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DIATOM STRATIGRAPHY OF FA-1 CORE, QARUN LAKE, RECORDS OF HOLOCENE ENVIRONMENTAL AND CLIMATIC CHANGE IN FAIYUM OASIS, EGYPT

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Abstract

This study evaluates changes in the environmental and climatic conditions in the Faiyum Oasis during the Holocene based on diatom analyses of the sediment FA-1 core from the southern seashore of the Qarun Lake. The studied FA-1 core was 26 m long and covered the time span ca. 9.000 cal. yrs BP. Diatom taxa were abundant and moderately to well-preserved throughout the core sediments. Planktonic taxa were most abundant than the benthic and epiphytic forms, which were very rare and sparsely distributed. The most dominant planktonic genera were *Aulacoseira* and *Stephanodiscus* followed by frequently distribution of *Cyclostephanos* and *Cyclotella* species. The stratigraphic distribution patterns of the recorded diatoms through the Holocene sediments explained five ecological diatom groups. These groups represent distinctive environmental conditions, which were mainly related to climatic changes through the early and middle Holocene, in addition to anthropogenic activity during the late Holocene. Comparison of diatom assemblages in the studied sediment core suggests that considerable changes occurred in water level as well as salinity. There were several high stands of the freshwater lake level during humid, warmer-wet climatic phases marked by dominance of planktonic, oligohalobous and alkaliphilous diatoms alternated with lowering of the lake level and slight increases in salinity and alkalinity during warm arid conditions evident by prevalence of brackish water diatoms.

Key words: Holocene, environment, climate change, Qarun Lake, diatoms, Faiyum Oasis, Egypt

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INTRODUCTION

Climate change and human activity are considered the main factors controlled the environmental changes in arid regions like Egypt. The climatic conditions in Egypt have changed many times with successive wet and dry phases during the Holocene time (Hassan, 1996; Zalat, 2015; Welc, 2016). These changes were associated with the climatic change in the North Africa (Said, 1993). The Faiyum Oasis located in northern Egypt is considered as one of the most interesting sites to constructing and understanding the environmental changes during the Holocene in northeastern Africa. It contained a large record of Holocene lacustrine sediments that were deposited in the Faiyum Lake and formed a continuous, natural and unique archive that provided long environmental records with a potentially high time resolution (Zalat, 2015; Marks *et al*., 2016; Welc, 2016). These sediments contained a wide range of palaeolimnolog-

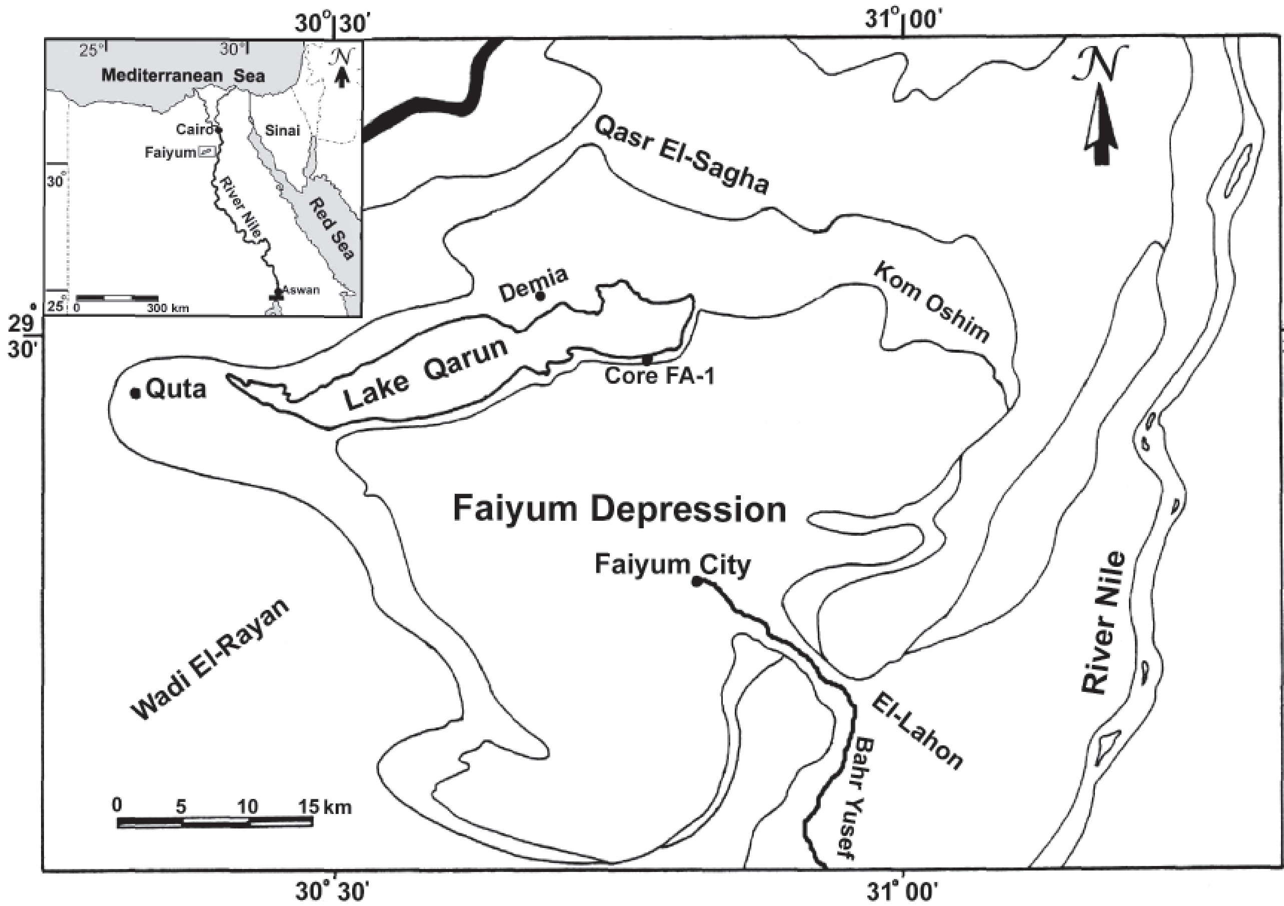

Fig. 1. Location map of Faiyum Oasis showing position of the studied FA-1 core at the southern part of Qarun Lake.

ical indicators such as diatoms, which were very important for environmental monitoring and reconstructing the palaeoenvironmental changes during the prehistoric time (Hall and Smol, 1999; Lotter, 2001; Bigler *et al*., 2003; Zalat and Servant-Vildary, 2007). In addition, the oasis comprised numerous archaeological sites, mainly of Epipalaeolithic and Neolithic age (Caton-Thompson and Gardner, 1929; Wendorf and Schild, 1976; Hassan, 1986; Schirai, 2010).

Diatom frustules are usually well preserved in many sedimentary environments; thus, many researchers have studied variations in diatom assemblages through sediment cores to describe paleo-lake environments, and how they have changed up to the present time (Fritz *et al*., 1989). Furthermore, diatoms respond rapidly to environmental changes through time, because they are very sensitive to many ecological factors (Sancetta, 1999; Birks and Koc, 2002). They are unicellular algae, and as biological indicators provide information on habitat types, water depth, alkalinity and salinity levels. Since, water depth and salinity fluctuations have been recognized as indicators of paleoclimatic change, and have provided significant evidences in paleoclimatic reconstruction (e.g. Gasse *et al*., 1987, 1997; Wilson *et al*., 1995; Zalat, 2015).

The present research aimed to estimate changes of lake water level and salinity during the Holocene, in order to reconstruct the Holocene climate change in the Faiyum depression in Egypt. It was based on fossil diatoms that were preserved in the sediments of the Qarun Lake.

SITE DESCRIPTION

The Faiyum Oasis is located at the boundary of northern and central Egypt, between latitude 29°00’ – 29°45’N and longitude 30°00’ – 31°10’E, immediately to the west of the Nile Valley and about 90 km to the south-west of Cairo (Fig. 1). It occupies nearly a triangular depression with an area of about 1700 km^2 surrounded by escarpments of the Eocene rock formations. The Oasis is separated from the Nile Valley in the east by a ridge running south from the Giza plateau. Its surface is almost flat and slopes downward in a north-westerly direction from 32 m a.s.l. to 45 m b.s.l. at the Qarun Lake, which occupies the lowest part of the depression (Hassan, 1986; Zalat, 2015).

The Faiyum Oasis has a long and rich archaeological history (Caton-Thompson and Gardner, 1934; Ball, 1939; Wendorf and Schild, 1976; Hassan, 1986; Welc, 2016), and there is abundant evidence for human water-based (irrigation) farming activity (Butzer, 1976). It plays an important role in developing the understanding of the Egyptian prehistory, in particular during the Epipalaeolithic–Neolithic time (early to middle Holocene age).

Today, the Faiyum depression is connected to the Nile Valley by artificial channel, Bahr Yusuf, which enters the depression via the el-Lahun corridor or Hawara Canal. During the Nile floods, the depression received huge amount of freshwater *via* the canal of Bahr Yusuf and formed during early and middle Holocene a large freshwater lake, named in turn the Paleo-, Pre-, Proto- and Moeris Lake. (Said *et al*., 1972; Wendorf and Schild, 1976). This ancient lake has left its traces in the desert area surrounding the Oasis in a form of beaches, terraces, or lacustrine diatom deposits located at different altitude. The remnant of this ancient lake survived until the present as the saline and shallow Qarun Lake (Wendorf and Schild, 1976; Hassan, 1986; Zalat, 2015; Marks *et al*., 2016; Welc, 2016).

The Qarun Lake is located at the northern part of Faiyum depression, (between 29°26'36" – 29°31'15"N and 30°23'52" – 30°49'55"E) and has an irregular shape of about 40 km length from east to west and maximum width of 9 km in the western part, at the El-Karn Island (Fig. 1). Its area of about 234 km^2, with depth between 4 to 8.5 m in the deepest part, and its water level occurs at 45 m b.s.l. (Baioumy *et al*., 2010). As it was mentioned, the Lake was fed by a branch of the River Nile – the Bahr Yusuf during the Holocene period (Said *et al*., 1972; Hassan, 1986; Said, 1990). Today it is an inland closed basin with no natural outlets and its water is trapped inside without any possibility of escaping, except through evaporation (Zalat, 2015).

MATERIAL AND METHODS

FA-1 core was drilled in the southern part of the Qarun Lake (Fig. 1). A total of 240 representative samples were obtained from the 26 m long core at 10 cm intervals for diatom analysis. The diatoms were extracted from the sediment samples according to the procedure proposed by Zalat (2002) and Zalat and Servant-Vildary (2005, 2007). Diatom identification and statistical studies were done in the Geological Department of the Tanta University in Egypt with a use of Carl Zeiss light microscope combined with a digital camera at a normal x100 oil immersion objective. In every rich-diatom slide 1000 diatom valves and in the samples with low-diatom concentrations at least 300 valves were counted. Percentage contents of the species were calculated for estimation of ecological parameters as life-form groups, pH and salinity. Relative frequencies of every species were calculated as percentage of total diatom valves (%TDV) in each sample.

Identification and ecological preferences of diatom species were based on previous works (e.g. Hustedt, 1930–1966, 1957; Simonsen, 1962, 1979; Cholnoky, 1968; Ehrlich, 1973, 1975; Stoermer *et al*., 1974; Foged, 1980, 1993; Kilham *et al*., 1986; Krammer and Lange-Bertalot, 1986–1991; Gasse, 1986; Zalat, 1991; Denys, 1991–1992; van Dam *et al*., 1994; Witkowski *et al*., 2000; Wolfe *et al*., 2000; Bradbury *et al.,* 2004; Zalat and Servant-Vidary, 2005, 2007). The grouping of diatoms into salinity preference categories has been used for the estimation of the salinity history of the Faiyum Lake. The ratio of planktonic to benthic and epiphytic forms was calculated for each sample to estimate type of habitats and water level changes. The most dominant species that have relative abundance over 5% of the total diatom valves in the examined samples were analyzed to determine stratigraphy of the lake sediments (Fig. 2).

LITHOLOGY OF THE FA-1 CORE

The basal part of the core sequence was composed of massive carbonate clay eluvium (depth 26.00–20.85 m) that was overlain by coarse sand layers at a depth 20.85–19.76 m (Fig. 2). Above it, there were thin-laminated silts and clays, resembling typical varves, deposition of which was interrupted by a sand at a depth 15.53–15.45 m. A thinly laminated part of the core at a depth of 19.76–13.05 m was composed of white diatomite, carbonate and mostly clayey (terrigenous) laminae.

A considerable lithological change occurred at a depth of 13.05 m (Fig. 2). Rhythmites common in the lower part of the log were replaced by massive silt and clay with irregular, thick diatomite and ferruginous interbeds. At 12.85–10.04 m, the core was composed mostly of silty clay with white-grey interbeds, 1–5 mm thick. Starting from the depth of ca. 8 m upwards, the core was composed of massive silty clay with sandy interbeds at ca. 7.6 m and 7.2 m. At 6.9–6.3 m they were replaced by silty clay with dispersed organic matter (plant detritus) and irregular crystals of gypsum.

Lithological characteristics of the sediment at a depth of 6.0–5.6 m indicated stable sedimentary environment, with deposition of steel-gray silty clay, locally interbedded with organic and white-gray lamina. At a depth of 5.5–4.0 m the core was composed of massive gray-brown silty clay. Above, at 4.0–3.4 m there was loose shell sediment with pieces of malacofauna and mixed with gray sludge silt. The overlying sediment at a depth of 3.4–1.9 m was composed of massive gray-brown silty clay with gravel grains, several mm in diameter (depth 2.57–2.65 m). Silt at a depth of 2.2 m was predominated by angular quartz grains (Marks *et al*., 2016).

RADIOCARBON DATING

Radiocarbon dating was performed for 32 samples from sediments of the FA-1 core, collected from organic-rich mud layers and mineral deposits with dispersed organic matter (Welc, 2016; Marks *et al*., in press). AMS dating was done in the Poznań Radiocarbon Laboratory in Poland, where ^{14}C measurements were performed in graphite targets (Goslar *et al*., 2004). Conventional ^{14}C age was calculated using correction for isotopic fractionation according to Stuiver and Polach (1977). In the calculation procedure, uncertainty of radiocarbon age was determined with a use of counting statistics and standard deviation of partial ^{14}C/^{12}C results, resulting in the so-called 1-sigma uncertainty of conventional ^{14}C age. Calibration of ^{14}C age was performed using the

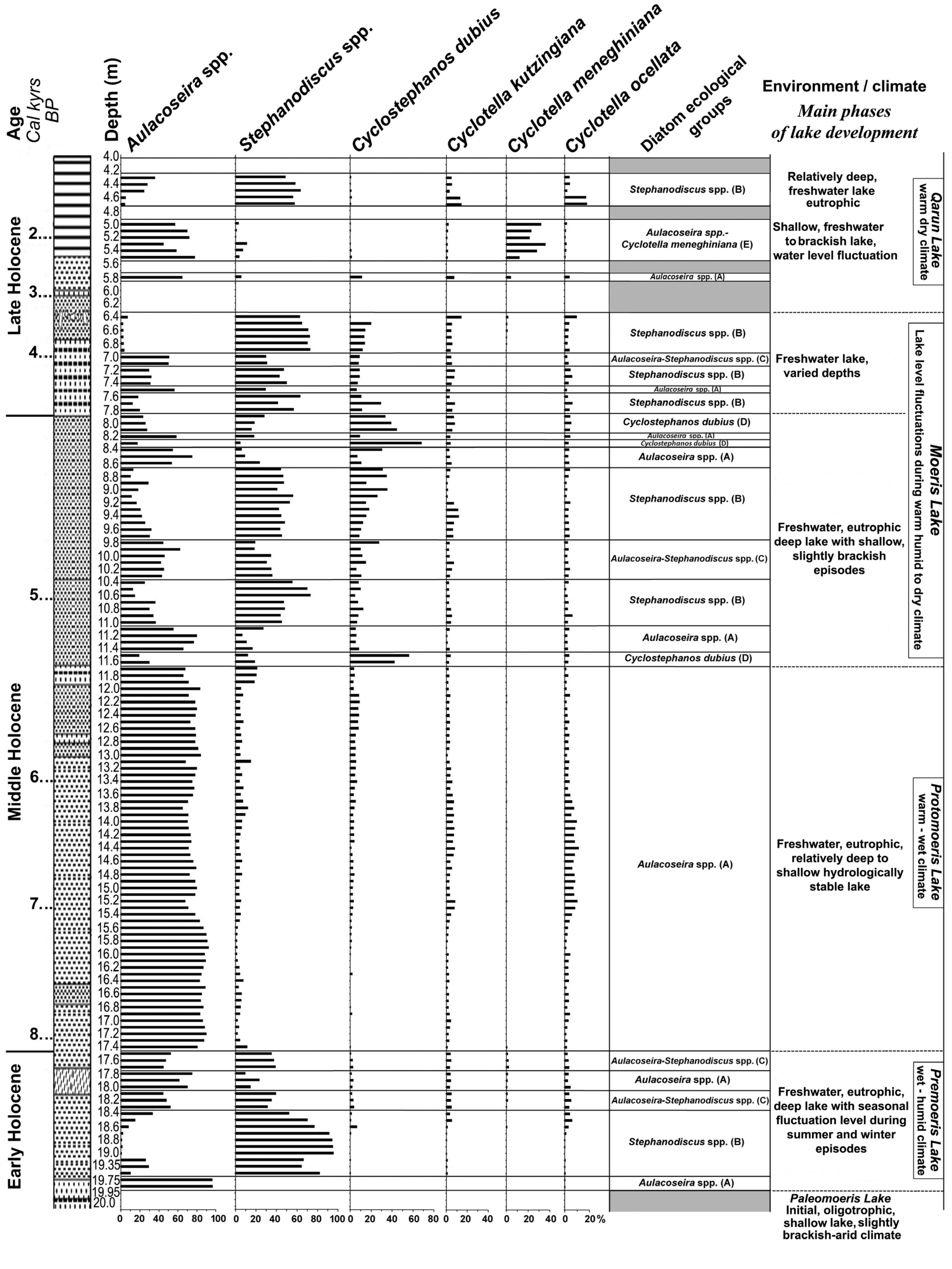

Fig. 2. Diatom stratigraphy of sediments FA-1 core with recognized diatom ecological groups and the main phase of lake developments after Marks *et al.* (in press), modified. Gray fields at the Diatom ecological groups – Barren of diatoms.

program OxCal ver. 4.2 (http://c14.arch.ox.ac.uk) designed by the Oxford Accelerator Unit and using the INTCAL13 calibration curve (Reimer *et al.,* 2013).

RESULTS

Diatom taxa were abundant and moderately to well-preserved throughout the FA-1 core from a depth 19.8 to 6.5 m, and relatively frequent toward the top but with some samples containing poorly preserved sporadic diatoms at depths of 6.3–5.9, 5.7–5.6, 4.9–4.8 and 4.2–4.0 m (Marks *et al*., in press). A total of 112 diatom species from 42 genera was recognized. Planktonic taxa were most abundant, reaching to 98% of the total assemblage, while benthic and epiphytic forms were very rare and sparsely distributed. The most dominant planktonic genus was *Aulacoseira* with 11 species, followed by the *Stephanodiscus* with 9 species. *Cyclostephanos* and *Cyclotella* species were distributed frequently. Results of diatom analysis and the relative abundance of the dominant taxa have been synthesized in the form of percentage diagrams (Fig. 2). The stratigraphic distribution patterns of the recorded diatoms, variations in content of dominant species and characteristic species in the FA-1 core indicate five diatom ecological groups, which are briefly described.

***Aulacoseira granulata* ecological group A**.—This group is dominated by the planktonic, eutrophication indicator *Aulacoseira granulata*, accompanied commonly by *Aulacoseira granulata* var. *angustissima*, *A. ambigua, A. italica* and *A. islandica.* The diatom association contains low contents of other planktonic taxa as *Stephanodiscus rotula, S. agassizensis, S. alpinus* and *Cyclostephanos dubius* with sporadic occurrence of *Cyclotella ocellata* and *C. meneghiniana*. The epiphytic and benthic forms are generally playing a minor role in this group. The assemblage was recorded 8 times throughout the FA-1 core (Fig. 2)

***Stephanodiscus* spp. ecological group B**.—This group is characterized by the highest abundance of planktonic freshwater *Stephanodiscus* species. *Stephanodiscus rotula* is the most dominant taxon associated with common occurrence of *Stephanodiscus neoastraea, S. agassizensis, S. alpinus, S. aegyptiacus, S. hantzschii,* and *S. niagarae.* The diatom association is represented by frequently distribution of other planktonic freshwater taxa *Aulacoseira granulata, A. italica* and *A. islandica*, associated with sporadic occurrence of *Cyclotella kützingiana, C. ocellata* and *C. meneghiniana*. The epiphytic taxa including *Epithemia* spp., *Cocconeis placentula* and *Staurosira–Staurosirella* spp are sparsely distributed with limited numbers of benthic forms. This group was observed seven times at different stratigraphic levels in the FA-1 core.

***Aulacoseira–Stephanodiscus* spp. ecological group C**.—This group was represented by mixed assemblage of common occurrence *Aulacoseira* spp. and *Stephanodiscus* spp. (80–90%). Other planktonic taxa as *Cyclotella kützingiana, C. ocellata* and *Cyclostephanos dubius* were distributed sporadically. The assemblage was recorded three times in the FA-1 core. The diatom group of *Aulacoseira* and *Stephanodiscus* spp. was indicative of high stand lake level with developed nutrient availability.

***Cyclostephanos dubius* ecological group D**.—This group was distinguished by high abundance of *Cyclostephanos dubius* (40–55%), accompanied by *Aulacoseira* spp., which was more abundant than *Stephanodiscus* taxa. Other planktonic taxa as *Cyclotella kützingiana* and *C. ocellata* were distributed frequently. This group was observed 3 times in the studied core. The epiphytic and benthic forms are recorded sporadically in limited numbers.

***Aulacoseira granulate–Cyclotella meneghiniana* ecological group E**.—The group was dominated by planktonic taxa *Aulacoseira* spp. with relative abundance ranges between 50 to 75%, associated with significant common occurrence of *Cyclotella meneghiniana* (25–40%). *Aulacoseira* taxa included *A. granulata*, *A. granulata* var. *angustissima*, *A. italica*, and *A. islandica.* The others *Stephanodiscus* spp. and *Cyclotella* spp. are distributed sporadically. The benthic and epiphytic groups are represented by few taxa dispersed sparsely. This ecological group was observed at the top part of FA-1 core, with thickness .05 m at depth 5.0–5.5 m.

DISCUSSION

Analysis of sedimentary diatoms in the FA-1 core reveal limnological changes during the Holocene that are related mainly to climate change, anthropogenic activities and natural disturbance. The stratigraphic distribution pattern of the recorded diatom taxa (Fig. 2) indicated seasonal and annual changes in the diatom assemblage, which divided the FA-1 core sequence into 28 units of these 5 units with sporadic occurrence of poorly preserved diatoms and 23 units represented by well preserved, high abundance of diatoms included in five ecological groups.

Aulacoseira granulata ecological group A is characterized by maximum abundance of *Aulacoseira granulata* associated with commonly appearance of *Aulacoseira granulata* var. *angustissima*, *A. ambigua, A. italic, A. agassizii* and *A. islandica*.. *Aulacoseira granulata* was recognized as a freshwater planktonic and alkaliphilous species, common in eutrophic water of higher silica and temperature (Hustedt, 1957; Ehrlich, 1973; Stoermer *et al.*, l974; Kilham *et al*., 1986). On the other hand, most of the *Aulacoseira* species indicated high growth requirements for silicon and demanded high silica content in water (Kilham and Kilham, 1971), presumably in different combinations of phosphorus and light (Kilham *et al*., 1986). *Aulacoseira* species were non-competitive, so their wide distribution normally coincided with low concentration of other diatoms (Wolfe *et al*., 2000). These taxa are also indicators of warmer climate, which may have led to wind-induced mixing in the lake, higher input of humic substances and increased precipitation (Laing and Smol, 2003). Moreover, *Aulacoseira ambigua* required increased turbulence to remain in a photic zone and reported high concentration of total phosphorus (TP) (Kilham *et al.*, 1986; Fritz *et al.*, 1993). *Aulacoseira granulata* and *A. ambigua* had summer blooms, which documented increasing moisture, greater flow through and higher lake level (Bradbury *et al.*, 2004).

Predominance of *Aulacoseira* species of ecological group A through several units in the studied FA-1 core denoted summer with high silica concentration. This ecological group was recorded in the early Holocene (19.6–19.8 m, 17.8–18.0 m), the middle Holocene interval (11.7–17.4 m, 11.1–11.4 m, 8.4–8.6 m, 8.15–8.20 m, 7.45–7.50 m); and the late Holocene at depth 5.75–5.80 m. Maximum abundances of *Aulacoseira granulata* associated with other *Aulacoseira* species and decreased abundance of *Stephanodiscus* and *Cyclotella* species could reflect a freshwater lake with relatively high level due to nutrient-rich influx from the Nile during a wet warm period. Moreover, maxima abundance of *Aulacoseira* species suggest stabilized conditions; remaining wet and windy with increased turbulence and upwelling in the lake, typical of a late phase of the Nile flood cycle (cf. Zalat, 1995). However, frequent occurrence of *Aulacoseira distans* in some intervals of the core pointed out probably to a slight tendency towards acidification of the lake with moderate decrease in pH of lake water, because *A. distans* was an acidophilous diatom, indicating pH < 7 (van Dam *et al.*, 1994). This might confirm a higher terrestrial nutrient supply with freshwater from the Nile during wet rainy periods.

Stephanodiscus spp. ecological group B is distinguished by highest abundance of planktonic freshwater *Stephanodiscus* species with relative frequency of 60–83% of the total assemblage. This group includes *Stephanodiscus rotula*, *S. agassizensis*, *S. minutulus*, *S. aegyptiacus*, *S.neoastraea*, *S. alpinus*, *S. hantzschii* and *S. niagarae.* These taxa were known to occupy slightly alkaline and eutrophic freshwater with low silica content (Gasse, 1986; Kilham *et al*., 1986; Zalat and Servant-Vildary, 2007). *Stephanodiscus minutulus* competed well for silicon but needed a plentiful supply of P and hence, it was more common in waters with relatively low silicon/phosphorus ratios (Kilham and Kilham, 1978). This species became frequently abundant in a spring diatom bloom of lakes enriched in P (Bradbury, 1975, 1988). *Stephanodiscus* taxa were dominant in winter and spring when increased turbulence could suspend these relatively heavy diatoms, therefore they could denote moist winters and springs with active circulation (cf. Bradbury, 1992; Bradbury *et al*., 2004). Dominance of small and intermediate-sized *Stephanodiscus* species (*S. minutulus, S. hantzschii*, and *S. agassizensis*) characterized spring bloom when nutrient loading was related to spring runoff, along with *Aulacoseira granulata*. The increased abundance of planktonic *Stephanodiscus* species reflected a high lake level, because of freshwater influx by the Nile and increased nutrient loading to the lake with low Si and high P supply rates prevailing at time of deposition (Zalat, 2015). These ecological conditions were repeated several times through the early Holocene (18.40–19.55 m), middle Holocene (10.40–11.05 m, 8.7–9.7 m, 7.6–7.8 m, 7.2–7.4 m) and late Holocene (6.4–6.9 m, 4.3–4.7 m). This reflects seasonal lake level fluctuations with rising slightly alkaline freshwater level several times during wet or humid climate in the Holocene (winter-spring season?).

Aulacoseira–Stephanodiscus spp. ecological group C was represented by mixed assemblage of common occurrence *Aulacoseira* spp. and *Stephanodiscus* spp. with relative frequency of 80–90% of the total assemblage. The group was recorded four times with different thickness in the FA-1 core at depths 18.1–18.3 m, 17.5–17.7 m. The appearance of *Aulacoseira–Stephanodiscus* spp. ecological group was indicative of deep lake with enhanced nutrient availability by repeated Nile water inflows to the lake at the transition of spring and summer.

Cyclostephanos dubius ecological group D was signified by high abundance of *Cyclostephanos dubius* (40–55%), associated with frequently occurrence of *Aulacoseira* spp., and *Stephanodiscus* taxa. This group was detected 3 times and had small thickness in the studied core. *Cyclostephanos dubius* was considered as a pelagic taxon, common in flowing and stagnant water in coastal area, oligosaprobic, alkalibiontic, halophilous "0.0–5 g/l" (Hustedt, 1930, 1957); eutrophic, in fresh and brackish water, pH value 6.99.0 (van Der Werff and Huls, 1957, 1974); planktonic, brackish water form (Cholnoky, 1968); halophilous, alkalibiontic, with pH value above 7.0 (Foged, 1973). The diatom assemblage of this ecological group is indicating a relatively high stand lake level with clear dominance of eutrophic freshwater conditions and slightly higher salinity and alkalinity through short time of warm-dry interval.

Aulacoseira spp.–*Cyclotella meneghiniana* ecological group E was characterized by high abundance of *Aulacoseira* spp. associated with commonly occurrence of *Cyclotella meneghiniana*. Other planktonic taxa including *Stephanodiscus* spp. and *Cyclotella* spp. were rare. This ecological group was recorded only once, with thickness of about 0.5 m. *Cyclotella meneghiniana* was recorded ecologically as a facultative planktonic taxon favored by moderately alkaline conditions (Hecky and Kilham, 1973; Richardson *et al*., 1978), in coastal and estuarine locations with water of varied chemistry (cf. Trigueros and Orive, 2000; Tibby and Reid, 2004). Its optimal development occurred at 20.1–20.6°C (Stoermer and Ladewski, 1976) but it was eurythermal (Gasse, 1986). It was reported from brackish water of the coastal Egyptian lakes, being dominant in spring and at the beginning of summer at water temperature 29–31°C (Zalat and Servant-Vildary, 2005, 2007). Common occurrence of *Cyclotella meneghiniana* with high abundance of *Aulacoseira* species and frequently to low amounts of *Stephanodiscus* taxa reflected warm eutrophic freshwater conditions with slight increased salinity and alkalinity during the time of deposition in the late Holocene.

In general, diatom analysis of lake sediments enabled to distinguish several freshwater and brackish conditions in the lake development during the Holocene (Marks *et* *al*., in press). At the beginning of early Holocene through the depth 19.95–26.0 m (ca. 9.5–8.7 cal kyrs BP), this unit is characterized by sandy muddy facies intercalated with bedded sand and completely barren to scarcely poorly preserved some heavily silicified diatom taxa. However, Zalat (1996) was recorded commonly abundance of *Nitellopsis obtusa* associated with sporadic occurrence of some *chara* taxa in the early Holocene unit that correspond to the basal unit of FA-1 core and suggested oligotrophic freshwater environment of a relatively deep lake with depth of about 4–12 m. This lake was coinciding with the Paleomoeris Lake, which had a low water level due to reduced annual influx from the Nile River (e.g. Hassan, 1986, 1988; Wenke *et al*., 1988; Kozłowski and Ginter, 1993). The absence of diatoms or rarely occurrence of poorly preserved forms could result from lowering levels of primary productivity, where the lake had poor nutrients in the early phase of the unstable connection between the Nile and the Faiyum depression.

Abrupt change in the environmental conditions occurred with deposition of diatom unit that completely dominant by *Aulacoseira* species. This phase was a result of distinct connection with the Nile and influx of freshwater into the Faiyum depression to the Premoeris Lake 8.8–8.2 cal kyrs BP (according to Wendorf and Schild, 1976). This interval was dominated by eutrophic freshwater planktic taxa, with peak abundance of *Aulacoseira* spp. (98%) of ecological group (A) (19.6–19.8 m), which suggests high trophic status of slightly alkaline freshwater environment. The rising lake level was continued to become deeper and the followed *Stephanodiscus* spp. ecological group (B) was flourished at depth 18.40–19.55 m. The early Holocene terminated with mixed assemblage of *Aulacoseira* spp.–*Stephanodiscus* spp. ecological group (C) at depth 17.45–17.70 m (ca. 8.2 cal kyrs BP). The predominance of these planktonic ecological groups A, B and C during the early Holocene suggests that the early Premoeris lake basin was already quite deep, freshwater, eutrophic and slightly alkaline environment during the wet climate. The prevalence of riverine taxa indicates increased discharge of the Nile water into the lake.

The middle Holocene started with lowering of the lake level to form slightly deep to relatively shallow hydrologically stable (late Premoeris and Protomoeris Lake) in the Faiyum depression in a long interval (8.2–5.4 cal kyrs BP), which was characterized by eutrophic, slightly alkaline freshwater environment with high silica concentration during warm-wet climate. This was followed by seasonal and annual changes in the diatom assemblages, which reflect seasonal fluctuations in lake level, between high stand freshwater and low stand slightly brackish water during warm and dry conditions through the period ca. 5.4–4.0 cal kyrs BP (Moeris Lake) due to the gradual disappearance of the hydrological connection between Faiyum Oasis and the Nile. In the late Holocene, the lake has been continuously diminished and shallower, presumably due to occasional disconnection to the Nile. But through some intervals, 3.9–3.4 cal kyrs BP, the lake water level returned to become relatively high with great abundance of *Stephanodiscus* spp. ecological group B, which point to deep, eutrophic and slightly alkaline freshwater environment most probably due to increased local rainfall episodes in the Faiyum area and occasional high stand of the Nile. The lower concentration of diatom valves at some depths (6.3–5.6, 4.95–4.8, 4.9, 42–4.0 m), particularly in the sandy units, may be due to lower diatom productivity. The upper part of the core (3.9–2.0 m) was completely barren of diatom frustules, reflecting marked environmental changes in the lake, connected with transition from freshwater through brackish to saline conditions.

CONCLUSIONS

Summarized in terms of diatom results, the environmental conditions and climatic changes in the Faiyum depression during the Holocene are interpreted as follows:

1) Freshwater, eutrophic, slightly alkaline episodes with relatively high stand lake level characterized by high silica during warm-humid climate (summer phase) coincide with maximum abundance of planktonic *Aulacoseira* spp. ecological group (A).

2) Deep open freshwater, eutrophic, slightly alkaline episodes with high stand lake level characterized by low silica and high phosphorus during cold to temperate –wet climate (winter-spring phase) coincide with maximum abundance of planktonic *Stephanodiscus* spp. ecological group (B).

3) Deep freshwater, eutrophic, slightly alkaline with enhanced nutrient availability by repeated Nile water inflows to the lake at the transition of spring and summer climate represented by mixed assemblage of *Aulacoseira* and *Stephanodiscus* spp. ecological group (C).

4) Slightly brackish, eutrophic shallow water environment with increased alkalinity and salinity during warm-dry conditions and represented by high abundance of *Cyclostephanos dubius* ecological group (D).

5) Slightly brackish, eutrophic, alkaline shallow water and relatively lowering lake-level during summer warm and dry conditions represented by great abundance of planktonic diatoms of *Aulacoseira*–*Cyclotella meneghiniana* ecological group (E).

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