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Authors

Koopman, Annelies
Kluiving, Sjoerd
Holdaway, Simon
et al.

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The Effects of Holocene Landscape Changes on the Formation of the Archaeological Record in the Fayum Basin, Egypt

Annelies Koopman,[1],* Sjoerd Kluiving,[1,2,3] Simon Holdaway,[4] and Willeke Wendrich[5]

[1]Department of Geo- and Bioarchaeology, Faculty of Earth and Life Sciences, VU University Amsterdam, Amsterdam, The Netherlands
[2]Faculty of Humanities, Department of Archaeology, Ancient History of Mediterranean Studies and Near Eastern Studies, VU University Amsterdam, Amsterdam, The Netherlands
[3]Department of Earth Sciences, Cluster Earth and Climate, Faculty of Earth and Life Sciences, VU University Amsterdam, Amsterdam, The Netherlands
[4]Department of Anthropology, School of Social Sciences, University of Auckland, Auckland, New Zealand
[5]Department of Near Eastern Languages and Cultures, University of California, Los Angeles, California

Correspondence
*Corresponding author; E-mail:
koopman.annelies@gmail.com

Geoarchaeological research was performed across an archaeological landscape along the hyperarid northern paleoshores of the modern Lake Qarun, Fayum Basin, Egypt. Objectives were to record sedimentary variability and to consider the correlation between the paleoenvironmental interpretations of these sedimentary data and the observed archaeological record dated to the early and mid-Holocene. Our approach combines hand-drilling and stratigraphic descriptions with detailed studies of sediments (grain size analysis, analyses of $CaCO_3$, and organic matter contents), densities of stone artifacts and bones, and chronometric data from associated contexts (AMS ^{14}C dates on charcoal from hearths). Analysis of deposits indicates initiation of lake deposition, reworking of lake deposits, and subsequent accumulation of wind-blown deposits occurred prior to the deposition of archaeological materials. Correlations between sediment and the archaeological deposits indicate a different use of areas covered by relatively coarse-grained sediment (sand) compared to areas where relatively fine-grained deposits are exposed (clay and silt). Reassessment of the associations between archaeological materials and sediments in the Fayum Basin is required to improve knowledge of the interrelationships between the Nile flood history, regional climatic changes, oscillations in levels of paleo-Lake Qarun, compared to the chronology of human occupation in the Fayum Basin. © 2015 Wiley Periodicals, Inc.

INTRODUCTION

The sedimentary record of the Fayum Basin, northern Egypt, provides evidence for periods of wind and water erosion that led to the development of a patchwork of hard land surfaces of different ages on which abundant archaeological material have been preserved. The archaeological remains, mostly stone artifacts, pottery, faunal remains, and associated hearths, are distributed in variable densities at different elevations along the hyperarid northern Fayum paleobasins of the modern Lake Qarun. In the past, these remains have been used to reconstruct paleolevels of Lake Qarun during past human occupation phases (e.g., Caton-Thompson & Gardner, 1934; Said et al., 1972; Wendorf & Schild, 1976; Kozlowski, 1983; Ginter & Kozlowski, 1986; Hassan, 1986; Kozlowski &

Ginter, 1993). However, despite this intensive research, there is a lack of consensus on the nature of the relationship between environmental change, particularly in relation to lake level changes, and early to mid-Holocene settlement (e.g., Phillipps et al., 2012). Among the many reasons for this is a lack of understanding of the geomorphological processes that have exposed the archaeological material at today's surface and how these relate to any proposed paleolake level changes.

The aims of this paper are therefore to document geomorphic processes, sedimentary environments, and sources responsible for the spatial-temporal variability of sediments within a specific region of the north shore where surface archaeological materials are abundant, and to consider the relationship between the

Figure 1 Map of the Fayum Basin, with the modern Lake Qarun, in Egypt, to the west of the modern Nile Valley. The study area is located within the desert northeast of Lake Qarun (between 36R 29.0476 m E 3274887 m N; 29.0202 m E 32.74229 m N and 36R 29.0754 m E 32.74664 m N; 28.9666 m E 32.7463 m N), and to the northeast of X Basin (Caton-Thompson & Gardner, 1934), a paleobasin of Lake Qarun. Arrows indicate the directions of Nile flow within the Nile Valley and into the Fayum Depression (modified from Keatings et al., 2010).
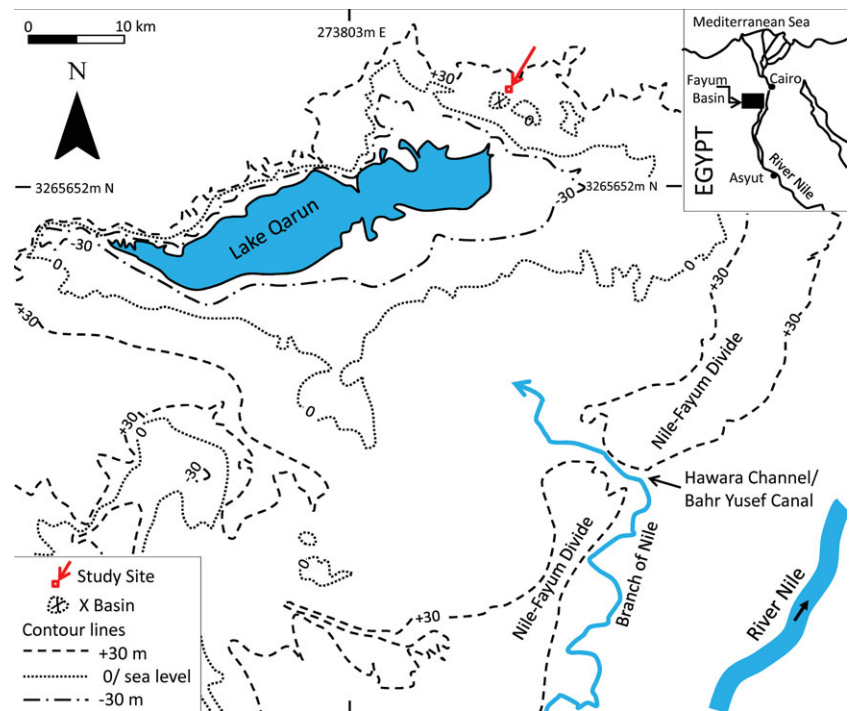
paleoenvironmental interpretations of these sedimentary data and the recorded archaeological evidence dating to the early and mid-Holocene.

We use a geoarchaeological approach adapted specifically to arid environments (Fanning et al., 2007, 2008, 2009; Holdaway & Fanning, 2014) to understand the nature of erosion and aggradation that shape today's desert land surfaces, and therefore how these processes impact on the visibility of the archaeological record. We combine detailed topographic survey with studies on sediments (grain size analysis, thermogravimetrical analyses (TGA)) and artifact concentrations, including chronometric data from secure archaeological contexts (AMS ^{14}C dates on charcoal from hearths). Our results lead to new insights into the timing of landscape changes that shape the sedimentary record of the study area and affect the spatial and temporal discontinuity in the preservation, exposure, and visibility of the archaeological record. We use this information to comment on the chronology of paleolake level fluctuations in the Fayum Basin since the early Holocene.

STUDY AREA

Geological and Environmental Background

The Fayum Basin is a circular depression formed in the limestone plateau of the Western Desert, Egypt (Figure 1) that obtained its current shape from tectonic subsidence that terminated in the Late Eocene (Said, 1990, 1993; Dolson et al., 2002). Rock units exposed in the greater part of the depression consist largely of sandstones, shales, and limestones that accumulated during the Middle and Upper Eocene, and Oligocene (Issawi, 1976; Dolson et al., 2002). Pleistocene deposits are assumed to be of fluvial origin, derived from natural breaks in the levee of several Nile ancestors, which repeatedly caused flooding of the basin (Said et al., 1972; Wendorf & Schild, 1976; Said, 1993). From the early Holocene onwards, Nile floodwaters are thought to have repeatedly reached the height of the channel cut in the Nile-Fayum limestone divide (Figure 1), and transformed the depression into a series of high, freshwater paleolakes with fluctuating water levels (Said, 1993). On the north shore these waters likely filled a series of basins described by Caton-Thompson and Gardner (1934) that are deepest to the west of our study region and become progressively shallower to the east (Figure 1).

The modern, terminal saline Lake (Birket) Qarun (Figure 1) is the shrunken remnant of the large freshwater paleolakes, currently about 40 km in length from east to west and 7 km in breadth at its widest point (Fathi & Flower, 2005). Maximum water depth ranges between 8 and 9 m, the present surface water elevation fluctuates between 43 and 45 m below current sea level, while the salinity of the lake today is near that of seawater

(Said, 1990; Fathi & Flower, 2005; Flower et al., 2006; Hussein et al., 2008; Foster et al., 2008). Modern cultivation extends to the southern shore of Lake Qarun, while the northern lake margin marks the start of the Western Desert, where the study area is located. Oscillations in paleolake levels in the Fayum Depression from the early Holocene onwards are thought to have been strongly influenced by seasonal as well as interannual factors, such as the Nile summer flood, local precipitation, and intra-annual Nile flood variations, combined with (human induced) hydrological control of Nile inflow instigated by Middle Kingdom Pharaohs since the Twelfth Dynasty from *ca*. 2000 B.C.E. (Wendorf & Schild, 1976; Hassan, 1986, 1997; Flower et al., 2006, 2012; Foster et al., 2008; Baioumy et al., 2010; Hassan et al., 2012).

Archaeological Context

Variable concentrations of lithics, grinding stones, pottery, faunal remains, and hearths are scattered across the desert surfaces northeast of the Lake Qarun basins (Figure 1) and indicate human occupation during the early and mid-Holocene. The archaeological remains have previously been related to the Epi/Terminal Paleolithic "Qarunian Culture"' (7500–6000 B.C.E.) as well as to the Neolithic "Fayum A Culture" (5200–4200 B.C.E.) (Caton-Thompson & Gardner, 1934; Wendorf & Schild, 1976; Wenke et al., 1988; Shirai, 2010). However, recent research has shown that this division between cultures does not do justice to the temporal and spatial distribution of the remains that show changes over a much longer period than originally thought (Wendrich, Taylor, & Southon, 2010; Phillipps et al., 2012).

The subsistence base throughout the early Holocene focused on lacustrine resources but also involved the hunting of wild game. Based on the analyses of animal bone assemblages from both surficial and stratified archaeological deposits, fish species predominate numerically and are accompanied by bird remains, and to a lesser extent wild mammals (e.g., hippopotamus, gazelle) (Wenke et al., 1988; Linseele et al., 2014). During later occupations hunting and fishing were supplemented with the use of domestic grain as witnessed by carbonized Emmer wheat and barley in hearth contexts, storage pits lined with basketry, which also contained domesticated Emmer wheat and barley, dated to approximately 5000 B.C.E. (Caton-Thompson & Gardner, 1934; Wendrich & Cappers, 2005) and domestic sheep/goat, cattle, and pig (Linseele et al., 2014). This is an example of low-level food production societies (Smith, 2001; Holdaway, Wendrich & Phillipps, 2010), in which domestic species added to, rather than replaced existing subsistence strategies dependent on wild food resources.

Description of Study Area

The lithological and sedimentological investigations reported here were performed approximately 5 km to the northeast of the modern northeastern shore of Lake Qarun (Figure 1). The study area, located in a desert region that was subsequently destroyed by cultivation and more recently by road construction, measures about 1 km east–west by 500 m north–south. The surface of the study area slopes downwards from approximately 20 masl in the northeast to 3 masl in the southwest, from where it continues to slope downwards in a southwestern direction toward the modern Lake Qarun.

The study area comprises E29H1 (Said et al., 1972; Wendorf & Schild, 1976), originally described as "the unnamed Fayum B site on the edge of X Basin" (Caton-Thompson & Gardner, 1934). The surface of the area contained scatters of stone artifacts and animal bones, with isolated hearths, visible as concentrations of fire-cracked stones that in some cases protect charcoal.

METHODS

Field Analysis and Sampling

The flanks of contemporary irrigation channels and bulldozer scars were investigated and described at 43 sediment outcrops to a maximum depth of 1.60 m below the surface. In addition, 38 cores were hand drilled with Dutch and Riverside Augers (ø7 cm) from the surface in between the irrigation ditches (Figure 2). The cores were all relatively shallow because of the heavy induration of sediment in the study area (to a maximum depth beneath the surface of 1.90 m). Lithological descriptions followed distinct stratigraphic parameters, such as lithology, texture, inclusions, and pedogenic features (following the International Commission on Stratigraphy). Munsell soil color charts were used to determine color of sediment. Sediment sampling was carried out by hand trowel from the inside of lithologically distinguished layers along a width of approximately 2–5 cm (207 sediment samples from 53 cores and sediment outcrops). Northing, Easting and height coordinates of cores and sediment outcrops were recorded in UTM, as was the surface morphology to construct a digital elevation model (using a Total Station, Leica 1200), with a maximum accuracy of *ca*. 1 cm horizontal and vertical.

In the northeast of the study area, across three irrigation fields, the locations of individual archaeological materials were measured to quantify the density of materials (Figure 2). Areas around these three fields were already cultivated and were not suitable for archaeological survey. The most abundant materials were stone artifacts
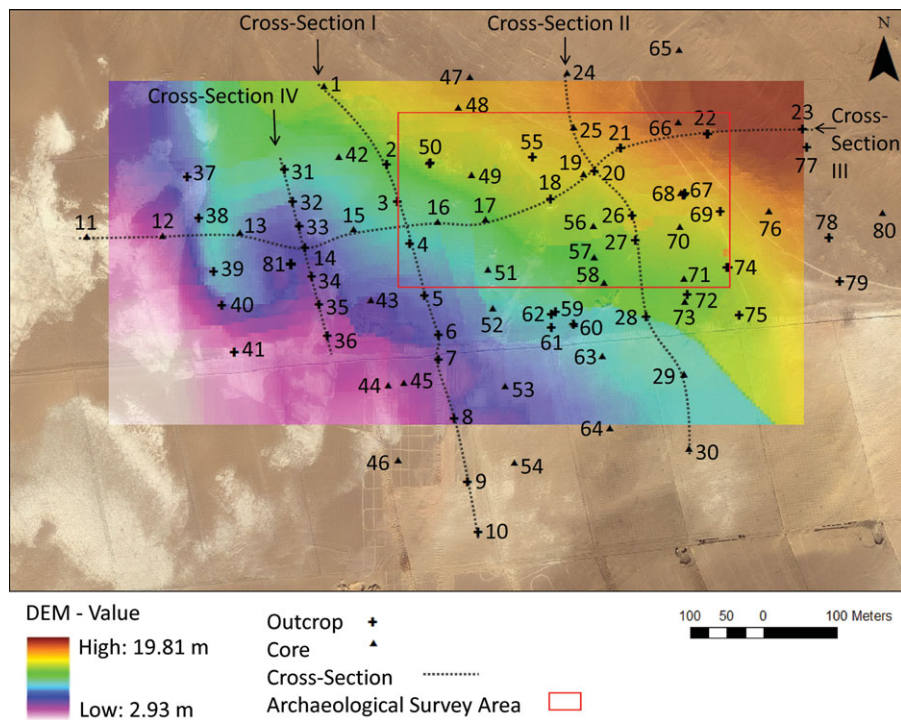
Figure 2 Satellite image showing the extent of the area investigated in this study, including the archaeological survey area in the northeast. The surface morphology within the study area is visualized by a digital elevation model. The spatial distribution of the investigated sediment outcrops ($n = 43$), cores ($n = 38$), and the positions of cross-sections I–IV are shown. Clearly visible on the satellite image are also the irrigation fields, bordered by irrigation channels running north-northwest/ south-southeast, as well as the white hue of the sediment exposed in the southwest.

(just under 80,000), followed by bone fragments (just under 14,000), while hearths are much less common (38). The density calculations on recorded numbers of archaeological materials (lithics and bones) were performed in ArcGIS 9.3, and are expressed in numbers per square meter.

Sediment Analysis

Samples were procured under an Egyptian Mining Resources Authority (EMRA). Analyses were performed at the Sediment Analyses Laboratory of the Faculty of Earth and Life Sciences of the VU University Amsterdam, the Netherlands (2009). Weight percentages of organic matter (OM) and calcium carbonate ($CaCO_3$) in 197 sediment samples were determined by TGA (TGA-601 Leco Corporation Germany). All sediment samples ($n = 207$) were analyzed for grain size distribution with a Fritsch A22 laser-diffraction particle sizer. Classification of the sand fraction followed the Udden-Wentworth grain size scale (63 μm to 2 mm) (Udden 1914; Wentworth 1922). The clay (<8 μm) and silt (8–63 μm) fractions follow the classification of Konert and Vandenberghe (1997).

Chronology

Under an EMRA, charcoal samples were collected from the remains of nine hearths in modern surface contexts, and dated by AMS radiocarbon in the Keck Carbon Cycle AMS Laboratory at the Department of Earth System Science of the University of California, Irvine, Los Angeles. Calibrations (CALIB 5.0.2) were performed using the Reimer et al. (2004) data set (2 sigma criteria) (Table I).

RESULTS AND INTERPRETATION

Facies Distribution

The lithostratigraphy, as observed in sediment outcrops and cores (Figure 2), provides evidence for the preservation of five types of sedimentary rocks and soft sedimentary facies, interpreted as bedrock (1a-d), fluvial (2a-b), lacustrine (3a-h), reworked lacustrine (4a-c), and aeolian deposits (5a-b) (Figures 3 and 4). Interpretations of depositional environments and processes are based on records of stratigraphic features, variations in lithology, color, texture, sedimentary structures, inclusions (e.g., molluscs and botanical remains), pedogenic features (e.g.,

Table I The radiocarbon determinations of nine charcoal samples obtained from nine hearths at the study site, expressed in conventional ^{14}C yr BP, equivalent calibrated probability distributions in calendar/solar years (cal. yr B.C.E.), and midpoint of the calibrations in excess of 0.70 probability.

Unit	Hearth ID	Elevation of Hearths (masl)		Radiocarbon Determinations			
		Max	Min	Lab Code	^{14}C yr BP	Cal. Yr B.C.E. (2 Sigma Criteria: 95% Probability)	Midpoint of Calibrated Range (>0.70)
2a	149	7.33		UCIAMS-57222	7430 ± 20	6375–6240	6307.5 ± 67.5
	148	7.36	7.18	UCIAMS-57188	7305 ± 25	6225–6085	6155 ± 70
3f	105	11.44		UCIAMS-57215	8245 ± 20	7365–7170	7267.5 ± 97.5
	141	11.55	11.33	UCIAMS-57221	8245 ± 20	7345–7180	7262.5 ± 82.5
	115	12.84	12.70	UCIAMS-57217	8200 ± 20	7315–7125	7220 ± 95
	112	12.56	12.40	UCIAMS-57216	8175 ± 30	7305–7215 (0.26); 7200–7070 (0.74)	7135 ± 65
4b	140	11.55	11.49	UCIAMS-57220	8050 ± 20	7075–7025 (0.86); 6880–6840 (0.10)	7050 ± 25
5a	123	11.33	11.28	UCIAMS-57219	8235 ± 20	7340–7180	7260 ± 80
	122	11.56	11.48	UCIAMS-57218	8185 ± 20	7305–7215 (0.30); 7195–7080 (0.70)	7137.5 ± 57.5

Maximum and minimum elevations in masl for the hearths are included (some hearth data were not available).

deposits enriched in evaporitic minerals such as gypsum, halite), and differences in weight percentages of $CaCO_3$ and OM (Table II).

Bedrock

Four units of diagenetically altered sediments were observed in the southwest and northeast of the study area (1a-d: Figures 3 and 4). The units are subdivided into silty clay (1d), predominantly clayey silt (1a-c), with gravel, pebbles, and sand intercalations (1b). The sediments have predominantly yellowish brown hues, are heavily indurated, overall calcareous, with fossilized marine shells (1a-b), and abundant gypsum crystals that are intertwined and vertically oriented (1d). In the southwest, the rock units 1a-b are exposed at the present-day surface as dome-shaped morphological higher locations, with a surface lag of abundant fossilized marine oysters and marine corals, worked by wind erosion. Based on the high degree of compaction and inclusions (gypsum crystals and fossils) the sedimentary facies of 1a-d are interpreted as bedrock.
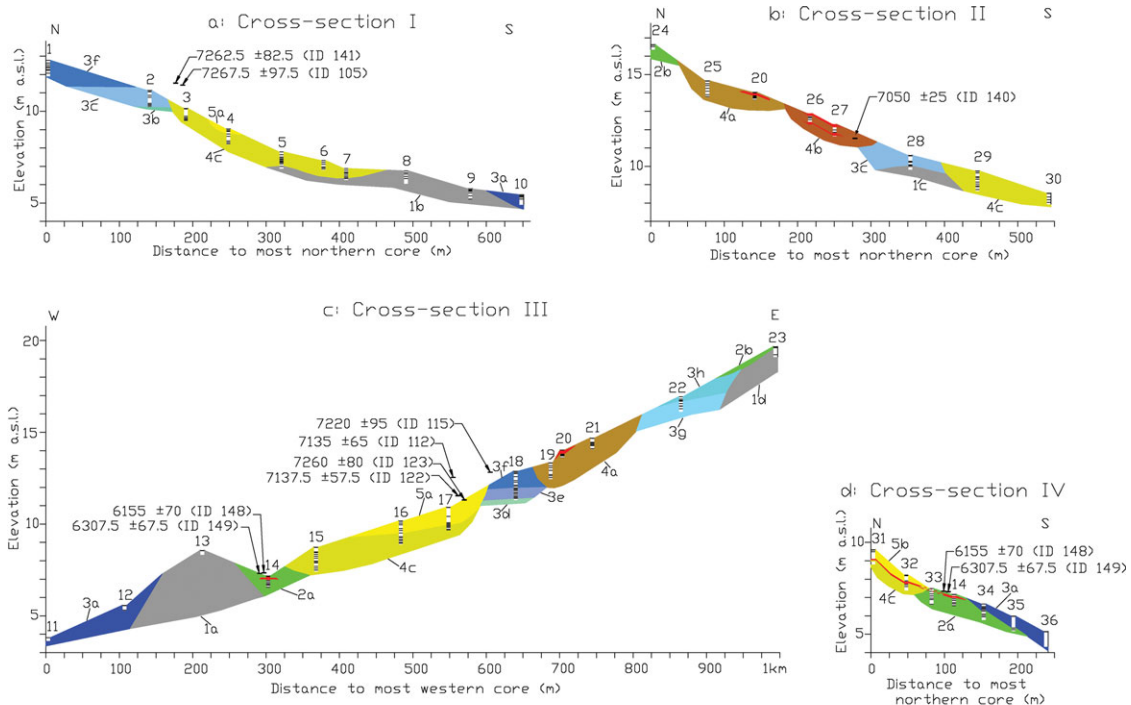
Fluvial Deposits

Two units, located in the lower southwest and northeast of the study area, are composed of medium grained, moderately to poorly sorted, poorly silty sand, with predominantly orange hues (2a-b: Figures 3 and 4). The sand is occasionally very calcareous and slightly organic. The deposits are low angular bedded, cross- to horizontally laminated, and occasionally indurated. The sediments contain occasionally salt crusts (2a), abundant gypseous

concretions and crystals (2a), as well as traces of fossilized shells (2b). Based on the relatively coarse texture and sedimentary structure (laminations, angular bedding), the sediments are interpreted as deposited in and along river courses. The fluvial deposits of units 2a and b unconformably overly the peneplained bedrock units (1a-d) in both the lower southwest and higher northeast parts of the study area (Figure 3).

Lacustrine Deposits

Eight units are composed of clayey silt or silty clay in the lower southwest (3a) and of fine- to medium-grained sands in the higher northeastern part of the study area (3b-h: Figures 3 and 4). All units have white to light gray and pale yellow hues. The silt and clay deposits (3a) are extremely calcareous, very indurated, with polygonal patterns of cracks where the unit is currently exposed (Figure 5a). The sand deposits (3b-h) are predominantly moderately sorted, not organic, relatively calcareous, and variably indurated. The sand units contain occasionally thin layers of abundant intact molluscs (3b, d), a calcium carbondate crust (3g), pronounced yellow oxidation stains in irregular to vertical orientations (3c, e), horizontal to wavy laminae (mm scale) (3c, e, f, h), as well as abundant root encrustations in exhumed hills in the north and northeast (3f, h, Figure 5b). Based on lithologies, hues, sedimentary structures, and inclusions all units 3a-h are interpreted to have formed within a lacustrine depositional environment.

The fine-grained texture and whitish hue of unit 3a indicates sediment deposited in the deeper parts of X Basin, similar to the unlaminated freshwater diatomite as

Figure 3 Interpretation models of cross-sections I–IV with the observed lithostratigraphic units, the locations of archaeological deposits other than lithics and hearths, and the radiocarbon ages determined on charcoal in hearths (a: cross-section I; b: cross-section II; c: cross-section III, d: cross-section IV). See Figure 2 for the locations of the cross sections.

described elsewhere (Aleem, 1958; Wendorf & Schild, 1976; Flower et al., 2012). The cracks formed inside the surface of unit 3a (Figure 5a) indicate subaerial conditions and prolonged dessication after lacustrine deposition (Nichols, 2006).

The coarser grained texture of units 3b-h, with distinct color mottling, laminae, and inclusions (molluscs, root casts) indicate deposition in the shallow parts of X Basin. Thin layers of abundant molluscs point to littoral accumulations that may form because of clastic sediment starvation or by winnowing of finer sediment, perhaps due to variations in basin water levels (Talbot & Allen, 1996:94). Distinct color mottling and the presence of a

calcium carbonate crust indicate switches between wet–dry conditions during the deposition of units 3c, e, and g. Pronounced horizontal to wavy laminae point to wave-dominated shore activity due to wind action during deposition of units 3c, e, f, and h. The presence of root casts (Figure 5b) provides evidence for vegetation along the X Basin shore during deposition of units 3f and h, as they are formed by secondary precipitation of calcium carbonate and/or calcium sulfate around plant roots (Glennie, 2005:179–181; Nichols, 2006:126; Hugget, 2007:15). The deepwater (3a) and shallow-water deposits (3b-h) bury the bedrock units (1a-d) and the fluvial deposits (2a-b) in the southwest (Figure 3).
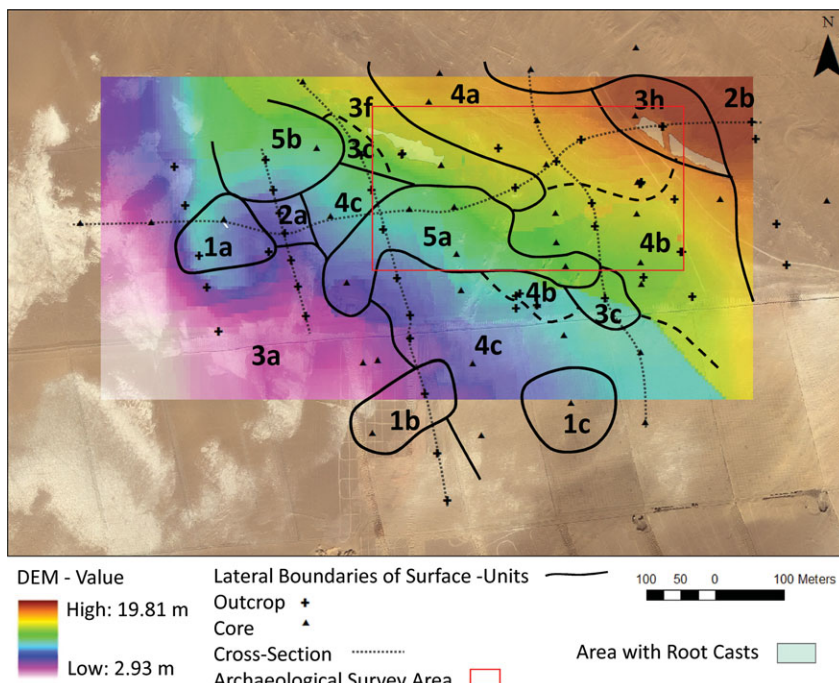
Figure 4 Lithostratigraphical units exposed at the present-day surface based on the available data.

Reworked Lacustrine Deposits

Three units are composed of very poorly sorted and heterogeneous mixtures of silt, clay, and sand, with gravel and/or pebbles (4a-c: Figures 3 and 4). The lithology of the deposits changes frequently along relatively short intervals, both vertically (<15 cm) and laterally (<1 m). The deposits have variable hues and the texture is mostly very fine (4a) to fine-grained sand (4b, c). The deposits have a predominantly high carbonate content, are slightly organic, variably indurated, and contain occasionally horizontal to wavy laminae (mm scale). The units contain abundant white concretions, most probably gypsum or calcium, as well as small gypsum crystals and much oxidation staining, most predominantly in the east (4b). Unit 4b also contains many patches of black silty deposits, both at the surface and in the shallow subsurface, with abundant fish bones and small molluscs, charred plant material, and vertically-oriented oxidized stripes (ca. 1 cm × 1–2 mm), occasionally surrounded by gypsum crystals.

Based on variation in lithologies, hues, and inclusions (mostly lacustrine), units 4a-c are interpreted as reworked lacustrine deposits. The presence of gravel and pebbles inside the deposits indicates action of ephemeral desert streams. The fine-grained deposits in the east of the study area, with an abundance of lacustrine biota as well as charred botanical material, point to the presence of subaqueous swampy conditions in the past, with

evidence of burning of vegetation under drier conditions. The pedogenic features observed (secondary precipitation of minerals, color mottling), most predominantly in the east (4b), indicate frequent changes between wet–dry conditions and oxidation of former plant roots. The reworked lacustrine deposits overly and/or cut the earlier lacustrine deposits (3a-h) at several locations (Figure 3).

Aeolian Deposits

Two units in the center and southwest of the study area are composed of moderately sorted, poorly silty sand, with a predominantly yellow hue (5a-b: Figures 3 and 4). The sand deposits are predominantly fine (5b) to medium (5a) grained, not calcareous and variably indurated, with some evidence for salt accumulations. Based on texture, hue, and minor calcium carbonate content the units are interpreted as wind-blown deposits. The aeolian deposits cover parts of the reworked lacustrine deposits in the southwest (4a-c: Figure 3).

The Archaeological Record

The archaeological record is located on the modern surface or in the shallow subsurface of units 2a, 3f, 4a-c, and 5a, with no traces of a deeply buried record

Table II Summary of the sedimentary characteristics of the lithostratigraphic units, moving from relative old (top of table) to young (bottom of table) based on superposition and cross-cutting relationships (* = base unexposed).

Unit	Core/ Outcrop	Max. Observed Thickness (cm)	Max. Observed Elevation (masl)	Lithology	Sorting	Color	Mode Sand Fraction (μm)	CaCO₃ tot (Weight %)	Organic Matter (Weight %)	Molluscs	Features and Other Inclusions	Interpretation
1 1a	13, 39, 81	25*	8.84	Clayey silt	-	Yellowish brown	-	58.72–79.12	0.33–2.26	-	10% fossilized marine shells	Bedrock
1b	5, 7–9, 46	72*	6.75	Clayey silt, with intercalations of gravel, pebbles, and sand	-	Yellowish brown	-	13.82–73.63	0.26–2.24	-	10% fossilized shells, gypsum crystal veins	
1c	64	30*	7.92	Very silty clay	-	Yellowish brown	-	-	-	-	-	
1d	23	54*	19.61	Silty clay, with sand lenses	-	Yellowish brown	-	0.99–3.70	0.61–2.51	-	10% gypsum crystals	
2 2a	14, 33–5	90*	7.48	Poorly silty sand	Moderately to poorly sorted	Deep yellow/ dull orange	250–500	0.19–41.47	0.19–1.49	<1%	10% gypsum crystals and concretions, a charred hollow culm of a herb	Fluvial deposits
2b	23-4, 65, 77–80	112	20.18	Poorly to moderately silty sand, with gravel and pebbles	Moderately to poorly sorted	Pale yellowish brown/ orange, light gray	250–500	0.19–4.81	0.14–0.28	<1%	<1% fossilized shells, <1% gypsum crystals and concretions, <1% salty concretions and bones	
3 3a	10-2, 34–8, 40–1, 44–5	200*	8.14	Clayey silt, silty clay	-	Light gray, white	-	4.45–61.53	0.21–1.68	<1%	-	Lake transgressive deposits
3b	2	2*	10.25	Poorly silty sand	Moderately sorted	Light gray, pale/ light yellow	125–250	1.98	0.22	>10%	-	
3c	2, 28	88	11.13	Poorly silty sand	Moderately to poorly sorted	Pale yellow, light gray	125–250	0.60–5.81	0.07–0.32	<1%	10% oxidation stains, laminae (mm scale)	
3d	18	12*	11.40	Poorly silty sand	Moderately sorted	Light gray, pale/ light yellow	250–500	-	-	>10%	<1% bone	
3e	18	47	11.87	Poorly to moderately silty sand	Very poorly sorted	Pale/ light yellow, light gray, olive brown	250–500	1.00–4.10	0.20–0.79	<1%	10% oxidation stains, laminae (mm scale), occ. 10% charcoal	
3f	1, 18, 49–50	110	13.19	Poorly silty sand	Moderately sorted	Pale/ light yellow, light gray	250–500	1.22–30.77	0.04–0.27	<1%	>10% root encrustations	

(Continued)

Table II Continued.

| Unit	Core/ Outcrop	Max. Observed Thickness (cm)	Max. Observed Elevation (masl)	Lithology	Sorting	Color	Mode Sand Fraction (μm)	CaCO$_3$ tot (Weight %)	Organic Matter (Weight %)	Molluscs	Features and Other Inclusions	Interpretation
3g	22, 66	60*	16.70	Poorly silty sand	Moderately sorted	Pale yellow, light gray	125–250	0.76–2.82	0.07–0.17	-	10% oxidations stains, CaCO$_3$ crust at upper boundary	
3h	22, 66	85	17.11	Poorly silty sand	Moderately sorted	Pale/ light yellow	250–500	0.55–3.08	0.06–0.15	<1%	>10% root encrustations	
4 4a	19-21, 25, 47, 48, 55, 67–8	100*	15.14	Heterogeneous: clayey silt, silty clay, with sand intercalations; poorly to moderately silty sand, with gravel	Very poorly sorted	Light/ pale yellow, light gray, white	63–125	1.11–27.47	0.18–1.80	<1%	<1% gypsum crystals, bones, and charcoal	Reworked lacustrine deposits
4b	26, 27, 56–7, 59–60, 62, 69–76	140	14.91	Heterogeneous: poorly to very silty/ clayey sand; sandy/ silty clay, with occ. gravel and pebbles	Very poorly sorted	Brown, blackish, grayish, yellowish	125–250	1.00–12.37	0.14–2.54	occ. 10% (intact and frag-mented)	<10% oxidized vertical stripes, <10% oxidation stains, <10% charred plant material, <10% gypsum crystals and gypseous concretions, (burnt/fish) bones	
4c	3-7, 15–7, 31–2, 29–30, 52, 54, 61, 63	110*	10.15	Heterogeneous: clayey silt/ silty clay; poorly to very silty sand, with occ. gravel and pebbles	Very poorly sorted	Pale/dull yellow, light gray, yellowish brown	125–250	0.48–36.42	0.12–3.69	Occ. 10% (mostly frag-mented)	<1% oxidized vertical stripes, <1% oxidation stains, <1% bone and charcoal	
5 5a	4, 16, 17, 43, 51, 53, 58	130	11.25	Poorly silty sand	Moderately sorted	(Pale) yellow	250–500	1.26–2.84	0.14–0.33	<1%	-	Aeolian deposits
5b	31, 32, 42	110*	10.25	Poorly silty sand	Moderately sorted	Yellow	125–250	1.66–2.87	0.17–1.77	-	<1% sandy salt concretions	
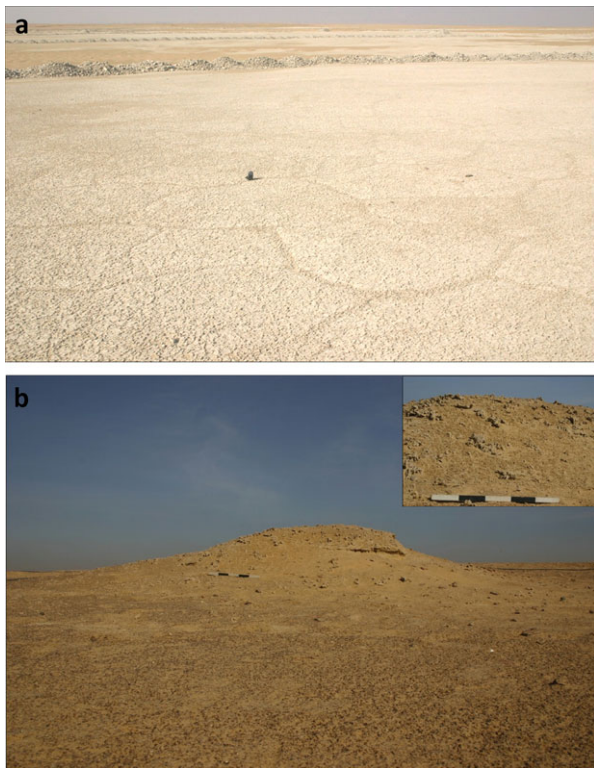
Figure 5 Photographs of distinct geomorphic features exposed at the modern surface (December, 2008). (a) Polygonal patterns of cracks observed at the modern surface of the deepwater lake facies 3a (GPS receiver is 10.5 cm in length. Photograph was taken to the northwest). (b) Exhumed hill with root casts (photograph was taken toward north-northeast).

(Figures 3, 6, 7; Tables I, III). No archaeological evidence was found on or within units 1a-d, 2b, 3a-e, g-h, and 5b.

The archaeological record is dominated by stone artifacts and animal bones (Figure 6). Artifact exposure is relatively high, as wind erosion currently predominates in the study area, with little sand dune formation. Artifacts are particularly concentrated on the northern part of the surface of aeolian sand unit 5a, with high densities of stone artifacts continuing on the surface of the southeastern part of the lacustrine unit 3f, and on the most southern edge of the reworked lacustrine unit 4a (Figure 6a). Lower densities of stone artifacts are observed to the north on the surface of the reworked lacustrine units 4a-b. Higher concentrations of animal bone (mainly fish) are found on the reworked lacustrine unit 4a (Figure 6b).

The remains of 38 hearths were identified across the study area, principally located within the archaeological survey area on units 3f, 4b, and 5a, with the exception of two hearths (IDs 148-149) located on unit 2a (Figure 7). Hearths are concentrated on the entire lacustrine unit 3f ($n = 17$) and on the northern part of aeolian sand unit 5a ($n = 16$). Three hearths are located on the southern part of the reworked unit 4a, two hearths at the fluvial unit 2a, and one hearth on the western most part of the reworked lacustrine unit 4b (Figure 7). The hearths are shallow deposits immediately below the modern surface level, identified because of fire-cracked rock present on the surface. The exception was one hearth (ID 148) that was found about 7 cm beneath the surface, partially sectioned by a drainage ditch (Figure 8). The fire-cracked rock of the youngest hearth (ID 148) is composed of very calcareous, fine-grained lithologies, with fossilized shells, most likely from the nearby bedrock outcrops (e.g., unit 1a). In some cases, the fire-cracked rock has helped to preserve sufficient charcoal for radiocarbon determinations that were obtained from nine hearths (Table I). The oldest hearths, located on the surfaces of the lacustrine unit 3f and the aeolian sand unit 5a, are dated between 7267.5 ± 97.5 and 7135 ±65 cal. yr B.C.E. (IDs 105, 141, 115, and 112) and 7260 ±80 and 7137.5 ±57.5 cal. yr B.C.E. (IDs 123 and 122). A younger hearth, located on the reworked lake unit 4b, is dated 7050 ± 25 cal B.C.E. (ID 140). The youngest hearths, located on the fluvial unit 2a, are dated between 6307.5 ± 67.5 and 6155 ±70 cal. yr B.C.E. (IDs 149 and 148).

Archaeological evidence other than lithics and hearths was recognized at the surface and in the very shallow subsurface of fluvial unit 2a, in the northwestern part of the reworked unit 4c, the southern part of the reworked unit 4a, and the entire reworked unit 4b, located both within and outside the archaeological survey area (Figures 3, 7; Table III).

A thin burnt, ashy layer, with abundant charcoal pieces was recorded in the shallow surface of fluvial unit 2a (with a depth from 18 to 25 cm). This layer continues, with a short interruption, toward the north and higher up, on top of the upper boundary of lacustrine unit 4c (depth 38–53 cm), where it becomes covered by aeolian sand unit 5b. Thin charred layers (<5 cm) succeed each other vertically in the shallow subsurface in the south of 4a, capped by heavily indurated oxidized material, forming a distinct ridge that steps up from the surface for about 25 cm, extending laterally for approximately 150 m in a northwest–southeast direction (depth 0–23 cm). Additional charred layers, with abundant charcoal pieces, fishbones, and vertically oriented oxidized stripes, representing former plant roots, are located on the surface in the southeast of unit 4a, at a similar maximum elevation (depth 0–12 cm). Abundant evidence for past firing episodes was observed on the surface and in the shallow subsurface of the greater part of unit 4b, consisting of blackish silty to muddy patches with abundant charred plant material (depth 0–23 cm and 47–62 cm).
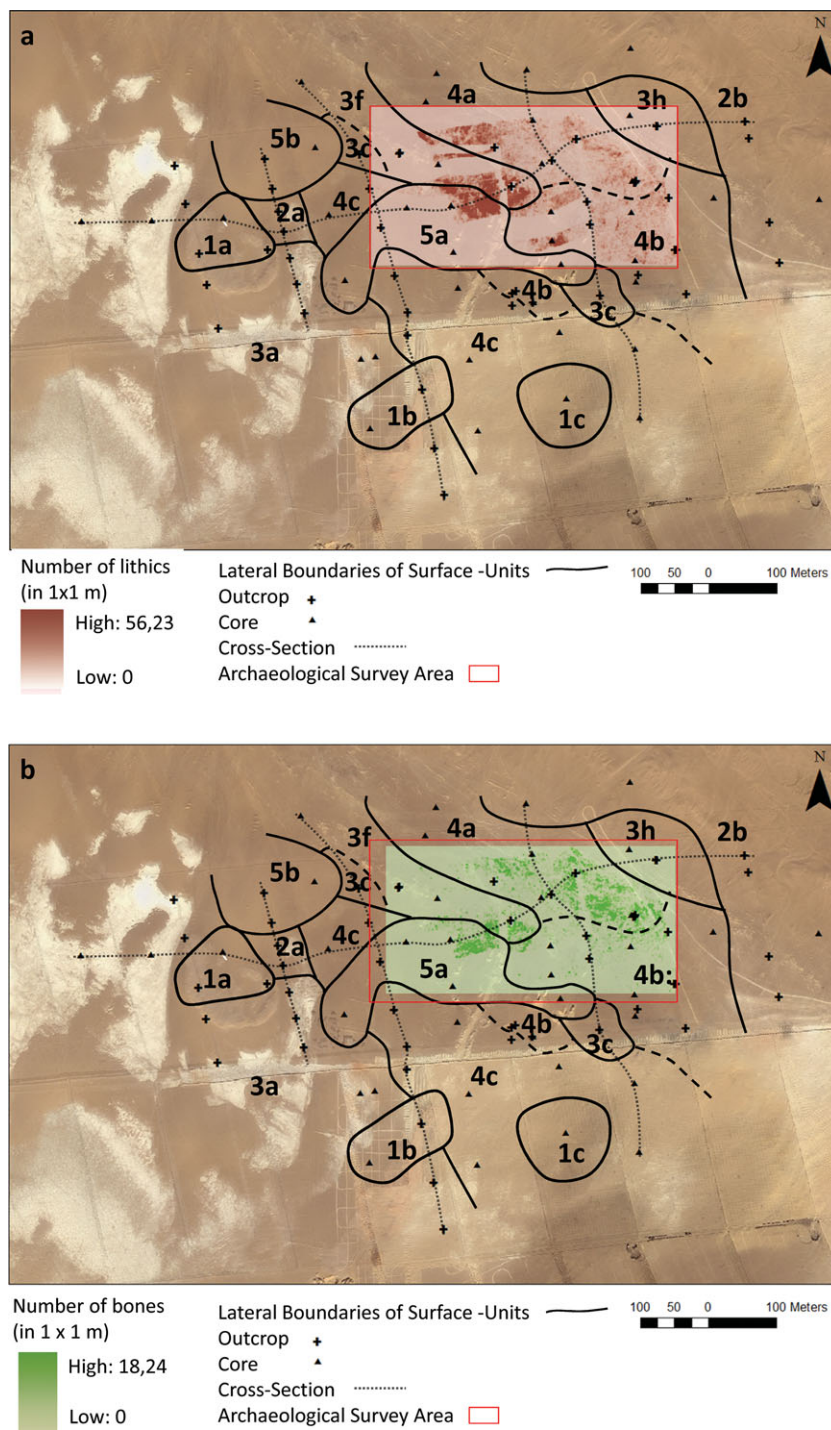
Figure 6 Differences in densities of observed archaeological materials (lithics and bones) on sedimentary facies exposed at today's surface (a: lithic densities; b: bone densities).

Stratigraphic Sequence

The vertical and lateral facies distributions (Figures 3 and 4) provide evidence for the reconstruction of a relative sequence of stratigraphic events in the study area. The bedrock and fluvial deposits in the northeast and southwest (1a-d, 2a-b) together form an undulating substratum on which was deposited sediments of lacustrine and aeolian origin (3a-h, 4a-c, 5a-b). The bedrock units are thought to date to the Tertiary based on earlier studies (Said et al., 1972, 1990; Issawi, 1976; Dolson,
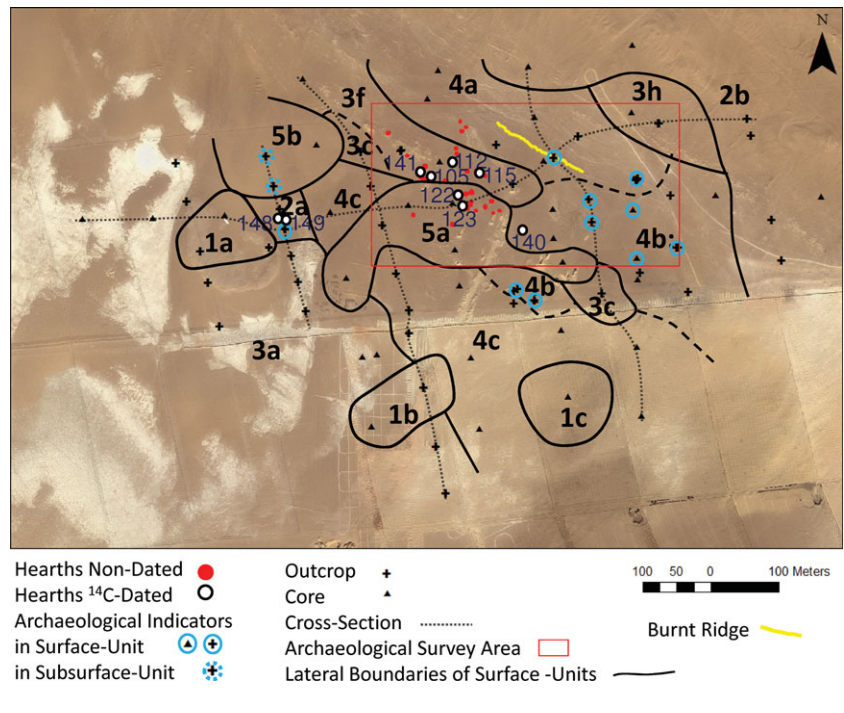
Figure 7 The locations of the hearths ($n = 38$) and archaeological indicators (other than lithics, bones, and hearths) identified at the study site. The hearths are shallow deposits immediately below the surface. Nine excavated hearths preserved charcoal that was used for AMS radiocarbon dating (see Table I).

2002). The overlying fluvial deposits (2a-b) point to local, high-energy stream action prior to the existence of lacustrine deposition in the study area. The fluvial deposits may relate to the Nile drainage system during the Pleistocene, when Nile water levels are thought to have been sufficiently high to sweep along and into the Fayum Basin, repeatedly causing flooding of the depression and accumulation of coarse sand and gravel (Said et al., 1972; Wendorf & Schild, 1976; Said, 1993), how-

ever we lack the absolute dates needed to demonstrate this.

Lacustrine deposits (3a-h) bury the bedrock and fluvial deposits indicating flooding of the study area. The lacustrine deposits indicate high water conditions at 13.19 m (3f) and 17.11 masl (3h) that may have been contemporary with the diatomite formation in the deeper parts of X Basin (3a) reconstructed in the southwest although again absolute age determinations would be

Table III Archaeological evidence other than artifacts or hearths observed at the surface or in the shallow subsurface of lithostratigraphic units.

Unit	Location			
	Core/ Outcrop	Depth from Modern Surface Level (cm)	Max. Observed Height (masl)	Archaeological Indicators Other Than Lithics and Hearths
2a	14	18–25	6.97	Ash, 10% charcoal
4a	20	0–23	14.03	Thin charred layers, capped by heavily indurated oxidized material
	67–8	0–12	14.01	Thin charred layers with10% charcoal, 10% (fish)bones, oxidation stains, and stripes (1 mm × 1 cm: vertical oriented)
4b	26–7, 70	0–23	12.93	Charcoal pieces, ash traces, blackish silty intercalations (churned?)
	26–7	47–62	12.35	10% charcoal pieces, blackish silty intercalations
	71, 74	0–15	12.23	10% charred plant material in blackish muddy patches
	59, 60, 62	0–21	9.75	10% charred wood, burnt molluscs, and (burnt) fish bones, <1% stone artifacts
4c	31–2	38–53	9.09	Ash, 10% charcoal

Figure 8 Profile of hearth (ID 148) embedded within fluvial unit 2a, with large pieces of charred wood covered by hearth stones. This was the only hearth that was found further beneath the surface, at a depth of c. 7 cm (GPS receiver is 10.5 cm in length; photograph was taken to west, December 2008).

needed to demonstrate this. The reworked lacustrine units (4a-c) cut the earlier deposited lacustrine deposits (3a-h) and indicate irregular erosion by a combination of water in the basin and ephemeral desert streams, including local redeposition of deposits during a recurrent retreat of the basin edge from east-northeast and west-southwest along the topographic slope. Shallow subaqueous swampy conditions in the east (4b), as well as discontinuous and patchy remnants of shallow-water lacustrine deposits covering the reworked lag deposits indicate occasional temporary rises of the water level or relatively short transgressive pulses. The observed evidence for changes between wet–dry conditions (e.g., color mottling, saline minerals), particularly dominant in the east (4b), provides indications for variations in groundwater level due to a combination of local water level changes and capillary action of water by intense evaporation (e.g., Flint & Howell, 1995; Glennie, 2005). Overlying aeolian sand deposits (5a-b) provide evidence for dry periods in the local region. Despite the predominance of wind erosion, evidenced by the lag pavements and exhumed sedimentary features (Figure 5), remnants of sandy lacustrine transgressive deposits (3c, f, h) remain preserved on contemporary desert surfaces, indicated by consolidated sediment from evaporation that covers the underlying unconsolidated deposits. The lacustrine units 3a-h, the reworked units 4a-c, and the aeolian sand unit 5a, stratigraphically underlie the oldest dated hearths located on units 3f and 5a. This indicates that the initiation of lacustrine deposition, the reworking of lake deposits as well as the subsequent accumulation of wind-blown deposits occurred prior to c. 7200 cal. yr B.C.E. Fluvial deposition of unit 2a must

have also occurred prior to c. 7200 cal. yr B.C.E., as unit 2a stratigraphically underlies unit 3a, the reworked lacustrine unit 4c, as well as the aeolian sand units 5a-b (Figure 3). Moreover, unit 2a is covered by a thin veneer of sand derived from the aeolian sand unit 5b, suggesting that unit 5b is dated younger than 6155 ±70 cal. yr B.C.E., the age of the youngest dated hearth embedded within unit 2a (ID 148).

Because the archaeological remains are lagged onto the deposits described above, it is uncertain what the environment looked like when these remains were deposited. However, we do know that the abundant artifacts, including hearths, were deposited on top of or within exposures of fluvial, lacustrine, reworked lacustrine, and aeolian sediments (units 2a, 3f, 4a-c, and 5a). Therefore the conditions that led to the deposition of these sediments must predate the deposition of the archaeological remains themselves. This observation is important since in many previous studies, it was assumed that the archaeology and the deposition of lacustrine sediments were contemporaneous.

Understanding the Relationship Between Sediments and the Archaeological Record

The results presented above suggest that there is a relationship between the nature of the sedimentary units onto which archaeological material, such as stone artifacts, has lagged, and the quantity of archaeological material preserved. Exposure of the archaeological record is generally very good, related to the predominance of wind erosion, with the exception of areas where sands accumulate to form dunes (e.g., unit 5b) that may bury archaeological deposits. Although stone artifacts are susceptible to loss within accumulated sand deposits, the relatively coarse-grained aeolian sand unit 5a and the coarse-grained sandy lacustrine unit 3f immediately adjacent have preserved the highest concentrations of stone artifacts and hearths, while lower concentrations of artifacts and almost no hearths are found on the fine-grained clayey-silty reworked lacustrine units 4a-b adjacent to the north and east (Figures 6a, 7). The high densities on the sandy units 5a and 3f may indicate that these deposits were more attractive for people than the clayey silty deposits 4a-b. However it is also possible that consolidated sediment (due to desiccation) that covers the underlying unconsolidated sandy deposits has improved the preservation and therefore visibility of artifacts and hearths, causing the archaeological remains to be lagged onto the resistant band and not to disappear in the accumulated sands.

Unit 4a contains somewhat higher concentrations of animal bones compared to the sandy units 5a and 3f more

to the south (Figure 6b). The relative sequence of stratigraphic events in the study area indicates that reworking of lacustrine deposits 4a-c occurred earlier than the deposition of aeolian sand unit 5a on which abundant artifacts accumulated in later times. This may suggest that the concentrations of bones on unit 4a represent natural death assemblages, as well as reworked bone deposits related to irregular erosion by ephemeral desert streams and/or local redeposition of lacustrine deposits. However, behavioral explanations might also explain the differences in animal bone concentration since the discard of fish remains and of stone artifacts was not necessarily related.

Abundant evidence for repeated firing is found on the surface and in the very shallow subsurface of the fine-grained units 4b and 4a (Figures 3, 7; Table III). This firing evidence is not present in the coarser grained sandy units 5a and 3f, although these both contain the highest concentrations of stone artifacts and hearths as described above. Although some of the burning may have been caused by natural fires, the repetition of the burnt layers could indicate human initiated burning. This may suggest a different (and thus targeted) use of the areas covered by the fine-grained facies 4a-b versus the coarser grained facies 5a and 3f.

Although containing one of the most intact hearths (ID 148) within the study area, the absence of stone artifacts on top of unit 2a is probably related to the recent removal of sediment from the modern surface by bulldozers. The preservation of the potential archaeological layer in unit 2a and higher on top of the reworked unit 4c indicates that the area in the lower southwest probably once contained a richer archaeological record than it currently does.

The youngest dated hearths (IDs 149, 148) are found within the relatively older fluvial facies 2a in the lower southwest of the study area (Figure 7). In contrast, the oldest dated hearths (IDs 105, 141, 115, 112, 123, 122, and 140) are clustered on the stratigraphically younger dated sedimentary units 3f, 5a, and 4a-b (Figure 7). With the exception of hearth 148 that was buried, for the hearths in the study area to be preserved on the contemporary surface at all means that it is unlikely that they were exposed over the long term and affected by processes such as repeated lake inundations.

DISCUSSION

The results and interpretations presented in this study differ from earlier published studies on the relationship between the location of archaeological materials and Holocene paleolake level fluctuations in the Fayum Basin (e.g., Said et al., 1972; Wendorf & Schild, 1976; Hassan,

1986; Ginter & Kozlowski, 1986; Kozlowski & Ginter, 1993; Hassan et al., 2012). Earlier studies suggested that paleolake levels in the Fayum Basin were high and fluctuated during at least three early Holocene lake transgressions, whereafter the lake rose to higher elevations during the mid- and late Holocene. In contrast, the lithostratigraphical evidence presented in this paper suggests that lacustrine sediments were deposited before the archaeological materials and that this likely occurred prior to c. 7200 cal. yr B.C.E., the age of the earliest dated hearth. Although it is likely that paleolake levels oscillated somewhat throughout the early Holocene, the sedimentary record holds no evidence of high lake levels after early Holocene human occupation in the study area. Hearths are very near the contemporary surface, yet retain a structure that preserves charcoal for dating in some instances. In addition, very large numbers of small stone artifacts were observed that seem not to have moved substantially other than by deflation.

Previous estimates for the age of paleolake fluctuations were not obtained from direct dates on the lake sediments, but from archaeological material that rested on top of, or were dug into these sediments. Unfortunately, it cannot be assumed that archaeological material, such as hearths, tracks the edges of the lake at any one time and therefore the presence of archaeological material should not be used as a proxy for past lake level fluctuations. People who made use of lake resources need not have occupied the immediate lake shore. While the results reported here indicate that people likely targeted particular locations, indicated today by particular sediment types, the stratigraphic position of the archaeological materials does not indicate an immediate lake shore location. The observed lacustrine sedimentary data do not relate to the landscape that people inhabited at the time that the archaeological record was deposited. Accordingly, it seems possible that the associations between archaeological materials and sediments indicative of past lake levels were not correctly interpreted in previous studies.

Well dated records for the dynamics of the River Nile in Northern Sudan and the Nile Delta now exist (e.g., Krom et al., 2002; Kuper & Kröpelin, 2006; Williams et al., 2010; Macklin et al., 2013), however correlation of these data with the data reported here remains problematic since we do not have direct dates on the sediments in which our data were observed. In the past, sediments indicative of past lake levels were correlated with archaeological materials and regional to global palaeoenvironmental records but as we suggest in this paper, these associations were not correctly interpreted due to the types of absolute dates that were obtained (i.e., from archaeological not lacustrine deposits). Therefore we suggest that future geoarchaeological studies should first reassess the

chronology of paleolake level oscillations in the Fayum Basin, in order to improve correlations with the Nile flood history as well as regional climatic changes.

CONCLUSIONS

The results of this study show that a systematic integration between detailed sedimentary studies and archaeological evidence in the Fayum Basin is essential to assess the effect of landscape change on the formation and preservation of the Fayum archaeological record. The archaeological record in the area studied is located on the modern surface or in the shallow subsurface of units 2a, 3f, 4a-c, and 5a, with no traces of a deeply buried record. No archaeological evidence was found on or within units 1a-d, 2b, 3a-e, g-h, and 5b.

Analysis of deposits indicates sedimentation in and along river courses, initiation of lacustrine deposition, and the reworking of lake deposits, as well as the subsequent accumulation of wind-blown deposits all occurred prior to the deposition of archaeological materials. These findings contrast with earlier published studies, which suggest that paleolake levels in the Fayum rose to higher elevations during the Holocene and at times inundated the archaeological remains discussed here.

Correlations between sediment and the archaeological deposits indicate a different use of land of areas covered by relatively coarse-grained sediment (sand) compared to areas where relatively fine-grained deposits are exposed (clay and silt). Bone deposits in the study area may include remains that represent natural death assemblages connected with the reworking of lacustrine deposits, however the observed patterns in the distribution of bone deposits mostly reflect the preservation of sedimentary land surfaces. Preservation of hearths on the contemporary surfaces indicates that their exposure was relatively recent, and that they were not affected by processes such as repeated lake inundations.

Studies designed to provide higher spatial and temporal resolutions in reconstructions are required in the future to establish exact correlations between the Nile flood history, regional climatic changes, and oscillations in the levels of paleo-Lake Qarun, compared to the chronology of past human occupation in the Fayum Basin.

REFERENCES

Aleem, A.A. (1958). A taxonomic and paleoecological investigation of the diatom flora of the extinct Fayoum Lake (Upper Egypt). Systematic Part. Bulletin of Faculty of Sciences Alexandria University, 2(1), 99–138.

Baioumy, H.M., Kayanne, H., & Tada, R. (2010). Reconstruction of lake-level and climate changes in Lake Qarun, Egypt, during the last 7000 years. Journal of Great Lakes Research, 36, 318–327.

Caton-Thompson, G., & Gardner, E.W. (1934). The Desert Fayum (Vol. 1 and 2). London: The Royal Anthropological Institute of Great Britain and Ireland.

Dolson, J., Barkooky, A.El., Wehr, F., Gingerich, P.D., Prochazka, N., & Shann, M. (2002). The Eocene and Oligocene Paleo-Ecology and Paleo-Geography of Whale Valley and the Fayoum Basins: Implications for Hydrocarbon Exploration in the Nile Delta and Eco Tourism in the Greater Fayoum Basin-Field Guide AAPG/ EPEX/ SEG/ EGS/ EAGE 2002 (Field Trip No. 7). Cairo: Rising Star Group Limited.

Fanning, P.C., Holdaway, S.J., & Rhodes E.J. (2007). A geomorphic framework for understanding the surface archaeological record in arid environments. Geodinamica Acta, 20/4, 275–286.

Fanning, P.C., Holdaway, S.J., & Rhodes E.J. (2008). A new geoarchaeology of Aboriginal artefact deposits in western NSW, Australia: Establishing spatial and temporal geomorphic controls on the surface archaeological record. Geomorphology, 101, 524–532.

Fanning, P.C., Holdaway, S.J., Rhodes, E.J., & Bryant T.G. (2009). The surface archaeological record in arid Australia: Geomorphic controls on preservation, exposure, and visibility. Geoarchaeology, 24(2), 121–146.

Fathi, A.A., & Flower R.J. (2005). Water quality and phytoplankton communities in Lake Qarun (Egypt). Aquatic Sciences, 67(3), 350–362.

Flint, S., & Howell, J. (1995). Applications of High Resolution Sequence Stratigraphy in Production Geology. A Short Course for Shell Companies Liverpool, UK: STRAT Group, University of Liverpool.

Flower, R.J., Stickley, C., Rose, N.L., Peglar, S., Fathi, A.A., & Appleby, P.G. (2006). Environmental changes at the desert margin: an assessment of recent paleolimnological records in Lake Qarun, Middle Egypt. Journal of Paleolimnology, 35, 1–24.

Flower, R.J., Keatings, K., Hamdan, M., Hassan, F.A., Boyle, J.F., Yamada, K., & Yasuda, Y. (2012). The structure and significance of early Holocene laminated lake sediments in the Faiyum Depression (Egypt) with special reference to diatoms. Diatom Research, 27(3), 127–140.

Foster, I.D.L., Oldfield, F., Flower, R.J., & Keatings, K. (2008). Mineral magnetic signatures in a long core from Lake Qarun, Middle Egypt. Journal of Paleolimnology, 40, 835–849.

Ginter, B., & Kozlowski, J.K. (1986). Kulturelle und palaoklimatische sequencz in der Fayum Depression: ein zusammenfassende Darstellung der Forschungsarbeiten in der Jahren 1979–1981. Mitteilungen des Deutschen Archaologischen Instituts, Abteilung Kairo, 42, 9–23.

Glennie, K.W. (2005). The Desert of Southeast Arabia. Bahrain: Gulf PetroLink.

Hassan, F.A. (1986). Holocene lakes and prehistoric settlements of the Western Faiyum, Egypt. Journal of Archaeological Science, 13, 483–501.

Hassan, F.A. (1997). Holocene Paleoclimates of Africa. African Archaeological Review, 14(4), 213–230.

Hassan, F.A, Hamdan, M.A., Flower, R., & Keatings, K. (2012). Oxygen and carbon isotopic records in Holocene freshwater mollusc shells from the Faiyum paleolakes, Egypt: paleoenvironmental and paleoclimatic implications. Quaternary International, 266, 175–187.

Holdaway, S.J., & Fanning, P. (2014). Geoarchaeology of Aboriginal Landscapes in Semi-arid Australia. Collingwood, Victoria, Australia: CSIRO.

Holdaway, S.J., Wendrich, W., & Phillipps, R. (2010). Identifying low-level food producers: detecting mobility from lithics. Antiquity, 84, 185–194.

Hugget, R.J. (2007). Fundamentals of Geomorphology (Second revised edition). New York: Routledge.

Hussein, H., Amer, R., Gaballah, A. Refaat, Y., & Abdel-Wahab, A. (2008). Pollution monitoring for Lake Qarun. Advances in Environmental Biology, 2(2), 70–80.

Issawi, B. (1976). Geology of the Fayum Depression. In F. Wendorf (Ed.), Prehistory of the Nile Valley (pp. 151-153). New York: Academic Press.

Keatings, K., Holmes, J., Flower, R., Horne, D., Whittaker, J.E., & Abu-Zied, R.H. (2010). Ostracods and the Holocene palaeolimnology of Lake Qarun, with special reference to past human–environment interactions in the Faiyum (Egypt). Hydrobiologia, 654, 155–176.

Konert, M., & Vandenberghe, J. (1997). Comparison of laser grain size analysis with pipette and sieve analysis: a solution for the underestimation of the clay fraction. Sedimentology, 44, 523–535.

Kozlowski, J.K. (Ed.) (1983). Qasr el-Sagha 1980: Contribution to the Holocene Geology, the Predynastic and Dynastic Settlements in the Northern Fayum Desert. Warszawa: Panstwowe Wydawnictwo Naukowe.

Kozlowski, J.K., & Ginter, B. (1993). Holocene changes in the Fayum: Lake Moeris and the evolution of climate in Northeastern Africa. In L. Krzyzaniak, M. Kobusiewicz, & J. Alexander (Eds.), Environmental Change and Human Culture in the Nile Basin and Northern Africa Until the Second Millennium BC (327-336). Poznan: Poznan Archaeological Museum.

Krom, M.D., Stanley, J.D., Cliff, R.A., & Woodward, J.C. (2002). Nile River sediment fluctuations over the past 7000 yr and their key role in sapropel development. Geology, 30(1), 71–74.

Kuper, R., & Kröpelin, S. (2006). Climate-controlled Holocene occupation in the Sahara: Motor of Africa's evolution. Science, 313, 803–807.

Linseele, V., Van Neer, W., Thys, S., Phillipps, R., Cappers, R., Wendrich, W., & Holdaway, S.J. (2014). New archaeozoological data from the Fayum "Neolithic" with a critical assessment of the evidence for early stock keeping in Egypt. PLoS One, 9(10), 1–22.

Macklin, M.G., Woodward, J.C., Welsby, D.A., Duller, G.A.T., Williams, F.M., & Williams, M.A.J. (2013). Reach-scale river dynamics moderate the impact of rapid Holocene climate change on floodwater farming in the desert Nile. Geology, 41(6), 695–698.

Nichols, G. (2006). Sedimentology and Stratigraphy (First published 1999). Oxford: Blackwell Science Ltd.

Phillipps, R., Holdaway, S.J., Wendrich, W., & Cappers, R. (2012). Mid Holocene occupation of Egypt and global climatic change. Quaternary International, 251, 64–76.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C., Blackwell, P.G., Buck, C.E., Burr, G., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Hughen, K.A., Kromer, B., McCormac, F.G., Manning, S., Bronk Ramsey, C., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., & Weyhenmeyer, C.E. (2004). INTCAL04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. Radiocarbon, 46, 1029–1058.

Said, R. (Ed.) (1990). The Geology of Egypt. Rotterdam: Taylor & Francis.

Said, R. (1993). The River Nile: Geology, Hydrology and Utilization. Oxford: Pergamon Press.

Said, R., Albritton, C.C., Wendorf, F., Schild, R., & Kobusiewicz, M. (1972). Remarks on the Holocene geology and archaeology of Northern Fayum. Archaeologia Polona, XIII, 6–22.

Shirai, N. (2010). The Archaeology of the First Farmer-Herders in Egypt, New Insights into the Fayum Epipaleolithic and Neolithic. Doctoral dissertation, Leiden University, Leiden, the Netherlands.

Smith, B. (2001). Low-level food production. Journal of Archaeological Research, 9(1), 1–43.

Talbot, M.R., & Allen, P.A. (1996). Lakes. In H.G. Reading (Ed.), Sedimentary Environments: Processes, Facies and Stratigraphy (pp. 83–124). Chichester: Blackwell Science Ltd.

Udden, J.A. (1914). Mechanical composition of clastic sediments. Bulletin of the Geological Society of America, 25, 655–744.

Wendorf, F., & Schild, R. (1976). Prehistory of the Nile Valley. New York: Academic Press.

Wendrich, W., & Cappers, R. (2005). Egypt's earliest granaries: evidence from the Fayum. Egyptian Archaeology, 2, 12–15.

Wendrich, W., Taylor, R. E., & Southon, J. (2010). Dating stratified settlement sites at Kom K and Kom W: Fifth millennium BCE radiocarbon ages for the Fayum Neolithic. Nuclear Instruments and Methods in Physics Research B, 268, 999–1002.

Wenke, R.J., Long, J.E., & Buck, P.E. (1988). Epipaleolithic and Neolithic subsistence and settlement in the Fayyum Oasis of Egypt. Journal of Field Archaeology, 15, 29–51.

Wentworth, C.K. (1922). A scale of grade and class terms for clastic sediments. Journal of Geology, 30, 377–392.

Williams, M.A.J., Williams, F.M., Duller, G.A.T., Munro, R.N., El Tom, O.A.M., Barrows, T.T., Macklin, M., Woodward, J., Talbot, M.R., Haberlah, D., & Fluin, J. (2010). Late Quaternary floods and droughts in the Nile valley, Sudan: New evidence from optically stimulated luminescence and AMS radiocarbon dating. Quaternary Science Reviews, 29, 1116–1137.