Geoarchaeology of Sidon's Ancient harbours, Phoenicia

Article *in* Journal of Archaeological Science · February 2006

DOI: 10.1016/j.jas.2006.02.004

ELSEVIER

Journal of Archaeological Science 33 (2006) 1514–1535

Journal of Archaeological SCIENCE

http://www.elsevier.com/locate/jas

Geoarchaeology of Sidon's ancient harbours, Phoenicia

Nick Marriner [a,*], Christophe Morhange [a], Claude Doumet-Serhal [b]

[a] *CNRS CEREGE UMR 6635, Université Aix-Marseille, BP 80 Europôle de l'Arbois, 13545 Aix-en-Provence, France*
[b] *British Museum, LBFNM, 11 Canning Place, London W85 AD, UK*

Received 8 November 2005; received in revised form 2 February 2006; accepted 7 February 2006

Abstract

Geoarchaeological data from Sidon's ancient harbour areas elucidate six evolutionary phases since the Bronze Age. (1) At the time of Sidon's foundation, during the third millennium BC, medium sand facies show the city's northern and southern pocket beaches to have served as proto-harbours for Middle to Late Bronze Age societies. (2) Towards the end of the Late Bronze Age and the Early Iron Age, expanding international trade prompted coastal populations into modifying these natural anchorages. In Sidon's northern harbour, transition from shelly to fine-grained sands is the earliest granulometric manifestation of human coastal modification. The lee of Zire island was also exploited as a deep-water anchorage, or outer harbour, at this time. (3) Although localised sediments evoke developed port infrastructure during the Phoenician and Persian periods, high-resolution reconstruction of the northern harbour's Iron Age history is problematic given repeated dredging practices during the Roman and Byzantine periods. (4) Fine-grained silts and sands in the northern harbour are coeval with advanced Roman engineering works, significantly deforming the coastal landscape. Bio- and lithostratigraphical data attest a leaky lagoon type environment, indicative of a well-protected port. (5) The technological apogee of Sidon's northern harbour is recorded during the late Roman and Byzantine periods, translated stratigraphically by a plastic clays unit and brackish lagoon fauna. (6) A final semi-abandonment phase, comprising coarse sand facies, concurs silting up and a 100–150 m progradation of the port coastline after the seventh century AD. We advance three hypotheses to explain these stratigraphic data, namely cultural, tectonic and tsunamogenic. Finally, our results are compared and contrasted with research undertaken in Sidon's sister harbour, Tyre.

Keywords: Geoarchaeology; Coastal geomorphology; Ancient harbour; Stratigraphy; Phoenicia; Lebanon

---

1. Introduction

The Sidon–Dakerman area chronicles a long history of human occupation stretching back to the Neolithic [67] (see Fig. 1). Canaan's oldest city according to Genesis, the tell occupies a modest rocky promontory that overlooks a partially drowned sandstone ridge and two marine embayments [17]. During the Iron Age, this geomorphological endowment allowed Sidon to evolve into one of Phoenicia's key city-states, producing and transiting wealthy commodities to trading partners in Assyria, Egypt, Cyprus and the Aegean. This trading ascendancy is corroborated by the Old Testament's use of the term Sidonian to encapsulate all Phoenicians. Sidon enjoyed its apogee during the sixth to fifth centuries BC, at which time it superseded Tyre as Phoenicia's principal naval base.

Although Sidon has a long history of archaeological research [13–15,20–24,64] the ancient city had, until very recently, never been systematically explored. In light of the difficult geopolitical context, it was only in 1998 that the Lebanese Directorate General of Antiquities authorised the British Museum to begin systematic excavations of the ancient tell [16]. Seven years on, a continuous stratigraphy spanning the third millennium BC through to the Iron Age has been established for the city [17].

2. Research aims

In tandem with the terrestrial excavations, 15 cores were drilled in and around Sidon's ancient port areas, with three

---

* Corresponding author. Tel.: +33 4 4297 1584; fax: +33 4 4297 1549.
E-mail address: nick.marriner@wanadoo.fr (N. Marriner).

0305-4403/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jas.2006.02.004

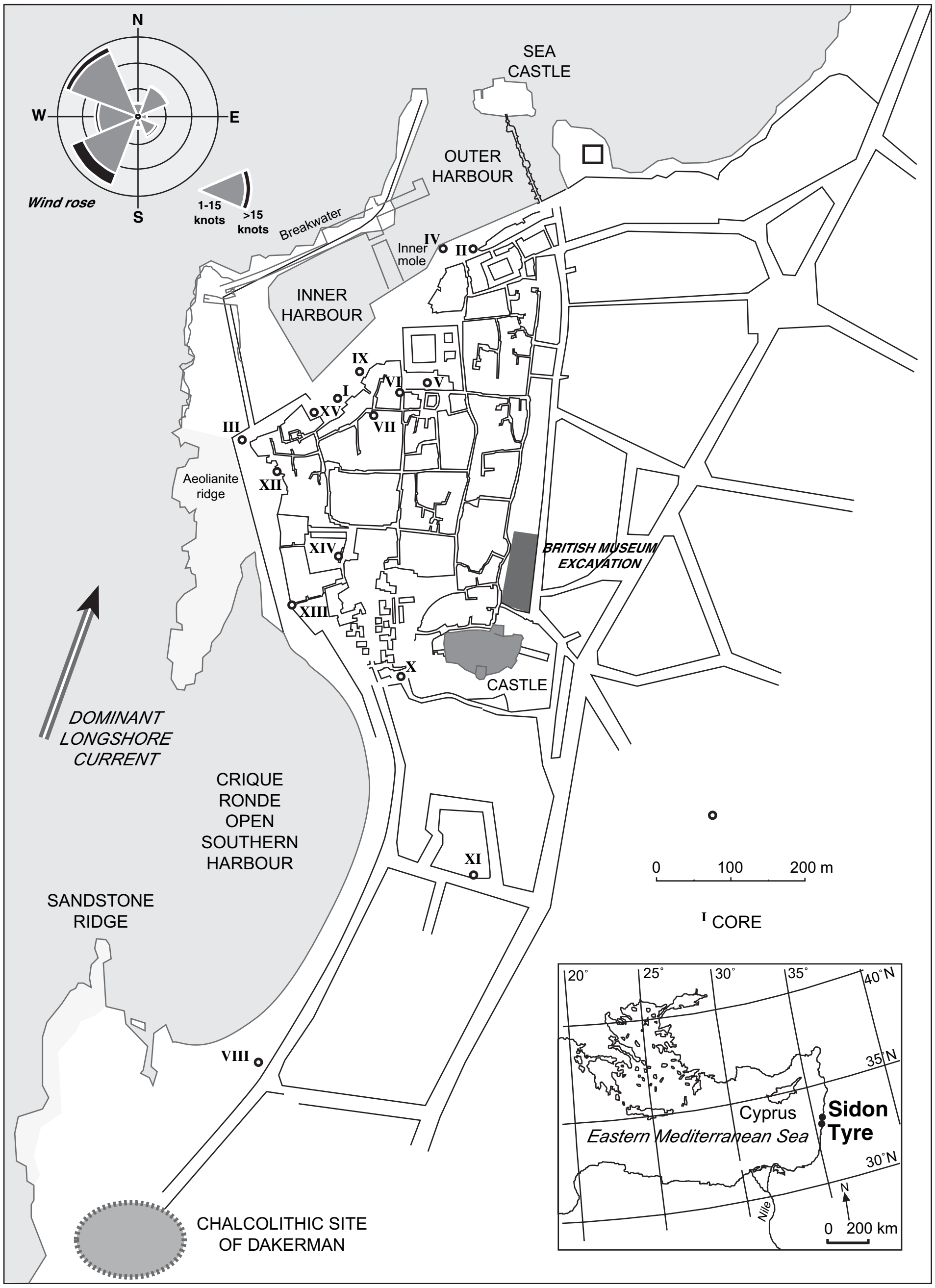


Fig. 1. Sidon's ancient harbour areas and location of cores.

main objectives: (1) to elucidate the evolution of the city's maritime façade and investigate its coastal palaeogeography [26,49]; (2) to compare and contrast these data with Sidon's sister harbour, Tyre [45,47]; and (3) to investigate human coastal impacts, and more specifically the problem of accelerated coastal sedimentation. Silting of the Mediterranean's ancient ports is a recurrent theme in coastal geoarchaeology, playing a significant role in littoral progradation and human exploitation of the anchorages [3,4,50,58,59]. Ancient societies strived permanently with the silting problem, and indeed in areas of high sediment supply it was a constant endeavour to maintain a viable draught depth [46]. From a geoarchaeological standpoint, the silting provides a multiplicity of research possibilities, not least because the fine-grained sediments and high water table anoxically preserve otherwise perishable artefacts, but also the port sediments are a high-resolution sedimentary archive, recording much of the site's maritime and occupation histories.

3. Geomorphological context of Sidon's maritime façade

Sidon's coastal plain runs from the Litani river in the south, northwards towards the Awali (Fig. 2). This low-lying topography, up to 2 km wide in places, comprises a rectilinear

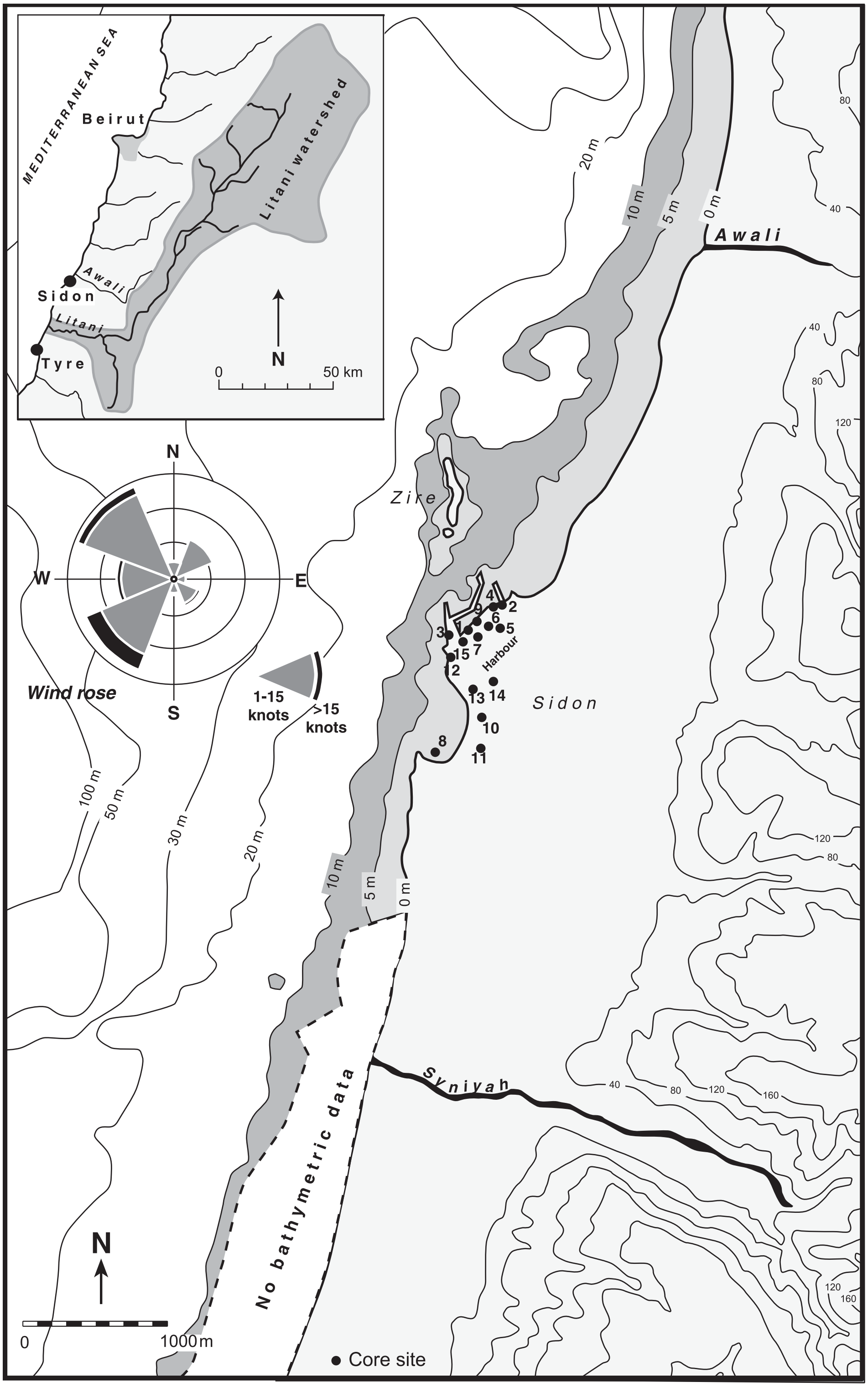


Fig. 2. Sidon's coastal bathymetry.

coastline. In the Sidon area, a series of faults has oriented the valleys and talwegs NW–SE [18,19,69]. The most important regional watercourses include the Litani, with headwaters in the Beqaa valley, and the Awali, which flows from the Jurassic anticlinal of Barouk-Niha. These watercourses alone transit ~$280 \times 10^6/\mathrm{m}^3$ and $130 \times 10^6/\mathrm{m}^3$ of sediment per year.

Sidon's coastal physiography makes it an ideal location for the establishment of three natural anchorage havens. Two pocket beaches lie leeward of a Quaternary sandstone ridge, partially drowned by the Holocene marine transgression (Fig. 3). To the south of the ancient city this ridge has been breached by the sea to form a large semi-circular embayment.

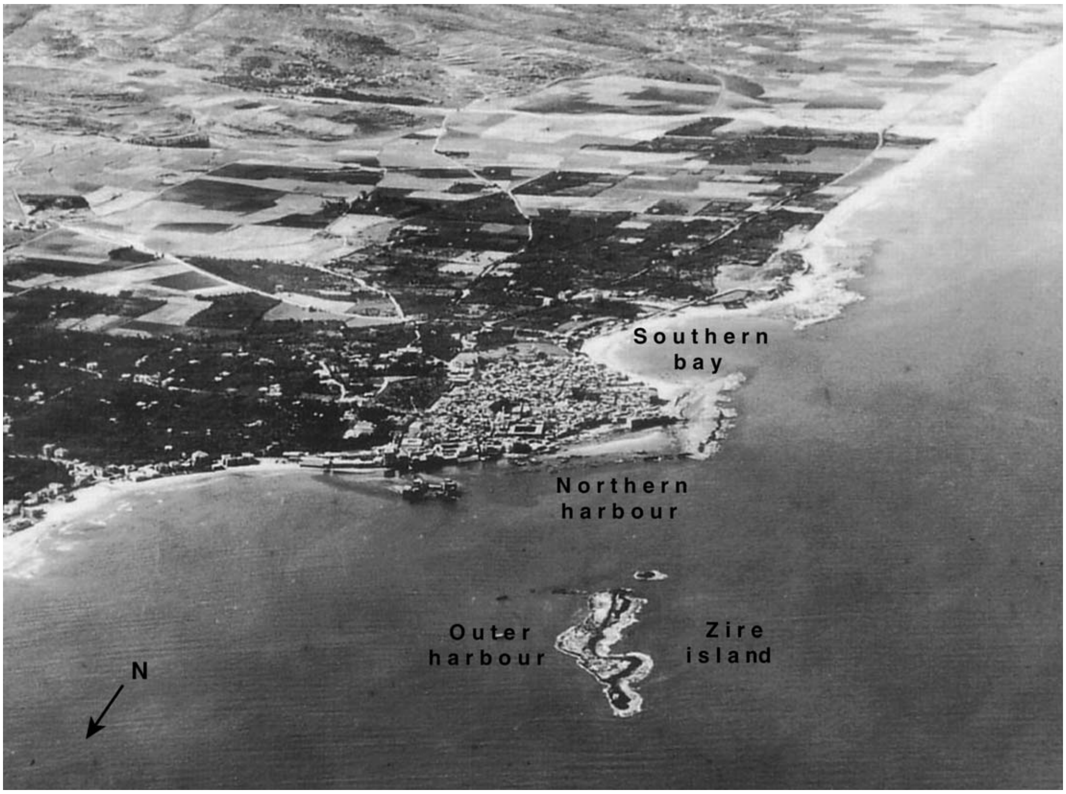


Fig. 3. Sidon and Zire (from [31]). In the foreground, Sidon's outer harbour lies in the shadow zone of Zire island. The promontory of Sidon separates two coves, the northern harbour and Poidebard's *Crique Ronde*.

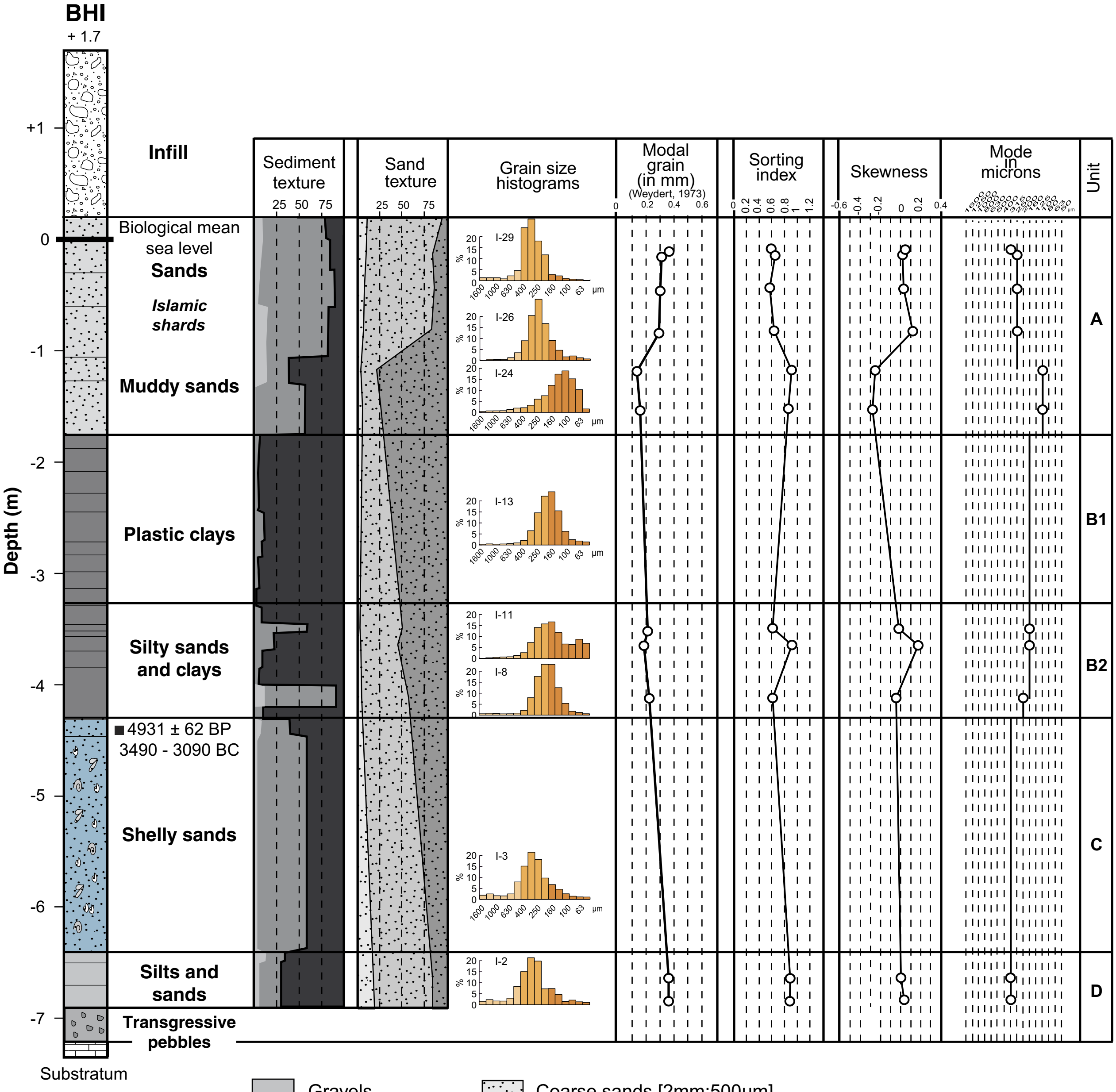
Named the Egyptian harbour by Renan [64] and later the *Crique Ronde* by Poidebard and Lauffray [57], this coastal zone presently comprises a sandy beach. Whether or not it was ever artificially protected by harbourworks has never been unequivocally demonstrated [57], a question we elucidate later in this paper.

North-west of the promontory lies a second bay, protected from the open sea by a prominent sandstone ridge. Five hundred and eighty meters in length, this coastal ridge shields a shallow basin still used to this day; a Medieval sea castle, built upon a small islet, closes the northern portion of the basin. This northern harbour, the centre of Sidon's economic and military activity in antiquity, is mentioned for the first time by Pseudo-Scylax who describes it as a closed harbour. Much of Poidebard and Lauffray's work was centred around this area where they identified a series of juxtaposed harbourworks. From their research emerged the vestiges of a closed ancient port comprising: (1) a reinforced sandstone ridge; and (2) an artificial inner harbour mole, perpendicular to the ridge, and separating two basins.

A third harbour area, the offshore island of Zire, is a unique feature of the Sidonian coastline (Fig. 3). First described by Renan [64], it was not until the work of Poidebard and Lauffray [57] that a preliminary plan of the island, with its quarries and harbourworks, was drawn up. They identified a double seawall sheltering a series of quarries and harbour quays on its leeward side. In 1973, underwater surveys by Honor Frost complemented her predecessors' work, uncovering a collapsed jetty and numerous scattered masonary blocks on the sea bottom in proximity to the island [29]. She concluded that the island had not only served as a quarry and harbour but also supported a number of constructions. Carayon [11] undertook the most recent archaeological work of note, in which he describes six quarry zones, detailing the cartography of Poidebard and Lauffray [57]. During our field investigations we surveyed and dated an uplifted marine notch (+50 cm) on these quarry faces, pertaining to a short-lived sea-level oscillation around 2210 ± 50 BP [44]. These data are in contrast with Tyre, where submergence of ∼3 m is recorded since late antiquity by coastal stratigraphy, submerged urban quarters and harbourworks [25,45,47].

4. Methods and data acquisition

A series of 15 cores was drilled around the two marine embayments (Figs. 1 and 2). Mechanised corers, with 200 cm by 10 cm chambers, were deployed to investigate the coastal stratigraphy and accurately reconstruct the evolution of the ancient city's maritime façade over the past 6000 years. All cores were GPS levelled (±10 cm) and benchmarked relative to present biological sea level (i.e. the summit of the subtidal zone, ±5 cm [40]). These data derive from the upper limit of contemporary *Balanus* populations living on the modern harbour quay faces [40].



- ▨ Gravels
- ▨ Sands
- ■ Silts and clays
- ▨ Coarse sands [2mm;500µm]
- ▨ Medium sands [500µm;200µm]
- ▨ Fine sands [200µm;50µm]

Fig. 4. Sedimentology of core BH I (northern harbour).

In-depth discussion of the techniques employed can be reviewed in Marriner et al. [45]. These include multi-proxy litho- (sedimentology and grain size analyses) and biostratigraphical (marine molluscan faunas and ostracods) lines of investigation. The robustness of such techniques to reconcile complex geoarchaeological questions has been demonstrated at a number of sites around the circum Mediterranean [10,39,48,63]. Radiocarbon datings provide a working chronostratigraphic framework. Material included marine shells, wood fragments, charcoal and seeds, calibrated using the Oxcal program (see Table 1). All marine material has been corrected for reservoir effects.

5. Results

Detailed descriptions of the litho- and biostratigraphical data from Sidon's closed northern harbour and the *Crique Ronde* follows.

5.1. Northern harbour facies

5.1.1. Unit D—Transgressive contact

Unit D comprises a marine pebble unit which overlies the sandstone substratum and marks the Holocene marine transgression of the harbour area (Figs. 4, 7 and 10). Many of the

Table 1
Radiocarbon determinations and calibration

Sample	Depth below MSL	Lab code	Material dated	13C/12C (‰)	14C BP	±	Cal. BP	Cal. BC/AD
BH I 6	437.5	Ly-9470	Marine shells	1.9	4931	62	5440–5040	3490–3090 BC
BHIX 8	167.5	Lyon-1798 (GrA 20857)	Marine shells	est 0	2370	50	2130–1860	180 BC–90 AD
BHIX 10	157.5	Lyon-1879 (Poz 998)	Marine shells	−2.26	2285	35	2000–1800	50 BC–150 AD
BHIX 24	86.5	Lyon-1878 (Poz 1016)	Marine shells	−0.35	2350	35	2090–1870	140 BC–80 AD
BHIX 36	236.5	Lyon-1796 (GrA 20859)	Marine shells	−1.61	2340	80	2180–1750	230 BC–200 AD
BHIX 35	273	Lyon-1797 (GrA 20858)	Marine shells	est 0	2240	60	1990–1690	40 BC–260 AD
BHIX 44	402.5	Lyon-1876 (Poz 1004)	Marine shells	1.37	3640	50	3680–3400	1730–1450 BC
BHIX 47	477.5	Lyon-1877 (Poz 1002)	Marine shells	1.58	4410	40	4720–4420	2770–2470 BC
BH VIII 6	350	Lyon-1799 (GrA 20809)	Marine shells	1.88	4220	50	4450–4140	2500–2190 BC
BH VIII 10	472.5	Lyon-1728 (OxA)	Marine shells	1.16	4060	40	4230–3960	2280–2010 BC
BH VIII 14	737.5	Lyon-1729 (OxA)	Marine shells	3.57	5955	45	6470–6270	4520–4320 BC
BH VIII 16	780	Lyon-1730 (OxA)	Marine shells	1.11	6030	45	6580–6310	4630–4360 BC
BH XV 3	161	Poz-13012	1 *Venerupis rhomboides*	−1.9	2255	35	1970–1760	20 BC–190 AD
BH XV 12	247.5	Poz-13374	2 grape seeds	−27.3	2515	30	2740–2480	790–530 BC
BH XV 17	315	Poz-13375	Charcoal	−29.5	3385	35	3720–3550	1770–1600 BC
BH XV 24	367.5	Poz-13013	1 *Nassarius reticulatus*	4.4	3670	40	3690–3450	1740–1500 BC
BH XV 28	425	Poz-13006	2 *Glycymeris glycymeris* (juvs.), 1 *Lucinella divaricata*	8	4840	40	5280–5000	3330–3050 BC
BH XV 31	555	Poz-13007	5 *Bittium reticulatum*	−3.6	5180	50	5650–5430	3700–3480 BC

pebbles are encrusted with marine fauna such as *Serpulae*. In core BH I, this grades into a silty sand with a medium sorting index of 0.88.

5.1.2. Unit C2—Pocket beach/proto-harbour

Unit C2 is characterised by a shelly sand unit, with poor sorting indices (1.17–1.27) and sand modal values of 250–200 μm. The sedimentological data concur a middle energy beach environment. In core BH IX, the bottom of the unit is constrained to 4410 ± 40 BP (2750–2480 cal. BC). Two *Loripes lacteus* shells from unit C of BH I yielded a radiocarbon age of 4931 ± 62 BP (3475–3070 cal. BC). Molluscan taxa from the following assemblages are attributed to this unit (Figs. 5, 8 and 11): subtidal sands assemblage (*Bulla striata* and

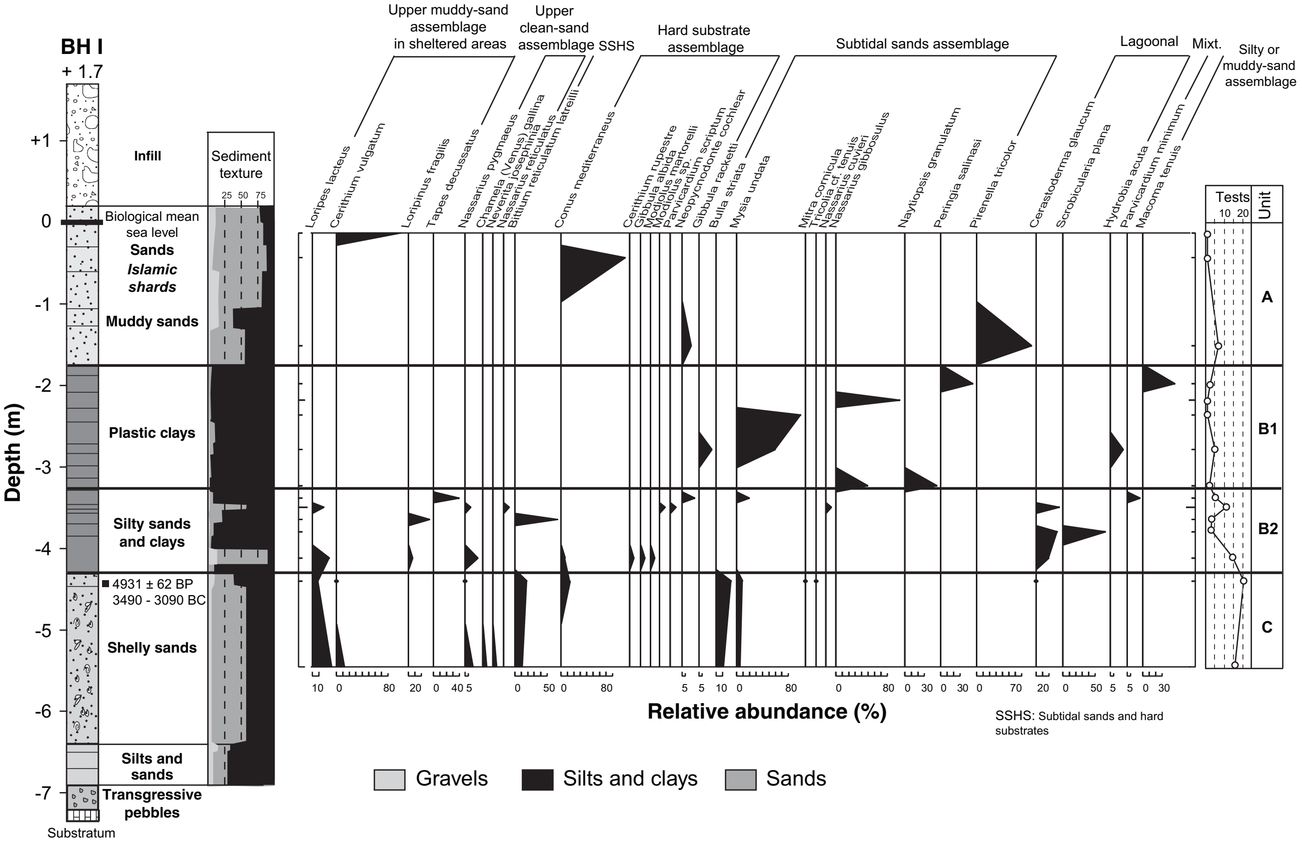


Fig. 5. Molluscan macrofauna from core BH I (northern harbour).

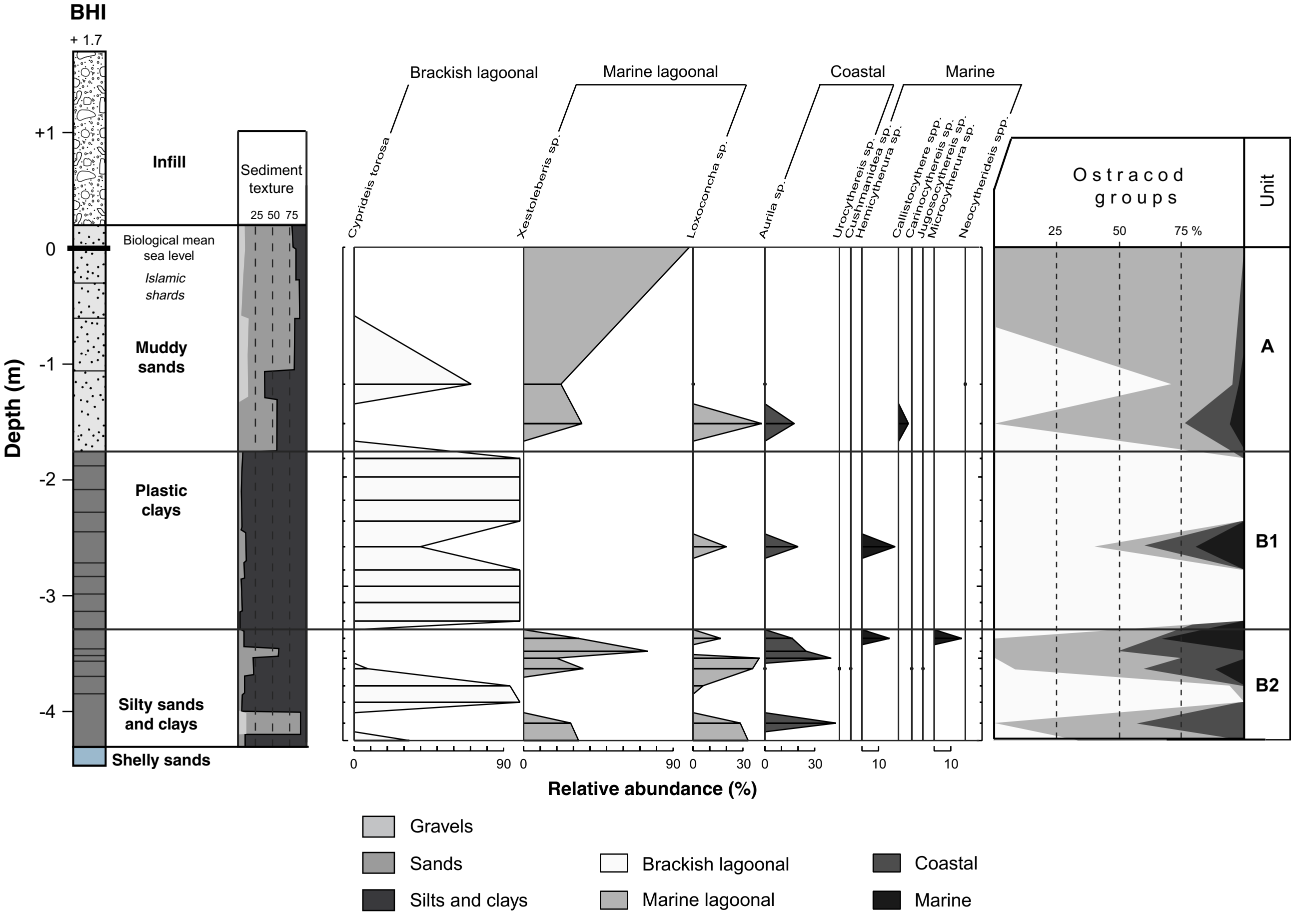


Fig. 6. Ostracod microfauna from core BH I (northern harbour).

Mysia undata), upper clean-sand assemblage (*Smaragdia viridis*, *Nassarius pygmaeus, Neverita josephinia*, and *Chamela gallina*) and the upper muddy-sand assemblage in sheltered areas (*Loripes lacteus* and *Cerithium vulgatum*). The ostracod fauna comprises taxa from the marine lagoonal (*Loxoconcha* sp. and *Xestoleberis* spp.) and coastal (*Aurila* spp., *Urocythereis* sp. and *Heterocythereis albomaculata*) domains with some marine taxa being drifted in (Figs. 6, 9 and 12). These biostratigraphic data are analogous to a pocket beach, sheltered by the sandstone ridge.

5.1.3. Unit C1—Artificial Bronze Age cove

A fall in energy dynamics is translated by a rise in the silts fraction (up to 59%). Medium sands dominate, with a well to medium sorted sediment. In BH IX, the base of the unit is constrained to 3640 ± 50 BP (1730–1450 cal. BC), a date confirmed by data from BH XV (3670 ± 40 BP or 1740–1500 cal. BC). We interpret this unit as corresponding to the Middle Bronze Age to Late Bronze Age proto-harbour, with possible reinforcement of the sandstone ridge improving the anchorage quality. Small boats would have been hauled onto the beach face, with larger vessels being anchored in the embayment. Molluscan taxa include tests from the subtidal muds assemblage (*Odostomia conoidea* and *Haminœa navicula*), subtidal sands assemblage (*Tricolia pullus*, *Mitra ebenus*, *Rissoa dolium*, *Bela ginnania* and *Mitra cornicula*), upper muddy-sand assemblage in sheltered areas (*Loripinus fragilis*, *Nassarius corniculus* and *Cerithium vulgatum*), upper clean-sand assemblage (*Nassarius reticulatus*) and the silty or muddy-sand assemblage (*Glycymeris glycymeris*). The ostracod data evince continued domination of marine lagoonal and coastal taxa, with a rise in the brackish lagoonal taxon, *Cyprideis torosa*, towards the top of the unit in BH IX. These all corroborate a semi-sheltered environment that served as a proto-harbour during the Bronze Age [30,62].

5.1.4. Unit B2—Closed Phoenician to Roman harbours

In unit B2, there is a net change in sedimentary conditions with a marked shift to silts and fine grained sands. Modal grain size values of 200–160 µm for the sand fraction and medium sorting indices are concomitant with a low energy environment. Dominant molluscan groups include the lagoonal assemblage (*Cerastoderma glaucum*, *Parvicardium exiguum* and *Scrobicularia plana*), the upper clean-sand assemblage (*Nassarius louisi* and *Nassarius pygmaeus*) and the upper muddy-sand assemblage in sheltered areas (*Gastrana fragilis*). Rise in lagoonal taxa is in compliance with anthropogenic sheltering of the environment by harbourworks. Ostracod fauna is poor, with less than 50 tests per 10 g of sand, and dominated by taxa from the brackish lagoonal (*Cyprideis*

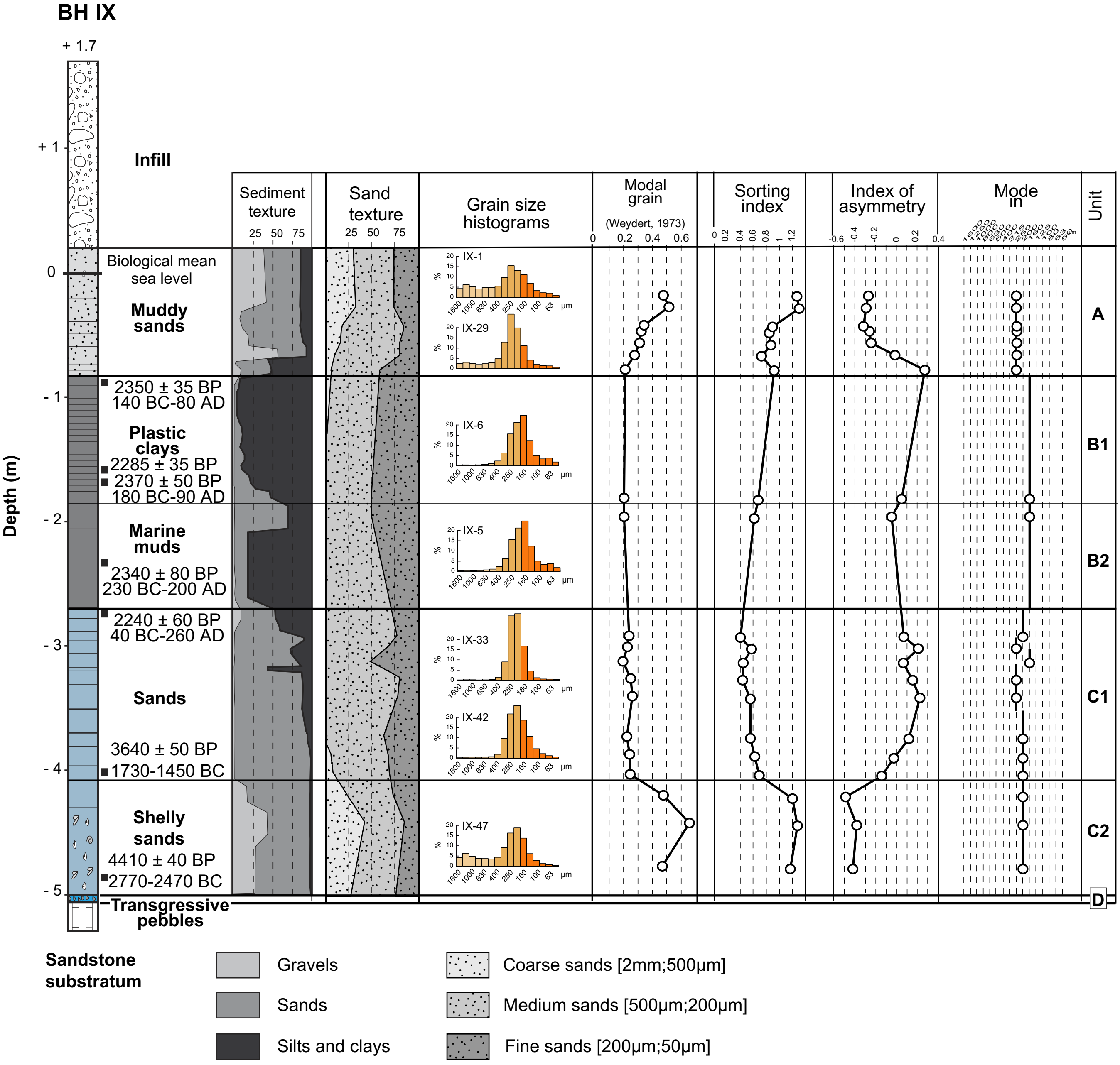


Fig. 7. Sedimentology of core BH IX (northern harbour).

torosa) and marine lagoonal (*Xestoloberis* sp. and *Loxoconcha* sp.) ecological groups, all indicative of a protected environment. In BH XV, peaks of *Aurila convexa* are concomitant with a proximal shoreface. Drifted-in valves of marine taxa (*Semicytherura* sp., *Microcytherura* sp. and *Hemicytherura* sp.) attest continued connection with the open sea and offshore marine dynamics. In cores BH IX and BH XV, radiocarbon dates constrain the chronology of the unit to 2515 ± 30 (790–530 cal. BC) and 2340 ± 80 BP (230 cal. BC–200 cal. AD), or the Phoenician/Persian to Roman periods. The lower foundation courses of Zire Island's jetties have also been dated to the Persian period [11,31]. Persistent age-depth anomalies concur analogous data in Tyre's ancient harbour, where strong chronostratigraphic evidence for dredging has been detailed from the Roman period onwards.

5.1.5. Unit B1—Closed late Roman and early Byzantine harbours

Accentuation of these low energy conditions is manifested in unit B1 by a plastic clays unit. Throughout much of this facies, the silts and clays fraction comprise >90% of the aggregate sediment. Radiocarbon ages are often stratigraphically incoherent for this unit. Lagoonal (*Cerastoderma glaucum* and *Parvicardium exiguum*) and upper muddy-sand assemblage in sheltered areas taxa (*Cerithium vulgatum*, *Venerupis rhomboides*, *Loripes lacteus* and *Macoma cumana*) continue

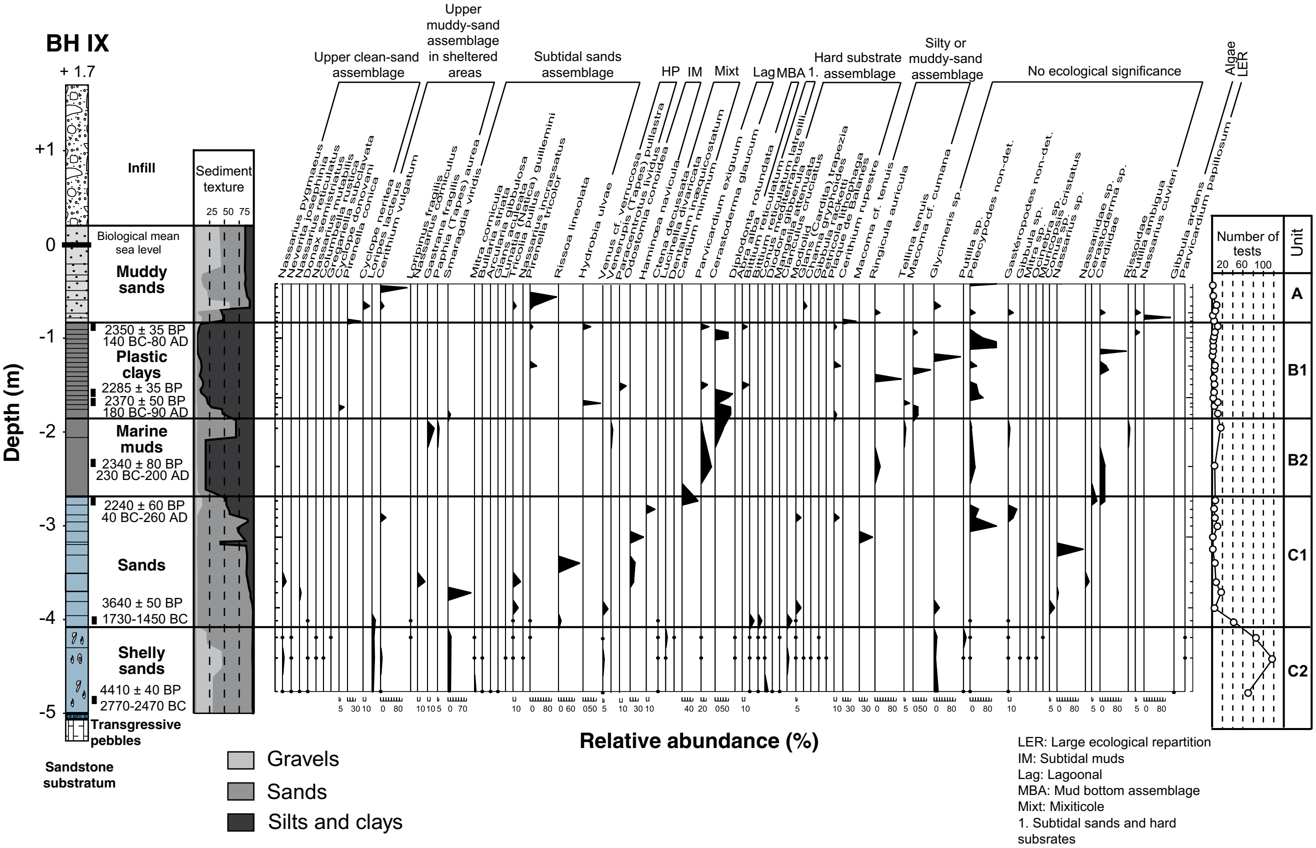


Fig. 8. Molluscan macrofauna from core BH IX (northern harbour).

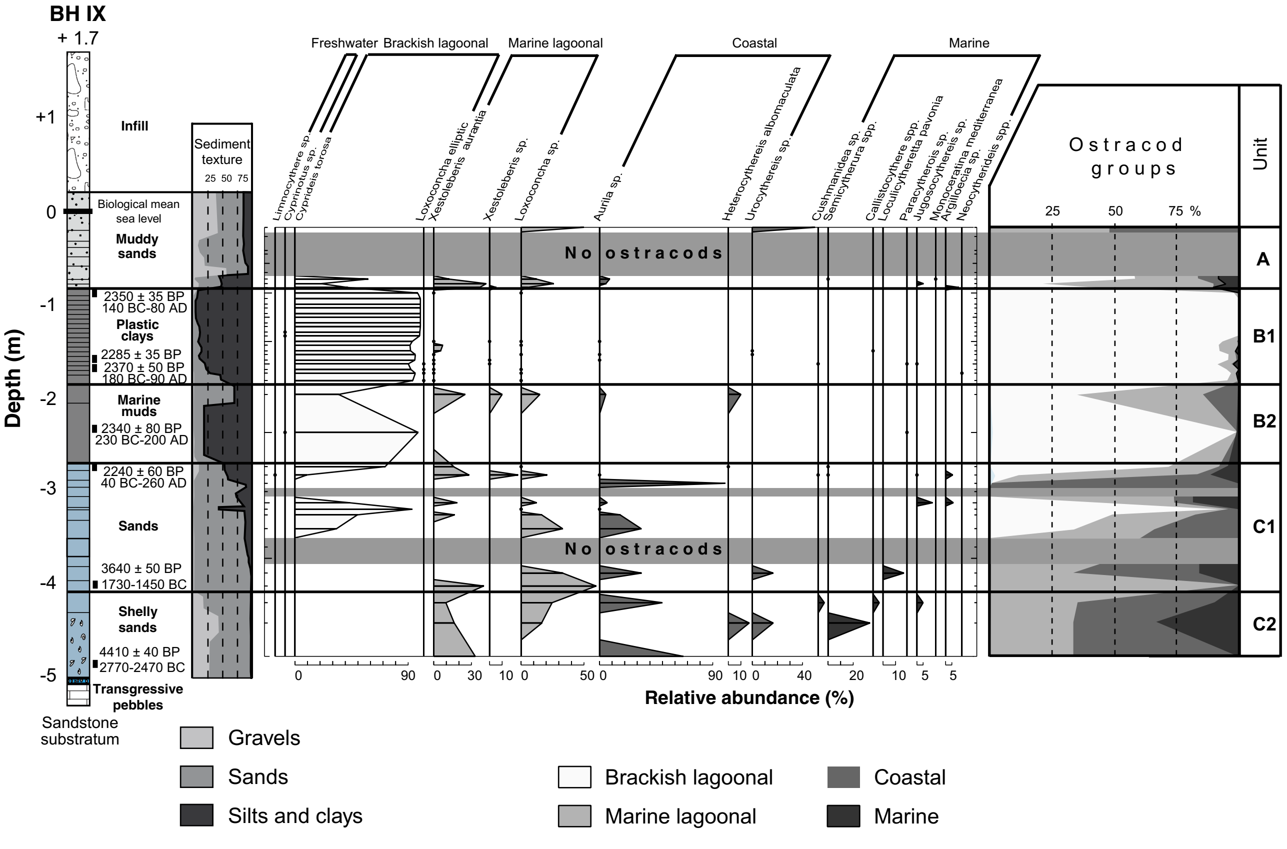


Fig. 9. Ostracod microfauna from core BH IX (northern harbour).

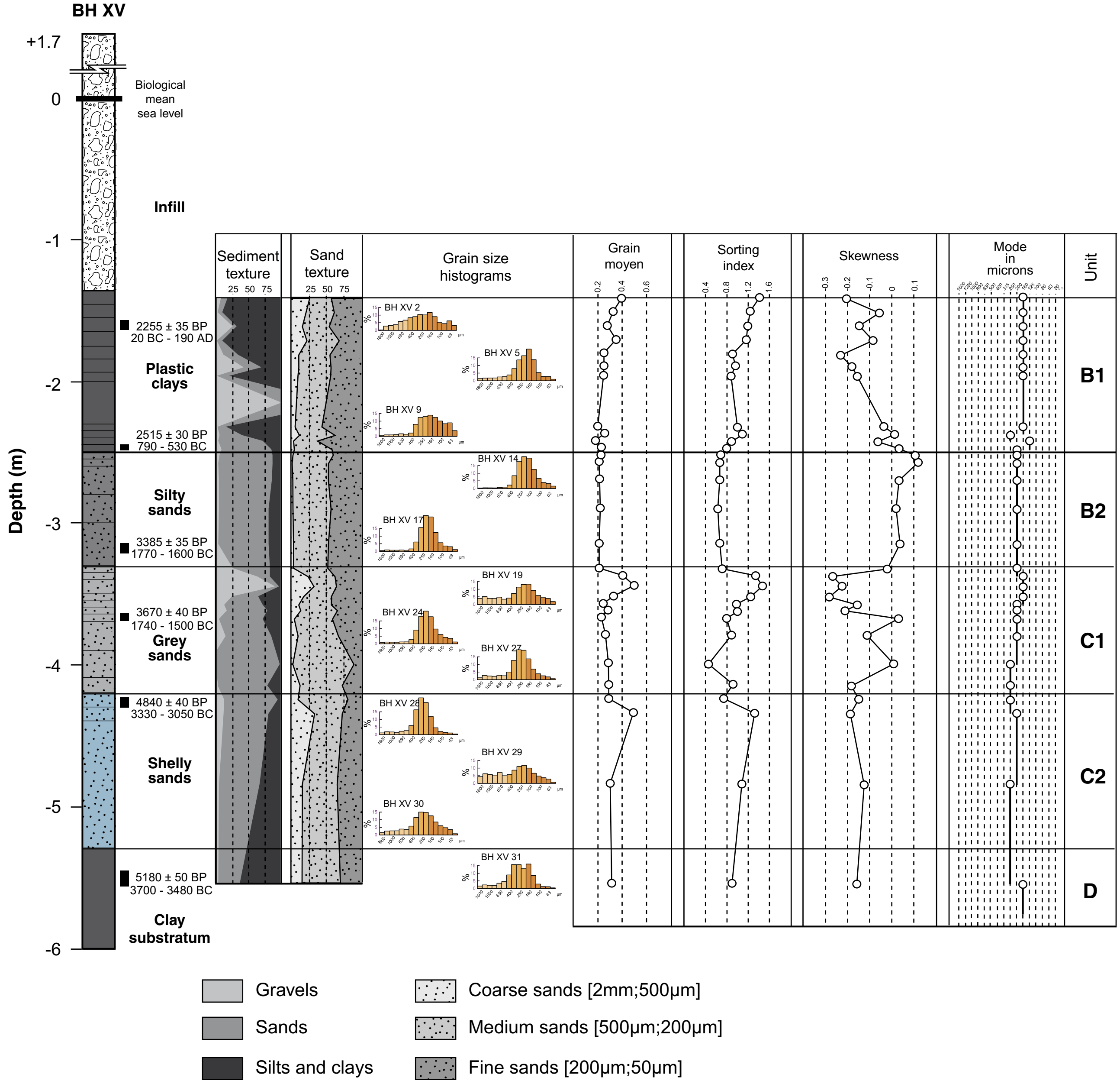


Fig. 10. Sedimentology of core BH XV (northern harbour).

to characterise the in situ taxa, attesting confined harbour conditions. Quasi-dominance of *Cyprideis torosa*, with a rich faunal density, indicates an extremely sheltered, lagoon-like harbour during the late Roman and early Byzantine periods.

5.1.6. Unit A—Exposed Islamic harbour

The base of unit A is marked by a sudden rise in the sands fraction to the detriment of the silts and clays. The relative abundance of the gravels and sands fractions gradually increases up the unit. Ceramics constrain this facies to the Islamic period. A shift from lower energy modal sand values at the base (100 μm) to middle energy values (up to 315 μm) at the top, could substantiate a gradual demise in harbour maintenance. Biostratigraphic data affirm a reopening of the environment to the influence of offshore marine dynamics, with taxa from the subtidal sands assemblage, the hard substrate assemblage and the upper muddy-sand assemblage. The ostracod suites manifest an increase in marine lagoonal (*Loxoconcha* sp. and *Xestoleberis* sp.) and coastal taxa (*Aurila* spp.) to the detriment of *Cyprideis torosa*. We posit that this could correspond to the gradual demise of Sidon as a commercial centre during the Islamic period.

5.2. Southern cove facies

5.2.1. Unit C—Holocene transgression

The sandstone substratum is overlain by a thin pebbly sand unit, dated 6030 ± 45 BP (4630–4360 BC) and marking the

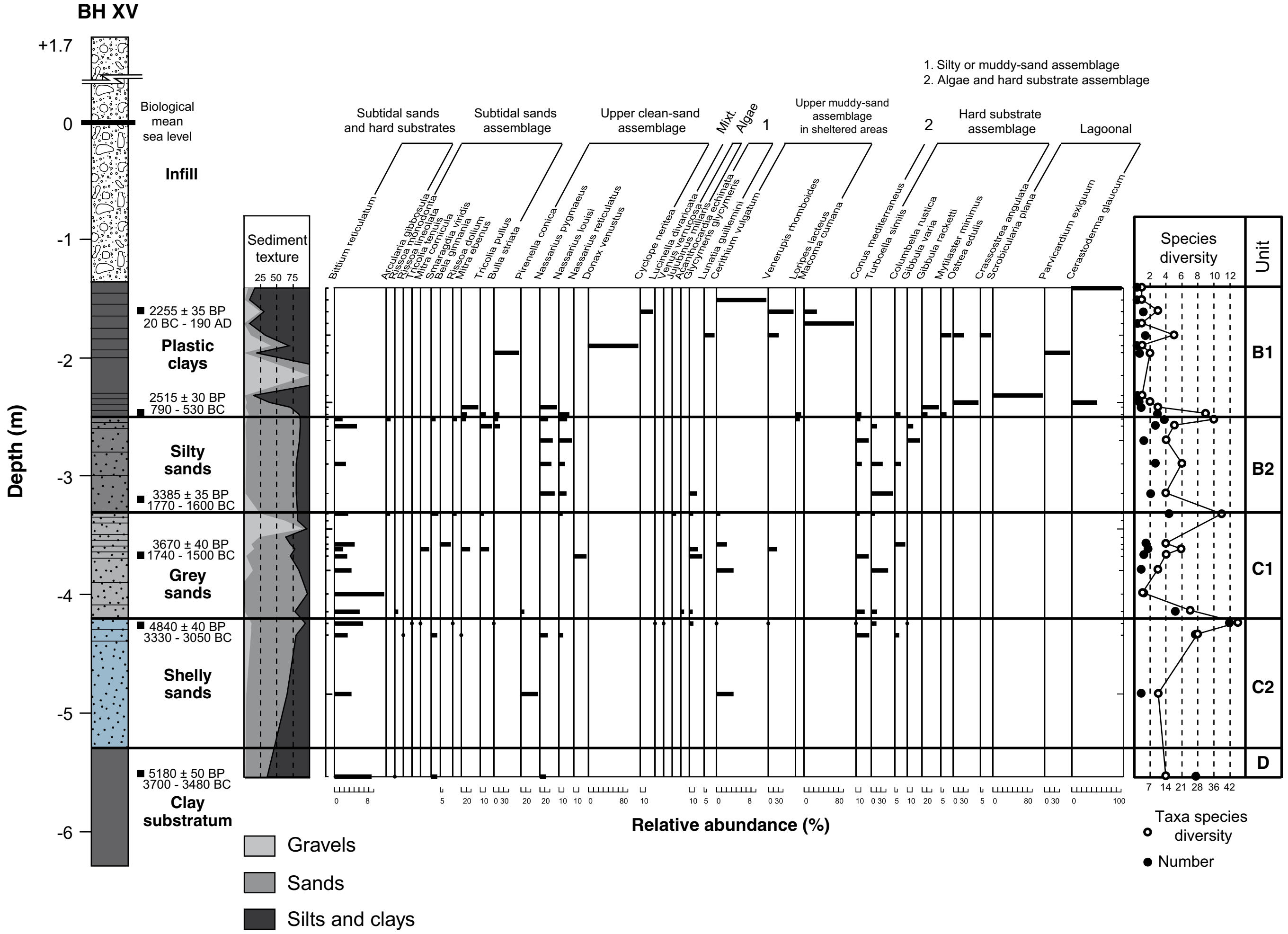


Fig. 11. Molluscan macrofauna from core BH XV (northern harbour).

Holocene marine transgression of the cove (Fig. 13). This subsequently grades into a coarse shelly sand fraction, constrained to 5955 ± 45 BP (4520–4320 cal. BC) and typical of the subtidal zone. *Bittium* spp., analogous of subtidal sands, characterises the molluscan fauna (Fig. 14). *Loxoconcha* spp. and *Xestoleberis aurantia* dominate the ostracoda and concur a shallow water marine embayment (Fig. 15).

5.2.2. Unit B—Bronze Age pocket beach

The onset of unit B postdates 5955 ± 45 BP, and comprises a medium to fine-grained sand unit. Sample BH VIII 10 yielded a radiocarbon age of 4060 ± 40 BP (2280–2010 cal. BC). The molluscan fauna is diverse with tests from a range of ecological contexts including subtidal sands, upper muddy-sand assemblage in sheltered areas, upper clean-sand assemblage, silty or muddy-sand assemblage and the lagoonal assemblage. Marine lagoonal ostracod taxa persist into the unit, and are accompanied by a gradual rise in coastal taxa (*Aurila* spp., *Urocythereis* spp. and *Cushmanidea elongata*). Sporadic tests of marine species indicate continued communication with the open sea.

5.2.3. Unit A—Prograding shoreline

Unit A comprises a shelly sands unit. An important rise in the gravels fraction (21–40%), and the much coarser nature of the sands is concomitant with a prograding shoreline. The molluscan fauna is poor and essentially comprises badly preserved tests and shell debris, reworked by the action of the swash. The higher energy dynamics of the swash zone were not conducive to ostracod test preservation.

6. Discussion

6.1. Chronostratigraphy: ancient harbour technology translated using sediment archives

Our geoarchaeological datasets elucidate a complex history of coastal change and human occupation. Investigation of the coastal archives has expounded understanding of Sidon's maritime history between the Bronze Age and Medieval periods. Multidisciplinary investigations demonstrate that harbour management advances are clearly translated by distinctive sedimentary facies and faunal suites. The sedimentary history of the harbour details six periods.

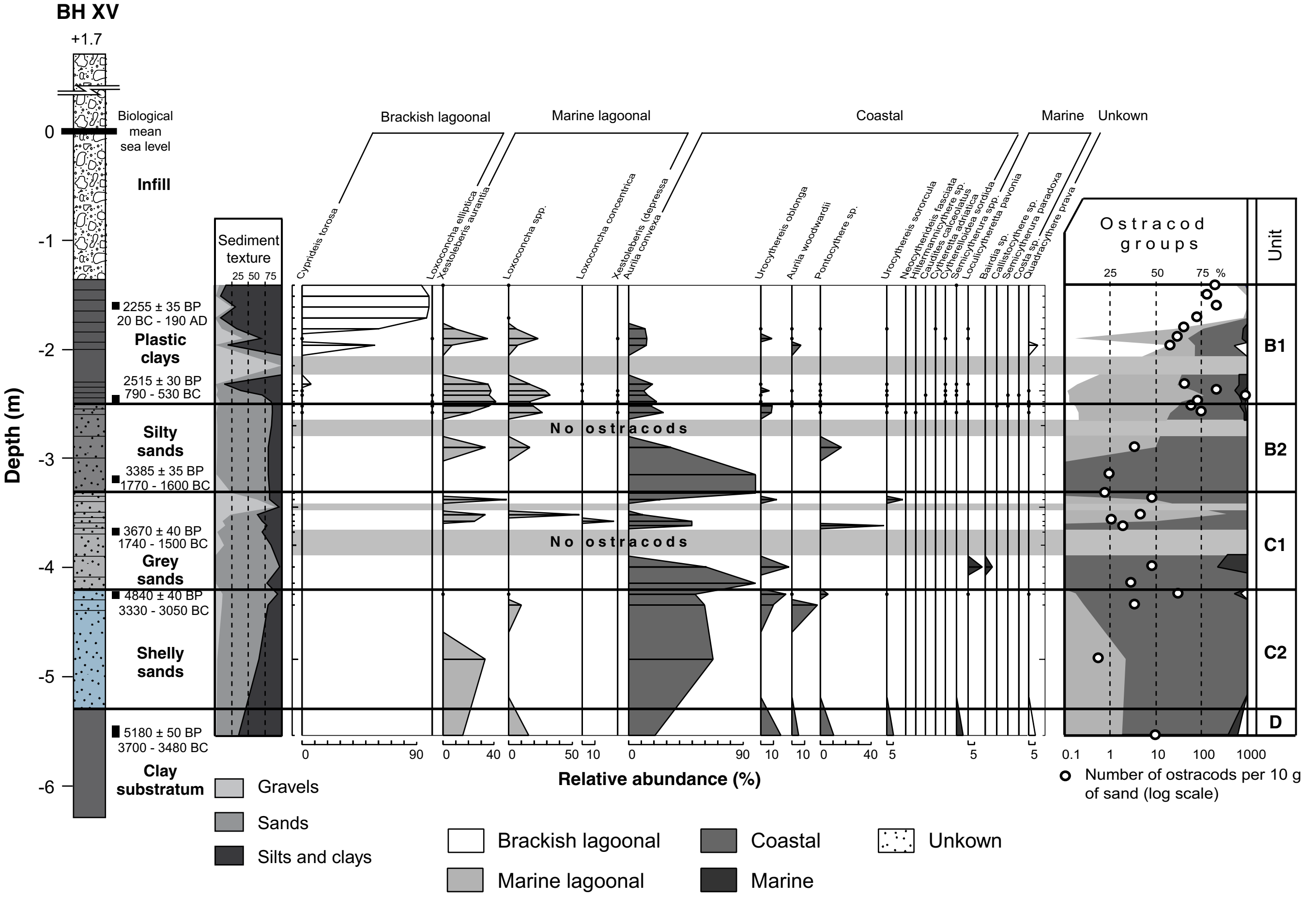


Fig. 12. Ostracod microfauna from core BH XV (northern harbour).

6.1.1. Bronze Age proto-harbour phase

At the time of Sidon's foundation, during the third millennium BC, maritime harbour technology was still very much in its infancy [27,43]. Existing Bronze Age evidence from the Levant shows a clear pattern of environmental determinism, whereby coastal populations founded settlements in proximity to naturally occurring anchorages such as leaky lagoons, estuaries and pocket beaches [60,61]. In Bronze Age Sidon, the northern and southern pocket beaches, either side of the promontory, were ideally predisposed to serve as proto-harbours. The northern cove, with its shelly medium sands facies, afforded the best natural shelter for larger merchant boats during storms. Conversely, the wide sandy beaches prevalent in the southern cove would have accommodated smaller vessels, drawn from the water onto the beachface. This phenomenon is still practiced today throughout the Mediterranean by fishermen with light, shallow draught vessels.

6.1.2. Dating the beginnings of the artificial harbour

Towards the end of the Late Bronze Age and the Early Iron Age (∼1200–1000 BC), expanding international trade prompted coastal populations into modifying these natural anchorages [43]. *Exempli gratia*, the Phoenician mole at Atlit has been constrained to the ninth century BC and is a paradigm of artificial harbour infrastructure in the Levant [35]. Another good archetype derives from Tabbat el-Hammam in Syria, where a quasi-identical mole has been dated to ca. the ninth/eighth centuries BC [8].

More speculative examples of harbour infrastructure are known from the Levantine coast [30]. The earliest harbour quays at Tell Dor have been attributed to the thirteenth century BC [59,60,62]. Also in Israel, the Middle Bronze Age site of Yavne-Yam attests the presence of submerged boulder piles, used to improve the quality of the ancient anchorage (Marcus, personal communication). Although open to fervent debate, texts from Ras-Shamra and Ugarit could comply a fifteenth century BC age for the foundation of Minet el-Beida on the Syrian coast [66,70].

In Sidon's northern harbour, transition from shelly to fine-grained sands appears to be the earliest granulometric manifestation of human coastal modification. A single radiocarbon date from core BH XV constrains this alteration to the Middle Bronze Age (∼1700 cal. BC) and must be confirmed by further data. The Phoenicians cleverly quarried sandstone ridges to form artificial quays. Surplus blocks were frequently reemployed to either construct (i.e. Arwad) or reinforce (i.e. Sidon and Tripoli) a seawall [11,12,73–75] (Fig. 16). In Sidon's northern harbour, modernisation means that these vestiges

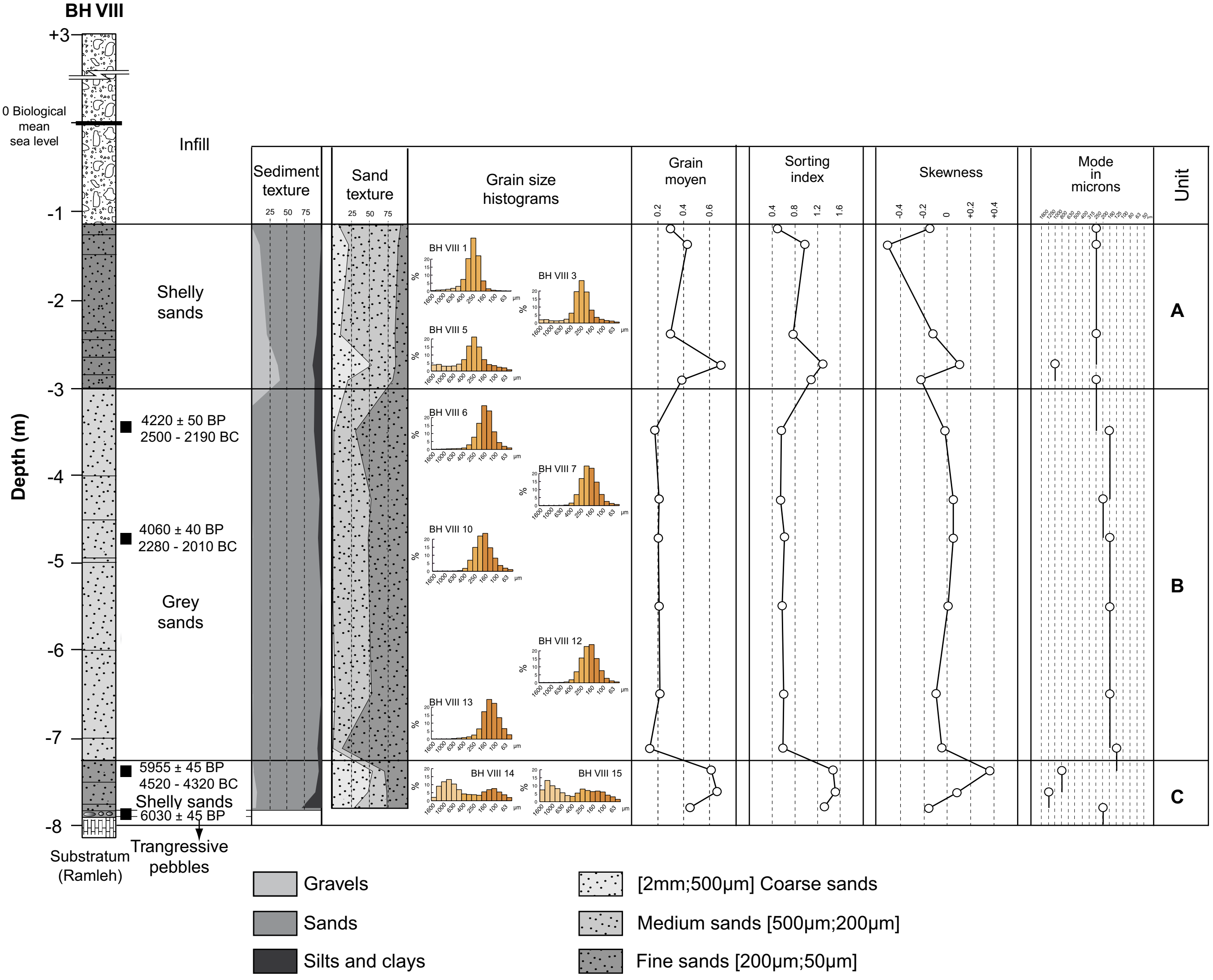


Fig. 13. Sedimentology of core BH VIII (southern cove).

are no longer visible, although they have been described by d'Arvieux [2], Renan [64], Lortet [42] and surveyed by Poidebard and Lauffray [57].

The lee of Zire was also exploited as a deep-water anchorage, or outer harbour, at this time although the island's two jetties date from the Persian period. In fair to medium weather, large merchant vessels would have loaded and unloaded goods at this geomorphologically predisposed hub, their cargos ferried to and from the shoreline by lighters [43,76]. A whole suite of harbourworks, including seawalls, quays and mooring bits have been dug into the Quaternary sandstone, rendering Zire an integral component of Sidon's port system.

The bio-sedimentological datasets show, however, that it was the northern harbour, naturally protected from the open sea by a sandstone ridge, which became the city's major port basin. Conversely, there is no evidence for harbourworks in the southern cove. Difficulty in dating the first phase of artificial confinement, in both Sidon and Tyre, appears concurrent with two complimentary dynamics: (1) modest artificial harbourworks during the late Middle Bronze Age and Late Bronze Age; and/or (2) intense dredging during the Roman and Byzantine occupations (see below).

6.1.3. Absence of Iron Age sedimentary archives

Given the relative absence of pre-Hellenistic facies, high-resolution reconstruction of the northern harbour's Phoenician history is problematic. Advanced harbour management techniques during the Roman and Byzantine periods culminated in the repeated dredging of Sidon's northern harbour, removing this strata from the geological record (Fig. 17). In cores BH I and BH IX, there is a clear sediment hiatus between ~1700 and 1500 cal. BC and the Roman period. As in Tyre, reworking of the marine bottom is delineated by the chronostratigraphic dataset and supports unequivocal evidence from Marseilles [36,37] and Naples [32,33]. In BH XV, a more coherent and continuous chronology suggests that this area was less affected by dredging activity. The data evoke

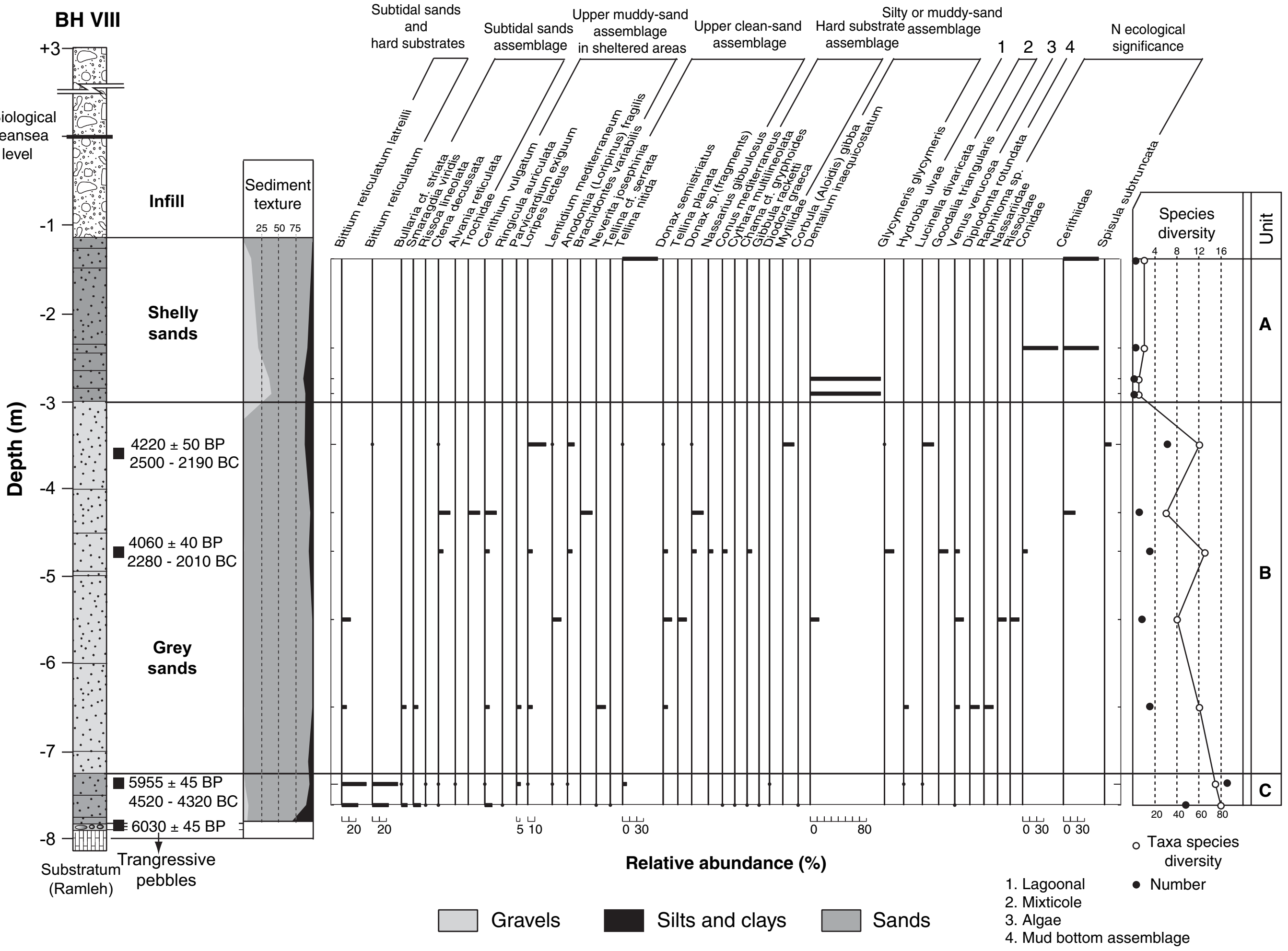


Fig. 14. Molluscan macrofauna from core BH VIII (southern cove).

advanced harbourworks during the Phoenician and Persian periods.

Siltation, notably under deltaic and urban contexts, was a well-recognised problem in antiquity with four sedimentary sources of note: (1) local watercourses; (2) regional longdrift currents; (3) erosion of adobe constructions and urban runoff; and (4) use of the basin as a base-level waste dump. Sidon's gravels fraction from the Roman period comprises a whole suite of discarded objects, trapped at the bottom of the basin, including ceramics, wood, seeds, leather artefacts etc. Indeed, an inscription from Roman Ephesus, demanding citizens not to throw waste into the port, attests that ancient societies must have been acutely aware of this problem (Die Inschriften von Ephesos, Bonn, I, 1979, no. 23).

It is postulated that extensive dredging during the Roman and Byzantine period explains (1) the observed stratigraphic hiatus and (2) dating inversions. Previously, these problems, in the absence of robust chronological frameworks, were most often ignored or left unexplained.

6.1.4. The Roman revolution

By Roman times, the discovery and use of hydraulic concrete greatly enhanced engineering possibilities (cf. Vitruve, V, 12), locally deforming coastal landscapes [9,51]. In effect, at this time we observe pronounced transition from environmental to anthropogenic determinism. The Romans were able to conceive long breakwaters or offshore harbour basins, Caesarea Maritima being an example *par excellence* [5]. All-weather basins could be constructed at locations where no natural roadstead existed. During this technological revolution, Sidon's northern harbour underwent significant changes with the edifice of an inner artificial mole perpendicular to the sandstone ridge [57]. This yielded an extremely well-protected basin, translated in the geological archive by a silt facies containing lagoonal molluscs and microfossils.

Under these closed conditions sedimentation rates rose significantly (~1 mm/year during the mid-Holocene compared to ~10 mm/year for the Roman period), not least because of the overriding confinement, but also linked to increasing human use and abuse of the surrounding watershed that flushed sediment into coastal depocentres. This dual phenomenon, increased confinement coupled with a rise in sediment yields, is consistently observed in base-level harbour basins throughout the circum Mediterranean. In its most acute form the ensuing coastal progradation led to harbour landlocking, isolating basins many kilometres from the sea.

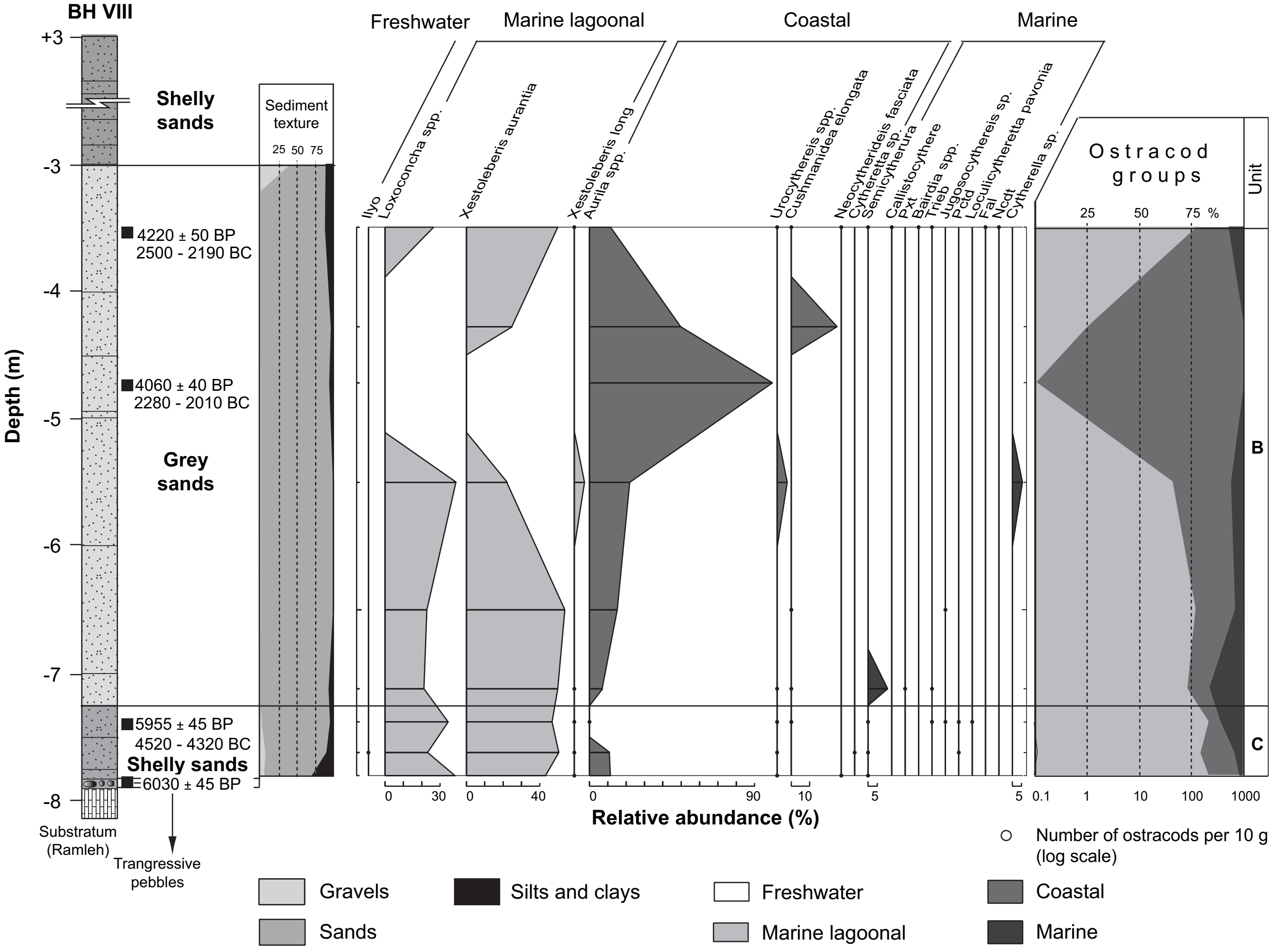


Fig. 15. Ostracod microfauna from core BH VIII (southern cove).

Celebrated examples are known from the Aegean Anatolian deltas and include the sites of Troy, Ephesus, Priene and Miletos [10,39].

In addition to artificial dredging, engineering solutions to the siltation problem have been asserted, although many of these remain speculative [4]. At Sidon, Poidebard and Lauffray [57] identified a flushing channel carved into the sandstone and linking the northern basin with the open sea. Undated, the two scholars hypothesised this to be an ad hoc desilting channel, dug to generate current through the inner harbour and alleviate the effects of sediment deposition. The stratigraphy shows dredging and coeval desilting infrastructure to have been insufficient in completely eradicating the problem; two thousand years later, rapid silting up means that the majority of the ancient basin is now buried beneath the Modern city centre.

6.1.5. *Byzantine apogee and persistence of Roman technology*

Whilst Bronze Age populations benefited from Sidon's geological endowment, Byzantine societies inherited the Romans' rich maritime *savoir faire*. The Byzantine period in Sidon is marked by advanced reinforcement of the antecedent port infrastructure, with a notable persistence of Roman technology and its opulent legacy of engineering achievements [38]. This is corroborated by a plastic clay unit with diagnostic lagoonal macro- and microfossils, typical of pronounced confinement. These geological data support archaeological evidence from Beirut's Byzantine harbour suggesting that the Levantine coast was still an important trade zone at this time [68]. Such a trade apex, coeval with advanced port infrastructure and management techniques, leads us to propose a harbour apogee for Sidon during the Byzantine period.

6.1.6. *Harbour semi-abandonment phase*

Radical coastal changes are witnessed during the Islamic period, with a gradual reopening of Sidon and Tyre's northern harbours. We advance three hypotheses to explain these data, namely (1) cultural, (2) tectonic and (3) tsunamogenic.

(1) Historians traditionally argue that the Byzantine crisis (sixth century AD) and ensuing seventh century AD Islamic conquest engendered profound changes in the eastern Mediterranean's trade network [53] (Fig. 18). During and after these permutations, it is speculated that harbour infrastructure fell

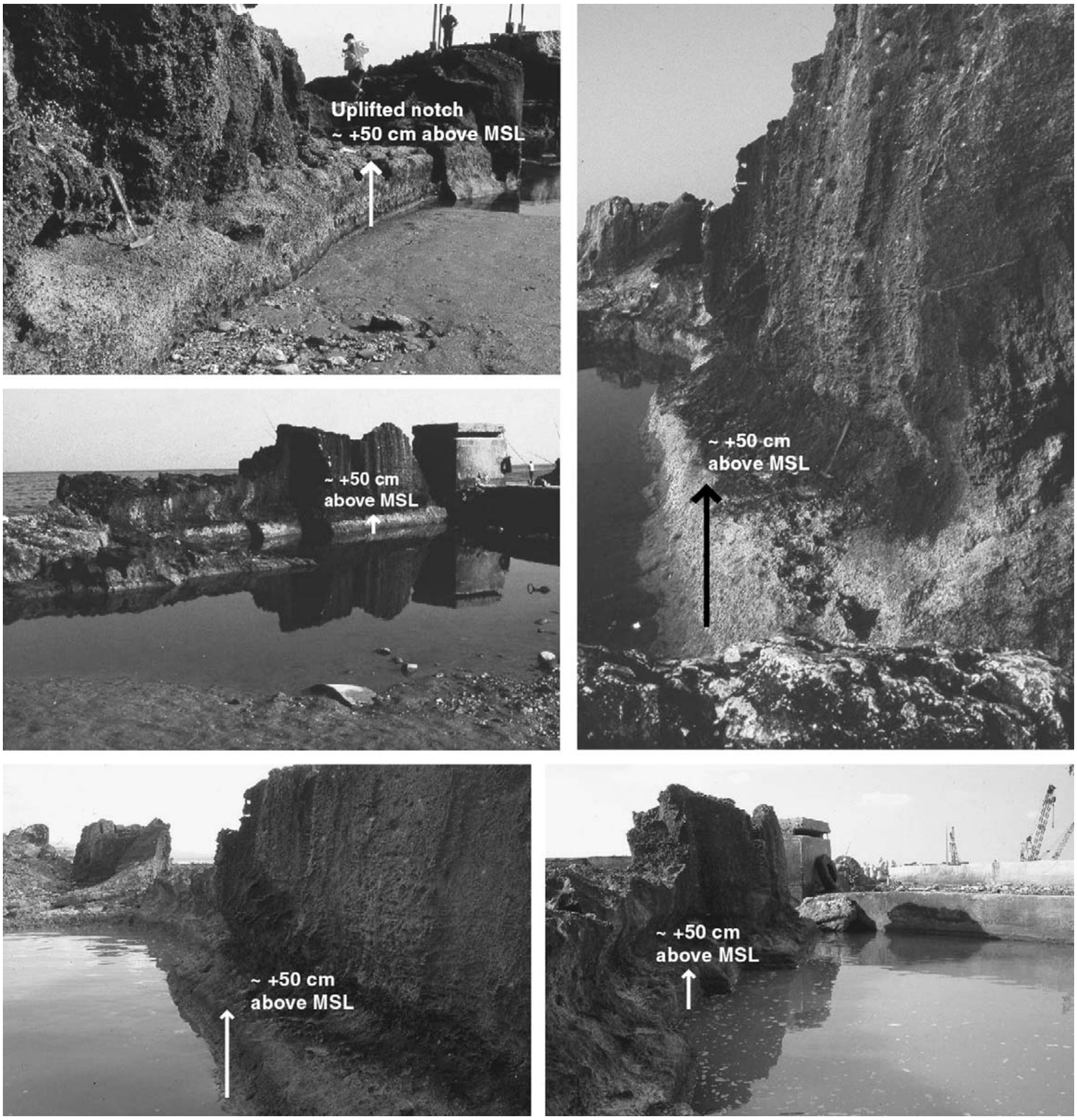


Fig. 16. Sidon's northern harbour and its ancient seawall. Before recent construction work an uplifted marine notch was observed at ∼50 cm above MSL. All photos C. Morhange (1998).

into a state of disrepair. A priori our sedimentological data are broadly consistent with these historical interpretations. Nevertheless, recent archaeological and historical research tends to moderate the premise of a general decline of 'Syrian' harbours at this time [6,28,41,72]. Historians believe the Levantine coast to have been the cradle of Islamic maritime development, control which opened the gates of the Mediterranean. For many Medieval authors, Tyre epitomises the harbour model *par excellence* [7]. Historical sources evoke three pivotal Levantine harbours of note, Acre, Tyre and Tripoli, whereas the other port sites seemingly disappear from the maritime map. Acre and Tyre were, for instance, important centres of naval construction during the ninth to tenth centuries AD. Our data indicate rapid coastal progradation from the sixth century AD onwards, entraining the deformation and dislocation of Sidon's harbour. Although smaller, it is difficult to accurately constrain the exact dimensions of this port as the post-Byzantine sediment record lies beneath the present basin and is not accessible at present.

(2) At Tyre, port opening may have been amplified by the ∼3 m late Roman tectonic collapse of the Phoenician island (see Fig. 17). Its northern Roman (?) mole is currently 2.5 m below present sea level, translating a subsidence of ∼3–3.5 m. On the southern shore, walls and drowned quarries at −2.5 m below MSL have also been discovered, and similar subsidence is translated in the city's coastal stratigraphy. By contrast, sea-level data from Sidon shows that the magnitude of crustal mobility is inferior to Tyre, ∼50 cm since antiquity, yet the same coarse sand facies is persistently observed. These data chronologically contradict, at least locally, the Early Byzantine Tectonic Paroxysm hypothesis dated to the fourth to sixth centuries AD [54–56]. In effect, the opening of Tyre

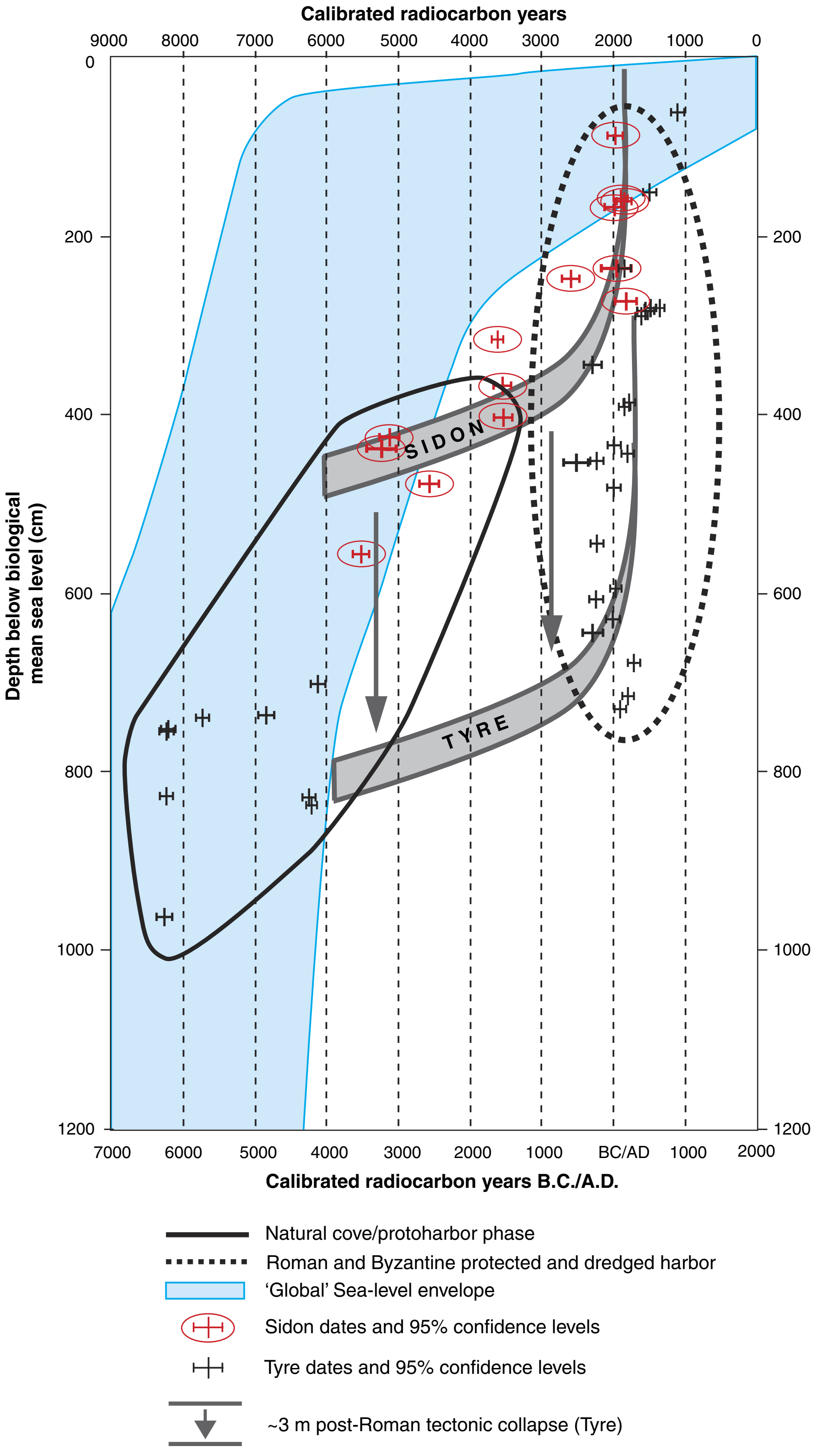


Fig. 17. Chronostratigraphic evidence for Roman and Byzantine dredging of Sidon and Tyre's ancient harbours. The older radiocarbon group corresponds to a naturally aggrading marine bottom. Quasi-absence of a chronostratigraphic record between BC 4000 to 500, coupled with persistent age depth inversions, are interpreted as evidence of harbour dredging (adapted from [46]).

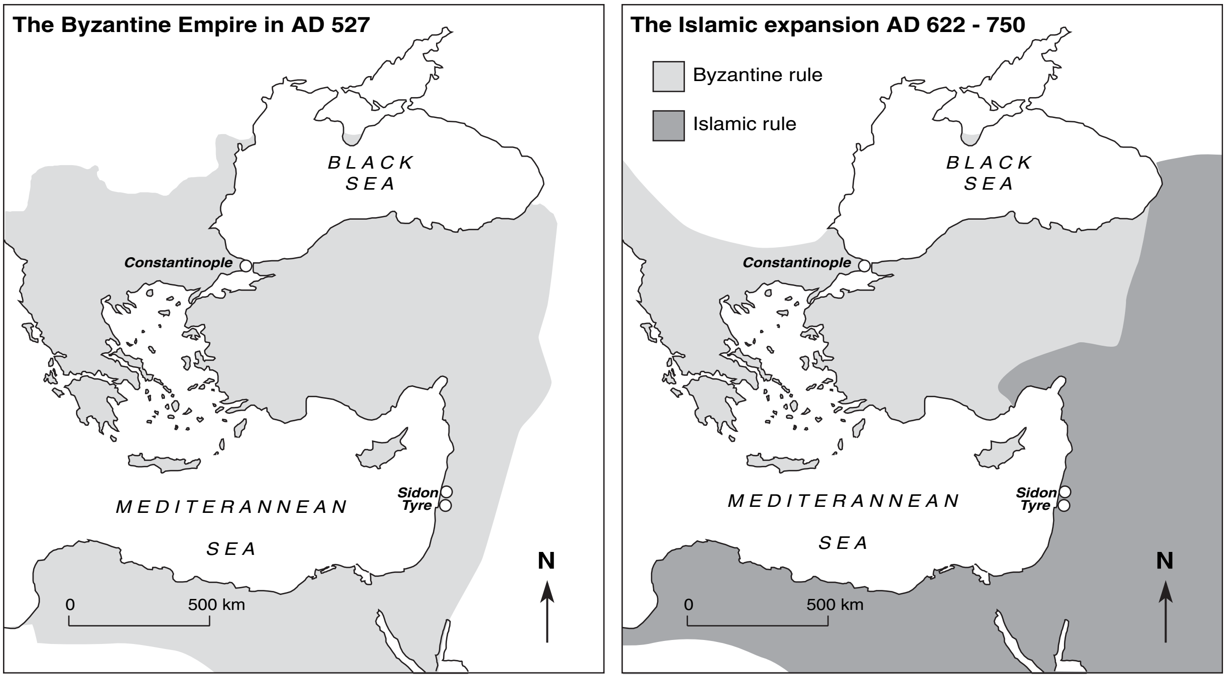


Fig. 18. Isolation of Sidon and Tyre from the Constantinople metropolis during the 7th to 8th centuries AD.

and Sidon appears to be later, after the sixth century AD. Fig. 19 plots earthquake and tsunami events on the Levantine coast illustrating that the fourth to eleventh centuries were characterised by repeated seismic shocks, possibly provoking partial harbour damage. According to data from various sources [52,65] it is interesting to note that during the EBTP a cluster of five earthquakes $\geq$8 are documented on the Levantine coast against a mere two during the period AD 600 to AD 1100 (scale *sensu* Plassard and Kogoj [52]).

(3) This discrepancy leads us to moderate tectonic collapse in favour of documented tsunamogenic impacts. In effect, more than ten tsunami struck the Levantine coast between the fourth to eleventh centuries AD, severely damaging harbour infrastructure [1,34,71]. For the AD 551 event, John of

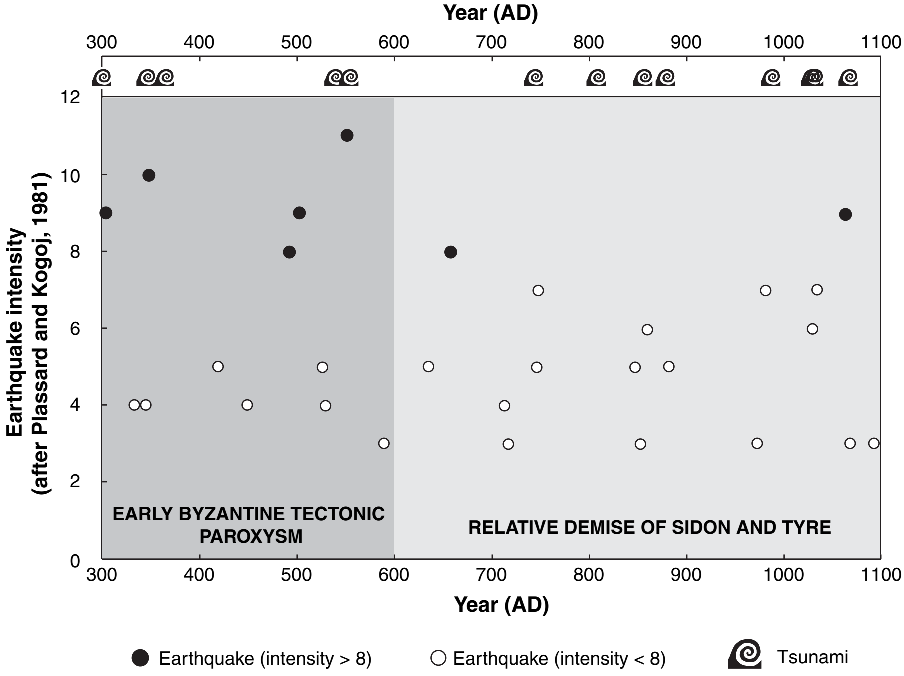


Fig. 19. AD 300 to 1000 earthquake and tsunami events affecting the Phoenician coast (data compiled from [1,34,52,65,71]).

Ephesus records that ‘‘[…] the sea withdrew and retreated from the coastal cities of Phoenicia for a distance of nearly two miles […] A tremendous surge of the sea rushed up to return to its original depth’’ [34]. Notwithstanding these catastrophist scenarios Sidon and Tyre's ports are still in use today, 5000 years after their foundation.

6.2. Comparison between Sidon and Tyre

Analogous sedimentary stories are observed at both Sidon and Tyre, reinforcing the premise that geoscience is a robust archaeological tool. Nevertheless, Sidon's northern harbour facies consistently comprises fine-grained material. During the Roman period for example, Sidon's harbour constitutes >80% silts and fine sands whereas in Tyre the sand fraction still predominates. How should such a sharp disparity be construed? We advance two hypotheses, technological and geomorphological, both of which are not mutually exclusive: (1) Tyre's northern harbour is comparatively open, with a wide ~100–150 m channel entrance separating the two ancient moles. This created increased exposure to outer marine dynamics. In contrast, the northern harbour of Sidon is quasi-landlocked by three main obstacles, *scilicet* the sandstone breakwater, the sea castle island and the inner mole. (2) Geographically, Tyre lies 9 km from the mouth of the Litani, Phoenicia's most important fluvial system. This river delivers coarse sediment inputs to the coastal zone, constituting mainly sands and gravels, trapped in base-level depocentres such as harbour basins (Fig. 20). In contrast, Sidon is situated south of the Awali river, a much smaller watershed yielding mainly medium sands and silts.

Multiple similarities are recorded between these two sister harbours. (1) Foremost, historical coastal progradation has led to the isolation of the ancient harbours beneath the modern city centres (Fig. 21). Around half of the basins are now buried beneath thick tracts of marine sediments, and the historical coastline presently localised 100–150 m inland. Such progradation has fossilised Sidon and Tyre's archaeological heritage offering significant scope for future research and our understanding of Phoenicia's maritime history [44]. (2) The difficulty in dating the first phase of artificial harbour confinement translates modest harbourworks during the Middle Bronze Age and the Late Bronze Age. Early seafarers used semi-protected pocket beaches with little need to modify the natural coastline. The weight of natural factors in influencing human exploitation of the coastal environment prevailed until the Phoenician period. Only sediment sections yield the resolution necessary to observe fine environmental details, although these are logistically and financially unrealisable at present.

7. Conclusion

In conclusion, we would like to insist on three research advances.

(1) It has been demonstrated that harbour history can be clearly chronicled by diagnostic litho- and biostratigraphies. Indeed, explicit use of the coastal geological record has the possibility to greatly enhance our understanding of human-environment interactions and their multiple facets; we therefore postulate geoscience to be a powerful tool in expounding the spatial organisation of harbour areas and their coastal evolution through time [47]. Ancient harbours are also appropriate for the analysis of numerous archaeological problems and cultural processes, providing a diversity of research possibilities.

(2) For Sidon and Tyre, the biological proxies asseverate a broadly similar chronostratigraphic pattern, under disparate geomorphological and geodynamic contexts, a paradox supporting the initial hypothesis of technologically forced

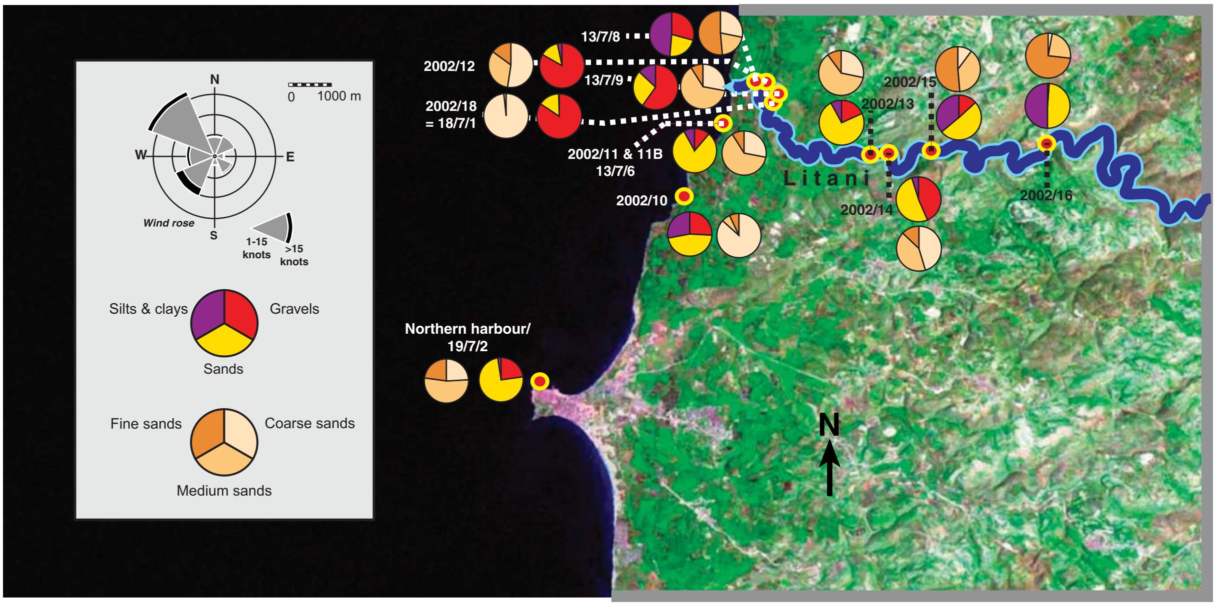


Fig. 20. Sedimentology of Litani sediments, north of the Tyrian peninsula (Landsat image).

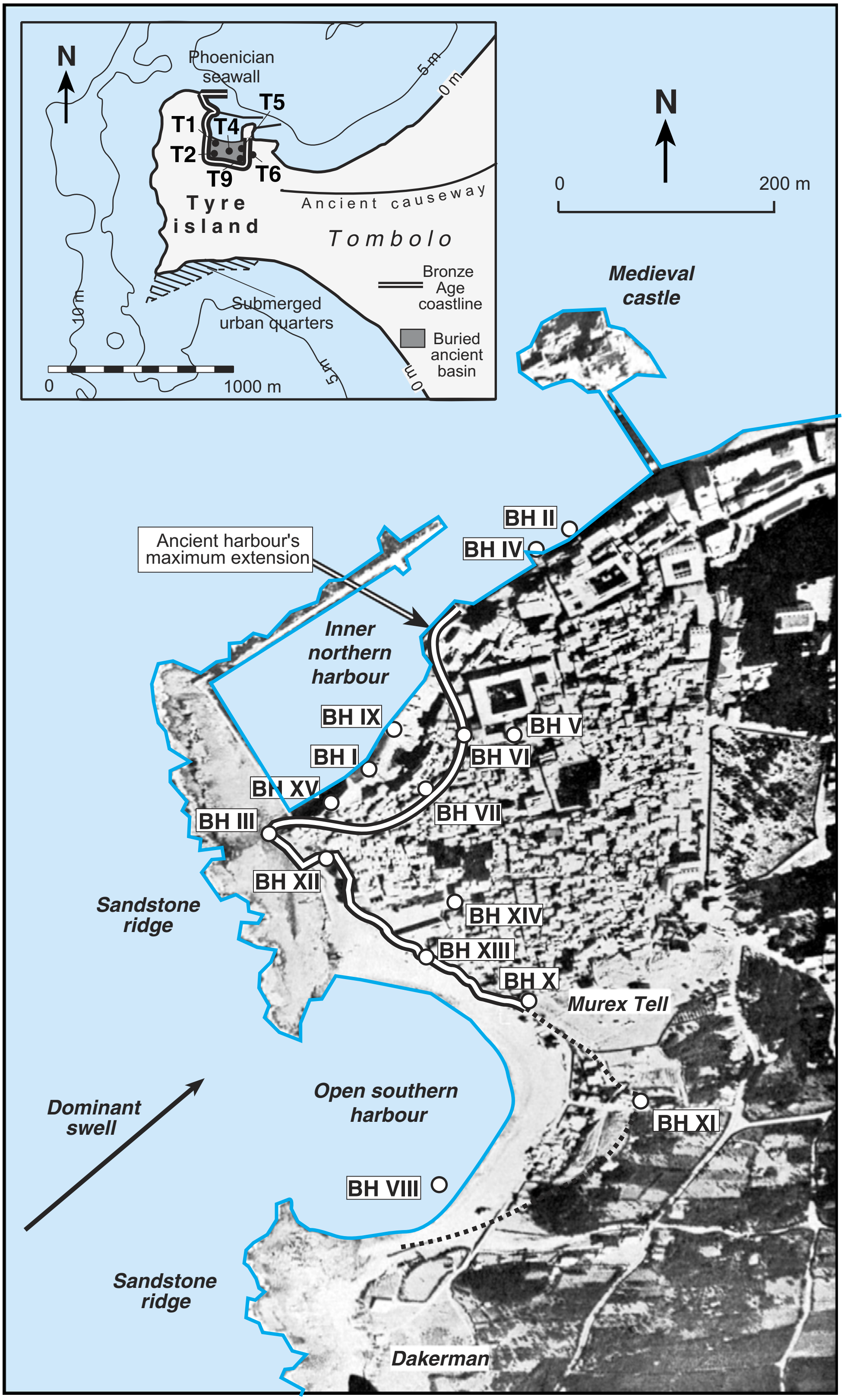


Fig. 21. Sidon's reconstructed harbour limits in antiquity. Inset: Tyre's northern harbour limits.

sedimentary changes. A clear transition is manifest in the stratigraphy from environmental determinism during the Bronze Age, through various intermediary phases, to full anthropogenic determinism by the Roman period.

(3) Emerging geological data delineates a largely analogous chronostratigraphic pattern for many of the Mediterranean's ancient ports. Locally, the most important factors in explaining coastal progradation are not small-scale relative sea-level

variations but anthropogenic sediment supply and harbour management.

Acknowledgements

We thank the Directorate General of Antiquities (F. Husseini), CEDRE (F60/L58), UNESCO World Heritage (CPM 700.893.1) and the Lebanese British Friends of the National Museum for technical and financial support. N. M. benefited from a Leverhulme Study Abroad Studentship. The authors also wish to thank A. Borrut, M. Bourcier, N. Carayon, K. Espic, J.-P. Goiran, N. Kashtan, J. Oleson and D. Sivan for kindly reviewing earlier versions of the manuscript.

References

[1] N.N. Ambraseys, Data for the investigation of seismic sea-waves in the Eastern Mediterranean, Bulletin of the Seismological Society of America 52 (1962) 895–913.

[2] L. d'Arvieux, Mémoires du chevalier d'Arvieux, envoyé extraordinaire du Roi à la Porte, consul d'Alep, d'Alger, de Tripoli, et autres échelles du Levant, contenant ses voyages à Constantinople, dans l'Asie, la Syrie, la Palestine, l'Egypte et la Barbarie, la description de ces pays, les religions, les moeurs, les coutumes, le négoce de ces peuples, et leurs gouvernements, Jean-Baptiste Delespine, Paris, 1735.

[3] D.J. Blackman, Ancient harbours in the Mediterranean, part 1, The International Journal of Nautical Archaeology and Underwater Exploration 11 (1982) 79–104.

[4] D.J. Blackman, Ancient harbours in the Mediterranean, part 2, The International Journal of Nautical Archaeology and Underwater Exploration 11 (1982) 185–211.

[5] D.J. Blackman, in: A. Raban, K.G. Hollum (Eds.), Caesarea Maritima: A Retrospective after Two Millennia, Brill, Leiden, New York, Köln, 1996.

[6] A. Borrut, L'espace maritime syrien au cours des premiers siècles de l'Islam (VIIe-Xe siècle): le cas de la région entre Acre et Tripoli, Tempora, Annales d'histoire et d'archéologie 10–11 (1999–2000) 1–33.

[7] A. Borrut, Architecture des espaces portuaires et réseaux défensifs du littoral syro-palestinien dans les sources arabes (VIIe-Xie s.), Archéologie Islamique 11 (2001) 21–46.

[8] R.J. Braidwood, Report on two sondages on the coast of Syria, south of Tartous, Syria 21 (1940) 183–221.

[9] C. Brandon, in: A. Raban, K.G. Hollum (Eds.), Caesarea Maritima: A Retrospective after Two Millennia, Brill, Leiden, New York, Köln, 1996.

[10] H. Brückner, M. Müllenhoff, M. Handl, K. van der Borg, Holocene landscape evolution of the Büyük Menderes alluvial plain in the environs of Myous and Priene (Western Anatolia, Turkey), Zeitschrift für Geomorphologie N.F., 127 (Suppl.-Bd) (2002) 47–65.

[11] N. Carayon, L'île de Ziré à Saïda: nouvelles données archéologiques, Archaeology and History in Lebanon 18 (2003) 95–114.

[12] N. Carayon, J. Viret, in: F. Denise, L. Nordiguian (Eds.), Une aventure archéologique: Antoine Poidebard, photographe et aviateur, Marseille, Arles, Beyrouth, 2004.

[13] G. Contenau, Mission archéologique à Sidon (1914), Syria I (1920) 16–55 and 108–154.

[14] G. Contenau, Deuxième mission archéologique à Sidon (1920), Syria IV (1924) 261–281.

[15] G. Contenau, Deuxième mission archéologique à Sidon (1920), Syria V (1924) 9–23 and 123–134.

[16] J. Curtis, New excavations at Sidon, National Museum News 10 (2000) 27–40.

[17] C. Doumet-Serhal, Sidon—British Museum Excavations 1998–2003, Archaeology and History in Lebanon 18 (2003).

[18] L. Dubertret, Carte géologique du Liban au 1/200,000, avec notice explicative, Ministère des Travaux Publics, Beyrouth (1955).

[19] L. Dubertret, Introduction à la Carte Geologique au 1:50 000 du Liban, Notes Mémoire Moyen-Orient 13 (1975) 345–403.

[20] M. Dunand, Chronique, Bulletin du Musée de Beyrouth III (1939) 79–81.

[21] M. Dunand, Chronique, Bulletin du Musée de Beyrouth IV (1940) 118.

[22] M. Dunand, Chronique, Bulletin du Musée de Beyrouth V (1941) 88–89.

[23] M. Dunand, Chronique, Bulletin du Musée de Beyrouth VI (1942–43) 82–83.

[24] M. Dunand, Rapport préliminaire sur les fouilles de Sidon en 1964–1965, Bulletin du Musée de Beyrouth XX (1967) 27–44.

[25] M. El Amouri, M. El Helou, M. Marquet, I. Nourredine, M. Seco Alvarez, Mission d'expertise archéologique du port sud de Tyr, sud Liban: résultats préliminaires, Bulletin d'Archéologie et d'Architecture Libanaises HSII (2005) 91–110.

[26] K. Espic, C. Morhange, M. Bourcier, C. Bruzzi, P. Carbonel, T. Nammour, C. Doumet-Serhal, Les ports antiques de Sidon: nouvelles données paléo-environnementales, Archaeology and History in Lebanon 15 (2002) 28–36.

[27] D. Fabre, Seafaring in ancient Egypt, Periplus, London, 2004/2005.

[28] A.M. Fahmy, Muslim naval organisation in the eastern Mediterranean from the seventh to the tenth century AD, National Publication and Print House, Cairo, 1966.

[29] H. Frost, The Offshore Island Harbour at Sidon and Other Phoenician Sites in the Light of New Dating Evidence, The International Journal of Nautical Archaeology and Underwater Exploration 2 (1973) 75–94.

[30] H. Frost, in: V. Karageorghis, D. Michaelides (Eds.), Proceedings of the International Symposium 'Cyprus and the Sea', University of Cyprus, Nicosia, 1995.

[31] H. Frost, Installations on the ancient offshore anchorage at Sidon (the rock island of Zire), National Museum News 10 (2000) 69–73.

[32] D. Giampaola, V. Carsana, in: E. Lo Sarde (Ed.), Eureka! il genio degli antichi, Napoli, 2005.

[33] D. Giampoala, V. Carsana, G. Boetto, Il mare torna a bagnare Neapolis. Parte II: dalla scoperta del porto al recupero dei relitti, L'archeologo subacqueo 10 (3) (2004) 15–19.

[34] E. Guidoboni, A. Comastri, G. Traina, Catalogue of Ancient Earthquakes in the Mediterranean Area up to the 10th Century, Istituto Nazionale di Geofisica, Bologna, 1994.

[35] A. Haggai, Excavation of the Phoenician harbour at Atlit: findings and reassessment of its foundation and purpose, Journal of the Tel Aviv Institute of Archaeology 33 (2006).

[36] A. Hesnard, in: L. De Maria, R. Turchetti (Eds.), Evolución paleoambiental de los puertos y fondeaderos antiguos en el Mediterráneo occidental, Rubbettino Editore, Soveria Mannelli, 2004.

[37] A. Hesnard, in: A. Gallina Zevi, R. Turchetti (Eds.), Le strutture dei porte e degli approdi antichi, Rubbettino Editore, Soveria Mannelli, 2004.

[38] R.L. Hohlfelder, Building harbours in the early Byzantine era: the persistence of Roman technology, Byzantinische Forschungen Internationale Zeitschrift für Byzantinistik 24 (1997) 367–389.

[39] J.C. Kraft, G.R. Rapp, I. Kayan, J.V. Luce, Harbor areas at ancient Troy: Sedimentology and geomorphology complement Homer's Iliad, Geology 31 (2003) 163–166.

[40] J. Laborel, F. Laborel-Deguen, Biological indicators of relative sea-level variations and co-seismic displacements in the Mediterranean region, Journal of Coastal Research 10 (1994) 395–415.

[41] A.R. Lewis, Naval power and trade in the Mediterranean AD 500-1100, Princeton University Press, Princeton New Jersey, 1951.

[42] L. Lortet, La Syrie d'aujourd'hui, Voyages dans la Phénicie, le Liban et la Judée, 1875–1880, Hachette, Paris, 1884.

[43] E. Marcus, in: E.C.M. van der Brink, T.F. Levy (Eds.), Egypt and the Levant, Interrelations from the 4th through the Early 3rd Millennium BCE, Continuum International Publishing Group, London, 2002.

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

[45] N. Marriner, C. Morhange, M. Boudagher-Fadel, M. Bourcier, P. Carbonel, Geoarchaeology of Tyre's ancient northern harbour, Phoenicia, Journal of Archaeological Science 32 (2005) 1302–1327.

[46] N. Marriner, C. Morhange, Geoarchaeological evidence for dredging in Tyre's ancient harbour, Levant, Quaternary Research 65 (2006) 164–171.

[47] N. Marriner, C. Morhange, C. Doumet-Serhal, P. Carbonel, Geoscience rediscovers Phoenicia's buried harbors, Geology 34 (2006) 1–4.

[48] C. Morhange, J.-P. Goiran, M. Bourcier, P. Carbonel, J. Le Campion, J.-M. Rouchy, M. Yon, Recent Holocene paleo-environmental evolution and coastline changes of Kition, Larnaca, Cyprus, Mediterranean Sea, Marine Geology 26 (2000) 205–230.

[49] C. Morhange, K. Espic, C. Doumet-Serhal, M. Bourcier, P. Carbonel, The ancient harbours of Sidon, attempt at a synthesis (1998–2002), Archaeology and History in Lebanon 18 (2003) 71–81.

[50] C. Morhange, F. Blanc, M. Bourcier, P. Carbonel, A. Prone, S. Schmitt-Mercury, D. Vivent, A. Hesnard, Bio-sedimentology of the late Holocene deposits of the ancient harbor of Marseilles (Southern France, Mediterranean sea), The Holocene 13 (2003) 593–604.

[51] J.P. Oleson, C. Brandon, S.M. Cramer, R. Cucitore, E. Gotti, R.L. Hohlfelder, The ROMACONS Project: a Contribution to the Historical and Engineering Analysis of Hydraulic Concrete in Roman Maritime Structures, International Journal of Nautical Archaeology 33 (2004) 199–229.

[52] J. Plassard, B. Kogoj, Catalogue des seismes ressentis au Liban, Ann. Sism. Observ. Ksara, CNRS, Beyrouth, 1981.

[53] H. Pirenne, Mahomet et Charlemagne, Les Presses Universitaires de France, Paris, 1937.

[54] P.A. Pirazzoli, The Early Byzantine Tectonic Paroxysm, Zeitschrift für Geomorphologie 62 (1986) 31–49.

[55] P.A. Pirazzoli, A review of possible eustatic, isostatic and tectonic contributions in eight late-Holocene relative sea-level histories from the Mediterranean area, Quaternary Science Reviews 24 (2005) 1989–2001.

[56] P.A. Pirazzoli, J. Laborel, S.C. Stiros, Earthquake clustering in the Eastern Mediterranean during historical times, Journal of Geophysical Research 101 (B3) (1996) 6083–6097.

[57] A. Poidebard, J. Lauffray, Sidon, aménagements antiques du port de Saïda. Etude aérienne au sol et sous-marine, Imprimerie Catholique, Beyrouth (1951).

[58] A. Raban, in: A. Raban (Ed.), Harbour Archaeology. Proceedings of the first international workshop on ancient Mediterranean harbours, BAR International Series 257, Caesarea Maritima, Haifa, 1985.

[59] A. Raban, Alternated river courses during the Bronze Age along the Israeli coastline, Déplacements des lignes de rivage en Méditerranée d'après les données de l'archéologie, CNRS, Paris, 1987.

[60] A. Raban, The Harbor of the Sea People at Dor, Biblical Archaeologist 50 (1987) 118–126.

[61] A. Raban, in: G. Entjes-Nieborg, W. van Zeist (Eds.), Man's role in the shaping if the Eastern Mediterranean landscape, Balkema, Rotterdam, 1990.

[62] A. Raban, in: V. Karageorghis, D. Michaelides (Eds.), Proceedings of the International Symposium 'Cyprus and the Sea', University of Cyprus, Nicosia, 1995.

[63] E.G. Reinhardt, A. Raban, Destruction of Herod the Great's harbor Caesarea Maritima, Israel, geoarchaeological evidence, Geology 27 (1999) 811–814.

[64] E. Renan, La Mission de Phénicie, Imprimerie Nationale, Paris, 1864.

[65] K.W. Russell, The earthquake chronology of Palestine and Northwest Arabia from the 2nd through the mid-8th century A.D, Bulletin of the American School of Oriental Research 260 (1985) 37–59.

[66] G. Saadé, in: M. Yon M. Sznycer, P. Bordreuil, Le pays d'Ougarit autour de 1200 av. J.-C. Ras Shamra-Ougarit, IX Actes du colloque internationalParis, 28 juin–1er juillet 1993, Paris, 1995.

[67] R. Saidah, Fouilles de Sidon-Dakerman: l'agglomération chalcholithique, Berytus 27 (1979) 29–55.

[68] M. Saghieh Beydoun, Urban planning in a seaport city: Beirut from Hellenistic to Byzantine periods, Bulletin d'Archéologie et d'Architecture Libanaises HSII (2005) 147–184.

[69] P. Sanlaville, Etude géomorphologique de la région littorale du Liban, Publications de l'Université Libanaise, section des études géographiques, Beirut, 1977.

[70] C.F.A. Schaeffer, Les fouilles de Ras Shamra-Ugarit, 6ème campagne (printemps 1934), rapport sommaire, Syria 16 (1935) 141–176.

[71] S.L. Soloviev, O.N. Solovieva, C.N. Go, K.S. Kim, N.A. Shchetnikov, Tsunamis in the Mediterranean Sea 2000 B.C.-2000 A.D., Kluwer Academic Publishers, Dordrecht, 2000.

[72] D. Sourdel, J. Sourdel-Thomine, in: E. Poleggi (Ed.), Città portuali del Mediterraneo: storia e archeologia, Sagep Editrice, Genova, 1989.

[73] J. Viret, Nouvelles données sur le port de Tripoli, Tempora, Annales d'histoire et d'archéologie 10–11 (1999–2000) 117–138.

[74] J. Viret, in: F. Denise, L. Nordiguian (Eds.), Une aventure archéologique: Antoine Poidebard, photographe et aviateur, Marseille, Arles, Beyrouth, 2004.

[75] J. Viret, Les "murs de mer" de la côte levantine, Méditerranée 104 (2005) 15–23.

[76] S. Wachsmann, Seagoing ships and seamanship in the Bronze Age Levant, A&M University Press, Texas, 1998.