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Holocene sea-level changes and landscape evolution on the northern Carmel coast (Israel)

Variations du niveau de la mer et évolution des paysages le long du littoral du Carmel Nord (Israël)

Ehud Galili, Dov Zviely and Mina Weinstein-Evron

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Abstracts

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Archaeological, fluvial and morphological features are used to reconstruct sea-level changes and landscape evolution on the northern Carmel coast, Israel during the Holocene. Between 8900 BP and 7000 BP[1] sea level lay between 35 m and 7 m below present, rising at an average rate of 12-14 mm/yr. This rate decreased to 2-4 mm/yr between 7000 BP and 4000 BP, with the sea between –7 m and present MSL. Since the Middle Bronze Age (4000 BP), sea level has been within ± 0.5 m. The landscape has evolved in five main stages, linked to the Holocene marine transgression and changes in the fluvial water regime. (1) Around 8900 BP, sea level lay around –35 m. The southern coastline between N. Megadim and N. Maharal was straight and sandy. North of N. Oren, the coastline was mostly rocky, with marshy clays embedded in the troughs between the coastal kurkar ridges. All southern wadis, from N. Megadim to N. Maharal, crossed the Carmel coast kurkar ridge through the N. Oren canyon. The northern wadis from N. Mitleh to N. Ahuza were blocked and flowed northward, crossing the Carmel coast ridge westward through N. Ovadia channel and at Kfar Samir. (2) Between 8200 BP and 7500 BP, sea level lay around –16 m. North of N. Oren the coastline was extensively indented, creating lagoons and shallow bays. To the south, the coast was straight and sandy. Alluvial sediments filled the eastern trough and water overflow allowed streams to flow directly to the sea. (3) Between 7000 BP and 6500 BP, the sea was around 9 m below present. A row of offshore islands was situated parallel to the coast from Atlit northward. (4) During the Chalcolithic period (6000-5700 BP) sand dune barriers interrupted natural drainage and a series of polyhaline lagoons was formed. (5) Between 5700 and the Middle Bronze Age, sea level has risen to its present position.

De nombreux indicateurs archéologiques et géomorphologiques permettent de mesurer les variations holocènes du niveau marin et de préciser les changements paysagers qui ont affecté la côte nord du Carmel (Israël). Entre 8900 BP et 7000 ans BP, soit entre –35 m et –7 m de profondeur, la vitesse moyenne de montée du niveau de la mer est de l'ordre de 12-14 mm/an. Cette vitesse ralentit ensuite à 2-4 mm/an entre 7000 BP et 4000 ans BP entre –7 m et le niveau marin actuel. Depuis 4000 ans BP (âge du Bronze Moyen), le niveau marin est stable à ± 0.5 m près. Le paysage a évolué en quatre étapes principales en relation avec la transgression marine holocène et la dynamique fluviale. (1) Vers 8900 BP, le niveau marin se positione vers –35 m. La côte méridionale entre les oueds Megadim et Maharal était sableuse et étroite et les cours d'eau recoupaient perpendiculairement la ride littorale gréseuse du Carmel. Au nord de l'oued Oren, la côte était surtout rocheuse et présentait des affleurements marneux et gréseux. L'écoulement fluvial était alors bloqué et dévié vers le nord. Les paléo-cours d'eau creusèrent ainsi un canyon à travers une ride aujourd'hui submergée (ride Tira). (2) Entre 8200 BP et 7500 ans BP, le niveau marin se positionne vers –16 m. La côte au nord de l'oued Oren présentait alors de nombreuses invaginations lagunaires ou marines. La dépression d'arrière-ride fut rapidement comblée par des sédiments alluviaux, permettant aux cours d'eau de déboucher directement vers la mer. (3) Entre 7000 BP et 6500 ans BP, le niveau marin se positionne vers –9 m. Au nord d'Atlit, le littoral présentait de nombreuses îles alors qu'au sud, la côte était meuble. (4) Pendant le Chalcolithique (6000-5700 ans BP), un cordon littoral se dévelope en

association avec des lagunes polyhalines.

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Introduction

1The coast is a boundary zone at the junction of two major ecosystems that combines some of the characteristics of each, as well as unique characteristics of its own that are products of an overlap zone. The coastline is a highly dynamic zone where a number of processes join together to reproduce, alter or destroy particular landscape forms and their associated resources. As a result, a variety of environmental changes operating over different time spans occur. It is here that the equilibrium between rivers and sea-level is resolved, leading to a series of erosional or depositional events of great significance to coastal populations. The coastline is thus a very sensitive area that responds to both marine and terrestrial change, and mediates between them (Bailey and Parkington, 1988).

2Sea-level and coastal changes have crucial impacts on natural and cultural resources, thus understanding coastal evolution patterns is vital to preserving, developing and managing the coastal zone. Archaeological, morphological and sedimentological data that were collected on the northern Carmel coast of Israel in recent decades enable us to reconstruct the paleo-morphological changes in the region during the Holocene. These include reconstructions of sea-level changes, paleo-coastlines and drainage patterns on the northern Carmel coast.

Methodology

3Underwater surveys and excavations carried out by scuba divers were used to reveal, document and map the archaeological and morphological finds. Sub-bottom physical data were obtained by water jet drillings (Galili, 1985a) and sub-bottom profiling by geophysical research (Adler, 1985). Useful information on the sea bottom morphology and bathymetry was obtained from bathymetric charts (Khaikin and Frydenrych, 1999) and a new hydrographic multi-beam echo sounder survey (unpublished data). The nomenclature of the main morphological units in the study area follows that of Eytam and Ben-Avraham (1992). In addition, coastal archaeological and morphological surveys and observations were performed. Relative sea-level indications from archeological finds were obtained according to interpretations suggested by Galili *et al.* (1988), Galili and Sharvit (1995; 1997) and Sivan *et al.* (2001).

The study area

4The northern Carmel coast (Fig. 1) is characterized by kurkar (the local term for aeolianite calcareous cemented sandstone) ridges, running parallel to the coastline, and between them, troughs filled with clays, sands, and alluvial sediments. East-west oriented wadis / Nahals (channels of ephemeral streams) drain the western slopes of Mount Carmel, crossing the coastal plain on their way to the Mediterranean. The study area can be roughly divided into northern and southern parts, separated by N. (Nahal / wadi) Oren, the Atlit Peninsula, and the north and south Atlit bays (Figs. 2, 3). In the southern part, there are three kurkar ridges on land, and one submerged, while in the northern part, two ridges are presently submerged and one is on shore (Figs. 3, 4). The submerged Tira ridge, is 6 km long (Eytam and Ben-Avraham, 1992). It is situated 2-9 km north of the Atlit Peninsula at a depth of 6-18 m (Fig. 4). East of this submerged ridge lies an elongated sandy trough at a maximum depth of 17 m, with a sand layer 1-3 m thick. The coastline in the southern part is rocky and highly indented with small bays and abrasion platforms, while the northern coastline is straight and covered with quartz sand. The sand was transported from the Nile Delta to the Israeli coast by consistent west-to-east and southwest-to-northeast longshore currents. It is estimated that the average net longshore sediments transport along the northern Carmel Coast is 70000-60000 m3/yr (Perlin and Kit, 1999). The shallow continental shelf in the study area (down to 20 m depth), is covered mainly with fine quartz sand (Fig. 4).

Fig. 1 - Location map of the Carmel coast and the submerged settlements

Zoom Original (png, 191k)

Fig. 2 - Aerial photograph of the northern Carmel coast (modified after Cleave, 1988)

Zoom Original (jpeg, 504k)

Fig. 3 - Main land morphological features of the northern Carmel coast

Zoom Original (jpeg, 396k)

Fig. 4 - Main sea bottom morphological features of the northern Carmel coast

Zoom Original (png, 278k)

5The main wadis in the study area (from north to south) are the N. Galim, N. Oren and N. Me'arot. In addition, there are small streams, each draining only few sq km. The wadis cross the Carmel coast kurkar ridge through canals, both natural (Oren Canyon) or modified in antiquity for drainage purposes (Me'arot rock-cut Canal).

Reconstruction of Holocene sea-levels and landscape evolution

6Geomorphological reconstruction based on bathymetric maps, coupled with archaeological and fluvial evidence, suggest five main landscape stages created by the Holocene sea transgression and changes in fluvial water regime patterns (Galili *et al.*, 2003).

1. The beginning of the Holocene (10000 yr BP - 8900 yr BP)

7At the beginning of the Holocene, the oceans and the Mediterranean sea-level were ~50-40 m lower than today (Pirazzoli, 1998: 78). Along the Carmel coast, marshy clays were embedded in the troughs between the coastal kurkar ridges. A submarine borehole a few km off Caesarea revealed a 8900 yr old organic terrestrial peat at 35 m below the present sea-level (Neev *et al.*, 1987: 21) (Fig. 5: 1, 2). The terrestrial peat (N. Bakler, personal comm. 2004) was probably embedded in coastal swamps that were slightly elevated above the ancient sea-level, thus sea-level ~8900 yr BP was more than 35 m below today's. (Fig. 5: 1, 2) and the coastline was situated ~3–4 km west of the present one.

Fig. 5 - Relative Holocene sea-level changes on the Carmel coast, based on archaeological and sedimentological markers

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8The discovery of an underwater canyon (named Adam Canyon after the fisherman diver who first identified it) some 1500 m west of Kfar Samir (Figs. 4, 6 and 7), provides the basis for a possible reconstruction of the drainage system in the region. The bottom of the canyon is at 20–25 m below the present sea-level, and it is covered with coarse sand and limestone pebbles originating in Mount Carmel. This canyon crosses the Tira kurkar ridge from east to west. Its walls are steep, and reach 3-5 m in height. The geomorphological characteristics of the canyon indicate that it was created by a relatively large wadi, during a low sea stand. The present Carmel coastal wadis east of the submerged canyon are too small to create such a large canyon. It is proposed that the Carmel coast kurkar ridge and the Tira ridge (that run continuously from Haifa to Atlit), blocked the natural flow of the coastal wadis to the sea. All the wadis, from N. Megadim in the north to N. Maharal in the south were forced to cross the Carmel coast ridge through the N. Oren canyon and the presently submerged Tira ridge through the «N. Oren Gap» to the west (Fig. 4). The northern wadis, from N. Mitleh to N. Ahuza (including N. Galim) were blocked by the Carmel coast eastern ridge creating marshlands and shallow bodies of water in the eastern trough. The water gradually flowed northward, and then drained westward by crossing the Carmel coast ridge at N. Ovadia passage, and near Kfar Samir where the present-day Carmel coast ridge disappears under the surface. These and other wadis from the north (N. Ezov, N. Siah and N. Amiq) eventually reached the sea by crossing the present day submerged Tira ridge through the deep Adam Canyon.

2.Pre-Pottery Neolithic C (8150-7550 yr BP) (Fig. 8A)

9The Pre-Pottery Neolithic C site of Atlit-Yam (Fig. 5: 3-6) is presently submerged, to a depth of 8–12 m some 200-400 m offshore. Radiocarbon dates of wood remains from the site provide a range of 8180-7550 yr BP (Galili *et al.*, 1993, Galili and Sharvit, 1999). The architectural finds consist of stone-built water-wells (Galili and Nir, 1993; Galili and Sharvit, 1998), foundations of rectangular structures, a series of long walls, ritual installations and stone-paved areas (Galili *et al.*, 1993). In addition, 65 human skeletons were recovered. Faunal remains include bones of wild and domestic sheep/goats, pigs, cattle and dogs as well as wild animals and more than 6000 bones of marine fish. Large quantities of botanical remains as well as artifacts made of stone, bone, wood and flint were also recovered. Many of these artifacts (such as fishing net sinkers and knives) may be associated with fishing activities. The archaeological material indicates that the economy of the site was complex, and was based on the combined utilization of terrestrial and marine resources, involving plant cultivation, livestock husbandry, hunting, gathering and fishing (Galili *et al.*, 2002; Galili *et al.*, 2004).

Fig. 6 - The underwater Adam Canyon (looking west) (photo: E. Galili, 1990)

Zoom Original (jpeg, 236k)

10During the occupation of the Pre-Pottery Neolithic C settlement in the north bay of Atlit, sea level was ~16 m below present-day level and the coastline north of N. Oren was extensively indented, creating lagoons and shallow bays (Fig. 8A). The submerged kurkar ridge situated ~200 m west of Atlit-Yam at a water depth of 6-10 m, was then a rocky coastal ridge that sheltered the settlement from southwesterly and westerly storm winds and sea spray. During the Pre-Pottery Neolithic C period, the Tira kurkar ridge must have been an elongated north-south oriented peninsula a few kilometers long, partially surrounded by seawater and connected to the mainland at its northern end. The western and southern slopes of the ridge formed rocky coastlines with small bays, coastal caves and E-W oriented erosion channels. Down to a water depth of 5-6 m (21-22 m depth today), the sea bottom west of this rocky peninsula was probably a highly productive and rich rocky habitat. The sand layer that covered the bottom of the trough during the Pre-Pottery Neolithic C, when sea-level was considerably lower and there was less sand in the region, must have been 1-2 m thinner than it is today. The trough situated between the peninsula and the mainland formed a 3-4 km long shallow (1-2 m deep) sandy lagoon. Another kurkar ridge, the Megadim ridge (Eytam and Ben-Avraham, 1992) 1-2 km wide, and ~8 km long, is located some 3.5 km northwest of the Atlit-Yam site, at a water depth of 32-42 m. At the time of occupation of Atlit-Yam, the summits of this ridge were at a water depth of ~16-25 m. Five different marine habitats can be postulated in this region during the Pre-Pottery Neolithic C:

1. an approximately 3-5 km long rocky coastline on the west slope of the peninsula (the presently submerged Tira ridge north of the village);

2. several sq km of shallow (0-5 m deep), rocky sea-bottom west of the peninsula;

3. about 1-2 sq km of shallow sandy lagoon east of the peninsula;

4. about 4-5 sq km of relatively deep (16-25 m) rocky sea-bottom (presently a submerged kurkar ridge at a depth of 32-42 m);
5. a sandy beach about 8 km long, with a sandy sea-bottom that may have been occupied by mollusks, crabs and fish.

Fig. 7 - Bathymetric map of the Adam Canyon (modified after: Khaikin and Frydenrych, 1999)

Zoom Original (jpeg, 444k)

11South of Atlit, the coast was sandy and straight. Alluvial sediments filled the eastern trough and in the northern section water overflowed directly via the wadis (e.g., through the N. Galim and N. Ovadia Passages; Fig. 3) to the sea. The overflow created alluvial fans abutting the western slopes of the eastern Carmel coast ridge (south and north of Tel Kones) (Fig. 3), while depositing limestone pebbles as well as boulders in N. Galim on top of the marshy clays.

3. Pottery Neolithic (7100-6300 yr BP) (Fig. 8B)

12Five Pottery Neolithic sites: Kfar Samir, Kfar Galim, Tel Hreiz, Megadim and Neve-Yam (Fig. 1), which were submerged at depths of 0.5-5 m, date to 7100-6300 yr BP (Fig. 5: 7). Finds in these sites include water-wells constructed of alternating layers of tree branches and stones, and pit-installations, some lined with undressed stones, and others dug into the clay sediment. The pits contained waste from olive oil extraction including thousands of crushed olive-pits (Galili and Weinstein-Evron 1985; Galili *et al.*, 1989; 1997). Bones of domestic animals and fish were also found (Horwitz *et al.*, 2002), as well as artifacts made of stone, wood, and flint. The ceramic assemblages included a variety of vessels for cooking and storage. At Neve-Yam, a cemetery comprising stone-built graves that contained six human skeletons was recovered. This represents one of the earliest known organized cemeteries located apart from the dwelling area of a site (Galili *et al.*, 1998).

Fig. 8 - Reconstruction of palaeolandscapes on the northern Carmel coast

Zoom Original (png, 138k)

A) 8000 years BP; B) 7000 years BP.; C) during the last 4000 years

13The economy of the Pottery Neolithic settlements was based mainly on terrestrial resources, cultivation and herding. During the occupation of the

Pottery Neolithic settlements between 7100 and 6500 yr BP, the sea was ~9 m below present sea-level. A row of offshore islands was situated parallel to the coast from Atlit northward, while to the south the coast was straight, with sandy bays (Fig. 8B). Compared with the Pre-Pottery Neolithic C, the amounts of highly reproductive rocky habitats and fishing grounds had declined, the shallow lagoon had disappeared, and wide sections of the coastal region had been flooded by the rising sea or covered with sand.

4. Chalcolithic period (6200–5700 yr BP)

14Until now, no cultural traces of Ghassulian Chalcolithic entities have been recorded on the sea bottom along the Carmel coast. However, several 14C datings of olive pits recovered from an installation used for the extraction of olive oil in Kfar Samir site (Galili *et al.*, 1997), indicate that sea-level during the Chalcolithic period was lower at least by 2.5-5.0 m than at present (Fig. 5: 8-9).

15Reconstruction of the paleo-coastal landscape at that period is based on the proposed reconstructed sea-level and on archaeological, sedimentological and biological finds. Lenses of dark-gray soft clay containing *in situ Cerastoderma glaucum* mollusks were located in the north bay of Atlit, west of the N. Megadim inlet and near the Kfar Samir site. The clay deposits were embedded on top of the dark brownish hard clays (termed Carmel coast clay) at 1-3 m water depth (Galili, 1985a; Galili and Inbar, 1987). The shells were uneroded, with the shell segments joined together, and smaller and more delicate than similar shells living in the open sea. The patterns of mollusk deposition indicate that they inhabited low-energy coastal areas. These mollusks can survive in severe conditions with extreme ranges of both temperature and salinity (brackish to hyper-saline, Barash personal comm., Galili, 1985a). These mollusks are common today in the salt ponds of Atlit, in which the salinity constantly changes during the process of salt production (high salinity caused by evaporation and lower salinity during winter rains). The dark-gray soft clay deposit, post-dates the submerged Pottery Neolithic settlements. This clay was deposited in brackish to hyper-saline coastal bodies of water, at an elevation close to the sea-level at the time of deposition. Since the gray soft clay is at 1-3 m below present sea-level, it can be dated to the Chalcolithic-Early Bronze periods. Judging by the *Cerastoderma glaucum* mollusks it is suggested that brackish to hyper-saline coastal bodies of water existed on the northern Carmel coast during the Chalcolithic period. Such bodies of water (at an elevation of 1-3 m below the present sea-level), could have been developed by a physical barrier (located east of the Chalcolithic coastline) that blocked natural fluvial drainage. The presently submerged Tira ridge, with its apex at elevations of 10–14 m below present sea-level, could not have created such a barrier, since it was too low. It is suggested that continuous longitudinal sand dunes, which had advanced eastward with the rising sea, created a barrier that blocked the flow of the coastal wadis. The considerable reduction in the rate of sea-level rise from the Chalcolithic period to the Early Bronze Age (~6000-5000 yr

BP) (Fig. 5), may have dramatically increased the accumulation of sand along the Israeli coast. Such a process could have created the dune barriers that blocked the coastal wadis'outlets. As a result, a series of brackish to saline water bodies were formed at 1-3 m below present sea-level. These coastal wetlands were at elevations of 1–2 m above the Chalcolithic sea-level, and their salinity varied according to the amount of precipitation and evaporation.

16With the continuous rises in sea-level, the sand dunes shifted eastward, and by the Early Bronze Age, sea-level reached ~2 m below its present level (Fig. 5). As the bodies of water east of the sand dune barriers mixed with sea water, salinity increased and a population of *Cerastoderma glaucum* mollusks, which can tolerate high levels of salinity, developed. During the Middle Bronze Age, sea-level reached its present level (Fig. 5), the sand dunes may have been eroded by the rising sea, and the coastal saline bodies of water drained or silted. The dark-gray clays that where deposited in brackish to hyper-saline coastal bodies of water, containing the *Cerastoderma glaucum* mollusks remain as isolated lenses on top of the brownish Carmel coast clay.

5. Historical Periods (Fig. 8C)

17- **Early Bronze Age (~5000 yr BP)**: an Early Bronze Age amphora containing *Aspatharia* (*Spatopsis*), cf. *nilotica* mollusks, was found in the north bay of Atlit (Fig. 2: B) at 10 m depth. The amphora was dated to ~5000 yr BP using 14C dating and parallels of pottery vessels (Sharvit *et al.*, 2002). It is not possible to use the amphora as an indicative sea-level marker, since it is not clear whether the pottery vessel originated from a wrecked ship that was washed ashore, or was dumped from an anchored vessel. However the amphora can provide, with some precision, the lowest possible sea-level for that period (Fig. 5: 10).

18- **Middle Bronze Age (~4000 yr BP)**: Middle Bronze Age graves and shipwrecks can provide a rough indication of sea-level in that period. Middle Bronze graves were recovered at elevations of 0.5-1.5 m above the present sea-level in the north bay of Atlit. The graves that were dug on shore can provide the uppermost possible sea-level during the Middle Bronze (Fig. 5: 11-12).

19Five clusters of Middle Bronze Byblos-type stone anchors and a few pottery vessels were recovered from the northern Carmel coast off Kfar Samir, Kfar Galim, Megadim, Atlit South Bay and Neve-Yam (Galili, 1985b; Galili *et al.*, 1988; 1996; Sivan *et al.*, 2001). The distribution patterns of the Middle Bronze assemblages on the sea bottom, at water depths of 3-4 m below the present sea-level, indicate that they originated from wrecked ships that were washed ashore by storms. The anchors may thus provide an upper and lower possible sea-level at that period with accuracy range of ± 0.5 m. It seems that during the Middle Bronze Age sea-level was at, or close to the present sea-level (Galili *et al.*, 1988).

20- **Late Bronze Age to Byzantine period (3500 –1500 yr BP)**: clusters of anchors and heavy objects originating from shipwrecks along the Carmel coast and the entire Israeli Mediterranean coast are found at 3-4 m depth. They indicate that sea-level from the Middle Bronze to the Medieval periods was stable (± 0.5 m) (Fig. 5: 13-16).

21Rock-cut installations, such as pools fed with sea water by gravity, quarries and installations for salt production on the Carmel coast are found at elevations that enable functioning at present sea-level (Bushnino and Galili, in press; Galili and Sharvit, 1995; 1997). These rock-cut installations date to 2500-1000 yr BP and support the hypothesis that sea-level was stable (± 0.5 m) during these periods.

Conclusions

22The proposed sea-level curve is an estimate of possible ranges of sea-level. However there are considerable gaps in the data and small fluctuations in sea-level may not be represented in the curve.

23The reconstructed Holocene sea-level curve (Fig. 5), based on archaeological and sedimentological evidence from coastal and submerged sites, shows two main varying rates of sea-level rise: from 8900 to 7000 yr BP (sea-level –35 to –7 m; 12 to 14 mm/yr), and from 7000 to 4000 yr BP (sea-level –7 m to present sea-level; 4 to 2 mm/yr). The consequent rapid landscape change and especially the loss of vital terrestrial and underwater resources (i.e., agricultural, pasture, hunting and fishing grounds) must have influenced the economy and subsistence strategies of the coastal settlements and required ongoing adaptations.

24In the last 4000 years no major changes (greater than 1 m) can be observed and the rate of sea-level change was less then 0.25 mm/yr. During this period newly established coastal urban centers enjoyed a relatively stable environment.

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1 All dates are uncalibrated ^{14}C BP. For calibrated dates, see Galili *et al.*, 1997; 2002; 2004; Horwitz *et al.*, 2002.

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About the authors

Ehud Galili

Israel Antiquities Authority, Marine Archaeology Branch, Atlit P.O.B 180, 30350, Israel. Email: udi@israntique.org.il

Dov Zviely

Department of Geography and Environmental Studies, University of Haifa, Haifa, 31905, Israel. Email: zviely@netvision.net.il

Mina Weinstein-Evron

Zinman Institute of Archaeology, University of Haifa, Haifa, 31905, Israel. Email: evron@research.haifa.ac.il

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