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Short Paper

Geoarchaeological evidence for dredging in Tyre's ancient harbour, Levant

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Abstract

Chrono-stratigraphic data from Tyre's ancient northern harbour delineate extensive dredging practices during the Greco-Roman and Byzantine periods. Radiocarbon dates from four cores consistently cluster between ca. 500 B.C. and 1000 A.D. and indicate rapid rates of sedimentation in the basin, namely ~10 mm/yr during the Greco-Roman and Byzantine periods, compared to 0.5–1 mm/yr for the period 6000–4000 B.C. Absence of strata between 4000 B.C. and 500 B.C. is not consistent with a natural base-level sediment sink and cannot be interpreted as a depositional hiatus in the high-stand systems tract. Ancient dredging is further corroborated by persistent age-depth inversions within the fine-grained harbour facies. These data support removal of Middle Bronze Age to Persian period sediment strata, with deliberate overdeepening of the harbour bottom by Greco-Roman and Byzantine societies.
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Keywords: Geoarchaeology; Geochronology; Stratigraphy; Coastal geomorphology; Dredging; Ancient harbour; Phoenicia; Mediterranean

Introduction

Founded around 2750 B.C., Tyre has a long history of human occupation spanning the Bronze Age up to present (Bikai, 1979; Katzenstein, 1997). Until recently, the exact location of Tyre's ancient northern harbour had been the source of longstanding speculation, and indeed little was known of the ancient palaeoenvironments of Phoenicia's most prominent city-state (Fig. 1). Recent geoarchaeological investigation by Marriner et al. (2005) reveals that the heart of Tyre's ancient anchorage actually lies buried beneath the Medieval and Modern urban centres. The work elucidates a clear evolution from a natural proto-harbour during the Middle Bronze Age (MBA) through various stages of anthropogenic modification between the Phoenician and Byzantine periods.

Geoarchaeological study of ancient harbour stratigraphy is a new area of inquiry that has been developed and refined over the past decade (Gifford et al., 1992; Brückner, 1997; Reinhardt and Raban, 1999; Kraft et al., 2003; Goiran and Morhange, 2003). Harbour basins are considered to be exceptional base-level archives because their sediment suites record both natural and anthropogenic evolutions; they are also a novel scientific means of retracing urban histories and port development.

Here we present new chrono-stratigraphical results from Tyre's ancient northern harbour, detailing evidence for extensive harbour dredging during the Roman and Byzantine periods. Although silting-up was problematic to ancient engineers, there are only scattered literary references to dredging in antiquity and archaeological evidence is, at best, sparse. Speculated engineering solutions included arched moles, desilting channels and sluice gates (Blackman, 1982a,b). Under deltaic and estuarine contexts, the silting problem was particularly acute and there is extensive geoarchaeological evidence to suggest that rapidly abandoned harbours silted over within a very short space of time (Raban, 1995; Brückner et al., 2002). To our knowledge, this is the first time high-resolution stratigraphical and geochronological techniques have been used to validate this poorly studied ancient practice.

Methods

A series of 25 boreholes were extracted from Tyre, of which five derived from within the ancient northern harbour.

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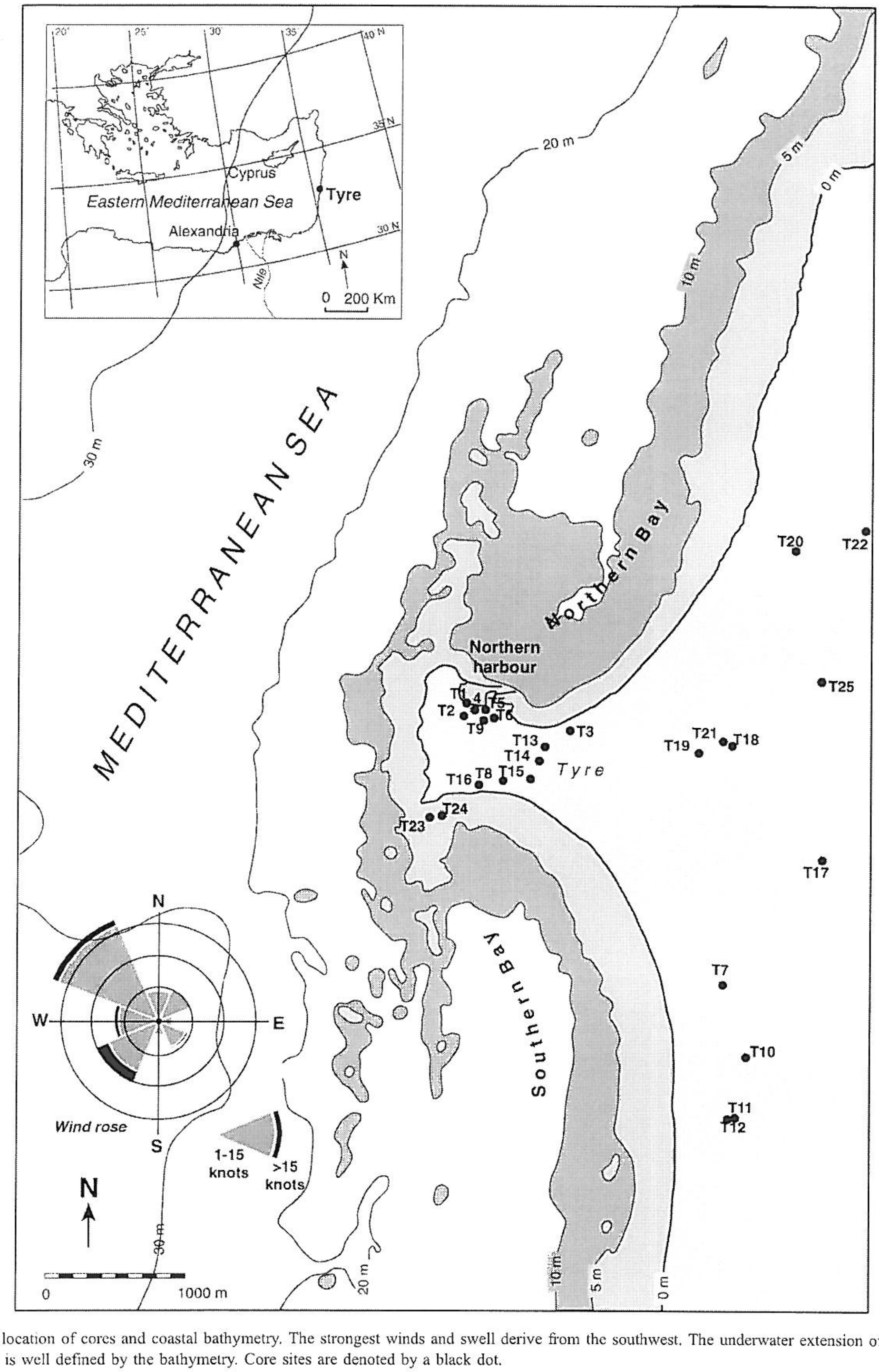

Figure 1. Tyre, location of cores and coastal bathymetry. The strongest winds and swell derive from the southwest. The underwater extension of the Quaternary sandstone ridge is well defined by the bathymetry. Core sites are denoted by a black dot.

Four of these cores, T1, T2, T5 and T9, have undergone extensive biostratigraphical, sedimentological and geochemical analyses, the results of which can be reviewed in Marriner et al. (2005). Thirty-four ^{14}C datings and archaeological data precisely constrain the chronology of the various sedimentary environments observed. The ^{14}C data are summarised in Table 1, consistent with standard reporting protocols (32 of the dates have been used in the age-depth plot). All cores have been GPS levelled (±10 cm) and depths quoted are relative to present biological mean sea level (BMSL, ±5 cm), as represented by the upper limit of local *Balanus* populations (Laborel and Laborel-Deguen, 1994).

All dates have been calibrated using OxCal and are quoted to 2σ. Dated material comprised seeds, wood, charcoal remains and in situ marine shells. Material deriving from the marine domain has been corrected for reservoir effects (Stuiver et al., 1998). To test the applicability and robustness of our radiocarbon chronology, two samples from the same stratigraphic level (T9-35) have been dated: (1) charcoal fragments (yielding 2215 ± 30 ^{14}C yr B.P. [Poz-5777]) and (2) in situ marine shells (yielding 2505 ± 30 ^{14}C yr B.P. [Poz-5775]). These dates indicate a constant marine reservoir age of ca. 290 yr, consistent with four published ^{14}C ages of known age shells from the Levantine (Reimer and McCormac, 2002) and Nile delta coasts (Goiran, 2001).

Table 1
Radiocarbon data set

Sample	Depth below MSL (cm)	Laboratory code	Material dated	$^{13}C/^{12}C$ (‰)	^{14}C yr B.P.	±	Cal yr B.P.	Cal B.C./A.D.
T1 4	62	Lyon-1469 (GRA 17972)	*Cyclope neritea, Nassarius pygmæus, Ringicula auriculata*	1.14	1560	35	1210–1030	740 A.D.–920 A.D.
T1-12	152	Lyon-1470 (GRA 18730)	*C. neritea, Haminea hydatis*	−0.31	1965	35	1600–1410	350 A.D.–540 A.D.
T1-30	237	Lyon-1472 (GRA 18732)	*Loripes lacteus, Tapes decussatus*	0.08	2255	35	1940–1770	10 A.D.–180 A.D.
T1-24	290	Lyon-1471 (GRA 19731)	*C. neritea*	−1.4	2055	35	1700–1530	250 A.D.–420 A.D.
T1-31	345	Lyon-1602 (GRA 19345)	*N. pygmæus*	0.89	2635	45	2430–2170	480 B.C.–220 B.C.
T1-36	497	Lyon-1603 (GRA 19346)	*Mitra cornicula*	0.94	5520	50	6000–5750	4050 B.C.–3800 B.C.
T1-39	482	Lyon-1473 (GRA 18733)	*C. neritea*	−1.67	2375	35	2100–1910	150 B.C.–40 A.D.
T2-13	285	Lyon-1604 (GRA-19347)	Marine shells	−1.35	1990	45	1680–1430	270 A.D.–520 A.D.
T2-18	435	Lyon-1474 (GRA-18735)	Marine shells	−0.72	2370	35	2090–1900	140 B.C.–50 A.D.
T5-19	281.5	Poz-2500	Charcoal	−22.6	1485	30	1420–1300	530 A.D.–650 A.D.
T5-41	392.5	Poz-2502	Charcoal	−27.4	1910	30	1930–1770	20 A.D.–180 A.D.
T5-43	452.5	Poz-5768	Charcoal	−18.9	2265	30	2350–2150	400 B.C.–200 B.C.
T5-58	595	Poz-5752	*Nassarius mutabilis*	4.4	2360	30	2060–1890	110 A.D.–60 A.D.
T5-60	607.5	Poz-5769	Charcoal	−23.3	2245	35	2350–2150	400 B.C.–200 B.C.
T5-70	702.5	Poz-2445	*Cerithium vulgatum* juv.	2.8	5730	30	6240–6030	4290 B.C.–4080 B.C.
T5-76	737.5	Poz-2451	*C. vulgatum* juv.	−1.2	6400	35	6970–6750	5020 B.C.–4800 B.C.
T5-77	740.5	Poz-2446	*C. vulgatum* juv.	−1.5	7300	40	7840–7660	5890 B.C.–5710 B.C.
T5-81	752.5	Poz-2447	*C. vulgatum* juv.	−4.1	7760	40	8330–8130	6380 B.C.–6180 B.C.
T5-82	755.5	Poz-2448	*C. vulgatum* juv.	−2.4	7780	40	8340–8150	6390 B.C.–6200 B.C.
T5-106	827.5	Poz-2449	*C. vulgatum* juv.	−5	7800	40	8350–8160	6400 B.C.–6210 B.C.
T9-6	281	Poz-5770	Olive seed	−27.2	1615	30	1570–1410	380 A.D.–540 A.D.
T9-20	387	Poz-5771	3 grape seeds	−26.9	1855	30	1870–1710	80 A.D.–240 A.D.
T9-25	445	Poz-5773	2 *N. mutabilis*	−0.8	2220	35	1900–1720	50 A.D.–230 A.D.
T9-26	455	Poz-5774	Seed	−9.8	2385	30	2710–2340	760 B.C.–390 B.C.
T9-35ch	545	Poz-5777	Charcoal	−21.3	2215	30	2330–2140	380 B.C.–190 B.C.
T9-35co	545	Poz-5775	3 valves of *L. lacteus*	4.6	2505	30	2290–2080	340 B.C.–130 B.C.
T9-43	630	Poz-5778	Seed	−24.8	2055	30	2120–1920	170 B.C.–30 A.D.
T9-45	645	Poz-5779	Charcoal	−23.1	2320	35	2440–2150	490 B.C.–200 B.C.
T9-49	679	Poz-5780	1 *C. neritea*	3.5	2140	30	1810–1630	140 A.D.–320 A.D.
T9-52	716	Poz-5781	3 valves of *Donax* sp.	2.9	2210	30	1880–1720	70 A.D.–230 A.D.
T9-53	730	Poz-7184	2 valves of *Donax venustus*	−1.8	2300	30	1980–1830	30 B.C.–120 A.D.
T9-62	829	Poz-5783	2 valves of *L. lacteus*	4.7	5850	40	6350–6170	4400 B.C.–4220 B.C.
T9-63	838	Poz-5784	3 valves of *L. lacteus*	4.3	5830	40	6310–6160	4360 B.C.–4210 B.C.
T9-76	963	Poz-5785	2 valves of *P. exiguum*	−1.6	7840	50	8390–8180	6440 B.C.–6230 B.C.

Results and discussion

Palaeoenvironmental summary

Our high-resolution litho- and biostratigraphical studies allow us to identify four different palaeoenvironments in the northern harbour, spanning the past 8000 yr (Figs. 2 and 3; for detailed data and discussion see Marriner et al., 2005): (1) A basal litho-dependent unit incorporating large amounts of shelly debris marks the Holocene marine transgression of the cove around 8000 ^{14}C yr B.P.; (2) transition to a medium-grained sand unit after 6000 ^{14}C yr B.P. concurs a semi-protected pocket beach unit. This northern façade was, and remains to this day, the most conducive environment for an anchorage on Tyre island, as it is naturally protected from the dominant south-westerly winds and swell (see Fig. 1). During the Bronze Age, the environment served as a proto-harbour, where shallow draught boats were pulled onto the beach face. Larger boats would have been anchored in the cove; (3) the first traces of anthropogenic modification are manifested in the shift to a fine-grained silty-sand unit, coeval with a marine-lagoonal-type environment from the Phoenician to Byzantine periods; (4) the economic decline of Tyre is represented by a coarse sand unit, suggesting the deterioration of harbourworks and a reopening of the coastal environment during Islamic times.

Chrono-stratigraphical evidence for harbour dredging

Until recently, direct evidence for ancient dredging had been difficult to corroborate in the field and consequently neglected in the literature. At the beginning of the 1990s, archaeological excavations in Marseilles' ancient harbour, Southern France, yielded strong stratigraphic and sedimentological evidence for dredging practices during antiquity (Hesnard, 1995; Morhange et al., 2003a). Indeed, Roman dredging boats dating from the 2nd and 3rd centuries A.D. were excavated by Pomey (1995). In Marseilles, rapid silting-up rates of ~20 mm/yr during the Greek and Roman periods, compared to <1 mm/yr prior to the city's foundation in 600 B.C., necessitated these measures to maintain a navigable water depth of at least ~1 m. More recently, analogous stratigraphic evidence from Naples records widespread dredging activity throughout the basin from the late 4th century B.C. onwards (D. Giampaola, unpublished data). Both sites manifest serious chronological anomalies, linked to the removal and mixing of older archaeological layers.

In Tyre, the absence of coastal archaeological excavations means that cores and not sections have been used to reconstruct the palaeoenvironments. When plotted against depth, ^{14}C dates deriving from the harbour cores consistently show the absence of 4000–500 B.C. strata, a time envelope which includes the Bronze Age to Persian periods, with a cluster of dates spanning the Greco-Roman to Byzantine periods. Given the sediment sink properties of harbour basins, we argue that this is not a natural depositional hiatus but rather strong evidence for dredging and removal of these older sediments during the Greco-Roman and Byzantine periods. A similar pattern has also been observed in the northern harbour of Sidon (Morhange et al., 2003b).

A high-stand systems tract should manifest a classic sedimentary superposition of coarse onlap layers (Coe, 2003). In complete contradiction with this stratigraphical model, Tyre's harbour basin is characterised by numerous ^{14}C age-depth inversions, concurrent with a chronological anomaly. This evidence supports the scouring and reworking of harbour sediments to maintain a navigable harbour depth. Linear regression, performed on the radiocarbon data set spanning the Greco-Roman to Byzantine periods, indicates average accretion rates of ~10 mm/yr. For a harbour bottom at −2 m below mean sea level (i.e., the maximum ship draught depth), this implies complete infilling of the harbour after just two centuries. Our data suggest that by Hellenistic times, Tyre's northern harbour was already suffering from silting problems, with the possible beginnings of dredging during this period. Persistent age-depth anomalies within the fine-grained harbour facies attest to repeated dredging activity throughout the Roman and early Byzantine periods.

Changes in sediment yields during antiquity

It has been demonstrated that Tyre's ancient northern harbour was approximately twice as large as present (Marriner and Morhange, 2005). After the Byzantine period, the data show clear evidence for accelerated progradation of the basin, which was no longer maintained and artificially protected. Such a tendency is consistent with other abandoned ancient harbours on the Levantine coast including Beirut, Sidon and Caesarea Maritima.

Rapid rates of harbour bottom accretion must not solely be attributed to changes in harbour infrastructure and coastal protection. Anthropogenic modification of the surrounding watersheds, notably the Litani river, influenced the sediment budget in a significant way. It is important to underline three fundamental changes since the Bronze Age, all of which contributed to a rise in silting rates: (1) The use of mud-bricks for construction yielded clay particles through runoff converging on Tyre's northern harbour (Brochier, 1994); (2) the beginnings of land clearance and agriculture in the Levant are dated ca. 4500–3500 ^{14}C yr B.P. (Bottema and Woldring, 1991; Yasuda et al., 2000), creating upstream soil erosion crises and accelerated sediment accumulation in low-energy base-level environments. These included ancient harbour environments, which preferentially trapped the fine-grained particles; and (3) finally, harbours served as huge waste dumps for ancient societies.

Conclusion

Age-depth data from Tyre's ancient harbour support extensive dredging practices during the Greco-Roman and Byzantine periods (Fig. 4). Dredging ensured a navigable water column was maintained, with limited loss of anchorage space through silting-up around the basin edges. Tyre's location at the distal margin of a small delta explains why this harbour is still

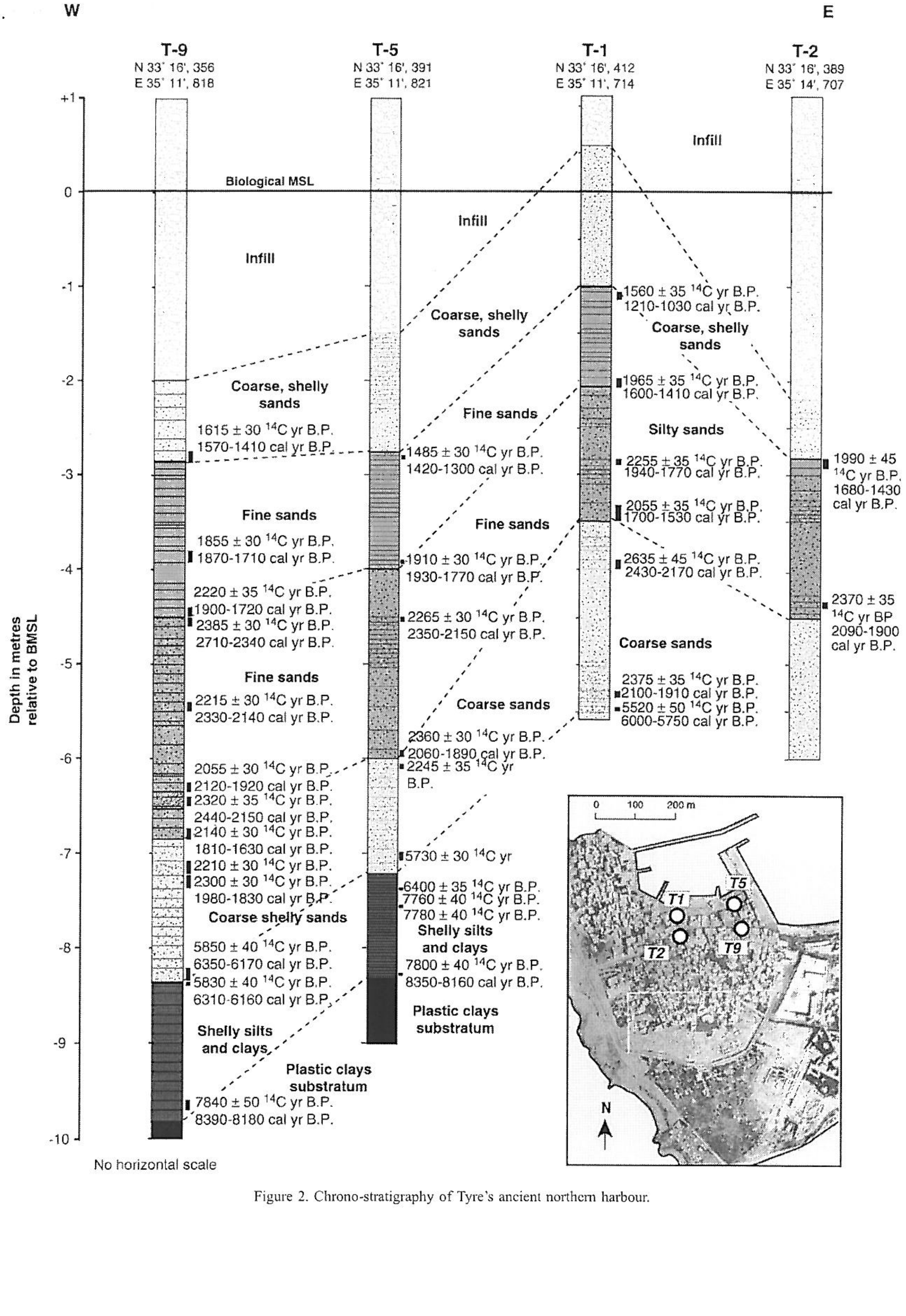

Figure 2. Chrono-stratigraphy of Tyre's ancient northern harbour.

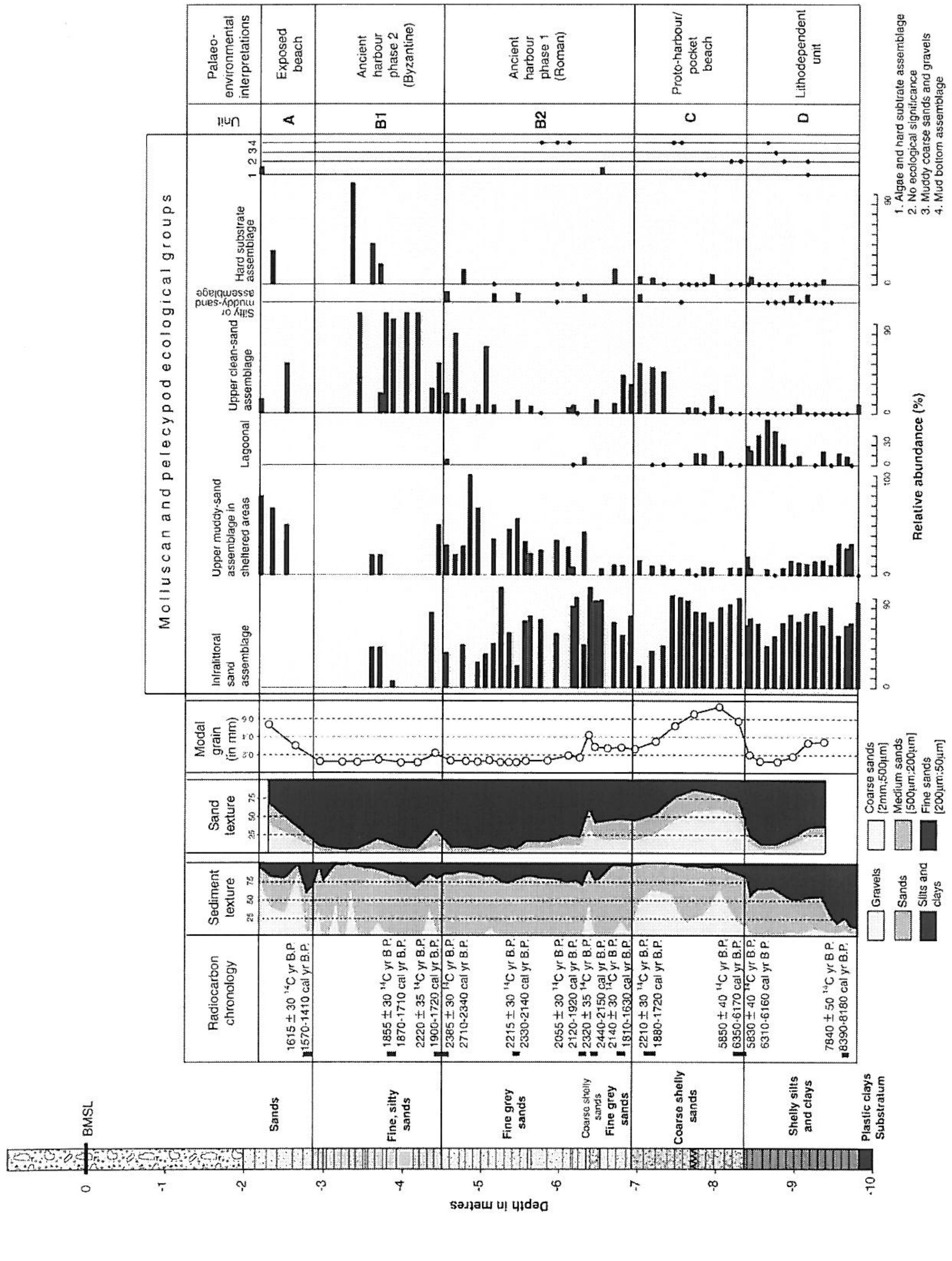

Figure 3. Litho- and biostratigraphical synthesis of core T9, from the heart of the ancient northern harbour. Four main Holocene stratigraphic units are identified.

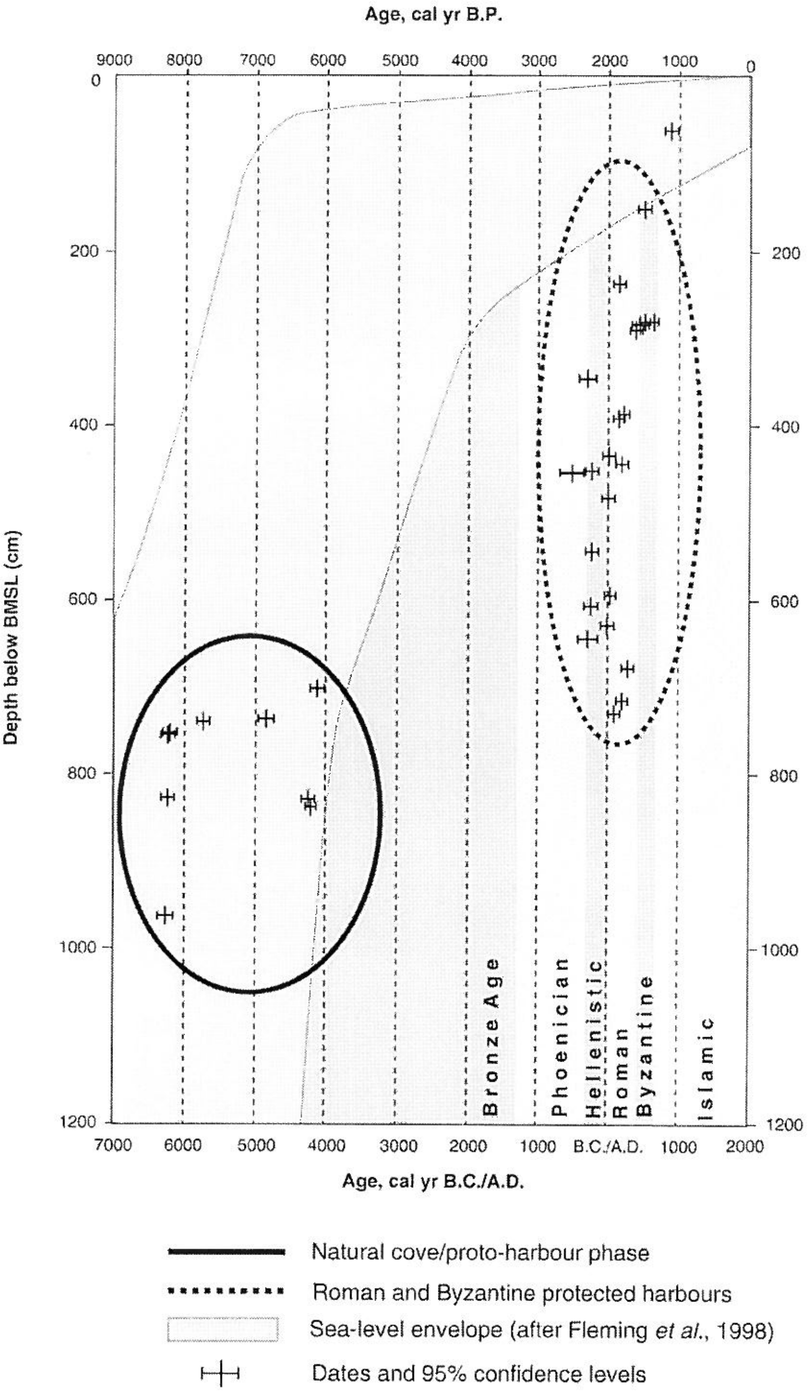

Figure 4. Age-depth plot of radiocarbon dates from Tyre's ancient northern harbour. Sea-level envelope after Fleming et al. (1998). All depths are quoted relative to present biological mean sea level (±5 cm).

in use today, and has not, as is the case of Troy (Kraft et al., 2003), experienced kilometre-scale coastal progradation to become a land-locked site.

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