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Integrative geoarchaeological research on settlement patterns in the dynamic landscape of the northwestern Nile delta

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ABSTRACT

Settlement activity in the Nile delta is characterized by its profound connection to the branches of the river Nile. Major ancient settlements were founded next to waterways. The constant shifting of these Nile branches – coming either too close or moving too far away – was a fundamental challenge for settlements. This research focuses on the region around Buto (Tell el-Fara'in) in the northwestern Nile delta. The massive increase in settlements in the Ptolemaic, Roman and in particular late Roman periods (4th c BC – 7th c AD) needs to be connected with a fundamental change in the landscape and the way people interacted with the landscape. A particular challenge to reconstructing the ancient land and waterscape was posed by the regional lack of an indicative modern surface relief. A linear settlement pattern of ancient sites was interpreted as showing the distribution along a defunct river branch. A combination of remote sensing data, in particular a new high resolution DEM based on Tandem-X data, and a program of over thirty cores on the ground, have clarified the landscape, especially its fluvial pattern, and the placements of associated settlements. In the north of the study region, the DEM shows elevated levees of former palaeorivers belonging to a finely ramified subdelta, with all settlements placed on alluvial levees. The corings uncovered different artificial channels and identified ancient natural riverbeds at a deep level but similar depth, suggesting that the streams were active during the occupation of these sites and the ancient settlements were either in direct vicinity of the natural rivers or connected via artificial channels. These artificial channels found in corings next to the settlements show characteristics of slack water regimes. In essence, the massive increase of settlements spread over the northwestern delta in Classical Antiquity was spurred by multiple branches that provided routes of transportation, fresh water for irrigation and good conditions for agriculture on their elevated and fertile levees.

1. Introduction

Archaeological research suggests that large parts of the northwestern Nile delta had been widely settled since the Ptolemaic period (4th c BC – 1st c BC) with the settlement activity reaching its peak in the Roman and late Roman periods (1st c BC – 7th AD) (Schiestl, 2012a; Wilson, 2015). Previous archaeological and geoarchaeological research hypothesized that ancient settlements within the delta were closely related to branches of the Nile (Bietak, 1975). Up to seven major water courses flowing through the delta were described by classical authors from the 5th c BC to 4th c AD. It was suggested that settlements of this time period mainly flanked these branches as higher elevated levees along the channels served as appropriate places for settlement. Moreover, the delta branches of the Nile were important transport routes. However, a closer view at the pattern of ancient settlements indicates that they are not only confined to the few major natural water courses but are more widely spread over the whole delta plain. This might be due to the high variability and shifting of the water courses that caused the abandonment and new foundation of settlements. Furthermore, it has to be taken into account that a number of smaller channels and artificial canals must have existed within the delta giving rise to a dispersed settlement pattern. In order to uncover the relationship between the highly variable waterscape and the settlement distribution in the northwestern Nile delta from the Ptolemaic to the late Roman period an integrated approach has been applied. It combines archaeological research, modern methods of remote sensing, and sedimentological studies on different spatial scales (see Fig. 2). The concept of this research is summarized in Fig. 1. On a large scale we juxtapose the location and distribution of archaeologically verified ancient settlements with the fluvial network which could be detected by means of a Tandem-X DEM. The fluvial network manifests itself primarily via positive elevation anomalies in the form of former river levees, which

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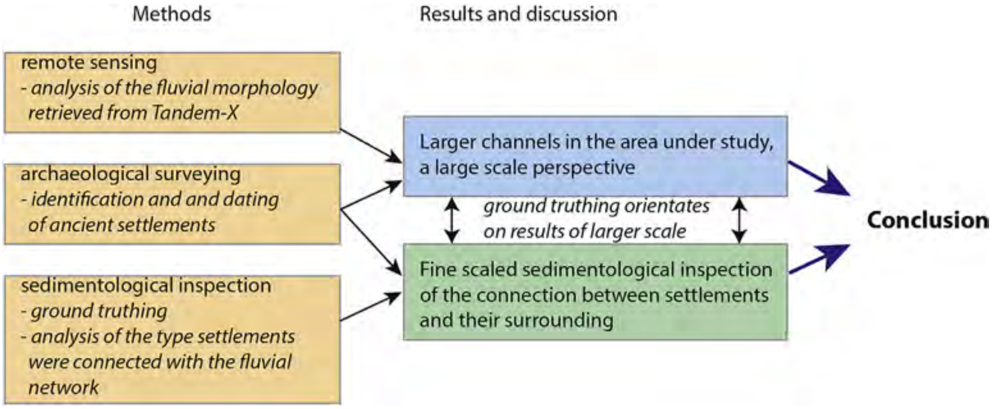

Fig. 1. Research design – The design gives an overview of this research. The different entities relate to the sections within this article.

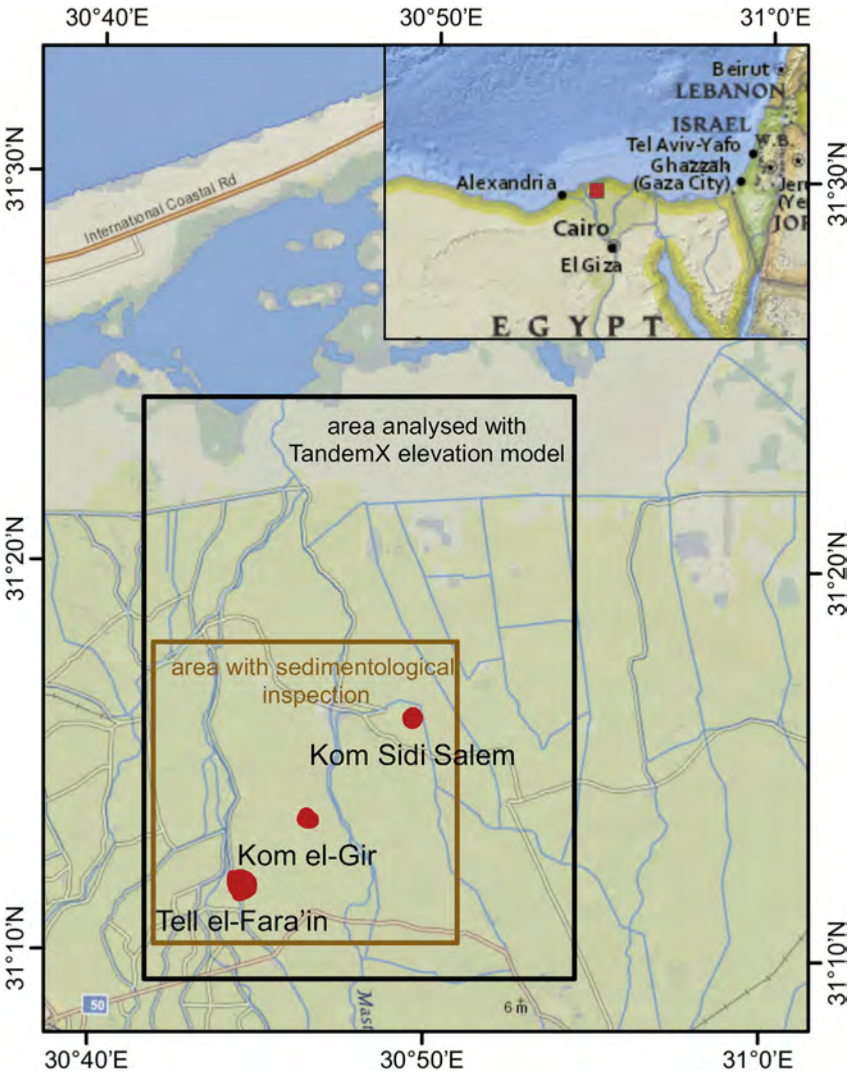

Fig. 2. Location of the study area – The study area is located in the northwestern Nile delta and comprises the area of the TandemX (large scale approach) model and the area with the sedimentological inspection (small scale approach). Most important tells (red) and settlements are illustrated. Map Copyright 2014 Esri, Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, BEBCO, NOAA, increment P Corp. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

later on were heavily transformed by agricultural usage as this could be verified with GPS measurements on the ground. On the smaller scale, individual core sites are studied in detail. The results serve as a ground truthing for larger-scale findings. Furthermore, results on the finer scale elucidate how settlements lying apart from major channels were possibly connected to these watercourses. Based on the analysis of sediments a differentiation between high energy (natural rivers) and low energy watercourses (man-made canals, oxbows) is suggested on the finer scale. Dating of former channels at different localities and analysing their depth profiles can clarify whether we are dealing with a network of channels that existed in a certain period of time. The following sections will give an overview of the research history on the fluvial landscape of the Nile delta based on various archaeological sources as well as on the results of landscape archaeological projects focusing on the reconstruction of watercourses and settlements in the Nile delta. Subsequently the settlement history and the physical setting of the study area in the northwestern Nile delta and relevant environmental changes and processes will be summarized. An integrative approach will be presented that combines archaeological findings, remote sensing data and sedimentological results from corings and we shed new light on the relationship between the Ptolemaic to late Roman settlement pattern, the waterscape and the environmental conditions to get a better understanding of how a changing waterscape affected the occupation of the study area at distinct time periods.

2. Historical and geological setting of the Nile delta

2.1. Research history on the fluvial landscape of the Nile delta

The investigations into the ancient landscape of the Nile delta have mostly focused on the reconstruction of the courses of defunct Nile branches. Other features of the ancient landscapes of the delta, such as lagoons, marshy regions, flood plains and the vegetation of the Nile delta, remain much less studied (for an up to date overview see Pennington et al. (2017)). This prioritization is due to the archaeological background of most research and the linking of watercourses and settlements, the latter mostly representing the primary research interest. The first suggestions for reconstructions of river branches were based on textual sources from classical antiquity. Classical authors from the 5th c BC to 4th c AD have named and described, in varying detail, the branches and mouths of the Nile. Most authors (Diodorus, 1st c BC; Strabo, 1st c AD; Pomponius Mela, 1st c AD; Ammianus Marcellinus, 4th c AD) list seven mouths of the Nile, with different names and courses (Toussoun, 1922; Ball, 1942). The existence of further smaller mouths, connected to minor branches, is occasionally mentioned, for example, by Diodorus (Oldfather, 1933) and Strabo (Radt, 2005), but these smaller features remain mostly nameless. Human intervention into the waterscape is already mentioned in the earliest source, Herodotus (5th c BC), who notes two man-made mouths, the Bolbitine and the Bucolic (Feix, 2006). By the 1st c BC the Bolbitine was, however, considered natural and no longer is listed among the man-made mouths (Diodorus). Ptolemy (2nd c AD) lists nine mouths and six branches of the Nile (Stückelberger et al., 2006) and gives the greatest amount of detail on the location of the water courses, providing coordinates and the relationship to important cities. However even this data, lacking details, allows only very rough placements of branches. Modern maps of the ancient delta (Kessler et al., 1980; Wittke et al., 2012; Talbert, 2000) have two fundamental shortcomings: firstly, they depict branches whose courses are unknown. The courses shown are essentially rough approximations. Secondly, maps tend to present an ahistorical static image, failing to convey the dynamic changes of the fluvial system over time. The maps of the *Tübinger Atlas des Vorderen Orients and Historischer Atlas der Antiken Welt* show the same fluvial system with nine mouths of Nile branches from the Old Kingdom (Kessler et al., 1980; Wittke et al., 2012) to the Third Intermediate Period 1st millennium BC, (Gomaà et al., 1977; Wittke et al., 2012), whereas the system is based on the description of Ptolemy of the mid 2nd c AD.

To date only the courses of two historic Nile branches have been reconstructed in their entirety and in detailed resolution, namely the Tanitic and the Pelusiac branches in the eastern delta (Bietak, 1975). Sections of the course of the Canopic branch in the western delta have been traced (Stanley and Jorstad, 2006; Wilson and Grigoropoulos, 2009; El-Qady et al., 2011; Cooper, 2014; Pennington and Thomas, 2016). The following provides a brief overview over the methods employed (for a recent summary see also Zakrzewski et al. (2016)). The Pelusiac and Tanitic branches of the Nile were reconstructed based on the tracing of raised linear features by means of contour lines on maps (Shafei, 1946; Bietak, 1975). These elevated features represent alluvial levees created by the sedimentation of active river branches. The data of the surface relief was combined with textual sources, both from the Pharaonic period and classical antiquity, to provide the first full length Nile branch reconstructions.

Egypt has a rich tradition of historic maps, which show both topographic features and numerous ancient settlements which have disappeared since the publication of the maps. Of central importance for the delta are the maps of the Napoleonic expedition (1:100.000 Jacotin and Jomard, 1828), the El-Falaki map of 1871 (1:100.000), and the series of Survey of Egypt maps, from the late 19th c to the 1930s (scales 1:25.000, 1:50.000, 1:100.000). The distribution of sites in certain significant linear patterns can be indicative of ancient watercourses which connected these sites. This has been used as a guideline for the courses of the Tanitic and Pelusiac branches (Bietak, 1975), discussed above, the lower reaches of the Pelusiac branch (Sneh and Weissbrod, 1973) or at the western edge of the delta (Trampier, 2014; Trampier et al., 2013; Bunbury et al., 2014). Reconstructing Nile branches by tracing levees can only be applied to levees visible on the surface. Areas with barely formed levees, such as some lower reaches of rivers, levees submerged by alluvial layers and levees levelled by natural or man-made activities, prevent the use of this method. Field walking was applied to the clarification of the lower reaches of the Pelusic branch. A slight physical depression, changes in colour and properties of the surface were detected, permitting the reconstruction of the lower reaches flowing through the plain of the northeastern delta (Sneh and Weissbrod, 1973).

Remote sensing methods have been introduced only relatively recently: aerial photographs were evaluated for the north eastern delta in the early 1970s (Sneh and Weissbrod, 1973). Landsat satellite imagery had been used for geologic purposes in the delta since the 1970s (El Shazly et al., 1975) and was applied for the detection of ancient water courses in the northwestern delta (Wunderlich, 1989). SPOT and SOYOUZ satellite images were used to study the lower reaches of the Pelusiac branch and the changes in the coastline of the northeastern delta (Marcolongo, 1992) and satellite imagery also was the basis for a suggested course of the Canopic branch of the Nile (Wilson and Grigoropoulos, 2009). Corona satellite images from the late 1960s and 1970s are the earliest regional satellite images which, however, only became generally available recently. They served as basis for studies of the Pelsusiac branch of the Nile (Moshier and El-Kalani, 2008) and the ancient waterscape of the western edge of the delta (Trampier, 2014; Trampier et al., 2013). Shuttle Radar Topography Mission (SRTM) data was used to clarify the lower reaches of the Canopic branch of the Nile (Stanley and Jorstad, 2006).

Submerged levees were first traced by means of a substantial coring program by the Amsterdam University Survey in the eastern delta (Sewuster and van Wesemael, 1987; van Wesemael, 1988), in the course of which both major and minor branches were detected. Core transects were placed perpendicular to assumed river courses, connecting elevated sand mounds, so called geziras (Arab. islands) and turtle backs (Butzer, 1976; Wunderlich, 1989; Pennington et al., 2017), where settlements were located. Large scale corings were undertaken in the northwestern delta (Wunderlich and Andres, 1991; Wunderlich, 1989, 1993) and the northeastern delta (Andres and Wunderlich, 1991). In the latter region, the area of Tell el-Dab'a/Avaris (Dorner, 1993/1994, 1999), 850 cores served as the basis for the reconstruction of the course of the Pelusiac branch at the ancient cities of Avaris and Piramesse. Coring was also conducted around Sais (Wilson et al., 2006) and at Naukratis, where the relationship of that town to the Canopic branch has been established with certainty (Pennington and Thomas, 2016). Electrical resistivity tomography served as the basis for delineating buried channels in the central delta (El-Gamili, 1988; El-Gamili et al., 2001) and sections of the Canopic branch (El-Gamili et al., 1994; Pennington and Thomas, 2016). Magnetic investigations have also been added to the study of water courses (Fattah and Frihy, 1988; Pennington and Thomas, 2016). In general, most projects currently combine above mentioned methods, depending on the specific questions addressed. To summarize, research has focused on the western and eastern parts of the delta. The central delta remains understudied – in archaeological terms, as well as concerning the ancient landscape and its water courses.

While most archaeological projects in the delta address issues of the ancient landscape, it is now generally done on a local or regional scale. New methods have led to the intensification of research, but also a reduction in spatial scope. This, on the one hand, allows for new levels of detail, and constructions are investigated in connection with waterways, such as inland harbors (river ports), reinforced riverbanks, terracing and quays. Such features are evaluated, for example, at Avaris/Tell el-Dab'a (Tronchère et al., 2008; Herbich and Forstner-Müller, 2013), Naukratis (Thomas and Villing, 2013; Thomas, 2014) and at Schedia (Bergmann and Heinzelmann, 2015). Smaller waterways and canals are also being investigated, e.g. at Naukratis (Thomas, 2015), and the local connection to the larger waterscape (Bunbury et al., 2014), as well as the width and depth of larger waterways, which is crucial for inferring ship capacities (Tronchère et al., 2012; Pennington and Thomas, 2016). On the other hand, the reconstruction of the entire length of branches has faded to the background and is currently not being tackled.

Dating of the ancient watercourses remains a major challenge. There are two approaches, an archaeological and a natural scientific one. By means of archaeological data, watercourses are, on a general level, dated by the association with dated settlements flanking the route. On a more detailed level, archaeological artefacts, generally pottery embedded in sediment cores, serve as indicators for dating (Toonen et al., 2017). The transportation and redeposition of such material in a fluvial environment, however, weakens this method as a dating tool. By scientific means, the crucial dating tool for fluvial deposits, OSL (Optically Stimulated Luminescence) dating, is not possible in Egypt. Based on sedimentation rates, the thickness of sediments has been used as a general dating tool (Sewuster and van Wesemael, 1987). Radiocarbon dates currently provide crucial chronological anchors. For example, based on a 14C date, the end of the activity of the Pelusiac branch was dated to the first half of the 1st c AD (Sneh and Weissbrod, 1973).

2.2. Research history of ancient settlements in the study region

Our current level of knowledge of the settlement history of the northwestern delta remains sparse and uneven. The annual Nile flood covered most of the delta plain with water. In order for settlements to remain dry, the delta only provided two elevated areas above the flood line: Holocene (western delta) or Pleistocene (eastern delta) turtle backs or geziras and the alluvial levees of active or former Nile branches. There is, however, also evidence for ancient settlements in the alluvial plain (Sais, Wilson and Grigoropoulos (2009), and possibly Ezbet el Qerdahi, Wunderlich et al., 1989). The occupation of the large important site of Buto (Tell el-Fara'in) has been intensively studied. Its settlement history is unusual in two respects: its great age and a long interruption. It was founded in the 4th millennium and the latest traces of occupation are from the Early Islamic period (7th c AD). This early occupation and very long settlement history is unique in the region. This long settlement continuity, however, is interrupted by a major gap: between the late Old Kingdom (late 3rd millennium BC) and the Third Intermediate Period (early 1st millennium BC), there is no evidence of occupation (Hartung et al., 2009; Ballet et al., 2011). The site seems to have been abandoned as a settlement for almost 1500 years, with possibly only the important temple of Wadjet, the main goddess of the site, persisting (Bedier, 1994; Schiestl, 2012b). The reason for this settlement gap remains unclear, but partial flooding of the late Old Kingdom site point to environmental reasons, possibly caused by a shifting Nile branch (Hartung et al., 2009).

The hinterland of Buto (Tell el-Fara'in) has long been archaeologically neglected and its settlement history remains only partially understood. Following some early small scale investigations (Petrie, 1896; Hogarth, 1904; Petrie et al., 1905; Edgar, 1911; Daressy, 1926) it was only in recent decades that more field surveys took this region into focus (Spencer, 1992; Ballet and von der Way, 1993; Wilson and Grigoropoulos, 2009; Schiestl, 2012b; a; Wilson, 2012a; b; Schiestl, 2015; Wilson, 2015; Schiestl and Rosenow, 2016) and http://www.ees.ac.uk/research/delta-survey.html.

2.3. Physical setting and environmental history

The current Nile delta is traversed by two large branches of the Nile, that of Rosette and that of Damietta, and numerous smaller watercourses. In the northwestern delta, most of the watercourses are manmade and consist of a system of drains and canals cut mostly since the late 19th c AD, when this part of the delta was being developed for modern agricultural purposes. The research area (Fig. 2) lies about 7 km south of the Burullus Lake and 20 km south of the Mediterranean coast. The land surface of the delta is almost flat with slight elevation differences of only several meters (Wunderlich, 1989; Butzer, 1975). The delta plain slightly dips for 15 m over a distance of 170 km from Cairo in a north-northwest direction to the coastline. The modern landscape is entirely covered by fields to grow crops, and settlements, which are rapidly expanding. No natural environment remains within this densely settled and agriculturally intensely used delta (Said, 1993).

The ancient landscape is obscured by the natural sedimentation of the yearly Nile flood, which ultimately ended in the 1970s with the construction of the Aswan High dam and the sediments being trapped in lake Nasser. Processes such as sea level changes, tectonic and isostatic movements also control the evolution of the Nile delta and are subject to many studies (Arbouille and Stanley, 1991; Butzer, 1975; Krom et al., 2002; Marriner et al., 2012; Stanley and Warne, 1993; Pennington et al., 2017). In summary, the modern surface relief and the current waterscape seem to offer very few traces of the ancient landscape. The investigations into the ancient landscape of this region by J. Wunderlich in the 1980s (Wunderlich, 1988, 1989, 1993) fundamentally changed our understanding of the northwestern delta. This large scale sediment core program showed that after the late Pleistocene, the flat delta body with local dunes and deeply incised main channels was affected by transgression due to rapid sea level rise. This caused a southward movement of the coastline and the deposition of peat layers on top of the former Pleistocene surface at about 5000 cal BC. Remnants of this great landscape change shaped the early period of Buto's occupation. A marshy region, a precursor of the later Burullus lake, extended much further south, rendering the region between Buto and the coast unsuitable for permanent settlements. This was followed by a phase of decreasing sea level rise and increasing clastic sedimentation which caused this movement to rebound and the marshy environment moved northwards again. Since then the floodplain deposits are constantly aggrading in the delta and nowadays cover former levees, dunes or slowly growing settlements reaching thicknesses of about 7–10 m (Wunderlich, 1989). What remains unclear as of yet is the date and the pace of landscape changes which permitted settling or caused abandonment in this region. The general stratigraphy of Wunderlich (1989) focused on larger scaled changes, namely the change from brackish lagoonal conditions to the development of the Nile floodplain. It does not further differentiate the Holocene floodplain deposits, which accumulated during about four millennia, and roughly amalgamates these sediments as a single homogeneous unit.

The present study focuses on the development of this sediment sequence and the information contained therein about changes of the fluvial system and the settlement history of this region. In a study on the Mississippi River, which serves as a standard for interpreting fine-grained floodplain deposits of meandering rivers, Aslan and Autin

(1999) showed that floodplains develop by overbank flooding, crevassing and avulsion. Especially the latter processes leave behind a complex alluvial architecture with a high local variety in texture. Nile river arms as well constantly changed their courses, vanished, reappeared or even fanned out (see section 2.1) into several smaller channels. In the Mississippi delta Aslan et al. (2005) demonstrated that avulsions were a key process in the development of river channel belts and subdeltas. Within the channels coarser material is deposited that differs in texture from the finer grained levees and the silty to clayey floodplain deposits. Especially the shifting meander belts cause a sediment body of remarkable thickness and horizontally and vertically varying texture of sediment (Aslan and Autin, 1999).

Within this context, levees are of special interest. They appear as positive height anomalies along rivers. Especially the latter qualifies levees as important witnesses for rivers in contour maps (Shafei, 1946; Bietak, 1975) or high resolution elevation models processed from Lidar and TanDEM-X elevation data (Erasmi et al., 2014; Palaseanu-Lovejoy et al., 2014). According to Branβ et al. (2016), levees form directly next to the main channel. They show a steep slope directed towards the channel and fall off gradually towards the floodplain. Levees tend to be made of fine sand, but grainsize decreases with transport distances, resulting in the fining-up of sediments towards the floodplain (Aslan and Autin, 1999; Cazanacli and Smith, 1998; Smith and Pérez-Arlucea, 2008). Additionally, the slope of the levees decreases with the average grainsize decrease (Cazanacli and Smith, 1998). In the Nile delta floodplain levees reach some metres in height with a wide lengthwise extension and a convex body that very slightly dips towards the floodplain (Butzer, 1976). The absence of visible indications for the ancient landscape on the modern surface terrain, in particular in the southern part of the study region, led to the application of the integrative approach discussed in the following.

3. Methods

Our methods focus on two different scales. On a larger scale archaeological prospection aimed at the localization, documentation, and dating of ancient sites (section 3.1) This was supported by recent satellite imagery which furthermore was analysed to trace levees of ancient watercourses (section 3.2).

On a smaller scale landscape units and ancient watercourses were studied via coring (section 3.3). The core localities were chosen based on their proximity to archaeologically relevant settlement sites. Our core transects focused on the transition between the settlements and the closer environment. Methods applied at this smaller scale concentrate on pinpointing ancient river channels and by chance we reached fluvial sediments of ancient watercourses.

3.1. *Archaeological methods*

The region investigated by archaeological means (Schiestl, 2012a, b, 2015) overlaps with, but is not identical to, the study region discussed here. The survey region is bordered approximately by the area of Kom Sidi Salem in the North, the modern towns of Qellin in the South, Kafr esh-Sheikh in the East and by Buto (Tell el-Fara'in) in the West (Schiestl, 2012b, Fig. 1). As no prior systematic survey of the region had taken place, the aims of the archaeological investigation of the region were primarily threefold: firstly, location and identification of ancient sites, secondly, documentation and further prospection of these sites based on field walking, and thirdly, dating of the occupation of the sites based on pottery fragments from the surface and from core material. The identification of sites in agricultural lands is challenged by an Egyptian particularity: the wide spread use of ancient settlement remains (sebakh) as fertilizer on fields (Bailey, 1999; Quickel and Williams, 2016). The ceramic sherds embedded in this material were thus dislocated from their original context and redistributed. Surface material alone cannot be considered an indicator for ancient activity. Positive identification of ancient sites requires further evidence. Therefore, within the survey region areas of interest were defined which were investigated more closely on the ground. The areas were chosen based on information from historical maps, editions of 1828, 1872, 1900s–1930s and 1940s, aerial photography from the 1950s, Corona satellite images from 1968 and satellite images from Google Earth from the 2000s. The areas of interest are composed of ancient settlement sites, tells, rising above the surrounding ground, partially or entirely levelled ancient sites, identified based on historic maps, and elevated areas identified on historic topographic maps, mainly the Survey of Egypt editions, 1:25.000, from the 1920s/30s. 31 sites were investigated by field walking in these designated areas and their current state was documented. Combining this information with changes traceable on satellite images, in particular the Corona images from 1968, and historic maps, in particular the Survey of Egypt series from the 1920s/30s, allows us to document the taphonomic processes affecting the site, primarily shrinkage and levelling of sites (Schiestl, 2012b). Dating of sites is primarily based on pottery sherds collected on the surface. Other artifact categories encountered are glass sherds, coins, metal objects and stone objects, but these play quantitatively a minor role. The pottery is dated typologically based on comparisons with dated examples from other sites. Additionally, 43 cores were placed at 14 sites in order to investigate the land the settlements were founded on and to retrieve pottery fragments from lower layers.

3.2. *Tandem-X digital elevation model*

Elevation data is of high importance in geoarchaeology, especially when working on a broader landscape scale in flat areas. The TanDEM-X satellite formation consists of two twin radar satellites flying in close formation to allow precise digital elevation measurements based on state-of-the-art radar technology. The TanDEM-X digital elevation model (DEM) is available globally and shows a pixel spacing of up to 12 m and with less than 10 m absolute vertical accuracy and around 2 m relative vertical accuracy in flat terrains (DLR Product Specification). Especially the new TanDEM-X data enhances the detection of fluvial structures significantly and allows a view of the Nile delta at a very detailed perspective. To give better quality information, the relative vertical accuracy was estimated via comparison with ICESAT elevation data (see Fig. 3, Zwally et al. (2011)). Several studies (Rao et al., 2014; Erasmi et al., 2014; Huber et al., 2009) showed the potential of ICESAT data for the quality assessment of TanDEM-X elevation data. Results of this quality assessment show that height residuals between ICESAT and TanDEM-X data stay around 0.7 m (1sigma). TanDEM-X data reflects the surface and consequently settlements and other solid man-made structures appear within the TanDEM-X model. Vegetation, especially fields with higher canopies, only slightly manifests itself within the data as the X-band waves partly penetrate vegetation. In general, Pipaud et al. (2015) showed the great potential of the TanDEM-X DEM for geomorphological applications in high mountainous areas in Tibet. This potential can be expanded to flat terrains such as the Nile delta as the Tandem-X elevation data allows for the detection of levees and other geomorphologic structures in unprecedented spatial resolution. A similar geoarchaeological approach was pursued by Erasmi et al. (2014) in the Cilician Plain in Turkey. Erasmi et al. (2014) focused on the potential of high resolution TanDEM-X data for the detection of landscape features such as ancient settlements and geomorphological elements and successfully uncovered old river patterns and levees of the river Seyhan in their region under study. Such structures are expected to occur in the Nile delta and manifest themselves with very low detail in SRTM data. But as Erasmi et al. (2014) state “the level of detail of the TanDEM-X DEM allows for a more detailed analysis of the shape and depth of those objects”.

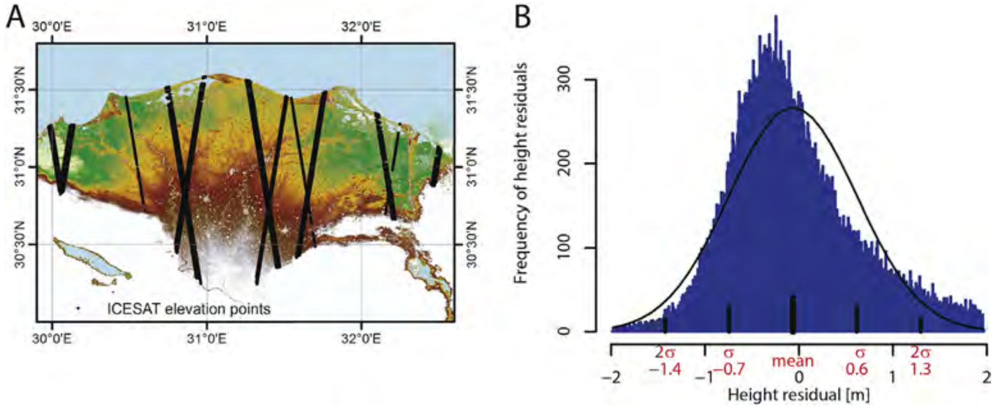

Fig. 3. Quality of TanDEM-X – Quality of the TanDEM-X is estimated for the Nile delta plain via comparison with ICESAT elevation data (Zwally et al., 2011). The map (A) shows the location of the ICESAT points. The histogram (B) shows the frequency of the height residuals. Tandem-X and ICESAT height distributions are adjusted to fit the same mean value and residuals are calculated. Additionally, outliers and ICESAT points lying on water areas are removed. The water areas are masked by Landsat 8 surface reflectance quallity assessment (qa) band data of scenes acquired between April 2013 and July 2017.

3.3. *Corings and geochemical analyses*

The lithology of the subsurface was obtained by means of a vibracoring device (Wacker BH65) and open steel probes with varying diameters (6.0, 5.0 and 4.0 cm) and 1 m length. Especially the extraction of sediment via coring (Stein, 1986) keeps sedimentary structures and boundaries between different layers intact. The sediment cores were described in the field in terms of colour (Munsell Soil Colour Charts), grain size and rounding, texture and carbonate content according to Eckelmann et al. (2006). Organic material was taken for radiocarbon dating and archaeological remains were used for age estimation. 14C dates were calibrated with Calib Rev 7.1 using IntCal13 and stated using the 2 sigma error range. For every age mentioned in the text the Radiocarbon age and the calibrated age is provided in the text. Dateable ceramic fragments were picked out by hand and analysed by Peter French and Rita Hartmann. The sherds occurred abundantly only in very close vicinity to the settlement sites. In most cases ceramic pieces were very scarce, badly preserved and not very indicative, as they were often present within fluvial deposits, and rounded. Therefore, the dating can often be only considered a rough estimate.

The bore holes were placed along different transects with the main transects leading away from the settlement sites of Buto and Kom el-Gir and other transects focused on the levees in the north and the Bahr Nashart depression lying east of Kom el-Gir (see Fig. 7). These transects cross the delta with distances between neighbouring cores of about 500 m or less.

Geochemical analysis on the sample material of the corings was conducted with a Niton XL3t 980He portable XRF (pXRF) analysator equipped with a Ag-Anode. The pXRF instrument runs at tube voltages of 9–50 kV and at beam currents of 0–40 μA. A helium purge was used to enhance quantitative measurements of light elements, of which phosphorus is most important. The XRF spectra were quantified using a fundamental parameter algorithm “Testall geo” that combines the mining and soil mode and which is supported by the device. The measurement time was set to 180 s. To optimize the results and gather information on the accuracy of the device to detect certain elements, certified reference materials (SiO2, NIST2780, Till4) and our own local standards, characteristic samples of our corings, were measured during each measurement series and statistical parameters such as standard deviation and mean were calculated. Precision of measurement is expressed with the coefficient of variation, which is the share of the standard deviation (2 sigma) to the mean. The element data presented within this study show the coefficients of variation given in Table 1.

Additionally, the handling of the samples was standardized in order to provide reproducible measurement conditions and to reduce influences of the sample matrix and sample surface. All samples were oven dried at 100 °C, homogenized with an achat mortar and sealed in certified XRF sample cylinders using a 4 μm XRF foil to allow best penetration of the analyzation and fluorescence radiation.

Table 1
Coefficients of variation for elements used within this study.

Al	4.50%	Nb	16.90%	Sr	1.40%
Ba	4.40%	**Ni**	12.70%	**Te**	32.10%
Ca	2.15%	**P**	21.40%	**Ti**	2.20%
Cr	8.70%	**Pb**	3.40%	**U**	31%
Cs	11%	**Rb**	1.70%	**V**	9%
Cu	3.70%	**S**	2.50%	**W**	27.80%
Fe	0.10%	**Sb**	19.70%	**Y**	11.40%
K	1%	**Sc**	42.40%	**Zn**	5.30%
Mg	11.30%	**Si**	2.30%	**Zr**	2.50%
Mn	5.40%	**Sn**	20.70%		

4. Results and discussion

Results are presented and discussed regarding the archaeological prospection and the two different spatial scales which were defined earlier. Results of the larger scale show that nearly all settlements in the Nile delta lie directly next to former rivers or in close vicinity (see Figs. 4 and 5). On a small scale we sampled several identified watercourses, landscape units and settlements and the transects cover the transition from the settlements to their wider surrounding. At this scale we could verify that the surrounding of settlements sampled via corings and sedimentological inspection reveals associated channels. These channels are also of artificial origin and likely linked with the natural rivers present in the area. These findings are presented and discussed in detail according to the two scales adopted within this study.

4.1. *Archaeological results*

To summarize the results of the archaeological survey: numerous new settlements could be documented, none, however, with a settlement history as long as Buto. Identification and closer inspection of archaeological sites in the survey region was difficult as most sites are overbuilt by modern cemeteries and settlements. Many sites are partially or entirely leveled. Free standing, non-overbuilt sites, are the exception (Schiestl, 2012b). This picture changes when moving to the northern part of the study region and in particular to the region between Kom Sidi Salem and the Burullus lagoon (Figs. 2 and 4). This region shows a large amount of remarkably well preserved free standing and non-overbuilt sites. As no site in this region has yet been excavated, dating of these sites relies to date on pottery from surface surveys and corings. The following picture has emerged for the settlement history of this region: In the vicinity of Buto (Tell el-Fara'in) there is evidence of traces of further early sites from the 4th millennium BC (Wunderlich, 1989). These remain, however, exceptional. What follows is a very long gap: no settlements of the 3rd or 2nd millennium BC are to date documented on a regional scale. The early 1st millennium BC

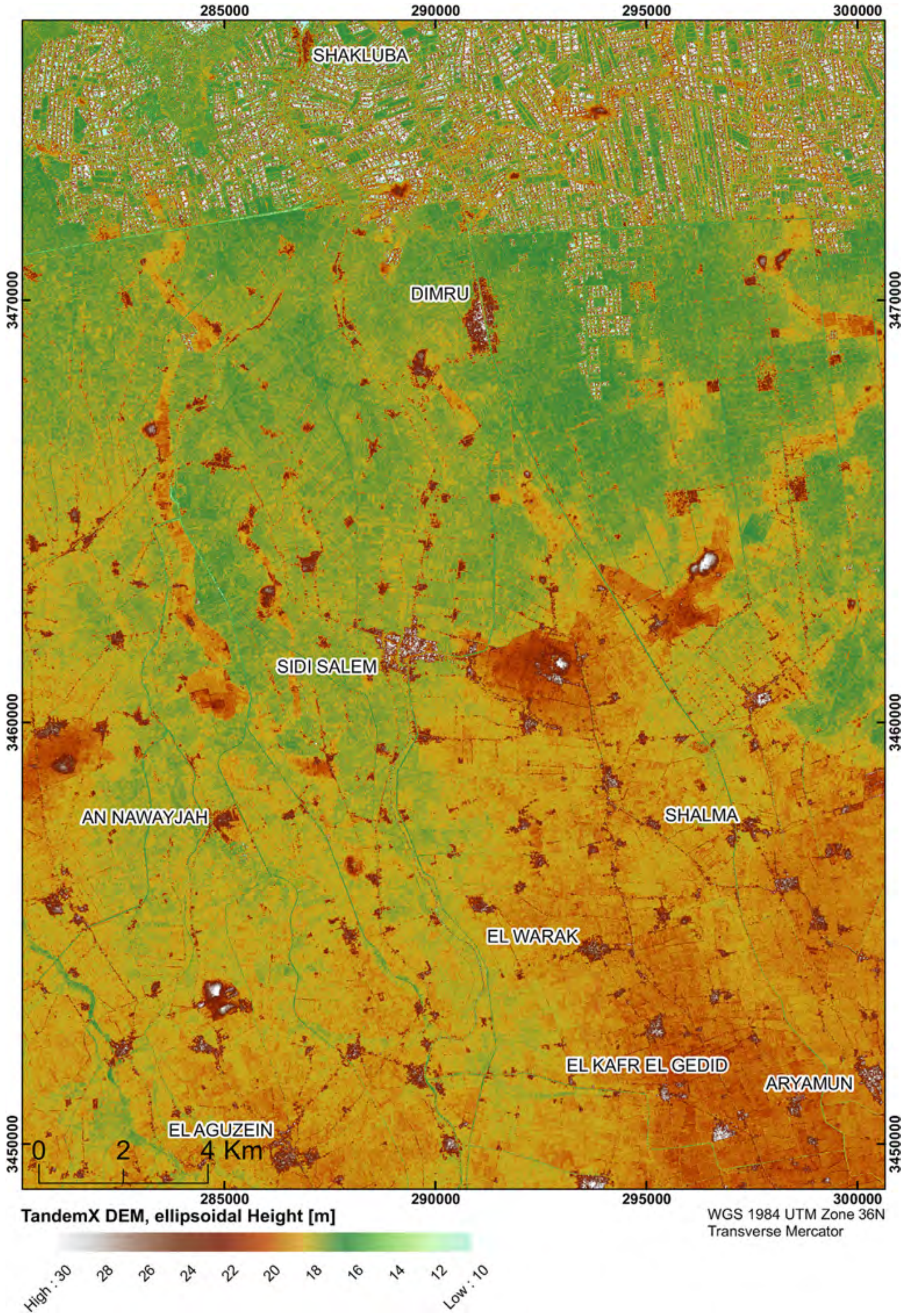

Fig. 4. TanDEM-X DEM – Undisturbed elevation model including names of prominent modern settlements. TanDEM-X elevation map (German Aerospace Center, DLR).

provides the first evidence for new settlements, such as at Kom Asfar. This is followed by a period of growth in the Ptolemaic period, and strong growth in the Roman and late Roman periods (Wilson and Grigoropoulos, 2009; Wilson, 2012a, 2017; Schiestl, 2012b; Schiestl and Rosenow, 2016, 4th c BC – 7th c AD). Some sites show continuity into the Early Islamic period. Individual sites, such as Kom Sidi Salem, contain substantial amounts of Medieval remains. The wide spread settlement growth in the northwestern delta can only be understood in connection with a fundamental change in the ancient waterscape and landscape. The basis for the economic development of this region must have been a network of Nile branches, in order to provide for the settlements, the irrigation of fields and the transport routes for people and goods. The modern surface offers no indication of the ancient land- and waterscape. Based on the settlement pattern, a linear distribution was interpreted as possibly flanking a central defunct Nile branch, roughly where today the Bahr Nashart and Masraf Nashart flow. The term Bahr refers to a larger irrigation watercourse and Masraf to a drain. This hypothesis was to be tested by the integrated methods of remote sensing, in particular the TandemX DEM, and sedimentological ground truthing with corings.

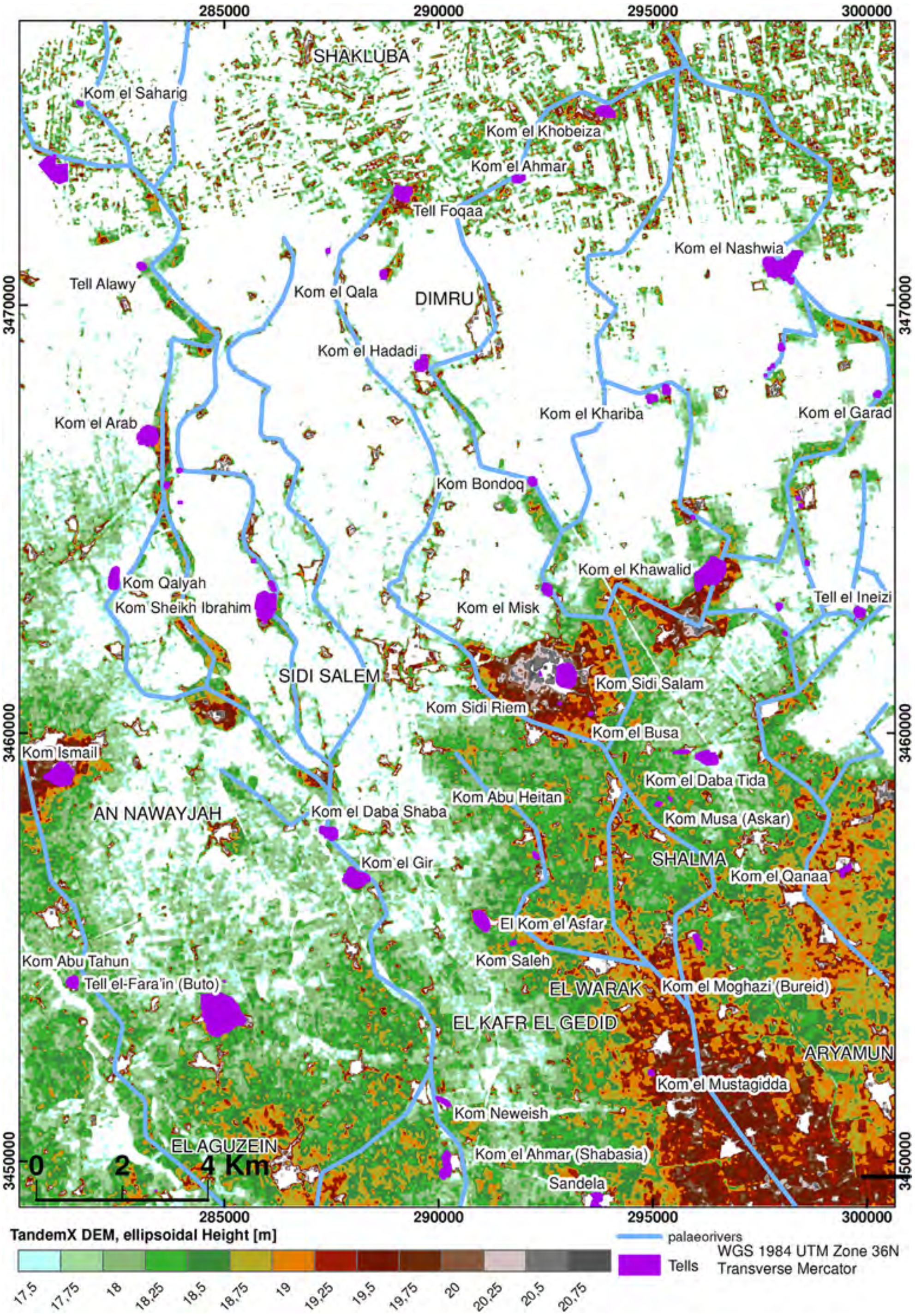

Fig. 5. Thresholded TanDEM-X DEM – Elevation values are thresholded for elevations lying between 17.6 and 20 m. Prominent palaeorivers are highlighted with lines. Additionally position and names of ancient settlements are included as well as modern settlements highlighted with capital letters. TanDEM-X elevation map (German Aerospace Center, DLR).

4.2. Larger channels in the area under study, a large scale perspective

In the Nile delta, the TanDEM-X DEM allows the visualization of traces of levees which are not visible with the naked eye (Fig. 4). Only the largest of these levees are traceable on historic maps, even on the detailed topographic maps of Survey of Egypt (1:25.000, 1920s/30s editions). With the new data, a picture emerges of a subdelta of finely ramified larger and smaller branches between Kom el-Gir and the Burullus lagoon. The levees are isolated in Fig. 5 via thresholding for heights between 17.6 and 20 m and applying focal median filtering. They mostly appear as single elongated ridges which evolved when both levees flanking a channel merged together. Only in few cases are both levees still preserved with a channel depression in between. Palaeorivers are reconstructed based on the evidence of the levees and highlighted with blue lines.

It becomes evident that all settlements in this region (see Fig. 5) are situated on levees alongside these palaeorivers. Very likely the levees in the delta did not only attract settlements as safe and elevated places along rivers. The levees also offered best conditions for agriculture with high soil fertility and access to irrigation water. Ginau et al. (2017)

studied vegetation performances in the Nile delta on the basis of NDVI time series. In their results, the areas along the palaeorivers, namely the elevated levees that slightly dip away from the channels, show highest vegetation performances. Several factors contribute to the high vegetation performances. Nutritious Nile flood deposits accumulate primarily on the levees and best soils formed along the rivers. Secondly, higher elevation and coarser sediments reduce ascension of groundwater and prevent soil salinization (Ginau et al., 2013, 2017). Results of Ginau et al. (2017) also showed that large settlement mounds show larger areas of high vegetation performances in their surroundings. They state that agricultural practices comprise tapping of the Nile channels for irrigation of fields resulting in the accumulation of nutritious Nile material in the irrigated areas next to the settlements which can explain the observed patterns of vegetation performance. The eccentric position of some settlements on the elongated ridges is notable, e.g. Kom el-Arab, Kom Sheikh Ibrahim and Tell Alawi are lying on the western side, Kom el-Misk, Kom Bondoq on the eastern side. These positions place the sites on the western bank and eastern bank of the branches respectively. Kom el-Nashwia actually is a double site, as expressed by the second name, Kom el-Nashawein, which is a dual construction. The two sites are separated by a depression, which, as suggested by Wilson (2017) represents the ancient watercourse.

It is actually easier to identify levees and consequently the system of palaeorivers in the northern part of the study area, where these features contrast clearly with the flat surrounding flood plain. Continuing these features further south is more difficult. Kom el-Gir seems to have been erected on a levee about 2 km south of the forking off into four smaller features. The southern part of the study area (Fig. 4, south of Sidi Salem) is generally higher and here levees tend to be wider and often are cut by other channels. Incised structures leading away from the levees directly into the lower lying areas possibly resulted from crevassing and formation of new channels. Incised structures running along the levees may be interpreted as remnants of the former river channel situated between the levees. This higher diversity in the southern half of the study area together with profound anthropogenic influence makes it much harder to perceive the location of former watercourses whereas we can clearly outline them in the north. Additionally, Wunderlich (1989) showed that north of Buto peat layers occur within the sediments and their thickness increases northwards. In a study dealing with the effects of peat on delta evolution, van Asselen et al. (2009) name peat as the most compressible of all natural sediments. This may lead to substantial subsidence in the northern delta areas and explains the considerable local variability of subsidence rates observed by Marriner et al. (2012) as they are influenced by variations in texture and organic content of the sediments. Along former channels and within the channel sediments no peat but fine to coarse sand deposits of remarkable thickness occur. As a result, these channel and levee deposits were not affected by compaction. The great difference in compaction rates between the sandy sediments and the surrounding peat layers very likely helped to enhance the traces of former watercourses. Taking a closer look at the area between Tell el-Fara'in and Kom el Gir, we hardly find any of these structures in the digital elevation model and the area in general seems to be heavily disturbed and transformed due to the intensive agricultural usage. This is due to the fact that the Nile delta is one of the most intensely cultivated areas on the earth and is shaped by the interplay of urbanization and intensive agriculture. Even the well pronounced levees in the northern part of the study area were substantially modified for agricultural purposes.

The cross profile through the levee was measured with a Topcon GR-5 DGPS and its location is illustrated in the TanDEM-X elevation map (German Aerospace Center, DLR) and in ESRI satellite maps.[1] A very good example is the levee running from Kom Sidi Salem northwards along Kom el Qala, exemplified in Fig. 6. The DGPS track reveals the levee as a flattened and leveled structure with cross profiles resembling a stepped pattern. This pattern possibly results from differences in height and size of the two levees situated at the former slip-off

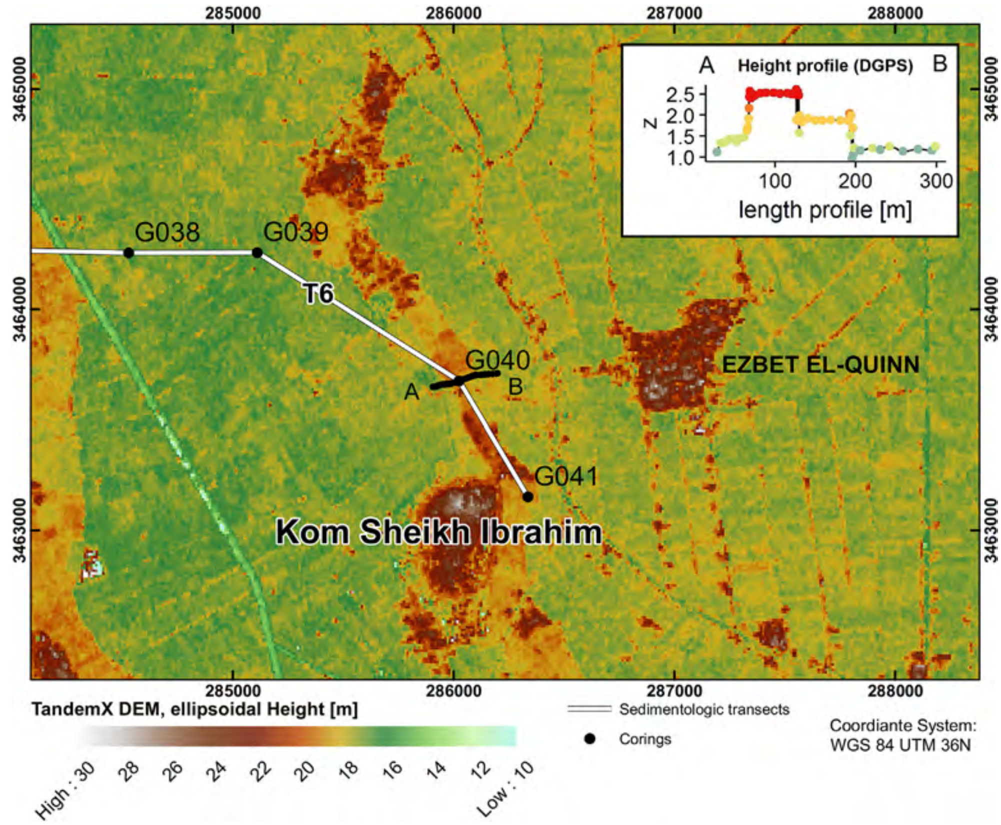

Fig. 6. Transformation of levees – Elevation profile of an elevated levee north of Buto.

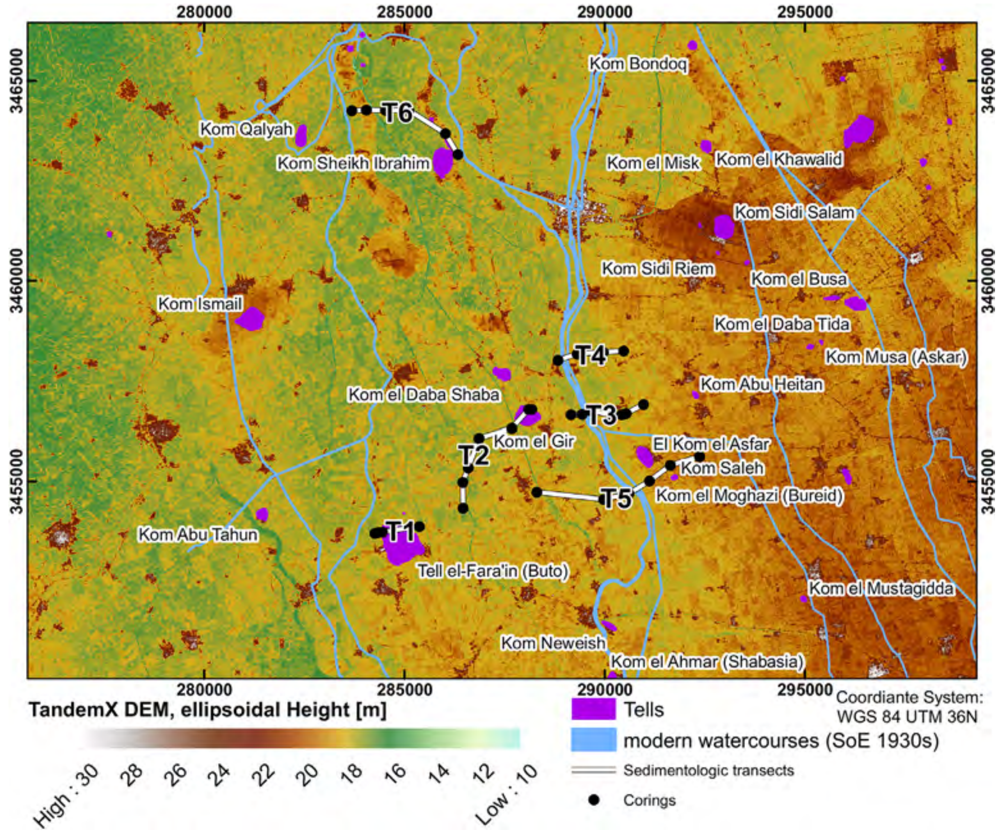

Fig. 7. Location of sedimentological transects – Transects are illustrated on top of the TanDEM-X elevation map (German Aerospace Center, DLR).

slope and eroding bank of the channel. The question why these levees were not completely leveled might be answered with their positive effects in preventing soil salinization. They increase the distance to the ground water table and reduce ascension and evaporation of ground water. Especially the northern delta suffers soil salinization (Kotb et al., 2000). Soils in this low lying area are categorized as highly saline by El-Guindy (1989). Even with sediment compaction and subsidence of the surrounding, clearly the levees are the result of a considerable period of fluvial activity and sedimentation. In a rough assessment, the levees had been forming since the 2nd millennium BC as a substantial amount of time is required to aggradate 2.5 m or more on which the settlements were founded. This raises the question why the area only seems to have been settled starting in the 1st millennium BC. Likely new methods of land-use for the areas of the low lying alluvial plains between levees played a crucial role. This expansion into the northern fringes of the delta opened huge swaths of new land (Butzer, 1976) and commercial opportunities. The challenges of agricultural activities in this marginal region are evident by papyrological sources from the region of Thmuis, in the eastern delta (Blouin, 2014).

4.3. Fine scaled sedimentological inspection of the connection between settlements and their surrounding

Our sedimentological work concentrates on the closer region around Buto (see marked area in Fig. 2) and Kom el-Gir. In this area hardly any recognizable fluvial structures appear in the remote sensing imagery. Finding watercourses and channels in the subsurface is challenging and time consuming as a dense net of corings is necessary to describe the courses of identified channels. Yet, it is the scope of this study to show that in this superficially disturbed region many channels and watercourses appear in the subsurface and especially alongside the settlements. In general, alluvial material of the subsurface reveals a complex lithology with inclusions of small sandy patches in the fine grained alluvial material. The coarse grained inclusions possibly originate from crevasse splays, levees or small channels. In addition, massive sequences of sand that cover widths of several hundred meters and a thickness of several meters occur and can only be explained via the action of moving meander belts.

Different core transects (see Figs. 7 and 8) are placed in this area. Fig. 7 gives an overview of the location of six different transects we studied in detail and Fig. 8 shows their lithological cross sections. In case of the transects and as a consequence of the high distances of several hundred meters between the cores it is unclear whether we touched individual watercourses at the margin or the base of the channel bed and the estimation of the channel depth is only a rough estimate. No statement can be made regarding the width of the channel. Nevertheless, our work provides important indications for further scientific studies on individual watercourses. It is planned to apply high resolution coring transects and geoelectrical measurements in future campaigns.

1 Transect 1 crosses Buto in W–E direction and includes results from Wunderlich (1989); Wunderlich and Ginau (2016). On both sides of the tell we find deeply incised channels that reach down to about 7 m below the sea level (bsl). The channel east of Buto dates back to Late Antiquity (4th c - 7th c AD) or earlier, as only the infill is dated, which comprises rounded Roman pottery at the channel bed at 7 m bsl and two radiocarbon dates (^{14}C) (Wunderlich, 1989) from 1980 ± 100 BP (HD11563-11388), or 350 cal BC – cal AD 253 (2σ) at 3.60 m bsl and 1595 ± 115 BP (HD11563-11388), or cal AD 177–659 (2σ) at 5.60 m bsl. The age inversion testifies to the channel dynamics with the reworking and redeposition of sediments. The channel infill is dominated by silty material and is rich in ceramic flitters, mollusk fragments and organic material between 3.25 and 7 m bsl. Together with the ceramic fragments, gravels occur at its bedline which is cut into underlying clayey alluvial Nile material. To the west of Buto at core site G3, predominantly loamy fine sandy material appears between 1 m and 7.5 m

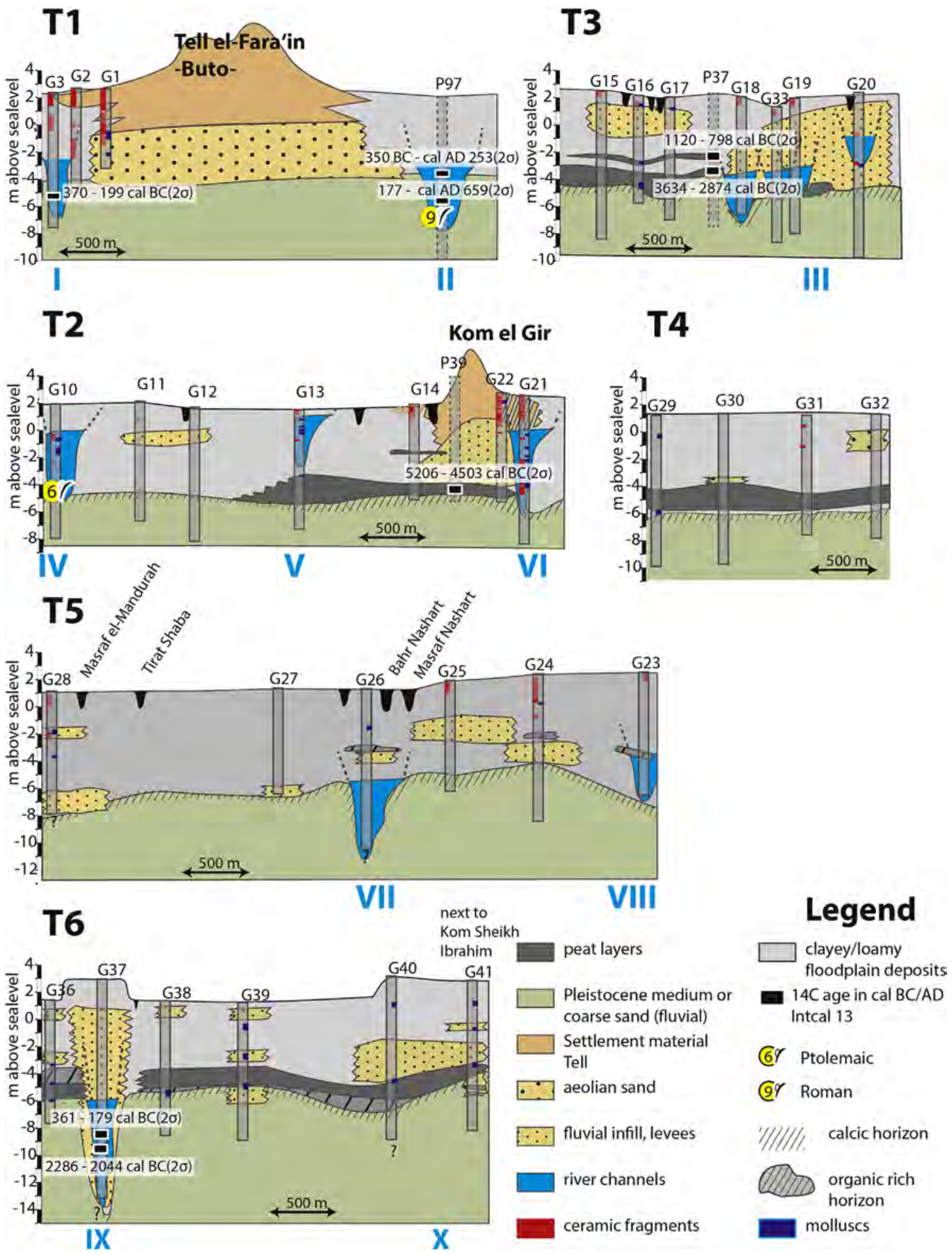

Fig. 8. Cross sections of sedimentological transects – Different cross sections of sedimentological transects were channels were found. The different channels within the cross sections are labeled with blue Roman numbers. A legend explaining the different signatures is included. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

bsl with small gravels found at 7 m bsl (Wunderlich and Ginau, 2016). Below 1.2 m bsl the sediments are brighter with only small proportions of clay. Yet a thin darker layer containing plant remains is found at 5.2 m bsl and seeds from this layer date back to about 2210 ± 30 BP (Beta-354940), or 370–199 cal BC(2σ) and corroborate the existence of younger channel infill material at such depths. Also indications for the Pleistocene surface such as the typical calcic horizon, which formed during stable conditions with soil formation (Wunderlich, 1989) are missing at this location due to incision of the channel. This calcic horizon can be found in the neighbouring core G2 at 4.75 m bsl and G1 shows the presence of gezira material upon which Buto was founded (Wunderlich, 1989) at about 2 m bsl and below.

1 Transect 2 leads SW–NE and crosses the settlement mound Kom el-Gir, which lies 5 km northeast of Buto. It reveals the typical

lithostratigraphy that Wunderlich (1989) uncovered displaying the occurrence of peat layers on top of the Pleistocene surface. Radiocarbon dates of this peat layer undertaken by Wunderlich (1989) provided a date of about 5930 ± 120 BP (HD10629-10561), or 5206–4503 cal BC(2σ). In the southwestern part of this transect at coring G10 these peat layers are replaced by channel deposits consisting of fine sand and clayey silt which occur below the clayey Nile alluvium between 2.5 and 5 m bsl. At 4–5.2 m bsl the sandy material contains many ceramic fragments, mollusk shells and carbonate concretions that concentrate at this depth. Several of these ceramic fragments can be assigned to the Ptolemaic and Roman periods (332 BC – AD 400). The fragments measure on average 1 cm in diameter; one Ptolemaic sherd at 5.1 m bsl has a diameter of about 4 cm. The concentration of these larger fragments suggest this being the channel bed but a clear boundary to the underlying fine sandy material cannot be drawn. But in general no ceramic fragments occur within this sandy layer below. Between 7 and 8 m bsl the fine sandy material contains thin organic enriched layers. At location G13 a smaller channel reaching down to about 2 m bsl lies above the peat layers below. It is filled with non-diagnostic ceramic fragments, mollusk shells and shows organic enriched silty material at 0 m asl. More significant is the channel uncovered directly next to the eastern edge of Kom el-Gir (G21) that reaches down to about 6 m bsl and cuts through the older peat layers that were eroded at this location. The channel infill of loamy fine sand shows concentrations of ceramic fragments as well as mollusk shells at two different sections from 2 to 3 m bsl and from 4 to 5.5 m bsl. In this lowermost section, charcoal fragments and plant roots appear whereas the upper section shows thin organic layers. Also many ceramic fragments occur at the surface reaching down to about 2 m bsl. These were eroded at the adjacent tell and redeposited as colluvial material in the surroundings of Kom el-Gir.

Transect 3 is located east of Kom el-Gir and crosses the Bahr Nashart depression in a W–E direction. The western half of this transect reveals the typical lithostratigraphy of two peat layers intercalated in silty clayey Holocene Nile alluvium and overlying the Pleistocene surface (cf. Wunderlich, 1989). According to Wunderlich (1989) the lowermost peat layer at about 3–5 m bsl dates back to 4490 ± 150 BP (HD10628-10558), or 3634–2874 cal BC(2σ) and the thinner layer above (2 m bsl) to 2765 ± 80 BP (HD10627-10557), or 1120–798 cal BC(2σ) (cf. Wunderlich, 1989). These layers appear in all corings of the western half of the study area west of G18. Additionally, between 1.5 m asl and 1 m bsl of these corings show clayey material with intercalated graded fine sandy layers possibly resulting from flood events. The corings of the eastern half including G18 are almost entirely made up of coarser material alternating between fine and coarse sand partly containing gravels. Layers containing gravels occur in corings G18 at 5.8 m and 6.4 m bsl, in G19 at 3.4 m and G20 at 0.2 m bsl. The coarse material represents channel deposits of a former prominent channel. In G33 a rounded ceramic fragment occurred at 4.3 m bsl. Peat material also occurs in this eastern part, specifically in corings G19 and G33 between 4.75 and 5.25 m bsl. But here the peat appears to be reworked and mixed with sand when the channel cut into the peat layers. As a consequence, activity and incision of the river is younger than the reworked peat material included within the channel sediments. In the eastern reach of the transect, fine grained material is restricted to a layer close to the surface that increases in thickness from only 0.5 m (G20) to 3 m (G18) westwards.

Transect 4 lacks any indications for deeply incised channels and reveals an intact horizontally layered sequence with the Pleistocene surface at about 6 m bsl and a layer of peat lying above with 2 m in thickness. Northwards the brackish environment in which the peat was formed (Wunderlich, 1989; Wunderlich and Ginau, 2016) prevailed longer causing the deposition of thicker peat layers than further south. The peat is overlain by clay deposits and only at very few locations in the profile do we find sand or fine sand layers originating from overbank floodings or crevasse events.

Transect 5 lies further in the south and does not cut through the area where the peat formed in the early to mid Holocene. In this transect two channels can be verified in corings G26 and G23. The channel at coring G26 reaches down to about 10.7 m bsl or more as the base could not be found. Below 3.5 m bsl coarse sand with fine-sand layers appear and gravels occur at 6.8 and 8.1 m bsl . Additionally, the sandy layers show segments enriched with heavy minerals. Similar findings occur in coring G23 below 3.5 m bsl with gravels at 6.5 m bsl. The channel bed was not reached at this location. Both channels are topped by organically enriched alluvial clays for which datings cannot be provided. At G24 we also find organically enriched material intermixed with sand at 2 m bsl.

Transect 6 lies further away in the north west of the study area and crosses the elevated channels that are observable in the TanDEM-X elevation data. Underneath the elevated structure at coring G37 a deeply incised channel was identified. The associated levees were leveled to different heights as described in the previous section. The channel fill reaches down to about 13 m bsl or more and cuts through the peat layers, which are present in the other corings of this transect. Also here a clear channel base could not be found. This elevated channel shows alluvial clay enriched with a downward increasing share of fine sand or intercalated sequences of differently sized sand. Gravels occur at 9.25, 11.75 and larger ones at 12.5 m bsl. Additionally, thin organic layers appear at 8.75 and between 10 and 10.75 m bsl. Mollusk shells occur between 8.5 and 9 m bsl and 9 and 9.5 m bsl. Radiocarbon ages of shells from these two layers date back to 2190 ± 30 BP (Beta-450880), or 361–179 cal BC(2σ) for the upper layer and 3760 ± 30 BP (Beta-450879), or 2286–2044 cal BC(2σ) for the lower layer. Very likely the younger date resembles the age of this channel and the much older shell fragment was reworked and redeposited. The other corings show the typical stratigraphy as described for transect 4. The Pleistocene surface lies at about 6 m bsl and is slightly incised to the east. Except for corings G37 and G38, mollusks occur at different depths and especially at the top or base of the peat layer which is present between 4 and 6 m bsl approximately.

In Fig. 9 the channels (see Roman numerals in Fig. 8) are compared according to the findings of the field documentation. On the basis of the work of Tronchère et al. (2012) and our own observations, parameters of the field documentation are chosen that help to differentiate between high and low energy watercourses. Especially parameters such as grain size, amount of ceramic fragments, organic layers and the layering of the sediments help to answer the question whether we are dealing with slack water and low energy conditions such as in canals or oxbows or high energy regimes, such as natural rivers.

The classification presented in Fig. 9 shows that channels VI, II, V and IV can be more likely attributed to the low energy domain, whereas channels VII, III, IX, VIII to high energy watercourses. Channel VI also shows characteristics of a natural stream as it is filled with coarser material, but this probably originates from Kom el-Gir which is founded on coarser grained levees. A similar relation can be drawn for the channel west of Buto (I) as Buto is located on top of a sandy gezira. Generally the channel west of Buto shows characteristics of both classes of watercourses. On the one hand, it comprises a great deal of ceramic fragments, and on the other hand alternations of sandy sediment sequences are visible that show higher contents of organic matter compared to the natural rivers.

Tronchère et al. (2012) also made use of such parameters to discriminate between river and fluvial harbor sediments and they observed a slowing down of the water regime and anthropoisation of the harbor basins resulting in the transformation of these deposits. According to Tronchère et al. (2012) these deposits are enriched with organic matter and show fine grainsizes due to a low energy flow regime, high magnetic susceptibilities, many mollusk fragments and are littered with potshards. Additionally, the layering is an important discriminating factor as the fluvial regime of the Nile river constantly changes and therefore layers with different grainsizes, graded sequences and discordances alternate in natural rivers. Low energy

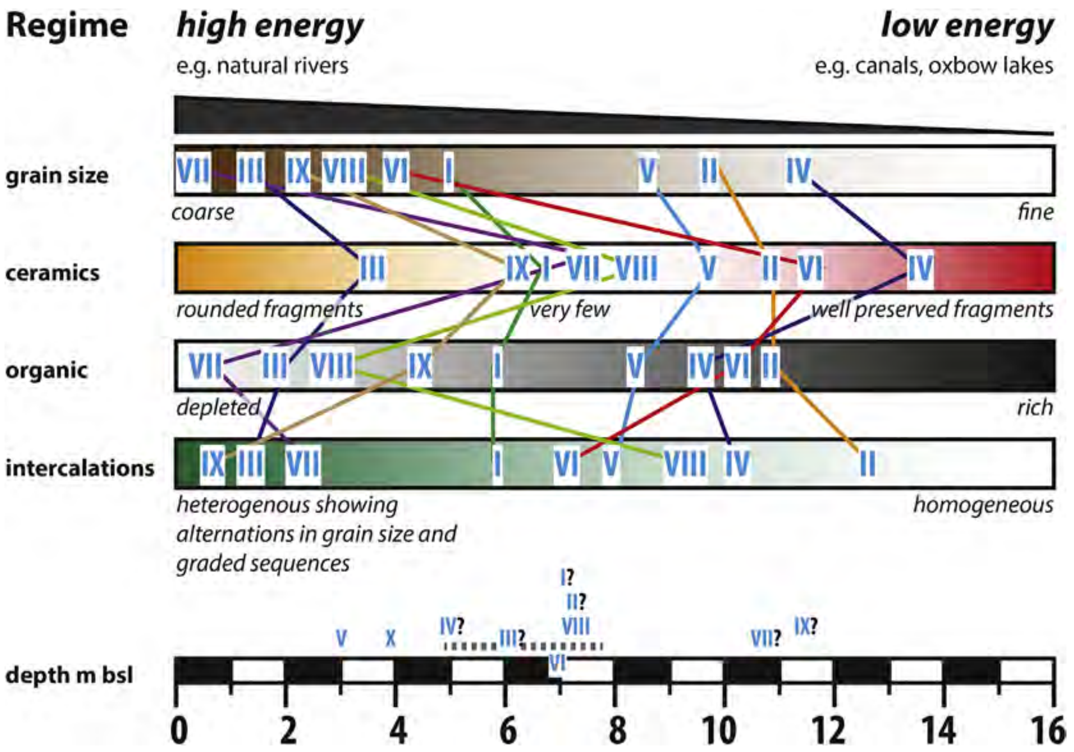

Fig. 9. Categorization of channels – Channels are compared according to the results of the field documentation. Individual parameters are only roughly differentiated and results of the channels are compared relatively to each other.

watercourses such as man-made canals are controlled waterways and the magnitude of change of their flow regime is weaker and sediments appear more homogeneous. On the one hand, changes in grain size are harder to recognize and on the other hand, biological mixing processes can be higher in canals as mollusks and plants are more abundant in these environments.

Results of geochemical analyses on the sample material hint at significant differences between sediments from low or high energy watercourses. PXRF results illustrated with the help of boxplot diagrams in Fig. 10, show significant differences between rivers with high stream velocities and the low energy watercourses. In general, the river sediments are bleached and sandy, therefore ion absorption is low and the river sediments contain only minute amounts of elements compared to the fine grained sediments of low energy regimes. In conclusion, the element contents reflect the grain size of the material. Such effects should diminish if ratios of these elements are plotted. The data distribution of the ratios shows that canals and rivers might show similar values, but the canals show very distinct ratios that do not fluctuate as much as the values of the river sediments, which cover a wide span of values. This corroborates the heterogenous nature of the river sediments consisting of an alternation of different layers showing different compositions. Looking in detail at the ratios we see that such a discrepancy is especially high for Al/Ti and Cu/Zn ratios. Both Al and Ti are extremely resistant to weathering (Wayne Nesbitt and Markovics, 1997; Wei et al., 2003) and tend to reflect the supply of siliciclastic materials of fluvial or aeolian origin (Arz et al., 1998; Chen et al., 2011; Jansen et al., 1998). Ratios of these two elements describe changes in the habitus of the transported sediments of the rivers such as density differences in siliciclastic materials derived from fluvial or Aeolian sources (Chen et al., 2013). In the case of the natural watercourses, the

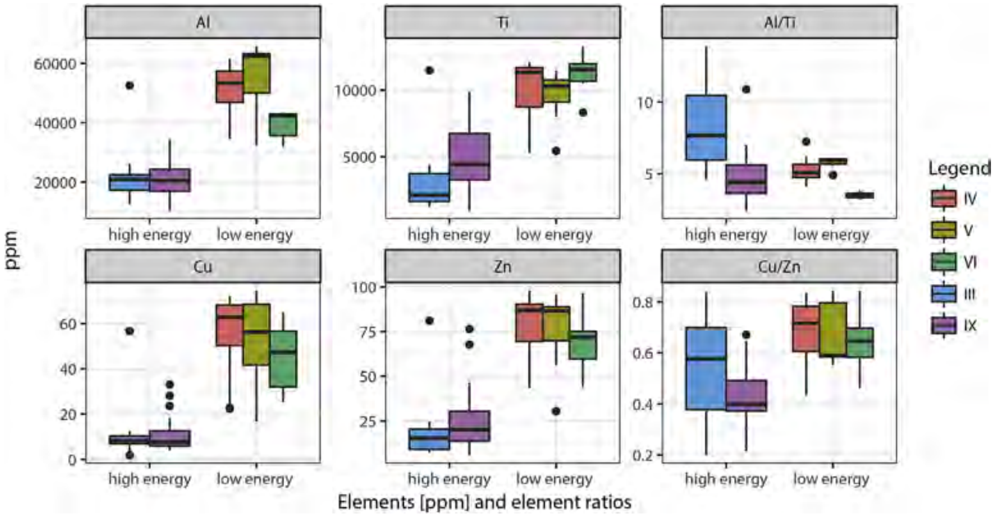

Fig. 10. Data distribution between channels with different energy domains – Boxplot diagrams showing the data distribution of pXRF results from high and low energy watercourses with the following frequencies: IV n = 18,V n = 7, VI n = 10, III n = 13, IX n = 26. Results for different elements (Al,Ti,Cu,Zn) and element ratios (Al/Ti,Cu/Zn) are presented.

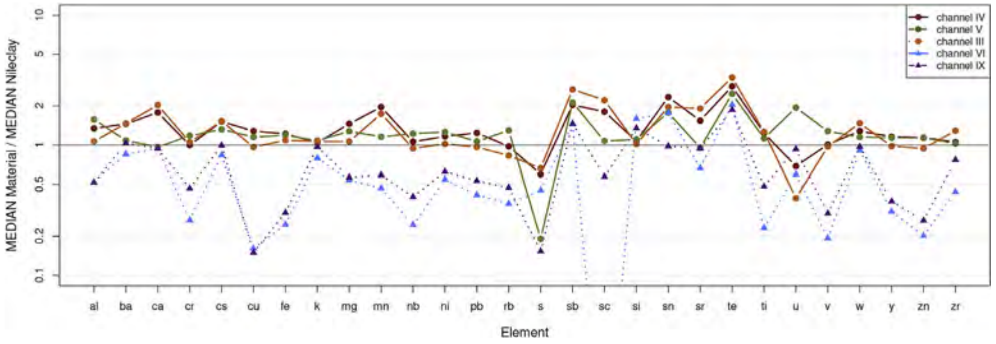

Fig. 11. Spiderplot showing pXRF profiles – A selection of elements is plotted along the x-axis against the ratio of the element to the concentration of reference Nile material. The element contents of the reference Nile material as well as the different channels are calculated as median element values. Additionally, samples representing the reference Nile material are spatially selected as fine grained material lying outside a 600 m radius of ancient settlements and within depths between 3 and 10 m bsl. The elements have been ordered alphabetically (according to chemical abbreviation from Ag to Zn).

sediments constantly varied with flooding events and changes in the Nile basin and, therefore, Ti/Al ratios show a wide span of values compared to the small data range of the canals, caused by the relatively stable sedimentary conditions. Similar findings can be shown for the Cu/Zn ratio, where we also notice this significantly higher data range for the Cu/Zn ratio in the case of the natural watercourses. But it is also interesting to notice that this difference is not so obvious in man made canals, which also show a wider range of values. This might relate to the fact that copper and zinc played an important role in Ptolemaic and Roman times (Healy, 1978) to which the man made canals can be dated. These man made canals lie close to the settlements and are connected with them. Therefore, they might be influenced by these elements, which explains the great variation, especially of copper, within the canal sediments.

Fig. 11 plots a selection of elements along the x-axis against the ratio of the element to the concentration of the same element in reference to Nile clay material. According to Reimann (2008) this technique was developed to compare the distribution of Rare Earth Elements between different rock types. The reference Nile clay material has been selected according to a spatial selection from the pXRF measurements. Specifically it is the clayey material outside a 600 m radius of the settlements found in depths between 3 and 10 m bsl in corings lacking any indications for channels. This subset allows us to exclude the modernly affected surface and material older than the Holocene era. In this plot, distinctive changes between low energy (curves with dots and continuous lines) and high energy watercourses (triangles with dotted lines) manifest themselves. Generally sediments in natural watercourses are depleted in many elements compared to the Nile clay material and show high changes between different elements. The sediments from low energy watercourses are slightly enriched with a wide variety of elements and of interest are higher contents of Al, Ca, Cu, Mn and Sn as they reveal information on the anthropogenic influence. Looking at the distribution of these low energy watercourses on the map we see that they appear east of the settlement sites Kom el-Gir and Buto and between these sites whereas natural river channels were identified in the Bahr Nashart depression and north of Buto, where the elevated channels can be traced in the elevation data. Most of the channels reach down to depths of about 6–8 m bsl. Deeper channels (VII, IX) show depths of about 11 m bsl and occur in transect 5 crossing the Bahr Nashart depression and further to the north below the larger elevated channel structures (IX). Channel VII is an older channel that is overlain by a thin peat layer and shows neither ceramic fragments nor thick layers of sand. Channel IX, situated within the elevated levee north west of Sidi Salem, cuts very deep into the sediments and shows thick layers of sand. It is important to emphasize that the depth of this channel is mainly shaped by flooding events. Such rhythmic events convey the biggest part of the flood waters. During such events the river cuts through the sediments well below its erosional base, which explains the greater depth of this channel. This over-deepening of the river beds in the Nile delta is first mentioned in Butzer (1976). The fact that most channels show similar depths suggests that they belonged to the same river system and were set to the same erosional basis of the main river or were part of the finely ramified subdelta that manifests itself on the larger scale. Additionally, channel activity in channels I,II,IV, IX can be dated, based on a combination of radiocarbon dates and pottery dating, to Greek and Roman times. For the activity of channel III we can establish a terminus postquem of 832 BC or younger as the channel eroded into the peat layers of coring P37 which Wunderlich (1989) dated to 4490 ± 150 BP (HD10628-10558) or 3634–2874 cal BC(2σ) for the upper peat layer and 2765 ± 80 BP (HD10627-10557) or 1120–798 cal BC(2σ). In essence, the existence of these interconnected channels fall together with the strong period of settlement growth in the Ptolemaic, Roman and late Roman periods (4th c BC – 7th c AD, (Wilson and Grigoropoulos, 2009; Wilson, 2012a, 2017; Schiestl, 2012b; Schiestl and Rosenow, 2016). But as the settlements were erected on tall levees, these watercourses already existed previously and the area was later colonized.

All settlements were situated along natural rivers. To this natural fluvial network artificial canals are added or old river branches were used. They all show depths similar to the natural waterways they were connected with. These are primarily in immediate vicinity of settlements, e.g. Buto and Kom el-Gir, as well as, in one case, between those settlements. The function of these canals is not yet clear. Possibly they served as branch canals between settlements and the adjacent natural watercourses and as connections between sites. Such infrastructural measures could reflect adaptive practices in a dynamic fluvial landscape, which is characterized by meandering courses.

5. Conclusion

Archaeological investigations aiming at the localization and dating of ancient settlements in the northwestern Nile delta showed that this area was widely settled. Based on a linear distribution of mainly Roman and late Roman settlements, the existence of a single defunct Nile branch was suggested. In the present study an interdisciplinary archaeological and geoscientific approach has been applied to verify this hypothesis. The approach views landscape and ancient settlements of the delta at two different scales: a large scale that incorporates archaeological prospection as well as satellite data, maps and elevation data, and at a smaller scale we focus on different sedimentological transects crossing archaeological sites and landscape units in the study area to prove and to refine results gained on the landscape scale. Our new results show that in the study area the situation is much more complicated and diverse. Single Nile branches could be traced with great reliability but these branches together form a subdelta with ramified larger and smaller branches whose elevated levees are merged and thus allow for a more dispersed settlement pattern. This larger perspective on the northwestern delta was realised using historic maps, satellite imagery and modern satellite elevation data from the TanDEM-X satellite configuration, allowing for an integrative view of the whole landscape. Especially modern satellite elevation data from the TanDEM-X satellite configuration of the German Aerospace Center reveals many incised and elevated linear structures in the flat delta and the subdelta. Detailed sedimentological research gave evidence that this subdelta formed prior to Ptolemaic and Roman times, and the levees and watercourses formed the basis for human settlements in the area studied. Remarkably, a remote sensing approach of the authors (Ginau et al., 2017) dealing with NDVI time series showed the high fertility of the levee sediments and their positive influence against soil salinization compared to the former remote and low lying swampy areas. This further qualifies levees as targets for the formation of settlements as they do not only offer a safe ground but also ground for the production of food.

Furthermore, with a closer look at the different sedimentological transects in the area under study and the channels we sampled, it is possible to gain a better understanding of different landscape units. We sampled elevated levees visible in the elevation map and we identified different categories of channels within the transects. Our field results and geochemical pXRF measurements on sample material of these channels allow us to discriminate between high and low energy watercourses. In the case of the channels next to settlements, such as Buto and Kom el-Gir, it is suggested that these sites were connected via canals with the larger watercourses. Moreover, these sedimentological transects crossing the northwestern Nile delta show the complex and changing nature of the Holocene delta landscape and its floodplain deposits. As described in the introduction, it is especially a result of the changing river patterns and processes such as crevassing and overbank flooding (see Aslan and Autin, 1999; Aslan et al., 2005) that lead to such complex sediment patterns and which very likely were responsible for the termination of this subdelta. An avulsion event upstream could have changed the entire network of watercourses and rendered this subdelta inactive.

The integration of both scales into this study supported new insights and made us reverse our original hypothesis of a single defunct Nile branch that could explain the linear pattern of settlement sites. The Tandem-X DEM opens fundamentally new possibilities to investigate the ancient delta landscape and a first reconstruction of a fluvial network with associated settlements can be presented. On the larger scale artificial channels were identified and they are the result of adaptive practices of the settlements in a dynamic fluvial landscape.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2018.04.047.

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