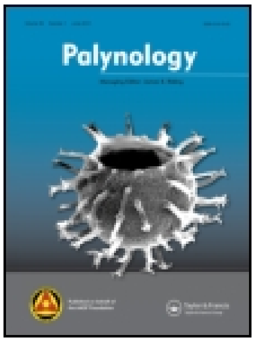

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A LATE QUATERNARY PALEOENVIRONMENTAL SEQUENCE FROM DOR, CARMEL COASTAL PLAIN, ISRAEL

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Abstract

The 10.5 m deep "D-Dor" core was taken at Dor (Tantura Lagoon), on the Carmel coastal plain, Israel. The established chrono-stratigraphic sequence (based on x-ray radiographs, and both luminescence and radiocarbon dating) covers the last about 26,000 years. It provides the paleoenvironmental framework for the transition from hunter–gathering to agriculture in the Levant. Three clay units were identified, overlying *kurkar* (calcareous sandstone) and covered by 6.3 m of sand. The bottom clay unit is a paleosol. Pollen was not preserved in this unit. Gray clay (the top of which was dated to about 12,000 cal. YBP) was deposited, overlying the paleosol, in a wetland environment. Pollen was preserved only in the upper part of this unit. It indicates a slightly drier climate than today's, probably correlative with the Younger Dryas. At the beginning of the Holocene, between 10,300 and 9,550 cal. YBP, a new marsh originated, depositing dark clay. High concentrations of well-preserved pollen allowed the reconstruction of several fluctuations in humidity. When the marsh was first formed, precipitation was higher than today, and oak maquis was more extensive in the area. The date of the earliest submerged Pre-Pottery Neolithic settlement embedded in its upper part indicates that the marsh dried out no later than 9,400–8,550 cal. YBP. Around 5,000 years ago, long after the Early Holocene marsh had dried up, sand began to accumulate in the region as a consequence of the Holocene sea level rise, covering several submerged Neolithic settlements off the Carmel coast.

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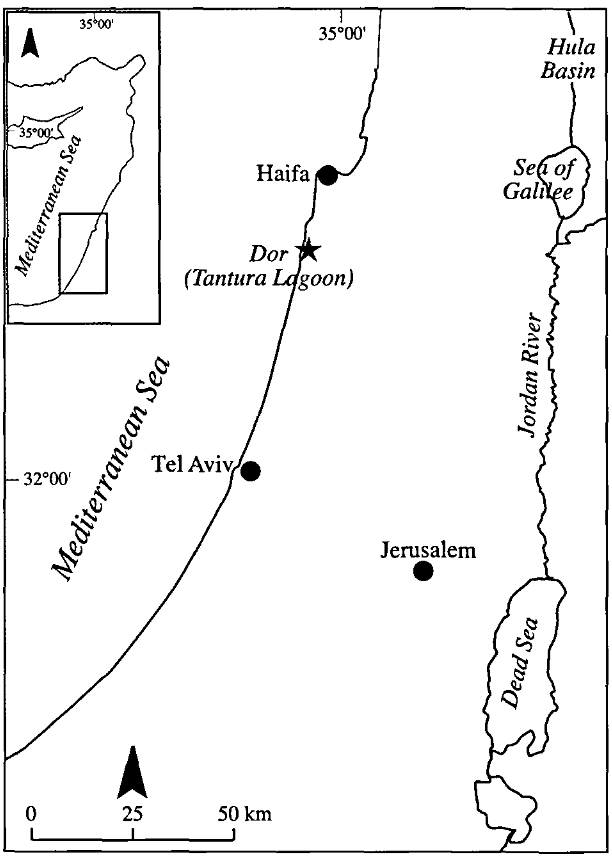
INTRODUCTION

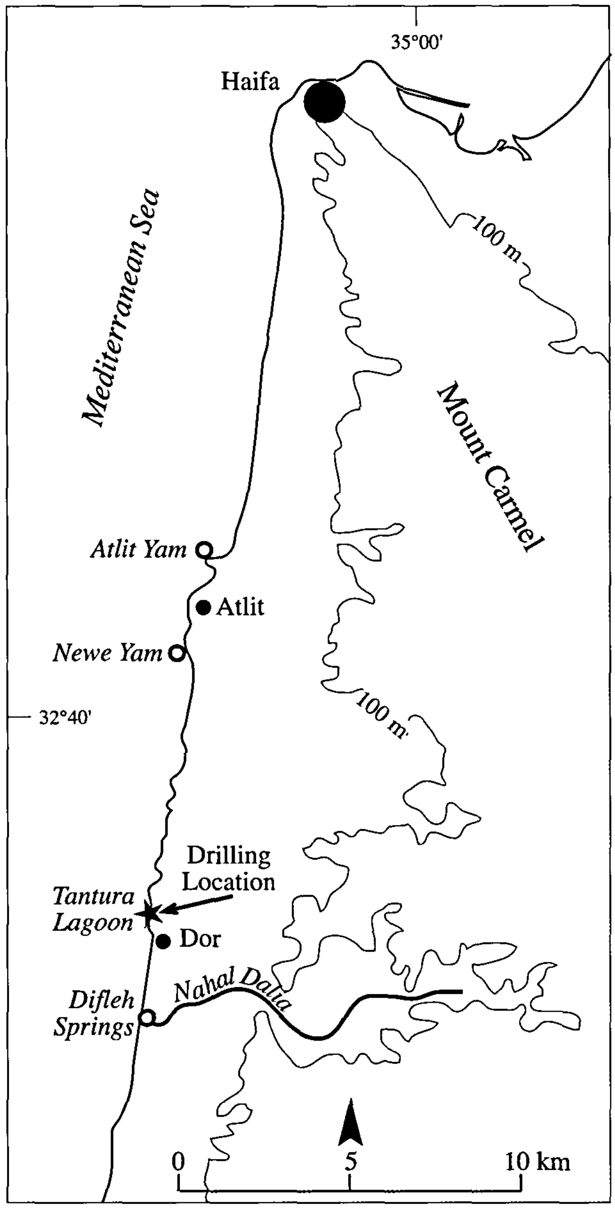
The last 25,000 years, between the Last Glacial Maximum (LGM) and the present, are characterized by significant climatic changes, which not only affected the fauna and flora, but also influenced human settlement patterns and cultural developments. This research aims to reconstruct the paleoenvironmental changes in the Carmel coastal plain, Israel (Text-Figures 1 and 2) during the transition from the Late Quaternary to the early Holocene. Our reconstructions, which are primarily based on pollen analyses, are intended to contribute to the understanding of ecological and cultural processes during the transition from nomadic hunter–gatherers to sedentary agricultural communities in the Levant.

Most of the available palynological studies in Israel are focused on the Dead Sea Rift (Hula Basin, Sea of Galilee and the Dead Sea: Horowitz, 1974, 1979, 1989, 1992; Baruch, 1986, 1994; Weinstein-Evron, 1983, 1990, 1994; Baruch and Bottema, 1991, 1999), while only a few such studies are available for the Israeli coastal plain to date (Rossignol, 1963, 1969; Horowitz, 1974; Galili and Weinstein-Evron, 1985). The present study deals with a core (hereafter "D-Dor") taken from the present shoreline of Dor (Tantura Lagoon; Text-Figures 1 and 2). The research is based on a stratigraphic analysis of the sequence, as well as on a detailed palynological analysis of the core.

Two calcareous sandstone (locally termed *kurkar*) ridges are exposed along the Carmel coastal plain, between Haifa



Text-Figure 1. The Israeli coast, showing the location ofthe study area.



Text-Figure 2. The D-Dor drilling site on the coast of Dor (Tantura Lagoon).

to the north and the Difleh Springs to the south (Text-Figure 2): the coastal ridge, and the eastern ridge. A sequence was deposited in the trough between the two ridges, composed of sands, clays and paleosol, which overlies the irregular topography of the *kurkar* (Sivan et al., 2004).

The climate of Mount Carmel and its coastal plain is Mediterranean influenced both by its topography and its proximity to the sea (Scharlin, 1980). Average annual rainfall varies from 600–800 mm on the mountain to 500–600 mm near the coast (Katzenelson, 1967). Rainy seasons extend from mid-October to mid-April, with occasional rains in September and May. Mean annual temperature is 18.8°C, ranging from 11.9°C in January to 28°C in August (Katzenelson, 1967). Prevailing winds are westerlies in summer and easterlies in winter, when strong winds are relatively common (Lomas et al., 1973). Winds are also influenced by the local topography, i.e., more frequent winds parallel to the mountain ridge, and strong winds through the wadis that cut through its western slopes (Scharlin, 1980; Asfur, 1997).

The Mount Carmel vegetation is primarily eastern Mediterranean. The main communities today are (Zohary, 1973, 1980):

1) The *Ceratonia siliqua–Pistacia lentiscus* association, which also includes wild olive trees, and occupies the lower belt of the mountain up to about 300 m. Representatives of this association are also found on the *kurkar* ridge near Atlit (Text-Figure 2).

2) The evergreen *Quercus calliprinos–Pistacia palaestina* maquis association is represented by a variety of trees, with *Q. calliprinos, P. palaestina, P. lentiscus, Ceratonia siliqua, Arbutus andrache, Crataegus anonia, Phillyrea latifolia, Cercis siliquastrum* and *Rhamnus palaestinus* as the main species. At the highest elevations in this zone *Laurus nobilis* and the deciduous *Q. boissieri* are relatively common.

3) Pine forest is mainly represented by the *Pinus halepensis –Hypericum thymifolium* association. Pine is a native component of the local flora and has invaded disturbed and abandoned areas in recent years (Weinstein-Evron and Lev-Yadun, 2000).

4) A *Quercus ithaburensis* park forest is limited to the southeastern parts of Mount Carmel.

The main components of the Carmel dwarf-shrub formations are *Sarcopoterium spinosum, Salvia fruticosa, Cistus* spp. and *Satureja thymbra*. The most abundant plant association on the coastal dunes is *Lotus creticus* and *Artemisia monosperma*. Quite large areas of Mount Carmel, as well as most of its coastal plain, have been, and still are, subject to construction, cultivation and deforestation.

The narrow Carmel coastal plain supports vegetation types confined to sand dunes (mainly *Lotus creticus* and *Artemisia monosperma* associations), *kurkar* hills (*Ceratonia siliqua–Pistacia lentiscus,* with *Coridothymus capitatus, Chritmum maritimum, Lavandula stoechas, Calicotome villosa,* and *Thymelaea hirsuta*), marshes (e.g., *Phragmites australis, Juncus fontanesii, Typha domingensis* and *Tamarix nilotica*), and salines (*Inula crithmoides,* Chenopodiaceae/Amaranthaceae [Cheno/Ams], *Tamarix tetragyna*) (Zohary, 1980, 1982).

During the last few thousand years the Dor area has been covered by sand deposits, which accumulated as the sea level rose from the beginning of the Holocene (Galili et al., 1988; Sivan et al. 2001, 2004). The sands overlie ancient marshy clays, which, in turn, uncomformably overlie *kurkar* layers (Michelson, 1970; Sneh and Klein, 1984; Sivan and Porat, 2004). Similar marshes were previously recorded from other locations along the Israeli coast (Galili and Weinstein-Evron, 1985; Galili et al., 1993; Gvirtzman et al., 1998; Sivan et al., 1999).

Several submerged prehistoric sites have been discovered off the Carmel coast, north of Dor. The earliest settlement, the Pre-Pottery–Neolithic C (PPNC) site of Atlit-Yam (Text-Figure 2), is dated to about 9,400–8,550 cal. BP (after Ramsey 1995; 8140 ±120 uncalibrated YBP; Galili et al., 1993). Similarly to later submerged prehistoric sites in the area, dated to the Pottery Neolithic and Chalcolithic periods, the site was embedded in the upper part of the Early Holocene dried marshy clay. With the rise in sea level, settlements were moved to higher ground, and the prehistoric sites were gradually buried under the incursion of sands from west to east (Galili and Weinstein-Evron, 1985; Galili et al., 1988; Sivan et al., 2001; Sivan et al., 2004).

METHODS

The D-Dor drilling was 10.5 m deep (Text-Figure 3). The sand layer of the upper part of the section (from sea level to a depth of 6.30 m) was extracted by a spiral drill. The lower part of the drilling (6.30–10.5 m) is composed of a series of clays that were extracted as cores. The coring stopped when it reached the *kurkar* layer at a depth of 10.5 m. The clay cores were described visually, x-rayed and sampled shortly after drilling. The sediments were stored in a refrigerator, and later sampled for organic matter determination and pollen analyses.

Two luminescence (IRSL) age determinations were obtained for the upper sand unit at the TL Laboratory of the Jerusalem Geological Institute, Israel. Six clay samples were AMS ^{14}C dated, at the Weizmann Institute, Israel. The Holocene ^{14}C dates were calibrated using the OxCal v.3.9 program (Ramsey, 1995), with a statistical error of 2; while the Late Quaternary dates were calibrated according to Bard et al. (1993).

The core was sampled for palynological analysis at sequential intervals of 10 cm. Forty-two clay samples were processed and examined, but fossil pollen grains were recovered from only 12 samples of the upper clay units. In order to compare the ancient reconstructed vegetation with the present-day vegetation in the area, a recent control mud sample was collected from the Difleh Springs, the closest natural water source in the surrounding area (Text-Figure 2).

Pollen grains were extracted, identified and counted, and a pollen spectrum was reconstructed for each sample. Forty grams of sediment were processed from each sample. A tablet of *Lycopodium* (contains 10,679 spores in average) was added to each sample, which was subsequently treated with HCl to remove the carbonates. Then a density separation was carried out by using $ZnCl_2$ solution with a specific gravity of 1.9, together with sieving. After a short acetolysis, the organic residue was stained with safranin and mounted in silicone oil.

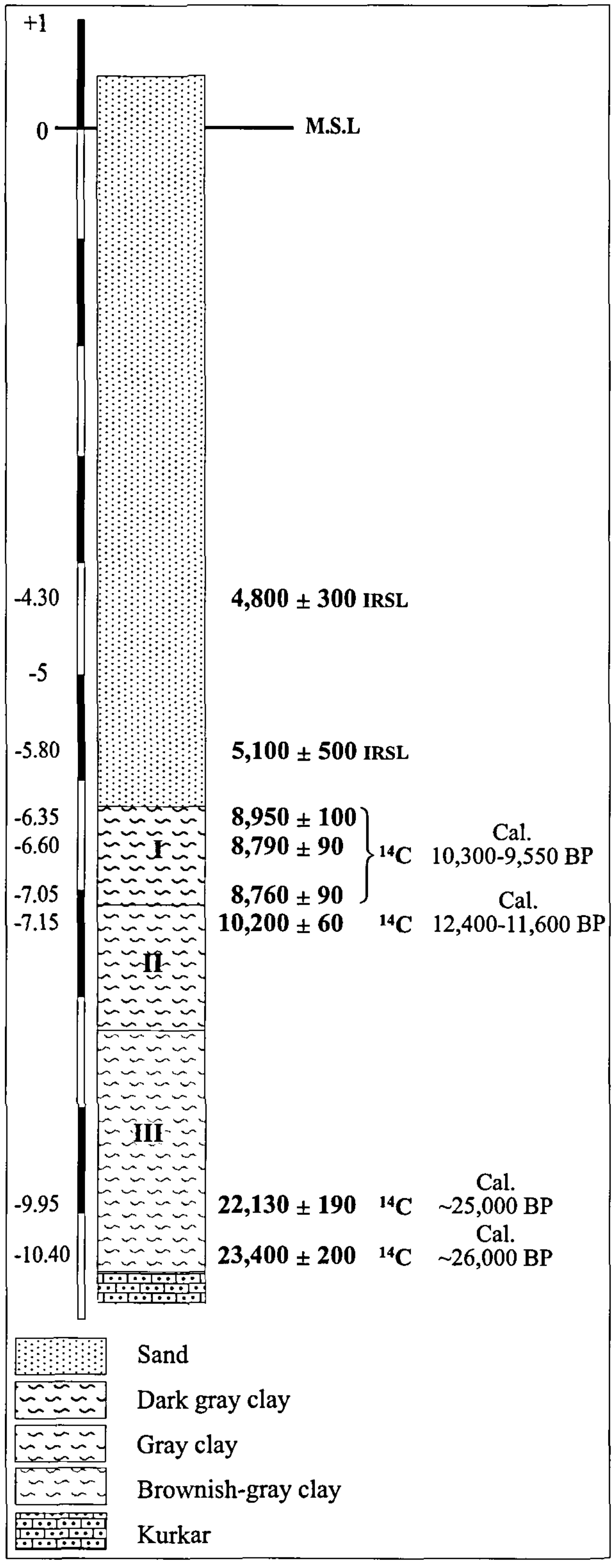
A light microscope, with magnifications of 200x, 400x and 1,000x (immersion oil), was used for identifiying and counting the pollen grains. The comparative reference collection of the Palynological Laboratory of the Zinman Institute of Archaeology, University of Haifa and the atlas *Pollen et Spores d'Europe et d'Afrique du Nord* (Reille, 1995, 1998, 1999) were used to identify the pollen at the family, genus and when possible, to the species level.

RESULTS

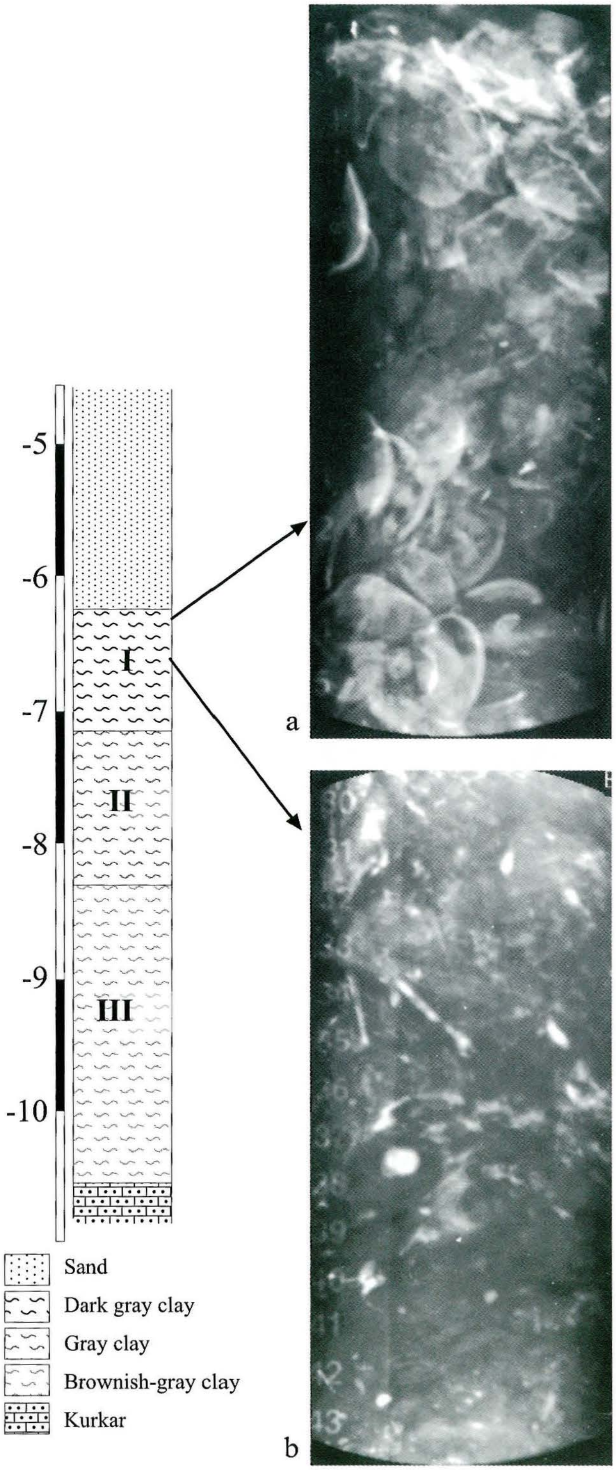
Stratigraphy

The core was 10.5 m deep. The upper 6.30 m of the sequence consist of light-colored sands, gradually (at depth 5.80 m.) changing into sand with very little dark clay. The clays of the lower part of the sequence can be divided into three units (from top to bottom; Text-Figure 3):

Clay Unit I (6.30–7.10 m). Dark clay composed of gray and black laminae. The upper part (6.30–6.55 m) includes marine shells, mainly *Glycymeris* (Text-Figure 4a), while various structures occur in the lower part (Text-Figure 4b). This unit contained high ratios of organic matter (average 1.7%).



Text-Figure 3. The stratigraphic sequence of D-Dor.



Text-Figure 4. X-ray radiographs within the general sequence. a) From a depth of 6.60–6.73 m, note the various structures. b) From a depth of 6.33–6.55 m, which includes marine shells, mainly *Glycymeris*.

Clay Unit II (7.10–8.30 m). Homogeneous gray clay characterized by relatively lower ratios of organic matter (average 0.7%).

Clay Unit III (8.30–10.5 m). Homogenous brown clay with small (≤ 1 mm in diameter) black organic, and white, carbonate concretions. A low organic matter ratios was determined for this unit (average 0.3%). This clay unit unconformably overlies the *kurkar*.

The Chronological Framework

Results of the dating are summarized in Table 1. For the statigraphical position of the dates, see Text-Figure 3. IRSL ages were obtained for the upper sand unit, while the clay units were ^{14}C-dated.

The dates indicate that the sequence was deposited from slightly before the LGM to the first half of the Holocene.

Palynology

The recent control sample, collected from the Difleh Springs (the closest natural water source in the surrounding area) contains 12.8% Arboreal Pollen (AP), mainly *Pinus halepensis* (5.3%) *Quercus calliprinos* (4.9%) and *Quercus ithaburensis* type (1.2%). The NAP group is characterized by high Poaceae percentages (23.3%), together with Asteroideae (11.9%), Cheno/Ams (11.5%), Apiaceae (9.3%), *Artemisia monosperma* (6.3%) and *Plantago lanceolata* (6.3%). The sample represents the regional vegetation (i.e., *Quercus*, *Pinus* and *Olea*), as well as sand dunes (*Ephedra fragilis* type and *Artemisia monosperma*), the local ruderal (*Plantago lanceolata*) and hydrophilous (*Juncus* sp. and *Polygonum aucum*) plant formations. The recent sample accords well with the present-day vegetation in the area. However, since the region has been largely disturbed by human activities, such as construction, fish ponds, and agriculture, it does not help much in the interpretation of the fossil data.

Results of the fossil palynological analysis are presented in the pollen diagram (Text-Figure 5). In total, 35 pollen species, genera or families, belonging to both Arboreal Pollen (AP) and Non Arboreal Pollen (NAP) groups, were identified, representing a typical eastern-Mediterranean vegetation. Several hydrophilous pollen types were also identified; their percentages were calculated out of the pollen sum and are presented separately in the right-hand columns of the diagrams. Pollen concentrations for each sample are presented in the last right-hand column.

TABLE 1. Chronology of the D-Dor sequence.

Depth Below Surface (m)	Dating Method	Age – YBP (laboratory number)	Calendar Age YBP*
4.30	IRSL	4,800 ± 300 (DOR-14)	
5.80	IRSL	5,100 ± 500 (DOR–17)	
6.35	Carbon 14	8,950 ± 100 (RTT4075)	10,300–9,700
6.60	Carbon 14	8,790 ± 90 (RTT4076)	10,250–9,600
7.05	Carbon 14	8,760 ± 90 (RTT4077)	10,250–9–550
8.65	Carbon 14	10,200 ± 60 (RTT4671)	12,400–11,600
9.95	Carbon 14	22,130 ± 190 (RTT4078)	~ 25,000
10.40	Carbon 14	23,400 ± 200 (RTT4079)	~ 26,000

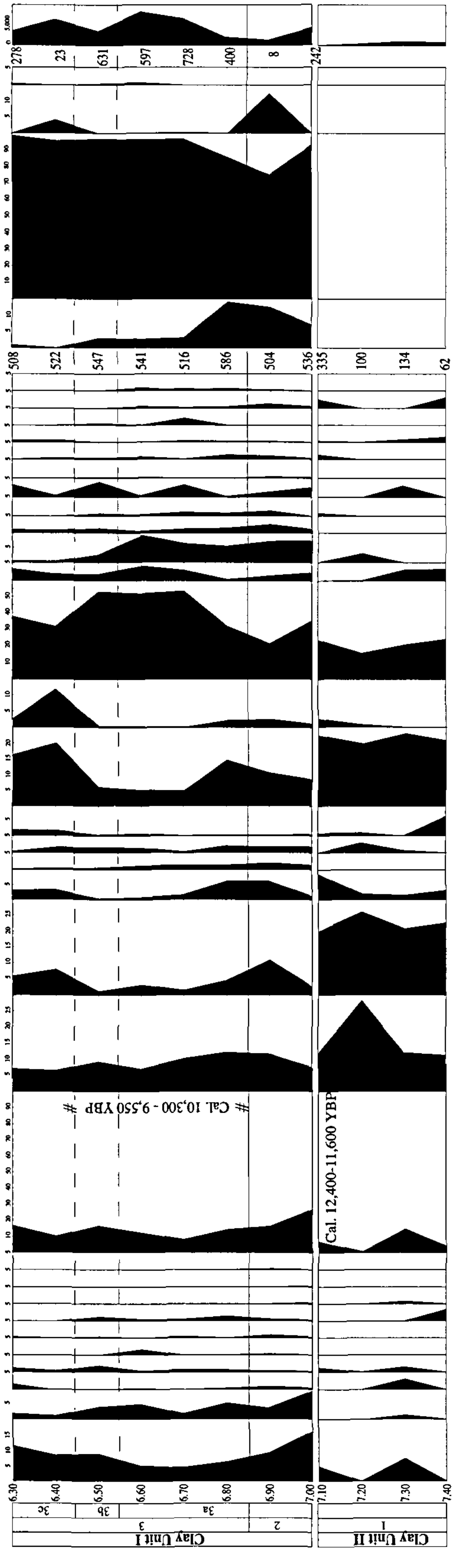
* The Holocene ^{14}C Dates were calibrated using the OxCal v.3.9 program (Ramsey, 1995) while the Late Quaternary dates were calibrated according to Bard et al. (1993).

In Clay Unit I the state of preservation of the pollen grains was good and their concentrations were high. Pollen grains from Clay Unit II were poorly preserved, with relatively low concentrations. Pollen was not preserved in Clay Unit III.

The pollen diagram is divided into three palynological zones (Text-Figure 5), from bottom to top:

Pollen Zone 1 represents the upper part of Unit II (7.10–7.45 m.). It is characterized by low AP levels (up to 14.2%), with *Quercus calliprinos* as the main element (not exceeding 7.5%). Other trees that were identified at lower percentages are: *Quercus ithaburensis* type (0–1.5%) *Pinus halepensis* (up to 3%), *Olea europaea* (0–1.5%), *Corylus* sp. (0–3.2%) and *Carpinus* sp. (up to 0.7%). While the former three types are typical of the Mediterranean vegetation in the area, the latter two do not grow locally in the natural environment today. The present distribution of *Corylus* sp. and *Carpinus* sp. is mainly in central Europe and their southern dispersal limit is around latitude 36°, in south-west Turkey (Browicz, 1982). They appear usually in insignificant percentages, in Levantine pollen sequences from the northern Rift Valley (e.g. Niklewski and van Zeist, 1970; Horowitz, 1979; Weinstein-Evron, 1983). Interestingly, *Corylus* sp. pollen was also documented in the Quaternary layers of Tabun Cave, Mount Carmel (Horowitz, 1979). Among the NAP group, Asteroideae (20–26%), Apiaceae (21–23.7%), Poaceae (11.3–28%) and Cheno/Ams (16–24.2%) exhibit high percentages throughout this zone. Other components of the NAP group (i.e., *Plantago lanceolata* and *Ephedra fragilis* type) appear discontinuously and at lower percentages. Pollen Zone 1 altogether suggests dry conditions at the time of deposition. However, based on the AP/NAP curve, it seems that the lower part of this zone represents somewhat more humid conditions than its upper part. The low AP percentages of the upper part of the zone are complemented by a rise in Poaceae, Asteroideae and *Artemisia monosperma* percentages. Apiaceae, Asteroideae and Poaceae percentages are relatively high throughout this zone, while Cheno/Ams exhibit the lowest percentages of the sequence. Hydrophilous pollen grains were not found in this zone, which is also in accordance with a dry climate. Pollen concentration values were extremely low (221–354/cm^3).

Pollen Zone 2 represents the lower part of Clay Unit I (6.85–7.10 m). Throughout this zone relatively humid and cool climatic conditions prevailed. AP percentages (up to 26.9%), are the highest in the diagram, with *Quercus calliprinos* (9.1–15.9%) and *Quercus ithaburensis* type



Text-Figure 5. The D-Dor pollen diagram. Note the different scales for AP/NAP and Potamogeton. The group "others" includes: Crassulaceae, Boraginaceae, *Asperula* sp., euphorbiaceae, and Polygonaceae.

(4.2–9.7%) as the main components. *Pinus halepensis* (0.4–0.8%), *Olea europaea* (0.2%), *Pistacia* sp. (0.2–0.8%) *Corylus* sp. (0.2–0.6%) and *Carpinus* sp. (0.2%) appear at relatively low percentages. *Juglans* sp. (0.2%) occurs occasionally in this zone only. The predominant types among the NAP are Poaceae (7.5–11.5%), Asteroideae (2.6–10.7%), Cichorioideae (1.1–6.2%) *Artemisia monosperma* (1.3–2%) and *Plantago lanceolata* (6.9–7.3%). Cheno/Ams values do not exceed 21.2%. *Potamogeton* sp. (75–93%) and Cyperaceae (up to 12.5%) constitute the main hydrophilous types. Pollen concentrations are fairly good (1667–4615/cm^3).

A minor drying characterizes Pollen Zone 3 in the upper part of Clay Unit I (between 6.30 and 6.85 m). AP percentages drop slightly (16.3–7.9%), with *Quercus calliprinos* (4.7–11.4%) as the main element, while Cheno/Ams reach their maximum values throughout this zone (31.6–53.3%). Pollen Zone 3 can be further subdivided into three sub-zones.

In sub-zone 3a (6.55–6.85 m), the marked decrease in AP content (to 7.9%) indicates dry conditions, with some wetting toward the end of this sub-zone. *Quercus calliprinos* is the most dominant tree in the AP group (4.7–6.1%), while *Quercus ithaburensis* type percentages are medium (1.7–5.5%). In spite of the low content of *Olea europaea* (0.2–0.8%) and *Corylus* sp. (0.4–1.4%), they appear almost continuously throughout this sub-zone. At the end of this section there are relatively high proportions of *Fraxinus* sp. (1.5%). Throughout this zone, high Cheno/Ams values compensate for the low AP percentages, with the respective curves exhibiting opposite trends. Among other herbaceous pollen types, the percentages of Asteroideae (up to 4.6%), Cichorioideae (not exceeding 6.1%) and Apiaceae (up to 14.5%) are higher at the beginning, and decrease toward the end of the section. *Plantago lanceolata* reaches its highest percentages (5.5–8.9%) in this zone. The main components of the hydrophilous group are *Potamogeton* sp. (85.8–96.8%) and *Sparganium* sp. (2.7–14.3%). Pollen concentrations reach their maximum values throughout the curve (3750–7907/cm^3).

Sub-zone 3b (6.45–6.55 m) is characterized by medium AP values (16.3%). *Quercus calliprinos* appears at a relatively high percentage (8.8%), while *Quercus ithaburensis* type is represented by medium percentages (4.4%). *Olea europaea*

(1.8%) reaches its maximum values in the core. Cheno/Ams (52.8%) and Poaceae (9.3%) dominate the NAP group, while low percentages were found for Asteroideae (1.3%), Cichorioideae (0.2%), *Artemisia monosperma* (0.5%) and *Plantago lanceolata* (2.7%). The hydrophilous pollen group is dominated by *Potamogeton* sp. (96.7%), with some *Sparganium* sp. (3%). Pollen concentrations are relatively high (up to 6836/cm^3).

A slight dryness (AP not exceeding 10.2%) is indicated at the beginning of sub-zone 3c (6.45–6.30 m), with some wetting towards the end of the period (AP up to 16.3%). *Quercus calliprinos* is the main component of the AP group (8.4–11.4%), while *Quercus ithaburensis* type appears in relatively low proportions (1.3–2.2%). *Pinus halepensis* exhibits its highest proportions (1.4%) in this sequence. *Corylus* sp., though continuously appearing throughout Clay Unit I, is absent from this sub-zone. Among the herbaceous plants, percentages of Asteroideae (6.5–7.1%), Cichorioideae (5.9–8%), Apiaceae (16.3–19.9%) and *Scabiosa* sp. (2.6–11.7%) are fairly high. Cheno/Ams contents are rather low (31.6–37.6%), as are the percentages of Poaceae (6.5–7.1%), *Artemisia monosperma* (0.2–0.4%) and *Plantago lanceolata* (0.6%). The main component of the hydrophilous pollen group is *Potamogeton* sp. (95.7–98.9%). Pollen concentrations are relatively low (635–2690/cm^3).

In sum, the palynological data suggest a relatively dry climate in Pollen Zone 1 (upper part of Clay unit II), more humid conditions in Pollen Zone 2 (lower part of Clay Unit I), and a aridity trend throughout Pollen Zone 3 (upper part of Clay Unit I).

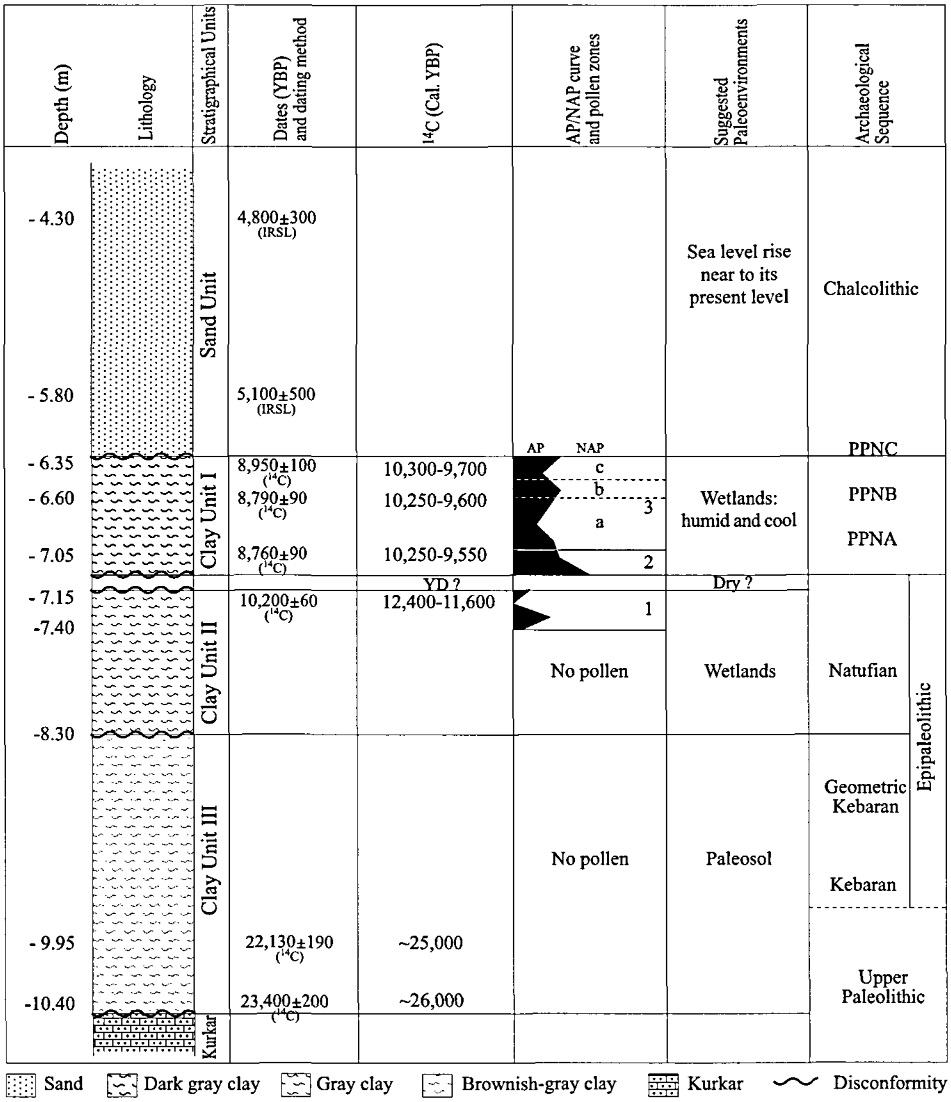
DISCUSSION

Based on the sedimentological and palynological data, the different units of the stratigraphic sequence represent diverse environmental conditions at the time of deposition (Text-Figure 6). During the first phase, dated to about 26,000 cal. YBP (Clay Unit III, depth 8.30–10.50 m.), a brown clay was deposited unconformably on the *kurkar*. Its characteristic color, the presence of carbonate concretions, and the similarity of its chrono-stratigraphic position to correlative units in other nearby drillings in the Dor area (Sivan et al., 2004), suggest that this unit is a paleosol. On the northern Israeli coast, paleosols were found to indicate long-term processes (Tsatskin and Ronen, 1999; Sivan and Porat, 2004). Clay Unit III could therefore have been formed over a few thousand years.

No palynological data are available for this period, and it is thus impossible to arrive at a coherent paleoenvironmental reconstruction for the area. The stable isotope analysis of speleothems from the mountainous area of Israel suggests that this paleosol corresponds to an arid phase (Bar Matthews et al., 1997, 1999; Frumkin et al. 2000; Vaks et al., 2003). In contrast, an increase in the total water input of the Lisan Lake (the precursor of the present-day Dead Sea) was inferred on the basis of high lake levels between 26,000 BP and 23,000 BP (Bartov et al., 2002). This is corroborated by palynological evidence from the Jordan Rift (Horowitz, 1979, 1992; Tsukada, cited in Bottema and van Zeist, 1981; Weinstein-Evron, 1983, 1990; Baruch and Bottema, 1991), that suggests a humid climate at the beginning of the period under discussion, followed by a dry LGM and a return to humid conditions about 17,500 years ago.

While the beginning of this phase corresponds with the last of the Upper Paleolithic entities in the Levant (see Belfer-Cohen and Goring-Morris , 2003 for a recent review), most of it contains the Kebaran and Geometric Kebaran Epipaleolithic cultural complexes. Both entities, differing mainly in their lithic tool-kits, and the somewhat richer material culture and more complex settlement pattern in the latter, represent small scale, dispersed, nomadic hunter–gatherer groups (e.g., Bar-Yosef, 1998, 2001; Goring-Morris, 1995; Kaufman, 1992). Sites of the Kebaran complex were limited to the Mediterranean coastal core area and isolated oases, as a result of environmental constraints during the LGM (Bar-Yosef, 2001). The following Geometric Kebaran foragers took advantage of the climatic amelioration about 17,500–16,800 years ago, and expanded into the formerly desertic belt that had become typical Mediterranean steppe. They were thus spread throughout the Levant. Sites of both cultural entities were found embedded in red loams, probably equivalent to the paleosol Clay Unit 1 at D-Dor, in the northern Sharon and the Carmel coastal plain (e.g., Ronen et al., 1975; Bar-Oz and Dayan, 2003; Godfrey-Smith et al., 2003).

Throughout the second phase (Clay Unit II, depth 8.30–7.10 m) a gray clay (the top of which was dated to 12,400–11,600 cal. YBP), was deposited in a body of water. This is in the same time range as previously reported by Sivan et al. (2004) for a correlative clay unit in the Dor area (between 13,800±1,000 IRSL and 12,075–12,200 cal ^{14}C). The abrupt change from gray clay (Unit II) to organic dark clay (Unit I), suggests a stratigraphical unconformity between the two units. This unconformity is also corroborated by the distinct break of the pollen curve between Pollen Zones 1 (the upper part of Clay Unit II) and 2 (Clay Unit I; Text-Figure 5). Furthermore, the pollen that was found in zone 1 was poorly preserved and in low concentration. In contrast, in zone 2, pollen was well-preserved and highly concentrated. This dissimilarity also implies different depositional and/or preservation conditions of the pollen grains in the two Pollen Zones.



Text-Figure 6. The chronostratigraphy and paleoenvironmental reconstruction of the D-Dor sequence.

The relatively low AP levels in Pollen Zone 1 indicate a dry climate during the time of deposition. However, the occurrence of pollen grains only in the upper part of Clay Unit II may suggest that they infiltrated into these layers through cracks in the surface of the marshy clays, which were by then dried up (i.e., Weinstein-Evron, 1986, 1994). If this is accepted, then the pollen found in Pollen Zone 1 does not represent the vegetation during the deposition of Clay Unit II, but rather the vegetation that later grew in the area on top of the dried-up clays of this unit, prior to the deposition of Clay Unit I. The low AP percentages and the absence of hydrophilous pollen indicate that this period was dry, with no coastal water bodies in the Dor area. The suggested interpretation may resolve the apparent contradiction between the humid conditions, as suggested by the sedimentological data (the deposition of clays and formation of wetlands), and the dry palynological phase. Because of the low concentrations of pollen, its poor state of preservation, and the suggested taphonomic origins, we have chosen not to elaborate further on the meaning of specific types within the pollen spectra, nor on the character of secondary fluctuations in the pollen curve.

If the pollen found in the upper part of Clay Unit II infiltrated at a later stage, we have no palynological evidence for the time of deposition of Clay Unit II at D-Dor. Other palynological evidence, mostly from the Jordan Rift, suggests a humid climate during this period (Weinstein-Evron, 1983, 1990; Tsukada, cited in Bottema and van Zeist, 1981; Baruch and Bottema, 1991, 1999). A relatively cool and humid period is also indicated by O^{18} and C^{13} speleothem data of the same period from two caves in the Judean Mountains near Jerusalem (Bar Matthews et al., 1997, 1999; Frumkin et al., 1999, 2000). Temperatures were slightly lower than today and precipitation was higher.

The pollen which infiltrated the cracks represents a dry period (low AP). Its stratigraphical position, between about 12,000 YBP (the date of the top of Clay Unit II) and the beginning of the Holocene (the base of Clay Unit I), suggests that these pollen spectra date to the Younger Dryas (YD). They represent the time gap suggested by the unconformity between these two clay units. Other lines of evidence suggest a relatively cool and dry YD phase (Bar Matthews et al., 1997, 1999; Frumkin et al., 1999, 2000). However, as indicated by the Levantine palynological data (e.g., Baruch and Bottema, 1991, 1999), it may have been relatively mild in the eastern Mediterranean area (Bottema, 1995; Weinstein-Evron, 2002; Lev-Yadun and Weinstein-Evron, in press).

The period encompassing Clay Unit II and the suggested depositional gap during the YD roughly corresponds to the Natufian culture of the late Epipaleolithic in the Levant; the entity that soon thereafter became the first agriculturalists during the Neolithic. The Early Natufian provides the first evidence for complex hunter–gatherer societies, with large-scale sedentary settlements, or hamlets, in the Mediterranean core area (e.g., Garrod, 1957; Bar-Yosef, 1983, 2001, 2002; Bar-Yosef and Belfer-Cohen, 1989; Henry, 1989; Goring-Morris and Belfer-Cohen, 1998). It developed during the humid Late Glacial stadial (Weinstein-Evron, 1998 and references therein). Characteristic features include varied architectural remains, large cemeteries, prolific ground stone and bone–tool assemblages, numerous art objects and items of personal decoration, and long-distance connections and exchange net-works. The Late/Final Natufian is thought by many scholars to show a return to a more mobile settlement strategy which is often related to the YD (e.g., Bar-Yosef and Belfer-Cohen, 2002; Grossman et al., 1999). Others (e.g., Tchernov, 1998) argue against a casual relationship between the local cultural changes and global climatic events. Given the relatively mild YD in the Levant (Bottema, 1995; Weinstein-Evron, 2002), climate alone cannot explain changes in social complexity. Rather, a combination of socio-cultural and environmental factors, and the delicate inter-relationship between them, should be better understood before a comprehensive interpretation of the apparent changes is achieved.

During the third sedimentological phase (Clay Unit I, 6.30–7.10 m) organic dark clay was deposited. This unit most probably represents a fossil marsh. Three ^{14}C dates (8,950 ± 100 YBP, 8,790 ± 90 YPB and 8,760 ± 90 uncalibrated YBP) were obtained for this phase, suggesting an Early Holocene age (Text-Figure 3). The dates show a slight reversal with depth, but they are all in the same range. Calibrated ages range between 10,300 and 9,550 cal. YBP, implying that the marsh may have existed for only a few hundred years. The dates of Clay Unit I are synchronous with ages obtained in previous studies for a correlative clay unit at Dor (Sneh and Klein, 1984; Sivan et al., 2004), and along the Carmel coast (Galili *et al.*, 1993, 1997; Galili and Weinstein-Evron, 1985).

The well-preserved pollen from Clay Unit I (Pollen Zones 2 and 3) and their high concentrations enabled the reconstruction of fluctuations in vegetation and climate in the area during this period (Text-Figure 5). At the beginning (Pollen Zone 2) humid climatic conditions prevailed, giving way to a slightly drier climate (Pollen Zone 3).The main component of the AP group in Pollen Zones 2 and 3 is the evergreen oak–*Quercus calliprinos*. The high percentages of this species indicate an expansion of the Mediterranean maquis in the area as a result of higher precipitation. Other dominant components of the AP group are the deciduous oaks, which are represented by the *Q. ithaburensis* type. Two deciduous oaks grow in the Carmel area today: *Q. ithaburensis* and *Q. boissieri* Reuter, and are similar to other deciduous oaks in the Levant. They are palynologically indistinguishable species (e.g., Weinstein-Evron, 1990). Therefore, it is impossible to determine whether the higher precipitation indicated by the rise in deciduous oaks was accompanied by cooler conditions (as would be the case were the pollen grains of *Q. boissieri* Reuter) or rather a warm climate (as would be indicated by a rise in the thermophilous *Q. ithaburensis*). In both cases, the changes in the AP/NAP ratio suggest that when the marsh was first formed (Pollen Zone 2), precipitation was higher than today and the oak maquis was probably more expansive in the area, both in the mountains and the coastal plain. Later (Pollen Zone 3), the climate seems to have become relatively drier, with several secondary fluctuations in humidity. Other trees that were identified in the AP group (i.e., *Olea, Pistacia, Pinus* sp.) are typical of the Mediterranean maquis or forests as well.

The palynological data suggest the highest humidity in Pollen Zone 2. Higher precipitations for the Early Holocene were also interpreted from various isotopic analyses of speleothems (Bar Matthews et al., 1997, 1999; Frumkin et al., 1999; 2000). Bar Matthews et al., (2000), who estimate a precipitation of between 675 and 950 mm in the Judean Mountain area, further correlate this period with the Early Holocene humid phase, as evidenced in the palynological analyses of sapropel 1 in the eastern Mediterranean

(Rossignol-Strick, 1999), a phase characterized by high dispersal of oak and pistachio forests in this area. Several fluctuations in humidity were documented in the Early Holocene along the Dead Sea Rift, with a slightly more humid initiating phase (Baruch and Bottema, 1991, 1999, Horowitz, 1992). During this period, various Early Neolithic socio-cultural entities of the Pre-Pottery Neolithic (PPN) developed in the Levant, and with them, domestication and cultivation of plants and animals, and the first farming communities (e.g., Bar-Yosef, 1998, 2001; Goring-Morris and Belfer-Cohen, 1998; Lev-Yadun and Gopher, 2000 and references therein).

The NAP group of Pollen Zones 2 and 3 (Clay Unit I) is dominated by Cheno/Ams, Poaceae and Apiaceae, together with some Asteroideae and Cichorioideae. In Pollen Zone 3, Cheno/Ams values are the highest of the whole sequence. In fossil records from the eastern Mediterranean (e.g., Rossignol-Strick and Planchais, 1989; Rossignol-Strick, 1995) and the Levant (Horowitz, 1974, 1979, 1989, 1992; Baruch, 1986, 1994; Weinstein-Evron, 1983, 1990, 1994; Baruch and Bottema, 1991, 1999; Niklewski and van Zeist, 1970; Yasuda et al., 2000) increases in Cheno/Ams contents are often interpreted as indicating dry conditions. This also seems to be the case in the current study, where a decrease in AP between Pollen Zone 2 and 3 is compensated for by a rise in Cheno/Ams. However, since the D-Dor coring site is located near the Mediterranean coast, the possibility that a certain amount of the Cheno/Ams represents local saline conditions should be also considered.

High Cheno/Ams percentages also characterize other coastal salines in Israel, with the highest levels (9–19%) retrieved from the fossil marsh at Newe-Yam (Galili and Weinstein- Evron, 1985). In some of the pollen spectra of D-Dor, Cheno/Ams pollen accounts for more than 50% of the total. Thus, the D-Dor samples exhibit the highest Cheno/Ams contents so far found in studies of the Israeli coast. Significantly, they outnumber even the values (47%) found at the recent pollen assemblage of the artificial salt pond at Atlit (Text-Figure 2) (Galili and Weinstein- Evron, 1985). This suggests that the ancient swamp at Dor was a coastal saline, and not a fresh, water pond. The similar trends of the Cheno/Ams and pollen concentration curves, and especially the concordance between periods of high pollen concentrations and high Cheno/Ams, may suggest that local Cheno/Ams plant formations, rather than regional ones, are the main contributors of pollen. However, it is also probable that the high Cheno/Ams contents should be attributed to both drying and local salinization. Salinity is also corroborated by the paleontological data from previous studies in this area (Galili and Weinstein-Evron, 1985; Sivan at al., 2004).

Asteraceae and Apiaceae pollen are represented in high percentages throughout the palynological sequence. Members of these families widely occur in the different plant formations of the area. Consequently, various types of Asteraceae and Apiaceae pollen are usually represented, and we were unable to identify any specific plants or to relate any of them to a particular marshy or coastal biotope. High Asteraceae levels are sometimes interpreted as a result of some sort of post-depositional, differential pollen decay biased towards exine-durable pollen types (e.g., Bottema, 1975; Weinstein-Evron, 1994). A similar mechanism has been suggested for Apiaceae pollen as well (Weinstein-Evron, 1994). However, given the high levels of Poaceae pollen, which are amongst the less-durable pollen types, the retrieved spectra possibly represent local biotopes that have no modern analogues in the area, rather than selective preservation of pollen.

Artemisia monosperma appears in small quantities, and only in Pollen Zones 2 and 3, which represent the Early Holocene. The absence of *Artemisia* from Pollen Zone 1 in D-Dor indicates that this species arrived in the area later than the deposition of Clay Unit II. *Artemisia* has its origin as a Saharan species. According to Zohary (1973), it penetrated the Mediterranean region only a few thousand years ago, and today it is a very common plant in the stabilized dunes along the coast of Israel. Our research clearly shows that it was present in the area from the beginning of the Holocene. This somewhat modifies a previous evaluation by Galili and Weinstein-Evron (1985), who suggested that the upper part of the correlative clays near Atlit were deposited prior to the penetration of Holocene sands and Saharan species into the area.

The ancient wetlands along the Carmel coastal troughs are now covered by sand (Galili and Weinstein-Evron, 1985; Galili et al., 1993; Sivan et al., 2004) that had accumulated from west to east as a consequence of the Holocene sea level rise, gradually burying the fossil clays and embedded prehistoric sites. The lower part of the D-Dor Sand Unit was dated by the luminescence method to 5,100 YBP. This date is synchronous with those previously obtained for the beginning of the sand accumulation at a number of sites on the central Israeli coast (Gvirtzman et al., 1998; Frechen et al., 2001; Engelmann et al., 2001). Based on archaeological evidence and comparisons with numerical models, the estimated mean sea level at the beginning of the Holocene was about 20 m below present sea level, and 1 to 2 m lower than msl at 5,000 BP, when the sand started to accumulate along the present coast (Galili et al., 1988, 1993; Sivan et al., 2001 and references therein; Sivan et al., 2004). As mentioned above, the marshy clays must have dried out before 9500 cal. YBP, and the accumulation of the sand in the Dor area is dated to about 5,000 BP, suggesting a gap of some 4,500 years between the two units.

The shells found at the top of Clay Unit I, beneath the sand (Text-Figure 4) are marine (Barouch Inbar, oral commun., 2002), suggesting that they were deposited at the base of the sand unit as a result of the rising sea level. This indicates that the sea was close to, or even at, its present level when they were embedded in the upper part of the Early Holocene marshy clays.

CONCLUSIONS

1. The detailed sampling and the inter-disciplinary approach enabled us to fine-tune the Late Quaternary stratigraphic column in the area (Text-Figure 6). Furthermore, it allowed the identification of several sub-units within the clays. Three clay units were identified and characterized within the D-Dor sequence, representing different depositional environments. The brown clay at the bottom is probably a paleosol that was deposited on top of the *kurk*ar, about 26,000 cal. years ago. Pollen grains were not preserved in this unit. The gray clay overlying this paleosol was deposited in a wetland environment that existed in the area until about 12,000 cal. years ago. The occurrence of pollen grains only at the upper part of the gray Clay Unit II may indicate the drying up of the marsh and a later infiltration of pollen through cracks in the surface of the clay. At the beginning of the Holocene, between 10,300 and 9,550 cal. years ago, the dark Clay Unit I was deposited in the newly-formed marsh. The good state of preservation and high concentrations of pollen grains in this unit (Pollen Zone 2 and 3) allow a reliable reconstruction of the paleoenvironments. At about 5,000 BP, sands started to accumulate in the area as a consequence of the Holocene sea level rise, gradually burying the fossil clays and embedded prehistoric sites, from west to east.

2. Changes in the AP/NAP ratios suggest fluctuations in humidity. Pollen Zone 1 is the driest. During Pollen Zone 2, dated to the beginning of the Holocene, when the marsh was first formed, precipitation was higher than today, and oak maquis was probably more extensive in the area. In Pollen Zone 3 the climate became relatively drier, with several secondary fluctuations in humidity.

3. The D-Dor sequence constitutes the most detailed Late Quaternary paleoenvironmental sequence from the northern Israeli coastal plain to date. It provides an important paleoenvironmental framework for the understanding of cultural developments in the area, most notably the passage from hunter–gathering to agriculture in the Levant.

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