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Multi-proxy geoarchaeological study redefines understanding of the paleocoastlines and ancient harbours of Liman Tepe (Iskele, Turkey)

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ABSTRACT

Determining the position of Liman Tepe's (ancient 'Clazomenae') archaeological features relative to the coastline is important for understanding their intended function and reconstructing the character of Aegean maritime activities and sea-based trade. Previous attempts at reconstructing harbour locations at Liman Tepe relied on extrapolating paleoenvironments based on modern surface topography. In light of this, samples from a sediment coring survey and terrestrial and underwater archaeological excavations were analysed using multi-proxy geoarchaeological methods to determine paleoenvironmental facies. Micropaleontological (foraminifera), sedimentological (grain-size analysis) and geochemical ($\delta^{13}C/\delta^{18}O$) analyses resulted in the reconstruction of the coastal paleogeomorphology, including the presence and absence of ancient harbouring areas. Neither of the previous coastal reconstructions was supported by the new results. Instead, two separate harbouring areas were recognized, one coincident with the Early Bronze Age (4800–3900 years BP) and a second during the archaic and classical periods (*c.* 2800–2400 years BP). These results emphasize the necessity for multi-proxy geoarchaeological studies when approaching coastal archaeological sites as a means to reconstruct paleocoastal geomorphology and understand ancient maritime development better.

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Introduction

Previous paleogeographical reconstructions of the archaeological site Liman Tepe (Fig. 1) have been, like many coastal archaeological studies, limited to using topography and archaeological data from surface surveys to extrapolate previous coastline positions (see Ersoy, 1993). Beginning in 1999, underwater excavations of a submerged feature adjacent to the coastline brought previous coastal reconstructions into question and necessitated approaching the issue using extensive multi-core subsurface data analysed with multi-proxy environmental proxies. Paleogeographical coastal studies along archaeologically-rich coastlines are central to reconstructing ancient coastlines, understanding ancient maritime activities and estimating future coastal change (Reinhardt and Raban, 1999; Marriner and Morhange, 2007). At present, the accuracy of such studies is even more important given an exponentially increasing human population, expected sea-level rise as a result of global warming and projected coastal development.

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Lesser known, but no less significant than its contemporaneous neighbor Troy to the north, Liman Tepe played a major role in the development of trade linking the Mediterranean and Aegean to the Asian continent during the Chalcolithic (5500–4800 years BP) and Early Bronze Age (EBA 4800–3900 years BP) (Erkanal and Günel, 1996; Erkanal and Artzy, 2002; Şahoğlu, 2002, 2005). Subsequently, Liman Tepe became a member of the Ionian League, a confederacy formed as early as 800 BC, which played a significant role in the power struggles between Persians and Greeks, most famously during the Ionian Revolts (499–494 BC). These battles were the first phase of conflicts within the 'Greco-Persian Wars' (499–444 BC, Herodotus). A century later, a causeway built from the island to the mainland is credited to Alexander the Great (335 BC, Heisserer, 1980).

Researchers from the Izmir Region Excavations and Research Project provisionally identified a submerged feature as the remains of an EBA harbour structure on the basis of similarities in construction materials and proximity to the terrestrial EBA archaeological site (Fig. 1). Another reconstruction based on the distribution of surface and near-surface archaeological remains indicated a large bay during the archaic period (*c.* 2800 years BP, Ersoy, 1993; Fig. 1). Based on these observations, underwater archaeological excavations (University of Haifa and Ankara University) and a multi-proxy geoarchaeological study (McMaster University) were initiated to determine the origin and age of the submerged feature and to reconstruct more broadly the coastal landscape of Liman Tepe.

Methods

Terrestrial cores (0.5 to 5-m length) were collected with an Eijkelkamp percussion corer system. The underwater samples were collected by grab

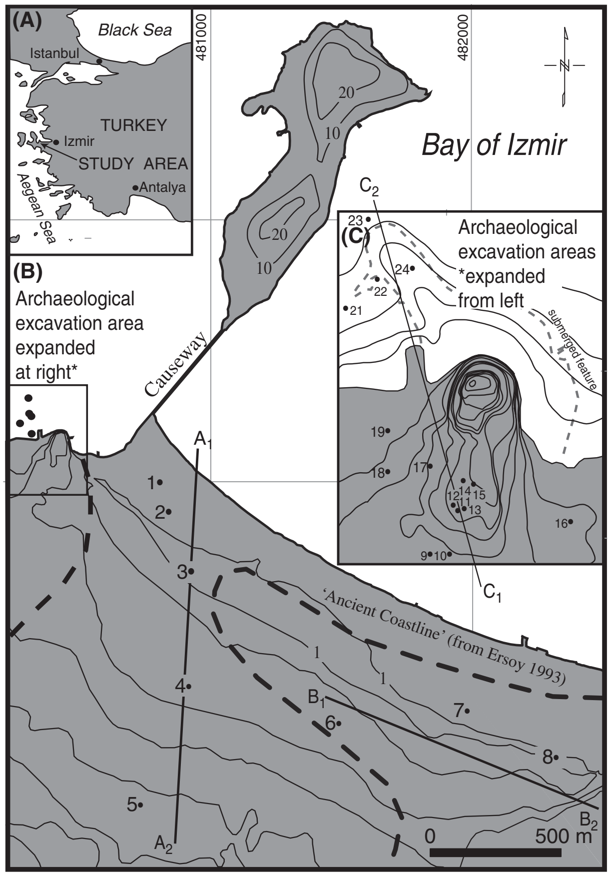


Fig. 1 Location of Liman Tepe. (A) Map of western Turkey. Study area is located west of Izmir. (B) Local map of study area with previous landscape reconstruction represented with a thick dashed line. (C) Expansion of archaeological excavation portion of the study site highlighted in map B. Transects A, B and C are indicated and coring locations are indicated with circles and associated core number. Unlabelled contours = 1 m.

sampling the exposed baulk sections within the archaeological trenches (see Dean *et al.*, 1994 for methods) and by collecting cores (2 to 4.5-m length) from the seabed.

The relative horizontal positions and chronological constraints of environmental facies (defined based on multiproxy analysis) were then compared to produce a model of coastal change. Previously analysed data (Goodman *et al.*, 2008) from outside the archaeological site (cores 1–8) were combined with data in this study (see Tables 1 and 2) to determine whether previously established facies categories were conserved and to consider those facies in the context of related anthropogenic activities. Micropaleontological analysis and environmental interpretations followed methods described in Scott *et al.* (2001) and Scott and Medioli (1986). Species of microfossils with a wide range of environmental tolerances were isolated to determine $\delta^{18}O$ and $\delta^{13}C$ values in the near-coastal environment (see Reinhardt *et al.*, 2001 and references therein). Overall averages for each biofacies were used to determine the presence of general environmental facies trends. An aliquot of each sample was subsampled and processed to determine particle-size distribution (methods Goodman *et al.*, 2008), which was then evaluated across cores. Comparative samples from the modern terrestrial surface and uppershoreface seafloor were analysed to provide a basis for defining environmental facies. Dated samples with known position relative to sea-level were plotted in comparison with previously established sea-level curves (see Figs 2 and 3).

Results

The paleogeography is reconstructed using the relative positions of environmental facies based on core summaries and sea level markers (Figs 2 and 3). Environmental facies include terrestrial, supratidal, wetland, foreshore, lagoon, upper shoreface, and harbour (see Tables 1 and 2).

The terrestrial biofacies are defined by an absence of or low foraminifera abundance (less than 2 specimens per cm^3, broken or eroded when present), silt-range grain-size average values and, in some cases, continuity with the modern surface (see Figs 2 and 3, Tables 1 and 2). The isotope value averages were $\delta^{18}O = -1.2‰$ (depleted by $-2‰$ relative to local seawater) and $\delta^{13}C = -2.4‰$ (local marine values *c.*1.5‰).

The foreshore facies is distinguished by low-abundance (average of eight specimens per cm^3) microfossils and therefore is distinguished from terrestrial primarily by grain-size averages, increased presence of marine fauna (e.g. marine gastropods, shell fragments) and position downcore. Grain-size averages range from fine to coarse sand and isotope value averages are $\delta^{18}O = -0.7‰$ and $\delta^{13}C = -2.4‰$.

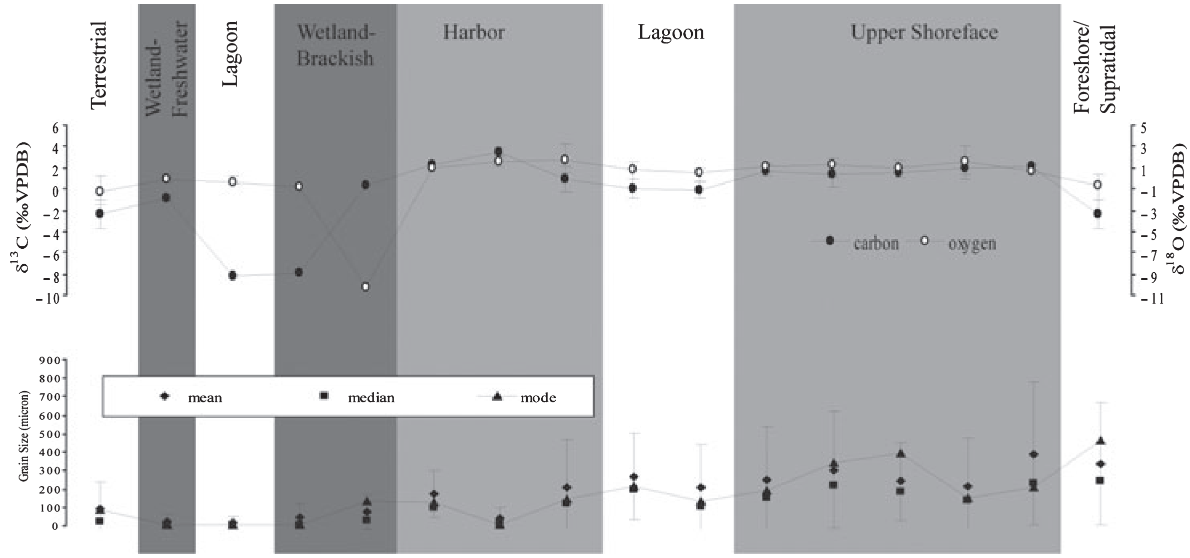
The lagoon facies is defined by *Haynesina, Ammonia* I and II biofacies groups. *Ammonia* I is distinguished by the dominance of *A. parkinsoniana* 'tepida' (71%) and *Trochammina* spp. The *Ammonia* II biofacies is distinguished by 19.3% *A. parkinsoniana* 'tepida', and similar abundances of *Rosalina brady, Eponides* sp A, *Elphidium macellum*, *Asteriginata mamilla*, and *Cibicides refulgens*. Grain-size averages range from fine to coarse sands with high standard deviation values. The *Ammonia* I isotope values are $\delta^{18}O = 0.0‰$ and $\delta^{13}C = 0.9‰$. *Ammonia* II values are $\delta^{18}O = -0.1‰$ and $\delta^{13}C = 0.5‰$. The $\delta^{13}C$ values of *Ammonia* I and *Ammonia* II are within marine values and the $\delta^{18}O$ values are about 1‰ depleted relative to seawater values.

A majority of samples (38 of 67) with high foraminiferal abundance clustered into the upper shoreface facies (marine). The five biofacies in this group include *Elphidium/Ammonia*

Table 1 Biofacies as determined by Ward's method clustering of normalized distributions of foraminifera. Table presents all foraminifera species in which abundance equals a minimum of 1% in a minimum of one biofacires after accounting for error. All diversity indexes determined using PAST software (Hammer *et al.*, 2001).

Biofacies	*Centropyxis/Difflugia*	*Trochammina* I	*Trochammina* II	*Rosalina*	*Bolivina*	*Brizalina*	*Haynesina*	*Ammonia* I	*Ammonia* II	*Elphidium/Ammonia* I	*Elphidium/Ammonia* II	*Elphidium/Ammonia* III	*Elphidium/Ammonia* IV	*Peneroplis*
Environmental Interpretation	Wetland-Freshwater	Wetland-Brackish		Harbour			Lagoon			Upper Shoreface				
Total no. of Samples	2 1σ	1 1σ	3 1σ	1 1σ	3 1σ	8 1σ	3 1σ	6 1σ	3 1σ	16 1σ	9 1σ	8 1σ	1 1σ	4 1σ
No. of individuals per cc	139 ± 47	16 ± –	28 ± 10	496 ± –	31 ± 1	325 ± 236	83 ± 10	286 ± 166	61 ± 28	756 ± 719	222 ± 342	41 ± 37	87 ± –	391 ± 155
Number of Taxa in sample	7 ± 1	17 ± –	3 ± 1	38 ± –	30 ± 37	35 ± 8	7 ± 4	9 ± 3	37 ± 5	42 ± 6	41 ± 8	27 ± 4	34 ± –	41±
Shannon H Diversity	0.75 ± 0.2	2.11 ± –	0.23 ± 0.2	2.20 ± –	2.79 ± 1.0	3.07 ± 0.2	1.2 ± 0.2	0.91 ± 0.3	3.04 ± 0.2	3.40 h0.2	3.29 ± 0.3	2.91 ± 0.2	1.94 ± –	3.31±
Abditodentrix rhomboidalis	– –	1.2 ± –	– –	0.3 ± –	2.2 ± 0.5	3.1 ± 2.4	– –	0.1 ± 0.2	3.3 ± 4.4	2.4 ± 2.0	0.7 ± 1.0	– –	0.4 ± –	0.7 ± 0.8
Ammonia parkinsoniana	0.8 ± 1.1	– –	– –	2.3 ± –	0.5 ± 0.5	2.5 ± 1.5	1.1 ± 0.8	6.5 ± 8.9	3.2 ± 4.3	1.4 ± 1.7	8.3 ± 4.3	6.7 ± 4.3	56.5 ± –	1.9 ± 2.8
Ammonia park. 'tepida'	1.1 ± 1.5	16.0 ± –	0.2 ± 0.3	– –	0.1 ± 0.2	0.8 ± 1.0	0.4 ± 0.4	71.4 ± 11.9	19.3 ± 4.5	2.6 ± 3.2	2.5 ± 2.5	0.8 ± 2.1	– –	2.3 ± 2.2
Ammonia sp. A	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –	0.2 ± 0.4	8.2 ± 5.2	– –	0.5 ± 0.5
Asterigerinata mamilla	– –	– –	– –	3.0 ± –	0.1 ± 0.2	1.6 ± 1.4	– –	– –	4.0 ± 2.7	1.3 ± 1.1	1.6 ± 1.4	2.2 ± 1.9	1.6 ± –	0.5 ± 0.3
Bolivina pseudoplicata	– –	1.2 ± –	0.3 ± 0.5	4.4 ± –	23.2 ± 4.3	6.1 ± 5.2	– –	– –	1.7 ± 0.8	2.1 ± 1.9	1.9 ± 1.3	0.6 ± 1.1	0.1 ± –	2.6 ± 2.1
Brizalina striatula	– –	0.6 ± –	– –	1.2 ± –	3.2 ± 0.8	8.3 ± 2.4	– –	0.2 ± 0.3	3.6 ± 3.1	1.7 ± 1.7	2.1 ± 2.2	1.2 ± 2.6	3.9 ± –	1.1 ± 1.6
Centropyxis aculeate	42.7 ± 11.4	2.5 ± –	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –
Centropyxis onstricta-silica	27.3 ± 11.2	– –	– –	– –	– –	0.3 ± 0.7	– –	– –	– –	– –	– –	– –	– –	– –
Cibicides refulgens	– –	– –	– –	3.0 ± –	3.1 ± 1.8	4.3 ± 2.1	– –	– –	4.0 ± 2.5	3.5 ± 1.9	3.3 ± 2.2	2.7 ± 2.7	0.1 ± –	1.6 ± 0.4
Cornuspira foliacea	– –	– –	– –	0.1 ± –	4.1 ± 2.2	0.2 ± 0.3	– –	– –	0.1 ± 0.1	0.5 ± 0.8	0.1 ± 0.2	0.2 ± 0.7	– –	0.8 ± 0.8
Difflugia oblonga	25.5 ± 3.0	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –
Elphidium advenum	0.2 ± 0.2	– –	– –	0.3 ± –	1.2 ± 0.6	2.6 ± 1.4	– –	– –	2.2 ± 1.6	3.2 ± 1.5	4.4 ± 1.7	8.7 ± 7.4	3.8 ± –	4.7 ± 0.7
Elphidium jenseni	– –	– –	0.2 ± 0.4	3.5 ± –	1.6 ± 1.4	3.2 ± 2.8	– –	0.6 ± 1.4	2.7 ± 2.3	2.5 ± 1.4	3.0 ± 2.4	0.8 ± 2.2	4.5 ± –	1.6 ± 1.7
Elphidium macellum	0.2 ± 0.2	0.6 ± –	– –	3.4 ± –	0.8 ± 1.5	2.3 ± 1.7	– –	0.1 ± 0.1	4.8 ± 2.5	3.1 ± 2.7	7.0 ± 1.9	5.2 ± 3.6	5.7 ± –	4.2 ± 1.1
Elphidium translucens	– –	– –	– –	3.0 ± –	– –	3.5 ± 4.2	– –	– –	2.4 ± 3.6	1.8 ± 1.0	2.3 ± 1.4	1.3 ± 1.0	2.0 ± –	0.9 ± 0.9
Eponides sp. A	– –	3.1 ± –	– –	1.7 ± –	2.7 ± 2.4	3.5 ± 3.5	– –	– –	6.2 ± 1.2	4.7 ± 1.9	4.5 ± 2.6	3.7 ± 3.5	1.2 ± –	2.6 ± 2.3
Haynesina depressula	– –	– –	– –	– –	– –	6.0 ± 6.0	9.6 ± 6.1	1.5 ± 3.5	4.1 ± 3.2	3.9 ± 2.1	4.2 ± 4.0	1.1 ± 2.1	4.3 ± –	1.5 ± 1.4
Haynesina sp. D	– –	– –	– –	– –	– –	– –	78.0 ± 9.9	– –	– –	– –	– –	– –	– –	– –
Miliolinella sp. B	– –	0.6 ± –	– –	2.1 ± –	7.0 ± 3.5	2.7 ± 2.0	– –	– –	0.6 ± 0.6	4.4 ± 2.7	1.2 ± 1.2	– –	0.3 ± –	2.4 ± 1.9
Peneroplis pertusus	– –	– –	– –	0.1 ± –	0.2 ± 0.4	0.1 ± 0.3	– –	– –	– –	0.3 ± 0.6	0.3 ± 0.7	1.3 ± 1.9	– –	11.1 ± 5.6
Pseudotriloculina cuneata	– –	3.1 ± –	– –	0.1 ± –	3.7 ± 1.0	1.0 ± 1.5	– –	0.2 ± 0.4	2.1 ± 0.9	4.5 ± 1.6	2.7 ± 1.8	0.3 ± 0.6	0.7 ± –	2.3 ± 3.5
Pseudotriloculina laevigata	– –	0.6 ± –	– –	1.8 ± –	5.6 ± 1.1	0.3 ± 0.4	– –	– –	0.7 ± 0.8	1.4 ± 1.4	0.5 ± 0.6	0.1 ± 0.2	0.1 ± –	1.3 ± 2.0
Quinqueloculina patagonica	– –	1.8 ± –	– –	1.7 ± –	7.8 ± 3.5	2.2 ± 2.4	– –	– –	1.2 ± 2.1	2.3 ± 1.1	2.1 ± 1.9	0.6 ± 0.9	0.1 ± –	1.1 ± 0.8
Rosalina bradyi	– –	0.6 ± –	0.1 ± 0.2	50.7 ± –	1.3 ± 0.8	7.1 ± 2.9	– –	– –	4.9 ± 0.7	5.6 ± 3.4	7.2 ± 6.4	3.1 ± 2.6	– –	2.4 ± 1.3
Rosalina floridensis	– –	– –	– –	2.8 ± –	3.6 ± 1.5	3.7 ± 4.3	– –	– –	– –	2.5 ± 3.0	0.7 ± 0.6	0.6 ± 0.9	– –	0.7 ± 0.8
Triloculina subgranosum	– –	– –	– –	0.5 ± –	– –	– –	– –	4.1 ± 5.7	– –	– –	– –	0.4 ± 0.8	– –	– –
Trochammina inflate	– –	21.5 ± –	5.7 ± 9.9	– –	0.6 ± 0.3	4.5 ± 6.2	– –	2.1 ± 4.1	2.1 ± 1.2	0.3 ± 0.7	0.5 ± 0.8	– –	0.4 ± –	0.5 ± 0.9
Trochammina macracens	– –	15.3 ± –	– –	– –	– –	0.2 ± 0.4	– –	2.8 ± 4.9	0.9 ± 0.9	0.4 ± 0.9	0.7 ± 1.6	– –	– –	– –
Trochammina sp. A	0.8 1.1	23.3 ± –	93.1 ± 9.4	– –	– –	0.1 ± 0.3	– –	– –	– –	– –	– –	– –	– –	– –
Total Represented %	98	92	100	86	73	70	89	90	74	56	62	50	86	49

Table 2 Average isotope and grain size values in environmental facies. Standard deviation of values is one sigma. Values with no standard deviation had only one sample in the biofacies. Low abundance samples have less than foraminifera per cm^3.



Biofacies	Low Abundance Sample	*Centropyxis/ Difflugia*	*Haynesina*	*Trochammina*		*Rosalina*	*Bolivina*	*Brizalina*	*Ammonia*		*Elphidium/ Ammonia*				*Peneroplis*	Low Abundance Sample
Sub-biofacies				I	II				I	II	I	II	III	IV		
Environment	Terrestrial	Wetland-Freshwater	Lagoon	Wetland-Brackish		Harbor			Lagoon		Upper Shoreface					Foreshore/ Supratidal
$\delta^{13}C$(‰)	−2.4 ± 1.3	−0.9 ± 0.3	−8.2 ± 0.1	−7.9	0.3	2.3	3.5 ± 0.5	0.9 ± 1.2	0.0 ± 0.9	−0.1 ± 0.8	1.7 ± 0.5	1.3 ± 1.1	1.6 ± 0.5	2.0 ± 1.1	2.1 ± 0.3	−2.4 ± 1.4
$\delta^{18}O$ (‰)	−1.2 ± 1.5	−0.1 ± 0.5	−0.4 ± 0.6	−0.8	−10.3	1.0	1.6 ± 0.6	1.8 ± 1.4	0.9 ± 0.7	0.5 ± 0.5	1.1 ± 0.4	1.2 ± 0.7	1.0 ± 0.7	1.5 ± 1.6	0.7 ± 0.5	−0.7 ± 1
Grain Size																
Average (μ) Mean	94 ± 62	25 ± 12	17 ± 10	44	73 ± 105	172	38 ± 11	211 ± 102	268 ± 297	209 ± 184	250 ± 114	303 ± 158	242 ± 157	215	392 ± 46	335 ± 200
Average (μ) Median	23 ± 20	6 ± 0	4 ± 1	6	27 ± 39	99	11 ± 3	125 ± 45	200 ± 246	105 ± 86	149 ± 78	221 ± 142	184 ± 118	140	233 ± 88	244 ± 216
Average (μ) Mode	86 ± 171	6 ± 1	5 ± 0	4	133 ± 223	128	6 ± 1	148 ± 34	217 ± 245	136 ± 15	193 ± 199	345 ± 428	394 ± 430	154	209 ± 108	465 ± 339
Average (μ) Std Dev	146 ± 83	41 ± 25	35 ± 21	80	93 ± 119	128	61 ± 13	258 ± 127	235 ± 195	232 ± 203	291 ± 117	316 ± 122	213 ± 179	262	388 ± 65	331 ± 132

I-IV and *Peneroplis*. *Elphidium/ Ammonia* clusters I-IV consist of high-diversity samples containing shoreface-preferring taxon. The *Elphidium/ Ammonia* biofacies have a greater than 10% presence of major abundance of *Elphidium* (*E. advenum, E. jenseni, E. macellum, E. translucens*) and the presence of *A. parkinsoniana*. The *Peneroplis* cluster is dominated by *P. pertusus* (11%), *Elphidium advenum* (4.7%), and *E. macellum* (4.2%). All upper shoreface facies grain-size averages range from fine to coarse sands with large standard deviations, indicating poor sorting. *Elphidium/Ammonia* upper shore facies isotopic averages range from $\delta^{18}O$ = 1.0 to 1.5‰ and $\delta^{13}C$ = 1.3 to 2.0 ‰. *Peneroplis* upper shoreface isotope values are $\delta^{18}O$ = 1.5‰ and average $\delta^{13}C$ = 2.1‰. All of the average values are marine or near-marine.

There are three biofacies groups in the harbour facies, which reflect the eutrophic artificial harbour environment ('*Brizalina*' and '*Bolivinid*' biofacies) and post-harbour ('*Rosalina*' biofacies). Average grain-size values are fine sand and average isotopic values are $\delta^{18}O$ = 1.8‰ and $\delta^{13}C$ = 0.9‰. The post-harbour facies is dominated by *Rosalina bradyi* (50%), fine sand-size sediment and average isotopic values of $\delta^{18}O$ = 1.0‰ and $\delta^{13}C$ = 2.3‰. Samples collected from the clay-rich matrix of the primarily framework-supported rubble deposit in Area 24, an archaeological trench in the submerged portion of the site (see Fig. 1 for location), clustered independently into a *Bolivina pseudoplicata*-dominated biofacies. The abundance of foraminifera in these samples is lower than in the normal marine facies (*c*.30 specimens per cm^3 vs. 300 specimens per cm^3), grain-size values are finer and isotope averages are within marine values ($\delta^{18}O$ = 1.6‰ and $\delta^{13}C$ = 3.5‰).

Discussion

The results provide a view of the local sea-level trends and related environmental change. The sea-level markers were in agreement with previous regional models (Peltier, 1994; Lambeck, 1995; Lambeck and Bard, 2000; Lambeck *et al*., 2004; see Figs 2 and 3). The environmental facies relationships between the cores described herein show that the coastal environment consisted of marine transgression from an estimated 9000 to 6000 years BP, followed by sea-level rise deceleration (see Figs 2 and 3A). The deceleration resulted in a positive coastal sediment budget, which, when

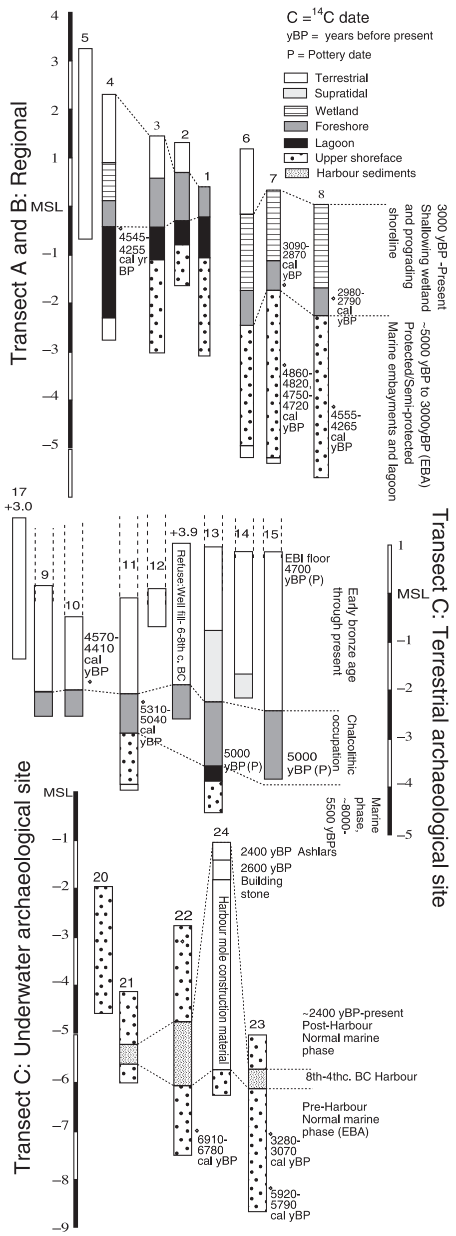


Fig. 2 Cores with facies designations, radiocarbon dates and dated materials relative to mean sea level (msl). Cores 16, 18, and 19 were short cores(less than 1.5-m length) characterized only by terrestrial facies, were consistent with the surrounding stratigraphy and were therefore excluded due to redundancy. Transect positions are shown in Fig. 1.

transported by the long-shore currents, created a consecutive series of sandbars that ultimately lead to beach barrier development. These sandbars contributed to the creation of near-shore lagoons and a tombolo formation that provided quiet anchorage for seafaring vessels during the EBA (4800–3900 years BP; see Fig. 3B,E). That same process of long-shore transport eventually isolated the lagoons from the sea (see Fig. 3C), ending the area's usefulness for harbouring activities. Between the final closure of the lagoon (*c.* 3000 years BP) and the construction of the quay structure at *c.* 2800 years BP, there is no evidence of a harbour, natural or otherwise, in the landscape. At *c.* 2800 years BP, artificial harbouring structures were constructed (Fig. 3C). Eventually, gradual sea-level rise and erosion of the structure led to its present position 1 m below sea-level (see Fig. 3D). The construction of a causeway probably accelerated the process of coastal progradation towards the east (Goodman *et al.*, 2008).

The information from this study helps provide the means to interpret between coastal changes and associated archaeological phases, most notably with regard to the time of appearance and disappearance of harbouring areas. During the EBA, large lagoon areas east of the site provided the necessary conditions for anchorage and/or beaching of boats (see Figs 3B,E), which supplied sea-based trade goods found at the site (Şahoğlu, 2005). If artificial harbouring structures existed in that period, they would most likely be located on the margins of those lagoons. A second harbouring area would have existed in the protected waters leeward of the headland (Figs 3B,E). These findings are in agreement with current theories regarding early Aegean sea-based maritime trade, which state that shipping during the EBA depended on the opportunistic use of natural harbours such as embayments and lagoons (Raban, 1985; Stanley and Warne, 1994; Wachsmann, 1998).

At approximately 3000 years BP, the brackish-marine lagoon areas east of the site became freshwater, indicating final closure and isolation of the area from marine influence (see Fig. 3 and Goodman *et al.*, 2008). Culturally, this event coincides with the transition between the Late Bronze Age and Early Iron Age, a period that is relatively poor in cultural materials relative to the phases, which preceded and followed it. As the earliest traces of harbour facilities elsewhere at the site begin *c.* 2800 years BP, there is no evidence for a functional harbour for some two centuries following the closure of the brackish-marine lagoon, an absence which perhaps reflects a real – albeit temporary – decline in maritime trade and communication in the area.

The submerged feature abutting the archaeological site constitutes clear evidence for harbour activity during the archaic and classical periods (*c.* 2800 years BP to 2400 years BP). Core 24 represents the central spine of the structure, the rubble foundation of which was laid directly on the seafloor

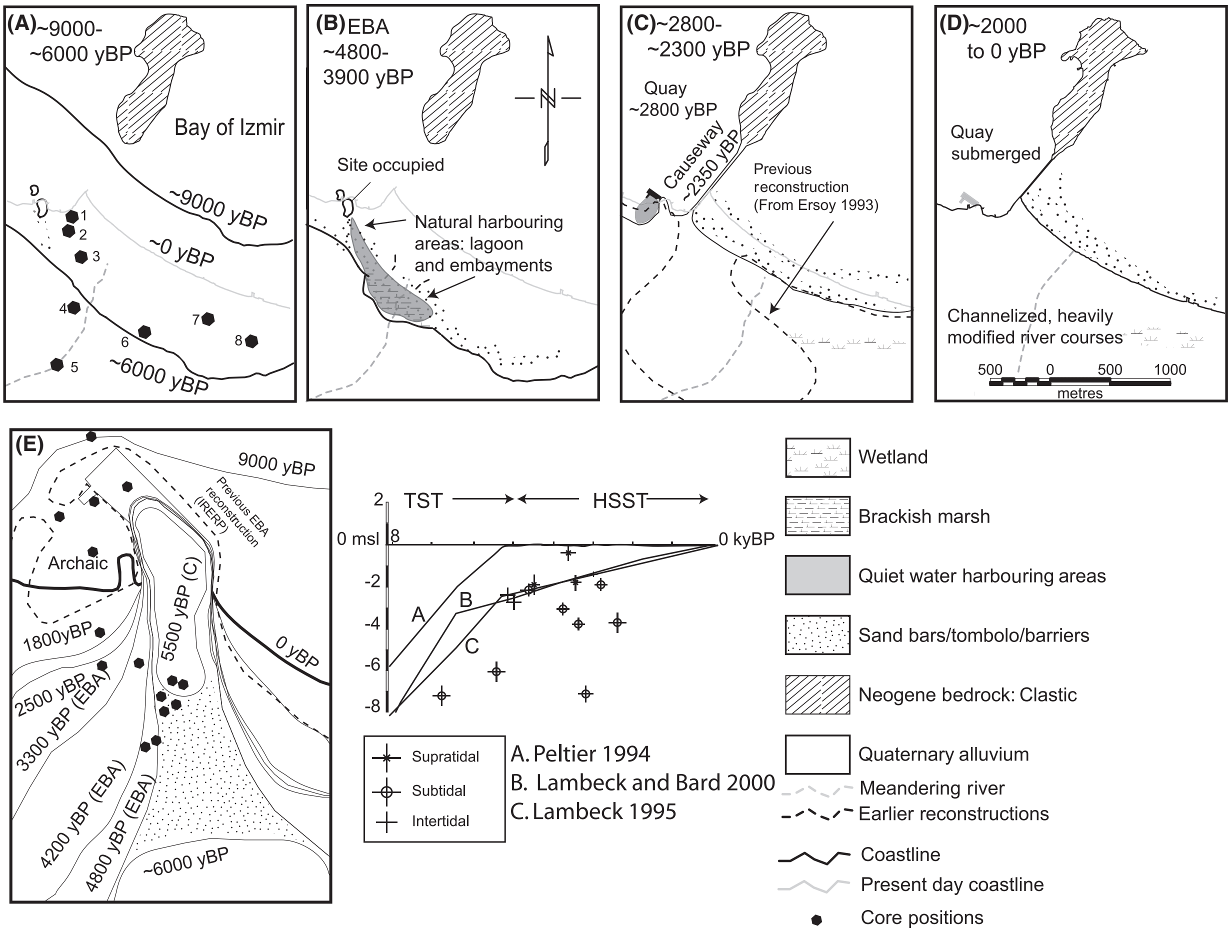


Fig. 3 Top plan of paleogeography and sea level curve. (A) Peltier, 1994; (B) Lambeck and Bard, 2000; (C) Lambeck, 1995.

(see Fig. 1C and 2 transect C). It remains to be established whether the entire length of the main body of the submerged feature, or merely a portion, is anthropogenic. All areas excavated reveal an artificial feature, although there is the possibility that bedrock knolls, smaller versions of the distinctive headland nearby, may have provided framework. The further possibility that the harbour included a second 'arm' farther to the west of the site also merits future exploration. In any case, the sedimentological, micropaleontological and geochemical data indicate the presence of a typical normal marine environment prior to the construction of the feature (pre-2800 years BP), followed by a more constricted, lower energy environment characteristic of sheltered harbours (*c.* 2800–2400 years BP) and finally, a return to normal marine conditions after the abandonment and/or partial destruction of the harbouring feature (*c.* 2400 years BP), when it no longer sufficed to block wave energy. Substantial quantities of archaeological material consonant with a harbour environment (including a recently-discovered wooden anchor, Artzy *et al.*, 2007) discovered in the vicinity of the quay confirm the identification of the port and provide good indicators for its dating.

Coastal geomorphology is also dependent on climate. Increased humidity and precipitation can result in increased terrestrial erosion, higher rates of sediment input and enriched vegetation (Aksu *et al.*, 1995). Paleoclimate studies conducted nearest to Liman Tepe describe higher humidity and higher temperatures from 4500 to 2600 years BP (Baruch, 1994), which includes the EBA through Archaic Period. The combined effects of humidity-driven increased sediment input and decreased erosion effects from deceleration of sea-level rise correspond well with the eventual closure of the EBA lagoonal areas.

Conclusion

Two conclusions emerge which stand in contrast to previous coastal reconstructions of the Liman Tepe site. First, the submerged feature was not associated with the EBA phase, but rather with a harbour installation in use from approximately 2800 to 2400 years BP. Second, while there was a large bay east of the site, it existed during the Bronze Age only, but not during the Archaic and/or Classical Periods as previously thought (see maps in Ersoy, 1993 and Bakır *et al.*, 2000). The paleogeographical reconstruction of Liman Tepe thus supports the theory that the coastal landscape of the EBA featured a relative abundance of natural harbouring locations, such that existing levels of shipping could be accommodated without recourse to extensive construction of artificial harbours. The intervening timespan (from *c.* 3000 years BP to *c.* 2800 years BP) between the silting of the older, natural harbour and the construction of the new harbour to the west, during which neither natural nor artificial harbouring areas can be shown to have existed, coincides with a period of reduced quantities of cultural materials (including overseas imports) at the adjacent settlement.

Previous geoarchaeological studies near Liman Tepe have addressed sites located at the mouths of large rivers, where coastal sites are now located far inland (e.g. Ephesus, Brückner, 1997; and Troy, Kraft *et al.*, 2003). This study, in contrast, illustrates the major coastal changes that can occur in less dynamic environments, even without a major alluvial point source. More broadly, it exemplifies the utility of multi-proxy geoarchaeological method in establishing the relationship between natural coastal processes and the human occupants of a littoral site over the course of several millennia. The study of ancient harbouring facilities is essential to understanding human impacts on the coastal environment, influence of landscape and resources on ancient site selection, sea-level change and effects of coastal change on human settlements (e.g Flemming and Webb, 1986; Kayan, 1988; Fleming *et al.*,1998; Morhange *et al.*, 2000, 2001; Rothaus *et al.*, 2004; Marriner *et al.*, 2006; Reinhardt *et al.*, 2006; Marriner and Morhange, 2007).

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