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RESEARCH ARTICLE

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Geoarchaeological investigations at Akko, Israel: New insights into landscape changes and related anchorage locations since the Bronze Age

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Abstract

Since the first archaeological excavations undertaken in the 1970s/1980s, Tel Akko is known to have been an important trade city from the early 2nd millennium B.C. onwards. Even if the site has been intensively excavated, no paleoenvironmental studies looking to understand coastal changes near the tell since the Bronze Age had been undertaken until recently. Our research is based on the study of sediment cores drilled at the foot of the tell and in the Old City of Akko, 1,500 m west of the tell. We validate the coastal changes, already proposed by previous studies, while clarifying the chronology of these changes. We propose that the southern anchorage was located in the river mouth of the Na'aman until the early Persian period. This anchorage shifted to the "open" western coast of the tell during the Persian period before its subsequent relocation to the rocky promontory of Akko in Hellenistic times. We attempted to locate the Hellenistic harbor of Akko by coring in the Old City, in proximity to the modern harbor. At that time, a harbor lay in a semi-protected pocket beach at the foot of the promontory.

KEYWORDS

ancient harbor, coastal changes, geoarchaeology, geomorphology, Haifa Bay, Israel, Na'aman River, paleogeography, Tel Akko

1 | INTRODUCTION

From the earliest Antiquity, coastal populations, in search of sheltered anchorage areas, have favored river-mouth environments (Marriner & Morhange, 2007). In the context of the southern Levantine coast, this hypothesis was first advanced by Raban (1985) to explain the significant number of coastal sites established near estuaries during the Bronze Age. Although such environments certainly constituted sheltered areas during storms and high swell, they were subjected to natural hazards of both continental and marine origin, mainly linked to high sediment supply leading to coastal progradation (Anthony, 2009; Anthony, Marriner, & Morhange, 2014; Morhange et al., 2015). In the microtidal regime of the Levant, we can identify wave-dominated lagoonal estuaries partially open to the sea by an inlet (Reinson, 1992). These estuaries are morphologically different and smaller than the common incised valley estuaries (Boyd, Dalrymple, & Zaintlin, 2006). Nowadays, the former estuaries of the southern Levant are mostly infilled and are no longer navigable. By contrast, the coastline of Prehistoric Gaza was more indented and the estuaries must have served as natural semi-protected harbors, as was the case for the navigable estuaries of Wadi Ghazzeh (Morhange, Taha, Marriner, & Humbert, 2005). These estuaries were progressively infilled due to the regularization of the coastline, driven by high sediment supply and longshore drift (Figure 1; Morhange et al., 2005; Stanley, 2002). In ancient times, the best natural anchorages of the region were located in Haifa Bay (Raban, 1991; Zviely et al., 2006). Facing Tel Akko, Tel Abu Hawam was the other major coastal city of the bay during the Bronze Age. It was situated at the mouth of the Kishon River, presently situated 1.5 km inland.

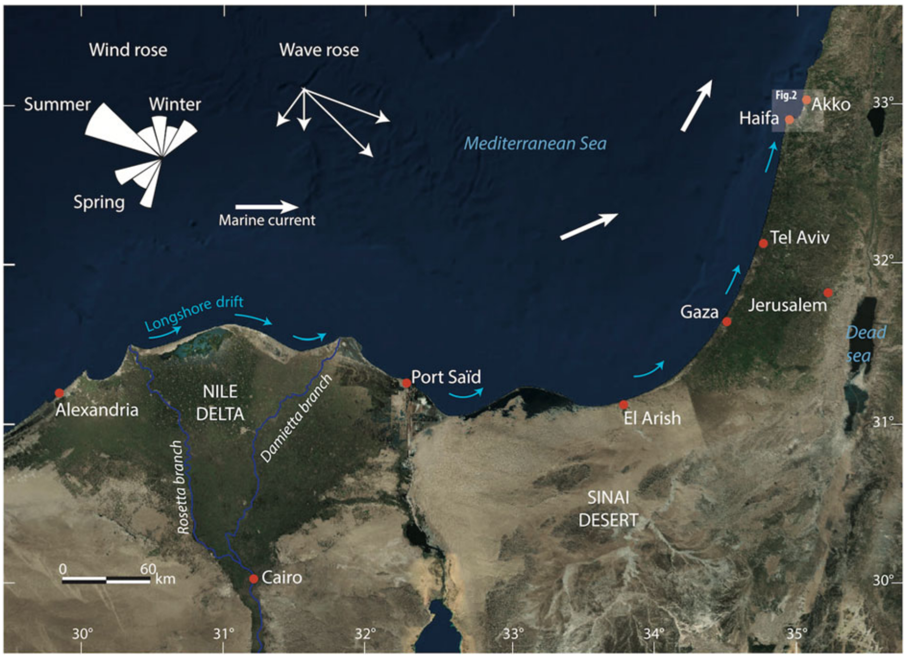

FIGURE 1 Location of Haifa Bay, on the northern limit of the Nile littoral cell (after Inman, 2003; image CNES)
Notes. The rose diagrams show the dominant wind and wave patterns along the coastal margin of Alexandria (Stanley & Bernhardt, 2010).
[Color figure can be viewed at wileyonlinelibrary.com]

This "port of trade" has furnished strong evidence for the environmental problems linked to the infilling of river outlets (Artzy, 2006; Balensi, 1985, 2000).

Tel Akko was founded around 2,000 years B.C. (Artzy & Beeri, 2010). It was an important city port between the Bronze Age and the Hellenistic period. We propose that natural processes, in particular sediment inputs, progressively led to a degradation of the harbor facilities, partly explaining the shift of the port city to the Akko promontory.

Using new sedimentary cores our aims were:

1. To test and nuance the landscape evolution of Tel Akko suggested by Morhange et al. (2016) and to investigate the different anchorage areas from the Bronze Age to the Late Persian period.
2. To investigate a depression in proximity to the present harbor of the Old City, close to Khan el-Oumdan, in order to locate the Hellenistic harbor, that moved westward (as did the whole city) in Hellenistic times (Artzy, 2012, 2015; Galili, Rosen, Zviely, Silberstein, & Finkielsztejn, 2010; Marriner, 2009).

2 | GEOMORPHOLOGICAL CONTEXT

The ancient site of Tel Akko (Figure 2) is located some 1.5-km east of the Old City of Akko (Saint-Jean-d'Acre) on Tell el-Fukhar (the tell of the sherds). The tell is situated in the northern part of Haifa bay that constitutes the extension of a continental graben flanked by two normal faults and delimited by the Carmel promontory to the south and the Akko promontory to the north. These faults were principally active during the Miocene and the Pliocene, while neotectonic activity appears to be modest during the Late Holocene in the area of Akko (Sivan, Gvirtzman, & Sass, 1999). The tell is situated on a fertile agricultural plain, with plentiful water supply from natural springs and rivers (Artzy & Beeri, 2010). It is bordered by a sandy beach open to waves coming from the west. Coastal changes in the Zevulun plain during the Late Holocene are related to sea-level change and sedimentary inputs. The maximum sea incursion in Haifa Bay occurred 4,000 years ago, flooding the Zevelun plain under several meters of sea water and leading to the displacement of the shore some 4 km landward (Zviely et al., 2006; Figure 2). After the stabilization of relative sea-level around 3,650 years B.P. (Porat, Sivan, & Zviely, 2008), coastal progradation resulted from the combined action of fluvial, aeolian, and marine sediment inputs. In fact, (a) the bay drains the water of two coastal rivers, the Kishon River to the south and the Na'aman River to the north that transport sediments to the plain, particularly during floods in a similar manner to present-day flood events (Vachtman, Sandler, Greenbaum, & Herut, 2012). Here, we focus on the Na'aman River because the change of its course during the last 4,000 years has been one of the main drivers of environmental changes near Tel Akko. Flowing at the foot of the tell during Antiquity, the Na'aman is now artificially banked and located some 800 m to the south. (b) Haifa Bay constitutes the northernmost and final sediment sink of Nile-derived quartz sand, transported from the Nile delta by longshore currents. This is the bay's main sedimentary source with an average annual quantity of sand of about 80,000–90,000 m^3 being transported before the 20th century (Zviely, Kit, & Klein, 2007). (c) Coastal sediments progressively formed important dune fields covering almost the entire western margin of the coastal plain (Figure 2).

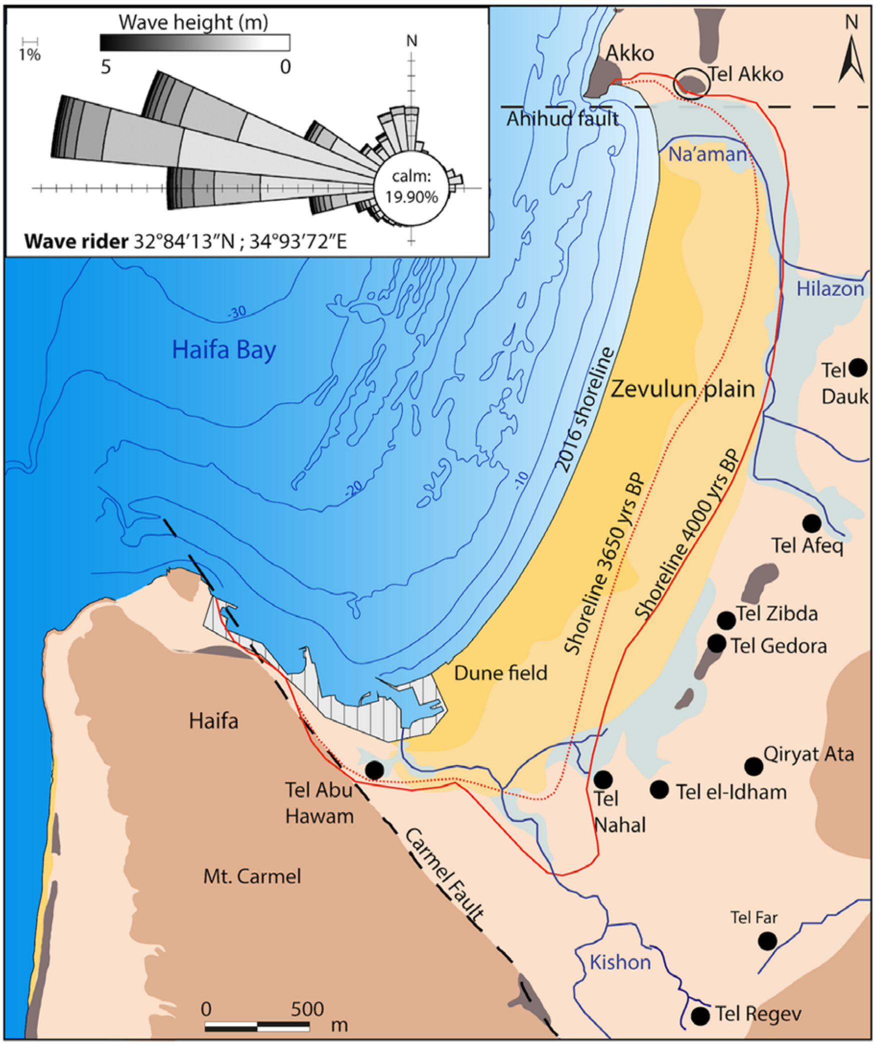

FIGURE 2 Geomorphological map of Haifa Bay

Notes. Location of the tells, the shoreline position around 4,000 years B.P., bathymetry and wave rose (measured using a directional buoy in the Haifa area between 1994 and 2005) after Zviely et al. (2006). The shoreline around 3,650 years B.P. (after Porat et al., 2008).
[Color figure can be viewed at wileyonlinelibrary.com]

3 | ARCHAEOLOGICAL CONTEXT AND HYPOTHESES REGARDING THE LOCATION OF THE ANCIENT ANCHORAGES

3.1 | History

The name Akko first appeared, with several other coastal sites, in the Ebla texts, dating to ca. 2400–2250 B.C. (Artzy & Beeri, 2010). Later, the ancient settlement is mentioned in the Ras Shamra tablets and Amarna letters (Pharaohs of the 18th and 19th dynasties; 1478–1213 B.C.). In the Old Testament, the book of Judges (Judges 1, 31)[1] indicates that the city is under the control of the tribe of Asher. Excavations on the tell since the 1970s have exposed a rampart reaching a height of 22 m and a width of 60 m dated to the Middle Bronze IIa period (2000–1750 B.C.; Dothan, 1976; Raban, 1983, 1991). The northern rampart was strengthened and a gate (Sea Gate) was erected (Dothan & Raban, 1980). Imports from the Lebanese coast as well as from Egypt, Cyprus, and Cilicia underscore the importance of the anchorage and the scope of Akko's trade network (Artzy & Beeri, 2010; Dothan & Goldmann, 1993). During the first part of the 1st millennium B.C., the site experienced a reduction in population size, probably linked to the transfer of the administrative center from Akko to Tel Keisan situated 8 km inland (Artzy & Beeri, 2010). The habitation pattern and the population density increased after ca. 700–600 years B.C., the period in which Phoenicians, Persians, and Greeks were present (Gambash, 2014). The importance of Tel Akko in the trading network of the Levantine coast during the Persian period is attested by the presence of Greek merchants in Akko mentioned by the orator Isaeus in the 4th century B.C. (Isaeus, 4, 7).[2] In 332 B.C., Akko fell to Alexander the Great and Ptolemy 2 changed the city's name to Antiocha Ptolemais. The town moved down to the peninsula sometime in the 3rd century B.C. (Artzy, 2015). The latest numismatic evidence dates the occupation of the tell to the early part of the 2nd century B.C. (Artzy, 2012). In the Old City of Saint-Jean-d'Acre, remains dating to the Roman period have been found, some alongside later Hellenistic finds (2nd century B.C.), mainly north of the peninsula (Abu Hamid, 2012) and a large cemetery was installed at the

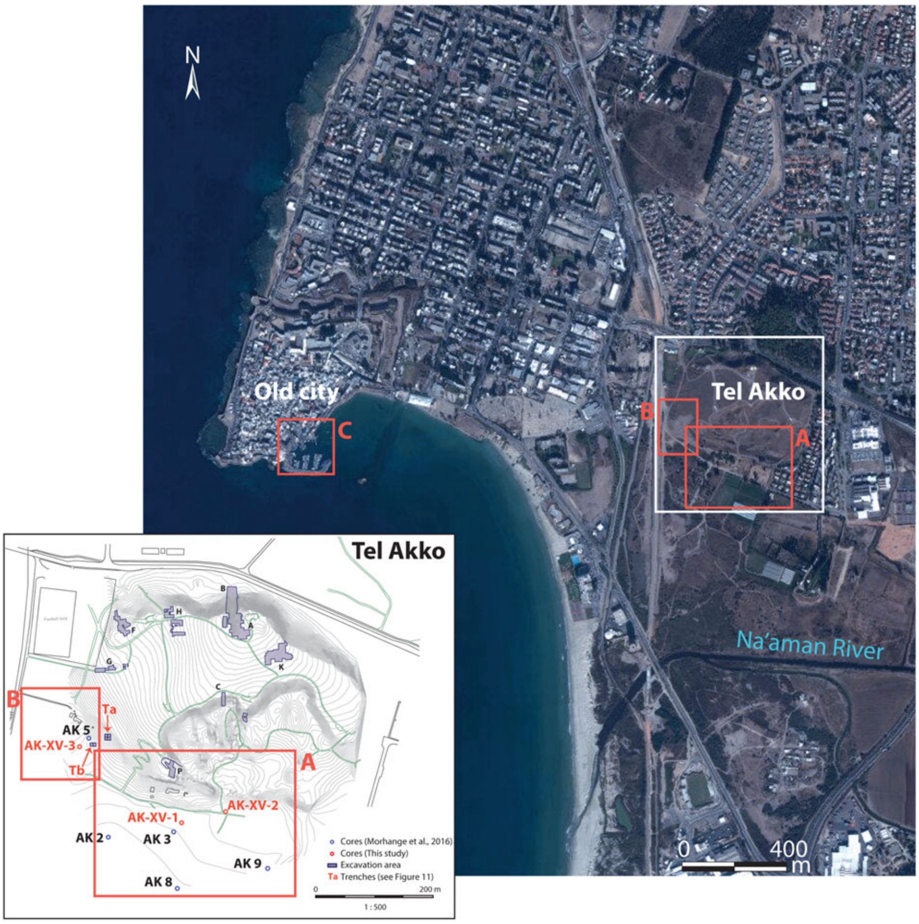

FIGURE 3 Location of the cores, image CNES
Notes. Squares A, B, and C correspond to the three areas studied. A corresponds to the southern part of Tel Akko; B to the western part of Tel Akko; and C to the Old City.
[Color figure can be viewed at wileyonlinelibrary.com]

north-western foothill of Tel Akko (Tepper, 2010). From an archaeological perspective, very little is known about the Arab period of Akko harbor. In the early 12th century, the city was conquered by the Crusader army, and became one of the important Crusader ports, where merchants and the military orders settled. In 1187 A.D. the city was captured by the Muslim army, but in 1191 A.D. was recaptured during the third crusade, led by Richard the Lion-Heart. Jerusalem remained under Muslim rule and thus Saint-Jean-d'Acre gained importance by becoming the capital and the main harbor of the Kingdom of Jerusalem.

3.2 | Location of the harbors

Imported ceramics found at Tel Akko demonstrate that the city must have had a harbor since the Bronze Age. Moreover, Haifa Bay provides the best-protected natural anchorages on the southern Levantine coast (Raban, 1985, 1991; Zviely et al., 2006). These strategic maritime links to the Levant were reinforced by terrestrial routes penetrating eastwards to the Jordan Valley and further to Transjordan. Morhange et al. (2016) proposed that the anchorage of Akko was first situated in a marine-dominated estuary south of the tell during the Middle Bronze Age. Later, the anchorage moved to the open coast on the western side of the tell because of the sedimentary infilling of the Na'aman outlet during the Persian period. Thereafter, the construction of a semi-artificial harbor during the Hellenistic period, in what is today known as the Old City of Saint-Jean-d'Acre, led to the displacement of the city from the tell to the Akko promontory where it remains to this day (Artzy, 2012; Galili et al., 2007, 2010, 2017; Gambash, 2014).

4 | METHODS

4.1 | Biosedimentology

Our work is based on four continuous cores. Three cores were drilled at the foot of the tell and another ca. 1,500-m to the west, in the Old City of Saint-Jean-d'Acre (Figure 3). The coring campaign was undertaken using a percussion corer (Cobra TT). The cores were altitudinally benchmarked relative to present MSL with a GPS-RTK. Core description (texture, macrofauna, organic remains) and sampling were undertaken during fieldwork. Bio-sedimentological analyses were undertaken in the sedimentology laboratory of the CEREGE based on the methodology detailed in Marriner and Morhange (2007) and Marriner (2009). The general sediment texture, including the

TABLE 1 AMS-^{14}C data

CORE	Sample	Laboratory number	δ^{13}C	Depth (cm b.s.)	Depth (cm b.s.l.)	Material	14C yr. B.P.	2σ cal. yr. B.P. min; max	2σ cal. yr. B.C./A.D. min; max
AK-XV-1	160–170	Poz-78030	−28,5	165	211 a.s.l.	Charcoal	recent		
AK-XV-1	280–285	Poz-78031	−22,9	282	94 a.s.l.	Charcoal	2,250 ± 30	2,156; 2,343	394 B.C.; 207 B.C.
AK-XV-1	350–360	Poz-78032	−26,4	355	21 a.s.l.	Charcoal	2,385 ± 30	2,344; 2,676	727 B.C.; 395 B.C.
AK-XV-1	403–410	Poz-78033	−24,5	406	10	Charcoal	2,425 ± 30	2,353; 2,698	749 B.C.; 404 B.C.
AK-XV-2	339–350	Poz-78034	−20,1	345	94 a.s.l.	Charcoal	2,540 ± 30	2,496; 2,747	798 B.C.; 547 B.C.
AK-XV-2	400–410	Poz-78035	−28	405	34 a.s.l.	Charcoal	2,475 ± 30	2,380; 2,720	741 B.C.; 431 B.C.
AK-XV-3	480–490	Poz-78036	−24,3	485	39 a.s.l.	Charcoal	4,226 ± 40	4,627; 4,859	2910 B.C.; 2678 B.C.
AK-XV-3	530–540	Poz-78037	−23,6	535	11	Charcoal	2,827 ± 35	2,855; 3,032	1083 B.C.; 906 B.C.
AKKO3	123–133	Poz-78039	−26,4	128	72 a.s.l.	Charcoal	238 ± 30	0; 424	1,526 A.D.; 1,950 A.D.
AKKO3	248–254	Poz-81536	6,2	251	51	Marine shell	1,995 ± 30	1,358; 1,748	202 A.D.; 592 A.D.
AKKO3	330–340	Poz-78041	−28,2	335	135	Charcoal	2,170 ± 30	2,066; 2,309	360 A.D.; 117 A.D.

The radiocarbon ages are expressed in calibrated years B.P. and B.C. at the 95% confidence level (2σ). b.s., below surface; b.s.l., below present mean sea level; a.s.l., above present mean sea level. Calibration using Calib 7.1. (Stuiver & Reimer, 1993) and the IntCal13 curve (Reimer et al., 2013).

TABLE 2 Published reservoir age dates used to calculate the local reservoir age at Akko

Lon	Lat	Delta R	Delta R Err	Reference	Locality	Collection year	Reservoir age	Reservoir Err
35.0138	32.8431	−115	50	Boaretto et al. (2010)	Israel	1937	174	54
34.9227	32.6432	−20	50	Boaretto et al. (2010)	Israel	1937	269	54
34.9227	32.6432	75	50	Boaretto et al. (2010)	Israel	1937	364	54
34.8482	32.3384	47	40	Boaretto et al. (2010)	Israel	1937	342	
34.8482	32.3384	−70	50	Boaretto et al. (2010)	Israel	1937	219	54
34.83	32.17	52	40	Reimer & McCromac (2002)	Israel	1937	349	41

gravel (>2 mm), sand (50 μm–2 mm) and silty-clay (smaller than 50 μm) fractions, was determined by sieving. Ostracoda were picked from the >160 μm fraction and identified to species level, when possible, using reference manuals (Athersuch, Horne, & Whittaker, 1989; Lachenal, 2000; Meisch, 2000) and scientific papers (e.g., Avnaim-Katav, Agnon, Sivan, & Almogi-Labin, 2016; Frenzel & Boomer, 2005; Ruiz et al., 2010; Salel, Bruneton, & Lefèvre, 2016). Macrofossils larger than 1 mm in size were also identified and assigned to assemblages according to the Mediterranean classification system (D'Angelo & Garguilo, 1978; Doneddu & Trainito, 2010; Poppe & Gotto, 1991, 1991, 1993).

4.2 | Chronology

The chronology is based on 11 Accelerator mass spectrometry radiocarbon determinations performed at the Poznan Radiocarbon Dating Centre on charcoal and marine shells (Table 1). We calibrated the dates using Calib 7.1 (Stuiver & Reimer, 1993) and IntCal13 and Marine13 curves (Reimer et al., 2013). For dated shell samples, we used a local marine reservoir age of 286 years (Morhange et al., 2016; weighted mean, $\Delta R = 3$; standard deviation = 73) calculated using six published ages from Reimer & McCormac (2002) and Boaretto, Mienis, & Sivan (2010); Table 2). The discovery of numerous fragments of ceramics allows us to obtain a high-precision relative chronology for the stratigraphic units because of the study of their typology. These results confirm the robustness of the radiocarbon chronology (Table 3).

5 | RESULTS

5.1 | Presentation of the cores drilled at the foot of the tell

The two cores presented in the first part (AK-XV-1 and AK-XV-2) were drilled on the southern side of the tell, they show the same stratigraphy and are divided into three main biofacies. The core AK-XV-3, undertaken on the western facade presents a different stratigraphy and will

TABLE 3 List of the ceramics discovered in the cores (identification by M. Artzy)

Core	Depth	Material	Age	Provenance
AK-XV-1	230	Amphorae	5–4 c. B.C.	Imported
AK-XV-1	288		4 c. B.C.	Imported (Egypt)
AK-XV-1	293		4 c. B.C.	Imported (Egypt)
AK-XV-1	301	Amphorae	5–4 c. B.C.	
AK-XV-1	303	Amphorae	5–4 c. B.C.	
AK-XV-1	317	Cooking pot	Persian	
AK-XV-1	323	Amphorae	5–4 c. B.C.	Imported (Greece)
AK-XV-1	328	Amphorae	5–4 c. B.C.	
AK-XV-1	360–369	Handle	6–3 c. B.C.	Imported
AK-XV-1	430–440		7 c. B.C.	
AK-XV-2	166	Amphorae	Byzantine	
AK-XV-2	253	Amphorae	6–4 c. B.C.	Imported
AK-XV-2	339–350	Amphorae	5–4 c. B.C.	Imported
AK-XV-2	353		Late Bronze	Tel Abu Hawam
AK-XV-2	359	Amphorae/cooking pot/closed vessel	Late Bronze	
AK-XV-2	359		Persian	
AK-XV-2	373–380	Tray	Late Bronze	
AK-XV-2	373–380		Middle Bronze	
AK-XV-2	380–390		Middle Bronze	
AK-XV-2	380–390	Storage Jar	Persian (5–3 c. B.C.)	
AK-XV-2	390–400	Cooking pot	Middle Bronze	
AK-XV-2	400–410		Middle Bronze	
AK-XV-2	400–410	Cooking pot	Persian	
AK-XV-2	410–420	Closed vessel (jug or jar)	4 c. B.C.	
AK-XV-2	410–420		5–4 c. B.C.	
AK-XV-2	410–420		Import Middle Bronze	
AK-XV-2	420–430	Storage jar	4 c. B.C.	
AK-XV-2	430–440	Cooking pot	2nd millenium	
AK-XV-2	440–450	Cooking pot	Late Bronze	
AK-XV-3	190–200	Amphorae	5–4 c. B.C.	Imported
AK-XV-3	240–250	Bowl	Middle Bronze	
AK-XV-3	260–270	Amphorae	6–4 c. B.C.	Imported
AK-XV-3	280–290	Amphorae	6–4 c. B.C.	Imported
AK-XV-3	280–290	Cooking pot	6–4 c. B.C.	Imported
AK-XV-3	300–312		4–5 c. B.C.	
AK-XV-3	300–312	Closed vessel (jug or jar)		Imported (Egypt)
AK-XV-3	320	Amphorae		Imported (North Africa)
AK-XV-3	236–336	Juglet	Iron Age	
AK-XV-3	420–430		Persian–Hellenistic	
AK-XV-3	420–430		Middle Bronze	
AK-XV-3	430–440		Persian–Hellenistic	
AK-XV-3	450–460		Persian–Hellenistic	
AK-XV-3	600–610	Cooking pot/jar	Middle Bronze/Iron Age	
AKKO3	188	Glazed pieces	Crusader period	
AKKO3	265		Not earlier than Crusader	
AKKO3	278–288		Not earlier than Crusader	Imported
AKKO3	320–330	Amphorae	Early Byzantine/Crusader	Imported

be presented in another part. Finally, the core AKKO3, drilled in the Old City of Saint-Jean-d'Acre, will be detailed in the third part.

5.1.1 | The southern facade of the tell

Core AK-XV-1 (32°55′10.48″N; 35°5′12.89″E) is located a few tens of meters south of the limit of the tell, 376 cm above the present mean sea level. With a length of 450 cm, it reaches the rocky substratum composed of kurkar (Figure 4).

Unit A in core AK-XV-1, between 300 and 450 cm depth, is radiocarbon dated to 749–404. B.C. (Poz-78033) at the base and 727–395 B.C. (Poz-78032) in the middle. The age of this unit is confirmed by the presence of an important quantity of rounded ceramics (4–6th centuries B.C.) throughout the unit (Table 3). These ceramics derive from amphorae and other pieces that are for the most part imported from Egypt and Greece among others. The sedimentary texture of the unit is sandy (>90%), including rounded pebbles probably of fluvial origin. This marine sand is mostly fine, with a few coarse layers at the base of the unit. The ostracod fauna is composed of a mixture of species presenting various ecological affinities. The coastal assemblage is dominant (41% of the total). Sixteen species have been identified. Three of them are dominant, namely *Aurila convexa*, *Loxoconcha rubrincta*, and *Pontocythere elongata*. They are characteristic of fine infratidal sands. In the lagoonal assemblage (31%), the species *Cyprideis torosa* and *Xestoleberis communis* prevail. The fresh (to mesohaline) species (26%) are represented by *Candona neglecta*, *Darwinula stevensoni*, *Heterocypris salina*, and *Illyocypris gibba*. The latter tolerate low to moderate salinity and are associated with estuaries or low salinity coastal lagoons. They are better adapted to variations in salinity. However, it is important to stress that the ostracod density is relatively low, between 1 and 100 valves for 20 g of sand. Macrofauna, with a low density in the whole unit, attest to both freshwater and marine influences.

Unit B within core AK-XV-1, located between 230 and 300 cm depth, is dated to 394–207 B.C. (Poz-78031) at the base. The sediments are composed of organic-rich silts and clay. Even if the sand fraction is less important than in unit A, the latter are coarser, in particular at the base of the unit. The ostracods are associated with fresh to mesohaline water environments. We found the same species as in the previous unit. At the base of unit B, *H. salina* is dominant then becomes less abundant. It is replaced by *C. neglecta*, *D. stevensoni*, and *I. gibba* that point to a decrease in the salinity linked to the closure of the lagoon and the growing influence of freshwater inputs linked to the Na'aman River. In this unit, the ostracods are abundant with 100–800 valves for 20 g of sediments. Coastal ostracods are quasi-absent from this unit. It is important to note that nowadays, *Illyocypris*, *Heterocypris*, and *Cyprideis* are still found in the Na'aman River mouth (Avnaim-Katav et al., 2016). The chronology of core AK 8 (Morhange et al., 2016) shows that the Na'aman River flowed near the tell at least until around 2,000 years B.P. (43 B.C.–79 A.D.; Poz-53647). Another radiocarbon date from core AK 2, drilled 150 m west of core AK 8, shows that the choked lagoonal estuary existed until 897–1117 A.D. (Poz-50075).

Unit C, in core AK-XV-1, is situated between 230 and 120 cm depth. It is composed of sands (75%) with a minor proportion of silts and clay (18%). The gravel fraction (7%) is composed of a majority of reworked ceramics (imported amphorae: 4–5th century B.C.). The ostracods are absent from the unit, except at the base. The macrofauna density is very low represented and composed of freshwater and terrestrial shells. This unit reflects the final phase of the progradation of the coastal plain after the infilling of the lagoon.

Core AK-XV-2 (32°55′9.86″N; 35°5′15.71″E) is located ca. 80 m east of AK-XV-1, closer to the tell, 439 cm above the present mean sea level. With a length of 450 cm, it also reaches the rocky substratum composed of kurkar. We were able to discriminate the same biofacies as in AK-XV-1, but with a different thickness (Figure 5).

Unit A in core AK-XV-2 is located between 286 and 450 cm depth. Two radiocarbon dates show that this unit developed before the 5th century B.C. (798–547 B.C.; Poz-78034). This age is confirmed by ceramics similar to those discovered in the core AK-XV-1 dated to the 5 to 4th century B.C. However, the identification of the ceramics shows earlier sherds dated to the Iron and Middle Bronze Age (Juglets, amphoraes, cooking pots; Figure 5). The important erosion marks on the ceramics attest to the presence of the sea. As for unit A of core AK-XV-1, the texture is sandy. The gravel fraction increases and represents 36% of the total sediment in the first two thirds of the unit. They are mostly composed of small rounded pieces of ceramics (non-identifiable) and pebbles. The ostracod fauna is composed of a mixture of species with various ecological affinities, as in the core AK-XV-1. However, in this core, the lagoonal assemblage, comprising *C. torosa*, is dominant (55%). The freshwater to mesohaline species represents 23% of the total species. The coastal assemblage is the third assemblage represented (19%). The same three species prevail (*A. convexa*, *L. rubrincta*, and *P. elongata)*. The faunal density varies throughout the unit. The maximum density (ca. 800 valves for 20 g of sands) occurs when the freshwater assemblage is dominant even though the mean density is lower than 100 valves for 20 grams of sediment. Macrofauna, with a low density throughout the unit, attest to freshwater and marine influences.

Unit B within core AK-XV-2, located between 270 and 286 cm, is thinner than in AK-XV-1. As confirmed by the discovery of a potsherd (amphorae) dated to the 6 to 4th century B.C., this unit was deposited during the same period as unit B of core AK-XV-1. Sediments are composed of brown silts associated with freshwater (e.g., *C. neglecta*, *I. gibba*, *H. salina*) and lagoonal (*C. torosa*) ostracods, although coastal species are present at the base of the unit (e.g., *A. convexa*, *L. rubrincta*).

Unit C in core AK-XV-2 is situated between 184 and 270 cm depth. It is composed of fine aeolian sands and fluvial-derived sediments. In this unit, the fauna is quasi-absent consistent with the final phase of the coastal progradation and the creation of a terrestrial environment.

5.1.2 | The western facade of the tell

Core AK-XV-3 (32°55′13.77″N; 35°5′6.71″E) was drilled on the western side of the tell, 524 cm above the present mean sea level. With a length of 625 cm, it also reaches the rocky substratum composed of kurkar. The biosedimentology results allow us to elucidate four units (Figure 6).

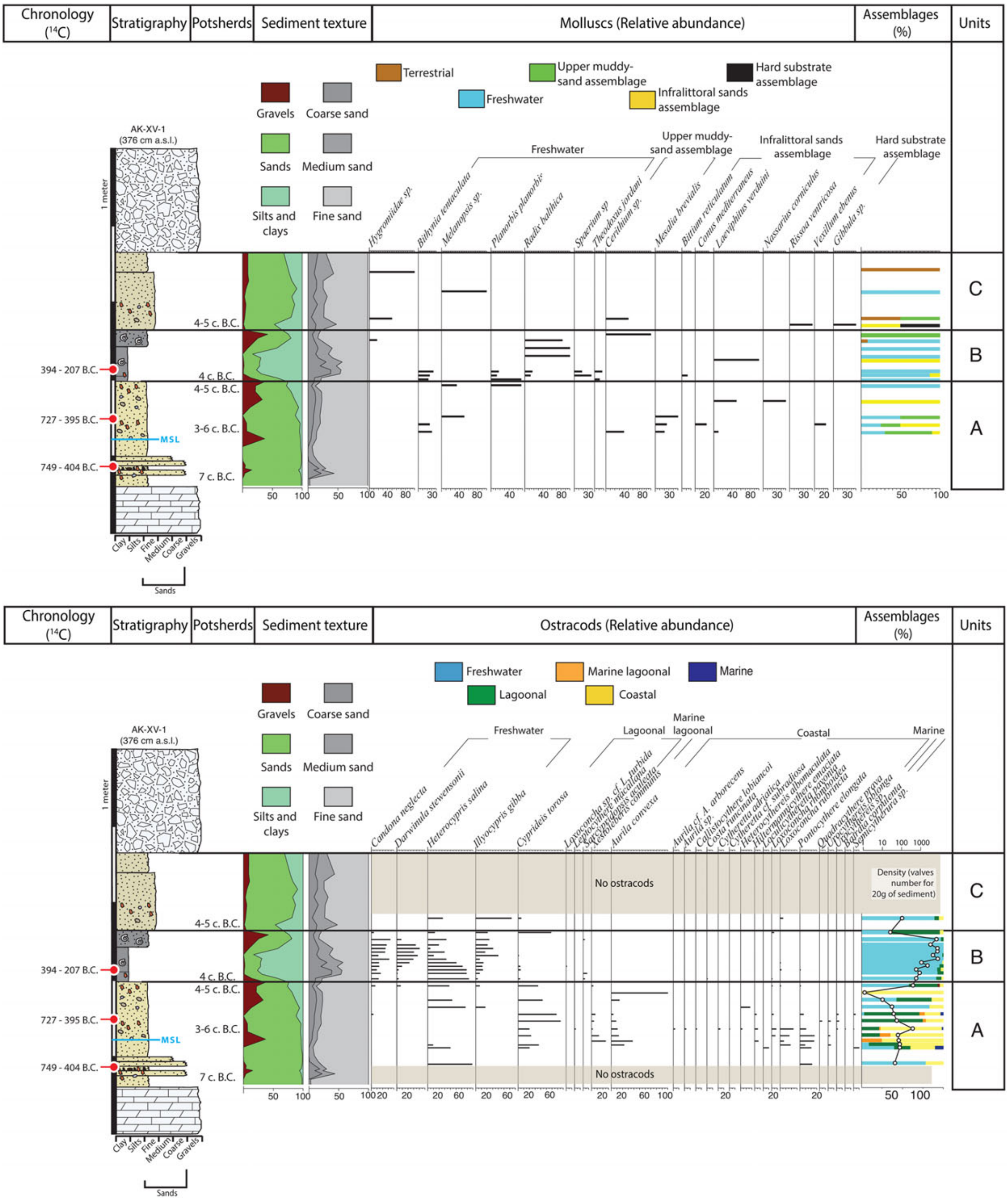

FIGURE 4 Biosedimentology of the core AK-XV-1
Notes. Top: Mollusk species and assemblages. Bottom: Ostracod species and assemblages. The location of the core is given in Figure 3. [Color figure can be viewed at wileyonlinelibrary.com]

The base of the unit A, in core AK-XV-3, is dated to the Middle Bronze or Iron Age, as confirmed by the discovery of a piece of amphorae (or cooking pot). The unit is situated between 440 and 600 cm depth and is radiocarbon dated to 1083–906 B.C. (Poz-78037) in the middle of this facies. Ceramics found at the top of unit A are dated to the Persian–Hellenistic period. These ceramics were transported by the sea and have been more eroded by waves than the ceramics discovered in the other cores that testify to a greater exposure to the open sea. The sedimentary texture of the unit is sandy (90%). The coarse fraction (10%) includes coarse gravels, rounded pebbles, pieces of ceramics, and some broken shells. This marine sediment is mostly composed of fine sand, identical to the present-day sandy facies of Haifa Bay, south of Akko.

The ostracod fauna comprises a mixture of coastal (51%), brackish lagoonal (29%), marine lagoonal (10%), and marine (10%) species. The lagoonal species are composed of *C. torosa*, a very euryhaline species

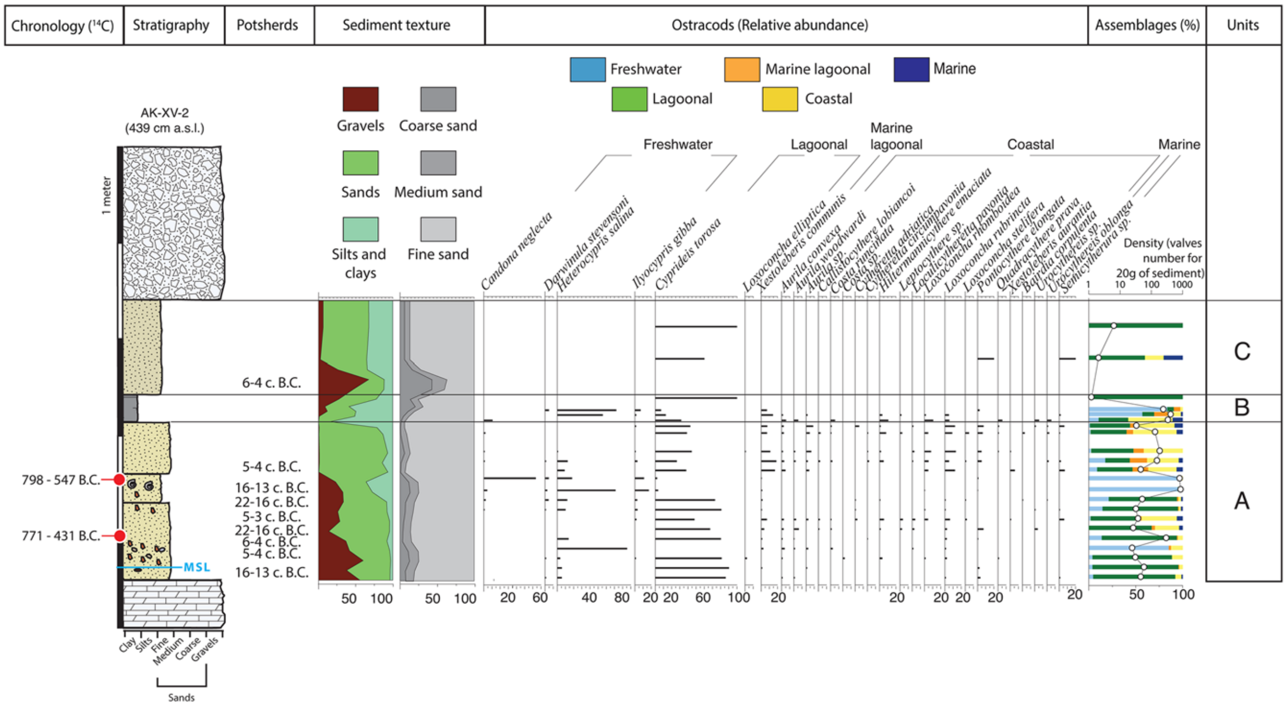

FIGURE 5 Biosedimentology of core AK-XV-2

Notes. Ostracod species and assemblages. The location of the core is given in Figure 3.

[Color figure can be viewed at wileyonlinelibrary.com]

that can tolerate fresh to marine waters. Coastal and marine species are very diversified. We identified 22 coastal and marine species, dominated by *A. convexa*, *Aurila woodwardi*, *Loxoconcha rhomboidea*, *L. rubrincta*, and *P. elongata*. The ostracod density is low, characteristic of an open coastal environment exposed to swell and waves. Some marine mollusk species have been reworked from the upper part of the infratidal zone, such as *Bittium reticulatum*, *Donax variegatus*, *Messalia brevialis*, and *Nassarius corniculus*.

Unit B within core AK-XV-3, located between 300 and 440 cm depth, is dated between the Persian and Hellenistic period, by ceramics found in the core, and the agricultural soil dated to the crusader period. The sediment texture is the same as in unit A. The gravels are less abundant and smaller than in unit A. In this unit, fauna is absent, typical of an emerged prograding beach. Furthermore, this unit is situated above present mean sea level.

The unit C within core AK-XV-3 is situated between 182 and 300 cm depth. It comprises a mixture of sands, silts, and clay and gravels composed of reworked ceramics of amphorae from the 6 to 4th century B.C. and other sherds from the Middle Bronze Age onward. This unit is interpreted as an agricultural soil. In fact, during the Crusader period (ca. 13th century A.D.), this area was a plowed agricultural zone. It was tilled by the Pisans who settled in Saint-Jean-d'Acre (Artzy, 2015).

Unit D in core AK-XV-3, situated between 120 and 182 cm depth, is composed of fine aeolian sand. This sand derives from the nearby beach. In fact, the western part of Haifa Bay is formed by an important dune field (Zviely et al., 2006).

5.2 | Presentation of the core drilled in the Old City of Saint-Jean-d'Acre

Core AKKO3 (32°55′12.32″N; 35°4′10.21″E) is located in the "Old City" of Akko, a few tens of meters from the modern artificial harbor, ca. 200 cm above the present mean sea level. With a length of 520 cm, the core is composed of marine sands and reaches the substratum of the Carmel coast clay (Figure 7).

Unit A in core AKKO3, between 340 and 500 cm depth, reached a hard layer of cemented rocks covering the clay substratum. The gravels represent 32% of the total sediment and are composed of angular pieces of gray sedimentary rocks of various sizes and of rounded gravels. The sands represent 56% of the total sediments and the fine particles 12%. The sand texture, dominated by medium sands (43%), is uniform throughout the whole unit. Ostracod faunal densities are relatively low and often <10 valves for 20 g of sands. There are brackish and marine lagoonal (53%), coastal (40%), and marine (7%) species. Coastal species are dominated by *A. convexa*, *A. woodwardi*, and *L. rhomboidea*. The most represented marine species are *Bairdia corpulenta* and *Quadracythere* sp. The macrofauna shows a typical infratidal faunal assemblage dominated by *B. reticulatum* and *Rissoa ventricosa* with subsidiary species from lagoonal environments (e.g., *Cerastoderma glaucum*), upper muddy-sand assemblages (e.g., *Cerithium vulgatum*), and from hard substrates (e.g., *Conus mediterraneus*, *Fusinus* sp.). According to unit B, this unit was deposited before the 4th century B.C.

Unit B within core AKKO3, situated between 238 and 340 cm depth, shows the same general texture as unit A. The sand fraction is dominant (60%). The gravels and the silts fraction, respectively,

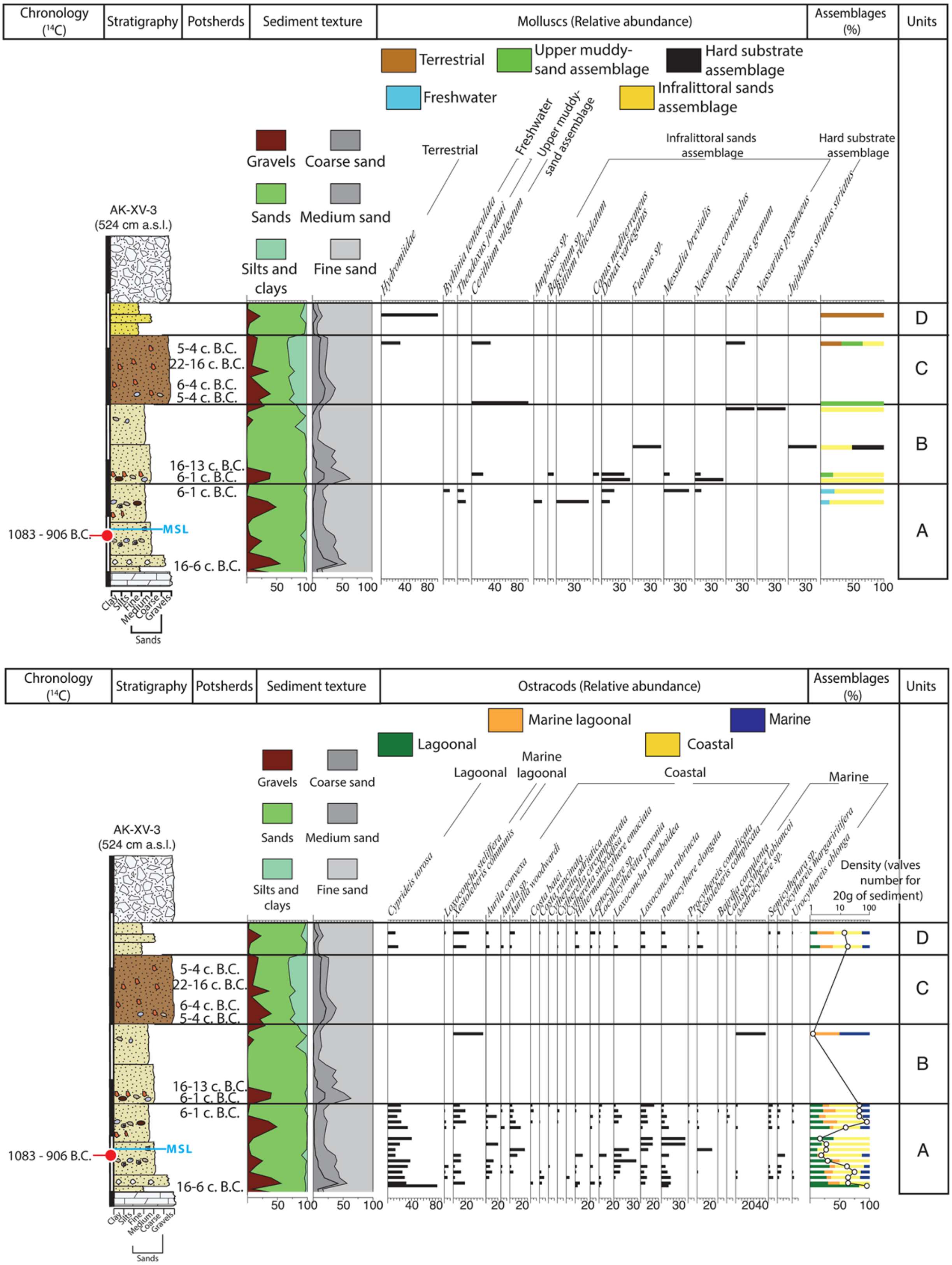

FIGURE 6 Biosedimentology of the core AK-XV-3

Notes. Top: Mollusk species and assemblages. Bottom: Ostracod species and assemblages. The location of the core is given in Figure 3. [Color figure can be viewed at wileyonlinelibrary.com]

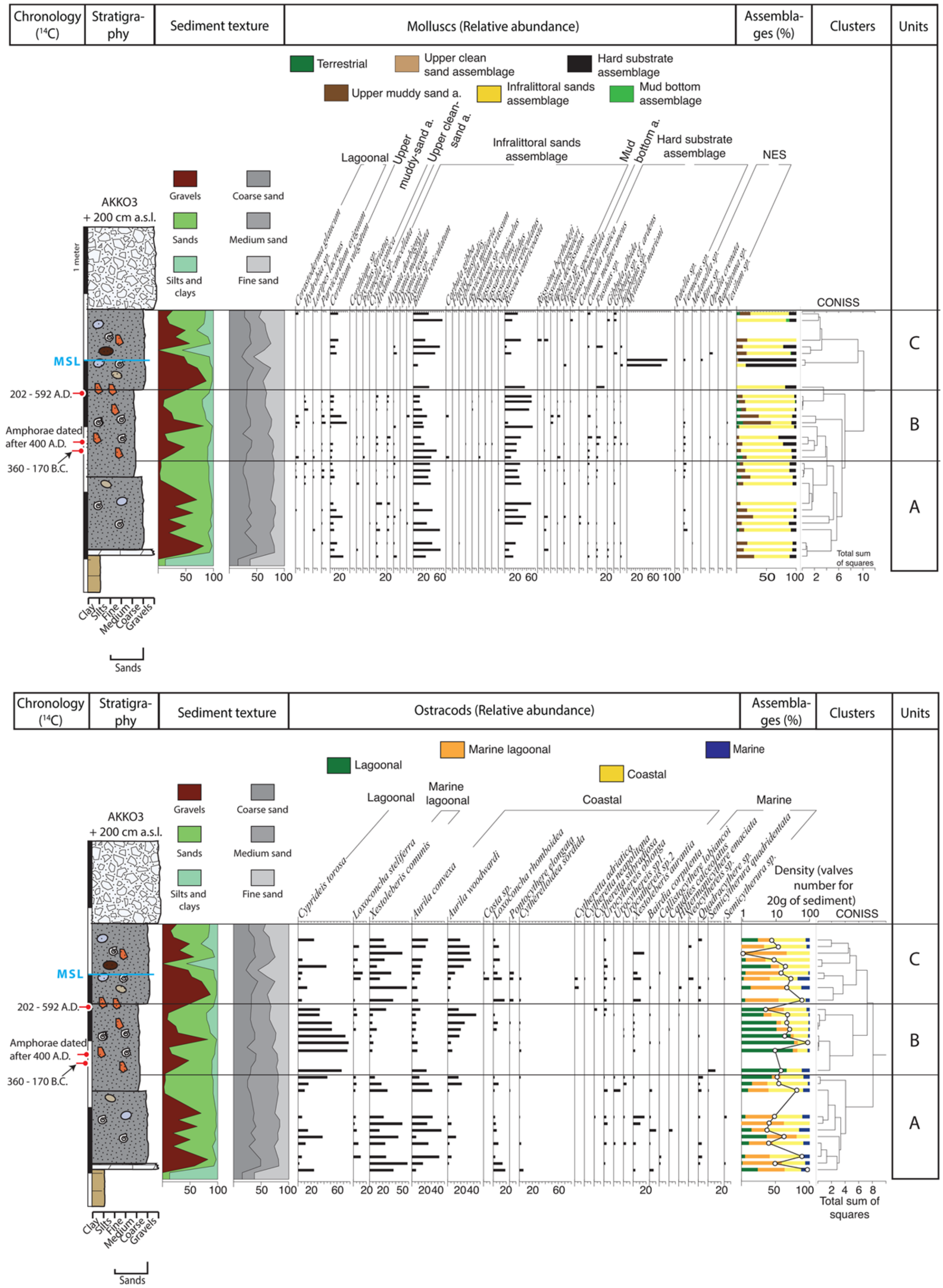

FIGURE 7 Biosedimentology of the core AKKO3

Notes. Top: Mollusk species and assemblages. Bottom: Ostracod species and assemblages. The location of the core is given in Figure 3. [Color figure can be viewed at wileyonlinelibrary.com] represent 30% and 10% of the total sediment. The base of the unit (340 cm depth) is radiocarbon dated to 360–170 B.C. (Poz-78041) and the top of it (248–254 cm depth) is dated to 202–592 A.D. (Poz-81536). Nevertheless, between 320 and 330 cm, we found two reworked sherds from the same maritime transport container (Storage jar or amphorae) dated between the Early Byzantine and the Crusader period (ca. 500–1300 A.D.). The sand texture is the same as in unit A. The ostracods show a little increase in density and exceed 10 valves for 20 g of sediments. We find the same ecological groups as in unit A, but the brackish lagoonal assemblage with *C. torosa* is dominant (57%). Marine lagoonal species (10%) occur increasingly at the top of the unit, like the coastal assemblage (29%). In contrast to the previous unit, marine species comprise just 3% of the total. Regarding the macrofauna, there are no discernable changes between the two units. The various proxies evoke a pocket beach environment, partially sheltered by the presence of the Akko promontory that protected the beach from the north-eastern waves.

This unit C in core AKKO3 is situated between 113 and 238 cm depth and is composed of coarse sediments. The gravel and the sand fraction, respectively, represent 41% and 43% of the total sediments. Coarse, medium, and fine sands each comprise a third of the sand texture. The radiocarbon date (202–592 B.C.; Poz-81536) does not match the broken ceramics dated to the Crusader period discovered at the same depth and probably attests to reworking or dredging. Nevertheless, these sherds are incrusted with marine organisms (*Vermetus triqueter*) that demonstrate that a very shallow marine environment was still present during Muslim or Crusader periods. This unit would correspond to the infilling of this sector of the harbor that could no longer be used for the docking of boats at the time of the Crusades, as proposed by Galili and Rosen (2017). Ostracods are dominated by coastal (43%) and marine lagoonal species (40%). The lagoonal assemblage shows a drastic decrease and represents 12% of the total species. The proportion of marine species (6%) is low and essentially concentrated at the base of the unit. Furthermore, the density decreases toward the top of the unit. The macrofauna is still characteristic of infratidal sand assemblages but, at the base of the unit, we note the dominance of the hard substrate assemblage species *Mytilaster marioni*.

From a stratigraphic perspective, this core highlights a classic regressive sequence (Coe, 2003). Deposition of marine sands after sea-level stabilization led to the progressive progradation of the coastline in a seaward direction. No classic ancient harbor parasequence *sensu* Marriner and Morhange (2006) has been identified.

6 | DISCUSSION

6.1 | Coastal changes and the paleogeography of Tel Akko

The study of the three cores undertaken close to the tell, in association with the results of previous studies (Kaniewski et al., 2013, 2014; Morhange et al., 2016; Sivan & Inbar, 1983), allows us to probe coastal changes related to sediment input at base-level in the area of Tel Akko during the last 4,000 years.

6.1.1 | Evolution of the southern shore of the tell: From an open marine bay to an infilled lagoonal estuary

On the southern facade of the tell, Morhange et al. (2016) analyzed three cores located more than 100 m south of the limit of the tell. Our two cores, drilled closer to the tell, allow us to elucidate the main stages of coastal evolution of the area.

The first transect was undertaken south of the tell in an east–west direction. Cores AK 8 and AK 9 (Morhange et al., 2016) are ca. 140 m apart (Figure 8). The stratigraphy attests to marine sand with coastal, lagoonal, and freshwater fauna. In AK 9, the marine sand unit is thicker and the top of this unit is situated ca. 180 cm above present mean sea level, a sign of the development of an emerged beach in this zone after 745–394 B.C. (Poz-78033). In AK 8, the top of the unit is situated 1 m below present m.s.l. and is contemporaneous to the unit identified in AK9. This could reflect the natural slope of the beach (ca. 0.28%). This marine sand is directly followed by fine gray silts with coastal and freshwater fauna at the base, changing to freshwater fauna at the top. Nevertheless, the chronostratigraphy highlights important differences between the two cores. It is difficult to precisely date the open marine environment. We can merely state that it is older than ca. 787–401 B.C. (Morhange et al., 2016).

The second transect comprises the cores AK-XV-1 and AK-XV-2, situated at the foot of the tell, and core AK 8 (Morhange et al., 2016), around 150 m to the south (Figure 9). This transect records the same units. At the foot of the tell, we observe a sandy beach including many rounded potsherds dating from the Middle Bronze to the 5 to 4th century B.C. and rounded pebbles corresponding to a relatively high-energy environment situated in the foreshore zone. The top of the marine-dominated unit in AK 8 is contemporaneous with the marine-dominated unit of AK-XV-1 and AK-XV-2 and highlights the natural slope of the beach situated in the southern part of the tell (ca. 0.30%). The upper unit (choked lagoonal estuary) is thicker to the south (AK 8) and is around 100 cm above present m.s.l. near the tell. The potsherds collected during the coring campaign show that the core AK-XV-2 was drilled close to the ancient entrance of the tell in contrast to AK-XV-1 that contains more harbor-like material.

6.1.2 | A natural open harbor on a prograding sandy beach on the western façade of Tel Akko in Late Persian/Early Hellenistic times

On the southwestern part of the tell, an Israeli Archaeology Authority salvage project, revealed the presence, on the slope itself, of a small industrial area dating to ca. the 4th century B.C. Late Persian to Early Hellenistic remains were discovered (Artzy, 2012; Figure 10).

Cores AK 5 (Morhange et al., 2016) and AK-XV-3 (this study) were drilled at the foot of the hill, just a few meters west of an excavation area (Artzy, 2012; Figure 10). The cores show that, during the Middle Bronze Age, the sea washed the western shore of the tell (Figure 11). Sediment input into Haifa Bay mainly came from local rivers and the Nile because the bay constitutes the northernmost and final depositional sink of Nile-derived quartz sand, transported from the Nile delta

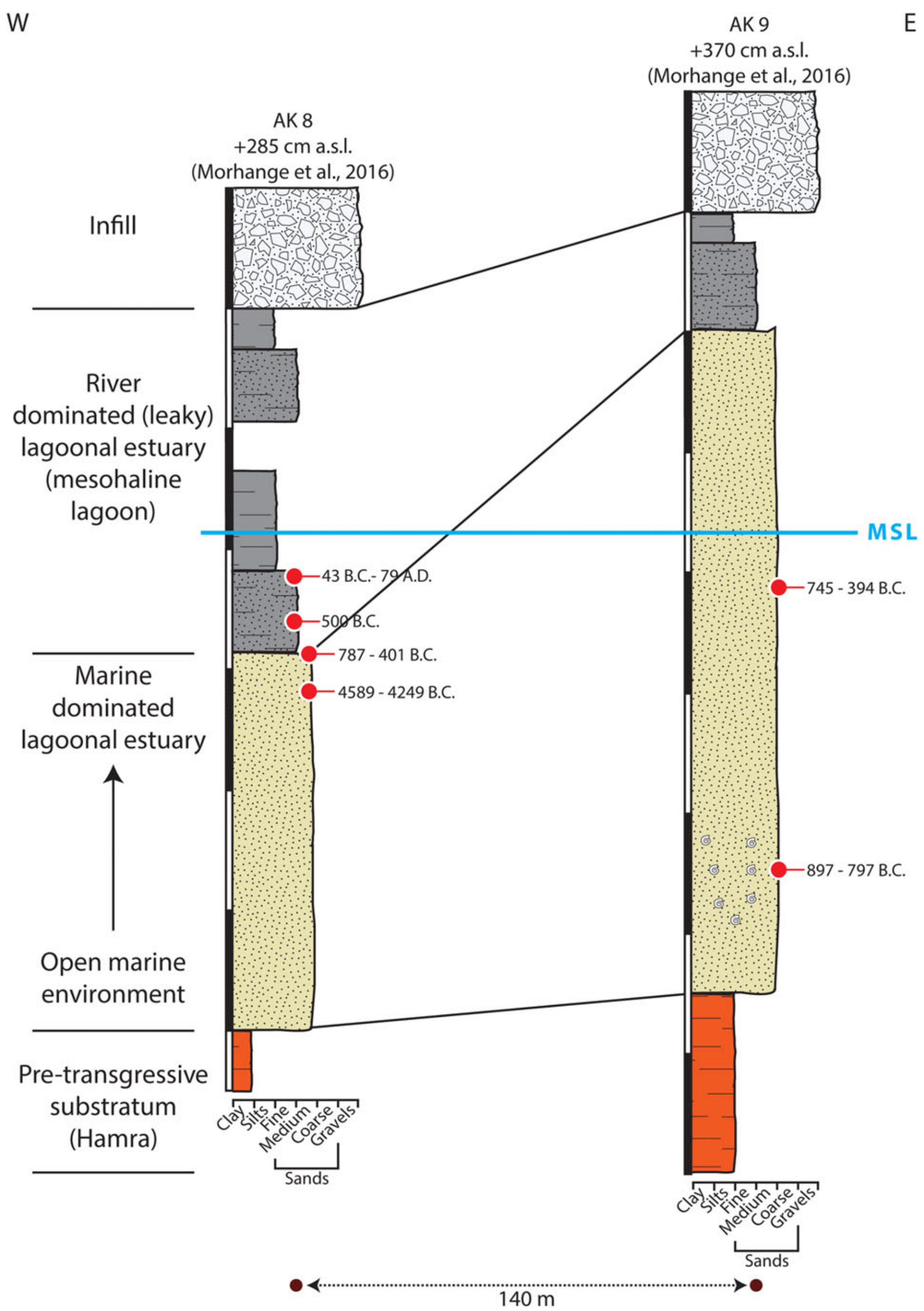

FIGURE 8 East–West transect in the southern part of Tel Akko (cores AK 8 and AK 9 after Morhange et al., 2016)
Notes. The location of the cores is given in Figure 3.
[Color figure can be viewed at wileyonlinelibrary.com]

by longshore currents (Zviely et al., 2007). Under typical weather conditions, the Carmel headland area at the southern entrance of Haifa Bay provides a natural barrier that prevents sand from entering the bay. Only rare high southwest breaking waves can produce the strong northerly longshore currents needed to overcome the headland barrier and move sand eastward into the bay. The annual net longshore sand transport into Haifa Bay was estimated by Zviely et al. (2007) to be 80 to 90 $\times$ 10^3 m^3 from south to north. This explains that, during the Holocene, the bay trapped more than 700 million m^3 of sand. However, in the northern part of the bay, where the Na'aman mouth is located, the annual net longshore sand transport is negligible (Lichter, Zviely, & Klein, 2009). Between AK 5 and AK-XV-3, the sand accumulation seems to have been relatively modest during the Middle Bronze Age, illustrating a difference with the aggradation rates measured by Porat et al. (2008) in the center of the bay. In fact, they show that the central Zevulun plain has prograded at an average rate of 40–50 cm/year since 4000 B.P. The sea was present until the Persian–Hellenistic periods as confirmed by sea-transported/eroded ceramics found in the cores. This facies corresponds to the sand facies bearing shells and ceramics discovered during the archaeological survey and delineates a high-energy coastline (Figure 10). It was at this time that the coast started to prograde westwards, probably associated with higher sediment inputs from the Na'aman River.

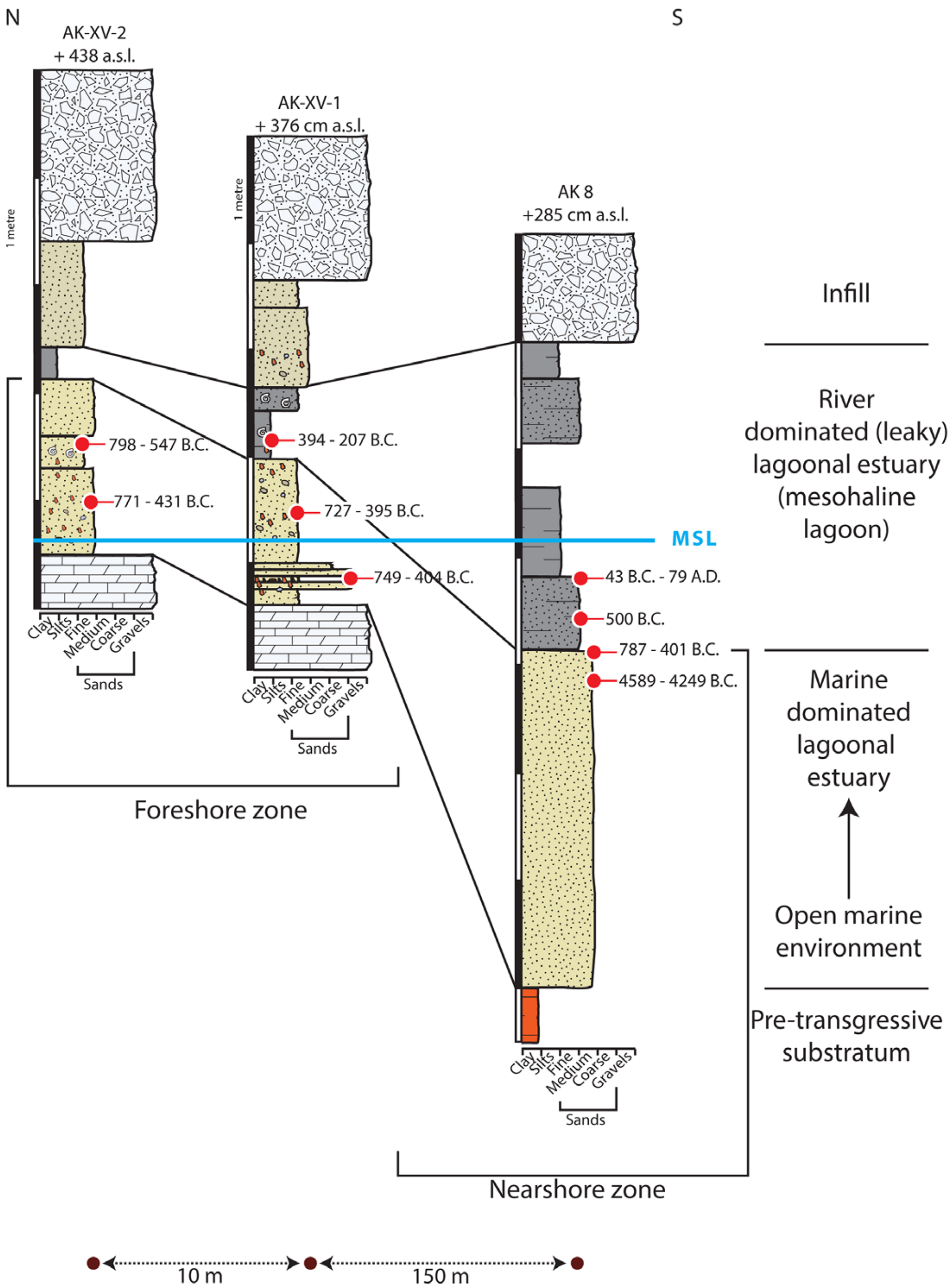

FIGURE 9 North–South transect in the southern part of Tel Akko (cores AK-XV1 and AK-XV-2, this study; core AK 8 after Morhange et al., 2016)
Notes. The location of the cores is given in Figure 3.
[Color figure can be viewed at wileyonlinelibrary.com]

6.1.3 | Paleogeographic changes of the southern and western shore of the tell

Analysis of the transects on the southern and western shores of the tell, compared and contrasted with other paleoenvironmental studies (Zviely et al., 2006; Porat et al., 2008; Kaniewski et al., 2014; Morhange et al., 2016), highlight two main stages in the evolution of the landscape:

1. First, the open marine environment formed during the Holocene marine ingression is recorded at the base of AK 8 and AK 9 (Figure 12A). Analysis of another core, south of the tell, highlights the presence of an open marine environment between 4000 and 2900 B.P. (Kaniewski et al., 2014). Progressively, the westward progradation of the coastal plain and the concomitant shift in the position of the Na'aman mouth led to the trans-

FIGURE 10 (A and C) Remains of an active sea coast; Ta, trench a; Tb, trench b; L171, level 171; L179, level 179; L219, level 219; (B) Ceramics found alongside the shell and coral fragments point to the first millennium B.C. (Artzy, 2012) [Color figure can be viewed at wileyonlinelibrary.com]

formation of the area into a leaky lagoonal estuary during the Iron Age and the Persian period, as attested by the presence of freshwater fauna in marine sands (Figure 12B). The course of the Na'aman was probably situated at the foot of the tell at this time. The presence of marine sediments in the cores until the 4th century B.C. is explained by the proximity of the inlet allowing deposition of marine sand. This sedimentation is the same for the current Na'aman mouth (Avnaim-Katav et al., 2016). They show that the river mouth is open to the sea all year round. This open lagoonal estuary was probably separated from the open sea by the accretion of a sand bar from the south (according to the longshore drift direction) as already proposed by Morhange et al. (2016).

2. The closure of the lagoonal estuary and the deposition of fluvial-derived fine sediments could be explained by: (a) the avulsion of the Na'aman displacing it closer to the tell; and/or (b) the closure of the inlet. This river-dominated environment (mesohaline lagoon) shows that the circulation of boats in this area was very limited (Figure 12c). The maximum extension of the estuary to the south is assumed according to the presence of swamps in maps dating to the middle of the 19th and the beginning of the 20th centuries (survey of the Lieut. F. G. D. Bedford, 1862; Triedel map, 1924–1925). The infilling of the estuary could explain the relocation of harbor activities on the western facade of the tell, forming an open anchorage easy to access (Figure 12c).

6.1.4 | Semi-open pocket beach in the Old City

Archaeological excavations show that the most recent finds at Tel Akko date to the 3rd century B.C. After this time, the tell was abandoned in favor of the Old City of Saint-Jean-d'Acre (Artzy, 2015). While previous scholars attributed the construction of the artificial harbor to the Persians, in order to accommodate Gambyse's fleet on its way to Egypt (Linder & Raban, 1965; Raban, 1983, 1993), Ptolemy 2 (285–246 B.C.) seems to have been responsible for the massive constructions in the "Old City" and of the harbor (Artzy, 2015). The harbor in ancient times was composed of two basins (Figure 13). Galili et al. (2010) analyzed the ceramic content of the sediments dredged in the artificial harbor, mainly in the western basin, and showed that the remains (potsherd, anchors…) are significant for the Hellenistic, Roman, and Byzantine periods while very few archaeological artifacts are earlier. Nonetheless, because dredging did not reach the substratum, they cannot exclude that the oldest remains have not been dredged. Discoveries show that the harbor had important trade activities because of the high quantity of imported amphorae and domestic vessels found in the harbor's sediments. These remains point to extensive trade relations with Mediterranean countries and to large-scale imports from the Aegean (Galili et al., 2010). The presence of stamped handles dated to the 2nd century B.C. may be related to military activity in the harbor, linked to the Ptolemaic and the Seleucid armies. For Galili et al. (2010), the abundant Hellenistic artifacts were embedded in fine silt sediment, which is characteristic of low-energy waves and

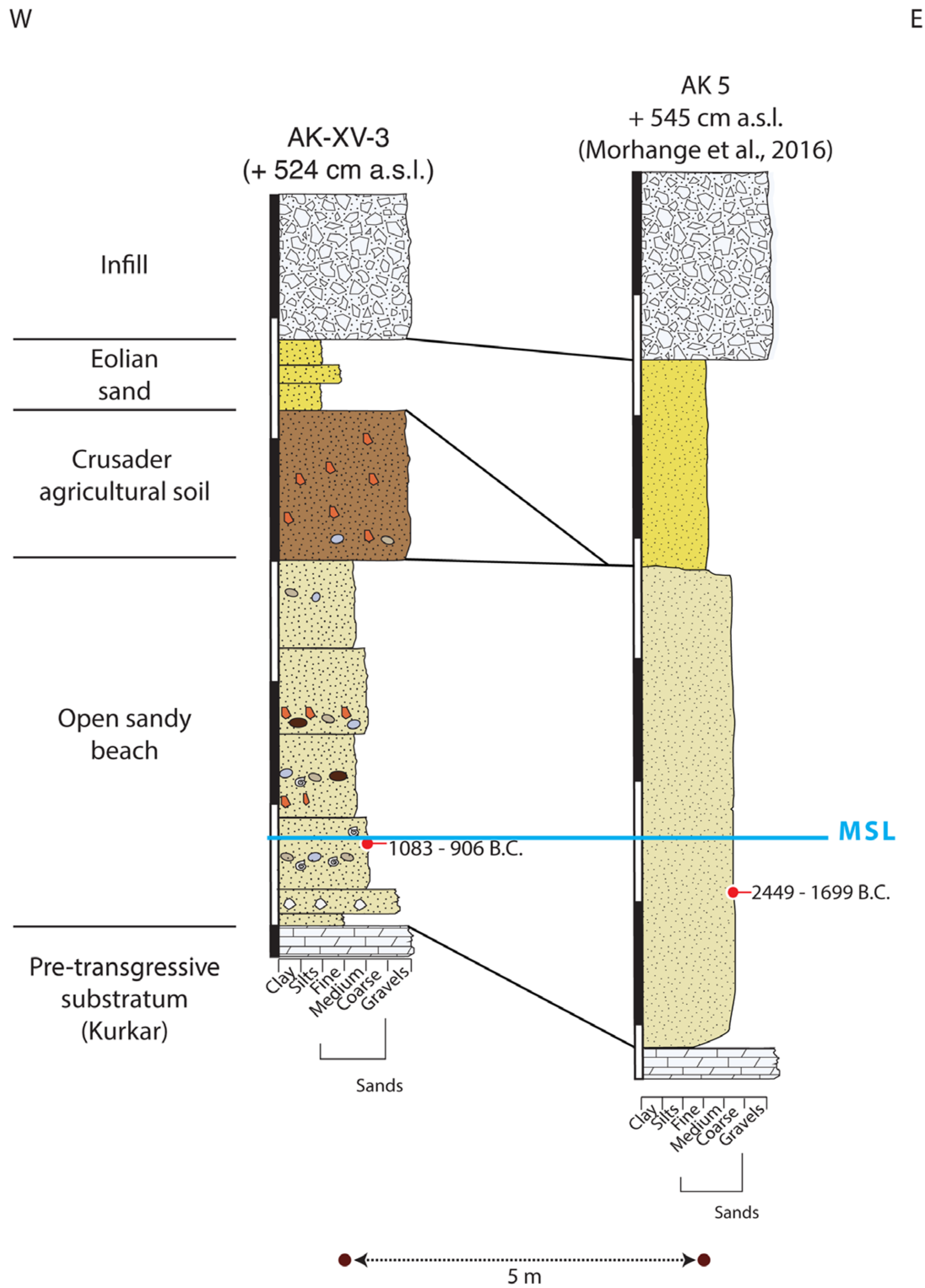

FIGURE 11 East–west transect on the western facade of Tel Akko (Core AK-XV-3; this study and core AK 5 from Morhange et al., 2016)
Notes. The location of the cores is given in Figure 3.
[Color figure can be viewed at wileyonlinelibrary.com]

good mooring conditions in the western basin. This basin was at least 3 m deep, thus enabling the anchoring of medium-sized and even large vessels (Galili & Rosen, 2017).

Our coring shows that the Old City has been in part built on a paleo-marine pocket beach much like other harbor cities of the Levant such as Tyre and Sidon (Marriner & Morhange, 2005). In fact, our work shows that the area situated east of the Khan-al-Oumdan (Core AKKO3) was washed by the sea during the Hellenistic period (360–170 B.C.; Poz-78041; at 135 cm b.s.l.). Even if the ostracod fauna seems to show a sheltered environment due to an increase in the proportion of lagoonal taxa (from 15 to 57% of the total ostracod assemblage), the sediment texture is coarse, composed of sands and pebbles. This coarse facies

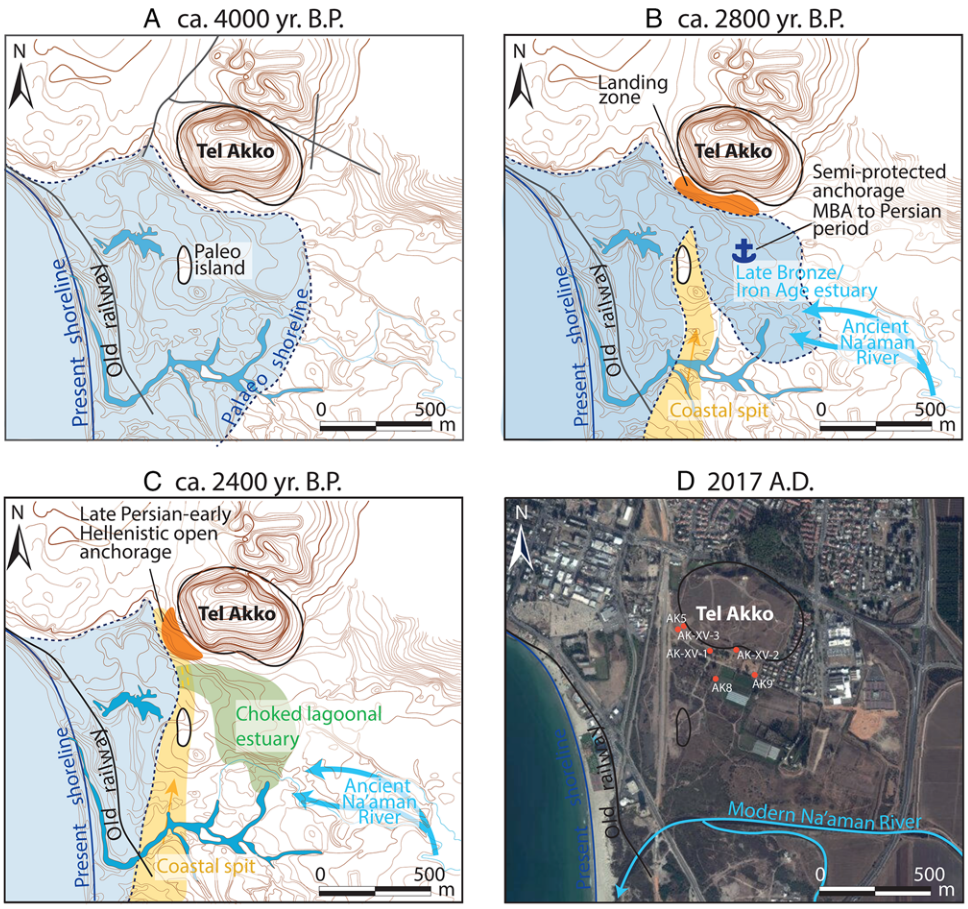

FIGURE 12 Coastline changes and location of Tel Akko's ancient harbors through time (adapted from Morhange et al., 2016)
Notes. Topography adapted from the Treidel map (1925–1926).
[Color figure can be viewed at wileyonlinelibrary.com]

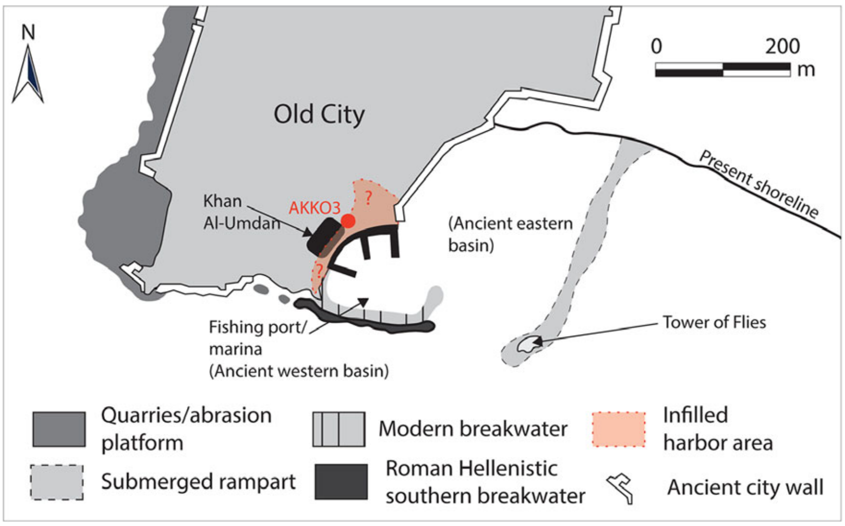

FIGURE 13 Location of ancient structures in the harbor of Akko (after Galili et al., 2010) and possible reconstruction of the harbor limits during the Hellenistic period [Color figure can be viewed at wileyonlinelibrary.com]

contrasts with the fine-grained sediments usually found in protected harbors (Marriner & Morhange, 2006). A recent study suggests that the southern mole was built during the Hellenistic/Early Roman period (Silberstein, Galili, & Sharvit, 2017). We propose that the coarse sediments recorded in our core are not linked to the absence of efficient harbor works, but that grain size could be explained by the location of the core (Figure 13). In effect, the core was probably drilled on the margin of the harbor basin and this unit reflects the sediments of the mid-tidal zone, reworked by the sea in contrast to the bottom of the harbor basin, much better protected (Galili et al., 2010). The effective protection of the harbor that began in Hellenistic times and was reinforced during Roman times is not clear in our core. The Roman period is characterized by a revolution in harbor design linked to the widespread development of hydraulic concrete that enabled the construction of large offshore structures (Brandon, Hohlfelder, Jackson, & Oleson, 2014). The need for a well-protected harbor is important, because Akko harbor was the main Roman sea gate to the land of Israel until the construction of *Caesarea*'s harbor by Herod at the end of the 1st century B.C. Because of the supremacy of the other harbors of Palestine (e.g., *Caesarea Maritima*), the harbor of the Old City of Akko rapidly became less attractive and important. The top of the core represents the harbor abandonment phase. The sediments are coarser, ostracods are very scarce, and the water column of the harbor does not allow the circulation of boats. Modern dredging of the western basin reveals very few artifacts dating to the Early Islamic, Crusader, and Ottoman periods. This suggests that the western basin was partially silted at that time because of poor maintenance (Galili et al., 2010). The larger boats were moored in the eastern basin, probably along wooden piers.

7 | CONCLUSION

Our new cores highlight important landscape changes along the coastal zone of Tel Akko during the last 4,000 years. This important trade city from the early 2nd millennium B.C. onward had two Middle Bronze Age maritime facades: one to the south and one to the west. The southern facade constitutes a better-protected environment linked to the presence of the Na'aman mouth even if the western facade was probably used to pull boats onto the beach. In the Persian period, the southern lagoonal estuary started to be infilled. On the western facade, the presence of buildings linked to harbor activities dated to the Persian period shows that the anchorage situated in the west probably became the main natural anchorage. From the Bronze Age to Early Hellenistic times, the harbors of Tel Akko can be defined as open harbors, much like Byblos in Lebanon (Carayon, Marriner, & Morhange, 2012; Stefaniuk et al., 2005). During Hellenistic times, the tell was abandoned in favor of the lower city of Saint-Jean d'Acre. A core drilled on the promontory shows that since this period, the coastline has prograded several meters in the area of the modern harbor of Akko.

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ENDNOTES

[1] Judges: Le livre des Juges. Chapitre 1. Lagrange M. J. Paris, Lecoffre, 1903. (Available online: https://archive.org./details/LagrangeJuges).

[2] *Isaeus: Discours*. Livre 4. Traduit par Roussel, P. Paris, Les Belles Lettres, 1922, 380 p.

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REFERENCES

Abu Hamid, A. (2012). Akko, the Post Office. *Hadashot Arkheologiyot—Excavations and Surveys in Israel*, *124*, 1–124.

Anthony, E. J. (2009). *Shore processes and their palaeoenvironmental applications*. Amsterdam and Boston, MA: Elsevier.

Anthony, E. J., Marriner, N., & Morhange, C. (2014). Human influence and the changing geomorphology of Mediterranean deltas and coasts over the last 6000 years: From progradation to destruction phase? *Earth Science Reviews*, *139*, 336–361.

Artzy, M. (2006). The Carmel coast during the second part of the Late Bronze Age: A center for eastern Mediterranean transhipping. *Bulletin of the American School of Oriental Research*, *343*, 45–64.

Artzy, M. (2012). Return to Tel Akko, its anchorages, harbour, and surroundings. *Recanati Institute for Maritime Studies Newsletter, University of Haifa*, *37*, 5–14.

Artzy, M. (2015). What is in a name? ‘Akko—Ptolemais— ‘AkkaAcre. *Complutum*, *26*(1), 205–212.

Artzy, M., & Beeri, R. (2010). Tel Akko. In A. E. Killebrew & V. Raz-Romero (Eds.), *One thousand nights and days—Akko through the ages* (pp, 14–23). Haifa, Hecht Museum.

Athersuch, J., Horne, D. J., & Whittaker, J. E. (1989). *Marine and brackish water ostracods (Superfamilies Cypridacea et Cytheracea): Keys et notes for the identification of the species*. Leiden, The Netherlands: E.J. Brill.

Avnaim-Katav, S., Agnon, A., Sivan, D., & Almogi-Labin, A. (2016). Calcareous assemblages of the southeastern Mediterranean low-tide estuaries. *Seasonal dynamics and paleo-environmental implications. Journal of Sea Research*, *108*, 30–49.

Balensi, J. (1985). Revising Tell Abu Hawam. *Bulletin of the American Schools for Oriental Research*, *257*, 65–74.

Balensi, J. (2000). Une île artificielle égypto-cananéenne (Haïfa, Israël). *Le Monde de la Bible*, *128*, 62.

Boaretto, E., Mienis, H. K., & Sivan, D. (2010). Reservoir age based on prebomb shells from the intertidal zone along the coast of Israel. *Nuclear Instruments and Methods in Physics Research*, *268*, 966–968.

Boyd, R., Dalrymple, R. W., & Zaitlin, B. A. (2006). Estuarine and incised-valley facies models. *Special Publication—SEPM*, *84*, 171–235.

Brandon, C. J., Hohlfelder, R. L., Jackson, M. D., & Oleson, J. P. (2014). *Building for eternity: The history and technology of Roman concrete engineering in the sea*. Oxford, England: Oxbow Books.

Carayon, N., Marriner, N., & Morhange, C. (2012). Geoarchaeology of Byblos, Tyre, Sidon and Beirut. *Rivista di studi fenici*, *39*, 55–65.

Coe, A. L.(Ed.) (2003). *The sedimentary record of sea-level change*. Cambridge: Cambridge University Press.

D'Angelo, G., & Garguillo, S. (1978). *Guida alle Conchiglie Mediterranee, conoscerle, cercarle, collezionarle*. Milan: Fabri Editori.

Doneddu, M., & Trainito, E. (2005). *Conchiglie del Mediterraneo. Guida ai molluschi conchigliati*. Cornaredo: Il castello.

Dothan, M. (1976). Akko: Interim excavation report first season 1973/74. *Bulletin of the American Schools of Oriental Research*, *224*, 1–48.

Dothan, M., & Goldmann, Z. (1993). Tell Acco. *The New Encyclopedia of Archaeological Excavations in the Holy Land*, *1*, 17–24.

Dothan, M., & Raban, A. (1980). The sea gate of ancient Akko. *Biblical Archaeologist*, *43*, 35–40.

Frenzel, P., & Boomer, I. (2005). The use of ostracods from marginal marine, brackish waters as bioindicators of modern and quaternary environmental change. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *225*(1), 68–92.

Galili, E., Rosen, B., Stern, E. J., Finkielsztejn, G., Kool, R., Bahat-Zilberstein, N., … Zviely, D. (2007). New insights on Maritime Akko revealed by underwater and coastal archaeological research. *The Israeli Society for Aquatic Sciences, Fourth Annual Meeting*, Haifa University, 64–74.

Galili, E., & Rosen, B. (2017). The Akko Marina Archaeological Project—Summary. In E. Galili (Ed.), *The Akko Marina Archaeological Project* (pp. 320–344). BAR International Series 2862. Oxford, England: BAR Publishing.

Galili, E., Rosen, B., Zviely, D., Silberstein, N., & Finkielsztejn, G. (2010). The evolution of Akko harbour and its Mediterranean maritime trade links. *Journal of Island and Coastal Archaeology*, *5*, 191–211.

Gambash, G. (2014). En route to Egypt: Akko in the Persian Period. *Journal of Near Eastern Studies*, *73*(2), 273–282.

Inman, D. L. (2003). Littoral cells. In M. Schwartz (Ed.), *Encyclopedia of coastal science. The Earth Sciences Encyclopedia Online* (pp. 594–599). Dordrecht, Netherlands: Kluwer Academic Publishers.

Kaniewski, D., Van Campo, E., Morhange, C., Guiot, J., Zviely, D., Shaked, I., … Artzy, M. (2013). Early urban impact on Mediterranean coastal environments. *Scientific Reports*, *3*(3540), 5.

Kaniewski, D., Van Campo, E., Morhange, C., Guiot, J., Zviely, D., Le Burel, S., … Artzy, M. (2014). Vulnerability of Mediterranean ecosystems to long-term changes along the coast of Israel. *PLoS One*, *9*, 7.

Lachenal, A. M. (1989). *Ecologie des ostracodes du domaine méditerranéen: Application au golfe de Gabès (Tunisie orientale): Les variations du niveau marin depuis 30 000 ans*. Documents des Laboratoires de Géologie de Lyon, 108, Lyon.

Linder, E., & Raban, A. (1965). Underwater survey of Akko Harbour. In *The Western Galilee and the Galilee Coast. The 19th Convention for Yediat Haaretz* (pp. 180–193). Jerusalem. (In Hebrew)

Lichter, M., Zviely, D., & Klein, M. (2009). Morphological changes in the last 200 years in the mouth of the Na'aman River, northern coastal plain, Israel. *Journal of Earth Science*, *58*, 63–80.

Marriner, N. (2009). *Geoarchaeology of Lebanon's ancient harbours (*British Archaeological Reports, S1953*)*. Oxford, England: Archaeopress.

Marriner, N., & Morhange, C. (2005). Under the city centre, the ancient harbour. Tyre and Sidon, heritages to preserve. *Journal of Cultural Heritage*, *6*, 183–189.

Marriner, N., & Morhange, C. (2006). The "Ancient Harbour Parasequence": Anthropogenic forcing of the stratigraphic highstand record. *Sedimentary Geology*, *186*, 13–17.

Marriner, N., & Morhange, C. (2007). Geoscience of ancient Mediterranean harbours. *Earth-Science Reviews*, *80*, 137–194.

Meisch, C. (2000). *Frehswater ostracoda of western and central Europe*. Wiesbaden: Spektrum Akademischer Verlag.

Morhange, C., Giaime, M., Marriner, N., Abu Hamid, A., Bruneton, H., Honnorat, H., … Artzy, M. (2016). Geoarchaeological evolution of Tel Akko's ancient harbours (Israel). *Journal of Archaeological Science: Reports*, *7*, 71–81.

Morhange, C., Marriner, N., Blot, M. L., Bony, G., Carayon, N., Carmona, P., Flaux, C., Giaime, M., Goiran, J. P., Kouka, M., Lena, A., Oueslati, A., Pasquinucci, M., Pototov, A. V. (2015). Dynamiques géomorphologiques et typologie géoarchéologique des ports antiques en contextes lagunaires. *Quaternaire*, *26*(2), 117–139.

Morhange, C., Taha, M. H., Marriner, N., & Humbert, J. B. (2005). Human settlement and coastal change in Gaza since the Bronze Age. *Méditerranée*, *104*, 75–78.

Porat, N., Sivan, D., & Zviely, D. (2008). Late Holocene embayment and sedimentological infill processes in Haifa Bay, SE Mediterranean. *Israel Journal of Earth Sciences*, *57*(1), 21–31.

Poppe, G., & Goto, Y. (1991). *European seashells* (Vol. I). Weisbaden: Verlag Christa Hemmen.

Poppe, G., & Goto, Y. (1993). *European seashells* (Vol. II). Hackenheim: ConchBooks.

Raban, A. (1983). The Biblical Port of Akko on Israel's Coast. *Archaeology*, *36*(1), 60–61.

Raban, A. (1985). The ancient harbours of Israel in Biblical times. Harbour Archaeology, Proceedings of the First International Workshop, 11–44.

Raban, A. (1991). The Port City of Akko in the MBII period. *Michmanim*, *5*, 17–34.

Reimer, P. J., & McCormac, F. G. (2002). Marine radiocarbon reservoir corrections for the Mediterranean and Aegean seas. *Radiocarbon*, *44*, 159–166.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., … Van der Plicht, J. (2013). IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal. *B.P. Radiocarbon*, *55*, 1869–1887.

Reinson, G. E. (1992). Transgressive barrier island and estuarine systems. In R. G. Walker & N. P. James (Eds.), *Facies models: Response to sea level change* (pp. 179–194). St. John's, Newfoundland: Geological Association of Canada.

Ruiz, F., González-Regalado, M. L., Baceta, J., & Muñoz, J. M. (2000). Comparative ecological analysis of the ostracod faunas from low-and high-polluted southwestern Spanish estuaries: A multivariate approach. *Marine Micropaleontology*, *40*(4), 345–376.

Salel, T., Bruneton, H., & Lefèvre, D. (2016). Ostracods and environmental variability in lagoons and deltas along the north-western Mediterranean coast (Gulf of Lions, France and Ebro delta, Spain). *Revue de Micropaléontologie*, *59*(4), 425–444.

Silberstein, H., Galili, E., & Sharvit, J. (2017). Hellenistic, Roman and Byzantine ceramics from the Akko Marina. In E. Galili (Ed.), *The Akko Marina archaeological project* (pp. 35–163). BAR International Series 2862. Oxford, England: BAR Publishing.

Sivan, D., & Inbar, M. (1983). Paleo-urban development and late quaternary environmental change in the Akko Area. *Paléorient*, *9*(2), 85–91.

Sivan, D., Gvirtzman, G., & Sass, E. (1999). Quaternary stratigraphy and paleogeography of the Galilee coastal plain, Israel. *Quaternary Research*, *51*(3), 280–294.

Stanley, J. D. (2002). Configuration of the Egypt-to-Canaan coastal margin and north Sinai byway in the Bronze Age. In E. C. M. van den Brink & T. E. Levy (Eds.), *Egypt and the Levant: Interrelations from the 4th through the early 3rd millennium B.C.E.* (pp. 98–117). London: Leicester University Press.

Stanley, J. D., & Bernhardt, C. E. (2010). Alexandria's Eastern Harbor, Egypt: Pollen, microscopic charcoal, and the transition from natural to human-modified basin. *Journal of Coastal Research*, 67–79. https://doi.org/10.2112/JCOASTRES-D-09-00089.1

Stefaniuk, L., Morhange, C., Saghieh-Beydoun, M., Frost, H., Boudagher-Fadel, M., & Noujaim-Clark, G. (2005). Localisation et étude paléoenvironnementale des ports antiques de Byblos. Bulletin d'Archéologie et d'Architecture Libanaises, Hors-Série II, 283–307.

Stuiver, M., & Reimer, P. J. (1993). Extended 14C database and revised CALIB radiocarbon calibration program. *Radiocarbon*, *35*, 215–230.

Tepper, Y. (2010). A Pagan Cemetery from the Roman period at the foot of Tel Akko: Evidence of the burial of Roman soldiers and citizens of Colonia Ptolemais. In A. E. Killebrew & V. Raz-Romeo (Eds.), *One thousand night and days, Akko through the ages* (pp. 33–39). Haifa: Hecht Museum, University of Haifa.

Vachtman, D., Sandler, A., Greenbaum, N., & Herut, B. (2012). Dynamics of suspended sediment delivery to the Eastern Mediterranean continental shelf. *Hydrological Processes*, *27*, 1105–1116.

Zviely, D., Sivan, D., Ecker, A., Bakler, N., Rohrlich, V., Galili, E., … Kit, E. (2006). Holocene evolution of the Haifa Bay area, Israel, and its influence on ancient tell settlements. *Holocene*, *16*(6), 849–861.

Zviely, D., Kit, E., & Klein, M. (2007). Longshore sand transport estimates along the Mediterranean coast of Israel in the Holocene. *Marine Geology*, *237*, 61–73.

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