 112 BC–AD 55 (at 2.80–2.83 m). This unit can be divided in two subunits. The base of the subunit B1 (7–5 m) is dominated by a silty-clay fraction between 6.86 and 6.19 m b.s. (up to 99.6% of the total sample weight), while the top contains more sands (up to 67%). The organic matter is between 3 and 14% and the carbonates between 10 and 20%. In the subunit B2 (5–2.36 m) the sandy fraction represents up to 90% of the total sample weight, with coarser sands. Proportions of organic matter and carbonates are lower than in the previous subunit, with respectively 2–4.5% and 12–16%. Quartz represents up to 70% of the mineralogical composition of the sample in the subunit B2. Halite is quite constant in the unit, and decreases very strongly after 3 m. Pyrite is also constant in trace (≤ 2%), but disappears after 4 m.

Unit C (2.36–0 m) is a homogeneous layer of ochre clays, corresponding to the present *chott*.

5. Interpretation and discussion

5.1. *The northern facade of the Utica promontory: a potential harbour environment*

The base (unit A) of the core UTC12 seems to correspond to a coastal environment influenced by currents (Fig. 3). Indeed, the laminated yellow sands that form unit A are between 1.90 and 4 m below the ancient sea level. The C/M diagram (Fig. 5; B), which gives indications about the transport and deposit processes, clearly shows that the sediments of unit A were subject to a graded suspension dynamic, indicating a turbulent current inducing good sorting. The top of this unit is dated to the 4th–3rd c. BC, which means that during the Punic period, the northern frontage of the Utica promontory was bathed by the sea. The depth of the water column (between 1.90 and 4 m below Roman sea level) shows that navigation was possible at this time, and that this sector was favourable to the mooring of ships. Estimates suggest that a depth of *c.* 3.6 m could accommodate a Roman merchant ship of 300–500 tons; 2.3 m of water could accommodate a ship of *c.* 150 tons; and a 70-ton ship could anchor in just 1.4 m of water (Boetto, 2010; Salomon et al., 2016). The coarse subunit may be the consequence of a storm, or the result of colluvial inputs coming from the slopes of the promontory.

The transition to the next unit, a white carbonate crust, is abrupt. In general, the presence of “calcretes” or carbonate encroachments is taken as an indicator of arid or semi-arid hot climates, with an important seasonal moisture deficit (Loisy and Pascal, 1998). Shallow water carbonate sequences in the geological history commonly show exposure surfaces indicating emersion of sediment due to sea level oscillations and progradation processes (Wright, 1994). Moreover, the presence of a calcareous substrate is necessary for the formation of a calcrete, which is not the case here (F. Boulvain, personal communication). Thin sections revealed the concomitant presence of quartz

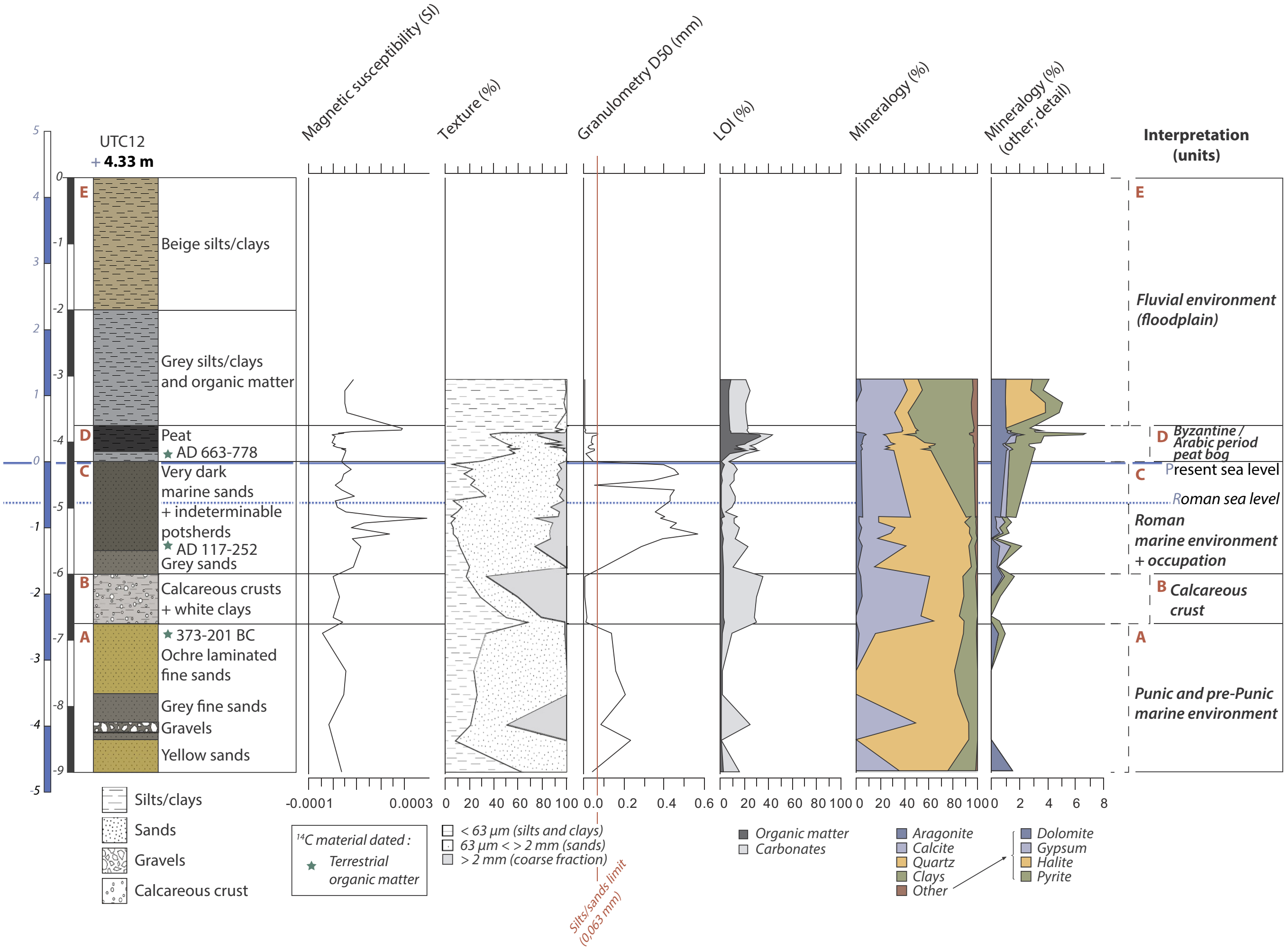

Fig. 3. Stratigraphic log of the UTC12 core and interpretation of the units. Magnetic susceptibility was measured by a Bartington MS2E and is expressed in SI. Texture analysis is carried out by wet sieving. Laser granulometry was performed using a Malvern Mastersizer 2000. For the loss-on-ignition (LOI), the organic content was obtained by heating 4 h at 550 °C and the carbonate content after 2 h at 950 °C (Heiri et al., 2001). Bulk mineralogy was carried out by X-ray diffraction (XRD), using a Bruker AXS D8 Advance diffractometer (Cu-Kα radiation, 40 kV and 25 mA), equipped with a linear detector (LINXEYE XE). Mineral characterisations were determined with the EVA 3.2 software and their abundance was calculated in a semi-quantitative way (± 5%) following (Cook et al., 1975).

grains of very different sizes, blunted or not (Fig. 6). This is not common in a calcrete. Many marine fossils and a fragment of volcanic rock are also visible in these thin sections. The presence of such a sequence is difficult to explain here. Indeed, taking into account the ancient sea level, the top of this layer of carbonate crust lay under a 1.1 m high water column. Moreover, according to the dating of the previous unit (unit A), this layer dates from after the 4th–3rd c. BC and no fluctuation of the sea level of such amplitude can be envisaged at that time. These sediments could thus not have emerged from the sea at any time. This unit probably represents either natural deposits of evaporation transported from a nearby lagoon or sebkha or an anthropic composite lime material composed of crushed shells, sands and some fragments of volcanic rock. This lime composition is found in Meninx and Kerkouane in the Punic period (Paskoff et al., 1991). The sharp transition between this layer and the previous unit argues in favour of an anthropogenic deposition. Moreover, this layer is local because it is not found in the nearby UTC13 core (Fig. 7). During a manual auger survey within a Punic ditch of the ancient city, a similar carbonate deposit was observed under a Roman soil. This suggests that it was a construction deposit from some activity nearby, or a demolition layer dumped into the harbour.

The carbonate deposit is covered by unit C, composed of dark sands mixed with fragmentary shells and ceramic sherds (Fig. 3). The sherds are water-worn and their state of preservation prevents any characterisation. This unit seems to be linked to a beach deposit, interface between land and sea, a mix of natural and anthropic elements, a reflection of human activities on the coast. The blunted aspect of the sherds and the grain size suggests a high-energy environment. According to the C/M image (Fig. 5; B), unit C presents a dynamic profile and was formed by rolling combined with graded suspension. With the decrease of the water column due to the sedimentary accumulation, the influence of the swell increases from unit A to unit C and induces a higher turbulence. If a mole or any protective structure was present, it must have lain to the west of this point, which was exposed to a significant hydrodynamism, the dominant swell coming from the north-east. Taking into account the age-model (Fig. 5; A), the basis of the unit would date from the 1st c. AD. But it should be noted that the previous unit can skew the age-model, if it is an intentional deposit that formed

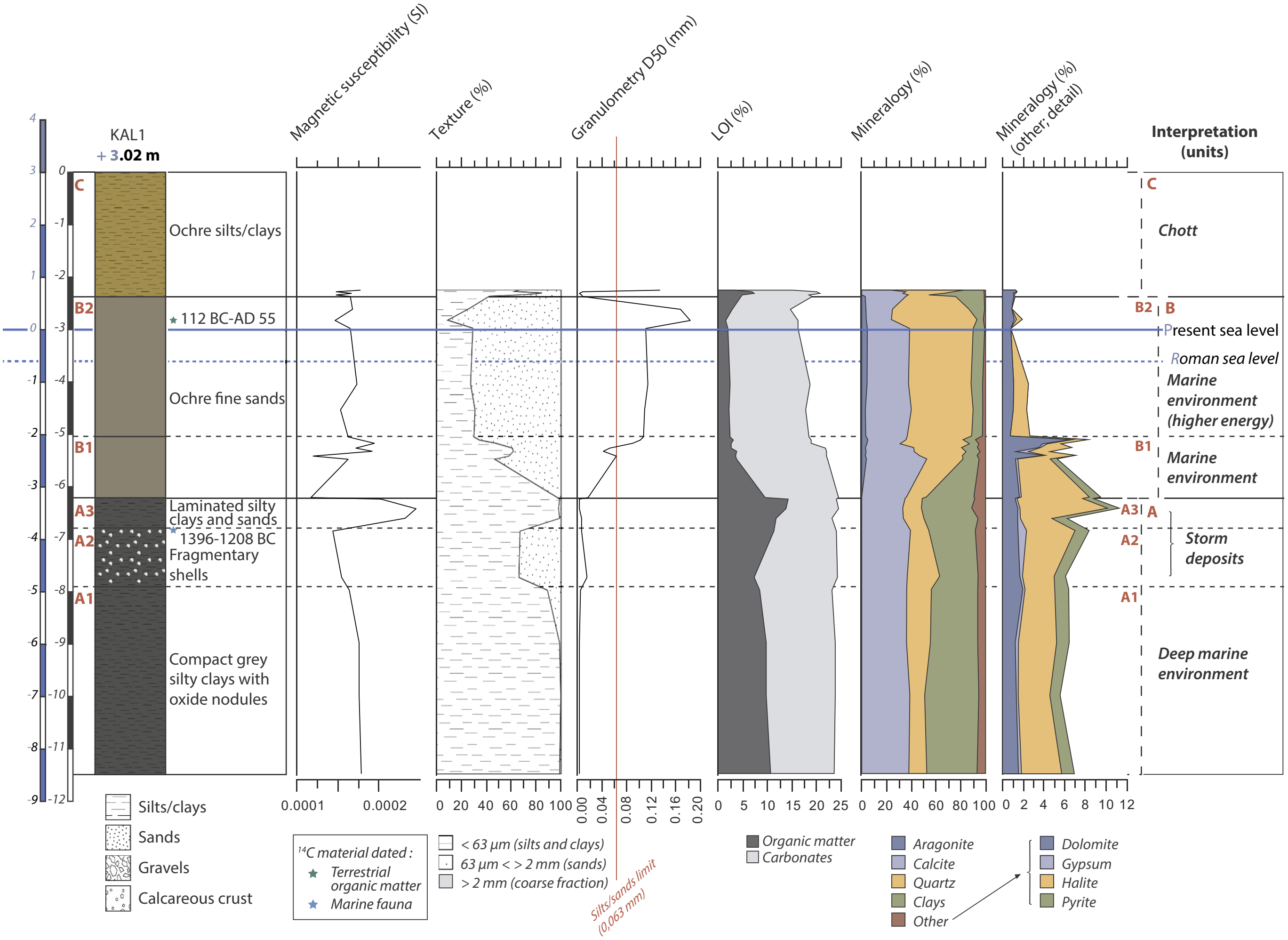

Fig. 4. Stratigraphic log of the KAL1 core and interpretation of the units. Magnetic susceptibility was measured by a Bartington MS2E and is expressed in SI. Texture analysis is carried out by wet sieving. Laser granulometry was performed using a Malvern Mastersizer 2000. For the loss-on-ignition (LOI), the organic content was obtained by heating 4 h at 550 °C and the carbonate content after 2 h at 950 °C (Heiri et al., 2001). Bulk mineralogy was carried out by X-ray diffraction (XRD), using a Bruker AXS D8 Advance diffractometer (Cu-Kα radiation, 40 kV and 25 mA), equipped with a linear detector (LINXEYE XE). Mineral characterisations were determined with the EVA 3.2 software and their abundance was calculated in a semi-quantitative way (± 5%) following (Cook et al., 1975).

in a very short period. At this point the depth of the water column in Roman times was 1.1 m, which is too shallow even for the navigation or anchorage of a small boat (Boetto, 2010). This sector was thus used as a mooring site during the Roman period, rather than as a port. According to the age-depth model and the ancient sea level, the aggradation of the sands follows the rise of the sea level until the 7th c AD.

The core UCN2(Figs. 1 and 8), drilled 600 m north of UTC12, showed that there was a marine environment about fifteen meters deep in the Punic and Roman periods (Pleuger et al., in prep.). The bay situated to the north of Utica was thus able to shelter a large number of boats anchored in it, while smaller boats could be drawn up onto the beach or dock on a mole or other port structure. It is essential to locate the shoreline and assess the depth of the water column to determine the maximum draft of ships that approach it. The draft of a fully loaded vessel would restrict its access to port infrastructure, and limit its circulation capacities (Boetto, 2010). Utica's northern bay, with a large span and wide opening, allowed any type of boat to manoeuvre. The deep bay of Utica, open towards the east, constituted a natural harbour protected from the prevailing winds which come from the northwest.

Given the stratigraphy of the UTC10 core and associated dates (Fig. 7), it is also probable that this was the area of the Roman harbour too. It appears that around 1 BC–AD 130, a water column of 4 m was still available at the UTC10 coring point. Much of the stratigraphic sequence of UTC10 could be interpreted as the consequence of the fluvial inputs generated by the progradation of the mouth of the Medjerda River. The chronological gap between the two deepest datings of UTC10 can be interpreted as an artifact generated by dredging, as underlined in similar cases (Salomon et al., 2017). Indeed, the first sedimentation rate is too low to be natural (0.33 cm/yr between 8.60 and 7.40 m b.s.), especially near a river carrying a high sediment load. This can only be explained by anthropic control of sedimentary accumulation, i.e. dredging. It was only later in the 4th c. AD that the sedimentation rate rapidly increased (7.3 cm/yr between 7.40 m b.s. and 5 m b.s.), which can be explained by a major alluvial crisis in the Medjerda river and by the cessation of dredging by the inhabitants of Utica, because they could not cope with the new sedimentation rate. The abandonment of dredging is probably also related to the notable decrease in the city activity in the late Roman period (Fentress et al.,

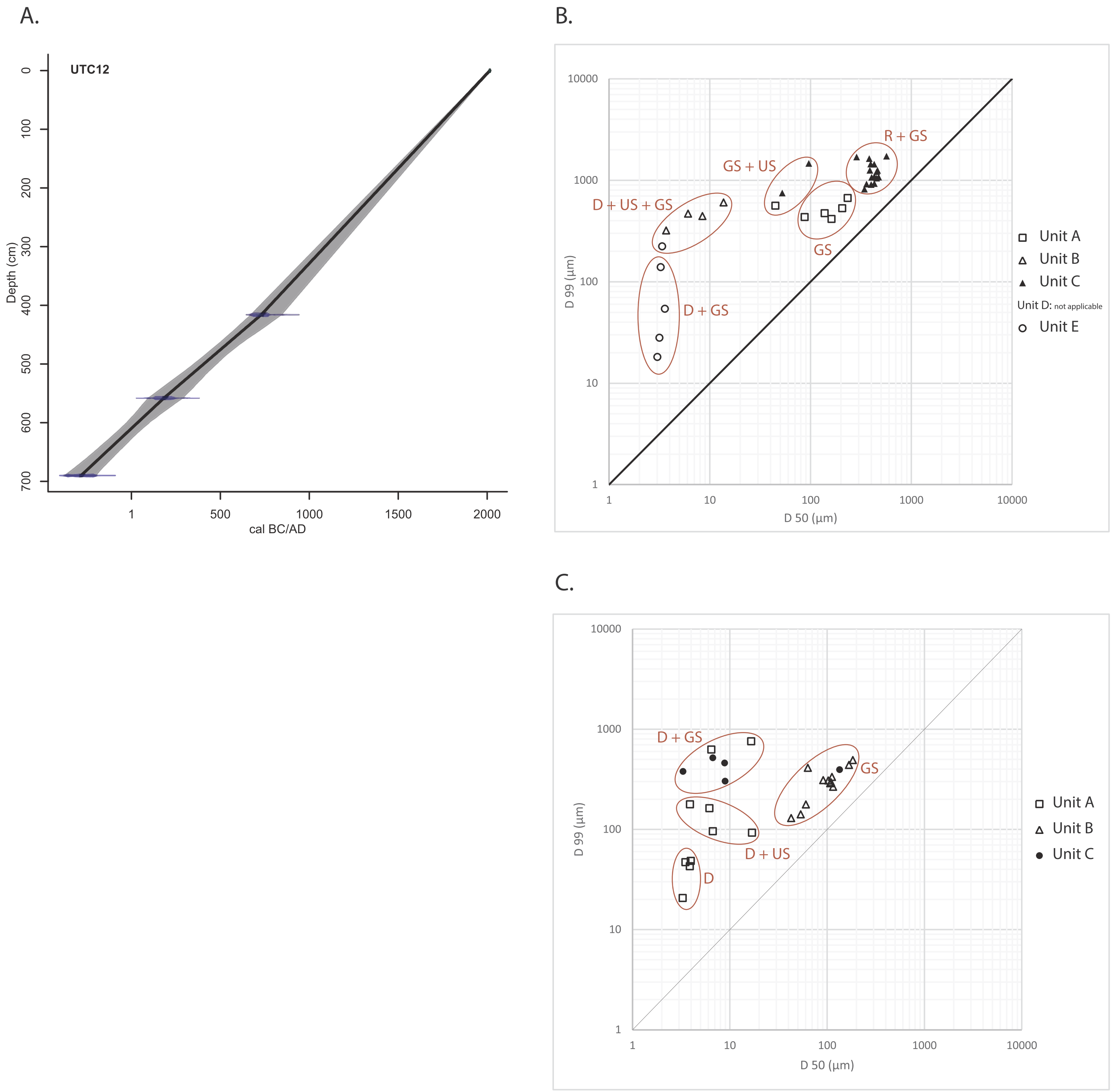

Fig. 5. (A) Age-depth model (software Clam for R (Blaauw, 2010)) for UTC12. (B) C/M diagram for the grain size (relation between the C = first percentile (D 99) and M = median (D 50)) for UTC12. (C) C/M diagram for KAL1. The different groups correspond to different sedimentation regimes. D: decantation; US: uniform suspension; GS: graded suspension; R: rolling. C/M representation of Unit D in UTC12 is not applicable because it is a peat accumulation.

2014). The area around UTC 10 could have been used as a port area, or at least the mooring site could have extended to this point. This transition zone between the vast seafront and the river was the first to suffer from the effects of siltation due to the progradation of the wadi.

The cores strongly suggest that the harbour of Utica lay in the sheltered bay to the north-west of the promontory where the original city developed. Neither archaeological survey nor coring have found any firm evidence of built port infrastructure—breakwaters, moles, or quays—and this is in agreement with the ancient texts, which as we have seen talk only of harbours (using a term which in ancient Greek need not imply built infrastructure) and an anchorage. From the 1st c. BC onwards the texts either explicitly say that the city had an anchorage but not an enclosed port, or they imply it. Large ships must have anchored in the bay and have been unloaded via lighters; smaller vessels may have been beached. The assumption by Lézine and others that before the 1st c. BC the city had a built port is unsupported; and if an anchorage in the bay was the form that the harbour took in the Roman period, it is perfectly likely that the same arrangement sufficed in the Punic period.

In core UTC12, the development of a peat bog is then attested after

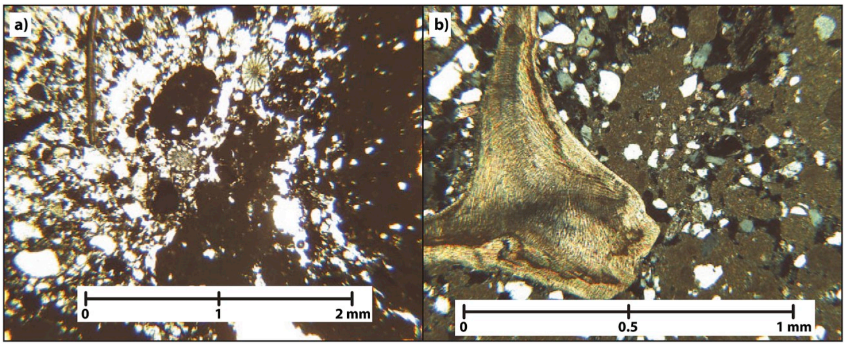

Fig. 6. Thin sections of unit B of the core UTC12; a) two echinoderms are visible under normal light; b) a fragment of mollusc and quartz grains are visible under crossed nicols.

the 7th or 8th c. AD, slightly above the current sea level. The dating from the base of the peat level is older by two centuries compared to the peat sequence of the UTC2 core described in Delile et al. (2015b) and of UTC10 (Fig. 7), suggesting that the peatland developed from east to west over the centuries, at a rate of 1.2 m per year. It can also be deduced that at the end of Antiquity, the embarkation area was localized further west than UTC10. Moreover, the absence of any peat layer in UTC13 suggests a localized peatbog (Fig. 7). Even localized, the presence of marshes would have made the place less and less salubrious and unsuitable for occupation.

Thereafter, a radical change in the environment is observed in the stratigraphy since the vertical accretion of the bog stops and gives way to clays probably of fluvial type, evidence for the gradual influence of the floods of the wadi Medjerda.

The northern frontage of the promontory of Utica became gradually unusable from the 4th c. AD, and was definitely isolated from the sea

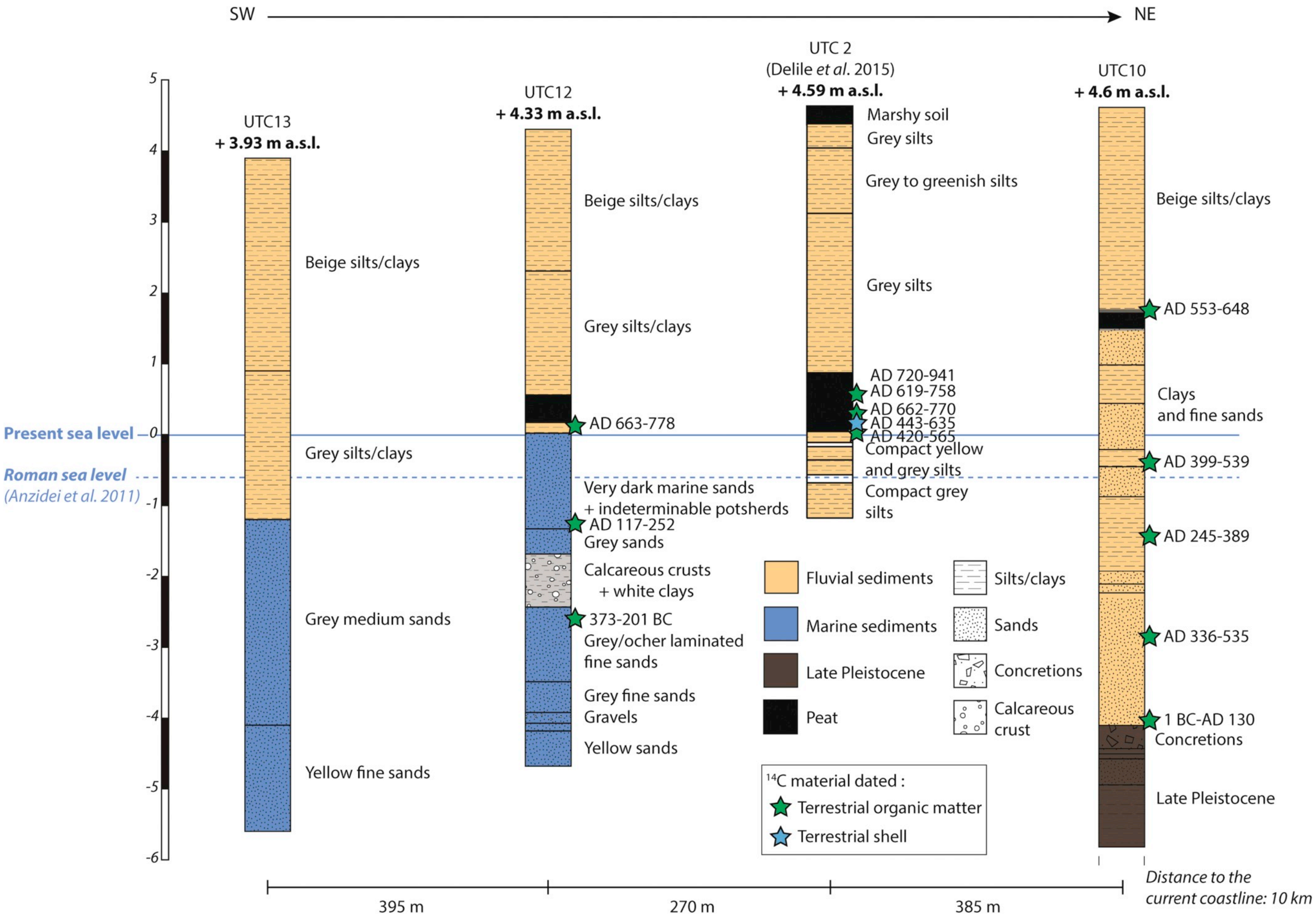

Fig. 7. Cross-section of the corings carried out in the northern façade of the Utica promontory. The cores UTC2 and UTC10 are described in Delile et al. (2015b) and in Pleuger et al. (in prep.), respectively.

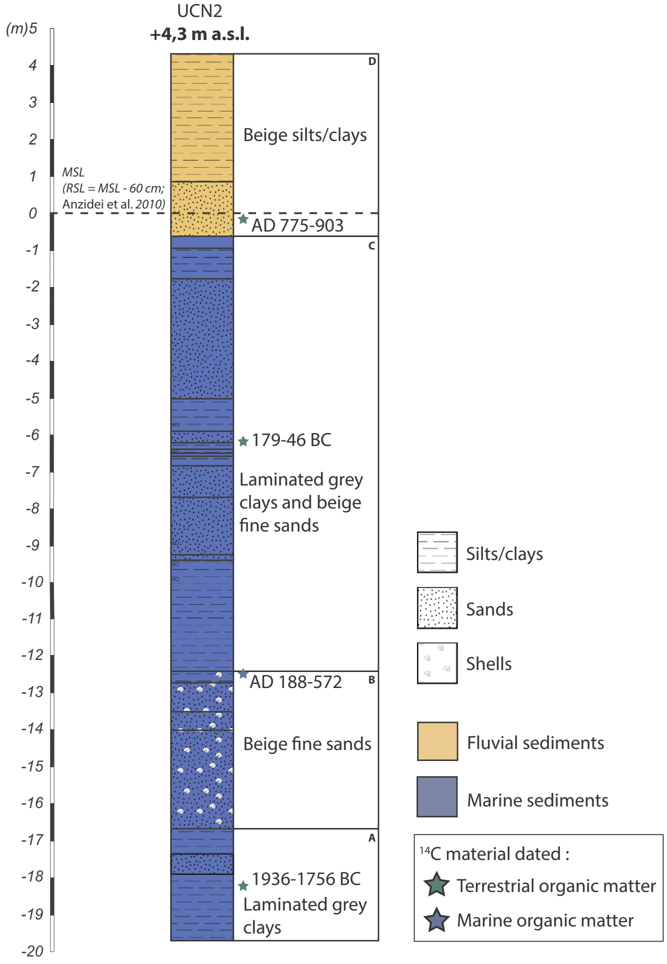

Fig. 8. Schematic stratigraphic log of the core UCN2. This core is described in Pleuger et al. (in prep.). The apparent inversion in the datings could be due to a remobilization of older organic matter by fluvial sediment inputs (Stanley and Hait, 2000).

from the 7th c. AD onwards, following fluvial contributions (Delile et al., 2015b). Then a peatbog progressively developed, forming from east to west until the 10th c. AD. A final environmental change occurred when the development of the peatbog stopped and gave way to alluvial deposits.

5.2. *East facade of the Kalaat El Andalous promontory: a potential harbour shelter*

The base of the KAL1 core (unit A; Fig. 4) consists of compact dark grey clays with exceptional induration. The particularly dark colour of this unit is due to the reducing environment, the presence of organic matter that has not been oxidized. The presence of oxidized pyrite nodules attests also a reducing and calm environment. The clay deposit indicates a calm subtidal environment. The A2 subunit would be the result of a storm or a landslide (presence of marine shells, spines of sea urchins, pebbles, etc.) at least for the top of the subunit. Bioturbation occurred later and resulted in the mixing and transport of these elements deeper in the subunit. The top of this A2 subunit dates from 1396–1208 BC, which supports the idea that this storm occurred before the legendary foundation of Utica and may have partly altered the configuration of the eastern facade of the promontory. In the A3 subunit, the numerous subhorizontal sand-clay laminations organized into multiple laminasets, indicative of high-frequency waves, could indicate a storm origin like that described in Morton et al. (2007).

Unit B is composed of fine ochre sands, witnesses of a marine environment less calm than in the previous unit. The upper part of this unit is dated from 112 BC–AD 55 at 2.80–2.83 m. According to the Roman sea level, a water column of 3.20 m deep was available around 1396–1208 BC In the Phoenician period, then, there was a coastal environment suitable for mooring small vessels, to access the promontory from the less steep side to the southeast on a gentler slope and sheltered from the prevailing northwest winds. An environment of higher energy is then attested within sub-unit B2, which is marked by coarser sands and by the disappearance of pyrite.

Taking into account the Roman sea level and the highest dating, it appears that these sands emerged before 112 BC–AD 55. In Roman times, the mooring of ships was thus no longer possible at this point, but only further east along the promontory or further south, where the slopes are gentler. At that time, the northwest tip of the promontory was already inaccessible because of the silting of the corridor between the two promontories of Utica and Kalaat El Andalous (Pleuger et al., in prep).

Fluvial influence begins to be felt from unit C, whose base is +1.24 m above the Roman sea level, when the muds from the mouth of the wadi flowing from the tip of the promontory began to seal the area and create a swamp/sebkha environment. Indeed, the C/M image (Fig. 5; C) shows that unit C presents a very different profile from that of the previous unit, marine and better sorted (Salomon, 2013). This unit C corresponds to decantation mixed with graded suspension, showing that the environment became influenced by the floods of the wadi Medjerda. According to the highest dating, this influence began after the 1st c. AD.

The eastern façade of the promontory of Kalaat El Andalous presented an environment suitable for the mooring of ships in Phoenician times, but the shoreline had already receded in Roman times, and mooring was therefore only possible in a more distal position to the east of the promontory (Fig. 9).

6. Conclusion

The deep bay to the north of Utica offered interesting port potential in the Phoenician period which evolved over the centuries with the progradation of the Medjerda delta (Fig. 9). Anchorage was possible in the sheltered bay, and the mooring of boats could be envisaged on the north face of the Utica promontory, in agreement with Delile et al. (2015b), but also on the northwest and the eastern face of the promontory of Kalaat El Andalous. But there is no evidence for major built port infrastructure such as harbour breakwaters, moles, or quays; and this is in fact consistent with the ancient texts. During the Roman period it was possible to anchor in the northern bay of Utica (where in places there was over 15 m of water column, but at some distance from the shore) and mooring along the northern frontage of the promontory of Utica remained possible until the 4th c. AD, when the Medjerda began depositing too much sediment and dredging was no longer carried out. Afterwards, a peat bog started to develop along this facade, following its isolation due to the alluvial deposits carried by the wadi. This chronology is in agreement with archaeological research, which indicates a decline of the city from the 4th c. AD. Mooring was probably still possible along the east side of the Kalaat El Andalous promontory, but more to the east than during the Phoenician period. It is probable that this promontory was no longer an island at the time of the first Phoenician settlement, because the corridor between it and Utica was

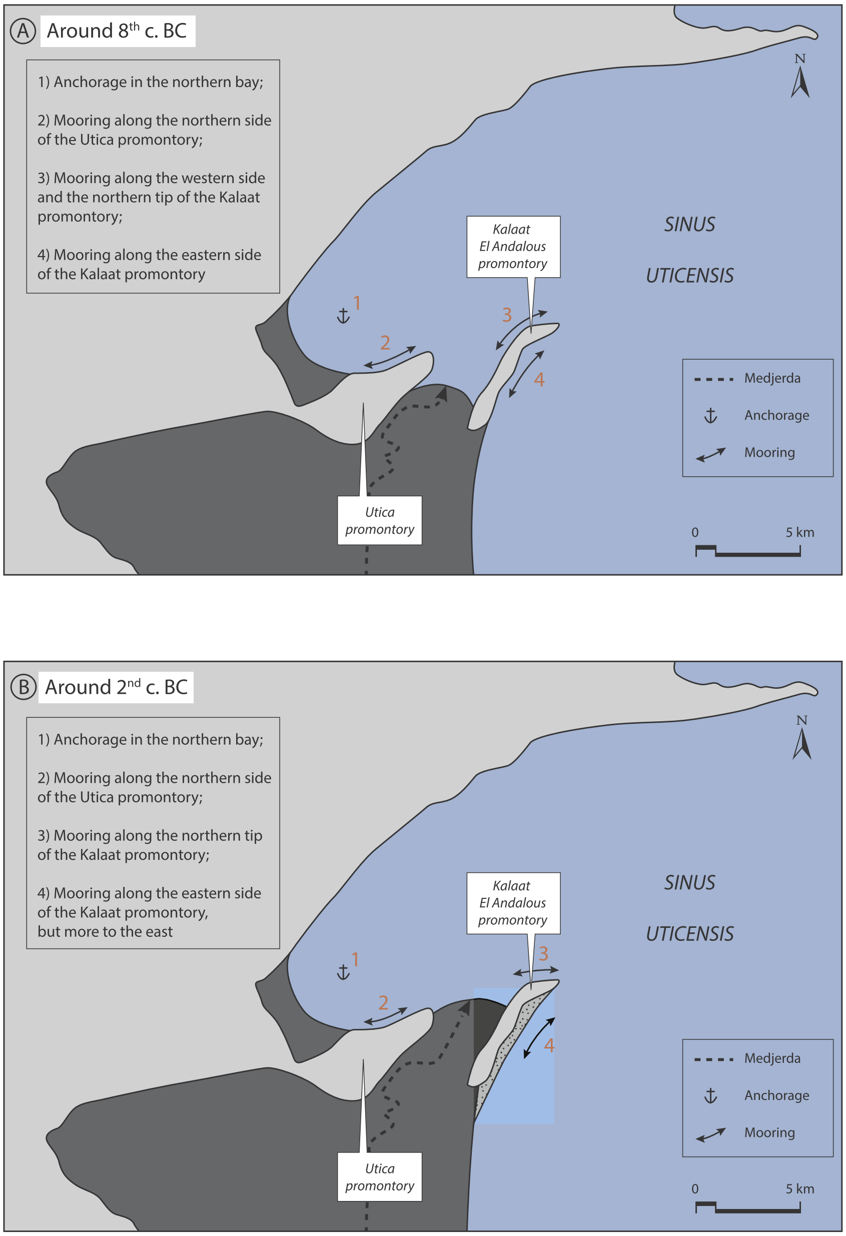

Fig. 9. Schematic map of Utica and its port potentialities around the 8th c. BC and around the 2nd c. BC.

already filling up at that time. Coring to the southwest of this promontory could attest if it was an island before the foundation of the city.

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