Late Pleistocene palynological sequence from Ohalo II, Sea of Galilee, Israel

Mina Weinstein-Evron, Dafna Langgut, Silvia Chaim, Alexander Tsatskin & Dani Nadel

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A new high-resolution palynological record from the Sea of Galilee (Israel), roughly spanning the Last Glacial Maximum (LGM) obtained from a trench dug in the vicinity of the well-dated prehistoric site of Ohalo II (23–24 ka cal. BP) — combined with detailed litho-stratigraphic and magnetic susceptibility analyses — provides evidence of vegetation, lake levels and climate change in the northern Jordan Valley. The sequence begins with laminated marls of the last Lake Lisan high stand and ends with the near-shore deposits containing the prehistoric site. Palynologically, the early phase of the high stand (pollen zone 1) is characterised by high-AP (mainly Quercus ithaburensis), reflecting a relatively humid climate. During its later part (zone 2), the increase in Artemisia indicates a regional drying. Several fluctuations in lake levels and humidity are recorded (pollen zones 3–4) prior to human occupation at the prehistoric camp, during a renewed humid climate (pollen zone 5); in its early phase Quercus calliprinos spread again in the mountainous areas around the lake, while the maquis of the later phase was typified by the deciduous Q. ithaburensis. The fact that a variety of data sets were retrieved from the very same section renders their correlation and combined environmental interpretation reliable and unique for this time period in the southern Levant. The reconstructed palaeoenvironmental picture indicates a rather mild LGM in the northern Jordan Rift. Although there are 17 14C and U-Th dates from the studied section, dating inconsistencies prevent direct correlations between the observed regional fluctuations and global events.

Keywords: LGM; southern Levant; palaeoclimates; palynological analysis; Jordan Valley

INTRODUCTION

The two large lakes in the Jordan Rift Valley (Israel), the Sea of Galilee transient lake and the Dead Sea terminal lake, provide deep exposures that record Late Pleistocene water-level changes and related climate fluctuations (e.g. Begin et al., 1974; Bartov et al., 2002; Hazan et al., 2005; Torfstein et al., 2013; Lev et al., 2014; Stein, 2014a,b and references therein). The vertical topographic difference between the Dead Sea (the lowest place on Earth) and the Sea of Galilee (Lake Kinneret) is 200 m. Lake Lisan, the precursor of the two, stretched over both and the entire expanse between them during wet spells of Marine Isotope Stage (MIS) 3 and MIS2, when it overflowed the Wadi el Malih and Yarmouk sills (Figure 1).

Direct data regarding past plant communities during these fluctuations are mostly provided by palynological studies of cores retrieved from the Jordan Valley lakes (e.g. Horowitz, 1979). However, the palynological records are partial, do not cover in detail the entire Late Pleistocene sequence, and commonly suffer from insufficient radiometric dating. Hence, correlation among them and their association with more northern palaeoclimate records (Develle et al., 2011; Gasse et al., 2015) or with global events is somewhat hampered (Weinstein-Evron, 1983, 1990; Baruch & Bottema, 1991, 1999; Langgut et al., 2011; Aharonovich et al., 2014; Gasse et al., 2015 and references therein). Significantly, compared to earlier periods (e.g. Weinstein-Evron, 1983) and especially the Holocene (Neumann et al., 2007, 2010 and references therein; Litt et al., 2012; Langgut et al., 2014), the time-period representing MIS2 and particularly the Last Glacial Maximum (LGM) is poorly known and is the focus of the current study. For the Sea of Galilee area, detailed studies are currently available only for the second half of the Holocene (Baruch, 1986; Langgut et al., 2015).

Severe droughts between 1989 and 2001 caused a dramatic water-level drop in the Sea of Galilee, exposing the submerged fisher-hunter-gatherers’ camp of Ohalo II, originally dated to 22.5–23.5 ka cal. BP (Nadel et al., 1995, 2001) and located on top of the Lisan Formation. The site is particularly interesting as human occupation here represents a low stand between the highest documented stand of Lake Lisan (c. 27 and 25 cal. ka BP) and later inundations, before its final retreat resulting in two widely separated water bodies: the Dead Sea and the Sea of Galilee (Figure 1). The Ohalo II site covers an area of at least 2000 m² and contains in situ remains of six brush huts, several adjacent open-air activity locales with hearths, and a grave (Figure 2). The charred building materials of one brush hut were studied and identified (Nadel & Werker, 1999) and three brush huts had on the floor grass bedding made of weed bundles...
A wealth of in situ remains was found in all features. These comprise charred seeds, animal bones, flint artefacts, grinding stones, stone bowls, bone tools and beads (Nadel et al., 2004b).

Several trenches were dug at the Ohalo II site as part of its archaeological investigation, in order to document and study the pre- and post-site geological sequence and the implied palaeoenvironmental settings. Furthermore, the last pre-occupation layers are used to reconstruct the environmental changes leading to the receding of the lake and the establishment of a lakeshore habitat hospitable to human occupation.

Trench 104–106 was cut during the 1999 archaeological excavation season at the site (directed by D.N.) to a depth of 5 m, through the archaeological and pre-occupation layers (Figure 2). It provides a rare opportunity for a multi-disciplinary study of past water-levels, palynological records and climatic fluctuations. The section was subjected to a detailed lithological/limnological analysis (Hazan et al., 2005), later complemented by isotopic and faunistic analyses (Lev et al., 2014). Further detailing of the sedimentary sequence was carried out while sampling for pollen analysis of the current work (Figure 3; see below). The palynological record retrieved from this trench enables the reconstruction of late Pleistocene vegetation and climate changes in the area from c. 27 to 25 ka until c. 23 ka, the date of the prehistoric camp capping the trench sequence. The prehistoric site, in turn, is overlain by a thin layer of laminated marls (Belitzky & Nadel, 2002; Tsatskin & Nadel, 2003).

Dating of the sequence exposed in the trench was based on re-calibration of previously published 14C dates (Hazan et al., 2005) and on Uranium-Thorium ages performed on aragonite stem casts (Lev et al., 2014). No dates are available for the lower part of the trench; however, based on stratigraphic correlations with the Lisan sequence in the Dead Sea area (Bartov et al., 2002), it is estimated at c. 27–25 ka (Lev et al., 2014). Most of the 17 dates from the trench relate to the

Figure 1. Map of the Lisan Lake at its maximum expansion c. 27/25 ka, with the location of Wadi el Malih and Yarmouk sills and the site of Ohalo II.
upper half of the section. While the dates are not always arranged coherently (Figure 3), it has been suggested that the marly sediments with Melanopsis and ostracods represent the period between 24 and 22/21 ka (see also Bartov et al., 2003). Three additional dates were obtained during the current study and are discussed below along with the other available dates.

Dating of the Ohalo II prehistoric site is based on samples from in situ archaeological features. Thus, 11 loci were directly dated by 34 14C readings provided by four laboratories, mostly ranging between 22.5 and 23.5 ka cal BP (Nadel et al., 1995, 2001, 2004b; Nadel, 2002).

Based on the lithological and sedimentological variations, the changing amounts of ostracods and other microfauna (e.g. foraminifera), the various isotopic analyses of ostracod shells retrieved from the trench and the dating of the sequence, several important changes in the environmental and depositional conditions during the period under discussion were implied (Hazan et al., 2005; Lev et al., 2014). At the bottom of the trench, c. 27–25 ka cal BP, lake levels reached 170 m bsl (below sea level), the highest level of the sequence; this part represents the wet and vegetated last glacial MIS2 in this region. During this period, Lake Lisan reached its maximum elevation and, crossing the Wadi el Malih sill c. 30

Figure 3. Lithology, magnetic susceptibility, palynological characteristics and chronology of Trench 104–106 section in Trench 104–106, Ohalo II. (1) massive marl; (2) thin laminated marl; (3) marl with calcareous and/or basaltic sand; (4) bedded (broadly spaced laminated) marl; (5) dark-coloured marl; (6) archaeologically related dark-coloured layers; (7) charred root remnants; (8) Melanopsis snails. Broken line delineates post-occupation laminated marl found in a previous study of the northern part of the site (after Tsatskin & Nadel, 2003).
km south of Lake Kinneret (Figure 1), extended northwards to the Sea of Galilee basin (Begin et al., 1974; Bartov et al., 2002, 2003; Hazan et al., 2005; Torfstein et al., 2013; Stein, 2014a,b).

The lake retreated to its last glacial low stand at c. 214 m bsl during the time interval of c. 24 to 22/21 ka cal BP. According to Hazan et al. (2005) and Lev et al. (2014), the beginning of this retreat (c. 24 ka cal BP) coincides with the age of the Heinrich event H2 at northern latitudes, with the high numbers of ostracods and the foraminifera Ammonia beysida further implying higher salinity during this period of increasing aridity. The later, low stand of the lake in the upper part of the sequence provided favourable conditions for human occupation of the newly-exposed shore (the Ohalo II site; Figures 2, 3).

In this paper we present a detailed palynological analysis of the Trench 104–106 section incorporated with its litho- and magneto-stratigraphic depositional context. Furthermore, we include palynological data from an in situ brush hut and the prehistoric camp’s surface, in order to enhance the environmental database regarding the occupation period. Our chronological framework is based on all available dates, including those derived from the in situ archaeological features that top the sequence and three new radiometric dates from the trench. Incorporating our results with previous studies, this paper provides new insights into past water-level changes and plant communities, resulting in a detailed palaeoenvironmental reconstruction of the Sea of Galilee basin during MIS2.

THE STUDY AREA

Ohalo II is located on the southwestern shore of the Sea of Galilee, at 211.5–213 m bsl (Figures 1, 2). The lake’s drainage basin includes the Galilee, the Golan Heights and Mount Hermon (Figure 4). Together with several small streams, it is fed mainly by the Jordan River which also drains the lake southwards to the Dead Sea.

On the west, north and east the lake is bounded by steep fault escarpments, rising as much as 500 m above the lake surface. The highest summits in the area are those of Mount Hermon (2814 m), located some 60 km northeast of the lake, and Mount Meron (1200 m), in the Upper Galilee, 20 km to the northwest. Cretaceous and Early Tertiary sedimentary rocks, with the derived Terra Rossa and Rendzina soils, characterise the lower slopes of the hills to the south-east and south-west of the Hula basin (Kafri & Lang, 1979), while further north the lower slopes (400–1200 m) of Mount Golan and the reaches of the northern Gilead) and west (Lower Galilee) a variety of Irano-Turanian vegetation (Zohary, 1962) extends to the southeastern parts of the Lower Galilee. An Irano-Turanian shrub steppe of Retama raetam grows on the lower slopes of the hills to the south-east and south-west of the valley. On the lower slopes of the mountains (up to 400 m) east (the southern Golan and the reaches of the northern Gilead) and west (Lower Galilee) a variety of heavily-destroyed Quercus ithaburensis formations occur with accompanying undercover of Mediterranean shrubs and herbs. Parts of the Gilead range are also covered by remnants of steppe-forest (Figure 4). According to Robinovich-Vin (1977), a similar kind of steppe-forest may have covered the eastern slopes of the Lower Galilee in the past. On the higher slopes (400–1200 m) Quercus calliprinos–Pistacia palaestina evergreen forests are the most common association, occasionally with some Pinus halepensis. Above 700–800 m the evergreen oak is joined by deciduous oaks, mainly Quercus boissieri. An Oro-Mediterranean zone (1200–1900 m) is confined to the Hermon, and is presently dominated by a sparse, low forest of deciduous oaks including Quercus boissieri, Q. cerris and Q. libani, that may have included Cedrus libani in the past (Shmida, 1980; Auerbach and Shmida, 1993).

It is overlain by an Alpinno-tragancathic zone which presently (above 1900 m) supports steppe vegetation of low, cushion-forming spiny shrubs dominated by the Onobrychis corvata and Bromus lactucomus association (Shmida, 1980). Remnants of Amygdalus communis–Crataegus aronia steppe forest occur mainly east of the Mediterranean vegetation belt. Further east, it gives way to an Irano-Turanian Artemisia herba-alba steppe. For detailed accounts of the vegetation in the area see Zohary (1962, 1973, 1980) and a summary by Baruch (1986).

Around the Sea of Galilee, the influence of the Irano-Turanian belt reaches the southern and eastern shores of the lake, where in several areas Chenopodiaceae and Artemisia are very abundant (e.g. on the eastern shores of the Lake). The banks of the lake support stands of Phrangmites australis and Vitex agnus-castus. Marsh vegetation is found in the Betheia plain, northeast of the lake, where it consists of Typha domingensis, Rubus sanctus and various Cyperaceae. The banks of the Jordan River, north of the lake, are covered by a forest of Salix acmophylla; also present here are Tamarix jordanis, Fraxinus syriaca and Populus euphratica. On the southern banks of the lake a Tamarix forest with some Phragmites australis, Vitex agnus-castus, Arundo donax and Salix acmophylla is widespread (Zohary, 1980). On the banks of ephemeral wadis draining into the lake, Nerium oleander is common; on wadi banks
west of the lake *Platanus orientalis* and *Ulmus canescens* may also be encountered (Waisel, 1969; Horowitz, 1979: 193 and references therein).

**METHODS**

**Lithostratigraphy**

Lithological and palynological samples were taken from Trench 104–106, dug by a backhoe perpendicular to the shoreline (Figure 2). Before sampling, the deposits in the trench were carefully characterised in the field in terms of their colour, texture, grading, presence of organic remains and malacoфаna. As shown by studies of the Lisan formation, high stands of Lake Lisan are generally represented by laminated aragonite and silt detritus (Begin *et al*., 1974; Bartov *et al*., 2002; Hazan *et al*., 2005). The identification of laminated Lisan-type deposits was thus used as a major diagnostic criterion along the studied section.

Low field magnetic susceptibility (MS) of bulk samples was measured at two different magnetisation frequencies (0.47 and 4.7 kHz) using the dual-frequency Bartington M2 susceptibility meter. Thus, the frequency dependence of susceptibility, or susceptibility difference (SD), could be determined (Evans & Heller, 2003). We have noticed that high-frequency MS values along the whole sequence were as low as 2–4%. Taking into account that high frequency MS values for magnetically weak samples (<10×10^{-8} m^3 kg^{-1} MS) produce unreliable data (Dearing, 1999), these results are not presented in this paper. Significantly, the MS measurements were made on the same samples, which were subjected to palynological analysis.

Petrographic thin sections were made from undisturbed samples of lacustrine deposits after polyester resin impregnation under vacuum. Thin sections were analysed with polarising light microscope Olympus-2 and described following Stoops (2003).

**Dating**

Three clay samples with organic material were radiocarbon-dated. The samples were prepared in the Radiocarbon Dating Laboratory of the Weizmann Institute of Science, Rehovot (Israel) and measured by the Accelerator Mass Spectrometry (AMS) Laboratory at the NSF-radiocarbon facility of the University of Arizona (E. Boaretto, personal communication, 2012). Calibration was performed using OxCal 4.2.2 (Bronk Ramsey & Lee, 2013) and the IntCal13 atmospheric calibration curve (Reimer *et al*., 2013). Age ranges are defined by the 2σ envelope error.

The chronological framework of the Ohalo II profile was constructed by integrating the three new dates with the dates which were previously published for the same sequence (Hazan *et al*., 2005; Lev *et al*., 2014) and were re-calibrated by us using the same IntCal13 program. Dating of the top of the sequence is based on 34 ^14C dates of the Ohalo II site (Nadel *et al*., 1995, 2001, 2004; Nadel, 2002).

**Palynology**

**Sampling and pollen extraction**

Ten short sedimentary ‘cores’ c. 0.55 m each were extracted from the southern wall of the trench using rectangular-sectioned, 6 cm x 6 cm, aluminium-covered plastic chases, together providing a 5-m deep continuous sequence. In order to avoid gaps in the sedimentary sequence, c. 5 cm overlaps between subsequent ‘cores’ were maintained. Altogether, 65 pollen samples were processed, each weighing 30 g. In addition to the geological samples, several archaeological contexts were sampled (Figure 2). These include the floor of one brush hut (Locus 2) and an open-air activity area with several hearths near the hut (Locus 7), represented by two samples each. In addition, the two upper samples from a trench dug through sediments more-or-less contemporaneous with the occupation period were studied (Locus 20; Figure 2). A study of the recent ‘pollen rain’ near the site is based on a sample which was collected in 2012 from sediments deposited on top of plastic sheets which were placed over the Ohalo II submerged site at the end of the last excavation season (2001). This sample therefore represents sediment and pollen accumulation of the last several years. The results will be discussed against those derived from lake surface sediments from different locations within the lake (Horowitz, 1979; Langgut *et al*., forthcoming).

The samples were processed using standard palynological techniques (Faegri & Iversen, 1989). A tablet of *Lycopodium* (∼10 679 spore grains in each tablet) was added to each sample for pollen concentration calculations (Stockmar, 1971).
Pollen identification and counting

Some of the samples proved to be poor in pollen but in most of them between 200 and 700 pollen grains were counted. The comparative reference collection at the Palynological Laboratory of the Zinman Institute of Archaeology, University of Haifa, and relevant atlases and reports (van Zeist & Bottema, 1977; Reille, 1985, 1988, 1989) were used to identify the pollen to the highest possible systematic level. Results of the pollen analysis are presented in the pollen curve (Figure 5), constructed using the POLPAL 2004 program (Walanus & Nalepka, 1999). The left column presents the Arboreal Pollen (AP) and Non Arboreal Pollen (NAP) ratios. Curves of the various pollen types are arranged in two groups: AP and NAP. The curves of the pollen concentrations and of the sum of the hydrophilous taxa ratios (calculated from the total palynomorph sum) are presented in Figure 3. Given the rarity of hydrophilous taxa, a detailed compositional curve is misleading and thus is not presented.

RESULTS

The lithostratigraphic sequence

The lithostratigraphic sequence is composed mainly of marls – massive or laminated – that contain varying amounts of Melanopsis snails. The depositional sequence (Figure 3) consists of three major units from bottom to top. Unit I (from 5.20 m, visible, to 3.60/3.70 m) is composed of closely spaced continuous laminated marls comprising mm-thick soft calcareous laminae alternating with silty clay detrital laminae. The upper contact is sharp and linear. Lithologically, this unit closely resembles in appearance the varved Lisan sediments in the Dead Sea area associated with high stands of the lake (Bartov et al., 2002; Hazan et al., 2005; Stein, 2014b and references therein). Unit II (3.60/3.70-0.90 m) shows a complex sequence of lacustrine, mainly massive marls with distinct beds of dark-coloured marls apparently rich in fine-grained organic matter, sand-rich levels and irregular widely spaced laminated marls. Melanopsis malaco fauna is scattered throughout the deposits, with higher concentration at c. 2.60 m depth. In addition, 0.5–1.0 cm thick remains of roots of apparently bank vegetation are present with maximal concentration at c. 3.00 m depth. The upper contact is gradual. Unit III contains the prehistoric site, incipient bioturbated soils and wetland deposits. While the uppermost part of the sequence was disturbed by the backhoe digging the trench, the deposits covering the archaeological remains (laminated marls) were observed previously within the excavated area of the Ohalo II site (Belitzky & Nadel, 2002; Tsatskin & Nadel, 2003).

Low field low-frequency magnetic susceptibility measurements sampled with high resolution allowed us to refine the studied lithostratigraphic sequence (Figure 3). There is a close agreement of the MS curve with the lithostratigraphic division. Unit I displays extremely low MS values – less than 5–10×10^{-8} m^3kg^{-1} – distributed uniformly along the entire lower part of the sequence. In contrast, Unit II shows a general increase in magnetic susceptibility values, although with strong fluctuations, somewhat different in the lowermost (subunit IIa) and uppermost (subunit IIb) units. The most pronounced pattern of fluctuation is recorded in subunit IIa, between 3.60/3.70 m and 1.80 m. Here, MS values are as low
as \(\sim 20 \times 10^{-8} \text{ m}^3\text{kg}^{-1}\) in magnetically weak samples, while peaks show values as high as \(\sim 60 \times 10^{-8} \text{ m}^3\text{kg}^{-1}\) MS. In subunit IIb, between 1.80 m and 0.90 m, the MS values in ‘lows’ are similar to those in the lower part of Unit II, while peaks show appreciably higher MS values (the highest along the sequence), reaching \(\sim 90 \times 10^{-8} \text{ m}^3\text{kg}^{-1}\) MS. Unit III (between 0.90 m and the top of the sequence) includes deposits related to the Ohalo II prehistoric site and the overlying laminated marls. The latter are characterised by a pronounced decrease of magnetic susceptibility values, less than \(\sim 10 \times 10^{-8} \text{ m}^3\text{kg}^{-1}\) MS, largely similar to Unit I (Isatskin & Nadel, 2003).

Thin sections of the post-occupation deposits that culminate Unit III display alternation of micritic, clay rich and silt detritus in somewhat disturbed discontinuous laminae (Figure 6a). Tabular-prismatic gypsum crystals, which provide evidence of post-depositional evaporative origin, are superimposed on earlier formed opaque orange-brown Fe nodules with diffuse boundaries (Figure 6a). The latter provide evidence of fluctuating redox conditions during deposition. Significantly, the observed lamination pattern (Figure 6b) bears certain resemblance to laminated marls in the Dead Sea area (e.g. Prasad et al., 2009).

**Dating**

Three \(^{14}\text{C}\) dates of clay samples with organic material yielded ages of 20720±170 BP, RTA 3612; 24050±300 BP, RTA 3613; and 20050±180 BP, RTA 3614, for depths of 0.65, 1.55 and 2.00 m, respectively. Their calibrated ranges are presented in Table 1. The new dates show some inconsistency, as the youngest date was obtained for the lowermost sample. Still, similar to the previously obtained dates, they fall within the same range argued for the later part of the section.

**Palynology**

Results of the palynological analysis of the trench sequence are summarised in Figure 5. Those of the archaeological features are presented in Table 1.

The palynological sequence can be divided into five pollen zones (from bottom to top):

1. Pollen zone 1, from the bottom of the sequence to a depth of c. 4.15 m, is characterised by high AP levels (37.3–53.0%): the highest in the sequence. *Q. ithaburensis* is the most common oak type, but *Q. calliprinos* is also high, especially at the bottom part of the sequence. *Pinus* appears continuously. Low levels of Chenopodiaceae and Amaranthaceae (Cheno/ Ams) (between 13.5% and 38.2%) and moderate levels of Poaceae (up to 21.2%) and *Artemisia* (9.3%) characterise the NAP. Apioaceae are relatively high (up to 9.1%). *Asteraceae Asteroidae, Centaurea* and Ephedra are common, with the latter appearing mainly in the upper part of the zone.

2. In pollen zone 2, between 4.15 m and 3.60 m, AP levels are lower (as low as 6.4%), mainly with *Q. ithaburensis*, together with *Q. calliprinos*, *Pinus* and some *Olea*. Cerealia-type (13.1–36.0%) and *Artemisia* (4.6–19.1%) reach their highest levels in the sequence and Cheno/Ams reach their lowest (18.9%). Poaceae, Apioaceae, *Centaurea*, some *Asteraceae Asteroidae* and *Ephedra* are the other main NAP types.

3. In pollen zone 3, between 3.60 m and 2.60 m, AP levels remain relatively low, mainly with *Q. ithaburensis* and some *Q. calliprinos*. *Q. ithaburensis* is slightly higher in subzone 3a (3.60–3.00 m) where Cheno/Ams reach their peak (up to 80.0%). In the later part (subzone 3b; 3.00–2.60 m) Cheno/ Ams decrease again, *Q. calliprinos*, *Pistacia* and *Pinus* become more abundant within the AP, while the NAP Poaceae, *Artemisia* and Apioaceae increase. *Ephedra* reaches its highest levels in the sequence (2.1–6.0%).

4. In pollen zone 4, from 2.60 to 1.20 m, AP levels and the various oaks are low, mainly in its upper part (2.3–25.9%). *Pinus* and *Olea* reach their highest levels, with the latter appearing continuously, especially in the lower part of this pollen zone. Amongst the NAP, Cheno/Ams levels are high, while Poaceae and Apioaceae decrease. *Ephedra* maintains relatively high ratios while *Artemisia* decreases until it practically disappears in the upper part of the zone, slightly before Cerealia-type pollen also disappears. *Asteraceae Cichorioideae* and *Centaurea* show their highest levels in the upper part of this zone, when Fabaceae, Liliaceae and Lamiaceae (within the other NAP curve) are also abundant.

5. In pollen zone 5, from c. 1.20 m to the surface, AP levels rise again (reaching maximum values of 26.6%). In the early phase (subzone 5a) *Q. calliprinos* is dominant while in the upper part (subzone 5b) *Q. ithaburensis* prevails. The composition of the AP is more varied in subzone 5a, where *Pinus* and *Fraxinus* (within the hydrophilous trees) appear almost continuously, accompanied by occasional *Cupressaceae, Betula, Castanea*, *Fagus* and *Juglans* pollen. Cheno/Ams, somewhat less-

![Figure 6](image-url) Photomicrograph of laminated marl overlying the Ohalo II prehistoric site, plane polarised light, 2.4 mm frame length. (a) Alternation of detrital silt (white arrow) with clay lamina (black arrow), note dense micritic lamina of greyish colouration between the two; (b) diagenetically formed scattered gypsum crystals (white arrows) that post-date the formation of Fe opaque nodule (possibly pyrite) with diffuse boundary (black arrow).
abundant in subzone 5a than in 5b, are the main NAP group, with occasional peaks of Asteraceae Asteroideae, mainly in the later phase, sometimes accompanied by \textit{Centaurea} pollen. Poaceae are well represented and Cerealia-type pollen peaks especially in the relatively low-AP period between subzones 5a and 5b and, again, at the top of the sequence. Apiaceae appear almost continuously throughout this zone. \textit{Ephedra}, \textit{Liliaceae}, \textit{Dipsacaceae}, \textit{Polygonaceae} and \textit{Caryophyllaceae} are more abundant in subzone 5a.

Pollen concentrations vary along the sequence with the highest levels (up to 64 500 pollen grains/g sediment, with an isolated peak of 282 690 pollen grains/g sediment) characterising the lower part of the sequence, where two peaks occur roughly between 4.90–4.40 m and 4.20–3.50 m (Figure 3). Much lower pollen concentrations (rarely exceeding 22 480 pollen grains/g sediment) characterise the upper part of the profile (3.50–0.35 m), with the top of the sequence attaining relatively high concentrations (42 360 pollen grains/g sediment).

Hydrophilous pollen appears in relatively low ratios along the sequence (Figure 3). This group is composed of bank vegetation (mostly \textit{Cyperaceae}, with sporadic \textit{Sparganium} sp. and rare \textit{Thypha} sp.) and some aquatic plants (\textit{Potamogeton} sp. and \textit{Myriophyllum}). The only marked appearance of hydrophilous taxa, where they continuously attain counts of between c. 110 and 380 grains, occurs at the 4.10–3.70 m section where high values of \textit{Potamogeton} sp. were documented.

Pollen extracted from various archaeological contexts of the Ohalo II site (Figure 2; Table 1) represents the top of the sequence. Percentages of the various pollen types are arranged in two groups – \textit{Arboreal Pollen} (AP) and \textit{Non Arboreal Pollen} (NAP) – followed by the calculated pollen concentrations.

<table>
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<th>Provenance</th>
<th>Locus 2 E85b</th>
<th>Locus 2 F85b</th>
<th>Locus 7 H 92 c</th>
<th>Locus 7 H 94 a</th>
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<th>Locus 20 # 2</th>
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<td>0.3</td>
<td>1.6</td>
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<td>–</td>
<td>–</td>
<td>0.8</td>
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<td>0.2</td>
<td>0.9</td>
<td>–</td>
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<tr>
<td>\textit{Rosaceae}</td>
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<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>\textit{Pinus}</td>
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<td>–</td>
<td>5.7</td>
<td>–</td>
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<tr>
<td>\textit{Olea}</td>
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<td>0.4</td>
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<td>\textit{Fraxinus}</td>
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<td>–</td>
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<td>0.2</td>
<td>0.4</td>
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</tr>
<tr>
<td>\textit{Rhamnus}</td>
<td>–</td>
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<td>\textit{Betula}</td>
<td>–</td>
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<tr>
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</tr>
<tr>
<td>Total AP</td>
<td>1.8</td>
<td>0.9</td>
<td>2.7</td>
<td>3.6</td>
<td>32.9</td>
<td>34.2</td>
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<tr>
<td>Poaceae</td>
<td>1.4</td>
<td>4.1</td>
<td>3.5</td>
<td>3.8</td>
<td>11.6</td>
<td>7.6</td>
</tr>
<tr>
<td>\textit{Cerealia}</td>
<td>0.9</td>
<td>0.6</td>
<td>–</td>
<td>4.6</td>
<td>6.6</td>
<td>4.7</td>
</tr>
<tr>
<td>\textit{Artemisia}</td>
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<td>–</td>
<td>0.5</td>
<td>2.8</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Cheno/Ams</td>
<td>94.0</td>
<td>92.2</td>
<td>90.7</td>
<td>52.1</td>
<td>26.4</td>
<td>27.6</td>
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<tr>
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<td>–</td>
<td>0.7</td>
<td>1.0</td>
<td>2.4</td>
<td>13.4</td>
<td>12.0</td>
</tr>
<tr>
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<td>–</td>
<td>0.3</td>
<td>1.0</td>
<td>1.4</td>
<td>2.5</td>
</tr>
<tr>
<td>\textit{Asteraceae Cich.}</td>
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<td>–</td>
<td>–</td>
<td>0.2</td>
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</tr>
<tr>
<td>\textit{Centaurea}</td>
<td>0.7</td>
<td>0.4</td>
<td>–</td>
<td>27.1</td>
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<td>3.3</td>
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<tr>
<td>Polygonaeeae</td>
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<td>–</td>
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<tr>
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<td>0.7</td>
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<td>0.8</td>
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<tr>
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<tr>
<td>\textit{Onagraceae}</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Total counted</td>
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<td>580</td>
<td>657</td>
<td>640</td>
<td>567</td>
<td>276</td>
</tr>
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<td>\textit{Cyperaceae}</td>
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<td>3</td>
<td>–</td>
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<td>\textit{Lemna}</td>
<td>–</td>
<td>–</td>
<td>4</td>
<td>4</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td>\textit{Potamogeton}</td>
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<td>–</td>
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<td>–</td>
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<td>–</td>
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<tr>
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<td>–</td>
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<td>–</td>
</tr>
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<td>Total hydrophilous (n)</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Concentrations</td>
<td>2797</td>
<td>3237</td>
<td>6388</td>
<td>9170</td>
<td>20432</td>
<td>32868</td>
</tr>
</tbody>
</table>

rare hydrophilous pollen is given as numbers only, at the bottom of the table.

AP levels are low in both the hut (Locus 2) and activity area near it (Locus 7), 0.9–1.8% and 2.7–3.6%, respectively, with mainly Quercus and Pinus. While still low, the Locus 7 samples exhibit a more varied picture, with some representation of Olea, Betula, and Salix pollen. Cheno/Ams are clearly over-represented in the hut samples (92.2–94.0%) and in one of the Locus 7 samples (90.7%); they are quite high in the other sample of Locus 7 (52.1%), where Centaurea levels are exceptionally high. Other NAP, more common and varied in the latter than in other samples of the two contexts, are Poaceae (1.4–3.8%), Cerealia-type pollen (0.6–4.6%), Apiaceae (0.7–2.5%) and Asteraceae Asteroideae (up to 1%). Hydrophilous pollen is rare in all samples. Worth noting is the occurrence of Artemisia and of water plants (Lemna) in the two samples of Locus 7.

The pollen spectra of Locus 20, an open area about 3 m from the nearest hearths and 12 m from the nearest brush hut, show high AP levels (32.9–34.2%), with mainly Quercus ithaburensis (14.5–22.5%). Pinus levels are relatively high in one sample (5.7%) and other tree taxa occur very sporadically. Cheno/Ams still dominate the NAP group (26.4–27.6%) with Poaceae (7.6–11.6%), Cerealia-type (4.7–6.6%) and Apiaceae (12.0–13.4%; mainly Bunium type) as the other main types. Asteraceae, Centaurea, Fabaceae and Ephedra are relatively abundant.

The recent pollen sample collected from the sediments accumulated on the plastic cover protecting the site is clearly dominated by Tamarix (more than 90%), and therefore mainly represents the nearby bank Tamarix ‘forest’ that has re-invaded the shores of the lake since the last, modern retreat of the lake. Palynological studies, which were conducted in the inner part of the lake (rather than on its shores), showed very low frequencies of common bank vegetation, due to the distance from the shore of the lake as well as from the Jordan River inlet (Horowitz, 1979; Langgut et al., forthcoming).

**DISCUSSION**

The current analysis of the depositional sequence at Ohalo II, incorporating data from the deep trench and the prehistoric lake-shore site, clearly indicates two high-stands of the lake represented by finely laminated calcareous, magnetically depleted marls. The earlier phase of this depositional environment is found in the 5.10 m to 3.60/3.70 m depth interval of the trench. The second high-stand, marked by similar deposits, occurred after the occupation of the prehistoric site. The post-occupation laminar deposits unconformably overlying the archaeologically-related layers are found sporadically within the excavation area due to subsequent erosion.

Depositional sequences around Ohalo II clearly show the late Pleistocene fluctuating levels of the lake (Belitzky & Nadal, 2002; Nadal et al., 2004b; Hazan et al., 2005) with corresponding changes in salinity of near-shore lacustrine environments, related changes in the ostracod/foraminifera composition and geochemical processes revealed by stable isotopes (Lev et al., 2014). Detailed rock magnetic studies also indicate strong geochemical and mineralogical transformations, e.g. sulphidisation of detrital ferrimagnetic minerals, such as (titano-) magnetite, into diagenetic mineral, such as ferrimagnetic iron sulphide (greigite) (Nowaczyk, 2011). Noteworthy, the combined magnetic susceptibility curve obtained in the current study along the trench section, and a previous study of archaeologically related deposits (Isaetkin & Nadel, 2003), agrees well with the results of detailed rock magnetism investigations in the cores drilled near the site (Ron et al., 2007).

Before embarking on the discussion of the pollen data, the chronological issue must be addressed. In spite of the seeming wealth of available dates from the trench (n=17, Figure 3), there are two kinds of inconsistencies. The first relates to the discrepancy within the series of 14C dates. The second involves the difference between 14C and U-Th dates, with the latter exhibiting a better age vs depth relationship. These inconsistencies prevent a reliable dating of the different pollen zones and the inferred climatic events or the assessment of their duration. All that can be confidently said is that the studied sequence was deposited between c. 25 ka BP (the top of the high stand of Lake Lisan, i.e. the top of the laminated layers at the bottom of the trench; Lev et al., 2014) and the date of the prehistoric site at the top of the sequence. The range of dates derived from the various brush huts at the Ohalo II site was estimated to be c. 23.5–22.5 cal. ka BP (Nadel et al., 2004b). Hence, if we accept the c. 25 cal. ka age of the top of the laminated layers suggested above, the section between c. 3.60 and 1.00 m was deposited within 1500–2500 years, which implies a rather high rate of sedimentation. The sedimentological and limnological changes along this part of the section indicate a dynamic depositional environment. Several erosional gaps are also suggested by the unconformities between various units. The occurrence of plant roots at various depths may also indicate depositional hiatuses and occasional sediment mixing. These roots, which must have penetrated earlier layers, may also partly account for the inconsistencies in 14C dates. Significantly, besides the temporal inconsistencies mentioned above, similar problems were also observed when dates from the same hut, for example, are scattered over a considerable range, sometimes with as much as 1000 14C years apart (Nadel et al., 1995). Since such a long time span for a single brush hut is hard to envisage, this further highlights the complexity of 14C dating in the discussed setting.

Pollen concentrations fluctuate but are generally higher at the bottom of the trench, up to c. 3.50 m depth (Figure 3), with most of the peaks observed within the laminated Lisan marls, which also exhibit low magnetic susceptibility values. The possible causes for this picture are complex. Anoxic conditions in the deep lake that deposited the laminated marls may have enhanced pollen preservation and hence its higher concentration, while the laminated layers together with relatively high compaction at the bottom of the trench could mean that this part of the section represents a longer time span than the less-compacted layers at the higher part of the sequence (Weinstein-Evron, 1987). The higher and fluctuating magnetic susceptibility values further up the trench are probably also related to periods of higher runoff and soil erosion that were much lower during the period of deposition of the laminated layers at the lower part of the sequence (see also Lev et al., 2014).

The high ratios of hydrophilous pollen and especially water plants in the upper part of the laminated Lisan marls, where the hydrophilous pollen spectrum is dominated by Potamogeton (a freshwater aquatic taxon), largely correspond to the high fluctuation of pollen concentration (Figure 3). This accords well with a high water level during the deposition of this part of the sequence. Slight increases in Potamogeton occur at other laminated-clay sections of the sequence
(especially in the 3.10–2.75 m interval) but the low grain numbers prevent further discussion. Given the relatively rare hydrophilous pollen and their poor occurrence in both recent pollen (Horowitz, 1979, Langgut et al., forthcoming) and in previous, Holocene accounts (Baruch, 1986), it is not possible to offer a more extensive depiction of the lake/shore environment. Still, while the current, largely disturbed vegetation is dominated by Tamarix (also quite common on the banks of the Jordan River and here biasing our pollen rain sample) and some Phragmites australis (Zohary, 1980), Cyperaceae may have been more widespread in the past (Baruch 1986, and this study).

Changes along the pollen diagram suggest several fluctuations in vegetation and climate. Pollen zone 1, which most probably covers the 27–25 ka BP time interval, represents the most humid part of the sequence. The high Q. ithaburensis levels suggest a widespread deciduous-oak park forest on the mountain slopes around the lake. High lake levels are also indicated by the laminated lake sediments (Lisan marls), the high water-plant levels and the magnetic study of the sequence, as well as the limnological-hydrological data (Lev et al., 2014).

The driest phase is represented by pollen zone 2, still within the high-level laminated lake deposits. AP levels are not extremely low but the high Artemisia levels – the highest in the sequence – suggest some movement of the Irano-Turanian vegetation belt north-westward, towards the site’s area (e.g. Weinstein-Evron, 1983). The high cerealia-type pollen, which seems to peak when Cheno/AmS decrease, is hard to interpret since a more specific identification is palynologically impossible. If some of the pollen represents Hordeum sp., as indicated by the seed composition of the Ohalo II site, this may be another indicator of the dry climate of these phases. Significantly, Hordeum is self-pollinated (Zohary et al., 2012) hence it must have grown not far from the site. Compared to wheat, for example, it withstands drier conditions, poor soils, and some salinity.

It is during the two early phases of a deep lake, fully inundating the study area, that the wider regional vegetation is best represented in the sampled trench.

During the following stage (pollen zone 3), lake levels were lower, possibly exposing some areas of the underlying Lisan marls thus creating wet salines in the southern basin of the Sea of Galilee, facilitating the wide expansion of the various Chenopodiaceae (e.g. Atriplex and Suaeda; see Nadal et al., 2004b). The laminated layers of pollen zone 3b indicate a short-spanned lake-level rise and a deeper lake than during the earlier part of this zone. The fluctuating nature of this water rise and a possible hiatus in the pollen sequence may be indicated by some reed roots found mainly in the lower part of this sub-zone. The decrease in Cheno/AmS is probably a result of the re-inundation of vast Lisan marl exposures in the area, where such plants grew. The increase in Potamogeton supports this notion. The decrease in Cheno/AmS together with the relatively high Artemisia levels in this laminated subzone again point to a more regional portrayal of the vegetation. The composition of the pollen spectra indicates that climate may have been only moderately humid, with the expansion of the Mediterranean maquis/forest on the hilly slopes around the lake, as evident also by the maximum percentages of Pistacia pollen. The constant, rather low appearance of Pinus pollen is probably a result of long-distance transport (Horowitz, 1992: p. 268; Weinstein-Evron & Lev-Yadun, 2000; van Zeist & Bottema, 2009; Aharonovich et al., 2014), most probably of *P. halepensis* pollen, at present the only native species of Israel and Jordan (Zohary, 1973: p. 341). Pine pollen may have been blown in from north-western Israel, where *P. halepensis* could have formed forest stands on marly and chalky Rendezsála soils, and where natural pine stands are still found, or occasionally carried with south-easterly winds from Jordan (Weinstein-Evron & Lev-Yadun, 2000). Some pine pollen may have originated from Lebanon where at present *P. brutia* (Turkish pine) is the predominant conifer (Zohary, 1973: pp. 342–343; van Zeist & Bottema, 2009). Lake levels fluctuated during pollen zone 4 times, but always remained shallower than during the early part of the sequence. The low AP suggests a rather dry phase. Since low temperatures may destroy the flowers of Olea europaea (Zinger, 1985), the high levels of this frost-intolerant species further suggest that this dry phase may have been rather warm. The high Cheno/AmS levels indicate that saline biotopes, largely due to the underlying Lisan marls, must have dominated the vicinity of the lake. Artemisia levels decrease along this zone, until they almost disappear in pollen zone subzone 2b, also suggesting a less-severe drying than during former dry fluctuations and a rather local expansion of halophytic biotopes near the shallow lake and adjacent wetlands.

AP level increases again in pollen zone 5, with a more mixed Q. calliprinos maquis (subzone 5a) later replaced by a deciduous Q. ithaburensis park forest (subzone 5b). The co-occurrence of several more northern taxa (Betula, Juglans, Castanea, Fagus, Tilia) may indicate some cooling (e.g. Weinstein-Evron, 1983), especially during the first half of this zone. Their very low numbers, however, indicate that these trees did not grow in the area surrounding the lake, but rather that their pollen was transported from further north, where these taxa occur even today (Browicz, 1982). Pollen zone 5b represents the Ohalo II site and some rather disturbed associated sediments, with signs of fissures and many roots. Pollen spectra of this section may be somewhat mixed, but still exhibit a distinct picture of a Q. ithaburensis park forest on the slopes and saline biotopes near the site, as has been suggested by the macro-botanical remains retrieved from the excavated brush huts (Nadal et al., 2004a,b). The sporadically high Asteraceae Asteroidaeae pollen may be derived from ruderal environments. However, their over-representation in some of the pollen-poor samples may also indicate some recent pollen contamination (Weinstein-Evron, 1994). Their relative rarity in the pollen spectra retrieved from the Ohalo II site supports this view.

The composition of the pollen spectra from Locus 20, on the surface of the site, largely accords with those from the contemporaneous zone 5b in the trench, with high AP (especially *Q. ithaburensis*) and Cheno/AmS values. *Pinus* levels are relatively high in one of the samples, probably a result of long-distance transport. The pollen spectra support the palaeoenvironmental reconstruction based on the composition of the charcoal (Liphschitz & Nadel, 1997; Nadal & Werker, 1999) and seed (Kislev et al., 1992; Weiss et al., 2004, 2008; Snir et al., 2015) assemblages of the site, suggesting an open Q. ithaburensis park forest on the hilly flanks of the lake and a halophytic wetland near the site. The dominance of Gazella gazella in the faunal assemblage, as well as the range of other mammal and bird species provide a similar picture (Simmons & Nadel, 1998; Nadal et al., 2004b; Rabinovich & Nadel, 2005).
The low Artemisia levels negate a significant drying. The relatively high cerealia-type pollen also accord with the archaeobotanical picture, featuring abundance of wild barley (Hordeum spontaneum) seeds and the presence of wheat (Triticum dicoccoides) and oats (Avena) found on brush hut floors and even associated with a grinding stone (Kislev et al., 1992; Weiss et al., 2004, 2008; Piperno et al., 2004; Nadel et al., 2012; Snir et al., 2015). Apiaceae pollen (mostly Bunium type) is also abundant but since more specific identification of this insect-pollinated pollen-type is impossible, its significance cannot be further understood. The pollen spectra of the brush hut (Locus 2) and the nearby activity area (Locus 7), on the other hand, are clearly dominated by Chenopodiaceae (more than 90% in the brush hut and 52–91% nearby). These spectra most probably reflect specific activities conducted here, as also evident from the composition of the seed assemblages of some of the edible Chenopodiaceae species (Suaeda palustina/bruticosa) (Weiss et al., 2008; Snir et al., 2015). Chenopodiaceae branches (e.g. Atriplex/Seidlitzia) were also used for the construction of brush huts (Nadel & Werker, 1999). While we cannot explain the high Centaurea levels (local contamination?) in one of the Locus 7 samples, the relatively high level of cerealia-type pollen may also be related to human use of edible plants.

Our research provides important insights into lake-level fluctuations and climatic changes during the last retreat of Lake Lisan. This was made possible by studying the unique setting of the site and deep trench, on the lake/shore boundary, thus echoing even small variations in the environment. The resulting picture is of a trended lake-level decrease from the 27–25 cal. ka BP high stand, punctuated by intermittent rises, the most pronounced of which was the one that inundated the Ohalo II prehistoric camp.

Given the lack of accurate dating of each event observed along the sequence, correlation to other regional environmental reconstructions (Bar-Matthews et al., 1997, 2003; Almogi-Labin et al., 2009; Bar-Matthews, 2014; Torfstein et al., 2015) is hampered. As a result, our reconstruction cannot contribute to debates concerning the apparent discrepancies between northern and southern Levantine records (e.g. Weinstein-Evron, 1990; Frumkin et al., 2011; Langgut et al., 2011; Gasse et al., 2015), nor could we correlate our results with specific global events (e.g. the H2 event) as argued by others (Bar-Matthews et al., 1997, 2003; Bartov et al., 2003; Frumkin et al., 1999, 2011; Enzel et al., 2008; Almogi-Labin et al., 2009; Langgut et al., 2011; Bar-Matthews, 2014; Gasse et al., 2015 and reference therein; Torfstein et al., 2015). The lack of cold climate indicators (e.g. Cedrus pollen: Weinstein, 1976; Weinstein-Evron, 1990; Aharonovich et al., 2014) does not agree with the suggestion of a very cold climate during the initial retreat of the lake (Lev et al., 2014). The later stages were probably rather warm, as suggested by the continuous presence of Olea europaea pollen.

CONCLUSIONS

Based on multi-disciplinary and independent data sets, all retrieved from one sequence, our research presents a detailed delineation of climate change during the last retreat of Lake Lisan. The sedimentological data reflect local changes in lake levels and their impact on the local landscape while the palynological data, by nature, provide a wider, regional picture. However, the various results largely agree with one another and thus enable a comprehensive environmental portrayal. Even though the exact dates of the events and changes observed along the studied sequence are yet to be firmly established, the chronological framework has an end date – the occupation of Ohalo II.

The studied sequence probably represents a short time span, and yet it provides a unique, high resolution data source for past climate during a dramatic course of events in the Jordan Valley.

In spite of certain chronological shortcomings, the fact that a variety of data sets were retrieved from the very same section renders their correlation and combined environmental interpretation reliable and unique for this time period in the southern Levant.

The discussed sequence, however short, provides a rare glimpse into the Last Glacial Maximum period in the southern Levant, from the highest stand of Lake Lisan, through its rapid retreat with intermittent fluctuations, and ending with its last apparent high pulse. When possible, humans that roamed the landscape made use of the recently-exposed shore for the construction of their camp. The rich faunal and floral remains from the site vividly indicate that the inhabitants of the Ohalo II camp exploited a wide variety of ecological niches, including the lake (e.g. fishing: Nadel et al., 2004b), salines and open-park forest. This picture is further supported by the new palynological data from both the section and the site.

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