Holocene evolution of the Haifa Bay area, Israel, and its influence on ancient tell settlements

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Received 14 November 2005; revised manuscript accepted 27 February 2006

A HOLOCENE RESEARCH PAPER

Abstract: The geographical evolution of Haifa Bay and Zevulun Plain, Israel, from the late Pleistocene to the Holocene, is based on detailed analysis of drilled cores. At the beginning of the Holocene the Bay area was still under terrestrial conditions. Only about 9500 to 9000 cal. yr BP, when sea level rose to about 35–30 m below present sea level (b.s.l.), did Nile-derived sand start to bypass the Carmel headland and Haifa Bay come into existence as a morphological feature. Between 8000 and 7150 cal. yr BP, when sea level was 14–10 m b.s.l., the invading sea crossed the present-day coastline. At about 6800 to 6600 cal. yr BP sea level rose to about 5 m b.s.l. and flooded the Zevulun Plain up to 2 km inland, and the River Qishon estuary up to 4 km inland. It is still unknown exactly when the sea reached its maximum penetration inland but later, about 4000 years ago, the coastline in the research area was still east of the present-day coast, up to 3 km in the Zevulun Plain and 4.8 km in the River Qishon estuary. When the coastline started to retreat westward, the reclamation was followed by intensive deposition of shallow marine sand and aeolian dunes, while to the east, different wetland conditions developed. The archaeological data indicate that during the Early Bronze Age I and Early Bronze Age II, dated to between 5600 and 4700 cal. yr BP, and even later, during the Middle Bronze Age II period, about 4600 to 3500 cal. yr BP, the coastline was still east of the present-day coast, but it never actually reached the bases of most of the tells, as has been suggested, except for Tel Akko and Tel Abu Hawam.

Key words: Israel, Haifa Bay, Holocene, palaeogeography, palaeocoastline, sea levels, human settlement tells.

Introduction

Haifa Bay, on the northern coast of Israel, is the most significant morphological structure along the southeastern Mediterranean coast. The bay is the northeastern end of the Nile littoral cell (Inman and Jenkins, 1984), and constitutes the final depositional basin of the Nile-derived quartz sand, which is transported from the Nile Delta along the northern Sinai coast and the coast of Israel (Emery and Neev, 1960; Goldsmith and Golik, 1980; Carmel *et al.*, 1985; Perlin and Kit, 1999). The bay area is divided into the land side, the Zevulun Plain, and the marine side, Haifa Bay. It is bounded by Mount Carmel in the south, by the Lower Galilee hills to the east and by the Akko promontory to the north (Figure 1).

Morphologically, the sea floor of the bay can be divided into three main subareas. In the central and northern parts of the

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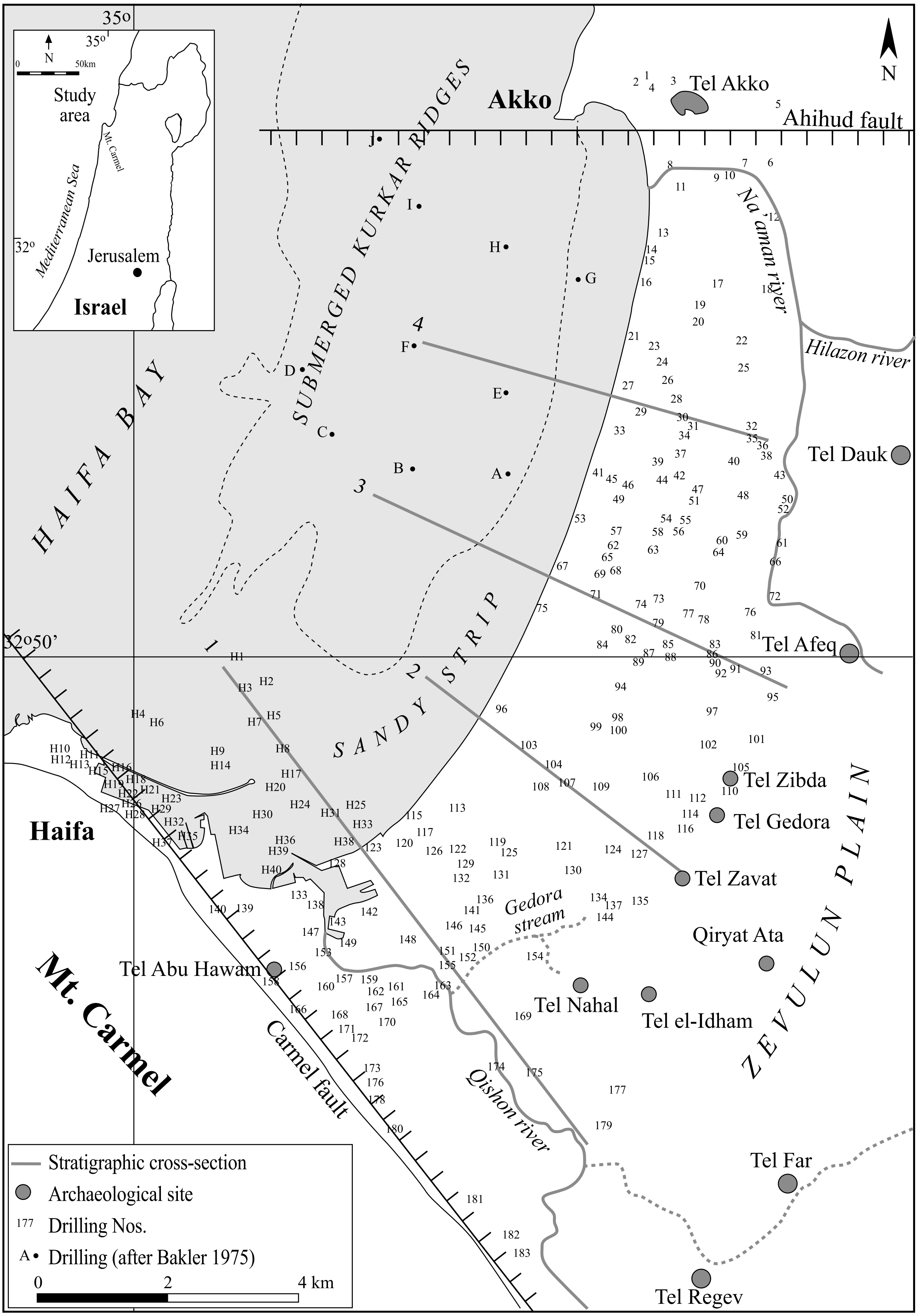


Figure 1 Location map of the study area with the locations of the cross-sections, the archaeological sites, the main rivers and streams, the main fault lines and the numbers indicating the location of the drillings used in the current research

bay, 10–25 m water depth, there is a row of four submerged parallel calcareous sandstone (locally termed *kurkar*) ridges (Bakler, 1975; Hall, 1976). In the southern and eastern parts of the bay a strip of Nile-derived quartz sand exists between the kurkar ridges and the coastline (Nir, 1980). West of the kurkar ridge area, down to about 30 m water depth, the flat surface is covered with sandy-silt sediments. The Zevulun Plain is a flat area tilted slightly westward. For about 3 km inland from the present-day coastline, it is mostly covered by sand dunes and, in the eastern and southern parts, by alluvial clay soils. The Zevulun Plain is traversed by the Rivers Na'aman and Hilazon to the north and the River Qishon to the south (Figure 1). Haifa Bay and the Zevulun Plain are a geological graben, bordered to the north and south by the Ahihud and Carmel (Yagur) faults, respectively (Kafri and Ecker, 1964).

Previous studies of Haifa Bay, mainly based on marine geophysical studies, obtained subsurface data (Hall, 1976; Ben-Avraham *et al*., 1998), while the stratigraphy and lithology of the Zevulun Plain are known from drillings (Slatkine and Rohrlich, 1963; Kafri and Ecker, 1964). Some previous researchers challenged the reconstruction of the late Pleistocene and mainly Holocene geological history, but they were restricted to relatively limited areas such as Akko (Inbar and Sivan, 1984) or the River Qishon estuary (Galantee *et al*., 1990; Shemer, 1995).

The current research seeks to present the Holocene chronostratigraphy of the Haifa Bay area as a whole, to reconstruct the coastline migration and the evolution of the landscape, and to verify the impact of these environmental changes on early human settlements.

During the last glacial maximum (LGM) about 18 000 years ago, the global sea level was about 120 m below the present level (b.s.l.) (Fairbanks, 1989; Bard *et al*., 1990). As a result, the coastline in the study area was located more than 20 km west of the present-day coast. Since then, and up to the beginning of the Holocene, sea level rose rapidly to about 40 m below the present level (Fairbanks, 1989; Bard *et al*., 1990, 1996; Lambeck and Bard, 2000; Lambeck *et al*., 2002, 2004). Sea level continued to rise rapidly until the mid Holocene, but by about 6000 years ago the rate of change had slowed considerably (Lambeck and Purcell, 2005). About 4000 years ago sea level was still 1–0 m lower than at present (Morhange *et al*., 2001; Lambeck *et al*., 2004; Marriner *et al*., 2005). Archaeological and geological research along the Carmel coast supports this conclusion, indicating that during the last 4000 years sea-level changes were less than 1 m (Sneh and Klein, 1984; Galili *et al*., 1988, 1993, 2005; Nir, 1997; Galili and Sharvit, 1998; Sivan *et al*., 2001, 2004b; Galili, 2004).

The Zevulun Plain attracted human settlers as early as the Neolithic and Chalcolithic periods (Marcus, 2002) following by the Early Bronze Age I (EBI) about 5600–5100 cal. yr BP, as witnessed in Tel Akko, where temporary EBI habitation was found at the basal level (Dothan, 1993), and in Tel Afeq during the Early Bronze Age II (EBII), about 5100–4700 cal. yr BP. However, the main sedentary settlement in the Zevulun Plain started during the Middle Bronze Age II (MBII) about 4600–3500 cal. yr BP, as witnessed in Tel Akko and Tel Zavat (Figure 1). Later, during the Late Bronze Age (LB) about 3500–3200 cal. yr BP, Tel Akko (Artzy, 2006a), Tel Zavat, Tel el-Idham (Ventura and Siegelmann, 2004) and Tel Abu Hawam (Artzy, 2006b) were settled (Figure 1). Knowledge of the environmental conditions during these periods can shed light on the nature of human settlement in the Zevulun Plain since the mid Holocene.

Methods

Stratigraphy and lithology

More than 1000 drillings have been carried out in the Zevulun Plain and Haifa Bay during the period 1934–2004. About 200 of them were carried out during the current research, and about 100 of these were analysed in detail. In addition, more than 100 selected drilling logs from previous research were re-examined. The lithological units were re-identified, and the definitions and terms used by previous scholars were coordinated. The lithological units were identified based on colour, granulometry, mineralogy and the faunal assemblages noted in the drilling logs. The re-examination of the cores enabled the use of 224 logs as a whole for establishing high-resolution Holocene stratigraphy of the Haifa Bay area (Figure 2). The data were superimposed on bathymetric charts, and were partly confirmed by scuba diving and coastal observations. The mid Holocene to late Holocene unconsolidated units, mainly sand, transported by the rising sea, were 'removed' to establish the palaeobathymetry at different periods.

Dating

In the current research, four samples (labelled RTT in Table 1), three from the grey clay and one from the brown clay, were ^{14}C-dated at the Radiocarbon Dating Laboratory of the Weizmann Institute by the AMS technique. The sediment material was analysed by Fourier Transform Infrared Spectroscopy (FTIS) before and during the pre-treatment procedure for radiocarbon dating. This analysis shows that the samples were composed mainly of carbonate, clay, and quartz. The percentage of material left after pre-treatment (residual%), mainly clay, is given in Table 1. The protocol used (acid-base-acid) was employed to separate carbonate and humic fractions. Both fractions can be a source of carbon with a different origin from carbon present in the clay. Three of the four clay samples had a very low C%. Only sample RTT 4902 had a significantly high C content (2.3%). The Holocene ^{14}C dates were calibrated using the OxCal v.3.10 program (Bronk Ramsey, 1994) and Reimer *et al*. (2004). A fifth radiocarbon sample (W-1494, Table 1) from an early investigation is also included in this work. The sample is a marine shell, and its calibrated age was obtained using the marine curve in OxCal v.3.10 based on Hughen *et al.* (2004). The reservoir age correction is included in the marine calibration.

Results

The late Pleistocene and Holocene chronostratigraphic units of the current study were based on drillings, geophysical marine data and dating results. The stratigraphic units were divided into Holocene and pre-Holocene units. The Holocene units were subdivided into terrestrial, shallow marine, coastal and aeolian phases.

Pre-Holocene units

Most of the pre-Holocene lithological units in the research study area are not exposed, except for a few kurkar outcrops. Dolomite, Cenomanian in age, is found along the eastern Mount Carmel flanks. The kurkar at the base of the young stratigraphic sequence of Haifa Bay is divided into two types: an older Kurdani kurkar, Plio-Pleistocene in age (Kafri and Ecker, 1964), and a younger late Pleistocene kurkar. The Kurdani kurkar is reddish-brown, hard, massive and homogeneous rock, usually with small hollows filled with reddish

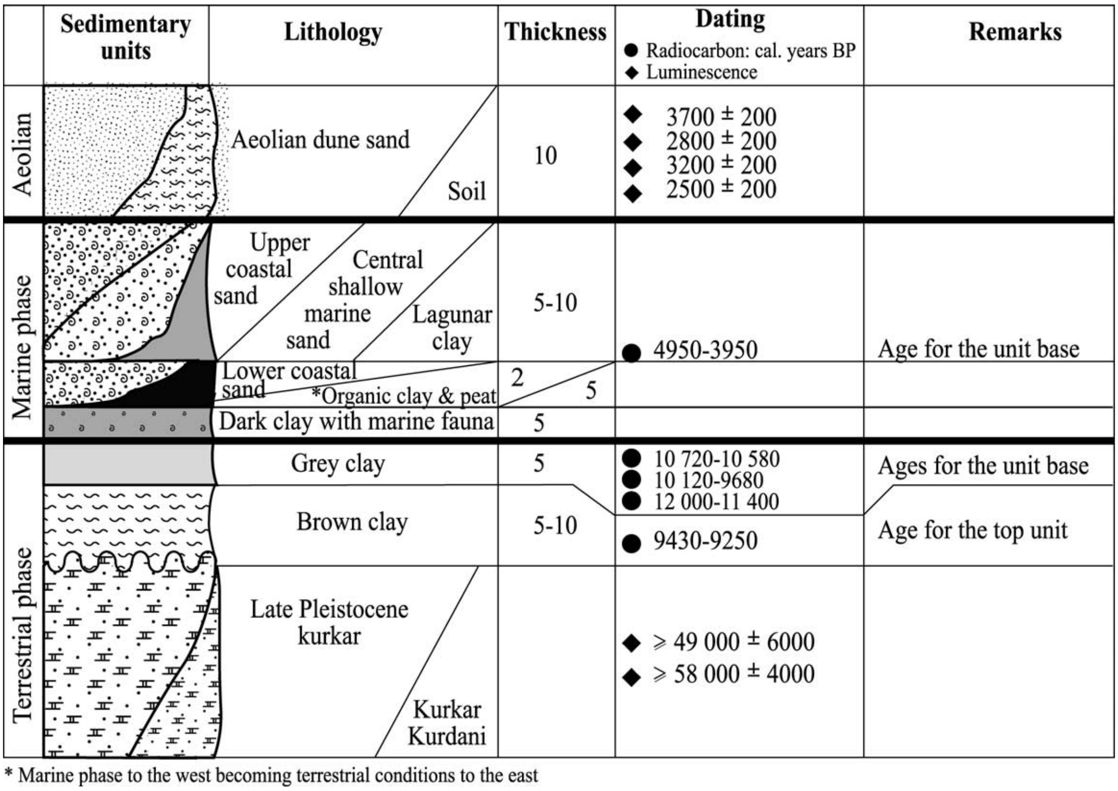


Figure 2 The generalized Holocene stratigraphic sequence of Haifa Bay area unconformably overlying the kurkar. The Holocene sequence consists of three sedimentary cycles: terrestrial, marine and aeolian. The marine sediments are mainly shallow marine and coastal Nile-derived quartz sand

loam. The late Pleistocene kurkar comprises alternating sand, aggregates and hard yellow to brownish plates, up to 5 cm thick, mainly of quartz and calcite, with small amounts of feldspar minerals. The kurkar is rich in fossils: molluscs, echinoidea spines, foraminifera and calcareous algae (Slatkine and Rohrlich, 1963). Unlike the late Pleistocene kurkar, which consists of submerged longitudinal kurkar ridges, most of the Kurdani kurkar is in the subsurface, with only few exposures in the eastern parts of the Zevulun Plain: Tel Akko (Kafri and Ecker, 1964; Sivan *et al*., 1999), Tel Afeq, Tel Dauk (Kafri and Ecker, 1964), Tel Gedora (Shalom Yankelevitch, personal communication, 2005) and probably Tel el-Idham (Ventura and Siegelmann, 2004). The spatial stratigraphic relation between the kurkar types in the Haifa Bay area is not fully understood, but they were first distinguished in the current research, based on sedimentary characteristics. Radiometric dates obtained so far were for the kurkar from the foot of the Carmel (Figure 1, drill 183). The kurkar found at 20–25 m below the present sea level was dated by infrared stimulated luminescence (IRSL) to 49 000 $\pm$ 6000 years before present (yr BP), and 58 000 $\pm$ 4000 yr BP, respectively (Amos Salamon, personal communication, 2005), and is therefore attributed to the late Pleistocene. Nine core drillings from the submerged kurkar ridges in the central and northern parts of the Bay previously studied by Bakler (1975) were re-examined in the current research (see Figure 1A–J) Based on the lithological characteristics and the fauna, this kurkar was attributed to the late Pleistocene kurkar.

The late Pleistocene to early Holocene units

The sedimentary units unconformably overlying the kurkar indicate three different sedimentary cycles (Figure 2): Terrestrial, coastal and shallow marine, and aeolian.

Terrestrial conditions

- *Brown clay* (Figure 2). Silt to sandy brown clay, homogeneous, with almost no fauna, unconformably overlies the kurkar (Figures 2–4). The unit is up to 10 m thick and is found mainly in two areas: in a strip about 10 km long and 2 km wide stretching from the central part of the Zevulun Plain to Akko (since the sea side was not drilled here, there are no data concerning the western dispersal of this unit), and in patches alternating with grey clay in the River Qishon estuary. The upper part of the brown clay was ^{14}C dated (Drill no. 73, see Figure 1) at depths of 5.0–5.45 m b.s.l., giving an age of 9430–9250 cal. yr BP (RTT 4900, see Table 1).
- *Grey clay.* A grey to dark grey clay overlies the brown clay or the kurkar units. The grey clay is homogeneous, sometimes containing scattered sand lenses or small calcareous gravels. The unit is up to 5 m thick (Figure 2). The grey clay mainly occurs in the southwestern research area, mostly in the River Qishon estuary. Three dates were obtained for the base of the grey clay by AMS ^{14}C. One in Haifa Port (Drill H2, see Figure 1) at a depth of 20.0–20.25 m b.s.l. (RTT 4562) gave an age of 10 720–10 580 cal. yr BP (calibrated for $\pm 1\sigma$). The other two samples: Drilling 168 from a depth of 13.7–14.2 m b.s.l. (RTT 4902) gave a date of 10 120–9680 cal. yr BP, and Drilling 172 from a depth of 13.1–13.6 m b.s.l. (RTT 4901) gave a date of 12 000–11 400 cal. yr BP (Figure 2 and Table 1). The three dates obtained so far indicate the first appearance of the grey clay unit at the end of the late Pleistocene to early Holocene.

The mid Holocene units

The main lithological units of the coastal and shallow marine phase consist of dark clay with marine fauna, coastal and

Table 1 ^{14}C dates obtained for Holocene units of the Zevulun Plain. The residual percent refers to the amount of material left after pre-treatment. The %C refers to the content of carbon in the pre-treated material. The calibrated age has been calculated using the OxCal 3.10 calibration program.

Lab no.	Drill no. (see Figure 1)	Coord. Israel Cassini-Soldner	Height (m) b.s.l.	Material dated	Residual %	% C	Unit	$\delta^{13}C$ ‰ PDB	$^{14}C \pm 1\sigma$ yr BP	Calibrated age yr BP ($\pm 1\sigma$)
RTT 4900	73	25°08.64'N 15°81.27'E	5.0–5.45	Clay organic fraction	23.4	0.25	Brown clay	−24.7	8300±50	9430–9250
RTT 4562	H2	24°70.15'N 15°22.84'E	20.0–20.25	Clay organic fraction	37.0	0.17	Grey clay	−26.0	9430±50	10 720–10 580
RTT 4902	168	24°44.87'N 15°30.43'E	13.7–14.2	Clay organic fraction	43.0	2.30	Grey clay	(−25.0)*	8800±75	10 120–9680
RTT 4901	172	24°41.66'N 15°34.94'E	13.1–13.6	Clay organic fraction	36.0	0.11	Grey clay	−23.5	10 100±55	12 000–11 400
W-1494		24°65.29'N 15°35.29'E	9.65	*Glycymeris violacescens*			Central shallow marine sand		4360±360	4950–3950

[a] The amount of CO_2 obtained by combustion of the samples was not enough for the MAS measurement and for the $\delta^{13}C$. Therefore we assumed −25‰ for this sample.

shallow marine sand and dark clays, which had been embedded simultaneously east of the marine units. Most of the coastal and marine units are now found below present sea level, with their bases ranging between about 20 and 15 m b.s.l. in the west to about 5 m b.s.l. to the east, and their tops up to present sea-level, with one exception (Figure 4b).

Shallow marine and coastal conditions

- *Dark grey clay with marine fauna*. A soft dark grey to black clay, sometimes containing lenses of grey sand and silt, small gravels and organic remains, was deposited over the grey clay. The clay contains small shell fragments of molluscs, among which *Loripes lacteus*, *Bittium* sp., *Cardium* sp., *Donax semistriatus*, *Pirenella conica* and foraminifera were identified taxonomically. The unit is restricted to a narrow strip in the eastern part of the Zevulun Plain (Figure 3), and is up to 5 m thick.
- *Coastal and shallow marine sands*. The unit is divided into three sub-lithological units.
- *Lower coastal sand*. Fine grey quartz sand, mixed with dark coarse sand rich with shells, shards, broken corals and echinoidea spines, and kurkar pebbles up to 6 cm, sometimes covered by marine patina. The macro-fauna includes: *Hydrobia* sp. (including *Hydrobia acuta*), *Bittium* sp., *Rissoa* sp., *Corbula gibba*, *Cerithium cfr.*, *Vulgatum, Caecum trachea, Tricolia pullus*, *Pirenella conica*, *Cerastoderma edula*, *Donax* sp. The unit, which is restricted to the central and northern part of the research area, extends up to 2.8 km east of the present coastline (Figure 4), and is absent in the Qishon estuary (Figure 3). The base of the lower coastal sand ranges from about 15 m b.s.l. in the west to about 7 m b.s.l. in the east. It overlies the brown clay and is up to 2 m thick.
- *Central shallow marine sand*. Well-sorted fine grain quartz sand, grey to dark grey with pyrite and feldspar, which includes a few well-preserved foraminifers and calcareous algae with very few molluscs. The unit is 5–10 m thick. The central shallow marine sand comprises most of the sand mass in the south (Figures 3 and 4a), and is rare in the central plain, where it was found only as bars 1 to 3 km east of the present coastline (Figure 4b). In the north (Figure 4c), the unit is absent except in the River Na'aman area. The unit overlies the brown and the grey clays or the lower coastal sand. An articulated *Glycymeris violacescens* had been previously found embedded at the base of the unit, and gave a radiocarbon age of 4950–3950 yr BP (Shemer, 1995).
- *Upper coastal marine sand*. To the north, the upper coastal sand unit (Figure 2) becomes thicker and dominant and comprises most of the shallow marine and coastal sand mass. This unit, containing medium to coarse sand and yellow to light grey, consists of quartz and calcite with feldspar and pyrite, molluscs and marine shell shards, corals, echinoidea spines and microfauna. The macrofauna includes *Donax semistriatus*, *Donax* sp., *Donax trunculus*, *Loripes lacteus*, *Bittium* sp., *Pirenella conica*, *Angulus planstus*, *Mactra corallina*, *Acanthocardia tuberculata*, *Glycymeris violacescens*, *Glycymeris pilosus* and *Venus* sp.

Wetland conditions

The stratigraphic sequence in the eastern part of the Zevulun Plain contains distinct patches of terrestrial dark clay units indicating freshwater wetlands differing in age and location.

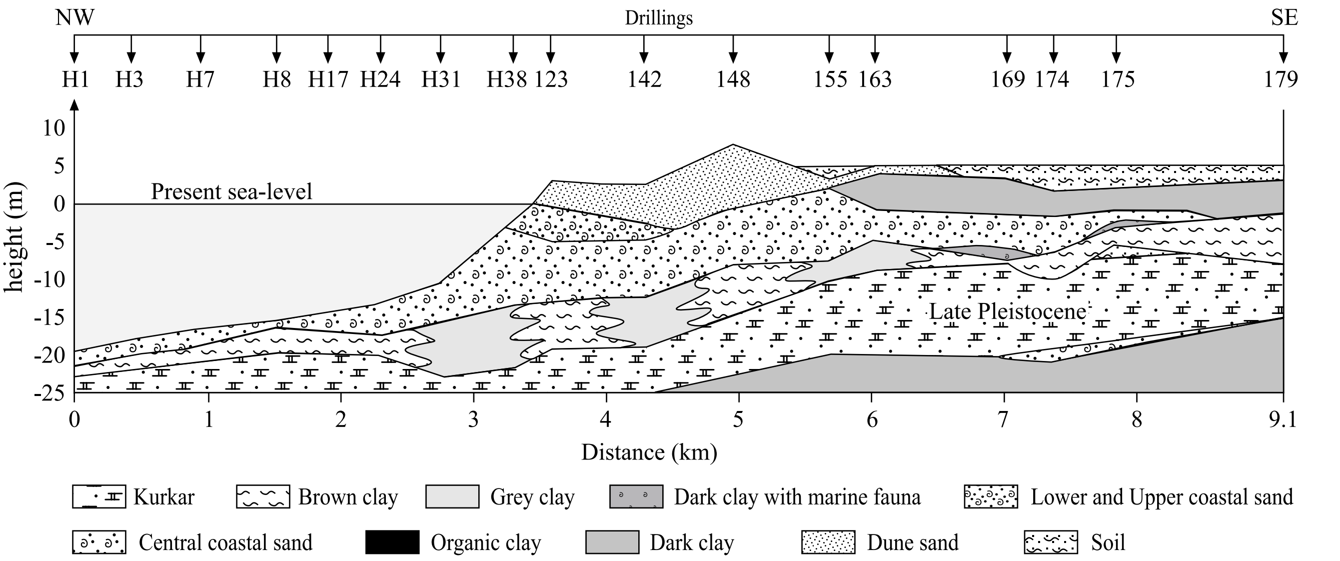


Figure 3 Cross-section 1. The southernmost section through the River Qishon estuary (for location see Figure 1). The base elevation of the marine sand at the sea side is at 21.5 m b.s.l., while at the land side the base reaches less than 5 m b.s.l. The marine sediments are found east of the present coastline, up to 3 km at Zevulun Plain and up to 4.8 km in the River Qishon estuary.

- *Dark organic clay*. To the east, soft dark grey to black clay with relatively high percentages of organic clay, in cases with few freshwater molluscs, was deposited in different places with different stratigraphic relations. The unit is up to 5 m thick and overlies the grey or brown clay. The unit exists in three areas: the main wetland west of Tel Afeq 4 km northward along the River Na'aman (Figure 4b), the second marsh stretching from Drills 127 and 124 southward to Drills 134 and 144 (Figure 1), and the third marsh along the Gedora stream around Drill 150 (Figure 1).
- *Peat*. A unit of brown dark to black thin laminae, which contains a high percentage of charcoal and vegetation remains, overlies the dark organic clay. The unit is less than 2 m thick with no faunal remains. The peat has been found only in few drillings (Drillings 32, 35, 36, 38, 43, 60, 64, 77, 83 and 92, see Figure 1) which define the fringes of the River Na'aman marsh.
- *Dark clay with brackish to hyper-saline fauna*. In the southern part of the Zevulun Plain, mainly in the River Qishon estuary, the dark clay unit contains *Cerastoderma edula* and *Pirenella conica*, which live in brackish to hyper-saline lagoons, estuaries or coastal marshes. The soft clay is dark grey to brown grey, and is highly organic. The unit is up to 10 m thick and overlies the central shallow marine sand or the late Pleistocene to early Holocene clays in places where the sea had not flooded. South of Drill 150 (Figure 1) the top of this unit was previously radiometrically dated to 7450–4850 cal. yr BP (Neev *et al.*, 1987).

Late-Holocene units

Aeolian conditions

The upper unit in the research area is aeolian sand alternating with cemented dunes (Figures 2–4). The sand consists of well sorted bright (mostly yellow) fine quartz, and small abraded micro-fauna and shell shards. The unit is up to 10 m thick. In many places the lower part which is around the present-day water-table, is cemented and appears in different facies: calcareous coarse sand, sand with up to 2 cm diameter rounded stiff aggregates, sand with finger type calcareous aggregates and thin laminae up to 1 cm thick. Four IRSL ages (Heimann *et al.*, 2001) from depths of 1.4–2.1 m below the surface (and which therefore did not reach the base of the dune unit), range from 3700 ± 200 yr BP to 2500 ± 200 yr BP (Figure 2)

Discussion

Since the LGM up to about 4000 years ago the coast of Israel moved eastward because of the global sea-level rise. Unlike most of the coast, in the low and flat Zevulun Plain the sea flooded landward to a distance of about 3–5 km east from the present coastline during the mid Holocene. Later the bay was filled by marine and terrestrial sediments, and the coastline retreated westward to its present-day location.

The Holocene palaeogeography of Haifa Bay

The Holocene lithological units of Haifa Bay area usually unconformably overlie the brown and grey clays, their tops are dated to 9430–9250 cal. yr BP (Table 1). The late Pleistocene kurkar and the brown clay, which have been interpreted as palaeosol or alluvium (Sivan and Porat, 2004; Kadosh *et al.*, 2004; Sivan *et al.*, 2004a; Cohen-Seffer *et al.*, 2005), indicate terrestrial conditions during the late Pleistocene and to early Holocene periods. Unlike the brown clay that had been deposited over most of Zevulun Plain (Figure 4a–c), the grey clay had been deposited mainly in the River Qishon estuary (Figure 3), indicating wetlands scattered in patches in the lower areas of the estuary. In the study area, the base of the grey clay age ranges between 12 000 and 9680 cal. yr BP (Table 1), which means that wetland environments prevailed in the River Qishon estuary at the beginning of the Holocene, similar to the Dor region of the Carmel coast (Sneh and Klein, 1984; Kadosh *et al.*, 2004; Sivan *et al.*, 2004a; Cohen-Seffer *et al.*, 2005).

The sea level rose rapidly to about 50 m b.s.l. between 11 000 and 10 500 cal. yr BP (Fairbanks, 1989; Bard *et al.*, 1990, 1996; Antonioli and Oliverio, 1996; Lambeck and Bard, 2000; Lambeck *et al.*, 2002, 2004) and the coastline shifted eastward to about 14 km west to the present-day coastline in Haifa Bay. During this period the lower part of the rocky Carmel headland (also named Carmel Nose by Neev *et al.*, 1976), which is now covered by the sea, was still exposed and

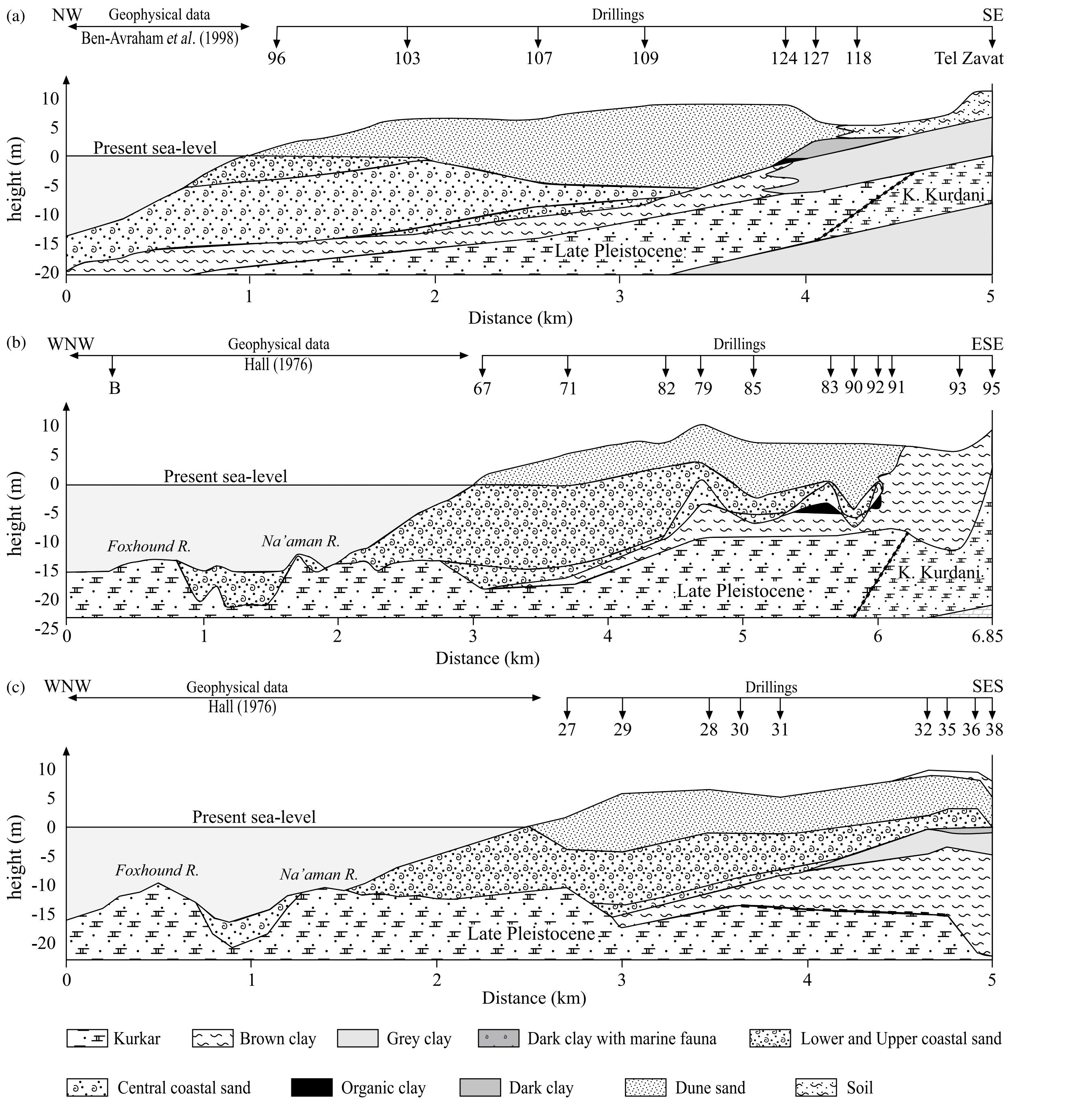


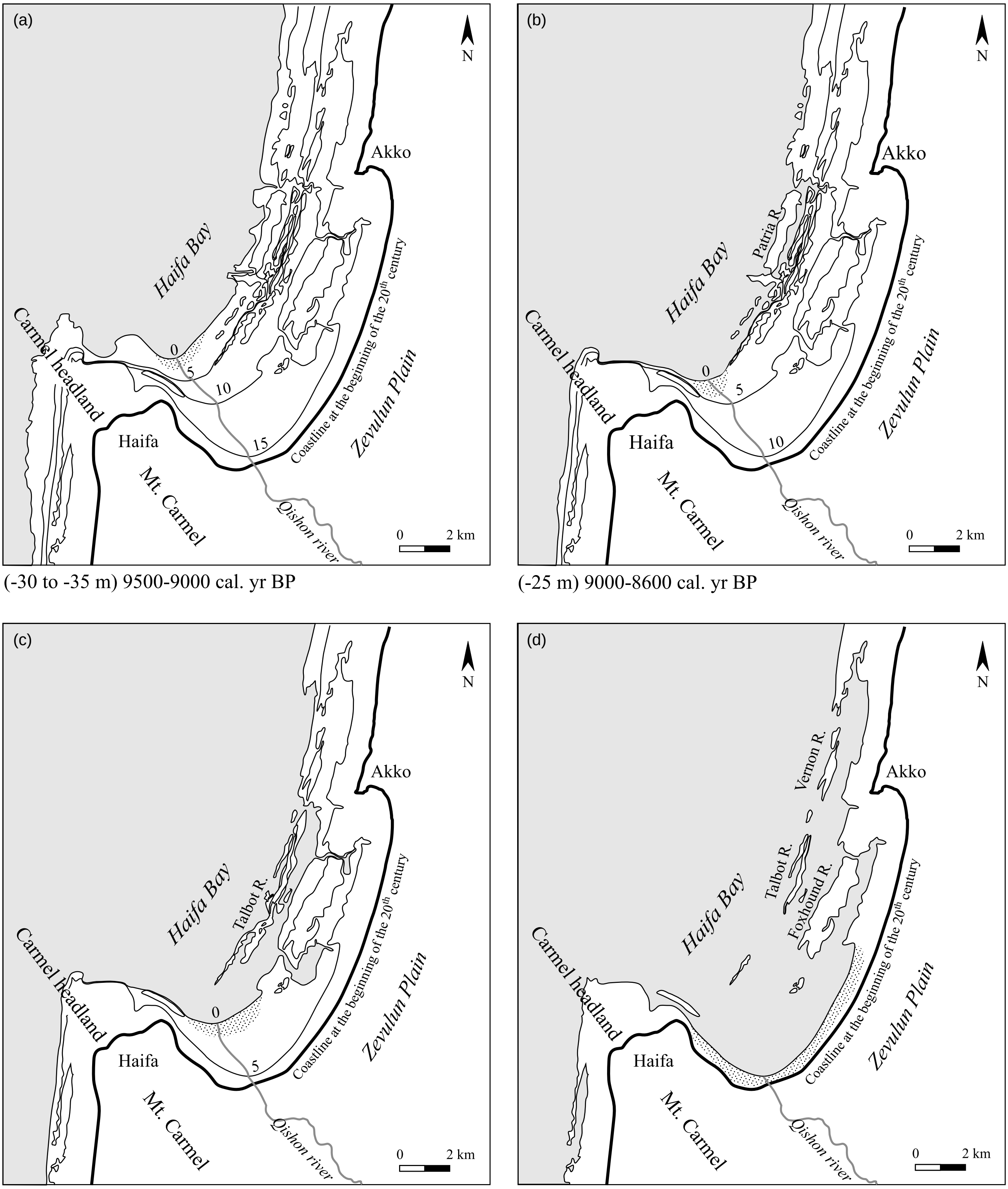
Figure 4 (a) Cross-section 2 (for location see Figure 1). The sea side data are based mainly on marine geophysics surveys, while the land side are based on data obtained from drillings; the marine penetration inland is about 2.5 km east of the present-day coast, and the palaeocoast at its maximum penetration was still about 1.5 km west of Tel Zavat. (b) Cross-section 3 (for location see Figure 1). Maximum landward penetration of the sea was about 3 km east of the present-day coast, still west of Tel Afeq. (c) Cross-section 4 (for location see Figure 1). Maximum sea penetration landward did not exceed 2.5 km, and was still west of Tel Dauk

projected 5 km northwest. This massive obstacle prevented the longshore currents carrying the Nile-derived sand from flowing northward, and they did not enter Haifa Bay, so that Carmel headland was the end of the Nile littoral cell (Zviely, 2006).

Only at about 9500 to 9000 cal. yr BP when sea level rose to about 35–30 m b.s.l. (Fairbanks, 1989; Bard *et al.*, 1990, 1996; Lambeck and Bard, 2000, Lambeck *et al.*, 2002, 2004), and the coastline was at about 5.5 km off the present-day coastline (Figure 5a), sand started to bypass Carmel headland, entering eastward into the bay. For the first time since the LGM, Haifa Bay came into existence as a morphological feature. During this time, to the east of the palaeocoastline, the brown and grey clays, now found in the subsurface of most of Zevulun Plain, accumulated under terrestrial conditions and the kurkar ridges were still exposed on dry land.

Later, between 9000 and 8600 cal. yr BP, sea level rose to about 25 m b.s.l., and the coastline shifted eastward to about 4.5 km west of its present position (Figure 5b). The southern part of the bay became sandy, while the central and the northern parts, along the western flanks of the Patria kurkar ridge, were rocky, with bays and offshore kurkar islets. During this time increasing amounts of quartz sand penetrated the southern part of the bay, but because this area was still more open to western storms, the sand hardly accumulated, and most of it was transported northward (Zviely, 2006).

At 8800 to 8200 cal. yr BP sea level reached about 20 m b.s.l., with the coastline about 3 km off the present coast (Figure 5c).



(-30 to -35 m) 9500-9000 cal. yr BP

(-25 m) 9000-8600 cal. yr BP

(-20 m) 8800-8200 cal. yr BP

(-15 m) 8500-7900 cal. yr BP

Figure 5

The flooding sea surrounded Talbot and Patria kurkar ridges, now covered by the sea, leaving only the highest crests as islets. The sea invaded eastward up to the western margins of Foxhound kurkar ridge. Because of the changing morphological conditions in the southern part of the bay, the Nile-derived sand that bypassed Carmel headland was deposited in larger amounts.

Between 8500 and 7900 cal. yr BP sea level rose to about 15 m b.s.l. (Bard *et al.*, 1990, 1996; Lambeck and Bard, 2000; Lambeck *et al.*, 2002, 2004). Archaeological and geomorphological finds from the Carmel coast, Israel, support the global and regional sea levels mentioned above (Galili *et al.,* 1988, 1993, 2005; Galili and Nir, 1993; Sivan *et al.*, 2001; Galili, 2004). Talbot and Vernon ridges were almost submerged with only a few rocky exposures above the water. Foxhound ridge became a long wide rocky island, and the trough between Foxhound and Na'aman ridges became a long coastal lagoon with the main connection to

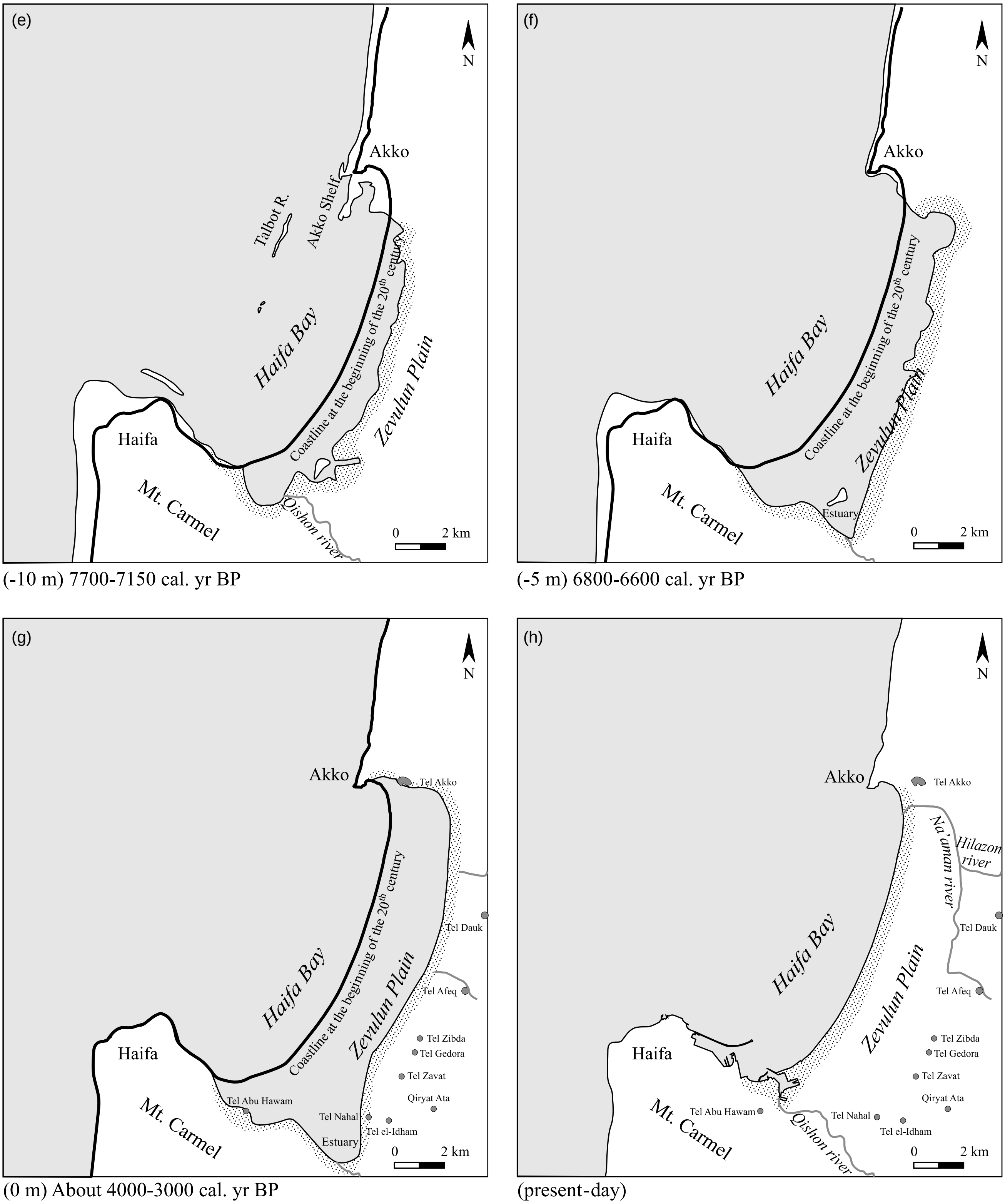


Figure 5 The locations of the palaeocoastlines and the positions of the sandy coastlines of Haifa Bay area during the Holocene period: in (a)–(c) the contours indicate the topography from the palaeocoastline landward up to the present-day coastline. (a) About 9500 to 9000 cal. yr BP the sea level rose to about 35–30 m b.s.l. and, for the first time since the LGM, Nile-derived sand passed round the Carmel headland and entered the bay; the area assumed the morphological feature of a bay for the first time since the LGM. (b) 9000–8600 cal. yr BP: sea level rose to about 25 m b.s.l., the southern part of the bay was sandy, while the central and northern parts were rocky with offshore islets. (c) 8800–8200 cal. yr BP: sea level reached about 20 m b.s.l., and sand accumulated in the southern part of the bay. (d) 8500–7900 cal. yr BP: sea level rose to about 15 m b.s.l., and the coastline was still west of the present coast, with islands and rocky coast in the central and northern parts of the bay. (e) 7700–7150 cal. yr BP: sea level rose to about 10 m b.s.l. and the sea penetrated for the first time east of the present coastline, first in the south and then in the north. (f) 6800–6600 cal. yr BP: sea level rose to about 5 m b.s.l., and the sea continued to invade inland over the whole Zevulun Plain. (g) 4000–3000 cal. yr BP: maximum sea invasion landward; the exact date is still unknown. (h) Present-day: from maximum sea penetration landward, the coastline started to retreat westward to its present-day position because of the reclamation of the bay

the sea at the south. The southern part of Haifa Bay was sandy (Figure 5d). The invading sea deposited the biogenic coarse-grained sand in the centre of the bay (Figure 4a–c). The elevation of the base of the marine sand along the present-day coastline at about 15 m b.s.l., combined with data obtained from sea-level curves, indicate that the flooding sea reached the present-day coastline at Haifa Bay only at about 8500–7900 cal. yr BP. The coarse grain size, the abundance of broken macro-fauna and the kurkar aggregates, which are typical of the lower coastal sand unit, imply a shallow sea with high-energy characteristics in the surf zone. The morphological conditions for deposition of the quartz sand in the southern part of the bay continuously improved (Figure 5d). It seems that during this time, no more Nile-derived sand was transported northward of Haifa Bay, and the Nile littoral cell ended at the kurkar ridges, now covered by the sea (Zviely, 2006).

Sea level continued to rise, and between 8000 and 7150 cal. yr BP, flooded areas in the Zevulun Plain east of the present coastline for the first time. This invasion occurred in two steps: first, sea level was 14–12 m b.s.l. about 8000–7700 cal. yr BP, and then the sea level continued to rise to 10 m b.s.l. at about 7700–7150 cal. yr BP. Local archaeological finds from the Carmel coast support these sea levels (Galili and Weinstein-Evron, 1985; Galili, 1988; Galili *et al.*, 1993, 2005; Galili, 2004). The southern part of the Zevulun Plain was flooded, first up to 1 km east of the present coastline, while in the northern part the coast still stretched along the eastern flank of the Na'aman kurkar ridge. The first marine invasion is recorded in the Zevulun Plain by dark grey clay with marine fauna, which is restricted only to the eastern part of the River Qishon estuary, and contains brackish to hypersaline fauna (Figure 2). The unit contains *Pirenella conica*, indicating low salinity to brackish water, *Donax semistraitus*, which lives in marine conditions; and *Cerastoderma edule* sp. (synonymous are *Cardium* sp.) and *Bittium* sp., which can tolerate a wide range of salinities from low and brackish through the intertidal zone up to hyper-saline water. The following sea flood carried the overlying marine sand units inland in the River Qishon estuary, creating sand bars. These sand bars blocked and detached some estuary branches from the sea and originated marshes that became more salty as they were increasingly protected from the sea by the overlying sand accumulation. The bases of the easternmost salty marshes are now at depths of about 10 m b.s.l. Later, the sea continued to rise, reaching up to 2 km southeastward in the southern part of the bay, and this time crossed the present-day coast also in the northern plain up to 1.5 km eastward. Only around Akko was the area of Akko ledge still exposed above the sea (Figure 5e).

At around 6800–6600 cal. yr BP sea level rose to about 5 m b.s.l. The sea continued to invade inland all over the Zevulun Plain up to 2 km, and in the River Qishon estuary up to 4 km inland. Only along Haifa coast and around Akko was the coast almost at its present location. For the first time all the kurkar ridges were submerged (Figure 5f). The rivers were blocked by large quantities of marine and coastal sand and, as a result, freshwater marshes developed on land, leaving dark organic clay, sometimes with freshwater molluscs and peat, on top in the sedimentary sequence (Figure 2). Sea-level rise slowed down about 6000 years ago, but sea level was still 0–1 m b.s.l. 4000 years ago. The sea continued to rise because of the small ocean volume increase until 3000 years ago (Lambeck *et al.*, 2002; Lambeck and Purcell, 2005). These conclusions are supported by archaeological observations along the Israeli coast, mainly underwater and coastal remains, and agree with the numerical models, which imply that the local sea level was at least lower than 3 m b.s.l. at about 6000 cal. yr BP, and remained below its present level until about 4000 years ago (Sivan *et al.*, 2001; Galili, 2004; Galili *et al.*, 2005). It is still unknown exactly when the sea reached its maximum incursion inland in the Haifa Bay area (Figure 5g), but it seems that between 4000 and 3000 years ago the sea invaded the whole Zevulun Plain up to 3 km, and the River Qishon estuary up to 4.8 km inland. The only age obtained so far for the marine sand is from an articulated *Glycymeris* found in the central shallow marine sand dated to 4950–3950 cal. yr BP (Shemer, 1995). Dating such units by one bivalve is not sufficiently reliable and, therefore, the chronostratigraphy relies mainly on the stratigraphy and its relation to the sea-level curves. About 2000 years ago (Early Roman period) sea level was already at its present level (Galili *et al.*, 1988, 2005; Galili and Nir, 1993; Nir, 1997; Galili, 2004; Sivan *et al.*, 2004b). The oldest luminescence age yielded in the study area for the aeolian dune sand overlying the marine and coastal sand is 3700 ± 200 yr BP. Since the dates were not obtained from the base of the sand, it seems that they started to accumulate earlier, as previously reported: at 5100 ± 500 yr BP (IRSL dating) in Dor, Carmel coast (Kadosh *et al.*, 2004); from about 5600 cal. yr BP at the central Israeli coast (Gvirtzman *et al.*, 1998) at about 6000 ± 500 yr (Engelmann *et al.*, 2001; Frechen *et al.*, 2001) or earlier (Porat *et al.*, 2004). The coastline started to shift westward because of sediment accumulation both by marine and coastal sediments from the west, and fluvial and wetlands sediments from the east. The reclamation was followed by intensive deposition of aeolian dunes. The clay, organic or brackish, was deposited in the eastern part of the studied area at different elevations, always related to the sand units that blocked the drainage during different periods. The wetlands phenomenon is essential for better understanding the environmental conditions during the late Holocene.

The relative tectonic vertical displacement rate along the Carmel fault has been estimated at about ± 0.2 mm/yr (Salamon *et al.*, 2001). Geomorphological features trending east–west, were interpreted as tectonic faults on the sea bottom southwest of Akko (Sivan and Galili, 1999) north of the Carmel headland coast (Galili and Eytam, 1988) and off the central coast of Haifa Bay. Studies of coastal and submerged archaeological features, (mainly rock-cut installations and submerged prehistoric settlements) on the Carmel and western Galilee coasts, (Galili and Sharvit, 1998; Sivan and Galili, 1999), indicate that these regions were relatively stable (± 0.5 m) during the last 8000 years (for the Carmel coast) and during the last 2000 (for the western Galilee coasts). The same rates had been estimated for maximum relative vertical movement at the Carmel coast, Israel, during the Holocene (Sivan *et al.*, 2001). Such rates are actually negligible in the frame of the current research, and therefore, it seems that the connection between the present-day elevation of the marine units and local sea-level data is reliable enough for ± 1 m accuracy.

Human occupation

The above wide-scale Holocene chronostratigraphy derived from the present study indicates that the first sedentary settlements in the study area faced totally different environmental conditions from those prevailing today. The archaeological data suggest that the first urban settlements were established as early as EBI in Akko and EBII in Tel Afeq, and during the two periods, between 5600 and 4700 cal. yr BP, in Qiryat Ata (Figure 1). During this time the coastline was still east of the present-day coast, but at a considerable distance west of the tells. According to the results obtained in the current research, the sea never reached the bases of most of the tells, as previously suggested by Flemming *et al.* (1978). Only Tel Akko was surrounded from the south and southwest by the sea before and at the very beginning of the occupation phase, as previously presented by Inbar and Sivan (1984). The MBII period is witnessed in the Zevulun Plain in Tel Akko and Tel Zavat (Figure 1), with the sea at its maximum penetration inland, but with the coastline still west of the tells. During the MBII the tells were probably surrounded by brown terrestrial clays and wetlands. It has been suggested that Middle Bronze Age harbours along the Israeli coast were located up the river channels and enabled inland navigation and access for sea-going vessels to settlements at a considerable distance inland (Flemming *et al.*, 1978; Raban, 1985, 1998a, b). In the Zevulun Plain specifically, it was suggested that Rivers Na'aman and Qishon were navigable and enabled access to Tel Akko, Tel Afeq, Tel Abu Hawam, Tel Nahal, Tel Far and Tel Regev. It was also suggested that Tel Zavat, Tel el-Idham, Tel Gedora and Tel Zibda, were marine-adapted settlements and located near the coastline (Flemming *et al.*, 1978). So far, no archaeological evidence has been found in the Zevulun Plain for inland Bronze Age harbours. In short, the location of the palaeocoastlines established in the current research and the low gradients of the Zevulun Plain, combined with high rates of sedimentation, show no evidence so far to support the hypothesis of the Bronze Age tells being harbour sites, except for Tel Akko and Tel Abu Hawam.

Later, during the LB, about 3600–3200 cal. yr BP, the shift of the coastline westward and the reclamation were followed by intensive deposition of aeolian dunes. For the last 3000 years there are no archaeological finds in the Zevulun Plain indicating the migration steps of the coastline westward towards its present-day location, except in Tel Akko and Tel Abu Hawam areas. Furthermore, there is no high-resolution dating for the Late Holocene sequence in the research area, but the large amounts of quartz sand that had accumulated during this period indicate that Haifa Bay has served as the end depositional basin for the Nile littoral cell during the last 3000 years.

Conclusions

The coastal changes that followed the Holocene sea-level rise in Haifa Bay area that have been identified for the first time in the current research, differ from those deduced for the western Galilee coast to the north and the Carmel coast to the south. The most significant difference is the stratigraphic sequence of Haifa Bay, which contains marine-derived sedimentary units, mainly marine Nilotic quartz sand, indicating extensive marine incursion inland during the Mid-Holocene. Only later, the coastline gradually shifted back to its present position, with aeolian sand now covering the marine sand.

At the beginning of the Holocene, at about 9500–9000 cal. yr BP, sand started to enter the bay and, for the first time since the LGM, Haifa Bay assumed its present morphological character. The coastline was still 5.5 km west of the present coastline, and the kurkar ridges were still on land. The sea invaded eastward and surrounded the kurkar ridges one after the other, and then inundated them all. Sand continued to accumulate in the southern part of the bay. Only at about 8000–7150 cal. yr BP did the flooding sea cross the present-day coastline, first in the south and later in the north. At around 6800–6600 cal. yr BP the sea invaded the Zevulun Plain up to 2 km and the River Qishon estuary up to 4 km southeast of the present coastline. It is still unknown exactly when the sea reached its maximum penetration inland, but it seems that at around 4000 years ago sea level was still 1–0 m lower than today, and the coastline in the research area was up to 3 km east of the present-day coast in most of the Zevulun Plain, and 4.8 km in the River Qishon estuary. While the coastline migrated westward, aeolian dunes accumulated on top of the marine sand. To the east of the dunes, different wetland conditions developed, mainly along the rivers and streams.

During the first sedentary settlement in the Zevulun Plain, dated to the EB Age, the coastline was still east of the present one, but west of the tells. Even later, during the second urban settlement phase of the MBII, the coast was still east of the present-day line, but the sea never reached the tells, except for Akko and perhaps Tel Abu Hawam. These occupations were therefore not marine-adapted as previously suggested.

Acknowledgements

The authors wish to thank Professor B. Galil of the Oceanographic and Limnological Research National Institute of Oceanography, Shikmona, Haifa, Israel, for her contribution to better understanding the depositional environments of the aquatic molluscs found in the drillings. Thanks also to Dr N. Porat and Dr A. Salamon of the Geological Survey of Israel, Jerusalem, for supplying dating information; to Arthur Steinberg of GEOPLUS–Projects Management, Pavement Materials and Geotechnics, for supplying data from drillings that had been carried out in Haifa Bay; and to the Technion Research and Development Foundation Ltd, Building and Infrastructures Testing Laboratory, for supplying marine drilling logs. Thanks are also due to Ms N. Yoselevich for the drawings and to Mr J. Tresman for reviewing the English.

References

Antonioli, F. and **Oliverio, M.** 1996: Holocene sea-level rise recorded by a radiocarbon-dated mussel in a submerged speleothem beneath the Mediterranean Sea. *Quaternary Research* 45, 241–44.

Artzy, M. 2006a: Filling in the void: observations on habitation pattern at the end of the Late Bronze at Tel Akko. In de Miroschedji, P. and Maeir, A., editors, *I will tell secret things from long ago – archaeological and historical studies in honor of Amihai Mazar on the occasion of his sixtieth birthday*. Eisenbrauns in press.

Artzy, M. 2006b: Tell Abu Hawam 2001/2 excavations. In Stern, E., Lewinson-Gilboa, A. and Aviram, J., editors, *The new encyclopedia of archaeological excavations in the Holy Land*. The Israeli Exploration Society, in press.

Bakler, N. 1975: Gross lithology of drilling and laboratory data, Haifa Bay, Tel-Aviv and Caesarea. *Final summary 1, UNDP-GSI offshore dredging project, ISR/71/682*. Geological Survey of Israel, 23 pp.

Bard, E., **Hamelin, B.**, **Fairbanks, R.G.** and **Zindler, A.** 1990: Calibration of the 14-C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals. *Nature* 345, 405–409.

Bard, E., **Hamelin, B.**, **Arnold, M.**, **Montaggioni, L.**, **Cabioch, G.**, **Faure, G.** and **Rougerie, F.** 1996: Deglacial sea-level record from Tahiti corals and the timing of global melt water discharge. *Nature* 382, 241–44.

Ben-Avraham, Z., **Tibor, G.** and **Golik, A.** 1998: *Haifa port expansion project. Environmental impact assessment*. Task 1.2.10 – Geological status of Haifa Bay and assessment of seismic risks. Final report, Israel Oceanographic and Limnological Research Institute, Report H-27/98, 26 pp.

Bronk Ramsey, C. 1994: Analysis of chronological information and radiocarbon calibration. *The Program OxCal Archaeological Computing. Newsletter* 41, 11–16

Carmel, Z., Imman, D. and **Golik, A.** 1985: Directional wave measurements at Haifa, Israel, and sediment transport along the Nile littoral cell. *Coastal Engineering* 9, 21–36.

Cohen-Seffer, R., Greenbaum, N., Sivan, D., Barmeir, E., Croitoru, S. and **Inbar, M.** 2005: Late Pleistocene–Holocene marsh episodes along the Carmel coast, Israel. *Quaternary International* 140–141, 103–20.

Dothan, M. 1993: Acco. In Stern, E., Lewinson-Gilboa, A. and Aviram, J., editors, *The new encyclopedia of archaeological excavations in the Holy Land*. Israel Exploration Society, 16–24.

Emery, K.O. and **Neev, D.** 1960: Mediterranean beaches of Israel. *Israel Geological Survey Bulletin* 26, 1–24.

Engelmann, A., Neber, A., Frechen, M., Boenigk, W. and **Ronen, A.** 2001: Luminescence chronology of Upper Pleistocene and Holocene aeolianites from Netanya South – Sharon Coastal Plain, Israel. *Quaternary Science Review* 20, 799–804.

Fairbanks, R.G. 1989: A 17,000-year glacio-eustatic sea-level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature* 342, 637–42.

Flemming, N.A., Raban, A. and **Goetschel, C.** 1978: Tectonic and eustatic changes on the Mediterranean coast of Israel in the last 9,000 years. In Gamble, J.C. and Yorke, R.A., editors, *Progress in underwater science.* Vol. 3 (New Series) of the report of The Underwater Association, Proceedings of the 11th Symposium at the British Museum (Natural History), 33–93.

Frechen, M., Dermann, B., Boenigk, W. and **Ronen, A.** 2001: Luminescence chronology of aeolianites from the section at Givat Olga – Coastal Plain, Israel. *Quaternary Science Review* 20, 805–809.

Galantee, Y., Inbar, M. and **Raban, A.** 1990: *The development of the Qishon river delta in the Holocene.* Horizons in Geography, Vol. 31, Department of Geography and Environmental Studies, University of Haifa, 133–46 (in Hebrew, English abstract).

Galili, E. 2004: Submerged settlements of the ninth to seven millennia BP off the Carmel Coast. Ph.D. Thesis, Faculty of Humanities, Tel-Aviv University, 492 pp. (in Hebrew, English abstract).

Galili, E. and **Eytam, Y.** 1988: Young faulting in the shallow continental shelf: evidence from northern Israel. *Israel Geological Society, Annual Meeting* February 1988, 30–31.

Galili, E. and **Nir, Y.** 1993: The submerged Pre-Pottery Neolithic water well of Atlit-Yam, northern Israel, and its palaeoenvironmental implications. *The Holocene* 3, 265–70.

Galili, E. and **Sharvit, J.** 1998: Ancient coastal installations and the tectonic stability of the Israeli coast in historical times. In Stewart, I.S. and Vita-Finzi, C., editors, *Coastal tectonics.* Geological Society, London, Special Publications 146, 147–63.

Galili, E. and **Weinstein-Evron, M.** 1985: Prehistory and paleoenvironments of submerged sites along the Carmel coast of Israel. *Paléorient* 11, 37–52.

Galili, E., Weinstein-Evron, M. and **Ronen, A.** 1988: Holocene sea-level changes based on submerged archaeological sites off the northern Carmel coast in Israel. *Quaternary Research* 29, 36–42.

Galili, E., Weinstein-Evron, M., Hershkovitz, I., Gopher, A., Kislev, M., Lernau, O., Kolska-Horwitz, L. and **Lernau, H.** 1993: Atlit-Yam: prehistoric site on the sea floor off the Israeli coast. *Journal of Field Archaeology* 20, 133–57.

Galili, E., Zviely, D. and **Weinstein-Evron, M.** 2005: Holocene sea-level changes and landscape evolution in the northern Carmel coast (Israel). *Méditerranée* 104, 79–86.

Goldsmith, V. and **Golik, A.** 1980: Sediment transport model of the southeastern Mediterranean coast. *Marine Geology* 37, 147–75.

Gvirtzman, G., Netser, M. and **Katzav, E.** 1998: Late-Glacial to Holocene kurkar ridges, hamra soils, and dune fields in the coastal belt of central Israel. *Israel Journal of Earth Sciences* 47, 27–46.

Hall, J.K. 1976. *Seismic studies, Haifa Bay, summary report*. UN/UNDP-GSI Offshore dredging project ISR/71/522. Geological Survey of Israel, Filed report No. 1/76, 36 pp.

Heimann, A., Frydman, S., Wachs, D. and **Talwani, P.** 2001: *Seismic hazard evaluation of the Haifa and Elat Bay areas, Israel.* Geological Survey of Israel, GSI/40/01 Final report, submitted to the U.S.–Israel Binational Science Foundation, 109 pp.

Hughen, K.A., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C., Blackwell, P.G., Buck, C.E., Burr, G., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Kromer, B., McCormac, F.G., Manning, S., Bronk Ramsey, C., Reimer, P.J., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J. and **Weyhenmeyer, C.E.** 2004: Marine radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46, 1059–86.

Inbar, M. and **Sivan, D.** 1984: Paleo-urban development and Late Quaternary Environmental change in Akko Area. *Paleorient* 9, 85–91.

Inman, D.L. and **Jenkins, S.A.** 1984: *The Nile littoral cell and man's impact on the coastal zone of the southeastern Mediterranean*. Scripps Institution of Oceanography, Ref. Series 84–31, 43 pp.

Kadosh, D., Sivan, D., Kutiel, H. and **Weinstein-Evron, M.** 2004: A Late Quaternary paleoenvironmental sequence from Dor, Carmel Coastal plain, Israel. *Palynology* 28, 143–57.

Kafri, U. and **Ecker, A.** 1964: *Neogen and Quaternary geology and hydrology of the Zevulun Plain*. Geological Survey of Israel, Bulletin 37, Jerusalem.

Lambeck, K. and **Bard, E.** 2000: Sea-level change along the French Mediterranean coast for the past 30,000 years. *Earth and Planetary Science Letters* 175, 203–22.

Lambeck, K. and **Purcell, A.** 2005: Sea-level change in the Mediterranean Sea since the LGM: model predictions for tectonically stable areas. *Quaternary Science Reviews* 24, 1969–88.

Lambeck, K., Yokoyama, Y. and **Purcell, T.** 2002: Into and out of the Last Glacial Maximum: sea-level change during oxygen isotope stages 3 and 2. *Quaternary Science Reviews* 21, 343–60.

Lambeck, K., Antonioli, F., Purcell, A. and **Silenzi, S.** 2004: Sea-level change along the Italian coast for the past 10,000 yr. *Quaternary Science Reviews* 23, 1567–98.

Marcus, E. 2002: Early seafaring and maritime activity in the southern Levant from prehistory through the third millennium BCE. In Van den Brink, E.C.M. and Levy, T.E. editors, *Egypt and the Levant: interrelations from the 4th through early 3rd millennium BCE*. New Studies in Anthropological Archaeology, Leicester University Press, 403–17.

Marriner, N., Morhange, C., Boudagher-Fadel, M., Bourcier, M. and **Carbonel, P.** 2005: Geoarchaeology of Tyre's ancient northern harbour, Phoenicia. *Journal of Archaeological Science* 32, 1302–27.

Morhange, C., Laborel, J. and **Hesnard, A.** 2001: Changes of relative sea-level during the past 5000 years in the ancient harbor of Marseilles, Southern France. *Palaeogeography, Palaeoclimatology, Palaeoecology* 166, 319–29.

Neev, D., Almagor, G., Arad, A., Ginsburg, A. and **Hall, J.K.** 1976: *The geology of the southeastern Mediterranean sea*. Geological Survey of Israel, Bulletin 68, 51 pp.

Neev, D., Bakler, N. and **Emery, K.O.** 1987: *Mediterranean coasts of Israel and Sinai*. Taylor & Francis, 130 pp.

Nir, Y. 1980: *Recent sediments of Haifa bay*. Geological Survey of Israel, Report MG/11/80, 8.

—— 1997: Middle and late Holocene sea-levels along the Israel Mediterranean coast – evidence from ancient water wells. *Journal of Quaternary Science* 12, 143–51.

Perlin, A. and **Kit, E.** 1999: Longshore sediment transport on the Mediterranean coast of Israel. *Journal of Waterway, Port, Coastal, and Ocean Engineering* 125, 80–87.

Porat, N., Wintle, A.G. and **Ritte, M.** 2004: Mode and timing of kurkar and hamra formation, central coastal plain, Israel. *Israel Journal of Earth Sciences* 53, 13–25.

Raban, A. 1985: The ancient harbours of Israel in Biblical times. In Raban, A., editor, *Harbour archaeology, proceedings of the first international workshop on ancient Mediterranean harbours, Caesarea Maritima, BAR International Series, no. 257*. Academic Press, 11–44.

—— 1998a: Anchorages and harbours along the Israeli Coast during the Bronze Age. *Kadmoniot*, *Journal of the Israel Exploration Society and the Israel Antiquities Authority* 116, 90–108.

—— 1998b: The Near Eastern Harbours: 13th–10th c. B.C.E. In Gittin, S., Mazar, A., and Stern, E., editors, *Mediterranean people in transition: 13th to early 10th centuries BCE, in honor of Trude Dothan*. Israel Exploration Society, 429–38.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C., Blackwell, P.G., Buck, C.E., Burr, G., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Hughen, K.A., Kromer, B., McCormac, F.G., Manning, S., Bronk Ramsey, C., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., and **Weyhenmeyer, C.E.** 2004: Terrestrial radiocarbon age calibration. *Radiocarbon* 46, 1029–58.

Salamon, A., Zaslavsky, Y., Shtivelman, V. and **Rockwell, T.** 2001: Seismic hazards analysis in the Nesher site: Bay of Haifa, Israel. *Israel Geological Society, Annual Meeting* march 2001, 85 and 101.

Shemer, R. 1995: Sedimentological changes in the South Coast of the Haifa Bay. MA Thesis, University of Haifa, Department of Maritime Civilizations, 121 pp. (in Hebrew, with English abstract).

Sivan, D. and **Galili, E.** 1999: Holocene tectonic activity in the Galilee coast and shallow shelf, Israel: a geological and archaeological study. *Israel Journal of Earth Science* 48, 47–61.

Sivan, D. and **Porat, N.** 2004: Late Pleistocene contemporaneous formation of calcareous aeolianite (kurkar) and paleosol (hamra) in the Carmel coast, Israel. *Palaeogeography, Palaeoclimatology, Palaeoecology* 211, 95–106.

Sivan, D., Gvirtzman, G. and **Sass, E.** 1999: Quaternary stratigraphy and paleogeography of the Galilee Coastal Plain, Israel. *Quaternary Research* 51, 280–94.

Sivan, D., Wdowinski, S., Lambeck, K., Galili, E. and **Raban, A.** 2001: Holocene sea-level changes along the Mediterranean coast of Israel, based on archaeological observations and numerical model. *Palaeogeography, Palaeoclimatology, Palaeoecology* 167, 101–17.

Sivan, D., Eliyahu, D. and **Raban, A.** 2004a: Late Pleistocene to Holocene wetlands now covered by sand, along the Carmel coast, Israel, and their relation to Human settlement: an example from the coastal site of Dor. *Journal of Coastal Research* 20, 97–110.

Sivan, D., Lambeck, K., Toueg, R., Raban, A., Porath, Y. and **Shirnam, B.** 2004b: Ancient coastal wells of Caesarea Maritima, Israel, an indicator for relative sea-level changes during the last 2000 years. *Earth and Planetary Science Letters* 222, 315–30.

Slatkine, A. and **Rohrlich, V.** 1963. Sediments du Quaternary de la plain de Haïfa. *Israel Journal of Earth Sciences* 12, 159–206.

Sneh, Y. and **Klein, M.** 1984: Holocene sea-level changes at the coast of Dor, southeast Mediterranean. *Science* 226, 831–32.

Ventura, R. and **Siegelmann, A.** 2004: Salvage excavations at Tell el-Idham and an Egyptian sealing of Seti I. *Atiqot* 47, 101–108.

Zviely, D. 2006: Sedimentological processes in Haifa Bay in context of the Nile Littoral Cell. Ph.D. Thesis, Department of Geography and Environment Studies, University of Haifa, 211 pp. (in Hebrew, English abstract).