Geoscience rediscovers Phoenicia's buried harbors

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ABSTRACT

After centuries of archaeological debate, the harbors of Phoenicia's two most important city states, Tyre and Sidon, have been rediscovered, and including new geoarcheological results reveal how, where, and when they evolved after their Bronze Age foundations. The early ports lie beneath their present urban centers, and we have indentified four harbor phases. (1) During the Bronze Age, Tyre and Sidon were characterized by semi-open marine coves that served as protoharbors. (2) Biostratigraphic and lithostratigraphic data indicate the presence of early artificial basins after the first millennium B.C. (3) The harbors reached their apogees during the Greco-Roman and Byzantine periods. (4) Silting up and coastal progradation led to burial of the medieval basins, lost until now.

Keywords: geoarcheology, coastal geomorphology, ancient harbor, Mediterranean.

INTRODUCTION

Since 1998, a multidisciplinary team under the auspices of the British Museum and the United Nations Educational, Scientific, and Cultural Organization's World Heritage Centre has been investigating the environmental history of Phoenicia's two most famous city states, Tyre and Sidon, located on the present-day Lebanese coast (Figs. 1 and 2). The sites have long histories of human occupation extending back to the Middle Bronze Age (Katzenstein, 1997), and both cities were important trade centers during the Phoenician, Persian, Greco-Roman, and Byzantine periods. Paradoxically, in spite of their celebrity and former splendor, very little can be gleaned from the ancient sources vis-à-vis their coastal paleoenvironments, and our knowledge of the cities' ancient harbors is meager at best. Since the seventeenth century, the locations of Phoenicia's ancient harbors have been the subject of continuous archaeological speculation (Renan, 1864; Poidebard, 1939; Poidebard and Lauffray, 1951; Frost, 1971, 1973). Unfortunately, research during the past 30 yr has been hindered by political unrest in the region, and until our investigation the scientific community has known nothing of the evolution of these harbors over the past 6000 yr.

Geological Context

The Tyre-Saida block is bounded to the east by the Roum fault and to the south by the Rosh Hanikra–Ras Nakoura fault. The internal fan-shaped fault pattern of this panel is characterized by dominantly NW-trending dextral faults to the south and WNW-trending sinistral faults to the north (Dubertret, 1975; Ron et al., 1984; Ron and Eyal, 1985). Subsidence in the Tyre area since antiquity is corroborated by submerged urban quarters and quarries on the island's southern coast, currently 2.5 m below mean sea level (MSL) (El Amouri et al., 2005); the northern harbor's ancient breakwater also lies 2.5 m below MSL. The breakwater, 3 m high and composed of at least 5 thick stone layers, has recorded a relative sea-level rise of at least 3.5 m since antiquity.

In contrast to Tyre, relative sea level in Sidon has been more stable during the late Holocene. Raised geomorphological shoreline markers are scattered and their elevations are low. On the offshore harbor island of Zire, 500 m from mainland Sidon (Fig. 2), the bottom of an ancient quarry is sealed by beach rock at +0.5 m. It contains quarried blocks mixed with well-preserved shells of *Pirenella conica*. The radiocarbon age of these shells constrains the submergence of the quarry to 2210 ± 50 B.P. The margins of the quarry also show an uplifted notch at +0.5 m concomitant with this underwater phase. Close examination of beach-rock thin sections shows that this sediment has experienced at least two different diagenetic environments, meteoric followed by marine. Zire Island has therefore undergone a minor movement, with the onset of the downward tendency being dated.

METHODS

Our discovery of the two Phoenician harbors was been made possible using high-resolution geoscience techniques, the robustness of which has been demonstrated at other ancient harbor sites around the Mediterranean (e.g., Reinhardt and Raban, 1999; Kraft et al., 2003; Goiran and Morhange, 2003).

Coring was used to elucidate the Holocene coastal stratigraphy of both Tyre (25 cores) and Sidon (15 cores). We used a network of cores to retrace Holocene shoreline evolution and harbor infilling. High-resolution lithostratigraphical and biostratigraphical analyses were undertaken under standardized laboratory conditions (see GSA Data Repository[1]).

New ^{14}C dates (n = 42) precisely constrain the chronology of the various sedimentary environments observed (Table DR1; see footnote 1). All dates were calibrated using the OxCal program and are quoted to 2σ. Material dated included seeds, wood, charcoal remains, and in situ molluscan marine shells. Marine shells have been corrected for a reservoir effect of 400 yr (Stuiver et al., 1998; Reimer and McCormac, 2002).

RESULTS AND DISCUSSION

Our geological data have identified the following four harbor phases (Fig. 3).

Bronze Age Protoharbors (ca. 3000–1200 B.C.)

During the Bronze Age, natural downwind embayments and coves north of the Tyrian and Sidonian promontories were attractive sites for anchorage havens. Since sea level attained broad stability ca. 6000 B.P. (Laborel et al., 1994; Bard et al., 1996; Fleming et al., 1998), the northern coast of Tyre has been naturally semiprotected by a small Quaternary ridge complex (Fig. 1). Up until the first millennium B.C., biostratigraphical and lithostratigraphical signatures from the Tyrian Bronze Age basin were typical of a semi-open marine cove. Medium to fine sands characterize the stratigraphic unit, which is dominated by brackish-lagoonal and coastal ostracod assemblages, with infralittoral sand and upper muddy sand macrofauna assemblages (Fig. 3; see Data Repository [footnote 1] for detailed data sets). Shallow draft boats would have been hauled onto the beach face, and more sizable merchant vessels anchored in the bay, their

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[1]GSA Data Repository item 2006001, Figures DR1–DR15, Table DR1, and methods, is available online at www.geosociety.org/pubs/ft2006.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

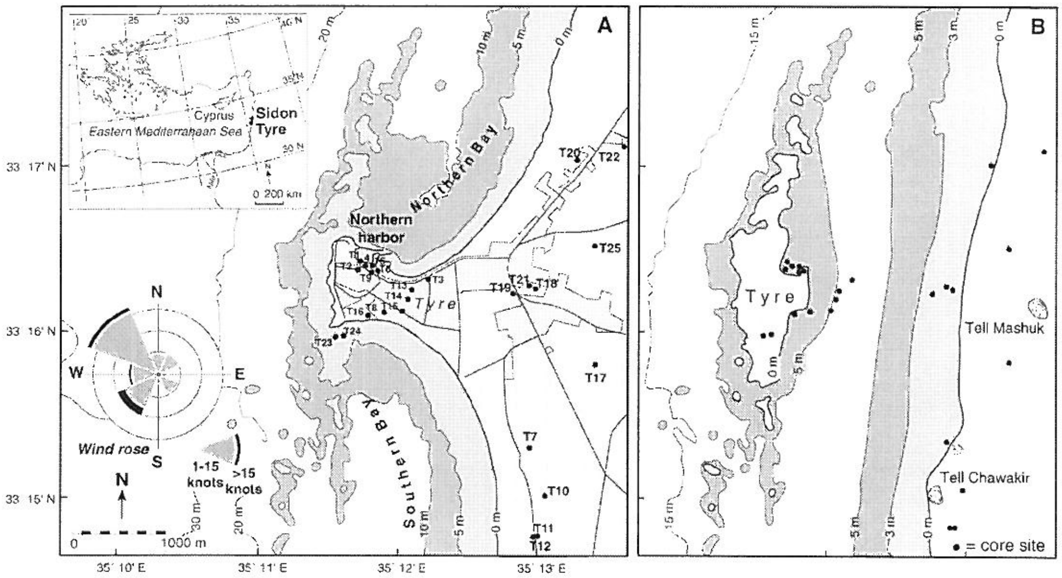

Figure 1. A: Positions of cores and coastal bathymetry at Tyre. Strongest winds and swell derive from southwest. Core sites are marked by black dots. B: Reconstructed paleobathymetry of Tyre ca. 6000 B.P. Site is on offshore Quaternary ridge, parallel to shoreline. Tyre was particularly attractive to early settlers because its location many hundreds of meters offshore ensured excellent defensive impregnability, and it remained unbreached until Alexander the Great seized the city in 332 B.C.

cargos ferried to and from the proximal shoreline by smaller vessels.

In the northern harbor of Sidon, a similar protoharbor phase has been dated to the Middle Bronze Age, ca. 3600 B.P. (1700–1450 B.C.). Compared with Tyre, Sidon's northern basin afforded better shelter because it has been naturally protected by a long, 600 m offshore Quaternary ridge for the past 6000 yr. Deposition of fine-grained sand records early sheltering of the bay. This facies is dominated by brackish-lagoonal (*Cyprideis torosa*, *Loxoconcha elliptica*) and marine-lagoonal (*Loxoconcha* spp., *Xestoleberis* spp.) ostracod assemblages, in addition to infralittoral sand and upper clean sand macrofauna assemblages. In Sidon, the Middle Bronze Age was a period of rapid urbanization with extensive economic activity (Doumet-Serhal, 2003), and this semi-protected harbor phase appears concomitant with the beginnings of early port infrastructure. The existence of artificial harbor works during the Middle Bronze Age is debated. Frost (1995) attributed the early maritime infrastructure of Arrados, Syria, on the Levantine coast, to the Bronze Age, and a harbor quay in Dor, Israel, has been dated to the 1200–1300 B.C. (Raban, 1995). The Middle Bronze Age site of Yavne-Yam, Israel, also shows the presence of submerged boulder piles, which were used to improve the quality of the ancient anchorage.

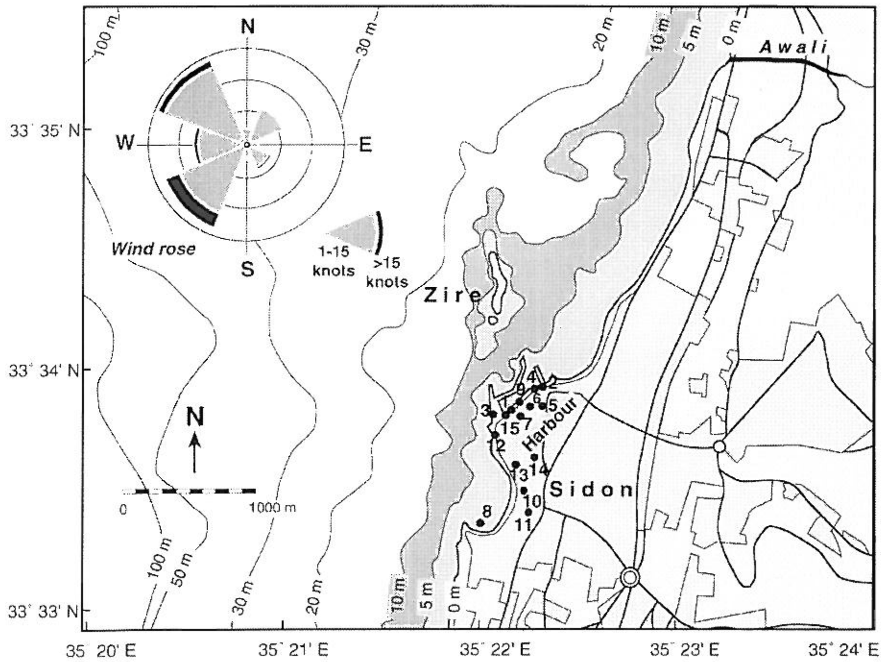

Figure 2. Position of cores and coastal bathymetry at Sidon. Sandstone island of Zire was used as outer harbor. Black dots denote core sites.

Semi-artificial Phoenician and Persian Harbors (ca. 1200–332 B.C.)

During the first millennium B.C., rising sea levels and expanding international trade (i.e., the need for greater docking capacities) forced the Phoenicians to build artificial harbor works. The widespread use of metal, notably iron, in naval construction meant that larger and stronger boats could be built, capable of sailing much greater distances. The semiprotected harbors built by the Phoenicians were characterized by accelerated sedimentation rates and a significant rise in silts (Fig. 3). Fine-grained tolerant biocenoses dominated assemblages of marine fauna.

Scouring and dredging practices during the Roman and Byzantine periods explain why early first millennium B.C. strata are often absent (see following). In Caesarea, dredging of muds has also been invoked to explain sediment gaps observed in the ancient harbor stratigraphy (Reinhardt et al., 1998).

Slight differences in molluscan assemblages between Tyre and Sidon are linked to the regional geomorphological context. The island of Tyre is located downwind of the Litani delta, a competent watercourse transporting mainly sands. Acting as a base-level sediment sink, Tyre's northern harbor preferentially trapped fine sands, creating biotopic conditions favorable to the development of upper clean sand assemblage taxa. By contrast, Sidon's northern harbor was much better pro-

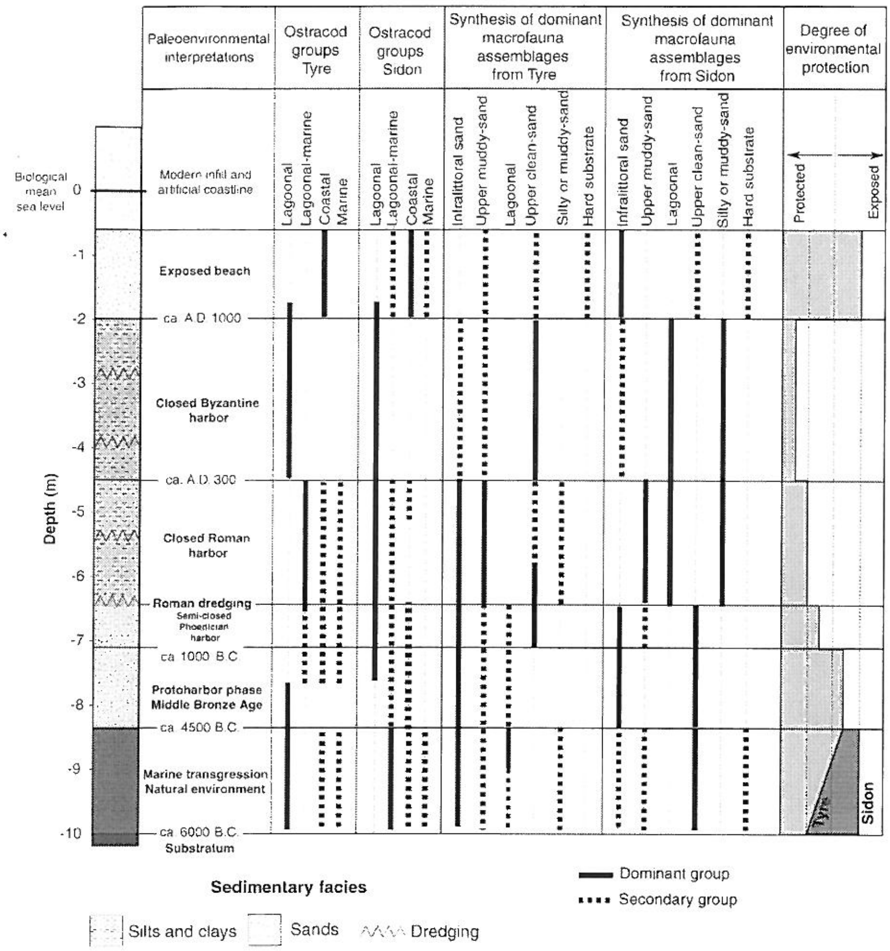

Figure 3. Synthesis of Holocene facies from Tyre and Sidon's ancient harbor basins.

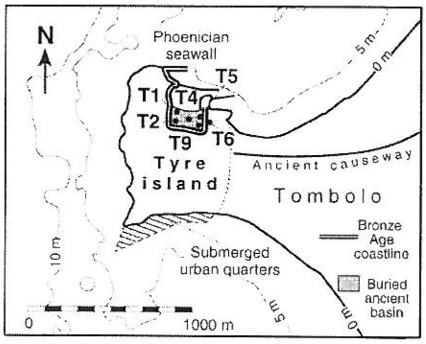

Figure 4. Maximum extension of Tyre's Middle Bronze Age northern harbor. Our work reveals that the ancient harbor was ~40% larger than present, with the heart of the ancient basin beneath the medieval and modern city center. Alexander the Great's causeway was constructed to breach the island city's defenses in 332 B.C. Core locations are denoted by black dots. Maximum harbor extent is represented by black and white line. Dotted line marks approximate island limit by Greco-Roman time.

tected by a natural aeolianite ridge, and later by its Phoenician seawall, trapping finer-grained sediments.

Greco-Roman and Byzantine Harbor Apogees (ca. 332 B.C. to A.D. 1000)

Tyre and Sidon's harbors were at their apogees during the Greco-Roman and Byzantine periods (consistent with other archaeological findings on the Levantine coast) and were characterized by well-protected and confined basins. Hydraulic concrete, invented by the Romans ca. 300 B.C., greatly enhanced the possibilities of harbor engineering (Oleson et al., 2004).

Fine-grained sands and muds from the cities' Greco-Roman and Byzantine harbors are akin to low-energy environments. The biostratigraphy manifests two phases of harbor confinement. (1) During the Greco-Roman period, brackish-lagoonal (*Cyprideis torosa*) and marine-lagoonal (*Xestoleberis* spp., *Loxoconcha* spp.) ostracod taxa attest to a first closed-harbor phase. The presence of secondary assemblages from the coastal and marine domains is consistent with inputs during high-energy sea states such as swell and storms. In situ infralittoral sand and upper muddy sand macrofauna typified these confined coastal environments. (2) During the Byzantine period, changes in harbor management techniques are recorded by a second closed-harbor phase. The monospecific domination of *Cyprideis torosa* indicates better-protected basins, analogous to choked lagoons.

In both closed-harbor phases, fine sands and muds indicate artificially sheltered environments, where low-energy sedimentation processes dominated. A poorly sorted sediment is concurrent with a sharp decrease in water-body competence. Surface runoff and erosion of the urbanized land surface yielded coarse waste material (seeds, wood fragments, and ceramics) for deposition at base level. Such heterometric sediment texture is typical of confined harbor environments in an urban context (Morhange et al., 2003). Seawalls were effective in sheltering the basins from the effects of swell, currents, and storms.

In contrast to protohistoric times, a 10-fold increase in sedimentation rates (0.5–1 mm/yr to 10 mm/yr) is measured during the Roman and Byzantine periods. Such rapid accretion is related to changing modes of land occupation during antiquity, and it is well documented that silting up of harbors was problematic at that time (Blackman, 1982). Our chronostratigraphic data demonstrate that, to abate this, the Romans and Byzantines dredged the shallow bottoms, maintaining a workable harbor depth and large docking capacity (Marriner and Morhange, 2005). Inside the coves, this human-induced shortening of the sediment column did not result in biofacies and lithofacies modifications; i.e., the composition of the biosedimentologic assemblages is identical from the Iron Age up to the Roman period. This phenomenon has been observed in sections at a number of harbor excavation sites; e.g., there is extensive evidence for dredging in the Roman harbor of Marseilles, and in Naples from the fourth century B.C. onward. Rapid silting up persisted in the harbor basins of Tyre and Sidon until ca. A.D. 500–900.

Medieval Destruction Phase

After the Byzantine period, the economic demise of Tyre and Sidon as important trade centers is clearly recorded by exposed beach units, a classic feature of all semi-abandoned harbors (Goiran and Morhange, 2003). At both sites, an increase in coastal (*Aurila woodwardii* and *Aurila convexa*) and marine ostracod taxa is to the detriment of formerly abundant brackish-lagoonal species (*Cyprideis torosa*). A plethora of extra situ macrofauna assemblages indicates a reopening of the environment to offshore marine processes,

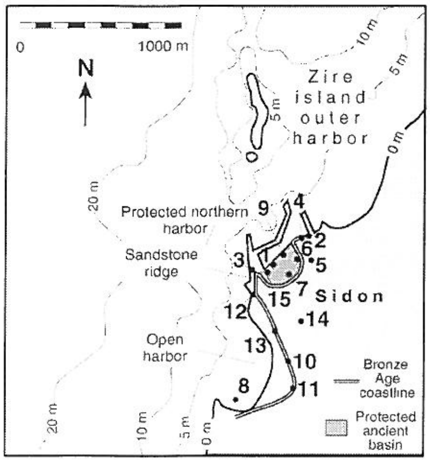

Figure 5. Maximum extension of Sidon's Middle Bronze Age harbors. Lithostratigraphic studies of cores from southern cove reveal no fine-grained harbor facies. This is consistent with a natural, fair-weather open harbor, where small vessels would have been hauled onto beach face. During storms, largest vessels sought shelter in better-protected northern harbor or on leeward side of Zire outer harbor. Core locations are denoted by black dots. Maximum harbor extent is represented by black and white line.

whereby deteriorating infrastructure no longer sheltered the ancient harbor confines.

CONCLUSIONS

We have demonstrated that a multiproxy geoscience methodology is a powerful archaeological tool, overcoming many of the financial and technical difficulties faced by field archaeologists today (Stanley et al., 2004). These nondestructive techniques have clear scope for use at other sensitive coastal sites, and the use of soft sediment geological records is an insightful means of deciphering ancient history. Our results allow us to accurately retrace the maximum limit of Tyre and Sidon's Middle Bronze Age basins, and to show that large portions of these have since silted up and are now buried beneath the city centers (Figs. 4 and 5). This evolution has been induced by sediment trapping, a phenomenon that has preserved these historical archives and offers exceptional prospects for future archaeological research. The locations of Tyre and Sidon at the distal margins of small deltas explain why these two harbors are still in use today and why they have not, as is the case of Troy's harbors (Kraft et al., 2003) and the Maeander delta (Brückner et al., 2002), undergone kilometer-scale coastal progradation to become landlocked sites. This work has far-reaching implications for our understanding of Phoenician maritime history and provides a unique opportunity to conserve Phoenician cultural heritage.

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