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Ancient harbors and Holocene morphogenesis of the Ras Ibn Hani peninsula (Syria)

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ABSTRACT

Ras Ibn Hani peninsula, a wave-dominated tombolo (800 × 1000 m) on the Syrian coast, provides evidence for significant Holocene changes that can be linked to geological inheritance, rising post-glacial sea level, sediment supply and human impacts. Initial development of Ras Ibn Hani's coastal system began ~8000 years ago when shallow marine environments formed in a context of rising post-glacial sea level. Following relative sea-level stabilization ~6000 cal yr BP, beach facies trace the gradual formation of a wave-dominated sand-bank fronted by a ~2300 × ~500 m palaeo-island whose environmental potentiality was attractive to Bronze Age societies. A particularly rapid phase of tombolo accretion is observed after ~3500 cal yr BP characterised by a two- to fourfold increase in sedimentation rates. This is consistent with (i) a pulse in sediment supply probably driven by Bronze Age/Iron Age soil erosion in local catchments, and (ii) positive feedback mechanisms linked to regionally attested neotectonics. Archaeological remains and radiocarbon datings confirm that the subaerial tombolo was probably in place by the Late Bronze Age. These data fit tightly with other eastern Mediterranean tombolo systems suggesting that there is a great deal of predictability to their geology and stratigraphy at the regional scale.

Introduction

A tombolo is a depositional landform (coastal spit or bar) that forms an isthmus between an island, or offshore rock, and a mainland shore (Woodroffe, 2002; Anthony, 2009). Recent studies suggest that their Holocene morphogenesis is linked to four main forcing agents: (i) sea-level change, (ii) high sediment supply (e.g., at deltaic or estuarine margins), (iii) a physical barrier in proximity to the shore, and (iv) human impacts (Goiran, 2001; Goiran et al., 2005; Millet and Goiran, 2007). In this paper, we present new high-resolution data from the peninsula of Ras Ibn Hani, a wave-dominated tombolo (800 × 1000 m) on the Mediterranean coast of Syria (Fig. 1). The site lies around 8 km north of the port city of Latakia and 4 km southwest of the Bronze Age site of Ugarit at Ras Shamra (Yon, 2006). Despite a long history of human occupation spanning back to the Neolithic (Contenson, 1992), there is a paucity of chronostratigraphic data pertaining to the coastline's palaeogeography. Questions remain as to when and how Ras Ibn Hani was linked to the continent (Sanlaville, 1978; Daoud and Ghazi, 2004–2005; Geyer et al., 2010). Furthermore, within the context of recent geoarchaeological work at Alexandria (Goiran, 2001) and Tyre (Nir, 1996; Marriner et al., 2007, 2008a), the present study provides a timely opportunity to compare and contrast the Holocene evolution of three equivalent coastal systems, pertinent in developing a morphogenetic model of eastern Mediterranean tombolos.

Plio-Quaternary bedrock frames much of the Syrian coastline (Sanlaville, 2000). This geological inheritance has played a major role in influencing its coastal system, shaping a series of Holocene islands, islets, pocket beaches and promontories, exploited by seafaring communities from the Bronze Age onwards (Carayon, 2008; Marriner, 2009). At Ras Ibn Hani, the partial transgression of this bedrock led to the formation of a large island barrier (~2300 × ~500 m) that is inferred to have sheltered a shallow marine bay (~3000 m × ~1500 m) ~6000 years ago.

The Ras Ibn Hani coastline is subject to a micro-tidal wave regime of ~40 cm, with a dominant longshore drift that runs south to north (Sanlaville, 1978). At present, the northern cove is particularly well sheltered by the sandy isthmus that intersects the palaeo-bay. The wind climate can be divided into two characteristic seasons (Fig. 1). A stable weather period from April to October is marked by low intensity winds from the southwest (Lisac, 1997). By contrast, from November to March, weather conditions are unstable: winds from the

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northeast and north are frequent, and storms arrive from the southwest (fetch of ~800 km) and west (fetch of ~100 km). The maximum wave heights are ~6–8 m and storms with waves above 4–5 m occur one to four times a year (Lisac, 1997). Although northerly winds can be very strong, the short fetch distance means that they do not generate high waves in proximity to the coast. Bedload sediment is supplied by: (i) the Nahr el Kebir, which meets the sea ~11 km south of Ras Ibn Hani, and (ii) a series of short (<20 km) and seasonal watercourses that drain the Latakia and Jableh coastal plains (Fig. 1). The role of Orontes sediments, whose delta lies ~55 km north of the Ras Ibn Hani peninsula, is unclear.

The great antiquity of human occupation at Ras Ibn Hani has been retraced back to the Late Bronze Age, when the settlement was an integral part of the Kingdom of Ugarit (Bounni et al., 1978; Lagarce and Lagarce, 1978; Lagarce et al., 1979; Yon, 2006). The main vestiges date to the 13th and the beginning of the 12th centuries BC, including two royal palaces attributed to the ruling classes at Ugarit (Bounni et al., 1998). The choice of the site appears to be partly strategic: the offshore island was both easy to defend and served as an ideal vantage point for the surveillance of commercial and military traffic (Bounni et al., 1978; Carayon, 2008). Despite the collapse of Ugarit at the beginning of the 12th century BC, Ras Ibn Hani's location meant that it

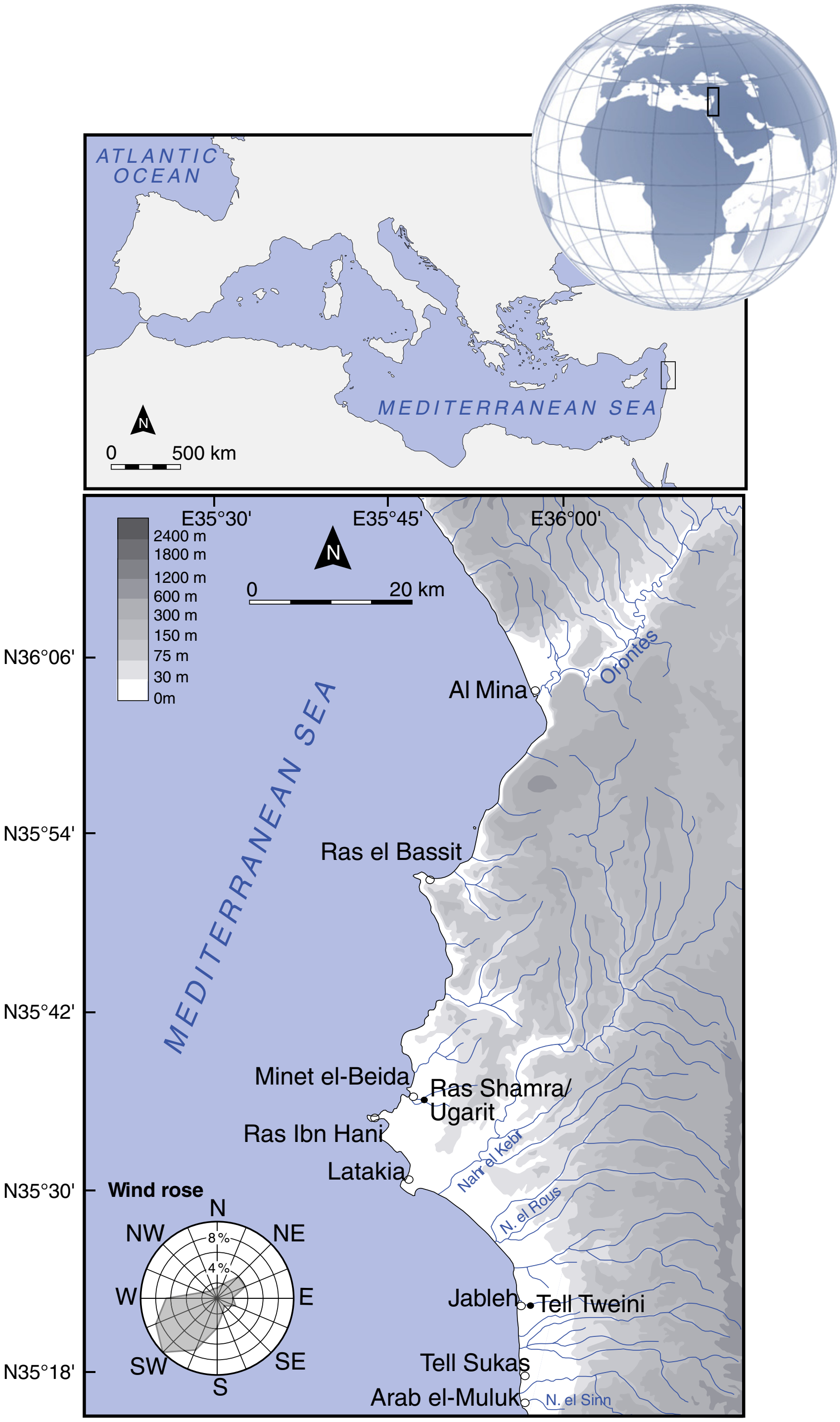


Figure 1. Location maps (adapted from Carayon, 2008).

continued to be occupied during the Iron Age, Persian, Hellenistic and Roman periods.

Within the context of a project supported by the *Mission archéologique syro-française de Ras Shamra-Ougarit* (MAÉE–DGAMS; www.ras-shamra.ougarit.mom.fr) and ANR *PaléoSyr,* we had a number of aims:

- to determine the Holocene stratigraphic history of Ras Ibn Hani's tombolo;
- to elucidate the peninsula's mid- to late Holocene palaeogeography in the context of existing archaeological data, particularly during the Bronze Age (period of the Kingdom of Ugarit);
- to investigate the role of various forcing agents (RSL changes, sediment supply, human impacts) in shaping the elucidated coastal changes; and
- to understand where, when and how Ras Ibn Hani's ancient harbors evolved.

Methods

We collected nine vibracores in May 2009 (Fig. 2). Cores were described and sampled in the field at a resolution of 10 cm. Three cores (RIH III, IV and IX) were exported to France for detailed sedimentological and biostratigraphical laboratory analyses in order to probe the evolution of the Holocene environments. All cores were benchmarked relative to Mean Sea Level (MSL). Detailed facies descriptions (e.g., colour, petrofacies) were undertaken under standardised laboratory conditions. Samples were oven dried at 40°C and subsequently described using the Munsell colour scheme. Dry sediment aggregates were weighed and washed through two mesh sizes, 2 mm and 50 μm, to separate out the gravels (>2 mm), sands (2 mm to 50 μm) and silts and clays (<50 μm) fractions. The dried fractions were weighed and data plotted on stratigraphic logs in percentages.

Identification of mollusc shells was undertaken upon the retained gravels fraction and assigned to assemblages according to the Péres and Picard (1964), Péres (1982), Poppe and Goto (1991, 1993) and Doneddu and Trainito (2005) classification systems. Both *in situ* and *extra situ* taxa have been identified on the basis of core lithology and shell preservation. Ostracods were picked from the dried sands fraction and assigned to four ecological groups: lagoonal, marine lagoonal, coastal and marine (Lachenal, 1989) on the basis of their ecological affinities. A minimum of 100 valves was picked and mounted on micropalaeotological slides. Lagoonal and marine lagoonal species are adapted to strong variations in temperature and salinity. Coastal species are adapted to dynamic nearshore contexts, and variations in temperature and salinity. Marine species tend to occupy the infralittoral and circalittoral zones; they are also euryhaline and eurythermal.

To constrain the rhythm and timing of tombolo formation, we isolated *in situ* marine molluscs, charcoal and wood fragments for radiocarbon dating. Sixteen samples were dated by AMS and calibrated to calendar years at 2σ (Reimer et al., 2009). Details of these results are reported in Table 1.

Chronostratigraphic results

Here we describe the litho- and biostratigraphical data based on three representative cores, from east to west: RIH IX, RIH III and RIH IV. Five chronostratigraphic units are elucidated consistent with the Holocene accretion of the tombolo. These have been categorized into units A–E.

Core RIH IX

Core RIH IX was drilled along the continental margin of the tombolo (Fig. 2) where ~6 m of Holocene fill record the marine transgression and progradation of the landward flank of the tombolo (Fig. 3; Supplemental Figs. 1 and 2).

Unit A is a silty sand unit (2.5 Y 7/3 light yellow) void of macro- and microfauna. It comprises 60–65% coarse sands. This unit represents late Pleistocene/early Holocene colluvions and denotes the pre-transgressive lowstand unit.

Unit B constitutes a shelly silt facies, brownish black (2.5 Y 3/2) to olive brown (2.5 Y 4/3) in colour. Radiocarbon dates from core RIH III, suggest that this unit accreted between ~9500 cal yr BP to ~7000 cal yr BP. The facies is dominated by silts and clays (47–98%). Molluscan tests are only present in the upper part of the unit and are dominated by the upper muddy-sand assemblage in sheltered areas, namely *Cerithium vulgatum* and *Loripes lacteus*. Secondary

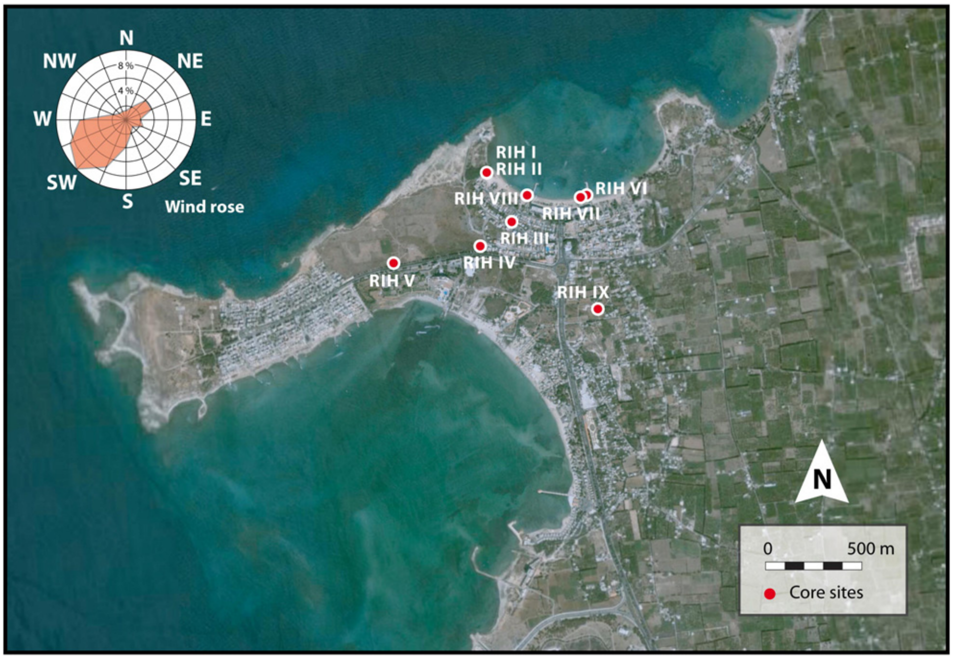


Figure 2. Aerial photograph of Ras Ibn Hani denoting the location of core sites (source GoogleEarth).

species include *Pirenella conica*, *Nassarius nitidus* (upper clean-sand assemblage), *Tricolia pullus*, *Rissoa lineolata* and *Mitra ebenus* (subtidal sands assemblage). Lagoonal (*Cyprideis torosa*) and opportunistic coastal species (*Urocythereis oblonga*, *Aurila woodwardii* and *Aurila convexa*) characterise the ostracofauna. The faunal density is high, ~520 ostracod tests for 10 g of sand. The litho- and biostratigraphical proxies corroborate an early Holocene marginal marine/lagoonal environment, forced by rising post-glacial sea levels and the ponding of catchment runoff behind the island of Ras Ibn Hani.

Unit C. The silty-clay unit B is onlapped by a poorly sorted (~1.3) coarse sand facies dated to ~7000 cal yr BP. There is a sharp increase in molluscan taxa, translating the Maximum Marine Ingression (MMI), dominated by the subtidal sands assemblage (*Tricolia tenuis*, *Tricolia pullus*, *Rissoa lineolata*, *Mitra ebenus* and *Glans trapezia*), the upper clean-sand assemblage (*Pirenella conica*, *Neverita josephinae* and *Nassarius nitidus*) and the upper muddy-sand assemblage in sheltered areas (*Loripes lacteus* and *Cerithium vulgatum*). High relative abundances of *Gibbula varia* (hard substrate assemblage) are reworked from proximal hard substrate outcrops. For the ostracofauna, a sharp decline in *Cyprideis torosa* is countered by marine lagoonal (*Xestoleberis communis* and *Xestoleberis dispar*) and coastal species (*Aurila convexa*, *Aurila woodwardii*, *Loxoconcha rhomboidea* and *Urocythereis oblonga*) with relatively high faunal densities of ~150 tests/10 g of sand.

Unit D. Transgressive ridges eventually breached the area with an onshore movement of coarse sand. Unit D is represented by poorly sorted medium to fine sands (1.4-1.5). An increase in the gravels fraction (10–50%) attests to a coarsening-up sequence concurrent with the rapid aggradation and progradation of the proto-tombolo. The macrofauna is dominated by the upper muddy-sand assemblage in sheltered areas (*Loripes lacteus* and *Cerithium vulgatum*). Secondary species include *Pirenella conica*, *Neverita josephinae*, *Nassarius nitidus* (upper clean-sand assemblage), *Tricolia tenuis*, *Tricolia pullus*, *Smaragdia viridis*, *Rissoa lineolata*, *Mitra ebenus*, *Glans trapezia* and *Cardita sulcata* (subtidal sands assemblage). The ostracofauna comprises marine lagoonal (*Xestoleberis communis* and *Xestoleberis dispar*) and coastal (*Aurila convexa*, *Aurila woodwardii*, *Loxoconcha rhomboidea*, *Urocythereis oblonga*, *Cytherelloidea sordida*, and *Hiltermannicythere rubra*) taxa. Outer marine species such as *Semicytherura incongruens*, *Loculicytheretta pavonia* and *Basslerites berchoni* are also drifted in. Species diversities (12–14 taxa) and faunal densities (200–560 tests/10 g sands) are high. This mixing of species is typical of a middle-energy shoreline and translates the gradual progradation of the mid-Holocene coastal system.

Unit E is marked by a sharp fall in the gravels fraction (<5%). The unit is dominated by moderately sorted medium to coarse sand (0.76–1) with a modal grain of ~0.6 mm. We obtained a date of 2515 ± 30 ^{14}C yr BP (2295–2095 cal yr BP) from the base of this unit. There is a sharp fall in species number (<3) and faunal densities, with just a few tests of *Cerithium vulgatum* (upper muddy-sand assemblage in sheltered areas), *Nassarius pygmaeus* (upper clean-sand assemblage), *Tricolia pullus* (subtidal sands assemblage) and *Conus mediterraneus* (hard substrate assemblage). The ostracofauna is made-up of marine lagoonal and coastal taxa, with a marked decrease in faunal densities (3–23 tests/10 g sand). The biosedimentological proxies are consistent with a subaerial beach and attest to the final phase of the tombolo's aggradation.

Core RIH III

Core RIH III was drilled on the central part of the tombolo (Fig. 2). A complete transgressive–regressive sequence is recorded by ~7 m of stratigraphy (Fig. 4; Supplemental figure. 3).

Unit A. Basal unit A constitutes an organic-rich peat void of marine macrofauna and microfauna. The unit is dated to the early Holocene (~10,400–9400 cal yr BP) and expresses the lowstand exposure surface.

Unit B is a dark silt and clay unit rich in organic content that accreted between 6675 ± 45 ^{14}C yr BP (7619–7460 cal yr BP) and 6203 ± 50 ^{14}C yr BP (6774–6503 cal yr BP). A rich macrofauna suite includes species from the upper muddy-sand assemblage in sheltered areas (*Cerithium vulgatum* and *Loripes lacteus*), the upper clean-sand assemblage (*Cyclope neritea* and *Pirenella tricolor*), the subtidal sands assemblage (*Tricolia tenuis*, *Tricolia speciosa*, *Rissoa lineolata*, and *Glans trapezia*) and the lagoonal assemblage (*Cerastoderma glaucum*). The tests are mostly intact and well preserved. The base of the unit is characterised by the monospecific domination of the euryhaline ostracod *Cyprideis torosa*, which attains high faunal densities of > 10,000 tests per 10 g of sand. Up the facies, *Cyprideis torosa* gives way to marine lagoonal (*Xestoleberis communis*) and coastal (*Loxoconcha rhomboidea*, *Urocythereis favosa*, *Aurila woodwardii*, and *Aurila convexa*) taxa.

Unit C comprises a shelly sand unit that began accreting ~6140 ± 30 ^{14}C yr BP (6660–6475 cal yr BP). The biofacies is dominated by the subtidal sands assemblage and the upper muddy-sand assemblage in sheltered areas, with occasional tests of hard substrate assemblage (*Gibbula racketti*, *Gibbula varia* and *Columbella rustica*) and algal species (*Alvania hispidula*). Species diversity is between 4 and 8. The ostracofauna is characterised by a sharp decline in *Cyprideis torosa*, replaced by species from the marine lagoonal (*Xestoleberis communis*) and coastal (*Aurila convexa*, *Aurila woodwardii*, *Heterocythereis albomac*, *Urocythereis favosa*, and *Loxoconcha rhomboidea*) assemblages. These biostratigraphical proxies support an opening up of the coastal environment consistent with the maximum marine ingression.

Table 1
Radiocarbon dates and calibrations (Reimer et al., 2009).

Laboratory code	Sample code	Material	^{14}C yr BP	Cal yr BP	^{13}C/^{12}C (‰)
LTL-4558A	RIH III 31	Marine shell	3947 ± 50	4095–3800	1.8
Ly-7310	RIH III 51	4 *Rissoa* spp.	6140 ± 30	6660–6475	2.44
LTL-4555A	RIH III 55	Marine shell	6203 ± 50	6774–6503	3.4
Ly-7313	RIH III 63	Seeds	6675 ± 45	7619–7460	NA
LTL-4556A	RIH III 65	Organic matter	8544 ± 60	9653–9440	NA
LTL-4554A	RIH III 71	Organic matter	9056 ± 65	10409–9935	NA
Ly-7314	RIH IV 12	2 *Loripes lacteus*	2720 ± 30	2550–2321	2.99
Ly-7315	RIH IV 21	4 *Loripes lacteus*	2915 ± 30	2763–2605	4.01
Ly-7316	RIH IV 27	3 *Loripes lacteus*	6245 ± 35	6796–6598	2.91
Ly-7317	RIH IV 29	2 *Loripes lacteus*	6315 ± 30	6874–6678	2.9
Ly-7318	RIH IV 36	Charcoal	6535 ± 40	7560–7332	NA
Ly-7319	RIH IX 7	1 *Fusinus pulchellus*	2515 ± 30	2295–2095	2.48
Ly-7321	RIH IX 23	2 *Tricolia tenuis* 1 *Nassarius louisi*	2895 ± 30	2745–2549	1.24
Ly-7322	RIH IX 32	6 *Loripes lacteus*	3275 ± 30	3225–2993	3.64
Ly-7323	RIH IX 39	1 *Cerithium vulgatum*	6340 ± 30	6901–6710	3.07
Ly-7324	RIH IX 42	2 *Cerithium vulgatum*	6505 ± 35	7138–6911	1.64

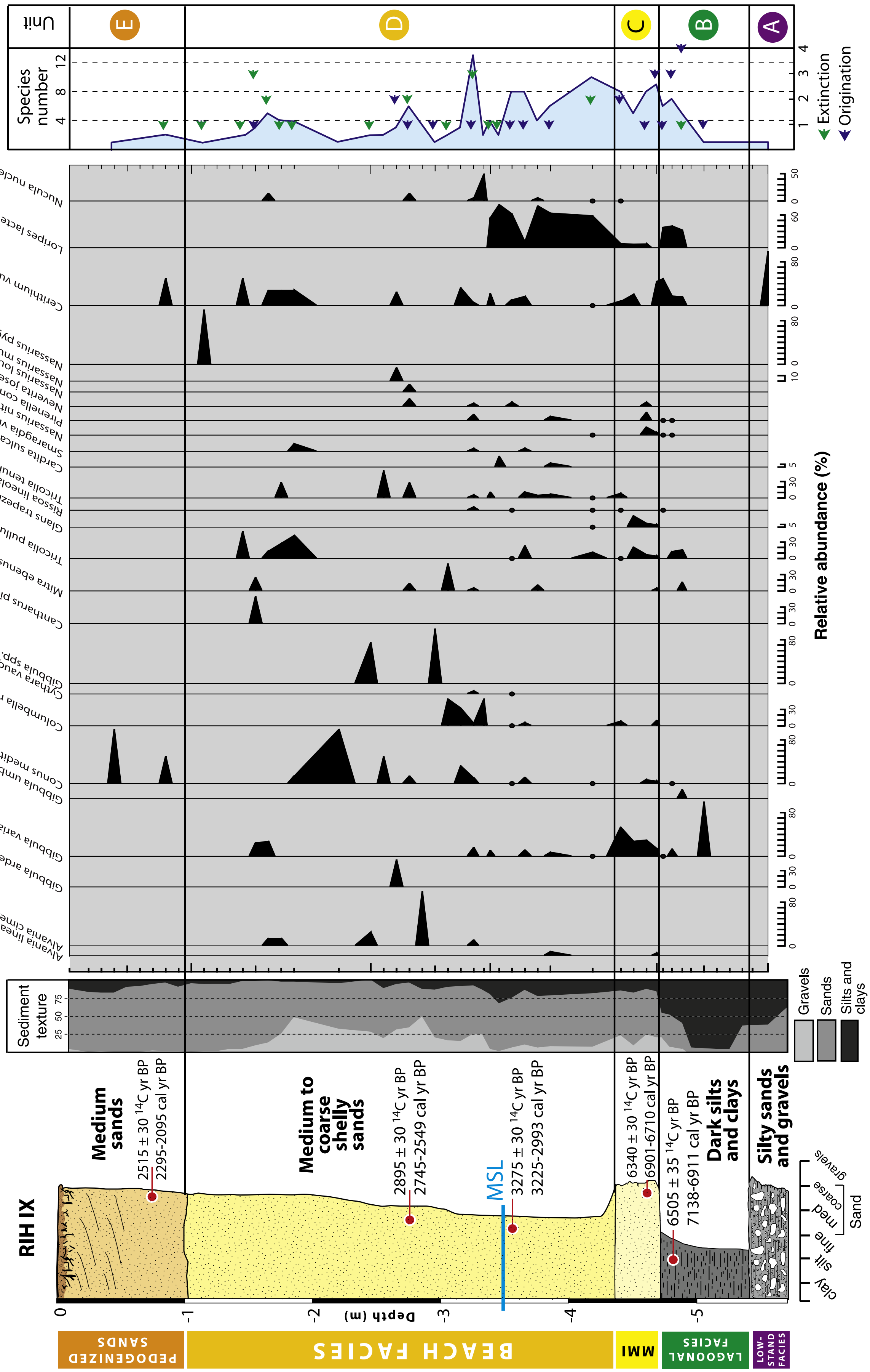


Figure 3. RIH IX marine macrofauna.

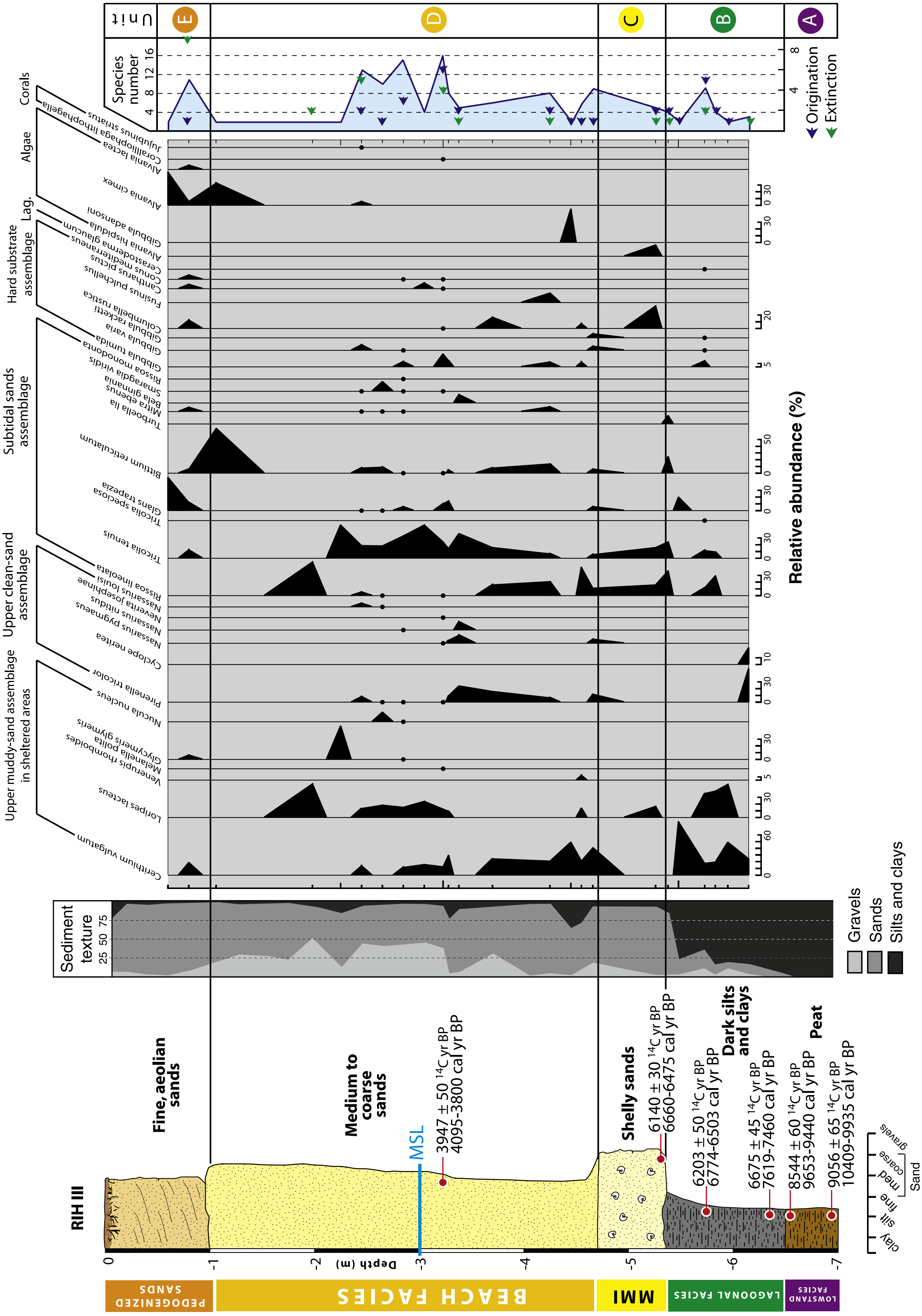


Figure 4. RIH III marine macrofauna.

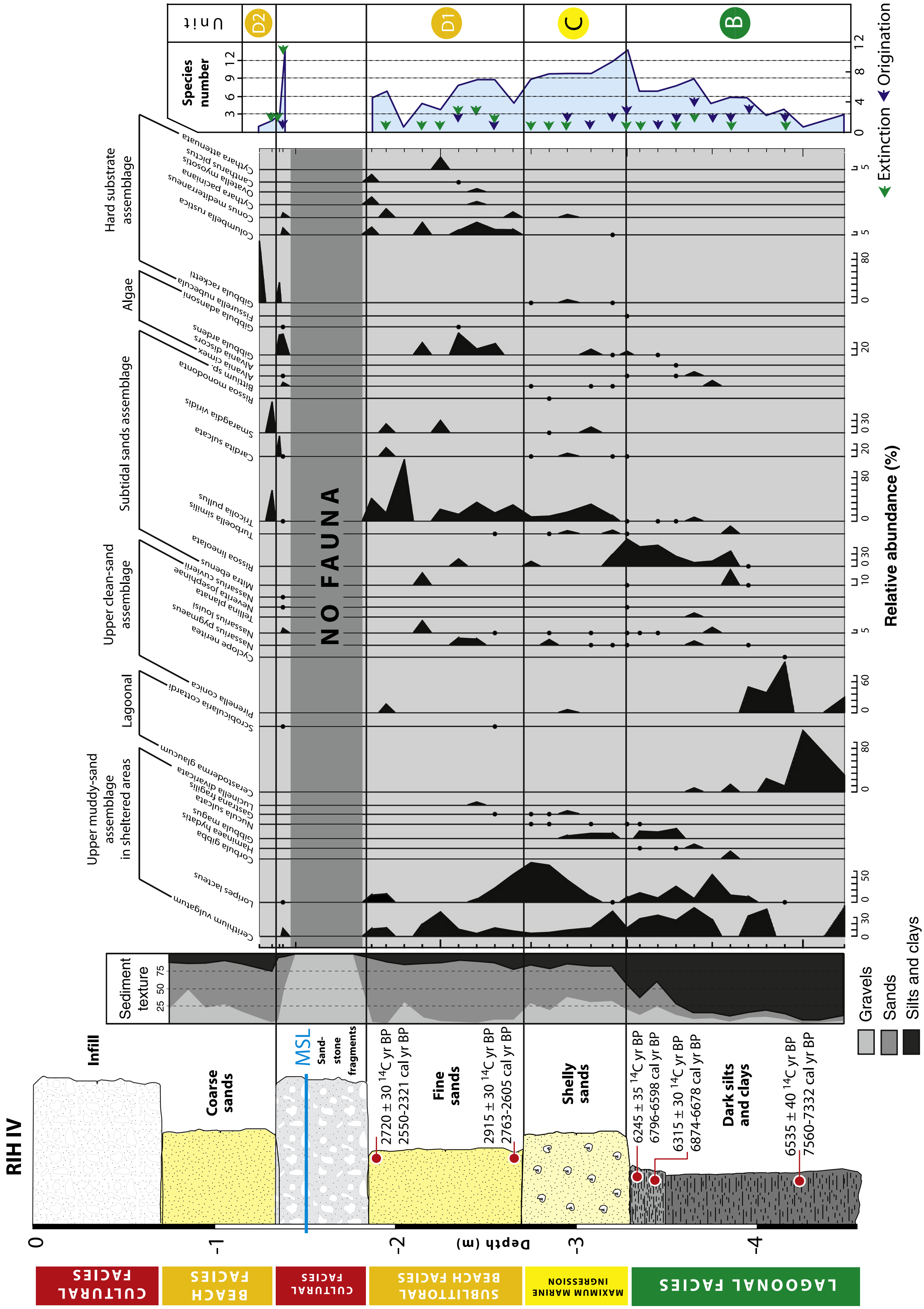


Figure 5. RIH IV marine macrofauna.

Unit D is a medium to coarse-grained sand unit dominated by species from the upper clean-sand assemblage (*Cerithium vulgatum*, *Glycymeris glymeris* and *Loripes lacteus*), the subtidal sands assemblage (*Tricolia tenuis*, *Tricolia speciosa*, *Turboella lia*, *Rissoa lineolata*, *Glans trapezia* and *Bittium reticulatum*) and the upper muddy-sand assemblage in sheltered areas (*Pirenella tricolor*, *Neverita josephinae*, *Nassarius pygmaeus* and *Nassarius nitidus*). Species diversity gradually decreases up-core from ~8 at the base to <4 towards the top. The ostracofauna constitutes marine lagoonal and coastal species. These litho- and biostratigraphical data corroborate the accretion of a beach facies.

Unit E is characterised by a pedogenized medium to fine-grained sand unit of supralittoral origin. We observe a sharp fall in ostracod species diversity, essentially reworked from the beach face.

Core RIH IV

Core RIH IV lies on the western flank of the 'island' of Ras Ibn Hani (Fig. 2). Around 4.5 m of fill have accumulated since the Holocene marine transgression. Three chronostratigraphic units have been elucidated (Fig. 5; Supplemental Figs. 4 and 5).

Unit B. Basal unit B comprises poorly sorted (1–1.7) dark silts and clays (up to 95%). The unit is rich in marine macrofauna, including species from the lagoonal assemblage (*Cerastoderma glaucum*), the upper muddy-sand assemblage in sheltered areas (*Cerithium vulgatum*, *Loripes lacteus*, *Corbula gibba*, *Nucula sulcata*, *Haminaea hydatis* and *Gibbula magus*), the upper clean-sand assemblage (*Pirenella conica*, *Tellina planate*, *Nassarius pygmaeus*, *Nassarius louisi* and *Cyclope neritea*) and the subtidal sands assemblage (*Tricolia pullus*, *Turboella similis*, *Rissoa lineolata* and *Mitra ebenus*). Lagoonal (*Cyprideis torosa*) and opportunistic coastal (*Aurila woodwardii*, *Aurila convexa* and *Loxoconcha rhomboidea*) ostracod taxa characterise the microfossils. Ostracod faunal densities are very high (848–2049 tests/10 g sand). These data translate a sheltered lagoon environment until ~6500 cal yr BP.

Unit C. Transition to a poorly sorted medium to coarse sand unit is consistent with retrograding berm ridges, reworking sediment stocks during the transgression of the lagoon environment after ~6500 cal yr BP. The marine macrofauna concur a well-sheltered marine environment with species from the upper muddy-sand assemblage in sheltered areas (*Nucula sulcata*, *Loripes lacteus*, *Gastrana fragilis*, *Gibbula magus* and *Cerithium vulgatum*), upper clean-sand assemblage (*Pirenella conica*, *Neverita josephinae*, *Nassarius pygmaeus*, *Nassarius cuvierii* and *Cyclope neritea*) and the subtidal sands assemblage (*Tricolia pullus*, *Turboella similis*, *Smaragdia viridis*, *Rissoa monodonta*, *Rissoa lineolata* and *Cardita sulcata*). A rise in marine-lagoonal (*Xestoleberis dispar* and *Xestoleberis communis*) and coastal (*Aurila woodwardii*, *Aurila convexa*, *Loxoconcha rhomboidea* and *Cytherelloidea sordida*) ostracod taxa is to the detriment of the formerly abundant *Cyprideis torosa*.

Unit D is consistent with a coarsening-up beach, tracing the aggradation of the proto-tombolo. It can be subdivided into two subfacies D1 and D2 intercalated by a coarse layer, probably of anthropogenic origin. The lower part of the unit (Unit D1) comprises a moderately to poorly sorted fine sand unit. The mode is between 63 and 100 μm attesting to a low-energy sublittoral environment sheltered by the extensive breakwater barrier. The marine macrofauna is characterised by the upper muddy-sand assemblage in sheltered areas (*Cerithium vulgatum*, *Loripes lacteus* and *Lucinella divaricata*), the subtidal sands assemblage (*Tricolia pullus*, *Turboella similis*, *Smaragdia viridis*, *Rissoa lineolata*, *Mitra ebenus* and *Cardita sulcata*) and the upper clean-sand assemblage (*Pirenella conica*, *Nassarius pygmaeus* and *Nassarius louisi*). The ostracods, with faunal densities of 187–265 tests/10 g sand, are dominated by marine lagoonal (*Xestoleberis dispar* and *Xestoleberis communis*) and coastal taxa (*Aurila convexa*, *Aurila woodwardii*, *Loxoconcha rhomboidea*, *Callistocythere mediterranea*, *Urocythereis oblonga* and *Cytherelloidea sordida*), with a number of marine species being drifted in from offshore areas during periods of high swell and storms. An increase in coastal ostracod taxa corroborates an accreting subaqueous salient.

From 135 to 185 cm a unit of sandstone fragments is observed. This facies is void of marine fauna. We speculate that it is linked to human activities, for instance artificial infill of a flood-prone area.

Unit D2 comprises a medium to coarse sand unit, with high proportions of gravel (25–50%). Only the bottom part of the unit yielded macrofauna, with taxa from the upper muddy-sand assemblage in sheltered areas (*Cerithium vulgatum* and *Loripes lacteus*), the upper clean-sand assemblage (*Nassarius louisi*, *Neverita josephinae* and *Nassarius cuvierii*), the subtidal sands assemblage (*Tricolia pullus*, *Cardita sulcata*, *Smaragdia viridis* and *Bittium* sp.) and the hard substrate assemblage (*Gibbula racketti*, *Columbella rustica* and *Conus mediterraneus*). The ostracofauna is characterised by the same species as unit D1.

Discussion and interpretations

Ras Ibn Hani's tombolo provides clear evidence for widespread landscape changes during the Holocene that can be linked to sea-level transgression, sediment forcing agents and human impacts. The first-order stratigraphy of the Ras Ibn Hani sequence constitutes an upward coarsening coastal succession ~5–8 m thick (Fig. 6). In this section, we (i) compare and contrast chronostratigraphic data from the different cores to define a morphodynamic model for the evolution of the peninsula (Fig. 7); and (ii) discuss a series of working hypotheses regarding the settlement's ancient anchorages.

Tombolo morphogenesis

On the basis of our analyses, four morphogenetic phases can be distinguished in the accretion of Ras Ibn Hani's tombolo. These are discussed from oldest to youngest.

Early Holocene pre-transgressive facies

West of Ras Ibn Hani the continental shelf is narrow, reaching depths of 400–600 m before falling steeply into the north Levantine basin (Krasheninnikov et al., 2005). During the late Pleistocene and early Holocene, the shoreline lay <1 km seaward of the study area. The stratigraphy is represented by colluvial deposits (gravels and sands) in core RIH IX, and an early Holocene peat layer in cores RIH III (unit A) and RIH VII. Marine fossils and microfossils are absent from these facies. After the Last Glacial Maximum, when global sea level lay around 120 m below present, transgression of the continental platform gradually displaced coastal populations landwards until broad sea-level stability led populations to settle along present coastlines.

The coastal sequence lies unconformably on the lowstand exposure surface and can be structured into: (i) the early Holocene marine transgression, and (ii) the morphogenesis of the proto-tombolo.

The Holocene marine transgression comprises two stages

The marine flooding surface is dated to ~8000 cal yr BP, coherent with delta initiation recorded throughout the circum Mediterranean (Stanley and Warne, 1994; Anthony, 2009). Under a context of rising sea level, the lowstand peat and colluvial deposits were covered by organic-rich muds (>80% silts and clays). Marine shells are mainly intact and well preserved. The litho- and biostratigraphical signatures translate low-energy lagoon environments (unit B, Fig. 8). This period corresponds to the Early Holocene Humid Phase and we infer a ponding of freshwater runoff from the hinterland plain behind Ras Ibn Hani to produce the brackish water conditions. Similar environments have also been attested at Tyre (Marriner et al., 2007). At this time, Ras Ibn Hani acted as a natural, shore-parallel breakwater.

The Maximum Marine Ingression (MMI) is characterised by a gradational transition to sand-dominated sediments (unit C, Fig. 8). This surface is dated to around 6000 cal yr BP and marks the maximum marine incursion (Stanley and Warne, 1994). It is associated with the most landward position of the shoreline. In the eastern Mediterranean, this phase marks a period when human societies began to settle along present coastlines. On the Levantine coast, the MMI shoreline clearly delineates the geography of early coastal settlements from this period (Morhange et al., 2005). The coarse, irregular bedding is typical of transgressive units characterised by the reworking of older sediment stocks from shelf areas and a sharp decline in brackish-lagoonal and lagoonal fauna. The chronostratigraphic evidence attests to a time-transgressive trend for this progradation wedge, beginning ~6340 ± 30 ^{14}C yr BP (6901–6710 cal yr BP) along the continental margin (RIH IX), and following a few hundred years later in the more westward cores RIH III and RIH IV.

Tombolo accretion phase

By ~6000 years ago, a slowing of sea-level rise (1 to 3 mm yr^{-1}; Fleming et al., 1998) resulted in a partial infilling of the bay by shelf and fluvial sediments that were reworked landwards by wave-dominated currents. Relative sea-level stability impinged on the creation of new accommodation space, leading to the aggradation of sediment strata. In the Levant, this was particularly pronounced in sediment-rich coastal areas such as deltas and at the margins of fluvial systems. Wave diffraction and attenuation resulted in the deposition of a medium to fine-grained facies on the leeward side of the Ras Ibn Hani barrier. Sunamura and Mizuno (1987) have calculated that a tombolo forms where the ratio of the island's offshore distance to its length is equal or less than 1.5; a salient forms where it is 1.5–3.5, and no protrusion of the coast occurs where it is greater than 3.5. At Ras Ibn Hani, the present ratio is 0.35 confirming that the lateral extent of the island barrier, and its close proximity to the shoreline, was particularly conducive to the morphogenesis of the tombolo. High relative abundances of marine lagoonal and coastal taxa corroborate a sublittoral sandbank protected by the island.

Two broad periods can be identified in the formation of the sandbank. Between ~6000 and ~3500 cal yr BP relatively low accretion values support both rapidly exhausted shelf supply following the marine transgression and low sediment inputs by local fluvial systems within the context of well-vegetated catchments (unit D, Fig. 8). We suggest that a dense tree cover, by increasing rainfall interception and inhibiting runoff, yielded only modest sediment supply to coastal depocentres that was preferentially entrapped at fluvial outlets.

This situation, however, appears to have changed after ~3500 cal yr BP, with the switch from a 'neutral' to a positive (two to fourfold increase) sediment budget concurrent with a pulse in alluvium. Fronted by the island barrier, the combination of high terrigenous sediment yield and low-energy wave processes permitted the rapid expansion of the sandbank (Fig. 9). This stratigraphic transition of Ras Ibn Hani's coastal system reflects a shift from vertical aggradation to a more progradational trajectory, characterised by a rough upward-coarsening pattern. These data fit tightly with the region's fluvial archives, many of which show an increase in soil erosion driven by Bronze Age

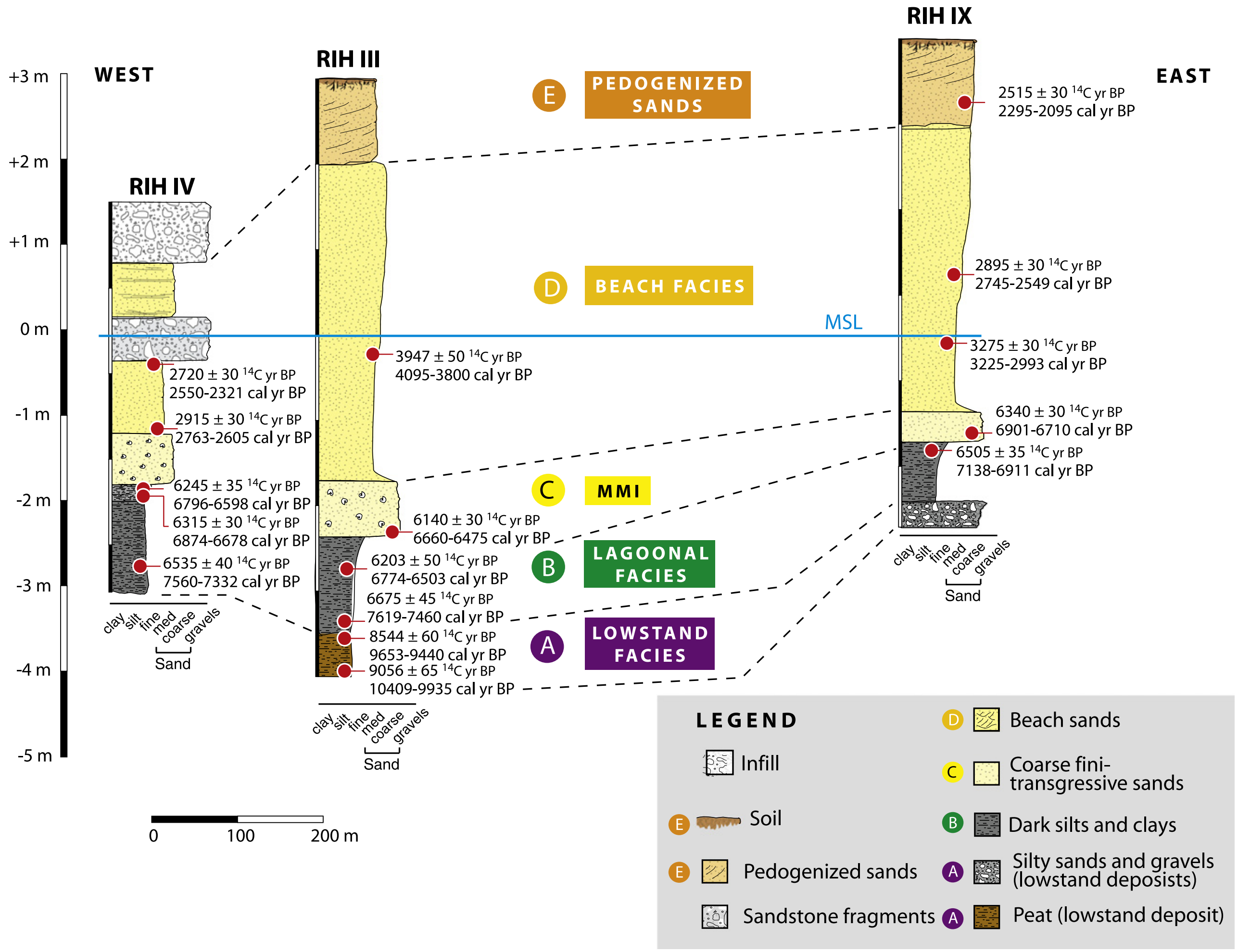
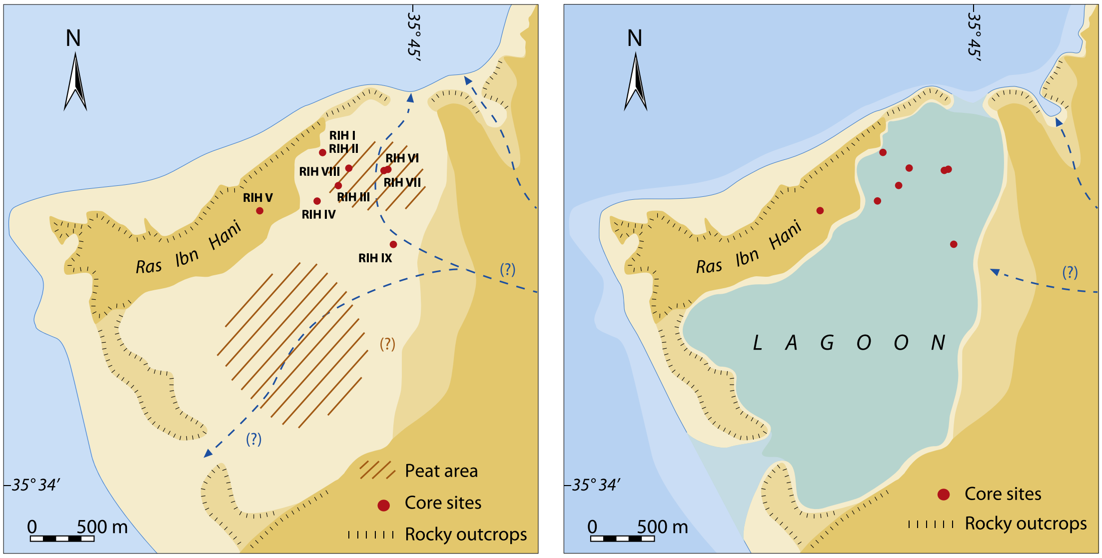
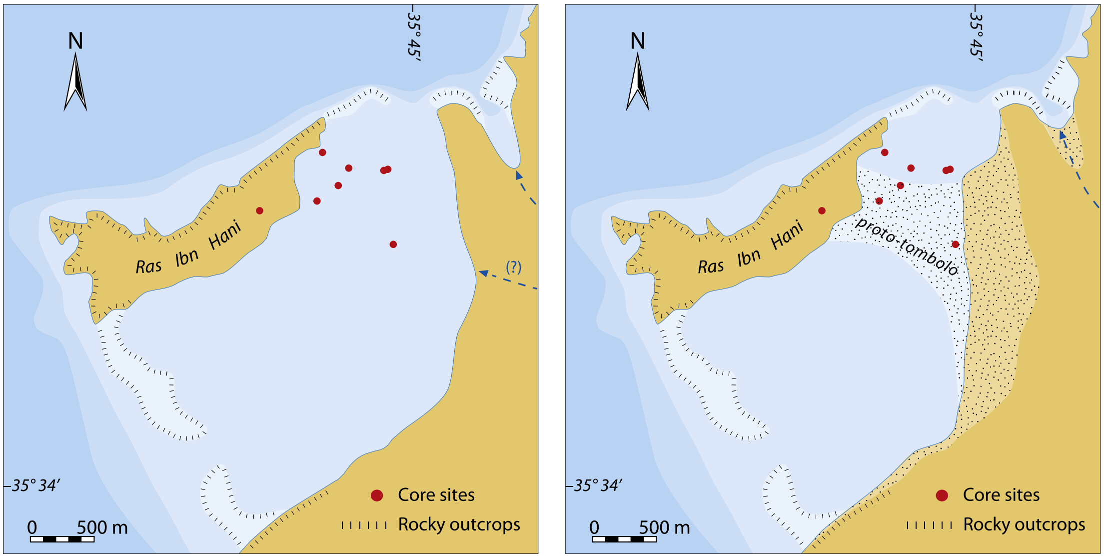


Figure 6. East to west transect of Ras Ibn Hani's tombolo stratigraphy.



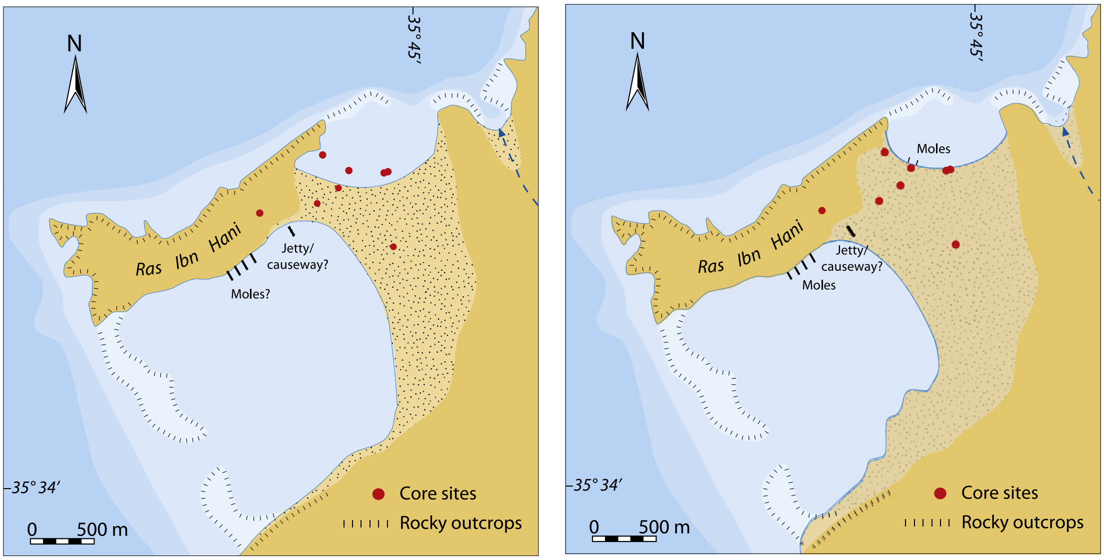
LOWSTAND LANDSCAPE - 10500 to 9500 cal. B. P.

LAGOONAL LANDSCAPE - 7500 to 6500 cal. B. P.



MAXIMUM MARINE INGRESSION - 6500 to 6000 cal. B.P.

PROTO-TOMBOLO - around 4000 cal. B.P.



LATE BRONZE AGE/IRON AGE

XXth CENTURY LANDSCAPE - 1980's

Figure 7. Hypothesized Holocene palaeogeography of the Ras Ibn Hani peninsula.

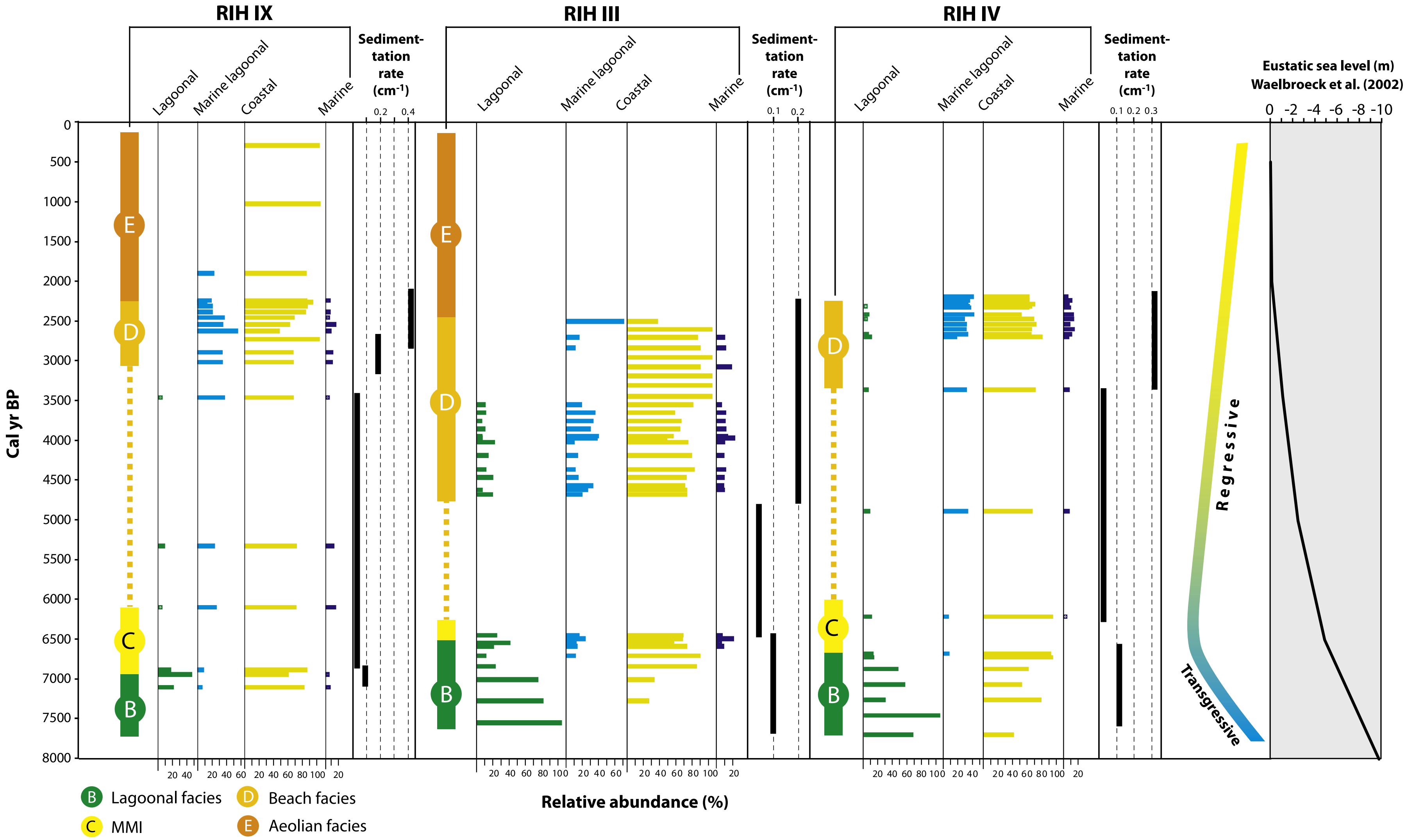


Figure 8. Evolution of Ras Ibn Hani sedimentological facies and ostracofauna assemblages during the past 8000 years. Eustatic sea-level data from Waelbroeck et al. (2002).

human impacts and environmental degradation (Geyer and Sanlaville, 1991; Wilkinson, 1999; Yasuda et al., 2000; Kuzucuoglu et al., 2004; Neumann et al., 2007; Deckers and Pessin, 2010). During the Late Bronze Age (3600 to 3200 cal yr BP) and early Iron Age, use of the plough and fruit cultivation became more commonplace (Akkermans and Schwartz, 2003). Furthermore, a pollen sequence from the nearby Rumailiah alluvial plain (Tell Tweini catchment) evokes a shift from an open deciduous forest towards a more arid/saline-tolerant vegetation cover, beginning ~3125 cal yr BP with a peak ~2850 cal yr BP (Kaniewski et al., 2008). A marked increase in cultivated species is also recorded during the third millennium BP (Kaniewski et al., 2010). A sparse tree cover and possible climate 'aridification' would have rendered local sediment generating catchments particularly sensitive to soil erosion during the flash flood-type events, acting as a key driver of geomorphological change at the regional scale.

We propose that this alluvial-derived sediment pulse created a positive feedback mechanism that rapidly raised the height of the sublittoral sandbank and accentuated the efficiency of sediment trapping. A similar pattern is also attested at Tyre (Marriner et al., 2007, 2008a), suggesting that Late Bronze Age/Iron Age human impacts were significant in modulating watershed erosion and rapid geomorphological change in Levantine coastal areas. Rapid infilling of many of the Levant's estuaries is also attested during this period (e.g., Morhange et al., 2005), characterised by the abandonment of estuarine harbors and settlements and relocation to more viable coastal sites away from silted-up fluvial outlets. By the beginning of the third millennium BP, a narrow subaerial tombolo probably linked the island of Ras Ibn Hani to the mainland. Rapid sediment entrapment might furthermore have been accentuated by the construction of a causeway between the Bronze Age island and the continent. For instance, Bounni et al. (1978) and Sanlaville (1978) have described a 6-m-wide jetty on the western side of the tombolo, southwest of core RIH III. The causeway/jetty trends northwest towards what the archaeologists believe to be the eastern entrance of the Southern Palace (Bounni et al., 1998). During their observations, this structure lay ~30–40 cm above the water table. Based on biochemical erosion marks on this structure, Sanlaville (1978) has attributed it to before the Hellenistic period, a hypothesis corroborated by radiocarbon dates of mortar binding the causeway's blocks: 3225 ± 55 ^{14}C yr BP and 2915 ± 50 ^{14}C yr BP (Dalongeville et al., 1993). A survey by Dalongeville et al. (1993) confirms that the 'causeway' was constructed upon the proto-tombolo sands.

Subaerial tombolo phase

Beach and dune sands cap the tombolo's highstand sequence and mark the transition to a supralittoral context. Archaeological remains and the radiocarbon chronology indicate that a subaerial tombolo was probably in place by ~3000 years ago. At present, however, the precise palaeogeography of this form is unclear. Supralittoral tombolo sands in the northern part of the tombolo were in place by the 3rd century BC because they support the walls of the town created by Ptolemy III (Bounni et al., 1978; Lagarce and Lagarce, 1978).

This geomorphological shift may have been accentuated by late Holocene neotectonic movements, characterised by ~1 m of coastal

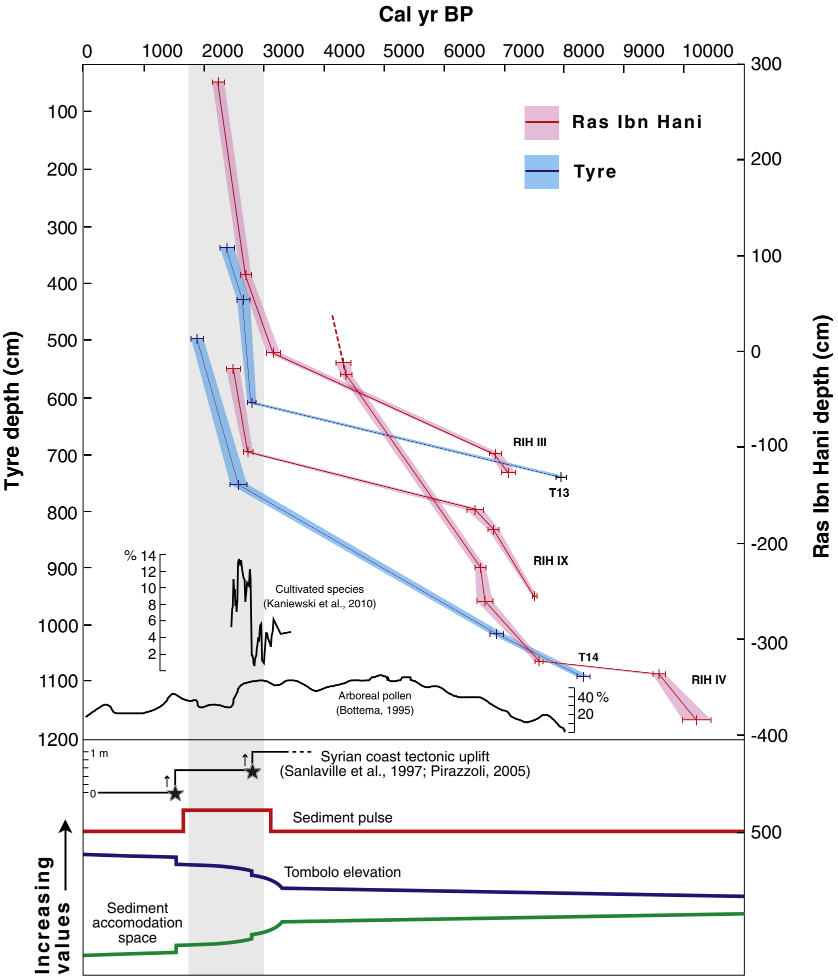


Figure 9. Age–depth plots for Ras Ibn Hani and Tyre's tombolos. Note the separate depth scales for Ras Ibn Hani (right) and Tyre (right). The bottom schematic diagram shows the effects of a pulse in sediment supply and coastal uplift on the morphogenesis of Ras Ibn Hani's salient. Arboreal pollen data from Bottema (1995).

uplift since the mid-third millennium BC (Dalongeville et al., 1993; Sanlaville et al., 1997; Pirazzoli, 2005). In a context of increased sediment supply to base-level depocentres, coastal uplift could potentially accentuate the efficiency of sediment trapping around the sandbank by reducing the accommodation space. Furthermore, sediment-trapping processes would have been accentuated by positive feedback mechanisms. Locally attested elevated shorelines demonstrate that this uplift took place in two phases. The uppermost shoreline at +100 cm accreted between ~6000 and 2900 ^{14}C yr BP (~6650 and ~2710 cal yr BP) before being uplifted by ~40 cm. A second lower shoreline at +60 cm formed between 2600 and 1800 ^{14}C yr BP and ended with coseimic uplift dated to the late Roman period (~1575 and 1381 cal yr BP). This uplift is related to the Holocene uplift of a 1000-km-long coastal stretch from Lebanon in the south (Sanlaville, 1977; Morhange et al., 2006; Elias et al., 2007) through to Turkey in the north (Pirazzoli et al., 1991; Pirazzoli, 2005), and resulting from the activation of the Levant Fault System and slip along transverse faults (Carton et al., 2009).

Ras Ibn Hani's ancient harbor environments

Although the Kingdom of Ugarit's coastline is ~80 km in length, geological inheritance means that the number of natural anchorages (estuaries, lagoons or sheltered bays) is relatively sparse. In this sense, the environmental potentiality of Ras Ibn Hani and the bay of Minet el-Beida around 3 km to the north is unique for the area and appears to have been particularly attractive to Bronze Age societies at a time when regional-scale trade was developing strongly.

The palaeo-island of Ras Ibn Hani accommodates a number of naturally sheltered areas whose use as an anchorage is conferred by undated harborworks (Weill, 1946; Dalongeville and Sanlaville, 1980), Late Bronze Age anchor finds and the importance of imported material from Cyprus, the Aegean and Egypt (Bounni et al., 1998). It has been suggested that Ras Ibn Hani was administrated as a suburban quarter of Ugarit, capital of the Kingdom, located on the tell of Ras Shamra (Bounni et al., 1998; Lagarce and Puytisson-Lagarce, 2008). Seen in this light, the settlement probably played some role in mediating maritime traffic with Ugarit, especially one when considers that Ras Ibn Hani is the closest point on the Levantine coast to Cyprus. Nonetheless, its function as an outer harbor complex (e.g., Carayon, 2003, 2008) in tandem with Minet el-Beida seems unlikely given the >3 km that separate the two complexes. The linear organisation of the area's port complexes is reminiscent of Tell Dor, which exploited a series of pocket beaches—fronted by a partially drowned Quaternary ridge—over more than 2 km (Kingsley and Raveh, 1994, 1996; Raban, 1995). Archaeological excavations attest to a near continuous occupation of the site from the Middle Bronze Age until the 3rd century BC (Stern, 1993); the maritime façade was used as a harbor complex throughout this period. Dor has notably yielded evidence for early constructed harborworks, possibly dating to the Bronze Age (Kingsley and Raveh, 1996).

During the Bronze Age, the Ras Ibn Hani peninsula provided mariners with a multiplicity of anchorage possibilities (Fig. 10). The coastal stratigraphy, coupled with our experience of Phoenicia's harbors (Marriner and Morhange, 2006, 2007; Marriner et al., 2006, 2008b,c; Marriner, 2009), allows us to propose a series of hypotheses.

Use of the present northern bay as a harbor area is corroborated by undated harborworks (Carayon, 2008). The coastal stratigraphy confirms a pocket beach environment at the northeastern extremity of the island (marked A on Fig. 10). This area lies in close proximity to the palatial complex and is well sheltered from the dominant southwesterlies. The impact of winter northeasterlies was probably relatively moderate because they are land-derived and do not generate significant swell in proximity to the coast. Our data suggest that the tombolo was already well developed by the Late Bronze Age, further reinforcing the natural protection of this pocket beach from the dominant swell direction. A series of jetties and moles are attested on the southern flank of the island (Fig. 10). These have been attributed to the Hellenistic period by Bounni et al. (1998) because of their alignment with the western Hellenistic wall. Nonetheless, they do stress that a Bronze Age chronology should not be excluded and Dalongeville et al. (1993) note that the architectural similarities

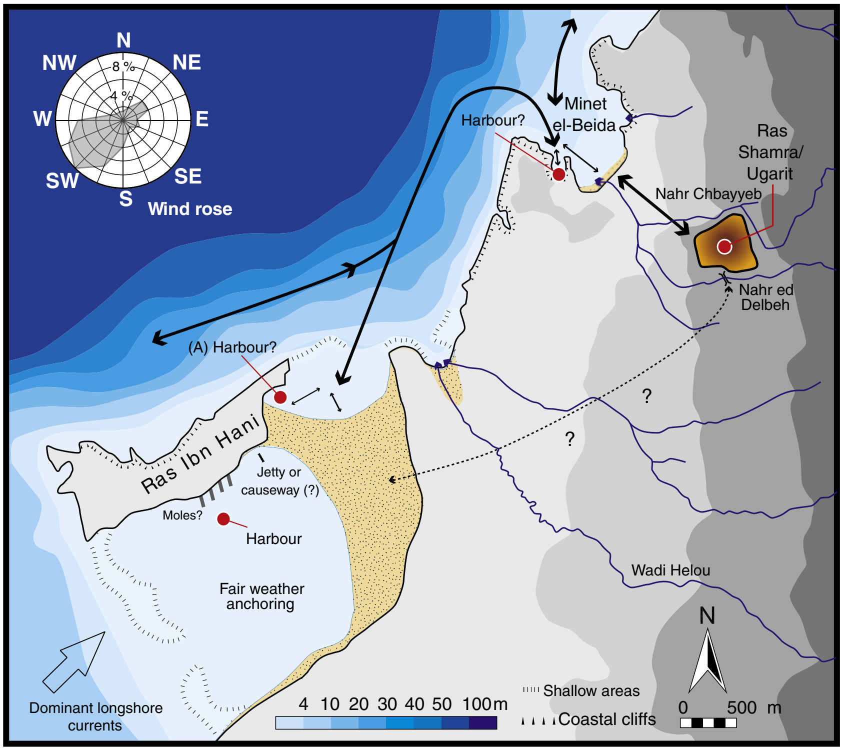


Figure 10. Schematic diagram of Ras Ibn Hani's harbor complex during the Late Bronze Age and speculated interconnections with Minet el-Beida and Ras Shamra.

between the ‘causeway’ and the moles suggest that they were constructed during the same period. Bounni et al. (1998) also speculate that the causeway could have been used to reinforce the natural separation between the two bays, northeast and south of the cape. It is of note that these southern moles lie in close proximity to the entrance of the Bronze Age city.

Ras Ibn Hani probably possessed a series of secondary anchorage areas to assure the day-to-day resourcing of the island settlement (Bounni et al., 1998). These almost certainly included outer anchorage areas that exploited the island barrier, and a continental beaching zone operating in tandem with the offshore hubs. Weill (1946) describes a rocky bar close to the water surface that closes the southern bay, with a 250-m passage into the cove. According to the present bathymetry, this bar is at least 200 m wide and would have acted as a breakwater obstacle for the southern bay's outer harbors, in addition to the harborworks attested along the southern flank of the island. Lighter vessels would have interlinked these complexes, as was commonplace during the Bronze and Iron Ages (Frost, 1995; Frost and Morhange, 2000; Carayon, 2003, 2008). After ~3000 cal yr BP, the northern bay, flanked by the subaerial tombolo, probably offered the best shelter from the predominant southwest winds and swell, where large vessels could anchor in the bay and smaller vessels be hauled up onto the beach face. A jetty of possible Hellenistic age in proximity to core RIH VIII confirms the importance of this bay as a harbor complex.

Conclusion

The vertical succession of coastal facies at Ras Ibn Hani is nearly identical to the Holocene tombolo sequence at Tyre (Lebanon). Taken together, these findings demonstrate that marine and fluvial boundary conditions, as well as the response of the two coastal systems to the Holocene marine transgression, were remarkably similar. This suggests that on wave-dominated coasts there is a great deal of predictability to tombolo geology and stratigraphy, a hypothesis that must be tested by future studies. Between 8000 cal yr BP and 6000 cal yr BP, relative sea-level change was the main control on Ras Ibn Hani's coastal dynamics. After 6000 cal yr BP, geological inheritance (through wave refraction and attenuation) and sediment supply were the key drivers of salient morphogenesis. The environmental potentiality of eastern Mediterranean tombolos—offshore breakwaters sheltering low-energy downwind façades—means that they played an important role in the foundation and development of many ancient coastal cities.

Supplementary data related to this article can be found online at doi:10.1016/j.yqres.2012.03.005

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