The geoarchaeology of ancient Mediterranean harbours

1. Introduction

Up until comparatively recently, coastal sediments uncovered during Mediterranean excavations received very little attention from archaeologists, even though, traditionally, the received wisdom of *Mare Nostrum*'s history placed emphasis on the influence and coevolution of physical geography in fashioning its coastal societies (Marriner and Morhange, 2007). Before 1990, the relationships between Mediterranean populations and their coastal environments had largely been studied within a cultural-historical paradigm, where anthropological and naturalist standpoints were largely considered in isolation. During the past twenty years, Mediterranean archaeology has changed significantly, underpinned by the emergence of a new culture–nature duality that has drawn on the North European examples of wetland and waterfront archaeology (Milne and Hobley, 1981). Because of the challenges of coastal and marine contexts, the archaeological community is today increasingly aware of the importance of the environment in understanding the socio-economic and wider natural frameworks in which ancient societies lived, and multidisciplinary research and dialogue has become a central pillar of most large-scale Mediterranean excavations.

It is against this backdrop that ancient harbour contexts have emerged as particularly novel archives, shedding new light on how humans have locally interacted with and modified coastal zones since the Neolithic. Their importance in understanding ancient maritime landscapes and societies makes them one of the most discussed archaeological contexts in coastal areas. Around 6000 years ago, at the end of the Holocene marine transgression, societies started to settle along 'present' coastlines. During the past ~4500 years, harbour technology has evolved to exploit a plethora of environmental contexts, from natural bays and estuaries through to the completely artificial basins of the Roman period. Although some of these ancient port complexes continue to be thriving transport centres, many millennia after their initial foundation, the vast majority have been abandoned and their precise whereabouts, despite rich textual and epigraphic evidence, remains unknown. Although not the sole agent of cultural change, these environmental modifications partly reflect the fact that long-term human subsistence has favoured access to the open sea. Key to this line of thinking is the idea that societies have adopted adaptive strategies in response to the rapidly changing face of the coastal environment and, in many instances, harbour sites closely mirror modifications in the shoreline (*e.g.*, Brückner *et al.*, 2004).

During the 1960s, urban regeneration led to large-scale urban excavations in many coastal cities of the Mediterranean. It was at this time that the ancient harbour of Marseille (France) was discovered. However, it was not until the early 1990s that two large-scale coastal excavations were undertaken at opposite ends of the Mediterranean in Marseille (Hesnard, 1994) and Caesarea Maritima in Israel (Raban and Holum, 1996). Both projects placed emphasis on the harbour archaeology and their articulation within the wider landscape. The first, at *Caesarea Maritima* investigated a completely artificial Roman harbour on the Levantine coast, active between the 1st and 2nd c. AD (Raban, 2009). Meanwhile at Marseille researchers set about reconstructing the archaeology and environmental history of the city's ancient harbour from the 6th c. BC, when it had been founded in a naturally protected embayment by Greek colonists. In contrast to deltaic areas, the smaller analytical scale of harbour basins meant that coastal changes could be studied more precisely. The research at Marseille (Morhange *et al.*, 2003) reconstructed a rapid shift in shoreline positions from the Bronze Age onwards and demonstrated the type of spatial resolution that can be obtained when large excavation areas are available for geoarchaeological study. These studies were unique in that, for the first time in a Mediterranean coastal context, both looked to embrace a multidisciplinary methodology.

Investigative sub-disciplinary fields included not only archaeology but also geomorphology, sedimentology and biology.

Since these studies there has been a proliferation of studies looking into coastal and ancient harbour geoarchaeology (see Marriner and Morhange, 2007 for references), building on pioneering archaeological work in the first half of the 20th c. (*e.g.*, Pâris, 1915, 1916; Lehmann-Hartleben, 1923; Poidebard, 1939; Poidebard and Lauffray, 1951). Ancient harbour basins are particularly interesting because: (i) they served as important economic centres and nodal points for maritime navigation (Arnaud, 2005); (ii) there is generally excellent preservation of the material culture (Rickman, 1988) due to the anoxic conditions induced by the high water table; and (iii) there is an abundance of source material for palaeoenvironmental reconstruction. Seaports are particularly interesting as they allow us to understand how people 'engaged with' and 'adapted to' environmental processes in coastal areas.

2. Mediterranean origins

The ease of transport via fluvial and maritime routes was important in the development of civilisations. Three areas – the Indus, China and Egypt – played an important role in the development of harbours and their infrastructure.

It has been suggested that the Egyptians were one of the earliest Mediterranean civilisations to engage in fluvial and maritime transportation. Circumstantial evidence for the use of boats in Ancient Egypt derives from deep-water fish bones found at prehistoric hunter/gatherer campsites (Shaw *et al.*, 1993). The earliest boats were probably rafts made of papyrus reeds, which enabled these societies to navigate between seasonal camps. It is speculated that wooden boats were adopted during Neolithic times (approximately 5 500 BC) with the introduction of agriculture and animal husbandry. The rise of chiefdoms during the Egyptian Predynastic period (3700 to 3 050 BC) was accompanied by the widespread adoption of boats as attested by rock art and pottery depictions. North of the First Cataract in Egypt, ships could travel almost anywhere along the Egyptian Nile. On the delta, the then seven branches of the Nile served as navigable waterways into the Eastern Mediterranean. The Eastern Mediterranean was also a natural communications link between the major cultural centres of Syria-Palestine, Cyprus, Crete, Greece and Libya. In light of this, it is unsurprising that the works along the river banks and coastlines of the Red Sea and Mediterranean were many and varied. During the 3rd millennium BC, canals were excavated from the Nile to the valley temples of the Giza pyramids so that building materials could be transported. Quays were also commonly established along the Nile, for instance at 14th c. BC Amarna, boats have been depicted parallel to shoreside quays equipped with bollards (Blackman, 1982 a and b). An artificial quay dating to the 2nd millennium BC is attested at Karnak, on the Nile River (Fabre, 2004/2005). High sediment supply and rapid changes in fluvial systems mean that few conspicuous remains of these early fluvial harbours are still visible, particularly on the delta. In Mesopotamia, a similar evolution is known. For instance, docking basins were excavated and enclosed within the city walls of late 3rd millennium Ur.

Navigation in the Red Sea during Pharaonic times is a theme that has attracted renewed interest during the past 30 years, underpinned notably by the discovery of numerous coastal sites shedding new light on the extent and chronology of human impacts in maritime areas. Extending for over 2 000 km from the Mediterranean Sea to the Arabian Sea the Red Sea was a major communications link. Since the discovery of remains at Mersa Gawasis in 1976, new findings have been made more recently at Ayn Soukhna, El-Markha and wadi el-Jarf (Tallet, 2009). At Mersa Gawasis, archaeological excavations have documented evidence for some of the world's earliest long-distance seafaring (Bard and Fattovich, 2010). The site was used extensively during the Middle Kingdom (ca. 4000-3775 years ago), when seafaring ships departed from the Egyptian harbour for trade routes along the African Red Sea coast.

The Egyptians and Mesopotamians were amongst the earliest western civilisations to engage in fluvial transportation and Bronze Age harbourworks are known from the banks of the Nile at Memphis and Giza. Despite excavations at a number of sites on the Nile delta, the exact location of many of the river ports is equivocal. There has been extensive research looking at the Canopic branch of the Nile delta coast (Stanley, 2007). The discovery of a series of active and abandoned channels around the Greek city of Naukratis attests to significant fluvial mobility during antiquity. These channels served as transport pathways for the ancient settlement, although the site's fluvial port has never been precisely located. In the northeastern part of the Nile delta two sites on the now defunct Pelusiac branch have attracted geoarchaeological interest. Goodfriend and Stanley (1999) have shown that *Pelusium*, an important fortified city located at the mouth of the Pelusiac branch, was abandoned during the 12th c. AD following a large and rapid influx of

Fig. 1. Sites discussed in the text.

Nile sediment due to flooding and reworking by long-shore currents. This discharge of sediment led to channel avulsion into a new distributary to the west. Also on the Pelusiac branch, recent research at Avaris (Tell el Dab'a) has attempted to reconstruct the evolution of the various palaeobranches that frame the site (Tronchère, 2010). The precise location of the ancient harbour basin(s) has proved particularly challenging due to the biosedimentological specificities of fluvial contexts.

3. Chronology and typology

In the Mediterranean, the first artificial structures appear to date to the Middle Bronze Age. For example, submerged boulder piles are attested at Yavne-Yam, a Middle Bronze Age site on the coast of Israel; these suggest premeditated human enterprise to improve the quality of the natural anchorage. Recent geoarchaeological work in Sidon has elucidated the presence of a semi-protected initial phase around 4410±40 BP (2750-2480 cal. BC; Marriner *et al.*, 2006a; Marriner, 2009). This sedimentological unit has been interpreted as a Middle Bronze Age to Late Bronze Age proto-harbour, with possible reinforcement of the shielding sandstone ridge improving the quality of the natural anchorage. It is suggested that small boats were hauled onto the beach, with larger vessels being anchored in the outer harbour of Zire (Carayon, 2008). After this period, the maritime harbours of the ancient Mediterranean evolved in four broad technological leaps that are described below.

3.1. Bronze Age to Early Iron Age ashlar header technology

A double ashlar wall with a filling of fieldstones is a harbour construction method common to the Phoenicians – it is known as the pier-and-rubble technique (Raban, 1985). This system has been noted at Sarepta, Lebanon, in a layer dated to the 11th c. BC. This technique possibly spread from Levant, to the western Punic colonies, Greece and North Africa, where it can be found as late as the 6th c. AD. For instance, the use of ashlar techniques can be seen in the Persian harbour of Akko (Israel), the Hellenistic harbour at Amathus on Cyprus and the Roman quay at Sarepta, Dor and Athlit (Israel). Iron Age Athlit is one of the best-studied Phoenician harbours (Haggi and Artzy, 2007). The northern harbour's mole extends about 100 m into the sea and is about 10 m wide. It is constructed of two parallel ashlar headers of two to three meters in width. Between the ashlar walls, a fill of stones was placed. This form of construction added stability so that the mole could withstand the high energy of the waves. The northern part of the mole ends with north-facing ashlar headers. The mole was placed on a foundation of ballast pebbles. As the underwater excavation revealed, the layer of pebbles extended to more than 5 m from the outer side of each mole wall, a total width of over 20 m. Radiometric dating of wood fragments constrains this Phoenician

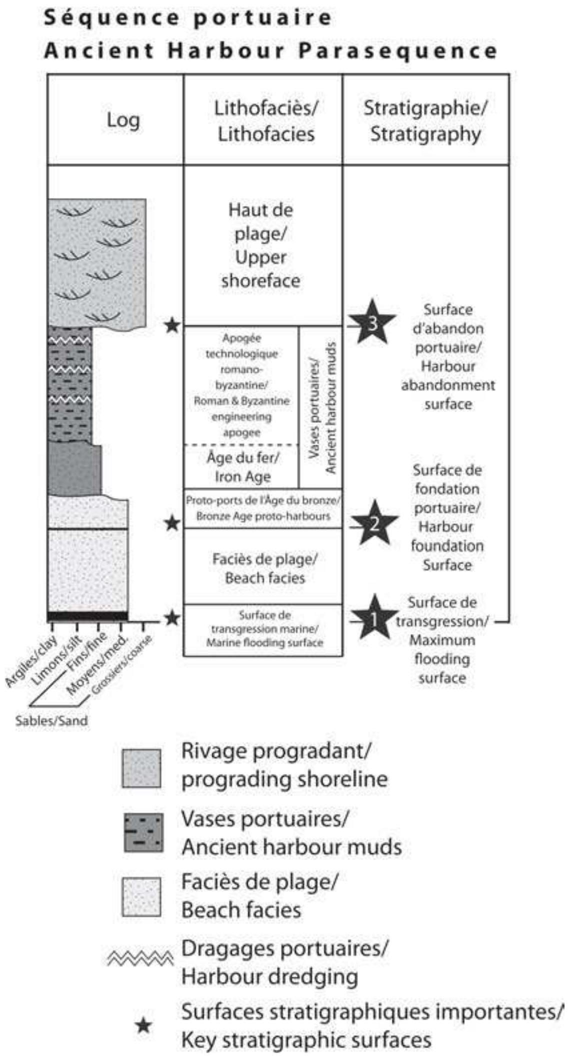

Fig. 2. The ancient harbour sequence (adapted from Marriner and Morhange, 2007).

structure to the 9th c. BC, although there is very little pottery dating from this period (Artzy, personal communication).

3.2. Cothons

The sites of Carthage, Mahdia, Phalasarna and Lechaion (West Corinth) are 'cothon' harbours. This best-known example is the port of Carthage. Nowadays, specialists agree that the term can be associated with an artificially dug harbour basin linked to the sea via a man-made channel (Carayon, 2005). It would appear that the carving of a cothon is a complex energy-consuming technique used to create a particularly well-sheltered basin. This type of infrastructure poses three problems: (i) rapid silting up in a confined environment; (ii) the difficulty of carving a basin in rocky outcrops; and (iii) maintaining a functional channel outlet to the sea. These shortcomings probably explain why few cothon examples are found in the archaeological record.

3.3. Hydraulic concrete

Pre-Roman ashlar block methods continued to be used throughout the Roman era. Nonetheless, another technique was introduced during this period that completely revolutionised harbour design and construction – the use of hydraulic concrete. This technological breakthrough meant that natural anchorages were no longer a prerequisite to harbour loci and completely artificial ports, enveloped by imposing concrete moles, could be located on open coasts. The material could be cast and set underwater, and it started to be used during the 2nd c. BC. Roman engineers were free to create structures in the sea or along high-energy shorelines (Hohlfelder, 1997; Brandon *et al.*, 2010). Hydraulic cement facilitated the construction of offshore basins such as Claudius' harbour at *Portus*.

3.4. Romano-Byzantine harbour dredging

Vitruvius gives a few brief accounts of dredging, although direct archaeological evidence has, until now, remained elusive. Marseille and Naples ancient harbours have both undergone widespread excavations (Morhange and Marriner, 2010a) and multidisciplinary datasets now exist for the two sites. At Tyre and Sidon, geoarchaeological research has led to the extraction of 40 cores that have facilitated a chronostratigraphic reconstruction of basin silting and dredging (Marriner and Morhange, 2006; maximum rate of sedimentation up to 15 mm yr^{-1}). Why were ancient harbours dredged? On decadal timescales, continued silting induced a shortening of the water column. De-silting infrastructure, such as vaulted moles and channels, partially attenuated the problem but in the long term these appear to have been relatively ineffective. In light of this, repeated dredging was the only means of maintaining a practicable draught depth and ensuring long-term harbour viability. At Marseille, although dredging phases are recorded from the 3rd c. BC onwards, the most extensive enterprises were undertaken during the 1st c. AD, at which time huge amounts of Greek sediment were extracted. At the excavations of Naples Piazza Municipio, the absence of pre-4th c. BC layers has been linked to extensive dredging between the 4th and 2nd c. BC (Carsana *et al.*, 2009). Unprecedented grooves or traces 165 to 180 cm wide and 30 to 50 cm deep attest to powerful dredging technology that scoured into the volcanic substratum, reshaping the harbour bottom. Notwithstanding scouring of harbour bottoms, this newly created space was rapidly infilled and necessitated regular intervention due to sedimentation rates up to ten times higher than those in a natural environment. Repeated dredging phases are revealed up until late Roman times, after which time the basin margins were completely silted up. At Marseille, three dredging boats, have been unearthed. The vessels were abandoned at the bottom of the harbour during the 1st and 2nd c. AD. They are characterised by an open central well that is inferred to have accommodated the dredging arm.

4. The Geoarchaeological study of harbour basins

Over the past two decades, ancient harbours have attracted interest from both the archaeological and Earth-science communities. In tandem with the development of rescue archaeology, particularly in urban contexts, the study of sedimentary archives has grown into a flourishing branch of archaeological inquiry (Walsh, 2004). This growing corpus of sites and data demonstrates that ancient harbours constitute rich archives of both the cultural and environmental pasts. Ancient harbour sediments are particularly rich in archaeological remains, with geo and bio-indicators, providing insights into the history of human occupation at a given site, coastal changes and the natural processes and hazards that impacted these waterfronts (Morhange and Marriner, 2010b; Bony *et al.*, in press). Ancient harbours are both natural and constructed landscapes and, from a geoarchaeological perspective, comprise three elements of note.

4.1. The harbour basin

In architectural terms, the harbour basin is characterised by its artificial structures, such as quays, and moles (Oleson, 1988). Since the Bronze Age, there has been a great diversity in harbour infrastructure in coastal areas, reflecting changing technologies and human needs. These include, for instance, the natural pocket beaches serving as proto-harbours, through the first Phoenician moles attributed to around 900 BC, to the grand offshore constructions of the Roman period made possible by the discovery of hydraulic concrete (Oleson *et al.*, 2004).

4.2. Ancient harbour sediments

Shifts in the granularity of these deposits translate the degree of harbour protection, often characterised by a rapid accumulation of varied sediments following a sharp fall in water competence brought about by artificial harbour works. The harbour facies is characterised by three poorly sorted fractions: (i) human waste products, especially at the base of quays and in areas of unloading. Harbour depositional contexts are particularly conducive to the preservation of perishable artefacts such as leather and wood; (ii) poorly sorted sand; and (iii) an important fraction (>90%) of silt that derives from the sheltered environmental conditions of the harbour. These areas are characterised by rapid accumulation rates of 10 to 20 mm yr^{-1}. High-resolution study of the sediments can help shed light on the nature of ancient harbour works, such as at Tyre (Marriner *et al.*, 2008) or Portus (Goiran *et al.*, 2010). Recent research has sought to characterise these chronostratigraphic phases using the unique sedimentary signature that each technology brings about. Changes in sediment supply at the watershed scale are particularly important in understanding base-level changes in deltaic contexts, as in Cyprus (Devillers, 2008) or the palaeo-island of *Piraeus* (Goiran *et al.*, 2011).

4.3. Relative sea-level changes

Nowadays, most ancient harbours are completely infilled with sediments. Within this context, it is possible to identify and date former sea-level positions using biological indicators fixed to quays, that, when compared with the marine bottom, allow the height of the palaeo-water column to be estimated (Laborel and Laborel-Deguen, 1994; Morhange *et al.*, 2006). Such relative sea-level data are critical in understanding the history of sedimentary accretion in addition to estimating the draught depth for ancient ships (Morhange *et al.*, 2001; Boetto, in press). These two reference levels, the palaeo-sea level and basal sediment surface, are mobile as a function of crustal movements (*e.g.*, local-scale neotectonics, regional isostasy, sediment budgets) and human impacts such as dredging. All these factors can potentially impact upon the available accommodation space for sediment accretion.

As outlined above, one of the key problems posed by artificially protected harbours relates to accelerated sediment trapping. In the most acute instances it could rapidly reduce the draught depths necessary to accommodating large ships. From a cultural perspective, therefore, harbours were important ‘economic landscapes’ and many changes in harbour location can be explained functionally by the need to maintain an interface with the sea in the face of rapid sedimentation. The best example of this coastal relocation derives from Aegean Anatolia where Brückner *et al.* (2005) have reconstructed a progradation of several tens of kilometres in a number of ancient rias such as the Meander.

5. Ancient harbour stratigraphy

During the past 20 years, multidisciplinary inquiry has allowed a better understanding of where, when and how ancient Mediterranean harbours evolved. This is set within the wider context of a new 'instrumental' or 'quantitative revolution' towards the environment. A battery of research tools is available, that broadly draw on (i) geomorphology, and (ii) the sediment archives located within this landscape complex.

5.1. Where?

The geography of ancient harbours constitutes a dual investigation that probes both the location and the extension of the basins. Biostratigraphical studies of sediments, married with a GIS investigations, can be used to reconstruct coastal evolution and identify possible anchorage areas (Ghilardi and Desruelles, 2009). Traditionally, urban contexts have been particularly problematic for accurate archaeological studies because the urban fabric can hide many of the most important landscape features. In such instances, chronostratigraphy can be particularly useful in reconstructing coastal changes. This approach helps not only in reconstructing ancient shorelines through time but can also aid in relocating ports for which no conspicuous archaeological evidence presently exists, as in the case of Cuma (Stefaniuk and Morhange, 2010) or Byblos (Stefaniuk *et al.*, 2005).

Geophysical techniques, such as electrical tomography and geo-radar (cf. ground penetrating radar), can provide a great multiplicity of mapping possibilities, notably in areas where it is difficult to draw clear parallels between the archaeology and certain landscape features. Because geophysical techniques are non-destructive, they have been widely employed in archaeology, and are gaining importance in coastal geoarchaeology (Hesse, 2000) and ancient harbour contexts. Reliable information can be provided on the location, depth and nature of buried archaeological features before excavation.

5.2. When and how?

Chronostratigraphy is essential in understanding modifications in harbour technology and the timing of human impacts, such as lead pollution linked to metal-working activities from the Bronze Age onwards (Véron *et al.*, 2006), or ecological stresses revealed by changes in faunal assemblages (Morhange *et al.*, 2003). The overarching aim is to write a 'sedimentary' history of human coastal impacts and technologies, using geoscience tools and a stratigraphic framework. Research in the Mediterranean attests to considerable repetition in ancient harbour stratigraphy, both in terms of the facies observed and their temporal envelopes. There are three distinct facies of note: (i) a middle energy beach sands at the base of each unit (*i.e.*, the proto-harbour); (ii) low-energy silts and gravels (*i.e.*, the active harbour phase); and (iii) coarsening up beach sands or terrestrial sediments which cap the sequences (*i.e.*, post-harbour facies). In the broadest terms, this stratigraphic pattern translates a shift from natural coastal environments to anthropogenically modified contexts, before a semi- or complete abandonment of the harbour.

There are a number of key stratigraphic surfaces key in understanding the evolution of ancient harbour basins:

- The Maximum Flooding Surface (MFS). Ancient harbours form integral components of the highstand sequence (aggradational to progradational sets). For the Holocene coastal sequence, the MFS represents the lower boundary of the sediment archive that is of interest to archaeologists. This surface is broadly dated to around 6000 cal. BP and marks the maximum marine incursion. It is associated with the most landward position of the shoreline. In the eastern Mediterranean, it is contemporaneous with the Early Bronze Age. Indeed, the MFS along the Levantine coast clearly delineates the geography of early coastal settlements from this period (Raban, 1987).

- Natural beach facies. The MFS is overlain by naturally aggrading beach sands, a classic feature of clastic coastlines. Since *ca.* 6000 BP, relative sea-level stability has impinged on the creation of new accommodation space, leading to the aggradation of sediment strata. This is particularly pronounced in sediment-rich coastal areas such as deltas and at the margins of fluvial systems. Where this sedimentation continued unchecked, a coarsening upward of sediment facies is observed, consistent with high-energy wave dynamics in proximity to mean sea level.

- The Harbour Foundation Surface (HFS) marks important human modification of the sedimentary environment, characterised by the transition from coarse beach sands to finer-grained harbour sands and silts. This surface corresponds to the construction of artificial harbour works and, for archaeologists, is one of the most important surfaces to date the foundation of the harbour.

- The Ancient Harbour Facies (AHF) corresponds to the active harbour unit. This artificial creation is translated into the sedimentary record by lower energy facies consistent with a barring of the anchorage by artificial means. Harbour infrastructure (quays, moles and jetties) accentuated the sediment settling properties by attenuating the swell and marine currents leading to a sharp fall in water competence. Research has demonstrated that this unit is by no means homogeneous, with harbour infrastructure and the nature of sediment sources playing a key role in shaping facies architecture. Of note is the granulometric 'paradox' of this unit consisting of fine-grained silts juxtaposed with coarse gravels made-up of ceramics and other urban waste. In some rare instances a Proto-Harbour Phase (PHP) precedes the AHF. Before the major changes characteristic of the AHF, bio-sedimentological studies can illustrate moderate signatures of human presence when societies exploited natural low-energy shorelines requiring little or no human modification. During the Late Bronze Age and Early Iron Age, improvements in harbour engineering are recorded by increasingly fine-grained facies. Plastic clays tend to be the rule for Roman and Byzantine harbours and sedimentation rates 10 to 20 times greater than naturally prograding coastlines are recorded. The very well protected Roman harbours of Alexandria, Marseille and Fréjus (Gébara and Morhange, 2010) all contain plastic marine muds consisting of 90% organic silts. Significant increases in sedimentation rates can also be attributed to human-induced increases in the supply term including, for example, anthropogenic changes in the catchments of supplying rivers (deforestation, agriculture), erosion of adobe urban constructions and finally use of the basins as *ad hoc* waste dumps. This underlines the importance of an explicit source-to-sink study integrating both the coastal area and the upland hinterland. Such high rates of harbour infilling were potentially detrimental to the medium to long-term viability of harbour basins and impinged on the minimum 1 m draught depth.

- The Harbour Abandonment Surface (HAS). The HAS marks the "semi-abandonment" of the harbour basin. A relative decline in harbour works after the late Roman and Byzantine periods is characterised by a return to 'natural' sedimentary conditions comprising (i) coarse-grained sands and gravels in a coastal context and (ii) terrestrial facies in fluvial environments. Following hundreds to thousands of years of artificial confinement, reconversion to a natural coastal para-sequence is sometimes expressed by high-energy upper shore-face sands. This shoreline progradation significantly reduced the size of the basins, often landlocking the heart of the anchorages beneath thick tracts of coastal and fluvial sediments.

6. Conclusion

Today, it is recognised that harbours should be studied within broader regional frameworks using a multidisciplinary methodology. There is great variety in harbour types and, broadly speaking, three areas or physical processes are important in influencing harbour location and design: (i) geographical situation; (ii) site and local dynamics; and (iii) navigation conditions dictated by the wind and wave climate. The diversity of contexts investigated during the past 20 years, has brought to light some striking patterns. Numerous processes are important in explaining how these have come to be preserved in the geological record including the distance from the present coastline, position relative to present sea level and geomorphology. Some of the main advances made during the past 20 years include: (i) the precise characterisation of harbour facies in coastal contexts, using a variety of sedimentological, geochemical and palaeoecological proxies; (ii) the characterisation and intensity of human impacts in coastal areas; and (iii) the scope to derive high-resolution RSL data. Ancient harbour research is a rapidly evolving offshoot of geoarchaeology and there is reason to be optimistic about its future prospects and applications. Major gaps remain with regards to the Bronze Age and future studies must look to probe this earlier period. Another area of concern is the rise in 'catastrophy-seeking' research in harbour contexts that mirrors the growth of neocatastrophic research in environmental archaeology (Marriner *et al.*, 2010) – we advocate the adoption of more nuanced approaches to the study of high-energy episodic events such as tsunamis impacts (Morhange and Marriner, 2010b).

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