

GEOARCHAEOLOGY OF AVARIS: FIRST RESULTS

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We present in this paper the first results of a palaeoenvironmental study, achieved in collaboration between the Austrian Institute of Cairo and UMR 5133 Archéorient (French CNRS). The studied site is the Hyksos capital city of Avaris, at Tell el-Dabʿa, on the eastern margin of the Nile Delta. An Austrian team led by M. Bietak and I. Forstner-Müller is excavating the area (s. www.auaris.at, BIETAK 1975).

In antiquity, Herodotus talked about five river branches in the Nile delta (Herodotus II § 17, in: TOUSSOUN 1925, 148–149). The eastern one is the Pelusiac branch, so called because of the city of Pelusium. This branch has since dried up and only scarce remains appear in the landscape. When Herodotus visited Egypt during the 5th century BC, the branch was still flowing water as it had been during the 2nd millenium BC. According to archaeological surveys the palaeo-Pelusiac branch was located close to the city of Avaris (BIETAK 1975, DORNER 1993/94, 1999). The river lay west of the city, between the modern villages of Khataʿna, Enbalaisa, Madrabi and ʿEzbet Helmi. The main branch seems to separate into two channels in the north, around the ancient city of Piramesse.

The goals of this program are to reconstruct Avaris' landscape during Hyksos times, to understand the evolutions of the Nile branch that crossed the city, and to locate the position of the city's harbours.

1. TOOLS AND METHODS

1.1. Sedimentary drillings

The Tell el-Dabʿa area has been studied for several years, introducing geomagnetic surveys. Archaeologists mainly use these surveys to locate buidling structures. However, geomagnetic surveys are also useful for the reconstruction of palaeo-landscapes, and are important in deciding where to locate drilling points: rupture lines in the

lithology, which may be linked to the presence of palaeo-lakes or river branches can be observed. The results of T. Herbich's surveys (FORSTNER-MÜLLER *et al.* 2004, 2006, 2007) were used in order to choose the coring points. A former landscape reconstruction done by J. Dorner (Fig. 1), also provided a useful first approach to the understanding or the area's palaeo-topography.

During a one month coring campaign, 35 drillings were made all over the archaeological site (Fig. 2). A hand-held drill was used, reaching a depth of around 8 metres. On several occasions, we were able to drill deeper, especially in a palaeo-river branch to the west. Drillings are the only way to gain reults, since the water-table is very close to the surface (because of the delta context), allowing us to avoid more expensive methods, such as draining the ground water (GOIRAN, MORHANGE 2003, 647–669).

We had two main objectives:

- 1) to reconstruct the evolution of the Pelusiac branch of the Nile
- 2) to locate the ancient harbours

The sediments extracted during the drilling campaign have been studied in two steps.

In the field, we described each sample according to several criteria: sediment type, colour (oxidation can be rapid once the sample is extracted), eventual presence of fauna (shells), organic matter (wood, plants, these elements can be used for radicarbon dating or macro-remains analysis) or any other noticeable element (such as a huge presence of gypsum that has been observed in some samples).

In the laboratory, the samples were studied under a binocular microscope. Micro and macro-fauna were extracted, notably ostracods. The appearance of some species can reveal a specific kind of sedimentation, which can be linked to a specific environment (marine, lagoon, river...).

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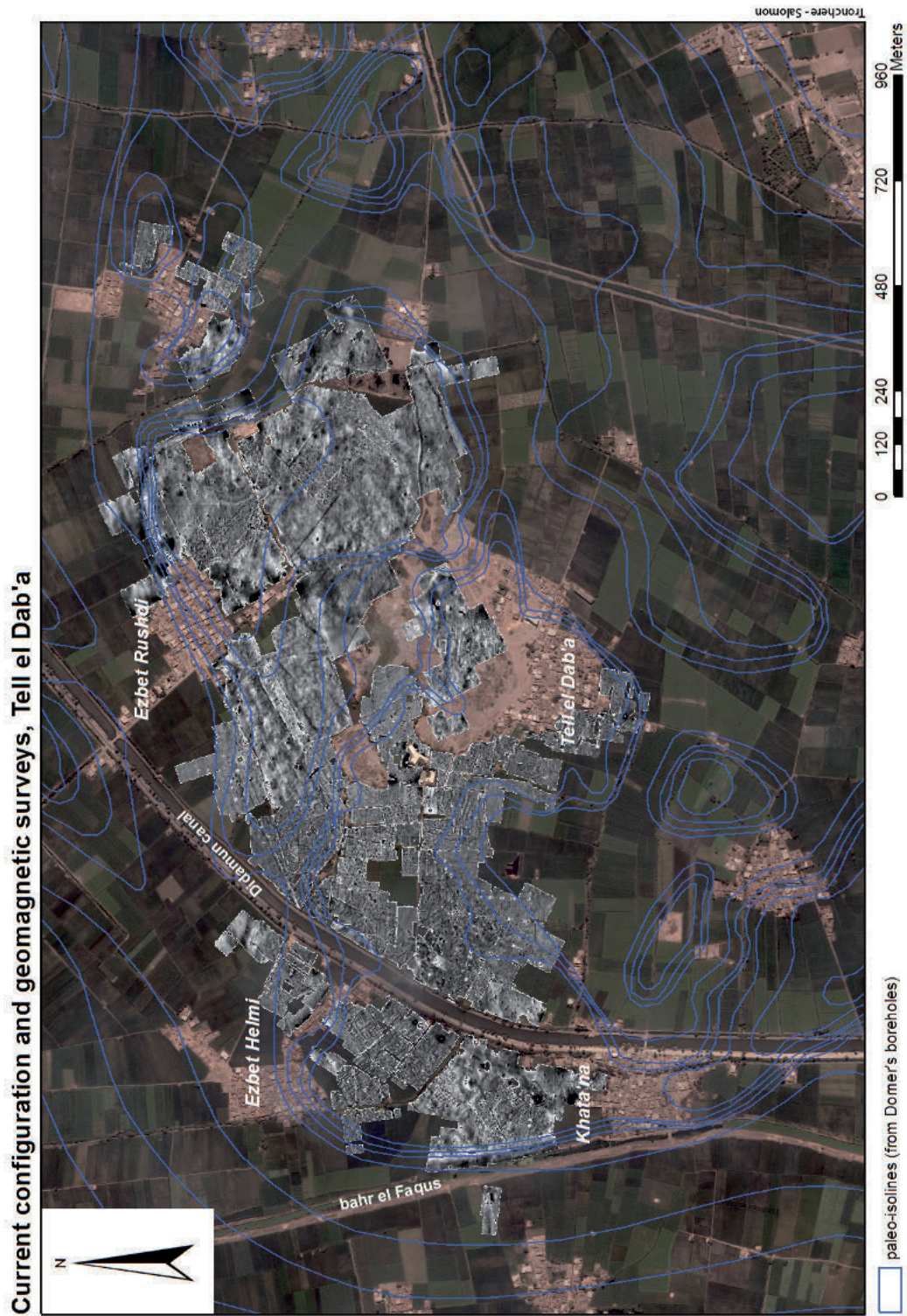


Fig. 1

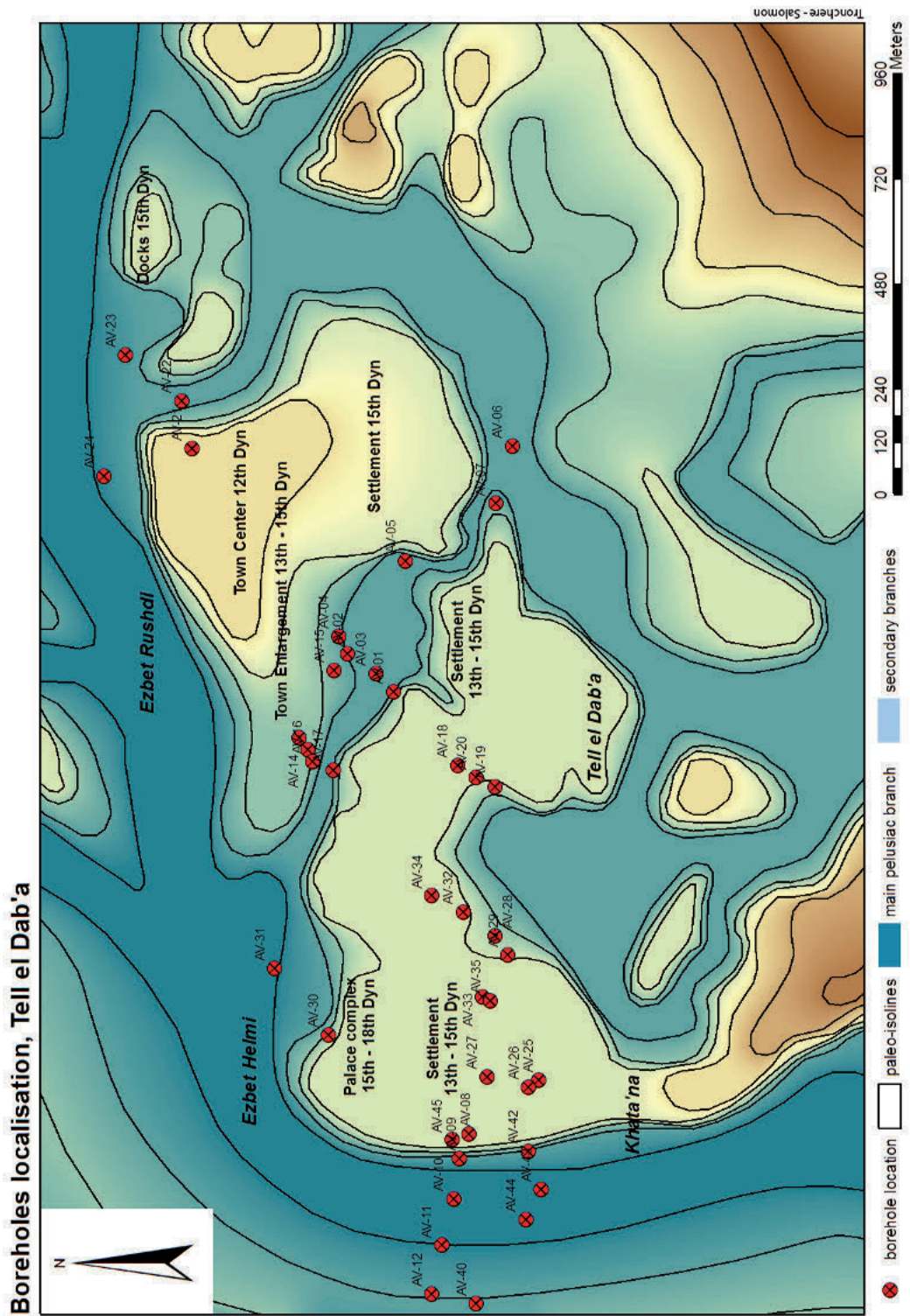


Fig. 2

In the Nile delta, the soils are very acid, thus most shells are destroyed. We only found a few ostracods, insufficient to perform statistical analysis to infer the depositional environments. This proxy, usually very efficient, probably won't help here. The high ground acidity tends to destroy any organic remains, so radiocarbon datings will probably be a problem too (since they are mostly done on shells, seeds or wood remains).

1.2. Granulometry and morphoscopy

Our vision of the palaeo-landscape can be summarized through a group of corings. Our aims were to understand the various ancient environments, both natural and anthropogenic (harbours), and thus we needed to break up every sample in order to get more information and details.

1.2.1. Granulometry

As we outlined before, there are not many proxies in our samples. We had to focus our work on the sedimentology. We aimed to describe the various depositional modes and the differences between them. The Nile delta sediments contain almost no coarse elements (>2mm), so it is therefore essential to know precisely the statistical distribution of the smaller grains, according to their size. To do this we did a granulometrical study of the samples. We chose our samples at regularly spaced points in our corings, taking into account the observed stratigraphy. For each chosen sample, we extracted 5 to 8 grams of a mud obtained by adding distilled water to the sample. We then destroyed the organic matter in these "sub samples" with oxygenated water so that the sample was exclusively mineral. Then, we separate the agglomerates in order to avoid mistakes when measuring the grain size. For this defloculation step, we use potassium chloride. The sample is then cleaned up with distilled water. The measurements were made using a Malvern Mastersizer Hydro 2000 laser micro-granulometer. This way, we obtained the statistical distribution of the grain sizes of our samples.

1.2.2. Morphoscopy

The second method used was the morphoscopy of the quartz grains. The granulometry shows that several sedimentation processes do exist, and the morphoscopy helps in defining them. Morphoscopy applies to the sand fraction (in between 63 µm and 2 mm). Quartz grains were observed with a binocular microscope. In our context, the goal was to establish the differences between the fluvial on sed-

imentation, linked to the Pelusiatic branch, and the aerial influence, linked to the gezira (turtleback). For this analysis, we systematically took one sample every 20 cm. A 20 g sampling was done, sometimes 50 g if the sample was mostly silty. The sand was extracted by wet processing sieving. Once dry, the grains were divided using a micro splitter in order to obtain a very small amount of sediment. 100 quartz grains, randomly chosen, were then described for each sample. Our criteria were as follows: general shape, surface aspect, and transparency. We differentiated between four wear states, according to CALLEUX and TRICARD (1965): no wear with sharp edges, blunted with softer edges, almost rounded without any edges, and very rounded when the grain was almost spherical. The shape provides information about the transport time: a sharp grain has not been transported very far. The surface aspect is the most important factor in determining the grain's origin: fluvial or aeolian. Aeolian quartz grains are dull, with small surface damages, due to the collisions between the grains. Fluvial grains are smooth and polished, since the hydraulic transport processes are less violent. The last information, transparency, is to be linked to the chemical composition of the grains. The grain can be opaque, translucent or hyaline.

2. OBSERVATIONS

2.1. Sedimentary facieses identification

We were able to isolate five main kinds of sediments in the study area. Each of them results from different processes, linked to different environments.

2.1.1. Brown or grey silts

Everywhere in the studied area, brown or grey silts were found at the top of our drillings. This homogeneous layer can measure between one and two meters. Most of the time, archaeological remains were found in this layer. Structures, composed of raw bricks show a colour similar to the ground.

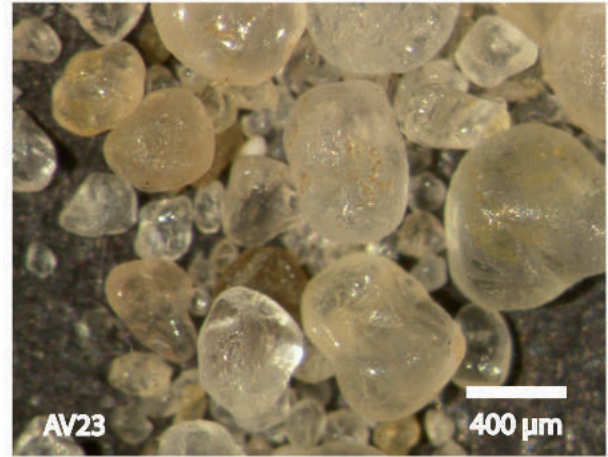
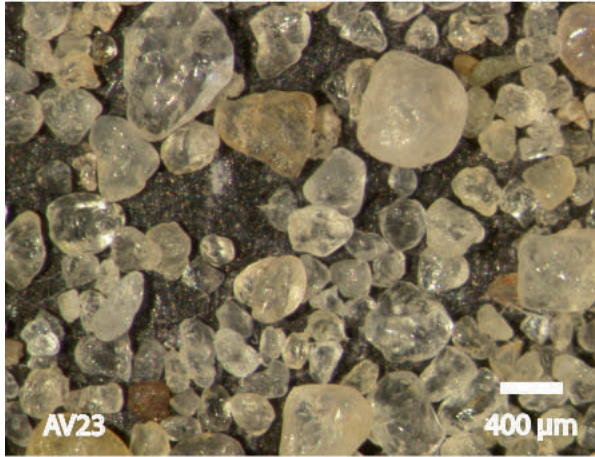
Modern agricultural activity largely contributed to alter the superficial part of this layer.

In its deepest part, this layer can be associated with flood sediments that participated in the filling of the river branches.

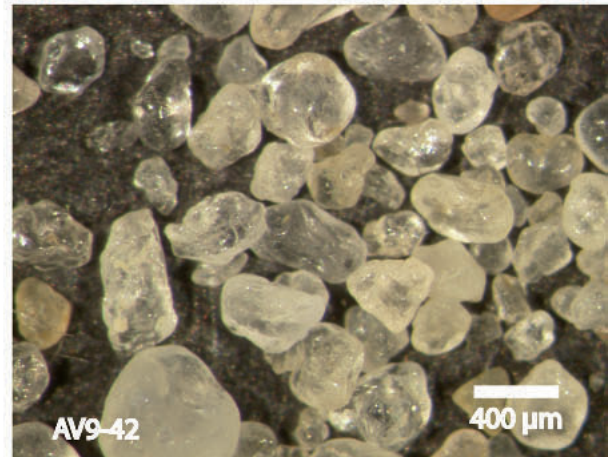
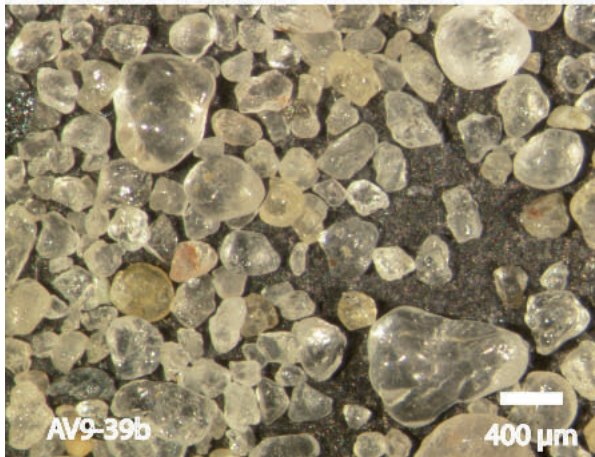
2.1.2. Compact grey clays

Sediments made of thick dark grey clays, denote a slow flow, allowing the deposition of even the thinnest particles. This layer is quite homoge-

Gezira sands



Fluvial sands near the gezira



Fluvial sands

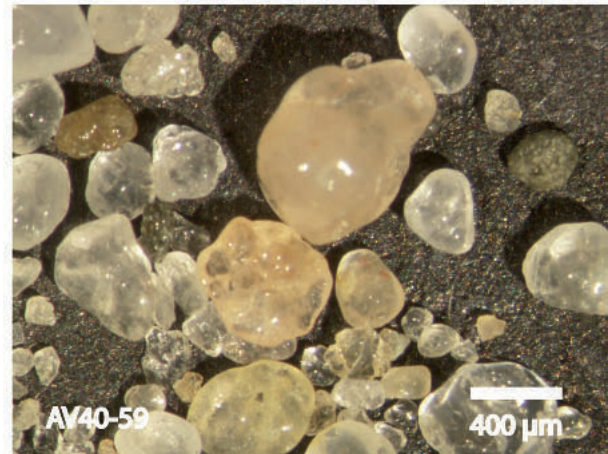
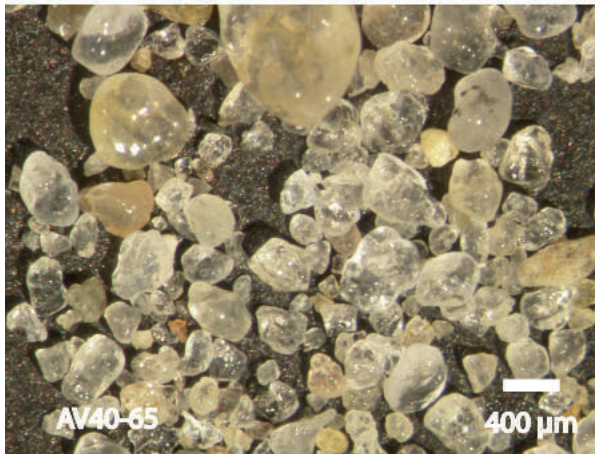


Fig. 3

neous, despite slight colour variations. Big gypsum crystals (1, even 2 cm in diameter) can be found in these strata. They have been extracted for further analysis. They are not present in the other depositional environments. Charcoal in

small quantities was also found: it only appears as dark traces when the samples were separated.

These grey clays are essentially to be found in what Dorner considers as secondary Nile branches (cores AV-06, AV-19...).

2.1.3. *Black organic silts*

These sediments only characterize just a few, highly specific strata. They are composed of almost black silts that contain lots of organic matter. We also found in these environments most of the macrofauna, but damaged and reduced to tiny fragments. The shell species are not determinable, which prevents us from using them to determine the environmental context. These silts are present at specific locations, in cores AV-02, AV-17, AV-29 and AV-23.

2.1.4. *Fluvial sands*

These sediments are typical of moderated energy flows. Their granulometry is quite homogeneous and is composed of coarse sands of various colour, without any silts. The shape of the quartz grains is polished and round. We mostly found these grains at the bottom of the cores situated in the main Pelusiac branch (cores AV-08 to AV-12). These sands were difficult to recover because of their low cohesion.

2.1.5. *Aeolian sands*

These sands are quite homogeneous, and their colour is mainly yellow, contrary to the fluvial sands. When observed with the binocular microscope, these sands appear as more irregular in shape and dulled, which is typical of sediments influenced by aerial processes. However, fluvial sands can also be found mixed with the aeolian sands. We can deduce that gezira sands originate from a juxtaposition of processes, which are harder to interpret. These sands can be found all over the gezira areas, just under the brown soil silts (cores AV-21, AV-32 and AV-34). They were difficult to take out, and we were unable to cross this layer.

2.2. **Granulometric analysis**

It is possible to differentiate the sediments according to five major types. A ternary diagram (Fig. 4) was used to represent the different kinds of distribution.

Our typology takes into account both the granulometric characteristics and the histogram shape. In a first class, we can find sands characterized by a mono or bimodal curve. A second class shows sediments in which the respective parts of clays/silts and sands are more or less balanced. The main mode is either composed of the silts or of the clays. In the two following classes, we can easily differentiate between mostly silty distri-

butions and mostly clay distributions by observing the diagram. This differentiation is easier as the sand proportion drops. The samples also tend to have a spatial distribution. Silty samples can be found in the main river branch, whereas clay samples can be found in the secondary branches. A last class includes samples with a complex distribution, without any distinctive mode.

2.3. **Morphoscopic analysis**

We are not yet able to provide strict quantitative analysis concerning the quartz analysis. However, we were able to establish a distinction between three main kinds of sands: fluvial sands, gezira sands, and mixed sands (Fig. 3).

Our main goal was to study the river sands. However, the river sediments result, at least partly, from the erosion of the gezira. The gezira sediments are exclusively composed of sands, but the size of the grains varies. Thus, the size criterion alone is not sufficient. According to Ebber's studies at Avaris (unpublished manuscript), turtleback sands are mainly, but not exclusively, of aeolian origin. A large proportion of fluvial sands was observed. Even without precise figures yet, we can already say that turtlebacks result from several processes.

The samples comprising fluvial grains were found mostly on the left bank of the main Pelusiac branch. The right bank shows trimodal diagrams incorporating what can be described as gezira sands. The secondary branches show a different behavior, having been largely influenced by aeolian processes.

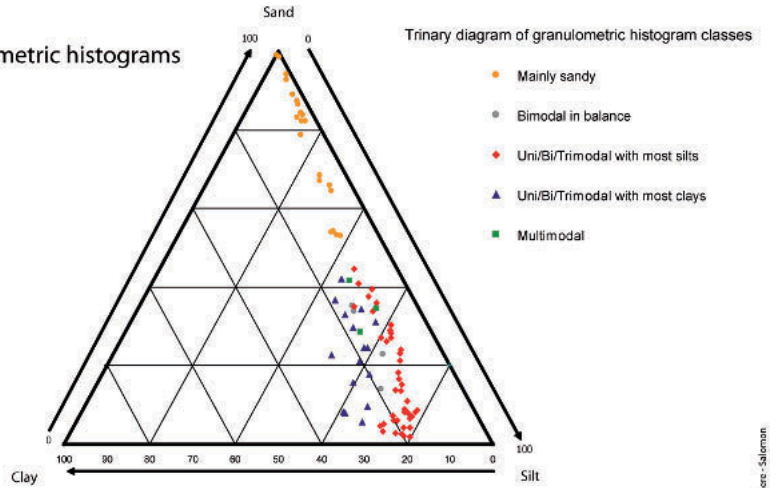
3. **INTERPRETATIONS**

3.1. **The main Pelusiac branch**

A series of six cores was drilled to the east of the city of Avaris, upstream of the supposed bifurcation of the river into two branches. Human settlements are situated almost only on the right bank of the river. The pot sherds found in the corings AV-08 and AV-09 tend to confirm this hypothesis. No sherd has been found on the left bank. This bank seems to comprise an embankment and a flood plain without any major human settlement. In other areas along the Pelusiac branch, embankments, to protect against Nile flooding, are favored by humans, but apparently not here (VAN WESEMAEL 1988, 125–134).

The drillings allowed us to reconstruct a stratigraphic profile of the main Pelusiac branch

Distribution of the samples according to the distribution of the granulometric histograms



Number of sample by granulometric classes

Classes		Mainly sandy	Bimodal in balance	Uni/Bi/Trimodal with most silts	Uni/Bi/Trimodal with most clays	Multimodal
Granulometric histograms forms						
Mean median (µm)		244.11	18.05	19.78	10.62	25.21
Principal branch	Boring AV8	1	1	4	4	1
	Boring AV9	2	0	7	2	0
	Boring AV10	2	0	10	0	0
	Boring AV11	1	0	9	0	0
	Boring AV12	2	0	6	0	0
Secondary branches	Boring AV2	6	1	2	0	0
	Boring AV17	4	1	2	1	1
	Boring AV23	4	1	3	3	1
	Boring AV29	3	0	0	6	0

Fig. 4

Cross-section through the pelusiac branch

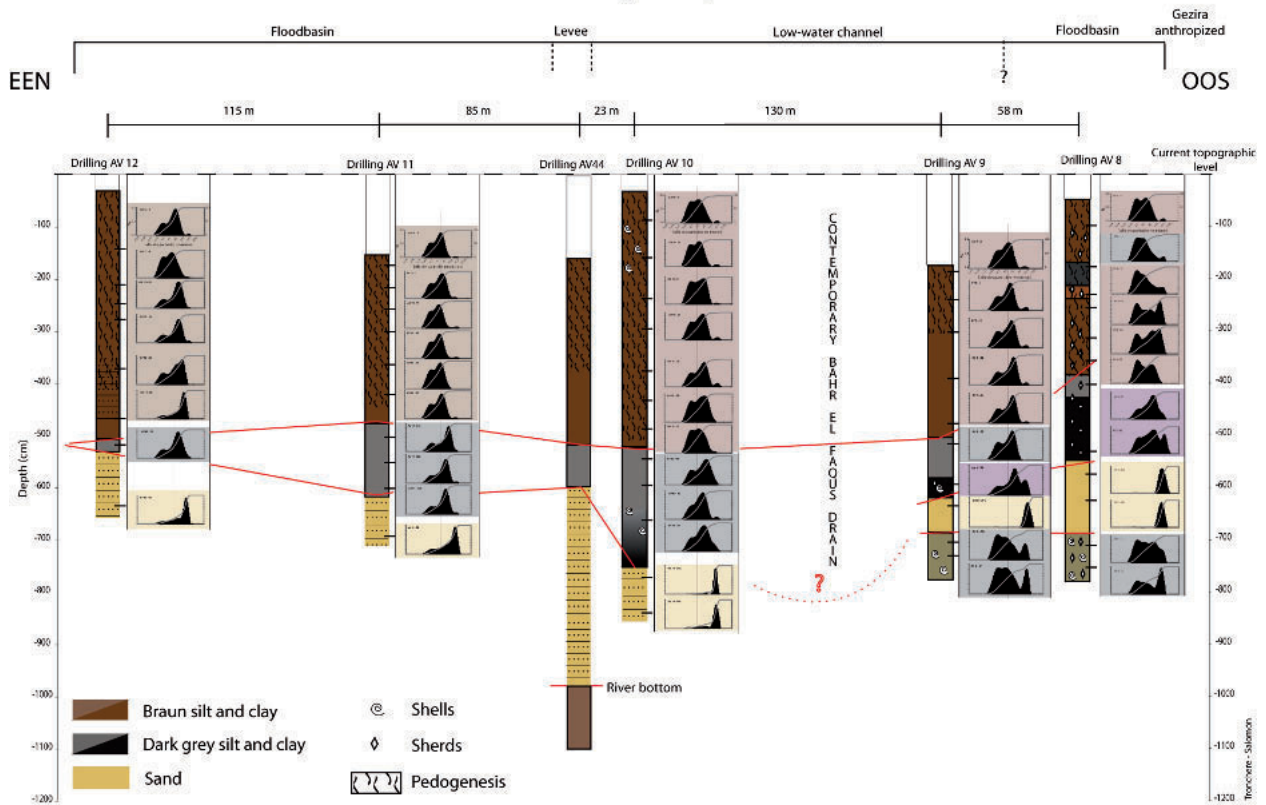


Fig. 5

(Fig. 5). Three main deposition sequences have been observed. At the bottom, we found sands ranging from fine to coarse, sometimes interrupted by silty clays (AV-44). On the left side, these sands were mixed with clays and silts that are noticeable on the granulometric diagrams. These sediments testify to a flowing river. The core AV-44 shows the depth of this layer (3.5 m) and a laminated structure of the sands.

Above these sands, a grey layer is composed of silts and clays. The filling of the river channel had already begun when these sediments appear. The channel's energy is lower, but the river still flows.

Higher in the core, the brown silts and clays mean that the channel is probably only flowing during flood periods. The branch is filling up, albeit irregularly, so a soil was able to form. Soil structuring, partly due to a pedogenesis, allowed by the slow sedimentation, can be observed in this layer.

The filling process is also noticeable when observing the AV-11 core granulometry. All the diagrams are bimodal. The right mode shows a variation, ranging from sands to silts. The bottom of the core, between six and seven meters, is a deep load, due to the high channel energy, mostly composed of sands (mode at 315 μm). The main class then decreases with the depth, to reach 15 μm at the top of the core (silts). The river energy decreases when it fills up. However, other cores, such as AV-12, have a slightly more complicated evolution, even if it remains comparable. On all the bimodal granulometric diagrams of this main river branch, only the main mode evolves, whereas the secondary mode remains stable.

The trimodal diagrams concern cores located on the right channel bank (AV-09 and AV-08). While bimodal diagrams obviously show fluvial processes, trimodal diagrams are harder to interpret. Morphoscopic analysis of the sands reveal a gezira origin. Therefore, in the AV-08 and AV-09 cores, this third granulometric mode is added to the standard bimodal configuration (AV-08-43 at 478 μm and AV-08-55 at 275 μm). Like in every gezira sand samples, this sandy mode is not stable. Here we observe a phenomenon caused by the gezira erosion on the right bank.

Several areas in this main Pelusiac branch transect can be isolated. A main river bed, 200 m wide, is delimited on its right by the gezira, and by a levy to its left (AV-44). The limits of the flood plain have not yet been located.

The AV-44 core also provides another important element: the bottom of the channel was located 11 m deep. It is below the levy, which suggests that the river is deeper to the east, in the main branch. The deposit below is composed of compact light brown silts and clays, with a few coarse particles. The limit between the homogeneous sands and these compact deposits may be the level upon which the Pelusiac branch originally stood.

The channel seems to have been clogged after the river moved to the west at a regional scale. (SAÏD 1981, 70, chapter 7; TOUSSOUN 1925, 147–153, chapter VIII). The successive avulsions have moved the Pelusiac branch as early as at the end of the 2nd millennium or the beginning of the 1st because of the sedimentary accretion of the region around the river mouth. The disappearance of the channel is difficult to date. A study based on archaeological data reveals that the river is absent during the Islamic period (TOUSSOUN 1925, 152). According to other authors, the death of the channel occurs around 25 AD (SNEH *et al.* 1973, 59–61) or even 500 AD (COUTELLIER and STANLEY 1987, 257–275).

More recent studies suggest the end of the 8th century AD (GOODFRIEND and STANLEY 1999, 147–150, STANLEY and WARNE 1993, 628–634, STANLEY *et al.* 2008; 451–462).

The small part of the river near Avaris has obviously had a shorter lifespan than the whole channel, due to the avulsion processes. It is currently possible to say that our small section must have been active at least from the middle to the end of the 2nd millennium BC, due to the presence of the archaeological remains at Avaris and Piramesse.

The small part of the river near Avaris has obviously had a shorter lifespan than the whole channel, due to the defluviation processes. It is currently possible to say that our small section must have been active at least from the middle to the end of the 2nd millennium BC, thanks to the presence of the archaeological remains of Avaris and Piramesse.

3.2. Swamps or potential harbour locations?

We observed several areas where the sedimentation process is highly specific. These areas may either be related to the development of swamps when secondary branches stop flowing (natural process), or to a direct human influence, which might be the building of harbour basins. The river morphology in these areas as reconstructed

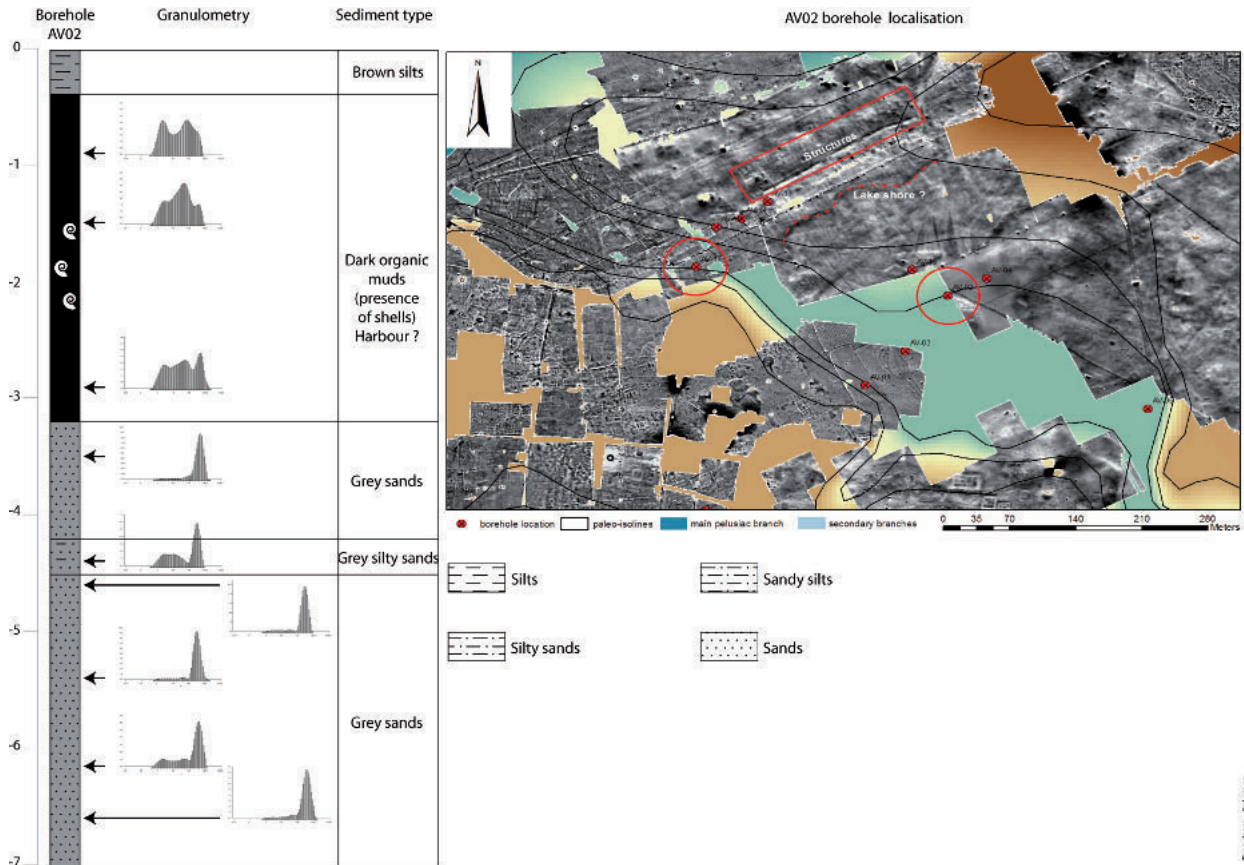


Fig. 6

by Dorner as well as the geomagnetic surveys tend to confirm these observations.

3.2.1. Core AV-02

The AV-02 core (Fig. 6) is located in a topographic depression (a lake remains near the drilling point). It is one of the few places where the palaeotopography still partly appears.

Dorner's reconstructed palaeotopography shows a secondary Nile branch, perpendicular to the main channel, with a kind of lake in the middle. The geomagnetic surveys tend to confirm this hypothesis, there is a rupture in the sedimentation mode, mainly in the north and the east, near the lake limits drawn according to Dorner.

Furthermore, human settlements have been found around this lake: to the east, temples, while to the west and south, city enlargements, dated between the 13th and the 15th Dynasties. On the north of the lake, geomagnetic surveys also reveal an almost perfect alignment of structures. Even if this area has yet to be excavated, we can emit the hypothesis that these structures could be warehouses and docks.

The sediments tend to confirm the hypothesis that this place could have been used as a harbour,

owing to a very low-energy environment. The deep strata (between -7 to -3.3) of the core are clearly sandy, and corroborate a dynamic river (the presence of silts in several samples, far inside the tell, invalidates the idea of an exclusively aeolian gezira environment, but a further morphoscopic analysis will confirm this). The stratum immediately above is composed of an accumulation of almost 3 m of dark organic muds. We also observed, between -1.5 and 2.3 m deep, the presence of shells (reduced to tiny broken fragments).

However, we must remain cautious when interpreting this organic level. Without any radiocarbon datings, we cannot exclude the possibility that this stratum, which is very near the current topographic surface, could be much more recent than the Hyksos period. It can be due to the presence of a completely closed lake (created by the sealing of the northwestern and southeastern channels linking it to the main river branches), unusable as a harbour, because of the shallow waters and absence of opening to the main river.

3.2.2. Core AV-17

The AV-07 core (Fig. 7) is also in the middle of the site of Avaris. The main goal of this drilling

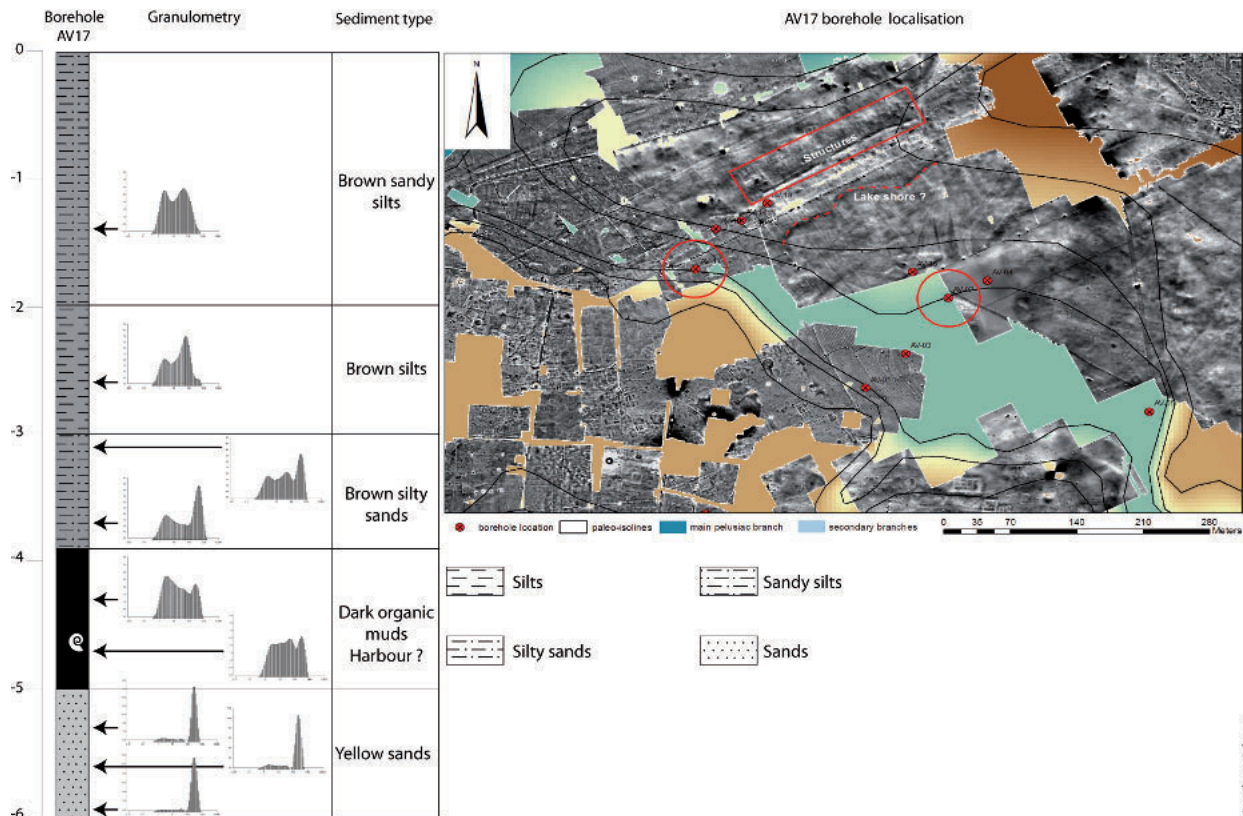


Fig. 7

was to confirm the existence of a link between the central lake and the main northern channel. A channel, or secondary branch, appears according to Dorner's cores, but does not show up on the geomagnetic surveys.

A four-core transect has been undertaken. The northern cores are typical of gezeira areas, mostly sandy whereas hydrological processes mark the AV-17 core. However, we did not only find, as we expected, the compact grey silts which seem to be typical of the secondary channels of the Pelusiac branch, but

In the lowest strata, we found yellow gezeira sands.

Immediately above, between -5 and -3.9 m, we observed dark organic clays, associated with low-energy sedimentary processes (usually matching harbour environments).

The levels above show a transition from silty sands to brown silts, the top level being composed of sandy silts.

The top levels, where silts are largely present, confirm the hypothesis of a channel, artificial or not, linking the central lake to the river. The unexpected organic level might be the sign of a potential harbour location, or, as for core AV-02,

be due to the slow death of a secondary branch turning into a swamp.

Radiocarbon dates are expected, unlike for core AV-02, since shells and organic fibers are present.

3.2.3. Core AV-23

The AV-23 core (Fig. 8) is located near the main Nile branch, but slightly set back from it, in a palaeotopographical depression.

This place seems interesting from a logistical point of view: near the river, but at least partly protected from the current. The site would also be at the confluence of the main channel and a north-south secondary channel. The surveys done by the archaeological team revealed the nearby presence of structures (labeled as warehouses by Dorner, on the east of the coring point, on the gezeira dating back to the 15th Dynasty).

The stratigraphy as well as the granulometry of this core is quite complex:

The base of the core, between -6.5 and 5.7 m deep, is composed of brown silty sands, matching a quite slow flow.

Between -5.7 and -5.3 m deep, the dark organic clays appear. This level's granulometry is

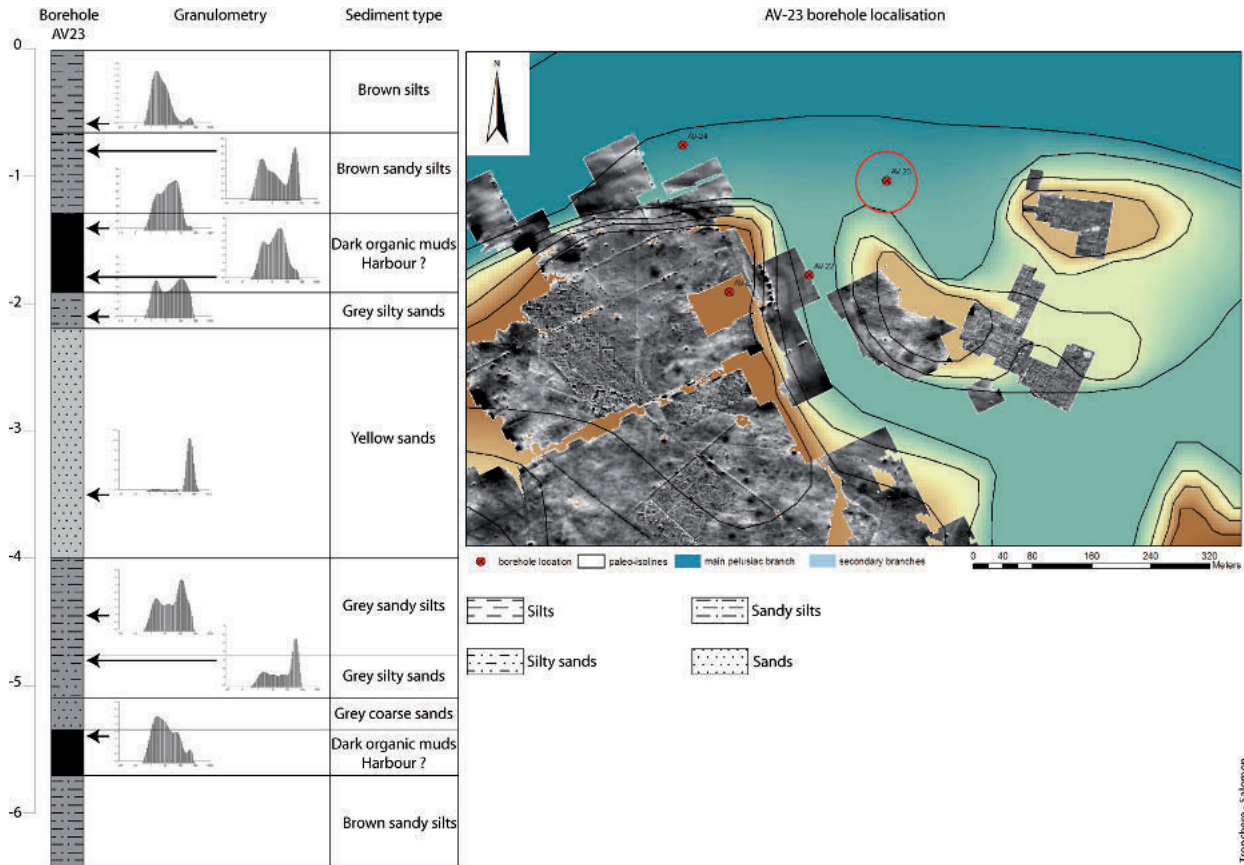


Fig. 8

distinguished by its silts peak and its relatively low sand proportion.

Several layers alternate between -5.3 and -4 m, ranging from homogeneous sands to sandy silts at the summit, suggesting a brief re-opening to a rapid flow before another closing sequence.

Between -4 and -1.9 m, the sediments are mostly homogeneous sands. A morphoscopic study, currently in progress, will determine the nature of these sands: fluvial or eolian.

We then encounter dark organic clays again, between, -1.9 and -1.3 m deep. We can suppose here the existence of a second quiet phase, favorable to a harbour implantation, either because of natural factors, or because of a human intervention (dykes?).

Brown sandy silts, with a localized sandy peak (aeolian influence?), are found in the above level, before the topmost strata, composed of brown silts created by contemporary pedogenesis.

This core could constitute a favorable environment and could have been used as a harbour during at least two periods. This area, because of its specific situation as a confluence as well as a shel-

ter, has indeed seen many sedimentary transformations.

3.2.4. Core AV-29

The location of the AV-29 (Fig. 9) core is directly related to the observation of the geomagnetic surveys and to previous archaeological surveys.

The geomagnetic image shows paths converging to the same point, a 15th Dynasty palace. During the study of these palace the archaeologists recorded muddy sediments in the southwestern angle of the structure. It is thus sensible to hypothesize the presence of a basin in this area.

The sediment's granulometry as well as their facies tend to support this hypothesis. The bottom of the core is composed of yellow geza sands, in between -5 and -4 m deep. A second stratigraphic unit is composed of grey silty sands, and is about 40 cm deep.

The dark organic muddy strata, as revealed by the archaeological excavations, sits between -3.6 and -2.1 m deep. These sediments' granulometry shows a clear majority of silts as well as the

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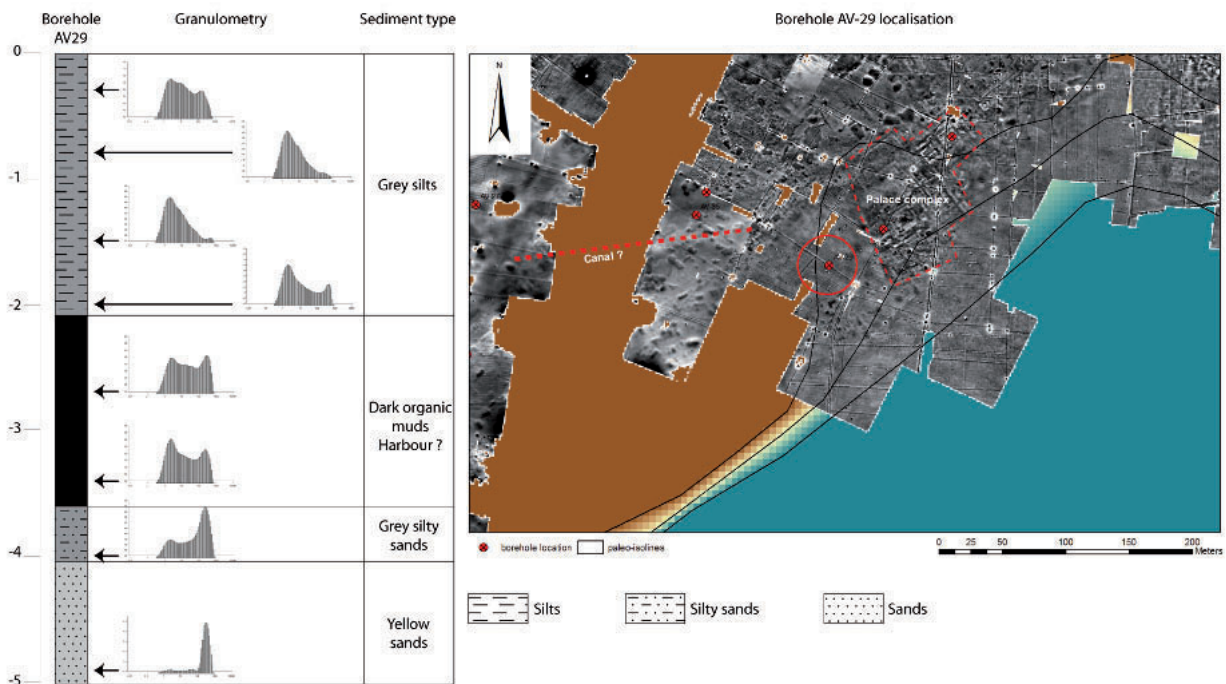


Fig. 9

remaining presence of a large sandy modal class (due to the eolian influence).

The topmost layer is composed of the expected grey silts.

The location of this core in the heart of the *gezira* and the presence of these two rectilinear potential canals (according to the geomagnetic surveys) may indicate the existence of a man-made structure, built directly inside the city.

These four corings do not confirm with certainty that a harbour existed in each place since these dark organic sediments, typical of slow flowing waters, can be entirely due to a natural evolution of the landscape (with secondary channels slowly disappearing to be replaced by swamps). However, harbours could have taken advantage of these naturally protected environments. We expect several harbours to have existed: from a chronological point of view, the evolution of the river may have led the inhabitants to relocate the basins. We can observe several relocations of the city center from the 13th to the 18th Dynasty; the harbours may have followed the same dynamics.

Furthermore, the Nile water level variations between the dry season and the flow season probably needed the existence of two harbours. A single harbour may not have been used during

the whole year. We can therefore expect a dry season harbour, and a flow season harbour.

CONCLUSION

These first geoarchaeological results allowed us to start exploring several research themes: a first stratigraphical analysis of the Pelusiatic branch has been done. This study will be enhanced by the use of radiocarbon datings, or better, OSL datings, which will allow us to better understand the sedimentary history of the river. A complementary study of the secondary channels will also help in understanding the landscape evolution. J. Dörner's reconstruction suggests that all the channels functioned in a similar manner. However, in a deltaic context, the avulsions can lead to the presence of many channels of different ages, which may not have flowed at the same time.

Concerning the second research theme, the potential harbour location areas, 4 cores amongst 35 have shown a very specific kind of sedimentation, present nowhere else at the site. This sedimentation pattern reveals the existence of extremely quiet flowing modes, and their location, as well as the nearby presence of the city centers, suggest a favorable place for a harbour. However, it is impossible at this point in our study to tell if these areas are due to a natural landscape evolution (natural infill of

the secondary channels) or to a direct human intervention. In this case, the results of radiocarbon and OSL datings will help in confirming our hypothesis.

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