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Geoarchaeology of an ancient fluvial harbour: Avaris and the Pelusiac branch (Nile River, Egypt)

Géoarchéologie d'un port fluvial antique : Avaris, sur la branche pélusiaque (Nil, Égypte)

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Abstract

The former city of Avaris is one of the biggest in the Nile delta. The city was the capital of the Hyksos kings who ruled Egypt during the Second Intermediate Period, around 1650-1550 BC. The city was built on the edge of the Pelusiac branch of the Nile River, in the middle of a complex anabranching river system. Historical sources mention the existence of a fluvial harbour in Avaris. This large town required a harbour complex to fulfil its economic and military role. Until recently, the precise location of Avaris' harbour basin was unclear. A pluridisciplinary project was set up in order to locate this harbour, by implementing various methods and tools. This project was part of a broader study of the palaeo-landscape of the whole city that provided us with a better knowledge of the palaeo-environment and its depositional processes. We were able to suggest the most likely area where a harbour could have been built. Extensive geomagnetic surveys backed the sedimentary boreholes analysis in order to get a precise image of the harbour basin, also helped by archaeological findings. The relationships between the basin and the Nile were also explored, especially a small channel linking the harbour to the main river as well as another one connecting it to a secondary channel of the Pelusiac branch at the south. We used OSL dating to reconstruct the history of the harbour, from the natural formation of a favourable geomorphologic site to its adaptation and maintenance by man during the apogee of the Hyksos capital.

Key words: geoarchaeology, fluvial palaeoenvironments, harbour archaeology, geomorphology, Nile delta, Pelusiac branch, Avaris, Egypt.

Résumé

L'ancienne cité d'Avaris est l'une des plus importantes du delta du Nil. Durant la Deuxième période intermédiaire, aux environs de 1650-1550 av. J.-C., elle fut la capitale des souverains hyksôs qui régnèrent sur l'Égypte. La ville fut construite au bord de la branche pélusiaque du Nil antique. Les sources historiques mentionnent la présence du port fluvial d'Avaris, une installation indispensable pour que la ville puisse assurer ses fonctions économiques et militaires. Cependant, jusqu'ici, l'emplacement du ou des bassin(s) portuaire(s) d'Avaris restait inconnu. Un projet interdisciplinaire a été lancé afin de combler ce manque. Diverses techniques et méthodes d'analyse ont été mises en œuvre. La connaissance préalable des différents environnements de sédimentation et du paléo-paysage d'Avaris en général a permis le repérage de l'emplacement le plus probable de son port. La combinaison des prospections géomagnétiques, de preuves archéologiques et de plusieurs campagnes de carottages, a permis d'établir la configuration du bassin et de mettre en évidence sa relation avec le fleuve, notamment l'existence de chenaux d'accès. Plusieurs datations OSL ont permis la reconstitution de l'histoire du port, depuis la mise en place naturelle d'une zone géomorphologiquement favorable à ce type d'implantation, jusqu'à sa mise en valeur artificielle durant l'apogée d'Avaris.

Mots clés : *géoarchéologie, paléoenvironnements fluviaux, archéologie portuaire, géomorphologie, delta du Nil, branche pélusiaque, Avaris, Égypte.*

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La cité d'Avaris fut la capitale des souverains Hyksôs durant leur règne sur l'Égypte, entre 1650 et 1550 av. J.-C. La ville fut construite au bord de la paléo-branche pélusiaque, sur la marge est du delta du Nil (fig. 1). Elle était un port commercial et militaire majeur, ce qui est attesté par les sources historiques. Toutefois, l'emplacement précis du ou des bassin(s) portuaire(s) d'Avaris restait jusque là inconnu. Il a été possible, en combinant diverses méthodes, de localiser le bassin principal de la ville.

Une ancienne campagne de carottages peu profonds a permis d'obtenir une première reconstitution de la paléotopographie du site (fig. 2 et fig. 3). Nos propres carottages sédimentaires, plus profonds, réalisés entre 2007 et 2009 (fig. 4), ont eu pour vocation d'affiner la chrono-stratigraphie et de mettre en évidence les processus ayant conduit à la genèse du paysage antique. Les prospections géomagnétiques (fig. 3) et divers indicateurs archéologiques ont également contribué à la localisation du port. Le paysage antique d'Avaris est marqué par son réseau fluvial anastomosé complexe : le chenal principal, formant un large méandre depuis l'ouest vers le nord, est complété par des chenaux secondaires, l'un au sud, le second, perpendiculaire au deux premiers, les reliant. Ce chenal transversal coupe en son milieu une large dépression (fig. 5), qui reste encore aujourd'hui un des seuls résidus, du reste toujours en eau, d'une paléotopographie totalement aplanie par l'activité agricole contemporaine. Deux canaux modernes reprennent en partie le tracé de l'ancienne branche pélusiaque.

Présentant une configuration sédimentaire unique si on la compare avec les autres milieux en eau du site (fig. 6), la dépression située en son cœur s'est rapidement révélée un point focal lors de la recherche du port. Sa géomorphologie a pu être attestée par l'observation des images géomagnétiques, sur lesquelles certaines de ses limites sont clairement visibles. Des alignements de structures archéologiques, parallèles à sa berge nord, sont potentiellement liés à une utilisation portuaire de la zone (entrepôts). La présence de palais et de temples nécessitant un accès au fleuve est de plus attestée. Un transect de cinq carottes (fig. 7 et fig. 8) à travers la dépression a fourni une stratigraphie complète et a mis en évidence des traces d'anthropisation. Une première unité, limono-sableuse, présente un faciès pléistocène, hypothèse validée par les datation OSL. L'analyse sédimentologique détaillée de cette unité suggère que la dépression a été formée par des processus hydro-éoliens. Une unité de transition, holocène mais plus ancienne que la branche pélusiaque, coiffe cette première unité. Par dessus, une épaisse unité largement composée de limons organiques (4 m) constitue un faciès qui n'a été rencontré nulle part ailleurs sur le site. Cette unité se met en place entre 4220 et 2900 av. J.-C. Une autre datation OSL, réalisée au sommet de l'unité et apparemment incohérente, est vraisemblablement révélatrice de remaniements anthropiques importants. Ceci suggère une utilisation portuaire (curages, dragages…), compatible avec l'écoulement à très faible énergie constaté à partir d'analyses granulométriques. Du matériel archéologique (tessons) a été retrouvé en abondance dans l'ensemble de la stratigraphie, confirmant une intense activité humaine. Ce bassin portuaire probable couvre environ 12 ha, pour une profondeur d'au moins 4 m, ce qui est suffisant pour les plus grands navires de l'époque. L'unité sommitale, difficilement interprétable, est composée de limons remaniés par l'agriculture actuelle.

La nécessaire communication entre le bassin et les deux bras de la branche pélusiaque présents sur le site était assurée par deux chenaux transversaux (fig. 6). Un transect de quatre carottes a été réalisé en travers du chenal reliant le port et le bras principal de la rivière (fig. 9), afin de dater et caractériser sa sédimentation. Seule une des quatre carottes s'est finalement révélée être dans le chenal même, les autres étant sur la berge et la gezira. Dans cette carotte, une unité composée de sédiments organiques identiques à ceux du port a été observée. Une datation ^{14}C (VERA 4795) a fourni une période de 1890-1680 av. J.-C. L'existence de ce chenal d'accès et du port associé, durant la période d'occupation du site, a donc pu être confirmée. La phase d'abandon du port reste imprécise, mais l'archéologie peut fournir des éléments de réponse : à la fin de la XVIII^{e} dynastie, le roi Horemheb construit un mur défensif, visible sur les prospections géomagnétiques. Cette muraille traverse le chenal d'accès. Ceci implique soit qu'un accès était ménagé dans cette muraille, soit que le bassin central n'était plus directement relié au chenal principal et devenait de fait plus difficilement accessible. Dans ce dernier cas l'existence d'un autre bassin (encore inconnu) devient alors implicite, Avaris étant connue sous la période Ramesside comme le port de Peru-Nefer. Le deuxième chenal, au sud de la dépression centrale, entre ce dernier et le bras secondaire de la branche pélusiaque, a été étudié de façon moins approfondie, sa configuration étant déjà bien connue grâce aux données d'anciens carottages ; néanmoins une analyse sédimentologique a mis en évidence l'existence d'une unité organique, confirmant son lien avec la zone portuaire centrale.

Le bassin principal d'Avaris a donc pu être localisé et ses liens avec le fleuve étudiés. Il a également été possible d'expliquer la mise en place naturelle de la dépression centrale. Celle-ci a ensuite vraisemblablement été adaptée par les Egyptiens pour les besoins de la construction du port, mettant ainsi à profit une configuration géomorphologique favorable.

Introduction

The Austrian Archaeological Institute has studied the ancient city of Avaris, near the modern village of Tell el Dab'a, since 1966 (Bietak, 1975). The city, capital of the Hyksos during their reign over Egypt (2nd Intermediate Period, between 1674 and 1548 BC), is located at the eastern margin of the Nile delta (fig. 1). The city was built near the now defunct Pelusiac branch of the Nile (Stanley *et al*., 1993). The disappearance of the Pelusiac branch is one of the many hydrogeomorphologic changes of the delta that took place at various spatial scales, some being natural (avulsions, sedimentation of abandoned channels), and others being anthropogenic (bank stabilisation, etc.; Coutellier and Stanley, 1987). Avul-

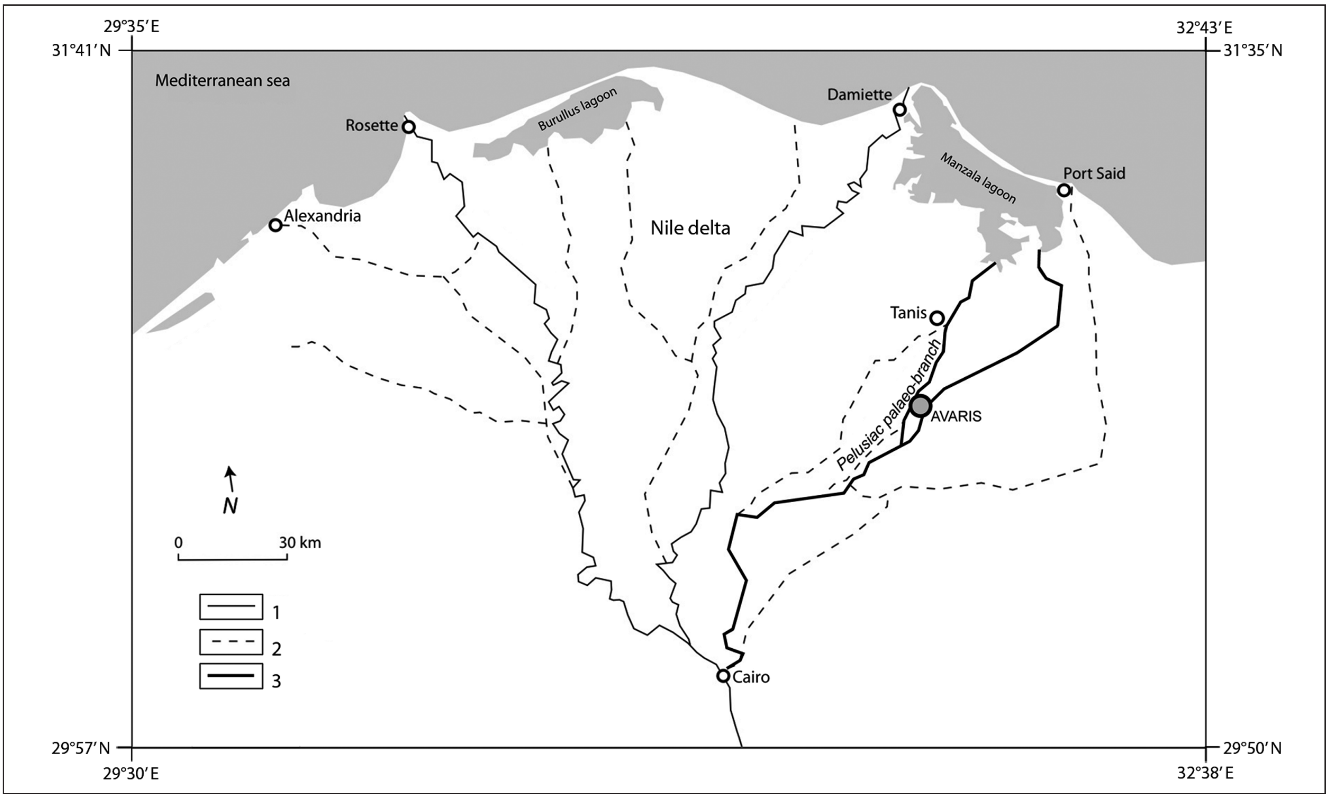


Fig. 1 – **Situation of Avaris on the Nile delta.** 1: modern Nile branches; 2: ancient channels; 3: modern channels (Faqus and Didamun) in the Avaris area.

*Fig. 1 – **Localisation d'Avaris dans le delta du Nil.** 1 : bras actuels du Nil ; 2 : anciens bras du Nil ; 3 : chenaux actuels (Faqus et Didamun) de la région d'Avaris.*

sions of the channels, maybe cyclical as in most anastomosing systems (Nanson and Knighton, 1996; Makaske, 2001), led to a changing landscape that had to be adapted by man to suit its needs (Tronchère, 2010). On a more regional scale, the delta itself forms a large, typical (Makaske, 2001) anastomosing system that underwent several large-scale transformations (shifting or disappearance of entire branches).

The site has been occupied from the early Middle Kingdom until the Roman Period with a hiatus during the 3rd Intermediate Period. A city of such importance had to be accessible by ship from the rest of the kingdom. Indeed, archaeological findings, such as Minoan inspired frescoes, reveal that the city was even in relationship with the whole Mediterranean world (Bietak and Marinatos, 2003). Such communication means that the city was equipped with a quite large harbour. Furthermore, the Khamose stele mentions that Avaris was the mooring place of the military fleet of the Hyksos (Montet, 1956). This is crucial because it implies that basins must have been present. Quays along the active channels would not have been safe enough for the mooring of military ships, and would not have been conductive to their easy maintenance. Until now, however, the exact location of the harbour basin in the city was unknown. Locating this harbour and reconstructing its chronology was our main objective. Harbour archaeology has been an especially dynamic field in modern geoarchaeological studies. It has concerned both marine [harbour of Rome (Goiran *et al*., 2010), Alexandria (Goiran, 2001), Phoenicia (Marriner, 2008)…] and river environments [Karnak (Ghilardi, 2009), Birket Habu (Kemp and O'Connor, 2007), Aquileia (Arnaud-Fassetta *et al.,* 2003; Carre *et al.,* 2003)], as well as lagoons and lakes (Marea, Taposiris; Boussac and El-Amouri, 2010). Sedimentology has been the main tool to analyse these specific, anthropised environments (Goiran and Morhange, 2003; Marriner and Morhange, 2006, Marriner *et al*., 2010) that play a considerable role in ancient economy and geopolitics.

To answer the questions specifically related to Avaris, several methods have been used. The modern landscape of Avaris is not a good analogue for the past because of recent (20th c.) terrain modifications for agricultural purposes, like the flattening of the ancient tell, so a reconstruction of the general topography of the area was the first step. This project started with a first reconstruction by Joseph Dorner and Manfred Bietak, using sedimentary drillings (Dorner, 1993), which served as a canvas upon which we based our own drilling campaigns, aided by geomagnetic prospections. Archaeology was also essential in our study.

The study area: an anastomosing fluvial landscape

The modern geomorphological context of Avaris is one of a largely anthropised deltaic area, far remote from its ancient state. Two modern canals drain an area essentially used for agriculture. The topmost strata of a mostly flat landscape

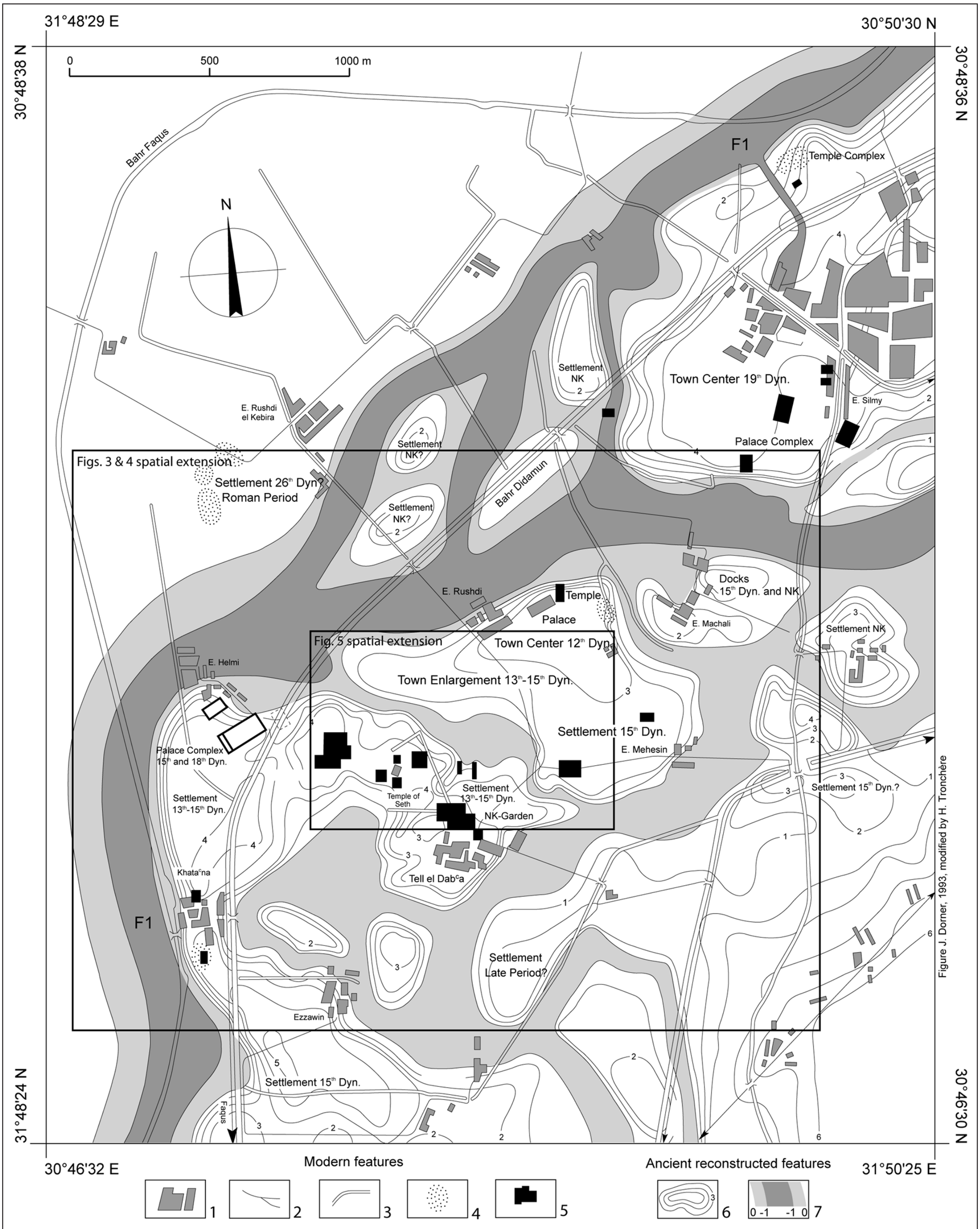


Fig. 2 – **Reconstructed ancient landscape of Avaris and main archaeological features.** 1: modern settlements, farms; 2: roads, paths; 3: channels; 4: tell areas; 5: excavation areas; 6: reconstructed topography, at the beginning of the New Kingdom; 7: course of the Nile branch and flood area.

*Fig. 2 – **Paysage antique reconstitué d'Avaris et principaux éléments archéologiques.** 1 : habitat actuel, fermes ; 2 : routes, chemins ; 3 : canaux ; 4 : tells ; 5 : zones de fouille ; 6 : topographie reconstituée au début du Nouvel Empire ; 7 : tracé du chenal du Nil et zone d'inondation.*

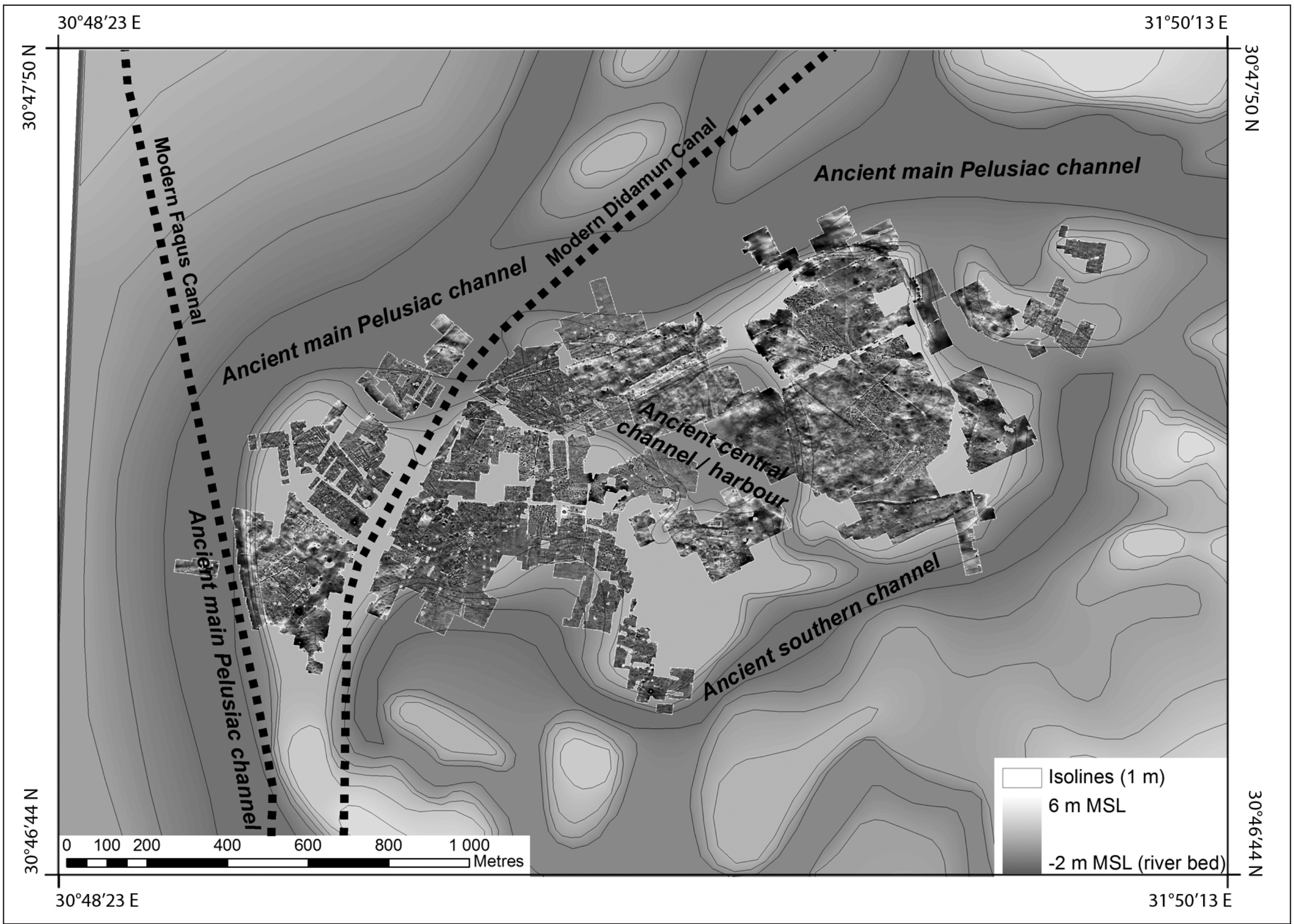


Fig. 3 – **Geomagnetic surveys coverage and main geographical features.**

*Fig. 3 – **Etendue des prospections géomagnétiques et principaux éléments géographiques.***

is composed of rich alluvial silts brought by the Nile during several millennia, and rests upon a Pleistocene substratum. Few data are known about the ancient, 'natural' morphology of the site. We can only suppose that a huge gezira (hill) covered the area. Maps from the Bonaparte expedition to Egypt reveal that the typical landscape was a network of river channels surrounding geziras. The Avaris region probably looked the same during the 19th c. AD.

The reconstruction of the palaeolandscape during the Second intermediate period (Hyksos period) and New Kingdom revealed a very complex system (Dorner, 1993), with several river channels forming an anastomosing channel network. Almost nothing of the ancient topography remains today, except parts of the former gezira. The two modern canals (Didamun canal and Faqus canal; fig. 2 and fig. 3) could be the only, largely regulated, remains of the Pelusiac branch. The ancient tell and the gezira below have been completely flattened for agricultural purposes, only the part below the Tell el Dab'a village remains. Even now, the topmost strata are constantly being reworked, which makes their analysis of little use. The main channel of the Pelusiac branch forms a large meander from the southwest to the northeast, around the city of Avaris (fig. 2 and fig. 3). The depth of the channel, as found in the drillings, is about 11 m: coarse sediments (sand and gravel, the largest particles to be expected in such a river bed) reveal the close proximity of the river's bottom. A second, slightly smaller, channel encircles the south of the city. The town itself appears to be mainly built in between these two channels. The most important places lie in this area, along the banks of the river. A small channel, about 5 m deep, with a northwest/southeast orientation, links these two river channels (fig. 3). This central channel is interrupted in its middle by one of the most striking features of the landscape: an enlargement of the channel forms a depressed area, one of the few elements that can still be observed in the modern topography. This central depression still contains water coming from the water table, which can be encountered as soon as 1 m below the topographical surface.

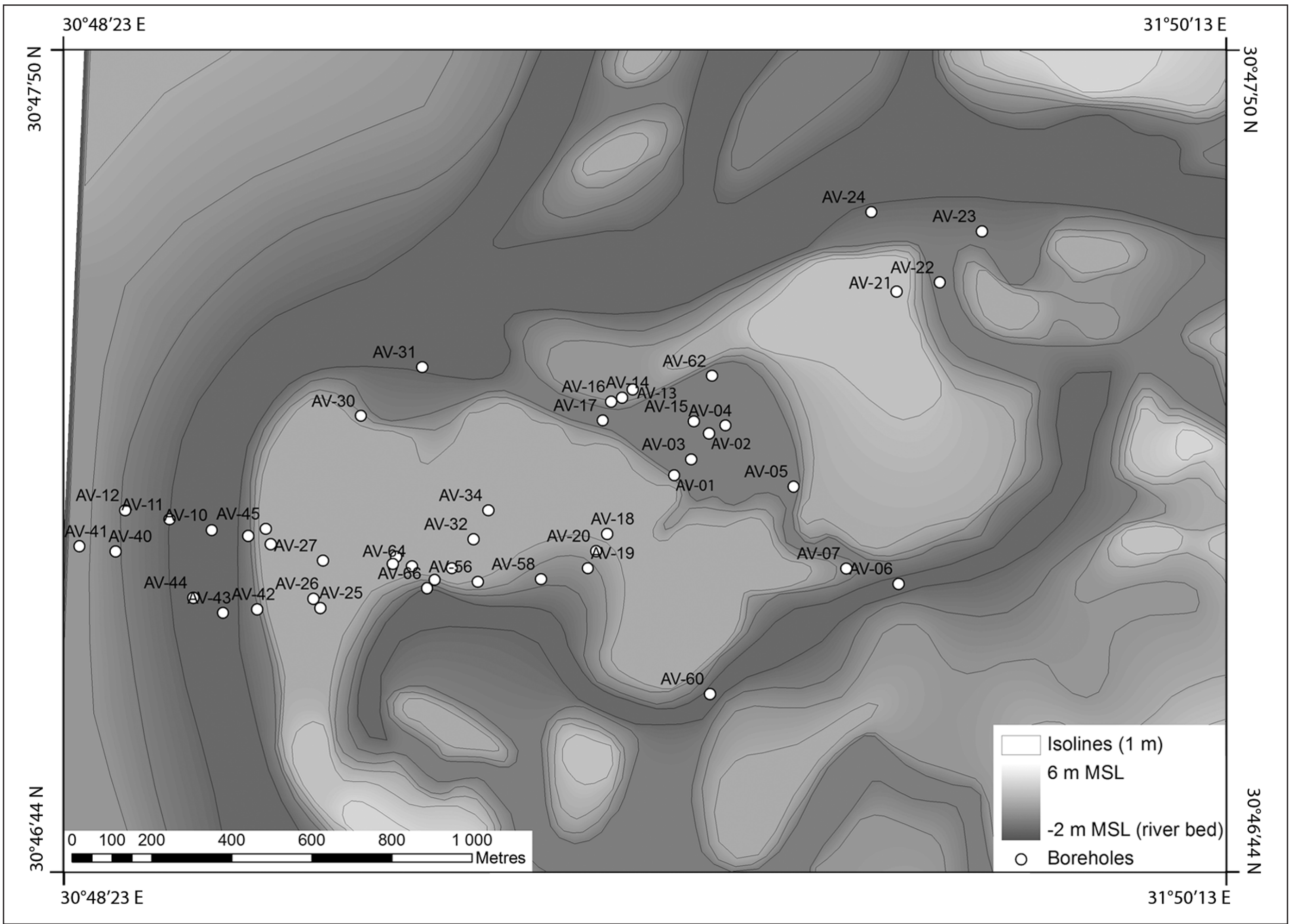
The human history of Avaris is quite long (Bietak, 1975; fig. 2) The city of Avaris has been occupied since the Middle Kingdom, attested by the presence of temples and palaces from the 12th dynasty, most of them being found in the northeastern part of the studied area. A strong spatial development occurs between the 13th and 15th dynasties. When the Hyksos access to power (15th dynasty), the city expands towards the south and the northeast. New palatial complexes are built. When the Hyksos are defeated, the city remains occupied. Palaces are even expanded during the 18th dynasty. During the Ramesside period, Avaris becomes the harbour of Pi-Ramesse, the capital city built on the northern bank of the river. The city is continuously occupied during the New Kingdom and until the Roman period, Roman settlements being present on the western bank of the river.

Methods

Several hundred drillings were made around the archaeological site by J. Dorner to reconstruct its ancient topography, and understand the situation of the various parts of the town relative to its landscape (fig. 2). However, these drillings were only up to 5 m deep, and thus insufficient to yield detailed information about the various depositional environments. The sediments were only described through visual analysis (texture and colour), which can be difficult in such a complex environment, characterised by multiple sedimentary facies due to intermixing deposition processes (fluvial and aeolian). However, the drillings made by J. Dorner provided a first reconstruction of the palaeotopography of Avaris, which was further refined and enhanced by our own program. We undertook three drilling campaigns from 2007 to 2009, providing us with about 60 cores up to 11 m deep (fig. 4). A panel of standard analytical tools has been applied to the samples. The key cores were studied with laser grain size analysis, quartz morphoscopy and magnetic susceptibility. This allowed to not only enhance the first palaeogeographic reconstruction, but also to understand the various processes in action, the most notable being obviously the fluvial activity linked to the ancient Pelusiac branch of the Nile. We could establish a typology of the different river flow phases according to the depositional environments. OSL age estimates (Preusser *et al*., 2008) were obtained on quartz grains on several boreholes, as well as a few ^{14}C datings. This allowed us to establish the chronology of the sedimentary sequences. The chronology of the sedimentary sequences was established by Optically Stimulated Luminescence (OSL) dating complemented by a few radiocarbon datings. Samples for OSL dating were taken using opaque liners that were transferred to the lab, where standard preparation techniques for coarse grain quartz were applied (Preusser *et al*., 2008; Fiebig *et al*., 2009). The accumulated radioactive dose was determined by the single aliquot regenerative dose protocol using small aliquots (2 mm). Several samples showed evidence for partial bleaching and we applied the minimum age model of F. Preusser *et al*. (2007) to extract the true burial dose. The amount of dose rate relevant element was determined by high-resolution low-level gamma spectrometry. Several campaigns of geomagnetic prospections undertaken yearly (Forstner-Muller *et al*., 2007) covered almost the complete archaeological site (fig. 3). Useful for purely archaeological purposes (like finding structures; Witten, 2006), the geomagnetic image of the area also contributed to the palaeotopographic reconstruc-

Fig. 4 – **Location of the recent boreholes.**

*Fig. 4 – **Localisation des carottages récents.***



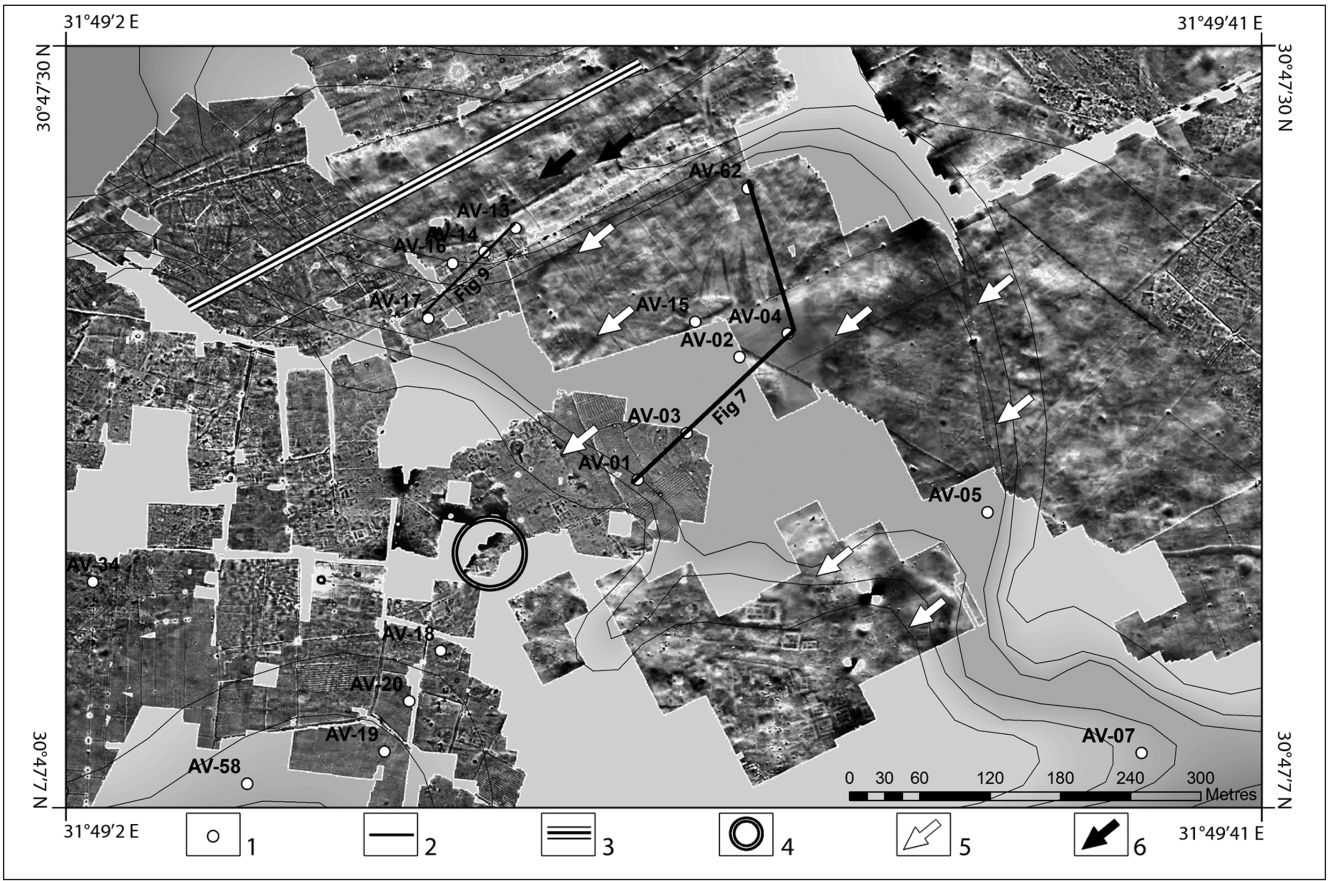


Fig. 5 – **Interpretation elements from the geophysical surveys and location of the cross sections in the central depression.** 1: boreholes; 2: boreholes cross sections; 3: Horemheb wall potential location; 4: ancient temple of Seth; 5: topographical ruptures revealed by the geophysical survey; 6: potential harbour-related structures revealed by the geophysical survey.

*Fig. 5 – **Eléments d'interprétation déduits des prospections géophysiques et localisation des transects dans la dépression centrale.** 1 : carottages ; 2 : transects de carottages ; 3 : localisation potentielle du mur d'Horemheb ; 4 : temple antique de Seth ; 5 : ruptures topographiques mises en évidence par les prospections géophysiques ; 6 : structures portuaires potentielles mises en évidence par les prospections géophysiques.*

tion. We also used the geophysical data to pinpoint our drillings on specific features (canals, river banks...). Combining geomagnetic surveys and drillings provided us with an almost complete coverage of the Avaris site. During all our study archaeological evidence was taken into account as well. The first one was the Khamose stele proving the existence of the harbour, but several other observations (structures, symbolic buildings, potshards, etc.) were beneficial to our study as well.

Location and characterisation of the harbour of Avaris

Discovering the likely harbour basin of Avaris required the combination of complementary methods listed above. The most favourable location for a harbour seems to be the central, enlarged area of the channel perpendicular to the main river arm (fig. 2 and fig. 5). Its topography, the close proximity to the main channel, and its position at the core of the city do support this assumption. A temple dedicated to Seth, a main divinity of the Hyksos pantheon, existed about 200 m to the south west of core AV-01 (fig. 5). During rituals, the statue of the god was carried on a ceremonial boat along the Nile. Such a ceremony implies a physical link to the river, as well as installations such as quays near the temple. This central place of the city was probably an important location, for economic, military as well as symbolic reasons. Stratigraphic analysis was used to compare the sediments encountered in this depression to the ones observed in the other river channels.

Stratigraphy

The central depression compared to the other river areas

The general stratigraphy of Avaris was studied through about 60 drillings. The three main facies we encountered were: gezira sediments, characterised by aeolian sands, forming the ancient ground surface, as well as river sediments and a specific kind of organic muds, both found in the water areas. These two last kinds of environments were studied in details (fig. 6). The five cores presented here come from the main channel, the southern channel, the central depression and its two small access channels (fig. 4). Coarse sands were notably found at the bottom of the drillings made in the main

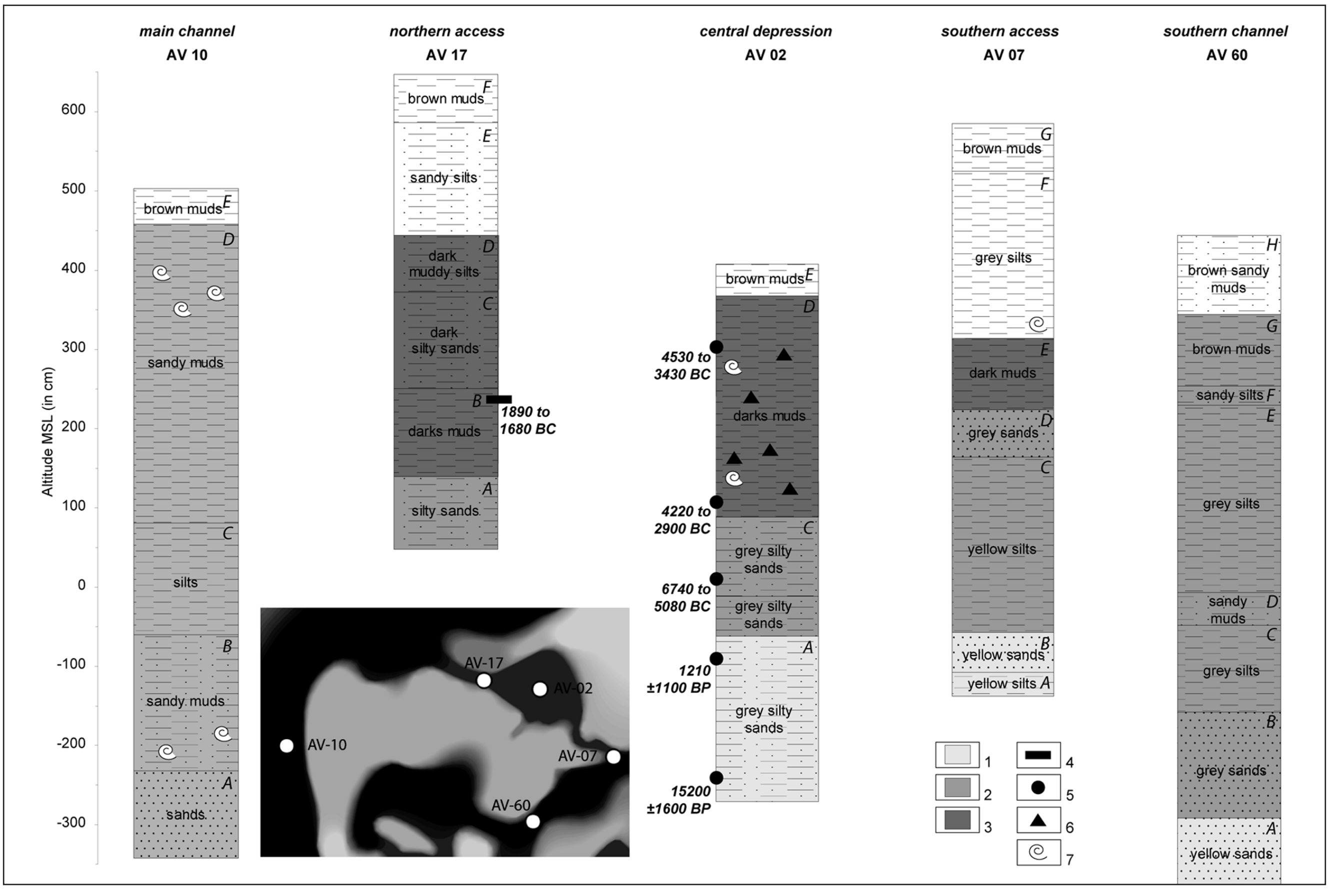


Fig. 6 – **Comparison of the different kinds of fluvial and harbour deposits.** 1: Pleistocene sediments; 2: river sediments; 3: Harbour sediments; 4: ^{14}C dating; 5: OSL dating; 6: pot-sherds; 7: shells.

*Fig. 6 – **Comparaison des différentes stratigraphies dans les zones fluviales et portuaires.** 1 : sédiments pléistocènes ; 2 : sédiments fluviatiles ; 3 : sédiments portuaires ; 4 : datation ^{14}C ; 5 : datation OSL ; 6 : tessons ; 7 : coquilles.*

Sample/ code	Grain size (in μm)	n	K (in %)	Th (in ppm)	U (in ppm)	Moisture (in %)	Maximum water saturation $W_{Max.}$ (in %)	Depth (in cm)	D (in Gy/ ka)	De (in Gy)	Age (in a)
AV 54-1	100-200	48	1.06 ± 0.06	4.36 ± 0.16	0.97 ± 0.15	28.6	52.6*	100	1.25 ± 0.11	7.50 ± 0.11	5980 ± 530
AV 54-2	200-250	46	0.65 ± 0.03	2.31 ± 0.09	0.81 ± 0.11	20.0	28.4	300	0.86 ± 0.07	4.80 ± 0.41	5560 ± 650
AV 54-4	150-250	47	0.64 ± 0.03	2.53 ± 0.09	0.84 ± 0.10	25.0	29.1	400	0.86 ± 0.06	6.76 ± 0.49	7910 ± 830
AV 54-5	150-200	47	0.67 ± 0.04	2.60 ± 0.10	1.02 ± 0.11	19.6	29.8	500	0.90 ± 0.07	10.92 ± 0.42	12100 ± 1100
AV 54-7	200-250	48	0.90 ± 0.05	2.89 ± 0.11	1.11 ± 0.14	20.0	31.6	650	1.05 ± 0.08	16.01 ± 1.03	15200 ± 1600

Tab. 1 – **Summary data of OSL dating giving the grain size used for dating, the number of replicate dose measurements (n), the concentration of dose rate relevant elements (K, Th, U), measured sediment moisture and water saturation level, sampling depth, dose rate (D), mean dose accumulated during burial, and the resulting OSL age.**

*Tab. 1 – **Tableau des datations OSL indiquant la granulométrie utilisée pour la datation, le nombre de mesures répétées de débit de dose (n), la concentration du débit de dose des éléments (K, Th, U), l'humidité du sédiment et sa saturation en eau, la profondeur de l'échantillon, le débit de dose (D), la dose moyenne accumulée lors de l'enfouissement et l'âge OSL déduit.***

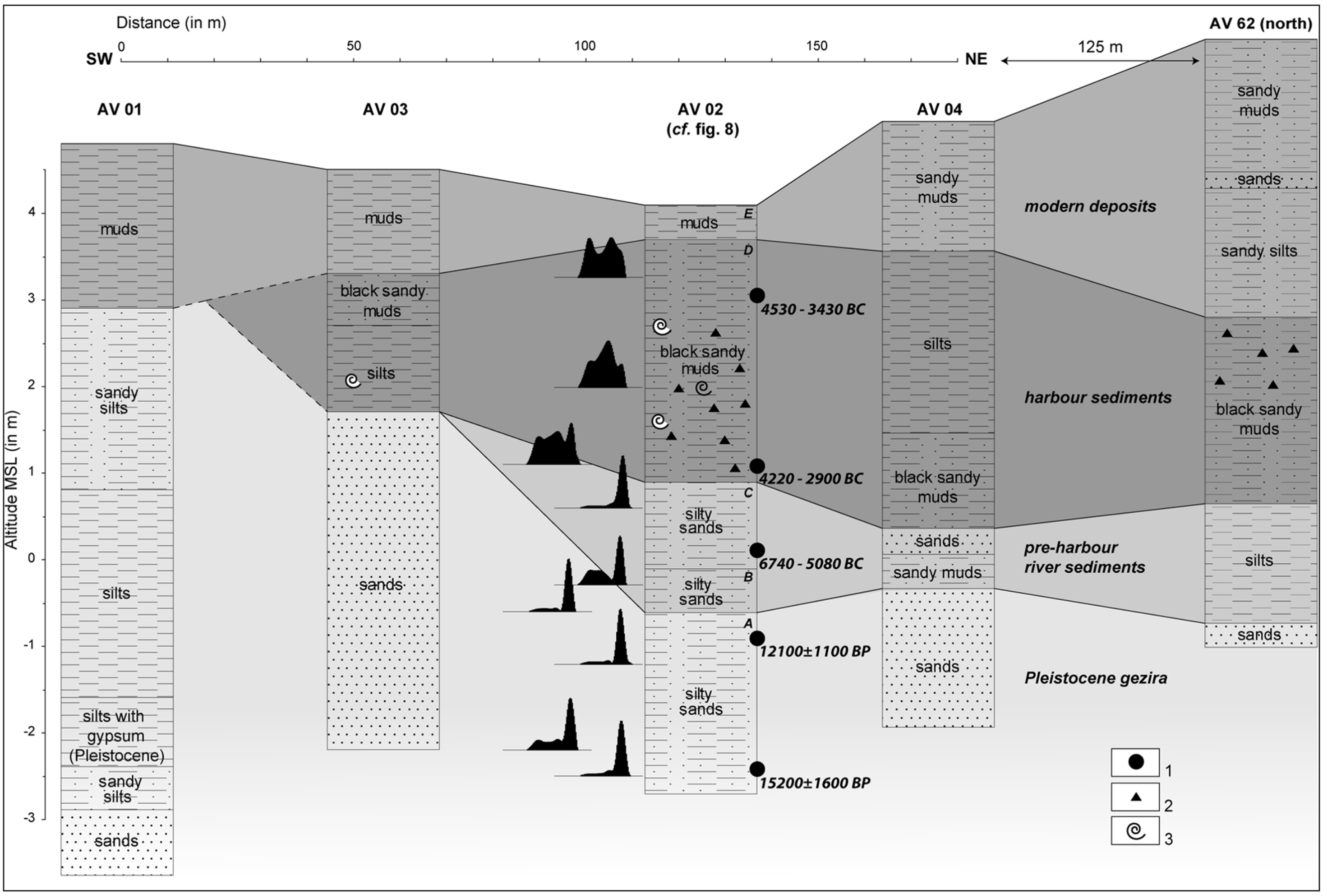


Fig. 7 – **Cross section through the central depression.** 1: OSL dating; 2: pot-sherds; 3: shells.

*Fig. 7 – **Transect en travers de la dépression centrale.** 1 : datation OSL ; 2 : tessons ; 3 : coquilles.*

(AV-10 A) and southern (AV-60 B) channels, revealing an active river. Finer sediments are then encountered in these two drillings (AV-10 B, C, D; AV-60 C, D, E, F, G). These imply lower dynamics of the river, and a general silting up of the area. However, none of these layers reflect the sedimentary facies found in the depression and it's accesses: a thick layer of dark, organic muds. Therefore, after gaining a better understanding of the various riverine sedimentary facies to be found in Avaris, we concentrated our study on the central depression with a five drillings transect (fig. 5 and fig. 7) and its two most important deposition layers: the pre-harbour environment, both Late Pleistocene and Holocene, and the organic layer interpreted as deposition in the harbour of Avaris.

The Pleistocene substratum and the pre-Pelusiac transition layer

The first observed sequence in the cross-section suggests a Late Pleistocene chronology because of its well-known lithology: a vertical alternation of sandy and compact grey silty layers, presenting gypsum concretion. This is similar to the observations made in the north of the delta by other authors (Ali and West, 1983; Zhongyuan and Stanley, 1993). This sequence appears at the base of all the drillings, with different facies: sands in boreholes AV-03, 02 and 04, or sand/silts alternation with gypsum nodules in borehole AV-01 and 62. The boreholes located at the border of the depression are the only ones where the silts are present. This could mean that aeolian deflation played a role in the formation of the depression. The winds were able to mobilise and evacuate the sands lying in what would later become the depression, whereas the silty areas were more or less immune to deflation, a well-known phenomenon (Callot, 2008; Campy *et al.*, 2003; Song *et al.*, 2006). The river could have then reused the deflated area. River activity itself probably had an impact on the formation of the depression: indeed morphoscopic analysis revealed both aeolian and fluvial transportation modes (Tronchère *et al.*, 2009). Aeolian deflation may have created the general shape of the depression, which was further defined by fluvial erosion. The Pleistocene age of this stratum was confirmed by two OSL ages in core AV-02 in layer A: 15200±1600 BP at the base (AV 54-7) of the sequence and 12100±1100 BP at the top (AV 54-5) (tab. 1). On top of this Pleistocene sequence, a layer quite similar to layer A and B from a grain-size point of view is present. Layer C of core AV-02 was dated (AV 54-4) to 7910±830 BP (6740-5080 BC), thus Holocene. According to V. Coutellier *et al.* (1987), the Pelusiac branch was not active at the time. This explains why the sedimentary facies do not change much

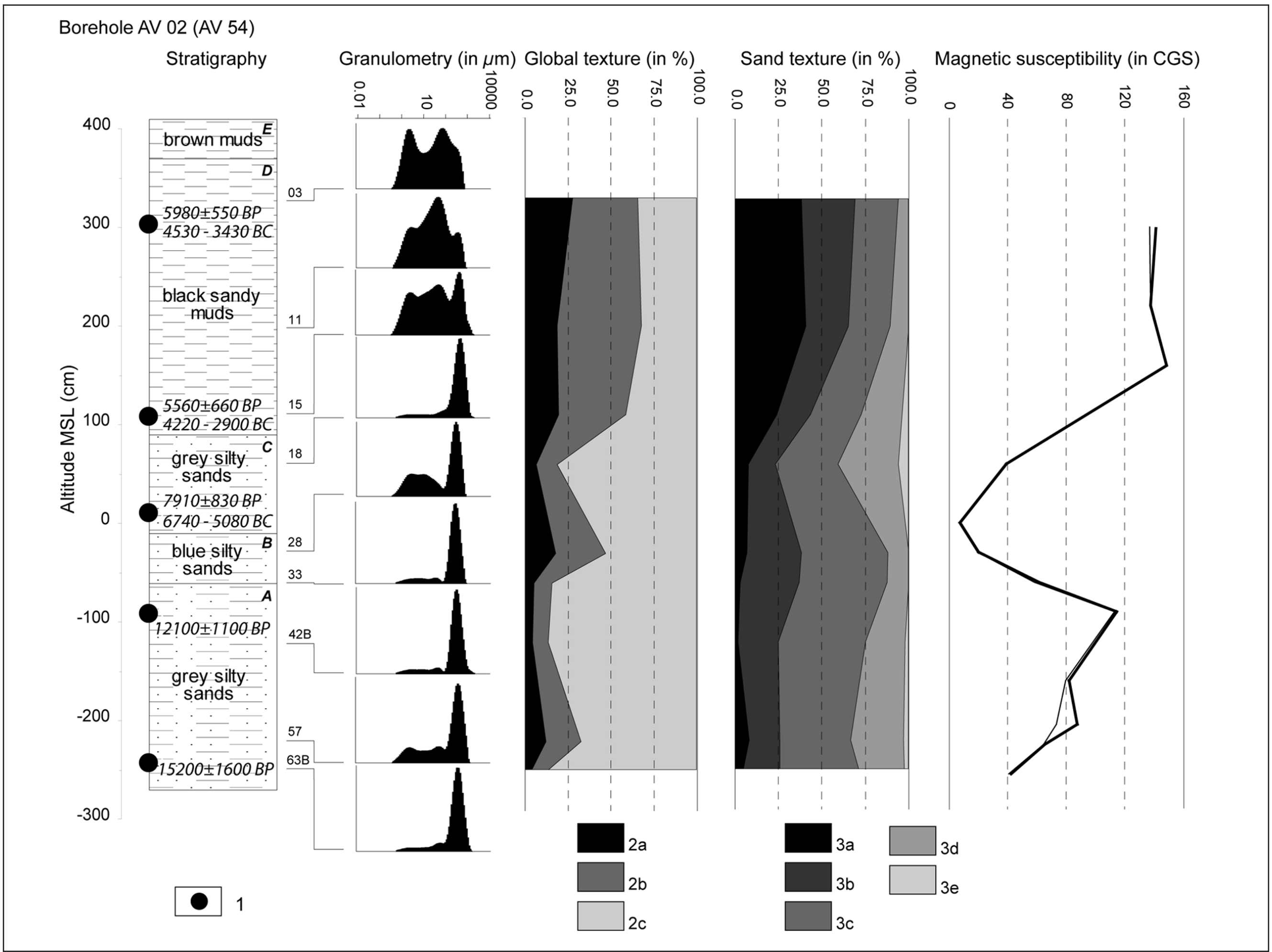


Fig. 8 – **Typical 'harbour' borehole from the central depression (AV-02).** 1: OSL dating; 2a: clays (<0.0039 mm); 2b: silts (0.0039-0.063 mm); 2c: sands (0.063-2 mm); 3a: very fine sands (0.063-0.125 mm); 3b: fine sands (0.125-0.25 mm); 3c: medium sands (0.25-0.5 mm); 3d: coarse sands (0.5-1 mm); 3e: very coarse sands (1-2 mm).

*Fig. 8 – **Carotte « portuaire » type dans la dépression centrale (AV-02).** 1 : datation OSL ; 2a : argiles (<0,0039 mm) ; 2b : limons (0,0039-0,063 mm) ; 2c : sables (0,063-2 mm) ; 3a : sables très fins (0,063-0,125 mm) ; 3b : sables fins (0,125-0,25 mm) ; 3c : sables moyens (0,25-0,5 mm) ; 3d : sables grossiers (0,5-1 mm) ; 3e : sables très grossiers (1-2 mm).*

between 15000 and 8000 BP: the deposition processes themselves are probably the same.

A thick organic layer with a societal imprint: the harbour of Avaris

The layer D in drilling AV-02 shows a clear sedimentary change (fig. 8). This sequence also observed in boreholes AV-03, 02, 04 and 62 is not appearing in the rest of the Avaris site, especially considering its thickness (up to 4 m). It presents a trimodal grain-size distribution, and an organic component (Ollive *et al*., 2006). This kind of deposit is also typical of well-protected environments, and is often found in harbour sediments (Goiran and Morhange, 2003; Marriner and Morhange, 2006). Although the discrimination between river and fluvial harbour sediments is less obvious than between sea and marine harbour sediments, the slowing down and anthropisation (reworking, dredging) of the basins also result in a transformation of the deposits (Skafel *et al.,* 1998). The layer is also notable because of its high magnetic susceptibility. The average value (120 CGS emu) is three times higher than the levels measured in other Holocene strata, which may be a sign of anthropisation. Shell fragments were found in boreholes AV-02 and 03. These shells are too thick for land species. This confirms the hydromorphism of the sedimentary environment, but the shell fragments were too small for more detailed biological or environmental analysis. The very fine grain size measured in boreholes AV-03, 02, 04 and 62 reveals a very low energy flow. The depression was filled with very quiet waters, which is compatible with possible human use of the area as a harbour basin: the ships are protected from strong currents, and this eases loading, unloading and other maintenance operations. Archaeology provides with regards to human activities in the depression. The entire landscape of Avaris is littered with potshards. However, most of the time, the potshards are only one or two meters below the modern topography, and form a fine layer. In our area of interest, potshards of the Hyksos period and later (Second

Sample ID	Lab code	Material	Calibration	^{14}C Age	Calibrated Age
AV 17-34	VERA 4795	Wood	Continental	3465 ± 40 BP	1890-1680 BC

Tab. 2 – **Radiocarbon datings.**

Tab. 2 – Datations radiocarbone.

Intermediate Period to New Kingdom, sherds dated by I. Forstner-Müller) are abundant and found consistently from 1 to 4 m below the surface. This suggests an important and long lasting activity. An OSL dating (AV 54-2) made at the base of the layer indicates an age of 5560±660 BP (4220-2900 BC). This result is in accordance with previous work (Coutellier and Stanley, 1987), dating the appearance of the Pelusiac branch around 5000 BP. Another date, at the top of the unit (AV 54-1), yielded an age of 4530-3430 BC. This apparent aberration (older sediment 2 m higher in the stratigraphy than the younger, in the same stratum, although both results fit within the margin of error) might reveal human intervention, such as a dredging of the basin (Wikander, 2000), or at least a reworking of the sediment. Such maintenance of the basin confirms its high strategic value. It's important to note that the dates are older than the human occupation of the site. Thus, the depression has been naturally created, and has not been man-made and specifically designed as a harbour basin. Human societies exploited a favourable topographical configuration. The fact that the depression was still present during the Hyksos occupation is proved by the presence of the potshards, as well as by a ^{14}C dating (VERA 4795 ; tab. 2) obtained in the same strata, but maybe less reworked, in the north-eastern access channel (*cf. infra* 'Stratigraphy of the north-western entrance'), providing an age of 1890-1680 BC, thus only a few years earlier of the Hyksos Period.

Shape of the basin

Geophysical and archaeological insights

Before even considering an eventual anthropogenic intervention in the central depression, it is essential to ascertain its shape. In this regard, geomagnetic prospections revealed several topographical features, due to different sedimentological facies (fig. 5). On the northern part of the depression, we could observe an ondulating dark linear shape. 40 m to the southeast of this first apparent limit, a second one appears. A third limit can be observed, 80 m from the first one. These suggest a series of steps, revealing either varying depths for the bottom of the depression, or different chronological sequences during sedimentation, or both. The east of the depression is equally clear. It is characterised by a change in the grain of the picture: the signal is perfectly regular and flat inside the depression, whereas the bank presents many small spots. Also, parallel steps can be observed, as in the northern part. The western limit of the depression can be observed by the absence of man-made structures, contrasting with the bank. The southern part of the depression is marked by a series of dark or white parallel lines, revealing a modification of the stratigraphy. We can observe the shrinking of the depression where it becomes a more conventionally shaped channel, linked to the southern river arm. Archaeological insights can also be provided by the geomagnetic images. We could notably observe a series of structures, aligned with the northern border of the depression. These could be warehouses or similar buildings, related to harbour activity. The archaeological team will soon excavate these structures.

Data derived from the drillings

The cross section through the basin (fig. 5 and fig. 7) also aimed at defining its spatial extent. In borehole AV-01, we didn't observe the dark, muddy, hydromorphic sediments that are otherwise present in all the other drillings. There is a sandy-silty layer between 80 cm and 290 MSL (Mean Sea Level), but it doesn't have an organic aspect. We could confirm that this borehole is more or less located on the bank. The geomagnetic surveys described earlier support this. Borehole AV-62, on the other hand, helped to define the north-eastern extension of the basin. The organic muddy layer was found, proving that the area was part of the basin. The central depression is about 400x300 m large. It covers an area of about 12 ha, and is at least 4 m deep. This is enough for a main harbour, the most generous estimations about the draught of ancient Egyptian ships quoting about 3 m at most for the biggest ones (Landström, 1970; Vinson, 1994). However, because of the water level difference between the flow period and the low water period, it remains possible that the harbour could have been difficult to access from the northern and southern channels during certain parts of the year, at least for the largest ships.

Accessing the harbour from the Nile: the two entrances

The configuration of the central basin is essential, but studying the access to this basin is also critical. The basin had to be linked to the main channel at least, and probably to the south-eastern one as well. Both these potential accesses to the harbour have been studied.

Stratigraphy of the north-western entrance

According to previous reconstructions, a 40 m-wide secondary channel, perpendicular to the main one, could have been the access path to the harbour. A cross section of four boreholes through the channel (AV-17, 16, 14, 13) was made (fig. 9), in order to validate its existence, and estimate its width and depth. A radiocarbon dating was made in core AV-17. The top of the deepest sandy layer forms a slope from core 13 to core 17. In boreholes AV-13, 14 and 16, the bottom layer comprises sands, consistent with the Pleistocene sediments encountered in the basin. Above this layer, a

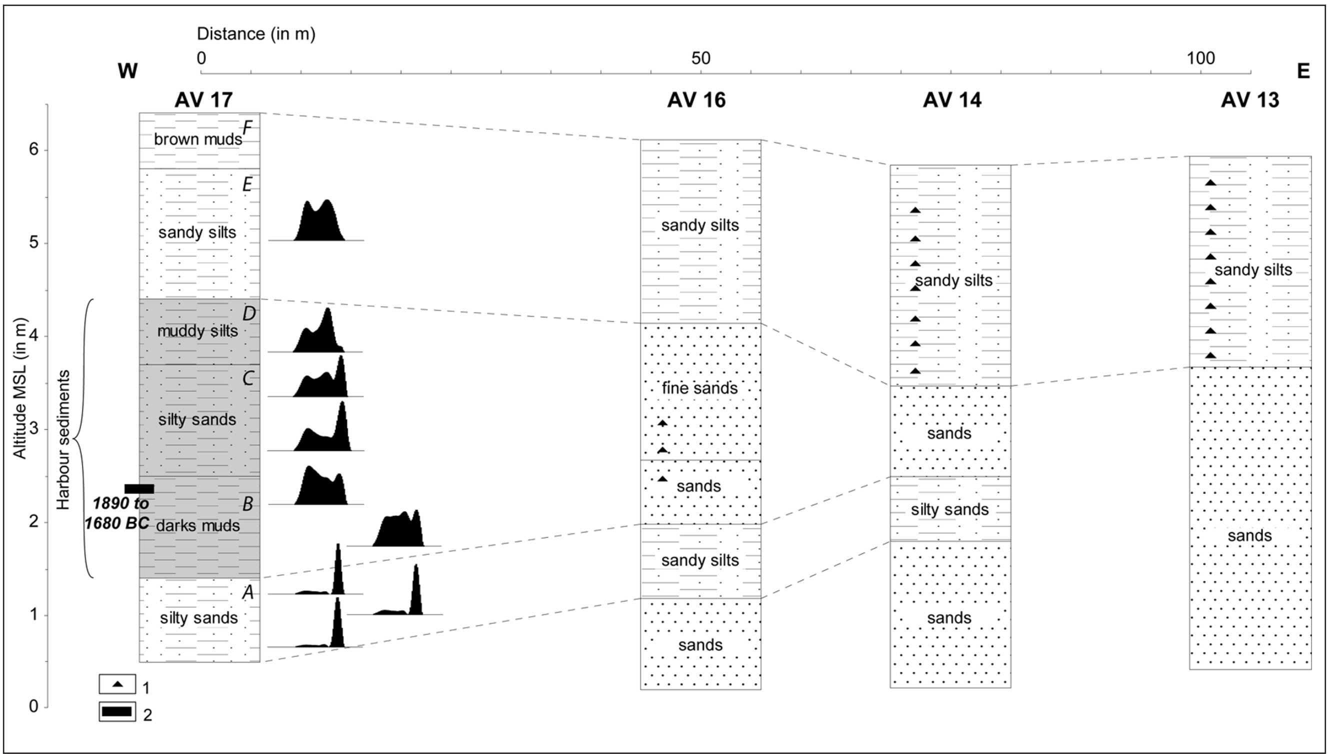


Fig. 9 – **Cross section through the northern access channel between the river and the harbour.** 1: pot-sherds; 2: ^{14}C dating.

*Fig. 9 – **Transect en travers du chenal reliant le fleuve au port**. 1 : tessons ; 2 : datation ^{14}C.*

sandy, slightly silty stratum can be observed in several drillings. Estimating the age of this stratum is difficult, but similar looking sediments in borehole AV-02, inside the basin, were dated by OSL to about 8000 BP. The stratigraphy of borehole AV-17 is different to the other cores. Layer B of borehole AV-17 has exactly the same characteristics as the organic harbour sequence described previously (dark organic muds, trimodal grain-size histogram), denoting low-energy flow. A piece of wood from this layer was radiocarbon dated. The age is 3465±40 BP, which is 1890-1680 BC after calibration (continental calibration curve; Reimer *et al.*, 2004). This sedimentary unit is contemporary with the Hyksos occupation of the site. This result is extremely important, because it provides both the confirmation of the existence of an access between the channel and the harbour during Hyksos time, and also dates the harbour sediments. Only the bottom of the organic layer could be dated precisely by OSL in borehole AV-02, since the dating made at the top revealed human reworking. We had no proof, without this ^{14}C dating, that the central depression was washed with river water during the Hyksos period. Following the organic stratum, we observed in layer C in borehole AV-17 a slightly more intense flowing phase, revealed by a coarser grain size. Layer D, on the other hand, corresponds to the final silting up of the channel. The sediments are silty, probably resulting from a disconnection from the main channel that could explain the very fine grain size. These harbour and fluvial layers are not present in the other boreholes. At the same level, we found sandy sediments. According to the ancient reconstruction, drilling AV-16 is at the limit of the channel, and AV-14 is on the levee. Our own results confirm this topographic evidence. The topmost layers of the four drillings correspond to the modern infill and agricultural activity.

Proof of the existence of the south-eastern entrance

Very few sedimentary data were available for the northern entrance before we made our own drillings. J. Dorner only made one borehole in the neighbourhood. That's why we concentrated our efforts on this area with the four drillings transect presented before. On the other hand, the potential southern access to the channel was much better documented. J. Dorner made about 30 drillings (4 to 5 m) along this small channel, so it's path was well known when we started our own program. However, in order to get a better insight of the stratigraphy of the channel, we made one drilling ourselves (AV-07; fig. 5 and fig. 6). Aside of the Pleistocene looking layers at the bottom of the core (layers A, B and C) and the Holocene river (layer D), we observed a 1 m-thick layer of dark organic muds (layer E) that correlates this drilling to the harbour ones of the central depression. We can conclude from this observation that there was a connection between the river and the harbour from the southeast as well as from the northwest.

The Horemheb wall, a testimony of changes made to the harbour?

The end of the harbour activity is still unclear. Our datings do not provide direct information about this yet, but archaeological evidence can help. During the late city occupation, at the end of the 8th dynasty, king Horemheb built a defensive wall at the north of the city. Visible on the geomagnetic prospections (fig. 6; Bietak, 2009), this wall goes through the northern access channel. It would seem strange that the channel would have been deliberately blocked. Such an action would leave the basin connected to just the secondary channel to the southeast. An access could have been built in the access wall for the ships. The southeastern channel leading to the basin could also have still been in function at the time. An access to the basin was a necessity since Avaris was supposed to have hosted the Peru-Nefer harbour at this time. Another hypothesis is that the central basin could have been rendered impractical by a disconnection of the northwestern access channel (upon which the Horemheb wall was built). This would imply that another harbour basin, that has yet to be found, existed in Avaris. Excavating the Horemheb wall area and ascertaining its shape and configuration would provide a very strong insight regarding this topic.

Conclusions

The whole city of Avaris is entirely centred on the Pelusiac branch of the Nile. The most important buildings are close to a channels and the decline of the city seems to coincide with the slow abandonment of the Pelusiac branch of the Nile. Of course, historical events, such as the fall of the Hyksos rulers, have not to be overstated. In fact, both elements are linked: the river was partially maintained by the ancient Egyptians. The landscape changes, as well as the silting up of the former harbour access despite the artificial maintenance would likely have accelerated the demise of Avaris as the capital city. The depression at the core of the Avaris site is definitely an essential feature of the landscape. The OSL dating reveals that it exists since 2000-1000 BC. However, the organic, muddy deposit, which is often found in harbour environments, lasts at least until the Hyksos period, according to the radiocarbon dating. Apparent anomalies in the OSL dating can be explained by human intervention, typical of harbour environments. No structure remains appear on the geomagnetic surveys. However, this is due to the traditional construction technique that uses adobe. These can be difficult to distinguish from thick, silty, but natural sediments. Some structures may have been built out of stone blocks, but most of these have been exported to Tanis to be reused in later buildings after the fall of Avaris.

Proof of human activity in the central depression is obvious, ranging from elements observed in the geomagnetic prospections to archaeological findings. Some of these clues still have to be confirmed by excavations, especially the structures at the north of the harbour and the wall of Horemheb that provides information about the end of the harbour life. We were able to explore the processes that led to the geomorphological formation of the depression. Ancient Egyptians obviously made use of pre-existing topographical features of the site to build their harbour. Regular maintenance was used to keep this natural low energy environment viable as a basin. It is possible that the central depression was not the only mooring place of such a large city. The varying water height during the flow period and the low water period may also imply that other places (maybe quays along the channel, although these remain to be discovered by excavations) could have been used during certain months. However, considering our knowledge of the ancient landscape of the area, the large central depression is by far the most plausible location of the harbour basin of Avaris.

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