GEOARCHAEOLOGICAL RESULTS FROM THE HARBOR OF TAPOSIRIS AND IMPLICATIONS CONCERNING THE CONSTRUCTION OF THE HARBOR

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Abstract

The harbor of Taposiris was once a gateway to Egypt during the Roman period, and possibly even as early as the Hellenistic period. Built on the northern shore of Lake Mariout, the probable harbor was separated from the lake by a long artificial levee. A channel provided a link between the lake and the closed area that would have encircled the harbor basin. Our geoarchaeological study revealed a brackish environment influenced by the phreatic level and the Canopic branch that provided fresh water. The generally silty sediments proved to be difficult to analyze and contained few elements for discrimination between natural lake deposits and man-altered harbor deposits. A numerical model of circulation of water masses has been used to discern the spatial distribution of currents and the most active zonation for sediment re-suspension. This model emphasizes the fact that only very fine particles could reach and be deposited in the area of Taposiris. Our study illustrates the fact that the most striking element of the harbor (the EW levee) was entirely man-made and did not take advantage of any apparent natural feature. The bottom of the lake was more or less flat and devoid of any pre-existing underwater ridge that could have facilitated the construction of the levee.

Introduction

Taposiris is an ancient city situated on the northern shore of Lake Mariout, 45 km west of Alexandria (fig. 1). Several occupation phases were discovered in the city, notably Ptolemaic and Roman, from the beginning of the Hellenistic period to the 7th century AD. During the imperial period, the city was one of the gateways to Egypt and was thus equipped with a large harbor complex, partially built on top of Hellenistic structures (Boussac *et al.* 2010). However, the way in which the harbor was built and the bathymetric context that existed when the construction began were debatable. We tried to address this problem by taking borehole cores from within the harbor as well as within the lake itself in order to compare the two environments. Conventional palaeoenvironmental analyses of sediments were carried out, particularly grain-size analyses, microfauna identification, and measurements of heavy metals in order to reveal anthropization phases. These analyses were backed up by several radiocarbon dates.

Geographical configuration of the potential harbor

Taposiris was built upon a consolidated sandstone ridge consisting of a combination of marine and aeolian material separating the lake from the sea (fig. 1) and dating back to the Pleistocene (A Wali *et al.*, 1994, Warne *et al.*, 1993). The lake in this area was only a few meters deep (fig. 2). At the beginning of the 19th century, before the rapid sedimentary accretion of the late 20th century, a depth of about 2 m was recorded in the area of Taposiris, compared to up to 10m in the eastern part of the lake south of Alexandria (*Description de l'Egypte*, 1828). Core samples taken demonstrated that the depth of the lake probably did not change much before the 20th century (Stanley *et al*, 1996); thus the data recorded by the expedition of Bonaparte can be used with caution. Taposiris' waterfront presents a well-preserved example of a closed harbor. The harbor itself is located to the south of the city, along Lake Mariout. It is one of many harbor installations around the lake, proof that the Mariout was a major commercial region (Rodziewicz, 2002; Blue 2010). The harbor basin of Taposiris is separated from the rest of the lake by a large levee, oriented west-east. This levee is about 1700 m long. The harbor is delimited on its western side by an

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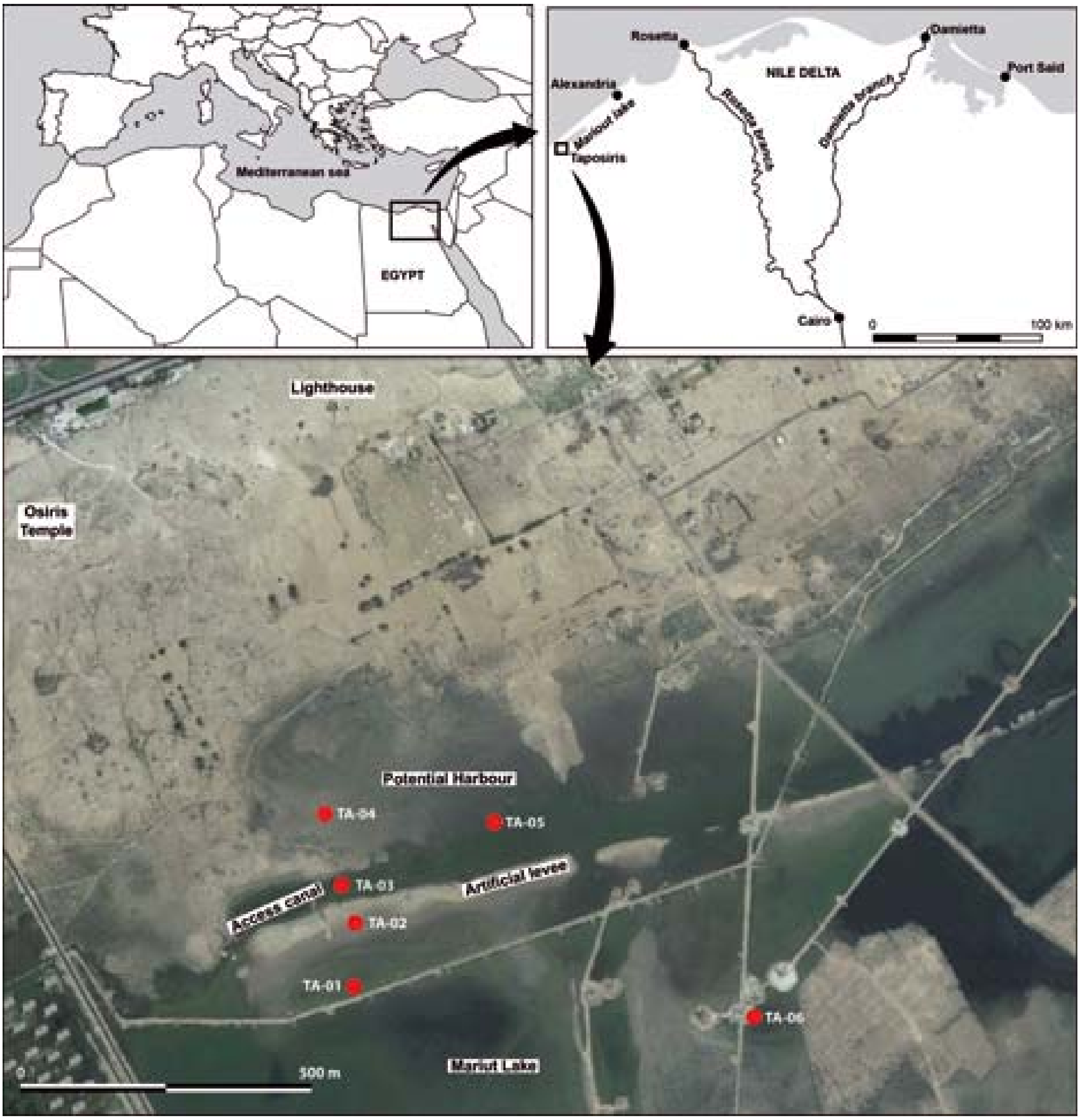


Fig. 1 Location of the harbor of Taposiris on Lake Mariout and position of the cores taken on the archaeological site

apparently natural cove that forms a half-closed basin, and on its eastern side by a stone jetty perpendicular to the sandstone ridge. The basin was accessed through two points. A short channel parallel to the coastline links the lake to the harbor on the west. On the east, there is a large opening between the extremity of the jetty and the levee (Boussac 2009).

Several questions remain unanswered. The delimitation of the basin is not especially clear: the harbor possibly extends further to the east, beyond the jetty. A stone bridge crosses the western access channel (Boussac 2006). The double-vaulted bridge is only 2.55 m high, and the two vaults are only 4.1 and 3.05 m wide. Thus, only small ships could enter the harbor. This was not a problem for the small lacustrine boats of the time, which also had shallow draught (Fabre, 2004; Vinson, 2008) Archaeological evidence proves that the bridge was built at the same time the channel was dug and belongs to the same system. Both date to the imperial Roman period (Boussac 2009, 2010). Insights

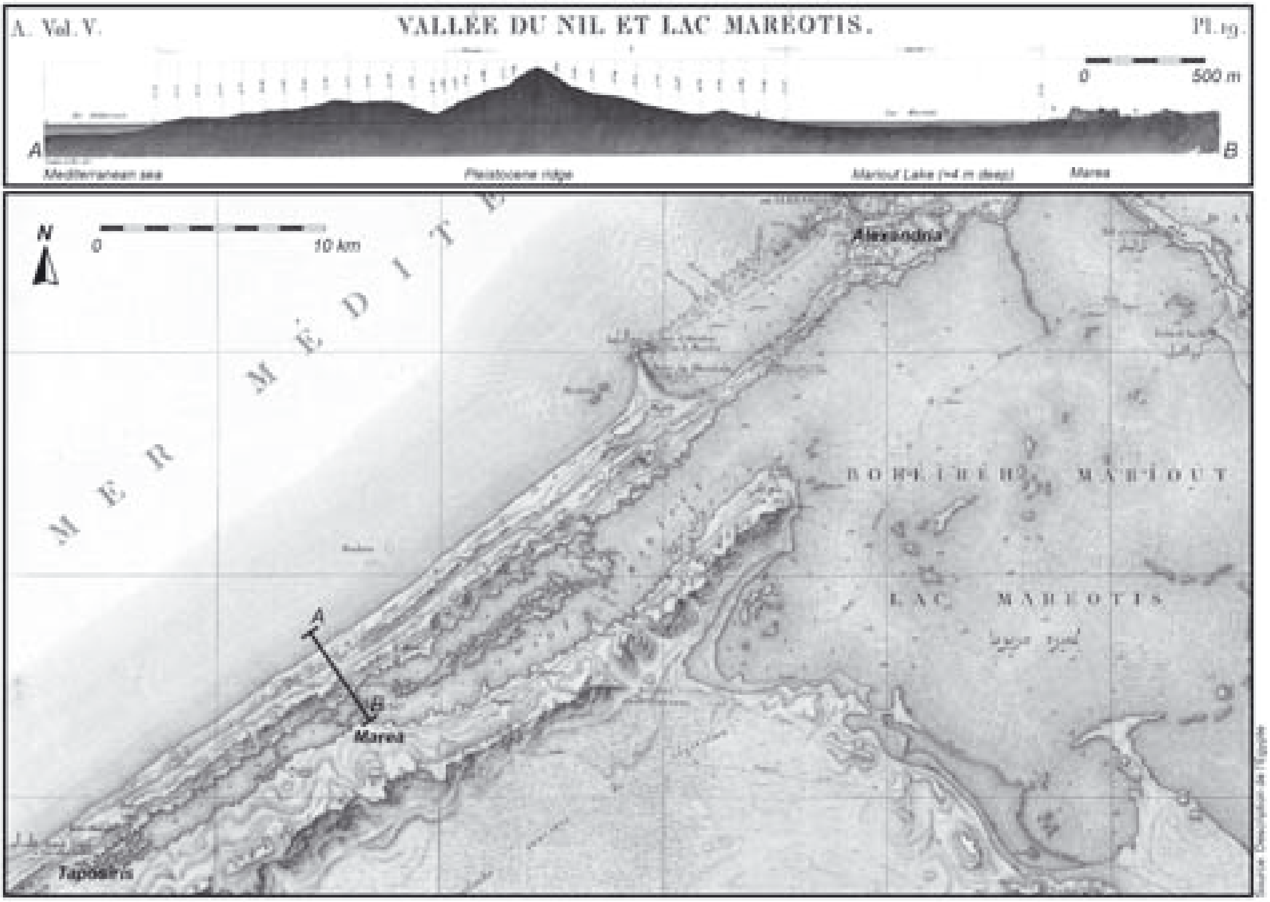


Fig. 2 Profile of Lake Mariout and of the Pleistocene ridge separating it from the Mediterranean Sea in the Marea area, 10 km northeast of Taposiris

into the abandonment of the harbor can be obtained in the eastern part of the closed system. Archaeological finds (pottery and coins) reveal that the harbor was used until the first part of the 7th century AD. Although we have these two dating elements (period of construction in the western part, period of abandonment in the eastern part), many uncertainties remain concerning the detailed chronology and history of the harbor.

A major question is the subject of this paper: to separate the basin from the lake, was the large levee built on top of an underwater ridge parallel to the coastline, facilitating its construction, or was the entire levee constructed? To address this issue, 5 boreholes were drilled in the area of the western canal. The cores taken provide a cross section through the five environments encountered in the area: the small cove in the western part of the harbor, the basin at what is probably one of its deepest points, the canal, the levee, and the theoretically natural lake environment. 14C dates could only be determined from samples taken at the bottom of each core, since the amount of organic material was very scarce in the other strata. Sedimentary analyses were conducted on the samples, in particular measurements of grain size. As very few macrofauna and microfauna were found; interpretation of these data is difficult.

Hydrodynamic model

The numerical model used to compute wind-driven currents was a classic 2D horizontal model based on depth-integrated equations of fluid dynamics; the equations of the model are detailed in previous papers (Millet & Guelorget, 1994; Millet *et al.* 2000). The model has been successfully used in different coastal areas and especially in modeling circulation features and sediment dynamics in the ancient harbors of Lacydon (Millet *et al.*, 2000) and Alexandria (Millet & Goiran, 2007). The model computed depth-averaged current velocities at steady state for homogeneous water masses under a constant wind forcing. This system is solved by a classic semi-implicit ADI scheme (Alternating Direction Implicit) with a short time step of 1 mn.

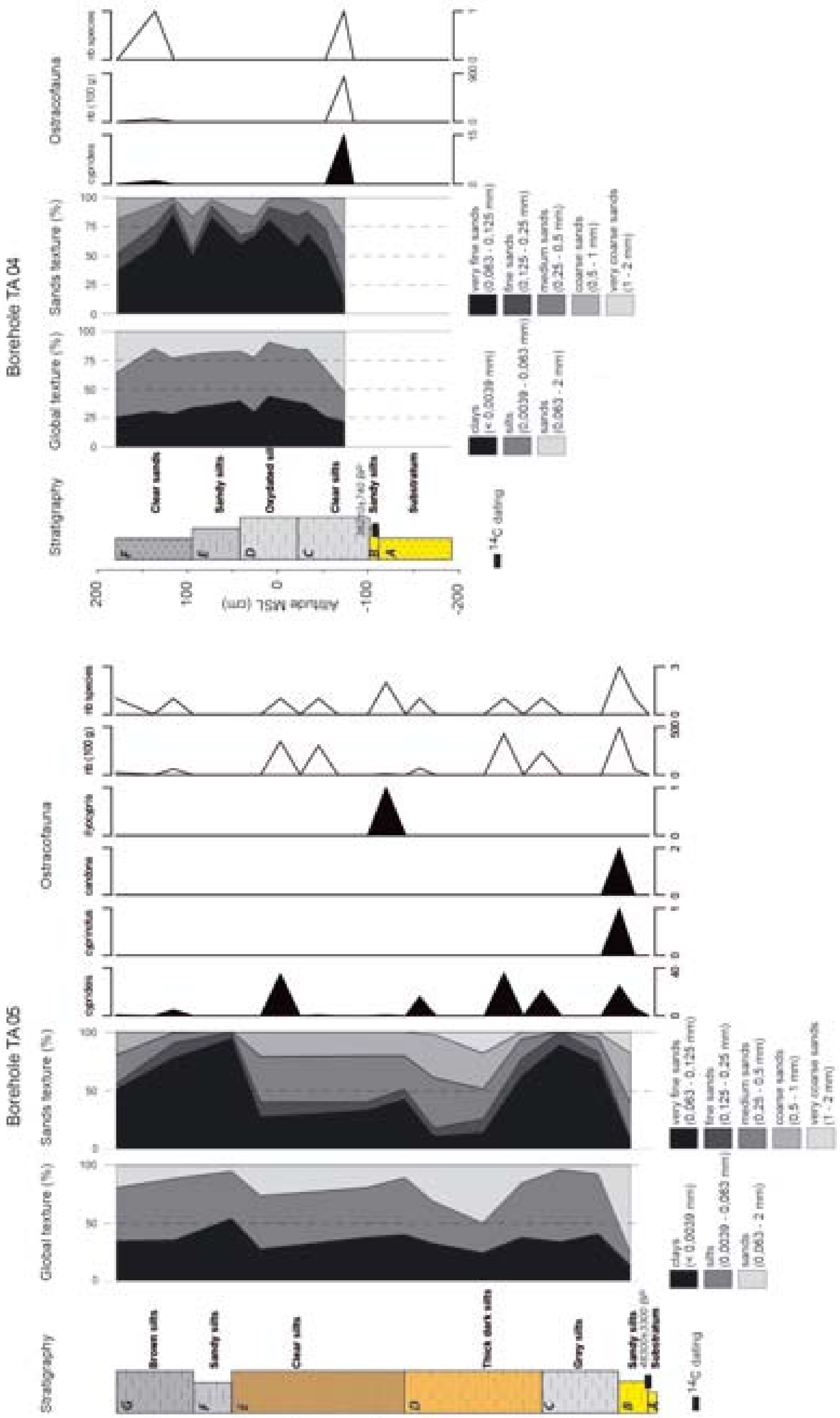


Fig. 3 Boreholes made in the cove (TA-05) and in the harbor (TA 04)

The model was adapted to Lake Mariout by using a 80 x 41 grid of regular 1 km squared meshes, with bathymetric measurements from three data sources: the depth of the water measured during Bonaparte's expedition in Egypt (*Description de l'Egypte*), using a quasi-modern hypothesis, the borehole cores of the MEDIBA program (Stanley *et al*., 1996) and the borehole cores described in the present paper.

Computations of the wind-induced water mass circulation within Lake Mariout were entered successively in consideration of the forcing of the three prevailing local winds: NE 30°, NW 330° and W 270°.

Sedimentary analysis

Five kinds of deposits were found in the cores, at different depths for each of them. They are, from bottom to top, the Pleistocene substratum, composed of clear sandstone, a transition layer of alterites, and three layers of much thinner sediments (silts and clays), corresponding to a natural lake environment (El-Wakeel *et al.* 1970), a sequence of what appears to be human-altered deposits, and a more recent post-harbor deposit.

The cove and the harbor (TA-04 and TA-05)

The base of both cores (fig. 3) reached the substratum of sandstone. The substratum is met at only 2.7 m below the modern topographical surface in the cove (TA-04). On the other hand, elsewhere in the basin (borehole TA-05), the substratum is encountered 6 m below the topographical surface.

The layer of alterites (particles from the substratum that have been torn from it) forms a small (20 to 50 cm thick) transition stratum. It consists mostly of coarse sands, and includes many fragments of sea shells, unfortunately too small to allow determination. Radiocarbon dates obtained from the shells established a Pleistocene chronology, still within the range of radiocarbon dating capabilities (Plastino *et al.*, 2001) (TA-05 28: 48300±3300 BP, TA-04 12: 36210±740 BP).

Layers C and D of core TA-04 are characterized by fine grain size. Silts and clays form the major proportion of the sediment. Most of the sandy fraction is composed of fine or very fine sands (less than 125 µm). The few ostracods found in these layers (*Cyprinotus* and *Ilyocypris*) suggest the influence of fresh water. The same observation can be made in the cove (TA-04), although the stratum is obviously much thinner.

The topmost stratum of both cores is characterized by a modification of the sandy fraction. Although the general distribution of grain size appears not to change significantly and is still dominated by fine particles (silts and clays, but in decreasing proportion), sands are more present, and even coarse sands (1–2 mm) can be found.

The canal (TA-03)

The base of the core from the canal (fig. 4) is similar to what was found in the other areas. An alterite layer (B) on top of the sandstone substratum (A) that lies 5 m below the topographic level shows an abundance of shell fragments.

A stratum 70 cm thick (C) lies above. The grain size is small; the sediments are mostly composed of silts, with a smaller proportion of clays and finer sands. Analyses of heavy metals were carried out on this core. The amounts measured in this stratum are the lowest in the core (5 ppm copper, 2 ppm lead).

This changes dramatically at the base of the next unit (D), where we can observe a peak in the sandy fraction, and within it, a larger amount of coarser particles. There is a peak in the concentration of heavy metals as well. After these initial high values, the sedimentary composition returns to a facieses close to the one in unit C, although with higher heavy metal concentrations and a slightly higher grain size.

The topmost units (E and F) consist of very fine sediments: silts, clays, and almost no trace of particles larger than very fine sands. The content of heavy metals is higher in these layers, the concentration of lead reaching a comparatively high value of 12 ppm.

14C dates

Sample ID	Lab ID	Material	^{13}C / ^{12}C ‰	Age (BP)
TA 01 33	Lyon-6937	Shells	–1,46	44300 ± 2000
TA 02 37	Lyon-6938	Shells	1,08	47900 ± 3100
TA 04 12	Lyon-6940	Shells	–0,06	36210 ± 740
TA 05 28	Lyon-6942	Shells	–3,55	48300 ± 3300

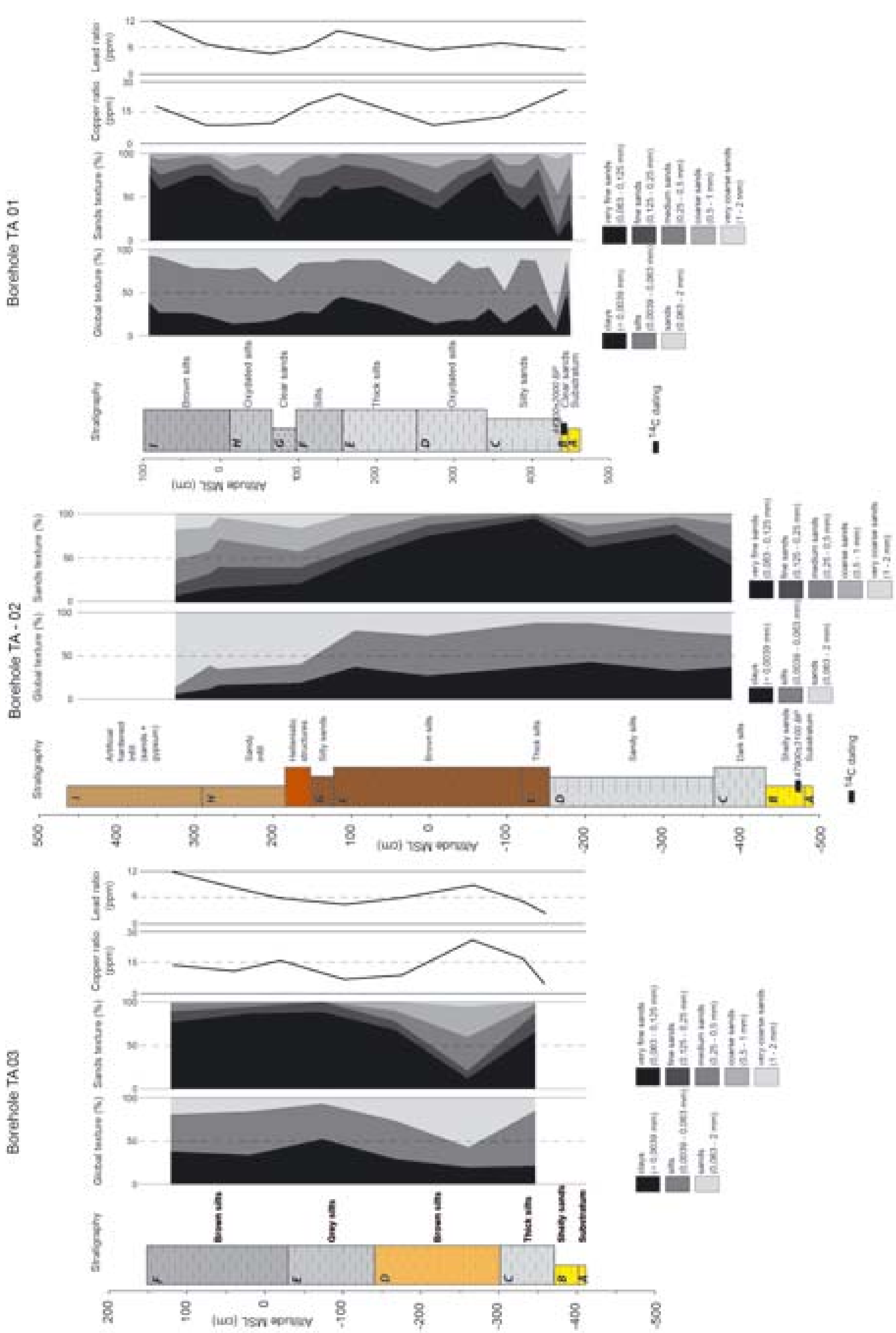


Fig. 4 Boreholes made in the canal (TA-03), on the levee (TA-02) and in the lake (TA-01)

The levee (TA-02)

Borehole TA-02 (fig. 4) is the deepest that was drilled. It reaches down to 9.5 m below the topographic level, and because of its location on top of the upswept levee, the topographical level of this core is about 4 to 5 m higher than the level of the other boreholes.

The bottom of the core is similar to the above-mentioned substratum (sandstone and alterites). Again, the Pleistocene chronology of this layer was provided by radiocarbon dates on the shells in unit B (TA-02 37: 47900±3100 BP). Above, a layer 70 cm thick is composed of fine particles (clays, silts and fine sands). The grain size in units D and E is even smaller, decreasing to a point where no particle larger than 250 µm can be found.

Unit F marks a change in this trend, the proportion of coarser sands rising. In unit G, this trend towards larger particles increases, until the proportion of sands reaches about 60% of the sediment. Among the sands, the mean size of the particles also increases, with the five classes of grain size being almost evenly distributed.

The last three meters of the borehole core correspond to that which projects above the modern water level of Lake Mariout. The archaeological excavations in the area show that the top of the levee consists of silty sands that were covered by a mix of sand and gypsum (unit H and then I, fig. 4). The Hellenistic occupation layer is found in unit H, and is covered by unit I. This levee was described as a man-made construction by Dr. J.-P. Goiran during his field mission in 2004 (Boussac 2004).

The lake (TA-01)

The sandstone substratum / alterites association is found again at the bottom of the borehole (fig. 4). Radiocarbon dates on seashells found in layer B confirmed that this stratum dates to the Pleistocene, as for the other cores (TA-01 33: 44300±2000 BP). Above it, units C and D are characterized by their irregular grain size, although in general they remain more silty. The amount of heavy metals is quite low (about 10 ppm copper and 6 ppm lead).

Unit E denotes a clear modification of the deposits. It is more homogenous than the previous strata. Grain size is fine, the most represented fraction being the silts. Clays are well represented, and the grain size of the sandy fraction is characterized by the absence of coarse and very coarse particles. Also to be noted in this layer is the peak of concentration of both heavy metals studied, copper (25 ppm) and lead (10 ppm).

Unit G (and, to a lesser extent, F, a transition facieses) is clearly sandier, the sands themselves being also coarser. Unit H presents a more conventional (compared to what has been encountered before) facieses of silty sediments. The concentrations of heavy metals have also returned to low values.

Finally, the top layer tends to be comprised of even more fine particles, while the amounts of heavy metals rise again, as in the topmost layer of borehole TA-03 (the canal).

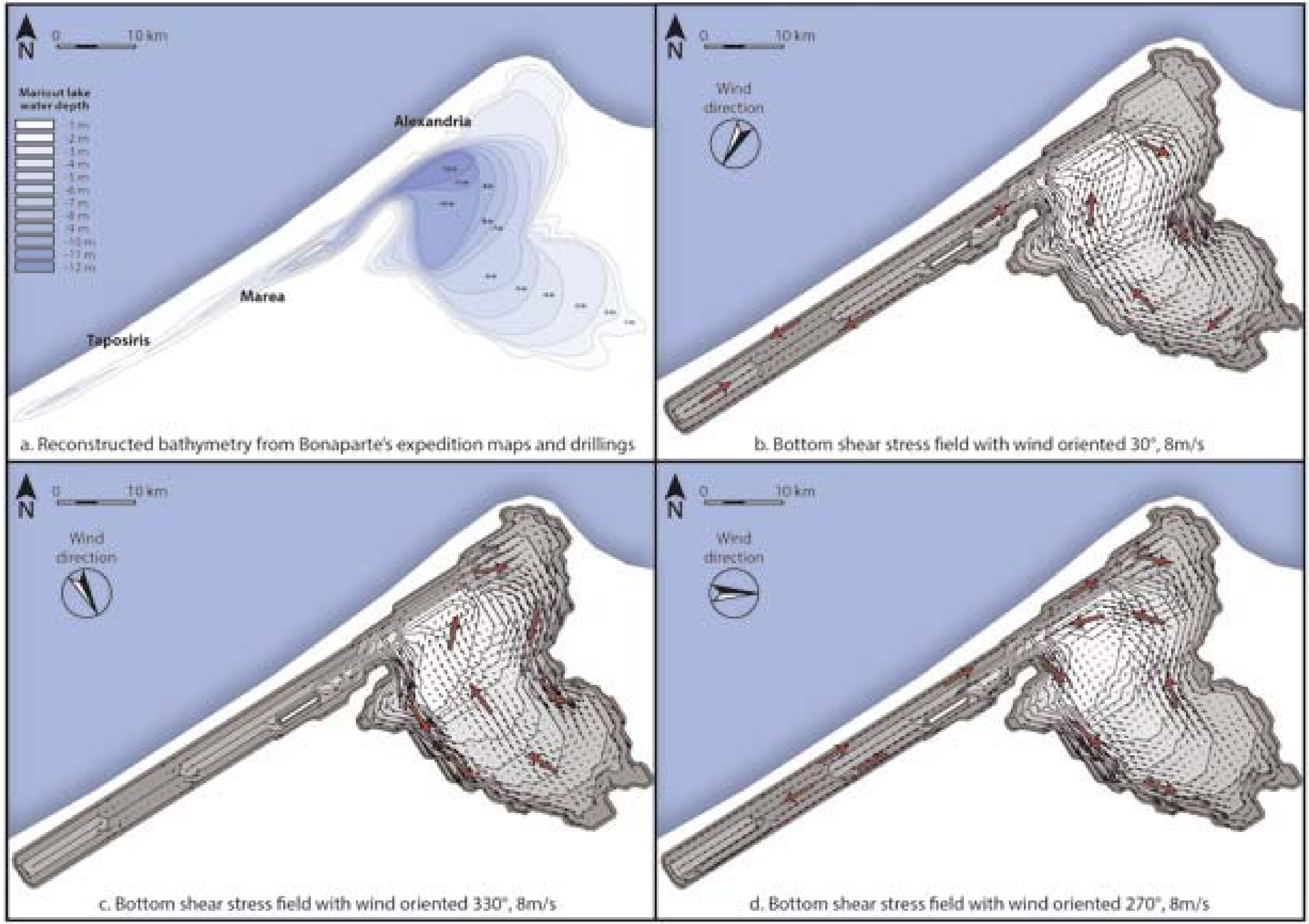
Interpretation

General considerations

Thanks to the few microfauna remains that were discovered in the samples, we can conclude that the area of Taposiris was a brackish environment influenced by the phreatic aquifer and perhaps the flow of the Canopic branch of the Nile. The mixed environment enables the development of euryhalin species like *Cyprideis,* while the presence of *Ilyocypris* is evidence for freshwater episodes. In regard to sedimentation, the entire environment of Taposiris is a very quiet one. This is reflected by the very fine grain size measured in all the strata except for the substratum and the fine laterite layer covering it.

Low currents explain the almost exclusively silty sedimentation

The very fine nature (silts and clays) of the particles that have been sampled in the lake and the potential harbor is typical of very quiet waters that allow the deposition of light particles and are too weak to carry heavier particles (sands and coarser particles). This has been demonstrated in Lake Mariout by the results of using the hydrodynamic model of water circulation and the resulting shear stress on the bed bottom. Figures 5b and 5d present wind-induced shear stresses on the bottom ($N.m^{-2}$), computed by the model, forced under NE 30° and W 270° 8 ms^{-1} wind conditions. The results present two opposite hydrodynamic structures relating to each wind direction, featured by a clockwise (anticlockwise) eddy in the eastern part of the lake corresponding to the NE 30° (W 270°) wind (fig. 5b and 5d). Mean depth-averaged current velocities were 11 $cm.s^{-1}$ (NE 30°) or 9 $cm.s^{-1}$ (W 270°); maximum current velocities of 31 $cm.s^{-1}$ (25 $cm.s^{-1}$) and bottom shear stress 0.22 $N.m^{-2}$ (0.14 $N.m^{-2}$) occurred along the eastern (western) shore of the lake for NE 30° (W 270°) wind. In addition, the results confirm the weaker circulation within the western channel of



a. Reconstructed bathymetry from Bonaparte's expedition maps and drillings

b. Bottom shear stress field with wind oriented 30°, 8m/s

c. Bottom shear stress field with wind oriented 330°, 8m/s

d. Bottom shear stress field with wind oriented 270°, 8m/s

Fig. 5 Reconstructed bathymetry of Lake Mariout using depth data from Bonaparte's expedition, MEDIBA project boreholes and present paper boreholes (5a) Results of the 2D hydrodynamic model. Computed fields of bottom shear stress ($N.m^{-2}$) relating to the wind-induced currents, superimposed on the bathymetry, under the 3 prevailing 8 ms^{-1} winds: NE 30° (5b), NW 330° (5c) and W 270° (5d) the lake, with three adjacent cells of current and bottom shear stress, operating in opposite directions depending on the wind direction: 2 cells of current relating to sediment transport flowing westwards (eastwards) along the shores and 1 cell flowing back eastwards (westwards) in the central channel for NE 30° (W 270°) wind. Weak current velocities (about 10 $cm.s^{-1}$) and bottom shear stresses (about 0.03 $N.m^{-2}$) were computed within the channel for both NE 30° and W 270° winds. It is noteworthy that water and sediment exchanges between the western channel and the eastern lake were oriented in opposite directions depending on the wind, with lateral (central) import towards the channel and central (lateral) export towards the lake for NE 30° (W 270°) wind.

Figure 5c presents a second contrasted pattern of circulation that occurred within the lake and in the channel under the NW 330° - 8 ms^{-1} wind condition. This pattern is characterized by 3 cells of water and sediment circulation within the eastern lake, flowing southwards along both shores of the lake and northwards in the central part. Mean depth-averaged current velocities were 9 $cm.s^{-1}$; maximum current velocities of 28 $cm.s^{-1}$ and bottom shear stress 0.16 $N.m^{-2}$ occurred along both eastern and western shores of the lake. The NW 330° wind-induced circulation in the channel presents a succession of adjacent slow eddies with weak current velocities less than 10 $cm.s^{-1}$ and bottom shear stresses less than 0.03 $N.m^{-2}$. These weak and discontinuous hydrodynamic structures in the channel, induced by the most frequent local wind (NW 330°), in the long term prevents this channel from strong sediment re-suspension and exchanges with the eastern part of the lake, which reinforces the rapid deposition in the channel of the fine particles of the local sediment.

Furthermore, X-ray diffraction analyses carried out on the samples show mainly a river influence as far as fine particles only are concerned. The signature in the silty and clayey fraction of the sediments, exhibiting high proportions of montmorillonite, is close to the signature of the Blue Nile. This means that only the fine particles originating from the floods of the Canopic branch of the Nile reached the area of Taposiris. However, coarse particles present in the cores from Taposiris exhibit a more nearby origin, not related to fluvial transport processes. Quartz morphoscopy analyses demonstrate that aeolian sands coming from the nearby desert and sands created by the erosion of the neighboring Pleistocene ridges by runoff water form the coarse fraction of the deposits at Taposiris.

This explains why the sediments observed in the potential harbor at Taposiris are very fine. The local sources of coarse sediments are only aeolian processes and ridge erosion, and the flood sediments from the Nile (already mostly fine particles), are quickly sorted by the low energy of the water in the lake.

The construction of the levee

Contrary to borehole TA-04, no trace of an uprising of the substratum under the levee was observed (borehole TA-02) (fig. 6). It does not appear to have been cut through either, since the alterite layer on top of the sandstone seems to be untouched, as attested by the radiocarbon dating. The rest of the levee consists of the same kind of fine sediments that can be found in the lake. It is therefore clear that the levee was artificially built using fine sediments found in the lake, and did not take advantage of a preexisting natural feature of the substratum.

Base unit D in borehole 3 (channel) may denote anthropic activity, because of the peak of sandy material and heavy metals (especially copper). The same peak in the amounts of heavy metals is observed at a slightly different depth in the lake, but is otherwise comparable. However, no dates have been determined to confirm that these strata are chronologically synchronous. Since the levee between the channel and the lake cuts through the stratigraphy, we can only assume that layer TA-03 D is equivalent to layers TA-01 E and F. Traces of a natural lake environment directly on top of the laterite layer can also be observed everywhere except in the harbor itself and is much thicker in the lake borehole (TA-01). The absence of natural lake sediments in the harbor means that they could have been reworked, again showing the effect of human activity.

The question of the levee during the Hellenistic period must be raised. The top of the levee as we can see it today was partially built on top of a Hellenistic area. However, even if we consider a partial sedimentary accretion in the lake that was later excavated in its northern part to create the later canal and harbor basin, it is extremely unlikely to have been high enough to emerge from the lake (that would in fact mean a complete infill of the lake). Considering that the Pleistocene substratum below the levee is as deep as in the other boreholes (about –4.5 m), this implies that a first step in the levee construction might have occurred as early as

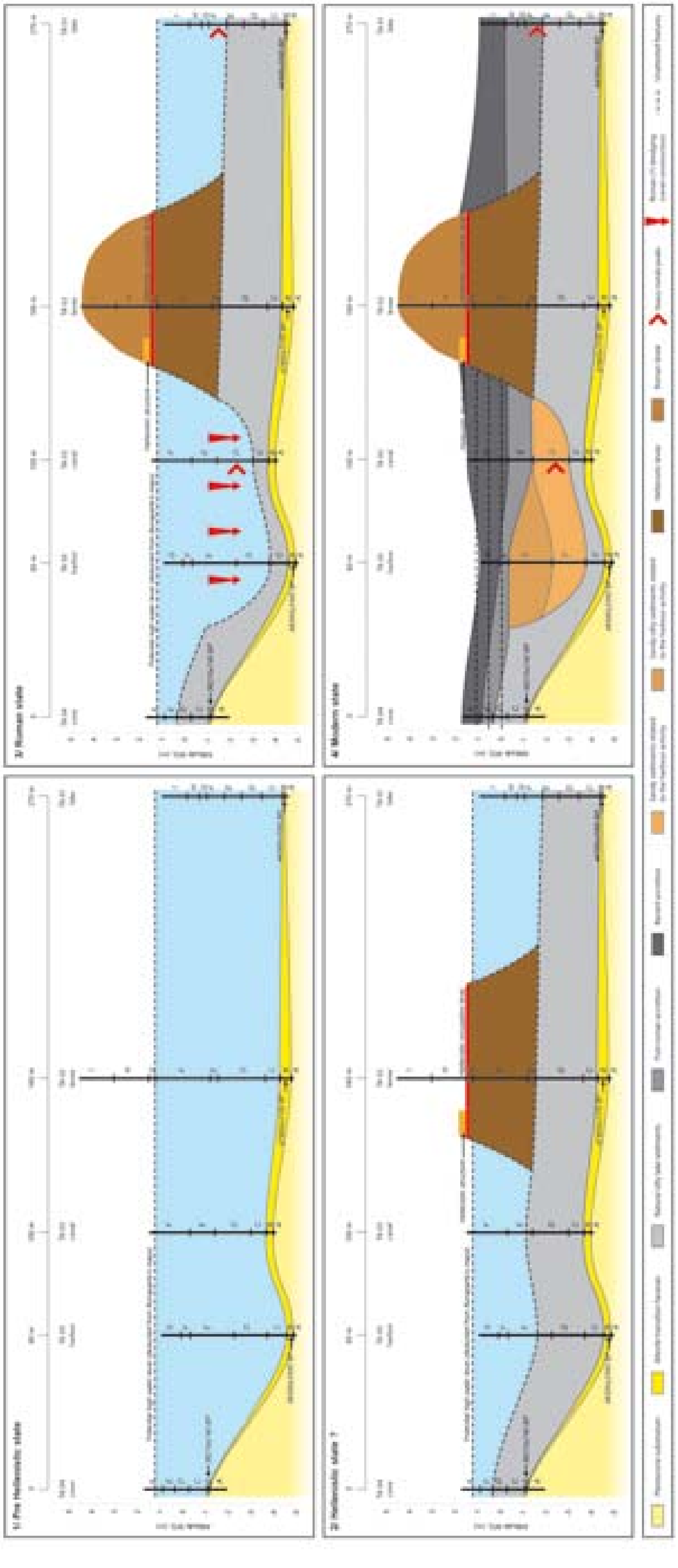


Fig. 6 Cross section presenting all studied boreholes and the potential chronological evolution of the area

the Hellenistic period. We can then suppose a two-step layout of the system:

During the Hellenistic period, a small levee is built above natural silted sediments from the lake, separating the city from the Mariout, possibly to act as a breakwater. This levee, constructed with lake materials (the grain size analyses show that the composition of the levee is indistinguishable from natural sediments), probably rose just above the lake level during the high water period. Comparing this information with the data of Bonaparte's expedition (a draught of about 2 m), we can infer that the approximate accretion level before any further anthropic modifications was about 2 to 3 m on top of the Pleistocene substratum.

Then, during the Roman period, the main developments were carried out. The levee was raised further, partly above the ancient Greek area. This time, the levee was consolidated with gypsum material to make it stronger. At the same time, the bridge linking the levee to the shore was built. Under the bridge and farther to the east, lake sediments were dredged to create a true harbor environment. This, combined with the construction of a jetty across the lake, could have induced slightly stronger currents in the only remaining passage between the western and eastern parts of the Mariout, the canal under the bridge at the entrance of Taposiris. These stronger currents then explain the deposition of coarser particles (the layer is notable by the presence of coarser sands) in the canal and in the harbor. In the case of the Taposiris harbor, the coarser sediments could be the sign of an artificially modified environment where the flow of water is facilitated, contrary to the extremely quiet natural environment where fine particles deposit slowly. The fact that this layer contains high quantities of heavy metal suggests that it was deposited during the occupation of the site.

The topmost sediments show a return to natural tendencies after the city is abandoned: a progressive silting up of the lake by deposition of fine sediments. The high values of heavy metals in the topmost strata could this time be caused by modern rather than ancient pollution.

Conclusion

The results obtained in our study shed some light on the construction of the harbor structures of Taposiris. The levee was entirely built on top of a layer of natural lake sediments, probably during the Hellenistic period but possibly earlier, using material from the lake itself, except for the top of the structure that had been hardened by gypsum particles in a later period. During this later period (Roman), a major modification of the area probably occurred, the dredging of ancient lake sediments to build a canal and a true harbor basin.

A major limit of our study is the lack of dating results except at the bottom of the cores, which provided a Pleistocene chronology. It is therefore impossible to correlate the sedimentation phases with the known historical occupation phases. This is especially true for the abandonment of the harbor. This data is known thanks to archaeology, but without dates in the sediments, questions concerning sedimentation rate in the harbor, discrepancies between sedimentary accretion in the lake and in the harbor, evidence of dredging phases, remain open. Furthermore, we have yet to ascertain the exact date of the construction of the base of the jetty and of the dredging of the canal.

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