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Geoarchaeology of Portus Mareoticus: Ancient Alexandria's lake harbour (Nile Delta, Egypt)

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ABSTRACT

Ancient Alexandria possessed not only an important maritime front but also a long lake waterfront on its southern side. This dual waterfront was praised by the ancient geographer Strabo in the first century BCE, because its geomorphological configuration opened Alexandria to Mediterranean trade, and also the Nile delta and Egypt. While the city's maritime palaeogeography has been widely described and studied, Alexandria's lacustrine waterfront has largely been neglected and little is known about its palaeo-geography and archaeology. Here we report the chronostratigraphy of the southern edge of the modern city. Bio-sedimentological analyses of sediment archives allow us to reconstruct the evolution of the depositional environments and palaeogeographies for parts of ancient Alexandria's lacustrine waterfront. The chronological framework spans the last 2000 years. By marrying our data with ancient maps and historical sources, we propose a location for Portus Mareoticus. The lake's geomorphology suggests the presence of three ancient jetties, perpendicular to the shoreline and several hundreds meters long. The occupation of the investigated area began at the end of the first century BCE, linked to Roman domination and probably ended during late Roman times. The waterfront was then disconnected from the city during the 9th century CE, due to the desiccation of Maryut Lake, concomitant with the drying-up of the Canopic branch. Alexandria canal subsequently became the sole waterway linking the city to the Nile. The most western part of the canal, which extended freshwater supply and fluvial navigation down to the western marine harbour of Alexandria, was completed in the 16th century, probably in relation to the development of the marine harbours at the beginning of the Ottoman period. Our research sheds new light on the topography of ancient Alexandria.

1. Introduction

During the past 20 years, multi-disciplinary studies have underscored the attractiveness of lagoonal shores and basins during Antiquity. These environments provide rich halieutic resources (Marzano, 2013) and natural navigation and anchorage facilities (Morhange et al., 2015). After Strabo visited Alexandria in 24–25 BCE, he reported that the city drew its prosperity from trade linked to its complex harbour system, not only on the sea, but also on the shores of Lake Mareotis, south of the city, "so that the harbour on the lake was in fact richer than that on the sea" (Strabo, 17.7; in Jones, 1969). Lake Mareotis, the precursor of the present Maryut lagoon on the western Nile coast (Fig. 1), was a heavily used waterway in Antiquity. The lake's shorelines accommodated major production centres for different industries such as glass (Nenna et al., 2000), pottery (e.g. Empereur and Picon, 1998) and wine (e.g. Rodziewicz, 1998), which contributed significantly to the economy of Alexandria (Empereur, 1998; Blue and Khalil (2010); Pichot, 2012). Quoting ancient sources, Rodziewicz (1995, 1998) and Khalil (2005) claim that nearly all goods for both local and export markets, were shipped from the countryside to Alexandria via Portus Mareoticus. More emphatically, Sly (2013, p. 41) assumed that the transport of the world travelled through Mareotis.

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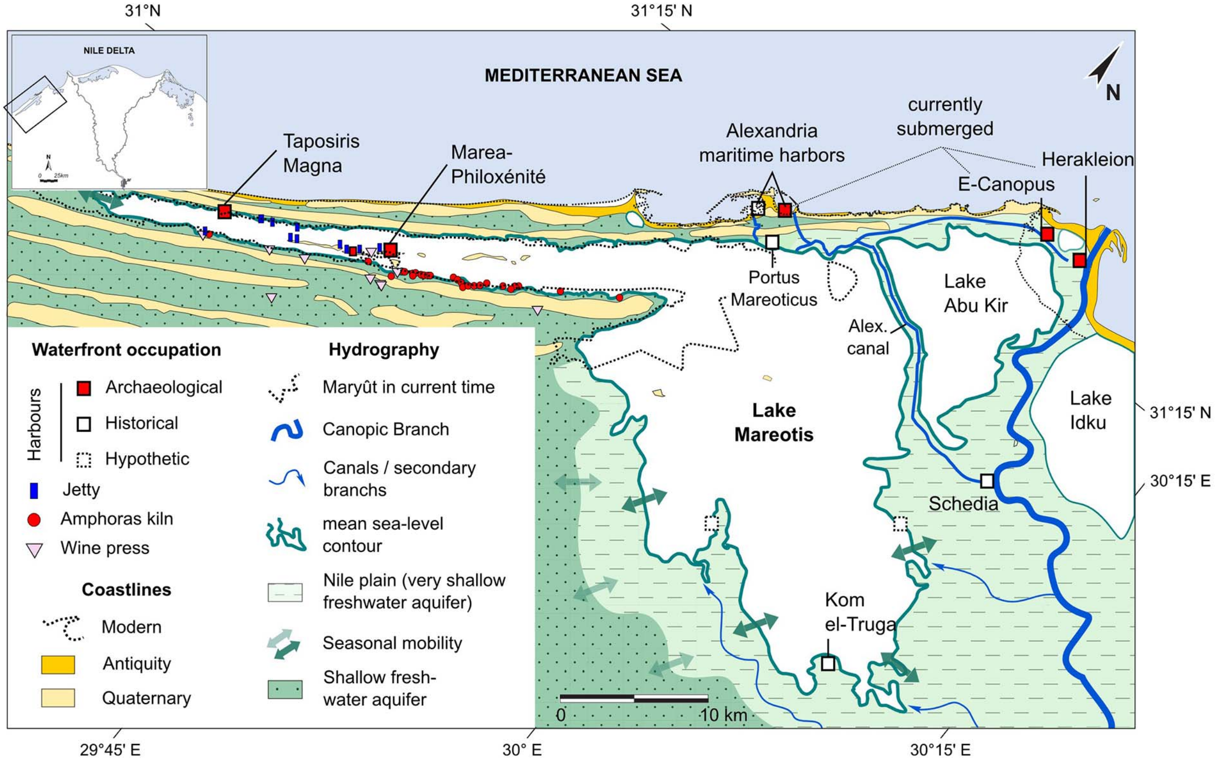

Fig. 1. Water networks on the northwestern Nile delta in Antiquity. Lake Mareotis is represented by the mean sea-level contour, assuming (1) that mean sea level in Antiquity was close to modern times (Sivan et al., 2004) and (2) that Lake Mareotis was connected to the sea by a canal crossing western Alexandria (Strabo, 17.10). Precise mapping of Canopic branch distributaries can be found in Wilson (2012). According to Strabo (17.16), the Alexandria canal was located at Schedia and had an outlet into lake Mareotis. Archaeological data for the western Mareotide are from the GEOMAR project (dataset in progress).

Rodziewicz (1998), based on the size of late Roman lake harbours still preserved on the western shores of Lake Mareotis shores, suggested that the Alexandrian "Portus Mareoticus" must have been very extensive, and was probably arranged all along the southern part of the city with several major and smaller basins.

In contrast to research efforts investigating the ancient maritime façade of Alexandria, including underwater archaeology (Empereur, 1998, 2004; Goddio, 1998; Hairy, 2006; Tzalas, 2015), geophysics (Hesse et al., 2002; Papatheodorou et al., 2015) and coastal cores (Goiran, 2001; Goiran et al., 2005; Stanley et al., 2006; Marriner et al., 2008; Stanley and Bernhardt, 2010), very little attention has been paid to the city's lacustrine waterfront. Its history, however, may provide rich data and elements of comparisons with the lacustrine hinterland, which has been extensively studied during the last thirty years (Blue and Khalil, 2010).

Rodziewicz (1995) explained that archaeological excavations are challenging along Alexandria's lacustrine waterfront because the area has been used for refuse disposal, industry and residential buildings. To fill this knowledge gap, we used geoscience methods to test the presence of lake sediments below the modern southern city and reconstruct the evolution of the lake's palaeo-shorelines.

2. Strabo and the geographical setting

"The place [Alexandria] is washed by two seas" wrote Strabo (17.7) when describing one of the main advantages of the site's geography. Indeed, the city was founded and developed upon a narrow calcareous sandstones ridge that separates the Mediterranean Sea to the north from the Maryut Lake to the south. The Maryut belongs to the lagoon belt of the Nile delta coast. Strabo wrote that the lake harbour imported more wares than the maritime harbours. He added that the latter exported more than it imported: "anyone might judge, if he were at either Alexandria or Dicaearchia [actually Pozzuoli, near Naples, Italy] and saw the merchant vessels both at their arrival and at their departure, how much heavier or lighter they sailed thither or therefrom" (Strabo, 17.7). These statements underline to what extent Alexandria's economy was based on exportation at this time (Yoyotte et al., 1997; Parker, 2011). Strabo did not provide any descriptions of the lake's harbour structures nor its topography. Nevertheless, his description of the region's hydraulic configuration demonstrates the connection between Alexandria's lacustrine waterfront to its hinterland and to the Nile delta's waterway network.

The city was connected to the Canopic branch and further deltaic waterways through the Alexandria canal (Fig. 1). The whole western delta was dependant upon the Canopic channel for its water resources, including freshwater and waterways. Although the Alexandria canal was probably dug during the early decades after the foundation of Alexandria (331 BCE), because of its crucial role in freshwater resources (Cosson, 1935, p. 81; Yoyotte et al., 1997; Hairy and Sennoune, 2006), Strabo gave the first description, and six inscriptions from Antiquity attesting to the consequent works on the canal are all dated to Roman times (from 10 to 390 CE; Hairy and Sennoune, 2006). However, because the canal was very prone to siltation by Nile sediments (Hairy and Sennoune, 2006), Bergmann and Heinzelmann (2015) suggest that the transfer of goods from the interior of Egypt would have occurred mainly on Lake Mareotis. Moreover, Strabo also added that Alexandria's canal had an outlet towards Lake Mareotis (Strabo 17.16), so that goods transported along the canal would have been transferred via Portus Mareoticus. According to Strabo, several other canals branched off from the Canopic channel (Fig. 1) and were also used for the transport of goods from the delta towards Alexandria via Lake Mareotis (Strabo, 17.4, 17.7 and 17.22). At least two of these canals were recently reconstructed using relic fluvial landforms. Their meandering paths suggest that they were ancient secondary deltaic branches. Archaeological sites bordering these palaeo-channels were active in Antiquity (Wilson, 2012).

At this time, Lake Mareotis extended for around 30 km into the southeastern deltaic plain (Flaux et al., 2012; Fig. 1). After extensive archaeological surveys in this region, Wilson and Grigoropoulos (2009) and Wilson (2010, 2012) have described farming towns, trans-shipping activities as well as points of control around the lake. Furthermore, the western arm of Lake Mareotis, situated between two late Pleistocene coastal sandstone ridges, has revealed numerous harbour structures (Fig. 1; Rodziewicz, 1998, 2002; Boussac, 2009; Boussac and El-Amouri, 2010, Pichot, 2010, Blue et al., 2011). The most impressive harbour remains belong to the cities of Taposiris and Marea-Philoxénité (Fig. 1), with respective customs functions (Boussac, 2009) and facilities for pilgrims travelling to the monastery of Abu Mena (Rodziewicz, 1983, 2003, 2010). Besides these specific activities, jetties and others harbour facilities were frequently associated with workshops and farming areas (Pichot, 2010; Blue et al., 2011). In particular, Empereur (1998) and Rodziewicz (2002, 2011) have underlined the strong relationship between amphora workshops, wine presses and harbour structures, a tripartite system of local wine production which supplied the Alexandria market. Thus, recent archaeological surveys all around ancient Lake Mareotis have underscored the region's agricultural vocation, connected to Alexandria's market via fluvio-lacustrine waterways. At the scale of Egypt, fluvio-lacustrine waterways appear in the voluminous papyrological documentation, from the 3rd century BCE to the 4th century CE, as the favoured transport means (Arnaud, 2015).

Finally, Strabo also evokes a navigable channel connecting Lake Mareotis to Alexandria's western maritime harbours (Strabo, 17.10). The lake harbour thus lay at the crossroads between three waterways: (1) to/from the delta and Egypt; (2) to/from western Mareotis' countryside; and (3) to/from the Mediterranean sea (Fig. 1).

3. Methods and data

Our reconstruction of Alexandria's lacustrine waterfront was made possible using litho- and biostratgraphic studies of radiocarbon-dated cores taken from the edge of the lake basin. The robustness of geoscience techniques in reconstructing the evolution of ancient harbour sites has been demonstrated around the Mediterranean (Marriner and Morhange, 2007). Two areas were investigated. The first area is located close to the promontory and jetty remains denoted on the map of *La description de l'Egypte* (Fig. 3). The latter was georeferenced and superimposed on the local cadastre using GIS. Four cores (A-3, A-6, A-7 and A-10) were drilled to reconstruct the late Holocene evolution of the shoreline and silting-up of the harbour. The second area concerns the termination of the Alexandria canal, whose outlet flowed into the western harbour (Fig. 2). Core A-2 was made to test whether this area could have been part of Strabo's canal linking lake Mareotis and the western maritime harbour. Core positions A-2, A-3 and A-6 were measured using a differential GPS (LEICA GRX1200G-GPRO). Core elevations were benchmarked against mean sea level (msl) using a tide gauge based in Alexandria's western harbour (Meulien, 1999). The elevations of cores A-7 and A-10 were estimated using an accurate topographic map from 1978 (1:5000).

Grain-size analyses and faunal assemblages of the sedimentary sequences were undertaken under standardized laboratory conditions. Strontium isotopes were measured in six samples composed of ostracod valves (ca. 30 when available; Table 2). This proxy helps to quantify relative Nile and marine water inputs into the basin. A single species, *Cyprideis torosa*, was choosen for analysis, because of its high tolerance to rapid environmental changes (Frenzel and Boomer, 2005). Details of analytical procedures for ^{87}Sr/^{86}Sr analyses can be found in Flaux et al. (2013). Replicate analyses of the NBS 987 standard yielded a standard deviation of ca. 30 ppm. Archaeological artefacts from the sand and gravels fractions were counted along the sequence, to detect changes in human inputs into the lake basin. Identified ceramics found in the cores helped in providing a general chronological framework. Eight radiocarbon dates performed on charcoal and one bone fragment constrain the chronology of the sedimentary sequence (Table 1). All dates were calibrated using Calib (Reimer et al., 2013). Furthermore, we used a compilation of 54 ancient maps of Alexandria by Jondet (1921), covering a period between the late 15th and early 20th century CE. Thuile (1922) commented on the atlas, providing useful information about the cartographers' biographies, the data used, the cartographic resolution and tools, and topics that the authors intended to show.

4. Results

4.1. Geomorphology of Alexandria's lacustrine waterfront

The southern side of the Mahmoudeya canal is characterized by a narrow strip of land, ca. 0.5 km wide, with low NW-SE slopes from 5 to 0 m msl. The slopes extend laterally to a flat plain consisting of polders reclaimed from the lake since the middle of the 19th century (Jondet, 1921; Fig. 2). Drainage and pumping of the lake since the early 20th century CE have led to a regression of the lake level in this area down to ca. 3 m below msl (Awad, 2010). The lake's shoreline has subsequently migrated southwards, promoting the industrial and commercial development of southern Alexandria. Thus, ancient maps from the first half of the 19th century CE are particularly important in understanding the palaeo-geomorphology of the lake's ancient waterfront in relation to settlement patterns (Fig. 3). The ruins of one ancient jetty were apparently still visible in the late 18th century (Fig. 3A), while west of Alexandria three others have been denoted on ancient maps (Fig. 3A-1). We used four ancient maps from 1798 to 1841 (Jondet, 1921) to superimpose shorelines and show a series of three sub-parallel palaeo-promontories whose longest axis lies perpendicular to the lake's shoreline (Fig. 3A-2). However, these jetties are today absent or have been buried below modern polders. By contrast, archaeology in the western Maryut Lake is still well preserved and visible today. As stated above, the rocky shores of the western Maryut were densely occupied in Antiquity, and recent surveys and excavations provide the opportunity to describe the geomorphology associated with ancient jetties. Fig. 3B provides two examples, from Taposiris and Marea-Philoxénité, where some of the most studied and well-preserved ruins can be found. In both cases, jetties orientated perpendicularly to the shores forced the accumulation of sediments at their edges, with the greatest accumulations on their western side. This asymmetric geomorphology is probably due to the dominant northwestern winds that characterize the region (Frihy, 2008), creating eastward currents and sediment transport within the narrow valley-like basin of the western Maryut basin. Similarly, the shore's morphology mapped in the *Description de l'Egypte* comprised an asymmetric promontory, with greater accumulation of material on its western edge (Fig. 3B). This geomorphology confirms the interpretation of an ancient jetty. In this sense, the two other promontories identified in early to mid-19th century maps (Fig. 3A-2) may also correspond to ancient lakeshore structures orientated perpendicularly to the shores, favouring the accumulation of sediment on their edges.

4.2. Stratigraphy of Alexandria's lacustrine waterfront

4.2.1. Core A-7

Core A-7 is located on the western side of the jetty mapped in the *Description de l'Egypte* (see Fig. 6). The retrieved sequence is 8 m thick. Five main units (A–E) were determined, characterized by drastic changes in sediment texture from muds to conglomerates, and a rich-archaeological component, although very fragmentary (Figs. 4 and 5).

At the base, unit A was composed of homogeneous dark silty clay (> 95% of the total sediment texture). The faunal record only comprised a few tests of *Cyprideis torosa* (ostracod), typical of lagoon muds, and some other unidentified small shell fragments. Archaeological artefacts were absent from these dark muds.

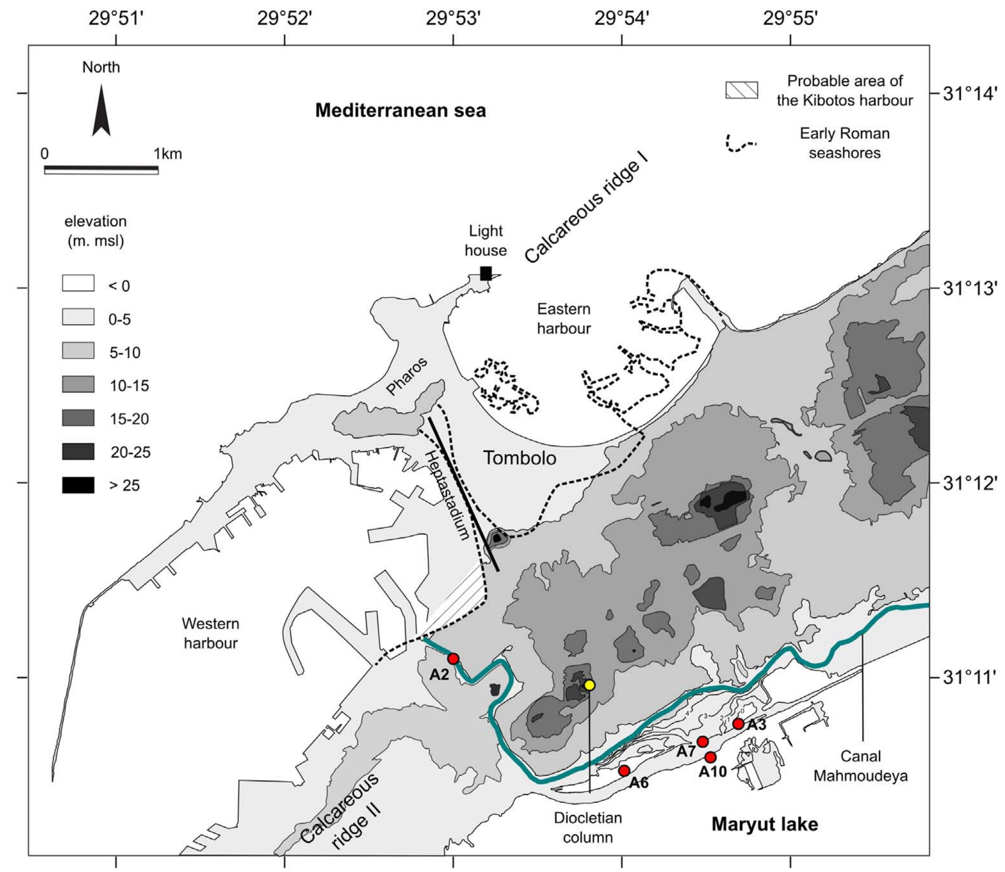

Fig. 2. Contour elevation map of Alexandria drawn from 1:5000 topographic maps of Alexandria, IGN, 1978. The Roman shores are after Goiran et al. (2005). The Roman harbour structures are after Goddio (1998). The Heptastadium is after Hesse, (1998). The Kibotos area is after Strabo (Strabo 17.10). The core locations are also shown.

Table 1
Radiocarbon dates used in this study. The Intcal13 calibration curve was used for calibration (Reimer et al., 2013).

Lab code	Core	Depth (in m below the surface)	Material	Conventional radiocarbon age	Cal. age CE
SacA 18914	A-2	2.3	Bone	145 ± 30	1808 ± 140
SacA 18915	A-2	4.3	Charcoal	260 ± 30	1735 ± 216
SacA 18916	A-2	4.6	Charcoal	295 ± 30	1575 ± 84
SacA 18917	A-3	3.1	Charcoal	1915 ± 35	112 ± 96
SacA 18918	A-6	3.8	Charcoal	1920 ± 35	104 ± 101
Beta – 406932	A-7	2.3	Charcoal	60 ± 30	1820 ± 130
Beta – 406933	A-7	5.9	Charcoal	1950 ± 30	45 ± 80
Beta – 406334	A-7	7.3	Vegetation macro-remains	1960 ± 30	41 ± 80

The latter appears abundant at the base of unit B, in conjunction with the gravel and sand fractions ($>$ 85% of the total texture), marking a very sharp transition between units A and B. The number of archaeological artefacts varies between 0 and 10 for 150 cm^3 of bulk sediment in the lower (7 to 6.6 m) and upper (5.9 to 5.4 m) parts of unit B, and from 0 to 20 in the middle part (6.6 to 6.2 m). The assemblage is dominated by fragments of mortar at the base of unit B (-7.2 to -7 m), followed by potsherds (-7 to -6.2 m) and then mortar again (-5.9 to -5.2 m). Fragments of carbonate sandstones (the city's substratum, as well as the main construction material used in buildings) are almost always present, while other minor materials include glass, bone and glazed fragments (Fig. 5). Potsherds from this unit were poorly preserved and could not be identified for dating purposes.

Unit C is characterized by dark gray sandy silts deposited between 5.4 and 4.8 m below the surface, delimited by sharp interfaces with the lower and upper units. The number of archaeological artefacts decreases to a few items per 150 cm^3 of bulk sediment, and is dominated by bone fragments. Potsherds are the main secondary component, while building remains, including sandstones, mortar and coated fragments mostly disappear from the assemblage.

The appearance of unit D is characterized by a sharp increase in the $>$ 1 cm fraction from ca. 10 to 75% of the total texture. As in unit B, this conglomerate made of centimetric pebbles is mostly composed of archaeological material. Potsherds dominate the assemblage, although these are persistently accompanied by glass, bone, coating, mortar and carbonate sandstone fragments. Of note is the great variability in the number of items, from a few to a few tens, mostly recorded in the lower unit D (from 4.8 to 3.6 m below the surface).

Finally, unit E comprises a heterogeneous texture, made of roughly equal quantities of silty-clay, sands and gravels $>$ 1 cm in size. The number of archaeological items remains low ($0-10$). Building fragments (sandstones, mortar and coating) dominate the assemblage, accompanied by minor quantities of glass, bone and ceramic fragments.

4.2.1.1. Strontium isotopes

Strontium isotopic analyses were undertaken on four samples of ostracod valves from the species *Cyprideis torosa* (Table 2). Two samples were taken from unit A and two others from unit C. The measurements provide an ^{87}Sr/^{86}Sr range between 0.70867 and 0.70894.

4.2.1.2. Correlations between artefact density, texture and magnetic susceptibility?

At the 5-cm scale, the number of archaeological items fluctuates between a few to a few tens of artefacts. Rapid changes in the ballast fraction are also clear within the main units (Fig. 5). Such rapid changes translate the heterogeneity of the sediment structure. The

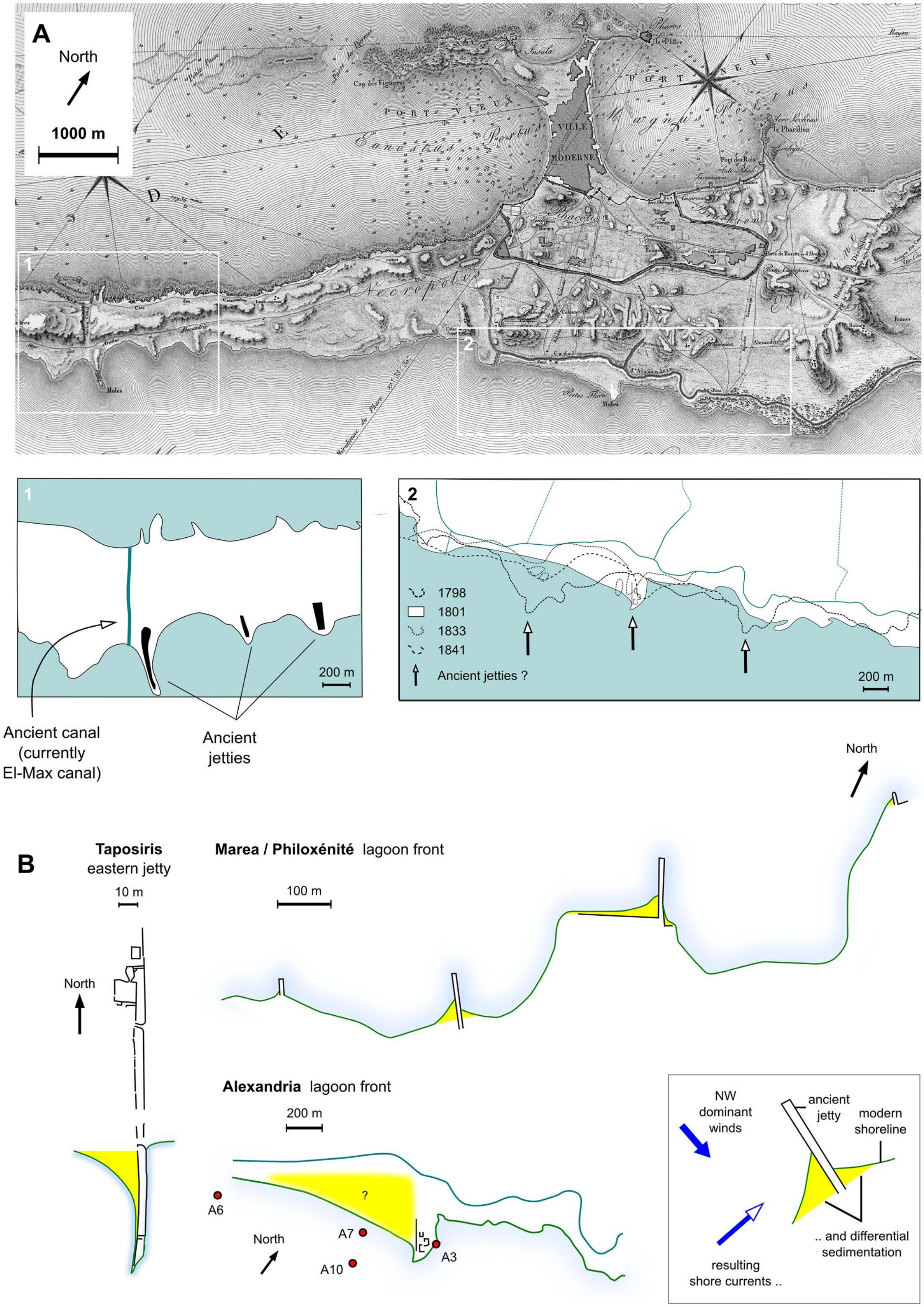

Fig. 3. A - Alexandria's waterfront after the Description de l'Egypte (Antiquité, vol. 5, pl. 31). Note the promontory and mention of a ruined mole at the southernmost point. A1 - Ancient jetties found close to the el-Mexx canal. A2 - Superposition of 19th century maps of Alexandria's lake waterfront (Jondet, 1921), showing three promontories. B - Geomorphology of well-preserved Roman jetties from the western part of the Mareotis Lake (location in Fig. 1), showing that the promontories are formed by the accumulation of sediment around the ancient jetties.

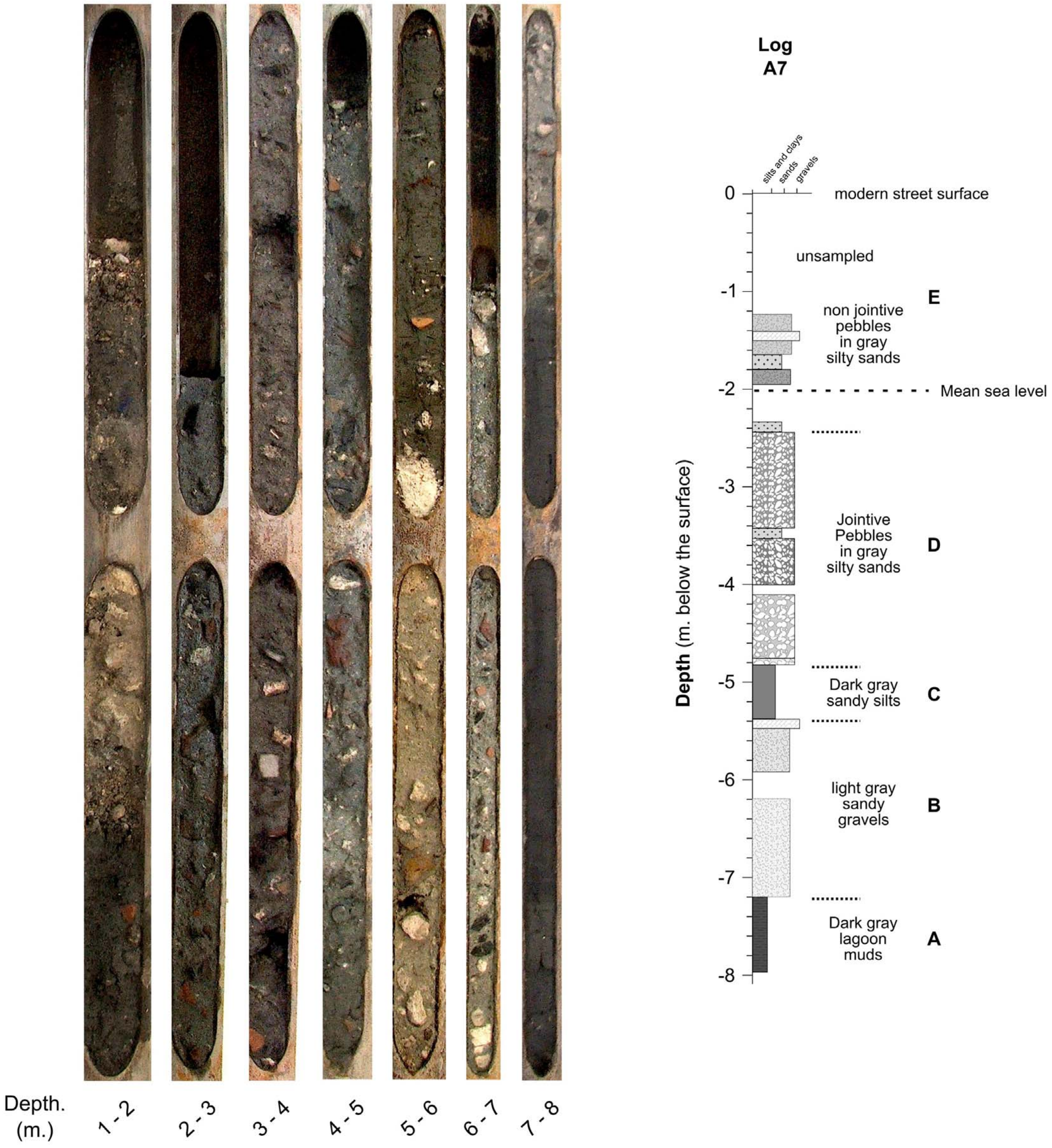

Fig. 4. Stratigraphy of core A-7.

moving average allows the general trend between artefact density, mean grain size and magnetic susceptibility to be compared and contrasted (Fig. 5). Overall, low and high mean grain-size values are positively correlated with the artefact density, except in the upper unit E ($r^2 = 0.55$ below -2.5 m). Magnetic susceptibility of the sand fraction broadly mirrors the density of archaeological artefacts.

4.2.1.3. Chronology. Although the ceramic record was rich for units B to E, only a few potsherds could be identified (20/325 fragments larger than 1 cm). Identifiable potsherds were found between 1.6 and 4.6 m below the surface (mainly in unit D). Amphora fragments dominate the assemblage (14/20 fragments). Other potsherds include a fragment of imported terra sigillata, a lamp fragment, an earthenware jar fragment, a faïence fragment, the rim of a bowl, the rim of a krater, a figurine fragment and the rim of a cup. All of the fragments were attributed to Roman times (late 1st century BCE to the early 7th century CE), except for one fragment dating to the Hellenistic period (4.1 m deep, Fig. 6). Two charcoals and a sample of organic remains were radiocarbon dated (Table 1). The upper lagoon muds in unit A were dated to 1960 ± 30 BP (40 ± 80 cal. CE). An identical age was provided by a charcoal sample taken at 5.9 m depth in unit B (1950 ± 30 BP; 45 ± 80 cal. CE). A charcoal taken from the base of unit E was dated to the modern period (60 ± 30 BP; 1820 ± 130 cal. CE).

4.2.2. Cores A-3 and A-6

Cores A-3 and A-6 were respectively drilled east and west of core A-7 (Fig. 6). The carbonate sandstone's substratum was reached in both cores A-3 and A-6, respectively at − 5.6 and − 4.9 m below msl. Both cores record dark gray sandy silts to silty sands, 3.5 m thick in core A-3 and 2.3 m in core A-6, buried beneath 1.5 m of modern gravel-rich infilling. Archaeological artefacts (> 1 cm in diameter) found within the fine dark matrix vary between 10 and 30 items per ca. 150 g of dry sediment. The artefacts comprise potsherds with associated mortar fragments.

Two *Cyprideis torosa* samples from core A-6 were taken at 3.75 and 2.25 m below msl for $^{87}Sr/^{86}Sr$ measurements. The Sr isotopic ratio of the biogenic carbonates respectively yielded values of 0.70871 and 0.70896 (Table 2). Regarding core A-7, only a few potsherds, attributed to the Roman period, could be identified. A piece of charcoal taken from core A-3 at 3.9 m below msl was radiocarbon dated to 1915 ± 35 BP (108 ± 104 cal. CE). In core A-6, a charcoal fragment taken just above the substratum was dated to 1920 ± 35 BP

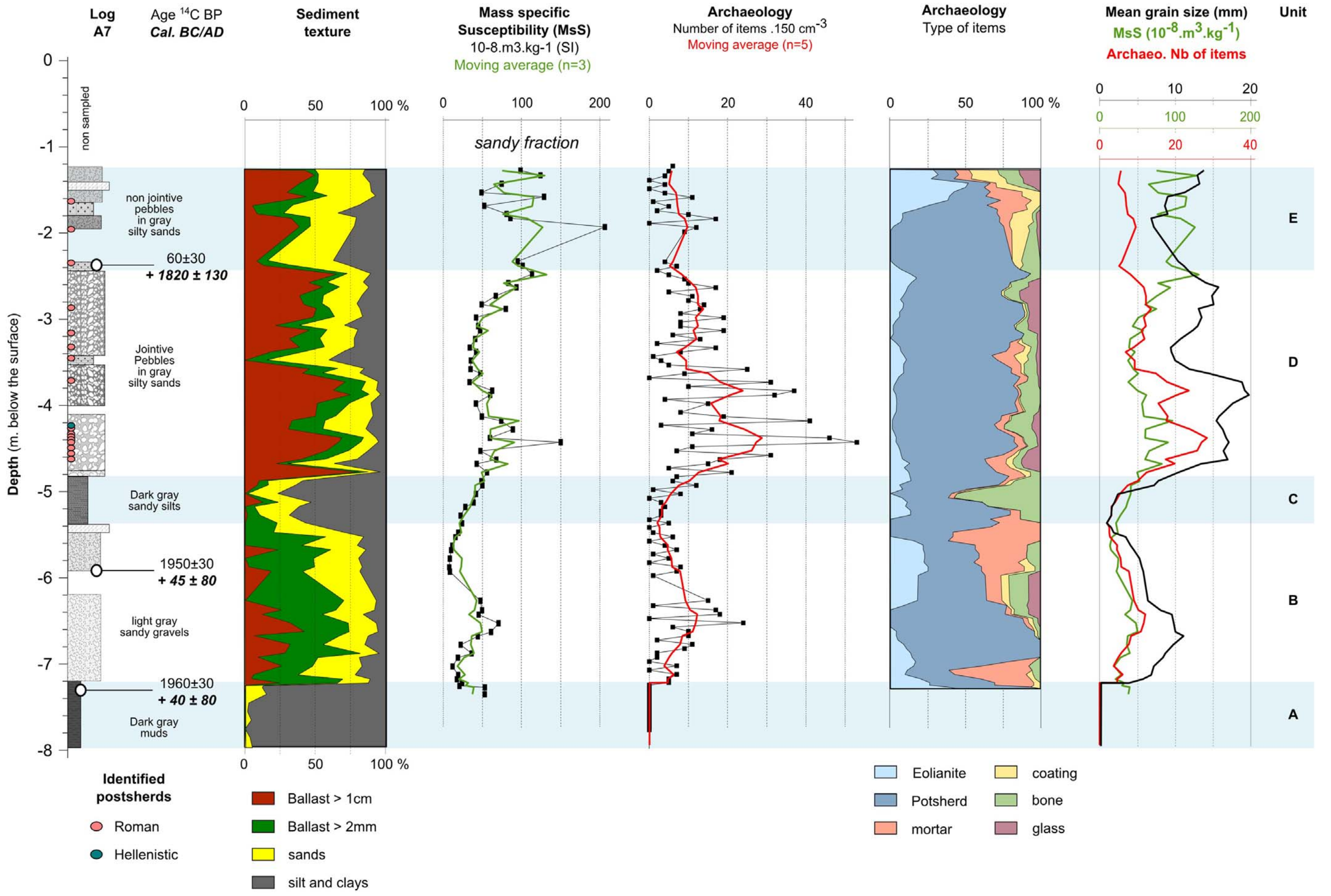

Fig. 5. Sedimentology and chronology of core A-7.

Table 2
Sr isotope data from the ostracod *Cyprideis torosa* extracted from cores A-6 and A-7. The mass fraction of seawater was estimated via a two-component mixing equation between the Mediterranean Sea and Nile water end-members (see details in Flaux et al., 2013).

Depth (cm below the surface)	Nb. ostracod valves	^{87}Sr/^{86}Sr (SD = 30 ppm)	Relative seawater inputs (%)
488	32	0.70876	15–18
513	32	0.70894	25–30
727	11	0.70891	23–27
785	50	0.70867	13–15
225	17	0.70896	26–33
375	21	0.70871	14–16

(106 ± 105 cal. CE).

4.2.3. Core A-10

Core A-10 was drilled around 100 m south of core A-7, just south of the railway built in the mid-19th century (Jondet, 1921). The area was reclaimed from the lake, creating a flat plain at the bottom of the city. Core A-10 is 7 m deep and shows five stratigraphic units (Fig. 6).

Unit A comprises dark shelly muds with thinly layered intercalations almost totally composed of shells and shell fragments. The molluscan assemblage is dominated by *Cerastoderma glaucum* and *Hydrobia ventrosa*. This biofacies has been observed and described in many cores taken from the Maryut lagoon, and it has been dated from 4310 ± 230 to 2790 ± 80 cal. BP (Flaux et al., 2011, 2012, 2013).

Unit B was recorded from 6.6 to 5.4 m below msl and is characterized by compact and homogeneous dark muds.

Unit C comprises dark sandy muds with relatively abundant gravels and pebbles of archaeological (potsherds) and lithic (carbonate sandstone) origin.

Unit D is made up of dark fine to coarse sands with some lithic gravels and pebbles. This marks the end of mud deposition and was subsequently covered with a coarse fill (Unit E), probably pertaining to the human infilling of the area since the mid-19th century CE.

4.2.4. Core A-2

Core A2 was drilled at the northward termination of the Alexandria canal, ca. 250 m from the western maritime harbour (Fig. 2). Although this feature is important in the topography of Alexandria, because it allows the western maritime harbour to be connected to the Nile, the age of this part of the canal is unclear. Core A-2 was drilled in the dried channel bed, presently overgrown with grass and trees. Five meters of homogeneous dark sandy silts and clayey silts were recovered, until the sandstone substratum was reached, at 2.5 m below msl (Fig. 6). Two charcoals respectively taken at 2.3 and 2 m below msl indicate that the onset of mud deposition at the core site occurred between 295 ± 30 BP and 260 ± 30 BP (1575 ± 85 and 1735 ± 215 cal. CE, Table 1). There was very little archaeological material deposited within these organic muds, including some gravels and pebbles in the top two meters and, between 2 and 2.5 m under the surface, one human vertebra, some palm tree fragments, and well rounded pebbles. At this level, shells of *Melanoides tuberculata*, an indicator of lightly brackish water (Bernasconi and Stanley, 1994), were also recorded. The vertebra was dated to 145 ± 30 BP (1810 ± 140 cal. CE).

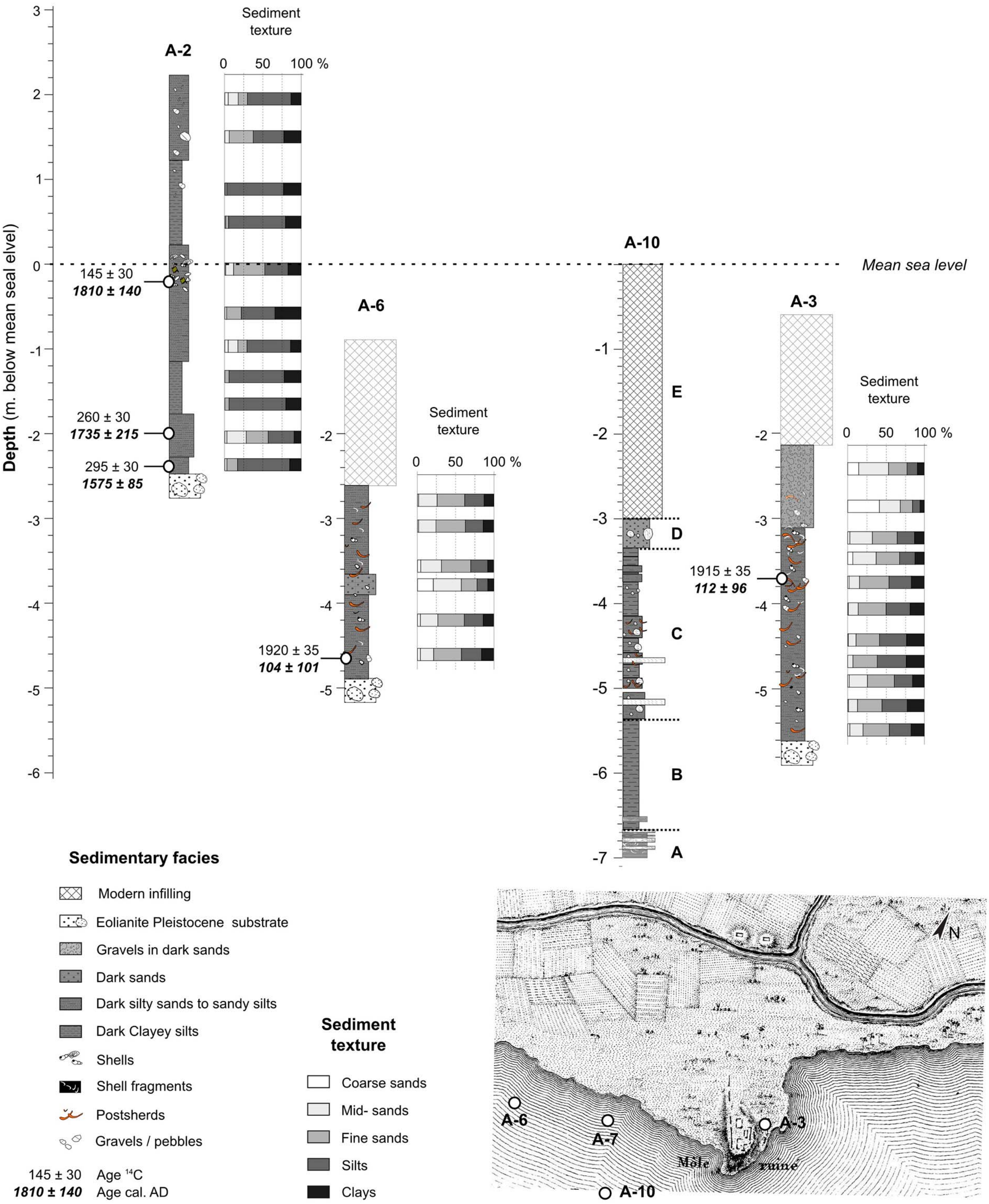

Fig. 6. Chrono-stratigraphy of cores A-2, A-3 and A-6. The map is from the *Carte Générale des côtes, rades, ports, ville et environs d'Alexandrie* (DVD La Description de l'Egypte, 2006).

5. Geoarchaeology of Portus Mareoticus

5.1. *A roman harbour*

The interface between anterior lake muds (unit A) devoid of any archaeological artefacts and the anthropogenic facies (unit B; harbour facies) recorded in core A-7 is very sharp (Figs. 5 and 6), suggesting new and rapid settlement on the shoreline of the lake. The base of the artefact-rich facies was dated to 41 ± 80 (A-7) and 106 ± 105 cal. CE (A-6). In core A-7, lake muds were buried below coarse (gravels comprise > 50% of the sediment aggregate) but heterogeneous deposits (including silty clays of lacustrine origin), comprising artefacts of various origins (amphorae, jars, bowls, lamps, figurine and cup fragments), which attest to infilling materials rather than lake deposits. Given that the upper part of unit B provides the same radiocarbon age as unit A, unit B was apparently deposited very rapidly. In this sense, the whole 1.8 m thick unit B may have been deposited during a single event and could thus have recorded the construction stage (infilling?) of the lake harbour. In core A3, a charcoal found ca. 2 m above the onset of the anthropogenic lake facies was dated to 108 ± 104 cal. CE, that is the same age as the base of the same facies in core A6 (Fig. 6). This means that sedimentation rates were very high along the lake's waterfront, including both silty clay inputs from the lake and human waste. In core A-10, drilled further south inside the lake, human artefacts were much less common in the lacustrine silty-clay matrix. Cores A-3, A-6 and A-7 were thus likely close to the lake shoreline of the Roman period. These cores are now located at the limit between the urbanized southern slopes of Mahmoudeya canal and the flat polder gained on the lake. This break in slope may have been inherited from the former Roman waterfront.

Following the deposition of unit B in core A7, unit C indicates a change in the depositional environment (Fig. 5). The gravels component declines sharply and the texture becomes dominated by silty clay. The number of archaeological artefacts decreases and bone fragments dominate the assemblage previously characterized by potsherds and mortar fragments. Unit C thus records a decrease in human waste inputs to the waterfront. Abruptly, unit D records very coarse inputs dominated by gravels > 1 cm in size forming a conglomerate of jointive pebbles mainly composed of potsherds from the Roman period (Fig. 6). Because the interface between units D and E has been radiocarbon dated to 1820 ± 130 cal. CE, it indicates that units C and D have recorded the last 2000 years. Our radiocarbon framework does not allow us to date the abandonment of the lake harbour. However, because no Islamic or Ottoman potsherds were discovered in any of the cores drilled on the southern shores, the occupation of the area dates essentially to Roman times. As a working hypothesis, unit D may have recorded the abandonment and degradation of the Roman harbour infrastructure (post-harbour facies). Unit E in core A7, radiocarbon dated to 1820 ± 130 cal. CE, was contemporaneous with the modern period and progressive urban development of the area, initiated in the middle of the 19th century CE based on the atlas of Jondet (1921).

According to our chronological dataset, the occupation of Alexandria's lacustrine waterfront began at the beginning of the Roman era. The jetty identified by French engineers was probably of Roman age, given that the ceramic assemblage found in cores adjacent to the archaeological structures were all dated, when identified, to this period. The assemblage was dominated by amphorae, consistent with harbour activities in the area. The base of the artefact-rich facies was consistently recorded between 5.5 and 5 m below msl in cores A-3, A-6, A-7 and A-10 (Fig. 6). The estimated range for the lake level of Mareotis during Antiquity was 0–1.5 m above mean sea level, a range related to Nile floods (Flaux, 2012). Thus, at the beginning of the Roman period, a minimum water column of 5 m was available for the mooring of vessels at the waterfront, even during phases of low Nile flow.

According to Given (2004) and Haas (2006), numerous papyri referred to Roman granaries in the area of the lake harbour. One sector, called Phialé, partially dedicated to the storage of grain, would have been located close to the ancient Serapeum in the area of the Diocletian column (Roques, 1999, see location in Fig. 2). Although the exportation of cereals is also attested during the Ptolemaic period, Egypt became, from the very beginning of Roman domination of Egypt, the main cereal supplier to Rome as well as others cities of the Eastern Mediterranean (Blouin, 2014). The first emperor Augustus took several measures to control and enhance the agricultural potential of the country (Blouin, 2006, p. 23–31). Kaiser (1994) also reported that the region of Alexandria was the object of a large construction policy to improve communications and water distribution during the Imperial period. For example, Hairy and Sennoune (2006) have described important works carried out on the Alexandria canal to improve the water run-off in the years 10/11 BCE. In this context, and according to our radiocarbon data, Portus Mareoticus may have been another important construction project undertaken by the new rulers at the very beginning of the Imperial period, in order to develop the exports capacity of Roman Alexandria.

5.2. *An open harbour*

Previous investigations of ancient lake structures in the western Maryut Lake have highlighted two major configurations: closed and open harbours (Rodziewicz, 2002). The first type is characterized by a box-shaped basin of artificial origin, with an entrance open towards the lake. Two well-preserved examples are known from the western Mareotis. The basins are either constructed by a series of perpendicular moles (site 09 after Blue et al., 2011), or dug into the bedrock (El-Fakharani, 1991). Another closed harbour was described in Alexandria by Strabo, called 'Kibotos' (i.e. a box or chest, Strabo, 17.10), located in the western maritime harbour (Fig. 2). Nonetheless, to date there is no archaeological evidence for the latter. Box-shaped harbours are thought to provide good shelter for vessels (El-Fakharani, 1991). At site 09, however, a mooring ring was discovered carved on the outer edge of the harbour (Blue et al., 2011, p. 124–125). Another closed harbour has been described at Taposiris (Cosson, 1935; Boussac, 2009; Boussac and El-Amouri, 2010). There, a navigation channel was dug during the 2nd century CE at the foothill of the city, separated from the open lake by a 1.7-km-long causeway running parallel to the city's shoreline. Such a closed harbour system would have been dedicated to the control of lake traffic and might also have served a customs function.

Conversely, the second harbour type is an open configuration, which is well represented at Marea-Philoxenite. Here, the shoreline is characterized by three long jetties, perpendicular to the shoreline, extending as far as 64, 109 and 150 m into the lake (Fig. 3; Rodziewicz, 2002). These jetties were primarily used by Christian pilgrims on their way to the sanctuary of Abu Mena, ca. 20 km further south (Rodziewicz, 2003, 2010). Also belonging to the same open harbour configuration are the 18 jetties found along the western Maryut lake (Blue et al., 2011). These jetties consist of two parallel single or double breadth piers of limestone filled with rubble that extend into the water perpendicular to the shore. They are mainly dated to the Roman period. Although a few of the jetties are associated with residential sites, most of them were related to commercial and industrial activities. Half jetties have a preserved length of 60 ± 10 m, but the jetty at site 23 is around 300 m long (Blue et al., 2011). The length may reflect the importance of harbour activities, however in lagoonal contexts long jetties are necessary because the short water column along the waterfront cannot accommodate the mooring of large vessels (e.g. in Tunisia, Slim et al., 2004).

By comparison with the geomorphology of well-preserved ancient jetties found in the Maryut Lake, the three promontories denoted on 19th-century maps of Alexandria were probably ancient jetties. It seems that they were several hundred meters long (Fig. 3). This configuration supports the idea that Portus Mareoticus belonged to the open harbour type. The commercial vocation of the harbour, together with its high level of activity, as underlined by Strabo, would tend to support an open configuration.

5.3. *A lake-sea harbour waterfront*

Strabo described a navigable canal connecting lake Mareotis to the western maritime harbours of Alexandria (Strabo, 17.10). The canal flowed east of the city and its outlet lay within or close to the Kibotos harbour. Khalil (2010, p. 40) describes a 3rd century BCE document that attests to a similar lake-sea canal pre-dating the Roman era. The history of this canal would provide significant insight into the history of Alexandria's harbour system, because it connects the lacustrine hinterland to maritime routes. Scholars have generally considered the pathway of the last section of the modern Mahmoudeya canal as a relic of the older Roman lake-sea canal. Core A2 was drilled into its dry bed but earlier muds were dated back to the early 16th century CE (Fig. 6) and cannot help in determining the Roman channel's location. Sr isotopic ratios measured on ostracods taken from sediment of Roman age in cores A7 and A6 indicate relatively important marine inputs (15–30%)

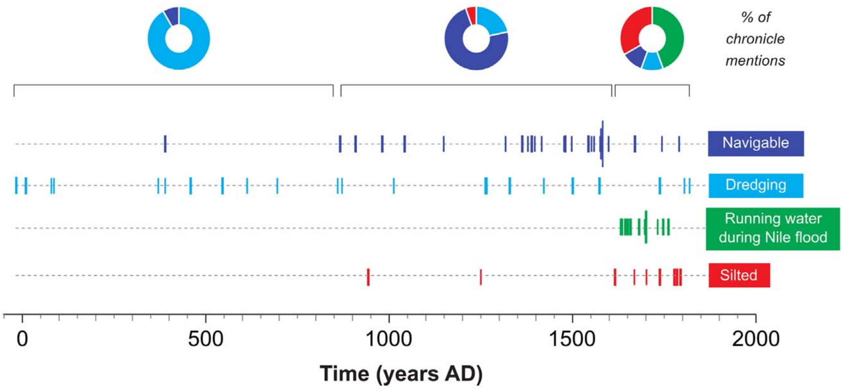

Fig. 7. Mentions of the Alexandria canal in ancient chronicles from the late 1st century BCE to the early 19th century CE (database after Hairy and Sennoune, 2006). Mentions were grouped into four types: (1) navigable, (2) dredging, (3) silted and (4) running water delivered to Alexandria during Nile floods. The taller bars denote two or three identical mentions in a single year.

along Alexandria's lake shoreline (Table 2). By comparison, ostracods from the 2nd–3rd centuries CE, sampled in core M3 taken from the central Maryut basin, indicate 5–10% of seawater inputs to the lake budget (Flaux et al., 2013). Sr data thus suggest that the Roman lake harbour lay close to a marine inflow, probably via a canal connected to the marine front.

On Belon's map of Alexandria, drawn in 1548 (see location in Fig. 2), the cartographer depicts a large channel between lake Mareotis and the Mediterranean Sea (Jondet, 1921, pl. II). Thuile (1922) thinks that such a "Nile mouth" was not contemporaneous with Belon but rather related to "ancient" times. However, we found five historical reports of a connection between lake Maryut and the sea at el-Mexx (west of Alexandria, see the location in Figs. 3A and 7) within the travellers corpus compiled by Sennoune (2015) for the 16th–18th centuries CE. Interestingly, three ruined jetties were still visible in the late 18th century CE on the lakeside close to the same canal, dry at this time (Fig. 3A-1). Considering that, to date, all jetties and lake-structure remains were systematically dated from the 3rd century BCE to the 7th century CE, a former lake-sea connection at El-Mexx was possibly available at some time during Antiquity. Indeed, as stated above, some of the Mareotide production uploaded to vessels at the lake's waterfront were destined for export to Mediterranean markets. A well-known example is the exportation of Mareotic wine, praised by Strabo (17.14) and other ancient sources (Empereur, 1998) and attested in the archaeological record by late Roman Mareotide wine amphorae found in southern France (Pieri, 1998). The western El-Mexx canal offered another access route to the sea, closer to the western Mareotide production area, and provides insights into the possible western extension of Alexandria's lake harbour system.

5.4. *Demise of the Roman harbour and the lacustrine waterway*

No Islamic or Ottoman potsherds were discovered in our cores drilled along the lake waterfront of ancient Alexandria. The construction of a new city wall during the 9th century CE, > 1 km further north than the ancient one, disconnected the city from its lakeshores (Rodziewicz, 1983). We did not find any allusion to a lake harbour in ancient travellers' texts compiled by Sennoune (2015), although a ruined pier was apparently still visible in the late 18th century CE (Fig. 3A). It seems that after its abandonment, harbour infrastructure vanished rapidly, as well as the memory of the site. At the regional scale, all the sites active along the Mareotis waterfront in the early 7th century CE, were rapidly abandoned (Rodziewicz, 1998; Blue and Khalil, 2010; Khalil, 2010; Blue et al., 2011; Wilson, 2012; Thomas, 2014). Décobert (2002) suggested that when commercial maritime routes towards Constantinople and the Eastern Roman Empire sharply ceased after the Muslim conquest, industrial farms based on this economy rapidly declined. Cooper (2009) demonstrated that the grain tribute was redirected from the Eastern Mediterranean to the Rashidun Caliphate in Egypt, and to Mecca and Medina. According to Rodziewicz (2002), from the very beginning of the Islamic period, Alexandria lost its standing as the first town of Egypt. Schedia (Bergmann and Heinzelmann, 2015), Naukratis (Thomas, 2014), East-Canopus and Herakleion (Goddio, 2007) located on the Canopic branch and mouth (Fig. 1) were also abandoned in the early 7th century CE. The new harbour city of Rashid was founded in the late 9th century CE at the mouth of the Rashid (Rosetta) branch (Wilson, 2012), east of the Canopic channel, and became the major port of Egypt until the 19th century (Rodziewicz, 2002). In this context, Portus Mareoticus would have rapidly declined after the Arab conquest, when waterways and the main trade routes moved eastwards.

Lake Mareotis' water budget in Antiquity was dominated by Nile inputs (> 90%), as recorded by palaeo-hydrological proxies (Flaux et al., 2012, 2013). Indeed, the Canopic's Nile distributaries flowed into the lake and this fluvio-lacustrine system connecting Alexandria to the Nile delta provided the basis for Portus Mareoticus' prosperity (Fig. 1). Lake Mareotis' water budget had strongly declined by the 9th–10th centuries CE and the basin hosted an ephemeral lake, forming a saline pool in the dry season, as low as 3.5 m below msl (Flaux et al., 2012, 2013). The main reason behind this desiccation was the silting up of the Canopic branch (Fig. 1). Consistently, the Alexandria canal was then connected to the Rashid (Rosetta) Nile branch further east by the 9th century CE (Hairy and Sennoune, 2006). Using ancient chronicles between Strabo's time and the early 19th century CE, Hairy and Sennoune (2006) have recorded 75 mentions of the Alexandria canal (Fig. 7). On the basis of this dataset, the first mention of a navigable canal appears in the late 4th century CE, but only became common in the dataset from the 9th century CE onwards (30 mentions). After the desiccation of Maryut lake beginning in the 9th century CE, the canal apparently became the main waterway connecting Alexandria to the Nile. Consistent with this idea, Hairy (2002) reported several travellers from the 14th and 15th centuries CE, who indicate the presence of a harbour on the canal, outside the city walls.

Thus, both changes in trade routes since the beginning of the Islamic period and progressive desertification of the western delta led to the abandonment of the lake's harbour systems, between the 7th and the 9th centuries CE.

5.5. *The western extension of the Alexandria canal at the beginning of the Ottoman period*

In the oldest available map of Alexandria dating to the 15th century CE (Jondet, 1921, pl. I), the Alexandria canal enters the fortified city on its southern to southeastern side, flowing east of the Diocletian column (see its location in Fig. 2). This is also the case in a map by Pierre Belon du Mans published in 1554 (Jondet, 1921, pl. II),

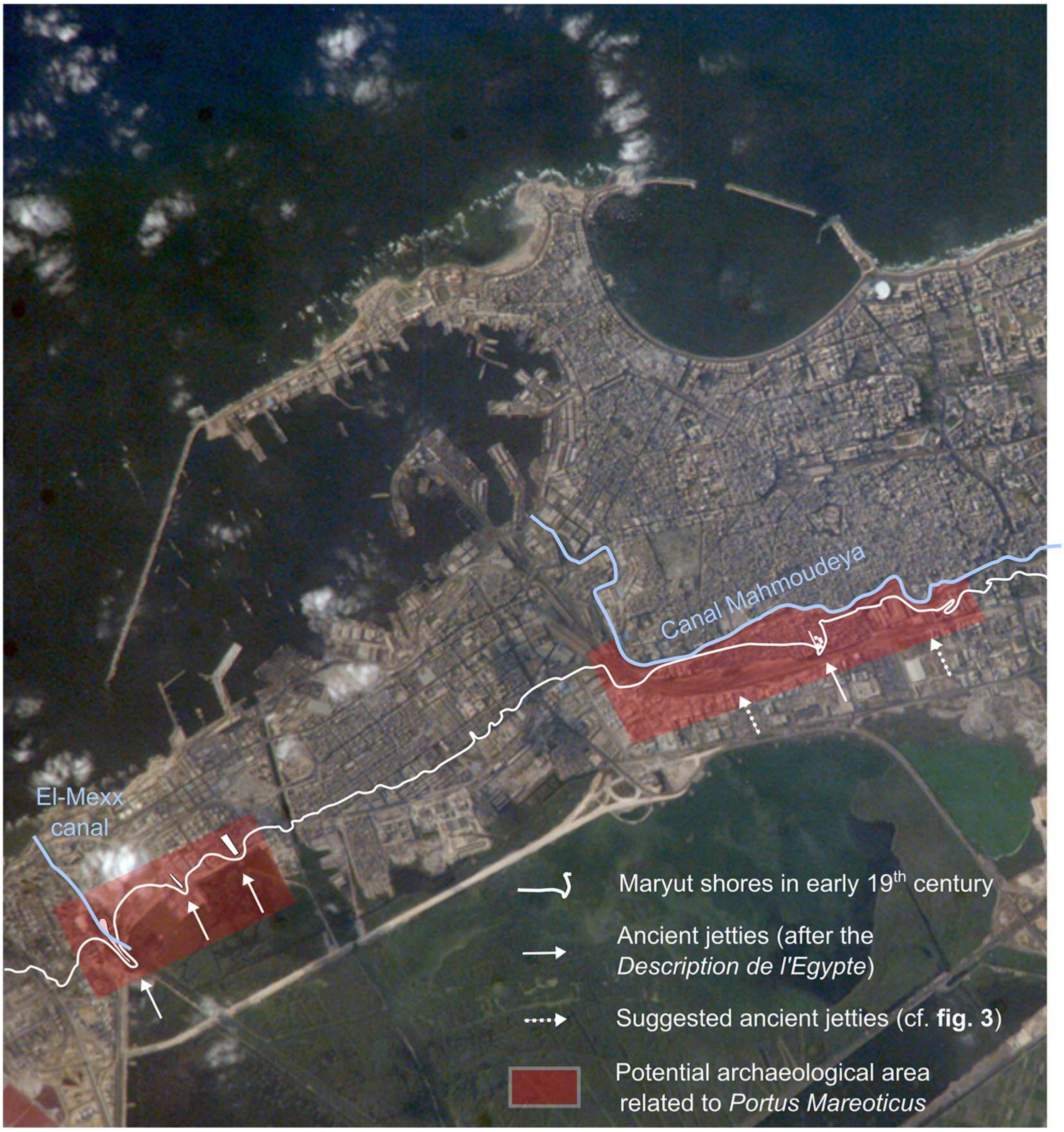

Fig. 8. Archaeology of the area related to Portus Mareoticus buried below the modern city of Alexandria. Image: Google Earth.

based on his travels in the Eastern Mediterranean between 1546 and 1549. Belon's work apparently inspired later maps from the 16th and 17th centuries CE, until Razaud provided, in 1687, the first representation of Alexandria based on in situ topographic measurements (by triangulation). The end of Alexandria's canal left the lake waterfront at a right angle and passed west of the Diocletian column. This configuration is found in later maps by R. Pococke in 1743, d'Anville in 1766 and Savary in 1785 (Jondet, 1921). Thus, the most western section of the Alexandria canal appears in the dataset provided by Jondet (1921) between the mid-16th and the late 17th centuries CE. Furthermore, based on the travellers' chronicles compiled by Hairy and Sennoune (2006), a first mention of a bridge crossing the southern canal's section close to the Diocletian column is given in 1613. The sedimentary record from core A2 indicates the deposition of muds in the canal bed since the 16th century CE. These independent data coincide with the extension of the western canal in the 16th century CE. During the early 16th century CE, Alexandria was attached to the Ottoman Empire and its activity was strongly boosted. Indeed, not only was the city connected with the many harbours of the vast Ottoman Empire, but also with the western Mediterranean, as attested by diplomatic documents showing new commercial relationships between Alexandria, Marseille and Venice (Tuchscherer and Pedani, 2011). In this context, Alexandria regained its position as one of the Mediterranean's most active ports and it is likely that the western extension of the Alexandria canal linked the western maritime harbour to the Nile. The canal outlet initially provided a water depth of ca. 2 m below mean sea level. Radiocarbon dates from core A2, however, indicate that sediments accumulated in the canal's bed at a mean rate of 12 ± 0.2 mm·yr^{-1}. This sedimentation rate is much higher than the maximum Holocene rate measured on the Nile coast (5 mm·yr^{-1}; Marriner et al., 2012b). Core A2 illustrates how much the silting of the Alexandria canal was a recurrent problem for the authorities, as attested by Hairy and Sennoune (2006) who found 22 mentions of dredging on the canal since early Roman times (Fig. 7; Morhange and Marriner, 2010). During the 17th and 18th centuries CE, running waters within the canal's bed occurred only a few months in the year, during the Nile's summer flood. Water delivery to Alexandria became more and more critical and the canal silted up, until the canal's navigability and freshwater supply was restored under the reign of Muhammad Ali in 1817–1819 (Hairy and Sennoune, 2006).

6. Conclusion

Sedimentological investigations in southern Alexandria provide evidence for 2000 years of lake shoreline evolution. Below the modern surface probably lie the remains of ancient jetties and human waste within lake sediments which broadly correspond to the lacustrine waterfront on the edge of the urban area, south of Mahmoudeya canal (Fig. 8). The radiocarbon chronology clearly dates the exploitation of this lake shoreline to the beginning of Roman domination in the late 1st century BCE. The geoarchaeology of the silted-up shoreline in the 19th century CE suggests the presence of three long and wide jetties, extending towards the lake and providing an open harbour configuration. A canal linked the lake to the western maritime harbour, as testified by Strabo and confirmed by Sr data attesting to marine inputs into the harbour area. Another harbour system, characterized by jetties and a lake-sea connection is suggested in the area of El-Mexx, and provides insights into the possible ancient extension of Alexandria's lake harbour front (Fig. 8). Thus, early Roman rulers undertook the development of harbour facilities on Alexandria's lake shoreline. The foundation or the extension of Portus Mareoticus may have favoured the development of the Mareotide area. Well-preserved harbours and jetties from the western arm of lake Mareotis are mostly dated to Roman times. The rapid and regional-scale abandonment of the lake's waterfronts in the early 7th century CE cannot be related to the lake's desiccation, which occurred some two centuries later (Flaux et al., 2012). It is more probable that many of the western delta's production centres were dependant upon Alexandria's Mediterranean export market. Indeed, not only did the Maryut's waterfront sites decline in the early 7th century CE, but also Naukratis, Schedia, Herakleion and East-Canopus, all located on the Canopic branch of the Nile. Since the 9th century CE, the lake's geography has fluctuated significantly. In effect, the lake was rarely navigable and Alexandria canal became the only waterway connecting the maritime city to the Nile. Our data indicate that the western part of the canal was extended during the 16th century CE to the western marine harbours, in parallel with the increasing activity of the latter, then opened to the Ottoman Empire. The canal, however, then silted up during the 17th and 18th centuries CE (Fig. 7). Later, when Muhammad Ali became the new ruler of Egypt and instigated vigorous economic and commercial policies to open Alexandria up to Europe, restoration work on the Alexandria canal was undertaken between 1817 and 1819 to once again reconnect the city to the Nile (Hairy and Sennoune, 2006). The history of the western Nile delta's waterways mirrors the history of Alexandria.

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