THE PORT OF *BERENIKE TROGLODYTICA* ON THE RED SEA: A LANDSCAPE-BASED APPROACH TO THE STUDY OF ITS HARBOUR AND ITS ROLE IN INDO-MEDITERRANEAN TRADE.

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"History loves a paradox, and there can be none greater than a taste for spices being responsible for the exploration of our planet. Sovereigns pledged their prestige, and navigators risked their lies, not in the quest for gold or the thirst for power but to redirect the distribution of a few inessential and today almost irrelevant vegetable products."
— John Keay, 'The Spice Route' 2005

THESIS ABSTRACT

The port site of *Berenike Troglodytica* — located on the Egyptian Red Sea coast — served the spice and incense routes that linked the Mediterranean World (specifically the Roman Empire) to India, Southern Arabia and East Africa. In the Greco-Roman period the site was at the cutting edge of what was then the embryonic global economy, ideally situated as a key node connecting Indian Ocean and Mediterranean trade for almost 800 years. It is now located in an arid, marginal, hostile environment but the situation must have been very different 2300 years ago, at the time of its founding. At the time of elephant-hunting trips during the Hellenistic period before the inception of its important role in the global markets of the day in the Roman period Berenike would have to have looked much different to what we can now imagine. What was it like then, when the first prospectors visited this location at the time of Ptolemy II? Why this particular place, and this particular landscape setting seemed such a propitious location for the siting of an important new harbour?

Given the importance of the port over almost a millennium it is perhaps surprising that very little is known about the different factors impacting on the foundation, evolution, heyday and subsequent decline of the city; or the size, shape, and capacity of its harbour. The intention of this research is to address this shortfall in our knowledge, to examine the drivers behind the rise and fall of this port city, and to explore the extent to which the dynamics of the physical landscape were integral to this story. Using an innovative Earth Science approach, changes in the archaeological 'coastscape' have been reconstructed and correlated with periods of occupation and abandonment of the port, shedding light on the nature, degree and directionality of human-environment interactions at the site. This work has revealed profound changes in the configuration of the coastal landscape and environment (including the sea level) during the lifespan of Berenike, highlighting the ability of people to exploit changes in their immediate environment, and demonstrating that, ultimately, the decline of the port was partly due to these landscape dynamics.

To further explore these themes the landscape reconstructions have been supplemented by semi-quantitative analyses of a suite of variables likely to influence the initial siting of new ports of trade. These have shown that although the site of Berenike was ideal in terms of its coastal landscape potential, possessing a natural sheltered bay and lagoon system, the choice of location was not solely influenced by its environmental conditions. Additionally, a detailed review of vessels that plied Red Sea and Indian Ocean routes is presented here in order to better understand the design and functioning of Berenike's harbour. This serves the purpose of identifying unifying features that provide more detail about the size and draught of vessels and the potential capacity of the harbour basin.

By using this multi-scalar approach it has been possible to reconstruct the 'coastscape' of the site through the key periods of its occupancy and those phases immediately before and after its operation. This has wide-ranging implications for researchers studying ancient ports along this trade network as a larger database will tease out more details about how influential the landscape was in the initial siting of the port and its subsequent use and decline.

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SPECIAL

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"On ne découvre pas de terre nouvelle sans consentir à perdre de vue, d'abord et longtemps, tout rivage." —André Gide, 'Les faux-monnayeurs' 1925

1. BERENIKE AND PORTS OF THE CLASSICAL WORLD: RESEARCH, PROBLEMS, SOLUTIONS

The ancient world was connected by a vast and highly prosperous network of maritime trade routes. These long-distance commercial exchange pathways linking the Mediterranean, the Red Sea and the Indian Ocean were largely based on existing local and regional seafaring itineraries that followed routes pioneered by early explorers and commercial 'trail-blazers'. The success of many of these shipping lanes developed because of the growing demand for foreign goods by the increasingly wealthy and aspirational societies, kingdoms and empires of the Mediterranean, Southern Arabia, India, Southeast, and East Asia, and the increase in quantity and quality of the port infrastructure available *en route* (Fig. 1.1).

What remains uncertain, however, is the level of importance of the various socio-political and/or enviro-climatic mechanisms that drove the growth of these networks, the mechanisms of their operation and the nodes of communication involved. The primary function of ports is to facilitate the movement of people and goods (Oleson 1988: 148), and it is well known that ports and harbours were operational over very long periods during which people continued to reuse and revisit them, sometimes adopting existing trading alliances and adjusting them to their own needs.

Although a small number of the larger Greco-Roman ports have been recorded for posterity, a significant proportion of these important nodes of trade and exchange are now largely lost, and their locations can only be mooted. This has encouraged a number of key questions that the new data presented here will endeavour to address and which have been borne in mind during the period of this research. What was the rationale for locating ports in these positions in the natural and political landscape? How did the ports look, what was their capacity and how were they modified over time? How did local communities adapt to the often inhospitable and variable environmental conditions, and how were they able to sustain themselves as well as re-victual their visitors? How did the coastal populations inhabiting these towns utilise and maintain coastal littoral zones? Whilst not an exhaustive list, these questions serve as a starting point for this thesis, and potential answers will be put forward in the discussion Chapters 5–7.

The doctoral research presented here will assess in detail the influence that the local environmental and climatic context had on the initial choice of location, development, and ultimate success or decline of key Classical ports of trade. For this purpose, this research will use a key port on the Indo-Roman trade route — the ancient city of *Berenike Troglodytica* — located on the southern Red Sea coast of Egypt, as a case study. The focus of this research has been placed on the period from the 3rd century BCE (the onset of the Hellenistic era) throughout the period of Roman rule in Egypt, to the beginning of the 7th century CE, contemporary with the advent of Islam and the Arab conquests. It is during this broad window of time that persistent and extensive long-distance trade began to emerge — arguably representing the beginnings of a global economy — and during which time Berenike was founded, flourished and finally collapsed.

1.1. ANCIENT RED SEA AND INDIAN OCEAN TRADE NETWORKS: AN INTRODUCTION TO CLASSICAL PORTS

There is a uniquely long record of seafaring and maritime trade on the Indian Ocean and its satellite basins, the Red Sea and the Persian Gulf. Current archaeological research is providing a growing body of evidence that far-distant contacts already thrived in prehistory, well before the Classical or Early Historic periods, and that these were most likely carried out by a "multitude of small-scale entrepreneurs" (Fuller et al. 2011: 544). Experiencing seasonally variable wind and ocean currents, the Indian Ocean and Red Sea constituted favourable grounds for maritime voyaging, contact and trade for millennia. This enabled sailors and merchants to travel long distances, bridging distant continents, accelerating the movement of trade goods and technological ideas, as well as the dispersal of domesticated plants and animals (Boivin and Fuller 2009; Fuller and Boivin 2009).

Whilst prehistoric contacts were most likely related to short coastal hops, a more structured and systematic exploitation of the monsoon routes is clearly visible in historical times. The knowledge of prevailing monsoon patterns, already mastered by Indian and Arab seafarers, was introduced to and exploited by the Roman Empire. It is this knowledge that held the key to answering the demand for luxury goods to the Mediterranean (e.g. Warmington 1928; Thapar 1992; Peacock 1994; de Romanis 1996; Reade 1996; de Romanis and Tchernia 1997; Mazzarino 1997; Tchernia 1997; Whittaker 1998; Ward 2003; Gupta 2005; Shcheglov 2005; Seland 2008a, 2008b; Sidebotham 2011). Indeed, by the end of the first millennium BCE the maritime networks and associated infrastructure were sufficiently developed to sustain complex commercial exchange and allow an explosion of what is now commonly known as 'Indo-Roman trade' (e.g. Charlesworth 1951; Wheeler 1954; Miller 1969; Raschke 1978; Singh 1998; Begley and de Puma 1991; Young 2001; Tomber 2008; de Romanis 2009; McLaughlin 2010, 2014).

Whilst limited attention within the Roman imperial agenda was given to direct exploration (e.g. campaigns to the source of the Nile), trade and diplomatic contact with the East remained an important part of Rome's foreign policy (Nicolet 1991), whilst the acquisition of '*Ex Oriente Luxuria*'[1] became one of its most guarded activities (e.g. Young 2001: 216; Parker 2002, 2008). The development of commercial institutions and advances in navigational and shipbuilding techniques, along with an increase in availability of accurate *Periploi*,

[1] '*Ex oriente lux*' means literally 'the light from the east'. Here, the term '*Ex oriente luxuria*' is borrowed from Parker (2002) and used for so-called 'western luxury goods' (e.g. Trinquier and Schneider 2014).

advanced the potential of maritime trade (e.g. Casson 1989; Adkins and Adkins 1998: 188; Dueck 2011: 40, 2010). A stable population with growing demands for imported goods, and a legal system with the administrative apparatus capable of monitoring exchange over very large areas, allied with complex fiscal policies and common currency systems, were sufficiently developed to sustain complex commercial exchange and to support a number of ports of trade located in often environmentally unattractive locations (e.g. Fitzpatrick 2011; Wilson and Robinson 2011: 6–7).

1.2. THE ARCHAEOLOGICAL AND HISTORICAL CONTEXT OF *BERENIKE TROGLODYTICA* IN THE PTOLEMAIC AND ROMAN PERIODS

Berenike Troglodytica was one of the most important port cities on the Egyptian Red Sea coast during the Ptolemaic and Roman periods. The city intermittently prospered for eight centuries, from *ca.* 275 BCE, when it was established as a small outpost, initially involved in the trade of African elephants, to the mid 6th century CE, when it finally ceased to operate (e.g. Sidebotham 2011). Located on the western coast of the Red Sea, the city was situated in a prime geographic position at the distal end of the influence of the monsoon wind, some 300 km from Myos Hormos, 825 km south of Arsinoe and Clysma (near Suez), 260 km east of Syēnē (Aswan) and 12 days by an Eastern Desert caravan route to Coptos (Quft) (Fig. 1.2).

The port of Berenike was sited just south of the large peninsula of Ras Benas, which offered the site protection from the elements (Figs. 1.3 and 1.4). During this time it was strategically connected with Alexandria, the capital of Roman Egypt, by three separate routes through the Eastern Desert, and the Nile and to the north up the Red Sea.

Three main phases/areas of occupation have been documented on a 28 ha site of Berenike, providing a clear spatio-temporaly division into:

- Fortified port and fort complex founded in the reign of Ptolemy II (c. 276 BCE);
- Early Roman emporium on the Spice Route from India to Rome (1st–3rd century CE);
- Port on the commercial routes to Africa, Arabia and India (4th–6th century CE).

In Roman times, Berenike became an important transhipment port, playing a significant and leading role in long-distance trade between the Mediterranean and the Indian subcontinent, connecting Arabia and sub-Saharan Africa with these disparate regions. Extensive excavations at Berenike have yielded floral and faunal remains, common trade goods, exotic luxuries, and evidence for long distance contact as far west as Gaul and Spain, and as far south and east as the kingdom of Axum in Ethiopia, coastal sub-Saharan Africa, South Arabia, the Persian Gulf, India, Sri Lanka, perhaps Vietnam/Thailand, and eastern Java (e.g. Sidebotham 2002: 234, 2011: 223).

The geographic location and landscape setting of Berenike — the starting point of the *Periplus Maris Erythraei*[2] — was well-suited as a commercial port, even taking into consideration the difficulties in developing a large port of trade in the marginal hinterlands of the Empire (Figs. 1.5 and 1.6). These difficulties include restricted access to fresh water, food and other essential resources (see Chapter 6). Therefore it is fair to say that demand for exotic goods was a leading factor in sustaining site's growth and popularity, with the wealth of archaeological material recovered from Berenike confirming the cosmopolitan character of the city. This transitory space situated on a crossroads linking the Indian Ocean and the Mediterranean with East Africa, Arabia, and India, brought together country folk, merchants, sailors, priests, officials, soldiers, quarry workers and slaves from across the world. Inscriptions found at the site show the use of at least 12 languages (Sidebotham 2011: 74–76) and a number of cults and religions (Rądkowska et al. 2013), a testimony to the international and multicultural aspect of the city.

During the Greco-Roman period, a number of factors, including advanced ship design and construction techniques; innovations in navigation and mooring methods; the increasingly busy shipping lanes of the Red Sea; location at the nexus of Indian Ocean and Mediterranean commerce; and the exploitation of natural features of the coastal landscape, should have ensured that Berenike represented an excellent choice as a sheltered harbour with sufficient water depth to accommodate high volume of incoming and outgoing merchant vessels. This being the case, questions arise such as what was the actual size and capacity of

[2] Classic translations by Schoff 1907 and Casson 1989 are used in this thesis.

this port; how did the city take shape and change shape over the centuries; and what drove these changes?

Given Berenike's key role in Indo-Roman commerce, we might also ask what were the geo-political and environmental conditions that indicated this particular location in the coastal seascape, or, in other words, what were the 'Parameters of Attractiveness' of the siting of this port, and others, along the growing trade network of the time? These will be explored in further detail in Chapter 6.

1.2.1. The Ptolemies and early Red Sea and Indian Ocean exploration

The period between the death of Alexander the Great in 323 BCE and the 'Muslim conquest' of the 7th century CE was especially significant for the expansion of maritime trade routes, port economies, and the increased development of maritime technologies (e.g. Warmington 1928; Vosmer 1996, 1999; Parkin and Barnes 2002; Ray 2003; Rice 2012). These maritime contacts and their relations with the 'dispersed hinterlands' (Horden and Purcell 2000: 155–122) laid the foundations for the connectivity of the later, medieval, Islamised Indian Ocean world (e.g. Chaudhuri 1985).

Alexander's 'conquest' of India vastly increased the extent of the 'known world' to Europeans, opening up new intellectual horizons (e.g. Kartunnen and Seura

1997). The Far East suddenly became readily accessible; the exploration of distant, oriental lands was possible, whilst the Mediterranean world was bound together as it never had been before (Casson 1974: 117). Alexander's successors did not only discover new territories but also cultivated a new mind-set for an emerging Roman Empire and the mentality of readiness to engage in far-distant economic exchange and exploitation (Casson 1974: 121).

The Ptolemies, the Hellenistic rulers of Egypt, controlled the western and northern ends of the sailing routes to Southern Arabia prior to Rome's conquest of Egypt. Since taking control of Egypt, they quickly seized the opportunity to exploit trade with India (e.g. Sidebotham 1986; Karttunen and Seura 1997; Rawlinson 2001: 88–100). It was, however, a relatively small-scale endeavour to begin with. Ptolemy I was the first of the Hellenistic kings to start exploring Red Sea resources (Pliny, *NH* 37.108; Burstein 1990: 32), followed closely in this venture by his son and successor Ptolemy II Philadelphus who significantly increased the kingdom's interest in the region.

Ptolemy II sent numerous expeditions to the African coast to hunt for elephants (Nossov 2008: 19–24), and to acquire ivory whilst establishing the first outposts to manage this increasing volume of imports (Müller 2006: 151–152). During his reign, Ptolemy II opened the Nile–Red Sea canal and established the port of Arsinoe in the Gulf of Suez. Moving southwards, he founded the city of Philotera (Strabo, *Geogr.* 16.4.5), established the port of Ptolemais Theron (Strabo, *Geogr.* 16.4.7; Casson 1989: 100–101), and ventured as far as the Arabian coast of the Indian Ocean (Burstein 1990; Agatharchides *PTET* 87a). Around

275 BCE, he connected, by caravan route, the river-port of Coptos located in the Nile valley, with a new sea-port *Berenike Troglodytica*, situated on the other side of the Eastern Desert (Strabo, *Geogr.* 17.1.45; Sidebotham 2011: 39–54; Wilson 2015). From this time onwards, Ptolemaic Berenike became interwoven in an organised network of maritime exchange and interaction, establishing itself as a valuable outpost from which to start southward journeys.

Recent research suggests that the state-led agenda behind the founding of Berenike was much more complex than simply to tranship war elephants (Müller 2006: 155) and exploit the economic potential of the region. This followed from the time of Alexander the Great, when to 'explore the edges of the known world and beyond' was an integral part of the imperial scheme (Müller 2006: 156). The Ptolemaic kings were not only interested in gaining access to the lucrative trade in gold, precious stones and slaves available in the southern margins of their Egyptian Empire, but also in region's significant strategic role. This role of Berenike was then strongly exploited throughout the period of Roman rule in Egypt.

The shipment of fighting elephants might simply have been an added bonus to the opening up of the region to trade. Egyptian advisors to the Ptolemies, who had knowledge of Pharaonic expeditions on and beyond the Red Sea to the mythical land of Punt (Nossov 2008: 19–24), for example, could well have been instrumental in informing decisions on potential port locations in the region (e.g. Kitchen 1971: 189–191, 2004; Phillips 1997; Bard and Fattovich 2003: 30–31; Bard et al. 2007; Ward and Zazzaro 2010: 27–43).

Elephantagoi, barges used in the Ptolemaic period to transport elephants from Africa (Casson 1971: 340, 1993: 258), would probably have been careened directly on beaches of such a port. The elephants would then be led off a ramp astern, or urged straight onto a beach as depicted on the 4th-century CE mosaic from Piazza Armerina (Fig. 1.7). The sandy beach around the lagoon at Berenike, protected by the elevated Crescent-shaped Ridge (CSR) (Fig. 1.8), could have offered an excellent location for such an operation, as well as a safe 'pen' for the animals before they were escorted further inland. It should be borne in mind, however, that the Ptolemaic 'elephant docks' need not have been particularly extensive. These installations, if they ever existed, were intended for the purpose of unloading occasional shipments of large, often recalcitrant, animals that could have easily walked through the water and did not necessarily need a ramp and a pier – the construction of which would have been a significant undertaking.

A potential reconnaissance group dispatched at the request of Ptolemy, with the requirement for mooring the *elephantagoi* in mind, might have been sent in search of a convenient location for a new harbour located at the opposite end of the route from Coptos. Prospection along the coastline would have easily identified the landscape of Berenike as one such suitable location. The sheltered lagoon, protected from prevalent northerly and north-easterly winds and waves by the cape of Ras Benas, and from southerly currents by a local Southern Promontory, was excellent in terms of sailing and transporting large animals, providing a safe anchorage and easily recognisable location (an ancient viewshed[3]), and a relatively easy approach from the south.

Recent findings from Berenike seem to confirm that its strategic position (see Section 5.8) must have been an instrumental factor in the choice of the location of the port in Hellenistic period or even prior to it (Fig. 1.8). A large flat island (or peninsula) situated on an elevated reef outcrop, fringed by ridges of fossil reef to the south, and by the crescent-shaped fossilised reef ridge to the east, offered an outstanding strategic position. A large, most probably defensive wall of Ptolemaic origin (dated by coins and associated artefacts), was found in 2013, seemingly confirming that the early Ptolemaic settlement could have been encircled by city walls, with a gate complex protecting the city against the ancient Bedouin tribes of the Eastern Desert (Sections 4.5 and 5.9; Figs. 1.9 and 1.10).

The establishment of a large fort in Berenike by the first Ptolemies confirms its rapid rise to ultimately become one of the most significant Red Sea outposts of this Hellenistic Kingdom (Manning 2003: 34) (Fig. 1.11). The fort is located behind the Crescent-shaped Ridge (Sections 2.4.3 and 5.6) situated on a limestone terrace, whilst the remainder of the site was surrounded by a tidal flatland to the north, a lagoon to the south and a coastal plain to the west. The later Roman town was located on an uplifted coral reef terrace (city-tell, see Fig. 1.8), southeast from the Ptolemaic area, and at the time, was most probably

[3] A viewshed is the area visible from a specific location. Viewshed analyses are a common tool in landscape archaeology and are used to understand sites' visibility and relationship between spatially discrete areas.

situated on an island, or connected to the land by a narrow isthmus (Harrell 1998). This area was perhaps also inhabited in the Ptolemaic period.

Succeeding the first half-century of intensive commercial activity at Berenike, there followed what appears to have been a period of relative stagnation. This probably reflected the general political situation in Egypt and the decline of the Ptolemaic Empire from the time of Ptolemy IV Philopator (221–203 BCE) (Bingen and Bagnall 2007: 240–255). This led to a cultural and commercial hiatus at the site that only revived in the Roman period.

1.2.2. Development of Mediterranean–Red Sea–Indian Ocean trade in the Roman period

Roman trade contacts with 'the East' existed from the late Republic, although initially these dealings, as in later periods, were facilitated through 'middlemen' situated in cities such as Alexandria or Aden (e.g. Margariti 2007). Originally, the Romans believed that the passage to India, by way of the route around Africa, was going to be extremely difficult (Strabo, *Geogr.* 1.2.31–4.6; 2.3.4-5; Pliny, *NH* 6.34.175-176). Despite Posidonius describing several successful attempts, the state of geographical knowledge at the beginning of the Common Era made them believe that the high temperatures experienced at the equator would prevent the passage (Strabo, *Geogr.* 2.3.4/146–147; Kidd 1988: 140–142).[4]

Following the route to the land of Punt, already established by the Pharaohs (e.g. Prasad 1977: 55; Pankhurst 1997: 4) Ptolemaic and Roman seafarers navigated down the Red Sea, aided by the re-opening of the Red Sea–Nile canal (e.g. Cooper 2009, 2014; Sheehan 2012).[5] By the 1st century CE, according to Pliny the Elder, trade worth up to 100 million *sestertii*[6] flourished (*NH* 12.41.84), and oriental luxuries were in very high demand, reaching Roman markets from East Africa, India, Central Asia and the Far East (Sidebotham 1986: 36–37; Parker 2002, 2008).

The growing demand from the significant wealthy population of the Roman Empire was fulfilled by supplies from the well-established, internal commercial networks, and supplemented by trade from five important routes linking the Roman world with surrounding lands. These were the so-called 'Amber', 'Salt/Slave', 'Trans-Arabian Incense', 'Silk' and 'Maritime Spice' routes

[4] For example Strabo (*Geogr.* 2.3.1) mentions: "for the regions next the equator and torrid zone are uninhabitable on account of the heat".

[5] This canal was first dug, arguably, by either Senuseret/Sezostris II or Ramses II in the 2nd millennium BCE. A new phase of construction was initiated by Pharaoh Necho II of 26th Dynasty in 6th century BCE, and then it was re-established by Darius I in the 5th century BCE. The canal was reopened once again by Ptolemy II between 270–269 BCE (Aristotle, *Meteo.* 1.15; Pliny, *NH* 6.33.165). It was extended under the Romans into the 180 km-long Trajan's Canal. Following the active period of usage the canal was neglected by the Byzantines but later reopened by the early Arabs. The canal was ultimately deliberately filled in by the 'Abbāsid caliphs for military reasons in 775 CE.

[6] It was about one-tenth of the finances needed to fund the entire Roman Empire for a year (950 mln *sestertii*), although the closed monetary system in Egypt meant that the *denarii* were readily sent to the East by Egypt-based traders (Lach 2011). With a vessel such as *Hermapollon* (Rathbone 2001) bringing in a cargo worth some 9 mln *sestertii*, an entire 'fleet' of 120 ships (if we take Strabo's estimate in *Geogr.* 2.5.12.) could therefore bring in to the Empire cargos worth 1 billion *sestertii* every year and generate approximately 250 mln in tax revenue for the state (Wilson 2015).

(Sidebotham 2011: 206). As a result of these far-reaching, multicultural trade connections, Pliny (*NH* 6.23.84) reports that by the 1st and 2nd centuries CE, delegations were sent to, or coming from, Sri Lanka and India and so it would have become commonplace to encounter foreign seamen and merchants immersed and integrated in everyday Roman life, not only in provincial ports such as Berenike but also in the capital (Rowland 1958; Young 2001: 54–61).

The demand for luxuries also increased in this period because of growing interest from the imperial court. For example, the Emperor Augustus sent an expedition commanded by Aelius Gallus to conquer Arabia Felix and to monitor the trade of frankincense (Sidebotham 1986: 120–130; Sartre 2005: 65–67), by this time one of the elite's staple luxury items (Peacock and Williams 2006; al-Salameen 2009).[7] On the globalised character of Rome's société Casson (1959: 224) writes:

> *"The Roman man in the street ate bread baked with wheat grown in North Africa or Egypt, and fish that had been caught and dried near Gibraltar. He cooked with north African oil in pots and pans of copper mined in Spain, ate off dishes fired in French kilns, drank wine from Spain or France and, if he spilled any of his dinner on his toga, had it cleaned with fuller's earth from the Aegean Islands. The Roman of wealth dressed in garments of wool from Miletus or linen from Egypt; his wife wore silks from China, adorned herself with diamonds and pearls from India, and made up with cosmetics from South Arabia. He seasoned his food with Indian pepper and sweetened it with Athenian honey, had it served in dishes of Spanish silver on tables of African citrus wood, and washed it down with Sicilian wine poured from decanters of Syrian glass. He lived in a house whose walls were covered with colored marble veneer quarried in Asia Minor; his furniture was of Indian ebony or teak inlaid with African ivory, and his rooms were filled with statues imported from Greece. Staples and luxuries, from as near as France and as*

[7] Frankincense was so highly regarded that Emperor Nero burnt the entire yearly harvest during the funeral of his favourite mistress Poppaea (Pliny, *NH* 12.41.83).

far as China, poured into the capital, enough of the one to feed a million people, and of the other to satisfy the extravagances of the political, social, and economic rulers of the western world."

Roman expansion into Egypt sparked a major political and economic revival in an otherwise declining economy (e.g. Ellis 2008; Riggs 2012), and Berenike appears to have been selected again as an important reloading harbour for oriental luxury trade, focused on spices and incense (Young 2001; Sidebotham 2011). This Early Roman Imperial restoration began with the installation of a Roman military garrison under the Flavians, as confirmed by a rich trove of ostraca from this period (Maxfield 1986; Bagnall et al. 2000; Bagnall 2001). Furthermore, the network of roads, such as the *Via Hadriana*, linked the Red Sea ports with the forts, *praesidia*[8], quarries and mines of the Eastern Desert (Zitterkopf and Sidebotham 1989; Sidebotham and Zitterkopf 1991, 1995, 1996, 2006; Sidebotham 1997; Sidebotham et al. 2000). These often solitary outposts facilitated the extraction of emeralds, amethyst, gold, galena, building stones and the importation of luxury goods from the East, such as spices and incense (e.g. Sidebotham 1986, 2011; Maxfield 2001; Sidebotham et al. 2001, 2008; Harrell and Storemyr 2009; Thomas 2012: 173).

Past and present archaeological results leave no doubt that Berenike was in intensive use as a port during the second part of the first, and throughout the 2nd century CE (Sidebotham and Wendrich 1995–2007; Sidebotham and Zych

[8] The names of the first generation of wells and desert stations at the Eastern Desert in 50s CE are known to us from Pliny's (*NH* 6.102–103) account. He mentions camps at the desert (in *monte*) and *hydreumata* – the wells (de Romanis 1996: 208). Later on, new terms are used, sometimes in the same text, such as Sikayt Inscription (Bagnall et al. 2001), including: *hydreumata, praesidium* (fortlet) and *lacus* (a cistern). The much more common use of the term *praesidium* over *hydreumata* in Trajanic ostraca suggests, according to Bagnall and colleagues (2001: 331), a change in habits and the militarisation of architecture in the Eastern Desert.

2011, 2015 *forthcoming*). The middle of the 2nd and 3rd centuries CE witnessed the apparent decline of Berenike's popularity and the growing importance of Myos Hormos, located some 150 km further to the north (e.g. Whitcomb 1996; Peacock and Blue 2006, 2011; Blue 2007; van der Veen 2011). This may have been due to the deteriorating political and military situation on the southern border of Egypt, and the resultant shift of the Red Sea/Nile Valley caravan trade to a safer, northern route — the *Via Hadriana* — in use until Late Roman/Byzantine times (Sidebotham et al. 2000: 126; Sidebotham 2002, 2011).

This change occurred contemporaneously with a potential minor environmental shift and the re-configuration of the size, shape and functionality of the harbour basin (Chapter 5, Figs. 1.12 and 1.13 for old interpretations). After that, from the beginning of the 5th century CE the city slowly decayed, and finally ceased to operate in the 6th century CE, most probably owing to the Justinianic plague that might have had an Indian Ocean origin (Little 2006: 67, 121; Sidebotham 2011: 220).

1.2.3. Berenike and its archaeology: Archaeological excavations in the harbour area

In 2008, the Berenike Excavation Project was revitalised as a Polish-American collaboration, under the directorship of Steven Sidebotham (University of Delaware, US) and Iwona Zych (Polish Centre for Mediterranean Archaeology, University of Warsaw, Poland). One of the major objectives was to initiate investigations in the area believed to be Berenike's southwestern port (Fig. 1.14) (Sidebotham and Zych 2011). Geomagnetic survey (Fig. 1.15) and targeted test excavations were carried out in this area before the augering and georadar survey work as part of this project. Whilst the author's initial role in the Berenike Excavations Project was as a Field Archaeologist, with the initiation of this DPhil programme, a geoarchaeological project was formalised with the results to form the core of this thesis and to play a major part in interpreting the archaeological site within its surrounding dynamic landscape.

A number of major discoveries have been found during these last 7 seasons. Those include Hellenistic fort, town fortifications and a gate complex from mid-3rd century BCE (Fig. 1.17), harbour bay with storage and workshop facilities (Ship Maintenance Area, Fig. 1.8) and a sacred Temenos of temples on an island in the harbour (including the "Lotus Temple", 4th–5th century CE; Fig. 1.8), pet dog, cat, and monkey cemetery, as well as early Roman ostraka and papyri archives on a rubbish dump (approx. 150–170 m north-west from the city-tell; Fig. 1.14), all of them reffered to later in this thesis.

Initial excavations in the harbour area commenced with an aim to test the hypothesis that the Crescent-shaped Ridge was a harbour jetty or a wharf in the Early Roman period (see Section 5.6 and Fig. 1.8 for location). Trenches BE09-55 and BE10-67 (supervised by the author), which crossed the top of the ridge, did not provide any direct evidence to support their connection with the port and were mostly of Late Roman date (Fig. 1.16). However, evidence from trenches

BE09-54, at the northern edge of the ridge (Sidebotham and Zych 2011: 27–43), and its extensions BE10-62/64 and BE11-78, as well as later BE14-100 and -101 (Sidebotham and Zych, *in prep.*), suggest the presence of an area with features dataed to 2nd century CE and similar to a ship repair workshop (Ship Maintenance Area, Fig. 1.8), which could have been located in the vicinity of the port (Section 5.6).

Significant excavation (consisting of 7 trenches, to date: BE10-61, BE11-70, BE12-81, BE12-87, BE12-89, BE13-92, and BE13-94, Fig. 1.16) was undertaken during the last four seasons, under the overall supervision of Joanna Rądkowska, on what is believed to be an island (Section 5.5) on which a Late Roman *Temenos* of Temples (Fig. 1.8) of most probably South Arabian cults were located (Rądkowska et al. 2013). The stratigraphy observed in sections of these excavations helped refine some sedimentological interpretations (Section 4.3.1.1).

The 6,600 m^2 area around what is believed to have been the 'Northern Anchorage' was targeted for further investigation, including augerhole and geophysical surveys (Section 5.7, Fig. 1.8). This was based on data derived from excavations in trenches BE98-23 and BE99-32 (located to the southwest), and BE97/98-17, BE96-7, BE95-4 (to the southeast, Fig. 1.16) with purported evidence of the wharf (Sidebotham and Wendrich 2001: 74–75).

1.2.4. Ancient sources and port locations

Extensive body of ancient literature exists as a record of commercial and seafaring activities on the Red Sea and the Indian Ocean, proving maritime contacts between these disparate lands and continents. The largest collection of work available to us consists mainly of Classical writings from Herodotus, Strabo, Pliny, Ptolemy, Aelian, Plutarch, Diodorus, Megasthenes and others (discussed in e.g. Majumdar 1960; McCrindle 1999 [1901]; Young 2001). The most well-known of these accounts include the *Periplus Maris Erythraei* – hereinafter referred to as the *PME* (Schoff 1907; Palmer 1951; Huntingford 1980; Casson 1989), Ptolemy's *Geographike Hyphegesis* – *Geogr.* (Berggren and Jones 2000; Curry 2005), Strabo's *Geographica* – *Geogr.* (Dueck 2010, 2011), Pliny's *Naturalis Historia* – *NH* (Healey 2004) and accounts by Cosmas Indicopleustes in his *Topographia* (McCrindle 2010 [1897]).

Only a few descriptions of Berenike's harbour are preserved in ancient texts. For example, at around 22 CE Strabo suggested that 'convenient landing-places' (*καταγωγὰς ἐπιτηδείους*) existed in Berenike, suggesting that the site at this time had an anchorage or roadstead, rather than a port with a significant harbour (he refers to the city as being *ἀλίμενον* – harbourless). He recorded: "thence one crosses an isthmus, which extends to the Red Sea, near a city Berenicê. The ***city has no harbour,*** but ***on account of the favourable lay of the isthmus has convenient landing-places***" [Ἐντεῦθέν ἐστιν ἰσθμὸς εἰς τὴν Ἐρυθρὰν κατὰ πόλιν Βερενίκην, **ἀλίμενον** μὲν τῇ **δ' εὐκαιρίᾳ τοῦ ἰσθμοῦ καταγωγὰς ἐπιτηδείους ἔχουσαν**] (*Geogr.* 17.1.45, emphasis added).

Conversely, the *PME* (40–70 CE) mentions: "Of ***the designated ports on the Erythraean Sea***, and the market-towns around it the first is the Egyptian port of Mussel Harbour. To those sailing down from that place, on the right hand, after eighteen hundred stadia, there is Berenice. The harbours of both [Berenike and Myos Hormos] are at the boundary of Egypt, and ***are bays opening from the Erythraean Sea"*** [Τῶν **ἀποδεδειγμένων ὅρμων τῆς Ἐρυθρᾶς θαλάσσης** καὶ τῶν περὶ αὐτὴν ἐμπορίων πρῶτός ἐστι λιμὴν τῆς Αἰγύπτου Μυὸς ὅρμος. Μετὰ δὲ αὐτὸν εἰσπλεόντων ἀπὸ χιλίων ὀκτακοσίων σταδίων ἐν δεξιᾷ ἡ Βερνίκη. Ἀμφοτέρων δὲ οἱ λιμένες ἐν τῷ ἐσχάτῳ τῆς Αἰγύπτου **κόλποι τῆς Ἐρυθρᾶς θαλάσσης κείνται**] (*PME* 1, emphasis added). According to this text, the 'designated harbour/cove' (*ἀποδεδειγμένων ὅρμων*) seems to have been located in an 'open bay' (*κόλποι*), most probably referring to Berenike's Lagoon (discussed further in Section 5.1).

Some fifty years after Strabo's comment, around the year 77 CE, Pliny the Elder wrote that Berenike had by this time a *proper* harbour, noting: "from ***the city of Berenice, situated upon a harbour*** of the Red Sea, […] and distant from Coptos by 12 days" [inde ***Berenice oppidum, ubi portus Rubri maris***, […] totum a Copto Berenicem iter duodecimo die peragitur] (*NH* 6.26.103, emphasis added). Pliny does not mention anything specific or special about the location of this port city (*oppidum*), and so one can only speculate whether he understood that it had just a 'typical' harbour (*portus*) in comparison to with those that he, as a well-travelled military and public officer, would have been more accustomed to.

A plethora of information regarding 'Eastern Trade' and the role of the port of Berenike within it can also be found in papyri, ostraca and inscriptions (i.e. commemorative), all of which preserve extraordinarily well in the dry Egyptian climate. Amongst significant collections of papyri and ostraca from both Berenike and Myos Hormos, the important 'Nicanor Archive' (*O.Petr.* 220–304; *O.Bodl. II* 1968–1971; *O.Brux.Berl.* 7) includes receipts for transport services provided by Nicanor and his family or friends between Coptos and Berenike and Myos Hormos (e.g. Meredith 1956; Bagnall et al. 2005; Sidebotham 1986: 83).

Contacts with East Africa, and the Kingdom of Axum in particular, are evidenced on the 4th-century CE Old Ethiopic inscription found on the Berenike–Nile road (Littmann and Meredith 1954; Sidebotham 1991: 33). Similarly, contacts with India are represented in a Tamil-Brahmi graffito from the 1st century CE, naming a Chera chieftain, Korran, and indicating that Berenike was at least visited by Indian speakers (Young 2001: 62). Numerous other epigraphic sources found on these Red Sea port sites, on the Eastern Desert and beyond add to a picture of the complexity of the 'Eastern trade', providing detailed information on a number of subjects including the price of goods and services, the organisation of the caravans, periods of usage of particular roads, and the people involved in these activities.

There also exists an abundance of Indian sources regarding *Yavanas* (foreigners, recognised originally as Ionians or Greeks) (e.g. Jackson 2009). These texts are unfortunately less well known to western scholars despite their potential as important sources of information (e.g. Vasant 1988; Ray 1988; Smith 1999b).

Works include the Brahmin chronicles and Tamil fairy-tales and poems (Zvelebil 1956; Nagaswamy 1995; Ramachandran 1996; Parker 2008: 173; Sundaresh and Gaur 2011), as well as fragments of inscriptions in Indian languages from Mediterranean countries; such as those written in Prakit and Old Tamil from Quseir, and in Kannada or another Dravidian language from Oxyrynchus (Salomon 1991: 731; Sidebotham 2004).

> *"The flourishing town of Muciri where the large beautiful ships of the Yavanas which bring gold and take pepper come disturbing the white foam of the little fair Periyar of the Cheras."*
> *— Ahananaru (149), Tamil Sangam Poem, 2nd c CE.*

Fresh body of literature, relating to international contacts, is also available form Sri Lankan sources and inscriptions, most of which are unpublished or not yet translated into English (Weerakkody 1997; Wijeranthe Bohingamuwa, pers. comm. 2010). *Yavanas* are also mentioned in the Buddhist discourse — the *Middle Length Sayings* — in which the Buddha talks with the Brahman Assalayana about the existence of the *Kamboja* and *Yavana* – those who have only two castes, master or slave (Thomas 2004 [1933]).

Furthermore, Chinese sources represent a substantial and useful repository of knowledge regarding Indian Ocean trade and contact with the western world (Section 7.1.5.5). Amongst them, sources such as the *Hou Han shu* (後漢書) by Fan Ye, the *Wei lüe* (魏略) by Yu Huan, the *Jin shu* (晉書) by Fan Quanling, the *Wei shu* (魏書) by Wei Shu, and the *Song shu* (宋) by Shen Yue (quoted after Hoppál 2011), mention *Daqin* (大秦), or 'the Great Empire in the West', which is likely to be the Roman Empire. This realm was located at *Haixi* (海西), i.e. 'west of the sea', which is distant by 'two months sailing with favourable winds, a year with bad winds, and three years without wind' (Hoppál 2011: 271). Other accounts by Chinese authors, such as Ss-uma Ch'ien (*Shih chi*; Watson 1958) and Ban Gu/Pan ku (*Chhien/Qian Han Shu*) are similarly known to be valuable for understanding early Indian Ocean trade dynamics from an Eastern perspective (e.g. Hirth 1885; Needham 1954: 192–193; Pulleyblank 1999; Hill 2009; Wilkinson 2012).

A number of later Arabic texts, such as by Ahmad ibn Mājid and Ibn Baṭūṭah or the stories of the adventures of Sindbad the Sailor can also provide some information regarding Indian Ocean and Red Sea ancient port cities and sailing conditions (e.g. Tibbetts 1971; Swan and Brown 1988; Dunn 2004; Lee 2009).

The interest in 'Eastern trade' recorded in ancient literary sources enabled the compilation of detailed information about particular activities undertaken by merchants, sailors and local citizens, which requires special consideration in the study of this long-distance endeavour. Berenike is noted on numerous occasions, sometimes also with mention of its harbour, adding a 'human voice' and special insight to our understanding of the everyday life and commercial activity in this port city. However, the variability of origin, quality and preservation of these epigraphic sources means that they do have to be treated with some caution.

1.3. AIMS AND OBJECTIVES OF THE THESIS

Ports and harbours can be located in extremely diverse social, political and physical landscapes and geomorphological settings. It is important to understand what drives these choices of location because cursory examination (Section 2.2) appears to reveal an unpredictable, non-linear approach to siting these coastal, lacustrine and riverine infrastructural nodes. It is therefore crucial to find a methodology through which we can attain a deep understanding of the land- and sea-scape settings, their contemporaneous environmental context and the availability of natural resources for these ancient commercial harbours. Comprehending their physical configuration and the level of human adaptation required to utilise and maintain them over long periods of time also remain key research issues.

1.3.1. Environmental and landscape reconstruction of the port town and its harbour

Despite Berenike playing such a significant role in transhipment and maritime trade during the Ptolemaic and Roman periods, only very limited focussed research has previously been undertaken to elucidate the location, size and capacity of its harbour basins, and the processes involved in the inception, evolution and eventual decline of the port town that developed around it. Changes in the local landscape and regional climate, however minor, must have played a crucial role in the rise and fall of this port, situated in such a dynamic, marginal environment. This variability also dictated the levels of maintenance and adaptation required to keep the port of Berenike operational. In light of these assumptions, the primary aim of this thesis was to fully comprehend and document 800 years of human–environment interactions at the site and to fully evaluate the site history within its dynamic environmental setting.

In order to address the primary research aim, this project generated new data and formulated a new approach for analysing these datasets that enabled the exploration and reconstruction of the ancient landscapes and environments of *Berenike Troglodytica*. The palaeoenvironmental and palaeolandscape data obtained through geomorphological surveys, augering and sedimentological analyses aimed at reconstructing the dynamics of the site in its landscape setting during its occupation in the Ptolemaic and Roman periods. This research intended to elucidate the landscape and site formation processes that have shaped Berenike, providing information about how the occupants of the city responded and adapted to environmental changes. The final palaeoenvironmental reconstruction used both cultural (historical) and scientific (archaeological, geoarchaeological) datasets to assess the correlation — if any — between environmental change and socio-political events.

An Earth Science approach[9] was employed for this research, which generated important new data, allowing for integration with traditional archaeological

[9] An Earth Science approach uses a multitude of interdisciplinary methods from geology, geomorphology and coastal geography (Rapp and Hill 2006). It builds on 'Earth System Science'

information. Earlier scholarly interpretations regarding the inception and development of Berenike, and the ultimate decline and abandonment of the city, were also scrutinised and reconsidered using extensive sub-surface topographic data that in turn allowed for the re-configuration of our understanding of different functional areas on site (Chapter 5).

1.3.2. 'Parameters of Attractiveness' of port locations

One of the aims of this project was to address, based on the available data from the case study site — Berenike Troglodytica — a number of fundamental questions, including: i) why were port sites located where they were; ii) what factors influenced these choices; and iii) what effect did the positioning of these sites have on the local, regional or international trade and exchange networks? Focusing on the port of Berenike was a way of developing a methodological framework and dataset that could ultimately be used to explore other contemporary ports and harbours located around the Red Sea and the wider Indian Ocean. Exploring numerous terrestrial, atmospheric, marine and infrastructural variables at a case study site (Chapter 6) allowed the author to determine whether natural or political factors (e.g. geopolitical location, proximity to existing trade routes) were equally — or more — important in the choice of location of the harbour and a city linked with it within its local and

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or simply 'Earth System' that was commonly used since the 1950s, and which acknowledges changes in the solid earth (land - lithosphere or geosphere) being a result of interactions among the atmosphere (air), hydrosphere (water, including oceans, rivers, ice), biosphere (life) and the lithosphere.

regional landscape. Conducted on a larger sample size, such a study could elucidate regional landscape patterns that resulted in the siting of these port sites in specific local landscapes.

1.3.3. Ancient Red Sea vessels and harbour usage scenarios

Owing to the relative paucity of research and limited evidence we have a rather poor understanding of the basic design and construction of ships that sailed the Red Sea and Indian Ocean trade routes in antiquity, although there has been some work recently to try to rectify this (e.g. Blue et al. 2011, 2012). Similarly, there are few indications as to whether any unifying features existed that made these vessels particularly suited to sailing in the Indian Ocean-monsoonal conditions or within semi-enclosed basins with strong prevailing winds mostly in one direction, such as the Red Sea, or both. A better understanding of the vessels plying these trade networks would also help us comprehend the size, shape and configuration of harbour infrastructure available along this route as it seems logical that the ancient harbour design and construction was linked to the types of vessels they were likely to receive. The study of the size, draught, capacity, and mooring apparatus of ancient vessels from the Mediterranean and Indian Ocean regions (Chapter 7) has facilitated the construction of a number of 'Scenarios' (Section 7.3). In each of them different functional areas of the site have been assigned particular roles in order to reconstruct the physical character of the port with different geomorphological features utilised for mooring and facilitating particular types and sizes of vessel. It also allowed for calculating a rough figure of Berenike's harbour capacity to hold large ocean-going vessels (Section 7.4.2).

1.3.4. Research objectives

There are seven main objectives of this doctoral research:

1. To develop, based on a case study site, a methodological framework through which to understand human–environment interactions at port sites, including their physical configuration, and the level of human adaptation and maintenance.
2. To reconstruct Berenike's ancient landscape and environment (Sections 4.5 and 8.1).
3. To clarify the location, size and capacity of Berenike's harbour basins.
4. To identify and elucidate natural and anthropogenic processes involved in the inception, evolution and eventual decline of the harbour and the port town that developed around it.
5. To identify the 'Parameters of Attractiveness' (PoA) that were instrumental in choosing location for Berenike's harbour and the city; and to use them as a methodological framework that could ultimately be utilised to scrutinise other known ports and harbours; and as a predictive tool to locate areas with high potential for finding as yet unknown port cities.

6. To provide information about the vessels that sailed on the Red Sea and Indian Ocean in the Greco-Roman period, which would have moored at Berenike.
7. To re-evaluate and assess earlier scholarly interpretations using the new science-based approach.

1.4. THESIS STRUCTURE

This thesis comprises eight chapters, of which one is this introductory chapter. Chapter 2 assesses the current state-of-the-art in the discipline of port geoarchaeology, and examines other Red Sea ports active in the Pharaonic and Greco-Roman periods and the geoarchaeological studies conducted on some of them. The second part of the chapter sets the scene in terms of the landscape, climatic and environmental conditions of the Red Sea basin, examining its coasts on a regional scale and then focusing on the coastal setting of Berenike.

Chapter 3 presents and justifies the methodological framework designed for this DPhil project, including the field, laboratory and data analysis components. Chapter 4 presents the main results and interpretations, focused on the geoarchaeological data and laboratory results. Two appendices presenting field data and the raw laboratory data are located in the second volume. The geoarchaeological results are given in Chapter 5, which offers an evaluation and discussion of the spatio-functional division of the site and the role of particular geomorphological features in site's history. It also provides the landscape reconstruction that has been generated from this research, and a critical assessment of the approaches employed.

Chapter 6 discusses the environmental, landscape and seascape parameters that likely represented the most attractive characteristics in initially choosing the site for the founding of Berenike. These are presented here as a comparative template for future analyses of the suitability of locations of other port sites in the region.

Bringing the results together, Chapter 7 examines both new and previously published data regarding Red Sea and Indian Ocean sailing vessels. Understanding ship and boat design and manufacture is crucial to reconstruct the ports in which they would have operated and in this chapter allowed for a creation of a number of Scenarios that provided a spatio-functional and chronological division of Berenike's harbour/s. Moreover, based on the presented data on the vessel types and sizes as well as the geoarchaeological results it allowed for estimates of potential number of visitors to Berenike and the capacity of its harbour to be calculated.

The concluding Chapter 8 presents a number of hypotheses for the design and capacity of the harbour of ancient Berenike, exploring the broader context of the findings and assessing the role which the site have played in the wider, Indo-Mediterranean trade network. An agenda for future research is then put forward, using integrated geoarchaeological and palaeoenvironmental analyses and the 'Parameters of Attractiveness' identified in previous chapters.

2. CONTEXTUALISING THE PORT OF BERENIKE WITHIN ITS DYNAMIC LANDSCAPE SETTING

The site of Berenike is currently located in harsh environmental conditions on the margins of human habitation. Distant from fresh water sources and suitable building materials, swept by strong winds, and occasionally at risk of flash floods, the site does not seem, at first glance, as if it could ever have been a particularly attractive location for the siting of an important port. The aim of this section is to explore the past landscape and environmental setting of Berenike, and provide background information for understanding the relationship between the site, the humans who occupied it, and the natural forces that shaped it at the time of its occupation – essentially the human-site-environment inter-relationships.

This section first defines the current state-of-the-art regarding the history of research on ancient ports, the geoarchaeology of ports and harbours and the development of conceptual frameworks for reconstructing human adaptation strategies for occupying ancient coastlines. The focus then shifts towards describing the coastal and environmental conditions of the wider Red Sea region, and the assessment of the site's conditions including the geology and the features of the contemporary landscape. In essence, the aim is to describe how the environment drives site-formation processes.

2.1. THE ANCIENT PORTS: REVIEW AND CURRENT STATE-OF-THE-ART

'Harbour archaeology has long been a poor relation of shipwreck archaeology' were the words with which David Blackman started his 2008 *Antiquity* review of Myos Hormos publication by Blue and Peacock (2006) and Portus publication by Keay et al. (2005). Although a comprehensive study of Greek and Roman ports is still lacking last century, and especially last few decades, have seen a great progress in the discipline.

The beginnings of synergistic research focusing on Roman ports can be dated to at least the 19th century, with the works of Ambroise Tardieu (1821), Charles Forster (1844), William Hazzlit (1851) and Gaston Jondet (1916) who refer to the importance of Roman ports. The work by Karl Lehmann-Hartleben, published in 1923, with over 50 pages dedicated to Roman harbours and followed by an influential *Antiquity* paper by Leopold H. Savile (1941) added greatly to the understanding of ancient ports at the time. The study of ports witnessed a great revival in the late 1960s and 1970s with more than 1,000 coastal sites identified and described in the Mediterranean by scholars including Honor Frost (1963, 1972), Nic Flemming (1969, 1971, 1978, 1979) and Paula de Coetlogon Williams (1976).

A number of important contributions to 'Roman port studies' were the pioneering works of David Blackman (1973, 1995, 2008), including a classic duplet of papers in International Journal of Nautical Archaeology (1982a and 1982b) focusing on the technical aspects of harbours and the current state of research. Importantly, the issue of sea level change and its connection to archaeological features (such as Roman ports) was raised in seminal works of Giulio Schmiedt (1972), Blackman (1973), Flemming (1979), Flemming and Webb (1986) and Paolo Antonio Pirazzoli (1988) and Lambeck (1995).

As progress in the discipline flourished, an increasing number of studies concentrated on the social and economic aspects of ports. Among these, it is important to mention the work of Geoffrey Rickman (e.g. 1985, 1988, 2008), George W. Houston (1980, 1988), and Avner Rabān (e.g. 1980, 1985, 1986, 1992; Raban and Hohfelder 1981). The technical details of Mediterranean artificial harbours were explored by John Peter Oleson (e.g. 1988, 1996; Oleson & Branton 1992; Oleson et al. 2004), Christopher Brandon (Brandon et al. 2005, 2008, 2010) and Robert L. Hohlfelder (2008), all of whom worked together on the The Roman Maritime Concrete Study (ROMACONS) project.

The late 1990s and particularly the early 2000s witnessed a further revival of ancient port studies, focusing now on a landscape-focused approach. This was pioneered, amongst the others by Lucy Blue in her PhD work (1995) and later dominated by the 'French School', with scholars such as Christophe Morhange, Nick Marriner, Jean-Philippe Goiran and Nicolas Carayon (see below 2.1.1).

A number of studies and research projects have recently focused on other aspects of Roman ports and harbours. These include, amongst the others, the ongoing Portus Project as well as the recent — European Research Council (ERC) funded — Rome's Mediterranean Ports Project (RoMP), under the direction of Simon Keay at the University of Southampton, UK. This project is exploring the connectivity between Roman Imperial harbours by the study of ceramics and marble exchange. It is important to also mention syntetic work carried out by Arthur de Graauw (2014) and published on his webpage www.ancientportsantique.com. Together, it is anticipated that this DPhil research will provide a much-needed comprehensive comparative synthesis and add a small contribution to the excellent body of research already available.

2.1.1. Developing geoscience methodologies and geoarchaeology of ancient ports

Multidisciplinary studies of sub-surface sediments and above-ground landforms in and around ancient harbour basins can reveal much about the anthropogenic and natural (climate-driven) processes that have shaped coasts and the port towns situated along them. It was realised at an early stage of this research that this type of holistic approach was required in order to understand the evolution of *Berenike Troglodytica*. The location of the site, within a very dynamic littoral environment, meant that natural forces played a key role in shaping and re-shaping the social and cultural landscape of this port town and that — on a basic level — the occupation horizons were often interstratified with sedimentary layers (e.g. wadi sediments) deposited by natural geomorphological forces.

Following the initial season (2010) of archaeological excavations and geomorphological observations, a multidisciplinary scientific approach was developed for the purpose of this thesis (Chapter 3). This approach benefits from advances in geoscience techniques used to study ancient ports and harbours primarily in the Eastern Mediterranean, developed over the past 25 years by a predominantly French group of scholars (e.g. Marriner and Morhange 2006a, 2007; Morhange et al. 2011, 2014a).

The paradigm was derived originally from several large excavation projects at famous port sites in the Mediterranean that pioneered the way geoscience techniques could be used to solve archaeological problems, including: Troy (Turkey) (Kraft et al. 1980, 1982, 2003b; Kayan 1991, 1995, and later: 2006, 2009, 2014; Kayan et al. 2003) (Fig. 2.1), Caesarea Maritima (Israel) (Rabān 1986, 1989; Oleson 1994; Rabān and Holum 1996), Marseille (France) (Hesnard 1994; Leveau 1995; Morhange and Weydert 1995), and Carthage (e.g. Gifford et al. 1992; Vitali et al. 1992). These projects employed a holistic approach, developed during these campaigns in the early 1990s, in which the cultural-historical model was successfully married with a natural-environmental stance (see for summary: Marriner et al. 2010a; Morhange et al. 2013a, 2014a, 2014b; Walsh 2013).

Building on their initial pioneering work, a French team of geomorphologists (currently under the leadership of Christophe Morhange) formulated a wider conceptual framework — referred to as a 'culture-nature duality' — shifting the focus of traditional, urban Mediterranean port studies (see Section 2.1) towards an enhanced landscape approach with emphasis on sea level and coastal changes (already signalled in works such as: Weill 1946; Flemming 1969; Blackman 1973; Kraft et al. 1977, 1980; Brückner 1986) and ultimately developing an environment-oriented geoarchaeological methodology (e.g. Provansal 2000; Carayon 2008; Rickman 2008; Marriner et al. 2010a; Morhange et al. 2013a).

The exceptional character of ancient harbour basins, with their limited depositional basins and location at the intersection of natural and human landscapes (Morhange et al. 2013a: 406), not only allows scientists to reconstruct natural landscape responses to fluctuations in climate, but also facilitates understanding of the anthropogenic impact on the changes in Holocene coastlines. This can be achieved using a series of 'parallel' proxies that include not just archaeological finds and structures and their relationship to historical sources, but also a suite of analytical techniques and wide range of geo- and bio-parameters.

It is now becoming routinely accepted that the scientific analysis of ancient ports should involve palaeoenvironmental reconstruction methods such as geoarchaeological augerhole coring (augering) to retrieve sedimentological samples (that can be studied using a range of proxies including lithofacies and bioindicators), and geophysics (to reconstruct the topography of ancient ports), all of which can usefully supplement the evidence for human 'adaptation to' and 'involvement in' the coastal environmental changes of the Mediterranean (e.g. Marriner and Morhange 2006a; Marriner et al. 2010a).

The close relationship between the evolution of harbour basins (e.g. foundation, siltation and management, abandonment), natural events (e.g. relative sea level change, tectonics, tsunamis) and transformations of the coastline by human agency, require a combination of methods, with augering used as a key technique for obtaining the palaeoenvironmental and geoarchaeological data from recovered sediment samples and other methods supplementing the geosciences dataset.

2.1.1.1. Sedimentology

The high-resolution analyses of bio- and litho-clastic inclusions of sediment samples acquired through augering is the most commonly used technique for unravelling the nature of ancient harbour environments (Morhange et al. 2013a: 405). Different types of analyses are often performed from site to site because of the different environments represented and the varying levels of preservation afforded by those environments. The diverse range of sedimentary materials examined in these analyses become indicators of processes on-going in the local geology.

Coastal sediments are commonly mixtures of two or more distinct sedimentary populations of differing origins. Two processes, namely natural aggregation and segregation, define their origin, availability and transport potential (Graf 1984: 233). Measurable data acquired by analytical techniques (such as SEM exoscopy, granulometry, magnetic susceptibility, mineralogy, geochemistry, isotopic studies) play a very important role in such studies, allowing for the detection of fluctuations in local and regional geomorphological processes, and for comparing and contrasting hyper-sedimentation of harbour basins with human and climatic induced accretion and erosion (e.g. Marriner et al. 2010a).

Physical coastal landscape change is often associated with the natural movement of sediments, which can be reworked out of and back into the coastal sedimentary environment (Carter 2002: 17). Sediments can also be deposited by human agency, especially in relation to the excavation of harbour basins, dredging activities, and the construction of breakwaters, all of which can create 'stratigraphic gaps' and stratigraphic reversals in sections and cores (Marriner and Morhange 2007: 177; Morhange and Marriner 2010a). Human modification of the environment can be recorded in the 'natural' harbour strata, if somewhat indirectly (i.e. dredging relicts), and can be studied in a variety of interlinked ways. The good preservation and abundance of diverse inclusions within harbour basins allows not only for the reconstruction of human occupation at these sites, but can also elucidate changes in coastal geomorphological processes acting within these dynamic landscapes.

2.1.1.2. Disentangling sea level changes: fish ponds and the development of biochronology

Sea level change and the evolution of ancient harbours are in most cases inextricable. This relationship has been long recognised, first among antiquarians and then subsequently taken up by scientists and scholars (e.g. Negris 1903, 1904, 1921; Cayeux 1907, 1914; Lehmann-Hartleben 1923; Weill 1946). Understanding relative sea level change in relation to coastal geomorphology was recognised as a key factor in comprehending sediment accumulation in a harbour basin and the landscape configuration at the time of founding, during the period of usage, and following abandonment. Moreover, devising the approaches used to study archaeological remains, including harbour infrastructure and other ancient fixed points in the land- and sea-scape (such as ancient fish tanks, or *piscinae*), to extract sea level change data, provided a unique opportunity to refine the chronology of coastal landscape change and the evolution of many harbour sites.

The close correlation between sea level and *piscinae* and the tight chronology of these structures, spanning a short two-century period of construction and utilisation (*ca.* 1st century BCE–1st century CE), makes them a Rosetta stone for changes in Relative Sea Level (RSL) (e.g. Schmiedt 1972; Lambeck et al. 2004; Erič 2008; Anzidei et al. 2011, 2014; Florido et al. 2011; Evelpidou et al. 2012; Morhange et al. 2013b). Since Schmiedt's seminal work in 1972, which determined that fish tanks need channels for tidal exchange of water and therefore can be used as indicators to study RSL, these coastal features are still important in coastal geoarchaeology today.

Recently, coastal wells identified in Caesarea Maritima and other archaeological features from Calabria, Italy, have been used to discern the RSL changes in a similar way to fish ponds. In Caesarea, establishing the depths of 64 coastal water wells provided evidence of the changing position of the ancient water table, on the assumption that this relates to the position of former sea levels. This was achieved by observing several modern wells on a daily and monthly basis to act as a modern baseline, with these data used to reconstruct historical RSL changes (Sivan et al. 2004). Other examples include five coastal sites located in the highly active seismo-tectonic Calabrian arc. At these sites, on the basis of the depth of dated Greek and early Roman submerged archaeological remains, the researchers were able to identify the rate of RSL change (Stanley and Bernasconi 2012).

Due to the relative stability of the RSL during the last 6000 years[10] (Lambeck and Bard 2000), Mediterranean ports from the Bronze Age and later periods became propitious research areas in which new methods such as bio-sedimentology (micobotanics and microfossils) could be developed (Morhange and Marriner 2015). The diversity of Mediterranean and Black Sea landscapes (e.g. including seismically active regions, those with very low RSL change) afforded the development of a varied array of techniques, producing a number of high-quality bio-sedimentological studies that could potentially be applied to other

[10] Brückner and colleagues (2010) comments on the continuous rise of the relative sea level in the Mediterranean from 6,000 BP (before present).

environmental zones (e.g. Galili and Sharvit 1998; Cazenave et al. 2002; Pirazzolli 2005; Auriemma and Solinas 2009; Bini et al. 2009; Stewart and Morhange 2009; Brückner et al. 2010; Church et al. 2010).

The early 1970s also witnessed the first attempts at biochronology, with Pirazzoli and Thommeret (1973) correlating known changes of RSL based on archaeological remains (e.g. Fig. 2.2) with studies of the bioclastic fraction (microorganisms such as ostracods, diatoms and foraminifera, as well as pollen and molluscan assemblages) of associated sediments. Numerous studies of biomarkers and bioindicators from sediment cores in ancient harbours followed (e.g. Laborel and Laborel-Deguen 1994; Kraft et al. 2003a; Bernasconi et al. 2006; Stiros and Pirazzoli 2008; Goiran et al. 2009; Di Bella et al. 2011; Morhange et al. 2012; Marriner et al. 2014; Morhange 2014) allowing the two strands — archaeological remains and bioindicators — to be combined to provide a refined biochronology of sea level change in the Roman Mediterranean (Lamebeck et al. 2004, but see discussion in Morhange et al. 2013b) and develop a tool to study coastal evolution in relation to RSL (e.g. Mourtzas and Marinos 1994; Morhange 2000; Morhange et al. 2001, 2006b; Kızıldağ et al. 2012)

2.1.1.3 Other methods

Aside from studies of litho- and bio-clastic fractions, alternative methods have also been established to develop geoarchaeological research in ports and harbours. The most popular of these are non-destructive, rapid and reliable geophysical methods, which allow for the reconstruction of the three-dimensional palaeotopography of ancient port sites. To this end, georadar, remote sensing and magnetometry are often used either separately (according to the suitability of the method to particular coastal conditions), or, more ideally, as an integrated approach. In this way information about the progradation of ancient shorelines, as well as the maximum extent of a past water body and associated coastal infrastructure can be discerned (Hesse 2000; Neal 2004; Marriner and Morhange 2007: 163–165). These methods have been quite commonly applied to the study of port sites on land and underwater (e.g. Vafidis et al. 2003, 2005; Boyce et al. 2004; Chalari et al. 2009; Herbich 2011; Bottari et al. 2012).

A novel method of using semi-aquatic coring and Optically Stimulated Luminescence (OSL),[11] allied with geoelectric cross-sections, was recently used on the harbour of the internationally significant site of ancient Pergamon (Elaia) (Seeliger et al. 2014). Such a geochronological method could prove very helpful in assessing dates of submerged sediments in Berenike's harbour. These could be retrieved through semi-aquatic coring, a method which has already been applied in coastal archaeology before (Stewart 1999; Gorham 2001), a refined methodology using microsampling of diversified percussion coring for studying site formation processes within ports, and on submerged sites such as

[11] OSL — optically stimulated luminescence — is a method of absolute dating of when the minerals in sediments (usually quartz) were last exposed to daylight.

shipwrecks, has been recently tested in West African Ghana (Horlings 2011, 2013).

In terms of examining archaeological materials, aside from the *piscinae* and wells mentioned above, ballast stone deposits are a relatively common addition to the basal facies of harbour basins and are often overlooked as a potential source of information about siltation processes and changes in size and depth of harbours (e.g. Boyce et al. 2009: 1516). Additionally, lead from hull sheathing used for ship protection during the Roman period (Section 7.2.2.2) can be discerned via isotopic signatures also allowing for the definition of harbour bottom surfaces (Delile et al. 2015). Layers of pottery and other human detritus (Sections 4.5 and 5.4) can also provide a useful marker for the deposition of material dumped over the side of moored vessels (e.g. dumping of used or broken amphorae, Piotr Dyczek, pers. comm. 2008) and can be discerned through the study of magnetic susceptibility (showing buried surfaces of stabilisation) and through geophysical work (Mike Morley, pers. comm. 2011).

2.1.2. Trends in ancient port geoarchaeology

The prominence of the 'French school' in ancient port geoarchaeological research and their Mediterranean-centric focus (although consideration of adjacent basins such as the Red Sea and Black Sea is gradually becoming evident) is very clearly visible in the published literature. The growing interest in the discipline is evident in the increasing number of publications between 1990 and 2004, with an almost exponential growth in the past decade (2005–2015). An in-depth synthesis incorporating data from the various schools working in different geographic areas is far beyond the remit of this thesis and so emphasis will be placed on looking at particular trends and issues that are currently major points of focus in geoarchaeological research on ports and harbours.

This relatively new discipline of port and harbour geoarchaeology is much more nuanced than the dominant Mediterranean-centric, French-led, Roman/Phoenician-focused research seems to suggest (e.g. Goiran and Morhange 2003; Morhange et al. 2013a). Whilst most attention still remains closely related to Phoenician and Roman harbours, several isolated examples of studies at coastal and riverine sites such as Seleucia on the Tigris (Erol and Pirazzoli 1992) go some way to buck that trend.

Within the equatorial region the most relevant studies include, amongst others, a detailed geoarchaeological analysis of the medieval port site of Julfar, Ras al-Khaimah, U.A.E. (Morley et al. 2011); the Swahili harbour of Unguja Ukuu, Zanzibar (Kourampas and Kotarba-Morley 2015 *forthcoming*); the Mayan port of Vista Alegre, Mexico (Glover et al. 2011); as well as various landing places and beach habitations on the Pacific Islands (Dickinson 2014). Some geoarchaeological work has also been undertaken in India, such as the Spice trade port of Pattanam (Shajan et al. 2004; Kotarba-Morley *forthcoming*); and the Chola port of Kaveripattinam (Rajendran et al. 2011). These studies have proved very useful in refining the methodology of this project and to help elucidate the reasons behind the positioning of Indian Ocean and Red Sea harbours and the ways in which they developed.

In addition to the distinct geographical and chronological divisions within most port geoarchaeological research, a few major overarching trends can be recognised throughout the discipline, and will be briefly reviewed here. Whilst most of the processes that have shaped and changed the landscapes of ancient ports can be related directly or indirectly to changes in sea level (Section 2.1.1.2) and coastal dynamics, there are other factors such as the geological configuration of the coast, modification of natural landscapes by human agency, and current socio-political context at the location that also need to be taken into consideration.

2.1.2.1. Coastal geomorphology and the geological structure of shores

The morphology of sea basins (e.g. enclosed, semi-enclosed, open basin) greatly affects the pattern of sea level changes through time. In semi-enclosed basins, such as the Mediterranean, Persian Gulf, Red Sea, and the Arabian Sea, different configurations can be distinguished. These vary from wide channels and archipelagos hindering water exchange (semi-enclosed basins), to very narrow straits, which determine the dynamics of water exchange (such as the Bab al-Mandeb). The dynamics of water exchange through these passageways can result in lead and lag times causing different ranges of sea level change within harbour basins situatetd in comparable landscape locations but lying on geographically different coastlines.

The geology of a shoreline also plays a role in dictating the morphology and history of ancient harbours. For example, ports such as at Lacydon (Marseille) (e.g. Provansal et al. 1995; Morhange et al. 1996a, 1996b, 1999, 2001, 2003; Millet et al. 2000, Morhange and Oberlin 2000; Morhange 2001), Phalasarna (Pirazzoli et al. 1992), Tyre (e.g. Nir 1996; Marriner et al. 2005, 2007, 2008a; Marriner and Morhange 2005a, 2005b, 2006b, 2006c; Noureddine 2010; Elmaleh et al. 2012), and Byblos (e.g. Frost and Morhange 2000; Stefaniuk et al. 2005), which were located on rocky slopes, on estuarine inlets or at the mouths of small drainages, were at particularly high risk of siltation from fluvial influx. The large number of port cities situated on rocky coasts means that, even though more challenging, these locations must have been seen as particularly attractive.

Sites situated on low coastlines were, conversely — on a short time scale — relatively easier to build and maintain because of the more favourable physical environment and reduced river velocity creating a more suitable habitation zone. However, in the long-term, it meant that ports situated on or near river outlets required high levels of laborious maintenance. Sites located on the edges of deltas such as Fos (Provansal et al. 1995; Morhange et al. 1998; Vella et al. 2000) Alexandria (Frihy 1992; Goiran et al. 2000, 2005, 2014c; Stanley 2005; Bernasconi et al. 2006; Véron et al. 2013; Marriner et al. 2007, 2008b; Frihy et al. 2010), or Aquileia (e.g. Arnaud-Fassetta et al. 2003) succumbed to even minor changes in the catchment area and were at risk of flooding and sediment accretion.

Sites located at the mouths of rivers and in the estuaries such as Frejus (Excoffon et al. 2006; Devillers et al. 2007; Gebara and Morhange 2010; Bertoncello et al. 2011; Bony et al. 2011; Morhange et al. 2013b), or Carthage (e.g. Gifford et al. 1992), were characterized by sediment accumulations and swamps. Those located on the fringes of lagoons at the mouths of rivers, such as Lattara (Garcia and Vallet 2002), were totally dependent upon both changes of water and sediment influx in the catchment, and marine influence with trans- and regression and storm surges.

Major environmental issues often affecting low-lying (and sometimes rocky) sites were delta growth and siltation – signatures of both of these processes are visible in Berenike's sedimentary archive. Similar situations could be traced at a number of sites providing comparative evidence to Berenike, but it is beyond the scope of this thesis to discuss each in detail (e.g. Ginouvez et al. 1992; Goodfriend and Stanley 1999; Arnaud-Fassetta et al. 2003; Brückner et al. 2005; Vött 2007; Vött et al. 2006, 2007a, 2007b; Carmona and Ruiz 2009, 2011; Devillers et al. 2010). This issue is exemplified by the important Roman ports of Ostia and Portus (e.g. Giraudi et al. 2006, 2009; Goiran et al. 2012; 2014a, 2014b; Bellotti et al. 2011; Salomon et al. 2012, 2014b; Millet et al. 2014; Vittori et al. 2014) and the major North African harbour, Utica in Tunisia (e.g. Chelbi et al. 1995), all of which are currently located inland due to lateral and vertical sediment accretion cutting the sites off from the sea.

At Troy, floodplain aggradation had led to the progradation of the shoreline seaward (e.g. Göbel et al. 2003; Kraft et al. 2003a, 2003b; Kayan et al. 2003; Kayan 2006, 2009, 2014). It is also possible for similar situations to occur with ports situated on lakes, such as Mareotis (e.g. Blue and Khalil 2010; Flaux et al. 2011, 2012, 2013) and Taposiris (Tronchere et al. 2012) at Maryut Lake. Whilst landscape dynamics related to prograding river deltas and palaeochannel migration and avulsion have been widely attested by scholars (e.g. Anthony et al. 2014), the relationship between coastal sites and seasonal wadi catchments still requires attention owing to our relatively poor understanding of these geomorphological dynamics.

2.1.2.2. Shoreline mobility and dynamics

The influence of the dynamic environment on human societies is undeniable, and there is a growing awareness in scholarly discussion over the last decade of natural processes impacting on ancient ports (e.g. Marriner et al. 2010a). The key processes related to shoreline dynamics are isostatic change (vertical mobility), including subsidence and uplift; horizontal mobility, including accretion (progradation) and recession (transgression, erosion); and eustatic fluctuations of sea level. A number of factors, often working in unison, drive these processes. The most common factors to take into account at pre-modern port sites are deltaic progradation, anthropogenic accretion or erosion (e.g. increased erosion and land destabilisation by farming practices), atmospheric weathering (e.g.

onshore winds, rain erosion), chemical and biological erosion, volcanism (seismic activity), earthquakes (tectonics), and extraordinary processes such as tsunamis, cyclones and hurricane-driven storm surges.

Peacock and Blue (2007: 139) conclude in their '*Topography of Periplus ports*' that there was a preference for port sites described in the text to be located on an island or peninsula guarding a lagoon (clearly reflecting the need for ease of access and defence). Complex shoreline dynamics in combination with numerous other sources hugely influence the character and functionality of ports. These natural phenomena are intrinsic elements of the harbour strata and cannot be ignored in reconstructing port histories. There are numerous examples of research where present-day geomorphology was used to extrapolate ancient palaeoenvironments, underscoring the need for an integrative methodology capable of reconstructing past changes in the landscape (e.g. Goodman et al. 2009a).

2.1.2.3. Catastrophism

Coastal ecosystem responses to catastrophic events had a huge impact on harbours at various scales (e.g. Morhange et al. 2007; Kaniewski et al. 2008; Marriner et al 2010b; Morhange and Marriner 2010b; Marriner and Morhange 2013; Morhange et al. 2013a), and is traceable in the sedimentological signatures recorded at Berenike (Chapters 4 and 5 for discussion of flash floods and storm surges). As particularly efficient and often sensitive sediment traps, harbour basins can contain sedimentological signatures of major natural events such as tsunamis and hurricane-driven storm surges (e.g. Papadopoulos and Chalkis 1984; Papageorgiou et al. 1993; Reinhardt and Rabān 1999; Papadopoulos and Vassilopoulou 2001; Morhange et al. 2006a; Reinhardt et al. 2006; Perinçek 2008; Goodman et al. 2009b; Dey and Goodman 2010; Rajendran et al. 2011; Papadopoulos et al. 2013). Records such as these can allow for a better understanding of the hazards encountered by ancient coastline settlers and sailors, and have sparked a revival of interest in identifying and interpreting catastrophes in history and their effects on society.

2.1.2.4. Human agency as a driver of landscape change

A significant proportion of past human populations had access to the open sea, and so occupation sites have often been dependent to some extent on changes in the shoreline. However, anthropogenic modification of the natural landscape can often be very difficult to distinguish from natural geomorphological processes. If humans can be singled out as drivers of change this allows a better understanding of the interactions between humans and littoral ecosystems and the ways in which societies strove to adapt to rapid coastal change, maintaining their access to the sea.

Geoarchaeological studies in harbour basins and their immediate environs can help evaluate the environmental potential of these sites, determining settlement patterns and modes of social behaviour (e.g. the locating of ports according to particular environmental conditions, or the 'Parameters of Attractiveness'; Chapter 6) and the degree of modification exerted by past communities (e.g. Marriner and Morhange 2006a; Morhange and Kalaora 2010; Morhange et al. 2013a; Walsh 2013; Kaniewski et al. 2014).

Human impacts on port sediment sequences are usually detectable by looking for signatures diagnostic of particular practices, such as excavating and dredging harbour basins (e.g. Morhange and Marriner 2010a), changing the course of a river and the resultant impact on delta morphology (e.g. Anthony et al. 2014), the creation of canals (e.g. Keay et al. 2014; Salomon et al. 2014a), artificial harbours with their hydraulic concrete structures (e.g. Bellotti et al. 2001; Brandon et al. 2008; Beltrame 2012; Stone 2014) as well as coastal urbanisation (e.g. Pucci et al. 2011; Kaniewski et al. 2013). Anthropogenic geochemical impacts on natural landscapes, and ultimately the local population, are also visible in isotopic signatures. For example, lead pollution within the Roman Empire has recently been elucidated through innovative geoarchaeological studies at sites such as Portus (Delile 2014) and Marseille (Le Roux et al. 2005; Véron et al. 2006) where the lead isotops originally derived from the dissolution of lead particles from the hull-sheathing can be found in the sediments.

Human agency in landscape change can also be inferred from stratigraphic sequences observed in fining-up sequences in deposits marking the confined character of the harbour basin (Marriner and Morhange 2006a: 13). At sites such as Berenike, located in a hyper-arid context, mineralogical signatures of human modification of the landscape can be in the form of neoformed (authigenic) minerals such as evaporitic gypsum crystals (with hyper-saline conditions being unfavourable to harbour activities over the medium to long term) and can be discerned within harbour basins. Moreover, ecological changes in port landscapes, such as vegetation dynamics (e.g. Djamali et al. 2012; Sadori et al. 2014) are visible within the faunal and botanical archaeological assemblages potentially revealing coastal landscape changes.

2.1.2.5. Harbour types

Ancient ports of trade have often been categorised according to their economic and administrational organisation and social structure. They have also been classified from the point of view of their natural and landscape characteristics based on a number of variables such as geomorphology, sediment supply, and their artificial structures (e.g. Flemming 1971; Galili and Sharvit 1991; Blue 1995; Goiran and Morhange 2003; Carayon 2008; Marriner and Morhange 2007; Marriner et al. 2010a).

One of the most intuitive classifications is proposed by Marriner and Morhange in their comprehensive (57 pages) *Earth-Science Reviews* paper (2007: 146–162). Seven different archaeological harbour types are identified according to their proximity to the coastline, position relative to sea level, sedimentary environs and taphonomy (Fig. 2.3). Using this scheme, Berenike falls into the category of a buried lagoonal harbour. However, since the 4th century BCE, technological advances allowed people sometimes to gain control over less favourable environmental factors, building artificial harbours, which are not included within this typological scheme.

2.2. PORTS OF THE RED SEA

Even though, as we will see below, the paucity of geoarchaeological research concerning Red Sea ports can look, at first glance, rather alarming, it is important to consider the contemporary social, political and economic factors that might have exacerbated this situation. The Red Sea coasts are generally sparsely inhabited and often rather inhospitable in terms of climate and lack of modern infrastructure. There remains a lack of facilities and resources available for survey for teams hoping to work in the region.

Moreover, the relatively unstable political situation and difficult climate for foreign expeditions in a few countries of the region increasingly hamper the research. This is notwithstanding the difficulties of obtaining export permissions for samples that need to be analysed externally and the bureaucracy involved when obtaining survey and excavation permits. This ultimately hinders applications for substantial research grants, which often require permits to be submitted ahead of application. For example, the extremely long and largely uninhabited coastline of Saudi Arabia has only recently seen comprehensive survey attempts with the increase in number of internally-trained archaeologists and an open approach to welcoming foreign teams (such as Polish Aynuna/potential Leuke Kome survey conducted by Prof. Michal Gawlikowski of University of Warsaw).

Two major chronologies of ancient ports on the Red Sea coast will be discussed in this short review, namely the Pharaonic and Greco-Roman ports of trade. As mentioned above, very little research has been undertaken in this part of the world, with studies mainly concentrated on the Pharaonic ports on the Egyptian Red Sea coast (e.g. Tallet 2009, 2012a), including Ayn Soukhna (Abdel-Raziq et al. 2012; Tallet 2010, 2012b, 2012c, 2013) (Fig. 2.4), Wadi Gawasis (Sayed 1977; Fattovich 2005; Bard and Fattovich 2007; Fattovich and Bard 2012) (Fig. 2.5), and Wadi El-Jarf (Tallet 2012c; Tallet and Marouard 2012, 2014; Tallet et al. 2012) (Fig. 2.6).

2.2.1. Pharaonic ports on the Red Sea

Outside of traditional archaeological excavations, only one geoarchaeological study has been performed to date on a Middle Kingdom port, at Marsa Gawasis (Hein et al. 2008, 2011). In this case, where several long, hand-cut galleries or 'nautical caves' were identified, carved into an uplifted Pleistocene fossil coral reef around the lagoon (Ward 2012: 221; Fattovich and Bard 2012), the geoarchaeological work allowed for the mapping of shifts in sea level, climate change and sedimentary processes, using a series of augerhole transects. Retrieved sediments were subjected to sedimentological, malacological, foraminiferal and radiocarbon analysis, and provided evidence for the mid Holocene sea level highstand. This in turn allowed identification of the fluvial input during early stages of bay evolution, determined as general thickening and coarsening of wadi sediments overlying lagoonal facies in a landward direction. Furthermore, it led to a closure of the coastal embayment that served as the harbour for long-distance trade.

In the late Holocene, a lowering of sea level accelerated shoreline progradation and had a significant impact on the local population that might have been required to keep moving further from the coast or to dredge the harbours. This could have ultimately led to the abandonment of the site (Hein et al. 2011). The palaeo-bay reconstruction presented by Hein and colleagues (2011: 687, Fig 1) shows that 'hand-cut' rock galleries, where remains of ships, cordage and associated materials were found, would have therefore been located within the extent of this embayment or on the water's edge. Whilst the methodology for this study proved to be in accordance with the conditions experienced in the region, the age of the site correlating with the mid-Holocene highstand means that it cannot be directly compared with the late Holocene site of Berenike.

2.2.2. Greco-Roman ports on the Red Sea

A similar deficiency can be seen in the literature focused on Greco-Roman ports of the Red Sea. Since 1910, when Couyat calculated, mostly from Ptolemy's Geography, the potential locations of five important Red Sea ports, very little progress has been made to locate 'missing' ports. Aside from Myos Hormos, Adulis and Berenike, no other port locations are certain, and it was not until the results of this research that the definite location of Berenike's harbours was established. Table 2.1, based largely on the work of Arthur de Graauw (2014), and Figs. 2.7 and 2.8 illustrate how few of the ports that were mentioned in ancient texts have been located in the study region. This shows how difficult it is to discern underlying patterns in the siting of ports in particular locations, or the 'Parameters of Attractiveness'.

Table 2.1. Locations of ancient ports mentioned in *PME*, Ptolemy's and Strabo's *Geographies* and in other ancient texts (confirmed or probable in bold and unidentified in regular font). Adapted from de Graauw's (2014) on-line database and supplemented by the author.

ANCIENT PORT	Modern location	Country
Major Ports on the MEDITERRANEAN		
Caesarea Maritima	Location confirmed	Israel
Ostia	Location confirmed	Italy
Portus	Location confirmed	Italy
Carthage	Location confirmed	Tunisia
Lepcis Magna	Location confirmed	Libya
Alexandria	Location confirmed	Egypt
RED SEA PORTS		
Aelana, Aila, Elaea, Berenice, Ezion Geber	Aqaba	Gulf of Aqaba
Iotabe	Jezirat Fara'un, Coral Island 14 km southwest of Eilat, on the Sinai coast; or Tiran island at the mouth of the Gulf of Aqaba ?	Gulf of Aqaba
Saba	Near Eilat (?)	Gulf of Aqaba
Ankale	Near Haql	Gulf of Aqaba
Potential port location	Nuweiba	Gulf of Aqaba
Potential port location	Tayyib al Ism	Gulf of Aqaba
Potential port location	Tell el Mashraba, near Dahab	Gulf of Aqaba
Makna	Near Magna	Gulf of Aqaba
Isle of sea-calves (dugongs?)	Tiran and Sanafir islands, at the entrance of the gulf of Aqaba (?)	Gulf of Aqaba
Leuke Kome, Leukos Limen, Albus Portus, Onne (?)	Port site on the Arabian side of the Red Sea where the road to Petra starts. Potentially located in the Bay of Aynunah near Al Khuraybah at 28°03' N(?). Ptolemy locates Leukos at 2°10' N of Berenike, but that is on the other side of the Red Sea. Others locate the port at Sharm Yanbu, also known as Charmuthas (opposite Berenike, 15 km north of Yanbu). However Ali al-Ghabban (pers. comm. 2010) believes it to be Umm Useila/Useyla in the Northern Red Sea on the entrance of the Gulf of Aqaba. Others believe it to be the site 47 km up the coast at Al Wajh (e.g. Nappo 2010)	Saudi Arabia
Modiana (?)	Al Muwalih	Saudi Arabia
Dabba, Modiana (?)	Dhuba at 27°21' N, 35°41' E	Saudi

		Arabia
Hippos Kome	Unidentified	Saudi Arabia
Egra and Phoinikon Kome	Al Wajh/Wedjh? Recognised as Egra such since at least the 19th c. however no associated archaeological evidence has ever been recovered from the site	Saudi Arabia
Ampelone, Akra (?)	At the outlet of Wadi al Hamd South of Al Wajh (?)	Saudi Arabia
Raunathou Kome	Near Khurayyim Said	Saudi Arabia
Potential port locations	Al Haura and Umm Lajj	Saudi Arabia
Charmothas, Charmute	Sharm Yanbu 15 km North of Yanbu? However, if Sharm Yanbu should be Leuke Kome then Charmothas could be located further south at the lagoon of Khor al_Kharar near Rabigh	Saudi Arabia
Farasan islands	Roman naval base in front of Jizan (Van Hecke et al. 1861: 747; Phillips et al. 2004: 244–245; Adams 2007: 35; Cooper and Zazzaro 2012: 408)	Saudi Arabia
Arsinoe, Cleopatris, Port Daneon, Klysma, Clysma, Clysina	Suez	Egypt
Phoinikon	Unidentified	Egypt
Marah	Near Ras Matarma	Egypt
Rhaithou	El Tor	Egypt
Potential port location	Tell el Raya	Egypt
Abu Shar	Roman fort at the end of the Via Hadriana, between El Gouna and Hurghada	Egypt
Potential port location	Wadi Safaga	Egypt
Philoteras Portus, Philotere, port of Aennus	Marsa Gawasis, 23 km south of Safaga. Ptolemy locates Phîloteras at 30' S of Myos Hormos, which would be near the airport of Marsa Alam and Ras Toronbi, where some creeks like that of Coraya beach and of Port Ghalib may have been used as ancient shelters. Pliny speaks of Aennus. However, some scholars seem to agree to locate this port at Marsa Gawasis near Safaga	Egypt
Arsinoe Troglodytika	Unidentified but somewhere between Philotera and Myos Hormos, perhaps near Kalawy Imperial Resort or Hamrawein (?)	Egypt
Myos Hormos, Port d'Aphrodite	Quseir al-Qadim, at the Mövenpick hotel site, 8 km north of Quseir. Ptolemy locates Myos Hormos at 3°25' N of Berenike. *PME 1* indicates that this site is at 1800 stadia (approximately 330 km), from Berenike, which would lead near Safaga. However, the location of the site is agreed upon 8 km north of Quseir	Egypt

Nechesia	Potentially Marsa Nakari, 18 km south of Marsa Alam	Egypt
Berenike Troglodytika, Berenike with ancient lighthouse	Pliny indicates that there is no shadow at noon on the day of summer solstice, which is the definition of tropic (located at 23°26' N). The present latitude of Berenike is 23°56' N. Large modern naval base — Baranis — is located some 8 km to the north of the site	Egypt
Ophiôdès, Agathonis, Tytis, Topasus Island	Isle of Zabargat/d, St John's Island, the island with topaz, some 80 km south of Berenike. The isle of Ophiôdès is well located as it seems to be the only one producing olivin stone in this area	Egypt
Bathus Profondus Portus	Dungunab (?) Ptolemy locates the 'deep port' of Bathus at 2°50' S of Berenike. This situates it in the large bay of Dungunab, which is sheltered from the northern waves prevailing in this area	Sudan
Dioscuror	Dungunab (?) Ptolemy locates Dioscuror at the same place as Bathus, perhaps on the west side of Mukawwar island	Sudan
Theon Soterum, Deorum Salutarium, Sotira	Suakin (?) Ptolemy situates Theon Soterum at 1° N of Ptolemais, potentially corresponding with Suakin at 19°08' N	Sudan
Evangeliorum, Evangelon	Protected bay of the island Saqir, near Trinkitat (?) Ptolemy situates Evangelon at 30' N latitude of Ptolemais, at 18°44' N	Sudan
Port Elaea	Ptolemy's Evangelon (?)	Sudan
Ptolemais (Epi)Theron, Ptolemais of Hunters, Epitherias	Probably Aqiq Kebir or Adobona village and the nearby island of Badhur	Sudan
Port Melinus	Unidentified	Sudan
Port of Colobônalsos, Cape Colobon	Ptolemy locates Colobon at 2° N of Adulis, which does not correspond with any prominent cape or promontory	Sudan
Berenice of Saba, Epidire, Berenice Panchrysos ?	Massawa (?) Ptolemy locates Saba at 50' N of Adulis, which corresponds with Massawa at 15°38' N. According to Pliny (*NH*, 6.170) Berenike Panchrysos might be located at the same place	Eritrea
Ery	Large bay of the isle of Dahlak, isle of Disset, Isle of Deses (?)	Eritrea
Gabaza, port of Adulis	Massawa (?) or Zula. *PME* locates Adulis at 3000 stadia (550 km) south of Ptolemais inside a south-facing bay, which corresponds to Zula at 15°15' N. Pliny locates it at 5 navigation days from Ptolemais, which leads to more or less the same location. It may be noted that Ptolemy is widely mistaken when locating it at 40' N of Diré, leads near Assab or Beilul, 400 km further south. It may be	Eritrea

	noted also that Assab still is a port nowadays, while Beilul does not show any nautical interest (today) except for a cape located about 15 km further east	
Isle of Diodore	Island located in the bay of Zula and now joined with land as 'Galala Hills' 6 km south of Zula	Eritrea
Port of Eumene	Port of Eumène (?)	Eritrea
Arsinoe	Ras Dumeira at Rahayta (?). Ptolemy locates Arsinoe at 20' S of Diré, which corresponds with the lagoon of Godoria on the north coast of Djibouti near 12°09' N. However he mentions it north of Diré on his list, which makes some authors think the site is at Ras Dumeira	Eritrea
Cape Dire	Ras Siyan, on the west side of Bab el Mandeb. Cape Diré is located in front of Cape Acila (Murat in Yemen) as Strabo indicates. It provides good shelter against the eastern waves prevailing in this area. The place called Fagal is at 12°27' N and seems to be an attractive location for ports mentioned by Ptolemy	Djibouti
Port Antiphile	Tadjoura (?). Ptolemy locates Antiphile at 45' S of Diré, which corresponds with Tadjoura located at 11°47' N on the coast of the gulf of Djibouti. Strabo locates it *'leaning against the territory of creophags'*, which probably leads to the south of the Bab el Mandeb straits	Djibouti
Port of Isis	Djibouti (?). The Port of Isis is at ten days rowing (500–1000 km) from Adulis according to Pliny, which leads near the coast of Djibouti (at 660 km) with its two islands located just in front of the port (as indicated by Pliny)	Djibouti
Avalitae, Avalites, Abalites, Aualis	Zeila in Somalia, 50 km east of Djibouti. Avalites seems to be located with some certainty at Zeila, where just a sand spit remains today or at the promontory of Djibouti	Somalia
Burnt island	Volcano island Jabal al-Tair northwest of Hodeida (?)	Yemen
Bolicas	Mokha (?). Port of the Omerits, in front of Adulis, on the Arabian side.	Yemen
Masala, port of Mouza, Muza	Mokha (?)	Yemen
Sosippi	Dhubab seems to be the only natural shelter between Murad/Océlis and Mokha/Mouza.	Yemen
Acila, Ocelis, Artemidore	Murad (?), south of Mokha and in front of Ras Siyan	Yemen

PORTS OF THE GULF OF ADEN		
Malao	Berbera (?)	Somalia
Mundus	Bandar Hais (?)	Somalia
Mosylium, Mosylon	Bosaso (?)	Somalia
Dioscoridis	Isle of Socotra	Somalia
Cape Elephant	Ras Felug (?)	Somalia
Cape des Aromates, Cape of Spices	Ras Guardafui	Somalia
Eudaemon Arabia, Porto	Aden	Yemen
Qana, Cana	Bir Ali near Bal Haf	Yemen
Trulla Portus	Near Qana (?)	Yemen
Tretos Portus	Near Al Ghaydah (?)	Yemen
Moscha Limer, Ausara, Sumhuram	Khor Rori, at the outlet of Wadi Darbat	Oman
Asichon	Ras Hasik, Hasek	Oman
Shabwa		Oman
Dhofar, Zofar	Salalah	Oman
GULF OF OMAN		
Cryptus Portus, Amithoscuta	Location within Muscat (?)	Oman
Omana	Sohar	UAE
Port Leupas	Al Liwa, Lua hinterland connection (?)	UAE
Port of Mont Orsa	Khor Fakkan, Chorfakan	UAE
Port of Goboea	Cuscan according to Forster, Haffah Bay (?)	Oman
Cape Asabon, Asaborum, Maketa, Mane, Mussendom	Jazirat al Ghanam (Goat Island)	Oman
Potential port location	Dibba	UAE
Potential port location	Orea (?)	UAE
PERSIAN GULF		
Port Machorbe	Al Rams, Rhums	UAE
Rhegma, Regama, Raamah	Al Rams, Rhums according to Forster, Ras Ras al Khaimah (?)	UAE
Potential port location	Ed Dur and Mleiha	UAE
Potential port location	Hofuf	Saudi Arabia
Gerrha, Dilmun	Uqair (?)	Saudi Arabia
Taboca, Cadara	Somewhere in Qatar (?)	Qatar
Tylos, Tyrus, Arados	Bahrain	Bahrain
Icarus	Isle of Failaka	Kuwait
Teredon, Diritotis	Near Basra (?)	Iraq
Apologos	Al Ashar, port of Basra	Iraq
Charax Spasinou, Alexandria, Antiochia	Jebel Khayabir, about 50 km north of Basra	Iraq
Antiocheia Persidos	Near Bushehr/Bushire capital city of Bukht Ardashir (?) Bandar Būshehr/Bandar-e Būshehr; previously known as Ram Ardashir	Iran

Ionaka	Near Al Rishehr Point (?)	Iran
WESTERN COAST OF IRAN	***Parthian Ports*** *are not included in this study*	
EAST AFRICAN COAST		
Cape Tabai	Ras Chenarif (?)	Somalia
Pano	Ras Binna (?)	Somalia
Opone	Ras Hafun	Somalia
Seven ports	Unidentified	Somalia
The small and great bluffs (*Apocopes*) of Azania	The small bluffs could be El Hazin and the great bluffs Sif El Tanil	Somalia
Small beach and Great beach	The small beach could be Barr Ajjan. The great beach could be somewhere along the Benadir coast	Somalia
Sarapion	Tentatively located at the ruins of Quarcheikh, well north of Merka. Other authors put the place much closer to Merka or associate it with Mogadishu	Somalia
Essina	Near Baraawe and Merka (?)	Somalia
Nicon	Barawa, Brava (?) or maybe Kisimayo or Jamaane (228 miles – 2000 stadii from Mogadishu/Serapion?) and a little north from Kisimayo	Somalia
Pyralax Islands	Lamu. The Pyralax islands are Pate, Manda, Lamu and some smaller ones. The channel is nowadays called the Siyu channel. It is understandable that the incoming vessels would stop along the channel and trade there on their journey along the coast	Kenya
Rapta, Rhapta	Has not yet been discovered. Potential locations include Rufiji delta, Dar es-Salaam or Tanga. The geography of Ptolemy also puts Rhapta around this region, about 40 km up a large river. If this view will turn out to be correct, then Zanzibar is the island Menuthias. Crowther and Kotarba-Morley's survey in the Rufiji Delta in 2011 identified it to be a potential location for Rhapta – however, dense vegetation and population, as well as the laterite character of tropical soils made it difficult to trace any archaeological presence during this short site visit	Tanzania
Menuthias	This could be the island of Pemba, Zanzibar or Mafia. Menuthias is reported in ancient texts to be 300 stadia from the shore. There were in the Greek world three different definitions of stadia: the Olympic (or standard) being 185 m; the stade of Eratosthenes being 153 m; the stade of Dio Cassius (*Hist. Rom.* 72.15, 73.3; 180 CE) 197.3 m. This means that Menuthias either	Tanzania

	55.5 km, 45.9 km or 59.2 km from the coast. Only Pemba Island is this far from the land — exactly 54.6 km. Zanzibar is some 40 km away, whilst Mafia is 25 km. Although the Rufiji Delta shifted progressively towards the island it is still max. 13 km from those heads/ peninsulas of the river mouth). Other authors such as Ptolemy sometimes mention locations assumed to be Comoros or Madagascar. However, Grande Comore is some 300 km away and Madagascar is some 440 km from the mainland and 300 km from each other. *PME* (15) says about Menuthias that it is '*low and wooded, in which there are rivers and many kinds of birds and the mountain-tortoise. There are no wild beasts except the crocodiles; but there they do not attack men. In this place there are sewed boats, and canoes hollowed from single logs, which they use for fishing and catching tortoise. In this island they also catch them in a peculiar way, in wicker baskets, which they fasten across the channel-opening between the breakers.*' Fieldwork on Pemba island undertaken by the author (Shipton et al. 2012) discovered crocodile bones in one cave thereby strengthening the hypothesis that Pemba is indeed the island of Menuthias	
	Beyond these places (Rhapta and Menuthias) the unexplored ocean curves around toward the west, and running along by the regions to the south of Aethiopia and Libya and Africa, it mingles with the western sea (*PME* 18)	Madagascar / Mozambique

What is obvious from information above (Table 2.1) is how little is known about these ports beyond a brief mention in classical texts. Although 48 ports were mentioned by ancient authors located on the Red Sea, to date only 9 of them have been successfully located. The remaining 39 are divided between 34 harbours provisionally identified or with a probable location, and 5 that have not been identified at all. Additionally, 5 locations have been identified that could not yet be correlated with any of the harbours mentioned in ancient texts, but which, according to the parameters of attractiveness discussed in Chapter 6, have great potential for accommodating a significant port. A similar situation can be observed in the Gulf of Aden, Persian Gulf and Indian Ocean, with most of these site locations yet to be confirmed.

Whilst a number of attempts have been made to geo-reference ancient texts (e.g. Isaksen 2012), and comprehend maritime connectivity through the use of GIS to model the seafaring networks (e.g. Leidwanger 2013), the process remains unreliable at this stage and the coordinates derived from such exercises have proven to lack support in the field.

2.2.2.1. Ports of the Northern Red Sea

Although the northernmost Late Roman and Islamic Red Sea port of Aila (Aela/Aelana/modern Aqaba) is never actually referred to as a harbour (Ward 2007: 163), Eusebius (*Onomasticon* 6.17–20 and 8.1) refers to ships sailing between Aila, Egypt and India, attesting to its maritime character. A number of geotechnical, geoarchaeological, archaeoseismical and GIS studies have been conducted over the years on the site and in its surroundings (Russell 1980; Niemi et al. 1999, 2006; Mansoor 2002; Mansoor et al. 2004; Al-Tarazi and Korjenov 2007; Thomas et al. 2007), but none has specifically targeted the potential harbour basin. Additionally, a number of Aqaba amphorae were discovered from the Black Assarca wreck in Eritrea (Pedersen 2008). Although recent excavations have produced some evidence for contacts with Berenike and Adulis, they did not confirm strong relationships with the Indian Ocean maritime trade network (Whitcomb 1994a, 1994b, 1997; Parker 1997, 2009; Retzleff 2003).

Some surveys and excavations (e.g. Bourdon 1925) were also undertaken at the important Red Sea port of Clysma (Cleopatris/Arsinoë/Islamic Qolzoum) in the 1920s and 1930s (Bruyère 1966) suggesting the location of the ancient harbour by the evidence of concretre quays. Recent work on the Nile–Red Sea canal (Cooper 2009, 2014) has brought into focus the importance of this port and renewed fieldwork at the site is likely to start soon.

To date, we do not have a clear understanding of the whereabouts of the harbour of ancient Nechesia, the smallest Ptolemaic–Roman Red Sea emporium, although Marsa Nakris has been put forward as a potential location (Sidebotham 2011: 186). Nor do we have any definite answers regarding the locations of Philoteras/Aenum (Sidebotham 2011: 184), Leuke Kome (Albus Portus/Leukos Limen) (e.g. Nappo 2010), or Ptolemais (Epi)Theron (Seeger et al. 2006; Sidebotham 2011: 186). It is clear that there is still a great deal of work to be done to begin to fill in the gaps in our knowledge of ports and harbours in the Red Sea region and it is certainly time that greater research effort is expended to bring the level of research in line with that undertaken in the Mediterranean.

2.2.2.2. Geological work at Berenike

From the mid 1990s onwards, pioneering geological work by James A. Harrell from Toledo University was carried out at Berenike and in its hinterland.

Subsurface coring of natural deposits around the site in the *sabkha*[12] area was supplemented with survey in the mountains and around the quarries, as well as detailed study of the mineralogical assemblages (Harrell 1996, 1998, 2001, 2007; Harrell and Storemyr 2009). Harrell's works laid the foundation for this geoarchaeological research and key elements of his research are discussed in more detail in Chapters 4 and 5.

2.2.2.3. Geoarchaeological work at Myos Hormos

The shortest route between the River Nile and the Red Sea is marked by Wadi Quseir, which forms a direct link between the important port of Myos Hormos and the site of Coptos (Quft) in the Nile Valley, and which is dotted with at least 65 watch towers along its length (Zitterkopf and Sidebotham 1989). The contemporary environmental conditions at the site are very similar to those reconstructed at Berenike, with a small bay (*mersa*) to the south, which was once an entrance to the harbour and is now occupied by a silted lagoon and *sabkha*. It is envisaged that Myos Hormos, like Berenike, also suffered from a deficiency of available fresh water in antiquity.

Between 1999–2003, a sediment sampling survey, including both test pits and coring, was designed by Lucy Blue (2006: 43) of the University of Southampton to understand the history of the former lagoon at Myos Hormos as well as the

[12] It is essentially a supratidal salt flat characterised by evaporite-carbonate deposits with some siliciclastics.

processes that resulted in its infilling. The main objective of Blue's research was to identify the location of the port in the Roman and Islamic periods using excavation, topographic and coring surveys and magnetometry data.

A key issue to address at the site was the nature and timing of the siltation of the lagoon that formed the main body of the harbour. To this end, Blue and colleagues concentrated their efforts on drilling a large number (~100) of cores (including 9 cores with a rotary drill) to confirm the generally accepted interpretation of a 'silted lagoon', which was at one time open to the sea and functioned as a harbour. Roman activity associated with another open surface area suggests that an identified channel facilitated a secondary mooring for ships in this area – a small embayment just like the one in the 'Niche' area at Berenike. This work also clarified its extent and depth in the Roman and Islamic periods, as well as identified the character and location of the Roman and Islamic waterfronts (Blue 2007: 268).

The discovery of waterfronts constructed from empty amphorae (Fig. 2.9) proved extremely valuable in developing our understanding, not only of Myos Hormos and its social context, but also of the technological connectivity across the Empire (Blue 2011a: 35–42) owing to this type of structure also being used across the Mediterranean, e.g. in Cadiz on the Atlantic coast of Spain (Bernal et al. 2005) or sites in northern Italy and southern France (Pessavento Mattioli 1998). Furthermore, ascertaining the location and depth of the harbour in the Roman and Islamic periods allowed for a better understanding of maritime traffic at the site. Blue's work also allowed her to discern the pattern of silting up of the harbour[13] with the migration of inner reaches of the lagoon gradually moving the sandbar towards the entrance of the lagoon, closing off the channel, and ultimately disabling the harbour.

In the late 1990s and early 2000s, Blue's geoarchaeological study was not only timely and innovative, but was the first to be undertaken on any ancient port of trade on the Red Sea coast. The use of a multi-parameter approach to the study of this site was a great step forward in understanding the maritime archaeology of this region. This study also represented a much-needed step towards an environmental and landscape approach that was only followed by three other geoarchaeological studies undertaken to date in the region (Berenike, Adulis, Marsa Gawasis).

2.2.2.4. Geoarchaeological work at Adulis

Further south, the city of Adulis on the Eritrean Red Sea coast — a key port of the Late Antique Axumite Empire — was connected with the capital, Axum, by a meandering mountain passage. The two harbours of Adulis — Diodorus Island and Orienê — were located by Peacock and Blue (2007) with the following geoarchaeological study initiated on site in 2004 including coring and geomorphological survey in different areas of the locale.

[13] Excavations in Trench 15 suggest that the harbour experienced siltation problems from at least the 1st c. CE.

The current location of the site, 7 km from the present shoreline, indicates considerable coastal change. While the results of coring by the team from Southampton may not have been conclusive in terms of direct evidence of a marine environment, they did provide indications as to the location of the ancient shoreline. This work also helped identify the seastack bisecting the Galala Hills in the southern part of the site as Diodorus Island, one of the harbours mentioned in the *PME* (4), in whose lee ships could safely moor (Blue and Peacock 2007: 47). The second port at the site, Orienê, had a magnificent lagoonal harbour and an adjacent settlement in the central valley of Dese (Peacock and Blue 2007: 137). Renewed excavation at the site under the leadership of an Italian team (e.g. Zazzaro 2013; Zazzaro et al. 2014) and much-needed geoarchaeological work on the harbours is planned by the Aix-en-Provence team under direction of Christophe Morhange (pers. comm. 2014).

2.2.3. Summary

A plethora of high-quality datasets from across the Mediterranean has essentially allowed the key aims of the discipline of port geoarchaeology to be defined and then its methodology to be refined (e.g. Marriner and Morhange 2007). However, due to the scarcity of similar research in the Red Sea region, lack of appropriate laboratory resources on the ground, and difficulties with export permits, it has not been possible thus far to 'test drive' these methodologies and approaches in the unique environmental conditions of this region.

Geoarchaeology needs to be an integral part of any archaeological investigation, and in this capacity such work should be carried out in advance of excavations, allowing archaeologists to undertake informed and targeted investigations. Without a deep understanding of site formation processes, their changes through time, and the level of anthropogenic impact on the natural environment of the site, it is impossible to clearly understand its depositional history. The detailed picture of ancient landscapes can only be discerned from the geoarchaeological study of its buried topography. Therefore, the lack of refined climatic and environmental data showing the impacts of natural processes on human adaptations handicaps any archaeological work and can lead to numerous misinterpretations and omissions of important data.

There is, consequently, a pressing need for high-quality scientific research on the Red Sea ports, which would entail the use of high-end apparatus and well-trained scientific staff. Ancient port geoarchaeology is a very accomplished discipline capable of discerning, in fine detail — and at a relatively low financial cost — the history of changing on- and off-site environments, driven by a combination of both natural and man-made mechanisms and the 'coevolution between the relief and human populations' (Devillers 2008). It is therefore surprising that before the commencement of this project only such a small number of geoarchaeological studies had been undertaken on Red Sea ports (two of them by Blue) and since the start of this research no other new work has emerged.

It is the firm opinion of the author that the lagging behind of geoarchaeological science in this region, in stark contrast to the ubiquity of such research in the

Mediterranean, means that all future archaeological investigations of maritime sites in the Red Sea region should incorporate a significant geoarchaeological component. This change should occur in tandem with scientific infrastructure and capacity building that is so urgently needed to further archaeological science in general in the region.

2.3. CHARACTERISTICS OF THE RED SEA COASTS AND BASIN

The ancient port of *Berenike Troglodytica* (23°54'37 N, 35°28'34 E) is situated just 52 km north of the Tropic of Cancer (23°26'), on the western Red Sea coast of southern Egypt. The semi-enclosed and narrow basin of the Red Sea, opening to the equatorial regions, has a long history of human occupation (e.g. Bailey 2009) and its coastal dynamics determine Berenike's natural conditions. The harsh marine environment at the site is controlled mainly by Bab al-Mandeb Strait dynamics and regional climate. The non-linear and non-uniform evolution of coastal systems during the later phases of the Holocene on the Red Sea coasts developed as an amalgamation of global, regional and local controls including sea level fluctuations, sedimentary processes, climate change, anthropogenic forcing and temporal shifts.

2.3.1. Climatic conditions – past and present

The climatic conditions of the Red Sea coasts today, and throughout the late Holocene, are semi-arid to arid with sparse rainfall, limited supplies of surface water, and no permanent river inflows (Edwards and Head 1987; Bailey 2009; Zahran 2010). The climate is relatively uniform with the exception of latitude-dependent temperatures (Edwards and Head 1987; Legge et al. 2006; Bailey 2009) allowing only limited zones suitable for human exploration and habitation. The Red Sea has the highest temperatures and salinities recorded in the world's oceans (Belkin et al. 2009) with a mean surface salinity of 42.5‰ and a mean temperature of 30° C during the summer months (Sofianos et al. 2002). This affects the distribution and diversity of marine species that provide subsistence for coastal communities.

Precipitation in the region is generally low and is largely exceeded by evaporation (Quadfasel 2001) with rainfall concentrated, once every several years, mainly in the winter months, varying from about 5 mm at Quseir to approximately 27–28 mm at Eilat. Heavy downpours observed once every few years lead to flash floods (*seyal/suyul* in Arabic) (Sidebotham 2011: 8), whose destructive power can also be visible in the sedimentary record (Chapter 4).

According to Maxfield (2001: 143) available evidence suggests that rainfall levels were similar during antiquity suggesting potential climatic variability. Decrease in precipitation could have made non-irrigated agriculture and keeping stocks of animals extremely difficult, with subsistence having to rely largely on coastal resources and imported goods. Precipitation increases in the mountains of the south, which receive summer rain from the Indian Ocean Monsoon (IOM) system. Comparably, precipitation rates range from *ca.* 300–1,000 mm in the highlands of Yemen and the Asir Mountains of Saudi Arabia, and from *ca.* 500–2,000 mm in the Ethiopian highlands (Bailey 2009) making herding and cultivation more practical (Fig. 2.10).

The absence of perennial streams or rivers on the Red Sea anti-estuarine coasts makes life in the region dependent upon springs, wells and oases (Bailey 2009: 7). This means that the whole region is extremely sensitive to even minor climatic shifts. A glance at the current landscape of Berenike, a bare desert swept by gusty winds, makes it difficult to imagine that it could once have flourished as an important trading outpost, or, as has been proposed, could once have been seasonally humid enough to sustain light soils for the use of small-scale horticulture (Jarosław Zieliński, pers. comm. 2011).

Even in the fairly recent past, large wadis in the vicinity of the site sporadically flowed from the mountains to the west, across the coastal plain, to the sea. Although, at the moment, these wadi systems are rarely active, they occasionally flow during heavy rains that cause the coastal plain to flood, resulting in the temporary greening of the desert (observed by the author in winter 2013, Fig. 2.11). From the earliest times the wadis provided natural tracks of communication, later becoming corridors of trade for the importing and exporting of Indo-Roman goods and commodities across the Eastern Desert (Schörle 2010).

Evidence for periodic humid phases has been recognised in archaeological trench profiles (e.g. Trench BE11-71) and wadi sections (e.g. in Wadi Kalalat), indicating the intensified flow of seasonal rivers at certain times. These cycles of wetter climate must have dramatically changed the appearance of the Red Sea coasts, increasing their attractiveness to settlers and passers-by.

There is no doubt that the Red Sea and wider Arabian Peninsula regions, which are so sensitive to climatic changes in both terrestrial and marine environments (Seeberg-Elverfeldt et al. 2007), have experienced periods of wetter conditions in the past (McLaren et al. 2009; Armitage et al. 2011; Rosenberg et al. 2011), which had implications for human populations occupying these regions. Establishing when these humid phases occurred in relationship to peak periods of human activity at this study site is crucial, and is presented in Chapters 4 and 5.

There is a considerable amount of published data regarding climate and sea level changes for the later phases of the Quaternary (Pleistocene and early to mid Holocene; e.g. Bailey 2009) but not for the late Holocene. However, a research group from the University of Bremen has recently developed a model of regional climate change over the past *ca.* 1,800 years (Seeberg-Elverfeldt 2007). This model, based on analysis of marine cores from Shaaban Deep, in the northern Red Sea, used stable oxygen isotopes, grain size data, microplankton and foraminifera (Seeberg-Elverfeldt 2004; Seeberg-Elverfeldt et al. 2004, 2005) and identified a pattern of alternating negative and positive climatic phases.

The four intermediate positive phases of regional climate variability for the northern Red Sea are characterised by heavier and coarser grains, which indicate colder, drier conditions with stronger winds. Five negative phases that occurred between 200–430 CE, 750–950 CE, 1180–1430 CE, 1550–1750 CE, 1850–present, are characterised by lighter and smaller grains. Fluctuations in $\delta^{18}O$[14], used here as a measure of temperature and precipitation, indicate that the negative phases relate to warmer, humid conditions with weaker winds in the northern Red Sea.

Comparison with published palaeoclimatic records reveals possible teleconnections to North Atlantic climatic variability as well as to the climate regime of eastern tropical Africa and Arabia (e.g. Seeberg-Everfeldt 2007; McLaren et al. 2009). These findings partially correspond with data collected by the CASTINE Project (Climatic Assessment of Transient Instabilities in the Natural Environment) that has identified four global periods of turbulent climatic change during the Holocene, at 9–8 kya,[15] 6–5 kya, 3.5–2.5 kya and 0.6–0 kya, with two more regional events at 4.2–3 kya and 1.2–1 kya (Mayewski et al. 2004).

14 $\delta^{18}O$ is a measure of the ratio of stable isotopes ^{18}O:^{16}O (oxygen-18:oxygen-16) used in geochemistry, paleoclimatology, paleoceanography, and climatic geology. Determination of $\delta^{18}O$ from corals, foraminifera and ice cores allows recording glacio-eustatic sea level and climatic fluctuations as well as seasonality. It is a proxy for temperature and precipitation, as a measure of groundwater/mineral interactions.

15 kya = thousand years ago

This means that whilst the period between 1000 BCE–800 CE is regarded as generally free from turbulent climatic change, the Red Sea coast experienced, according to Seeberg-Everfeldt (2007), colder, drier conditions with stronger winds before 200 CE, and then warmer, humid conditions with weaker winds between 200–450 CE (the peak in Berenike's activity). Such signatures are only partially visible in the sedimentary record, which exhibits signs of another potentially humid phase (flash flood events in the stratigraphy; see Chapters 4 and 5) somewhere between the late Ptolemaic and early Roman period. Whilst absolute dating of sedimentological columns could not be achieved on the site due to the high prices and long queues for dating in local institutions and difficulties with obtaining export permissions, the relative dating seems to agree only partially with the Seeberg-Everfeldt data and points towards Berenike's climatic change being stimulated mostly by local forces rather than regional dynamics.

2.3.2. Winds and climatic systems

The Red Sea climate is influenced by two distinct systems that interact dynamically around the area in which Berenike is located. Within the borders of the Red Sea basin itself, the general surface circulation is cyclonic (Longhurst 1998). In the north however, precipitation is driven by both the Mediterranean cyclones and by the North Atlantic Oscillation (NAO) cycle, which affect oscillation on the site and bring winter rains. This results, according to Felis and colleagues (2000), in arid seasons approximately every six years; however Sidebotham observed (pers. comm. 2012) that it is more like 15–17 years in the region of Berenike.

The Mediterranean climate system also controls the formation of deeper waters during the drier and harsher winters (Arz et al. 2003) that might have had a profound effect on navigation, making the sailing along the challenging coasts of the Red Sea safer. In the south, the monsoonal climatic system regulates nutrient input, and the shifting northward position of the Intertropical Convergence Zone (ITCZ) [16] at the times of monsoon intensification (Hemleben et al. 1996; Edelman-Furstenberg et al. 2009) when its force shifts as far north as Ras Benas (peninsula north of Berenike). During the winter months, the northeasterly monsoon extends as far north as the Gulf of Aden and the southern Red Sea, causing the seasonal reversal of wind regimes in the whole region (Patzert 1974). Knowledge of changes in the prevailing wind patterns would have played a crucial role in planning sea voyages and sustaining complex trading networks.

As already mentioned above, Red Sea circulation is dominated by winds, evaporation and the monsoon system. Changes in wind direction in the southern Red Sea are influenced by seasonal and monsoonal vector changes, with northerly–northeasterly winds dominating. In the winter months, when this region is under the influence of the Mediterranean cyclones, strong but short-lived westerly to southwesterly storm winds occur. Over the surface of the Red

[16] Known as the doldrums to sailors, it is an area of a low pressure (of a varied location), which is encircling the earth near the equator and where the northeast and southeast trade winds merge and the prevailing winds are calm. It appears as a band of clouds, usually stormy.

Sea the predominant wind patterns are usually northerly trade winds (e.g. Edwards and Head 1987; Davies and Morgan 1995: 29) (Fig. 2.12). In weak wind the course would be north-east by north and due west (Whitewright 2008: 139, Fig. 2.24) whilst in a strong wind, as Sulaimān al-Mahrī tells us,[17] sailors would allow for an east by north or due east course for the Arabian coast and west-southwest or southwest by west for the African coast (Tibbetts 1961: 327) (Fig. 2.13).

The prevailing northerlies in the northern part of the Red Sea (in which Berenike and Myos Hormos are located) blow almost all year round, with the central part of the basin experiencing more mixed conditions, with prevailing northerlies supplemented by some westerly blows. In the southern part of the Red Sea the northerlies still prevail in the summer, with the reverse pattern in the winter when southerlies prevail approximately 55–70% of the time (Davies and Morgan 1995: 29–30). The strong seasonal (0.5 knot) currents follow the directions of winds aiding the northward journeys (Whitewright 2007b: 85). In the Gulf of Aden the winds blow in during the winter and out during the summer months, determining the schedule for the maritime trade in and out of the basin.

On the Indian Ocean, the northeast monsoon blows during the winter, from about November to March, with a general force of 4–5 BFT[18] (10–20 knots) and ocean currents usually follow the prevailing wind in the ½ to 1 knot range. This,

[17] A sailing-master (*muʿallim al-baḥr*) and author of "Sailing Instructions" in the first half of the 16th c. CE (Ferrand 2014).

[18] The Beaufort Scale relates to the empirical measurement of wind speed and observed conditions at sea or on land.

according to Beresford (2013: 219), presented little threat to seafarers and would have presented favourable conditions 'making for very pleasant passage'. The northeast monsoon brings hot and humid conditions and a rainy season, which means that the westerly passage is recommended at or around the beginning of the year. The southwest monsoon blows during the summer, from May to September/October with a force of around 7–8 BFT (28–40 knots), bringing cooler and drier weather (e.g. Cadet 1979; Hourani 1995 [1951]; Margariti 2007) (Fig. 2.14). April/May and October are transitional periods on the Indian Ocean (Seland 2011: 401). Separating those two seasons are inter-monsoonal cycles characterised by light and highly variable winds (Beresford 2013: 216).

Traditionally it is understood that specific conditions of the harbour basin meant that vessels leaving Egypt around August arrived in India some time in September, and then set out for the return journey from India as soon as possible, any time after the onset of the north-easterly monsoon around December and no later than early January (Pliny, *NH* 6.106; Whitewright 2007b: 78), bringing the vessels to the southern part of the Red Sea by the end of March at the latest. This was in time for southeast winds prevailing from January to March that are reliable up to Berenike's latitude (Facey 2004: 9–11). This would allow them to exploit any 'decent' southerly and offshore (diurnal) wind that was experienced on the Red Sea (Whitewright 2007b: 78). After that, from April to December, the northerly winds prevailed on the southern Red Sea making the passage very difficult if not impossible (de Romanis 2009; Seland 2011: 401).

The journey from India to Arabia could have been performed anytime between late October and early March (Tibbetts 1971: 231) with no 'closing' date of arrival in the Persian Gulf. However, according to the speed calculated by Seland (2011: 401) if a vessel left Northern Red Sea at the beginning of the season and took two months from India to the Gulf the merchants would have arrived there around mid-December (Fig. 2.15, see further discussion in Chapter 7). The so-called southern passage to Africa was also available from July to August (Horsburgh 1841: 484).

During the northern hemisphere summer, intertropical fronts move northwards bringing strong winds and thunderstorms thus making a passage in the peak summer months of June and July almost impossible for smaller vessels (Curtin 1984: 99). The trough pattern, however, sometimes shows anomalies and promotes Sub-Tropical Westerly Jets (STWJ)[19] over the Red Sea (Williams 2011: 36). The border between the northerly and southerly winds is approximately 20°N, representing the most northerly position of the ITCZ during the summer time (Patzert 1972a, 1972b, 1974; Edwards and Head 1987; Stenchikov 2011). Sailors departing Berenike, after approximately three months in port would, therefore, have to set sail early enough to arrive in India by September (Curtin 1984: 99), where, again, they would spend some three months trading and performing ship maintenance before leaving again around December (Fig. 2.15).

[19] Earth's major jet streams are fast flowing, narrow air currents.

2.3.3. Sea level change

In addition to shifts in climate, the Red Sea basin has also been subject to changes in RSL (e.g. Wanner et al. 2008; Rohling et al. 2013; Murray-Wallace and Woodroffe 2014: 244–246). The Quaternary has been a period of major climatic and sea level change caused by fluctuations of the polar ice masses (Murray-Wallace and Woodroffe 2014). However, the Red Sea is distant from the former ice sheets and therefore its isostatic response is dependent upon the contribution of the water load from other basins, which is limited by the strait's dynamics (Lambeck et al. 2011: 3547).

More data for the Roman-period environmental and climatic changes (e.g. McCormick et al. 2012; Manning 2013; McCormick 2013; Wilson 2013) as well as sea level fluctuations have recently emerged for the Mediterranean. The sea level data was based on the correlation of biomarkers and archaeological features in order to discern sea level fluctuations (e.g. Morhange et al. 2006b, 2013b; Stewart and Morhange 2009; Anzidei et al. 2011, 2014; Morhange and Marriner 2015) (Section 2.1.4.2). Based on the total isostatic contribution to the change in RSL on the Tyrrhenian coast at 2000 years BP estimated at -1.22 ±0.06 m (for the weighted mean earth model) some scientists calculate Mediterranean sea level during the Roman period as being -0.13 ±0.09 m below current mean sea level (bmsl) (Lambeck et al. 2004: 563, 573). Unfortunately, the Mediterranean results cannot be applied directly to the Red Sea, which is a much less tectonically active basin, and because the isostatic effects are different.

The Red Sea basin has been subject to relative sea level fluctuations on two scales: local, e.g. local tectonic uplift and coastal sedimentation; and eustatic (global), e.g. those connected with glacial-interglacial cycles and long-term factors of tectonic deformations associated with rifting, faulting and volcanic activity (Bailey 2009). Although the tectonic activity in the Red Sea region during the past 150,000 years is thought to have been negligible, even minor fluctuations at base level must be taken into consideration when analysing apparent sea level change (Plaziat et al. 1995).

Eustatic sea level fluctuations over the past 2,000 years have generally been limited (e.g. Anzidei et al. 2011; Hein et al. 2011; Lambeck et al. 2011; Murray-Wallace and Woodroffe 2014) given the comparatively stable climate. However, periodical changes did occur during the Medieval Warm Period (950–1250) and Little Ice Age (1300–1850) (Carozza et al. 2014), making it difficult to isolate their effects from general rates of isostatic uplift/subsidence over this broader timescale. Furthermore, as the Red Sea basin is almost totally enclosed, it is unreliable to use changes in RSL outside the basin as a proxy for basin-wide fluctuations owing to the effects of precipitation and evaporation (Siddall et al. 2004).

There is also still some debate as to the nature and timing of lead and lag times between global climatic events and the response of regional sea levels on the Red Sea (Armitage et al. 2011; Lambeck et al. 2011). It is likely that significant lags would have occurred as polar ice caps responded slowly to subtle changes in global climate (e.g. Sierro et al. 2009). This is especially relevant for sea level curves derived for the Red Sea, as the semi-enclosed nature of the basin probably increased the likelihood of lead/lag times.

Current coastal landforms around Africa and Europe formed largely during the last *ca.* 6,000 years of the Holocene when the sea achieved its current level (Marriner et al. 2010a; Hein et al. 2011) and as such they can be used to address archaeological questions. Although there is a great deal of published research concerning sea level change in the Red Sea during the earlier periods including Pleistocene and early to mid Holocene (e.g. Bailey et al. 2007; Bailey 2009; Hein et al. 2011; Murray-Wallace and Woodroffe 2014; Schneider 2014a), there are very few published data for the later Holocene.

Plaziat and colleagues (1995: 18–19) report the change in mid Holocene sea level, based on variation in size of truncated colonies of coral south of Hamata (about 40 km north of Berenike), dated to 6410 ±84 BP, and north of Wadi Gemal, dated to 7670 ±206 BP. This 0.5–1.0 m increase in sea level in the last 6–7 kya has also been verified by the presence of erosional surfaces between mean sea level (MSL) and mean low water (Plaziat et al. 1995: 21). However on the basis of their model developed exclusively for the Red Sea basin, only a minor change in sea level was observed during the last 2000 years and this assumption has been accepted by scholars such as Blue (2006: 43) as a basis for their research.

In Wadi Gemal (between Berenike and Quseir), another reef dated to 5800 ±250 BP occurs at 1 m above mean sea level (amsl) (Plaziat et al. 1998), but due to the suspected minor tectonic uplift and with a tidal correction of 0.25 m, the upper limit of RSL change lies in a range of 1.2 ±0.5 m. Around Wadi Lahami (just north of Berenike), the compromise medium is 1 m AMSL between 6500 and 4500 BP (Plaziat et al. 1995, Lambeck et al. 2011: 35501) and the curve does not, again, go as far as the late Holocene.

The data for the late Holocene period are scarce, particularly because of a lack of high-resolution studies (e.g. Smeed 2000, 2004; Edelman-Furstenberg et al. 2001, 2009; Siddall et al. 2002, 2004; Seeberg-Elverfeldt 2005; Lamy et al. 2006; Lambeck at al. 2011). However, what is known is that the evidence of the late Holocene sea level can be observed along the Red Sea coasts, but without characteristic mid-Holocene highstands that occur in the central part of the basin (Lambeck et al. 2011: 3542). Additionally, Lambeck's prediction models (E2 and E7) for the Ras Benas area (just north of Berenike) for 2000 years BP show approximately +50 ±20 cm change in RSL (Lambeck et al. 2011: 3550, Fig. 6) (Fig. 2.16).

As it is commonly accepted in the Mediterranean to infer RSL changes from the study of archaeological remains in ancient harbours, it is hoped that the results of this work at Berenike (Chapter 4; Appendices 1 & 2), allied with the finding of an amphorae wharf at Myos Hormos, will contribute to our understanding of these changes and introduce this methodological proxy to a new region (further discussion on RSL changes in Section 5.1.1). It is highly likely that even very minor global sea level changes and minor shifts in the RSL could have had a severe impact on the volume and quality of trade at Berenike, by affecting the viability of the harbour and its approaches, so a clear understanding of these fluctuations through time is absolutely crucial for understanding the mechanisms of ancient maritime commerce in the Mediterranean–Red Sea–Indian Ocean.

2.4. THE ENVIRONMENTAL SETTING OF BERENIKE

Berenike is located some 825 km south-southeast of Suez and 260 km east of Aswan, in the littoral zone between the Red Sea and the Eastern Desert. This location is entirely determined by its role as a port (see Fig. 2.17). Changes in the landscape and climate, however minor, must have played a crucial role in the fluctuating fortunes of this port, located in a marginal and dynamic area, and these changes are discussed in detail in Chapter 5. This section aims to present the key geomorphological features that dominate the current landscape in and around the site, some of which — allied with results from the sub-surface composite sections (Chapter 4) — aided the reconstruction of past landscape changes.

Berenike is situated on top of Quaternary sediments only ~9.5 km east of the foothills of dominantly metamorphic mountains, incised by numerous east-west running wadis that drain to the Red Sea. The site is located in the catchment area of three wadis, which also serve as major sources of sediment transported to the site: Wadi Mandit, Wadi Umm Salim al-Mandit and the northern branch of Wadi Kalalat to the west with Wadi Abu Greyah, connecting from the north-northwest

(Fig. 2.18). These wadis have a significant effect on the environment of Berenike, serving as the main source of material influx to the site and forming transport routes connecting the site to the hinterland. From the east and south, tidal *sabkha* (see Fig. 2.17) surrounds the site, and to the east and southeast it is adjacent to the lagoon.

2.4.1. Local seascape

The local seascape at Berenike comprises a wide range of geomorphic features, such as coastal shelf and coral reef, the Lagoon (Section 5.1), the Southern Promontory (an uplifted reef outcrop joined to the mainland by a tombolo[20]) (Section 5.2, Fig. 2.19), and the Southwestern Embayment (also known as the Southern harbour) (Section 5.3, Fig. 2.20). The average tidal range of the semi-enclosed and narrow basin of the Red Sea is low at ~60 cm (Blue 2006a). At Berenike this tidal range is even lower at ~25–50 cm (Harrell 1996), although owing to the bathymetry of the shallow bay, the lateral movement of the shoreline is often in the range of a few kilometres.

[20] A deposition landform in which an island is attached to the mainland by a narrow piece of land such as a spit or bar.

2.4.2. Shore

The shores to the northeast and southeast of the Greek and Roman site contain long and narrow beaches, whilst on the western shore of the lagoon, directly east from the site, the beach is much wider. The swash zones on these beaches (an area covered and exposed by the water run-up) rarely show fossilised marine organisms and consist mainly of fine to medium sands, whilst the beach of the lagoon is especially rich in manganese particles (see Fig. 2.21). In both the northern and southern areas the narrow beach faces slope slightly towards the sea, and at their toe end, just below the wrack line (the highest reach of the daily tide), they turn into a berm that displays a single line of low dunes behind which the *sabkha* starts (Fig. 2.22).

2.4.3. Coastal plain margins – *sabkhas* and *nebkhas*

At the margins of the coastal floodplain the ground surface is irregular and soft, consisting of dunes of silt and clay *parna* (aeolian desert sediments) deposits, sand sheets, ridges, and vegetation-stabilized mounds of aeolian clay and silt particles – the *nebkhas* (El-Bana et al. 2002). Geomorphological survey allowed the identification of four major sedimentation processes affecting the margins of the coastal plain where the site is located: i) intertidal beach and shallow marine processes, indicated by narrow beach flats and lagoons; ii) alluvial sedimentation at the toe of an alluvial fan system; iii) saline evaporite precipitation in a *sabkha* environment (e.g. an infilled embayment); iv) aeolian deposition creating *nebkhas* (i.e. coppice dunes); and, v) anthropogenic accretion (e.g. the tell of the Roman town, the mound over the *Temenos*[21] of Temples). The most prominent local coastal feature modified by human agency is an uplifted reef terrace on which the Roman city is located. Originally just 2 m amsl, the city-tell was formed by accumulated cultural material, and stands up to 7 m at present.

Sabkha dominates a large area of the landscape in the immediate vicinity of the site, encircling it from the south, east and north (Fig. 2.22). Previous coring surveys conducted by Harrell in 1995 and 2001 were aimed at establishing a clearer understanding of the *sabkha* stratigraphy, generally regarded as shallowing-upward and prograding. The 1995 campaign comprised 62 shallow augerholes in 9 traverses in the *sabkha* where it borders the southern and eastern sides of the reef outcrop with the main area of the settlement and perpendicular to it (Harrell 1996: 112).

The *sabkha* stratigraphy was shown to be essentially identical in all of the traverses with the upper recorded layers being divided into three depositional facies: lagoon fill, erosional lag and lagoon bottom (Harrell 1996: 114). According to Harrell's description (1996: 114), wadi and wind activity caused the lagoon fill and represents the progressive infilling of the lagoon.

[21] The *temenos* enclosure is commonly referred to as dedicated to a god, a sanctuary, holy grove or sacred precinct.

The 'Erosional Lag Facies' (Harrell 1996: 114, 124) consist of sand similar to the fill of the lagoon. Inclusions consist of pottery sherds, pebbles (those appear close to the ruins of the town possibly as a result of sloping processes) and shells of pelecypod and gastropod (whole and disarticulated). Harrell regards the interpretation of this facies as problematic, attributing it to a lag formed from the reworking of the lagoon bottom during the high-energy wadi activity. He also points to possible minor reworking by waves in the intertidal zone. The 'Lagoon Bottom Facies' (Harrell 1996: 124) is compositionally similar to that of the lagoon fill and contains large molluscs. The formation of this facies is a result of very early wadi activity, comprising sands buried with organic matter and poorly oxygenised sediments at the bottom of the lagoon (anaerobic), similar to deposits from the bottom facies recorded in cores in the northern area (Section 4.5.7).

The clay and silt mounds of the *nebkha* fields have long been the subjects of interest to scientists working at Berenike. In 2012, a coastal 'shovel pit survey' helped identify these features as classic *nebkhas* (coppice dunes[22]). *Nebkhas* most commonly form around desert dwelling plants, which obtain their water (in significant portions) from the phreatic zone (zone of saturation) or the capillary fringe above the phreatic zone using their extremely long tap-roots (~9 to 15 m). These plants and shrubs serve both to stabilise the substrate and to act as a sediment trap with the windblown sediments settling around them forming a mound, ultimately creating a hummocky landscape (Fig. 2.23).

[22] Other terms such as hummocky dune, dune hummock, small vegetated dune, phytogenic hillock, phreatophyte mound, bush-mound, shrub-coppice dune, knob dune, dune tumulus, rebdou, nebbe, and takouit are also known from literature.

Decomposing plant matter around the *nebkha* allows for the creation of light palaeosols that, in turn, create favourable conditions for the further development of plant growth, ultimately accelerating the size of the mound through a positive feedback mechanism. Some of the *nebkhas* in Berenike reach over 5–6 m above ground surface and can contain archaeological remains. During the 2013, season a short pedological study was undertaken to investigate the archaeobotanical evidence for horticulture or light agriculture, and to ascertain the speed of soil development in arid environments, exploring the possibility of different plant species growing in these environments. A sondage and core through one of the *nebkhas* was excavated and samples collected for sedimentological, pollen, ^{14}C and OSL analyses, holding great potential for environmental and landscape reconstruction (Fig. 2.24).

A line of crescent-shaped reef outcrops and reef terraces, potentially of mid-Holocene or Pleistocene origin (Harrell 1996: 102–105, 1998: 125–130), is present all along this stretch of the coast on the border of the coastal plain and the *sabkha*. One of these outcrops — hereinafter referred to as the Crescent-shaped Ridge (CSR) — is a prominent feature of the Berenike landscape, and has long been interpreted as a potential wharf structure (Sidebotham 2011: 60–61), although augering, excavation, and geophysical investigation as a part of present study have since shown that this is a natural formation (Section 5.6).

2.4.4. Coastal plain and alluvial wadi fans

A low-lying, flat coastal plain stretches between Berenike to the east and the foothills of the mountains to the west. The main features of this plain are the alluvial fans and the limestone buttes (Fig. 2.25). Isolated buttes, with steep, almost vertical slopes and relatively flat tops are distributed around the coastal landscape, at a distance between 1 and 5 km away from the site. These features would have probably been used as building material sources, although no unambiguous evidence for gypsum anhydrite quarrying was identified during the survey.

As mentioned above, alluvial fans are the most prominent features on the coastal plain of Berenike. Alluvial fans found in desert area systems can be subject to periodic flash floods caused by thunderstorms and orographic precipitation originating in the nearby mountains. Alluvial fans aggrade through the rapid deposition of sediments as flow speeds markedly reduce following the change from a steep gradient to a shallow one (i.e. from mountains to plains). They are often located on the margins of sedimentary basins where the steep mountainous watercourses debouch onto the flat coastal plain.

Wadi fans on the coastal plain adjacent to Berenike are funnel-shaped and open out into a fan-shaped 'delta' at the distal end. Out of the mouths of wadis, the fans take the form of multiple braided streams, which are usually active during peak flow periods (Fig. 2.26). Coarse and poorly sorted sediments begin to settle out of suspension with the decrease in flow competency. As the channels flow around these sediment aggradations they gradually form a slightly hummocky, shallow conical or braided fan shape. The sorting of material in particular flood events is evenly graded (as seen on the example of Facies F; Section 4.2) although repeated flood events make the whole package poorly-sorted.

Flash floods are highly visible in the sedimentary record obtained during augering (Chapters 4 and 5), and were probably both a form of boom and bust for ancient Berenikeans: on one hand generating turbid water in the harbour that prevented the growth of potentially dangerous corals, but on the other hand flash floods led to silting of the basin (Sidebotham 2011: 9). They also had a direct impact on human habitation in the coastal plain — the Ptolemaic Industrial Zone (PIZ) and Ptolemaic Fort — which lay just west of the CSR (see later Fig. 5.13) and are sheltered from alluvial influx by limestone buttes to the west (Section 5.9).

2.4.5. Coastal hinterland

The mountain chains to the west of Berenike, on the northern side of Wadi Mandit and set behind the igneous foreland on the southern side of Wadi Kalalat, comprise mainly of Precambrian, low-grade metamorphic rocks, such as metagranite, metagranodiorite and metaquartz diorite (Fig. 2.27). Low-grade metamorphic rocks such as metadiorite and metagabbro are present between those two formations, around Wadi Na'ai and to the north from Wadi Lahami, as well as around Wadi Kansisrub (Harrell 1996: 100–101). The nearest recorded water source is a system of large fortified wells (*hydreumata*) located at intervals some 7–8.5 km west-northwest of the site. To the north and northeast, the site is flanked by Miocene mountains situated along the imposing Ras Benas peninsula, both an ancient viewshed, and a shelter against the strong southerly currents.

2.4.6. Berenike and its dynamic landscape

Coastal environments, including harbours and port towns, are sensitive to numerous geomorphological and Earth surface processes, including tectonics, sea level change, the effects of tides, waves, currents, variations in temperature, pressure and wind action (Bird 2008). The diversity of natural forces shaped and re-configured the ancient landscape of Berenike before, during and after its occupation during the early Ptolemaic and Roman periods. In order to better understand the major forces and influences that shaped the site, a number of primary processes are presented in Table 2.2 and schematically on Fig 2.28.

Table 2.2 Processes at play in Berenike.

INFLUENCE	DESCRIPTION
Fluvial	Sediment originating from the mountains transported by wadis during heavy rains and flash floods
Marine	Sediments delivered by forces such as tides and currents; includes storms and stronger winds that also intensify aeolian action
Windblown (aeolian)	Silt and sand deposited as dunes and sand sheets
Colluvium	Processes acting under the influence of gravity, such as slopewash (e.g. on the slopes of the Roman tell)
Erosional	Weathering, wind, evaporation (e.g. the walls of the temples and buildings)

INFLUENCE	DESCRIPTION
Evaporitic/precipitation	The precipitation of salt and gypsum in large evaporitic semi-enclosed basins (e.g. approximately 10 cm below the surface in most trenches) or crustation (e.g. around the *Temenos* of Temples)
Anthropogenic	Archaeological deposits and human modification of the natural landscape, such as dredging, landscape re-configuration, etc.

Ascertaining how the past coastlines were shaped, and whether this was by horizontal (deposition or erosion) or vertical (uplift or subsidence) movements, or via anthropogenic processes, is extremely important for our understanding of archaeological visibility and the issue of the presence or absence of a port in any given location. Based on an understanding of the processes that determined these changes in Berenike's landscape, elucidated using geoarchaeological techniques, the conditions encountered by the inhabitants of the site were modelled and are presented in Chapters 4 and 5.

2.5. SUMMARY – NATURAL AND ANTHROPOGENIC FORCING AND LANDSCAPE CHANGES ON THE RED SEA PORTS

As we have seen in this review, it is only through a truly multidisciplinary collaboration between archaeology and the geosciences that our knowledge about ancient harbours — sharp interfaces between humans and the natural landscape — can really be furthered. The paucity of comparable research on the coasts of the Red Sea, and the very different land, sea and climatic conditions from those encountered on the widely researched coasts of the Mediterranean, mean that it is challenging to develop a bespoke methodological framework and approach for this under-studied region. Owing to the difficulty employing the available methodologies a bespoke framework was devised based upon practices used in the Mediterranean and adapted specifically to address the parameters of the Red Sea environment.

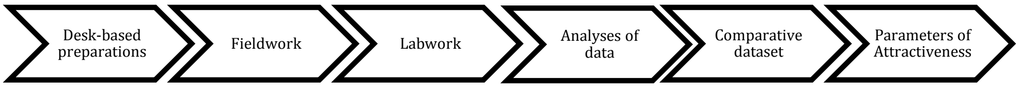
Most of the available studies and methodologies were developed in tectonically active coastlines influenced by marked perennial fluvial activity characteristic of the Mediterranean. This disparity means that it is meaningless to directly transfer the 'Mediterranean methods' to the Red Sea coast with its arid/semi-arid climate, ephemeral rivers (wadis), and tectonically stable coastlines (compare Chapter 3 and Section 2.1). The understanding of the changing landscape (Section 2.2) and the temporal resolution obtained from augering (Chapters 4), allied with the detailed study and discussion of available literature (Section 2.1), was therefore vital in unravelling the history of changes and fluctuations in the appearance of Berenike and its surrounding landscape. Having presented an overview of the research trends and frameworks employed in different regions, and contextualizing the site in its natural landscape to provide an environmental background for understanding its foundation, evolution and eventual decline, it is now appropriate to link this information with the methodology developed for the analyses of Berenike, which is the focus of the following Chapter 3.

3. METHODOLOGY

In order to investigate the nature of the sub-surface topography, define the harbour basin, and reconstruct the landscape contemporaneous with the archaeology of the port of *Berenike Troglodytica* a large-scale augerhole survey was conducted over two consecutive seasons between 2011 and 2012 and was followed by laboratory analyses in 2013. Sediment samples obtained during these 2 subsequent campaigns have been essential in providing the basis for understanding of the palaeoenvironmental evolution of the site, the maximum extension of the water table and the shoreline mobility of the ancient basins. In addition, the results from sediment analysis provide the potential for more informed, targeted archaeological excavations, which commenced in 2014.

This chapter describes the multi-parameter methodological framework employed to answer the questions posed by this research. The following Sections (3.2–3.4) outline the development of the project (Table 3.1); firstly, the fieldwork techniques used for data collection; secondly, the laboratory methodology providing a detailed rationale and description of the analytical techniques used to develop a cohesive geoarchaeological framework for the reconstruction of the ancient port landscape; and finally, the analytical methods used to study the resultant data and to compare ancient ports.

Table 3.1 Linear representation of the development of this DPhil research



3.1. FIELDWORK SEASONS

Fieldwork and sample collection took place at Berenike from January 2011 to February 2013 over three separate field visits (F1–3) undertaken in conjunction with the work of Berenike Excavations Project led by Steven Sidebotham and Iwona Zych. The aims of these field seasons are outlined in Table 3.2 below. The desk-based preparations (DB1–3), laboratory analyses (L1–L4), suspension (S) and final writing (W) stages are also included in this table.

Table 3.2. Outline of DPhil activities – desk based assessments, fieldwork, laboratory analyses and writing.

Phase	Date	Objectives
DB1	Oct–Dec 2010	To identify areas suitable for survey and augering; to carry out literature review and set out the methodological framework
F1.1	Jan–Feb 2011	To target areas suitable for geoarchaeological augering
F1.2	Jan–Feb 2011	To perform geoarchaeological augering in what was believed to be the southwestern harbour basin and to establish the existence and location of the port
F1.3	Jan–Feb 2011	To record a significant archaeological section in trench BE11-71 and to extend its vertical profile by augering
F1.4	Jan–Feb 2011	To undertake a preliminary coastal and geomorphological survey
L1	Mar–June 2011	To undertake initial sediment sample preparations
L2	Oct 2011	To undertake ^{14}C sample preparations, analyses and Bayesian modelling

Phase	Date	Objectives
DB2	Nov–Jan 2012	To identify areas suitable for survey and augering; GPR preparations; writing
F2.1	Feb 2012	To target the northern 'marina' with geoarchaeological augering and establish the existence and location of the harbour basin
F2.2	Feb 2012	To core in the southeastern part of the bay to establish the modern analogue sequence of the lagoon deposits
F2.3	Feb 2012	To undertake a comprehensive coastal geomorphological survey in the shore areas around the site of Berenike extending towards the coastal plain
F2.4	Feb 2012	To undertake geological and geoarchaeological survey in the mountain ranges and wadis directly to the west and northwest from Berenike
L3	Mar–June 2012	Analyses; writing
S	Sept 2012–Mar 2013	Academic Suspension (ICCROM/UNESCO internship)
DB3	Dec 2012	To choose areas for geophysical survey
F3.1	Jan–Feb 2013	To undertake geophysical survey using ground penetrating radar (GPR);
F3.2	Jan–Feb 2013	To sample a profile and core through the bottom of one of the *nebkhas* (coppice mounds) to calculate rate and degree of pedogenesis.
L4	Mar–Aug 2013	Analysis of sediment samples in laboratory
W	Sept 2013–March 2015	Writing up and revisions

Additionally, the author participated in several excavations and surveys of major ancient ports of trade on the Indian Ocean, from which comparative data were derived for the 'Parameters of Attractiveness', discussed in Chapter 6. Field seasons conducted for the purposes of this research are outlined in Table 3.3.

Table 3.3. The timetable of supplementary fieldwork carried out from Jan 2011 to Feb 2013.

Phase	Date	Site	Tasks performed
F4	Apr 2011	Pattanam/Muziris, Kerala, Southern India	Geoarchaeological augering in the canals of ancient Muziris; in the vicinity of the 1st c. BCE canoe

Phase	Date	Site	Tasks performed
F5.1 **F5.2**	July 2011 Aug 2012	Unguja Ukuu, Zanzibar, Tanzania	Excavations in the capital of Zanzibar archipelago possibly dating back to the 4^{th} c. CE
F6	Aug 2011	Rhapta (?), Tanzania	Survey to identify the ancient site of Rhapta in the Rufiji Delta
F7	Sept 2011	Coastal Southern Kenya	Survey for ancient port sites
F8	July 2012	Menuthias (?), Pemba, Tanzania	Survey for ancient port sites
F9	Nov 2012	Khor Rori, Oman	Excavation in ancient port town

3.2. FIELDWORK METHODOLOGY

The primary method of field data collection at Berenike was by augerhole survey. Additional techniques included sampling of sediments from archaeological trench profiles and obtaining modern analogue samples from the natural (non-cultural) locations in the vicinity of the site, such as augering in the lagoon, sampling a *nebkha* coppice dune, open sections in wadi valleys, and ground surface in the *sabkha*. Additionally, geological samples were collected to establish the source of sediments to the site. All of the sampling work was augmented by detailed stratigraphic logs, extensive notes and observations, and through a photographic archive.

3.2.1. Coastal and geomorphological survey

Direct observation of the geological sequence in the area of Berenike was conducted during pedestrian surveys around the lagoon, along the coast and through the *sabkhas*, and on the southern promontory and tombolo (Fig. 3.1). This work aimed at providing a better understanding of the basic geological formations present in the area to provide clues about potential site formation processes (Section 2.4). The initial work informed the next stage of the research – a targeted augerhole survey in the eastern part of the lagoon (Transect BE12-T04) and *sabkha* area. Reconstruction of the palaeohydrological landscape of the site focused on understanding coastal geomorphological features such as *sabkha*, wave-cut notches and platforms (around the sand-bar), braided wadi estuaries, ephemeral wadi palaeochannels, lagoons, beach ridges, and reef outcrops such as the Crescent-shaped Ridge (CSR) along what was thought to be the southwestern harbour basin (Fig. 1.8).

During the geomorphological survey (Fig. 3.2), four major sedimentary environments were identified at the site: i) intertidal beach and shallow marine processes, forming narrow beach flats and lagoonal environments; ii) alluvial sedimentation at the toe of an alluvial fan system; iii) saline evaporate precipitation in a *sabkha* environment (an infilled embayment) and, iv) aeolian deposition creating *nebkhas* (coppice dunes). The manifestations of these processes have been recorded in sub-surface sediments during the augerhole survey, and are described in detail in Sections 4.2 and 4.3.

Understanding RSL change is absolutely critical to reconstruct the changing use (or disuse) of the harbour during successive chronological periods. Recording of coastal geomorphological features that could provide evidence for changes in RSL, such as wave-cut notches (Fig. 3.3), was therefore a significant component of this geomorphological survey.

3.2.2. Sediment sourcing survey (mountains and wadis)

The sediment sourcing survey was conducted over two seasons in the mountains to the west of the site. During a number of trips to the Eastern Desert, rocks and sediment samples from the wadi valleys and mountain ranges were collected to create a reference collection for future material sourcing studies (Fig. 3.4). Should the restrictions regarding the exportation of samples and the importation of portable XRF machines to the site be relaxed, these samples will represent an important source of data for understanding the dynamics of the catchment area and sediment delivery to the archaeological site of Berenike and in particular the harbour basin.

3.2.3. Augerhole coring

Augering was used to reconstruct the buried topography of Berenike, its harbour and the immediate surroundings. Before the 2011 season the locations of a series of augerhole transects were set out using a desk-based examination of geological maps, geophysical survey data, archaeological reports and satellite images (Phase DB1). In 2012, pre-season planning used data derived from the 2011 study (Phase DB2) to help target key areas for augering (see Fig. 2.28).

The main precept governing the choice of locations for these transects was to work from 'the known to the unknown', therefore connecting 'known' points of fixed chronology such as stratigraphic profiles (e.g. archaeological trenches and exposures) with 'unknown' areas of the site and its adjacent hinterland and strata in the embayment. Due to the limitations of the available equipment (hand-held auger) and only a small number of cores attaining 5 m in depth, the decision was made to conduct a widespread augering survey using numerous cores and transects, rather than target a smaller number of undisturbed deep holes at higher resolution.

The first stage (Phases F1.2 and F2.1) included fieldwork data collection (augering), with the next stage (Phase L) being the off-site laboratory analyses of sediments recovered during the fieldwork. The 2011 augering methodology was provisionally devised based on descriptions from Harrell's 1996 and Blue's 2006 reports, and partially adhering to standard core sampling methodologies devised by a UK-based commercial unit (Museum of London Archaeology – MoLA). The 2012 campaign built on and refined that used during the previous 2011 campaign. Harrell's 1995 campaign comprised nine very shallow transects — usually 0.6 m in depth — situated in the *sabkha* area, east of the site (Harrell 1996) and in 2001 one transect in the *sabkha* area in the vicinity of the dig-house.

The initial locations of these transects were determined off-site using geo-referenced satellite images, with X–Y co-ordinates recorded. These locations were re-evaluated and located at ground level in the field through the use of a hand-held GPS and/or Total Station (Phase F1.1). The transects were positioned across areas with potential to identify the southwestern 'harbour' (Phase F1.2) (Fig. 3.5) and northern 'anchorage' (Phase F2.1) basins, as well as the southeastern side of the lagoon (Phase F2.2), to build up a picture of the bathymetry of the potential ancient anchorage and to refine the sub-surface topography of the area (Fig. 3.6). All cores were levelled and altitudinally benchmarked relative to present mean sea level (MSL).

The augerhole survey was conducted using a hand auger fitted with a 120 mm 'Dutch head' (standard type of auger head used for combination soils), and 6 x 1 m extension rods (Fig. 3.7). The author chose the 'Dutch head' based on Harrell's (1996 and 1998) descriptions of sediment characteristics and his problems with using the 'bucket head', which was designed specifically for use in sands and, therefore, not suitable for clays, sediments with large inclusions, fine sands and silts. The 'Dutch head' was successfully employed on most occasions in this diverse sedimentological environment, with some augerholes attaining a depth of up to 5.15 m in 2011 and up to 6 m in 2012. The 'Dutch head' auger did not, however, work effectively with waterlogged sediments and extremely loose sands.

Augering was undertaken with sediment samples taken at 10 cm intervals or when a new lithological unit was identified (Fig. 3.8). When a context exceeded

30 cm in thickness it was subsequently sampled at 20 cm intervals. Each sample recovered in the 'Dutch head from below ground was cleaned using a small, flexible trowel. A thin coating of contaminated sediment (resulting from pulling it up against the walls of the hole) was removed from both sides of the core. The clean core was assigned a colour using a notation scheme of Munsell Soil Colour Charts (2000 washable edition) and packed into a 'zip-loc' plastic sample bag and labelled.

Other descriptions in the field (aided by a hand-lens) included thickness of the deposit, composition, compaction, inclusions, sorting, and field interpretation. Each sample received a unique number, prefixed with BE (for site, Berenike) 11 (year), AH (augerhole), and number – for example BE11-AH1-1 (sample 1 from augerhole 1 taken during 2011 campaign). Additionally, each sample was given a context number. Some contexts were repeated in adjacent augerholes and in this instance they received the same number.

Problems encountered while drilling augerholes included side-wall collapse (mostly in loose sandy layers), total collapse, and difficulties getting the augerhead stuck in clay-rich and waterlogged layers. Most of these problems were solved with simple measures using locally available materials. These included, for example, pushing the top of a five-litre plastic water bottle, with the bottom cut off, upside-down into the top of the augerhole to prevent the fine and dry sand from pouring back into the hole.

The issue of collapsing was partially addressed in 2012 by inserting 12 cm diameter plastic pipes into the ground and augering inside them. This, however, proved to be very time-consuming and largely unsuccessful. In the case of looser sediments occurring deeper inside the augerhole, a few drops of clear, fresh water were poured into the hole (whilst the head and rods were already down) to harden and consolidate loose sediment (in this instance the Munsell colour readings were not taken from the wet sample and were undertaken in laboratory conditions).

Using a simple leverage system solved the problem of the auger head sticking in the clayey sediment. This was made using a formwork of timber planks on which longer (~2–2.5 m) and a stronger timber — 10 cm^2 in section — were used as a lever. This assisted with pulling out the auger from great depths (especially below 4.5 m). However, the metal rods brought by the author in 2011 and which were acquired from a UK supplier were too weak to sustain this method and as a consequence of the extreme forces often bent out of shape. Locally made metal rods acquired from a Marsa Alam plumbing shop, using 1 inch diameter standard plumbing pipes, proved to be more durable.

Augering in the lagoon posed what transpired to be an insurmountable hurdle. Two easternmost augerholes, BE11-AH36 and 37, were cored in the tidal area and had to be abandoned at ~1 m depth due to the auger sticking and the wet sample falling out of the core head before being pulled from the ground. A further transect was planned in 2012, BE12-04 in the western part of the lagoon on the western (inside) side of the tombolo. This allowed for the augering of 5 cores, although the closer the transect moved towards the water body the more difficult and shallower the augering became, to the point that it had to be abandoned altogether. Additionally, the southern side of the Lagoon, including parts of the Southern Promontory could not be investigated owing to the possible unexploded mines.

3.2.3.1. Augering campaigns rationale and summary

A total of ten transects, with 89 augerholes, were cored during the 2011 and 2012 seasons (Figs. 3.5 and 3.9; Appendix 1 follows from Section 4.3). During the 2011 season a series of six inter-crossing augerhole transects were augered (Fig. 3.10) and thus named: BE11-T01–06. Transects BE11-T05 and BE11-T06 were roughly aligned to west-southwest–east-northeast (west–east according to the site grid). Transects BE11-T01, BE11-T02, and BE11-T04 are generally orientated north–south, whilst BE11-T03 follows a northeast–southwest direction.

These transects (Figs. 2.28, 3.5, 3.9, 3.10 and 3.11) were drilled to:

i. locate the purported infilled Ptolemaic and early Roman 'harbour basin' (AH36, AH37 and others to the north);
ii. delineate the braided channels of the alluvial fan of Wadi Kalalat (AH52, AH53) in order to establish the depth of sedimentation caused by fluvial influx over time;
iii. delineate the crescent-shaped coral reef ridge that was thought to be the wharf of the 'harbour basin' (AH2–4, 43, 54) and to establish its origin;

and also to understand whether it was originally a natural structure adapted for use by harbour facilities or whether it remained a natural feature of the landscape throughout the use of the port;

iv. define and delineate the so-called 'island' in the middle of this possible basin (AH20–24 and AH31–34) on which a *temenos* with late Roman temples (including the Temple of Lotuses) is located. This is one of the key questions that had emerged from recent work in Berenike, where a potential southern Arabian temple complex was discovered on the high ground (possibly a natural uplifted platform) in the Southwestern Embayment (SWE) on the edge of the *sabkha*. Establishing the relationship of this complex to 'dry land' and with the site itself might prove to be extremely important in understanding its origin, role, function and significance for the population of ancient port of Berenike.

In 2011, the augerhole survey was completed in 22 working days over 3.5 weeks in the field with 64 augerholes, covering an area of over 85,000 m^2 (total area of 'Southern harbour including the SWE and the Lagoon is approx. 17.3 hectares, see Section 5.3), and a cumulative depth of 76.24 m. Cored sediments were recorded at 10 cm intervals. 277 sediment samples were taken, each of them sub-sampled leaving half as a repository/archive in the storeroom on site. A selection of 182 of these was the subject of palaeoenvironmental analysis at the University of Oxford.

The corpus of samples collected during augering in the southwestern port area (SWE) in 2011 provided a great deal of important information and an invaluable insight into the changing landscape of this port city. Preliminary laboratory analyses of sediments augered in 2011 demonstrated that it was necessary to undertake a second phase. The 2012 augering campaign was therefore designed to target the northern part of the site and any possible harbour or anchorage in this location (Fig. 3.11).

The area targeted in 2012 was situated in what Sidebotham (2011: 61) describes as the 'northern harbour' of Berenike. This assumption was based on: evidence for a 'seawall' uncovered in trench BE97/98-17 and dated with a *terminus ante quem* to the 1st century CE (Sidebotham and Wendrich 2000: 74–75, 77); and results from a 1999 geomagnetic survey showing 'no structures'. These excavations could unfortunately not be re-visited by the author and could be assessed only on the basis of photographs (Fig. 3.12) and the site report.

During the 2012 season, an additional four transects were augered, of which three were undertaken in the 'Northern Anchorage'. The final transect from 2012 was located across the southeastern part of the embayment in the vicinity of a tombolo connecting the Southern Promontory with land. This last transect, BE12-T04, was aimed at collecting modern analogue sediment samples and was an over-the-water extension of the transect BE11-T01.

In 2012, the augerhole survey was carried out over 7 days of augering, plus two days for pre-assessment and the targeting of specific areas including a total station survey. During this period, 20 augerholes in the 'Northern Anchorage'/the 'Niche' were cored to a total depth of 65.8 m (Fig. 3.11). Additionally, 5 augerholes were cored in the southeastern part of the lagoon, with a total depth of over 20 m. 215 samples were recovered, of which 78 were chosen as a representative selection for palaeoenvironmental analysis. Following preliminary field observations and during subsequent post-excavation analyses a total of 13 facies were identified, which represent sediments diagnostic of particular environments of deposition.

3.2.4. Archaeological excavations

The methodology employed by the Berenike excavation team uses a derivation of the single context recording system, in which a context is termed a 'locus'. In this system there is no clear definition of a cut, and usually this is included in the locus description, which is a clear deficiency in the scheme. Each locus is divided into arbitrary daily units called PBs (pottery bucket), designed in order to tighten stratigraphic control. All excavation is carried out using local Ababda Bedouin labourers, working mostly with large building trowels with an archaeologist supervising and recording the excavations and stratigraphy. The sediments recovered from the trench are sieved on 5 mm screens and sorted by a group of trained workmen.

3.2.4.1. Geoarchaeological studies of archaeological profiles

Geoarchaeological sampling of archaeological trench profiles was undertaken in trench BE11-71 due to its significance for understanding changes in the palaeoshoreline (Sections 5.3 and 5.4). Each context (cultural and natural) was sampled after cleaning and drawing the profile. About 100 g of sediment was sampled from each context. After sampling from the section, a small test-pit was excavated at the base of the trench through the laminated beach deposits, and this material was sampled at high-resolution (every 2 cm). An augerhole was cored at the bottom of this trench to extend the vertical sedimentological profile. This was sampled accordingly to the methodology described in Section 3.2.3.

3.3. LABORATORY METHODOLOGY

As ancient harbour basins are particularly sensitive to changes in sediment input and act as very effective sediment traps, the sediments encountered in the augerhole survey are likely to yield useful palaeoenvironmental data. The following sections outline the rationale for the laboratory-based analytical techniques used to develop the palaeoenvironmental reconstruction at the site of Berenike. Data obtained from laboratory analysis (Chapter 4) were used to re-contextualise the site of Berenike within its changing contemporary landscape (Chapter 5) and to provide background for the evaluation of the 'Parameters of Attractiveness' of the locations of ports (Chapter 6). A table detailing the results of the analyses, the types and quantity of samples, and techniques used, is provided in Appendix 2.

3.3.1. Sedimentology

Sediments form the essential matrix material of all archaeological sites, and so understanding the environments of deposition, and post-depositional history, of the sediments is the crucial first step in any study of site formation processes. There is a range of parameters that can be analysed, including the basic (but essential) physical characteristics of a sedimentary (lithological) unit, such as, for example, grain size, sorting, roundedness/angularity, structure, imbrication. These basic data can reveal much about the mode, tempo and energy of deposition. Mineral magnetic (e.g. magnetic susceptibility) and bulk chemical (organic matter and carbonate content) data can provide additional information relevant to the depositional environment at the time of sedimentation and the conditions prevailing up to the moment of sampling.

These sedimentological, bulk chemical and mineral magnetic parameters can be additionally supplemented by biological proxies (e.g. pollen, plant macrofossils, phytoliths, ostracods, foraminifera, insects, plant macrofossils, molluscs) and geochemical proxies (e.g. oxygen isotopes, carbon isotopes such as ^{14}C, other isotopes and ratios analyses), which serve as palaeoenvironmental proxies against which the sedimentological data can be compared and contrasted. However, due to time and financial constraints and lab accessibility these analyses were not included in this project; however the author envisages carrying them out as a part of a post-doctoral project.

3.3.1.1. Grain size analysis

The size of the constituent particles of a sediment sample or disaggregated rock sample primarily provides information on the depositional environment in which those particles were laid down, and is important in understanding environments and modes of deposition. In general, larger particles require more force in order to mobilise them than do smaller particles. This force could be current velocity in a watercourse, or gravitational force in colluvial sediments. By examining changes in particle size in a sedimentary sequence it is possible to infer depositional environments and it should be possible to differentiate between dune sands, channel sands, beach sands and lagoonal silts and hence different sediment source inputs within the harbour strata. The sorting of the grains within a given sample may also support these observations.

Laser diffraction granulometry was used to determine sediment particle size and particle size distribution on the <2 mm size fraction. Granulometric analyses were carried out using a Malvern Mastersizer 2000 laser particle size analyzer from Malvern Instruments at the Geomorphology Laboratory, Earth Sciences Department, the University of Oxford. Fractions >2 mm were separated and analysed using a standard nested sieve method.

The Mastersizer 2000 uses laser diffraction to measure particle size. Two lasers (red and blue light sources and a convergent beam lens) measure the intensity of light scattered as a laser beam passes through a dispersed particulate sample. Each sample was dried at 36° C and sieved through a 2 mm screen ahead of laser diffraction. Samples were gently disaggregated and dispersed in distilled water using a pump (at 2,500 rpm), and further disaggregated ultrasonically to ensure that particles were delivered to the measurement area of the optical bench at the correct concentration and in a stable state of dispersion. The sediments passed though the measurement area of the optical bench, where a laser beam illuminates the particles. A series of detectors then accurately measures the intensity of light scattered by the particles within the sample over a wide range of angles. Three measurements were made on each sample and results reported as an average of these data (Malvern Manuals 2005).

Particle size and statistical data derived from these measurements include volume weighted mean (μm), mean particle size (μm), particle description (i.e. silt, sand, etc.), skewness (measure of the asymmetry of the probability distribution of a real-valued random variable), kurtosis (a descriptor of the shape of a probability distribution) (Dodge et al. 2003), and sorting coefficient. These data were then analysed to calculate the size of the particles that created the scattering pattern. The Mastersizer 2000 measures particles ranging in size from 0.02–2000 μm, therefore excluding coarser (>2 mm) grains (gravels and pebbles).

3.3.1.2. Magnetic susceptibility

Assessing the magnetic susceptibility of materials such as sediments or rocks is currently one of the standard techniques used in archaeological science (Clark

2005). This technique provides a quantitative measure of the extent to which a material may be magnetised in relation to a given applied magnetic field (Merrill et al. 1998; Dearing 1999). The ability to derive environmental data from the magnetic properties of sediments relates to: i) the ubiquity of magnetic minerals such as iron-oxides (Gale and Hoare 1991); ii) their sensitivity to climate; iii) the depositional environment; and iv) transport mechanisms (Sangode et al. 2007). Magnetic susceptibility, therefore, is an essential tool for palaeoenvironmental reconstruction and can be used for a variety of purposes and materials of very diverse environmental origins, as all substances have magnetic properties that originate at the atomic level (Smith 1999a).

This method can provide information about the location of former occupation sites, and can be used as an aid for stratigraphic studies as well as to test for magnetometer 'surveyability' (Dearing 1999: 10). It is also diagnostic of processes such as burning and waterlogging (Turney et al. 2005: 51). As such, this technique is important for studying ancient harbours, waterways and their surroundings. It can also be particularly useful in differentiating periods of stabilization (stable land surfaces such as harbour bottoms). These stabilisation surfaces can correspond with harbour floor sediments accumulated over relatively short periods of time during particularly active periods of detritus deposition associated with heavy harbour traffic.

Magnetic susceptibility measurements were carried out using the Bartington magnetic susceptibility meter MS2 with a sensor B (single sample dual frequency sensor) at the Oxford Brookes Sedimentology Laboratory (Fig. 3.13). The sensitive high-frequency measurements were made at an amplitude of 0.1 in small plastic pots. The size of each sample was approximately 10 cm^3 and the weight varied between 5–13 g. Samples were dried at 40° C for 15 h, then gently disaggregated in a glass pyrex dish using a rubber plug. High-frequency measurements allowed for the detection of very fine ferromagnetic minerals. This is a standard technique for laboratory analyses of archaeological sediment samples and is simple, fast and non-destructive.

3.3.1.3. Loss-on-ignition (LOI)

Loss on ignition (LOI) is a technique of burning off particular components of a sample (i.e. its organic matter or carbonate content) and weighing the loss in its mass. It is used in archaeological science to estimate the total organic matter and carbonate content of sediment samples (Heiri et al. 2001). Both components can form part of the pedogenic (soil formation and evolution) processes, and can be introduced by anthropogenic factors. Therefore, the loss-on-ignition technique is extremely useful in understanding the depositional character of the study area.

Relative changes of LOI parameters throughout a sequence are regarded as useful in interpreting the impact of changing climatic conditions on different biogeochemical processes (Dean 1974; Heiri et al. 2001; Veres 2002; Santisteban et al. 2004), and show relative precision as well as direct correlation with other methods of analysis. The method generates interesting results in the study of ancient harbour deposits, as well as highly active littoral environments (like those in Berenike) and allows for an estimate of whether sediment was formed in, for example, a marshy area, an intertidal environment, or was a part of a dune.

Samples were analysed in the Geomorphology Laboratory at the University of Oxford and Oxford Brookes University Sedimentology Laboratory. All specimens were placed in rectangular ceramic crucibles of regular size (5 cm length x 1 cm width x 0.5 cm height) and similar wall width (1 mm at the sides and 2 mm at the bottom), which were carefully cleaned and weighed with a precision balance (0.0001 gr accuracy) (Fig. 3.14).

Samples were first dried in an oven at 105° C to drive off all moisture, and were then weighed again, obtaining the moisture content loss (Fig. 3.15). Dry samples were disaggregated and carefully placed in ceramic crucibles of known weight, and weighed to calculate the sediment weight. They were then placed in a furnace and subjected to an initial burn at 550° C for 4 h to drive off organic matter (Fig. 3.16). The total loss of organic matter was then measured with a balance. A second burn at 950° C for 2 h removed the carbon dioxide from the sediment allowing for a figure of the total loss of carbonate content to be calculated,

Factors such as sample size, exposure time, the position of the sample in the furnace and the laboratory measurements were taken into consideration whilst carrying out LOI measurements (Heiri et al. 2001: 101). All measurements were taken to ensure that the procedure met the highest scientific standards. An experiment was performed in which 15 samples were burned three times in different conditions and in different furnaces to compare results and assess the possible error which position in the furnace (e.g. slightly lower or higher temperatures). The resulting differences in values were shown to be very insignificant proving that one analysis was sufficient for the full set.

3.3.2. Radiocarbon dating

Radiocarbon dating analyses have been carried on a number of samples retrieved from geological sediments. Their significance lay in the strong affinity with what is believd to be one of the levels of the harbour floor and a Ptolemaic beach. Three charcoal samples (AH17b, AH17c and AH19) and one bark sample (AH16) were prepared by Dr Mike Dee and the author according with the Oxford Radiocarbon Accelerator Unit's routine pre-treatment procedures (Brock et al. 2010). The first three steps were identical for both material types, involving dissolution in acid (HCl, 1 M, 80° C, 20 min), base (NaOH, 0.2 M, 80° C, 20 min), and acid (HCl, 1 M, 80° C, 20 min).

A final oxidation step was then employed in order to extract the holocellulose fraction from the wood samples (acidified NaClO2, 0-5%, 20-80° C, 20 min). The extracts for all four samples were freeze-dried overnight. Approximately 3–4 mg of each extract was subsequently combusted in an elemental analyser coupled to a mass spectrometer, which measured the $\delta^{13}C$ value. The CO_2

produced was collected cryogenically, graphitised and dated at Oxford's Accelerator Mass Spectrometer facility (see Bronk Ramsey et al. 2004).

3.4. DATA INTERROGATION AND PRESENTATION

Analyses of the data were performed using C2 software, used for the analysis and visualisation of ecological and palaeoenvironmental data and developed by Dr Stephen Juggins at the University of Newcastle, UK (Juggins 2007). This software allows for the graphical representation of the different proxies and parameters derived from laboratory analysis. Datasets displayed on the X-axis include median grain size (μm); sand, silt and clay contents (%); magnetic susceptibility value; total loss of organic mater and total loss of carbonate content (%). The Y-axis shows the depth of the augerhole or section (in cm at 5 cm intervals).

In order to correlate sedimentation phases in adjacent augerholes or across transects, groups of sediments were phased using the C2 program, providing information that was used to model sub-surface topographies. These are displayed as continuous sub-surface composite sections, or transects. The potential locations of these transects were originally planned using Google Earth, with the GPS points fed into a hand-held GPS and cross-referenced during the fieldwork stage. The final locations of transects and augerholes established and recorded in the field were then fed into ArcGIS 10 software to create transect location maps.

The data generated from the augerholes are presented as sub-surface composite sections. These sections comprise schematic representations of the stratigraphy encountered and are interpolated relative to the depth and distance between each augerhole. Extents of different environmental and/or landscape zones are delineated on top of each transect. Suspected sediments are correlated through analyses of interface depth data and when they represent the same depositional environments they are linked together to create sub-surface topography (or buried surfaces). All of the transects were drawn in Adobe Illustrator.

4. RESULTS AND INTERPRETATIONS

This chapter presents the results of the geoarchaeological augerhole survey work in Berenike and is divided into six major parts. The results of the sub-surface stratigraphy and buried topography analyses are presented first in order to generate the palaeotopography and palaeolandscape of the site. This is followed by the interpretations of the Facies and Groups identified in the augerhole sequences. The radiocarbon dates are then presented and discussed. The two concluding sections provide interpretations of transects and the overall stratigraphic sequence. Detailed transect and augerhole descriptions are presented in Appendix 1, and the raw data in Appendix 2.

4.1. OBJECTIVES OF AUGERHOLE SURVEYS

The augerhole surveys carried out in Berenike were designed to develop a better understanding and appreciation of the landscape setting of this ancient port through the study of sub-surface sediments and their vertical stratigraphy (Fig. 4.1). This component of the research was designed to situate the site within the dynamics of the local landscape whilst complementing on-going archaeological excavations.

The overarching aims of these augering campaigns were to: 1) try to locate the southern Ptolemaic and early Roman harbour basin of Berenike, and to establish whether the assumed 'northern anchorage' actually existed; 2) establish where the late Roman port would be located; 3) delineate the boundaries and spatial extent of this/these ancient harbour/s; 4) demarcate its shape, size, depth and aspect (including understanding RSL change); 5) understand the sedimentological history of this area, and use the changes in sediment delivery to the site as a proxy for studying environmental changes in Berenike.

Another objective of the 2011 augerhole survey was to tie in the sediments recorded in these transects to archaeological layers already recorded in particular trenches (see Figs. 1.8, 1.14 and 1.16) such as:

i. BE09-55 (AH4) located on top of the Crescent-shaped Ridge (CSR) in its southwestern part (Rądkowska 2011);
ii. BE11-71 (AH17 and AH18) located at the bottom of the slope of the CSR to its east and at the western edge of the 'embayment';
iii. the Ptolemaic Industrial Zone (PIZ) outside the harbour (AH1) and west from the CSR;
iv. the remains of the late Roman town (AH48–51) situated on an uplifted coral ridge overlooking the 'embayment'; and finally
v. what is thought to be the ancient lagoon (AH36, AH37) to understand the breadth of processes that have been at work since its infilling.

4.2. BRIEF DESCRIPTIONS OF SUB-SURFACE STRATIGRAPHY AND BURIED TOPOGRAPHY

For a better understanding of the sub-surface stratigraphy across the site, and for the convenience of the reader, descriptions of the sedimentological units (Facies) recorded across all of the transects are displayed in brief in Table 4.1 (BE11) and Table 4.2 (BE12) below, and are followed by detailed descriptions and interpretations. Included, at this stage, are the interpretations based on field descriptions of the sediments (i.e. colour, texture composition, compaction, sorting, inclusions) and further laboratory analyses. Groups are presented in Table 4.3 below.

Table 4.1 BE11 sedimentological Facies field descriptions and interpretations.

Facies BE11	Field description	Field interpretation	Occurs in	Group
A	Orange brown, oxidised, loose, very poorly-sorted, coarse sand	Modern dune sand	AH1, 2, 4–21, 25, 26, 29, 30, 42, 43, 48, 51	I
B	Light grey to light brownish-grey, loose, poorly sorted, fine to medium silty sand with salt	Relict *sabkha* surface	AH4, 11, 14, 16–18, 42–45, 51, 53-54	VI
C	Brown, loose to friable, poorly sorted, medium silty sands with marine inclusions	Beach sands at the margins of *sabkha*	AH4?, 16–20, 44–45	VII
D	Light grey to brownish-grey, extremely friable but moderately compact, homogenous but very-poorly sorted, laminated, medium to coarse sands and fine silty sands	Terrestrial windblown sand intermixed with anthropogenic detritus and occasional colluvium	AH5?, 16–18, 20	III

Facies BE11	Field description	Field interpretation	Occurs in	Group
E and E[1]	Dark to rusty brown, densely packed and slightly compacted, organic silty sand	Early Ptolemaic (?) layer with burnt and water-abraded pottery and hearths	AH5?, 6?, 7–14, 16, 17?, 18–20, 39–41, 46–47	II
F	Greenish, compacted, pure, homogenous, well-sorted, clay	Flood event and water pooling	AH17, 18, 21	V
G	Dark olive brown/very dark grey to black, loose/friable to waterlogged, fine to medium silty sand	Inter-tidal zone, intermittent inundation	AH7–13, 16–20, 39–41, 46, 47, 53	VIII
H	Dark grey to very dark grey, waterlogged, medium to fine silty sands often fining upwards	Inter-tidal environment with backwater influences	AH9–11, 13, 16, 18, 39, 40, 46	VIII
I	Very dark grey to black (or bluish-black), waterlogged, fine silty sands	Backwater/lagoonal environment	AH10, 16, 18, 40, 41	IX
J	Yellowish, loose, very clean and homogenous, well-sorted, medium to fine sand	Modern intertidal sands and interstratified fines	AH23, 36	I
K	Dark grey to yellowish, clean and homogenous, well-sorted, medium sand	Beach sands	AH21–23, 33, 34, 36	VII
L	Dark greyish-brown, waterlogged, medium sands	Marine sands (moderate to deep water depth)	AH36, 37	X
M	Dark blackish and light yellowish, interstratified and laminated layers, well-sorted, fine to medium sand	Laminated dark and light beach deposits	AH10, 11, 16–18	VIII
N	White, moderately compressed and friable, very well-sorted, clean and homogenous, chalky calcareous layer of silt with clay	Evaporitic calcareous/gypsiferous surface	AH33, 34, 38–41, 46, 48	VI
O	Light grey, loose and calcareous, clean and homogenous, fine sand with some silt and high content of heavier minerals (black manganese grains)	Calcareous fine aeolian sand possibly with marine influences	AH9, 10, 12–15, 19, 20, 25–30, 41, 46, 48	VI

Facies BE11	Field description	Field interpretation	Occurs in	Group
P	Dark greyish- to olive-brown or light grey, poorly-sorted, fine to coarse silty sand	Relic land surface with aeolian and colluvial influence and occasional wadi influx	AH4?, 8–14, 41–43, 46, 51–54	III
R	Dark greyish-brown, loose to friable, medium sand	Mixed transitional layer	AH38–41, 46, 47, 51	III
S	Light olive to light yellowish-brown, loose, poorly-sorted, medium to coarse sand with shells	Relic land surface with notable marine activity	AH12, 47	II
T	Pale olive colour, loose but friable and brittle, highly oxidised, coarse sand	Marginal *sabkha*-wadi interface	AH53	IV
U	Light to olive brown, very loose, fine sand with coarser grains inclusions	Modern dune/aeolian deposition	AH29, 31–33	I
V	Very pale brown to light yellowish-brown, loose, fine to medium silty sand with some clay	Sub-recent windblown	AH1	I
W	Pale brown, organic, medium to fine silty sands	Modern colluvium	AH1	I
AA-AM		Archaeological layers	AH2–6, 42, 43, 49, 50	II

Table 4.2 BE12 sedimentological Facies field descriptions and interpretations.

Facies BE12	Field description	Field interpretation	Occurs in	Group
A²	Greyish, poorly-sorted, compressed but friable to loose, calcareous, fine silty material with coarse quartz inclusions	Modern windblown	AH1–10, 12 –15, 18–20	I
B²	Olive brown, consolidated but friable, poorly-sorted, medium silty sand	Colluvium and sporadic exploited land surface	AH1–7, 10, 12–14, 19, 20	III
C²	Olive brown, compressed but friable, organic and ironised, medium silty sand	Ferruginous transitional	AH1–3, 6, 14–17	IV

Facies BE11	Field description	Field interpretation	Occurs in	Group
D^2	Dark greyish to brownish, dense, fine to medium silty sand	Shallow marine/inter-tidal *sabkha*	AH1, 2, 6–7, 12–17, 20	VIII
E^2	Dark greyish-brown, waterlogged, very fine to fine sandy silt	Moderate depth marine anaerobic	AH1–3, 6, 7, 12–15, 19-20	X
F^2	Black, waterlogged, fine sandy silt	Deeper marine anaerobic	AH1–3, 7, 12, 13, 15, 19-20	XI
G^2	Greyish, loose to friable, poorly-sorted, silty material frequent gravel, broken shells and very occasional calcified granules	Transitional silty colluvium	AH7, 19, 20	III
H^2	Reddish-brown, ironised layer of very organic silty sand	Ferruginous wadi material	AH3, 6, 13, 14	IV
I^2	Pure white, compressed but loose, clean and homogenous, very organic medium sand	Modern beach sand	AH16	VII
J^2	Grey, dense, fine sand	Distal wadi sands (channel marginal?)	AH16, 17	IV
K^2	Greyish-green to blackish green, sandy silt with clay	Anaerobic environment with large shells	AH16, 17	X
L^2	White to light grey, clean and homogenous, clayey and silty sand with shells	Limey silt/offshore shallow lagoon	AH16, 17	IX
M^2	Reddish-brown, iron-rich, ferruginous silty sand with clay lenses and with mica inclusions	Inwashed wadi material with ferruginous clay and mica	AH3	IV

4.3. INTERPRETATION OF THE SUB-SURFACE STRATIGRAPHIC SEQUENCE

The results of the augerhole survey, including field observations and laboratory analyses, have enabled each of the facies to be interpreted in terms of changes in the environment at the site. The section below provides an interpretation of the results shown above, with each Facies representing a distinct depositional environment.

4.3.1. Facies interpretations

To facilitate the description and interpretation of the wide range of sedimentological units recorded during the drilling of transects, units that indicate similar environments of deposition have been grouped together into facies. These facies are interpreted below on the basis of their presence in one or more augerholes recorded during the two successive seasons of geoarchaeological work at Berenike. The first part in each facies description contains field observations and sediment characteristics, whilst the second briefly summarises key laboratory results and interpretations.

4.3.1.1. Southeastern 'embayment' (2011 campaign)

Facies A: ***Modern dune sand***

Facies A is formed of laterally extensive, orange-brown, oxidised, loose, very poorly-sorted coarse sands. It is the uppermost, disturbed, recent to sub-recent land surface material, probably mixed with colluvium. This unit comprises windblown sand, although the poor sorting suggests that this material has been reworked and remobilised to some extent. The poor sorting indicates a former land surface subject to aeolian processes as well as trampling and erosion.

Facies B: ***Relict sabkha surface***

A light grey/light brownish grey, loose, poorly sorted fine to medium silty sands form Facies B. It is occasionally calcareous in character and with inclusions of evaporated salt crystals, patches or lenses, and comprises locally a very compacted salt layer with a thickness of 8–10 cm. Coarser inclusions are sometimes present, including occasional broken shells, gypsum nodules and archaeological material. There is a direct relationship between an increase in grain size and total organic matter (up to 10%) and carbonates of (~3%).

Facies B represents a combination of minerogenic sand and salt evaporates (Fig. 4.2) that probably reflect groundwater leaching of salt by capillary action up through the sequence. This large flat area represents a low-lying infilled coastal embayment that still has a strong connection to the sub-surface marine environment, and is therefore in places still linked to tidal changes. Salt locked in the sub-surface infilled sediments can be brought to the surface by capillary action or by tidal rises.

Facies C: ***Beach sands at the margins of sabkha***

Facies C consists of a brown, loose to friable (but occasionally compact in some areas), poorly-sorted, medium silty sands with occasional gravel. Inclusions of heavier and darker minerals such as manganese, moderate frequencies of coral and shell fragments, occasional intact shells, and archaeological material occur higher up in the sequence. Occasional inclusions of white (calcareous?) granules (chalk?), but no sign of sub-aerial weathering (oxidation) were observed. An inverse relationship is visible between the increase of magnetic susceptibility (MS) values and the decrease of total organic and carbonate matter, along with a slight increase in grain size. Coarse components and the presence of heavy minerals suggest an inter-tidal zone that was probably inundated for a significant period of time. Human activity may have taken place around the edge of this marginal area.

Facies D: ***Terrestrial windblown sand intermixed with anthropogenic detritus and occasional colluvium***

Facies D (Fig. 4.3) comprises thick beds of a light grey to brownish grey, very loose but stratified with compact layers, medium to coarse sands. Extremely friable, and only moderately compact, it is a homogenous deposit that is very poorly sorted and laminated. It contains fine silty sands, to coarser, lenses of sand-sized material. Inclusions of moderate frequencies of coral and shell fragments (anthropogenic detritus), and occasional archaeological material are encountered higher up in the sequence. Very distinct and abrupt upper and lower interfaces can be observed.

Large grain sizes indicate a higher-energy environment, and sorting suggests a littoral zone with marginal sedimentation. Shell and coral fragments indicate a beach facies, with interstratified compact layers indicative of intertidal action within a wetting and drying zone. The finer, oxidised layers interstratified within the sequence may indicate recurring drier intervals with a greater input of aeolian particles, hence the oxidised fine dune-like sands. A sudden decrease in MS values and total organic matter, as well as a pronounced increase in silts (in AH20) may reflect a shift to landscape instability and the winnowing out of magnetic minerals. This landscape instability could be the reason why anthropogenic material is rarely found in this unit. However, in the western part of Trench BE11-71, a poorly preserved early Ptolemaic coin has been uncovered, tentatively dating this facies.

Facies E and E[1]: ***Early Ptolemaic (?) layer with burnt and water-abraded pottery and hearths***

Facies E consists of a very distinct dark (rusty) brown layer of organic silty sands and densely-packed, chemically-weathered, water-abraded and fragmented pottery with occasional inclusions of shell and gravel. In AH18 abundant Hellenistic pottery (Roberta Tomber, pers. comm. 2011–2012) was located directly above thin patches of oxidised, reddish to pinkish, baked clay. The MS value increases at the very bottom of this layer pointing towards some level of stabilisation. The fine component grain size is in an inverse relationship with high but decreasing, organic (6% maximum) and carbonate (15% maximum) contents occurring due to the baked character of this deposit.

This deposit, in its water-abraded form, is found across the site confirming a widespread horizon of archaeological importance with broken and dissolved pottery in the bay. Samples obtained from features recorded in AH17 and AH18, presumably anthropogenic in origin, and most likely hearths or fireplaces, were not water-abraded and contained charcoal. This material was subsampled and extracted from the sediments under laboratory conditions, and dated using radiocarbon dating techniques (see Section 4.4 for results).

The results confirmed expectations based on field observations, and from the dating of the pottery, that these levels were contemporary with the first phase of habitation of the site in the Ptolemaic era. They also proved to be invaluable for understanding the chronology of local landscape change. After calibration and Bayesian modelling these dates fall between 390–205 and 386–204 cal BCE (Section 4.5).

Facies F: ***Flood event and water pooling***

The greenish, well compacted, pure, homogenous clay deposits that comprise Facies F shows a strong correlation with modern analogue samples of basal deposits present in the modern-day lagoon and uncovered in transect BE12-T04. Composed almost entirely of fine-grained sediments (65% silt, 10% clay) this sediment gives almost no MS signal but it does exhibit a high organic (~10%) and carbonate (~30%) content.

This very fine-grained unit was deposited in an extremely low-energy environment that settled out of suspension in either very slow moving or still water. Owing to its location on higher ground, often covering beach facies, this appears to represent a flood deposit with sediment settling out of pooled water.

Facies G: ***Inter-tidal zone, intermittent inundation***

A dark olive brown/very dark grey to black, loose, fine to medium sands with abundant heavy minerals including manganese forms Facies G. A higher concentration of fine-grained silts and clays (maximum 35% silt, 4.5% clay) correlated with occasional inclusions of abraded pebbles. The samples from the Facies G had moderate to high (~30 m^3kg^{-1}) MS signal with low total organic and carbonate content.

These characteristics are consistent with a move to a higher energy environment, possibly related to a stronger link with either a shallow marine or fluvial (*wadi*) system. The olive grey colouration (Fig. 4.4), evidence of oxidiation, and the presence of frequent grains of heavier minerals (primarily manganese) together confirm a shift to a tidally influenced environment. This area is now situated in the inter-tidal zone where wave action preferentially winnows and separates light grains (e.g. quartz) from heavier minerals such as manganese.

The presence of silt and small quantities of clay indicates occasional deeper water. Facies G is a marginal environment in the inter-tidal zone. A sharp rise visible in the total organic matter is also consistent with this interpretation. The pronounced spikes and troughs in the grain size data suggest cycles of increased energy. This probably relates to the location of some augerholes closer to the coastline and so in a marginal area prone to inundation and slight shifts in the sea level, or in response to subtle switches in coastal sedimentation/progradation. Sharp increases in silt and clay contents, however, indicate that the water body did exist at various points during the deposition of Facies G, although the general trend was shifted towards a progressive draining of the lagoon/backwater area as the sea level dropped or the coast prograded.

Facies H: ***Inter-tidal environment with backwater influences***

Facies H represents dark grey to very dark grey, waterlogged, medium, silty sands that often fine upwards. Inclusions consist of abundant heavy minerals such as manganese and occasional abraded pebbles and stones. The MS is moderate to low, along with low organic and carbonate values.

Facies H was deposited in a low-energy environment, but with some pulses of higher energy. Heavy minerals are consistent with an inter-tidal environment. A dark colouration (Fig. 4.5) suggests an anaerobic environment of deposition. Although the sedimentological data did not exhibit any marked variations, the trend to a finer grain size and a slight reduction of silt in the upper levels may indicate a lowering of water level and an input of fine aeolian sand to the water body. Fining up at the top of the sequence could, therefore, suggest a reduction in energy as clay and silt particles settled out of suspension in a very low-energy environment.

This facies relates to the presence of a body of slow moving or still water in close proximity to the coast, with a reasonable water-depth, such as a backwater lagoon. A slight reduction of water depth may indicate a lowering of the RSL and the occasional erosional event introducing coarser material to the margins of the water body.

Facies I: *Backwater/lagoonal environment*

The sediments in this facies comprise very dark grey to black (or bluish black), waterlogged, fine silty sands with inclusions of water-abraded pebbles. Moderate MS values were observed throughout, and organic and carbonate values were generally low. The relatively high silt content indicates a low-energy environment with fine-grained silts and fine sand settling out of suspension, and with occasional inclusions of water-abraded pebbles. Some occasional introduction of coarser material, probably by erosion, has been noted.

These characteristics, along with the fine-grained nature and dark grey colouration of the sediments, suggest a marine proximal, backwater/lagoonal environment. The very dark colouration indicates anaerobic conditions in a deep-water scenario (reduced free oxygen), symptomatic of a moderate to great water depth. An up-core decrease in MS may indicate an overall decrease in landscape stability through time. This facies represents deposition in a backwater lagoon environment linked closely to the marine environment.

Facies J: ***Modern intertidal sands and interstratified fines***

Facies J comprises a yellowish, loose, very clean and homogenous, well-sorted medium to fine, wet sands (Fig. 4.6) with clay and fine silt lenses. Modern to sub-recent marine sand in this facies is associated with medium energy sedimentation within the inter-tidal zone. Lenses of fine-grained clays and fine silts relate to the pooling of water in localised depressions in the inter-tidal zone, and the settling out of fine particles presumably during low tide (compare with Fig. 4.7).

Facies K: ***Beach sands***

Facies K is a dark grey to yellowish, well-sorted, clean and homogeneous layer of medium to coarse beach sands with minor silts and clays content. High MS appears in contrast with low total organic and carbonate content. Facies K represents recent beach sand deposition extending over a large area both landwards and parallel to the coast.

The dark colouration most likely relates to both the influx of heavy minerals such as manganese as well as the anaerobic conditions associated with a considerable water-depth at this time. High values in MS reflect the enrichment in heavy minerals in these sediments. This is a relatively high-energy environment, but with additions of fines during very high or very low tides. It can be compared to the contemporary beaches in Berenike such as those on Figures 4.8 and 4.9.

Facies L: ***Marine sands (moderate to deep water depth)***

The dark greyish-brown, waterlogged, medium sands of Facies L (Fig. 4.10) have a lower MS value relative to Facies K, perhaps suggesting a less dynamic environment. Given the greater depth of this facies, it appears to have been deposited in the low water zone and therefore often submerged beneath shallow- to moderate- water depths in an area where agitation or erosion of the sands is not so prevalent. Total organic and carbonate values are very low.

Facies M: ***Laminated dark and light beach deposits***

Facies M was made up of interstratified and laminated layers of dark blackish and light yellowish, well-sorted, fine to medium sands (Figs. 4.11 and 4.12). A decrease in MS value is observed upwards, while organic content (albeit low overall) increases. Carbonates are essentially absent in these layers.

The medium sands of Facies M are indicative of a moderate to high-energy environment, with an almost total absence of silts and clays reflecting the winnowing away of this fine material. The light-dark laminations (Fig. 4.13) indicate a marginal environment, presumably the inter-tidal zone, given its location within the coastal topography (Fig. 4.14). It is likely that the elevation of this beach sand, ~1 m higher than median tide, shows that sea levels immediately prior to the 3rd century BCE were higher than those experienced today (Section 5.1.1). The marginal environment, probably only inundated at high tide, was slowly opening up to human exploitation at this time, which is evidenced by the hearths uncovered in association with Facies E^1.

Facies N: ***Evaporitic calcareous/gypsiferous surface***

The exposed surface layer of Facies N comprises white, moderately compressed and friable, very well-sorted, calcareous sandy silts with ~6% clay content. This deposit is made of very fine fractions and forms a level, semi-consolidated surface. Low MS values are in inversely related with the high organic content.

Facies N covers, with a compact calcareous surface, most of the area of the plateau around the 'island' in an 'infilled embayment' of the Central Zone. Similar to deeper buried horizons observed in AH19, 20 and 46. This deposit is enigmatic in terms of its possible natural or anthropogenic origin. If the former, this may relate to a calcareous marine silt that could have formed at the margins of the island. Alternatively it may be of anthropogenic origin either from the dissolution of the limestone walls of abandoned buildings or some sort of a chalky floor laid down to protect them.

Facies O: ***Calcareous fine aeolian sand possibly with marine influences***

A light grey layer of loose and calcareous, clean and homogenous, fine sands with some silts forms Facies O. It also has a high content of heavy minerals (e.g. black manganese grains), intermixed with yellow and red mineral grains (Fig. 4.15). Facies O represents a widespread, laterally extensive sand body recorded across the site. This has probably accumulated as part of the late infilling of the lower lying land to the south of the site. The high level of sorting and the relatively fine-grained nature may indicate a primarily aeolian composition, potentially with some addition or erosion during periods of past higher sea level.

Facies P: ***Relic land surface with aeolian and colluvial influence and occasional wadi influx***

A mixed layer comprising dark greyish to olive brown or light grey, poorly-sorted, fine to coarse silty sands (20–30% silt). Inclusions of frequent fine grains of heavier dark minerals and oxidised quartz grains can be seen on Figure 4.16 and were observed along with occasional gravel and organic material (approximately 6–10%) such as charcoal. Decrease in MS signal, and in the quantity of fine grains can be observed along with an increase in carbonate content.

This upper facies represents one of the final sedimentary accumulations following the infilling of the main basins around the site. Its poorly sorted character implies a mixed origin, probably a land surface that has an input of aeolian and colluvial material. Occasional gravel stringers and lenses may suggest input from the fluvial (wadi) system. It is likely that this facies has accumulated over a prolonged period of time, and would have most likely acted as a surface upon which human activity (at a background level) was carried out.

Facies R: ***Mixed transitional layer***

Facies R is a layer of dark greyish-brown, loose to friable, medium sands (~5–15% silt and ~2.5% clay) that displays MS values ranging from 12–15 m^3kg^{-1} and has a moderate organic content (9–6%). This transitional phase would have occurred during the move from archaeological layers such as Facies E, which are related to human activity on the newly exposed semi-terrestrial surface, to relict land surfaces such as Facies P.

Facies S: ***Relic land surface with notable marine activity***

Facies S is a light olive to light yellowish brown, loose, poorly sorted sands. The grains are mainly medium to coarse with frequent inclusions of shell fragments and very high organic content. This enigmatic layer could represent either the inundation of a low-lying depression in the topography by distal inter-tidal sediments intermixed with windblown sediments or the result of a specific human activity such as the industrial processing of various gastropod shells for economic purposes, which were found within the matrix.

Facies T: ***Marginal sabkha-wadi interface***

Facies T is formed from a pale olive, friable and brittle, very coarse sands. This deposit has a loose compaction and is highly oxidised. Occasional inclusions of stones and pebbles are evident, especially with frequent yellowish quartz pebbles.

The oxidised sands of Facies T could have a polygenetic origin, with sand introduced from the wadi system to the east (the channel connecting the wadi system to the Berenike basin area) and by the margins of the *sabkha* basin to the southeast. The coarse clastic component almost certainly derives from pulses of wadi activity, debouching material out on to the margins of the *sabkha*.

Facies U: ***Modern dune/aeolian deposition***

Facies U consists of a light to olive brown, very loose, fine sands mixed in with coarser sand. It contains inclusions of orangey oxidised particles along with very fine manganese grains. Facies U is an oxidised, semi-terrestrial sand deposited in the upper part of the sequence on high ground around the edge of the temple island. Much of the fine sand is probably windblown, with some minor reworking of coarser beach facies. Oxidisation shows that sub-aerial weathering plays a significant role in its character.

Facies V: ***Sub-recent windblown***

Facies V is a very pale brown to light yellowish brown, loose deposit of fine to medium silty sands with ~4–6% clay. Increases in MS, relative to previous underlying facies, are recorded attaining 5–10 m^3kg^{-1}. Carbonate content is very high ranging from 11 to 18%, whilst the organic content remains level at ~5.5%. This facies represents recent to sub-recent windblown calcareous sands that accumulated at the base of the landwards side of the CSR. The calcareous nature of these sands may reflect *in-situ* or proximal weathering of the coral substrate that makes up the nucleus of the ridge.

Facies W: ***Modern colluvium***

Facies W consists of pale brown, organic, medium to fine silty sands (~15% silt) with low (~1–1.5%) clay content. This poorly sorted facies represents colluvial sedimentation downslope on the landward side of the CSR. MS values rise towards the upper part of this facies, most likely reflect the increasing stability of this area just outside the confines of the site. The total organic value is higher at the base (7%), consequently dropping down to ~5%. Carbonate content is low, averaging ~2% at the surface.

Facies AA–AM: ***Archaeological deposits***

These facies represents mixed deposits of anthropogenic origin and therefore will not be discussed here.

4.3.1.2. Northern 'anchorage' (2012 campaign)

Facies A^2: ***Modern windblown***

This Facies A^2 (Fig. 4.17) comprises a pale greyish, poorly-sorted material that is compressed but friable to loose and calcareous. It is fine in texture and silt-rich, intermixed with coarse quartz grains and displays a high frequency of heavier manganese grains. The windblown, weakly calcareous, sands are consistent with deposition in contemporary climatic and topographic conditions. The aeolian material is the product primarily of eroded material from the mountains.

Facies B^2: ***Colluvium and sporadic exploited land surface***

This deposit is made up of olive brown, consolidated but friable, medium silty sands (Fig. 4.18). It is poorly sorted, containing frequent inclusions of heavy minerals (e.g. manganese), very occasional chalk fragments and some limited archaeological material. This thick, laterally extensive layer could represent long-term stability as a land surface with the background accumulation of colluvial sediments. Human activity would have taken place on surfaces formed within this facies.

Facies C^2: ***Ferruginous transitional***

Facies C^2 is an olive brown, compressed but friable, organic and ironised deposit of medium silty sands with a high (10%) organic content and a large quantity of heavier mineral inclusions (Fig. 4.19). This sediment most likely originates in the mountains to the west and north, being washed out to the coast by the wadi system. Occurrences of this facies are at the southern edge of the Abu Greyah wadi system. This erosional phase might be correlated with slightly wetter and warmer climatic conditions, though the lack of a high-resolution chronology precludes any correlation with known climatic events.

Facies D^2: ***Shallow marine/inter-tidal sabkha***

Facies D^2 is made of dark greyish to brownish, dense, fine to medium silty sands with microfauna preserved as calcified lumps (Fig. 4.20). These sands indicate deposition in a moderate-energy environment, most likely when sea levels were higher than today. At this time the sea would have regularly inundated the low-lying area to the north of the high ground, on which Berenike was situated, with shallow water. The clayey lenses are consistent with the pooling of water and oxidisation caused by sub-aerial weathering.

Facies E^2: ***Moderate depth marine anaerobic***

Facies E^2 is a dark greyish-brown, waterlogged, very fine to fine deposit of sandy silts with very low MS (~2 m^3kg^{-1}) and moderate organic matter (5%) and carbonate contents (~10–12%) forms Facies E^2. This fine sediment has been deposited in a relatively low-energy environment in which there is limited free oxygen resulting in highly anaerobic conditions. Given its stratigraphic context and sedimentological characteristics (Fig. 4.21), this facies can be associated with depositional processes occurring in a moderate depth marine environment. The high carbonate values reflect the introduction of calcareous marine organisms (i.e. calcite shells) to the sub-marine environment.

Facies F^2: ***Deeper marine anaerobic***

Facies F^2 consists of black, waterlogged fine sandy silts with low MS values, high levels of organic matter and a high carbonate content (similar to Facies E^2). The fine composition and dark colouration of Facies F^2 (Fig. 4.22) indicates a reduction in free oxygen relative to the overlying Facies E^2. This is consistent with a deeper-water marine environment.

Facies G^2: ***Transitional silty colluvium***

Facies G^2 comprises greyish, loose to friable, poorly-sorted silts with frequent gravel, broken shells and calcareous granules/nodules. Facies G^2 is located on the downslope area at the northwestern margins of the high ground and as such accumulated as lowering sea level exposed the lower fringes of the high ground. Subsequent colluvial processes have resulted in a mix of material accumulating at the base of the slope.

Facies H^2: ***Ferruginous wadi material***

Facies H^2 is a reddish brown, iron-rich, organic silty sands layer. It possibly formed over the sandbank that is still visible in current topography (in the vicinity of BE12-AH14), which blocked access to the small embayment inside. The material may have been deposited by local wadi activity (most probably from the Wadi Abu Greyah from the northwest), as a part of the braided alluvial wadi fan system that is still visible around the site. The ferruginous character relates to prolonged sub-aerial weathering.

Facies I^2: ***Modern beach sand***

A pure white, compressed but loose, clean and homogenous, very organic layer of medium beach sands was distinguished as Facies I^2. It showed a very low MS but highly organic character (>25%) and low (~3.5% carbonate content) that correlates with the modern beach sand.

Facies J^2: ***Distal wadi sands (channel marginal?)***

The grey, dense, fine sands of Facies J^2 display high MS (~22 m^3kg^{-1}) values and low organic (~2.5%) and moderate carbonate (~5%) contents. This material, seen in the northern part of the 'Northern Anchorage', most probably relates to sub-recent wadi activity. High levels of MS likely reflect the input of mineral-rich sediments from the mountains to the west.

Facies K^2: ***Anaerobic environment with large shells***

Facies K^2 is a greyish green to blackish green deposit. It comprises 55% of sandy silts with ~10% clay, has very low MS and a downward increasing carbonate content (~10–15%). Facies K^2 is essentially the seaward extension of Facies E^2, deposited in moderately deep water in the near offshore environment. Inclusions of large shells (probably *Murex*) in this facies differentiate it from Facies E^2 and indicate the proximity to the marine environment.

Facies L^2: *Limey silt/offshore shallow lagoon*

Facies L^2 is a white to light greyish layer of clean clayey and silty sands with inclusions of large shells. This calcareous silt consists of ~30% carbonate content and ~10% organic matter, with a negligible MS signal. This layer is similar to that described below in the context of transect BE12-T04, which was cored in a lagoon to obtain modern analogue samples. Facies L^2 is a highly distinct and unusual sedimentary unit, comprising of very pale and homogeneous material with a high calcium carbonate content. The fine composition and the light colouration suggests low-energy sedimentation in a relatively shallow environment, maybe as an offshore shallow lagoon that was present at some time prior to the main sequence in this part of the site.

Facies M^2: ***Inwashed wadi material with ferruginous clay and mica***

Facies M^2 consists of a reddish brown, iron-rich, ferruginous silty sands with clay lenses and mica inclusions (Fig. 4.23). It is unusual at Berenike, made of inwashed ferruginous sands and very frequent inclusions of other heavier minerals. This oxidised material is brought in by local wadi valleys – the reddish colour indicating extreme weathering as material is slowly washed across the coastal plain from the mountains. Fine clayey lenses indicate the pooling of water, probably as it subsided after peak flows.

4.3.2. Groups (of Facies) interpretations

For the ease of interpretation of the sequence, corresponding facies have been categorised into groups that are briefly described and named in Table 4.3 below (the colour code on the transects in Figs. 4.31 and 4.34–4.41 below is included in the table).

Table 4.3 Groups of facies and their descriptions.

Group	Name	Description	Includes facies	Colour code
I	**MODERN (NATURAL)**	Group I represents the most recent period of sedimentation at the site and its environs. These processes may be on-going, relating primarily to windblown sedimentation, but with exposures of colluvial sequences in some areas.	A: dune sand J: inter-tidal sands/fines U: modern dune W: colluvium V: dune sand A^{2}: modern windblown	yellow
II	**ARCHAEOLOGICAL LEVELS**	Direct evidence for human exploitation of the landscape and the port city contained within facies of Group II.	E: pottery layer (water abraded) E^{1}: burnt pottery and hearths AA–AM: archaeological layers	red
III	**EXPOSED STABLE LAND SURFACE (OCCASIONAL BACKGROUND ARCHAEOLOGICAL SIGNAL)**	The facies of Group III are likely to be broadly equivalent chronologically with the archaeological levels. These facies represent periods of stability, with gradually accreting land surfaces. This group acts as a part of the landscape surrounding Berenike, but not necessarily as part of the archaeological landscape of the city.	D: terrestrial windblown sand mixed with anthropogenic and colluvial P: wadi influx but transitional R: mixed transitional B^{2}: colluvium and sporadic human activity G^{2}: silty colluvium on margins of high ground	light green
IV	**FLUVIAL (WADI SYSTEMS, MARGINAL AND PROXIMAL)**	The facies in Group IV indicate interaction with the fluvial systems in close association with the site. Three main wadi systems drain the mountain ranges to the west, and it is likely that there was variable input of these fluvial systems to the basins and low lying areas around Berenike.	T: fluvial into *sabkha* system C^{2}: ferruginous transitional H^{2}: ferruginous wadi material J^{2}: distal wadi sands M^{2}: inwashed	pink

Group	Name	Description	Includes facies	Colour code
V	**FLOOD EVENT (POOLING)**	Facies F is unusual and so demands its own category. The fine-grained sediments of this facies appear to bear witness to a time when large quantities of standing water were present at various locations on the site. It is not possible to say whether this relates to a period of higher sea level (and ultimate regression), a period of increased precipitation, or is indicative of large flash flood events. The latter is thought most likely.	F: flood event and water pooling modern analogue middle facies from BE12-T04	dark green
VI	***SABKHA* (INFILLED EMBAYMENT, GYPSIFEROUS)**	The facies of Group VI are associated with *sabkha* formation. Infilling of the low-lying areas around the site, and subsequent surface gypsum formation (via tidal or capillary action) provide large, levelled areas of potentially periodically inundated salt and gypsum flats.	B: relict *sabkha* surface N: gypsiferous surface O: calcareous fine sand	orange
VII	**BEACH FACIES (NOT INUNDATED)**	Group VII contains sediment facies that lie above the high water mark and are indicative of beach sediments. As such they are largely stable and potentially useful for human exploitation in the form of careening/beaching/landing areas. These areas are prone to marine influence and could sporadically flood during exceptionally high tides or storm surges.	C: beach sands at margins of the *sabkha* K: beach sands S: notable marine activity I^2: modern beach sand	light purple
VIII	**INTER-TIDAL (TIDALLY INUNDATED, STRATIFIED)**	The facies of Group VIII, unlike Group VII, were inundated on a regular (probably daily) basis and therefore display a much stronger marine influence. Waxing and waning of the tides often produces finely stratified sediments, such as recorded in facies of this group, which are caused by the winnowing of lighter material due to wave action.	G: inter-tidal, intermittent H: inter-tidal (backwater proximal) M: laminated beach sands D^2: shallow marine/inter-tidal *sabkha* modern analogue top facies from BE12-T04	light blue

Group	Name	Description	Includes facies	Colour code
IX	**LAGOONAL/BACKWATER (LOW-ENERGY)**	Group IX facies relate to low-energy, shallow to moderate depth deposition in a backwater or lagoonal environment. Lagoons such as these are present near the site today, close to the present day coastline.	I: backwater/lagoonal environment L^2: offshore/shallow lagoonal modern analogue bottom facies from BE12-T04	dark purple
X	**NEAR SHORE MARINE (SHALLOW)**	Facies of Group X represent sedimentation in a marine environment, close to the shore, and just outside the influence of the inter-tidal zone. The depth of the water and the lack of wave action (compared to the inter-tidal zone) mean that there is a lack of free oxygen and a closer link to the marine biological ecosystem.	L: marine sand/moderate to deep water E^2: moderate depth/anaerobic K^2: anaerobic with large shells	medium blue
XI	**OFFSHORE MARINE (MODERATE)**	Sediments of Group XI are very similar to those of Group X, but they are laid down in an even greater depth of water, slightly further offshore.	F^2: deeper marine/anaerobic	dark navy blue

4.4. RADIOCARBON DATING RESULTS

Five Accelerator Mass Spectrometer (AMS)[23] radiocarbon dates, on unidentified charcoal and bark from augered sediments from Facies E and G were obtained as described in Section 3.3.2.[24] Two dates were generated from the same charcoal sample from AH16 (Facies G), transect BE11-T01, and can therefore be averaged (OxA-24145 and OxA-24085). The uncalibrated dates are presented in radiocarbon years BP (Before Present – 1950 CE) using the half-life of ^{14}C – 5568 years. Isotopic fractionation has been corrected for by using the measured $\delta^{13}C$ values measured on the AMS. The quoted $\delta^{13}C$ values are measured independently on a stable isotope mass spectrometer (to ±0.3 per mil relative to VPDB – Vienna 'Pee Dee Belemnite' (PDB) standard for ^{13}C work) (Bronk Ramsey et al. 2002: 1–149; 2004: 17–24, 155–63).

The attached calibration plots (Figs. 4.24–4.29) show the calendar age ranges at 95.4% probability (2σ) (see also Table 4.4). These were generated using the OxCal computer program (v4.2) with the IntCal13 calibration curve (Bronk Ramsey 2009b). The calibrated dates are (slightly) improved by incorporating them in a Bayesian model (see refined results and OxCal model code in: Fig. 4.30). Overall, after the Bayesian modelling, the results seem to be in agreement (although 'passed' and 'failed' models are considered in Section 4.4.3), dating discussed layers (Facies E and G) to the Ptolemaic era.

[23] Accelerator mass spectrometry is commonly used to resolve stable nitrogen-14 from radiocarbon and determine the concentration of carbon-14 (^{14}C) for radiocarbon dating.
[24] This part of the study has been conducted thanks to and with help from Dr Mike Dee (Research Laboratory for Archaeology and History of Art, RLAHA, The University of Oxford).

It should be noted that there are three main components to radiocarbon dates obtained on charred wood and bark: (a) growth age: inner tree rings are older than bark edges; (b) storage age: the wood may have been, for example, stockpiled or used on a boat or ship for an extended period of time before its deposition; (c) the time elapsed from deposition to now. It is the latter age that is of interest, therefore it is hoped that the effects of the former two factors are insignificant. However, as this remains unknown, and the wood (and ultimately charcoal) samples from port towns such as Berenike might have been used on site in their secondary context long after they were cut down to be used as ship timbers, the ^{14}C dates will generally be regarded here as *termini post quos* (TPQs).

Table 4.4 Chart of Unmodelled and Modelled Calibrated Dates

Reference Number	Location	Material	Depth (m bgl)	^{14}C Date (BP)	^{14}C Error	$\delta^{13}C$	Unmodelled Date range (cal BCE)	Modelled Date range (cal BCE) passed test)
OxA-24144	**AH17b/18 Facies E**	Charcoal	1.84 m	2230	27	-21.5	386–204	386–204
OxA-24084	**AH17c/18 Facies E**	Charcoal	1.84 m	2239	28	-25.4	390–206	390–205
OxA-24145	**AH16 Facies G**	Wood (bark)	1.95 m	2133	26	-26.6	337–56	202–58
OxA-24085	**AH16**	Wood (bark)	1.95 m	2112	26	-27.8		
OxA-24086	**AH19**	Charcoal	1.30 m	2105	27	-28.2	197–51	200–50

4.4.1. Botanical results

The $\delta^{13}C$ stable isotope values for samples AH17c, AH16, and AH19 ranged from –25.4 to –28.2 parts per ml and are consistent with woody C_3-photosynthesizing species[25] according to Stephen Harris from the University of Oxford (pers. comm. 2011). Harris singled out AH17b, with a slightly enriched $\delta^{13}C$ value of –21.5, as charcoal of 'uncertain origin'. This may imply that the charcoal consisted of some C_4 material (tropical grasses and sedge). Both of these interpretations are in agreement with the current state of macrobotanical research at the site and with visible remains of C_3 and C_4 species in macrobotanical material from sieving of the archaeological deposits (Cappers 2006; Zieliński 2011). This also means that the potential growth rate on the samples was minimal and therefore they can be interpreted without the need for further adjustments.

4.4.2. Discussion of calibrated radiocarbon dates from Berenike

AH17b – Facies E[1], transect BE11-T01 + T02 + T03

Charcoal of 'uncertain origin' possibly including some C_4 material; depth 1.84 m bgl; OxA-24144; 2230 ±27 BP

[25] C_4 and C_3 materials refer to types of perennial grasses with different types of carbon fixation. The classification between C_3 and C_4 plants is based on the different pathways they use to capture carbon dioxide during photosynthesis. Additionally to primitive 3-carbon molecule products, more complicated C_4 pathways evolved in species in wet and dry tropics.

This sample, which was recovered from one of the hearths in Facies E^1, calibrates to 386–204 cal BCE ('passed' Bayesian model) or to 331–206 cal BCE ('failed' Bayesian model) (Section 4.4.3). Although only a TPQ, it clearly correlates with historical estimates for the port's foundation in the reign of Ptolemy II (reign 283–246 BCE) (Fig. 4.24). Whilst this is described as belonging to AH17 the sample was collected from the surface between AH17 and AH18 and is representative of both.

AH17c – Facies E^1, transect BE11-T01 + T02 + T03

Charcoal on C_3 plant; depth 1.84 m bgl; OxA-24084; 2239 ±28 BP

This sample is from the same depth and context as AH17b, and with the calibrated age of 390–205 cal BCE ('passed' Bayseian model) or to 331–206 cal BCE ('failed' Bayesian model) agrees exceptionally well with AH17b (Fig. 4.25). Whilst this is described as belonging to AH17 the sample was collected from the surface between AH17 and AH18 and is representative of both.

AH16 – Facies G, transect BE11-T01

Inner bark of a woody C_3 plant; depth 1.95 m bgl; OxA-24145; 2133 ±26 and OxA-24085; 2112 ±26 BP

According to Harris (pers. comm. 2011) these samples are bark and therefore include a negligible growth age. The two results are statistically identical and (being on the same material) can be averaged. Because of the shape of the calibration curve, there still remains a small amount of probability that they belong in the 4th century BCE, but the Bayesian model discounts this possibility (Fig. 4.30). The 'passed' Bayesian modelled ranges: 202–58 cal BCE should therefore be considered as the most likely date of this deposit. However, in the 'failed' Bayesian model, it is considerably older at 360–220 cal BCE (Figs. 4.26–4.28).

AH19 – Facies G, transect BE11-T01

Charcoal; depth 1.3 m bgl; OxA-24086; 2105 ±27 BP

This discussed date is barely younger than the comparable bark sample from AH16 (OxA–24145). This might imply that the date includes some growth and storage age. The 'passed' model (partially reverse stratigraphic order) age range is 200–50 cal BCE and this sample was not taken into consideration whilst constructing the 'failed' model due to the fact that it was a piece of charcoal on bark that had been found very close to the top of this facies and could have moved laterally along the section (Fig. 4.29).

4.4.3. Modelling the dates

The results of calibrated and modelled radiocarbon dates of charcoal and bark samples from Facies E^1 and G indicate their origins within the Hellenistic period. The stratigraphic order of these dates, however does not model well using

Bayesian mathematics,[26] perhaps due to factors such as material limitations, dynamics of the tidal zone and hence a possible movement along the sequence of intrusive material, limitation of the technology, growth age of wood samples.

The Bayesian model that takes into consideration the basic stratigraphic order, i.e. that Facies E^1 is younger than Facies G, does not pass the modelling routine (60%) in OxCal v4.2 and fails with only 34% probability (Fig. 4.30). Tests show that this could have been rectified if the raw (uncalibrated) radiocarbon dates were just 15 years older. This later model would pass with approximately 65% of probability. However, even if the sample from AH19 is discarded on the basis of it possibly belonging to the upper part of the sequence i.e. Facies E, modelling based on correct stratigraphic order still fails the probability test, suggesting the presence of some intrusive material, in-mixing, lag time in deposition of organic material, or growth age difference.

Under these circumstances it is possible to model the dates in the reverse order excluding or reversing a sample from AH16. This is based on the assumption that the average date from these samples could be on material that was deposited later and have shifted slightly through the sequence (Fig. 4.30). Such an exercise refines the model and associates the pottery findings on the beach of Facies E^1 with the early Hellenistic period and the time of the first settlement at Berenike, whilst the top of Facies G, an infilled intertidal zone of the pre-Ptolemaic lagoon, can be dated to just before the early Ptolemaic period.

[26] Bayesian mathematics provides a statistical tool for modelling of both the information from the new measurement and information from the ^{14}C calibration curve forming 'a core element in many ^{14}C dating projects' (Bronk Ramsey 2009a).

Although the insufficient probabilistic evidence does not allow the dates to be modelled in a completely satisfying manner, the radiocarbon results nonetheless show that this part of the sequence, comprising a foreshore/beach environment and the fill of a silted up lagoon/backwater, can be dated confidently to the Ptolemaic period. However, any further conclusions concerning the absolute chronology of the stratigraphic sequence constructed for the site are beyond the scope of the very small dataset of only five samples (two of them from the same facies) and do not allow for far-reaching conclusions regarding the relative stratigraphy of the site. In comparison, most of the sites on the Mediterranean coast are dated with at least ten times as many samples (i.e. >50), and in some cases or even up to 200 dates (including both AMS and OSL) are obtained from each augering campaign (e.g. Kaniewski et al. 2014). This kind of resolution would allow for a very detailed absolute chronology of the environmental change and silting-up events at Berenike, but, unfortunately, such geochronological work is hampered by the high costs of dating facilities in Egypt and export permit restrictions.

4.5. TRANSECT INTERPRETATIONS

The results of augerhole surveys in Berenike revealed highly distinctive and environmentally diagnostic sedimentary sequences beneath the present site and its immediate environs. They also allowed observation of the changes in sedimentology that reflect marked fluctuations in landscape dynamics at the site through time. This section looks at each of the 10 transects in turn (Figs. 3.5, 3.9–3.11 and 4.1), assessing the archaeological implications of the transect interpretations and how these results address the research questions posed at the beginning of the chapter. Additionally, Appendix 1 provides description of each sub-surface composite section followed by detailed narratives of the sequence encountered in each augerhole. Appendix 2 shows a table with the results of laboratory analyses.

4.5.1. Transect BE11-T01 and BE12-T04

Transects BE11-T01 (Fig. 4.31) and BE12-T04 (a later extension on the other side of the bay) were invaluable for linking the archaeological site to the wider coastal landscape. In the north, transect BE11-T01 successfully defined the archaeological sequence of the site with a gradual descent (~10°) in a seawards direction. Importantly, this transect records archaeological layers (e.g. Facies E, Group II, a Ptolemaic beach recorded in BE11-71) present at the margins of the site, allowing for the archaeology-bearing sediments to be stratigraphically associated with the naturally-derived sediments. This permits human activity to be linked with shifts in landscape dynamics at the site for the first time.

Working from the archaeological site outwards, the first part of the sequence is the archaeological profile exposed in trench BE11-71 at the very northern edge of the Central Zone of the Southwestern Embayment (SWE) where a beach facies (Facies M, Group VIII) with associated Ptolemaic occupation (Facies E, Group II) and clay deposit suggesting a pooling event (Facies F, Group V) had been exposed in the southern part of the trench connecting AH18 and AH17 (Fig. 4.32). This is an important starting point as it is necessary to appreciate how this recorded archaeology relates to the surface and sub-surface topographic features present in the vicinity of the site. The deepest part of the sequence, exposed at the base of AH18 and AH16, testifies to a time when this area of the archaeological site was submerged beneath a moderate to deep lagoonal backwater environment (Group IX).

Between 0.5 m and 0.9 m asl (Group VIII) there is a marked change in the sedimentology in the northern area of the Central Zone of this transect (see Fig. 4.31). In the northern augerholes (from AH18 in the north to AH20 in the south) there is evidence for either sea level regression or a progradation of the contemporary coastline (or a combination of both processes). The basal parts of the deeper augerholes (AH18, AH16) contain sediments consistent with deep, slow moving or standing water. A switch to coarser, darker sediments, up to around 50 cm asl, shows that the northern sector of the transect was subsequently situated within the intertidal zone (Group VIII), possibly with some higher elevation areas of the coastal landscape being intermittently exposed as dry land. Two radiocarbon dates generated from wood (bark) and charcoal (Facies G, Group VIII in AH19 and AH16) were calibrated using Bayesian modelling techniques to 202–50 cal BCE or to 360–220 cal BCE if we take into consideration the partially reversed stratigraphic order from the 'failed' Bayesian model (Section 4.4.3).

Owing to the constraints of the augerhole methodology (Section 3.3.3) it was not possible to link up the northern and southern parts of this transect for some of the lowest facies. However, at an equivalent elevation of the intertidal sediments present in the north (Facies G, Group VIII), in the very south of this transect, deeper water marine sands were deposited (Facies L, Group X). The slope gradient angle between AH18 and AH37 on the surface is 10°, whilst the top of Facies G (AH16) and Facies L (AH36) is 1°, and Facies L in AH37 is 3°. This being the case, it is possible that sediments contemporaneous with Facies G (Group VIII) could underlie Facies L (Group X) in AH36 and AH37, and given that the top of Facies G (AH16) to the base of Facies L (AH37) has a gradient of only 6.5° – some 3.5° shallower than the surface gradient.

Due to the difficulties experienced during augering in the waterlogged tidal zone, transect BE11-T01 was not extended to depths below current sea level any further out than AH37. Instead it was continued in the 2012 season on the other side of the bay as transect BE12-04 (see Fig. 1.16). This transect includes the natural deposition of lagoonal sediments collected as modern analogue samples. Grey clay silts (Group IX, basal Facies) and pure green clays (Group V, middle Facies) were recorded, indicative of an anaerobic environment almost directly (50 cm) below the ground surface. They therefore evidence periods of inundation by flash flood events in the upper part of the sequence. The discussion about RSL change since antiquity is taken up in Sections 2.3.3, 4.6, 5.1.1, and 8.1.

A gradual lowering of sea level (minor regression?), possibly coupled with the progradation of the coastline, continues up-core to a maximum elevation of 1 m asl, as recorded in AH18 and AH16. Alternating pale and dark laminated sands (Facies M, Group VIII) reveal the first signs of exposure to the subaerial environment, as intertidal sands interstratify with shallow marine sediments indicating that the area immediately below the archaeological site of Berenike and its immediate environment was exposed as dry land on a regular basis.

A subsequent shift from shallow marine/inter-tidal sediments to semi-terrestrial coastal sediment correlates with the first signs of human activity in this area (Facies E, Group II). This is superimposed directly on top of evidence for a short period of inundation in the very north of the site in the form of a thin layer of clay (Facies F, Group V), proof of a most likely short-lived flash flood event. This may relate to a storm surge event originating from the sea or a flash flood event in the mountains causing inundation by wadi flooding. Either way, the clays have settled out of suspension in the resultant floodwater pools and slow-moving channels.

It is possible that a wetter event relating to the aforementioned slackwater deposition observed in Facies F (Group V) of AH17 and 18 (Section 4.3.1) could have caused a rise in the local water table of the lagoon, and a concomitant transgression into the depression of the embayment. This water would have pooled for an extended period of time, in so-called 'mud ponds', allowing the thin layer of greyish/greenish clay to form as clay minerals settled out of suspension in the low-energy environment across the base of the lagoon. This is visible in the modern analogue study from the southeastern corner of the current lagoon (BE12-T04, Fig. 3.9).

Due to the lack of comparative regional palaeoenvironmental data for this period the interpretation of this 'wetter phase' will only be limited to the area of the site of Berenike *per se*. However, it is obvious that the evidence of slackwater deposition suggests increased humidity at the site, which might have been connected with a regional wetter phase or a very dynamic flooding/rainfall event. The evidence for greenish clay in AH17, 18, and 21 as well as in augerholes from BE12-T04 suggest ponding of the bay and shows the area of topographic high.

Immediately or soon after this flood event appears the first unambiguous, stratified evidence for human activity at what was to become the site of *Berenike Troglodytica*. A very notable archaeological layer (Facies E^1, Group II) was excavated in trench BE11-71. This layer comprises an admixture of archaeological material including combustion features interpreted as hearths containing an abundance of pottery tentatively identified as early Ptolemaic (Roberta Tomber, pers. comm. 2011–2012) and radiocarbon dated modelled to 390–205 cal BCE (calibrated using a Bayesian model, Section 4.4).

Given that the hearth features are cut into the underlying flood silts, which are located on top of foreshore/backbeach[27] deposits (Facies M, Group VIII), it appears that the first Ptolemaic exploitation of the costal landscape utilised the

[27] The beach has three major parts: beach face, berm and backbeach. The backbeaches, located behind the berm, are usually fine-grained and well-sorted. They vary in width and character and often merge with dunes without a clear boundary.

hard surface represented by this baked fine-grained clay. It is plausible to suggest that following the increased presence of water associated with the flood/inundation, the area of Berenike and its surroundings is likely to have been a greener and less harsh environment for early settlers (such as seen in 2013 after a season of prolonged rainfall) (Figs. 2.11 and 4.33).

The period of human activity associated with Facies E and E^1 is intensive and recognised widely across the site, with post-depositionally water-abraded pottery recorded in other augerholes towards the south (AH19–20, Facies E, Group II, at the current sea level). Facies E varies from the ~5–10 cm thick horizons with dense pottery concentrations, to pottery spread more sparsely where the layer is up to 30 cm in thickness.

The water-abraded and fragmentary character of the pottery, and the dense concentration of material could be suggesting accumulation by dumping of waste overboard whilst vessels were moored in the harbour basin (David Blackman, pers. comm. 2012). It can be correlated topographically with a possible bottom of a lagoon/intertidal zone at this time. To support this hypothesis there is a plethora of comparative evidence from other ports confirming that harbour floors (Section 5.4) were often covered by discarded and, further, water-abraded pottery sherds (e.g. Galili et al. 2010).

To the west of transects BE11-T01 and BE11-T02 there is evidence for abandonment or a hiatus in human activity at this part of the site (possibly a shift to a different area of the site) following the deposition of Facies E (Group II).

A thick layer of dune sand with a low background scatter of archaeological material overlies Facies E in AH18 and AH16. This represents the natural accumulation of windblown sediments following the period of human activity at the site. It may be that it is this abandonment/hiatus that was documented in the augerhole record that was also recognised across the site in archaeological sections between late Ptolemaic and early Roman layers (a thick sand deposit that could be correlated with Facies D; Iwona Zych, pers. comm. 2011). Facies D (Group III) could also be interpreted as evidence for shifts in environmental conditions, with stronger winds and an increase in aridity bringing more windblown material to the site.

Facies C (Group III), composed of mostly marine characteristics, is recorded across the site and shows a series of laminations that could be interpreted as intermittent inundations either by storm surges or from the wadis. It can be connected with yet another local climatic shift to a wetter period.

Sedimentological evidence in a form of thick accumulation of fluvial sands (Group III) in the northern part of the transect shows that after a period of a possible hiatus in this area there was a reactivation of human activity in late Roman times. To the south of the archaeological site, however, a very strong marine influence remains visible, with sediments being laid down in a very shallow marine or beach environment with plethora of shells and coral fragments. This shows that during the occupancy of the archaeological site the coastal and intertidal zones were much closer than they are today to the high ground of the Coral Shaped-ridge (CSR) (by ~40 m) and the sea level was higher.

By extrapolation, this provides a very broad estimate of the rate of coastal regression, amounting to ~300 m in 2,300 years (calculated from the Ptolemaic beach facies to the current shoreline).

Taking this rough estimate, the 'island' with a *Temenos* of Temples (although of a later 4th century CE date) could have been at an earlier period cut off from the land, at least by tidal waters (see Section 5.5). It is worth noting that short-lived increases in mean global temperature (such as the later Medieval Warm Period that led to shifts in monsoon rainfall patterns across Africa and South Asia, e.g. Broecker 2001, Graham et al. 2011) could have, theoretically, raised the sea level. This could have manifested itself in the northern Red Sea with a significant lag time owing to the delayed response of polar ice cap melting to subtle changes in temperature (compare with Toker et al. 2012). It is possible that some laminated marine deposits recorded at Berenike could be evidence for such an event, but without a detailed site chronology and sea level curve for this period this remains only conjecture.

The transects have shown that the landscape of *Berenike Troglodytica* has changed profoundly through time, most likely as a response to changes in sea level and/or the progradation of the coastline (Fig. 4.33), with some minor contributions from fluvial processes occurring within the wadi system. It would appear that a lowering of relative sea level following the mid-Holocene highstand opened up the northern area for exploitation by Ptolemaic prospectors looking for an area suitable for setting up a cargo port. This also raises the question of whether this progradation had a natural or anthropogenic origin, and whether some of the walls found on site in the vicinity of the ancient water edge (such as purported 1st-century CE 'seawall'; Section 5.3) could have been used as dams or sea-defences.

Given that there was a considerable water depth and marine/lagoonal environment (of at least 3 m accordingly with the current depth and recorded level of sedimentation) within 150–200 m of the site (distance calculated from trench BE11-71), this could support the hypothesis that the site could have been used as a landing station for vessels such as *elephantagoi* (Casson 1993: 253, note 25; Sidebotham 2011: 48–53). These were most likely large and wide, possibly flat-bottomed barges carrying heavy cargoes of elephant livestock that could have been beached close to the Crescent-shaped Ridge (CSR) from where animals could then be led to their holding pen to the north (Section 5.9).

4.5.2. Transect BE11-T02

Transect BE11-T02 (Fig. 4.34) is parallel to BE11-T01 (but sharing AH18) and was established in order to find the extent of ancient water bodies within the Southwestern Embayment (SWE). It was also intended to confirm, or reject, the hypothesis that linear features running parallel to the CSR that are visible in the terrain, on satellite images and on the geomagnetic map were jetties or a series of wharf infrastructure buildings (visible to the east between trenches BE09-55 and BE10-67 on Fig. 3.10).

Roughly aligned to the site's north-south axis (along which it has a sloping gradient to the south), this transect is almost entirely limited to what author calls — the Central Zone — of the 'embayment' and therefore exhibits a similar stratigraphic sequence to the northern part of the BE11-T01 transect. The gradient is steep, sloping down at an angle of 20° from AH17 to AH44; rising up to higher ground around AH10 at an angle of 14°, finally sloping down towards AH47 at 17°.

The sequence described above and exposed in AH17 is a horizontal equivalent to the sequence recorded in AH18, both of which were obtained from trench BE11-71. Samples acquired from hearth features in AH17 (Fig. 4.13, top, left of the beach), and in the vicinity of AH18, were presumably anthropogenic in origin and most likely hearths or fireplaces, which contained some charcoal. This material was subsampled and extracted from the sediments under laboratory conditions, and dated using radiocarbon dating techniques (Section 4.4). As mentioned above, these results confirmed expectations based on field observations, that these levels were contemporary with the first habitation of the site in the Ptolemaic era. These dates also proved to be invaluable in our understanding of the chronology of landscape change and the occupation of the site. After calibration with a Bayesian model these dates fall between 390–205 and 386–204 cal BCE or between 331–206 cal BCE in the 'failed' model (Section 4.4 and Fig. 4.30) and can be further refined to after 275 BCE based on the occurrence of Ptolemaic pottery.

Sedimentological analyses of units recorded in AH17, AH18 and AH10 show the uniformity in this part of the sequence. Facies E (with pottery) is roughly horizontally aligned between these augerholes, while from AH10 towards the south of the transect the different facies follow the natural topography of the surface terrain.

Towards the southern part of the transect, Facies N (Group VI) is present on the surface suggesting an erosional character for the southern part of the Central Zone, despite being located ~40 m to the west of the 'island' with the Temenos of Temples that is also covered by a similar calcareous friable surface. The occurrence of a shell-rich layer (Facies S, Group VII) in southernmost AH47, close to the edge of the *sabkha*, suggests some more recent marine activity in this area that seems to transition into Facies R in AH46 and AH40. The basal part of the sequence remains a horizontal (topography-independent) continuation of the northern part of the sequence.

These results show the environment changed markedly at around 1 m asl in the northern part of the Central Zone, at which time human populations of the Ptolemaic city were able to exploit the recently exposed coastal landscape. Observed changes in sedimentological facies, such as flood events or fluvial deposition, highlight the human-environment interactions at the site, indicating that environmental fluctuations can change the viability of an area as a port and settlement site. As ports are almost without exception located in littoral zones, they are prone to minor changes in geomorphological systems (in this case marine transgressions and regressions), and are often extremely efficient sediment traps allowing for detailed and high-resolution geoarchaeological and chronometric analyses.

4.5.3. Transect BE11-T03

A large part of transect BE11-T03 (AH18–AH41), orientated on a northeast–southwest axis, is located in the Central Zone of the 'embayment', whilst its southwestern part rises to the edge of the CSR before dropping down towards the mud ponds on its southern side (Fig. 4.35). The whole site spreads between those two distinct areas: one exposed to the mountain alluvial fans and wadi systems (especially where the Ptolemaic Industrial Zone, the Ptolemaic fort and Roman Cemetery are located); and another protected from their influence but more prone to the forces of the sea, coastal geomorphological processes and turbulent coastal winds (mostly the areas of Roman occupation and the SWE). This transect, therefore, gives an interesting insight into the diverse material sources at the site, the different modes of deposition and the sedimentological character of deposits, which binded the two distinct landscape zones together.

This important transect slopes down from AH18 towards AH41 on an 11° gradient. It then rises up towards the southeastern end of the top of the CSR at 1.5 m asl. Subsequently, it drops down into the braided-plain of the wadi channels and mud ponds on the southern part of the ridge, located about 0.5 m asl, at an angle of around 16°.

The stratigraphic sequence recorded in the first part of the transect (including AH18, 11, 46 and 41) corresponds with that observed in the northern part of the transect BE11-T01 and the general sequence recorded in the Central Zone already described in detail above, and will therefore be omitted here to avoid unnecessary repetition. The southern part of the transect reveals a greater fluvial (wadi/water-borne) influx, recorded at the top of the sequence (Facies P, Group III), corroborating the role that the ridge played in providing a shelter against the introduction of material from the mountains to the west.

The upper part of the sequence in transect BE11-T03 was not recorded in any other transect and therefore requires some more detailed attention. The stratigraphic order recorded in AH54, located on the top of the ridge in its southern part, is not in agreement with that recorded in AH4, despite the fact that they are both located at the top of the ridge (one in the south and the other in the central area; note that they are laterally distant and at different elevations).

Although short, AH54 shows an interesting sequence. The top 1 m contains a relict *sabkha* deposit with large quantities of evaporate salts contained within the matrix. At a little over 1 m in depth, the base of this augerhole reveals what may be the rocky core of the CSR at the same level as the surface of the mud ponds recorded in AH53 (see further discussion regarding the height of the core of the CSR in the interpretation of BE11-T05). The continuation of this sequence is seen at the basal part of AH54 with sediments of alluvial characteristics (i.e. Group III).

Within the limits of the landscape, features referred to as 'mud ponds', a representative sequence of AH53, was recorded. This augerhole was not able to achieve greater depth due to the waterlogged nature of the substrate, but the ~1 m depth that was augered enabled the recognition of three main vertical zones in the accumulation of this deltaic area of the wadi channel/alluvial fan: i) interstratified relic *sabkha* and mud flat surfaces; ii) waterborne fluvial sediments; iii) sediments of the intertidal zone. This has been interpreted as a stratified section of a wadi channel with its diverse input sources.

4.5.4. Transect BE11-T04

This relatively short and shallow transect is aligned with what was believed to be the western edge of the 'island' with the *Temenos* of Temples (Figs. 1.8 and 4.36). The latter, southernmost part of this transect connects with the two last augerholes of BE11-T01 (AH36 and AH37) and enters the *sabkha* area and the intertidal zones. The southernmost part of the sequence including AH34, 36 and 37, repeats the interpretation already presented above in BE11-T01 and will not be repeated here.

The northern part of this transect (AH29, 31–33) reveals a very shallow sequence. The granular (crunchy) character recorded at the base of each one of these augerholes is most likely the reef core (or potentially a structure preserved below ground) and could lend weight to the hypotheses that an ancient reef outcrop forms the nucleus of the high-ground on which the Temple of Lotuses and the associated religious complex are located. It is envisaged that future open area excavations, targeted by the results of the detailed GPR survey conducted by the author in 2013, could help delineate the limits of this island. What the results of this transect has shown is that limits of the island core extend further towards the east than was previously acknowledged.

4.5.5. Transect BE11-T05

Transect BE11-T05 (Fig. 4.37) can be divided into three main zones: i) a Central Zone containing a sequence very similar to that observed for example in the northern part of transect BE11-T01 (Section 5.4); ii) a western high elevation zone associated with the Cresecent-shaped Ridge (CSR) and associated archaeological deposits (Section 5.6) and, further to the west, the Ptolemaic Industrial Zone (PIZ) (Section 5.9); and iii) an eastern mid-elevation zone that picks up high ground at the margins of the Central Zone and the edge of the city-tell with the Roman remains located on top of another uplifted coral outcrop (Section 5.8). This transect is therefore vitally important in recording a profile through — and linkages between — buried topographic features across a large area of the site that appear to have had a strong influence on its formation.

In AH5–8 on the eastern side of the ridge, downslope colluvium exists in relation to the downslope movement from the ridge. Bounded by the ridge to the west and higher ground to the east, the Central Zone is formed by what appears to be an infilled basin of the Southwestern Embayment (SWE) (Figs. 3.5, 3.9–3.10 and 4.1). Similar to the situation in the northern area of BE11-T01 and other transects, the deepest sediments recorded in BE11-T05 in the Central Zone Facies I and H (Groups IX and VIII) are deposited in moderate- to deep-water lagoonal/backwater environments. A similar shift into the intertidal zone is recorded in this central region relating to the lowering of the sea level and/or progradation of the coast.

The deepest of the cores (and realistically the technical limits of hand augering) achieved 5.10 m in depth but it remains inconclusive as to whether the bottom of the bay had been reached. At Myos Hormos, some of the coring was undertaken with a power drill, and the results suggested that the harbour base there is located 28 m below the modern surface (Blue 2006a: 53). It is therefore possible that the bottom of the older lagoon in Berenike could have been significantly deeper. However, Blue's sedimentological descriptions seem to be consistent with earlier, Pleistocene deposits, which could have been inundated during this period with a much lower sea level.

The archaeological layer rich in water-abraded pottery, observed in the northern area of BE11-T01 (Facies E, Group II), and believed to represent the harbour bottom, is well defined within this transect and extends for ~100 m along the east–west axis. At the time of deposition of this layer (either an anthropogenic or a natural layer with anthropological material – this cannot be determined clearly without further investigation), the embayment had infilled to such an extent, possibly allied with lowering of RSL, that in the early Ptolemaic period intensive activity in this area was presumably above the intertidal zone. This was close enough to the coast and waterways that connected to the coast. It is also worth mentioning that the water-abraded character of the pottery is probably to be connected with it being constantly moved, rubbed and grounded by the tidal action.

As mentioned in the interpretation of BE11-T01 there is a possibility that this layer represents the Ptolemaic harbour floor (Section 5.4) at the time when Facies M (Group VIII) were used as a foreshore/backbeach area on which human presence (Facies E^1, Group II) was first recorded. The gentle slope of the beach could allow Ptolemaic elephant and ivory hunters and merchants to careen their wide vessels (such as *elephantagoi*) in the area sheltered by the CSR.

In the eastern sector of this transect the ground begins to rise up in an area where it is thought that the northern edge of a small island was once located on a remnant reef outcrop (Section 5.5). The 4th century CE *Temenos* of Temples could therefore be located on higher dry land that was once (in Ptolemaic and maybe also in early Roman period) an island, possibly a tidal island (with what seems to be a tidal pool in one of the structures in the complex). It is possible that some phenomenological mode of continuity of landscape usage would have encouraged the later Roman occupants of the site to construct a temple on what was an island in the early Ptolemaic era when Facies M sediments were part of the existing beach limit remaining high and dry above the tidal surge at this time. Alternatively, the higher ground on which the Temple was constructed, close to the edge of the (partially infilled) harbour, might have simply been the most suitable location for the purpose of constructing a 'harbour temple'.

The eastern margin of the eastern zone rises up in elevation associated with the higher ground of the 'tell'. This is located on an uplifted reef outcrop and its surface deposits are associated with the late Roman town (based on numerous seasons of excavations: Sidebotham and Wendrich 1995, 1996a, 1998, 1999, 2000, 2007a).

To the south and southwest, the origins of the CSR are somewhat enigmatic. It was long believed that this high ground was a remnant of a man-made wharf (see Figs. 1.12 and 1.13 for previous interpretations of the usage of the harbour). This hypothesis was later brought into doubt based on the interpretation of geomagnetic survey data that suggested a natural origin for this feature with a reef nucleus forming the structure (Tomasz Herbich, pers. comm. 2011). This new hypothesis appears to be consistent with the lack of any port-related infrastructure discovered along the ridge in excavation trenches BE09-55 and BE10-67, located on the top of CSR, and by field observations by the site geologist (Jerzy Trzciński, pers. comm. 2012).

The results of the augering are not in total agreement with these new interpretations. The depth of AH4 (280 cm), which was cored through a sequence of archaeological deposits and sands, seems to bring the possible top of the ridge only to the surface level of the Central Zone without reaching any sign of a reef core right below the surface; although the lower facies may be natural in their origin they are highly weathered (which could evidence their long-term erosion).

It should be noted that trenches BE09-55, BE10-67, BE14-100, and BE14-102 were all generally very shallow (maximum 1 m in depth) and only recorded late Roman structures. Certainly the upper 2 m of the core of the ridge appears to be archaeological in origin but cannot be directly dated based only on the augering results. Deeper excavations need to be carried out in this area, ideally in the form of deeper but laterally smaller sondages. At this point, however, the results of the augering seem to partially undermine Herbich's interpretation suggesting a hard core/reef outcrop nucleus forming the majority of the CSR, and instead suggest a lower reef core with a high accumulation of archaeological and windblown material deposited on top of it.

4.5.6. Transect BE11-T06

Transect BE11-T06 (Fig. 4.38) runs parallel to BE11-T05 (described above) and whilst the BE11-T05 bounds the northern limits of the island, BE11-T06 flanks it from the south. Field observations and laboratory analyses have revealed a complex stratigraphic sequence within this transect. It can be divided into 3 main zones: i) the slope and the Central Zone (AH43–39); ii) the southern limits of the high ground of the 'island' (AH38, 20, 32); and iii) a single core in the northeastern part of the Southwestern Embayment located at the bottom of the Roman city-tell situated on the central elevated reef outcrop.

The western part of the Central Zone contains colluvial sediments and windblown material that has moved downslope from the ridge above, between AH43–41, and along a ~20° smooth gradient. The middle part of the Central Zone is roughly level and horizontal in comparison with corresponding augerholes in adjacent transects. This sequence has already been described above.

AH20, located on what is believed to be the southern limits of the island, roughly repeats the sequence of the Central Zone, with intertidal Facies G (Group VIII) recorded at its base suggesting a less pronounced southwestern corner of the 'island'. The short and invariable sequence described in AH32, with the basal granular material, is in an agreement with the first part of the BE11-T04 sequence and suggests a reef or hard rock core within the island (or a structure) at this depth.

The easternmost AH51 is roughly in agreement with two shallow cores north of it (AH30 and AH48 in BE11-T05), representing a unique sequence that differentiates the eastern part of the 'embayment' from its central and 'island' zones. The modest depth of AH51, reaching only 110 cm, does not allow for far-reaching interpretations and either way would not change the overall interpretation of landscape change in the area of the Embayment, but it does suggest a need for further research in this part of the site.

4.5.7. Transect BE12-T01

This transect (Fig. 4.39) provides an important sedimentological sequence linking three different and diverse local environments in the northeastern part of the site: i) archaeological deposits with colluvium and anthropogenically disturbed sediments in the northern part of the Roman town (Groups I and II); ii) an area believed to be an infilled 'northern bay/anchorage' (Group VIII); and iii) contemporary *sabkha* deposits and the intertidal zone of an older bay (Groups X and XI).

The southernmost part of the sequence is located on a slope with a gradient of 8°, presenting a sequence that could in some respects serve as a comparison with the Central Zone of the Southwestern Embayment. Sediments recorded in the basal part of this sequence are anaerobic, shallow and moderate depth marine sediments suggesting that this part of the area was forming underwater as a part of the sea-connected bay. For the purposes of this thesis the author settled on calling the area situated in between two 'limbs' of a reef extending from the large reef outcrop upon which the city-tell — a 'Niche' (see Fig. 1.8) — distinguish it from a bay or embayment, and in order to differentiate it from the interpretative nomenclature used by Sidebotham (2011: 61) who prefers to call it the 'northern port'.

The upper part of this sequence is mostly colluvium mixed with some archaeological and windblown material. Due to the sheltered character of the

'Niche' (partially enclosed at its northern end by an elevated narrow sandbank, see Fig. 3.11) there is no record of the wadi-derived fluvial material that was evident in the augerholes in the southern part of the transect. However, the last, southernmost augerhole in this area (AH13) has a layer with distinctive alluvial characteristics, located directly above the marine-influenced facies, which has been interpreted as terrigenous wadi material. This layer continues below the narrow sandbank on top of which AH14 is located, suggesting its recent genesis or an intermittent inundation caused by fluvial sediment influx from the mountains.

The narrow sandbank mentioned above, well defined on satellite images (top of a Fig. 3.11), rises up by ~20° to the height of 2.30 m asl, subsequently dropping by 43° on the northern side. The first waterborne deposit, Facies H^2 (Group IV) is overlain by the alluvium of Facies C^2 (Group IV). In AH14 this sequence shows intermittent colluvial and wadi-derived deposition phases. Located just below the narrow sandbank (on its northern side), AH15 follows the same order in the basal part of the sequence, with the top exhibiting a strong influence of wadi-derived material. As observed throughout the transect and towards the south, the whole area is covered by windblown material.

The northern part of the transect is very different in sedimentological character and in terms of its genesis. The basal deposits in AH17 are fine, pale silts that appear to indicate a low-energy, shallow-water environment (Group XI). Higher up the sequence, but still below current sea level, sediments that possess very strong marine characteristics (shells, medium to coarse sand, anaerobic environments) were recorded suggesting a possible bottom of the bay deposit (Group X). Overlain by shallow marine Facies D^2 (Group VIII) they postdate deposits uncovered at the base of augerholes recorded within the 'Niche'. The topmost part of the northern zone of the 2012 augering area shows interstratified wadi and marine sediments (Group IV) with beach sands, relic *sabkha* deposits and fluvial sediments (Group VI).

Transect BE12-T01 gives an interesting insight into the sedimentation processes that were underway in the northern part of the site and shows the major influence that the wadi systems (especially Wadi Abu Greyah and Wadi Lahami) had in infilling this previously inundated (or marshy) landscape. The topmost part of the sequence shows an admixture of colluvial and windblown sediments intermittent with more stable land surfaces indicating less intense wadi activity in the recent past.

4.5.8. Transect BE12-T02 and -T03

Two parallel transects, BE12-T02 (Fig. 4.40) and BE12-T03 (Fig. 4.41), that are located in the southern part of the 'Niche', will only be mentioned in passing here as their sequences repeat that encountered in BE12-T01 in the southern zone. This includes fluvial deposits recorded at their western fringes where the western 'limb' of the reef does not shelter the 'Niche' sufficiently to block sediment influx washed down from the mountains.

4.6. CHAPTER SYNTHESIS

Geoarchaeological augerhole surveys can provide critical information regarding the buried topography and sequence of sediment accumulation at coastal archaeological sites and the driving forces behind these changes in sedimentology and geomorphology (Section 2.1.1). Valuable but limited published geoarchaeological research on Red Sea coastal sites have focussed on harbour sequence stratigraphy and microbiological inclusions (e.g. foraminifera) (Sections 2.2.1, 2.2.2.2, 2.2.2.3).

This research has not only built on this work but has also developed a new approach that achieves a new level of insight into the dynamics of the evolving archaeological landscape through the analysis of modern landforms, reconstructed buried land surfaces, sediment infill stratigraphy, and associated coastal, fluvial and shallow marine stratigraphic sequences, representing a wide range of depositional environments. It is worth noting at this point that the results of the sedimentological analyses are consistent with the basic environmental reconstruction obtained by the author during diverse fieldwork analyses and observations that have already been presented in Chapter 2.

Additionally, these geomorphological processes and changes in sediment delivery to the site have been linked to the archaeological narrative of the site in order to explore the degree and nature of human-environment interactions (see more in Section 8.1). Such a holistic approach allows for the recreation of the changing port landscape and history of human exploitation in its entirety, rather than focusing on individual parameters or elements of the story, allowing for more weight to be placed on the resulting reconstruction.

5. RE-DEFINING THE HARBOUR BASINS AND RE-THINKING THEIR CHARACTERISTICS: DISCUSSION OF THE RESULTS

This chapter brings together the results of the various analyses to reinterpret key archaeological and landscape features that played a significant role in the development of the site. Focusing on crucial aspects of those new data, this chapter combines the results of the coastal geomorphological survey (Section 2.4) with those from the analyses of the sub-surface sediment samples (Sections 4.2–4.3, 4.5–4.6, Appendix 1). Geochronological data (relative and absolute) (Section 4.4) are also used to reconstruct how, when and why landscape and environment along with associated ancient harbour complexes evolved during the late Holocene.

Using data derived from an Earth Science approach and integrating these datasets with traditional archaeological information, this chapter aims to document *ca.* 800 years of human–environment interactions at Berenike, and to fully evaluate the site history within its dynamic environmental setting. This chapter will also revisit interpretations previously put forward regarding the founding and evolution of the site, the configuration of its functional areas, and its ultimate decline and abandonment that were based solely on field observations and archaeological material, without the benefit of sub-surface topographic data. Moreover, an attempt will be made to rectify numerous inaccuracies and inconsistencies regarding Berenike's harbour(s) in the scholarly literature.

As we have seen in the previous chapters, the coastal location of *Berenike Troglodytica* benefits from at least two basins (the Lagoon and the Embayment), both of which are highly conducive to accommodating significant mooring areas with little need for human modification of the existing natural landscape (Section 2.4.1, Figs. 1.4, 1.8, 1.14, 1.16, 3.9, 4.1 and 4.32). However, given that these basins are also very efficient sediment traps, with the potential to infill with coastal, fluvial and windblown sediments, high levels of maintenance must have been necessary to prevent them from silting up and becoming unnavigable.

Whilst the current coastal situation of the site does not seem propitious for hosting a large volume of maritime traffic, the design and construction techniques of ancient merchantmen, the available navigational and mooring techniques of the time (e.g. using oars for entering and exiting ports), the location of the Red Sea at the crossroads of Indian Ocean and Mediterranean commerce, and the configuration of natural features of the coastal landscape, all meant that Berenike must have possessed a sheltered harbour with sufficient water depth to accommodate high volumes of incoming and outgoing merchant vessels. It is the reconstruction of this harbour and its configuration that are the key concern of this thesis.

This chapter provides discussion of the results and is divided into nine main sections, each focusing on describing new interpretations of a particular landscape or archaeological feature. The sections are arranged in geographical order — starting from the east — from the entrance to the lagoon towards the Embayment, and progressing inland towards the Roman and Ptolemaic sectors of the site. Much of this interpretation is based on the results presented in Chapter 4.

5.1. THE LAGOON

The exact size and depth of what is now the almost completely infilled lagoon, located within the sheltered bay (Fouls Bay), has remained unknown since the first explorers visited the site in the 18th and 19th centuries, such as the Italian Giovanni Belzoni (1821/1822). To distinguish between different phases of commercial activity in the port it is important to know how the configuration of the harbour basin changed through time.

Calculating the size and depth of the harbour, at least indirectly, would also provide us with an estimate of the potential intensity of use of the port. To do this, we must first gain an appreciation of the mechanisms that drove the infilling and whether the port community had the capacity and resources to maintain (i.e. dredge) the harbour when required. Constant maintenance would have meant that the Berenike lagoon was transformed into an anthropogenically modified landscape rather than one exploited in its natural state.

5.1.1. Relative sea level change

The size of the lagoon and its change through time is probably the result of a complex interplay of variables including changes in relative sea level (RSL), sediment supply, and, potentially, tectonics (e.g. Purser and Bosence 1997). Coastal and topographic surveys in and around Berenike recorded evidence of palaeo-shorelines such as wave-cut notches (at the Promontory), raised beaches (towards the South), *sabkha*, the formation of a tombolo and coastal ridges. Such features, when precisely dated, can yield information regarding the size, depth and dynamics of Berenike's lagoon (Fig. 5.1) through time. Diagnostic sedimentary signatures recorded during the augerhole survey, such as interstratified terrestrial (dune sand) and shallow marine (fine sands and silts) sediments (see Section 4.3.1), also provide evidence for fluctuations in RSL.

The sea level at the time of occupation would have dictated the location of the port relative to the coastline, and fluctuations in RSL would have impacted on the population living and working in Berenike (e.g. Blackman 1973, 1995; Morhange et al. 2006b; Goiran et al. 2009). Reconstructing changes in RSL is therefore critical to our understanding of the evolution of the lagoon, and how this coastal landscape was exploited (or not) during different periods

(Section 2.3.3). This can be achieved through detailed geoarchaeological analyses of the site stratigraphy, and can be supplemented by the use of proxy microfossil indicators such as diatoms, foraminifera or testate amoebae. Recent advances in palaeoclimatology (e.g. Rohling et al. 2014; Schneider 2014a) may allow more refined sea level reconstructions during different periods of occupation of the site using oxygen-isotopes in microfossils.

Unequivocal primary evidence for a change in RSL at Berenike is represented by a buried beach horizon with a dense layer of water-abraded pottery sherds (recorded in Trench BE11-71; Fig. 4.13). This horizon attains an elevation of +~0.85 m above current MSL and has been dated to the early Ptolemaic period by radiocarbon dating (Section 4.4) and pottery association (Roberta Tomber, pers. comm. 2011 and 2012). This means that the ancient sea level at the time was ~0.85 m higher than today. This estimation is in accordance with Lambeck and colleague's E2 and E7 predictive models for the Ras Benas area (just north of Berenike) where a small peak is observed at around +0.40 m at 2.3–2.1 kya (approximately 300–100 BCE) (Lambeck et al. 2011: 3550, Fig. 6) (Fig. 2.18). This is also close to Plaziat's observations from Wadi Gemal (approximately 90 km north of Berenike) of +1.2 ±0.5 m (Lambeck et al. 2011: 3551) (Section 2.3.3).

However, the new data obtained here are at odds with Harrell's (1996: 104–105) estimates that Roman sea level was 1 m lower than the current levels at the site. This interpretation is based almost solely on field observations of *sabkha* sediments to the north and east of the elevated reef outcrop on which the

Roman city-tell is situated. Given the rapid accretion of *sabkha* deposits "which rose in elevation faster than sea level with the net effect that the sea and lagoon retreated progressively further from Berenike over time", Harrell (1996: 104–105, 124) suggests that this put it out of step with a potentially much slower sea level rise, with the rapid accumulation rates of *sabkha* creating the appearance of a slower net rise in RSL.

Harrell's (1996) observations regarding sea level change at the site are also based on a basic misunderstanding of the nature of urban planning, relying too heavily on his comment: "it seems unlikely that Berenike would have been built so close to sea level even given the area's benign wave and tidal regimes; this suggests that there may have been some rise in sea level (perhaps up to 1 m) since the settlement's founding in the third century BC" (Harrell 1996: 104).

This reasoning is dubious as it does not take into consideration literature from similar sites. Published data from port sites across the Mediterranean (e.g. Ostia, Meiggs 1973: 124, 126, 132; Goiran et al. 2014a) and later Islamic ports on the Indian Ocean (e.g. the port of Unguja Ukuu, Kourampas and Kotarba-Morley 2015 *forthcoming*), show that many wharf buildings were positioned directly on the waterfront and domestic/industrial port infrastructure often extended out onto the beach, as it still does in many areas of the world. The sedimentological and sub-surface topographic data (Section 5.3) that indicate a ~0.85 m decrease in RSL over the past two millennia (Section 4.5), raise the possibility that the wharves and part of the city were, in places, located directly by the water.

5.1.2. Entrance to the lagoon

One of the first explorers to conduct research at Berenike, J. G. Wilkinson, wrote that: "the town stands on a small bay, at the extremity of a deep gulph […]. The inner bay that constitutes the ancient port is now nearly filled with sand, and at low tide its mouth is closed by a bar which is left entirely exposed" (Wilkinson 1835: 418).

A similar situation can be observed some 200 years later. At present, thick sand sheets to the north and abutting the promontory to the west (Fig. 5.1) partly enclose the mouth of the lagoon, with an elevation high enough to remain exposed at high tide. The entrance of the narrow channel, some 260 m to the northeast around the tip of the Promontory (Fig. 5.2), is located between the sand-spit accumulated against the Promontory on its eastern side, and the sandbar to the north. The sand-spit to the south, which now partially blocks the channel entrance, seems to be a modern feature of the coastal landscape, created by longshore drift.

The northern sandbank, limited by the coral reef to the northeast, extends ~115 m into the lagoon to the northwest of the promontory, with a less substantial, lower elevation sand platform stretching for a further ~165 m in the same direction. The lower-lying part of the sand-sheet platform is inundated only by high tides attaining ~1.5 m in elevation, whilst at low tides they can be totally exposed and the lagoon can be completely cut off. Sediments have also bankedup against the western edge of the lagoon, creating a higher elevation 'middle platform' stretching ~260 m southeast–northwest. This middle platform is inundated during spring tides but not always during average high tide.

A narrow channel, if present in antiquity, could have caused significant problems for port maintenance. It would have facilitated the trapping of sediment in the basin and could have formed tidal eddies and potentially lowered the flushing rate of the basin (e.g. Yin et al. 2000) leading to the need for regular dredging. If we assume that many of these deposits accumulated contemporaneously or possibly penecontemporaneously with the *sabkha*, then in terms of the efficacy of maritime traffic it would have been difficult for such a narrow channel to provide the main entrance for the port. The connection between the port and the sea would have to be of sufficient width for incoming and outgoing traffic, and hindering this traffic flow could have resulted in the Roman port falling into disuse.

We do not know the average yearly growth rate of coral reef in the vicinity (towards the northeast) of Berenike. However, it should be taken into consideration that the reefs here are amongst the most productive ecosystems on Earth in terms of biomass growth, which can change significantly over just a few centuries. In optimal conditions (clear water with a temperature of 18–25° C), a coral reef can grow as much as 10 cm per year (Sampsell 2003: 172–174) drastically changing the coastal topography and the bathymetry of the harbour entrance.

Nevertheless, estimating the growth of the reef and the speed at which it was eroded by the action of water, as well as exposure of the reef at low tide and current sea level,[28] shows that the northern part of the channel could have been wider around the 2nd century CE. With the higher sea level of ~0.85 m in the Roman period the entrance channel could have been wider even by as much as ~100 m or more. Without the newly-formed sand-spit to the south and the sand sheet to the northwest, and the coral reef situated much further to the north, the lagoon of Berenike (Fig. 5.2) could have possessed a wider and deeper entrance for vessels than it does now. In comparison, the entrance to the harbour of Myos Hormos has been estimated at approximately 40 m deep (after Blue 2011b).

5.1.3. Maintenance and dredging

Harbour basins, whether natural or man-made, had to be subject to regular maintenance in order to keep them serviceable. If the lagoon at Berenike was used as an outer 'satellite' harbour, rather than an occasional roadstead, it probably needed minor or even major modifications or maintenance in order to keep it in service (e.g. dredging or extending/adapting the margins).

Harbour dredging in archaeological contexts is first recorded in the Mediterranean during the Bronze Age (Pydyn 2011), reaching its peak in Roman times. There is archaeological evidence from sites such as Sidon (Marriner et al.

[28] Reefs cannot grow above water.

2006a, 2006b), Tyre (Marriner and Morhange 2006b; Marriner et al. 2006a) and Marseilles (Morhange et al. 2003; Hesnard 2004) dating from the 4th century BCE, as well as brief accounts of dredging by Vitruvius (*De Archit.* 5.12) (Kirk 1953) and scattered references to dredging harbours, such as at Ephesos (Strabo, *Georgr.* 14.1.24). They show that the management of harbour dredging in the Roman Mediterranean was extremely well-organised (e.g. Bini et al. 2009; Morhange and Marriner 2010a: 29; Mazzini et al. 2011).

Different *collegia* of workers were involved in a variety of activities around the Roman port. Although we are unsure about the specific name for the dredgers, some suggest that *saburrarii* (literally 'sandmen' or 'gravelmen'; the porters of sand used for ballast on ships in Portus) might have been identical or associated with the *collegium* employed as dredgers (Oleson 1988: 156). Some researchers also believe that it may have been a guild of *saburrarii* (CIL XIV.102) that dredged gravel or sand from the harbour basin for ballast (Oleson et al. 2004, 2014).

Members of another *collegium* are also known from Ostia[29] — the *urinatores* (Fig. 5.3) — were used as salvage divers to rescue cargoes from sunken ships (Aldrete 2004: 213; Oleson 1988: 148). As trained and professional divers, *urinatores* would have often inspected hulls and anchorages and assisted in the maintenance of bridge footings and harbour infrastructure[30] (Oleson 1976: 24). They could have also provided aid during dredging campaigns. Such a

[29] From a mid 2nd-century inscription found at Ostia (CIL XIV 303; supp. 4620; Paschetto 1912; Meiggs 1973)

[30] Symmachus (*Relat.* 26) mentions the utilization of such an *urinandi artifex* to inspect the workmanship of a crumbling bridge abutment.

sophisticated structure of working *collegia* might not have been required in a small and potentially seasonally operating provincial harbour such as Berenike. However, some division of labour in the port according to specialisation would have been necessary. [31]

The level of maintenance, including cost and the techniques of dredging are little known from provincial cities such as Berenike, but harbour de-silting was always both time-consuming and costly. Moreover, it must be remembered that dredging was a short-term fix requiring regular costly, specialist work. Designed Mediterranean ports usually included features such as sluice gates, vaulted moles and channels (Blackman 1982b: 199–202), all of which limited the supply of sediment to the harbour, managed its outflow and allowed water to freely flow so that its energy would prevent siltation. No structures diagnostic of this practice have been found at Berenike's natural harbour to date, and on the available archaeological evidence it appears likely that such work was not undertaken on a comparable scale as in other provinces of the Roman Empire.

Stratigraphic signatures diagnostic of dredging within a harbour basin are very difficult to identify, and are usually only identified through high-resolution geochronology and the identification of a chronological hiatus (e.g. Morhange

[31] Representatives of a few *collegia* or their equivalents, such as *lenuncularii* – rowers, loaders and ferryman, *fabri navales* – shipbuilders, *stuppatores* – the caulkers, *restiones* – the ropemakers, *mensores* – measurers of goods, *geruli* – stevedores, *phalangarii* – porters of amphorae and carriers of any heavy load, *saccarii* – porters of grain sacks (Friedman 2011: Fig. 3.7.48 and 3.7.49), or *custodiarii* – warehouse guards (Aldrete 2004: 213; Houston 1980: 166), could have therefore been employed in the port of Berenike. However, in small to medium size communities such as Berenike some workmen might have been involved in one or more tasks. To date we do not possess epigraphic sources to demonstrate the existence of guild organisation (*collegia*) at Berenike (Bagnall et al. 2000, 2005).

and Marriner 2010a). However, given a large enough exposure through harbour sediments it could be possible to recognise truncation horizons related to dredging activity. They may manifest themselves as an uneven bottom surface and a homogenised layer of mixed rubbish from the harbour floor such as discarded objects, industrial refuse and fragments of surrounding vegetation (e.g. van Rijn 1995: 28).

In the instance of Berenike, the hummocky landscape of the Southwestern Embayment could be linked to some sort of disturbance, possibly related to the dumping of the up-cast of dredging. The *nebkhas*, clearly visible in the landscape (Fig. 2.23), were once thought to be potential heaps of dredging refuse. However, the data from the section and core-sampling through one of these coppice dunes, undertaken by the author as a part of her pedogenic survey on site in the 2013 season, determined the primarily aeolian character of these sediments. They were homogenous light soils containing the organic detritus of tamarisk plants. This proves that the *nebkhas* are most likely a modern feature of a coastal landscape and have no direct connection with ancient dredging.

Some abrupt changes in sedimentation were, however, visible in cores from the Central Zone of the SWE but they cannot be clearly attributed to a dredging event. Whilst one harbour floor (Facies E, Group II) is preserved in sedimentological signatures, numerous levels of such floors would have formed over a long period of usage of the harbour at least partially in the same areas. Their absence in the sedimentological record might suggest that Berenike was similar to one of the quasi-archiveless[32] Phoenician harbours (Marriner et al. 2008a), or could raise the possibility that it was situated in a slightly different location. It seems most probable that Roman ships would have been berthed close to (with the difference of possible siltation deposits) the location where Ptolemaic vessels were first moored. This seems to be confirmed by high sedimentation rates observed in the archaeological trenches and augerholes (i.e. Facies D) throughout the period between the late Ptolemaic and Early Roman eras, suggesting that the Roman coastline could have migrated seawards. Due to the fact the site and geoarchaeological chronologies are not as robust as we would like, and the material that could be used for absolute dating is scarce in augerhole samples, the clear spatio-chronological association of the extents of Ptolemaic and Roman harbours are yet imprecise.

We should assume that the harbour basin of Berenike was dredged periodically to keep it in functioning order, and given the practice in use elsewhere in the Roman Empire, this was probably conducted from a shallow barge-like vessel. If dredging from a boat was undertaken, it was most likely carried out using simple methods such as moving sediment from the shallow areas of the basin and into the deeper parts (van Rijn 1995: 27–28).

Other methods might have involved, for example, the dragging of scooping sleds in areas with a smooth bottom, and nets in rougher or rockier areas, or using the scoop and basket technique launched from a special boat or barge (Oleson 1988:

[32] One that did not yield a full and chronologically sound stratigraphic record due to intermittent phases of dredging, which repetitively truncated the 'sedimentary archive'. They could have left none or only a few *in situ* harbour floors as could be possible at Berenike (Facies E).

148). Only three such dredging ships, dating to the 1st–2nd centuries CE, are known, all from an archaeological site at Place Jules-Verne in Marseille, France (Pomey 1995), a harbour which also exhibits dredging events in its stratigraphic sequence (Morhange and Marriner 2010a: 25–26).

Known only from ancient literature prior to this discovery (Hesnard 2004), dredgers such as the Jules-Verne ships (3, 4, and 5) have a rectangular opening in the central area of the vessel for the dredging wheel. The best-preserved, *Jules-Verne 3*, with estimated dimensions of 52 ft x 16 ft (16 m x 5 m), shows that it had numerous repairs before it finally sunk in Lacydon, the ancient harbour of Marseille (Pomey 1995: 463–464). The signs of repairs seem to attest to the prolonged use of these vessels and the dredging techniques for which they were used. They also show the value of dredging boats to the local community that was required to incur the maintenance costs to keep these specialist pieces of equipment fully working. With regard to Berenike and the high siltation rates that it experienced, it is likely that a vessel adapted to dredging would have to be in active use throughout the lifespan of the harbour.

5.2. THE SOUTHERN PROMONTORY

An interesting natural feature of the coastal landscape of Berenike, which must have been viewed as a positive asset at the early stages of the planning of the port, is a large (~670 m x 300 m along the northeast–southwest and northwest–

southeast axes) low-lying reef limestone outcrop. It is often referred to in the Berenike literature as the 'Southern Promontory', or commonly (but inaccurately) 'the Sandbank' (Harrell 1998: 130) (Fig. 1.6). A significant quantity of sediment has accumulated along the seaward margins of the promontory since its formation, linking it to the south with a *sabkha* and to the mainland by a tombolo. The top of the limestone is currently at an elevation of around 1–1.5 m asl at the shore zone, rising inland, and could be associated with the mid Holocene highstand (~6–4 ka BP).

In antiquity, with sea level at ~0.85 m higher, this ridge of higher elevation limestone would have served as a natural first-line breakwater, reducing wave penetration into the port and helping protect the bay. Sand accumulating against the outer edge of the promontory would have been washed northwards by longshore drift, thus producing the sand-spit present at the margin of the channel (Section 5.1.2). The reef limestone promontory may have developed later further towards the southeast into a tombolo, the size of which increased forming a wider promontory. However, the uplifted head of the promontory is very clearly a reef outcrop with a solid limestone core, whilst its southern side has been created due to sedimentary accretion.

In his 1996 season report, Harrell (1998: 13) comments on the similarity between the Southern Promontory and the reef outcrop with the city-tell, in terms of how these features might have affected the siting of the port city. In light of our new understanding of the functional areas of the site, the Roman geomorphology and RSL, Harrell's comparison does not appear valid as the Promontory, at times when it was exposed to winds and waves, would only be *ca.* 0.5 m asl. In his most recent, unpublished manuscript concerning Berenike, Harrell (2001) favours the theory that the seaward sandy eastern part of the Promontory could be an ancient dump for harbour dredgings (also mentioned by Aldsworth et al. 1995: 19–20 and Sidebotham and Wendrich 1996b: 442). Coastal survey undertaken for the current research did not confirm the presence of these spoil heaps. In any case, had they ever existed, it is likely that they would have been eroded by waves.

Harrell (2001: 3) also claims that this area may contain "dredgings from a defensive 'moat' where the northern and southern embayments now exist". Recent discoveries of a large, ashlar wall dated to the Ptolemaic period (Trench BE13-95; Fig. 1.9), and what is interpreted as a gate uncovered in the 2014 season (Fig. 1.10), could indicate some type of defensive system or city wall erected around Berenike at one time, but archaeological excavations to date do not confirm the existence of a moat. The two embayments to which Harrell refers must be the Southwestern Embayment and 'Northern Anchorage' that are currently dominated by the *nebkha* fields (Section 5.1.3).[33]

A few sherds of Roman pottery has been found around the northern tip of the Promontory, both on the ground and from underwater locations (pers. observ. and Steven Sidebotham and Ignacio Crespo, pers. comm. 2012), and early surveys mention possible ruins visible along its edge (Steven Sidebotham, pers.

[33] Areas in the Northern part of the site and within the Southwestern Embayment that are dotted by sand dunes that have accumulated around the vegetation (e.g. Cooke et al. 1993: 357).

comm. 2010), although no excavations were undertaken in the 1990s due to military restrictions and the threat of land mines. Even if ruins, such as lighthouse foundations, remained visible on the ground, the contemporary role of the Promontory as a meeting point for ceremonies of the local Ababda Bedouins (Fig. 5.4) would have probably resulted in them being disturbed, reused or destroyed.

To sum up, the Southern Promontory may have played a dual role in the development of the port. Its primary role, as mentioned, was to act as a natural breakwater that would have sheltered the harbour basins from the damaging effect of storm surges, high winds and aggressive waves in the winter seasons, providing safety to the moored vessels. Given the occurrence of sand-sheets (Section 5.1.3), the Promontory had a negative effect in terms of the long-term maintenance of the port, serving as an obstacle that trapped wadi sediments in the harbour. In its secondary role, it did, however, serve as a useful vantage point from which incoming ships could be identified. This spine of higher-elevation ground would have afforded a panoramic view across the whole bay (Fig. 5.5), and as its rocky northern end is elevated above the rest of the lagoon, it would have served as a perfect head of the harbour — an ancient viewshed.

It is on such a vantage point that a beacon, rudimentary lighthouse or a leading mark (such as a stone cairn or obelisk) is likely to have been erected to guide ships through the channel between the head of the Promontory and the reef, into the harbour. No structural remains are evident now, but given the lack of sediment on the tip of the promontory at present it seems very unlikely that any such material would have survived. A very porous rocky surface, highly susceptible to erosion due to its exposed location on the edge of the Promontory, means that insufficient sediment could have accumulated on the reef in which archaeological material could have been preserved.

5.3. SOUTHWESTERN EMBAYMENT OR 'SOUTHERN HARBOUR'

There has been a great deal of speculation that Berenike's port basin covered the entire area of the Southwestern Embayment (SWE) during the Ptolemaic and Early Roman periods, an area that is now completely infilled with sediment (Figs. 1.6 and 5.6) (e.g. Rądkowska and Woźniak 2011; Sidebotham 2011). This part of the site has been variously referred to in the literature as the Southern or Southwestern Harbour or Port.

The recent excavation of trenches BE14-100 and -101, located in the vicinity of the SWE, exposed a large building with a courtyard indirectly dated by pottery to 1st century BCE/1st century CE. This is in agreement with the interpretations of the augering results, which suggest that the SWE could not have been a harbour basin in its entirety, and only its Central Zone possessed sufficient water depth to be used as a harbour in Ptolemaic times. An eastward migration (progradation) of the coastline is evident from the sedimentological results and is currently supported by archaeological results obtained after the 2010 season. Additionally, the two wall structures provisionally interpreted as wharves (Sidebotham 1996: 25, 27, 29–31, 2000: 74–77, 2008: 313–314, Fig. 14, 2011: 61; Harrell 2007: 167–168) may not necessarily have had such a function. It is equally plausible that instead of a wharf located directly on the sea, the larger wall in the eastern part of the site could have been a protective seawall running around those portions of the city adjacent to the shore.

As discussed in Sections 4.5.1–3 and 4.5.5–6, the ancient beach feature revealed in trench BE11-71 (Facies M), radiocarbon dated to *ca.* 280 cal BCE, indicates the former extent of the inundated area (harbour basin) during the early Hellenistic period, significantly diminishing in size what was believed to be the 'Southern harbour'. Nevertheless, Sidebotham (e.g. 2011), among others, interpreted the entirety of the SWE as the Ptolemaic and/or early Roman harbour based on field observations and magnetic resistivity surveys carried out from 2008–2010.

In his recent summary, Sidebotham (2011: 61) suggests that *"the limited excavations here in 2009–2010 indicate that this was indeed a harbour and that it had been abandoned by the early Roman era"*. This interpretation may be too optimistic given that new data show that the depth of water in the Central Zone would be at least 1–1.5 m (the depth of Facies E + higher sea level + tidal range) and, as such, could have been insufficient for mooring of medium size (to large) ships. There are also obvious issues with the assignment of any of these events to a particular period without a robust absolute geochronological framework. Such interpretations as we have seen above may have seemed valid in the early stages of the 2010 season, when excavations in the 'harbour area' had only just commenced and the four trenches excavated till 2014 in the CSR did not achieve a useful depth.

As already mentioned, Harrell's estimate from 1995 of Roman sea level at 1 m lower that at present (Section 5.1.1) is incorrect in light of new data, which shows that the ancient sea level was ~1.85 m higher than Harrell's original assessment, resulting in flooding a greater area of the SWE and making the existence of a port more viable.

Furthermore, Sidebotham states that: "sometime in the Roman period, perhaps early, certainly later, the western portions of the huge harbour works located immediately south/southeast of the early to middle Ptolemaic industrial area had been abandoned and the piers, breakwaters, seawall, and so on, due to the circumstances of harbour silting, were built anew farther east toward the ever-receding coastline. However (…) the eastern portions of this large southern harbour may still have operated in Roman times" (2011: 61), which is consistent with the geoarchaeological data (i.e. Facies E) possibly suggesting differing extents of the Ptolemaic and Roman harbours.

Sidebotham mentions 'huge' harbour works located directly south of the Ptolemaic Industrial Zone (PIZ), located within the limits of the CSR. Although the results of the geoarchaeological survey allowed the rough delineation of the Ptolemaic harbour (Section 5.4), at present we are still unable to determine the exact extent of the harbour basin in the Roman period and there is no evidence, to date, for harbour works.

Results from the auger survey in the SWE clearly confirm that mean sea level during the Ptolemaic occupation of the port most likely only covered what is termed 'the Central Zone' (CZ) (Section 4.5, Fig. 1.8). The extent of the potential harbour basin would have formed roughly a third of the original SWE area, extending southwards and eastwards from archaeological trench BE11-71. The combined results of the augering survey, primary field observations and the analyses of Facies M, E, E^1, and F (discussed extensively in Section 4.3.1) indicated that the CZ was a relatively shallow basin (see below, and discussion on the gradient sloping in Section 4.5).

The Ship Maintenance Area, which yielded a wooden bollard, ship timbers and ropes (Fig. 5.7), located at an elevation of 3.75–4.75 m asl in the northwestern part of the SWE, was probably associated with harbour infrastructure in the Roman period. However, it seems unlikely, based on the new evidence for the sea level change, that this elevated area was located directly on the water, or close to the edge of the port or the beach, as earlier interpretations suggest. This sheds doubt that it was ever part of a wharf structure *per se*, but makes it very possible that it was more likely used for ship repairs or for locating workshops on land.

5.4 THE CENTRAL ZONE – EVIDENCE OF THE HARBOUR BOTTOM

The Central Zone is the area delineated by the author within the Southwestern Embayment (SWE) based on the results of sedimentological analyses, and which, accordingly with the sea level data presented above (Section 5.1.1, Fig. 1.8), was most likely inundated during the Ptolemaic occupation of the site. This area extends east from trenches BE11-71 and BE11-72, around the *Temenos* of Temples to the north, becoming shallower at the edge of the wadi channel and *sabkha* towards the south, with its eastern edge abutting the Southern Promontory (Fig. 4.32).

The augerhole data indicate that the buried pottery layer (Facies E), which stretches across the SWE and entire Central Zone is, in places, located approximately at the ancient mean sea level (between +0.85 and ±0.25–0.5 m asl of tidal action) and follows the present topographic contour, therefore delineating the Ptolemaic harbour floor and giving indication about its contemporary sea level. Given the abraded and chemically modified characteristics of the pottery fragments recovered from this layer, and their horizontal and vertical distribution, it is likely that this layer once formed the floor of the ancient harbour and that, as mentioned before, the Ptolemaic sea level was at least ~0.85 m higher than today.

The extremely water-worn nature of the abundant pottery fragments is certainly consistent with the type of anthropogenic detritus[34] that would accumulate at the bottom and margins of a busy harbour basin, and possibly on its shores. The oxidised condition of the pottery could indicate periodic sub-aerial exposure of the material on the foreshore of the basin before becoming incorporated into the basal deposits suggesting that the layers were found could have been located within the tidal zone.

Since it was not practical to trace this layer across the entire basin during the augerhole survey it is not possible, without further fieldwork, to provide a satisfactory estimate of the depth of the basin(s), although current data seem to suggest a shallow basin in the antiquity, with Facies E sloping to *ca.* 1.4 m depth below the current sea level at around AH41. Taking into account the ~10° gradient at the break of the slope (Section 4.5), and the ancient sea level calculated as +~0.85 m, a necessarily broad estimate of depth of the basin within the Central Zone would be in the order of ~1.2 m some 80–100 m southeast of the Ptolemaic beach in trench BE11-71 (generally in a range of 1–1.5 m), and sloping towards the east (see Figs. 4.34 and 4.35). This seems to be implying that the careening or beaching of sailing crafts was possible, if required, on the shores of Berenike's inner harbour basin.

Fine-grained sediments of polygenetic origin, most likely derived from fluvial, coastal and aeolian processes, accumulated in the harbour basin. The mixed

[34] Such as for example ballast stones traced using magnetic survey on the harbour floor of Caesarea Maritima (Boyce et al. 2009).

sedimentological signature of these deposits, which seal earlier harbour floor layers is conspicuous in the particle size data (see Appendix 1). However, without a robust geochronology we cannot be sure of the timescales involved with the infilling event, and therefore cannot determine the role that harbour infilling played in the decline of Berenike as a port town.

5.4.1. Mooring and anchoring

The process of mooring a vessel is one of the most poorly studied aspects of everyday life for maritime people of the ancient world. A recent comprehensive study by Greg Votruba (2014) shows that in most circumstances beaching would not necessarily have been the most practical option, even for warships and the smallest cargo vessels. Rather, vessels were equipped with specialized gear for mooring offshore or close to undeveloped shores. This gear included ship's boats enabling access to the shore.

Shallow-draft vessels, particularly galleys, could approach unbuilt shores and use mooring stakes and cables, whilst the ship's landing-ladder would be deployed into shallow water. Quays and jetties, where available, would have facilitated more efficient cargo loading and offloading. If quay space was unavailable a captain would usually choose to moor close to the lee shore but this could mean that even in the harbour the vessel would not always be safe (Blackman 1982b: 193).[35]

Another option for mooring available to ancient seafarers would be on the roadstead, offshore. However, such anchorage had a number of disadvantages and therefore smaller vessels with a shallow draft, which could afford to come closer to shore without threat of grounding, would have usually chosen near-shore mooring (Votruba 2014). It is important to mention that due to the lack of available evidence for mooring infrastructure on-shore, or for mooring offshore at Berenike, vessels could have been careened or beached on the southern banks of the Roman city-tell, and in the SWE, most probably within the Central Zone, according to choice.

Additionally to the lack of infrastructure, at present, the remains of mooring facilities such as stern-cables and land-cables, anchors, mooring stakes, hook-shaped bollards, and so forth are very rare at the site, possibly partly due to the difficulty recognizing this material. At the moment we only know of a few anchors, some chains and one example of a timber post that was so far provisionally interpreted by its excavators as a nautical wooden bollard. It was made of *Cedrus libani*, 28–31 cm in diameter and 66 cm in excavated height, and was 'reinforced with a closely packed ring of pebbles and cobbles set in resinous bedding that formed the lower wharf terrace' (Woźniak 2011: 29).

[35] Tacitus (*Annales* 15.18.23) records that a storm in 62 CE wrecked 200 ships in Portus, possibly because of overcrowding and vessels that did not find space on the quays being moored in the middle of the harbour (Blackman 1982b: 193).

The bollard was located approx. 4 m above current sea level (3 m above ancient sea level), near the top of the CSR (Fig. 5.7), making its interpretation as mooring-related dubious at best. In terms of evidence for anchors, large chunks of iron built into the walls north of the Serapis temple, and near the church, could potentially be the remains of anchors (Sidebotham 2011: 205). Some chain rings recovered from the site have been tentatively interpreted by Martin Hense (pers. comm. 2014) as mooring chains.

We know that in the Mediterranean many Roman harbours of high importance were modest in size and depth, and large roadsteads were not usually used as anchorages (Blackman 1982b: 193). With the lack of sufficient direct evidence at Berenike, it is possible that based on historical and ethnographic evidence, ancient merchant ships arriving at the port could have been brought to the shore at the highest tide (i.e. spring tide as the daily change is between 0.25–0.50 m, see Section 2.4.1), staked with posts and propped up attached to mooring poles, bollards or cables, allowing them to re-float at the change of tide. The most likely locations for such a 'beaching' would be on the banks of the Central Zone and on the eastern slopes of the City-tell.

As in other ports of this type, ships and boats in this part of the SWE and Lagoon could have also stayed anchored in the middle of these bodies of water, perhaps attached to a pontoon allowing for a greater water depth during tidal changes. In this scenario, lighters and smaller crafts would then have been required to load and off-load the moored vessels such as that depicted on one of the mosaics from the Piazzale delle Corporazioni at Ostia (Friedman 2011:

Fig. 3.7.23). Given that the location of Berenike is well sheltered from the elements, vessels could also have also moored at the roadstead (see Section 7.3).

5.5. THE *TEMENOS* OF TEMPLES

Targeted excavations of the *Temenos* of Temples commenced in 2010 following a geomagnetic study that revealed outlines of structures in the area. The structures were situated on one of the most prominent *nebkhas* roughly in the middle of the SWE (Fig. 1.8). The results of the archaeological investigations that followed exceeded expectations, ultimately uncovering an exceptionally well-preserved group of votive edifices (Rądkowska et al. 2013).

The current interpretation of the Temple of Lotuses suggests that the latest phase of construction, built from relict coral heads, which incorporated parts of an earlier ashlar structure and was dated to 4th–5th century CE, was devoted to "multiple creeds…, including one perhaps of South Arabian origin [36]" (Rądkowska et al. 2013: 209). Of special interest is one of the earlier buildings in the group that may have had a water-related function, potentially a tidal pool used for ablutions. This small building was constructed of white gypsum/anhydrite ashlars that could have been submerged during high tide.

[36] Rądkowska's interpretation is based on numerous findings of votive objects similar to those from southern Arabian sites such as Khor Rori and Qana.

Late Ptolemaic sea level has been estimated here to have been ~ 0.85 m above present sea level. Given that only small changes in eustatic sea level would be expected during a 300-year period — between the late Ptolemaic and early-late Roman period — it is highly likely that Roman (at least early Roman) sea level was also around +0.85 m above modern sea level. The location of the *Temenos* so close to such ancient sea level is enigmatic, and begs the question of why the temple was built in such a location, and what the area that it was built on would have looked like at the time of its construction. Based on the evidence it was most likely an island either:

i. permanently surrounded by water on a natural uplifted platform in an embayment;
ii. seasonally flooded by tidal action;
iii. located on just slightly higher ground surrounded by mud-flats or salt-marsh, that could have developed in a partly infilled harbour basin in Late Roman period;
iv. connected with dry land by a peninsula; or,
v. situated on dry land (the embayment already being infilled) during its usage?

Establishing the relationship of the *Temenos* with the site and the local land- and sea-scape is important for our understanding of the origin, role, function and significance of these sacred buildings for the people of Berenike but difficult without a refined chronology. Despite this, the geoarchaeological survey data have helped elucidate some associations and relationships with other areas of the site. It now seems likely that the temples were located on what would have been a small flat island during the time that the Central Zone was being used as a commercial port, when sea level was ~0.85 m higher than it is today. Situated

~2 m asl on an elevated, calcareous platform (Fig. 5.8), this area would have been encircled by water certainly during the Ptolemaic period.

As we see in Section 4.3.1, the well-cemented calcareous layer (Facies N, Group VI) covers the *Temenos* up to ~20 cm below the present day ground surface. It is most likely partially dissolved and re-precipitated marine sediment that formed at the margins of the island as evaporitic deposits (a sort of gypsum crust) mantling a bedrock core (*cf.* Drake 1997). Alternatively, it may be of anthropogenic origin, possibly as a prepared calcium-carbonate bonded foundation base made in advance of the temple construction, or a *Temenos* floor, or a natural feature formed through the dissolution of gypsum ashlars from walls during their usage. If the first hypothesis is to be believed then we might suppose that the extent of Facies N relates to the coverage and minimum depth of the water level around the island. Its extent and location within the Central Zone shows that it was possible to walk to the island (if it was still such in Late Roman times) at low tide, but necessitated a boat or canoe to gain access at a high tide. This could have given the '*Temenos* Island' a special place in terms of its cultic function and since it was located within the harbour we can hypothesise that it may have been frequented by sailors and used in a maritime cult.

Other examples of temples frequented by sailors were found in caves located on small islands, such as the 4^{th}–2^{nd} centuries BCE site of Phoenician Grotta Es Cuyam on Ibiza that was referred to as an "ideal place of worship for navigators and sailors"; or a small building of sacred association, just east of Carthage's merchant harbour that was described as a 'sailor's shrine' (Brody 2005: 180; Christian 2014: 385–387).

An indirect strand of evidence that may support an island origin for the land upon which the *Temenos* was built, and its possible connection with maritime cult, is a huge coral head situated in a pit (about 0.40–0.45 m in diameter) that was devoid of archaeological material and located in the southern part of the temple (Fig. 5.9). The pit has been dated to between 4th and 5th centuries CE (Rądkowska et al. 2013: 217–218, Fig. 2B and 5) and contained four wooden offering bowls indicating a votive character. We can hypothesise that such a 'maritime votive' could have be used by sailors who safely passed the treacherous reefy coasts of the Red Sea, giving the *Temenos* its nautical character — a common association recorded in temples located on island settings and in the vicinity of waterways.

5.6. THE CRESCENT-SHAPED RIDGE AND 'SHIP MAINTENANCE AREA'

The Crescent-shaped Ridge (CSR) is a prominent feature in the Berenike landscape and has for many years been thought to be a man-made structure with a natural core (Fig. 1.8). It was also believed to delineate the edges of the harbour at Berenike (Figs. 1.12 and 1.13; Rądkowska and Woźniak 2011; Sidebotham 2011: 60–61). This hypothesis was supported by the observation of five long parallel, southward-orientated ridges, also visible in the landscape and easily distinguishable on satellite images and the geomagnetic survey. These regularly spaced ridges extended from the CSR into the bay and were originally interpreted as jetties. However, the delineation of the palaeoshoreline, with the remains of Ptolemaic hearths, during the geoarchaeological survey shifts the known water's edge further to the east by at least 100 m in the Hellenistic period, therefore placing these purported jetties on dry land.

There is very little unambiguous evidence from archaeological work to date to suggest the existence of any kind of man-made port installations or infrastructure at the site. However, excavations in the northern area of the ridge, in trenches BE09-54, BE10-62/64, BE11-78 and BE14-98 (Woźniak 2011; Woźniak 2015 *forthcoming*; Osypiński 2015a *forthcoming*; Crespo *unpublished report*) have revealed ship timbers including a frame (Fig. 5.7, above), evidence of tarring (Woźniak 2011: Fig 4.19), and a wooden bollard (Fig. 5.7, below; Woźniak 2011: Fig 4.5–4.8), all of which could be taken to represent harbour infrastructure and activities such as a ship repair workshop. The bollard was first interpreted as a mooring pole, but it could just as easily have been a feature located in a dry dock or in a ship-repair, maintenance and dismantling area (Fig. 5.10). Some glass fragments discovered in the trenches indicate an early 1st century BCE dating for the establishment of this 'Ship Maintenance Area' (Woźniak 2011: 41).

Despite being much older, the timber from the Pharaonic port of Mersa/Wadi Gawasis appears to indicate that on returning to port, ships that had spent a considerable amount of time at sea could have been disassembled (Borojevic et al. 2010; Ward 2000: 126–128, 2012: 219). However, if such a practice was undertaken in winter it would be worthwhile to investigate whether timbers were re-used in the town or re-assembled to form a new vessel in the spring.

It is possible that old ships or those too damaged to warrant repair were dismantled and reused. Damaged and sea battered vessels would need to undergo repairs whilst the fleet would require maintenance and for such a purpose a large and well-protected storage and repair area would be necessary (Fig. 5.10). The maritime maintenance would logically have to have been undertaken close to the port, and since the Ship Maintenance Area is located some 3 m above the ancient sea level, it could have served as a dry and protected storage and workshop area.

Finds that might be associated with woodworking, such as a plank of wood interpreted as either a half frame or a futtock from Pit 8600, and wood chippings from Trench 16A, have also been found at Myos Hormos (Peacock and Blue 2006). They seem to confirm that the Islamic port maintenance and potential ship-building area in Quseir al-Qadim was located directly on the edge of what is believed to be a marine/embayment interface (Blue et al. 2011: 185). Concentrations of other maritime artefacts in two areas around Trenches 7A and 14 confirm their proximity to the Roman harbour and the loading and off-loading area (Blue et al. 2011: 188).

Numerous barnacles found in association with wood impressions and patches of resinous pitch were also found in the vicinity of Trenches 10 and 14 at Myos Hormos (Whittaker 2006; Whittaker et al. 2006), representing evidence of the cleaning and antifouling of ship's hulls (Section 7.2.2). The port location inferred from this evidence is similar to the Ship Maintenance Area in Berenike. The presence of ballast on higher ground and farther inland at Myos Hormos is similarly reminiscent of the basalt ballast scattered on top of the CSR in Berenike. The significance of these numerous similarities further confirms the 'sister-ports' connection between Berenike and Myos Hormos with both ports being used for similar purposes and in a similar way, although on a different scale.

Even though there is no unequivocal evidence for a ship repair area at Berenike dating to the Ptolemaic period, possible evidence for re-fitting of vessels in this port comes from papyrology. A papyrus from the Fayum (*P.Petrie* III 66a), dated to 224 BCE, mentions a large deep-water vessel (possibly an *elephantagos*) that was outfitted at a port named Berenike (Mitteis and Wilcken 1963: 533–535; Sidebotham 2008: 307), although we cannot be sure if this is the same port given the popularity of this name.

Archaeological evidence thought to relate to buildings associated with trade, commercial activities and port infrastructure have been found during excavations within the Southwestern Embayment (trenches BE11-71 and -72), refuting the hypothesis that the CSR was used as a Ptolemaic or Roman wharf directly on the waterfront. Buildings located on its eastern side, inside the SWE, would have been sheltered from sand storms, winds and flash floods originating in the mountains, making the 'inner' part of SWE a favourable location for light harbour infrastructure (Figs. 1.12 and 1.13). In terms of a Ptolemaic ship-repair area, if this did exist, the area encompassing trenches BE11-71 and -72, containing the remains of hearths where the Ptolemaic beach was recognised, could potentially have served this purpose.

5.7. THE NORTHERN ANCHORAGE – THE 'NICHE'

Hypotheses have been proposed regarding the location of a possible second anchorage in the northeastern area of Berenike that could also have been used to accommodate small vessels (Sidebotham 2011: 61) (Figs. 1.8 and 1.12 top part of the drawing, in the vicinity of a 'mystery cult centre, no. 8'; and 3.11 where the Northern Anchorage is marked by the yellow BE12 transects). Such an area could have hosted prestigious vessels, possibly the boat of a local governor. This hypothesis was put forward based on two observations. First, a northeast–southwest, 1.3 m wide and 6.6 m long, apparent 'seawall' with a number of wooden bollards was uncovered on the northeastern edge of town in Trench BE97/98-17 (Fig. 3.12), "beneath a temple or major public edifice (…) and dated with a *terminus ante quem* to the first century CE" (Sidebotham and Wendrich 2000: 74–75, 77, Fig. 4.5; Sidebotham 2011: 61). Second, the results from a geomagnetic survey undertaken in 1999 did not reveal any structures in this area, perhaps suggesting the presence of a body of water instead (Steven Sidebotham, pers. comm. 2012).

This hypothesis was tested by the augerhole survey and georadar survey undertaken in the 'Niche' (Section 4.2 and further 4.5 for results). This 6,600m^2

area is situated between two north–south aligned promontories, with a temple located on the eastern arm and high-status buildings on the western arm (Fig. 5.11). It is also adjacent to the ridge on which trenches BE98-23 and BE99-32 are located to the southwest, and trenches BE97/98-17, BE96-7 and BE95-4 to the southeast (Sidebotham and Wendrich 1996a, 1998, 1999, 2000, 2007a). Archaeological evidence from occupational Phase II found in trench BE97/98-17 shows this purported 'seawall' or 'a pier facing the water' (Sidebotham and Wendrich 2000: 74–75, 77) (Fig. 3.12).

The results of the augerhole survey have shown that certain elements of the stratigraphy in the 'Niche' were deposited in an anaerobic environment, possibly consistent with a submarine context. This evidence provides some credence to the existence of a second harbour. However, owing to the lack of datable artefacts and an absence of organic material for radiocarbon dating, it is not possible, at this stage, to ascertain with certainty the presence of a water body in this area that could have been used as second harbour contemporaneously with the sites occupation. Whilst it is suggested here that this area could have been partially submerged during the Ptolemaic and maybe even the Early Roman periods when the sea level was ~0.85 m higher, its distance from the sea and its elevation make it an unlikely location for a significant anchorage for larger vessels. Nevertheless, small boats with shallow draft could potentially access this part of site and be pulled out onto the beach in the vicinity of the governor's house.

5.8. CITY-TELL — THE EVOLUTION OF THE *SABKHA* AND MARSHLAND

Previous geological research has suggested that Roman Berenike was strategically located on an island formed by an elevated reef-limestone outcrop (e.g. Harrell 1996: 112–126, 1998: 125–130). In this scenario, such an island would have been located either just offshore or connected to the mainland by a narrow isthmus (subsequently surrounded by *sabkha* to the north, east and south). Harrell (2001) later proposed that Berenike's topography and sedimentary history corroborate its island status; a scenario that was also supported by archaeological findings (Sidebotham and Wendrich 2007b: 369–370). Sedimentological data obtained for this research confirm that the *sabkha* could well have formed after the founding of the city, even possibly immediately following its abandonment, thus giving the appearance of an ancient city surrounded by water on three sides (Section 5.7). However, without a more refined geochronology, it is not possible to estimate the rate of *sabkha* formation.

Based on field observations and the analysis of geological maps, Harrell (1998) claimed that the terrace on which Berenike was built attained a maximum elevation of 3 m above current high tide level (ahtl). He also argued that the underlying limestone reef dated to 5000 BP rises between 1 to 2 m amsl (Harrell 1998: 129). However, this elevation and the probable existence of a significant water column that supported life above the reef, it is more probable that the higher terraces have an origin in the last interglacial (MIS 5e, ~120 ka BP), whilst the lower 1–2 m terraces and wave-cut notches are more likely associated with the mid Holocene highstand (~6–4 ka BP) (e.g. Lambeck et al. 2011).

Examination of the *sabkha* environment at Berenike is likely to provide important information regarding sedimentation regimes at the site, and how these might reflect the changing configuration of the archaeological landscape. Harrell (1996: 112–126) also noted this possible connection in some of his work at the site. Taking these ideas further, the study of the *sabkha* sediments could also help determine the degree of fluvial sediment delivery to the site and the extent to which input from the wadi (if any) occurred during the time of occupation of Berenike. To explore and test some of these ideas, one of the aims of this research was to delineate the braided-plain of the alluvial fan draining from Wadi Kalalat (AH52–53), and to establish the depth of these deposits (Fig. 5.12).

Detailed survey showed that the *ca.* 11 km wide alluvial fan extends over the coastal plain, draining into the sea in the vicinity of the site only 30 m south and west of the CSR. It then changes course eastwards into the *sabkha* area, ultimately draining into the SWE. Sediment accumulation from a second alluvial fan (Wadi Mandit), located due west from the site, is partly limited because of two barriers protecting the site from this side: the CSR and limestone buttes parallel to the coast (Fig. 5.12 inset).

If the city was founded on an island surrounded by sea or salty marshland, it is likely that such a setting would have been mentioned in historical sources, many of which are accurate in describing the topography of ports and any special characteristics of their locations (e.g. *PME* 30 describes the location of the port of Dioscorida on an island). In terms of the attractiveness of the site, it is uncertain whether or not the marshy area would have been exploitable. If a marsh was present when the Roman port was in use, this could either increase Berenike's appeal as a strategic location that was inaccessible from the hinterland, with a better potential for the development of light soils suitable for horticulture or light agriculture using organic-rich marshy sediments. On the other hand, it could have hindered the approach to the site from the hinterland and/or accessibility of the site from the sea, thus reducing its attractiveness.

5.9. THE PTOLEMAIC INDUSTRIAL ZONE AND FORT ON THE COASTAL PLAIN

Human occupation and exploitation of the coastal plain during the early stages of Berenike's existence in the early to mid Ptolemaic period has been largely ignored until recently. The Ptolemaic Industrial Zone (PIZ) was a production centre primarily for metals, including iron and copper alloy, and the manufacture of bricks (Sidebotham 2008: 165). The PIZ, together with the Ptolemaic Fort, are located in the western part of town (Figs. 1.8, 1.10 and 5.13), sheltered from wadi sediment delivery by the limestone buttes to the west.

A shift in construction techniques and building materials was well evidenced in the PIZ, with limestone blocks and other cobblestones used as the primary building materials from the early to mid Ptolemaic period to a dominance of sand bricks in the late Ptolemaic and Early Roman periods. Sidebotham (2011: 57) suggests that this could reflect a change in the ethnic demography of the local population leading to the exploitation of different resources as building materials. This is an interesting observation, but there could be another reason for this development, possibly relating to natural (climate-driven?) changes in the landscape. These changes may have resulted in different exploitation strategies being adopted in different areas of the site, and hence the use of varying construction techniques. Alternatively, the over-exploitation of one type of material may have prompted the use of others, or different building techniques could have been economically driven or linked to changes in the popularity of a particular design.

It is likely that the PIZ afforded the early Ptolemaic inhabitants better access to the port, and that the coastal plain was well suited for building a fort and holding imported elephants in large pens. Potential 'elephant-pen' installations would have been connected directly with the area just beyond the CSR to the north and west, where the so-called 'elephant ditch' containing an elephant tooth was uncovered in trenches B10-66 and -68 (Osypiński 2015b *forthcoming*).

The PIZ was well protected from sea winds and storms due to its location west of the CSR and east of the limestone buttes. However, the lower-lying areas of the PIZ could have quickly become impractical as an occupation space due to flooding or increased waterflow to the wetland area. Whilst we cannot currently establish whether Ptolemaic layers underlie Roman deposits on the city-tell, the distribution of Ptolemaic findings across the site seems to suggest the spatial separation of both settlements. A shift in the role of Berenike from an elephant transhipment port to a trading port for smaller volume luxurious goods might have meant that the large flat area in the western part of town, where fort and animal pens were formerly located, was not required anymore, and so settlement in Roman times moved to a more attractive area on the uplifted coral reef outcrop.

5.10. SUMMARY

Berenike was founded in a harsh, marginal environment where relatively small environmental changes (e.g. fluctuations in sea level, changes in coastal geomorphology, increase in seasonal floods) might have had a dramatic effect on the short- and long-term viability of the site. It is only by understanding the changing landscape features that we can make sense of the complex archaeological data and their landscape context within the site. This chapter has analysed the new data key to the re-interpretation of vital aspects of the formation and exploitation of different landscape zones within the site. This has allowed for the interrogation of old questions in a new light, resulting in novel interpretations of well-studied landscape features.

The main outcomes of this discussion show that:

i. there has been a drop in relative sea level of ~0.85 m since the Ptolemaic period;

ii. the role of the Southern Promontory was both as an ancient viewpoint (with a potential beacon to guide vessels), and a barrier guarding against wave action and providing shelter to the bay. It also acted as a trap for alluvial sediments resulting in the silting-up of the lagoon, most likely contributing to the decline of the harbour;

iii. the size of the harbour in Ptolemaic times was outlined and limited to the Central Zone of the Southwestern Embayment, with one of the harbour floor levels identified;

iv. the previous interpretations regarding the role of the CSR as a harbour wharf with piers are suspect. The location of the Ship Maintenance Area and the interpretation of the function of a wooden bollard as a mooring device have also been re-evaluated;

v. new data have been generated that provide clues as to the location of the *Temenos* of Temples and the 'Northern Anchorage' (the 'Niche');

vi. the attractiveness of the location of the Ptolemaic fort and Ptolemaic Industrial Zone have been reinterpreted in light of the potential environmental marginality of the location.

This discussion has demonstrated that the founding, evolution and cultural history of this coastal port can be assessed through the examination of its local landscape dynamics. This is not to say that the point of view in which we ascertain how environment influenced how people responded to it is the only way in which the site can be understood. Of course, we must be mindful of the idiosyncratic nature of the peoples who founded populated and used the site, not to mention the political powers that 'controlled' it, and finally those who studied it many centuries later. Nevertheless, fundamental questions can still be addressed in a meaningful way by understanding the changing environment during the various occupation periods. It is only once we have reconstructed that dynamic environment that we can begin to situate people within those landscapes, to explore the interactions between them and to estimate the degree of linkage between the archaeological narrative and the influence of the changing landscape.

6. ‘PARAMETERS OF ATTRACTIVENESS’ OF LOCATIONS OF HELLENISTIC AND ROMAN PROVINCIAL PORTS OF TRADE: BERENIKE AS A CASE STUDY

Ports and harbours can be located in extremely diverse political, landscape and geomorphological settings. They are not only hubs connecting different cultures, but also centres of social and cultural diversity and hybridity (e.g. Falck 2003, Ilves 2011). Owing to their favoured positions in the coastal landscape, and functional and cultural sub-divisions within them, ports constitute excellent study areas for understanding ancient marine technologies, cultural interactions and large-scale geographic networks. It is therefore necessary to develop a deep understanding of the environmental context and landscape setting to fully appreciate the reasoning behind the choice of their land- and sea-scape locale.

To this end, this study has identified and quantified a number of ‘Parameters of Attractiveness’ (hereinafter referred to as PoA) to determine the extent to which the landscape and physical environment dictated the location of a Hellenistic or Roman provincial ports of trade (or one of its trading counterparts), and whether other variables (e.g. geopolitical location, proximity to existing trade routes) were equally — or more — important. These variables were primarily derived from a comprehensive review of both modern and ancient literature pertaining to the physical and socio-political characteristics of port sites and supplemented by available data from the case study site, *Berenike Troglodytica*. Four primary categories of variables have been identified as playing a role in the siting of new ports. These can be broadly divided into: i) Sea; ii) Land; iii) Resources; and iv) Socio-political and economic factors. Detailed descriptions of each category and their application to the site of Berenike are provided in Sections 6.2–6.5, followed by a discussion of these results in Section 6.6.

The questions listed below were originally part of a list proposed by Rickman (1985) and discussed also by Karmon (1985) in a study of Mediterranean harbours. They are highly relevant to the issue of Paramteres of Attractiveness (PoA) and as such drove forward the initial strategy to quantify the variables that may be included in a list of Parameters of Attractiveness.

i. What factors influenced people's decisions to position ports and harbours in particular areas of the coastal landscape?
ii. Was the choice purely pragmatic (relating to landscape and resources for instance) or potentially also linked into the politics of the region?
iii. How did port towns integrate and communicate with hinterland routes and other systems of communication, such as rivers, canals and lagoons, and with each other?
iv. What was the relationship between the ports and areas producing raw materials (agricultural goods, quarries, etc.), and were the ports also centres of manufacture?
v. Which of these ports were the centres of population and consumption?
vi. What factors influenced the economic and financial success of a port – natural factors or human need

vii. What factors triggered the decline of a port city (e.g. geographical, political, social or economic changes)?

viii. Who maintained the harbours and at what cost?

ix. Given the presumably high expense of maintaining a functioning port, how would individual municipalities have financed them, e.g. from harbour taxes, loans, benefactions from local magnates, or merchants guilds, or was it always an external source such as a state treasury?

x. Can ancient harbour sediments provide information about human-environment interactions?

6.1. QUANTIFICATION METHODS

In order to carry out a semi-quantified assessment of the Parameters of Attractiveness for the port of Berenike, a series of hierarchical sliding scales (1 to 5) was designed. These were specific for each parameter in the four categories identified (sea, land, resources, and socio-political-economic). In this model the higher the value, the more favourable the location. As such, the highest score in each of the parameter groups would mean the most favourable site from the point of view of its sea or land position, access to resources, or its position in the socio-political-economic landscape. It also suggests that not only did these parameters influence the initial sitting of a port, but also, once founded, they affected the degree to which a harbour and the associated town may have developed into an important port or a regional hub. Given that each of the parameter groups has a different number of variables within them, the data were normalised using a simple formula: *total score/total possible score*.

6.2. SEA PARAMETERS

The Sea parameters are variables that can affect marine environments, such as winds, currents, waves, reefs and maritime resources (Table 6.1). The achievements of ancient sailors and navigators reveal a deep local knowledge of the marine environment and a symbiotic relationship with the tides, currents, waves and winds. Similarly, the designs of ancient vessels prove that ancient shipwrights had an insightful understanding of materials and ways of using them to allow vessels to handle a diverse range of weather conditions. The suite of variables outlined below are therefore derived from a detailed appraisal of ancient navigational techniques and ship designs at the case study site Berenike and from the ports beyond, and will allow for a better appreciation of the natural, physical and geographical characteristics of Hellenistic and Roman provincial harbours and their Indian Ocean (including Gulf of Aden and Persian Gulf) counterparts, and to establish possible navigation patterns and draw out the major factors that could have been influential in ancient navigation.

Table 6.1 Semi-quantification of the Sea parameters used in the study and relevant scores for the site of Berenike.

CATEGORY: SEA PARAMETERS			
Parameter	*Parameter characteristics*	*Berenike score*	*Berenike justification*
WIND	***Seasonality, strength and direction***	**5**	Seasonal, strong, northerly winds
1	Only seasonal, very weak (or too strong) winds in opposite directions		
2	Seasonal winds in desirable direction but either too weak or too strong		
3	Good winds (strong most of the time), seasonally in desirable directions		
4	Strong winds in prevailing in desirable directions, seasonal		
5	Strong winds prevailing in a desired direction		
CURRENTS	***Strength, direction, seasonability and predictability***	**3**	Strong southerly currents
1	Extremely strong, unpredictable patterns of currents in undesirable directions, ripples, river currents		
2	Strong and sometimes unpredictable currents, ripples, river currents		
3	Seasonably favourable currents in either strength or direction		
4	Favourable currents – in either strength or direction		
5	Favourable currents – in both strength and direction		
WAVES	***Strength, size, length, seasonability***	**5**	Very minor wave range
1	Extremely strong and high, short waves hindering any form or seafaring or mooring		
2	Strong and high waves, seasonal		
3	Low and long waves, seasonal		
4	Little or only seasonal waves		
5	No waves or only waves that can be beneficial to sailing		

CATEGORY: SEA PARAMETERS			
COASTAL GEOMORPH	*Shoals, reefs, rocky coast, space to manoeuvre and to set out beacons at the entrance of the port*	3	Reefs and shoals; potentially narrow entrance to the port; shallow shelf
1	Very rocky, dangerous coast with high tidal range, rip currents, prevailing winds against the harbour direction, little space to manoeuvre and occasional fog		
2	Dangerous coast, little space to manoeuvre but approach still possible and easy enough for an experienced navigator		
3	Approach relatively difficult for a navigator who does not know the area. Only seasonally favourable winds		
4	Relatively easy approach with shoals and reefs which are well known to the navigators; enough space to manoeuvre		
5	Easy approach to port, no underwater dangers such as shoals or reefs, suitable area for manoeuvring; beacon at entrance of harbour to aid night-time and fog navigation		
TIDAL RANGE	***Range and size***	**2**	Approx. 0.5 m; shallow shelf meant that the water retreats over a large distance
1	Difficult access, large tidal range		
2	N/A		
3	N/A		
4	N/A		
5	Easy access, low tidal range		
	Berenike Sea parameter total score	18/25	**0.72**

6.2.1. Winds: dealing with gusts, gales, and squalls

The prevailing forces propelling ancient sailing vessels along trade routes were atmospheric winds. The reliance of trade networks upon the correct prediction of wind speed and direction was so great that mitigation for accidents occurring in strong winds was included in both Greek and Roman legislation (*Aquilian laws,* D.h.t. 29 §3, Grueber 1886: 218; and *The Rhodian Sea Law* (*Νόμος Ῥοδίων ναυτικὸς)* Ashburner 1909: cclxii). Merchant vessels playing the Red Sea and Indian Ocean in antiquity, and using ports such as Berenike, were usually propelled by sails rather than the oars (although some might have also carried oars onboard). The dominant sail design at this time was the square sail in Roman tradition (Sections 7.1.3 and 7.2.3), which made large vessels more stable but potentially less accustomed to sailing close to the wind (e.g. Casson 1971; Campbell 1995).

It would be the likely wind conditions and the choice of vessels that could safely exploit them that would be a chief consideration when planning ancient shipping campaigns. Whilst scholarly discussion about the comparison between the performance of lateen and brailed square sails is ongoing (e.g. Wilson 2011a, 2011b), Whitewright (2008) shows square sails to hold similar capabilities in terms of long-distance sailing, although lateen sails are regarded as superior in entering and exiting harbours (Casson 1971).

Berenike's location is extremely favourable with respect to winds, being situated in a part of the Red Sea/Indian Ocean that receives seasonal, strong winds with northerly seasonability, and as such scores highly — 5 — in this PoA category (see Table 6.1). The wind patterns on the Red Sea meant that vessels arriving from the south would often be sailing into Berenike's harbour between January and March, and from April/May onwards if arriving from the north (Facey 2004: 9–11). The passage north was viable owing to the southeast monsoonal winds that attained Berenike's latitude, supplemented by the southerly and offshore (diurnal) winds.

The northerly winds that prevail on the Red Sea for most of the year allowed vessels from the northern Red Sea to sail to Berenike but ensured that the passage north was much more laborious (Section 2.3.2). This also had an important implication for port sites such as Myos Hormos or Clysma, which would score poorly on this parameter (e.g. 2) owing to the presence of seasonally weaker winds. The favourability, or not, of wind is also depended upon the technology of the time and its ability to deal with wind conditions making this parameter culturally specific and dependent upon equipment and expertise (this is addressed in Chapter 7).

6.2.2. Currents

Ocean currents are movements of water in response to prevailing wind patterns, variations in salinity, water temperature and water density. Wind-driven currents are strongest when wind drives surface water to the gulfs, through narrow straits, or into and out of estuaries and lagoon straits (Thurman et al. 1999: 208), as is the case at the southern end of the Red Sea and, on a smaller scale, at the entrance to Berenike harbour. Tidal currents in the open ocean rarely exceed 2 knots, but strengthen where flow is channelled through gulfs, island straits, or estuary and lagoon entrances, where they can attain speeds of up to 9 knots (Admiralty 1995), creating extremely challenging navigational conditions.

These marine and riverine phenomena can make nearshore and riverine navigation (and mooring) extremely dangerous, and their strength, direction, seasonality and predictability would have been important in the prospecting for the site of a new port. The currents at Berenike are strong but only favourable in a southerly direction, thus the site attracts only a moderate PoA score of 3 in this category (Table 6.1). The other part of the justification for such score is that strong currents that might have existed at the entrance to the lagoon at the time when it was much deeper could have, potentially, hindered smooth operation of entering and exiting the port. Currents are to a large extent predictable, and so their position and speed would have been well known to experienced navigators. Information about currents would have been passed on via oral tradition and via specialist texts such as the *Periplus Maris Erythraei* .

6.2.3. Wave action

Waves are extremely efficient energy transporters and are important in navigation, with implications for sailing conditions. Upon reaching the coast, waves change height and direction due to shoaling and the effects of refraction and diffraction (de Graauw 1986). Waves can be potentially devastating to vessels (see Casey 2011 on the subject of rogue waves), and so assessing wave strength, size, length, and seasonality would need to be taken into consideration by ancient port prospectors. The hydrological conditions on the Arabian Sea indicate that almost 50% of swells for the months of August are classified as 'heavy', whilst around the Arabian Peninsula the ratio is 56% (Beresford 2013: 222), however the Red Sea waves are recorded as much lower and the coastal configuration at Berenike, when the harbour was operational, would have meant that waves broke on the Southern Promontory, which sheltered the Lagoon and the SWE.

The ability to withstand these large swells would have been one of the considerations of ship designers and even though capsizing a sailing vessel is difficult even in large waves (due to the trigonometry of the behaviour of mast and keel and their length ratio) examples of large, breaking and barrelling swells violently breaking masts and then toppling vessels are still well known. Sailing on top of long waves, if performed proficiently, could however increase a vessel's speed as long waves move quickly and lose relatively little energy, therefore propelling the boat, whilst short waves move more slowly, consequently losing more energy and slowing the craft (Pethick 1995: 13) (Fig. 6.1).

The approach to the harbour mouth at Berenike would have been treacherous due to the extent of the underwater coral reef but at the same time this reef acted as a first wave break before much lowered and reduced in strength waves reached the Southern Promontory. This would have been obvious to the ancient prospectors and the configuration of Berenike's immediate coastline would have been highly attractive owing to this sheltering feature in topography. Berenike scores very highly in Wave PoA (score = 5) due to the fact that not only it is sheltered but the wave range at Berenike is generally very low and does not disrupt the incoming or outgoing traffic.

6.2.4. Near-shore coastal shelf geomorphology and bathymtery

The shape and configuration of the near-shore environment (or 'the hard bits around the edge') would have been extremely influential in the locating of a new port, most likely only second in importance to the presence of a natural sheltered harbour or lagoon. When considering the final approach to a port, a number of factors would have been taken into consideration beyond those already mentioned such as prevailing winds, currents, and tidal cycle, including submerged obstacles such as rocks, reefs and shoals, incline and depth of coastal shelf, and space to manoeuvre. However, the way in which they were dealt with by ancient mariners was culturally and temporally specific and depended upon the level of technology available to a particular cultural group at a particular time in history.

A technical innovation to help mitigate for near-shore, submerged obstacles was the introduction of sounding weights, used in both navigation and mooring (Oleson 1996, 2000, 2006, 2008; Kirkland 2010: 3). The technique of the sounding line was first reported by Poseidonius who calculated the Mediterranean to be a thousand fathoms deep (Strabo, *Geogr.* 1.1.37). This method could be used to assess the distance from the coast, the bathymetry of the sea floor, and to identify a safe passage to (or from) the port (Morton 2001: 207).

Berenike scores 3 in the coastal geomorphology category for a number of reasons. Although taking into consideration each of the above-described variables separately, it is clear that they would not have generated such a low score. However, when combined they show that Berenike's nearshore geomorphological setting was only partially satisfactory. First, the underwater reefs and shoals around the site are clearly visible on satellite imagery and empirical water depth testing by the author recorded a depth of between 1–1.5 m depending on the tide level. Even with the ~0.85 m higher sea level in antiquity they would still have represented hazards for ancient sailors. With an over half a metre increase in water depth the shallow coastal shelf surrounding the site would have remained risky for ancient navigators.

As Pedersen (2015: 128) shows, the ubiquitous Red Sea reefs blocked access to most of the coast, preventing vessels from reaching the shore. At Berenike, however, a break in the reef located at the mouth of a wadi or a *sharm*[37] (Murray and Warmington 1967: 25) was present due to the flow of fresh water precluding reef growth. Whilst size and depth data for the lagoon entrance remain unclear, the deepest part of the access channel is likely to have been almost as narrow as it is today, whilst the overall depth would have been in a range of 100 m. It seems that increased coral growth within the channel in the last 2000 years could have been a result of decreased fresh water output from the wadis, most likely due to sediment accumulation on the sandbanks of the lagoon entrance in the later stages of site occupation (and the creation of *sabkha*). Even if the entrance was much wider, the reefs surrounding the area ensured a potentially perilous entrance to the port, raising our expectations for finding shipwrecks in the vicinity of the roadstead.

6.2.5 Tidal range

The tidal range of different basins, seas and oceans can be very different depending on a number of variables. Given that the Red Sea is a semi-enclosed basin (similar in fact to the Mediterranean) the tidal range is very small, in the region of 0.6 m (Section 2.4.1). The local tidal cycles and their connection with the phases of the moon would have been well known in antiquity (e.g. Flemming 1995), and the dates of major culminations could have been calculated and used

[37] Passage, usually between mountains.

in planning shipping voyages.[38] Tides could have also been used to the advantage of skilled seafarers who were able to sail out of the harbour using the tide as a mean of propulsion henceforth rigging the sheer occurrence of this natural phenomena with the techno-culturally driven factors – vessel design and sailors expertise.

The tidal cycles dictated the rhythm of life in the port city, with ships arriving and offloading, crews resting on shore, whilst taking care of resupplying of the ships and undertaking essential repairs, and finally re-loading and timing to leave the harbour on the rising tide. These cycles could have also affected the port administration, as it does today in smaller natural havens. The seasonal tides (neap and spring), related to the earth-sun orbital cycles, would have in turn affected the efficiency of trade, in particular in the period of the year when the tides were especially high, and could have been connected with an intensified period of fishing, trading and sailing activities additionally associated with favourable winds (such as monsoons in the Indian Ocean).

Entry into the harbours of the Red Sea would have been totally dependent upon understanding the tides and the ocean's bathymetry, especially important at Berenike owing to the danger of grounding at low tide on the shallow (1–1.5 m) reefs or mobile sandbanks. This is why Berenike scores only 2 in this category – although the 0.5 m tidal range is low the shallowness of the coastal shelf means that a large area is exposed at low tide making for a dire possibility of grounding.

[38] For example, Julius Agricola is said to have gained the island of Mona (Ynys Môn or Anglesey Island off the north-west coast of Wales) because of extremely low tide (Tacitus, *Agricola* 14–15).

6.3. LAND PARAMETERS

The physical configuration of the landscape in which the new port is to be situated is of the utmost importance as in most instances it will dictate city's layout and connections with the hinterland. The exception to this rule is when the political or strategic position of a proposed port is so critical that the port is ultimately founded in an otherwise unattractive location regardless of the configuration of the landscape. The Land parameters (Table 6.2) are those physical aspects of the coastal landscape that are likely to have been attractive to the prospectors of new port sites, most probably because they already serve a purpose in its role as a port. The most obvious of these would be the presence of a sheltered bay that would protect a number of ships from the destructive powers of stormy seas and high winds.

The littoral environment represents a third of all ecological and economic resources in the world at present, and has been widely explored by humans throughout history (Benedetti 2007). However, coastal landscapes can comprise a wide diversity of physical environments, from wetlands, lagoons, estuaries, bays, mangroves and high cliffs, as well as a very broad range of biological ecosystems. The process of prospecting for new port sites in the Classical world in marginal areas of the Hellenistic and Roman Empires is essentially unknown. It is likely that already existing local harbours would be utilised in the first instance, either modifying them to suit their needs or retaining them as they were if suitable. However, it is equally likely that there were so many of these small moorings along any given stretch of the coast that the PoA would still be used to assess which of these would have been the best for larger-scale development. Below we look more closely at some of the most likely Land parameters that would have been assessed by ancient prospectors and engineers, and assess their attractiveness for the case-study site of Berenike.

Table 6.2 Semi-quantification of the Land parameters used in the study.

CATEGORY: LAND PARAMETERS			
Parameter	*Parameter characteristics*	*Berenike score*	*Berenike justification*
NATURAL LAGOON	***Level of availability of natural bay or lagoon***	**5**	Large sheltered bay
1	No bay or natural lagoon		
2	N/A		
3	Half natural, improved by humans		
4	N/A		
5	Very suitable natural lagoon or bay, potentially with an inlet		
SILTATION RATE	***Speed and volume of siltation, available dredging technology***	**2**	High siltation rate
1	Very high unmanageable siltation rate or high siltation rate with no technology to rectify it		
2	Fast and high siltation rate with little technology to rectify it but with efforts made by local population to deal with a problem		
3	Fast and/or high and/or seasonable siltation rate with technology in place to rectify it but only partially and at a slow pace		
4	Slow and relatively low siltation rate but technology in place		
5	No siltation or very slow siltation rate, which can be easily dealt with using locally available technology		

CATEGORY: LAND PARAMETERS			
RIVERS, CREEKS ETC	***Accessibility, size of estuary, degree of protection, depth, current***	**2**	Powerful wadis; providing source of fresh water only from deep wells; no irrigational properties but fresh water influx allowed for an opening of the channel at the entrance of the harbour; also used as corridors of connectivity with the hinterland
1	Difficult to access, few natural food and water resources, hindered access to the hinterland via river transport		
2	Difficult approach to the river or a riverine port, difficult or hindered access to hinterland and its resources through the river		
3	Decent access to the river or a riverine port, some resources available easily through the riverine transportation routes, others not		
4	Good access to the riverine port and good availability of resources		
5	Good and safe mooring facilities, easy access to the site and into the hinterland		
	Berenike Sea parameter total score	**8/15**	**0.53**

6.3.1 Presence and physical configuration of a natural bay, lagoon or inlet

Once the demand for a port serving a particular region had been identified (Section 6.5.1), one of the major prerequisites for the siting of the new facility would have been the existence of a natural sheltered bay, lagoon or inlet that could be used to safely moor the quantity of vessels required. Exploitable basins could be either entirely natural or artificially manipulated landscape features, and ancient port prospectors and builders would have certainly favoured locations with natural bays or lagoons.

The exception to the rule is where harbour basins would, for whatever reason, be constructed entirely artificially, such as the port of Caesarea Maritima/Palestine on the coast of Israel, Portus in Italy, or Carthage in Tunisia (Fig. 6.3).[39] Flavius Josephus gives an important account of the building of Caesarea's harbour, "… a haven, that was always free from the waves of the sea" (*Antiq.* 15.9.6), in which the engineers have overcome the hazards common to older ports of Joppa and Dor that suffered from "the impetus of the south winds that beat upon them, which rolling the sands that come from the sea against the shores, do not admit of ships lying in their stations" (*Antiq.* 15.9.6).

However, in the present context of the Red Sea and Indian Ocean littoral, it is unlikely that such costly endeavours would have been approved in areas where

[39] Dug harbour-basins opening onto the sea through a channel, such as in Carthage, are referred to as *cothons* (Carayon 2005).

such a large expense could not be justifiably explained (Fig. 6.4). Specifically, even though we know of shipments of *opus signinum/pulvis puteolanus*[40] over 2,000 km distance from Italy to Israel (on vessels similar in size to the *Madrague de Giens* wreck) for the purpose of building the port of Sebastos (Oleson and Branton 1992; Oleson et al. 2014), the availability of this material in marginal areas of the Empire, such as Berenike, is unlikely. However, it should be added, that given a high enough demand, even the most inhospitable coastline without bays or inlets could have hosted an artificial harbour.

Sometimes, the size and depth of the harbour basin could have been dictated by the type of facility needed or a demand (e.g. large international trade hub or smaller, regional stopping point). Therefore, when a suitable natural location was identified, ancient engineers would have carried out a basic survey to establish the depth as well as the maximum and minimum extents of the basin, determined in part by the tidal range and coastal geomorphology (Section 6.2.4), to ascertain whether they were suitable as found or whether need to be expanded. In antiquity, basic bathymetric survey measurements were usually taken using the sounding weight technique (e.g. Oleson 1996, 2000, 2006, 2008; Kirkland 2010: 3, see above Section 6.2.4).

Berenike scores very highly (5) in the 'Natural lagoon' category because of the large, sheltered bay with an adjacent smaller embayment that could both support

[40] Hydraulic concrete was arguably used from at least the late 2nd/mid 1st century BCE (when it was found in a harbour *pilae* in Cosa, Oleson et al. 2004: 202) to build underwater structures as it sets subaqueously (Vitruvius *De Archit.* 2.6.1, 5.12.2-3; Gazda 2001: 171–177, 2008; Lancaster 2005: 58; Brandon et al. 2008).

mooring of a significant number of vessels in two separate basins. This would have safely sheltered a large number of boats and ships from strong northerly and offshore winds, especially in the winter, and the associated waves and storm surges.

6.3.2. Siltation rate and regime

Siltation, or sediment infilling, from terrestrial (rivers, wadis), marine (tides and currents), and atmospheric sources (windblown sand), was, and is, one of the most significant problems faced by engineers, port builders and their maintenance teams (e.g. Blackman 1982b; Yin et al. 2000). Evidence for primitive harbour dredging used to maintain basins has been recorded in the Mediterranean as dating to the Bronze Age (Rabān 1990; Pydyn 2011), and reaching a peak in Roman times (Section 5.1.3). Furthermore, and as noted above (Pedersen 2015: 25), the gaps in the reef along the Red Sea coast, where vessels could enter bays and harbours, were usually located opposite wadi or river mouths, emphasising the importance of understanding siltation rates for the engineers planning new Red Sea ports.

Although Roman engineers may have had the technological capability to estimate the future degree of sediment infilling of a harbour basin, we do not know if they carried out such calculations and if so how accurate these would have been. Such estimates would allow for the evaluation of the time and resources needed to keep dredging operational. Although harbour dredging was a routine activity in the Roman Mediterranean (e.g. Bini et al. 2009; Morhange and Marriner 2010a: 29, 2010b; Mazzini et al. 2011), the level of maintenance and associated costs are little known for provincial cities such as Berenike, which as mentioned above (Section 5.1.3) would have necessitated at least occasionally dredging to keep the harbour operational and accessible for large ships.

There is evidence, however, that rates of siltation were ignored if the location seemed particularly suitable in other ways (e.g. strategic location). This was the case at Ostia Antica, the harbour city of Ancient Rome, where fluvial influx from the Tiber caused significant long-term siltation issues (Section 2.1.2.2; Blackman 1982a; Giraudi et al. 2006, 2009; Bellotti et al. 2011; Goiran et al. 2012; 2014a, 2014b; Salomon et al. 2012, 2014b; Millet et al. 2014; Vittori et al. 2014). Skilled harbour engineers could have moved between large cities such as Alexandria, Rome or Lepcis Magna (e.g. Rickman 1988), possibly moving as far as remote ports such as Berenike. Whilst most Indian Ocean harbours show no signs of major dredging activities, such a practice could have been undertaken using simple and relatively low-tech equipment when undertaken on a small scale (e.g. Hoyle 1989) (Fig. 6.5).

Berenike's siltation rate is very high and so the site scores very low (2) in this category. Seasonal flash floods flowing through the wadis resulted in a large flux of fluvial sediments each year to the coast and harbour basin area. Additionally, the marine sediment accumulation also contributed to the siltation of the lagoon and the embayment. These rates of sediment accumulation may have ultimately become unmanageable to the local maintenance teams at some stage, and the harbour was eventually abandoned.

6.3.3. Rivers, creeks and backwaters

Ports and harbours can be effectively and strategically located in the estuaries and backbeach areas of rivers, which in turn provide crucial conduits for the inland movement of cargo using riverine craft (riverine connections and their role as corridors into the hinterland are discussed below in Section 6.5.2) (Salway 2004). Rivers are also sought-after locations for settlement and trade as the estuarine areas encompass many different littoral environments and represent one end of a riparian corridor that might penetrate many hundreds (or seasonally thousands) of kilometres inland connecting markets located up the navigable river.

The lives of fishing, farming and foraging communities inhabiting estuaries, backbeaches, coastal backwaters or creeks were relatively easy as food was plentiful and the river attracted trade and commercial opportunities with the hinterland (Fig. 6.6). Such environments afforded sustainable fishing, permitting also fish farming and large-scale fish-nets (Fig. 6.7), and often had nearby rich and fertile alluvial soils to cultivate. These backbeach or backwater environments represented excellent locations for founding a port town, and were widely exploited in South and Southeast Asia at sites such as Pattanam (Kerala, southern

India), believed to be the ancient port of Muziris (Shajan et al. 2004; Cherian et al. 2009; Selvakumar et al. 2009).

With brackish water and tidal sea connections, creeks were also attractive settings for new ports (Fig. 6.8). Good locations are often available at the mouth of a creek sheltering the harbour from the winds and sea currents, and allowing for an extensive roadstead without the need for significant harbour installations. Saltwater fish are also readily available and the connection with the hinterland more accessible.

It should be noted, however, that sailing in the tidal reaches presents a number of unique navigational challenges, and river estuaries could pose great hazards for sailing (Strabo, *Geogr.* 1.3, 6–7; Seneca, *Nat. Quest.* 6.26,1; Pausanias, *Perieg.* 5.5, 7; 7.2, 11). Franconi (2014) notes that river deltas were not a popular place for settlement in most of the western Roman world. This was mainly due to the configuration dynamics of the coast, likelihood of silting up of harbour entrances and vortices (Fig. 6.9). Rainfall (and in different latitudes also snowmelt), irrigation, flooding and seasonality also strongly affected the volume of discharge of water and sediment into the sea. Shifting sandbars, shaped in or near estuaries due to alluvial sedimentation debouching from the river and exposed at the low tide, would additionally create obstacles for incoming and outgoing shipping and would affect siltation. These could be increased by strong onshore and offshore winds, vortices or swell, creating additional hazards for those attempting to enter a river harbour.

The location of Berenike on the semi-arid Red Sea coastline with only ephemeral wadi-systems means that the site scores only 2 in this category. Whilst there are no perennial rivers in the region, the wadis replenished the water table, providing sources of fresh water from deep wells. Fresh water output to the sea, generated by precipitation in the mountains, created a break in the coral reef range that in turn provided access to the lagoon. Wadis served as corridors of connectivity between the people of the Nile Valley and those of the Red Sea – usually separated by the vast and inhospitable Eastern Desert — and this role will be discussed further in Section 6.5.2.

6.4. RESOURCE PARAMETERS

Natural resources are understood here as materials and components that are derived from the regional or local environment, such as water from aquifers or rivers, stone from quarries, and wood from forests or plantations. These natural assets (Table 6.3) can be divided into biotic resources, such as animals and animal products, plants and plant products, timber for shipbuilding and building construction, fossil fuels such as coal; and inorganic materials such as metal ores, rocks or sediments.

This section explores the major Resource parameters, including fresh water, marine and other food resources, as well as building materials, types and qualities of pasture and arable land, and evaluates the attractiveness of these parameters at

Berenike. The accessibility of raw materials that represent trade commodities, including good quality wood (e.g. cedar, teak, mahogany), rock (e.g. marble), metal ore and luxury goods such as spices, frankincense, tortoise shell, emeralds, topaz are also taken into consideration. Ancient prospectors would have also assessed the availability of these sources and their proximity, the effort required to procure and safeguard them, and their value on the open market and 'portability' (i.e. the different methods were required to transport elephants and for teak timber compared to spices or tortoise shell), which seems to have been one of the major requirements in the case of Berenike.

Table 6.3 Semi-quantification of the Resource parameters used in the study.

CATEGORY: RESOURCE PARAMETERS			
Parameter	*Parameter characteristics*	*Berenike score*	*Berenike justification*
FRESH WATER	***Fresh water availability, accessibility, proximity, quantity, and quality***	**1**	Fresh water available, but the closest well is located 7.6 km away on the edge of the mountains; caravan of donkeys had to ferry water to town at all times.
1	Very low availability and/or low accessibility of freshwater; sources located far from the site and/or having only low water reserves and/or poor quality		
2	Low availability and accessibility; poor quality water, not in sustainable quantities, has to be transported to the site		
3	Water available in the vicinity of the site, however it needs to be imported on pack animals; water quantity and quality varies from fair to good or is seasonally dependant		
4	Good water available on site or in its proximity, easy or easy enough to access; sustainable quantity producing limited amount of surplus		
5	Good quality water available on site in sustainable quantities for humans, animals and agriculture leaving enough surplus for merchants and their crews		
MARINE RESOURCES & GAME	***Demand for fish, availability of fish, available technology, possibility of trade in seafood and fish-products (if surplus)***	4	Plentiful fish, large quantities of fish bone from archaeological record; also hunting for game in the mountains and access to donkey and camel meat and to birds
1	Very little fish supply, no available technology and little demand (subsistence strategies lie in other areas of food resources)		
2	Demand in place, but not much fish available in the area that could be sustainably fished, or there is no technology in place to fish it		

CATEGORY: RESOURCE PARAMETERS			
3	Demand in place with a good supply of fish and good enough technology or/and fishing conditions but not producing surplus		
4	Demand in place producing enough surplus for some trade		
5	Sustained demand, producing plenty of surplus, which when traded provides the community with a good income source		
AGRI-CULTURE & PASTURES	***Quantity and distribution of cultivable land, crop production, animal power and transport. Quality, quantity, sustainability, seasonability of pastures***	**1**	Potentially, brackish water could have been used for horticulture or light agriculture. Macrobotanical evidence shows that there could have been a small-scale agriculture in Berenike (Jarosław Zieliński, pers. comm. 2011). Pastures probably only suitable for camels and donkeys
1	Very poor conditions, including no arable land, lack of soils and insufficient water to sustain irrigation. No pastures, and fodder has to be imported		
2	Poor soils, marginal irrigation potential, small-scale agriculture and horticulture possible with great effort. Seasonable small pastures with fodder imported from hinterland		
3	Fair quality soils, however irrigation cost possibly high. Some moderate quality pastures but small and seasonal, abundance of seaweed for collection (but high effort)		
4	Good quality soils, moderate irrigation required. Good pastures, either in the vicinity of the site or in nearby satellite villages, sustainable fodder acquisition		
5	Optimal conditions for agriculture, large tracts of arable land, good quality fertile soils and abundance of water. Excellent pastures and plenty of fodder for animals		

CATEGORY: RESOURCE PARAMETERS			
WOOD & BLDG. MATS.	***Level of availability of biotic (e.g. forests) and abiotic (e.g. building materials, ore) resources for ships and buildings***	**2**	Abundance of gypsum anhydrite and coral, however of a very low quality. Only acacia and mangrove wood and the rest of the wood have to be brought through the caravan route and Nile route from the Mediterranean or from the South/Indian Ocean
1	No wood, ore, nor building material available in the area; all materials have to be imported		
2	No suitable wood available for ship repairs; wood can be imported or collected (such as mangrove) for urgent ship repairs. Same situation for building materials		
3	Limited supply of decent wood and decent building materials; need to transport		
4	Good source of wood and building materials but either a limited supply and/or no maintenance facilities and/or skilled craftsman		
5	Very good wood freely available, skilled craftsman, shipyard with dry docks, local quarries for stone and ore; easily available good quality building materials		
RAW MATERIALS & TRADE GOODS	***Availability, portability, quality***	**4**	Raw materials such as gold, emeralds, topaz, etc.
1	Very little or an almost total lack of raw materials and/or trade goods in the area		
2	Some raw materials and natural resources are available near the site but they are either of a poor quality or are difficult to obtain/hard and distant to transport		

CATEGORY: RESOURCE PARAMETERS			
3	Good quality or easily accessible type or raw resources or trade goods that justifies an effort expended to obtain it		
4	Sustainable quantity of decent quality resources within the manageable distance		
5	Abundant good quality natural resources that are easily accessible and in the vicinity of the site		
	Berenike Sea parameter total score	**12/25**	**0.48**

6.4.1. Availability and proximity of fresh water

Access to potable water is arguably the most important consideration when prospecting for a new port city, although we might be surprised how counter-intuitive the siting of ports (and presumably other facilities) is with respect to this resource when political machinations have to be taken into account. Where fresh water is not easily available, it immediately becomes apparent how difficult and expensive it is to purify and transport (either through 'manual carriage' or via aqueducts or pipelines). Water is essential to food production, economic development, and life itself, and access to it would have been a major factor of attractiveness of any given location to ancient settlers. It perhaps reveals the importance of Berenike as a strategically important port when we consider that it did not have a direct fresh water source and would have to rely on the transport of water from around 7–8 km away.

The demand for water by humans is extremely high, especially if we include water for irrigation or the sustaining of livestock. With the development of large ports of trade, the demand increased significantly compared to smaller coastal communities. Water is the only commodity on which it is very difficult to compromise, and so a permanent and near-continuous supply had to be in place at all times. Although slightly brackish water can be imbibed if necessary — potentially leading to a water hierarchy in which the sweetest water is consumed by the higher ranks or used to re-victual the ships, for example — it was nonetheless a top priority in any administrational agenda to access, acquire, store, protect and distribute sufficient quantities of fresh water (e.g. Sidebotham 2011: 87).

Fresh water could be sourced from five main environments: i) rivers; ii) lakes and reservoirs; iii) groundwater aquifers (both deep or shallow and including wells); iv) rainwater; or v) salt or brackish water purification.[41] The quantity of water for irrigation would depend upon the season, the source and the character of the crop. If irrigating large areas of land, loss such as through evaporation, leakage from canals and percolation below the roots of the crop would also need to be accounted for. Rivers are amongst the most reliable sources of irrigation, however, seasonal flow fluctuation means that most rivers, similarly to lakes and artificial reservoirs, are very responsive to rates of precipitation (and therefore flooding or drought). Most reliable were the groundwater aquifers, which formed an important source of clean water tapped mainly through wells (Fig. 6.10).

The Romans were extremely skilful in sourcing, transporting and storing water. They mastered long-distance transportation using aqueducts, employed hydraulic engineering and artificial irrigation, constructed water-mills, cisterns, fountains, as well as built private and public baths and engineered sanitation systems (e.g. Adam 2005; Wilson 2000, 2001a, 2008, 2009, 2012; Malouta and Wilson 2013). This required specialised administration, legislation, taxation, and management of

[41] There is evidence that water treatment and purification in antiquity was used, with variable results, on a small scale (Wilson 1997). For example Hippocrates conducted experiments on water purification using cloth bag filter later known as a 'Hippocratic sleeve' (Baker and Taras 1981). Additionally Diophanes of Nicaea in the 1st century BCE discovered that adding macerated laurel improves the rainwater, whilst Paxamus proposed that a bag with bruised coral or pounded barley is to be immersed in the 'bad' water (Bitton 2014: 31).

water supplies, which operated on similar principles in the provinces (e.g. North Africa) as in the core of the Empire (Wilson 1995, 1998, 2001b, 2009).

Even with limited bathing and cooking, a human being comfortably needs about 15–20 litres of water a day during a hot summer, especially in the desert, and a little less in a winter (Zitterkopf and Sidebotham 1989: 164; Sidebotham 2011: 89). An ostracon from *Mons Claudianus* gives an indication of the maximum rations received by 917 people working in the quarries there, which amounted to — depending on status and difficulty of work — between 1 (roughly equivalent to 6.5 litres) and $^{1}/_{3}$ (approx. 2 litres) of a *keramion* each (e.g. Bagnall 2009: 42; Hirt 2010).

The growth of ports imposed responsibility not only for supplying water to the town but also for both incoming and outgoing ships and caravans (e.g. Hansen 1983; Crouch 1993; Angelakis et al. 2012). Water was required not only to re-stock ship supplies, but also for drinking, bathing and laundry whilst in port. Estimates of water requirements for ship crews have recently been re-evaluated in light of a series of experiments and sea trials. The *Olympias* and other trials have shown, for example, that a member of a galley crew would need a minimum of 8 litres per day (approx. half of the 'comfortable' amount), including their main meal (Morrison and Coates 1986; Shaw 1993; Hattendorf and Unger 2003), substantially more than estimates as low as 2.25 litres (Sleeswyk and Meijer 1998). However these approximations are for oarsmen who would have needed to drink much more water than a sailor.

A very rough estimate, assuming that 100 large ships visited Berenike throughout the seasons with crews of 6–10, with each crew member requiring 6.5–8 litres (between the amount recorded for quarry workers and a galley crew in an *Olympias* trial) of freshwater a day for a period of 2 weeks (approximate time required for unloading the cargo and re-provisioning) would amount to 150,000 litres (to sustain crews visiting a port per season). Additionally, ships would have to re-supply with water to last a few months when they were setting off on a journey east to India. A rough calculation shows that a similar amount of water would be required by a local population of 2,000 people (Steven Sidebotham, pers. comm. 2011) consuming a ration of over 6.5 litres (1 *keramion*) of freshwater per person per day.

Moreover, both incoming and outgoing caravans would have to take water for themselves as well as their pack animals. During summer months, and with a heavy load, a donkey requires around 10 litres per day, a camel about 20 litres per day (Schmidt-Nielsen 1964: 85–92, 1965),[42] similar to a horse. These animals would have to water well before, and after, a 2-week (or longer) journey across the Eastern Desert. Whilst desert animals could go for long periods without water, this was only possible in cooler seasons and with light loads. In all, it seems that supplying ships, crews and terrestrial merchants would account for an additional two or three times the ordinary supply of the port's permanent population, and an estimate like this would have to have been kept in mind when setting up a Roman town in place of a Ptolemaic elephant port.

[42] However a large and thirsty camel, which did not drink for an extended period of time (i.e. travelling in the desert) can drink up to 200 litres a day (pers. observ.).

The freshwater issue at Berenike was clearly significant. Not only was it without a water source, but the source that was used was quite distant, approximately 7.5 km away. These sources comprised a number of wells, or *hydreumata*, located at the foothills of the mountains. Berenike therefore only scores 1 in this category, because the distance and effort of supplying large qualities of water to town — potentially up to 35,000 litres a day[43] in the peak season — was huge and would require a constant flow of water ferried on pack animals such as donkeys, distributed around town and into the harbour and stored in the cisterns.

6.4.2. Availability of marine resources including hunting and gathering

Fishing and the procuring of marine resources (e.g. fish, molluscs, shellfish, seaweed, marine mammals, birds, reptiles, etc.) provide a relatively comfortable subsistence strategy for coastal populations and people who work on the sea. Seafood represents not only easily harvestable food, but also a trade commodity for local populations, especially in some of the arid regions of the Red Sea or North Africa (e.g. Wilson 2002). Needless to say, the availability of marine resources, access to terrestrial game, and the availability of foraged food must have had influence on potential choice for port location.

[43] Calculated using rough estimates of water use for local population (of approx. 2,000 inhabitants consuming a min. 6.5 litres a day and comfortably 15–20 litres), moored vessel crews (approx. 100 ships x 6–10 crew + passengers), ships re-supplying for a journey to the Indian Ocean and the caravans (humans and pack animals).

Variables such as the availability of good fisheries, the development of fishing techniques (e.g. Bekker-Nielsen and Casasola 2010; Trakadas 2010) (Fig. 6.7) and the social cohesion that comes with the practice of fishing, fish processing and dealing with fishing gear (Fig. 6.11), were key to creating a connection between people, the sea and the coastal landscape – favourable factors for the development of a harbour and associated trading outpost.

The Red Sea is particularly renowned for its fish resources and the diversity of its coral reefs (Morgan 2004), and much is known about the available fishing techniques in antiquity (Thomas 2010). While it is not one of the 'big game' fishing zones, it is active perennially, providing a wealth of resources, making it more attractive to human exploitation than seasonally propitious basins (e.g. Mannino and Thomas 2002; Dulvy and Polunin 2004). Most of the Red Sea coasts are fringed with 1–3 km wide reefs, with abundant fish and marine mammals, adjacent to an outer barrier of several hundred metres depth, allowing for the fishing of deep marine species. It is worth mentioning that the collection and 'cultivation' of seaweed and algae would have also been an important part of a subsistence strategy as well as a tradable commodity (e.g. Woodward 1951; Fleurence 1999) (Fig. 6.12).

The abundance of fish remains recovered from archaeological sites across East Africa, Southern Arabia and the Indian Peninsula shows that the exploitation of rich fish resources in antiquity was a key subsistence strategy. Recent zooarchaeological data confirms consumption of large quantity of fish (and even shark) from the Red Sea (only one fish bone belonging to the Nile fish) in the

Eastern Desert forts such as *Mons Claudianus* and *Mons Porphyrites*, located 2 days camel ride away from the sea (Hamilton-Dyer 1990: 76–77, 2001; Marzano 2013).

In the Roman era, *umami* foods[44] were very popular, and fish and fish-products were an important part of the diet creating a huge demand (Curtis 2009) (Fig. 6.13). Any surplus catch would not only have been preserved (e.g. Wilson 2007), but also traded, and "substantial fortunes could be made" on Roman fish sauce (*garum*) and the fish business (Haley 1990: 72; Van Neer et al. 2004; Lund and Gabrielsen 2005; Wilson 2006).

Valuable fish were often transported fresh using ingenious systems of transportation (e.g. Beltrame et al. 2011) and *garum* was exported in amphorae across the entire Empire and beyond, including India (e.g. Corcoran 1963; Tomber 2009). Another salted fish product, known as *salsamenta*, was transported to sites such as *Mons Claudianus* on the Eastern Desert or the port of Myos Hormos (Van Neer et al. 2006). The fish tanks (*piscinae*), built for storage and breeding on the Mediterranean coast, were also very common coastal architectural features in some areas, especially Tyrrhenian Italy (e.g. Higginbotham 1997) (Section 2.1.1.2). Cured fish provided trade income for many coastal towns/cities, and the jobs that came with large-scale trade industries (e.g. Curtis 2005; Wilkins 2005; Lytle 2006, 2012; Bekker-Nielsen 2010, 2011; Marzano 2013).

[44] It is a taste of foods that are rich in glutamic acid and 2 -ibonucleotides, 5'-inosinate and 5'-guanylate such as *garum* (Curtis 2009).

Given the coastal location, populations of port cities would undoubtedly have relied predominantly on fish for their sustenance. However, despite the propensity for a seafood-based diet (e.g. in Berenike an estimated 30% of the archaeozoological assemblage is fish bones – Marta Osypińska, pers. comm. 2013), cultivated plants and domestic animals would have also constituted part of the diet (Cappers 2006; Zieliński 2011), as well as supplying materials for clothing and other secondary products.

Hunting would have been an important means of supporting or supplementing the seafood diet. Eastern Desert-dwelling animals such as the Dorcas gazelle, the fennec (a small, desert-dwelling fox), the Nubian ibex, the Egyptian/cape hare, and two kinds of jerboa (a mouse-like rodent with long hind legs for jumping), as well as feral camels and goats could have been hunted for food, with diet possibly supplemented by smaller animals such as turtles, frogs, lizards and birds (Hughes 2014: 93) and by beekeeping (Crane 1999: 203–211). So popular was hunting in ancient Rome that mosaics and paintings often depicted it as a genuinely heroic pastime (Tuck 2005). Hunting with dogs was particularly popular, and indeed there were specially bred animals that were regularly exported to the Empire. Unusual for this period, carefully interred dog burials found in Berenike (e.g. in trench BE10-63/65) might indicate an individual's attachment to their hunting dogs (Osypińska 2015 *forthcoming*).

Different strands of subsistence strategies mean that Berenike scores 4 in the 'Food' category. Plentiful fish attested by large quantities of fish bones from the archaeological record, especially in the port area, showing the exploitation of marine resources. However as many of them could be just a natural waste, it is not unambiguous whether all of the fish bone material was a part of post-consumption remains. Additionally, some evidence for hunting for game in the mountains is available, whilst domestic animal meat – such as of donkey, pig or a camel was also often utilised. Bird and rodent bones are also present in the archaeozoological record, howevere mostly in the trash dump deposits suggesting unlikely food source. (Osypińska 2011, 2015 *forthcoming*).

In terms of the chronological distribution of different species in the archaeozoological record at Berenike, the majority of animals consumed for meat comprised sheep, goat and pig in the Ptolemaic period. Numerous bones of camels and donkeys are also present but it is not clear whether their meat was consumed after the death of the animal. The early Roman period yields evidence for the 'richest diet'. Aside from sheep, goat and pig, there is evidence for the consumption of beef. Without more material it is not possible to unequivocally state whether these remains were indeed cattle or rather Asian buffalo or zebu that contemporaneously entered from India to Africa via Egypt. Moreover, the presence of poultry, again imported from the East (most likely originally from Indonesia, Storey et al. 2012; Mwacharo et al. 2013) is well attested for. The meat diet in the late Roman period appears more modest, with evidence for larger animals limited to sheep, goat and camel (Osypińska 2011, 2015 *forthcoming*).

6.4.3. Agriculture – cultivable lands and pastures

The ancient assessment of agricultural value must have taken into consideration the availability of fertile soils and cultivable land. Although access to the hinterland and local supplies would have been an important consideration, the ability for the port to at least partly sustain itself (through a symbiotic relationship with satellite villages, for example), or even creating agricultural surplus (Fig. 6.14), is likely to have been important in the creation of a new port.

Although many attempts have been made to quantify agrarian economy in the Ptolemaic and Roman Empires (*cf.* Kron 2012; Bowman and Wilson 2013), scholars admit that the results have been largely inconclusive (*cf.* Bowman 2013). Early Roman (Republican, 509 BCE–27 BCE) agriculture is deemed to have been not only "technically simple", but the "yields were low, transport was difficult and costly, and storage was inefficient" (Roberts 2007). However, the picture of Republican agriculture is much more complex with an introduction of Punic farming techniques, a noted rise of villa agriculture, and the drafting of agronomy handbooks (Andrew Wilson, pers. comm. 2015).

At the peak of its development (Principate, 27 BCE–284 CE), the Roman agrarian system was diversified and well developed. It not only benefited from a prosperous network of local and urban markets, and "the wide-spread use of convertible husbandry, crop rotations, heavy manuring, drainage and irrigation, pruning and grafting, and improved fodder crops producing remarkably high yields and large livestock", but also the general security and excellent overland and maritime transport infrastructure (Kron 2012). This implies that good quality agricultural products could have been delivered to port cities such as Berenike, and technological advances in farming would have allowed for more efficient use of available soils and local microclimates. This would have made it possible to develop small-scale agriculture or horticulture.

Grasses grow in abundance in climates with annual rainfall ranging between 500–600 and 900–1500 mm and temperatures between -5° C and 20° C (Woodward et al. 2004), although some grasslands occur in colder (-20° C) and warmer (30° C) climates. When considering the availability of pastures, the negative effects of over-grazing such as increased soil erosion, adverse water quality due to increased runoff, and loss of biodiversity should also be taken into consideration. Grasslands can provide positive benefits relating to other industries, including food production (as grain, sprouted grain, shoots, etc.), drink (such as beer), thatch, papyrus, fuel, clothing, insulation, construction, basket weaving, toiletries, and many others.

Port city populations would have been dependent to some extent upon animals domesticated for power (plough oxen), meat, and by-products (hides, dairy). Given the coastal locations of new ports it was likely that the need for primary meat products would have been offset by use of marine resources, such as was the case at Berenike. However, if secondary products such as dairy and hides were sought for then they may have required pastureland to allow grazing of fodder, pack and work animals.

The most popular desert-crossing pack animal, the camel, requires approximately 10–20 kg of fresh food a day (or 5–10 kg of dry fodder) dependent upon the size of the animal, but up to 30–50 kg when working. Camels eat mostly grasses, herbs, bushes, trees such as acacia, and salt-tolerant plants (Fig. 6.15). They can also chew gazelle bones and fish waste in order to recover minerals from them. A density of 2–3 kg of fresh food per hectare is considered favourable for camel grazing, whilst 1–1.5 kg as poor (Sultan al-Dowaish, pers. comm. 2009). That means that the supply of fodder would have to have been transported to sites such as Berenike in large quantities, preferably from sources in the near vicinity.

The significance of particular parameters for sites located in specific climatic and environmental zones is worth a comment. There is evidence from Myos Hormos that caravans would have supplied hay for animals brought all the way from the Nile Valley (Van Der Veen 2011). This must have been a complex logistical problem. With a lack of good pastureland directly adjacent to the sites and suitable for grazing stocks of animals the existence of shrubs or small grasslands on the coastal plain or in the wadis could bee seen as an added benefit. Additionally, some animals (such as pigs that were kept on sites in the Eastern Desert) could have been partially fed on human waste, this solving two problems with one solution.

In terms of this PoA, Berenike scores a very low 1, chiefly because of the absence of sustainable agricultural land or suitable pastureland. It is possible that brackish groundwater could sustain some types of salt-tolerant horticulture or light agriculture, but to date there is no unequivocal evidence for such. Macrobotanical evidence appears to show that there could have been small-scale farming at Berenike (Jarosław Zieliński, pers. comm. 2011). Evidence for potential pastures, dominated by C_4 grasses, have been identified by Zieliński who claims that it would probably only be suitable for camels and donkeys. More recently, a sampling program designed by the author and undertaken on-site by Nicholas Bartos, has collected a suite of samples that will be tested for the existence of microbotanics, including pollen, phytholiths, lipids, and starches that will allow for the reconstruction and better understanding of past environmental changes and their direct and indirect impact on human subsistence strategies.

6.4.4. Availability of wood and local building materials

The availability of construction and repair materials (for boats, infrastructure and buildings) would have been important for setting up and maintaining a port town. The building materials would not have been used exclusively for port infrastructure, but also for the various storage, industrial and domestic buildings and installations. Whilst material could be imported from outside areas, and as mentioned above, in unusual cases, specialist materials such as *pozzolana* were imported from up to 2,000 km away, within the Mediterranean, it is likely that the availability of basic building materials would have been an attractive asset in the siting of a new port.

A wide variety of materials could be used for building. These include easily available sediments such as clay and sand which could be fired or sun-dried to produce bricks and mud bricks (and baked clay), lime plaster, rubble, cement, gravel, as well as quarried rocks of various types ranging from perishable gypsum anhydrite or poor quality limestone to hard and extremely durable granites, marbles or basalts. Organic materials could also have been widely used for the construction of houses, administrative buildings, and fences, as well as jetties and wharfs. These could include, depending on environmental conditions, cob (a mixture of clay and grass/hay), wood, reed mats, thatch, sod/peat, bitumen, animal skins, leather, bone, and textile. An interesting example of the use of amphorae as the base for a wharf is also known from Myos Hormos (Peacock and Blue 2006: 68–74).

One significant aspect in the siting of an ancient port would have been the availability of wood for shipbuilding and for repair material. Wood such as Indian teak (Fig. 6.16), African blackwood or Lebanese cedar (Fig. 6.17) was ideal for ship construction, but many other species could have been used for a diverse range of repairs (Section 7.2.1). Whilst top-quality wood was often exported over large distances and therefore was sometimes readily available in transhipping ports such as Berenike, access to moderate quality wood for repairs would have been an important consideration.

Typical features of the Red Sea coasts are lagoons and sheltered bays (*mersas*) fringed by mangrove trees (Fig. 6.18), which are ideal locations for harbours (Khalil 1994: 126). An ethnohistorical study undertaken by Pierre Schneider

(2015 *forthcoming*) on the coasts of the Red Sea confirms that mangrove wood could have been used as a freely available ship repair material. Theophrastus (*Hist. Plant.* 4.7.1–2) mentioned using mangrove wood for building boats, and specifically *Avicennia maritima* or *Avicennia officinalis* (white mangrove) to repair them (Section 7.2.1). Dionisius Agius (pers. comm. 2012) also remarks on sources from Djibouti corroborating the use of mangrove for shipbuilding, most likely for repairs. This new information shows the need to re-evaluate our understanding of the availability of and the demand for wood on the Red Sea and other deforested coasts.

The landscapes around Berenike support an abundance of gypsum anhydrite and coral that can be used as a low-quality building material and which are widely utilised on this archaeological site for this purpose. In terms of wood, only acacia and mangrove are locally available. Other wood species such as cedar, pine or oak were imported via the caravan route from the Nile valley and the Mediterranean, and those originating in Africa or India such as blackwood and teakwood were imported through the maritime route. The very limited amount of low-quality building materials available locally at Berenike scores only 2 in this category.

6.4.5. Accessibility of raw materials and trade commodities

The accessibility of natural resources is likely to be a key factor in positioning any production centre that could have been associated with a port of trade. A growing population and rapid economic development resulted in an increased demand for fuel to produce light and heat in both domestic and industrial contexts, as well as in public baths (Veal 2013). Wood was not only used as fuel but also for industrial processes such as mining, smelting, and pottery making, as well for military purposes and shipbuilding. Allied with large-scale agriculture and animal overgrazing, consumption of wood fuel (which constituted 90% of all energy-producing efforts) were major factors in deforestation in the Roman period (Hughes 2014) showing the importance of this resource to humans.

The economic boom during the early Principate also increased the need for heavy metal ores by the Roman Empire (gold, silver, copper, tin, lead, zinc, iron, mercury, arsenic, and antimony were used in the Roman Empire; Healy 1978). With a demand for tools, weapons, ornaments and jewellery (Craddock 1995), ore-deprived Central Italy necessarily relied on imports. As such, heavy minerals mined on the fringes of the Empire were usually carried by sea – departing and approaching via ports of trade. The importance of heavy metals to the State was so huge that the army oversaw mining undertaken by locals and convicts condemned to the *metalla* [45] and some scholars suggest an existence of a centralised bureau in Rome that was responsible for mining (Hirt 2010).

[45] *Metalla* were the imperially owned mining and quarrying districts of the Roman and Byzantine Empires (Friedman 2008).

Specific sediments such as clays were also required for pottery manufacture, and sand with high quartz (silica) content were needed for glass production. Although these resources are plentiful at Berenike, there have been no production centres identified to date, and the high quantity of wood required for such manufacture would mean that it was not viable on a large scale at the site where wood resources were scarce. The development of roads, aqueducts and other types of infrastructure, the foundations of new ports and cities, and the expansion of old ones, necessitated extensive quarrying (Russell 2013: 16).

Three different types of stone were sourced in the area around Berenike: i) ordinary stone for building and infrastructure such as gypsum anhydrite; ii) stones such as granite, marble, and basalt used for decorative purposes (Crouch 2004; Russell 2013) and exported to the Mediterranean via the Nile Valley, and; iii) gemstones such as olivine, topaz or emerald. Important regional differences in demand for stones from the second group could be observed within the Empire, connected with an increase in urbanisation. This 'building boom' between the 1st century BCE and 3rd century CE (the peak of Berenike's activity) had important implications for stone consumption. Access to quarries, from which ships can transport acquired material to other locations (Russell 2012), could have been one of the reasons that prompted the prospection for ports, or, on could have at least been a serious consideration when prospecting for new ports (Figs. 6.19 and 6.20).

Berenike scores highly (4) in this category as it is located in an area with plentiful raw materials. Gold, emeralds, olivine, topaz, and basalt were excellent trade commodities representing valuable assets when located nearby, boosting the economy of a port, not by direct trade but by connection with the quarries. Other raw materials such as good quality wood and metal ore, as well as non-essential foodstuffs and goods for elite consumers such as spices, frankincense, tortoise shell, ivory, and others (Fig. 6.21), were not immediately available at Berenike but were traded from this port. For example, the Alexandrian Tariff mentions 54 commodities (including 20 plant products) (Miller 1969: 278–280) subjected to import tax in Alexandria (Cappers 2006: 3), whilst *PME* mentions 34 plant products, 18 of which were traded from Berenike (Cappers 2006). Such luxury items could easily be obtained in some areas of the African Red Sea coast and therefore convenient access to their sources and a method of re-distributing them could have been a valid consideration when setting up a port such as Berenike.

6.5. SOCIO-POLITICAL-ECONOMIC PARAMETERS

The parameters presented in this section, in contrast to the environmental parameters set out in the sections above, relate to human decision-making (Table 6.4). These variables would have not only affected the choice of location made by those who were setting up the new port, but would have also mattered to those who were to inhabit and use the facility. Demand aside, strategic location, ease of access to the hinterland, and political stability, including the safety of the inhabitants and visiting ship crew and cargo, would play an important role and would ultimately determine the popularity of the ports and the expectations of sailors and merchants.

Table 6.4 Semi-quantification of the Socio-political-economic parameters used in the study.

CATEGORY: SOCIO-POLITICAL-ECONOMIC PARAMETERS			
Parameter	*Parameter characteristics*	*Berenike score*	*Berenike justification*
DEMAND	***Scale od demand***	**5**	Need to situate a port on the Red Sea coast at the southernmost edge of the Empire and within the reach of monsoon winds
1	No demand		
2	Low demand		
3	Sufficient demand		
4	Significant demand		
5	Strong demand		
STRATEGIC POSITION	***Connection with hinterland***	**4**	Fort, defensive walls, island locale; Caravan road through the desert, *hydreumata* stations, forts and *praesidia* on the way; Closer than Myos Hormos for the sea journey and no need to fight the northerly winds; but longer route for the caravan through the desert
1	Difficult and dangerous, seasonally impassable road, no watchtowers, difficult or impossible to obtain supplies		
2	Difficult or dangerous route, possibility of attacks, could be fully or partially seasonally impassable, no or very little access to supplies		
3	Connection with hinterland by good route, with reasonable safety, however one which is either seasonally impassable or has little access to supplies		

CATEGORY: SOCIO-POLITICAL-ECONOMIC PARAMETERS			
4	Good connection with hinterland through safe and sound road or river which becomes more difficult to pass seasonally, some supplies available *en route*		
5	Good connection with hinterland through a network safe and sound roads or rivers that are not particularly affected by seasonal changes, facilities and supplies available *en route*		
STABILITY & SAFETY	***Political situation in a region; civil unrest; war; predictability of conflict***	**4**	Nomadic tribes in the hinterland, however the routes are well protected by *praesidia* and forts
1	Permanent state of war, dangerous place		
2	Unpredictable situation in the region		
3	Generally safe port but with a limited safety in its surrounding and tensions that may turn violent		
4	Safe and stable port with some neighbouring tribes susceptible to occasional revolts		
5	Safe harbour under stable rule		
ATTRACTIVENESS TO SEAFARERS	***Accessibility of human expertise, administrative facilities, hospitality service***	**4**	*Tetarte* (25% tax) charged in Alexandria or duties levied in Coptos
1	Lack of facilities		
2	Poor facilities		
3	Decent facilities exist on site, however in a limited supply		
4	Good facilities and decent administration		
5	Very good administrative and hospitality services lower taxes, no harbour duties, no queues to enter the harbour; good workshops and shipwrights; easy and cheap supplies; a bar; a brothel		
	Berenike Sea parameter total score	**17/20**	**0.85**

6.5.1. Demand

Probably the most important of all parameters, and one that was in the hands of the higher political powers rather than the prospectors and engineers, was the actual demand for the new port facility. It would have only been after this demand was identified, communicated and made official that the environmental variables would then come into play to decide its exact location (although the location of the new port would have been constrained to some greater or lesser extent at this time).

The 'Linder Hypothesis' regarding international trade patterns (Linder 1961) is very applicable for describing the demand network created between the Roman Empire and its eastern counterparts. The increasingly complex and aspirational societies, kingdoms and empires of India, Southeast Asia, East Asia and the Arabian Peninsula (Casson 1974; Manguin et al. 2011; Ray and Salles 2012) increased the demand for trade goods. Empires and states such as the Axumite Kingdom in Ethiopia, the Himyarite, Qataban, Sabaean and Ma'in Kingdoms of Southern Arabia, the Parthian and Sassanian Kingdoms of Iran, along with the empires of the East including the Ruhuna kingdom in Sri Lanka, and the areas ruled by, amongst others, the Sātavāhana, Chola and Guptas dynasties in India, were extremely developed civilisations that had similar demands to those expressed by Roman élites. For example, in exchange for gold *denarii* and wine Indians sent spices to the Roman markets.

Similarly the Funan in Vietnam and Cambodia, the Champa kingdoms in Vietnam, the Langasuka and Pan Pan kingdoms in Malaya, the Arakan and Pyu monarchies in Myanmar/Burma, along with the empires of Han, Three Kingdoms, Jin and Northern and Southern dynasties in China had very advanced societies in need of luxury items. They were interested in taking part in the emerging global economy and pursuing its benefits. As Linder proposes (Frankel 1997: 60, 133–134; Choi 2002), the closer the preference structure between two countries, the larger the trade volume becomes (whilst creating a specialisation within the production of differentiated goods between the two nations). For example, the growing demand in Rome for luxury items was similar to that observed in Chinese markets where the demand for goods from the borderlands of South Asia (such as lapis lazuli from northeastern Afghanistan) and the western regions (such as jade from Khotam) was similarly high (Srinivasan 2007: 91).

Analogously, the notion of 'opposite shores' developed through observation of the popularity of ports situated on the western shores of 19^{th}-century Britain during the increased Atlantic trade (Harvie 2008) might be successfully applied to the Indo-Roman trade, with the Mediterranean representing Western Europe and the Indian Ocean region representing North America. It is an obvious point that the ends of the supply chain have a major impact on the development and growth of particular ports during periods of intensified trade activity.

The highest score of 5 in this category for Berenike may indicate that 'Demand' played a key role in siting Berenike. Both the Ptolemies and the Romans required a port located as far south on the Egyptian Red Sea coast as possible in order to connect with the southernmost edge of the Empire, and within easy reach of the monsoon winds. Whilst the initial demand differed, with Ptolemies interested mainly in the transportation of African elephants and Romans concerned with the efficient transhipment of Indian Ocean goods, the chosen location for a port was required to, similarly, remain easily connected with the hinterland via wadi corridors and within easy distance of one of the large Nile riverine ports and commercial centres.

6.5.2. Strategic position and connection with hinterland

The strategic position of the proposed site would have been an important factor in the setting up of a port city or town. Depending on the needs of the port community, the coastal landscape, weather conditions, and relations with local tribes and surrounding political entities would have to be taken into consideration in evaluating the attractiveness of particular locations.

There are two ways to evaluate the strategic position of a port. First, it can relate to the provision of safety for the inhabitants in case of an attack. The Romans were great tacticians who understood the importance of strategic positions in the landscape and are known to have taken advantage of them wherever possible, usually exploiting higher ground and natural defences (e.g. promontories and headlands such as for example for setting up a Roman lighthouse of the *Portus*

Dubris at Dover in England). Such strategies were used for creating an advantage over a potential enemy and for defending their interests in marginal areas of the Empire (e.g. Luttwak 1976: 173–180). Even though in many ways this is a purely landscape parameter, the strategic position of a site within the political landscape would have made it more or less susceptible to attack.

Some ports and landing places on the Red Sea would also have served, as in the Mediterranean, as naval bases (such as Jizan on the Farasan Islands; Phillips et al. 2004: 244–245; Adams 2007: 35) (also see Table 2.1). These were usually located in a separate harbour basin from the commercial harbour (e.g. Carthage, Portus, Figs. 6.3 and 6.4). The key factors that would have been taken into consideration by ancient port builders when thinking about good strategic positions would have included:

i. Safety of the position in regard to the hinterland routes;
ii. Location on a hill, uplifted terrace or other easily defended elevated position (good visibility and good observation points);
iii. Readily defended approach from the sea, possibly blocked by harbour chains or watched over by a fortified building.

A second way to interpret the strategic location of a port is in terms of its connection with the hinterland areas. This would have been a major concern when setting out a maritime trading emporium. The supply and distribution of goods by land (or river) would have to occur by river-boat, pack animal or be hauled by slaves. This would often have to be supplemented with supplies of water and food for both human and animal consumption, as well as building materials and ship parts.

The quality, (seasonal) accessibility, and safety of roads and rivers towards the hinterland, including rest areas where porters and pack animals could rest and water, would have been critical for merchants distributing goods inland. The assurance of safe passage inland would have determined the price of goods being distributed and therefore might have swayed the choice of port from which they would set sail. It was therefore in the interest of the port community, or even, at an earlier stage, of port planners, to be within easy distance of a good road inland and a corridor to connect with the hinterland. Such a connection would allow for the procurement of goods and supplies from inland, and for the distribution of sea-trade commodities enabling merchants to charge higher prices on their goods to the middleman.

The recently discovered Ptolemaic fort and substantial defensive city walls indicate conscious improvements in the defensibility of the site in its early stages of existence. Berenike is naturally strategically located on top of an uplifted promontory with good all round views, including the entire Foul's Bay, and this position would have enabled the sending of signals to forts and stations located in the foothills of the mountains. A score of 4 is achieved by Berenike not only due to its defensive position and viewshed location, but also because it benefitted from good connections with the hinterland via a number of caravan routes supported by stations, forts and *praesidia*. Whilst this meant that the caravan journey was 6 days longer (6 days from Myos Hormos and 12 days from Berenike), the ships did not have to follow the northerly passage to Myos

Hormos, which could take much longer (even weeks) with unfavourable northerly winds.

6.5.3. Political stability and general safety

The political stability of a region must have played a crucial role in deciding which port to trade in. An unstable political situation would be a serious impediment to trade, potentially driving up prices and creating an unreliable trade situation. Conversely, a stable situation and safe harbour would have allowed for the development of unhindered trade. Similar to the 21st-century Horn of Africa, the presence of pirates, competing tribes, marauders and other outlaws would have made some areas of the coast and inland routes difficult to pass or stopover at, affecting sea traffic, trade prices and the general wellbeing of merchants and their agents.

Coastal sites are threatened from both the sea and hinterland, as Karl Polanyi (1963: 30–45) notes in his seminal *Ports of Trade in Early Societies*. These nodes of activity are, accordingly to his 'port of trade' concept, the neutral zones, administered by the powerful and centralised state in the hinterland and potentially located within hostile surroundings. They are situated outside a riparian village or coastal city, where foreign and native merchants interacted and the 'royal' officers dictated prices and maintained the neutrality zone.

Ten *praesidia*, part of a Roman early-warning system, were situated within a distance of 7.2–35 km from Berenike. They not only supplied the town with water but also protected valuable trade routes through the wadis, with many of them housing garrisons consisting of soldiers from different regions of the Empire (i.e. Roman auxiliary troops). For example, inscriptions and votive dedications provide evidence for Palmyrene archers patrolling the Koptos–Berenike desert road in the time of Marcus Aurelius. Although 'unruly' nomadic tribes populating the Eastern Desert could have occasionally caused strife the well-protected caravan routes with their *praesidia* and forts meant that Berenike scores 4 in this category.

6.5.4. Attractiveness to merchants

Meeting the expectations of the sailors and merchants who would use the facility would also represent an important part of the planning of a port. A number of environmental factors such as ease of re-supplying with food and water, availability of resources to carry out ship-repairs (Fig. 6.22), as well as the availability of raw materials and trade goods were discussed above. However, intelligence about the particular types of human expertise, such as specialist workshops, talented craftsman or artists, or a renowned and capable shipwright, a good brothel, bar or any other form of entertainment, could potentially result in the modification of a route as the crew of the vessel choose a more attractive port for their needs, if one was available.

Whilst such facilities were unavailable prior to the setting of the harbour, the availability of human resources, the capacity of the port to develop such amenities, and the location on a particular node of trade network with, for example, pre-set taxes, would have been a crucial consideration (e.g. Leidwanger et al. 2014). The closest major port was Myos Hormos but a number of other smaller anchorages were available *en route* to Berenike. Although some of them, such as Nechesia, Ophiodes, Bathus Profondus Portus, and Dioscuror, are mentioned in texts as receiving moderate traffic, a lack of archaeological data regarding their location and character does not allow us to assess how competitive could they have been to Berenike. Therefore access to these 'human resources' and their 'willingness' to settle in a new port town would be crucial (see the Coptos Tariff for a tax paid for the transport of prostitutes from the Nile valley to Red Sea ports; Young 2001: 44).

Another influential factor would be the potential risk of queues to enter the harbour, and the level of taxes and custom duties,[46] which could have convinced the merchants to travel to other locations to trade. Customs duties were high in some areas of the ancient world. For example, the *tetarte*, as mentioned by the Muziris Papyrus (Rathbone 2001), was a 25% customs fee on eastern trade imports from Red Sea harbours such as Myos Hormos or Berenike, levied in Alexandria that had to be paid on all commodities (Temin 2004; Fitzpatrick 2011; Wilson 2015) (Section 1.3.2). Usually the imported goods would be raw materials

[46] Compare with establishing Delos as a freeport in 167 BCE to counterbalance Rhodes 2% harbour tax (Duncan-Jones 1990: 37; Adams 2011: x). Within a year, trade immediately bypassed Rhodes in favour of Delos (Adams 2001: 90). Similarly, the growth in importance of the 18th-century CE port of Az-Zubarah in Qatar, which created a duty-free zone led to the quick decline of the otherwise popular and successful port of Muharraq in Bahrain (Rob Carter, pers. comm. 2010).

that were then sold in Alexandria itself (Cottier 2010), so subsequent taxes of a value close to 2–2.5% would have been less significant. Only a limited number of bureaucratic centres had the power to levy taxes and so the queues could be long and frustrating, potentially lasting for days whilst tax officers were highly officious (Cottier 2005).

Berenike attains 4 in this category based on the evidence from ostraca and papyri (Bagnall et al. 2000, 2005) attesting to the importation of variety of foodstuffs and wine to the town. There are both references to prostitutes and brothels, as well as temples and religious and cultic worship, serving a diverse array of creeds and interests, from explorer, merchant to pious traveller. Based on this written evidence it seems clear that the city provided good quality services to merchants and sailors, comparably much better than anything they could obtain in the immediate area. Whilst a similar level of tax would be levied in all Red Sea ports under Roman political rule, ports located outside the Empire could have competed for popularity by adjusting their customs duties. Under such circumstances the attractiveness of the port would depend on its level of connectedness and how quickly merchants would be able to move the delivered goods making highest possible profit.

6.6 DISCUSSION OF BERENIKE'S 'PARAMETERS OF ATTRACTIVENESS'

The Parameters of Attractiveness (PoA) scores Berenike attained for each of the categories can be seen in Tables 6.1–6.4. From these semi-quantitative data we can now draw a number of conclusions. As can be seen from the tables, Sea parameters score 0.72 whilst Socio-political-economic parameters score a very high 0.85. At the same time, values for both Land parameters and Resource parameters are low at 0.53 and 0.48 respectively. Berenike scored a total of 2.58 out of 4 overall.

These data suggest that the decision behind the siting of Berenike was not entirely due to environmental factors. Whilst Berenike scores highly in terms of the excellent marine and political context of the site, it falls well short in terms of the physical landscape setting, and is especially poor with regard to the water supply. Despite this, Berenike flourished in that challenging landscape for almost a millennium. This shows that political will and economic demand were often — especially in the Roman Empire — much more influential than fundamental considerations such as the scarcity of fresh water available at the site. The lack of other ports in the region, and indeed the lack of demand for more meant that, due to its specific location, Berenike was able to flourish, with barely with any competition, intermittently for 800 years.

So, why was there such a strong political or economic impetus to locate Berenike in this particular location? There must have been a great deal of thought that went into the weighing up of the pros and cons of this location when plans were being made and advisors were petitioning for this site to be used. Strategically it must have filled a gap along the young but flourishing trade network, but could there have been other locations nearby?

The prevailing wind patterns reaching Berenike from the south, along with the natural harbour and lagoon system must have represented a landscape configuration so suitable that it could not be ignored. The sheltered location just to the south of the large peninsula of Ras Benas, with the wadi corridors (logistical transport super-highways) connecting the site with the hinterland, must have been crucial factors in the decision-making process. Although there are other sheltered bays along this coast within 100 km north and south of the site, Berenike's Parameters of Attractiveness must have tipped the balance.

We cannot know whether the initial decision to exploit the coast at Berenike was rushed, but the sudden need for the war elephants in the time of the Ptolemy's II struggles with the Seleucids may have added an element of urgency to the decision-making. But later in the Roman period, situating a port in a 'known' Ptolemaic location may have made it the most obvious strategic choice, since it already had some infrastructure to connect it with the Nile developed. It would also be the fastest port to utilise with the necessity to provide for the steadfast 'picking-up' of the trade networks.

The ancient port of *Berenike Troglodytica* supported its citizens and transient visitors for almost a millennium. This was primarily due to the urgent demand for commodities feeding the needs of the Empire, enabling its survival for a sustained period of time in this marginal environment. However, as the above study shows, its location was ultimately attractive enough to successfully provide for the port, its inhabitants and its visitors.

6.7. FUTURE WORK

The Berenike case study presented here demonstrates the utility of the Parameters of Atractiveness approach for quantifying and evaluating the many competing factors that were likely to have influenced the choice of ancient port locations. It is envisaged that future work will be carried out to enlarge and enhance this dataset. To this end a number of port sites on the Indian Ocean and its associated basins that the author has worked on, or visited, including for example: Khor Rori, Unguja Ukuu, Rhapta, Pattanam, Dibba and Failaka Island, would be examined in more detail and the 'Parameters' already employed at Berenike will be used to assess different aspects of their 'attractiveness'.

An enlarged dataset will also allow for a more objective and hence more robust evaluation of each parameter. It is anticipated that the evaluation system will be greatly refined and enhanced after patterns have been observed on a larger sample size. For example, if 'Demand' is observed repeatedly to be one of the key parameters, it may need to be valued between 1–10, whilst "Tidal range', which might turn out to not necessarily play such a huge role in the siting of a port, might be valued between 1–3. More advanced normalisation can then be employed along with the introduction of a more robust confidence-scoring system. A larger and more diverse dataset would also help to create a buffer against the misinterpretations of secondary data, particularly when assessing sites that cannot be visited or examined first hand.

A simple scheme of semi-quantitative sliding scales also allows for cross-checking of the viability of the models themselves. It would similarly allow for lists of relevant, irrelevant and neutral variables to be created. The hypothesis that the attractiveness of the sites of harbours in the Indian Ocean and Red Sea was dependent primarily on landscape and environmental factors, with a strong influence of political will from Rome, at marginal sites of the Roman Empire can then be tested more robustly.

'[--.] we will [...] take a ship, such as the Egyptians construct for our seas and launch for the exchange of Egyptian goods against Indian wares. For there is an ancient law in regard to the Red Sea, which the king Erythras laid down, when he held sway over that sea, to the effect that the Egyptians should not enter it with a vessel of war, and indeed should employ only a single merchant ship. This regulation obliged the Egyptians to contrive a ship equivalent to several at once of those which other races have; and they ribbed the sides of this ship with bolts such as hold a ship together, and they raised its bulwarks and its mast to a great height, and they constructed several compartments, such as are built upon the timber balks which run athwart a ship, and they set several pilots in this boat and subordinated them to the oldest and wisest of their number, to conduct the voyage; and there were several officers on the prow and excellent and handy sailors to man the sails; and in the crew of this ship there was a detachment of armed men, for it is necessary to equip the ship and protect it against the savages of the Gulf that live on the right hand as you enter it, in case they should ever attack and plunder it on the high seas"
— Philostratus (Vita Apoll. 3.35)

7. THE MARITIME CONTEXT OF BERENIKE AND IMPLICATIONS FOR THE SIZE, CAPACITY AND OPERATION OF ITS HARBOUR BASIN

Undoubtedly, the design of many harbours was dependent upon the type and size of vessels that it was intended to receive. At Berenike the harbour was situated in the natural bay where, to date, no unequivocal port infrastructure has been identified. In lieu of structural archaeological evidence for such facilities we must therefore rely on reconstructing the depth and extent of the harbour basin (in relation to changing sea level and rate of sedimentation; Chapter 5) to glean information regarding the capacity of the basin (Sections 7.3 and 7.4.2) and the size and type of boats that could have used it (Sections 7.1 and 7.2). These considerations would have been absolutely crucial during the prospection for the port, and as we have seen in the previous chapter Berenike receives a high Parameters of Attractiveness score for the presence of its sheltered natural bay. In this chapter the types of vessels that were likely to have visited Berenike will be looked at, with the focus concentrating on the various strands of evidence that can shed light on the size, shape and constructions techniques of sailing crafts that plied the Red Sea trade routes at this time.

To do this, the shipwreck evidence will be discussed first, followed by the discussion of available maritime archaeological material from Berenike (much of which is unpublished at present), such as hull planking and sheathing, nails, sails, rigging, knots and ropes. These materials will be compared with those found at Berenike's sister port Myos Hormos, the only contemporary site in the region with a published comparative dataset. The similarities and differences between the material from the region and that found at Berenike will be explored to more fully understand the characteristics and functioning of its harbour in antiquity, and to present a number of possible 'scenarios' exploring different sets of logistics of mooring merchant vessels in Berenike's harbour.

7.1. ANCIENT VESSELS OF THE RED SEA

Despite a great deal of research by historians, archaeologists and other maritime scholars, there remains a rather poor understanding of the design and construction of ships that sailed the Red Sea and Indian Ocean trade routes in antiquity. Similarly, there are few indications as to whether any unifying features existed that made them particularly suited to sailing in monsoonal conditions or within enclosed sea basins or both. This kind of information is crucial if we are to obtain information about the types of vessels that would have moored at Berenike and the size, shape and configuration of its harbours.

Most of what we know about seafaring on the Red Sea in the Roman era is derived from a small number of shipwrecks and from the archaeological records of two major ports: *Berenike Troglodytica* and Myos Hormos. The variety of finds related to rigging and sailmaking recovered from these sites reveals a marked diversity of vessel type and size. This archaeological evidence shows that these ships were rigged and planked in the Mediterranean square-sail fashion, but with the use of eastern (Indian and African) materials. Despite the fact that Mediterranean-style rigging has not been discovered in archaeological contexts from the Indian Ocean region, iconographic representations exist that depict rigging features similar to those used by Mediterranean vessels, either representing foreign vessels or designs that were cross-culturally appropriated.

7.1.1. Shipwreck evidence (Indian Ocean and the Red Sea)

In comparison with the Mediterranean, where almost two thousand Greco-Roman shipwrecks have been identified to date (Strauss 2013),[47] very few historic wrecks have been discovered in the Western Indian Ocean and its connected basins (Figs. 7.1 and 7.2). The only confirmed pre-modern wrecks with preserved hull structure are from Indonesia, Sri Lanka and Thailand (e.g. Flecker 2000, 2001, 2004: 2–39; Carlson and Threthewey 2013; Svasti 2014) and to date no pre-modern shipwrecks have been reported from the coast of East Africa (Lane 2012). This apparent bias reflects numerous geographical, political and social factors, as outlined by Parker (1992: 6). Whilst research has flourished in some areas of the Red Sea and Indian Ocean, piracy, kidnappings, civil unrest, and religious fundamentalism has thwarted post-conflict reconstruction and corruption has stunted the progress of scientific investigation and still poses a threat to scientists working in these regions.

Wrecks in shallow waters often remain undiscovered regardless of repeated survey attempts because wood does not preserve well in hot, nutrient-rich seawaters, and violent storms and monsoon winds can scatter all but the deepest shipwrecks (e.g. Ray 2003: 80). Also, rapid coral growth rates in the Red Sea (Sampsell 2003: 172–174), and in parts of the Indian Ocean coast (McClanahan et al. 2000), make it extremely difficult to locate 'amphorae wrecks' (Greg Votruba, pers. comm. 2014) because ceramics deposited on the sea floor quickly become enveloped by new coral growth (although see Blue et al. 2012).

[47] Since 1992 when seminal work by Parker was published over 600 wrecks have been discovered.

To exacerbate the problem, the Red Sea seabed offers only a thin protective layer of sand that might preserve the wreck, whilst the steep gradient coastal shelf puts many wrecks out of reach to all but the most financially endowed archaeological surveys.

Despite this, there are *some* wrecks known from this period recovered from the Red Sea and Indian Ocean sea floor (Table 7.1; Figs. 7.1 and 7.2). However, we still have very little information regarding hull structure, draught, size, potential speed and manoeuvrability of these vessels, factors crucial to our understanding of ancient ports and harbour basins. This is perhaps unsurprising given the small number of wrecks that have been scientifically and systematically researched (e.g. Pedersen 2008; Blue et al. 2012; Carlson and Threthewey 2013). In fact, the paucity of archaeological evidence is the main obstacle to the furthering of this line of inquiry, although there are some newly discovered wrecks currently awaiting assessment and the publication of new primary data.

Table 7.1 Red Sea and Indian Ocean Greco-Roman period shipwrecks.

NAME	LOCATION	DATE	COMMENTS
Quseir shipwreck	Near the ancient harbour of Myos Hormos, at a depth of 65 m	100 BCE–100 CE	This approximately 33 m long, poorly preserved wreck has been known to the Institute of Nautical Archaeology (INA) since 1993. A survey conducted in 1994 by a team led by Douglas Haldane revealed a cargo of Campanian amphorae from Italy. There were plans to conduct an initial survey of the wreck site in 2002, but this was postponed at that time until appropriate dive safety measures were put in place (*The Red Sea Wreck Project* 2013).
Fury Shoals wreck/ Satayah wreck	Sha'ab Sataya in Fouls Bay, close to the site of *Berenike Troglodytica* (some 35 km to northeast), in a shallow bay created by reefs	50 BCE–100 CE	Small shipwreck already known for a few decades (Amsler and Ghisotti 1995) and revisited and documented between 2010–2013 by the joint University of Alexandria, University of Southampton, British Museum and Supreme Council of Antiquities expedition (Blue et al. 2012: 91). This is, to date, the best-preserved Roman shipwreck from the Northern Red Sea. It is assumed to have been loaded in an Egyptian port and have visited Southern Arabia at some point of its life (Blue et al. 2012: 95). The wreck consists of up to 34 amphorae (plus at least 8 removed since 1996) encrusted together to the seabed in two tight groups. The cargo included: 20 Campanian (with original wine sealed with pozzolanic Italian stoppers), 6 Alexandrian AE4, and 7 unidentified Roman amphorae, as well as a single Organic Storage Jar similar to ones from South Arabia (Blue et al. 2012: 94–95, Fig. 11.1, 11.4; Blue 2014: 6246). No remains of hull, timber, nails, or stone anchors were discovered, however, a number of basalt pieces were found. These could probably be ship ballast such as these found at Berenike (pers. observ.) that could have originated from South Arabian ports of Aden and Qana (Peacock et al. 2007: 28–70). The real size of the cargo remains unknown due to extensive evidence of looting (at least 20% of cargo since just 1996).
'Zabargad'/ Zeberged shipwreck	In the vicinity of St John's Island, some 80 km south of *Berenike Troglodytica*	50 BCE–100 CE	In accordance with amphorae finds from the wreck, this boat was probably on its way out from Zabargad (Wainwright 1946; Verri 1994; Sidebotham 2011: 199), ancient Topazus/Ophiodes. From there peridot was exported to India by way of Berenike (Harrell and Bloxam 2010: 18–21). No hull fragments were recovered from the site.

NAME	LOCATION	DATE	COMMENTS
Abu Fendera shipwreck	Some 135 km to southeast from Berenike and Fouls Bay, in the vicinity of Siyal Islands, next to a series of reefs. Scattered over 28 x 31 m area at a depth of 21–23 m	End of 1st c. CE – no later than mid 3rd c. CE	Discovered independently by recreational divers around 2007 and then re-documented by a joint British and Egyptian expedition (Blue et al. 2012: Fig. 11.6; Blue 2014: 6246). The wreck consists of a mixed cargo of between 21 and 42 Roman amphorae (currently on the seabed) of at least five different types, mostly of Alexandrian and Egyptian origin, but also Italian, French/North African and some Spanish forms. Except for one example all of the amphorae were used to transport wine (Blue et al. 2012: 96–98, Fig. 11.5). Other findings include two bronze bowls, a potential copper alloy javelin head, five (?) copper nails, three two armed stock iron anchors (between 2.4 and 2.9 m length and resembling Mediterranean types also found in Berenike), an iron bar from potential fourth anchor, and most importantly lead sheathing with what seems to possibly be an outline of the shape of a part of the ship hull's (Blue et al. 2012: 97–98, Fig. 11.8). No ballast stones were found.
Shab Rumi shipwreck	In an atoll 40 km from Port Sudan. Lies in shallow water	50 BCE–100 CE	This ship was most probably bound for India. No hull remains were discovered (Dumas 1972: 187–191; Parker 1992: 1077).
Black Assarca	Between the Buri Peninsula and the Dahlak archipelago in the middle of Massawa Channel and close to the Black Assarca Island. Some 40 km to the northeast from the port of Adulis, Eritrea. The 'main pile' at 4–6 m depth	Late 4th–early 7th c. CE	Surveyed in 1995 and excavated in 1997 this small coastal trader (probably of a size similar to *Kyrenia* – 14 m), with a cargo of Aqaba amphorae (previously known as Assarca types 1–3) was probably involved in a shipment between Aila and Adulis (Pedersen 1996, 2000, 2008: 89–90, Fig. 3; Cicci 2012). Recent research on the provenance and identification of the cargo resolves 'firmly, but not conclusively toward wine or date products' (Peacock 2007: 95) of amphorae produced in Aqaba in this period (Tomber 2008: 92); the other potential produce is *garum* (Van Neer and Thomas Parker 2008). Some ballast stones were also discovered, but exploration of deeper parts of the scatter where the cargo slid down the slope was hindered by rough seas and limited resources (Pedersen 2008: 81). Found beneath the 'main scatter' — a potential "layer of artefacts lying in position since the original wrecking of the ship" was however not excavated due to the time constraints of the project (Pedersen 2008: 82).

NAME	LOCATION	DATE	COMMENTS
Dahlak Kebir	Near the small island of Dahlak Kebir archipelago in Eritrean waters	3rd–4th c. CE	Ceramic scatter (Pedersen 2008: 91).
Uninvestigated deep wreck in Eritrean waters	Deep water wreck lying between Black Assarca and Massawa		Un-investigated deep wreck reported by Pedersen (2008: 91).
Eliza Shoals wreck	Eliza Shoals, just northwest from Jeddah, Red Sea coast of the Kingdom of Saudi Arabia	Late 3rd–early 4th c. CE	This probable amphora wreck (no hull remains) was discovered during a 2012 survey undertaken by the Marburg University Nautical Archaeology Survey (Pedersen 2013). The findings include a Dressel 24 Similis D type amphora used for transportation of olive oil and a body sherd with drilled holes most probably used to vent young wine (Pedersen 2015).
Persian Gulf Shipwreck	70 km from the historical port of Siraf in Boushehr province, Iran. At a depth of 70 m	Partho-Sasanian period 250 BCE–650 CE?	This unpublished (and unexcavated?) wreck was discovered in 2006 by fishermen. Some of the remains of earthenware and amphorae were recovered from the shipwreck (Tabeshian 2006; CAIS 2007). The dating of the wrecks is contested by some researchers who regard the available evidence insufficient to provide tight chronology for the shipwreck (e.g. Ralph Pedersen, pers. comm. 2014).
Bet Dwarka	Near Bet Dwarka island jetty (potential 'Baraca' of the *PME* and the 'Barake' of Ptolemy) located in the Gulf of Kachchh, in the Jamnagar District of Gujarat state, India. At a depth of 5–8 m	100 BCE–200 CE	During 2000–2002 seasons, the remains of a shipwreck with seven amphora necks and bases, a large number of pottery sherds, two possible lead anchors, and one circular lead ingot, as well as a large number of stone anchors of different types (some of them similar to a ring-stone anchor from Oman) were uncovered. There are no remains of timber possibly due to the wreck's location in the mouth of the bay that experiences severe tidal action (Gaur et al. 2006).

NAME	LOCATION	DATE	COMMENTS
Pattanam canoe	In the archaeological trench. Within an infilled canal, by the wharf structure, in an ancient town of Muziris (Pattanam village), on the Malabar Coast of Kerala, India	?	Although not a shipwreck *per se*, the canoe uncovered in Pattanam village (where the author carried out geoarchaeological survey in 2011) should be included in this category. A *ca.* 6 m long and approximately 30 cm wide canoe was found in 2007 in the trench adjacent to the wharf structure (Fig. 7.4). From preliminary observations made by Cherian (2007: Section 3.2), before the boat was re-buried in its trench: "[…] it is evident that the boat had been repaired and made waterproof. In some parts it has got two layers of wood and in between these layers evidence of caulking can be seen. No nails were used. A particular material (organic?) was used for caulking. Additionally, three planks/poles in a highly damaged condition were also found near the canoe and seven wooden bollards were found in a line almost parallel with the wharf and the canoe. The *in situ* finds of amphorae suggest this area of the site being an access point, with a well-planned wharf structure suitable for unloading and loading goods." The shape and size of the canoe gives direct indication as to how small local craft that could have been used as lighters offloading large seagoing ships looked.
Godavaya shipwreck	Near Godavaya, Hambantota District, the coast of southern Sri Lanka. At a depth of 33 m	100 BCE–100 CE	Excavations conducted by the Institute of Nautical Archaeology (INA) during 2012–2014 seasons uncovered what is believed to be 'the oldest shipwreck on the Indian Ocean' (Carlson and Threthewey 2013) (Fig. 7.3). The ^{14}C dates on wood samples suggested that it was contemporary with the dating between the 100 BCE and 100 CE (Carlson 2010). The ongoing excavations and publications of this important 'wooden wreck' (suggesting hull remains that are potentially covered by heavy concretions and metal cargo) are envisaged to shed more light on what types of vessels were plying the maritime routes of the Indian Ocean in the Roman times.

Table 7.1 shows that shipwreck data is scarce (Figs. 7.1 and 7.2). A close look at this incomplete dataset allows us only to hypothesise that the era between 100 BCE and 100 CE was characterised by a variety of vessel sizes (usually small to medium size) carrying mainly amphorae cargoes towards the East, and a mix of different, usually bulky and light, cargoes back towards the West. Apart from the unpublished Godavaya wreck (Fig. 7.3), there has been a striking lack of *in-situ* hull remains, and no sails or rigging components have been found underwater.

While any preserved cargo can, in most instances, allow for some tentative calculation of the vessel's size, shape, draught, and potential speed, the estimate of the manoeuvrability of the ship often remains elusive. The identification of lead sheathing and iron nails, potential traces of hull beneath coral encrustations, as well as Mediterranean-type anchors from the Abu Fendera shipwreck (Blue et al. 2012: 96–98) are in stark contrast with other known shipwrecks from this region – preserved almost entirely as an amphora cargo.

The difficulties associated with obtaining research permissions, the high costs and complex logistics of conducting full-scale underwater survey, as well as looting and the slow — or often entirely absent — dialogue between recreational divers, tour operators and archaeologists, seem to suggest a somewhat sombre future for maritime archaeological research on the Red Sea and Western Indian Ocean that can only be invigorated by a real concerted push forward in the discipline.

7.1.2. Nautical finds from terrestrial contexts

With the near absence of structural data obtained thus far from shipwrecks, other forms of nautical archaeological evidence must be used as a secondary source of data regarding marine technologies available on the Red Sea in the Greco-Roman period. These items can include anchors (Cooper and Zazzaro 2012; Sidebotham et al. 2008: 155); metal objects such as mooring chains, sail needles, nails, tacks and lead sheathing (Sidebotham 2008: 37; Blue et al. 2011: 186–188); recycled fragments of sail cloth (e.g. Wild and Wild 2005) and rigging, including wooden and bone components such as sheaves, deadeyes, brail rings and toggles from both Berenike and Myos Hormos (Whitewright 2007a, 2008; Sidebotham 2008; Blue et al. 2011); ropes, knots and nets (Veldmeijer 2004, 2006); gum, resins and tar, such as those recovered in Trenches BE10-62/64 in Berenike (pers. observ.); as well as barnacles with impressions of wood and traces of pitch that had been stripped out of the vessels during antifouling, such as at Myos Hormos (Whittaker et al. 2006; Blue et al. 2011: 186–187, Fig. 15.7).

Epigraphic evidence on papyri and ostraca from the Roman period, as well as depictions as rock carvings, also serve as a valuable source of information. Representations of what might have been Red Sea vessels from the 1st–3rd century CE have been recorded (Lankester 2012a: 221, 2012b: Map 4, 2013), along with letters and other documents, attesting to shipments of wood to the Red Sea coast by way of the Eastern Desert from the Mediterranean.

These documents include the famous Coptos Tariff[48] that mentions a tax of 20 drachmas for the transport of a mast, and 4 drachmas for a yardarm,[49] from Coptos to the Red Sea.

Other taxation sources that mention ship elements include an ostracon from Krokodilopolis (*O.Krok*. 41) that provide evidence for the high price of wood transported along the wadis (Bülow-Jacobsen 2003: 420; Sidebotham 2011: 212–216) the most expensive of which were long straight planks (Lewis 1983: 141; Bagnall et al. 2005). Another ostracon from Berenike (*O.Ber*. II 131) lists various ship equipment coming from the Nile Valley and awaiting customs declaration, including sail braces, pulleys, rope, mast belts, 'gum' and 'branding irons' (Bagnall et al. 2005: 47). Given that the maintenance of wooden boats is an ongoing exercise,[50] requests and deliveries would have transmitted back and forth across the Eastern Desert ceaselessly, and more of such accounts should emerge with Bagnall's anticipated publication of Berenike's documents from the 2009–2014 seasons.

[48] A tariff posted at the Coptos toll house (90 CE) refers to different goods and persons taxed under orders from *praefectus montis Berenicidae* for the maintenance of the Eastern Desert roads and military (Burkhalter 2002).
[49] Comparable with e.g. 8 drachmas for a passage of a 'helmsman/skipper of the Red Sea', 10 drachmas for ship's lookout, 5 drachmas alike for a sailor, shipbuilder's servant and a guard, 4 drachmas for a covered wagon and 108 drachmas for women for the purpose of prostitution (Young 2001: 44). These numbers show that people of different skills who were associated with ship industry must have been highly valued and relatively well paid if such large sums of tax were paid for their passage (Blue et al. 2011: 188).
[50] As the present author learned through her own experience owning a historic 1930s Tasmanian huon pine sailing yacht.

7.1.3. The Mediterranean tradition

In trying to obtain information regarding ancient technologies, designs and the capacities of Roman Red Sea vessels that may be relevant to reconstructing Berenike's harbour it may be possible to use Mediterranean shipwreck data, as well as epigraphic and iconographic sources. A growing body of evidence, such as the Abu Fendera shipwreck and finds from Berenike and Myos Hormos, suggests that long-distance vessels used in the northern Red Sea were similar to those found in the Mediterranean, built using the classic shell-first, pegged mortise-and-tenon technique (Section 7.2.1) and propelled by square sails with Mediterranean style rigging (Section 7.2.3) (Blue et al. 2011; Sidebotham 2011). However, these vessels might best be thought of as hybrids because as well as acquiring Mediterranean supplies they used materials sourced from around the Indian Ocean, such as cotton sail-cloth from India (Wild and Wild 2005: 10–15), and teakwood and blackwood from India and East Africa (Vermeeren 1999b, 2000a: 1–11, 2000b: 311–343). These materials were either specifically imported for maritime use, acquired during repair at their destination port, or purposefully cut and shaped in the East to Mediterranean specifications.

The extraordinary typological diversity of merchantmen in the Mediterranean is exemplified by the numerous representations of vessels depicted in Greek and Roman art (Pomey 2009). These vary from small, short haul vessels to large seagoing merchant ships, ancient freighters and war galleys, as well as a range of fishing and auxiliary crafts and ship's boats (e.g. Casson 1965). However, representations of merchantmen in Mediterranean, especially true in Hellenistic depictions, are rare and often overshadowed by depictions of warships and fishing vessels (Casson 1969), so there are no known depictions of the *elephantagoi* that would have used the Ptolemaic harbour at Berenike.[51] These elephant carriers[52] are believed to have often been forced to travel by night in order to use the strong offshore winds because their size made it all but impossible to sail into small harbours to secure overnight anchorages (Agatharchides, *PTET* from Diodorus, *Hist.* 3.40.3):

> *"The ships, which carry the elephants, being of deep draft because of their weight and heavy by reason of their equipment, involve their crews in great and terrible dangers. Since they run under full sail and often are driven before the force of the winds during the night, sometimes they strike the rocks and are wrecked, at other times they run aground on slightly submerged spits. The sailors cannot go over the sides of the ships because the water is deeper than a man's height, and, when in their efforts to rescue their vessel by means of their punt-poles they accomplish nothing, they jettison everything except their provisions."*

Some believe *elephantagoi* had a shallow draught of around six feet and a maximum of 18 feet[53], whilst others claim that they had to have had a very deep draught (Belozerskaya 2006). If estimates by Casson (1969) are taken at face value, a range of 6–18 feet (2–5 m) might be plausible if a flat-bottomed

[51] The only tentative representation is known on a 4th-century CE mosaic from Piazza Armerina (Sicily), depicting elephants coming down the ramp of the ship.
[52] Built by the Ptolemies to bring elephants – the tanks of antiquity – from Africa to Egypt and use them in wars against the Seleucids. This was the original purpose for the construction of the port of *Berenike Troglodytica* in 285 BCE by Ptolemy II and it was still used for the same purpose till at least 217 BCE when 73 African forest elephants are reported to have been fighting in the Battle at Raphia – between Antioch III and Ptolemy IV (Nossov 2008: 20).
[53] This is approximately 2–5.5 m draught. After Casson 1993: 253: "Diodorus' statement (*His.* 3.40.5) that, when an elephant-carrier runs aground "the crew is unable to go over the side because the depth is greater than a man's height and, when they try to help the vessel by using boat poles, ... and accomplish nothing" sets the minimum draught, while his mention of the depths encountered (*His.* 3.40.3) sets the maximum. However, if the men were able to use boat poles, the maximum was very likely a good deal less than eighteen feet."

elephantagos was to be beached at Ptolemaic Berenike, which according to recent geoarchaeological results (Chapter 5) would be able to support this draught.

During the Imperial Roman period, two major types of seagoing ships[54] crossed the Mediterranean — the military long ship (*naus makra, navis longa*) (e.g. Pitassi 2011, 2012) and the cargo-carrying round ship (*naus strongule, navis oneraria*) (Casson 1971: Fig. 137; Ericsson 1984: 15). The Mediterranean merchant ships reached their apogee between the late Republic and the early Empire after significant developments in maritime and shipbuilding technologies following the turbulent years of Alexander's conquests. With the development of naval ships there was a move to introducing new and innovative naval technologies into the merchant fleet (Steffy 1994; McGrail 2001; Pomey 2004; Blackman and Rankov 2013: 76–91), particularly at the beginning of Imperial rule.

7.1.3.1. Technology and design

Roman cargo-carriers — *naves onerariae* — were primarily propelled under sail (although there are examples of ancient merchant galleys with both oars and sails) and were usually built at minimum expense with no real requirement for speed (Ericsson 1984: 15). These vessels had a "broad, fairly shallow, hull of the double-ended type; the stern was raised, rounded and buoyant, while the bow was sharper with a convex cutwater curving outwards and upwards" (Ericsson

[54] Ship refers to a boat over 50 ft in length.

1984: 38) (Fig. 7.5). They were usually built shell-first, in 1:4 or 1:3 beam-to-length ratio, and were round-hulled and flat-bottomed, up-curving at the bow and stern (giving a symmetrical shape), keelless or keeled, with edge-fastened planking using mortise-and-tenon joints (Adkins and Adkins 1998: 204–207) (Figs. 7.6–7.9). Such a broad, flat-bottomed ship could have been easily accommodated at Berenike, where conditions might have favoured more stable vessels of shallower draughts.

7.1.3.2. Size and tonnage

Based on historical and ethnographic data (Casson 1989), vessels that sailed the Red Sea trade routes can be divided into three groups: i) large ocean-going ships of either Southern Arabian, Indian or Mediterranean origin that sailed from Egypt to the Malabar Coast, and were described in *PME* as 'very large';[55] ii) smaller coastal boats used for local and regional trade and larger-scale fishing activities; and iii) lighters, barges, tug boats, dredgers(?) and other port maintenance and auxiliary vessels. Using data from preserved Mediterranean ship remains, which could also be applicable to Red Sea vessels, Parker (1992: 26) proposes a further division of Roman vessels based on size and chronology into

[55] A characterisation used only twice in the text — the second time for the Indian vessels that sailed from the Coromandel Coast to the Ganges or the Malay Peninsula (*PME* 56). The vessels that exported pepper and *malabathron* from the Malabar Coast, and those of an Egyptian origin were also considered to be of a remarkable size by later historical accounts (i.e. Philostratus, *Vita Apoll.* 3.35; 170–250 CE). Marco Polo (Polo and Rustichello) deemed such vessels the 'first of the wonders of India'. These early modern vessels were said to have been able to carry a load of 5,000 or even 6,000 *esportes* of pepper and (de Romanis 2012: 76). *Esportes* is believed to be some 210–225 kg each (Ashtor 1982: 475–476) — thus making the load an extraordinary 1,000 to even 1,350 tonnes!

three main capacity types: i) the smallest, holding ~75 tonnes of cargo, is the most common; ii) a medium size, *ca.* 75–200 tonnes, used primarily between 1st century BCE and 3rd century CE; and iii) the largest, with a cargo exceeding 200 tonnes, which have been tentatively dated to the 'Roman Imperial period' (31 BCE to 400 CE) or 'Roman period' (150 BCE to 400 CE) (Russell 2011: 144).

Using known harbour regulations, depictions and archaeological material, Casson (1971: 171–173), suggests that the 'largest' of the merchant freighters in the Classical period weighed in at ~350–500 tonnes. Although much larger ships, of up to 1,000 tonnes' capacity, are known.[56] A 1,000-tonne ship would probably not be manoeuvrable enough to comfortably enter a port such as Berenike and whilst a small number of such vessels might have been able to be accommodated in the deepest part of the harbour it is unlikely that the majority of long-distance fleet would be of such a large size. Beresford (2013), however, argues that it would be those large vessels that would most likely withstand the Indian Ocean monsoonal weather conditions. It is more likely that to optimise manoeuvrability

[56] Available evidence confirms that the Romans were capable of building over 1000-tonne vessels. The largest Roman boats include: colossal 1st-century CE pleasure ships known as Nemi lake barges (67–71 m long) that were designed as floating palaces — one sailing ship and one oared galley (Carlson 2002); obelisk-carriers including: 1st-century CE Augustan carrier for the Flaminian obelisk that has been described as of 3,000 tonnes displacement (Duncan-Jones 1977: 332; Wirsching 2000, 2003; Bronkorst 2013); Caligula's obelisk-carrier (1,300 tonnes) sunk by Claudius for a mole in the harbour at Portus (Duncan-Jones 1977) and 2nd c. CE Alexandrian grain freighters that were in the range of 1,000–1,300 tonnes (Casson 1971: 186–188), such as the *Isis* (actually a multi-purpose vessel) that had a capacity of 1,200 tonnes, was 180 ft long, some 45 ft wide with the maximum depth through the hold of 44 ft (Lucian *Nav.* 5; Rickman 1980); shipbuilding skills that allowed for building such monumental vessels were however already known in the Hellenistic period and manifested by the *Syracusia* — acclaimed the largest Hellenistic merchantmen and prestigious vessel was estimated by Turfa and Steinmayer Jr. (1999: 106) to have been 1,700–3650 tonnes and 360 ft (Fig. 7.10). It only sailed once, from Syracuse in Sicily to Alexandria (Meijer and Sleeswyk 1996) and does not look as if it could withstand the strong blows of monsoon or *shamal*. Additionally, there was no large enough harbour in the mid 3rd century BCE in the Mediterranean to house this vessel.

and allow the vessel to access smaller ports most long-distance trade cargo ships would have been smaller than the 625-tonne-capacity *Hermapollon*.

Whilst, as acknowledged above, the larger ships could have performed better in adverse weather conditions, it could have been more efficient to send a number of smaller (mid-size) vessels to mitigate for a potential loss (as the risk factor seems to have been rather large). These ships could have travelled in groups that would be able to dock in smaller harbours such as Berenike. In this way the risk of loss through wreckage would be mitigated to some extent as the cargo would be spread over a number of boats instead of smaller amounts of very large vessels. This mitigating commercial risks in antiquity was extremely important as most of the 'Eastern' commerce relied on maritime loans — *pecunia nautica* or *pecunia traiecticia* or 'money that travelled' — in which ships and their cargos often served as security for the loan (Andreau 1999: 54–56; Arnaud 2011b). However, in the instance of loss or wreckage in which the borrower was not at fault, the money-lender incurred the entire cost (Temin 2004) therefore making sure that he might be better off insuring a larger amount of smaller vessels.

New data have recently been calculated by de Romanis (2012: 89) for the weight of the cargo vessel *Hermapollon* returning from India. It was ~20,500 talents of 95 Roman pounds each, corresponding to more than 625 tonnes, enough to qualify her as a 'very large' ship even by Mediterranean standards (Pomey and Tchernia 1978; Tchernia 2011). In total, 87% of the *Hermapollon's* cargo was pepper[57] and as the specific weight of pepper is 500/550 g per litre, 544 tonnes of pepper would have occupied approximately 1,000 m^3 (de Romanis 2012: 96). Accounting for the curvature of the ship, to accommodate 1,000 m^3 of pepper, the remaining 13% of the cargo,[58] and provisions for the crew, a 625-tonne vessel would either have to be built with multiple lower decks or with a high hold below the deck with cargo stored on multiple levels (Fig. 7.11) or be roughly 150–200 ft x 25–35 ft in size (45–60 m x 8–10 m) with some 10–12 ft (3.5 m) draught[59]. A 625-tonne ship might have found navigation within the entrance of Berenike's lagoon, surrounded on both sides by the coral reef, a difficult proposition. The shallow banks of the harbour might also have required a good mooring position in the middle of the lagoon from where it would have been difficult to manoeuvre in a crowded season. These reasons do not preclude, however, being able to berth at the harbour.

Numerous ancient sources such as the *PME* (56), Pliny (*NH* 6.101) and Philostratus (*Vita Apoll.*) state that the ships that sailed to Muziris from Berenike were of such a size that they could have carried 'cohorts of archers' (e.g. Leveau and Trousset 2000). A large vessel such as the *Hermapollon* would have required a

57 This is very similar to the average percentages of pepper in the cargoes of some Portuguese ships returning from India in the 16th and early 17th centuries CE (Steensgard 1985: 22; Pearson 1996: 121-139).

58 De Romanis (2012) mentions that the remaining cargo could have been a load of *malabathron* (a name given to cinnamon-like aromatic plant leaves and an ointment prepared from them). The stowage area of the *Hermapollon* would have to be even larger if the transport consisted of leaves that had a very high bulk to weight ratio, rather than already processed ointment — *Oleum Malabathri*. In his 2014 paper, De Romanis also mentions that among the commodities shipped on board the *Hermapollon* were 167 elephant tusks weighing 3,228.5 kg and *schidai* (fragments of tusks trimmed away from captive elephants) weighing 538.5 kg, which he has included in his weight calculations.

59 These approximate dimensions have been calculated by the author based on the wide-spread comparison of Roman shipwrecks with available sizes and cargo estimates and known historical vessels.

large crew to operate her, in turn necessitating more provisions, as well as material for running repairs. Although her performance in adverse weather conditions would have been better than a smaller ship, her size would have rendered her less manoeuvrable in close quarters and along the treacherous 'reefy' coasts of the Red Sea, and would require a suitably deep harbour to shelter her in. Since we know that *Hermapollon* made a voyage between Berenike and Muziris, and given that we have some data for the depth and the extent of the ancient harbour and the size of the Lagoon entrance (see Sections 5.1, 5.3 and 5.4), it is obvious that in the mid 2nd century CE the harbour of *Berenike Troglodytica* was capable of receiving a 625-tonne merchant vessels, albeit maybe not comfortably.

7.1.3.3. Speed and performance

The performance and speed of Greco-Roman Mediterranean vessels can be estimated using data generated by replicas of ancient merchantmen, constructed based on information from recorded shipwrecks. A number of replicas have been based on the famous *Kyrenia* wreck, a 47 ft, a 30-tonne merchantman, with a significantly profiled hull that sank around 300 BCE and is amongst the best-preserved Mediterranean trading vessels (Katzev and Katzev 1968; Katzev 1969) (Fig. 7.12). The *Kyrenia* wreck was found with *ca.* 75% of the hull intact, including the keel, substantial sections of the planking and frames (22 strakes of outer planking), as well as over half of the stern, sternposts and other structural details (Steffy 1985: 71) (Fig. 7.13).

The replica ship, *Kyrenia II*, was completed in 1985 (Fig. 7.14), and for almost two decades sailed across the Mediterranean and other seas, generating invaluable comparative data (Katzev 1981, 1990; Katzev and Katzev 1986, 1989; Tzalas 2007: 306; Katzev 2008). For example, a 660-mile voyage from Cyprus to Greece, proved that a small merchantman such as the *Kyrenia* ship could sail comfortably during the winter with a small crew, and she sailed exceptionally well under different sea and wind conditions, with an average speed of 2.95 knots (usually 2–6 knots) (Katzev 1990). *Kyrenia II* was capable of sailing in force 9–10 gales (40–55 knots) and storm-winds before having to seek shelter, whilst Beaufort force 5 conditions (17–21 knots) were ideal (Katzev 1990: 249; for discussion see Beresford 2013: 121–122). This work has not only proven the great seaworthiness of a shell-first boat construction. With all of these advantages, the size of the vessel proved inadequate for its load (17 tonnes of cargo were recovered from the excavations), suggesting that it may have sunk due to overloading rather than structural and age issues (Katzev 2008: 78–79).

These 'replica data' are comparable with the analyses of VMG (*Velocity Made Good*)[60], which show that Mediterranean square-rigged vessels were able to travel at VMG 1.9 knots — equalling 45 nautical miles in 24 h — in upwind conditions, noting a record average speed of 6.2 knots documented during a 670-mile

[60] Velocity Made Good (VMG) describes the relative speed of the vessel directly to windward and was observed as a good measure of sailing capabilities of vessels during replica trials in Scandinavia (Englert 2006: 39; Whitewright 2007b: 84).

journey between Corinth and Puteoli (Casson 1971: 284; Whitewright 2007b: 84). Further analyses indicated that in favourable conditions, during 'reaching' (travelling perpendicular to the wind) and 'running' (travelling roughly 30° either side of dead downwind) courses, such vessels could make an average of 4–6 knots, achieving potential speeds of over 12 knots (Whitewright 2011a: 9–10).

Using these figures, the passage from Berenike to Myos Hormos (approximately just over 200 nautical miles allowing for tacking) could take up to 5.5 days with VMG 1.5 knots, and a minimum of 32 h with a high average long distance speed of 6.2 knots (Whitewright 2007b: 85). This challenges the accepted notion put forward for siting Berenike in its current location north of which most sailors would favour stopping due to unfavourable winds.

Whitewright's research shows that, contrary to conventional belief, the sophisticated and efficient rigs fitted on Mediterranean vessels of the Imperial period were capable of sailing upwind (i.e. using brails for reefing and changing the shape of the sails, and the use of a new sail type, the *artemon*, to stabilise the vessel on an upwind course; *cf.* Arnaud 2011a), equating them in performance, if not marginally superior, compared with the lateen/settee rig (Whitewright 2011a: 14–15, Fig. 5, 2012: 152–154, Fig. 16:6). Aside from the efficiency of the square-rig,[61] the shape of the hull played an important role in sailing upwind, with the deeper and more developed keels performing better to windward (Palmer 2009: 316–318; Whitewright 2011a: 5, Fig. 3) and flat-bottomed boats

[61] With an ability to 'at its best' steer a course 65–80° off the wind, in optimal conditions 60–65° (Whitewright 2011a: 9–10).

(possibly *elephantagoi* of the Hellenistic period) experiencing more leeway and hence performing poorly. This, therefore, made Roman 'Mediterranean' vessels more capable of reaching larger ports further north such as Myos Hormos or Clysma.

Whitewright also argues that the sailors accustomed to these conditions might not have thought of sailing windward (upwind) as such an obstacle (Davies and Morgan 1995: 40–44; Whitewright 2011a). In turn, the 'visiting' seafarers from distant lands of the Indian Ocean — used to favourable leeward (downwind) direction — might have found this sailing very challenging (Whitewright 2007b: 83–85) and therefore it would have been undertaken either with the local (Red Sea) navigator on board or using 'local' vessels and/or crews.

7.1.3.4. Draught

Based on shipwreck data an estimate of the draught of ancient merchantman can be calculated (Table 7.2). However, these data must be used with a modicum of caution as the Red Sea and Indian Ocean-going vessels built in the Mediterranean tradition might not have had directly comparable draughts and keel depths to their Mediterranean prototypes as they would have been designed to suit particular sea conditions and the bathymetry of harbour basins that they have visited.

Table 7.2 Approximate draughts and lengths of a keel of selected ancient shipwrecks of different sizes (and those that mainly frequented Portus). Based on Pomey and Tchernia 1978; Steffy 1989; Turfa and Steinmayer Jr 1999: 110; and Boetto 2010: 118.

Size estimate	Ship and shipwreck	Approx. draught	Keel (length)
Very large (~1,000 tonnes)	Syracusia	8 m (speculative)	
	Isis	4.5 m (speculative)	7–10 m
	Sane		8–12 m
Large (350–500 tonnes)	Madrague de Giens	3.5–3.7 m	4.5 m
	Albenga		5.5 m
Mid size (130–150 tonnes)	Bourse de Marseille	2.2–2.3 m	3 m
Small (80–50 tonnes)	St Gervais 3	2.36 m	2.8 m
	Port-Vendres I	1.89 m	1.95 m
	Fiumicino I	1.57 m	2.53 m
	Fiumicino II	1.4 m	2.26 m
Very small (30 tonnes)	Kyrenia	1.2 m	9.33 m

These data are important, as it was the ships' draught that defined water depth at the moorings, and thus the height and structure of any piers (Marriner and Morhange 2007: 159). The draught of a vessel would also have influenced the location of moorings and the level to which the water depth at the harbour entrance was maintained. If we assume that Berenike received ships carrying cargo somewhere in the range of 50–625 tonnes, the port infrastructure would have had to accommodate draughts of *ca.* 1.4–3.7 m, according to these data (Table 7.2). Recently recovered wooden fragments from Berenike, including a ship frame or frame floor found in 2014 (Fig. 7.15), suggest either mid-size vessels[62] (if it is a ship frame) or mid- to relatively large (if floor frame), with a draft of no more than 3 m. The results of the geoarchaeological work and sea level estimate of +~0.85 m would allow for accommodation of such a vessel;

[62] Approximately 50 ft.

within Berenike's Lagoon and even the central portion of the SWE (see Scenarios in Section 7.3 below).

7.1.3.5. Section Summary

Many argue that the unprecedented level of communication and connectivity occurring during the Roman Imperial period across the entire Mediterranean allowed for both widespread specialization and an effective homogenisation of maritime culture in the region (e.g. Scheidel 2014). However, others (e.g. Pomey et al. 2012; Votruba 2014) argue for a more regional-focussed picture. Whether this apparent continuity of ship design and construction existed and whether it extended east beyond the Mediterranean and into the Red Sea and areas of the Indian Ocean is, at present, a moot point. It is certainly highly probable that repairs carried out in one region on ships constructed in another would have resulted in the exchange of technologies.

7.1.4. Sewn and dugout traditions

A deep interest in maritime technologies and a broad knowledge of vessel types, including those of sewn-hull tradition, is apparent from the *Periplus Maris Erythraei* (Schoff 1907; Casson 1989). It is likely that the author of the text gathered this information from sailors first-hand, and he mentions in meticulous detail numerous types of coastal and harbour vessels, including small lighters in Adulis (*PME* 3, 7), sewn and dug-out boats in Opone (*PME* 15), sewn boats in Rhapta known as *rhapton ploiarion* (*PME* 6), rafts held up by inflated skins and boats of a particular design in Qana (*PME* 27), boats 'sewn together after the fashion of the place' travelling from Ommana to Qana (*PME* 36), 'well-manned' large boats called *tappaga* and *cotymba* voyaging from Syrastrene to Barygaza (*PME* 44), to some small boats of 'single blocks bound together' from Barygaza called *sangara* (*PME* 60) and *kolanidiophonta*. The '*Κολανδιοφωντα τα Μεγιστα*' was apparently the largest sewn-plank ocean-going vessel operational between Burma and the Ganges River (McGrail 2001: 260) and argued (Christie 1957: 34; Manguin 1993: 261, 1996) to have been based on *kun lun po,* non-Chinese craft mentioned in Chinese sources from the 3rd century CE onwards.

This abundance of vessel shape and size variation is also recorded in epigraphic and iconographic evidence, suggesting that more than twenty different ship and boat types sailed the Red Sea and Indian Ocean in the Greco-Roman period (Van Rengen 2011; Thomas 2012; *PME* 3–4, 7, 10, 15–16, 18–19, 27, 32–33, 36–37, 39, 44, 52, 56, 60; Pliny, *NH*. 4.34, 6.105; Strabo, *Geogr*. 2.5.12, 16.4.18, 16.4.23; Diodorus, *His*. 3.39–43).[63] Importantly, these accounts also highlight the way in which contemporary writers, historians, artists and everyday seamen were accustomed to collecting data about boats and various types of maritime technologies, potentially in order to use or adapt them for their own purposes.

[63] This also includes war galleys from Trajan's war fleet stationed on the Red Sea and known from the Latin inscription from Farasan Islands mentioning a Roman military unit on the island in 144 CE. This was probably an anti-piracy measure but as some argue could have been established in the anticipation of 'Eastern Wars' that Romans thought might extend to India (Phillips et al. 2004: 244–245; Adams 2007: 35; piracy on the Indian Ocean in antiquity is discussed by Schneider 2014b).

This also exemplifies just how ingrained and intertwined maritime life was in the general culture and everyday life of people in coastal areas.

As we see, most, if not all, of the vessels mentioned by *PME*, and those represented in artistic depictions (Agius 2008: 115–134), were small harbour boats designed to unload and offload larger ships, for fishing, and to carry out coastal runs along tidal areas. For these purposes the practice of beaching at high tide was employed, which was the most common method of mooring around the Indian Ocean rim, and especially so for at least smaller craft sailing on the Red Sea. Additionally, as Hourani (1995 [1951]: 28) notes the sewn-hull vessels operating on the Indian Ocean "were fair weather craft which would fall apart in heavy seas. It is extremely unlikely that they ever went out in the south-west monsoon", but they might have potentially been used for travelling along the Red Sea and to the Gulf of Aden.

Boats known from later literary sources (i.e. medieval Arabic vessels travelling across the Persian Gulf, Red Sea, Gulf of Aden and parts of the Arabian Sea), depictions in art, and ethnographic comparisons (e.g. Nicolle 1989; Agius 2002, 2005; Tripathi 2006) were built with a relatively shallow draught, usually a very low keel and not a very pronounced hull, also specifically designed to be beached or moored on exposed anchorages and sometimes equipped with oars to help navigate into and out of a harbour without the need for a tug boat (Tibbetts 1971: 145, 152; Agius 2008: 187, 309).

The designs of most known traditional crafts of the Western Indian Ocean, with the exception of a small number of sewn boats, were either based on the classic dugout hulls of African or Indian canoes (e.g. Hornell 1920: 40; Forde 1928: 3; Prins 1965: 81; Austen and Headrick 1983: 166–169, 177; Ray 1990: Figs. 2 and 3, 2003: 55–59; Blue 2009: 10; van Rensburg 2010), a combination of a logboat with sewn components (similar to those from Bangladesh and eastern India) (Greenhill and Morrison 1995: 121–126), or inspired by Indian, Bay of Bengal or Southeast Asian rafts or outriggers (e.g. Johnstone 1980: 171–184; Ray 1990: Figs. 1 and 3, 2003: 59–64; Blue et al. 1998; McCarthy 2005: 11–29, Fitzpatrick and Callaghan 2008). In each instance these boats were designed to be beached while fully loaded (Fig. 7.18).

The use of nails in ship construction in the Red Sea region before the arrival of the Portuguese, from the 16th century CE, is confirmed only from archaeological finds from Tomb 2 in the Islamic cemetery of Quseir al-Qadim (Blue 2006a; Blue et al. 2011: 182–184). This site has also yielded examples of sewn-vessel planks recovered from Tomb 1, dated between the 12th and 15th centuries CE (Blue 2006a; Blue et al. 2011: 183, Fig. 15.4 and 15.5) (Fig. 7.17). In comparison, vessels constructed in the Mediterranean tradition (such as those found at Berenike) used tenons and pegs (treenails) in shell-first, and in the medieval period in skeleton-first, construction.

The notion that indigenous vessels of the Red Sea could have been built in the sewn-hull construction tradition remains strong (e.g. Pedersen 2008: 90). Such vessels survived in this region until the early decades of the 20th century CE

(Newberry 1942: 65; Thomas 1932: 2.), but owing to the current lack of data from the Red Sea to either prove or refute such notions it can only be said that this was the preferred construction of vessels in the wider Indian Ocean region, from antiquity until the 20th century CE.

Hulls sewn with fibres without the use of nails (Procopius *Bell. Pers.* 1.19.23–26; McGrail and Kentley 1985: 279–302; Said 1991: 107; Hourani 1995 [1951]: 88–97; Ray 2002: 5; Blue 2006b, 2009: 5) (Fig. 7.16) were often referred to as leaky and in need of extensive maintenance.[64] However, they were more resilient during careening and maintained their structural integrity on occasions of grounding on coral reefs (Devendra 2002: 120), and are claimed to withstand rough seas more capably than their mortise-and-tenon hull counterparts.

The most attractive advantage of sewn was that they were easy to repair by a crew with even modest skills, in an emergency situation for example. Smaller vessels did not require a shipwright or a dedicated carpenter onboard, as was the case with larger shell-first constructions (Turfa and Steinmayer Jr 2007: 125). In terms of building materials, most of the wood used for the construction of sewn-hull boats, such as those that could have potentially visited Berenike from the Southern Arabia, originated in the Western Indian Ocean, with teak from the Malabar Coast of India being the preferred timber type, and the best coir[65] coming from the Laccadive Islands (Severin 1985: 279–280).

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[64] Waterproofing was mainly undertaken by way of application of fish oils and tree resins (Mathew 1997: 45).
[65] Natural fibre extracted from the husk of coconut.

In light of comparative ethnoarchaeological data from the Indian Ocean and Arabian coast (Mookerji 1912; Forde 1928: 49–59; Ray 2003: 55–64; McGrail 2001, 2003, 2006; Vosmer 1996, 1997, 2005), and taking into account mooring conditions, it seems possible that sewn-hull vessels could have been used on the Red Sea coasts. The current lack of evidence of freely available resources to build such vessels and necessary local expertise suggests that they might not have been in use in the region during the Ptolemaic and Roman periods (Fig. 7.19). With regard to the dug-out/log boats, the lack of suitable timber to construct such watercrafts would have presented a major obstacle to their production and might serve as an explanation for their absence in archaeological record (although *hāwarī*[66] were imported to the Red Sea onboard of larger vessels).

7.1.5. Iconographic representations of ships and boats

Iconographic representations of ships and boats around the Red Sea and the Indian Ocean are much more common than their physical remains. Depictions of

[66] The term *huri* (sing. from *hāwarī*) describes the double-ended logboat canoe on the Red Sea (Moore 1920: 138; van Rensburg 2010: 101). It is interesting to note that a very common design of log boat from India, mentioned in *PME* 15 — the *huri* — is still operating on the Indian Ocean today and continues to be constructed in the same way that it has been for over two millennia (Hornell 1942: 30; Boxhall 1989: 295; Blue 2009: 10). Such dugout canoes are found all around the coasts of the Indian Ocean, and an ethnographic study conducted by Lucy Blue (2009: 10) confirmed that the majority of *huri* canoes found on the Red Sea originated in India. These boats must have been introduced on the return journey from India on the decks of merchantmen, as they are not sufficiently seaworthy to make the crossing on their own and are also unlikely to be able to carry enough supplies for the sailors. Accounting for the high volume-to-weight ratio of spice transported from India, ship timbers and boats such as *Hawārī* may have served, in a secondary function, as ballast on trading vessels and could have been produced during the voyage (*cf.* Villiers 2010 [1940]). The comparatively large quantity of timber originating in India and found on the Red Sea coast could support this hypothesis, especially given that the high demand for expensive spices makes it unlikely that precious space on merchant vessels would be dedicated solely to the transport of such canoes and timber, even as good as teak.

ancient boats in South Asian and Red Sea contexts have been recorded as paintings, reliefs or engravings, on walls, seals, amulets, coins, and pots, and in the form of models and reliefs (Tripathi 2006; Blue 2009: 5). Although some of these can be dated by associated finds and decorative motifs, many remain chronologically ambiguous.

7.1.5.1. Maritime(?) engravings from the Central Eastern Desert

Despite difficulties with relative and absolute dating, some examples that could be contemporaneous with the occupation of Berenike appear on rock art identified at Wadis Hammamat, Shalul, Abu Mu Awad, Abu Iqaydi, Qash, and other sites on the Egyptian Eastern Desert (Lankester 2012a, 2013). Based on various surveys (Rohl 2000; Morrow and Morrow 2002; Rothe et al. 2008), and by using stylistic comparisons with the Nile Valley representations, Lankester (2012b: Map 4, 2013) distinguished three chronologically different site types termed 'Predynastic', 'Late' (including Greco-Roman period and numbering 34 sites in total) or 'Mixed'.

Traversed by nomadic tribes for centuries, the Eastern Desert has been a crossroad for merchants, soldiers, quarry-workers, and port and garrison-staff. These social and professional groups represented many cultures and ethnicities found within the Pharaonic, Roman, Muslim and later Western European states. Whilst any one of these people, belonging to any number of clans or allegiances, could have inscribed such an engraving during an overnight camp, or stop for water or provisions, it seems likely that some of these graffiti were carved by sailors, people connected with the sea, or port inhabitants who were familiar with the shapes of ships that plied the Red Sea. This appears to be confirmed by some adjacent Greco-Roman inscriptions (Lankester 2013).

Lankester's typology (2012a: 189–190, Fig. 6.1) divides the boat petroglyphs into five categories: 'Sickle,' 'Incurved Sickle,' 'Square,' 'Incurved Square' and 'Flared' The majority of representations from the Central Eastern Desert that can be reliably dated to the Pharaonic and Greco-Roman periods consist of sickle-shaped boats shown with a mast and/or sail. However, there are also two examples of square-hulled boats that can be compared with one contested example depicting a boat with a very high prow on a ceramic sherd from the Ashmolean Museum (Lankester 2012a: 221, 2012b). In terms of dating, Lankester believes that most boats with a central mast should belong to at least the New Kingdom period or later, including some of those provisionally dated to the Greco-Roman period (Fig. 7.20) (Lankester 2013). Whilst Wilkinson (2003) and Sidebotham (2011: 203) date the majority of these carvings to around 4000 BCE, Blue (2009: 5) is more in agreement with Lankester and interprets many of them as potentially Greco-Roman in origin.

Wadis that often formed the route of major Roman roads, connecting the Red Sea ports of Berenike, Nechesia and Myos Hormos with mines and the Nile Valley (i.e. Wadi Hammamat and Baramiya) were useful 'superhighways' with plentiful resources available *en route* including fresh water, game, and other food to forage, as well as the presence of Roman garrisons to ensure their safety. They are the most likely places to yield boat depictions engraved by visitors to those Red Sea ports and it is relatively safe to say, then, that some of the Wadi Hammamat — the busiest of the 'highways' — representations of sickle-shaped boats with at least one central mast can be interpreted as depictions from the Greco-Roman period.

7.1.5.2. Ship and boat depictions from Mons Porphyrites, Wadi Quseir, and Berenike in the Red Sea Region

Four depictions of sailing vessels are known from the freestanding plastered pilasters found in the vicinity of the well/cistern in *Mons Porphyrites* (Maxfield and Peacock 2001: Fig. 2.55). In this case the operation of a quarry dated to 1st–4th/5th centuries CE can determine a chronology for the depictions. However, their origin as well as the technological details and materials used in their construction remain elusive. It is also difficult to calculate the potential size of the original boats based on the distorted scale of the depictions, in which different elements are particularly exaggerated whilst other diminished. Nevertheless, these types of images can be used to derive some basic structural details such as the quantity and shape of sails or the general shape of the hull.

Such carvings, depicting six distinctively different ships, have been discovered at Wadi Quseir al-Qadim (Blue et al. 2011: 199, 205). For example, an enigmatic three-masted ship (Vessel 3/6) on a rock-drawing near Myos Hormos (Fig. 7.21) is assumed to be connected with the Historical period (Tchernia 2011: 85). However, it is deemed too generic to be dated to any particular period (van Rengen et al. 2006: 18) (Fig. 2.11). The carving appears to show a three-master with two front masts supported by diagonal yards. What seem to be two steering oars are also visible at the stern. The line above the bottom of the hull in approximately ¼ of the full height of the hull, from which the masts rise, is probably not the waterline and therefore the draught of this vessel cannot be discerned.

The report mentions that the carving is located immediately to the west of the mid 1st–2nd centuries CE Greek Inscription 2 (van Rengen et al. 2006: 23–24, Fig. 2.32) that shows only one word: '*of Askles*'. To date, we know of only one reference to this name in papyrological documents from the Eastern Desert in the form of a letter from Askles to his brother showing regret that the latter has 'missed the boat'. Based on this tentative association, van Rengen and colleagues correlate their Vessel 3 (Vessel 6 in Blue et al. 2011) with the Indo-Roman trade era. Subsequent work by Whitewright (Blue et al. 2011) appears to disprove this hypothesis, giving this carving a post-medieval date, but no later than the late 19th century CE (Blue et al. 2011: 204–205, Fig. 15.21).

Other craft depictions from Wadi Quseir al-Qadim are either Pharaonic (Middle and New Kingdom) or later, and may represent carvings carried out by Bedouin tribes (van Rengen et al. 2006: 23; Blue et al. 2011: 199–205). Although transportation of parts of vessels from the Nile Valley occurred by way of the wadis (such as Quseir-al Qadim), starting in the Pharaonic period (Wachsman 1998: 238) and extending throughout the Roman period (Bülow-Jacobsen 1998: 66), probably little or none of this rock art is associated with the Roman period (Whitewright, in Blue et al. 2011: 205). It seems more likely that most of these vessels had a non-maritime religious and/or symbolic meaning and purpose (van Rengen et al. 2006: 23), rather than intending to be an accurate description, and so might not depict reliable technical details in terms of their construction.

Amongst the graffiti on artefacts representing sailing vessels, one from Berenike (Trench BE95-4) stands out from the rest. It depicts "a ship in a harbour with sails furled and with two lifts above and two braces trailing down from the main yardarms and tied off below. There is a pennant clearly waving in a strong wind, above the spindle" (Sidebotham 2008: 310, Figs. 7 and 8) (Fig. 7.22). An interesting feature in this representation is a row of eight or nine holes pierced through the gunwale that could be oar-ports or crossbeams suggesting, as in the Mediterranean, some Red Sea/Indian Ocean merchantman could have been, if need be, propelled by man-power.

This graffito appears to depict a vessel built in the Mediterranean tradition, being a single-masted ship with a square main sail and an *artemon*, and can be securely dated through associated finds to 50/60–70 CE (Sidebotham 2008: 309, 2011: 202). Unfortunately, as the ceramic type cannot be distinguished, it is unclear whether the sherd was of Indian Ocean or Mediterranean origin. Regardless of this, the graffito could have been a later addition to a discarded ostracon, but it does seem to represent what is envisaged to be a typical Indo-Roman trade Mediterranean tradition vessel.

7.1.5.3. Graffiti from the Gulf of Aden

Engravings on the walls of Hoq cave located on Socotra Island, in the Gulf of Aden, Yemen (Strauch 2012: 364–365 Fig. 2:16, 5:11, 6:11, 6:13) are dated to the Greco-Roman period. The poorly preserved drawing 2:16 (Fig. 7.23) shows a boat with only one mast, and the full height of the hull (above and below the waterline) of approximately ¼ mast height. The better-preserved example 6:13 (Fig. 7.24) clearly represents a vessel with multiple masts — most likely three (Strauch 2012: 364). It also shows a higher ratio (approximately 1:3) of hull height to height of a mast when calculated from the bottom of the hull rather then the deck. According to Dridi (2002: 584), this second example can be easily compared with Indian engravings from Ajanta (Figs. 7.25 and 7.26), especially those from Cave 17 (Simhala tale) and Cave 2 (Pūrṇa-Avadāna) (Schlingloff 2000).

A carving of a two-masted ship recorded in the wall plaster from Sumhuram (Fig. 7.27) is dated to the peak in the site's trading activity between 1st–3rd centuries CE (Avanzini 2007: 27–28, 2008: 616). The vessel depicted on the engraving has two masts with flags on the mastheads and diagonal yards on each side of the masts. The front mast seems to be approximately in the middle of the vessel whilst the aft one is at about ¾ of its length. Two steering oars that could be of either Indian, or Mediterranean traditions are visible at the stern and two lines on the hull parallel to the deck may demarcate the waterline. If we assume that the top line represents the waterline, and the proportions of the vessel are depicted broadly accurately, then the draught of this two-master would be a little less than half the length of its mast. The nature of the engraving appears to bear some resemblance to depictions from the Sātavāhana/Andhra dynasty coins (Fig. 7.28), but although it cannot be discerned unambiguously whether it was of Eastern or Western origin, it seems very probable that it represents one of the Indian Ocean merchantmen.

7.1.5.4. Representations of maritime crafts from India and Sri Lanka

Some interesting graffiti recorded on pots dated to 3rd century BCE–2nd century CE originate from the Pandya port of Alagankulam, Tamil Nadu, on the southeastern coast of India (Sridhar et al. 2005: 67–73, Fig. 7, Fig. 24, Pl. 23). One of these carvings, recorded on a Rouletted Ware sherd, represents part of a cow-horned vessel with twin steering oars or paddles and two or potentially three masts supported by double fore and backstays (Fig. 7.29). Two lines running from the mast forwards and upwards seem to be the double backstay for another mast in full sail, but with no discernable details. The entire depth of the hull in this representation is approximately 35–40% of the length of the mast, but the lack of recognisable waterline makes it impossible to give an estimate of the draught of this vessel. This kind of rigging configuration, with two masts supported by double stays and with the presence of twin steering oars at the stern, is reminiscent of depictions of vessels seen on Andhra coins from southern India (Elliot 1886; Whitewright 2008: 307) (Fig. 7.26) but also of the vessel from the Berenike ostracon and from the representations from Southern Arabia.

Another graffito from Alagankulam, carved on a sherd of local coarse-ware, shows a vessel with a crescent-shaped hull. It has one surviving mast (which is probably the original number), a flag flying above the masthead, and three horizontal damaged lines that could be steering oars or stone anchors (Fig. 7.30). Two evenly spaced horizontal lines on either side of the mast could be yards, and suggest square rigging with a square main and topsail (Whitewright 2008: 306). These are similar to Mediterranean rigging (although here topsails are triangular), with a series of horizontal lines possibly representing the furled sail hanging beneath the yards (Whitewright 2008: 307). The schematic representation of the section through the ship showing only the enclosed hull frame without an easily discernable waterline does not allow the draught of this craft to be estimated. Some scholars have attempted to identify both of these vessels with traditional boats of Tamil Nadu known as *Vattai* (Tripathi 2006: 27), whereas others, most likely more justifiably, prefer to associate the first vessel with a large three-masted Roman trading vessel (Tchernia 1998: 455–456; Sridhar et al. 2005: 69–70).

Some of the most notable depictions of ancient Indian vessels are those from the 4th–mid 7th centuries CE Caves 1, 2 and 17 in the Buddhist Rock Temples at Ajanta, Aurangabad district of Maharashtra (Burgess 1878; Needham 1971;

Schlingloff 1976, 1987, 2000, 2013; Nicolle 1989: 181; Hourani 1995 [1951]: pl. 4; Deloche 1996: 205; McGrail 2001: 254). The vessel from Cave 2 has a flat-bottomed hull curved upwards at both ends with no distinguishable sign of a waterline (Fig. 7.25). However, the decoration panels on both bow and stern suggest that the ratio between the parts of the hull — above and below the waterline — would be at least 1:1.

The vessel depicted in Cave 2 has three masts that are located towards the front of the ship, rigged in the same configuration with quadrilateral sails, twin steering oars and an *artemon*. This type of rigging and the presence of twin oars are comparable to depictions from other caves in Ajanta and from Aurangabad, which Deloche (1996: 205, Fig. 3) states is consistent with an Indian origin. However, others argue that the rigging is arranged in a similar fashion to Chinese junks (Hourani 1995 [1951]: pl. 4; McGrail 2001: 255). Although a diagonal arrangement of long twin steering oars is typical for Indian vessels, it can also be present in Mediterranean crafts. To add to the confusion, the presence of an *artemon*-like sail could suggest a Mediterranean influence or even origin (Whitewright 2008: 309).

This aggregation of different features convinced Needham (1971: 454–455) that the Ajanta Cave 2 vessel is a composite image combining characteristics of multiple merchantmen from different cultural circles. Whilst Needham's 'composite' interpretation seems safest, the author believes that, because so little is known about Indian seagoing ships from this period, a few design elements that look like those known from the Mediterranean, do not mean the vessel necessarily has a Mediterranean origin, and it could be that exchanges between the shipwrights and sailors from different cultures brought aspects of Mediterranean design traditions to the Indian Ocean.

In this light, we might also look at other ships such as “a three-master with the narrow, upright mast, the size of which must have been at least three-quarters of ship’s length” represented on a wall of Cave 17 in Ajanta (Schlingloff 1976: 19). On this painting the masts are not evenly spaced on the ship but clearly moved towards the forecastle in a similar way to those in the drawings from Caves 1 and 2. Depictions from these caves are very similar to those from the Hoq cave on Socotra (Strauch 2012: 364; Figs. 7.23 and 7.24) and as mentioned above, even India-based scholars see potentially Western technological patterns in their designs (Deloche 1996: 205) (Fig. 7.26).

Similar representations from the reverse of 2nd century CE Andhra-Sātavāhana coins show vessels with two masts supported by a forestay and a backstay and with either one or two steering oars (Schlingloff 1976: 21) (Fig. 7.28). Two of these depictions (a and c) show flat-bottomed crafts in the shape of an ‘inverted hat’, whilst two others (b and d) are scimitar- or sickle-shaped. Two different mast types can also be distinguished but without a connection to the hull shape. The first one is straight or slightly tapering with a flag flowing on the masthead, whereas the second has a bottleneck shape with a circle at the bottom and a triangular shape slightly tapering towards the top, with a small sickle-shaped platform and a circle on a masthead.

Only representation 'a' can give potential evidence for the depth of the waterline. However, in this case it seems most likely that the line parallel to the deck is a type of lip or a wider part of the deck, rather than an extremely low over-the-water part of the hull. Some earlier scholars (e.g. Schoff 1907: 244) tried to show that these types of ships would have had square-rigging, but sadly there are no grounds at the moment for such bold claims to be made based solely on these depictions, given their often ambiguous date and origin (Deloche 1996: 243–244; McGrail 2001: 253–255).

In terms of seagoing vessels, one controversial example of what is referred to as an Indian Ocean ship comes from Anuradhapura, Sri Lanka (Coningham et al. 1996: 92, Fig. 16). It is a ship graffito on a fine greyware bowl,[67] dated to ~360–190 BCE (Coningham 2006: 298, sf. 10548; Coningham and Gunawardhana 2013) (Fig. 7.31). The vessel has a single mast with supports for a fore and backstay, but with no sail shown. Two lines on the sides at the stern could be steering oars (Whitewright 2008: 305). Although Coningham (2006) suggests that it is an Indian Ocean seagoing vessel there is no evidence to agree unequivocally with this statement.

Regardless of the detailed way in which they are represented, most of the depictions discussed above show seagoing vessels with one, two or three masts, and these vessels do seem in many ways similar. The masts are usually spaced evenly around the hull, they have equal proportions, and are supported by the fore and back stays. Additionally, twin steering oars are almost always present.

[67] Which seems to copy Rouletted Ware of Early Historic Period (Coningham et al. 1996: 92).

In terms of the sail, the general assumption is that they were square-rigs (Schoff 1907: 244; Sridhar et al. 2005: 69–70; Whitewright 2008: 150) making for what might be recognised as a stylistical pattern representing some of the aspects of real boats from this region. In summary, most of the representations seem to depict Indian Ocean vessels that are Mediterranean or local but which are so similar that it is impossible to distinguish.

Despite the lack of absolute dating and often inconclusive relative dates, these depictions and representations can serve as a general aid in recognising and distinguishing the type, size and potentially function of different water-craft, and allow for the recognition of their distinctive structural components. The detailed study of representations of Indian Ocean vessels can, therefore, with more comparative material in place, provide some insight into the possible marine technologies employed by local shipwrights at Berenike.

7.1.6. Discussion

The evidence shows that contrary to some established opinions, which tried to associate number of masts with cultural circle of origin, depictions of single-masted merchantmen are evident from South Asian sources (i.e. Anuradhapura and Anagankulam), and these cannot be reliably called Mediterranean, especially when two- and even three-masters were popular in the Mediterranean until the 5^{th} century CE.

Although we have positive evidence for trade connections between the Red Sea and the Indian sub-continent, there is no evidence thus far to support the use of sewn-tradition vessels on the Red Sea coast in the Greco-Roman period. Nor is there any evidence for the use of Indian or African shipbuilding and rigging materials or techniques in any Mediterranean vessels of the period on the Mediterranean itself.

The evolution of nautical technologies can best be traced through improvements of particular elements of the sails, rigging and hull designs. The sail and rigging were important in maintaining a heading in relation to different wind speeds and direction, and as such are likely to have varied accordingly in different geographic regions. As to the hull, its function was mainly to provide space for the cargo and safety for the crew. Nevertheless hull and keel size/shape were also important factors in terms of mooring and manoeuvrability, meaning that they were partially dependent upon the environmental conditions present in the different geographical areas that the vessel visited, as well as the type of cargo it carried.

Therefore, sewn-hull vessels rigged with lateen sails, although highly manoeuvrable and more resilient in the case of a collision with a coral reef, might have not been suitable for Indian Ocean southwestern monsoon conditions. These Southern Arabian predecessors of dhows could have, however, been very effective in the coastal waters with treacherous reefs and leeways (on the Red Sea or Persian Gulf for example) and might therefore have had a role to play in Indian Ocean–Mediterranean commerce where they were only undertaking the South Arabia–Red Sea leg of this trade, potentially stopping over at Berenike.

Recent finds from Red Sea ports (e.g. Blue et al. 2012) appear to show a reliance on 'Roman ships' sailing all the way to India and back and experiencing regular high seas during their passage (Beresford 2013: 222), requiring them to be especially robust. Whilst most of the currently available evidence (from Berenike and Myos Hormos, see Section 7.2 below) points towards this hypothesis, it is possible that different types of vessels would have sailed different legs of the journey. For example, sewn-hull Southern Arabian ships could have performed the East Africa – South Arabia – Persian Gulf leg of the journey, whilst Roman mortise-and-tenon ships could have potentially taken over the Red Sea – India direct route. That is not to say, however, that Indian Ocean-style (sewn-hull) trading ships never visited the Red Sea, nor that the trade in eastern goods, once in Red Sea waters, was only carried out using Mediterranean tradition ships, but only that we are faced with an extremely fragmented picture of the past and information limited to the Roman or Western end of the trade narrative.

7.2. MARITIME FINDS FROM BERENIKE

Many artefacts that fall into the broad category of maritime finds have been discovered during excavations at Berenike. However, most of these artefacts have been recovered from secondary contexts (both as re-worked and re-deposited finds). These artefacts paint a vivid picture of the maritime culture of this commercial, administrative, military and religious centre, whose inhabitants were almost entirely involved either in sailing, fishing, trading, or in ship and harbour maintenance.

The study of the nautical material also allows for the tentative reconstruction of the types of vessels sailing in and out of the port, and the ways in which the port operated. Sails, ship-frames, hull planking and sheathing, as well as rigging elements and other associated finds including nails, pegs, etc. were recovered from different areas of the site (including rubbish dumps), but primarily concentrated in the so-called 'Ship Maintenance Area'. No specific mooring apparatus or infrastructural element has been excavated to date, with the possible exception of a debatable wooden bollard (Section 5.6).

The square-sailed Mediterranean ships were not particularly manoeuvrable, especially in the enclosed waters of a bay or port, necessitating the use of oars or tugboats to bring them in to their moorings. However, if oars were available in such instances, as may have been the case given the depiction of merchant galley on the Berenike ostracon (Section 7.1.5.2; and such as on numerous galleys evidenced in the Mediterranean), they could still, potentially, be efficiently employed in the Red Sea environs. As to the hull, this mainly provided space for the cargo and safety for the crew. Nevertheless, hull shape was also important for mooring (see Section 7.1.4 for sewn-vessels and coral reefs: Devendra 2002: 120), meaning that it was partially dependent upon the environmental conditions present in different geographic areas that the vessel was destined to visit, as well as the type of cargo.

7.2.1. Planking and hull construction

Mortise-and-tenon joints in 'shell-first' construction were commonly used by Roman shipwrights in the Mediterranean. The basic principle of this type of fastening of longitudinal hull planks (strakes) edge to edge is that the tenon tongue fits into a mortise hole, cut into opposing edges of planks thus holding them together (Figs. 7.7 and 7.32). Epigraphic evidence from the Roman period attests to the shipment of wood from the Mediterranean or the Nile Valley to the Red Sea coast by way of the Eastern Desert (e.g. Whittaker 2004). Many of these consignments were undertaken specifically for the purpose of shipbuilding, as was also the case in the Pharaonic period (Creasman and Doyle 2010) (Section 7.1.2). Undoubtedly, during boat refitting and repairs (usually during over-wintering at the terminal port such as Berenike(?)) aspects of the hull and other elements of the ship's structure would require repair with new ship-parts brought in from distant locations.

In the Mediterranean, vessel frames were most commonly made of oak; the hulls of pine, fir, cypress or Lebanese cedar, and sometimes elm below the waterline; whilst treenails were often made of garland thorn (*Paliurus spina-christi*), bog oak or other types of hardwood (Adkins and Adkins 1998: 205). The presence of species such as pine (*Pinus halepensis/pinea*), elm (*Ulmus* sp.) and cork oak (*Quercus suber*) in Berenike's finds assemblage appears to indicate that some parts of the incoming ships were either constructed in the Mediterranean or from timber imported from Europe or North Africa. However, to date, no dedicated study of

Berenike's nautical assemblage has been conducted to discern which ship parts were built/repaired using which species of wood.

Other exotic species found on site, such as vibernum (*Viburnum* sp.) from Southeast Asia or the Atlas Mountains, date palm (*Phoenix dactylifera*), bamboo (*Bambusa* sp.), sandalwood (*Santalum* sp.), myrtle (*Myrtus* sp.), beech (*Fagus sylvatica*) and possibly willow (*Salix* sp.), as well as tropical African species such as teak (possibly of Rhodesian origin) or pterocarpus (*Baikiaea* sp./*Pterocarpus* sp. type), are useful in mapping the extent of trade routes to the Mediterranean, central Europe, the Nile Valley, India and northeast Africa (Vermeeren 1999b: 199, 2000a: 7) and possible deliveries of timber for ship construction or repairs.

Owing to the scarcity of construction material available on the Red Sea coast, quantities of Indian and African wood were often shipped back to the West. The import of wood from the East is corroborated by Pliny (*NH* 16.80.221), whilst *PME* (36) refers to the transport of 'teakwood', 'beams' of wood, sapling and logs, primarily of sandalwood (native to southern India; grows, amongst the others, in the Western Ghats), teakwood timbers (northern India), blackwood logs (Punjab and western Indian) and ebony (native to southern India and Indonesia) that were shipped from the port of Barygaza to the city of Omana (e.g. Groom 1995: 189; Blue 2009: 9). Teak is a particularly hard, flexible and durable wood that does not split, crack, shrink nor alter its shape — perfect for ship-construction (e.g. Sidebotham 2011: 204) — and attested in antiquity as very resistant to decay (Theophrastus *Hist. Plant.* 4.7.7 and 5.4.7; Hort 1986; Vermeeren 2000a: 8).

A high proportion of teakwood (*Tectona grandis*) from India, including reused planks most likely sourced from dismantled ships, has been recorded at Berenike (Vermeeren 1999b: 199–204). Given that the voyage between the Red Sea and India was long and treacherous it is very likely that Indian teakwood would have been a prime source used for repairs and replacements on vessels that had made the journey East. Additionally, as some of the cargo heading West had a much higher volume-to-weight ratio than that imported to the East, it is possible that good quality wood for repairs and shipbuilding was used as ballast on boats going to Berenike.

The site has also produced an abundance of evidence for the shipwright's craftsmanship and working of teak, and other timber. This is present in the form of woodchips and other industrial waste products, as well as axe and knife marks that are also visible in the material from Myos Hormos (Vermeeren 2000a: 7; Blue et al. 2011: 185). Most of the re-used teak wood had a previous nautical function as part of a ship structure (e.g. mortise-and-tenon joints) and nail holes are still visible on some fragments (Vermeeren 2000a: 8).

Re-used ship timbers found at Berenike were in most instances found in the 'Ship Maintenance Area', located in the northern sector of the CSR (Fig. 7.33 and Section 5.6). Recycled or 'abandoned' timbers from trenches BE09-54, BE10-62/64, BE11-78 and BE14-98 are quite clearly made in what is regarded to be the

Mediterranean mortise-and-tenon tradition. The longitudinal planks (strakes) related to those fragments are fastened to each other edge-on-edge, providing the shell construction. Elaborate dowel holes observed in re-used teak planking seem to confirm the western technological association (Sidebotham 2008: 310).

Planks found at Berenike exhibit features consistent with a double-planked hull such as in — mostly 1st century BCE to 2nd century CE — Mediterranean vessels: *Punta Scaletta* and *Albenga* found in Italy, *Mahdia* found in Tunisia, and *Magdrague the Giens* and *Dramont I* wrecks found in France (McGrail 2001: 156). The thickness of planks in these vessels ranges between 56–135 mm (FitzGerald 1994: 178) and is in accordance with Juvenal's (*Sat.* 12.58–59) recommendation for merchant ship's planking in the range of four to seven finger-breadths (70–130 mm). In these vessels, wooden pegs (dowels or treenails) held tenons firmly in place, keeping the planks together with mortises carved into their opposing edges. Additionally, long copper nails (later made of iron) were driven into these treenails to add strength (Adkins and Adkins 1998: 204) as in the case of the findings from Berenike.

The mortise-and-tenon planking found in Berenike's sister port — Myos Hormos — shows a lot of similarities. On this site, two pieces of re-used wooden planking (Fig. 7.34) were discovered from Trench 8A in 2002 (Blue et al. 2011: 179–180), both of them part of a mortise-and-tenon joinery of a Mediterranean tradition shell-first vessel. In terms of ship-frames, a fragment found in a trench BE14-98 was tentatively interpreted as either a top part of a frame or a frame floor (Fig. 5.7). More research is required in order to fully understand the primary and secondary functions of these fragments and — from there — to calculate sizes and shapes of the vessels to which they have originally belonged.

Notwithstanding the material imported from the Mediterranean and the East, a limited supply of wood, such as acacia (*Acacia tortilis*) and mangrove (*Avicennia marina*), was also available locally (Vermeeren 1999b: 199–204). Acacia is commonly observed on hinterland sites such as Shenshef, from which it was recovered in both desiccated and charcoal forms. Palm wood was also encountered and locally cultivated in kitchen gardens, as well as being imported from the Nile Valley (Vermeeren 1999a: 427–429). Though contested by contemporary shipbuilders and sailors (Capt. Ahmad, pers. comm. 2011) as suitable for shipbuilding, the use of mangrove wood was already mentioned by Theophrastus (*Hist. Plant.* 4.7.1–2) [68] and further attested by Pierre Schneider (2015 *forthcoming*) during his ethnohistorical survey (see Section 6.2.5). Minor on-site ship repairs and the construction of simple new elements could have used the mangrove locally available in the coastal Red Sea region, including in some *mersas* (bays) south of Berenike. Dried sea-blite (*Suaeda aegyptiaca*), so common in Berenike, could have also been used for fuel and for tarring, caulking and other waterproofing processes.

Those vessels that reached the end of their useful sea-going life were reused in a variety of different ways — including non-maritime — such as roofing (Fig. 7.35), for stairs, for levelling the walls (Fig. 7.36), in shrines (Fig. 7.37) and

[68] The Greek philosopher (*ca.* 371–287 BCE) who wrote *Hist. Plant.* (*Enquiry into Plants*), in which he studied many plants brought from Asia by Alexander the Great (a pupil of his predecessor Aristotle) such as cotton-plant, banyan, pepper, cinnamon, myrrh, and frankincense (Hort 1986).

other domestic purposes including furniture.[69] Those that were badly damaged by shipworm would have been discarded or used as fuel (e.g. Ward and Zazzaro 2010). In the harsh environment such as of Berenike, with a shortage of trees suitable for ship-timber, building material and fuel (in comparison to tropical South Asia and coastal Africa) nothing would usually go to waste.

It is important to note that the absence of Indian Ocean sewn-hull vessels in the Red Sea assemblages might be, amongst the other reasons, due to the ease with which they could be dismantled and the preference towards dismantling them, if not suitable for further use, in their mother-harbour. For example, although the majority of vessels (not-shipwrecked) discovered in Heraclion (Abu Quir, Alexandria, Egypt) are Egyptian watercraft, a very different interpretation can be drawn from the anchor assemblage, which shows a large number of foreign vessels visiting the port (Damian Robinson, pers. comm. 2015). Thus, the study of the many re-used timbers and rigging that were excavated during the 2009–2014 seasons at Berenike, especially in the 'Ship Maintenance Area' is highly anticipated in order to confirm or disprove the above hypotheses.

[69] As it can be still observed on Zanzibar where old canoes and parts of dhows are commonly re-used for furniture, stairs, doors, lamps, cutlery, etc. (pers. observ.).

7.2.2. Maintenance and repair: sheathing, caulking and waterproofing

Trade vessels represented such an immense outlay in collateral for their owners that their maintenance, repair and upkeep were of the utmost concern. It was common practice in the Greco-Roman world for the underwater surface of the hull to be sheathed in lead as a protection against marine worms such as *Teredo navalis*[70] (Casson 1978: 139; Basch 1979: 29; Parker 1992: 27; Hocker 1995: 199). Extensive knowledge of tidal systems in different regions of the journey must have therefore been an integral part of the suite of navigational skills possessed by a captain and his sailors, allowing them to choose optimal locations for overwinter mooring and the careening or beaching of the vessels, such as Berenike, to mitigate the effect of borers.

The final process in making a vessel watertight was termed caulking, and involved smearing the seams, and sometimes the entire exterior and interior of the hull. Materials such as tar, bitumen, resin, pitch (such as pine *Pinaceae sp.*, Meiggs 1982: 467), or a mixture of pitch and beeswax (Blackman 1990: 39–40; Adkins and Adkins 1998: 206; Pomey et al. 2012: 297) were used, often with hardening agents, fibre or material and sometimes with pigments (Hocker 1995: 199; Colombini et al. 2003: 659). This type of waterproofing has been recorded

[70] These bivalve molluscs — borers from the *Teredinidae* family, also known also as 'termites of the sea', '*teredo* worms' or 'shipworms' — cause significant damage to wooden ships, boring long cylindrical holes in the hull so frequent that usually only a thin surface layer of wood remains (Lane 1959; Nair and Sraswathy 1971; Calloway and Turner 1988; Govorushko 2011: 351). Other burrowing bivalves that were a significant economic threat to wooden vessels included the *Martesiinae* from *Pholadidae* family, known as 'piddocks' or 'angelwings' (Evans et al. 2007).

on excavated Roman ships from the 2nd century BCE–5th century CE. However, only minimal caulking was required on these vessels owing to the excellent fit of the mortise-and-tenon joints typical of earlier Roman merchantmen. As it was quite crucial for protecting the hull from worms, crustaceans, and microorganisms as well as abrasion, sheathing and caulking were common (Black 1999: 53) and never really abandoned in Roman shipbuilding and the evidence of that is available in the form of lead sheets and gums from Berenike (Sidebotham and Wendrich 2007a: 35–36; Sidebotham 2011: 205).

The waterproofing gums and resins used for this purpose were transported from the Nile Valley to Berenike by way of the Eastern Desert (Bagnall et al. 2005: 45–47). They were found on structural timbers from re-used ship planks at Berenike (Trench BE96-10, Vermeeren 2000a: 5), confirming that most, if not all, of the planking was caulked. As some types of caulking materials need to be heated up before their application, the hearths that were encountered on the beach in Trench BE11-72 and in the 'Ship Maintenance Area' might have been associated with the waterproofing process.

Some of these resins could have also left organic residues that, if studied, can provide us with identifications of species of plants used for this process. Additionally the presence or absence of caulking materials and gums and their amount could potentially give an indication of the type of vessels (fishing boat, merchantman or military ship), or of its potential construction (sewn-hull or mortise-and-tenon – different type of caulking required) and origin (different types of materials and species of plants would have been used to prepare gums and other caulking material in different parts of the world).

After caulking the hull, 1–2 mm thin lead plating was nailed over a layer of tarred fabric using lead-dipped copper nails.[71] This process of sheathing — putting a protective layer of material on a ship's hull — was necessary not only to prevent burrowing by shipworms, but also to reduce or eliminate fouling[72] and to ensure the waterproof quality of the hull. Other prevention measures included anti-fouling,[73] graving (covering the hull with tallow or resin mixtures), careening and hull-scrubbing (Hocker 1995: 197). Up until the 2nd century CE, when the transition towards iron nails occurred, copper nails were primarily used in Roman shipbuilding (Parker 1992: 27; Pomey et al. 2012: 296). As copper was also used to poison barnacles, this can explain the extensive use of copper alloy tacks in both Myos Hormos and Berenike (Martin Hense, pers. comm. 2014).

Unlike warships, cargo ships were normally kept afloat and not hauled ashore, meaning that without lead sheathing they were especially vulnerable to worm infestation and barnacle growth. The growth of seaweed (algae), coralline algae and barnacles on the hull reduced the speed of a vessel[74] and making it more difficult to navigate. Therefore, the hulls were in frequent need of scraping especially when they were stationary for extended periods of time. Large amounts

[71] The presence of lead-sheathed boats may also be helpful in discerning particular harbour floor surfaces by studying the lead isotopes in the sediments of infilled harbour basins (Delile et al. 2015).

[72] Fouling is the process of accumulation of marine organisms, mainly algae, which is detrimental to the functionality and strength of the ship's hull, also creating drag.

[73] A Tamil word *chunam* describes an anti-foul based on lime, sand and oil (Staniforth 2014: 5).

[74] These acorn barnacles, according to Ross Thomas (in Blue et al. 2011: 186–187, Fig. 15.7), could have resulted in a 40% loss in speed of a vessel in just 6 months.

of removed discarded barnacles, with signs of pitch and impressions of wood, have been recovered from the early Roman rubbish dump at Berenike (Sidebotham and Wendrich 2001: 43), and the southern foreshore at Myos Hormos, especially Trench 14 in the ship maintenance area (Blue et al. 2011: 186) (Section 5.6).

Evidence of sheathing in Berenike was recovered in the western part of the Ptolemaic Industrial Zone, including lead sheets and both long and short copper nails/tacks. The latter were most likely used for fixing the hull and substructure of the ship (long nails), and fixing the sheeting to the hull (short nails) [75] (Sidebotham and Wendrich 2007a: 35–36; Sidebotham 2008: 307, 2011: 205) (Fig. 7.38). A sector of the Ptolemaic Industrial Zone area in Berenike appears to resemble a metal-working area where a variety of copper-alloy nails and tacks, as well as lead sheets, were manufactured (Sidebotham 2011: 205).

This is comparable to the evidence uncovered at Myos Hormos, where hearths and metal working installations in the harbour area were found in association with maritime artefacts (Whittaker 2006; Whittaker et al. 2006). The majority of nails discovered at Myos Hormos are sheathing tacks found in the vicinity of Roman shorelines (Whittaker et al. 2006: 80; Thomas and Masser 2006: 138; Van Rengen and Thomas 2006: 147, 149, 153; Blue et al. 2011: 186–188; Copeland 2011: 112) (Fig. 7.39), similar to the situation at Berenike, with the exception of construction nails also regularly being encountered.

[75] Nails form the most frequent category of metal finds in Berenike (Hense 1995: 51).

Lead is found in Late Ptolemaic–Early Roman contexts in a number of trenches.[76] Roughly 10 fragments per trench were found, and 95 kg of lead sheets were recovered from trench BE00-36[77] (Sidebotham and Wendrich 2007a: 35–36). Based on the density of lead (11.34 g/cm^3), a sheet measuring 1 m x 1m x 1 mm would have weighed 11.34 kg, making the material found in trench BE00-36 capable of producing a sheet of a total area of 8.4 m x 1 m x 1 mm. Given that the dating of some areas of trench BE00-36 is not well-defined, and that context *022* from which the lead originated may represent a trash dump, there is the potential that it could be of a later origin. Ross Thomas (in Blue et al. 2011: 188) suggests that this 'sheathing hoard' could have been a part of a specialised fit-out of a large Ptolemaic vessel such as an *elephantagos* although its small size does not corroborate such interprettions.

Supplementary evidence for hull sheathing comes from Myos Hormos, where lead sheets and tacks were found in the harbour area (Peacock and Blue 2006: 67–94; Blue et al. 2011: 186). There, the original 'gum-based' caulking was replaced by driven or clamp seamed caulking (e.g. Parker 1992: 199; Hocker 1995: 202). An example of such a caulking wedge was identified by Blue and colleagues (2011: 188) at Myos Hormos.

The use of lead sheathing appears to have ceased by the end of the 2nd century CE or in the 3rd century CE in the Mediterranean (Parker 1992: 199)

[76] Including: BE96-11, BE97-5, BE10-64, BE10-66, BE11-71, BE11-72, BE11-75, BE11-76.

[77] Although the report claims that the finds were mostly slag, they were in fact pure lead, in some stage of the recycling process, mainly corroded after deposition (Martin Hense, pers. comm. 2014). Some flat sheets were also discovered in a dump context, probably located in the vicinity of a lead-working area, although no evidence for smelting was uncovered.

even in the face of relatively cheap prices of this metal in antiquity. This is possibly due to the increasing cost of labour and of the transportation of bulk materials (Blue et al. 2011: 188). With an intermittent development and changes in the construction of hulls, more thorough caulking and waterproofing that seem to have achieved similar results subsequently replaced lead sheathing.

The fragments of hull and other wooden elements of the ship structure from both *Berenike Troglodytica* and Myos Hormos point unambiguously to their Mediterranean origin. The use of lead sheathing, caulking and other maintenance and waterproofing techniques aimed at preventing the growth of marine organisms on wood show a similarity with mechanisms used in the Mediterranean and are well represented in all studies of Greco-Roman ports of the Red Sea. Summarising, the current state of research of Red Sea vessels suggests that they were built in the Mediterranean tradition with some slight derivations in terms of materials used for some of the components.

7.2.3. Sails and rigging

Although representations of sails and rigging are frequent in depictions of ancient vessels, their exact character remains elusive. With only a limited knowledge of their size, shape and configuration derived from iconographic material, and the near absence of preservation in ancient wrecks, textile fragments recovered from the hyper-arid environments of Red Sea ports are an invaluable source for the study of sails and rigging. By examining these fundamental components we can obtain a basic understanding of the types of rigging, sailing mechanisms and navigational capabilities used.

The most popular rig arrangement in the 1st and 2nd centuries CE was a square-rig with a broad mainsail made of square or rectangular pieces of cloth usually sewn together with the corners reinforced by leather patches and the edges protected by boltrope[78] (Fig. 7.40). Such a sail would be hoisted on a single mast with the occasional addition of a triangular topsail, or sometimes with an *artemon*[79] or a *mizzen*[80] — fore and aft sails that played a crucial role in balancing and steering a vessel on close-hauled courses (Adkins and Adkins 1998: 207; Whitewright 2008: 71–74, 2011a: 8).

This type of rig, as depicted on a mosaic from Ostia (Fig. 7.4), with a mainsail, *artemon*, and a *mizzen*, was the final variation of a single-masted square-sail arrangement (Whitewright 2008: 150) gradually replaced by lateen sail. However, to date, we have no evidence for lateen/settee rig configuration, which might have required a larger crew on a smaller vessel, being used on Red Sea vessels (Whitewright 2008, 2009, 2011a, 2011b).

78 Boltrope in modern sailing terminology is a line sewn into the forward edge (luff) and foot of a mainsail and used for hoisting the sail or moving the foot back along the boom.

79 A small mast with a square foresail, 'rigged at a pronounced angle over the bow of the vessel' that provided a counterbalance for a mainsail (Whitewright 2008: 71). See Section 7.1.5.2 for discussion of a ship graffito from Berenike that shows a furled *artemon*.

80 An aft mast with a square sail called mizzen that was used for balance and steering allowed for improved tacking and better manoeuvrability of the vessel (Whitewright 2008: 150).

7.2.3.1. Sails

Generally speaking, most of the sail material in the Mediterranean was made of linen (Pliny, *NH* 19.21; Apollonius of Rhodes *Argon*. 1.565; Virgil, *Aeneid* 3.686; Casson 1971: 234; Black and Samuel 1991: 220), although Theophrastus (*Hist. Plant*. 4.8.4) and Pliny (*NH* 22.72) mention sails and cordage made from the inner bark of papyrus (Black and Samuel 1991: 220). Almost half of all textiles recovered from Berenike and Myos Hormos have been identified as cotton (Whitewright 2007a: 289; Wild and Wild 2001: 211–220, 2005) — an unprecedented amount in the region. Moreover, much of the sail-cloth cotton has its yarn spun in an 'intrusive' clockwise, Z-direction technique (Fig. 7.41) that is extremely rare, rather than in the traditional Egyptian S-spun, anticlockwise method (Wild and Wild 2001: 212).

Because it is less prone to stretch, with a tighter weave and lower porosity, cotton is considered by many to be a better fabric for sailmaking than linen (Black and Samuel 1991: 222). Wild (2002: 9) states that the cotton sails recovered from Berenike were of a very advanced design and had the same weave count as those found on the 17th-century CE Swedish warship *Vasa*. Even though cotton was produced in Egypt from at least the 1st century CE (Wild 1997: 289–290), it was commonly spun in a S-direction. It has been argued that Z-spun cotton originated in India, which had a well-established cotton industry at this time (Wild and Wild 2000: 271–273, 2005; Wild 2004).

Only 13 other examples of cotton sails are known from the Red Sea, all of them found at Myos Hormos. *PME* (36, 48) also mentions 'a considerable amount of cloth of ordinary quality' from — amongst others — the northern Indian port of Barygaza (Casson 1989: 73, 81; Hourani 1995 [1951]: 90). This implies that not only the spinning methods, but also the manufacture of sails, were not local to the Red Sea region (Blue 2009: 9).

The cotton sail-cloth fragments from Berenike exhibit a visible grid pattern that served as a reinforcing band with flex webbing and examples of brail rings[81] exhibiting two small holes (Wild and Wild 2001: 216, Fig. 5; Wild 2004: 62, 64, photo 1) (Fig. 7.43). These sail-cloths were made of reinforced vertical and horizontal cotton strips, possibly woven on Mediterranean looms, providing a maximum length of 1.5 m, which were then sewn together (Wild and Wild 2001: 214; Whitewright 2008: 90).

Some of the wood and bone brail rings from Berenike were found in the same deposits as the sail-cloth, or physically attached to them, confirming their maritime function. One of these was uncovered still with a cotton string through its holes, with which it was fastened (Wild 2004: 62, 64, Fig. 1). Nevertheless, Sidebotham (2008: 308) cautions that the design of some of the reinforcing straps is similar to straps that could have been used as parts of tents or animals' girths, meaning that the interpretation of this material as sail-cloth cannot be

[81] Brail rings were used for more effective reefing (taking up or lowering down) of the sails and allowed for a self-stowing action as the sail was progressively brailed. Introduction of brail lines and brail rings for sail control (known already from Aegean boats of the Bronze Age, Roberts 1991: 55–59, XX) allowed sailors to shape the sail in a most optimal way accordingly to the conditions on the sea (Fig. 7.42).

absolutely certain. Whilst this is possible, the association with brail rings and the location of findings within the site seems to attest their maritime origin.

There is some debate as to how much the Berenike sail-cloth can tell us about sail and mast configurations of the boats on which they were used. Wild (2004) suggests that a comparison of Berenike's sail-cloths (Fig. 7.44) against Roman rigging materials shows that they were used on single-masted Mediterranean ships. This suggestion seems only partially relevant in terms of our current knowledge about Mediterranean rigging and its Red Sea derivations (e.g. Whitewright 2007a: 282–292).[82] But the size of discovered sail fragments, preservation of some of the fastenings, as well as the design of different types of sails, make it difficult to distinguish which particular fragments belonged to a mainsail, an *artemon*, a *mizzen* or some other type of sail or, whether they would have unequivocally taken Mediterranean rigs as their origins. The size of the fragments does not always indicate the size of the craft they came from (whether from a large sail of a seagoing ship or a smaller local or a fishing boat), or provide information about the quantity of masts.

Sails uncovered from Roman levels at Myos Hormos (Fig. 7.45) show a striking similarity to those from Berenike. Brailed square Mediterranean-type sails, made primarily from non-Mediterranean materials such as Indian cotton (Blue et al. 2011: 194), seem to dominate the assemblage, whilst the main components of the rigging — the deadeye, sheaves, brail rings and sailcloth — are similar to

[82] Unfortunately this is based solely on a few finds from Berenike and Myos Hormos (e.g. Whitewright 2008: 87–93, Blue et al. 2011: 189–199).

Mediterranean examples (Whitewright 2009). The Myos Hormos sail-cloth shows a repetitive pattern of using reinforced strips of heavier material to which the brail rings were attached. These webbing strips are spaced out between 0.6–0.8 m on recovered fragments (Blue et al. 2011: 191).

Excluding the examples of Berenike, Myos Hormos (and from Thebes in the Nile Valley), there are no other surviving cotton sail fragments of a similar age from the Roman world known to date (Blue 2009: 8). However, another comparative finding comes from Edfu where an Egyptian linen sail fragment was found (Black and Samuel 1991: 220), though S-spun (Wild and Wild 2001: 213) and reinforced with locally produced flax (Wild 2002: 13). This sail fragment includes a brail ring attached to a horizontal strip at the intersection with a vertical fragment (Black 1999: Fig. 5 and 6). It may have belonged to a Nile *felucca* or could have been pre-fabricated for transportation to one of the Red Sea ports. Such a pattern is also confirmed from some of the iconographic record, appearing to show light ropes or straps of leather used to reinforce the sails (Casson 1971: 68–69, 234; Whitewright 2008: 90). Even though the material differs, this type of sail-making technique (sewing reinforced vertical and horizontal straps) shares more similarities with Berenike than with Myos Hormos.

In his detailed study of rigging materials and reinforcement strips, Whitewright (2007b: 290; 2008: 150) suggests that there were at least three different techniques of sail-making employed in the Red Sea at this time. The first (examples from Edfu and Berenike) used vertical and horizontal webbing strips, to which brail rings were attached, and which intersected across the face of the sail. The second (one example from Myos Hormos) used only horizontal webbing strips, whilst the third only vertical ones (Thebes).

7.2.3.2. Rigging

Several finds of rigging elements were uncovered at Berenike and Myos Hormos, including brail rings of both cattle horn (Fig. 7.46) and wood (Fig. 7.47); bamboo matting, probably of Indian or African origin, that could have been used for awnings or sails (Wendrich 2000: 260–261; Sidebotham and Wendrich 2001: 43); a deadeye, wooden toggle, and a few block sheaves (Sidebotham and Wendrich 2001: 43; Sidebotham 2008: 308; Blue et al. 2011: 189–193) (Fig. 7.48). Items of rigging such as these are mentioned on one of the papyri from Berenike (BE99-29-0415) that lists a cargo inventory including items associated with sailing such as "bundles or ropes, both new and old, some made out of papyrus, mast-belts, block-and-tackle equipment and branding iron"[83] (Bagnall et al. 2005: 45–47).

The Mediterranean character of these rigging elements, but made with Indian Ocean materials, seems to confirm the origin of the rigging tradition of Red Sea vessels. Furthermore, the variety of sizes of these components indicates the wide range of vessel sizes operating on Red Sea routes at this time. Although, of course, larger brail rings would have furled larger sails, the introduction of two-

[83] Branding irons are by some (see discussion in Bagnall et al. 2005) read as kilns.

masted Mediterranean vessels meant that larger ships could still have used small brail rings on two equal size masts, which together had a much larger sail area.

7.2.3.3. Knots and ropes

Although it is very difficult to assess unequivocally the function of a rope before it entered the archaeological record, and whether it served either a maritime or terrestrial industrial use (or both),[84] the large number of cordage remains with 'good knots'[85] found at coastal sites, such as Berenike (Veldmeijer 2006: 339) and Myos Hormos, can easily confirm their maritime function. It is believed that Myos Hormos was a centre of a wholesale rope-making facility (Blue et al. 2011: 198), presumably part of the supply network for the large sailing and fishing community in the region. However, it is debatable whether it would have also been supplying sites such as Berenike, some 300 km away, or whether there would be another rope-making facility further south.

Rigging ropes used on Mediterranean vessels were usually made of flax, hemp, papyrus or esparto grass (Adkins and Adkins 1998: 207). However, in the Red Sea region, at Berenike and Myos Hormos, ropes were usually made of animal

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[84] Most of Berenike's assemblage consists of linear cordage but with a few examples of fishing nets, carrier netting, sandals and other objects, often of an unknown use (Veldmeijer 2004: 101–112, 2005a, 2005b, 2006: 337).

[85] 'Good knots' refer to knots that are tied correctly and serve their purpose without the knot untying itself. The known spectrum of ancient 'good knots' is very similar to the modern ones and includes, amongst the others, half knots, overhand knots, reef knots, mesh knots but also hitches and figure-of-eight knots (Veldmeijer 2006). Tying knots in the correct way requires skill and training that is widely, and almost exclusively, available within maritime communities.

hair, cane, grass, palm, and reed (Blue et al. 2011: 198) (Fig. 7.49). Published data from earlier excavations at Berenike (pre-2001) concerning knots on cordage suggests that, in broad terms, the population of Berenike was very proficient in knotting, unlike on other sites in the hinterland such as Shenshef (Veldmeijer 2006: 353). It is important to mention that only a very small number of the knots from Berenike were 'bad knots' (Veldmeijer 2006: 352), and as good knotting is one of the requirements of seafaring this reaffirms the strong presence of seafarers and fishermen in the town's population. This suggests that as well as being an international port, the population of Berenike was also involved in an active 'local' maritime economy.

7.2.3.4. Summary

The broad range of finds associated with rigging and sailmaking recovered from Berenike and Myos Hormos reveal an interesting cultural pattern in which Greco-Roman ships are made with the use of Eastern materials. As we have seen, the archaeological record shows that the ships that sailed to the Roman ports of the Red Sea were mid- to large-size mortise-and-tenon vessels, rigged and planked in a Mediterranean square-sail fashion, but utilising eastern (Indian and African) materials. Such constructions could withstand the adverse weather conditions but were seemingly less manoeuvrable in close-quarters (e.g. entering a harbour or negotiating coral reefs or atolls) unless equiped with oars.

Even though Mediterranean-style rigging (square sails and brail rings for furling) has not been confirmed in archaeological contexts from the Indian Ocean region, some of the representations on reliefs and coins described in Section 7.1.5 appear to depict rigging features similar to those used by Mediterranean vessels (with what seems to look like furled square sails, e.g. on Ajanta depitions, Fig. 7.25; or with an *artemon* such as on Khor Rori carving, Fig. 7.27, on Andhra-Sātavāhana coins, Fig. 7.28 or on a sherd graffito from Anagankulam, Fig. 7.30). These depictions either represent actual foreign vessels ('beautiful big ships of the *Yavanas*' mentioned in Indian literature) or display designs that were appropriated across different cultures. Additionally, covering a broad range of time, these assemblages highlight how even minor changes in the design of rigging elements and sails could have resulted in major improvements of the efficiency and safety of sailing.

7.3. PROPOSED SCENARIOS

This section presents a number of alternative scenarios that allow us to explore potential reconstructions of the port city of Berenike based on the results of the geoarchaeological and archaeological interpretations. These hypothetical scenarios allow for the articulation of different site narratives, specifically trying to understand the form, function and configuration of Berenike's harbour basins (Fig. 7.50). These scenarios emphasise different aspects of the interpretation of the ancient lagoon and embayment topography. This allows us to 'test' slightly different interpretations of the same dataset, examining how the port might function given small changes to the environment (possibly in different periods of utilisation) that still fall within the overall interpretation.

The scenarios below are based on specific datasets generated during this project, including our current knowledge of the characteristics of tidal ports (Chapter 2), the geoarchaeology of the available water-bodies (SWE and the Lagoon) and ancient sea levels (Chapter 4 and 5), and the types of sailing vessels that were accommodated in them (Sections 7.1 and 7.2). The reconstructions show that this was a natural haven that was probably extensively adapted over time to accommodate the changing volume of traffic, types of boats and the needs of the local population, as well as adaptation to meet the dynamic changes within the landscape, such as siltation and local changes in sea level.

7.3.1. Scenario 1

Most traffic in the inner harbour (including smaller and large vessels); overflow in the outer harbour; potential seasonal use of the roadstead

Scenario 1 assumes that the evidence for ancient sea level, derived from sediments recorded in trench BE11-71 at +~0.85 m, means that the inner harbour was of sufficient depth (at least in the Ptolemaic period and at the beginning of the Roman occupation of the site) to accept and accommodate large sea-going ships with a draught of up to 3 m, similar to the *Madrague de Giens* merchantman shipwreck, as well as a number of military vessels that we know were stationed at the port. This 'inner harbour' was located within the Central Zone of the Southwestern Embayment, attaining a depth of around 0.85–1.4 m around the edges and up to 3 m at its deepest part (accordingly with reconstructed buried topography, Sections 5.3 and 5.4), with smaller fishing, coastal and ancillary vessels beached or moored in the shallower parts of this basin.

Whilst most of the traffic can be accommodated in the 'inner harbour' only the overflow is directed into the 'outer harbour', or the Lagoon. The 'outer harbour' in this scenario would have either been a single basin comprising only the southeastern part of the Lagoon, or, dependent upon the size of the first basin and the amount of traffic, consisted of two outer harbours. In this case the northwest sector of the Lagoon, situated at the foot of the city-tell, is also adapted to accommodate vessels and is treated as another 'overflow basin'.

If we assume that all marine traffic was accommodated within the inner and outer harbour (west of the Southern Promontory), vessels would be restricted by the maximum draught that could safely be accommodated by the depth of the channel through the coral reef (Section 5.1.2) leading to the Lagoon. Additionally, the roadstead to the east of the Promontory and entrance of the Lagoon would only need to be used seasonally, if at all. The Northern Anchorage is not utilised in this Scenario.

7.3.2. Scenario 2

All traffic accommodated between both an inner (smaller crafts) and an outer (larger crafts) harbour; roadstead used episodically

In this scenario, all marine traffic is accommodated between the 'inner harbour' (catering mostly for smaller coastal and ancillary vessels), and the 'outer harbour(s)', including the Lagoon, which, with a depth of over 3 m, would accept larger, ocean-going ships. The roadstead on the north-eastern side of the Southern Promontory could be either episodically or permanently used for mooring long-distance merchantmen and navy vessels that were transiting through Berenike on their way south or north. The Northern Anchorage is not utilised in this Scenario.

In this scenario, vessels would have to be moored even further east or north into Fouls Bay (and loaded/unloaded via lighters), i.e. in the roadstead located in the bay, some 1.5 km north of the city-tell. Despite the sheltered, back-reef setting, the coast of Fouls Bay is persistently exposed to the action of waves and storm surges posing potential risks to vessels. Therefore, the more exposed roadstead northwest of the Southern Promontory might have only been used in favourable weather conditions.

7.3.3. Scenario 3

All traffic accommodated in both the inner and outer harbours; potential usage of the roadstead and/or Northern Anchorage

In Scenario 3 both the 'inner' and 'outer' harbours are used in combination to accommodate marine traffic, forming a joint, single basin. The roadstead may have also been used to accommodate the overflow of the traffic, but it is unlikely to have been essential. The Northern Anchorage (Section 5.7), in this case, is used to house important and/or prestigious, smaller vessels such as bureaucratic vessels or those belonging to visiting dignitaries or rich merchants from the south. In this Scenario, taking into account the high sedimentation rates in the northern area of the site (at least 1 m recorded in the northern part of the site), and the subsequent lowering of sea level by some 0.85 m, it is possible that the depth would be sufficient, even at a low tide, for small to medium vessels to access this part of the shoreline.

7.3.4. Scenario 4

Most traffic located within the outer harbour; potential second outer harbour

In Scenario 4 we assume that most of the maritime traffic, including small and large vessels, is accommodated within the outer harbour (Lagoon), and in the absence of any visible remains of direct port infrastructure (waterfront, jetties, etc.), that beaching on the eastern slope of the city-tell would have been the most likely way of housing ancillary vessels. The roadstead would have been used only sporadically.

7.3.5. Summary

References to the harbour of Berenike in ancient literature and in epigraphic sources are rare, and whilst the augering results have allowed for the delineation of the Ptolemaic harbour basin, the absence of a geochronological framework makes it difficult to establish an accurate timeline for phases of coastal topographic change and concomitant shifts in port configuration. However, reconstruction of the physical characteristics of the basins and associated coastal features (Chapter 5) examined for this research have shown that the character of Berenike's harbours could have been a hybrid version of a Mediterranean and Indian Ocean style port, in which the natural landscape was modified to accommodate the needs of the local population and their maritime visitors.

The four scenarios above have presented snapshots in time of potential spatio-functional divisions of the port and its harbour, and the potential mechanisms of operation of Berenike's port. In summary, the entire 'Southern port' (including all maritime landscape features discussed in Chapter 5) can be divided into the 'inner' (SWE, 0.85–1.4 m depth in Central Zone, up to 3 m depth in the remainder of the SWE) and 'outer' (Lagoon, over 3 m depth) harbous the roadstead (deep), and the Northern Anchorage (some 1.85 m depth or less).

Although plausible, it is nonetheless unlikely that each of these areas was used throughout the entire lifespan of the port. First, at times when traffic was persistently less intensive maintaining all of these basins would have been very inefficient. Second, due to the high level of alluvial sedimentation recorded on site (Chapters 4 and 5), it is clear that some parts of these basins, such as the Central Zone and/or Northern Anchorage, could have become infilled rendering them nonoperational during later periods of occupation. Last, the type of cargo, the design of the delivering vessel, and the particular arrangements made with the merchants on land might have dictated where the vessels would be moored and/or unloaded.

Such a system (e.g. mid-sized vessels beached on the footsteps of the city-tell whilst large ships berthed in the centre of the Lagoon, or all large ships anchored at the roadstead) could have been adapted seasonally or been undertaken in varying configurations depending on the current conditions (e.g. unusual tidal range, flood, draught, harbour in need of dredging or just dredged). This shows that clearly defining the functional areas of the harbour and identifying where particular sizes of vessels could be moored is a very difficult task. Above presented data (Chapter 4 and 5) seems to suggest that the most inclusive Scenario 1 would have been most likely, at least in the Early Roman period when the town was at the top of its maritime trade boom.

7.4. CHAPTER SUMMARY

To date, the paucity of wrecks or nautical finds means that there is insufficient evidence to answer unequivocally questions of how, where and by whom the majority of Red Sea and Indian Ocean vessels of this period were built, repaired and maintained. The corollary of this is that we do not know what were the most common types, sizes and capacities of crafts that moored at Berenike. Still, the data presented in Sections 7.1 and 7.2, however limited to a small sample size, indicates that Greco-Roman-design vessels dominated these routes.

Available assemblages of nautical finds allow for an estimate of the types of vessels likely to have visited Berenike given the reconstruction of various relevant parameters. The size and depth of the harbour, the approach to port, design and construction of the trade vessel, and the strategic position within trade network can all be used as sources of indirect evidence for potential traffic flow and accommodation space at this important Red Sea port.

7.4.1. Potential crafts at Berenike

The Romans were very fond of adopting technological innovations from other cultures and so it seems likely that they would have drawn upon examples from shipbuilding techniques established by Indian Ocean rim societies that were sailing using monsoon winds for centuries before them. However, the evidence from Berenike portrays a rather different picture. It seems that these were the Mediterranean style vessels that plied the Red Sea and Indian Ocean routes.

In his book on *The Ancient Sailing Seasons*, Beresford (2013) presents a compelling argument that ancient Mediterranean ships and boats and their crews were very capable vessels and seamen, optimally exploiting the micro-scale regional variability of wind and weather patterns. Beresford (2013: 225) further argues that the lateen-rigged, sewn-hull vessels were unsuitable to undertake southwestern monsoon voyages and that it is 'almost certain' that vessels plying the Indian Ocean in the Hellenistic and Roman period were similar to their Mediterranean counterparts. Whilst this assertion is based primarily on our current understanding of the performance of Mediterranean vessels in Mediterranean conditions, compared and extrapolated to Indian Ocean conditions, it is potentially also supported by literary sources such as *PME* (21), which states that the Greco-Roman seafarers 'used their own outfits' and Indian textual evidence referring to 'beautiful big ships of the *Yavanas*', seemingly different to those of the Arab sailors.

Whereas material evidence of vessels found at Berenike and Myos Hormos confirm the Mediterranean origin of their design, even minor innovations resulting from encounters between ship builders, or observations by shipwrights of foreign vessels (i.e. from India, Southern Arabia), could have influenced Roman Mediterranean ship design in ways that are extremely difficult to identify and disentangle in the archaeological record, especially when this record is so scant at present. Reconstructing the chronology and origins of these innovations could significantly advance our knowledge of the history of seafaring, maritime trade, and navigation, not only on the Red Sea, but also in the Mediterranean and the Indian Ocean.

The maritime artefacts found to date from ancient ports such as *Berenike Troglodytica* and Myos Hormos present a very interesting technological pattern confirming earlier notions that a mixture of Mediterranean and Indian Ocean techniques were used in developing 'Red Sea' vessels. Despite the fact that Indian Ocean seafaring *per se* is barely perceptible in an archaeological context, data from epigraphy, iconography and the study of raw materials can shed light on this issue. Sails recovered from Berenike and Myos Hormos are woven from Indian cotton in Z-spun fashion, presumably by Indian seamstresses; the ship timbers and rigging components are often made either using teak from India or blackwood from Africa (with some additions of Mediterranean and European wood); examples of ropes are made with fibre from coconut husks, some with cane, palm and reed. But, despite this obvious technological connection and exchange of ideas between East and West, the actual hull construction and rigging is in the Mediterranean technological style.

The huge diversity of shapes and sizes of these components indicates a high level of specialisation of maritime crafts on site. The size, manoeuvrability and draught of the ancient vessels, as well as the local availability of building resources and the natural conditions of the bay, were key factors in defining the type and design of infrastructure in Berenike's port (Chapter 6). The aforementioned diversity of ships and boat designs may not necessarily have made harbour planning more difficult. Different parts of the lagoon and harbour embayment would have been reserved for particular types of vessels, with shallower-draught craft beached and larger merchantmen anchored in the deepest parts of the bay. Our knowledge of the potential size and shape of the harbour (Sections 5.3–5.4 and 7.4.2) and the types of crafts that used it (Section 7.2) supports the notion that Berenike possessed a good quality harbour in which a variety of trading and fishing vessels received shelter and provisions and underwent repairs.

In summary, there is currently no firm evidence to suggest that there was a shipbuilding tradition particular to the Red Sea region during the Ptolemaic and Roman period. On this premise, and according with the sailing conditions and characteristics of the harbours of *Berenike Troglodytica* (Chapters 5 and 6), Myos Hormos (Blue 2007, 2011a) and other harbours *en route* (Section 3.2), it would seem likely that a hybridised mix of the more rigidly planned and structured Mediterranean tradition and the more free-flowing and flexible Indian Ocean traditions would be most suitable. However, as Beresford (2013: 225) notes, the 'fair-weather dhows' would have come across significant difficulties sailing the southwestern monsoon.

Nevertheless, the small amount of epigraphic evidence and primary shipwreck data, as well as maritime finds found in secondary contexts in Red Sea ports, hold twofold potential. Either, we are dealing with evidence of the hybridisation of vessels, with Eastern adaptations to what were most likely originally Western boats; or, rather, we are seeing the use solely of Mediterranean engineering to build vessels using readily available and possibly superior Eastern materials (e.g.

wood and textile). This is perhaps unsurprising given that these vessels spent a great deal of time in the East (trading, undergoing repairs and sometimes waiting for winds to change so that they could come back from India) and so that a gradual evolution taking place in local traditions is really to be expected. Further analyses of the maritime finds from the Red Sea region, and especially from the recent 2009–2014 seasons from Berenike, as well as potential new discoveries of ancient shipwrecks, will provide more information regarding this exciting topic in the near future.

7.4.2. Estimates of the capacity of Berenike's harbour

Whilst the calculations of the capacity of ancient ports put forward by de Graauw (2014) and Boetto (2010) are useful for estimating the volume of traffic in Mediterranean harbours (both artificial and natural), they are based on the assumption that vessels were moored stern or side on to the quay. However, as we have seen, the style of mooring at Berenike is likely to have been very different. Based on the new reconstruction of site conditions presented here (Section 2.4 and Chapter 5), the types of vessels that could have moored in this port (Section 7.2 and 7.4.1), and personal experience of navigating into and out of small and medium size harbours under sail, some new estimates have been calculated as part of this research.

A calculation of the 'comfortable' capacity of the 'Southern Port' of Berenike (including both the 'inner' and the 'outer' harbours presented in Section 7.3) is based on a series of assumptions expanded in this chapter and some modern analogue mooring experiments undertaken by the author in small and medium size harbours (chiefly Shellharbour and Wollongong, NSW, Australia) during different phases of the tidal cycle. It assumes that:

i. the majority of larger merchant ships moored at Berenike were on average 25 m x 7 m in size (based on the size and tonnage data presented in Section 7.1.3.2 may have had a 250–350 tonnes deadweight tonnage), but up to 625-tonne vessels, such as *Hermapollon*, are recorded);
ii. the ships under investigation would have had an average draught of 3.5 m, but no less than 2 m (based on draught data presented in here), meaning that, accounting for the tidal range of approx. 0.5 m it would not be possible to moor them safely anywhere more shallow than +1.5 m of their draught at high tide;
iii. a large number of ancillary and fishing vessels of a variety of sizes and draughts could be moored on the edges of the embayment and the lagoon, in their own area of the harbour, or simply beached (these vessels are not taken into consideration in the estimate as they were most probably not directly linked with the Indian Ocean trade, i.e. did not contribute to its quantity);
iv. based on the geoarchaeological results (Chapter 5) a rough 'ballpark figure' was calculated for the capacity of different functional areas of the site (see Fig. 4.33 and 7.50). The 'Southern Port' (including 'inner' and 'outer' harbours from the Scenarios in Section 7.3) was likely to be approximately 17.3 hectares (Section 5.3), and the potential 'Northern Anchorage' approximately 0.48 hectares (Section 5.7); the town on the elevated reef outcrop was approximately 6.2 hectares in size (Section 5.8), whilst the island with the *Temenos* of Temples was approximately 0.16 hectares (Section 5.5);

v. our understanding of the bathymetry of the Lagoon and the Embayment makes it clear that the entire 17.3 hectare basin could not have been used to moor large merchant vessels. The available data (Sections 5.1, 5.3 and 5.4) shows that the near-shore part of the Central Zone would have a depth of approx. 0.85–1.4 m, whilst the SWE would range from 2.85–3.35 m and deeper. It is assumed that little over a half of this body of water would have attained a depth of 5 m or greater. The other half would be capable of accommodating shallower-draught fishing and ancillary crafts and mid-size merchant vessels. Given these data, we would therefore only be able to accommodate merchant ships in 9 hectares of the harbour;

vi. taking into account the tidal range, the direction and strength of offshore winds, and the experiments conducted in similar size harbours on board vessels of various sizes and capacities, the space between the boats on 'swing' moorings or on anchor should be at least 1.5–2 times their width side to side, and at least 1 times their length stern to bow.

With such numbers in mind, a merchant ship of 25 m x 7 m would take up an area of 175 m^2 (based on Assumption I. but using a square rather than a circle for an the ease of calculating the area required[86]). As mentioned above, the vessel would also need sufficient free space between it and any adjacent vessel, and a channel between the rows of moored ships through which to travel. This creates a requirement of 875–1,200 m^2 per vessel (based on Assumption VI.) to accommodate a merchant ship comfortably in the harbour, meaning that an area of 90,000 m^2 (based on Assumption V) would accommodate around 75 medium to large ships at an absolute maximum although it is unlikely that such a large

[86] This could also be calculated by using the long axis (length of the vessel) and the length of the anchor chain (at least twice the size of the length of the vessel) as the radius of a circle that the vessel could swing around its mooring – i.e. 25 m vessel + 50 m anchor chain = a circle with a radius of 75 m. This sort of calculation would be used in a harbour with a high tidal range and where the vessels would moor using anchors only on the bow/or stern.

number of vessels would be moored at Berenike at any one time (Fig. 7.51). Additionally, Berenike would accommodate a much larger number of smaller ancillary and fishing vessels that would be located in shallower waters and beached.

Whilst there are obvious limitations to this estimate, and there is obvious need for much more data derived from a multiple disciplines to further enhance these calculations, this figure has been presented to allow us to imagine how the port of Berenike might have looked and what was its potential capacity and the maximum occupancy for large ocean-going merchant vessels (see Fig. 7.51). Despite the general assumptions used to calculate this figure, it still reflects a fair estimation of Berenike's capacity on the basis of our current state of knowledge.

8. CONCLUSIONS

During its 800-year operational lifespan, the port city of *Berenike Troglodytica* was located in a somewhat inhospitable, marginal environment on the edge of an arid or semi-arid coastal plain adjacent to the Red Sea. Based on the results of this research it is clear that even though the reason for Berenike's initial inception was partly political and strategic, the physical configuration of the coastal landscape (especially the 'Sea parameters') was also important in the choice of its location, whilst a key factor instrumental in its subsequent decline was the political shift and the changing dynamics of its environment. The presence of a natural lagoon and the favourable prevailing winds provided such an attractive location for a port that neither the proximity of three large wadi systems prone to deliver silt to the harbour basin, nor the scarcity of fresh water, could deter the development and continued occupation of the city. Clearly the political and economic requirement for a port outweighed potential disadvantages of its location.

8.1. LANDSCAPE RECONSTRUCTION

It has been demonstrated in this thesis that Berenike has a very well preserved sub-surface stratigraphy that could be used to reconstruct changing coastal environment. This stratigraphic record has been interrogated not only alongside the existing archaeological evidence, but also in relation to the present-day above-ground geomorphology. Coastal geomorphological surveys around the site and its hinterland linked contemporary landscape features (Section 2.4) with the reconstructed ancient landscape (Chapter 5), allowing for a far greater appreciation of the 'Parameters of Attractiveness' that ancient prospectors, settlers, and traders would have considered when siting this new port (Chapter 6). Using the sedimentological, geochemical and geochronological data derived from the analysis of core sediment samples (Appendix 1), and the relative age determination of diagnostic ceramic fragments in conjunction with absolute AMS radiocarbon dates (Section 4.4), a chronology for landscape change has been developed and is presented below.

8.1.1. Early landscape (Prehistoric and Pharaonic)

Geomorphological and sedimentological features recorded around the site indicate that the entire site of Berenike was inundated in prehistory. A small and undiagnostic stone tool assemblage was found on top of the limestone buttes/terraces to the southwest of the site, during a survey conducted by the author and a Palaeolithic specialist, Piotr Osypiński. It confirms the ephemeral presence of prehistoric human groups in this landscape, at a much earlier time when this area of the coast would have looked strikingly different.

Wave-cut notches recorded at the base of these limestone outcrops, at an elevation of ~12 m above the ground surface, indicate higher sea levels during, potentially, Marine Isotope Stage (MIS) 11.[87] This is supported by the subsurface stratigraphy recorded in geoarchaeological transects indicating the base of the lagoon at a much higher elevation towards the CSR. Following a lowering of sea level in the terminal Pleistocene during the Last Glacial Maximum (LGM)[88] the land around Berenike became viable for human exploitation as a port site, opening up the possibility of a proto-Berenike and the beginnings of human occupation in the area of the site.

It is possible that Berenike could have been occupied or used in the Middle Kingdom but there is no evidence for such to date. However, future findings are possible since there are other sites in the area dated to this period (e.g. Marsa Gawasis) and numerous accounts referring to the journeys to the land of Punt along the Red Sea are available from the time of pharaoh Hatshepsut.

8.1.2. 'Proto-Berenike'/Ptolemaic settlement

Early Ptolemaic settlers and elephant carriers were the first to use the area of what is currently the archaeological site of *Berenike Troglodytica*. It was most likely a relatively small-scale venture initially, before becoming a formalised part of the

[87] MIS 11 that occurred 424–374 kya was the longest and warmest interglacial interval of the last 500 ky. It corresponds with geological Hoxnian Stage.
[88] LGM occurred between 26.5 and 19–20 kya.

infrastructure of maritime trade, gaining a fort, city walls and a gate.[89] At this time the foreshore area would have been used for seafaring activities such as the loading and unloading of boats, vessel repairs and maintenance, and the temporary storage of goods. The prograding backbeach environment and the shore, from the Central Zone of the SWE towards the narrow sand bank in the northern 'anchorage' area, would have been particularly responsive to a lowering of sea level and conducive to carrying out of such activities.

On the basis of our current knowledge regarding the archaeological site and its buried stratigraphy, it can now be suggested, with reasonable confidence, that the pottery layer (Facies E and E^1) correlates with the bed of the Ptolemaic harbour basin and indicate a lowering of the sea level by ~0.85 m from that time to the present. Charred pottery from Facies E^1 formed a component of former hearth structures constructed at a time when the beachfront (observed in trench BE11-71) was utilised for maritime activity. However, pottery recovered from Facies E in augerholes further to the east is heavily water-abraded and the layer angles downwards in a gradient and pattern similar to that of the intertidal zone of the current lagoon.

[89] The Ptolemaic city walls and Ptolemaic gate were uncovered during the 2013 and 2014 field seasons (Marek Woźniak, pers. comm. 2013–2014; Woźniak 2015).

8.1.3. Roman Berenike (Early)

Following the Ptolemaic period the harbour basin and lagoon areas began to infill with silt and other fine sediments. The exact mechanism of this process is currently unclear, but natural factors such as coastal progradation and wadi discharge would have certainly contributed, possibly also with an influx of windblown fine sands. Human modification of the landscape would have exacerbated the situation with practices such as the overgrazing of livestock (especially caprine) causing landscape destabilisation and a marked increase in sediment availability.

The siltation could well have been initiated during the main occupation phase at Berenike, with pulses of wadi sediment discharging during heavy rains and flash flood events (potentially linked with an increase in local precipitation or increased seasonal floods, for example). An increase in sediment flux to the coast most likely occurred between the late Ptolemaic/early Roman and late Roman times, as seen by the approximate limits of coastal progradation marked by the *Temenos* of Temples.

Prior to this phase of siltation, the sedimentology indicates that during the Ptolemaic period, and probably much of the early Roman period, the harbour extended right through the Central Zone of the SWE to the Lagoon. It is at this time, when the Lagoon achieved its greatest extent, that it was exploited for international maritime trade. Intensive commercial activity would have most likely necessitated regular episodic dredging.

Evidence of dredging is often only recorded in very subtle stratigraphic changes (e.g. Morhange and Marriner 2010a), and such evidence was not directly identified during the augering of the Berenike's SWE (Section 5.1.3). This could be due to the limitations of the equipment and/or the lack of robust geochronological framework with which to identify gaps in the stratigraphic record associated with dredging events, or a relocation of the harbour further into the Lagoon where augerhole coring was impossible. Alternatively, it might be related to the lateral shift of a functional area of the port, such as moving from the Central Zone favoured by the Ptolemies further into the SWE and Lagoon during Roman use, when the Central Zone may have already partially silted up.

8.1.4. Roman Berenike (Late)

During the late Roman period, Berenike started a slow decline. The level of Roman control over this area of Egypt from the late 3rd century CE is unclear, but reduced trade with the east and the overall decline of maritime trade in the Mediterranean — a part of a general economic pattern — had a severe impact on the port. A detectable gradual deterioration of living conditions in the city (e.g. architecture, diet, etc.) seems to be mirrored in the decline of the functionality of the port. This may have been dictated not only by geo-political machinations, but also subtle changes in the geomorphology of the catchment area leading to enhanced siltation to the coast and harbour basin. Events such as increased wadi sediment discharge and gradual lowering of sea level would have hindered port operations and required ever-increasing costly and time-consuming maintenance, ensuring that areas such as the Central Zone and Northern Anchorage were most likely non-operational at this time.

The increased sediment flux and subsequent silting up of the basin would have necessitated either extensive dredging at the entrance of the harbour/lagoon, or partial reconfiguration of functional areas of the port and associated infrastructure. Whilst events such as disease or an epidemic (e.g. the Justinianic plague) are invisible in the geoarchaeological record (although the human skeletal record could identify some pathological evidence for such causes and large amount of contemporaneous burials could be seen at the cemeteries) minor climatic events could have occurred at this time, although none can be unequivocally confirmed nor dated at this stage.

8.1.5. Arabic times and East India trade

Because of the lack of historical or archaeological evidence to date for the continuing use of Berenike during the Islamic period, when most of Berenike's trade moved to the port site Myos Hormos (some 260 km to the north), it is important to question why the site, after its initial decline in the 6th century CE, was not revitalised by the Arabic caliphates and later by Portuguese traders. Extensively modifying or even re-building the already abandoned port of Berenike, which may have possessed a partially or wholly silted up lagoon at this time, may have represented a far greater effort and expense than simply transferring operations to another port in the region such as Quseir (Roman Myos Hormos), which was of a much greater significance as it lay directly on the *hajj* (pilgrimage route) to Mecca.

Although post-16th century CE East India trade passing through this area is seen not only in the historical records but also by engravings in the Eastern Desert (such as those of ships; Blue et al. 2011), the geoarchaeological evidence from Berenike shows that the Southwestern Embayment would have been by this time almost totally silted up and therefore probably insufficient for Portuguese or English ships of the 16th century CE and later.

8.1.6. Modern

Although the present-day coastal landscape of the archaeological site of Berenike is not viable as a shipping port, it is important to note that in the area of Berenike, 10 km north of the site, a major naval and air force base — Baranis — exists. It is equipped with a naval harbour proving that this area of the coast still possesses the ‘Parameters of Attractiveness’ for modern maritime activity. It is currently unknown why the original Ptolemaic and early Roman port was not situated in this location and whether the activities would have moved here in the late Roman and/or early Islamic period (and if not why) as this military area is inaccessible for research.

8.1.7. Summary

The archaeological excavations at Berenike, yielding an abundance of high-quality imported material and ancient textual evidence, demonstrate that the site was of great importance as a seaport during the late Ptolemaic and early Roman times. During this time, the environmental conditions and size of the lagoon were optimal for the operation of this international port and harbour. The results of the sedimentological analyses and the geoarchaeological research component of this research have provided an understanding of the dynamics of the lagoon at Berenike and its changing viability as a harbour as well as given some approximate estimates of its size, depth and capacity.

Although only limited information regarding port infrastructure and installations is available from the archaeological excavations and ancient texts, the environmental conditions during peak periods of occupation were highly conducive for the siting of a port. The site would have been extremely attractive for human settlement as it was located relatively close to accessible fresh water sources and the wadis through which a 12-day caravan route to the Nile Valley was marked out (compared to the 6-day route from the more northerly port of Myos Hormos, sailing time to which may have been much longer than a week). The Roman infrastructure in the Eastern Desert seems to have developed in unison with the rise of maritime trade on the Red Sea, with state-sponsored provisions for establishing roads, wells, security and alike on the ground, and support for private entrepreneurship. It should also be noted that, in the Roman period, it was within easy reach of a large complex of mines and quarries, and therefore represented a very good location not only for a commercial port town but also a regional administrative centre.

At present, despite new data available regarding the changing landscapes and coastal seascapes of Berenike, there remains insufficient archaeological data pertaining to the delineation of the harbour and its functional zones, and the mechanisms of its operation. What we can say with reasonable certainty is that the harbour was at its highest extent in the Ptolemaic and Early Roman periods, with the +0.85 m sea level providing at least 2.85 m water depth in the Lagoon. High sedimentation rates would have instigated the slow decline of the harbour, and the basins would have started contracting in the Early Roman period unless dredging was undertaken. If dredging was performed — and it is likely that it was, despite the lack of hard evidence to date — it probably occurred in the early Roman period when maritime trade was at its peak.

The late Roman port appears to have been much smaller, without the use of the Central Zone or the Northern Anchorage. The location of the late Roman *Temenos* suggests that much of the Central Zone would have already infilled at this stage. The gradual lowering of sea level over ~500–600 years, allied with the high sedimentation rates, would have also impacted on the depth of the Lagoon that may have diminished even by 2 m (or more) in some places, especially at the margins and in the centre.

On the archaeological evidence alone it appears that during the early Ptolemaic period vessels could have simply been beached or anchored in the Central Zone. This may also have been the case during later periods in some parts of the city and for some types of boats as no jetties or wharf structures have been found. By the late Roman period, as the lagoon began to choke with silts, the roadstead could have been used more commonly, with small boats loading and unloading the cargo outside the old main harbour, or anchoring and using a boarding ramp to unload directly into the shallows with goods then being carried ashore.

The geoarchaeological survey has allowed for a clearer understanding of local environmental dynamics. However, what is lacking to take this research further is a high-resolution geochronological framework on which to hang this palaeogeographical reconstruction.

8.2. OBJECTIVES REVISITED

This research has successfully addressed the overarching aim of the study, and significant landscape change has been recognised at different scales driven by both natural and anthropogenic processes. The multi-parameter scientific approach developed to undertake this research has allowed the author to address all seven main objectives of this thesis. In addition to the detailed interpretations and discussion of the results were presented in Chapters 4–7, and the chronological landscape reconstruction presented in Section 8.1, the following section will address each of the objectives in turn to evaluate the success of these data.

To develop a methodological framework through which to understand human–environment interactions at port sites, including their physical configuration, and the level of human adaptation and maintenance.

A multidisciplinary approach for studying ancient ports of trade using Earth Sciences, archaeological and historical datasets, and semi-quantitative data analysis has been developed during this research. To this end, a geoarchaeological augerhole survey undertaken in tandem with coastal geomorphological and geological survey in the hinterland, and subsequent laboratory analyses, have generated an integrated archaeological, landscape, palaeoenvironmental and geochronological dataset.

These data have shown that even minor or subtle changes in environmental variables (e.g. fluctuations in sea level, changes in coastal geomorphology, fluvial sediment flux) might have had a dramatic effect on the viability of the port and harbour in both the short and long term. It has also shown how humans have interacted with this changing landscape. This vindicates the type of landscape-based approach, suggesting that methodological frameworks such as this should be an integral part of any archaeological port study.

Furthermore, the various analytical scales of research have supplemented the picture of Berenike's port town and harbour obtained from the geoarchaeological and landscape study. The political, social, economic and environmental factors behind Berenike's establishment and development have been assessed using a semi-quantitative pilot study that assigned the attraction variables into four major groups and rated the relative importance of these 'Parameters of Attractiveness' in the initial siting of this port city.

The third major component of this doctoral research was the comprehensive study of 'Red Sea vessels'. This was undertaken to elucidate the types of ships and boats that could have moored in Berenike's harbour, allowing for a better understanding of how it was designed, operated, and looked to sailors and citizens and what was the port's capacity. To this end, evidence from shipwrecks, iconography, epigraphy and nautical finds recovered from secondary, terrestrial contexts, from the Mediterranean, the Red Sea and the Indian Ocean, has been studied to understand the technology and design, size and capacity, speed, performance and draught of Red Sea vessels.

It is the author's contention that whilst disentangling particular aspects of ancient port characteristics can be extremely useful, employing a holistic approach using different disciplines in unison and merging various strands of evidence proves to be much more efficient at creating a robust reconstruction of the site and its history.

To reconstruct Berenike's ancient landscape and environment

The results of the geomorphological surveys and geoarchaeological augering (Section 2.4 and Chapter 4) have allowed for a clearer understanding of the local and regional climatic and environmental shifts that have shaped the site and its landscape setting, making it more, or less, amenable for human exploitation. The new interpretations of the site in its environmental context (Chapter 5), based on the new data, and comparison with other sites in the region (Section 2.2), have been assessed and we now understand how landscape dynamics had a real and tangible effect on the volume of trade passing through the port and the success of this port city. These new data also had a huge significance in ultimately defining and measuring the potential maritime capacity of Berenike's harbour basin(s) (Section 7.4.2).

This research has demonstrated that the inception, evolution and cultural history of this coastal site can be linked to the dynamics of the landscape in which it is set. A series of augerhole transects situated across the site and its harbour allowed for the recreation of the buried site topography and insights into a number of key issues:

i. Recognition that there has been a drop in relative sea level of ~0.85 m since the Ptolemaic period;

ii. Understanding that the archaeological site and the coastal and intertidal zones were much closer than they are today to the high ground of the CSR (by ~40 m) when the sea level was higher. By extrapolation, this provides a very broad estimate of the rate of coastal regression, amounting to ~300 m in 2,300 years;
iii. The delineation of the western extent of the Ptolemaic harbour;
iv. The identification and radiocarbon dating one of the harbour floor levels;
v. Confirmation that 'the Niche', or 'Northern Anchorage', most likely accommodated a significant water depth at some point in time.

To clarify the location, size and capacity of Berenike's harbour basins.

This research has, for the first time, shown the extent of the Ptolemaic harbour and pinpointed its former whereabouts to the Central Zone of the Southwestern Embayment. It has also shed light on the siltation processes active at the site and the likely provenance of the sediments that form a harbour fill. The reconstruction of potential scenarios (Section 7.3) has allowed for the division of functional areas of the inner and the outer ports, and a roadstead in different periods of its usage (Chapter 5). This data has also allowed to, at least provisionally, determine that the Ptolemaic and Early Roman harbour (at least at its beginning) were of the largest extent using most probably Central Zone of a SWE as the 'inner' harbour and the Lagoon as an 'outer' harbour. The Northern Anchorage, if such indeed existed, could have also been used at this time. The sedimentation rates and slow economic decline were most likely mirrored in deteriorating state of the harbour in the Late Roman period where the Central

Zone was no longer viable for exploitation by larger vessels and which Lagoon was much shallower.

Importantly, the information derived from the study of the Red Sea vessels in the Roman period has allowed for a rough estimation of the approximate number of ocean-going ships that could have been comfortably moored in the early Roman harbour of Berenike (at the peak of the season). Based on these new data this estimation is 75 medium to large (25 m x 7 m, approximately 350 tonnes), potentially long-distance ships (Section 7.4.2).

To identify and elucidate natural and anthropogenic processes involved in the inception, evolution and eventual decline of the harbour and the port town that developed around it.

Despite the paucity of textual evidence describing the physical appearance of the harbour at Berenike and how it may have changed through time, the augering results have shown that a number of natural and environmental factors led to the silting up of the basin (Table 2.2). These factors can be roughly explained as a reduction in maintenance activities of the gradually infilling harbour, associated with the decline of the scale of trade and general deterioration of the economy. For example, local coastal changes such as coastal progradation, sea level change, wadi activation and flood periodicity would have re-configured and re-shaped the harbour(s), adding to the impacts of other factors operating within the wider economy. On a local scale, the silting up of the harbour may have been the result of a lack of trade traffic, and so Berenike gradually neglected the need for regular dredging, maybe as the smaller number of vessels could be accommodated in the outer, deeper areas of the harbour, allowing for the shallower areas to infill completely. This would have self-perpetuated the situation marking the beginning of the end for the operation of the harbour.

It is clear that flash precipitation events in the mountains would have had a significant impact on the site in the form of wadi activation (i.e. Facies F). Especially during the winter months or in wetter years, wadis would have discharged large quantities of sediment onto the coastal plain and to the site and its harbour. This would have hampered the navigability of the entrance to the harbour and necessitated dredging (see Section 5.1.3). The accumulation of windborne material from the coastal plains would have supplemented the infill of harbour basin, although probably in less significant quantities.

Local changes in climate and precipitation observed at Berenike were related to both monsoonal changes and the northward migration of the ITCZ, or the south and eastwards extension of Mediterranean cyclones. These resulted in warmer humid conditions with weaker winds or colder, drier conditions with stronger winds (see Section 2.3.2). Lastly, anthropogenic pressure and control over the natural port landscape in Berenike, undoubtedly played a significant part in the changes of the harbour(s), leaving its signature in the form of a preserved harbour floor (Facies E).

To identify the 'Parameters of Attractiveness' that were instrumental in choosing the site on which Berenike was developed; and to use them as a methodological framework that could ultimately be utilised to scrutinise other known ports and harbours; and as a predictive tool to locate areas with high potential for finding as yet unknown port cities.

The Red Sea region is hostile to long-shore nautical activity and lacks natural topographic features that could be used as harbours; with only a few suitable bays for landing, where the wadi mouths allow the break in the reef, are located on its coasts. The suite of variables outlined in Chapter 6 allowed the investigation of the rationale behind the location of ports, and the evaluation of whether they were related to landscape, cultural, economic or socio-political factors, or a combination thereof.

This pilot study determined the extent to which the landscape and physical environment and their changes through time, dictated initial site selection and the further development of a new port of trade of Berenike. It also sought to understand, more objectively, how ports, as hubs of socio-political interactions between different cultural groups, were designed to generate profit and prosperity.

This semi-quantitative pilot study appears to show that the decision behind the siting of Berenike in its location was not purely influenced by environmental factors and in fact its location probably owed much to many socio-political and economic variables. Whilst Berenike scores highly in terms of the excellent marine and political context of the site, it falls short with regards to aspects of the landscape setting. However, despite the sub-optimal landscape context the city did flourish for the best part of a millennium. This shows that political will and a well-connected location could be more influential than other fundamental considerations.

To provide information about the vessels that sailed on the Red Sea and Indian Ocean in the Greco-Roman period, which would have moored at Berenike.

The study of sailing vessels on the Red Sea was included in this research as it became clear that their construction methods and technological capabilities had a strong connection with the design and infrastructure of the harbour basin and the type of mooring apparatus and techniques used within it. This in-depth review allowed not only a better understanding of the extant nautical archaeological material from the Red Sea (Section 7.2), but also examined indirect evidence that may shed more light on the form of these vessels (Section 7.1). Importantly, this work provided a framework in which to propose a number of scenarios for the utilisation of different functional areas of Berenike's harbours and to calculate roughly the potential capacity of this port (Sections 7.3 and 7.4.2).

As summarised in Sections 7.1 and 7.2, available information from the Red Sea region presents a very interesting technological pattern in which a combination of both Mediterranean and Indian Ocean techniques were used in developing

'Red Sea' vessels. Although there are no clear patterns for this 'Red Sea' style, the Mediterranean techniques were mostly used in conjunction with Indian materials. Additionally, the huge diversity of shapes and sizes of the marine components discovered thus far demonstrates a high level of specialisation of maritime crafts at the site and in the region. As is discussed in the reconstructed scenarios (Section 7.3), the diversity of boat designs might have made the operation of the harbour more efficient as different parts of the inner and outer harbour would have been reserved for particular types of vessels, with smaller crafts in shallower waters and larger merchantmen anchored in deeper areas. The estimates of size and draughts of vessels as well as the potential size of the harbour in different chronological periods allowed calculating that maximum of 75 large ocean-going vessels could be moored at Berenike's harbour at any one time.

To re-evaluate and assess earlier scholarly interpretations using the new science-based approach

Only limited studies have ever attempted to elucidate the location, size and capacity of Berenike's harbour basins, and the natural processes involved in the inception, evolution and eventual decline of the harbour and the port town that developed around it.

During the course of this research a number of previous interpretations regarding Berenike have been re-examined. First, earlier reconstructions of the size and location of Berenike's harbour(s) were revisited and rectified based on the augerhole data. Then, the role of one of the main reef outcrops, the Crescent-shaped Ridge, which was interpreted as a harbour wharf with piers and quays, was shown to be incorrect as the data show that this was a natural feature far removed from the ancient water level. The augering results also allowed for new data to emerge providing clues regarding the location and nature of the *Temenos* of Temples.

Additionally, the existence of a potential 'Northern Anchorage' was re-assessed. Although the augering results from this part of the site have shown that this area was indeed submerged at some point in time, the prodigious accumulation of colluvium and the thickness of the deposits, relative to other parts of the site, suggest that this particular area ('the Niche') was dry land during both Hellenistic and Roman periods.

Moreover, the attractiveness of the location of an earlier Ptolemaic part of the town (Ptolemaic fort and Ptolemaic Industrial Zone), located towards the west, was reinterpreted in the light of potential environmental hazards to which it might have been exposed, and the changing function of the port.

Lastly, the role of the Southern Promontory and an associated tombolo were re-established, both as an ancient viewshed (with a potential beacon to guide vessels) and a breakwater against wave action enabling the sheltering of the bay. On the other hand, it also acted as an obstacle preventing the alluvial sediments deposited in the Lagoon from being washed out into the sea, leading to the silting up and ultimately decline in the usability of the harbour.

8.3. BERENIKE IN THE NETWORK OF INDO-MEDITERRANEAN TRADE

The results presented in this thesis clearly show that the seafaring culture of the Red Sea was a diachronic mixture of two types of traditions. On the one hand, we see strong influences of the long-standing, technologically advanced Mediterranean seafaring cultures. These seafarers and their vessels were accustomed to sailing in a well-connected basin with abundant attractive landing-spaces, sheltered havens and harbour infrastructure. On the other hand, Red Sea harbour designs have strong affinities with the Indian Ocean model, dependent upon seasonal winds and currents and sited almost entirely on the basis of the natural harbour location without further adaptation or modification. Additionally, the 'Red Sea vessels', although constructed in the Mediterranean tradition, were built using Indian and African materials.

In summary, this demonstrates that the political will of a Mediterranean Empire and the long tradition of using the Nile Valley and Red Sea as connectivity corridors for international trade (dating back to at least the Middle Kingdom) resulted in the adoption (or appropriation) of a Red Sea location that was transformed into a globally important and thriving port. This port used primarily Greco-Roman-influenced maritime technologies operating in what was more akin to an Indian Ocean-type harbour.

The provincial port of trade *Berenike Troglodytica* was located at the nexus of two diverse cultural spheres. Although the site was first a part of the Ptolemaic and subsequently the Roman Empire, and as such used a Roman administration and system of laws, it also catered for Indian, Arabian, African and Southeast Asian merchants, accommodated vessels from across the oceans, and housed peoples of various creeds, language groups and religious beliefs. As such, the town was not only a hub of trade and exchange designed to accommodate visitors and their vessels, but it was also a centre for cultural exchange and social diversity — a meeting point between different cultures located at the intersection of two environments, the sea and the desert.

The desire for very specific commodities imported from overseas shaped social, political, and religious institutions within this community, whilst the introduction of foreign materials and ideas transformed local traditions. In turn, trade networks, such as the one that connected the Mediterranean with the Indian Ocean in antiquity, facilitated the exchange of a diverse range of mundane and esoteric commodities and ideas, providing common trade goods and luxury items, and enhancing cultural understandings or perpetuating misunderstandings.

APPENDIX 1: DETAILED TRANSECT AND AUGERHOLE DESCRIPTIONS

The following sections take each sub-surface composite section in turn and describe it in terms of the overall picture it provides (see Section 3.4 for methodology). Detailed descriptions of the sequence encountered in each augerhole along with a graph showing the results of laboratory analyses are also provided.

TRANSECT BE11-T01

Overview

The north–south aligned transect BE11-T01 (Fig. 4.31) attained a total length of 190 m and comprised 10 augerholes (from the north): AH18, AH16, AH15, AH14, AH19, AH20, AH21, AH23, AH36, and AH37. The primary purpose of setting out this transect was to explore the inter-relationship between the archaeology recorded in trench BE11-71 and other parts of the Southwestern Embayment (SWE). AH18 was cored from the base of the archaeological trench to a total depth of 4.80 m, and so the record of AH18 also includes the profile exposed in this trench and the archaeology yielded from these sediments. From this known point, the transect continues through what is referred to later as a Central Zone of an SWE and around what is believed to be the western edge of an 'Island' on which the Temple of Lotuses is located (AH16–21). Towards the south, this transect enters a *sabkha* formation, dotted with vegetated nebkha (coppice dunes) mounds (AH22, 23); continuing through to a waterlogged, muddy, salt-crusted sabkha (AH36). The final auger-hole (AH37) is located in the intertidal zone.

Augerhole sequences

Augerhole 18

Augerhole 18 is located inside archaeological trench BE11-71. The whole sequence comprises two parts: i) a sedimentological column from the western end of the northern profile, and, ii) a core drilled from the base of this trench (Fig. A.1). These two parts of the augerhole together form one of the most insightful sequences recorded during the survey and as such will be described in some detail here.

A basal deposit (Facies I) was recorded from 510–415 cm below the ground level (bgl), comprising dark grey, fine silty sand (20–30% silt content). There is a general trend of decreasing MS, whilst other variables remain low and static.

Overlying these silt-rich sands, between 415–260 cm bgl (below ground level), a moderately homogenous, dark grey sand unit (Facies H), fining upwards from medium, through fine to very fine sand (at around 300–270 cm) was recorded.

An abrupt interface at 260 cm depth marks the base of Facies G. There is a marked change in the sedimentology at this time with a significant increase in grain size from fine to medium sands and a reduction in silt.

Another abrupt interface (230 cm bgl) denotes the base of pure sands (Facies M; Figs. 4.11 and 4.12), an increase in grain size from fine to medium sand was recorded alongside a very pronounced drop in finer-grained components (12 to 2% silt; and 1.2 to 0% clay). This has a positive correlation with increased MS values and a reduction in organic material.

The uppermost Facies revealed in the archaeological trench (F, E, D, C, B, A) are described below in AH17 and so left out of this section to reduce the amount of repetition.

Augerhole 16

Moving southwards, sediments recorded in AH16 (Fig. A.2) reveal a significant sequence within transect BE11-T01. Owing to its topographic location on the high ground (1.95 m above sea level – asl) AH16 achieved a total depth of 5.0 m. At the base of the sequence, notably black, moderately homogeneous fine sands and silts, with inclusions of water-abraded pebbles, are present from 505–395 cm bgl (Facies I).

Overlying Facies I sands, a 240 cm thick sand unit (Facies H) comprises consecutive accumulations (395–155 cm bgl) and can be divided into three sub-phases (1: 395–240 cm, 2: 240–185 cm, 3: 185–155 cm). The first phase comprises very dark grey, fine to medium sand containing ~30% silt with an abundance of grains of black, heavier minerals including manganese. Occasional inclusions of rounded, abraded pebbles have also been recorded. The base of this lower phase registers fining of grain size to fine sands. Variation in the grain size and the MS also occur around 185–260 cm (with two peaks of thicker fraction around 190 and 240 cm) and shows an inverse relationship especially around the 220 cm marker. It is noted, as well, that the 260 cm level has an increase of its clay content to 5% with an average content of silts at approximately 30%.

From 155–138 cm bgl a thin layer of dark blackish to dark olive brown, loose, fine sand (Facies G) was recorded. This marked a switch to various sedimentological parameters, with sharp increases (and subsequent decreases) in finer sediments (35% silts and 4.5% clays, maximum values). A prominent increase in MS is also evident in the data.

Facies E is an 8 cm thin layer of moderately compact, dark olive brown medium to coarse sand (with ~25% silt) located 138–130 cm bgl and with pottery fragments in a dissolved, water-abraded state.

Facies D in AH16 (~100–80 cm bgl) comprises a dark brown fine to medium sand. Decreases in grain size and in MS values inversely correlate with an increase of total organic and carbonate matter. The latter might be connected with a presence of microscopic (below 2 mm) fragments of the abovementioned pots that have been included during the analyses of sediments. Facies E can be therefore interpreted as an archaeological horizon (see Hypotheses section at the end of the chapter).

Above, brown medium sand (Facies C) has been observed between 98–28 cm bgl. It is compressed, with inclusions of heavier and darker minerals such as manganese. There is an inverse relation between increase of MS values and decrease of total organic and carbonate matter, along with a slight increase in grain size.

Towards the top, a very hard compacted light brownish grey layer of silt and sand with a lens of very compacted crystallised salt (Facies B) is located between 20–28 cm. This indicates evaporitic action in this phase (or storms that leave salt from sea-water on a surface?).

The uppermost 20 cm of the sequence contains very loose, orange coloured sand (Facies A) that is very poorly sorted with coarse and fine grains. The sands are heavily oxidised.

Augerhole 19 and 20

Augerholes 19 and 20 are located in close proximity and as it is possible to correlate horizons between these two sequences they will be described in tandem. These augerholes are located northwest from AH18, and up-slope from the temenos of temples. AH19 is located on 1.42 m asl with a depth of 160 cm and AH20 on 1.28 m asl with a depth of 155 cm (Fig A.3).

Recorded at the base of the augerholes, Facies G (Fig. 4.4) comprises moderately compact silty sand with occasional grains of coarser material. The colouration of the sands is dark grey to black. This Facies has a low organic content and so the dark colouration most likely relates to its anaerobic origin or possibly the presence of dark heavy minerals.

Overlying Facies G was a reddish to dark brown, rusty layer of medium silty sand with abraded and decayed pottery (Facies E) located between ~50–80 cm BGL.

Facies D is only observed in AH20 and exhibits a sudden decrease in MS values and total organic matter, as well as a pronounced increase in silt. This has not been observed at similar levels in either AH19 or AH16.

Facies C is characterised by an iron-stained and dark brown medium sand with ~30% silt content. It is moderately poorly sorted and includes small quantities of fine gravel. An increase in total organic matter and carbonate content was recorded along with an increase in grain size and a slight decrease in MS values. This may suggest a return to a stable landsurface with some input of colluvial material.

The most recent sedimentation, Facies O, comprises light grey, loose, poorly sorted, calcareous sand, with grains ranging in size from medium to very coarse. This layer shows a direct relationship between the increase in grain size and the total organic matter and is possibly picking up recent and sub-recent aeolian sedimentation.

Augerholes 36 and 37

Augerholes 36 and 37 are located to the south of the Temenos of Temples and due to their proximity to each other and the similar environmental conditions that they are located in they will be described together. These two augerholes are located at the edge of the *sabkha* with a more southerly augerhole (AH37) augered during the low tide in the area where the *sabkha* meets the intertidal zone. Both of these augerholes are shallow due to the very muddy and waterlogged character of sediment and the auger-head being incompatible with this wet material. However, AH36 located 0.78 m asl attained a depth of 20 cm below present sea level (BSL), whilst the top of AH37 was located 13 cm BSL with the base reaching to 130 cm BSL.

Facies K was recorded only in AH36 from 5 to 60 cm BSL and situated some 18 cm asl. It comprises a clean, pure, medium, dark grey beach sand with a very low silt and clay content. Whilst having a very high 80 m^3kg^{-1} MS value it observes a very low (to insignificant) level of total organic and carbonate matter.

Facies L (Fig. 4.10) is located below 18 cm asl in AH36 and comprises the whole observed part of the sequence at AH37. It consists of a very wet sandy deposit with a fairly high, starting from 40 m^3kg^{-1}, MS value that declines down the profile. The total organic and carbonate values remain very low. Described deposits seem to be a part of a tidal flat/*sabkha* and are under the constant pressure from the dynamic tidal environment.

TRANSECT BE11-T02

Overview

Transect BE11-T02 is north-south orientated and is running downslope from the mid-slope of the crescent-shaped ridge all the way to the bottom of the slope and the edge of the *sabkha* (Fig. 4.34). With a total length of 108 m it comprises 8 augerholes (from north): AH17, AH18, AH45, AH44, AH10, AH46, AH40, AH47. This transect focuses on connecting what was previously believed to be a part of harbour facilities ('jetties', Fig. 1.4 and 1.5) with the Central Zone of the SWE sheltered by crescent-shaped ridge.

Augerhole sequences

Augerhole 17

Augerhole 17 is located inside the Trench BE11-71 and shows similar sequence to this uncovered in AH18. This augerhole was located 2.84 m asl and reached the depth of 210 cm (Figs. A.4 and A.5).

The basal layers of the sequence, Facies G and M, (210 to roughly 180 cm bgl) comprise a fine to medium sands made up of interstratified and bedded/laminated dark and light-coloured, fine to medium pure sands (as on Figs. 4.9 and 4.16–18). A decrease in MS value is observed upwards which is in an inverse relationship with and increase of (still low) organic content. There are almost no carbonates in these layers.

Further on, compacted, pure, greenish clays of Facies F, that corresponds with the bottom deposits of the modern-day lagoon in transect BE12-T04, are observed. They comprise almost entirely fine fractions (65% silt and 10% clay) and deliver no MS signal. They also observe a very high organic (about 10%) and carbonate (about 30%) contents.

Then, a unit located around 180 cm bgl, believed to be associated with Facies E, is noted and comprises a very thin patches of oxidised, reddish to pinkish, baked clay. Fine fraction remains and this unit holds a high silt (50%) and clay (4%) content with an observable increase of MS value to about 24 m^3kg^{-1}. Fine grain size is in an inverse relationship with still high, however decreasing, organic (to

6%) and carbonate (15%) contents that occur due to the baked character of this deposit.

Overlying the hearths, thick beds of medium to coarse, light grey to brownish grey sands were recorded (Facies D). These units are dominated by very loose sands, but microstratified with more compact layers. The sands are very poorly sorted and dry, from fine silty sands, to coarser, sand-sized material with moderate frequencies of coral and shell fragments, and occasional archaeological material higher up in the sequence. The finer, oxidised layers interstratified within the sequence may indicate recurring drier intervals with a greater input of aeolian particles, hence the oxidised fine dune-like sands.

At the top of the sequence, from 68 cm upwards, lies loose, fine to medium silty sands (approximately 20% silt content) deposit (Facies C) with some coarse inclusions and archaeological material mixed in within the matrix. The top part of this deposit (22–4 cm) is composed of, amongst other inclusions described above, evaporated salt crystals (Facies B). The topmost context (Facies A) is very loose, oxidised, coarse windblown sand mixed in with fine to very fine aeolian fraction.

Augerholes 45 and 44

Augerholes 45 and 44 are both located approximately 20 m southeast from the trench BE11-71. AH45 was located at 1.42 m asl and reached a depth of 60 cm, whilst AH44 was located at 1.64 m asl with a depth of 60 cm. Both of these augerholes had two observed stratigraphic phases Facies B and C.

Augerhole 10

Augerhole 10 is located at 1.86 m asl and reached the depth of 510 cm (Fig. A.6). It is situated in the northwestern part of what is referred to SWE and at the break of the slope running down from the Crescent-shaped Ridge.

Facies I at the bottom of AH10 is dark greyish brown and waterlogged silty sand. Higher up, Facies H is very dark greenish grey unit of silty sands that are compressed and waterlogged. This Facies observes an increase in finer fraction content (30% of silt and about 3% of clay). As it will be seen along the whole sequence MS, organics and carbonate content values are very low and a scale of their changes seems to range at the error level.

A 165 cm long, fairly homogenous part of a sequence, Facies G (from 325–160 cm bgl) comprises black coloured medium sands and is heavily waterlogged. Grain size fines upwards along with a small increase in silt and clay contents and a decrease in organic and carbonate contents.

Further on, a short (160–135 cm bgl), greyish black to black deposit is located, supposedly intermittently with lenses with a higher silt content and a decrease in clay fraction, along with an almost total demise of organic and carbonate contents and comparatively high (within this sequence) MS value of approximately 14 m^3kg^{-1}.

Above, a very dark greyish brown, wettish sand of Facies M, of about 40 cm thickness (between 130–90 cm) is observed. It shows a low volume of silt, low MS value of about 8 m^3kg^{-1} and an insignificant organic and carbonate content (as mentioned above in underlying units).

Next unit, Facies E comprises compressed and wet, silty sand of a very dark greyish brown to rusty brown colour with inclusions of oxidised and manganese grains and some small gravel. It contains a concentration of broken and dissolved pots and some pieces of stones. It also shows a fairly low level of MS value along with fairly insignificant carbonate content, which is pointing towards it being an archaeological horizon.

A 40 cm thick layer, Facies P has a mixed character and is poorly sorted. It is composed of olive brown in colour, very wet and quite compressed unit with frequent inclusions of fine grains of heavier minerals and oxidised quartz grains as well as occasional gravel.

Then, Facies O is located between 30–6 cm bgl and consists of a mixture of finer fractions (silt and fine sand) and coarser sands. It is light grey, very loose and calcareous, with high content of heavier minerals, such as black manganised grains, mixed in with very occasional highly oxidised material.

A 6 cm from the surface Facies A can be recorded across the entirety of this part of the SWE and comprises a coarse loose sand, which is very oxidised, poorly sorted and has an orangy colour.

Augerhole 46

Augerhole 46 is located 16m south from AH10 near the break of the slope, in the triangle formed by the northern and western edges of the Crescent-shaped Ridge and some 50 m north from the edge of the *sabkha*, and about 65 m from the top of the ridge. It was situated at 0.89 m asl and reached the depth of 330 cm (Fig. A.7).

The bottom part of the sequence comprises a waterlogged silty sand of very dark grey colour, Facies H that stretches from 330–190 cm along 140 cm to the artificial bottom of this augerhole. The sand is mainly fine and is mixed with a silty fraction and some 4% of clay. The level of organics and carbonates is very low and at approximately 1–1.5% whilst values of around 20 m^3kg^{-1} are observed for MS.

Then, a 65 cm thick unit (Facies G) comprises wettish, dark greyish brown, fine sand is located between 190 and 120 cm bgl. It retains very low organic and carbonate value similarly to the underlying Unit 1 with MS values reaching up to 25 m^3kg^{-1}. Further on a thin, 10 cm thick, dark brown lens is located between 120–110 cm. It is silty sand that is observing a decrease in grain size and sand content towards the silt as well as a small increase in MS value.

Between 110 to 90 cm bgl Facies E is a thin, rusty to dark brown layer with frequent inclusions of broken and dissolved pots as well as shells and some gravel. It observes decrease in MS value whilst retaining insignificant total organic and carbonate content.

Facies P, above, comprises a wet and a bit sticky dark greyish brown fine to medium sand with some silt. Oxidised grains start becoming more present from here upwards. This unit is characterised by a fairly high (9%) ratio of total organic content and unchanged low value of total carbonates and MS (at around 10).

A 40 cm thick unit (Facies R), located between 75–35 cm bgl, has a quite wet character and dark greyish brown colour. MS, organic and carbonate values remain low and in a direct relationship.

Top 25 cm of the sequence comprises very loose, chalky, whiteish and calcareous fine sand with some silt (Facies O and N). It shows low MS, total organic and carbonate value, which point towards its evaporatic character.

Augerhole 40

Augerhole 40 is located 16 m to the south from AH46 and about 30 m north from the edge of the *sabkha*, with a base at 0.68 m asl and a bottom reached after 360 cm (Fig A.8). This augerhole reached almost 3 m BSL, and therefore it has been chosen as one of the important representatives of the deep sequence.

Downwards from around 213 cm bgl the core seems to be reaching into some sort of an underground stream (liquefaction?) within a matrix of Facies I. The augerhead goes down very easily and comes out clean and dripping with water. Between 213–170 cm very wet, waterlogged deposit of sand with some occasional gravel is observed.

Further on Facies H and G comprise medium sand with silt that is compressed and also very wet. They also observe a low (comparably to overlying) MS value.

Upwards, a 20 cm thick (between 106–82 cm) unit is characterised by dark reddish grey to dark brown (described above as rusty brown) medium sands with approximately 30% of silt content and some clay (about 3%). This Facies E contains dissolved pottery. It is fairly loose and the MS value increases at the very bottom of this layer pointing towards some level of stabilisation. It corresponds with other similar units of Facies E across the site confirming a widespread horizon of archaeological importance with broken and dissolved pottery.

Above, Facies R that comprises loose, compressed, beach like sand is located between 82 and 7 cm bgl. It consists of a medium sand (over 85% of it) with a low silt and clay content. It also observes a minor decrease of MS value to 15 m^3kg^{-1} inversely related to an increase in organic and carbonates contents (6% and 4% respectively).

An exposed layer on a surface (Facies N), from 7 to 0 cm bgl, comprises a fairly compressed but friable, calcareous, chalky sandy silt with about 6% of clay content. This whitish deposit is composed of very fine fractions and has a low MS value of 5 m^3kg^{-1} that is in an inverse relationship to high organic content (about 12%) and some 5% of carbonate content.

Augerhole 47

Augerhole 47 has quite a shallow sequence, located 15 m south from AH46 and near the edge of the SWE and the beginning of the *sabkha*. This augerhole starts at 0.57 m asl and reaches 115 cm depth.

From the bottom of this augerhole, Facies G, a black and wet silty sand deposit was observed until 95 cm bgl. This deposit comprised mainly medium sand with approximately 30% of silt and very little clay. It shows an increase in MS values to around 16 m^3kg^{-1} and an increase in organics to 6% with carbonates at about 4%. Then, a 27 cm thick deposit (Facies E between 95–68 cm) comprises a rusty brown layer with dissolved and broken pots.

Above, Facies R consists of fine sand with some 15% of silt. This level is a dark greyish brown deposit with a low organic and carbonate content and is located between 68–52 cm below. Then, an almost 20 cm thick layer of fine to medium sand of a brownish colour is located between 52–33 cm. It represents a decrease in MS values to around 12 m^3kg^{-1} and slight increase in organic and carbonate content.

Lastly, Facies S, located from 33–0 cm bgl, comprises poorly sorted, light olive to light yellowish brown, loose sand, mainly medium to coarse with inclusions of some broken pieces of shell.

TRANSECT BE11-T03

Overview

Transect BE11–T03 is northeast–southwest orientated and is running upslope from the mid-slope of the Crescent-shaped Ridge where the Trench BE11–71 with AH18 and AH17 is located (Fig. 4.35). It then climbs up a slope of the crescent-shaped ridge in the area of AH54, reaching its peak at AH52 and sloping down towards the alluvial fan of the wadi in AH53. With a total length of 182 m it comprises 7 augerholes (from northeast): AH18, AH11, AH46, AH41, AH54, AH52, AH63.

This transect shows connection between the braided wadi alluvial fan, to the south from the Crescent-shaped Ridge ('outside' it), the ridge itself, and the area of Central Zone of the SWE that is guarded by the ridge. The importance of understanding of the depositional processes that occur on both sides of the ridge — one towards the mountains (winds) and wadis (fluvial inundation), and one open to the activity of sea waves, tides and sea-winds — is undeniable. Therefore, different sedimentological inputs and modes of deposition that are resulting in complex sedimentological structure with diverse sources of material are studied in this transect.

Augerhole sequences

Augerhole 11

Augerhole 11 drilled from 1.66 m asl is 240 cm deep (Fig. A.9) is located in the vicinity of AH10 (16 m to the west), AH12 (12 m to the east) and AH18 (40 m towards northeast). The shortest distance to the Crescent-shaped Ridge, 64 m, is to the west and AH11 is located on a slope.

A thick, very dark grey, non-homogenous unit, Facies H, of about 110 cm spans from 240–130 cm bgl. Firstly, the very bottom part of this deposit is a waterlogged medium silty sand of a black colour (240–180 cm). It records decreased MS value of 15 m^3kg^{-1}, fairly low organic content (which is increasing upwards up to 4%) and a low carbonate content (approximately 1.5%).

Then, next part of the sequence (180–155 cm), is characterised by a slight increase in grain size and almost total disappearance of clay. It is waterlogged and includes not only heavy minerals such as manganese but also oxidised and white (quartz) crystals. Further on (155–130 cm), this deposit observes an increase in quantity of finer fractions (approximately 20% of silt and 3% of clay) with a slight increase of MS values and carbonate content.

Medium dark brown silty sand (Facies G) includes some small broken pieces of pots (different in preservation to those from Facies E described below) and an increased MS level up to approximately 28 m^3kg^{-1}.

Above, only 4 cm thick white layer of chalk (Facies N) is located between 104–100 cm and it is very calcareous. No laboratory analyses could have been performed on this layer as it was extremely hard to obtain a sufficient sample size.

Fine, dark to olive brown, silty sand (approximately 30% of silt) is located between 100–55 cm bgl. This deposit is compressed and waterlogged. It has numerous inclusions in form of organic material (approximately 6%) such as charcoal and dissolved and broken pots (Facies E). Decrease in MS signal can be observed along with an increase in carbonate content.

Poorly sorted, light grey, fine and coarse sands (with a predominance of the latter) are located between 55–5 cm within Facies P and B. Inclusions of broken shells, broken pieces of coral, pieces of chalk and granules of salt along with manganese and oxidised grains have been observed. This unit shows a rapid decrease in the quantity of finer fractions as well as lower MS level of 16 m^3kg^{-1} that are inversely related to an increase of organic content (up to 10%). Carbonates form approximately 3% of this deposit.

The top Facies A is a poorly sorted fine and coarse, highly oxidised material that is located between 5–0 cm and is a windblown material.

Augerhole 41

Augerhole 41 is situated downslope some 55–60 m from the northwestern corner of the Crescent-shaped Ridge; it is also approximately 45 m to the north from the edge of the *sabkha* and in the middle of the circle of some 20–22 m diameter formed around it by AH40, 47, 42 and 46. This augerhole was located 0.88 m asl and reached a total depth of 268 cm. It repeats the sequence of AH40 with Facies (from the top): N, O, P, R, E, G, and therefore its detailed description will be omitted to save repetitions.

Augerhole 54

Augerhole 54 is located on top of the Crescent-shaped Ridge and at its southeasternmost end. This hole was located 1.45 m asl and achieved a total depth of 102 cm. Three major sedimentary Facies have been distinguished (from the top): S, R, and P.

Augerhole 52

Augerhole 52 is located downslope approximately in the middle of the western side of the slope of the Crescent-shaped Ridge (outside of the embayment). This augerhole has been located 0.75 m asl and has reached a total depth of 51 cm. Only one unit (Facies P) was distinguished in this augerhole due to its modest depth.

Augerhole 53

Augerhole 53 is located at the bottom of the slope of the western side of the Crescent-shaped Ridge and in the middle of one of the infilled channels/mud ponds that are part of the wadi alluvial fan. It has been locate at 0.36 m asl and reached a total depth of 102 cm with Facies (from the top): T, B, P and G.

TRANSECT BE11-T04

Overview

This northeast–southwest orientated shallow transect attained a total length of 172 m. It runs downslope and comprises 7 augerholes, all of them very shallow (max. depth apart from AH37 and AH36, which are described above, is AH33 – 62 cm deep). This transect runs along the eastern edge of the Temenos of Temple and includes: AH29, AH31, AH32, AH33, AH34, AH36, AH37 (Fig. 4.36).

Augerhole sequences

Augerholes 31 to 34

Located in each other's vicinity — AH31–34 — mostly comprise olive to light olive brown silty sand to fine sand, loose deposits. They are highly oxidised and include a fair amount of transparent orangy quartz grains and some heavier materials such as manganese (weathered from nearby basalts mountains?). Deposits around 50 cm asl become wetter and stickier whilst retaining their sedimentological character.

Augerholes 29, 31, 32

Augerholes 29, 31 and 32 create 47 m long sloping sequence located between 1.8–1.25 m asl of very shallow surface deposits (up to 27 cm depth). They include approximately 0–3 cm on the top of coarser, loose, light grey sand with inclusions of frequent shells, corals and pots. Below up to the depth of approximately 27 cm another very loose layer is located comprising fine sand to silt mixed in with coarser material. This context, very common across the embayment is very light grey, a little oxidised and with inclusions of gravel (Facies U).

Augerhole 33

Augerhole 33 was located 1.37 m asl and reached a total depth of 62 cm. It was divided into three sedimentological Units: Facies U, N, and K.

Augerhole 34

Augerhole 34 is situated at the northern edge of the area with the *nebkha* mounds and some 30 m north from the AH36 and the edge of the *sabkha*. It is located at 0.98 m asl and has reached a total depth of 50 cm. This augerhole can be divided into two fairly distinctive layers: Facies N (chalky surface) and sandy Facies K.

TRANSECT BE11-T05

Overview

Transect BE11-T05 has a total length of 303 m and lies on a west–east axis (Fig. 3.5). It comprises 23 augerholes: AH1–7, AH9, AH8, AH 10–14, AH25–30, AH48–50 and shows a sloping down sequence of augerholes – to the north (AH18, AH16, AH15, AH14); along the western edge of the Temenos of Temples (AH19, AH20, AH21, AH22, AH23); and then reaching the *sabkha* area (AH36) all the way to its meeting point with the tidal zone (AH37).

The fifth transect turns out to be the most important for the understanding of the underground profile of the embayment and the relationship of natural deposits with the uncovered archaeology on both sides of the ridge (to its southwest and on the northeastern side of the SWE. It therefore connects the Ptolemaic Industrial Zone on the western side of the Crescent-shaped Ridge, SWE and the late Roman remains on top of the city-tell.

Augerhole sequences

Augerhole 1

Augerhole 1 is located on the western side of the crescent-shaped ridge in the vicinity of the 'Dog's burial' in trenches BE10-63 and BE10-65 and Ptolemaic Industrial Zone with trenches BE00-40 and BE01-45. These trenches are all clearly dated to the Ptolemaic period on basis of ceramic typologies. It also lays approximately 60 m to the east from a massive wall (Context 039) that possibly demarcated the limits of the Industrial Zone. This augerhole was located 1.76 m asl, is 122 cm deep and comprises four main stratigraphic units (Fig. A.10).

Facies V is composed of a pale brown fine silty sand with approximately 5% of clay content. Laboratory analyses show that the MS level ranges around 10 m^3kg^{-1} whilst organics take up approximately 5 % of the volume of this deposit. There is also a high carbonate content of approximately 11%. Between 90–78 cm bgl clay content rises to approximately 6%, whilst MS value decreases to 5 m^3kg^{-1} and is in an inverse relationship with the carbonate content that rises to a very high 18%. Organic content remains at the level of approximately 5.5%. Between 78–64 cm bgl it is still very pale brown fine silty sand with approximately 5% of clay content. A small rise in MS value can be observed reaching 7.5 m^3kg^{-1} with a drop of carbonate content to approximately 10%.

Above, Facies W is located between 64 cm and the surface. It comprises medium to fine silty sands (approximately 15% of silt) with very low (approximately 1–1.5%) clay content. The MS value rises comparatively to the Facies V and continues rising upwards along the sequence reaching 27 m^3kg^{-1} at 15 cm depth. The total organic value rises at the bottom of this deposit to 7% and the consequently drops back to approximately 5–5.5% value. The carbonate value is really low and stays at approximately 2% throughout the surface.

Augerhole 4

Augerhole 4 (A+B) is located on the top of the Crescent-shaped Ridge at 4.51 m asl. The sequence is formed by: a part of the northern section of the BE09–55 trench with a total depth of 110 cm, and then by the core drilled through from the bottom of this trench with a depth of 280 cm (Fig. A.11).

Bottom 40 cm (until it collapsed) comprised olive brown deposit between 365–325 cm bgl. It is possibly Facies P (Fig. 4.16) that is a looseish fine silty (26%) sand, wet and a little sticky (2% of clay). This layer contains manganese grains inclusions as well as occasional small and large angular pebbles of high sphericity. Its MS value ranges between 10 to 12.5 m^3kg^{-1} and is in a direct relationship with total organic and carbonate contents that are at approximately 6–2% and 3–1% respectively.

What is believed to resemble Facies C (from 'inside' of the SWE) comprises approximately 65 cm of dark to lighter yellowish brown deposit between 325 and 260 cm bgl. It is mainly medium silty (20–24%) sand that is loose but a little sticky (2% clay). Its MS value decreases to approximately 7 m^3kg^{-1} in conjunction with a decrease of total organics to approximately 2.5% and carbonates staying at the 1% (error range) level.

Above, a unit that is similar to Facies B (from the 'inner' side; Fig. 4.2) is characterised mainly by its chalky and calcareous character and light brownish grey to light grey colour. It is located between 260–190 cm bgl and is quite loose with occasional tiny crystals of salt and a few grains of manganese. The sediment is of a medium to fine grain size and comprises silty (36–37%) sand with some 3% of clay. The MS value decreases to 5 and then to 3 m^3kg^{-1} at the top of the unit, whilst total organic and carbonate contents increase to 8% and 3% respectively.

Further on, an archaeological unit Facies AI, consists of fine silty (38–45%) sands and sandy silts with clay content of approximately 4–6% of dark yellowish brown colour located between 190 and 145 cm. This level includes some broken pottery sherds and other archaeological material such as fragments of charcoal. The MS value rises dramatically at its bottom to 16 m^3kg^{-1} and then decreases to approximately 8 m^3kg^{-1}. Total organic matter stays at 7% value whilst total carbonate is about 3%.

Then, an archaeological Facies AH is a little less silty (32%) medium to fine sand with some 3% of clay content situated between 145 and 85 cm bgl. It consists mainly of fines, with moderate amount of chalk, manganese grains and gravel as well as occasional shells. The MS value is a little higher than below and ranges around 7.5 m^3kg^{-1} with total organic content decreasing to some 6% and carbonates increasing to 5-6%. It is interpreted as an archaeological layer, which directly correlates with layers described by Rądkowska (2011) in her Trench BE09-55 report where she refers to a 'fairly sandy yellowish-brown locus' 025 between 100 and 85 cm bgl and which belongs to her Phase I.

Facies AG is again based on Rądkowska's (2011) interpretation and it is 'an olive brown sand' (context 015 and 016) with 'piles of fist-sized cobbles scattered within layers 010 and 021. This correlates with Rądkowska's Phase II situated between 85–55 cm bgl.

Facies AF is based on Rądkowska's (2011) report and it corresponds with 'pale brown sand locus 009, approximately 0.3 m thick and the superimposed and more widespread light brown sand loci 003–004/002 (about 0.35 m)

Augerhole 5

Augerhole 5 is located in the vicinity (approximately 19 m to the east of AH4) and at the break of the slope towards the SWE. It was located at 3.49 m asl and reached 198 cm depth. No samples have been chosen for analyses as they all relate to archaeological layers deposited on top of the Crescent-shaped Ridge rather than natural sediment aggradation. However, the major stratigraphic units (Facies A, AC, D, E, AD) could have been distinguished throughout the sequence (Facies D on Fig. 4.3).

Augerhole 6–8

Augerholes 6, 7, and 8 are located further towards the east on the transect BE11-T05 and in their character are similar to AH9 and AH10. AH6 is located 2.82 m asl with 172 cm depth and with five distinctive stratigraphic units (Facies: A, AC, E, AD, and AE). AH7 lays at 2.19 m asl and is 185 cm deep representing four stratigraphic units (A, AF, E, and G), whilst AH8 is situated at 2.02 m asl with 142 cm depth and further four stratigraphic units (Facies A, P, E and G).

Augerhole 9

AH9 is located in the small depression, at the bottom of the slope of the Crescent-shaped Ridge and between AH7 and AH8 respectively 5 m and 3 m apart on west–east axis. It is located at 1.69 m asl and is 230 cm deep (Fig. A.12).

Bottom deposit (Facies H; Fig. 4.5) comprises a 1 m thick deposit of bluish black, medium to coarse, waterlogged sand located between 230 and 132 cm bgl. Inclusions of organic fragments as well as pottery sherds have been noted throughout the sequence. Silt content varies along this sequence from 5% at the bottom through 20–22% across and decreasing at the top to approximately 8–9%. A similar pattern is followed by clay content however this ranges between 1.5–3%. Variation in MS value seems to be in direct relation with fining of grains and from approximately 10 it raises to 13.5 and then drops back to 11 m^3kg^{-1}.

Organic content forms approximately 3–5% and carbonate content approximately 1–2.5% of the layer. This unit seems to be one of the bottom (earliest) archaeological deposits that can possibly be indirectly related to Trenches BE11-71 and BE11-72.

Then, a waterlogged, compressed, very dark greyish brown, medium silty (23%) sand, which resembles Facies G is noted. The MS value increases to around 13 m^3kg^{-1} with a lower organic content of approximately 3.5% and carbonate content of 2.5%.

Above, a rusty layer of decayed Hellenistic pots (Roberta Tomber, *pers. comm.*; Facies E) is observed and is comparable with that recorded across the site.

Then, Facies P consists of medium silty (27%) sand, dark olive brown, wet sand situated between 105 and 22 cm. Increase of quantity of finer fractions is directly related to the increase in organics content (up to 5.5%). MS value remains at around 13 m^3kg^{-1}.

Top part of the sequence is occupied by Facies O that comprises fine to medium, light grey to very pale brown silty sand that is calcareous and seems to be windblown. Top-most part is Facies A is a windblown orangy coarse sand.

Augerhole 13

Augerhole 13 is located in the middle of the SWE, west and just a little south from trenches BE11-71 and BE11-72. It was located at 1.79 m asl and reached a depth of 214 cm, after which it collapsed (Fig. A.13). Bottom part of the sequence with Facies H is located between 214 and 116 cm and comprises medium to fine, jet black, silty (22–25%) sands with some 2.5% of clay. Organic content ranges at around 4% whilst MS values between 12 and 14 m^3kg^{-1}.

In AH13 Facies G comprises fine, dark brown, very wet and compressed, silty (35%) sand with some 3.5% of clay and is located between 116 and 95 cm bgl. MS value increases to 19 m^3kg^{-1} in relation with the rise of organic matter to 7% and carbonate content to 3%. Above Facies G a rusty layer with dissolved pots, Facies E, can be observed.

Further a fine to medium, olive brown, wet and a little compressed, silty (20–22%) sand that resembles Facies P is noted. A decrease in fine grains quantity corresponds with a slight decrease in MS values to approximately 16 m^3kg^{-1}, decrease of carbonate content to 1% (error range) and an increase of total organic matter to approximately 10%.

Top part of the sequence between 40 and 3 cm bgl is formed by coarse sand (only 8% of silt and traces of clay) that is very loose and light grey (Facies O; Fig. 4.15). It is highly organic (approximately 14%) but has a low MS value of 7 m^3kg^{-1}. Facies A is situated top-most and is a windblown, coarse, highly oxidised and poorly sorted sand observed between 2 cm below a surface.

Augerhole 26

Augerhole 26 is located 60 m to the north from the Temple of Lotuses and 30 m to the east from the Trench BE11-71. The conditions allowed for obtaining only a very short sequence located 2.32 m asl of 62 cm depth and with two stratigraphic units.

The sequence starts from the bottom with Facies O, which is very loose, medium, light grey silty (20%) sand with some coarser grains mixed in the matrix, along with some gravel located between 62–25 cm bgl. MS value of approximately 14 m^3kg^{-1} was observed along with 4% of organic content and some 1.5% of carbonate content.

Facies A is very loose, poorly sorted, light brownish grey coarse sand (with some 10% of silt). It is located between 25 cm below the surface and shows exactly the same values of MS, organic and carbonates content as an underlying context, which is in reverse relation to the decrease in finer grains.

Augerhole 49 and 50

Both AH49 and AH50 are located on the city-tell and represent archaeological, settlement type, deposits. The sedimentological analyses have been carried out on 3 samples from AH49 to create a comparative dataset of signals for this kind, densely packed with archaeological material and organic remains archaeological layer. AH49 is located on 3.38 m asl and is 85 cm deep whilst AH50 was situated on 3.45 m asl and is 75 cm deep.

An archaeological layer named Facies AB is located between 85–44 cm and comprises medium size, dark brown, silty (26–28%) sand with some 2–2.5% of clay content. MS value ranges around 11 m^3kg^{-1} with organic content being approximately 8–9.5% and pointing towards a really high density of refuse or domestic goods within the samples. High carbonate content of 10–12% indicates presence of pottery fragments or burning residue in the sample.

It is followed above by another archaeological layer, Facies AA, that consists of fine, pale brown, silty (27%) sand and some 3% of clay located between 45 cm and a surface. MS value decreases to approximately 9 m^3kg^{-1} whilst both organic and carbonate content raise to 11.5% and 14% respectively pointing towards even higher density of archaeological materials.

TRANSECT BE11-T06

Overview

Transect BE11-T06 (Fig. 4.38) attained a total length of 256 m and was aligned on west-east axis. It is parallel to the transect BE11-T05 (Fig. 4.38) and comprises 9 augerholes: AH43-38, AH20, AH32, and AH51. The main purpose of this transect was to explore the inter-relationship between archaeology recorded in the trench BE13-91 that is located in what is currently believed to be the South Arabian quarters of the Roman town and where one of the houses was excavated (BE13-91).

From this archaeologically known point, the transect continues towards the southwest and passes just east from the edge of a Temenos of Temples (in the vicinity of trenches BE13-89, BE13-92 and BE13-94). Towards the southwest, this transect continues across the eastern part of the SWE and then follows upslope to end at the very edge of the slope of the Crescent-shaped Ridge.

Augerhole sequences

Augerholes 43 and 42

Both of these augerholes are located at the eastern side of the slope of the Crescent-shaped Ridge at its southwestern-most extent. AH42, at 1.38 m asl, reaches 110 cm, whilst AH43, at 1.93 m asl, was cored to a total depth of 126 cm.

The bottom deposit (Facies AL) could be a burnt layer, of very fine to coarse character, and with high quantity of fine fraction (40% silt and 5% clay), some decayed wood and pieces of pottery. It is located between 126–78 cm and is jet black. It has a MS level of approximately 14 m^3kg^{-1} and a high organic content of approximately 10–15% with carbonates forming 5–7% of a layer.

Facies P above is compressed, friable, brown, medium to coarse silty (12–24%) sand. The MS value remains around 12–14 m^3kg^{-1} whilst organics at approximately 8%. Carbonate content slightly decreases to 5–3%. Further, Facies B comprises loose, fine to medium silty (20%) sand with 5% of clay. It also includes some coarse granules and orangy quartz grains as well as some coarse translucent particles, broken pottery fragments and occasional salt concretions. The MS value remains at around 13 m^3kg^{-1} whilst organics and carbonates stay without a change from the previous layer.

At the top of the sequence Facies A is a windblown, poorly sorted coarse sandy layer of high MS value of 18 m^3kg^{-1} and a very low organic and carbonate content that is seen across the site.

Augerhole 39

AH39 is located approximately in the middle of the Central Zone, in the vicinity of the intersection of 4 transects: BE11-T01–03 and BE11-T06. It was located on 0.68 m asl and has reached 184 cm.

Bottom deposit, Facies H, is a 44 cm thick layer that seems to have a large quantity of salt concretions making it really hard to core through. It is fine to medium silty (20%) sand with a MS value at approximately 15 m^3kg^{-1} and organic and carbonate matter ranging at 5% and 1.5% respectively.

Above, Facies G comprises medium to fine silty (25–30%) sand that is wet and compressed and has inclusions of frequent granules. The MS value rises to approximately 25 m^3kg^{-1} with organic content remaining constant at approximately 4% level and carbonate content slightly increasing from 1 to 3%.

Then it changes into a medium, compressed, wet, black, silty (20%) sand that occupies level between 95–70 cm bgl. The MS value rapidly decreases to approximately 5 m^3kg^{-1}, whilst carbonate content increases to approximately 3%. The organic value remains constant.

The distinctive Facies E is of a rusty, reddish brown colour with decayed pots, and can be observed across the site. In AH39 it is located approximately between 70–50 cm.

Facies R is a beach like sand, brown, loose, with fine to medium median grain size and a very sandy matrix (only approximately 5% of silt and 2.5% of clay). The MS value ranges at around 15 m^3kg^{-1}, whilst organic value decreases to approximately 6% and carbonate to 3%.

The top part of the sequence, Facies N is compressed, white, chalky calcareous silty layer (45% silt, 6% clay) of a very low 5 m^3kg^{-1} MS value and very high organics and carbonates quantity (12% and 5%).

Augerhole 51

Augerhole 51 is located at the western edge of the Roman town, just below the slope, and south from AH49 and AH50. It was located on 0.95 m asl and reached 110 cm depth.

Bottom deposit, Facies X, is a clayey (4%), grey, medium silty (30%) sand located between 110 and 92 cm. The MS value ranges around 15 m^3kg^{-1} with organics at approximately 4% and a really high (11%) carbonate content.

Facies R, located above, comprises medium to fine, compressed, very dark brown to black, silty (18%) sand. The decrease of the finer fraction coincides with a decrease in carbonate content to approximately 3% and a rapid increase of

MS value to 35 m^3kg^{-1} (at a lower part) and 20 m^3kg^{-1} higher up in the sequence. The level of organics remains at approximately 3.5–4%.

Further on, Facies P observes a compressed, fine silty (22%) sand of very dark greyish brown colour. It consists of some quite angular gravel, and occasional yellowish quartz grains. It lies between 64 and 46 cm and laboratory analyses show a slight decrease of MS value to approximately 16 m^3kg^{-1}, a rise of organic value to approximately 5% and a constant in carbonate content.

Towards the top, Facies B is a loose, medium to coarse sand (low, approximately 10% level of silt) that is calcareous, and includes some salt concretions. The MS value decreases along with the coarsening of the sequence and a slight decrease of carbonate content to approximately 1.5% but shows an inverse relation to organic matter that rises to a high value of 12%. The top-most deposit, Facies A, is windblown, poorly sorted, light coloured, coarse sand observed across the site.

TRANSECT BE12-T01

Overview

Transect BE12-T01 (Fig. 4.39) is a 106 m long north-south aligned transect that crosses the 'Niche' above the 'Northern Anchorage' along its axis. This transect starts at the top of the ruins in the northeastern part of the Roman town, continuing northwards from the town down into the bottom of 'the Niche', through the thin sand bar, and far into the sabkha area.

This transect was aimed at giving an insight into the sedimentological history of the so-called 'Northern Anchorage', determining whether it could have possibly been flooded/underwater contemporaneously with the surrounding occupation, as well as whether it could have really been used as an anchorage – with a connection to the open sea or through some sort of a channel. Transect BE12-T01 was almost directly superimposed over BE95-T09 that was cored by Harrell in order to compare the methodology and results with his earlier surveys.

Augerhole sequences

Augerhole 2

AH2 is located at the bottom of the slope coming down towards the north from the city-tell. It was located some 2.12 m asl and has reached a depth of 480 cm (Figs. A.4 and A.5).

The bottom of the sequence is very dark grey to black waterlogged deposit (Facies F; Fig. 4.22) of medium to fine silty (25–28%) sand with some clay (2%) located between 480–305 cm bgl. It has an insignificant MS value that is in an inverse relationship with the carbonate content that ranges around 16–20%. Organics comprise approximately 4% of the volume of this deposit. Coring through this deposit was very hard and crunching noises could be heard. The colour and composition seem to suggest deeper water and an anaerobic environment of deposition.

Further on, another dark, bluish black to dark navy blue layer, Facies E. of fine to very fine silty (32–35%) sand with some 2.5% of clay content. It has frequent inclusions of broken shell fragments and very coarse granules of translucent quartz. It has an insignificant value of MS and its organic matter stays constant in comparison with an underlying Facies F at the level of 4% whilst the carbonate content continues at the level of 11–14%. Fine fraction, bluish colour and low MS value point towards a dynamic, anaerobic environment.

Above, between 210 and 185 cm Facies D is located. The colour becomes darker, almost black, whilst all other readings remain the same as in underlying Facies: fine to very fine, wet, silty sand, low MS value, organics at around 5% and carbonated at approximately 12%.

Further along the sequence three colluvial deposits are located: Facies B, C and A. Facies B is a post-anthropogenic layer of fine to medium, reddish brown silty sand to sand and with a MS values increasing to about 14–18 m^3kg^{-1} whilst organic and carbonate contents decreasing up to about 1–2%. Between 65 and 58 cm a white, very loose layer of chalky material has its organic content increasing to approximately 10% whilst MS slightly declines. Carbonate content remains insignificant.

The top-most part of the sequence is Facies A that is coarse, orangy sand mixed with frequent grains of finer fractions and of increased MS value. Organic and carbonate contents are insignificant.

Augerhole 13

AH13 is located just a little south (towards inside of 'the Niche') on the edge of an uplifted narrow sandbank that closes so-called 'Northern Anchorage'. It was located at 1.89 m asl and has reached the depth of 450 cm (Figs. A.16 and A.17).

Bottom-most Facies F is located between 450–340 cm bgl. It is bluish black fine waterlogged silty sand with inclusions of complete and fragmented shells. The colour and inclusions indicate its marine origin.

Above it, Facies E is situated between 340–210 cm and is represented by fine to very fine waterlogged silty sands with some 2.5% of clay. The MS value remains at the insignificant level of 2 m^3kg^{-1}, whilst organic and carbonates contents range between 7–5% and 15–25% respectively and are decreasing upwards.

Facies D that occupies the area between 210 and 175 cm bgl shows continued falling of organic and carbonate values to 2% and 5–1% respectively. It is dark grey, wet, compressed, silty (35%) sand with frequent manganese grains, fragments of shell, and some small lumps of calcified microfauna. This indicates a shallow marine environment of deposition.

Further on, a transitional, yellowish layer is located. It comprises calcified silty sand located between 175 and 135 cm bgl. The presence of shells subsides at this level whilst the occurrence of heavier minerals such as manganese becomes more visible.

From approximately 135 cm bgl colluvial post-anthropogenic material, Facies B, continuous all the way to 40 cm. Below this level windblown material, Facies A, is more present.

Augerhole 16

Augerhole 16 is located at the edge of *sabkha* some 20 m north from the narrow sandbank closing 'the Niche'. AH16 as well as located some 25 m to the north of it AH17 show totally different sedimentological sequences to augerholes cored 'inside the bay'. The top of AH16 is at 1.23 m asl and it reaches the depth of 265 cm (Fig. A.19).

The bottom-most deposit (Facies L) is a very light, very clean, light greenish grey fine, wet, silty sand with approximately 3% of clay content and it is located between 265 and 145 cm bgl. As a Facies of anaerobic origin described above in AH2 and AH13 (Facies F, E, D) it has an insignificant MS value whilst high organic and carbonate contents (respectively 8% and 22%).

Further up, Facies K is a grey, compressed, fine, sandy (40%) silt with approximately 9% of clay. It shows inclusions of heavier, darker minerals such as manganese as well as calcified lumps (microfauna) and fragmented shells. The MS value remains insignificant indicating unstable environment. Organic and carbonate contents decrease to 2–3% and 8–12% respectively.

Facies K is overlain by Facies D that is a clean, grey to bluish, fine silty sand with some 3% of clay and some occasional inclusions of pebbles and heavier minerals such as manganese. It observes a rapid increase of MS value to 16 m^3kg^{-1} that is in an inverse relationship to the continuing decrease of organic and carbonate content to approximately 2%.

Further on, between 80–55 cm bgl, Facies J is located. This unit is loose, fine silty sand with a peak of MS value of 20 m^3kg^{-1} at around 78 cm. The organic and carbonate volumes remain insignificant.

Above, Facies C is located between 55–30 cm bgl. It is a compressed silty sand of reddish brown to rusty colour with some clay and with inclusions of some decayed pots.

Facies I that is a coarse to medium, whitish silty (17%) sand with inclusions of some crystallised salt and clean, washed white sand. It is, most probably, a part of a beach deposit that has a fairly low carbonate and MS values at the same time observing a peak in total organic mater volume that ranges at approximately 25%.

Augerhole 17

Augerhole 17 is located on the *sabkha* area approximately 25 m north from the AH16. It was located at 1.10 m asl and reached the depth of 230 cm (Fig. A.20). It was divided into five major Facies from the bottom upwards: L, K, D and J. Those retain same qualities as in AH16. Facies C is very loose, very oxidised, reddish to orangy medium to coarse sand with manganese and calcified lumps inclusions. Comparably with AH16 its top-most unit Facies I is missing from the

AH17 and this is most probably caused by the change in the topography of the terrain and moving deeper into the *sabkha* area.

TRANSECTS BE12-T02 AND BE12-T03

Overview

Transect BE12–T02 (Fig. 4.40) is east–west aligned and perpendicular to transect BE12–T01. It runs across the top of 'the Niche', and connects it to the ruins on the slopes to the east and west. Transect BE12–T03 is also perpendicular to BE12–T01 and at the same time parallel to the BE12–T02 and located to its north, however covering only a short distance on the western side of BE12–T01 (Fig. 4.41).

Sequences presented in both of these transects could be divided into 3 major groups of Facies. Group 1 including Facies F, E and D that are connected with marine/backwater/lagoonal and anaerobic environment; Group 2 including Facies M, H and G that are transitional layers connected with washed-in ferruginous wadi material; and finally Group 3 including Facies B, C and A that are mostly colluvial and windblown post-anthropogenic or modern deposits.

TRANSECT BE12-04

Overview

The fourth transect cored during the 2012 campaign was aimed at extending — over-the-water — the transect BE11–T01 that had to be stopped at AH37 in a tidal area due to waterlogging even at the low tide. It was also designed to deliver a corpus of comparative modern analogue samples to relate the current natural sedimentation with possible ancient lagoon deposits that were obtained from the SWE. This transect comprises 4 augerholes (BE12–AH21–25) and was located across the southeastern part of the bay and in the vicinity (on the southwestern corner) of the 'Southern Promontory'.

Augerhole sequences

Augerholes 21–25

These four augerholes have revealed 4 major sedimentological Facies that have been analysed in a laboratory. Apart from the uppermost *sabkha* deposit, all of the remaining Facies are fine grained, with extremely low MS, high carbonate content (from 30–35%) and approximately 5–9% organic matter.

The basal layers comprise very fine silt with some clay-rich, light grey deposits that have accumulated during the siltation process. Above this a more clayey deposit is located.

Third Facies is a pure green clay (BE11, Facies F) that was also uncovered in AH17, AH18 and AH21 this could be the evidence for one of the most recent flash flood events.

Topmost deposit (BE11, Facies L) comprises thin layer of *sabkha* sedimentation that was only observed in AH21 (the easternmost one).

APPENDIX 2

Appendix 2 contains selected raw quantitative laboratory data presented in tabulated form. These data are provided so that if ever the dataset needs to be revisited then future researchers can do so without bias from subjective interpretations. The data displayed here were generated from the analysis of the key variables and, for the sake of brevity, is not an exhaustive list.

Sample nr	AH nr & bag nr	Depth (cm)	Median grain size (µm)	Sand content (%)	Silt content (%)	Clay content (%)	Magnetic susceptibility	Total organics	Total carbonates
BE11									
2	AH1B-2	20	257.189	82.579261	15.494142	1.926596	26.90247253	4.894384338	2.897990726
3	AH1bB-3	38	311.012	87.162704	11.677277	1.160018	15.75530587	4.790686015	1.615463889
5	AH1B-5	64	393.616	84.320791	13.933603	1.745606	12.01506591	6.964512424	2.681216371
6	AH1B-6	78	240.992	69.229678	25.520554	5.249768	5.978723404	5.560366602	10.44598398
7	AH1B-7	90	330.116	72.295665	21.423911	6.280425	4.970457903	5.820969481	19.82102778
8	AH1B-8	104	251.844	69.300442	26.232858	4.466698	9.713235294	5.428191096	11.46280136
18	AH4-1	30	260.108	65.004336	32.104091	2.89157	8.125	6.403154633	5.163834382
19	AH4-3	45	199.659	68.057544	29.040731	2.901723	9.589442815	5.968628146	3.766394895
20	AH4-4	70	164.889	47.507271	46.817653	5.675076	7.331499312	7.995881949	3.050407992
21	AH4-6	90	160.724	48.100955	46.657794	5.24125	7.21340388	7.735758077	4.580836261
22	AH4-7	105	179.626	54.754192	41.390172	3.855637	14.4015444	7.253697567	3.434898569
23	AH4-8	110	153.351	57.814647	39.725727	2.459625	3.301075269	8.900445765	2.724120852
26	AH4-11	150	264.751	60.306782	36.027306	3.665909	6.666666667	6.670058941	2.968239834
27	AH4-12	180	314.195	80.8155	17.628635	1.555865	15.99350046	4.627101595	0.826268142
28	AH4-13	210	280.572	83.291305	15.00482	1.703875	6.722037652	2.862868594	1.022044088
29	AH4-14	250	148.963	70.633851	27.362573	2.003576	10.5292172	3.343916074	1.207812824
30	AH4-15	265	220.801	71.227078	26.750304	2.022618	12.00421941	5.261719284	2.733360667
48	AH9-1	80	313.985	70.180514	27.142329	2.677157	12.76410256	4.756787736	1.970055162
49	AH9-2	120	276.504	72.785163	25.014015	2.200823	13.23057432	3.146415751	2.991406505

50	AH9-3	140	359.258	81.021365	17.582762	1.39587	11.86746988	3.033908388	2.082093992
51	AH9-4	150	322.439	81.340101	17.107932	1.551968	12.23904382	2.739260612	3.397532542
52	AH9	160	326.857	77.662629	20.02095	2.316422	12.13035871	4.813879612	1.764817681
53	AH9-7	180	305.435	77.524628	20.427699	2.047674	11.45311049	3.199983746	22.85702676
54	AH9	200	268.487	74.824803	22.820987	2.354209	13.26635514	4.722821833	1.42325118
55	AH9-9	225	459.169	81.879495	16.573525	1.546979	10.95744681	5.13043857	2.177605505
56	AH10-1	70	263.553	69.273761	27.874526	2.851712	10.01626016	3.889267694	4.63657439
57	AH10-2	110	386.627	79.483972	18.654922	1.861107	14.98207885	2.980950008	3.171223413
58	AH10-3	135	301.899	77.483956	20.053596	2.462449	20.88235294	2.49774014	3.5682002
59	AH10-4	150	219.69	70.80385	25.406793	3.789359	17.71452846	2.078151838	1.490452922
61	AH10-6?	235	331.652	82.764374	15.276473	1.959153	11.96982759	2.721607529	2.225613633
62	AH10	280	367.769	86.831846	11.754536	1.413616	15.26196929	2.950545187	2.960754686
63	AH10-8	335	181.217	62.789711	33.904401	3.305891	7.514619883	2.747759068	4.467900924
65	AH10-10	385	242.292	63.029994	33.754126	3.21588	5.520446097	3.541757761	5.309513399
66	AH10-12	400	259.83	71.997966	25.214335	2.7877	15.084246	3.389793273	1.443353325
68	AH10-14	430	148.728	68.185176	30.201027	1.613798	4.888663968	3.946230119	7.486524256
69	AH10-15	450	280.271	65.58208	32.074621	2.343298	3.539387309	4.438185879	5.826939885
70	AH10	492	380.959	76.386348	21.758772	1.854879	13.31390135	3.938426993	2.807439715
71	AH10	500	437.559	73.95466	23.903973	2.141369	9.032634033	5.339148744	3.443526171
72	AH11-1	20	449.34	84.772761	13.723327	1.503913	17.58241758	9.779614325	3.443526171
73	AH11-2	70	279.039	67.934567	30.10379	1.961642	22.29185727	4.47284345	3.993610224
74	AH11-3	80	213.535	66.930017	30.6963	2.373683	19.34485896	3.386004515	3.611738149

75	AH11-4	110	273.74	71.619418	25.812009	2.568571	28.6075407	2.777777778	2.777777778
76	AH11-5	150	267.686	76.521492	20.93164	2.546868	21.12831858	1.576182137	2.626970228
77	AH11-6	160	320.399	79.15142	19.481633	1.366946	20.04712535	1.803607214	2.004008016
78	AH11-7	185	273.653	77.988516	19.83984	2.171645	19.6698523	4.202586207	1.400862069
79	AH11-8	200	296.37	76.747245	20.897168	2.355589	18.78029079	2.067669173	1.503759398
80	AH11-9	220	221.087	70.359904	27.035329	2.604769	15.32846715	1.843817787	1.409978308
85	AH13-1	20	661.285	91.307647	8.128975	0.563378	7.974413646	13.23279367	1.910992829
86	AH13-2	60	312.138	77.996629	20.048084	1.955289	15.75112108	8.362629168	1.388445013
87	AH13-3	70	331.576	74.347519	23.048275	2.604205	15.92627599	9.284097436	2.172370688
89	AH13-4	110	201.217	59.566263	36.687643	3.746095	18.19299905	5.599057584	2.866514217
90	AH13-5	160	266.561	72.122198	26.050343	1.827459		3.788573174	1.482548412
91	AH13-6	170	210.53	71.781626	25.761741	2.456631	13.59750668	4.213752938	0.987023603
92	AH13-7	190	317.398	71.23569	25.962564	2.801747	11.9800995	3.811289135	1.190869157
93	AH13-8	210	393.753	74.59298	22.57012	2.8369	13.51375333	3.831168831	1.258594347
97	AH16	75	318.004	72.213283	25.299819	2.486899	14.5473251	3.749292238	3.640973881
98	AH16	105	289.503	68.189872	28.842765	2.967363	11.24043716	4.292541636	4.935553946
99	AH16	120	177.166	59.054723	37.648076	3.297199	9.324324324	5.877917848	7.259183304
100	AH16	130	385.698	72.330858	25.38339	2.285753	6.238761239	5.962725291	7.375111302
101	AH16	135	455.033	69.299167	28.399196	2.301639	8.238416988		
102	AH16	140	168.899	63.724081	32.964019	3.3119	7.5	2.378940966	3.450140236
103	AH16	160	378.338	68.87559	27.916675	3.207735	11.33130081	2.73308958	2.751371115
104	AH16	170	185.195	66.250893	29.800574	3.948531	18.23022312	1.58479606	2.14042177

106	AH16	190	321.002	76.900576	20.244178	2.855246	7.682926829	1.02712596	2.046056765
108	AH16	220	205.828	66.201762	29.062516	4.735724	4.858156028	1.110218392	2.859542765
110	AH16	240	172.145	66.57984	29.891985	3.528172	7.425409047	1.56128025	3.074521107
112	AH16	260	163.618	65.874832	30.453528	3.671639	8.721037998	1.571377553	2.860296744
114	AH16	290	259.157	66.430354	30.011244	3.558402	10.50755034	1.713076713	3.368140868
116	AH16	335	305.545	72.172353	25.112688	2.714956	12.12415541	2.115162871	2.915105218
118	AH16	370	N/A	N/A	N/A	N/A	10.87209302	1.678455473	2.919179035
120	AH16	405	N/A	N/A	N/A	N/A	10.97247706	1.666538963	2.501724006
122	AH16	450	N/A	N/A	N/A	N/A	8.431855501	1.786304995	3.274892491
123	AH16	470	N/A	N/A	N/A	N/A	9.184641933	1.693483212	2.270222614
124	AH16	500	N/A	N/A	N/A	N/A	11.67238422	0.901847842	1.435809035
126	AH17-1	20	387.157	77.263583	21.102154	1.634264	12.7251462	0.857142857	10.57142857
127	AH17-2	26	317.138	74.465542	23.941509	1.592948	18.03834808	4.700854701	5.128205128
128	AH17-3	38	236.976	73.511442	24.632795	1.855764	18.30199765	4.104477612	2.611940299
129	AH17-4	56	491.877	92.832272	6.906555	0.261171	29.70380195	2.793296089	1.675977654
130	AH17-5	80	341.374	80.643315	17.540113	1.816575	20.80882353	5.774278215	3.149606299
131	AH17-6	120	485.041	98.302416	1.697584	0	38.54624085	0.886524823	0.602836879
132	AH17-7	172	497.22	97.879817	2.120183	0	38.22075209	0.654450262	0.654450262
133	AH17-8	184	246.312	99.810228	0.18977	0	27.36032389	1.382488479	0.460829493
134	AH17-9	188	333.274	97.865622	2.134375	0	36.11919612	1.556420233	0.194552529
135	AH17-10	134	399.235	97.941545	2.058456	0	30.48459564	1.224489796	0.408163265
137	AH17-12	186	295.605	100	0	0	36.66976456	0.308641975	0.617283951

138	AH17-13	190	381.563	98.90344	1.09656	0	55.86604361	0.62305296	0.62305296
139	AH17-14	180	246.298	46.842595	49.916918	3.240488	13.66197183	3.21888412	2.789699571
142	Ah17-14/15	180	252.123	53.956485	43.552214	2.4913	21.62973223	5.303030303	14.24242424
143	AH18-1	20	340.843	97.307841	2.692161	0	31.76809211	0.711743772	0.355871886
144	AH18-2	50	271.325	88.006553	11.625948	0.3675	30.89411765	0.754716981	0.566037736
145	AH18-3	85	216.598	82.087149	16.743401	1.169451	28.10993976	0.704225352	0.528169014
146	AH18-4	100	255.416	78.717611	20.10383	1.17856	28.13829787	1.222493888	0.855745721
149	AH18-5	120	168.726	76.843705	22.018153	1.138143	22.17247098	1.704545455	0.568181818
150	AH18-6	150	140.116	67.765115	30.510426	1.724457	17.93927126	0.837988827	1.25698324
151	AH18-7	170	143.005	65.102092	33.038877	1.859032	18.79454132	1.219512195	1.341463415
152	AH18-8	190	161.051	68.654774	29.6754	1.669826	18.50294365	1.617250674	0.808625337
153	AH18-9	220	173.132	68.04495	30.171868	1.783183	19.8241206	1.179941003	1.327433628
154	AH18-10	250	260.956	71.827325	26.691216	1.481459	18.54530341	1.369863014	1.643835616
155	AH18-11	280	182.261	71.099873	27.454686	1.44544	17.14869281	1.126760563	2.253521127
156	AH18-12	300	211.74	70.34379	28.104495	1.551711	21.72193878	1.142857143	0.857142857
157	AH18-13	325	218.103	70.311029	27.938207	1.750765	17.12707182	1.630434783	1.630434783
158	AH18-14	355	238.32	76.59986	22.01957	1.38057	25.15771028	0.995024876	0.870646766
159	AH18-15	380	195.48	69.453843	28.883172	1.662985	27.5173439	1.428571429	0.714285714
160	AH19	80	412.345	74.967757	21.261879	3.770364	11.11566018	3.233246301	4.027415144
161	AH19	95	340.078	66.333179	30.142665	3.524154	12.06286837	4.549505983	3.366141359
162	AH19	150	195.772	65.174883	31.742736	3.082382	14.3172043	5.727670206	2.598376015
163	AH20	50	182.075	59.611935	36.344134	4.043931	16.12719752	7.460729253	1.750434758
164	AH20	70	227.4	62.598194	33.933614	3.468195	15.22590361	8.77762834	2.116375263

165	AH20	90	218.067	58.9137	38.022428	3.063871	6.847389558	6.398257849	5.236823685
166	AH20	110	403.115	67.560713	29.897796	2.541487	10.28037383	8.263405344	6.153663036
167	AH20	120	228.256	62.743767	34.696533	2.5597	11.52152152	8.034483691	4.499635165
174	AH26	20	552.988	88.482282	10.305139	1.212579	14.25337187	4.199148215	1.359866504
175	AH26	45	395.512	78.140752	20.034784	1.824462	13.59657948	4.463166487	1.338075387
187	AH36	30	314.246	94.709648	4.736471	0.553882	76.54273504	2.212421547	0.622773645
188	AH36	60	252.796	85.901468	11.706117	2.392416	41.148	3.165031961	1.423358609
189	AH37	40	284.587	93.635163	5.604301	0.760535	34.47132616	4.173753032	0.574344105
190	AH37	60	279.88	89.05787	9.19117	1.750961	22.34293194	5.055980096	1.47799301
191	AH37	110	289.394	89.873882	8.476323	1.649793	20.07507508	3.854179087	1.442708954
195	AH39	6	176.86	51.215372	42.99183	5.792799	6.609271523	12.73518132	5.332921525
196	AH39	40	293.382	84.742726	12.704318	2.552954	14.09536542	5.169319691	3.23956464
197	AH39	60	456.794	88.998613	9.130424	1.870961	9.982378855	2.059945654	3.14001043
198	AH39	85	335.171	76.874042	20.738137	2.387822	6.139674379	3.918320868	3.907968633
200	AH39	110	240.814	66.489691	30.815887	2.69442	16.37737478	5.005527419	2.318944906
201	AH39	120	287.171	71.759096	26.158502	2.082402	18.40503247	4.01075411	1.652783287
202	AH39	130	333.414	71.961263	25.5959	2.442838	26.19929453	3.765746449	0.928513995
203	AH39	145	407.19	78.318978	19.735986	1.945035	18.76576577	4.768359071	1.579824464
204	AH39	170	288.426	77.783153	20.171535	2.045312	15.85638298	5.191517708	1.654268902
207	AH40B	90	288.905	67.600787	30.080681	2.318533	13.32278481	6.457057302	2.561589765
208	AH40B	110	279.087	69.901975	27.910629	2.187396	21.28215121	7.023670935	2.771120089
210	AH40B	145	224.279	70.554697	27.378498	2.066803	14.48415922	4.60630965	1.756362672

211	AH40B	165	282.41	70.400036	26.731249	2.868716	12.38834217	3.817240408	2.274745987
212	AH40B	180	320.825	71.14179	26.070624	2.787588	11.64984472	3.331368568	2.290043007
213	AH40B	260	306.804	72.191625	25.245771	2.562605	14.86535662	4.087213242	2.644952086
214	AH41	5	88.453	20.852956	73.185748	5.961298	3.458333333	4.547906552	1.369351425
215	AH41	65	275.548	73.539705	23.748911	2.711382	13.09024613	10.06397928	5.137967579
216	AH41	85	210.705	64.256068	32.820002	2.923928	16.08118361	8.027020138	1.506500127
218	AH41	130	211.65	66.623993	30.770822	2.605184	18.44551282	16.1521358	2.013939368
219	AH41	150	330.214	75.835372	22.266223	1.898405	16.11111111	6.077225392	1.729688922
220	AH41	175	287.56	72.930754	24.689025	2.380219	16.91915228	3.407767482	1.248164464
221	AH41	185	209.443	70.857373	26.36655	2.776076	15.10368664	7.956199889	2.358152029
222	AH41	205	257.155	71.001959	26.396412	2.601628	15.55316092	3.61567103	2.416692036
223	AH41	225	224.388	72.368279	25.119115	2.512608	13.6504065	4.026280998	2.103281119
224	AH42	15	490.239	73.857792	22.012597	4.129611	13.21505376	11.65803109	4.398120255
225	AH42	45	728.128	86.977943	11.524552	1.497505	12.66666667	9.695621634	4.521189417
226	AH42	70	366.664	71.332866	26.152336	2.514796	14.03345725	9.910995279	6.4122738
227	AH42	80	532.637	69.601275	27.903406	2.49532	13.37748344	15.22750704	6.982640921
228	AH42	110	165.832	54.419761	41.17525	4.404991	14.1875	10.31324662	5.791522874
229	AH43	4	726.98	96.17613	3.322801	0.50107	17.6614011	1.628359834	2.528404299
236	AH46	25	215.874	77.10296	20.186564	2.710475	12.4408284	3.528680242	1.873154049
237	AH46	55	315.878	77.852072	19.959451	2.188476	16.39224138	3.923509943	2.014087296
238	AH46	75	259.232	78.807605	19.777949	1.414445	13.63313008	8.92201498	1.362167719
239	AH46	95	243.8	76.205246	21.79285	2.001905	18.48063973	1.71623369	0.746444105

240	AH46	105	200.524	71.833561	25.087634	3.078805	38.33956619	1.43067649	0.806430007
242	AH46	130	220.253	77.43698	20.299682	2.263337	22.52983294	1.2776264	1.27459885
244	AH46	175	221.412	83.17257	15.194689	1.632741	30.67424242	1.701013034	0.978319185
245	AH46	205	294.315	71.868187	25.626509	2.505303	24.05674847	2.773059939	2.102955254
246	AH46	220	214.279	72.812895	24.895398	2.291707	20.20650264	3.160040775	1.489845527
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248	AH46	280	202.821	81.680756	16.740465	1.578777	30.79749104	3.013038549	0.72845805
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189	AH19	330	174.853	61.787292	35.324395	2.888314	3.689591078	4.027119752	12.15079235
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198	AH20	180	138.487	50.727796	46.126644	3.14556	15.45918367	4.129355038	1.087626437
201	AH20	200	282.083	57.998447	38.0721	3.929454	6.163655685	5.19235389	1.369298878
205	AH20	240	173.865	54.098808	42.685132	3.216062	1.622103387	3.371055148	8.065030284
207	AH20	260	258.524	58.572603	38.47949	2.947906	0.657298277	3.000744602	8.469843634
211	AH20	340	395.886	72.954997	25.339399	1.705604	0.727186312	3.351573187	14.66740766
S6	AH21	50	211.221	56.44442	37.528631	6.026947	1.071800208	6.502751691	32.3111464
S10 - 1	AH25	100	216.884	65.703562	30.72554	3.570899	0.159728945	4.837172115	35.20403456
S10 - 2	AH25	125	346.262	68.871861	27.934448	3.193691	0.123885035	5.193903528	35.20018514
S10 - 3	AH25	340	154.731	30.448138	60.433599	9.118263	0.262276786	8.923739416	29.64008263

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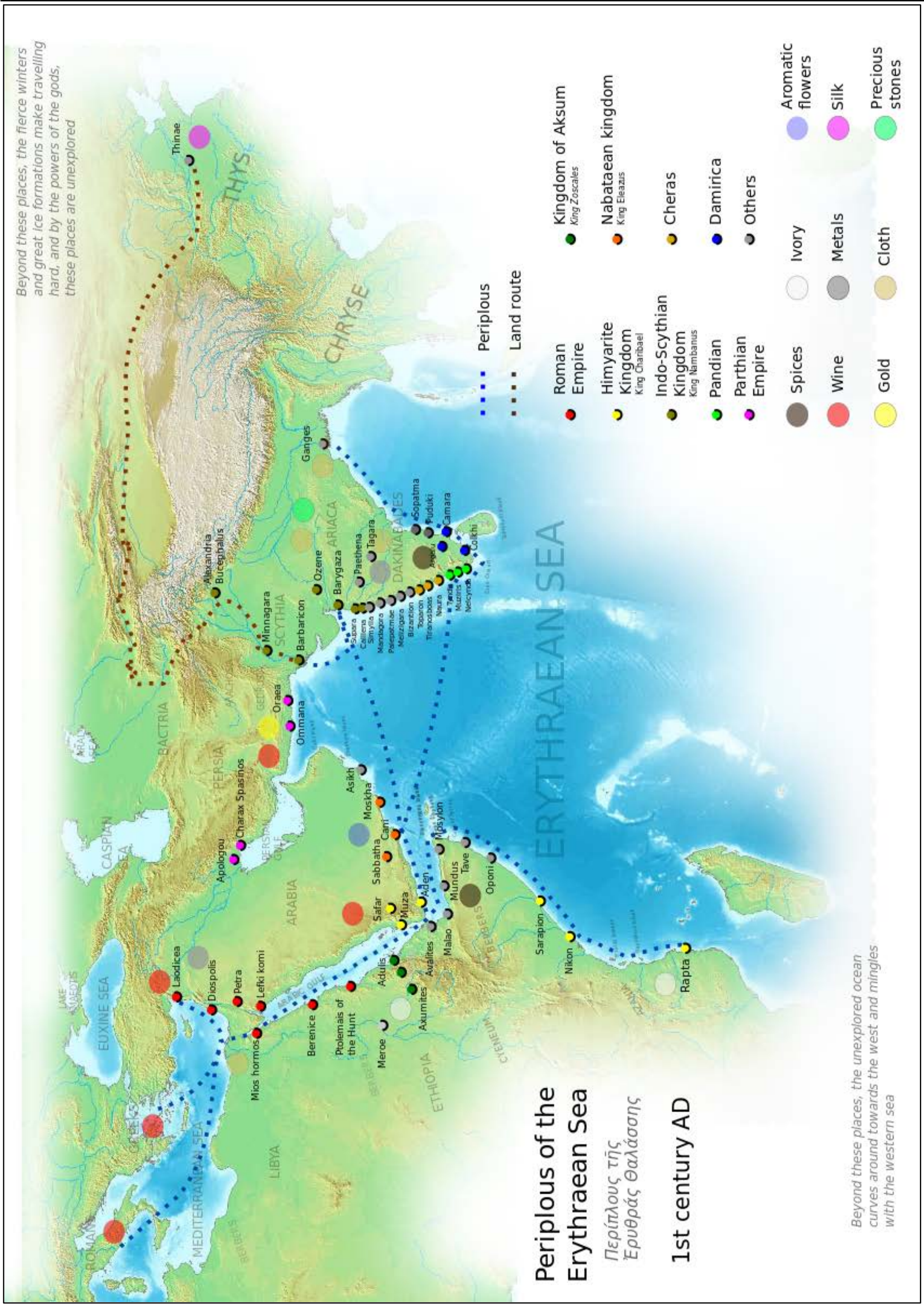


Figure 1.1 Map of the 'old world' in the times of *Peripus Maris Erythraei* (Source: Wikipedia http://en.wikipedia.org/wiki/Periplus_of_the_Erythraean_Sea#; Drawn by: George Tsiagalakis / CC-BY-SA-4 licence).

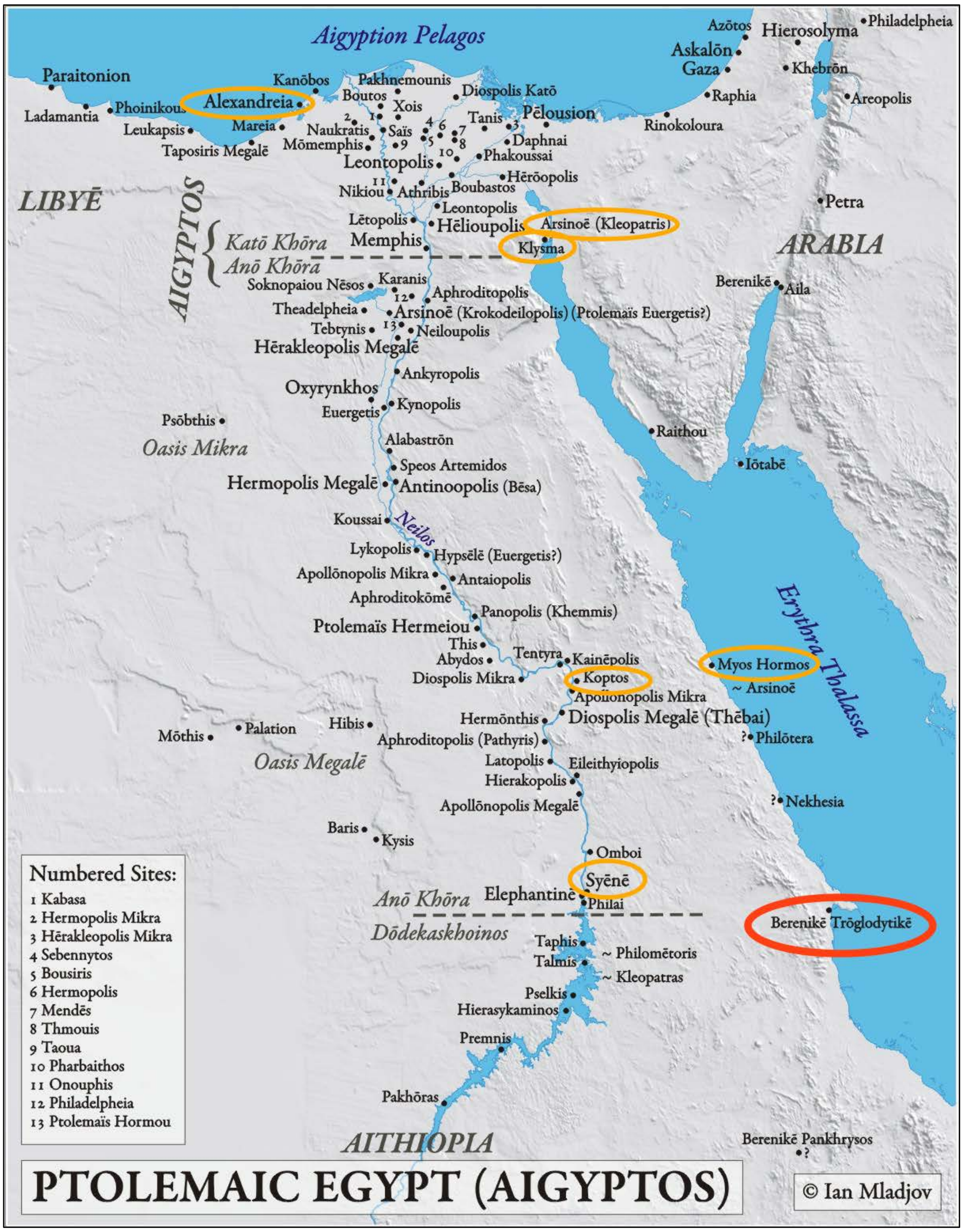


Figure 1.2 Map of the Ptolemaic (and Roman) Egypt with locations of cities. *Berenike Troglodytica* encircled in red and cities with which it was connected in orange (Source: Department of History, University of Michigan, http://sitemaker.umich.edu/mladjov/maps&; Drawn by: Ian Mladjov; Modified by: AM Kotarba-Morley).

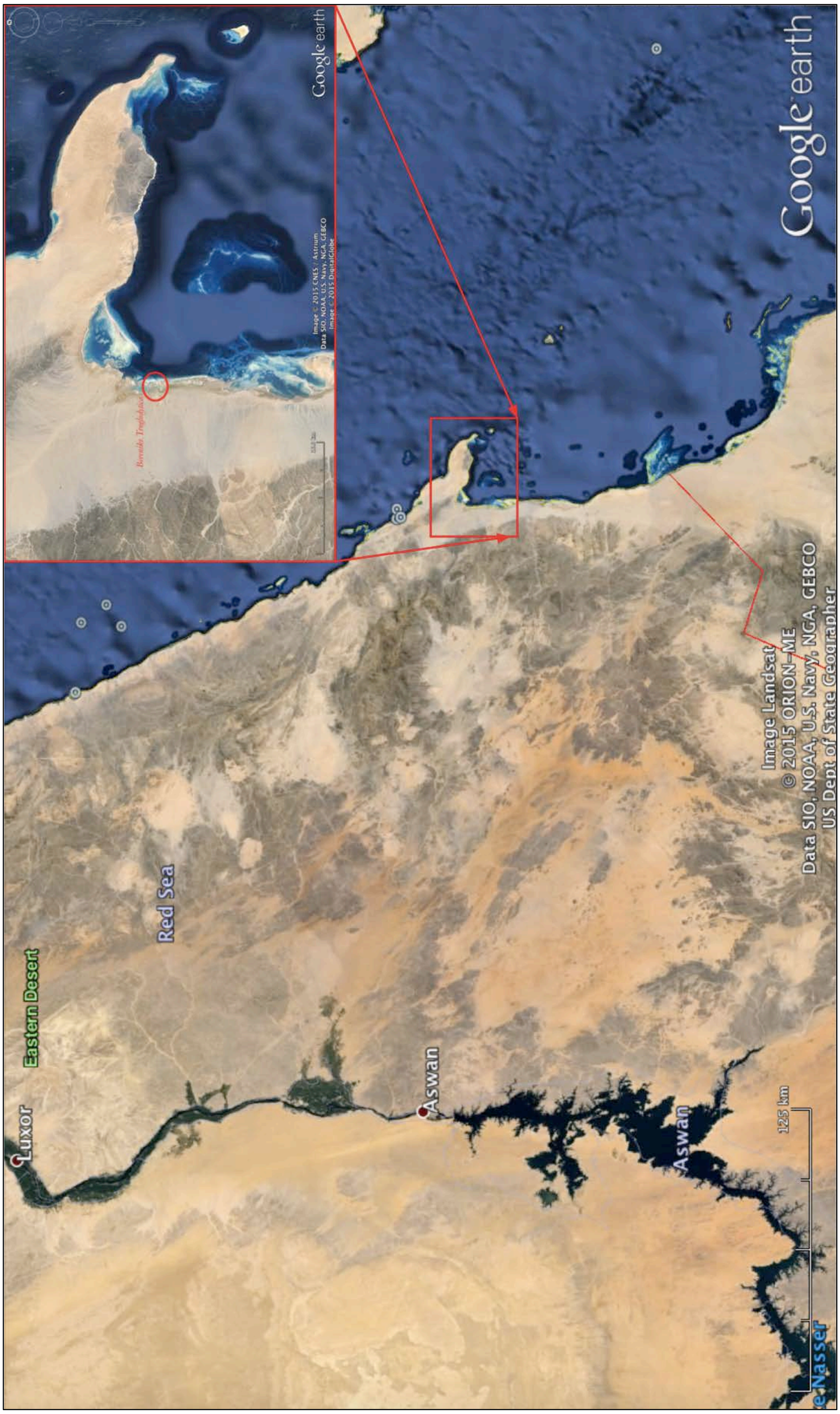


Figure 1.3 Location map of *Berenike Troglodytica* showing the Red Sea coast, the Eastern Desert and part of the Nile Valley. In the inset Berenike,the Fouls Bay and the Ras Benas Peninsula (Source of image: Google Earth 2015; Drawn by AM Kotarba-Morley).

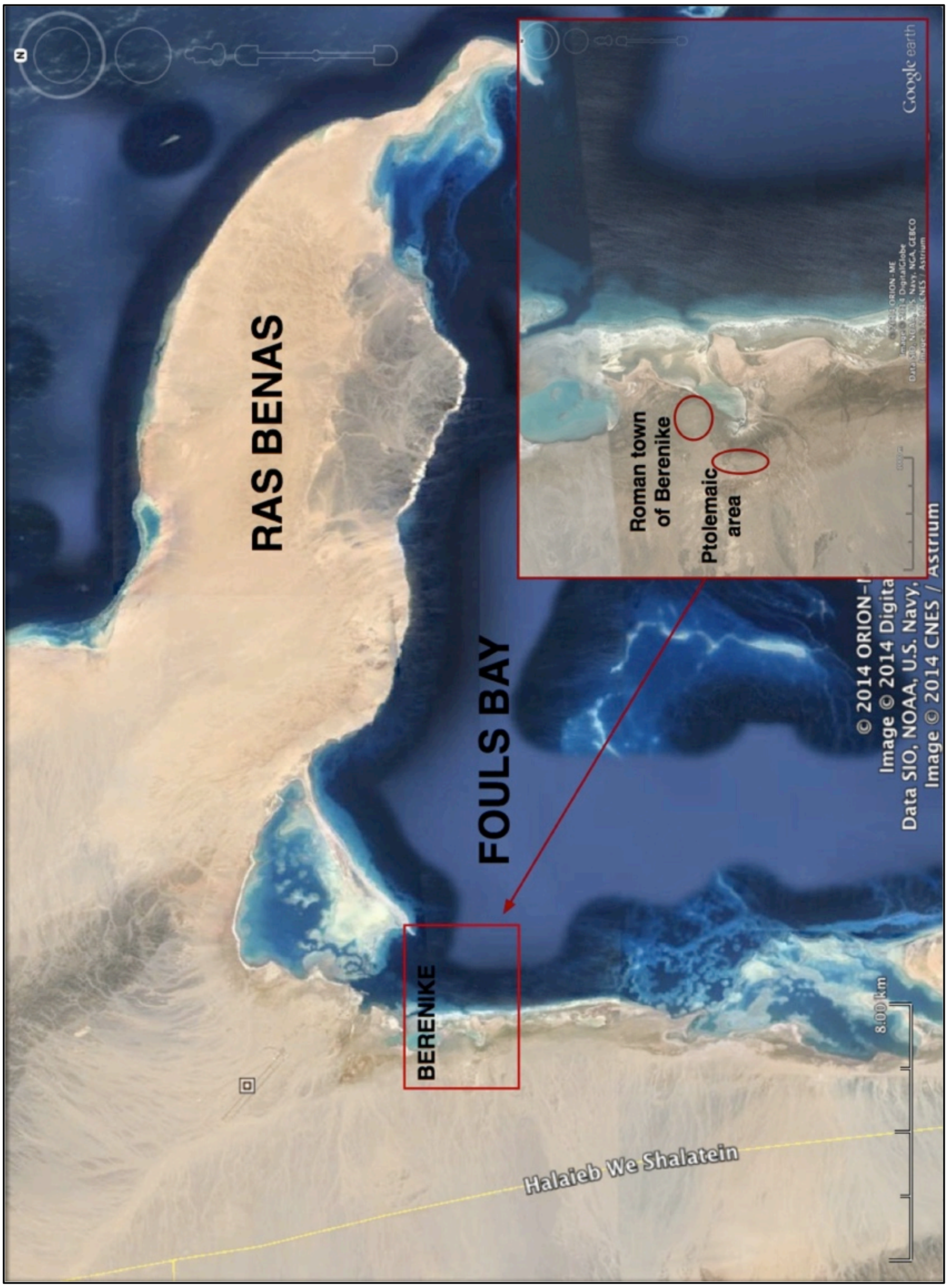


Figure 1.4 Satellite image showing Fouls Bay sheltered by the peninsula of Ras Benas. Inset: location of the site of Berenike showing partly enclosed lagoon (Source: modified from Google Earth 2014, drawn by AM Kotarba-Morley 2013).

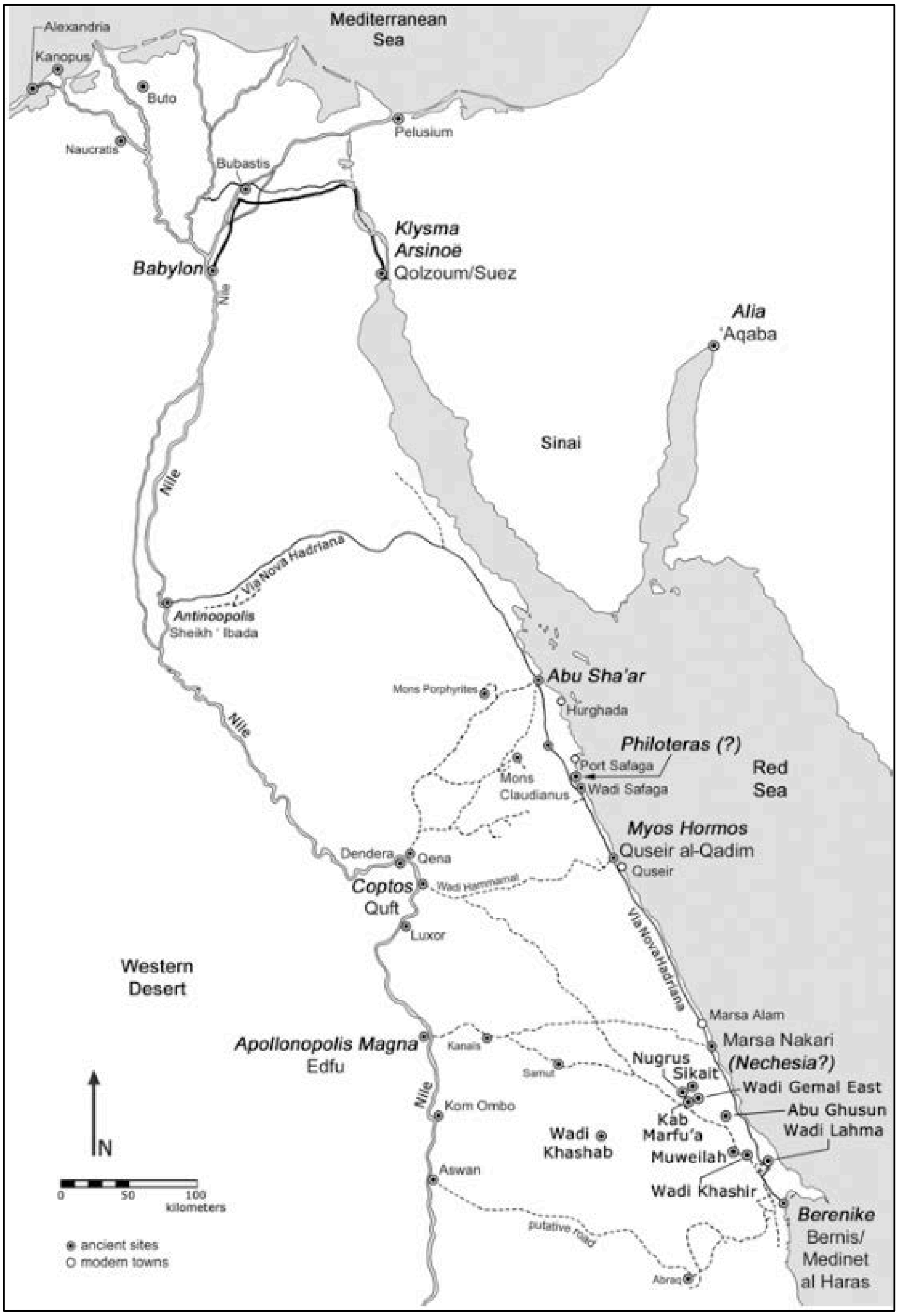


Figure 1.5 Map of Roman Egypt with archaeological sites marked (Source: Berenike Excavations Project, Sketch courtesy of Martin Hense).

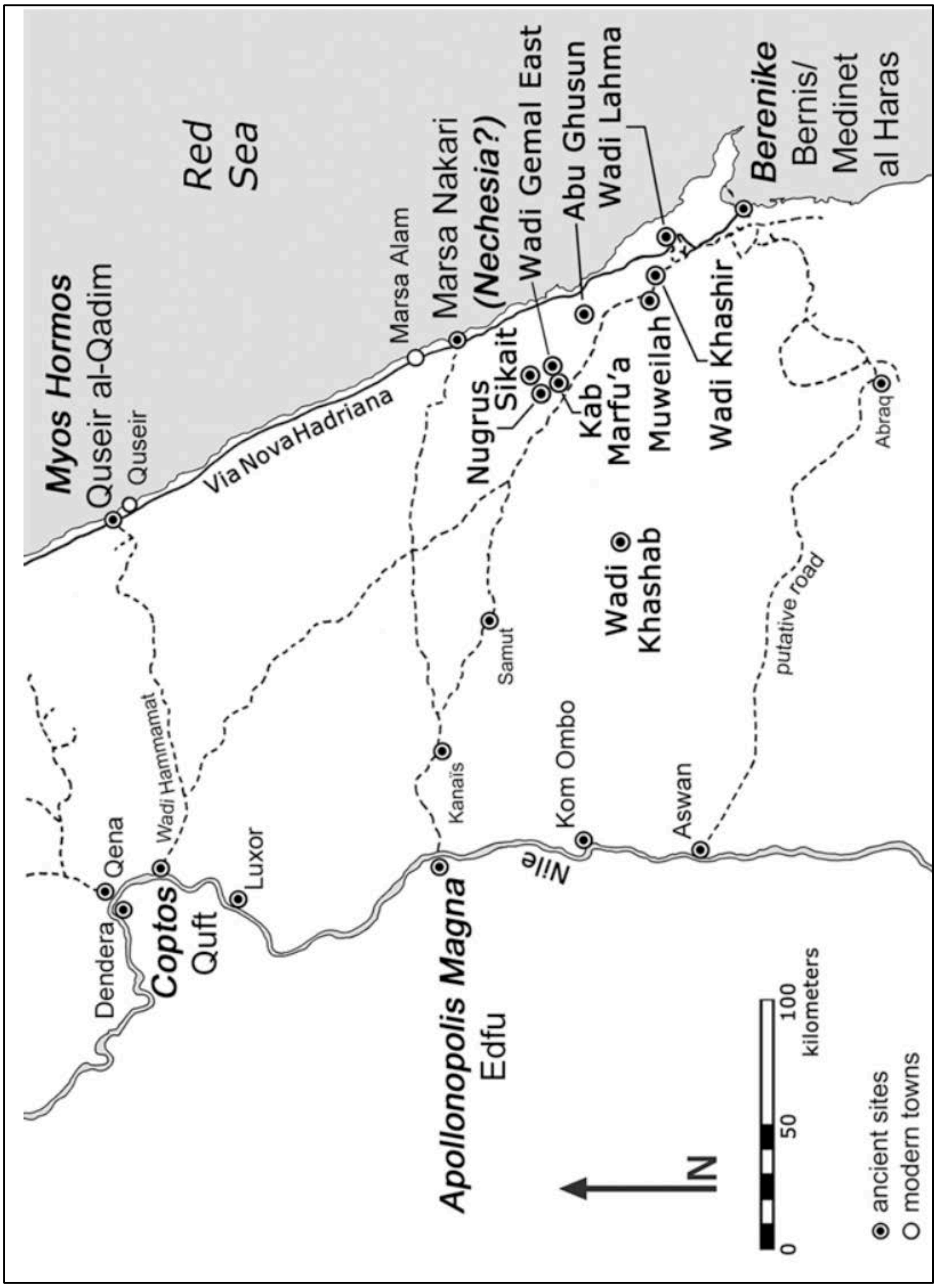


Figure 1.6 Map of the Roman Egypt showing the sites between Myos Hormos (to the North) and Berenike (to the South) (Source: Berenike Excavations Project, Sketch courtesy of Martin Hense).

Figure 1.7 Charging and discharging wild animals on a ship on a Roman mosaic (3rd-4th CE). Detail of the Big Game Hunt in the ambulatory of the Villa Romana del Casale, Piazza Armerina, Sicily, Italy (Source: Lessing Photo Archive).

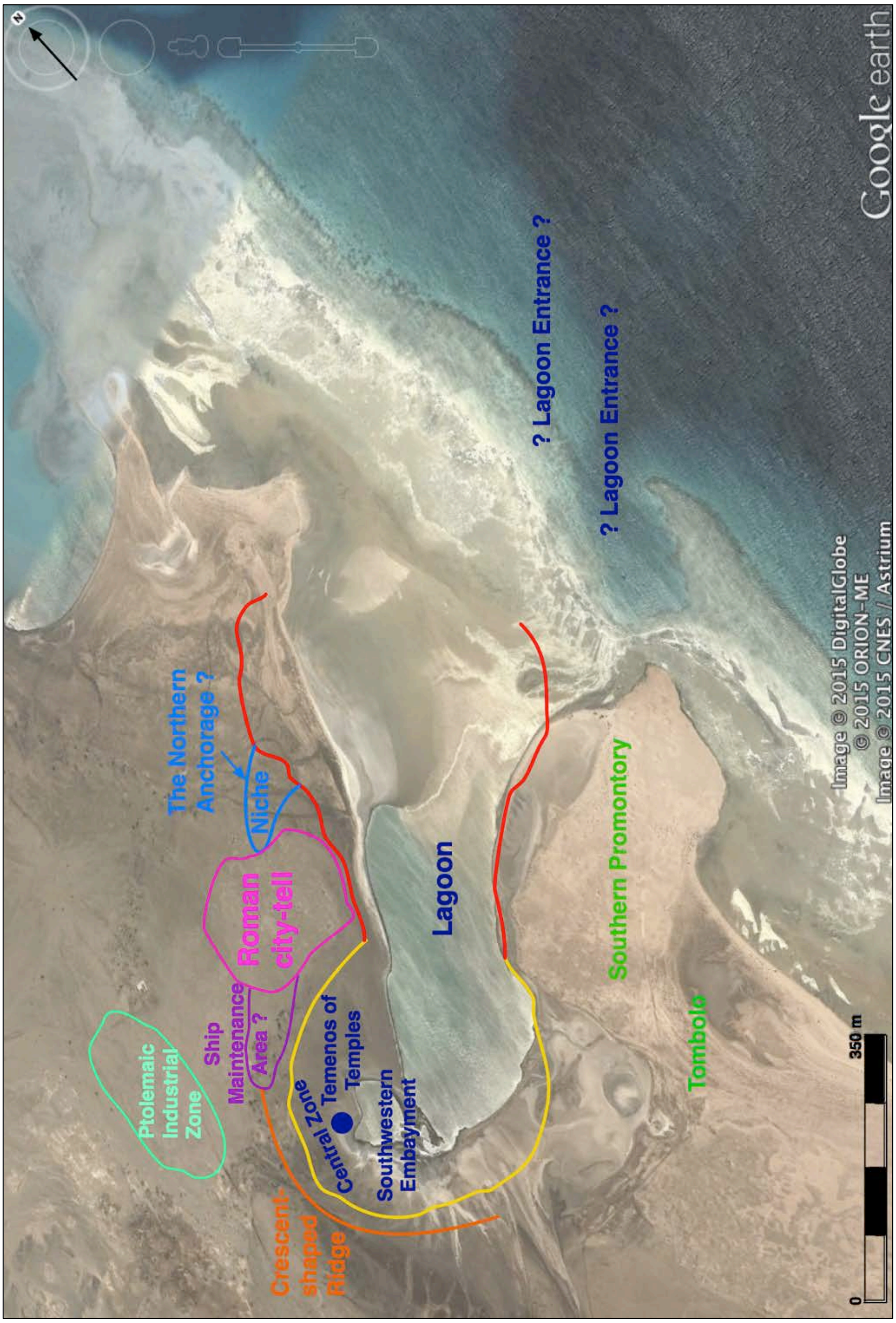


Figure 1.8 Division of functional zones within the port of Berenike that has been used to create the 'Scenarios' (Section 7.3) and to calculate the capacity of the harbour (Source of image: Google Earth 2015; Drawn by AM Kotarba-Morley).

Figure 1.9 Supposed Hellenistic city walls in trench BE13-90/93 (Photo: AM Kotarba-Morley 2013).

Figure 1.10 Hellenistic gate complex uncovered in 2014/2015 (Source: Berenike Excavations Project).

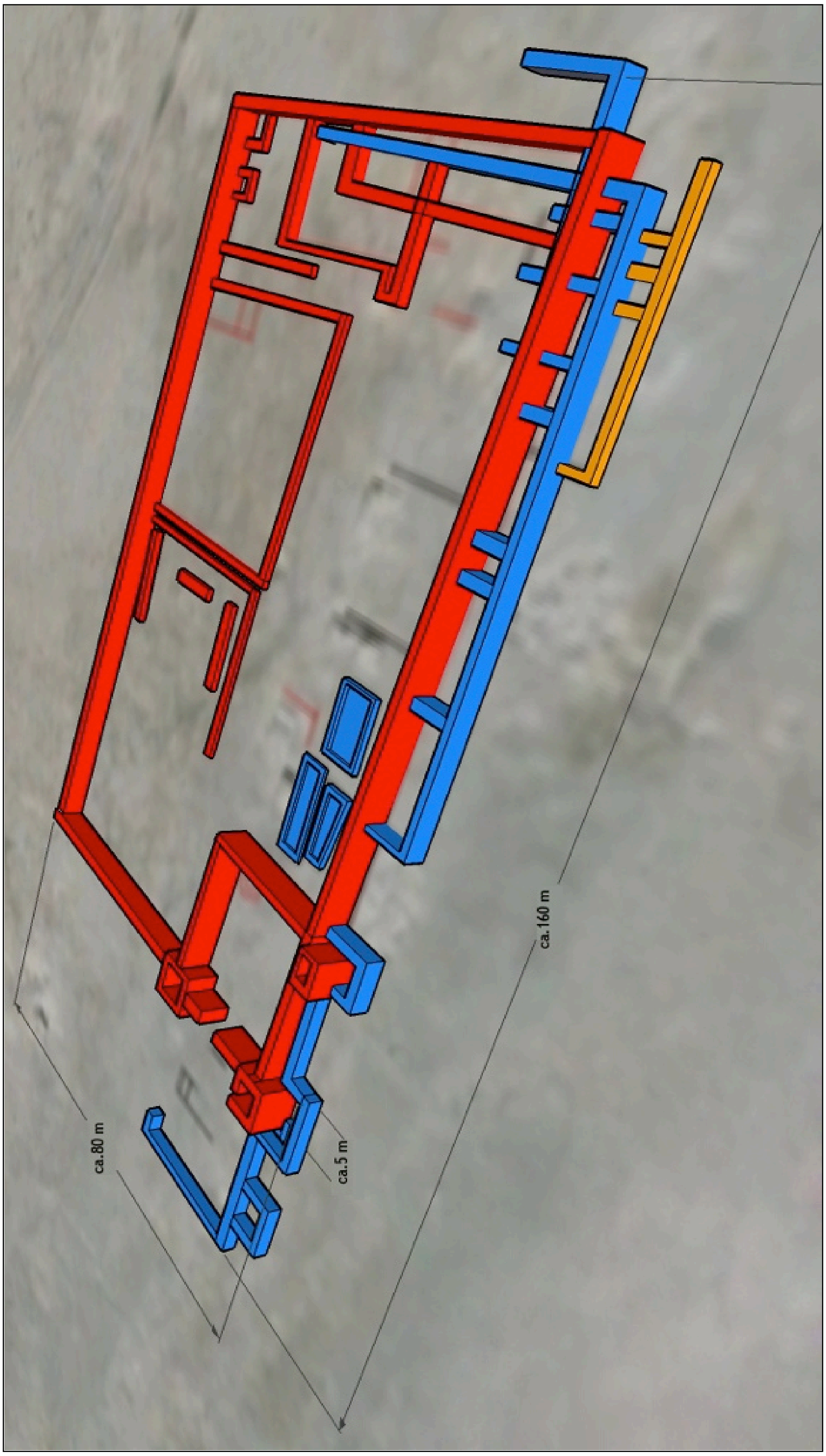


Figure 1.11 The Ptolemaic fort at Berenike. Reconstruction based on geomagnetic survey (Source: Berenike Excavations Project, Drawn by Joanna Rądkowska).

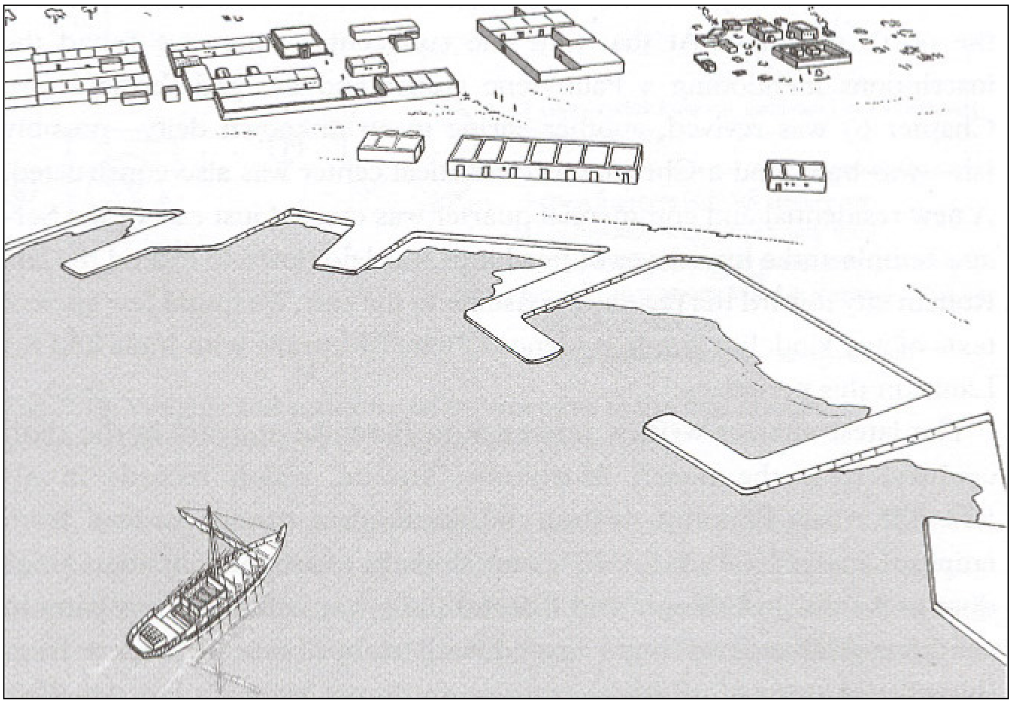


Figure 1.12 One of the early (1990s) reconstructions of the harbour at Berenike (Sketch courtesy of Martin Hense).

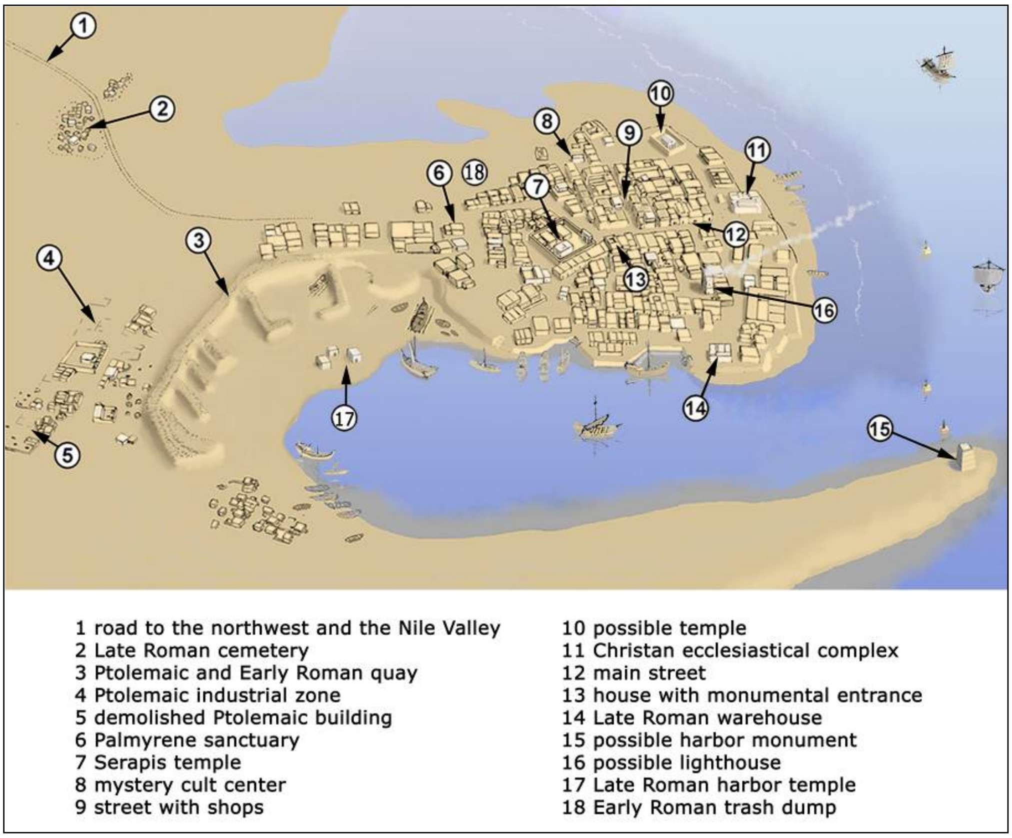


Figure 1.13 Artistic reconstruction of Berenike port city and harbour basin implying that the Crescent-shaped Ridge was a Ptolemaic and Early Roman pier (Sketch courtesy of Martin Hense).

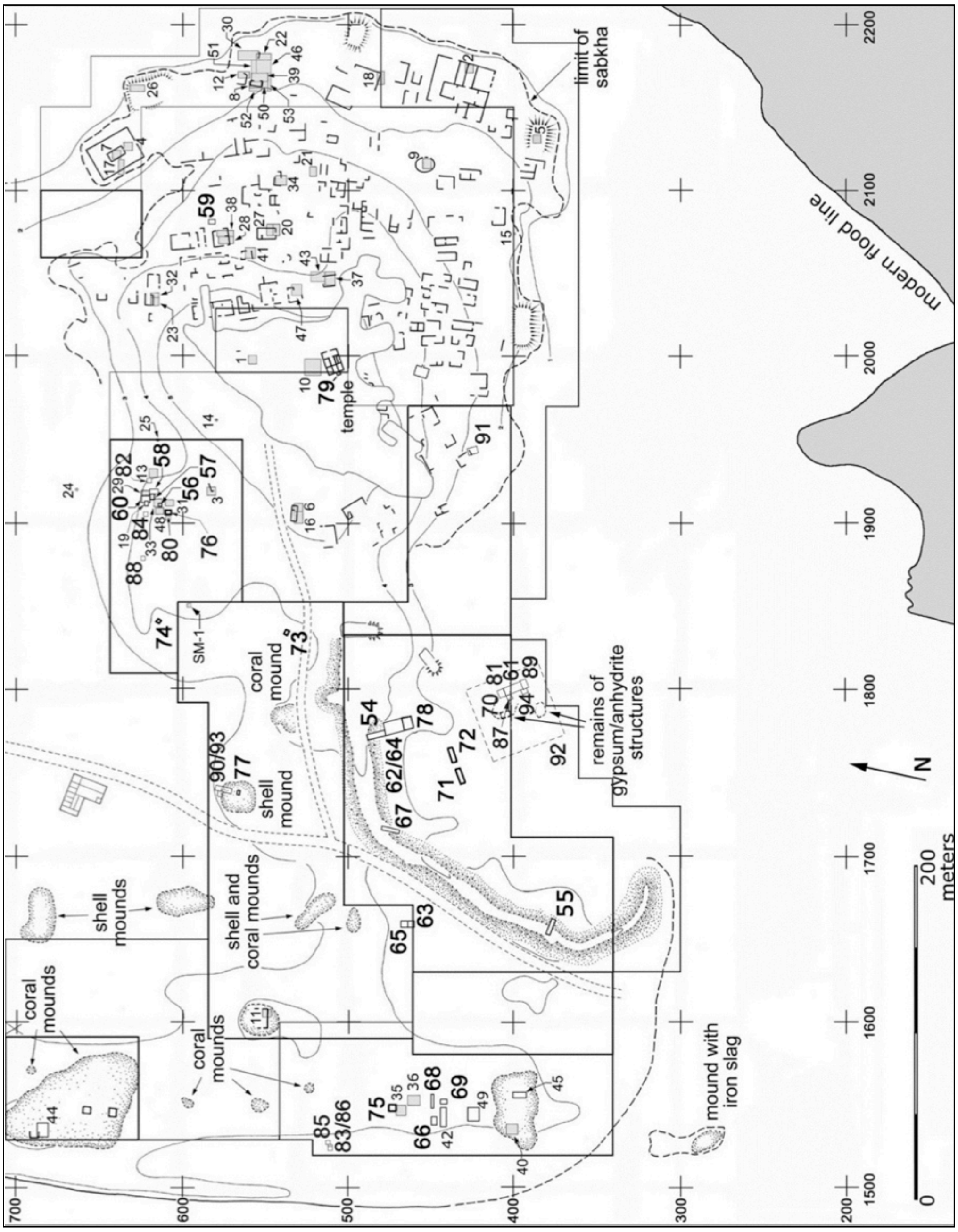


Figure 1.14 Plan of the archaeological site of Berenike with locations of trenches. The area of the southeastern 'harbour' lies between roughly 1650-2000/ 200-500 of the site grid, and the northern 'anchorage' between 2050-2100/600-700 of the site grid (Source: Berenike Excavations Project 2013).

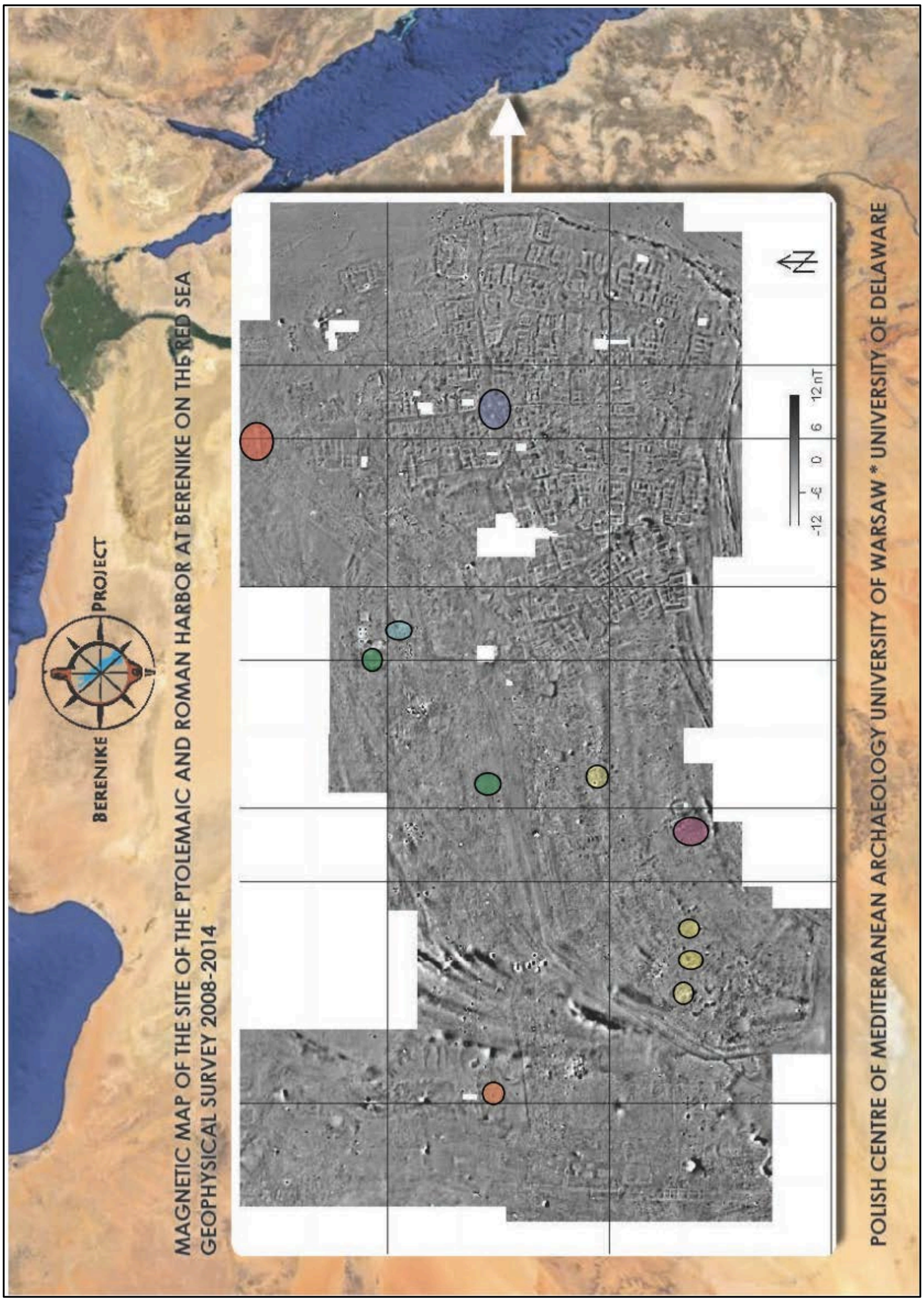


Figure 1.15 Geomagnetic map of Hellenistic and Roman sites at Berenike (Source: Berenike Excavations Project, Prepared by Tomasz Herbich).

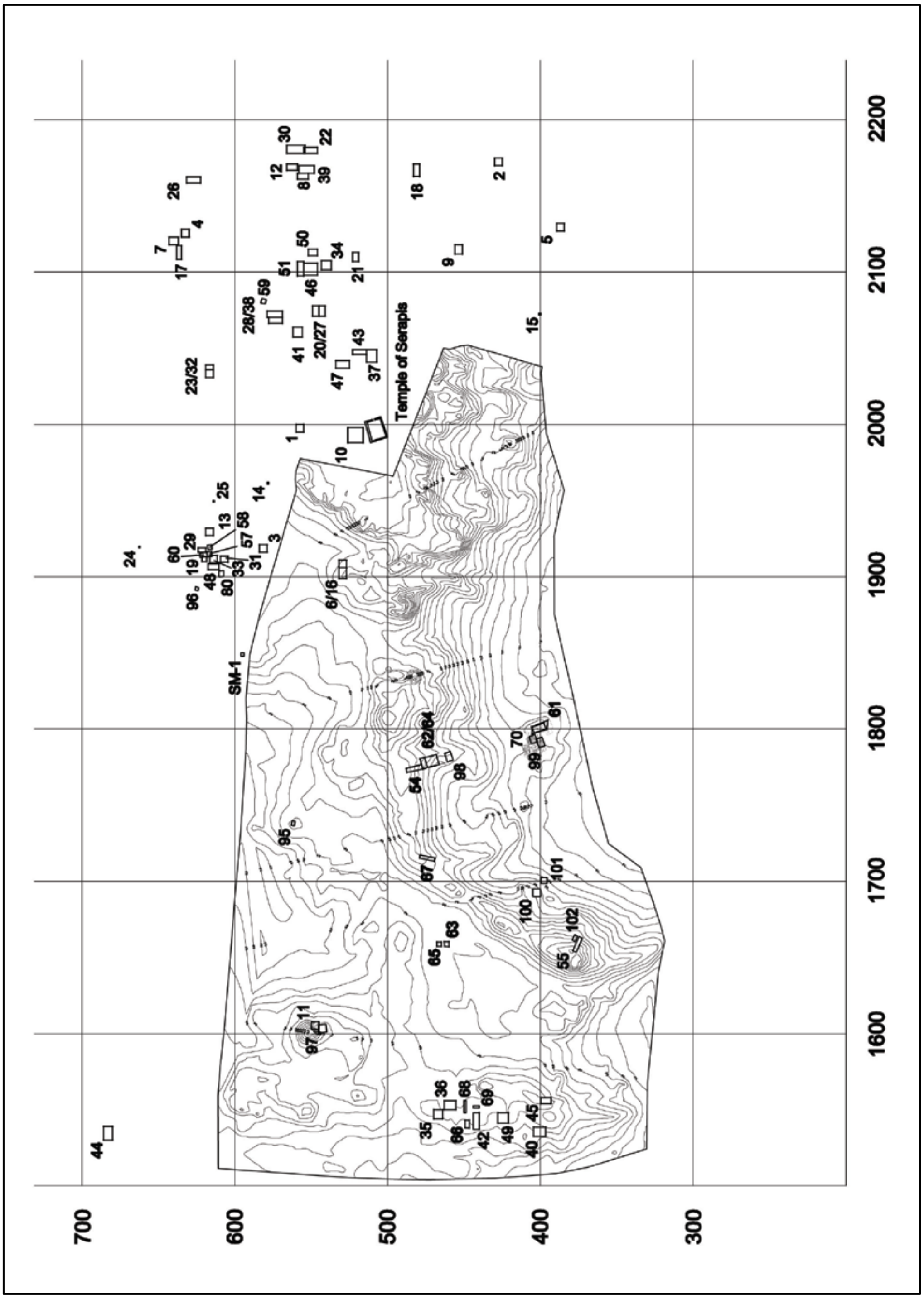


Figure 1.16 Contour map of Berenike with locations of trenches (Source: Berenike Excavations Project, Drawn by Bartosz Wojciechowski, 2014).

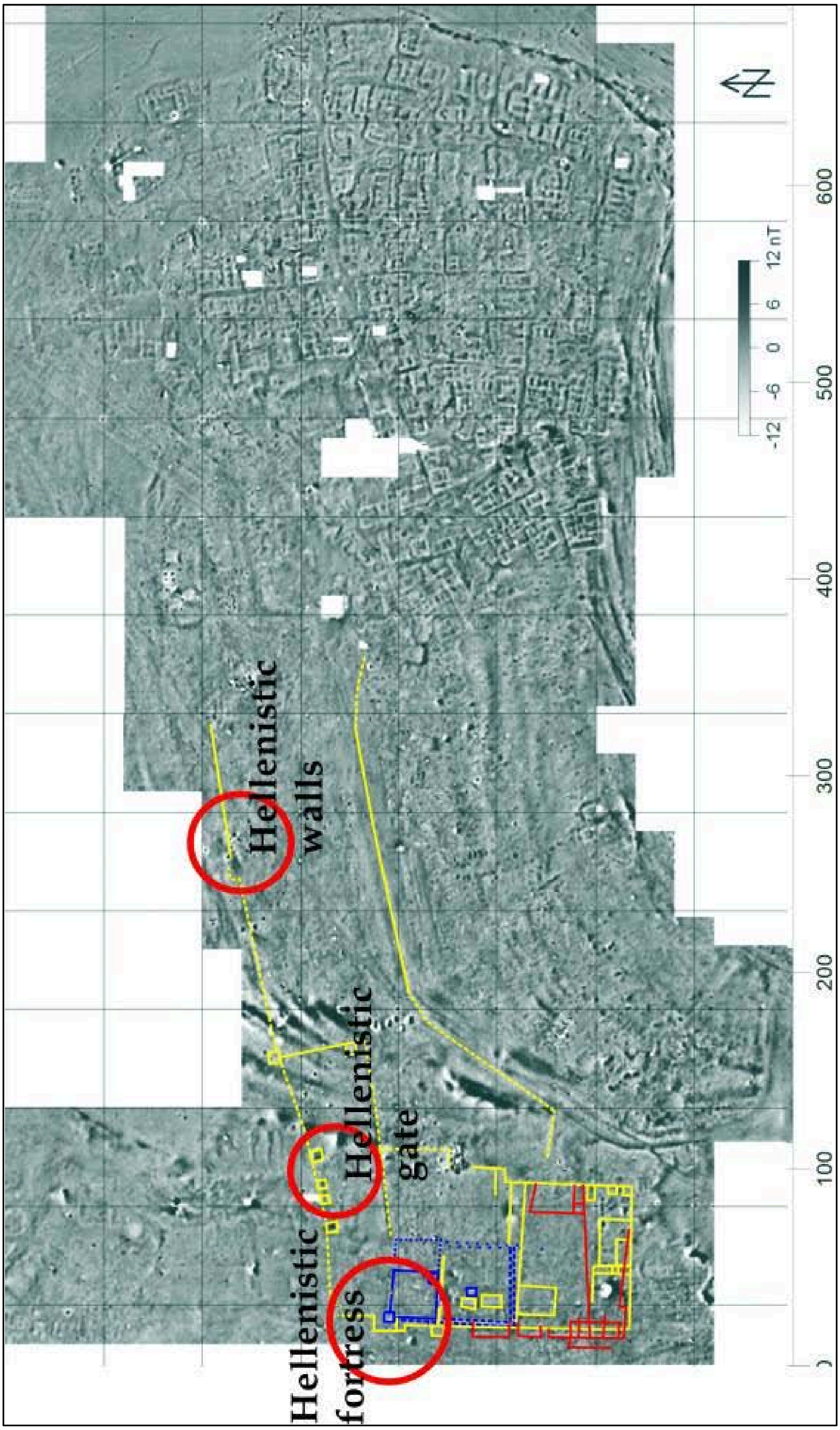


Figure 1.17 Hellenistic city superimposed on the geomagnetic map (Source: Berenike Excavations Project, 2015).

FIGURES: CHAPTER 2

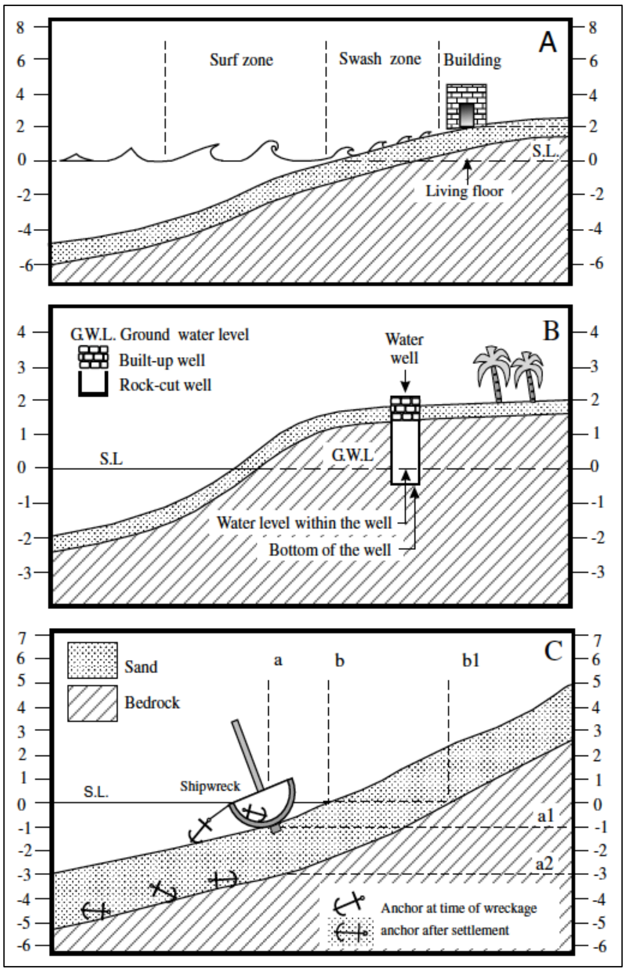


Figure 2.1 Pioneering coring in Troy (Hisarlik) in 1977 achieved a depth of 37 m (7 m asl). The lower 15 m of the profile indicated a marine environment covered by 8 m of deltaic and 7 m of fluvial-terrestrial sedimentary unit respectively (Source: Kayan 2014: 704, Fig. 3).

Figure 2.2 Three examples of archaeological sea-level indicators. Top: Living floors of buildings. Middle: Ancient wells. Bottom: The dispersion line of shipwrecks and heavy objects from the wreckage approximating the palaeocoastline (Source: Sivan et al. 2001: 104, Fig. 2).

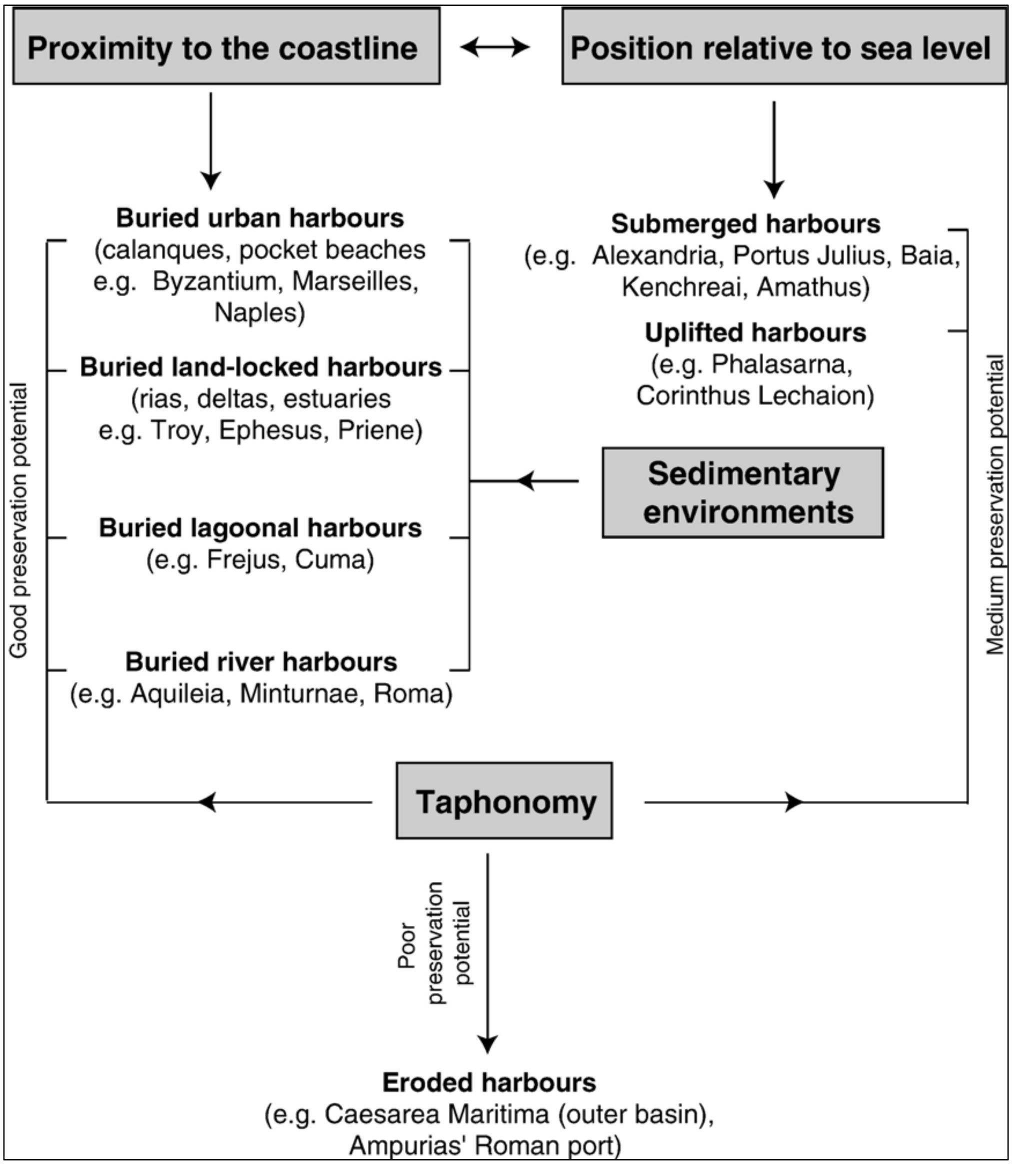


Figure 2.3 Archaeological harbour typology according to Marriner and Morhange (2007: 146, Fig. 7).

Figure 2.4 Plan of the port area in Ayn Sokhna (Source: Tallet 2012b: 34, Fig. 4.2).

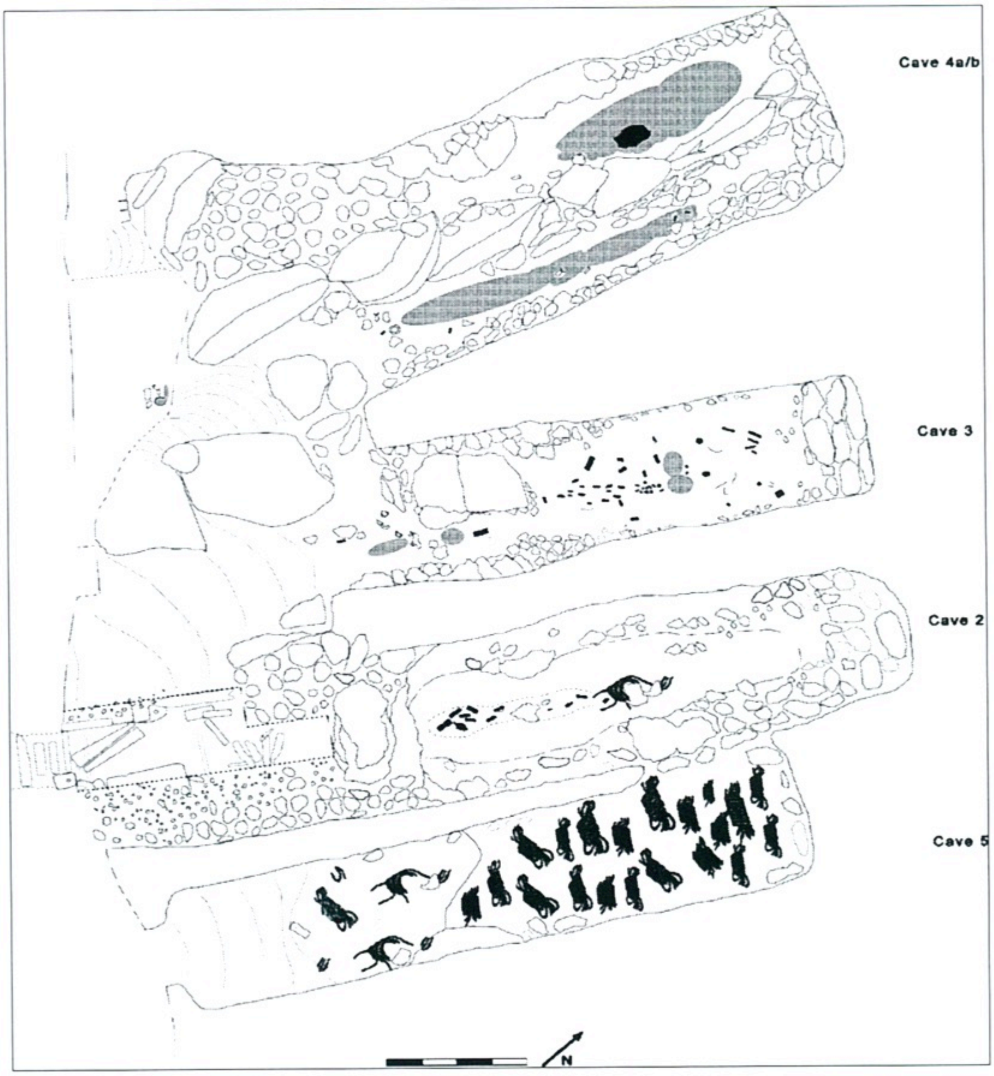


Figure 2.5 The 'nautical' caves at Marsa Gawasis (Source: Bard et al. 2007: 145, Fig. 13.1).

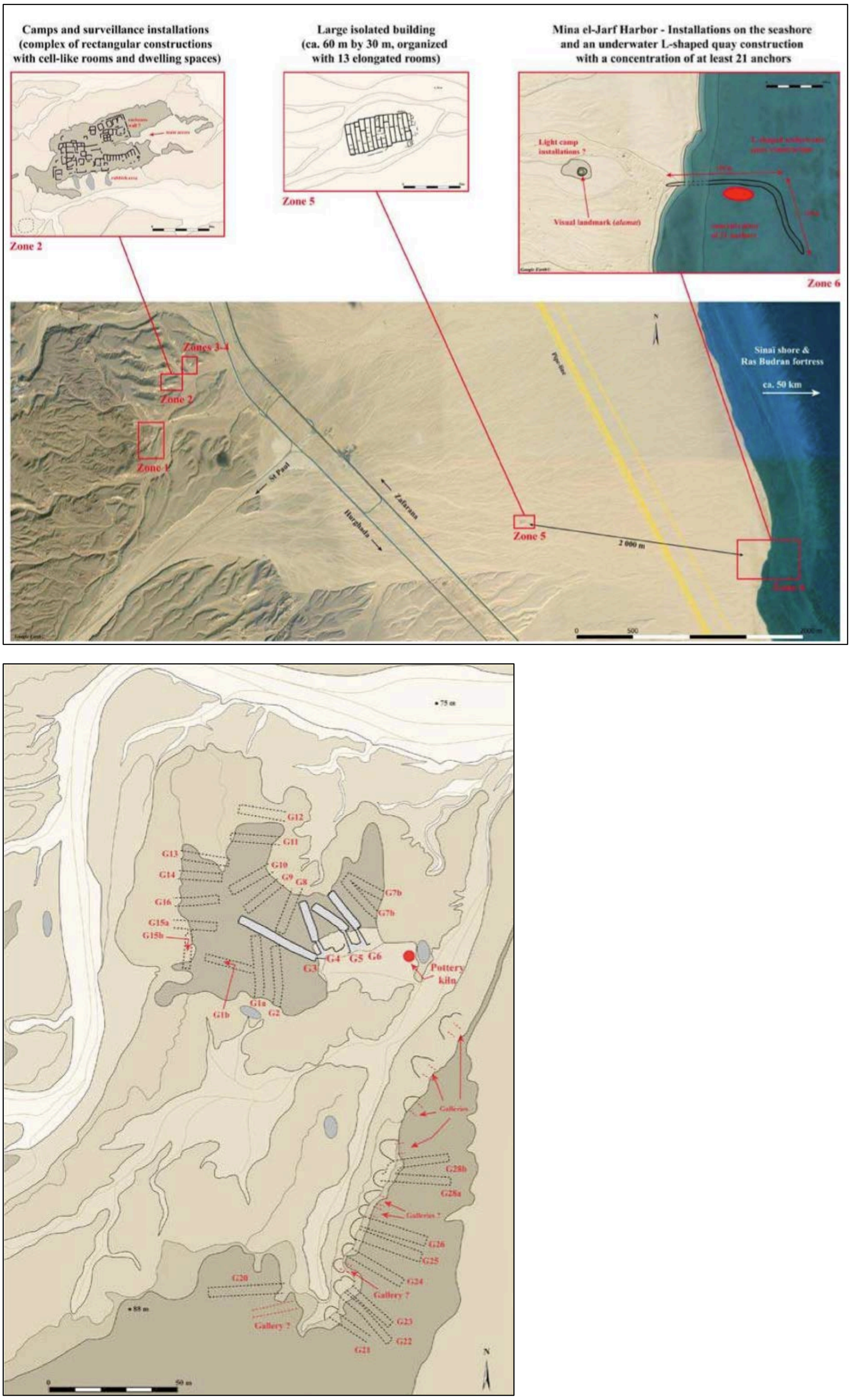


Figure 2.6 Location and zones of the pharaonic harbour of Wadi al-Jard (Source: Tallet and Marouard 2012: 2–3).

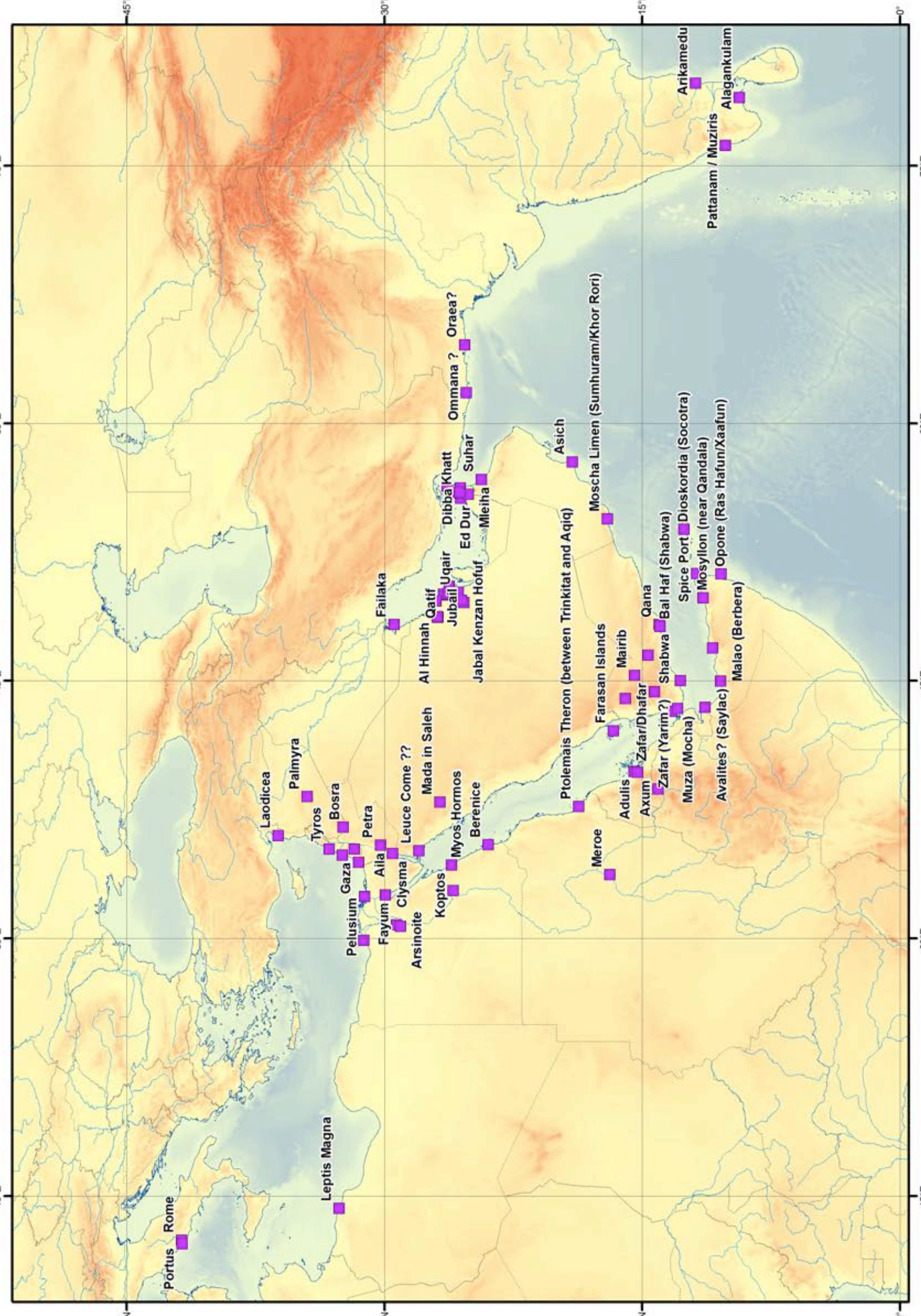


Figure 2.7 Early Historic sites on the Red Sea, Indian Ocean and the Persian Gulf (Source: AM Kotarba-Morley and C Green 2012).

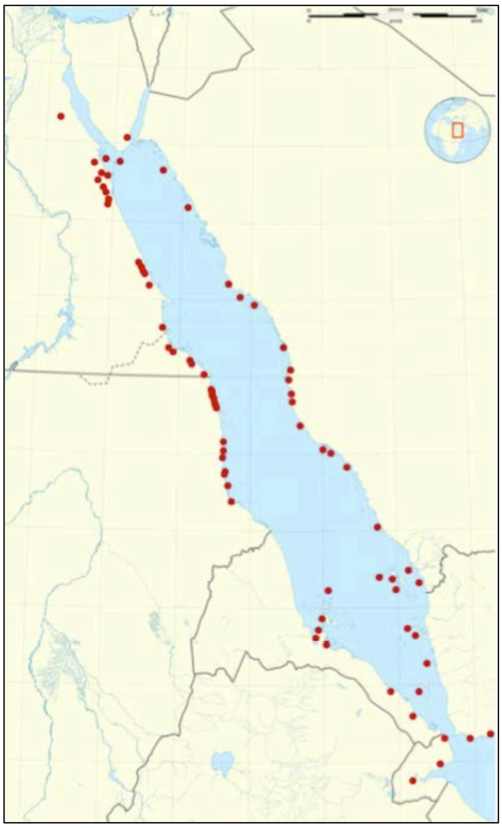


Figure 2.8 Potential Ancient Harbours on the Red Sea (Source: de Graauw 2014: 9, Fig. 4).

Figure 2.9 Amphora wharf in Trench 7A at Myos Hormos (Source: Blue 2011: 36, Fig. 4.2a).

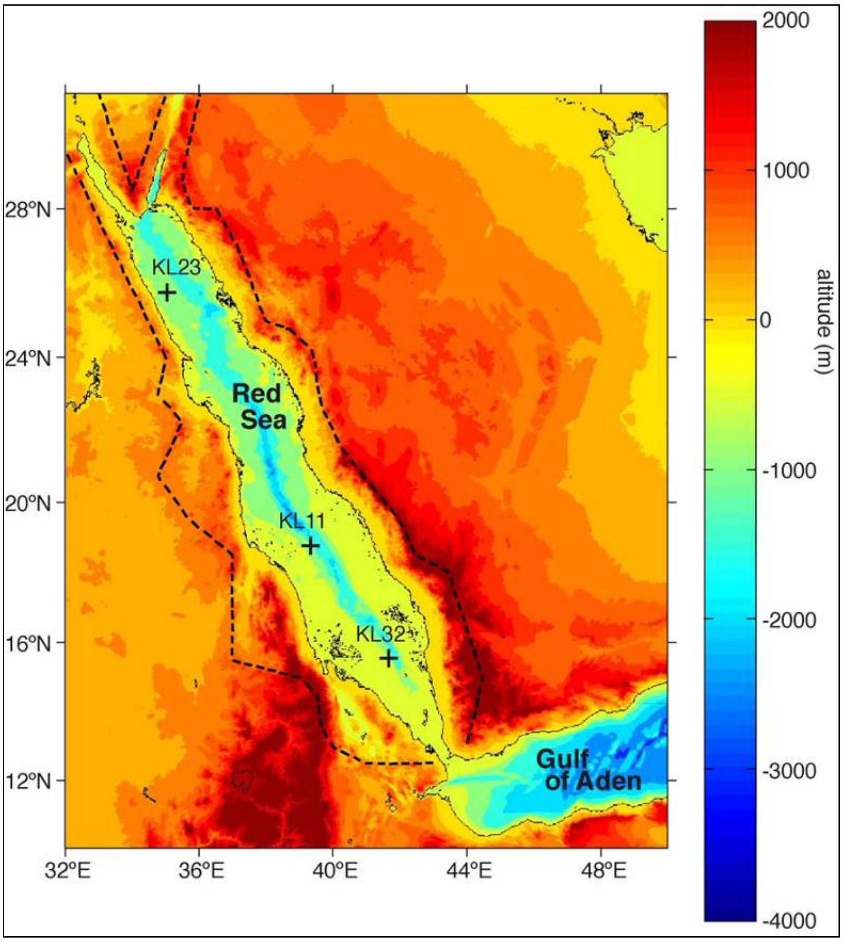


Figure 2.10 Map of Red Sea bathymetry and surrounding topography. Note the small surface area of the Red Sea rainfall catchment marked by the bold dashed line (Source: Siddall et al. 2004).

Figure 2.11 Greening of the desert in 2013 after propitious rains and flooding (Photo: AM Kotarba-Morley 2013).

Figure 2.12 Red Sea wind patterns (Source: http://earthobservatory.nasa.gov/IOTD/view.php?id=81743).

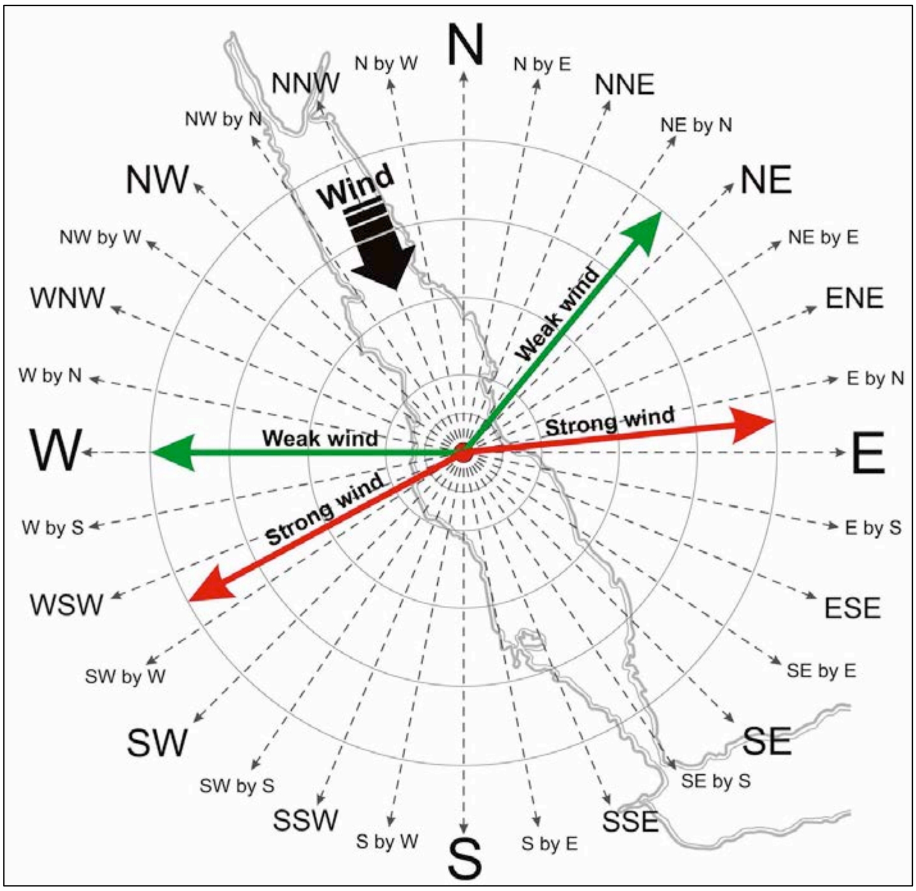


Figure 2.13 The *takkiya* headings (a range of courses) for variable wind direction given by Sulaimān al-Mahrī (Source: Whitewright 2008: 140, Fig. 2.24).

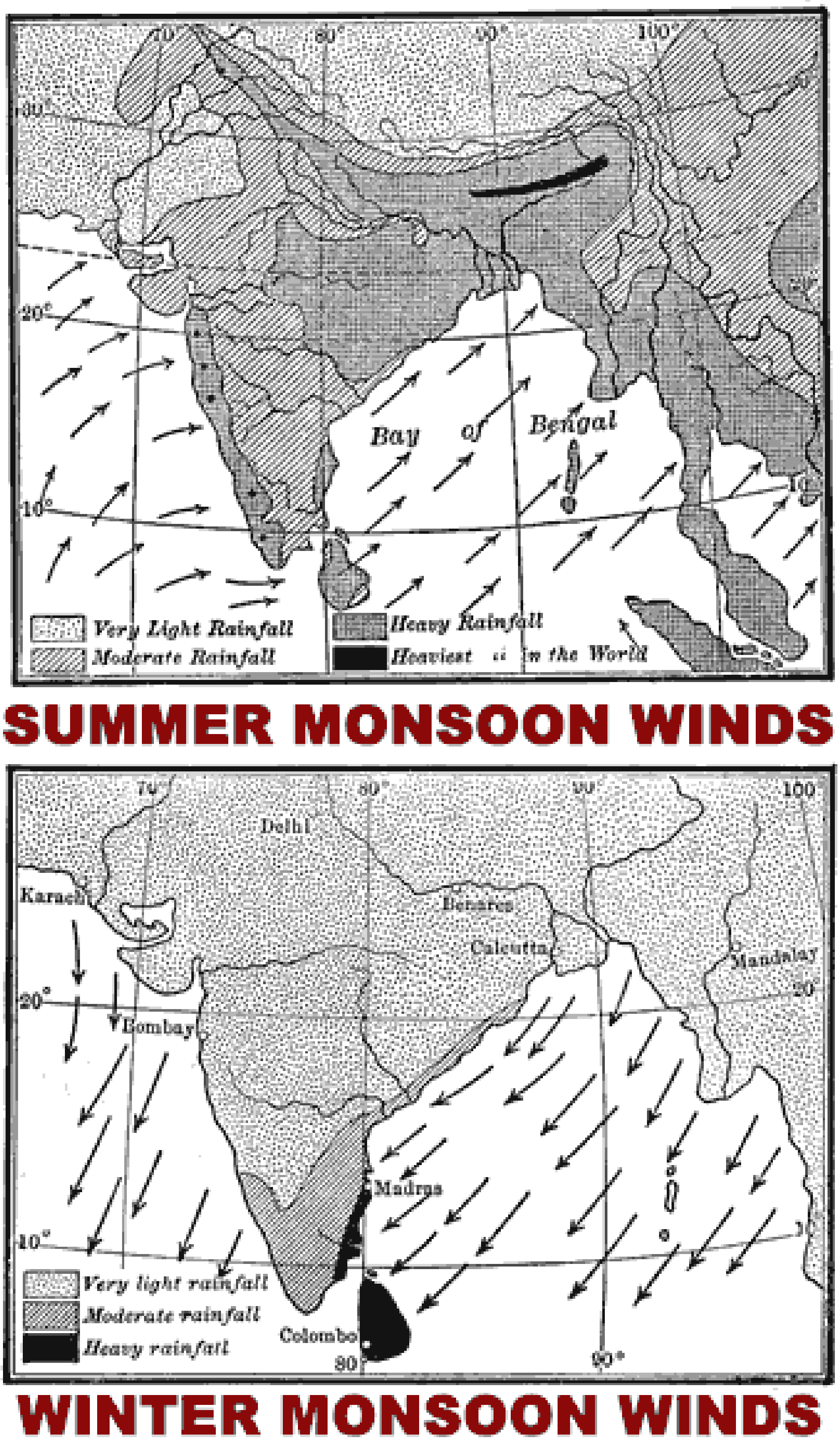


Figure 2.14 Indian Ocean monsoon winds patterns (Source: Kaplan 2011: xx).

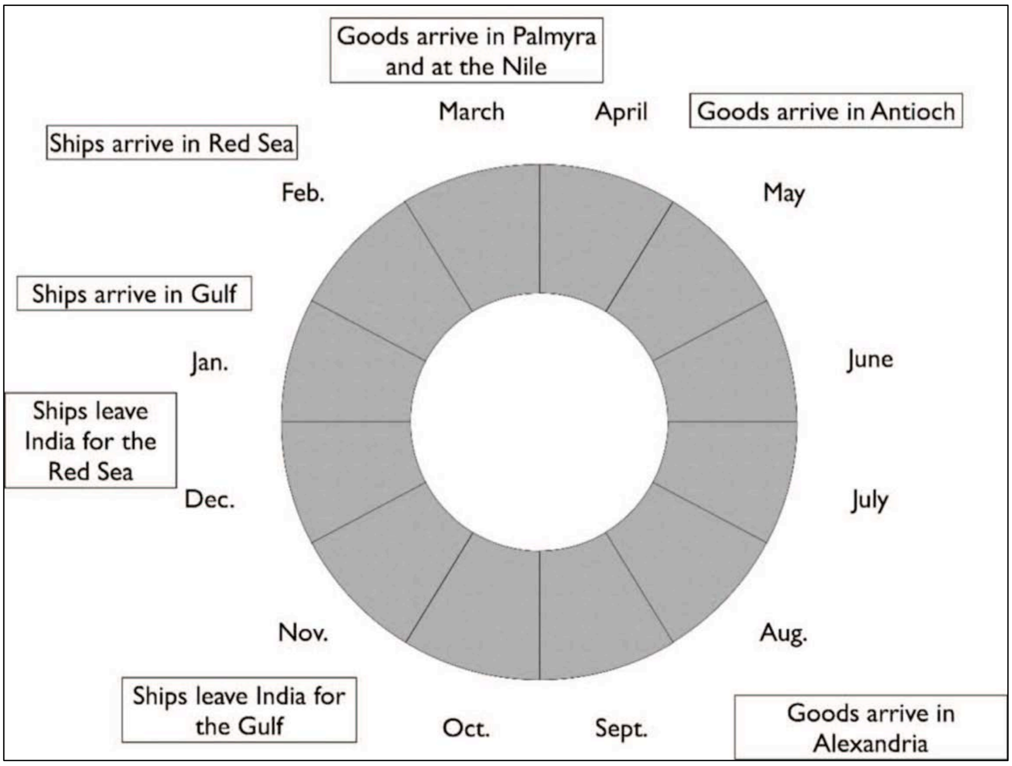


Figure 2.15 Seasonal patterns of departure and arrival times for commodities in the ancient world (Source: Seland 2011: 405, Fig. 1).

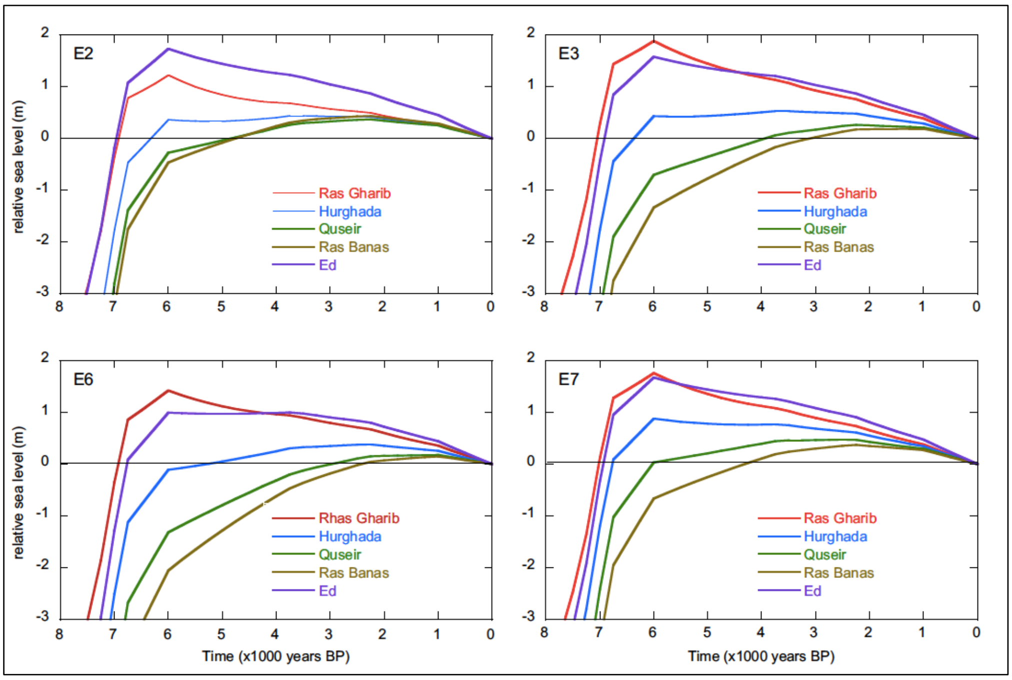


Figure 2.16 Graphs representing mid to late Holocene sea-level predictions at representative sites for different earth models. Take a special note of different curves in E2 and E7 specially for Ras Benas (Source: Lambeck et al. 2011: 3550, Fig. 6).

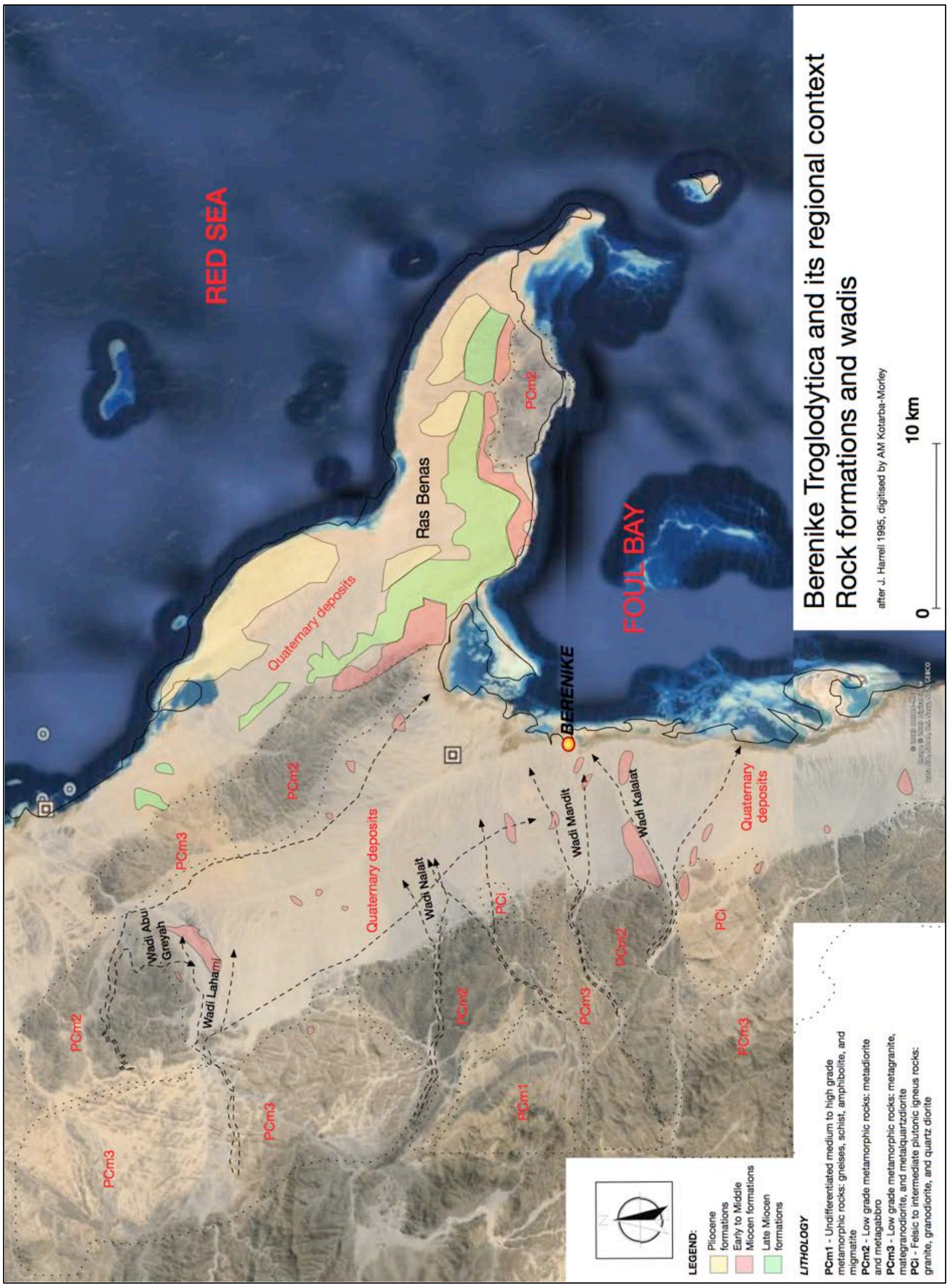


Figure 2.17 The regional geological context of the location of Berenike Troglodytica, showing rock formations and wadis (Drawn by AM Kotarba-Morley 2013, after Harrell 1996).

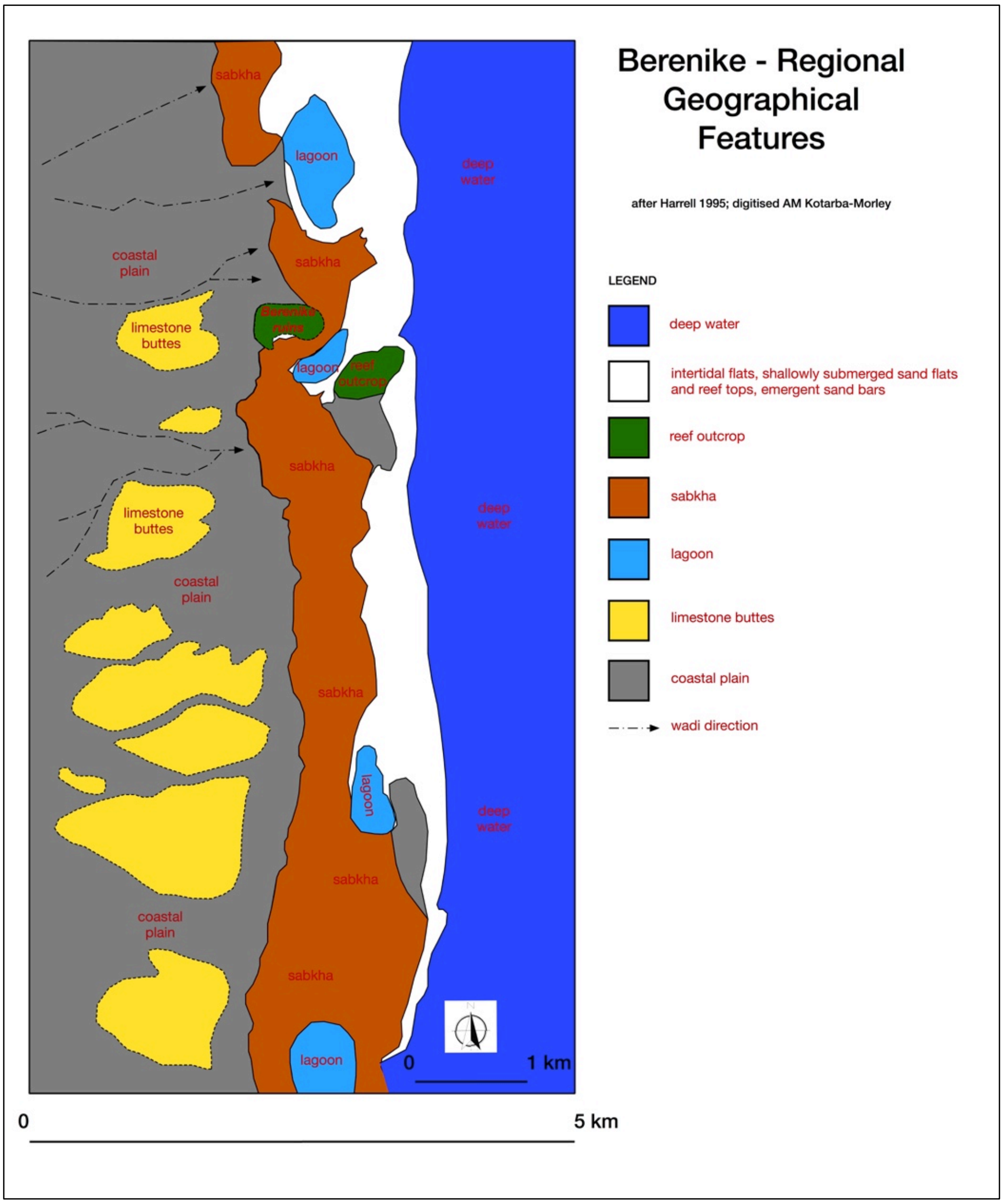


Figure 2.18 Local geological map of Berenike – the site shown in dark green (Drawn by AM Kotarba-Morley 2013, after J. Harrell 1996: 100).

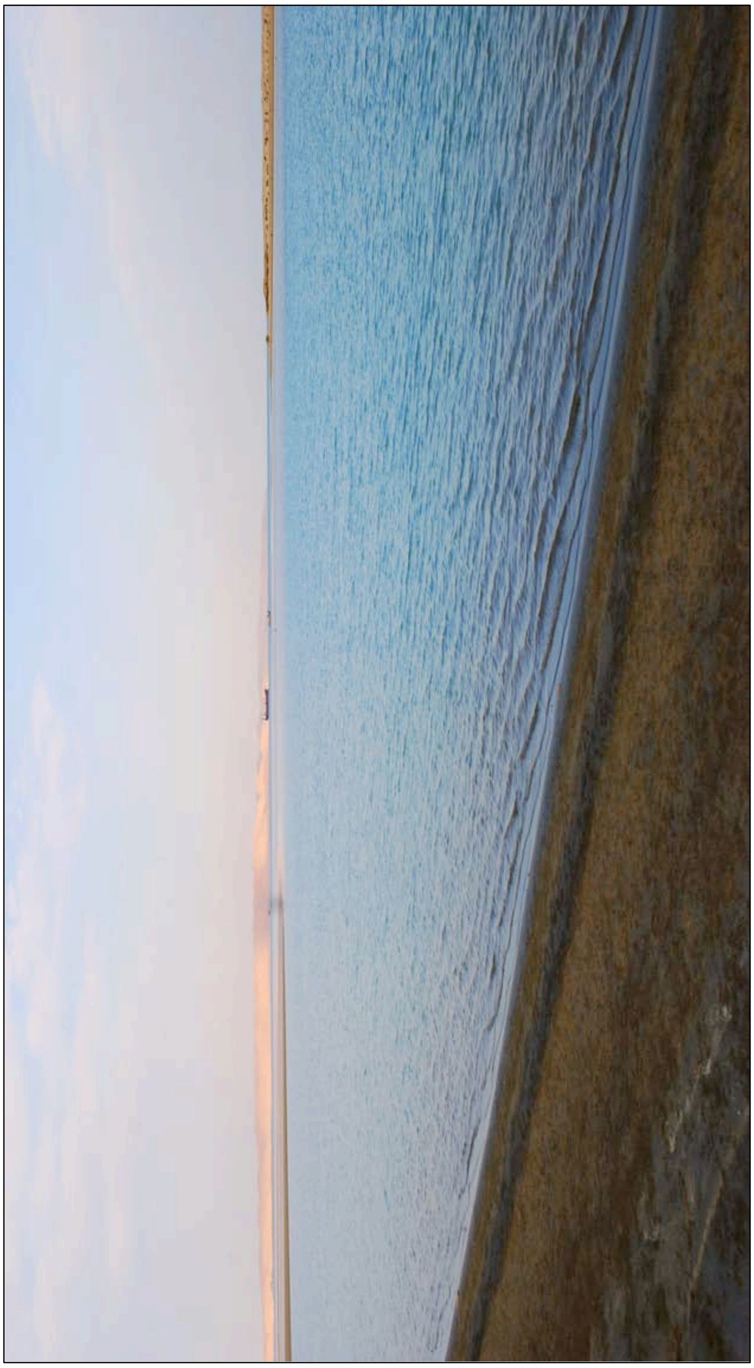


Figure 2.19 View of the lagoon, its beach, the entrance to the Lagoon, and the Southern Promontory at Berenike. Looking northeast towards Ras Benas (Photo: AM Kotarba-Morley 2011).

Figure 2.20 A 180-degree panorama collage of the Southwestern Embayment from the west (Photo: AM Kotarba-Morley 2012).

Figure 2.21 Top: The 'northern' beach at low tide. Note a short swash zone, low dunes towards the south and immediate commencements of *sabkha* in the berm zone. Bottom: The southern beach at low tide. Note the very different landscape and character of the dunes compared to the northern beach. The site of Berenike is visible to the far north (Photos: AM Kotarba-Morley 2013).

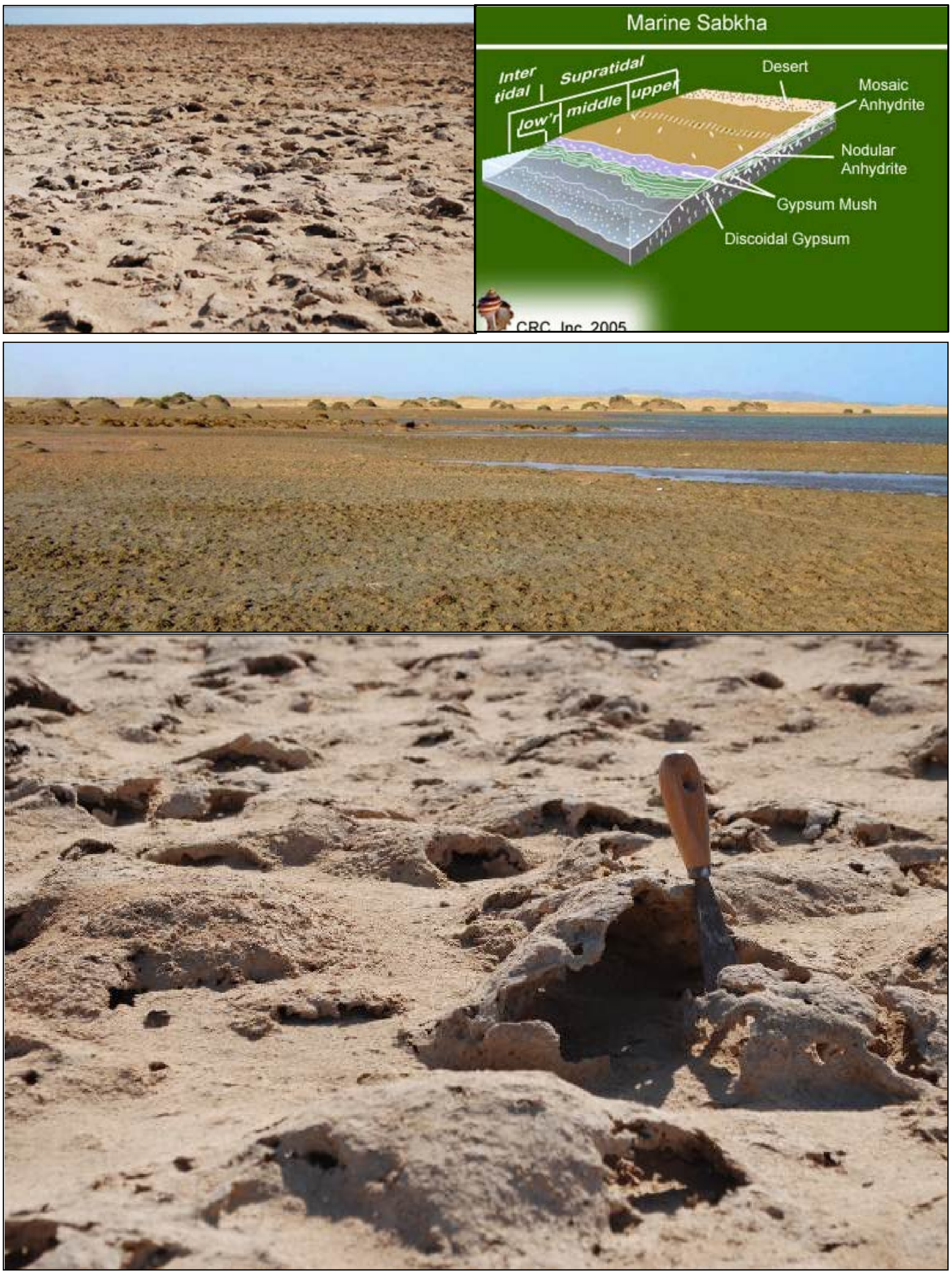


Figure 2.22 Top left and right: details of *sabkha* encountered south from the embayment. Bottom: *Sabkha* dominated landscape in the southwestern part of the embayment. *Nebkhas* visible further afield (Photos: AM Kotarba-Morley 2012; Section Figure: CRC 2005, after Shinn 1983).

Figure 2.23 *Nebkha* fields. Top: the northern field. Bottom: the southern field (Photos: AM Kotarba-Morley 2011, 2012).

Figure 2.24 The pedological survey in *nebkha*. Top left: location shot from the top of the studied nebkha. Bottom left: location of the sondage and the author inside as a scale. Right: Stratigraphic profile showing layers of light soil formation (Photos: AM Kotarba-Morley 2013).

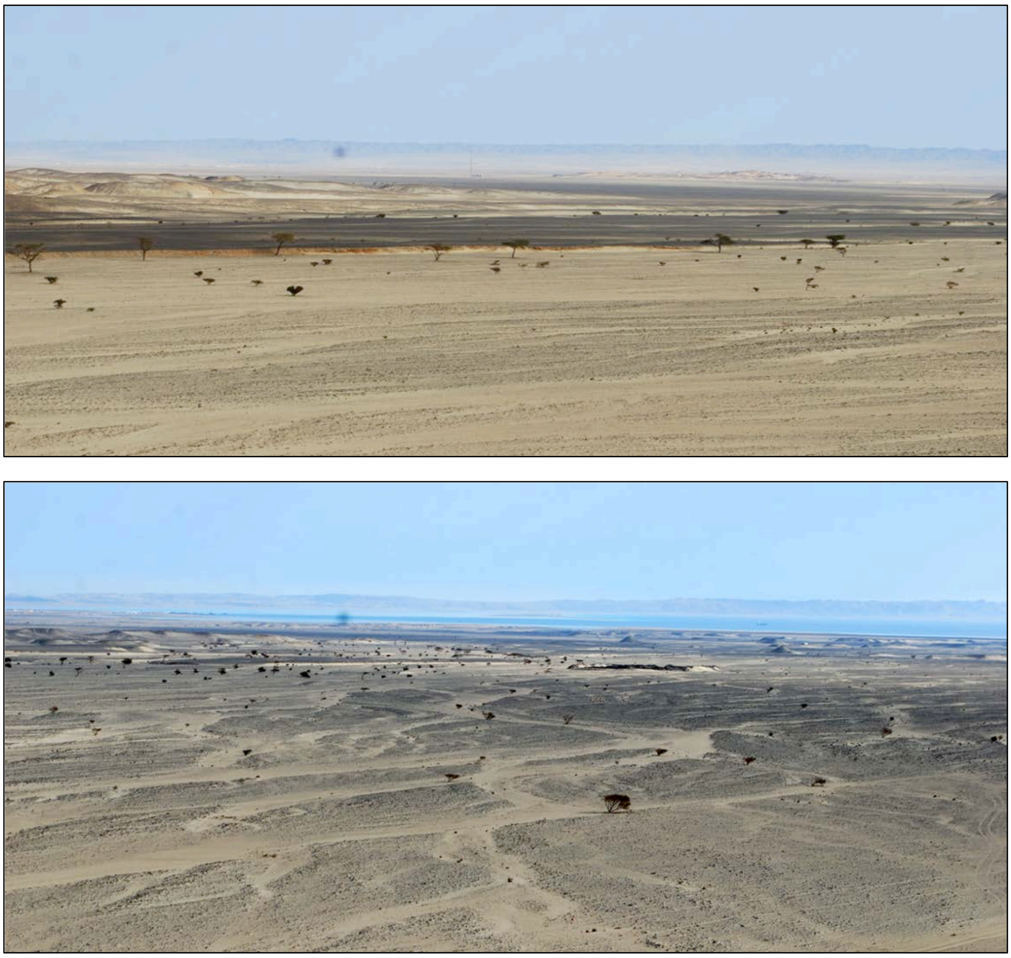
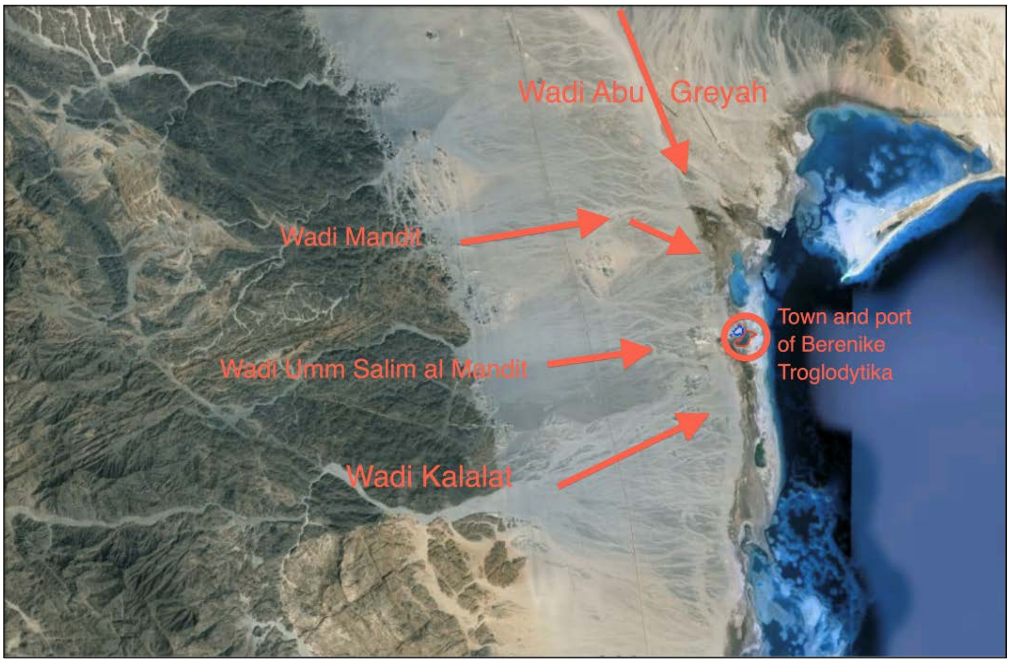


Figure 2.25 Top and bottom: the panorama of the coastal plain from the top of the foothills. Note braided structure of the alluvial fan, the limestone buttes and Ras Benas peninsula in the distance (Photos: AM Kotarba-Morley 2012).



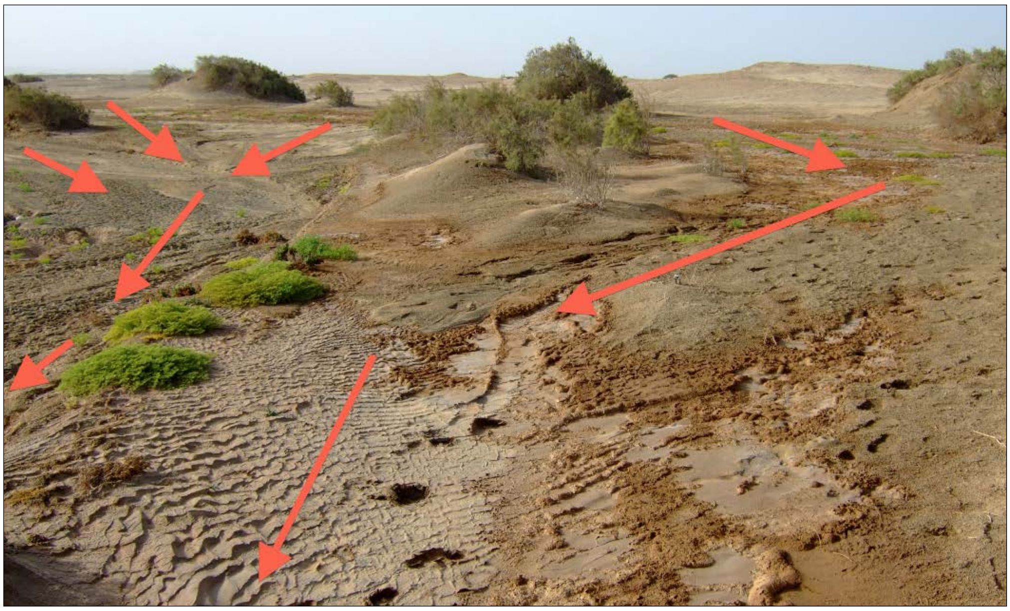


Figure 2.26 Top: Directions of material accretion from particular wadis (Source: modified from Google Earth). Bottom: Braided channels of the Wadi Kalalat alluvial fan just south from the crescent-shaped ridge (Photo: AM Kotarba-Morley 2011).

Figure 2.27 Top: Mountains in Wadi Kalalat. Bottom: Mountains and wadi Abu Greya (Photos: AM Kotarba-Morley 2012).

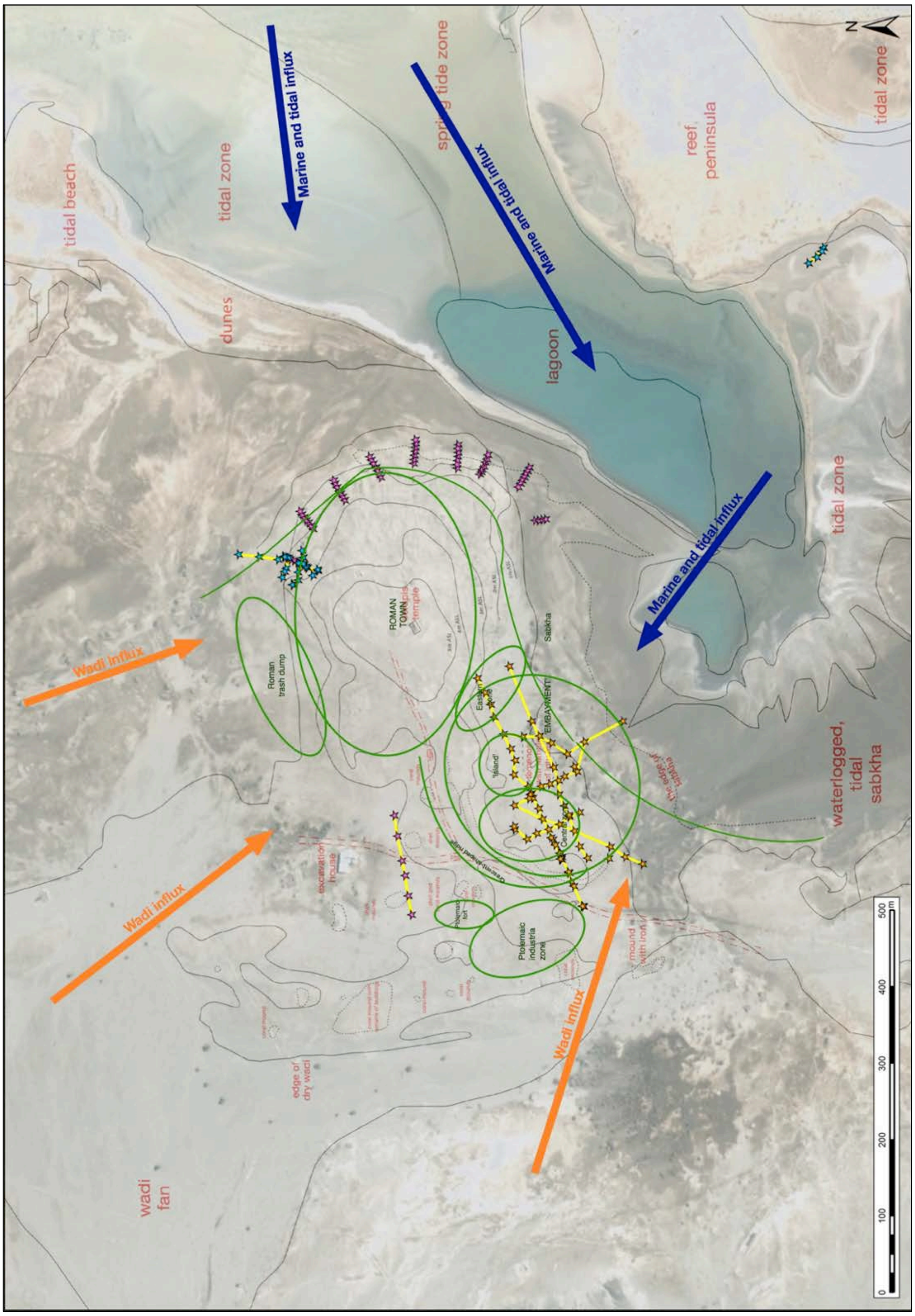


Figure 2.28 Map of Berenike showing the site's archaeological and geomorphological zones and the various marine and terrestrial forces at play. Green circles = site zones, yellow = coring transects, orange starts = AKM 2011 augerhole locations, blue starts = AKM 2012 augerhole locations, pink starts = Harrell 1995 and 2001 augerhole locations (Source: AM Kotarba-Morley 2013).

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Figure 3.1 The view towards the Ras Benas to northeast showing the coastal shelf next to the entrance of the lagoon. Photograph taken from the top of the Southern Promontory at Berenike (Photo: AM Kotarba-Morley 2013).

Figure 3.2 Author during the geomorphological survey (Photo: J Trzcinski 2012).

Figure 3.3 Wave-cut notch on the eastern side of the sand bar showing evidence for sea level change in progress (Photo: AM Kotarba-Morley 2011).

Figure 3.4 Author recording the formation of the foreland of the Eastern Desert mountains at the entrance of Wadi Umm Salim al Mandit (Photo: J Trzcinski 2011).

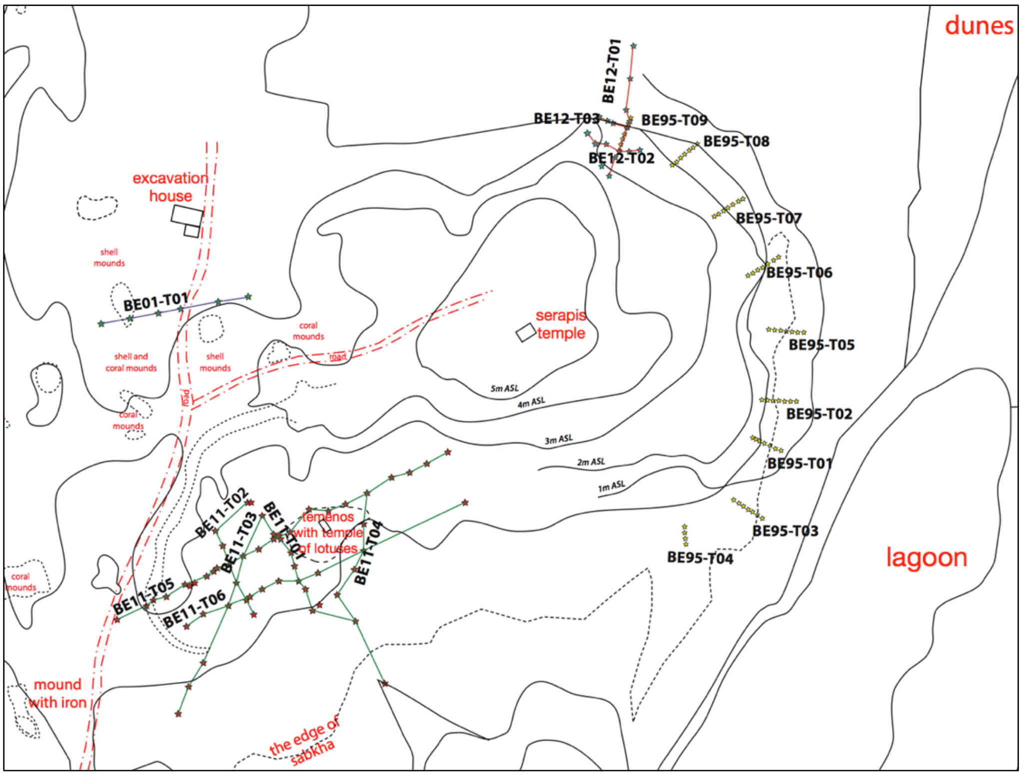

Figure 3.5 Map of Berenike showing transect locations. Zoom in from Fig. 3.9 (Drawn by AM Kotarba-Morley 2012).

Figure 3.6 View from the Southern Arabian temple (of lotuses) towards the lagoon to the east (Photo: AM Kotarba-Morley 2010).

Figure 3.7 Left: View from the top of one of the *nebkhas* (coppice mounds) showing one of the local Ababda Beduin workmen, Hassan from Manazik, screwing in the auger head. Right: Hassan pulling out the hand auger from the hole (Photos: AM Kotarba-Morley 2012).

Figure 3.8 Author sampling the core in the northern 'anchorage' in February 2012 (Photo: T Witkowska 2012).

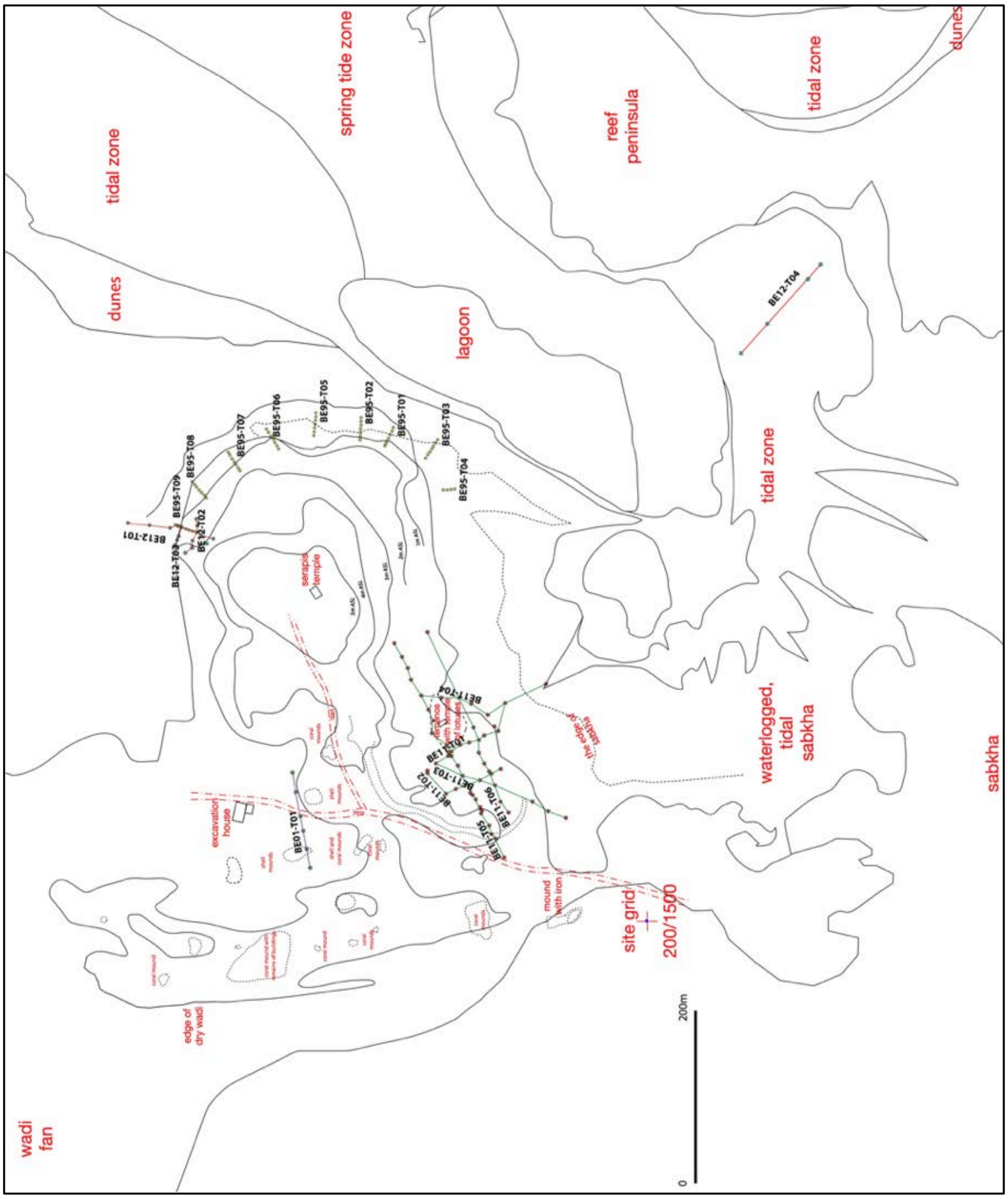

Figure 3.9 Schematic view of Berenike with coring transects from 2011 and 2012 campaigns by the author and 1995 and 2001 campaign by J Harrell (Drawn by AM Kotarba-Morley 2013).

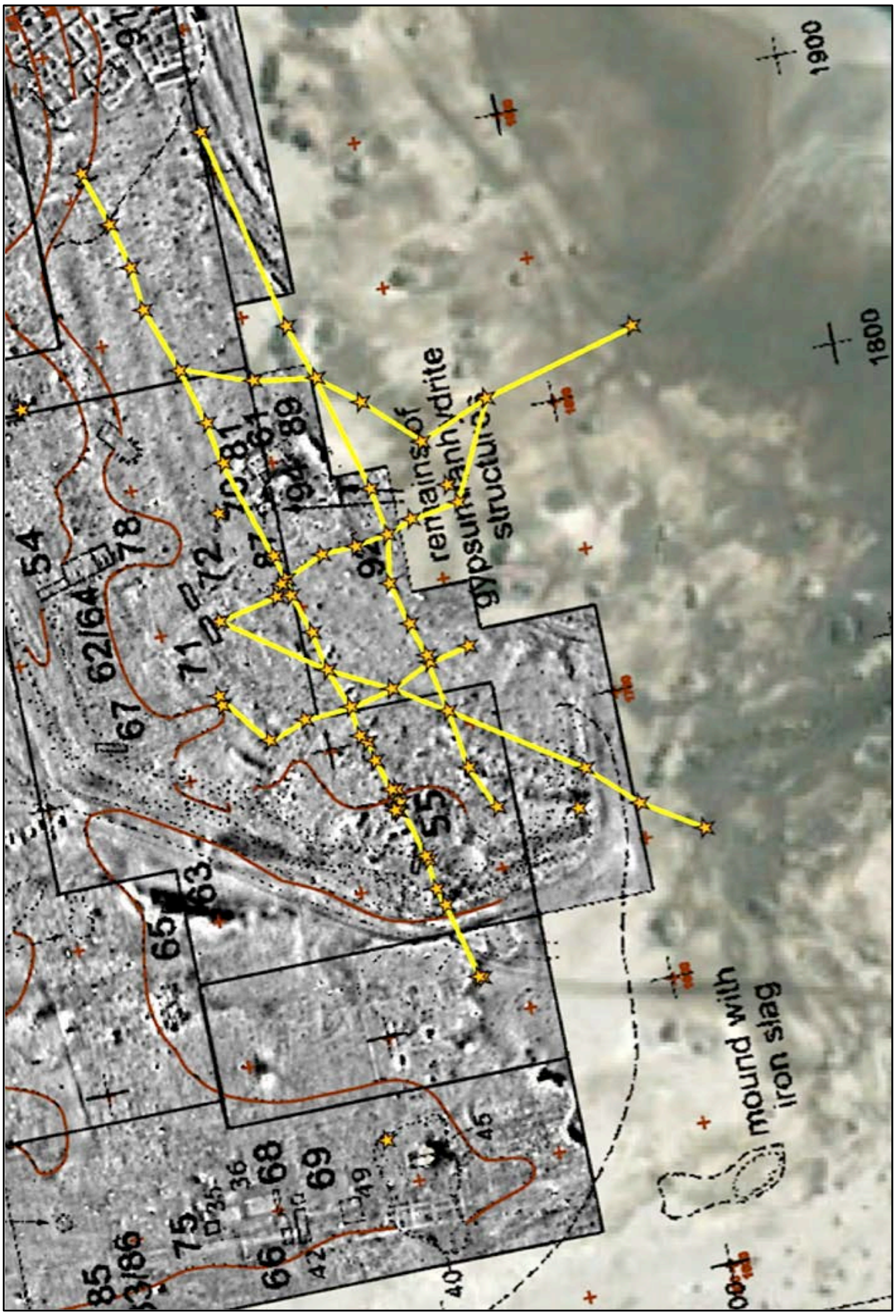

Figure 3.10 Transects cored during 2011 campaign by the author in the context of the site, the archaeological excavation, geomagnetic survey and the landscape. Black croses with site grid are 100 m apart (Drawn by AM Kotarba-Morley & C Green 2012).

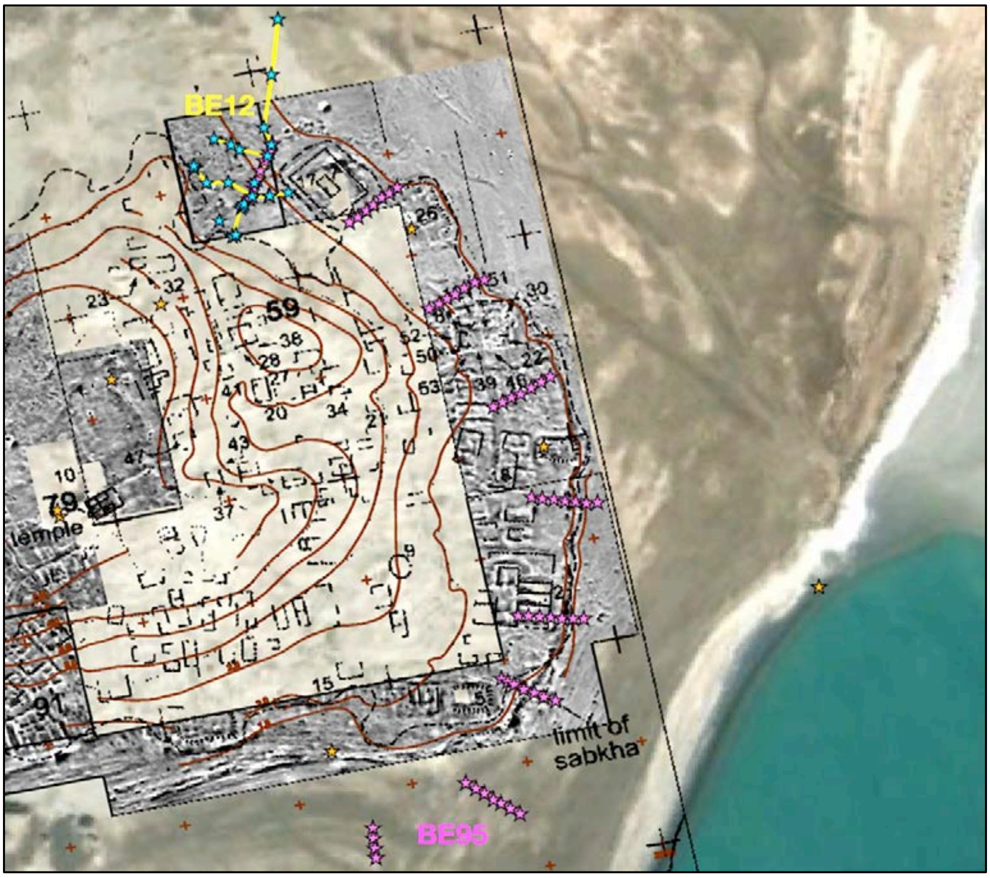

Figure 3.11 Transects cored during 2012 campaign by the author (yellow) and by Harrell in 1995 (pink) in the context of the site, archaeological excavation, geomagnetic survey and surrounding landscape. Black croses with site grid are 100 m apart (Drawn by AM Kotarba-Morley& C Green 2012).

Figure 3.12 Remains of a wall of the assumed wharf in trench BE97/98–17 (Source: Sidebotham and Wendrich 2000: 77).

Figure 3.13 Author using Bartington MS2 magnetic susceptibility meter to undertake measurements (Photo: M Morley 2013).

Figure 3.14 Author weighing samples on a precision balance (Photo: A Parton 2013).

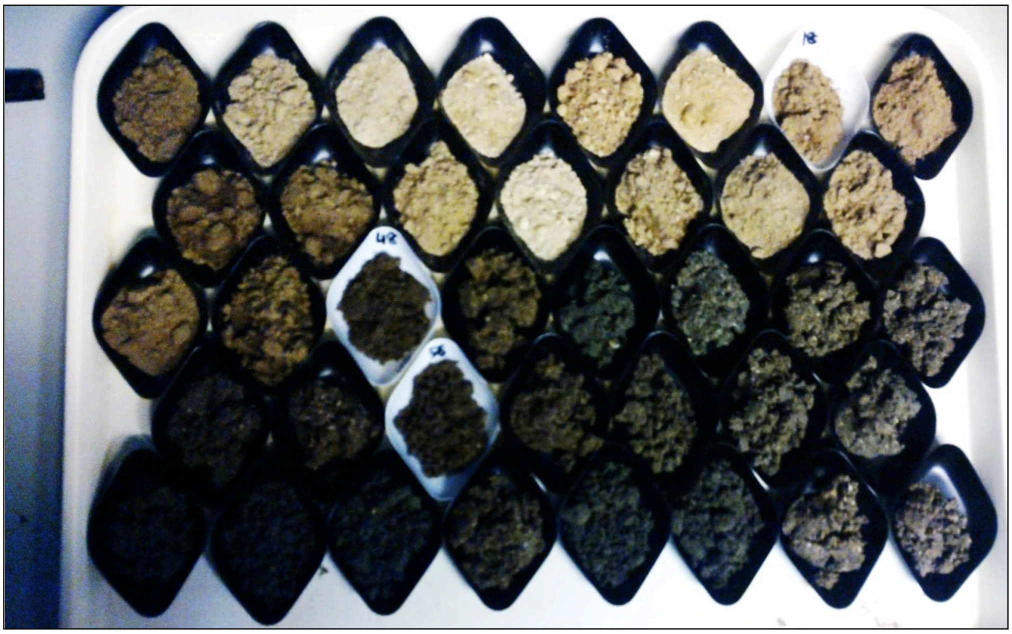

Figure 3.15 BE11 samples ready for drying (Photo: AM Kotarba-Morley 2013).

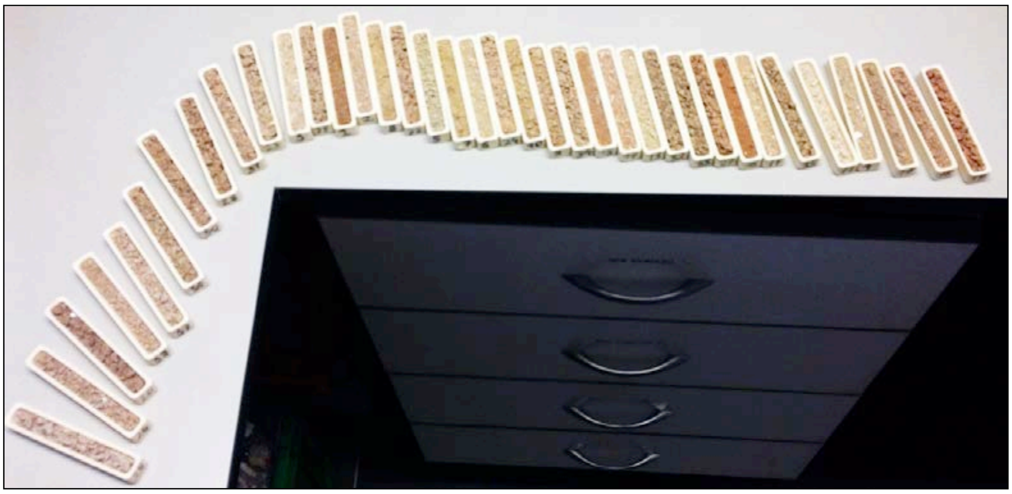

Figure 3.16 Sediment samples from cores from BE11 after weighing after 550° C burn and ready for 950° C burn (Photo AM Kotarba-Morley).

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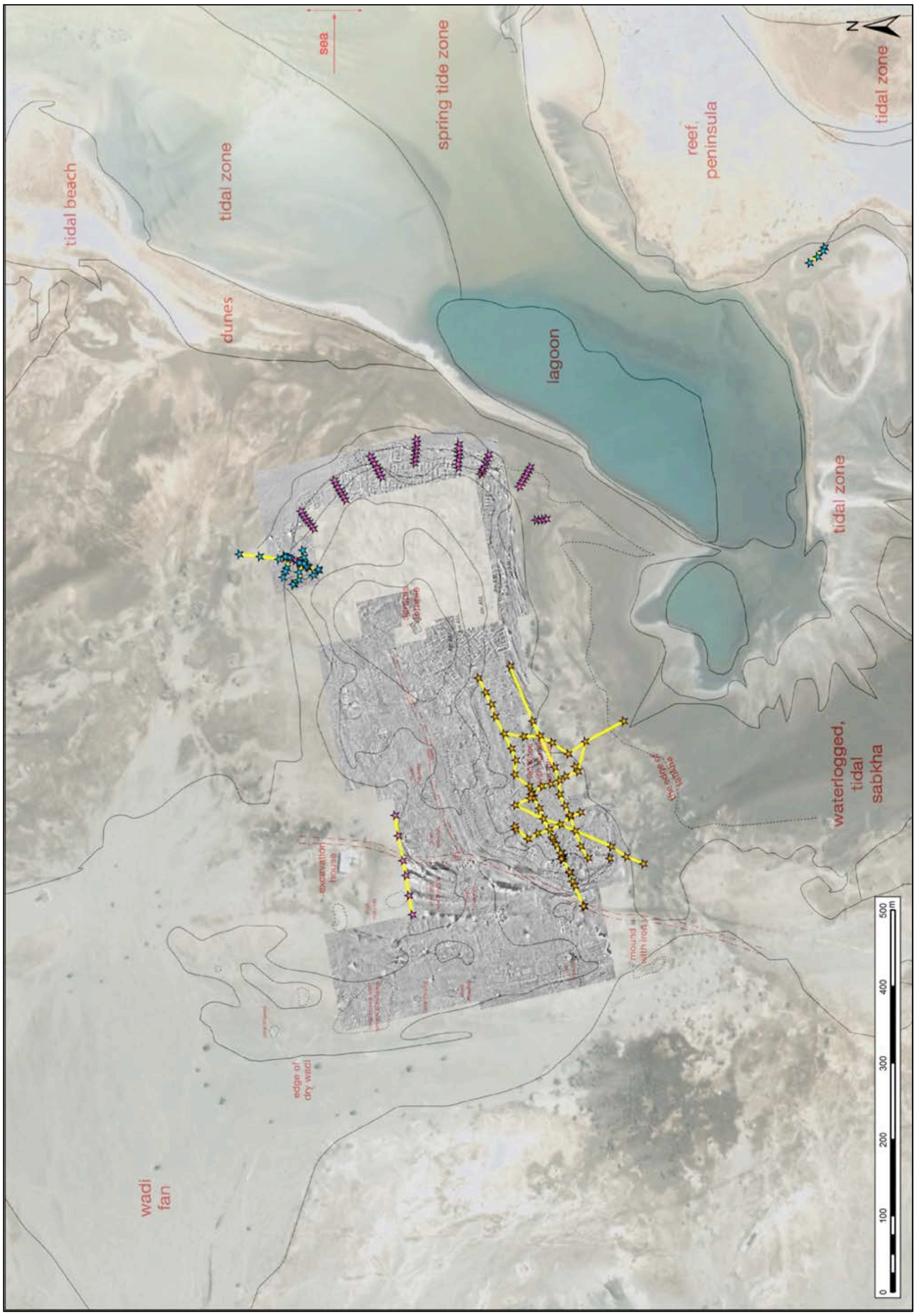


Figure 4.1 Map of the site showing baseline plan, geomagnetic results and coring transects from Harrell's 1995 & 2001 surveys (in pink), and the author's 2011 & 2012 surveys (in yellow) (Drawn by AM Kotarba-Morley 2013).

Figure 4.2 Microscopic photograph of Facies B in AH4. All taken using a handheld Dino-Lite microscope with 200x magnification (Photo: AM Kotarba-Morley 2011).

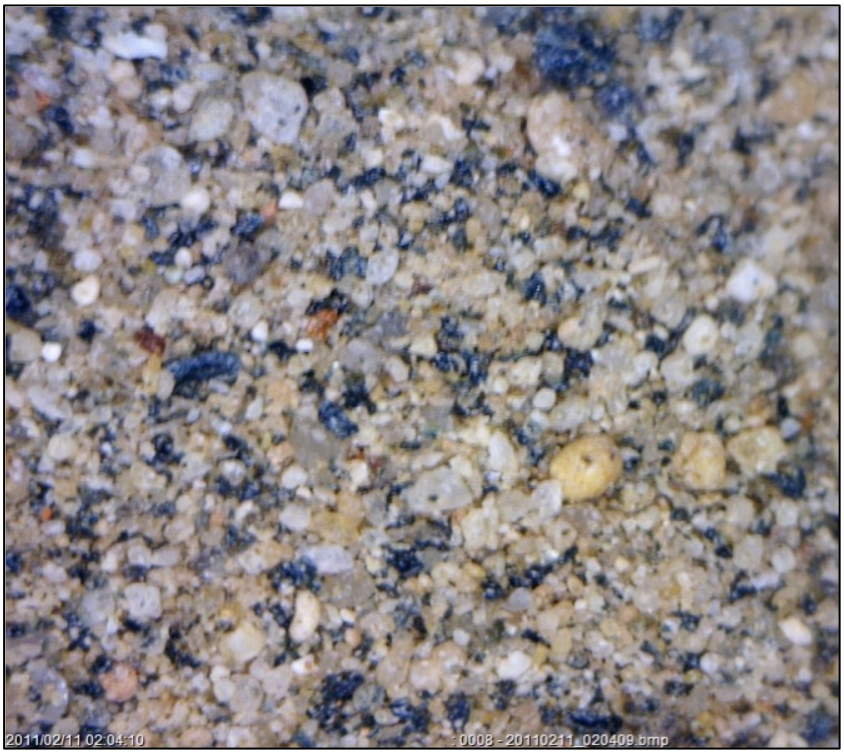


Figure 4.3 Microscopic photograph of Facies D in AH5 (Photo: AM Kotarba-Morley 2011).

Figure 4.4 Microscopic photograph of Facies G in AH20 (Photo: AM Kotarba-Morley 2011).

Figure 4.5a Microscopic photographs of Facies H in AH9 and AH16 (Photo: AM Kotarba-Morley 2011).

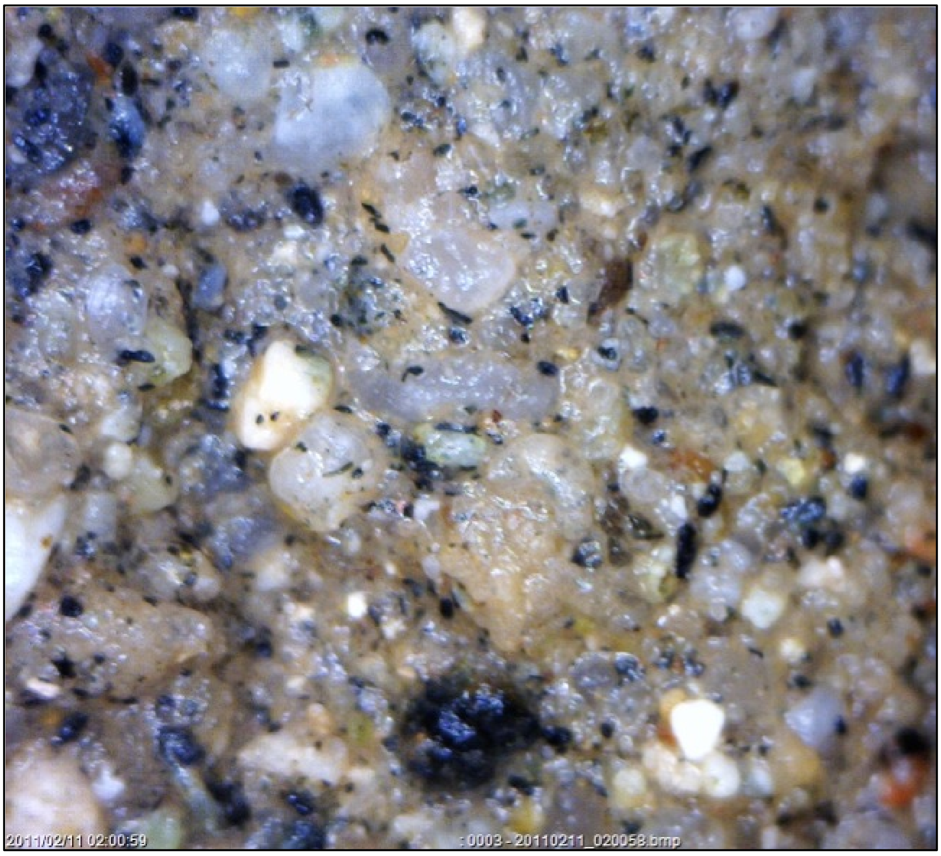


Figure 4.5b Microscopic photographs of Facies H in AH9 and AH16 (Photo: AM Kotarba-Morley 2011).

Figure 4.6 Microscopic photograph of Facies J in AH24 (Photo: AM Kotarba-Morley 2011).

Figure 4.7 Tidal sands around the bay – modern analogue (Photo: AM Kotarba-Morley 2011).

Figure 4.8 Beach sand south of the 'sandbank' area in Berenike – modern analogue (Photo: AM Kotarba-Morley 2012).

Figure 4.9 The beach located south from the site, view at low tide – modern analogue. Compare with the beach to the north of the site on Figure 2.21 (Photo: AM Kotarba-Morley 2011).

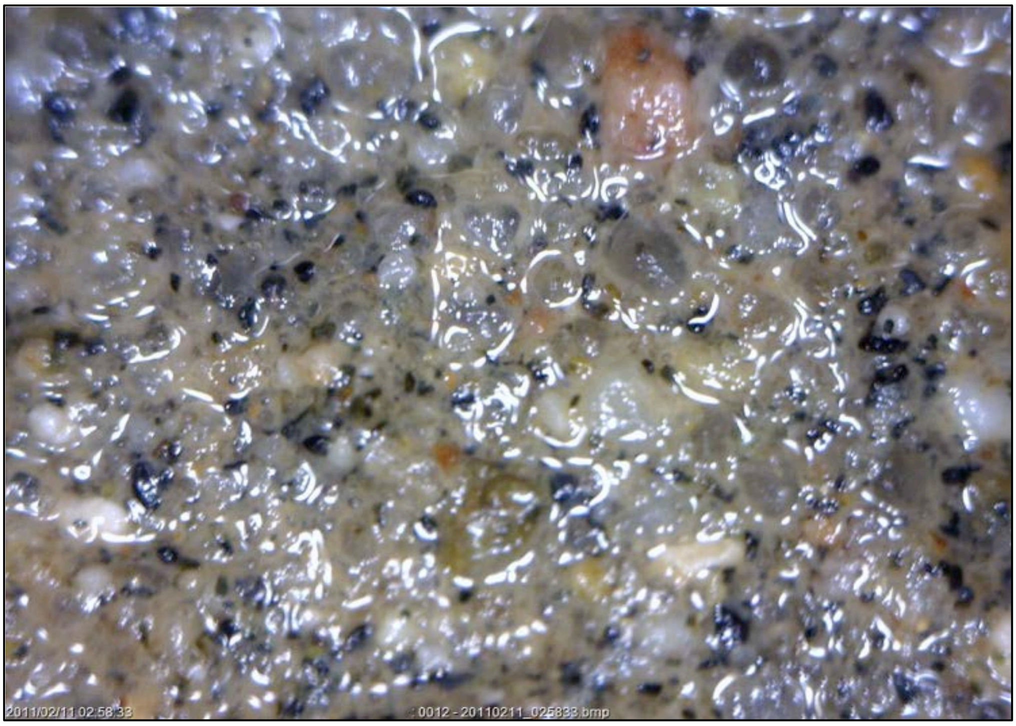


Figure 4.10 Microscopic photograph of Facies L in AH36 (Photo: AM Kotarba-Morley 2011).

Figures 4.11 Microscopic photograph of Facies M (dark and light laminas) in AH18 (Photo: AM Kotarba-Morley 2011).

Figure 4.12 Microscopic photograph of Facies M (dark and light laminas) in AH18 (Photo: AM Kotarba-Morley 2011).

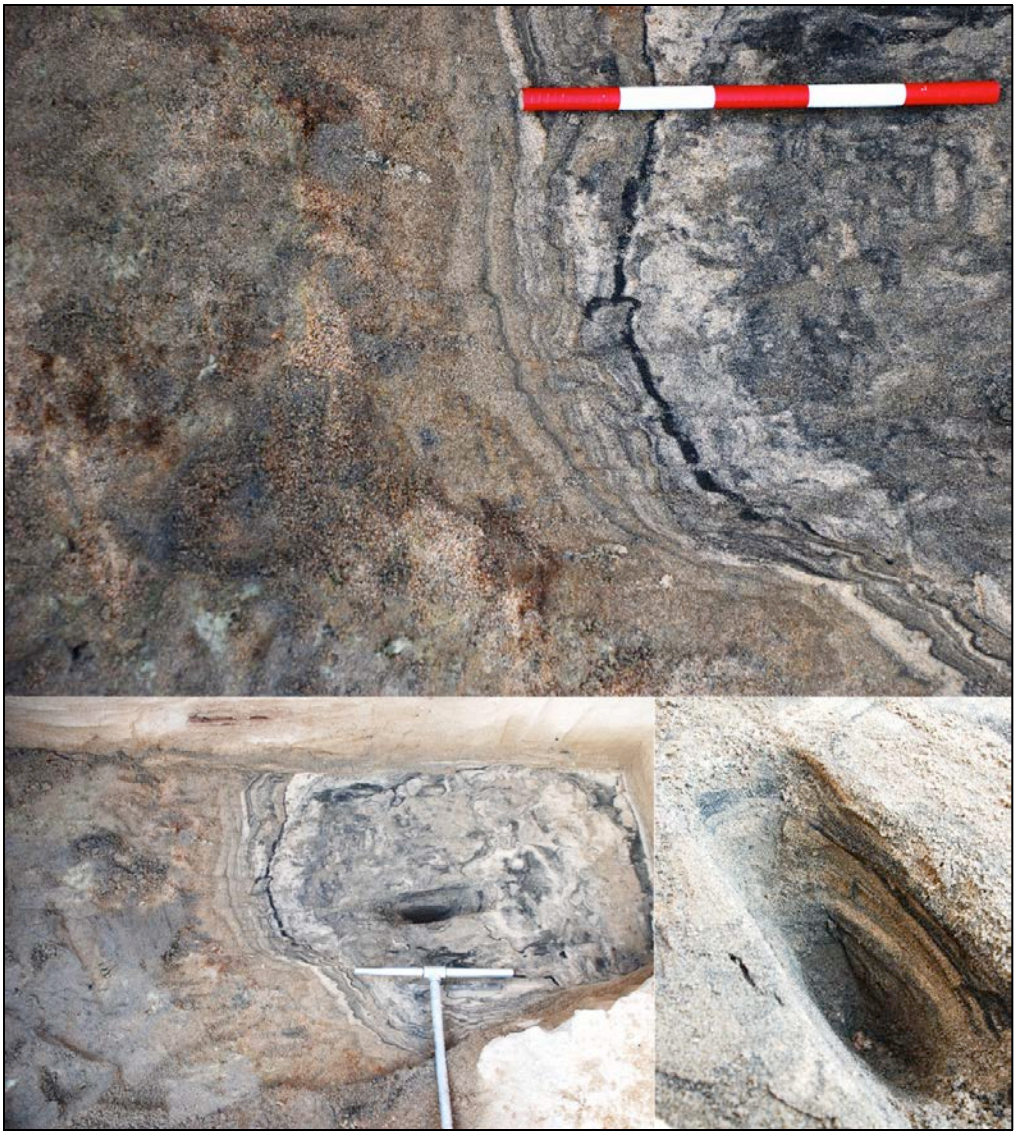


Figure 4.13 Remains of the laminated tidal beach underlying the hearths uncovered in trench BE11-71 (Photo: AM Kotarba-Morley 2011).

Figure 4.14 Modern view of the surface of the tidal beach with manganese mineral staining. View towards the south (Photos: AM Kotarba-Morley 2011).

Figure 4.15 Microscopic photograph of Facies O in AH13 (Photo: AM Kotarba-Morley 2011).

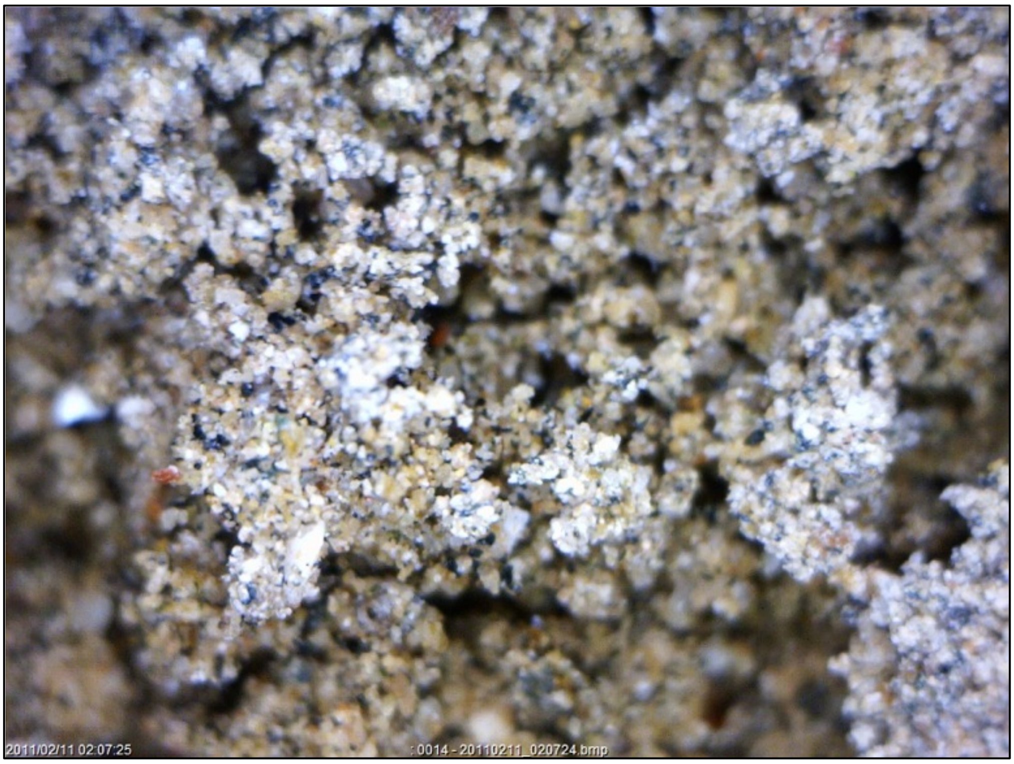


Figure 4.16 Microscopic photograph of Facies P in AH04 (Photo: AM Kotarba-Morley 2011).

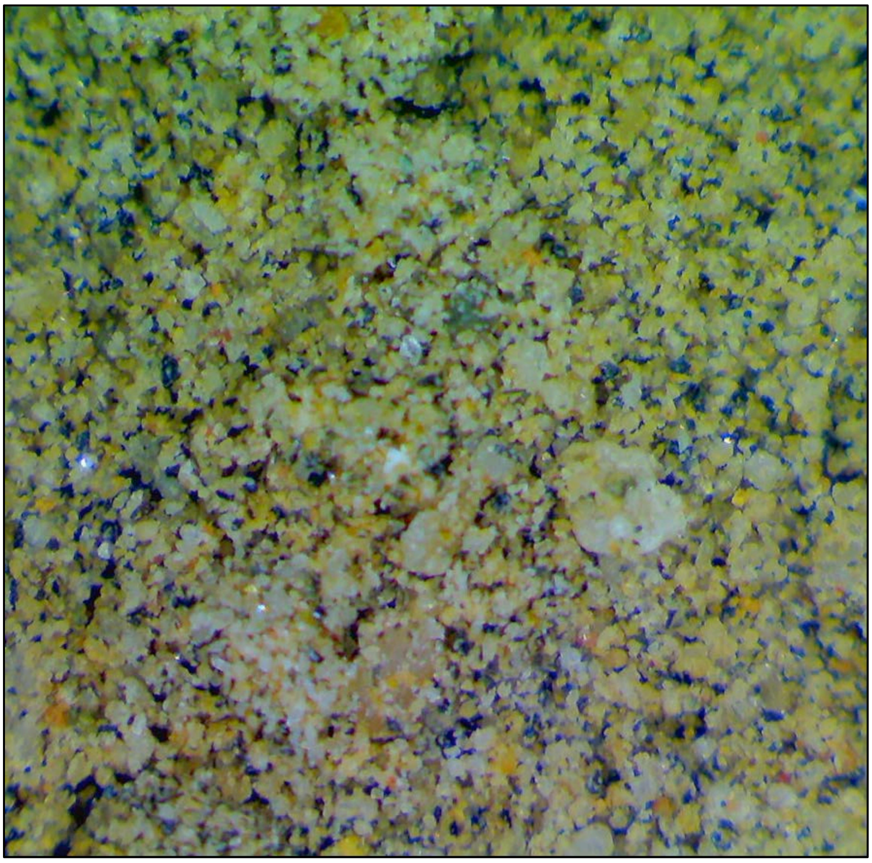


Figure 4.17 Microscopic photograph of Facies A² in AH01² (Photo: AM Kotarba-Morley 2012).

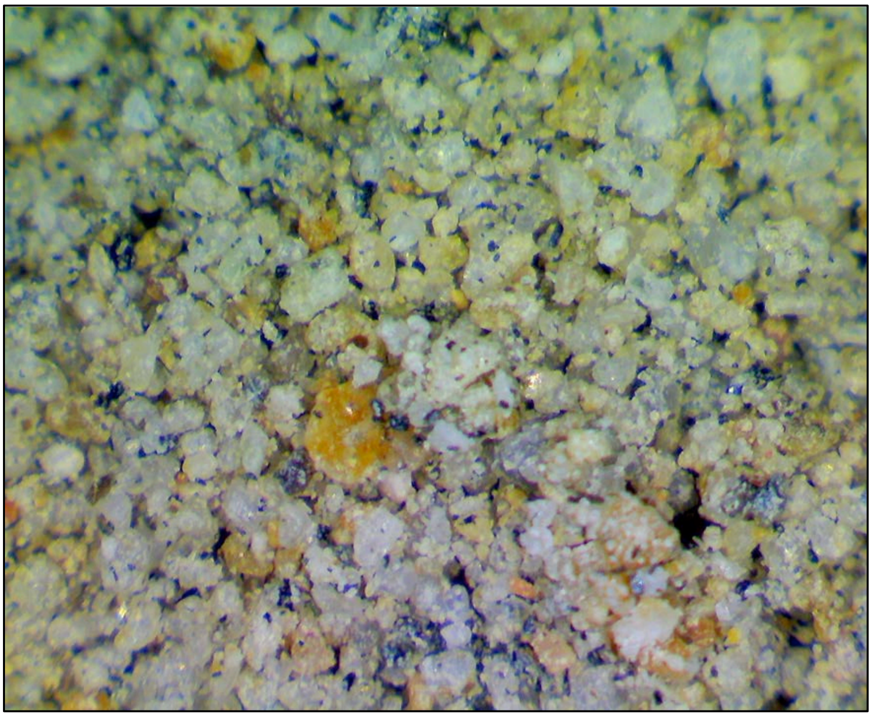


Figure 4.18a Microscopic photograph of Facies B² in AH01² and AH03² (Photos: AM Kotarba-Morley 2012).

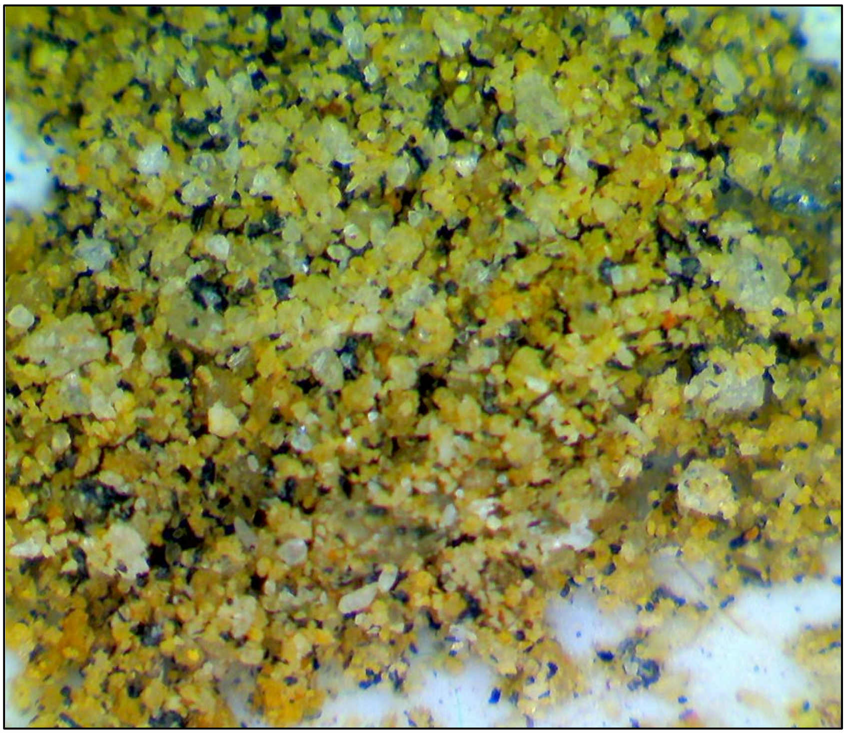


Figure 4.18b Microscopic photograph of Facies B² in AH01² and AH03² (Photos: AM Kotarba-Morley 2012).

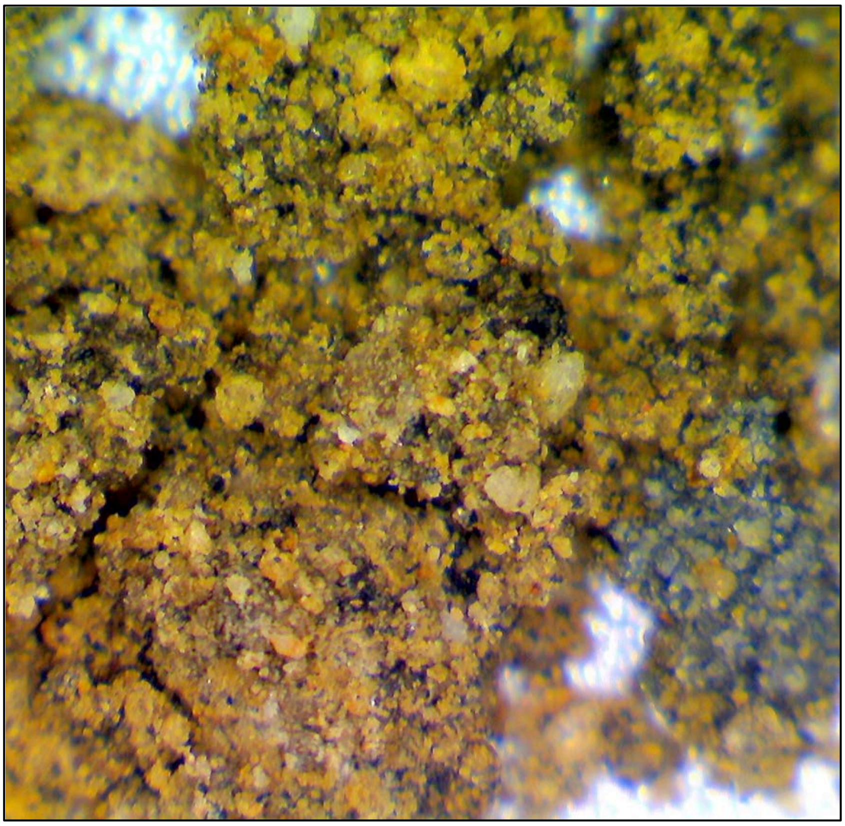


Figure 4.19 Microscopic photograph of Facies C² in AH03² (Photo: AM Kotarba-Morley 2012).

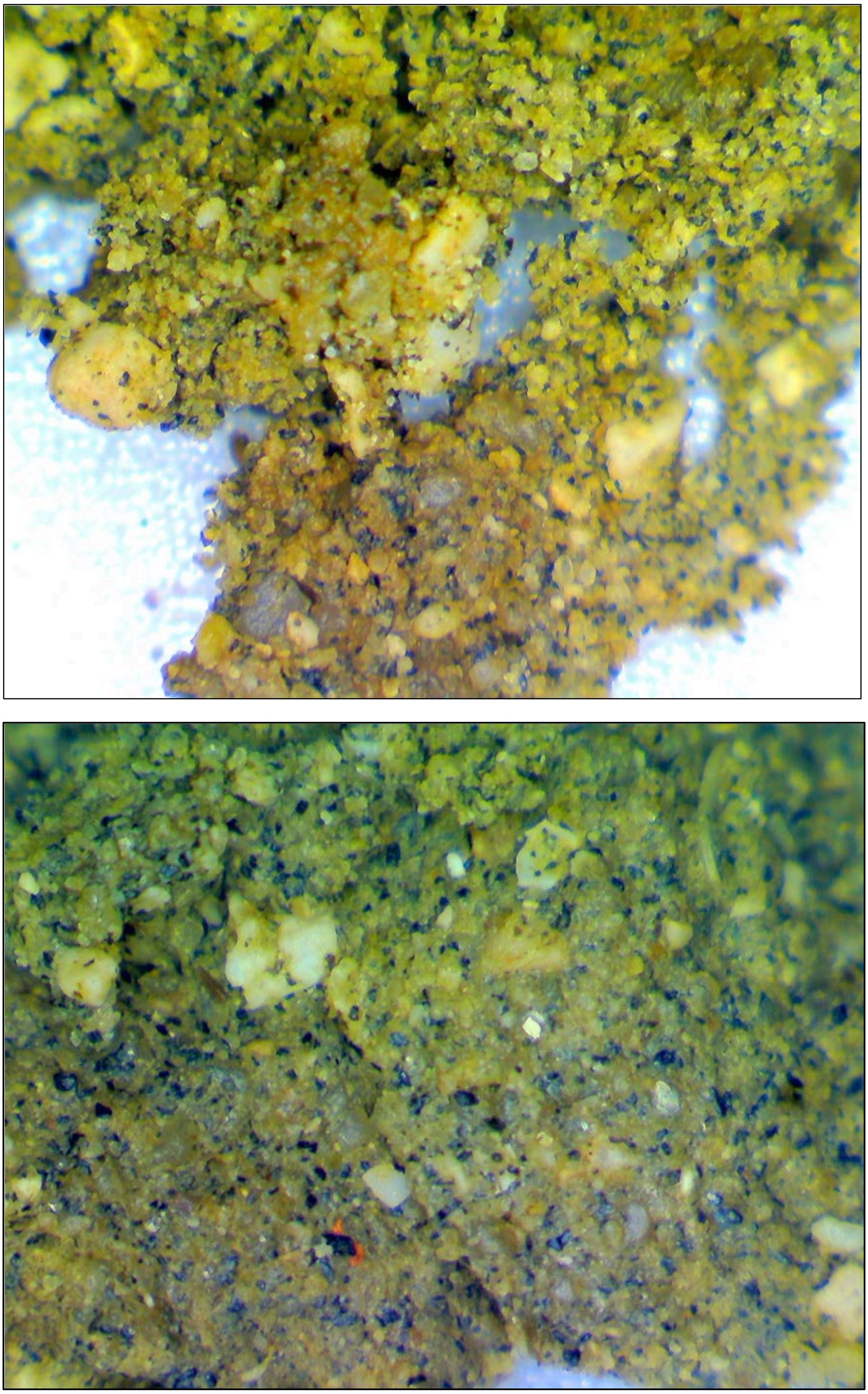


Figure 4.20 Two microscopic photographs of Facies D[2] in AH01[2] (Photo: AM Kotarba-Morley 2012).

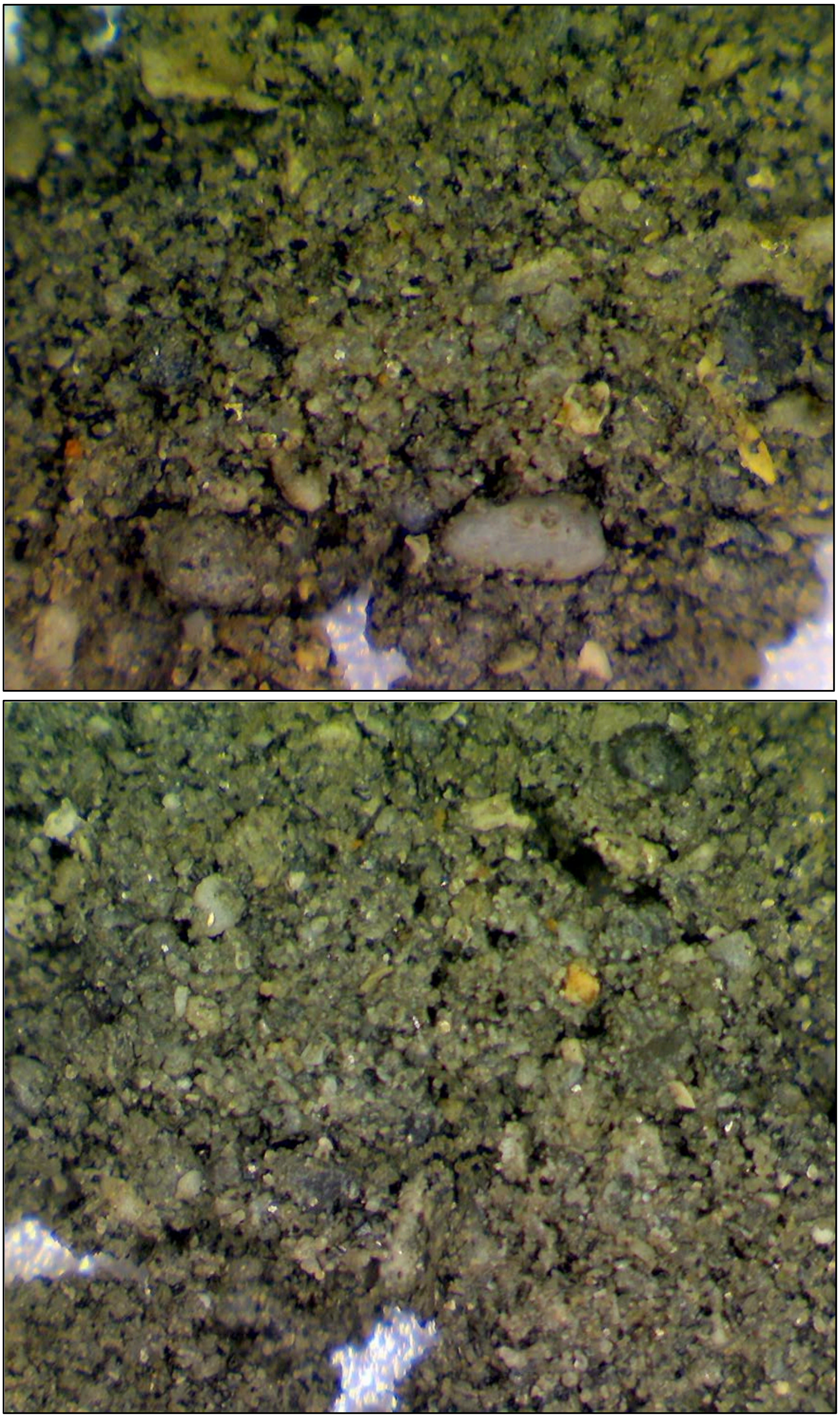


Figure 4.21 Two microscopic photographs with visible pebbles and fragments of shell of Facies E² in AH01² and AH03² (Photo: AM Kotarba-Morley 2012).

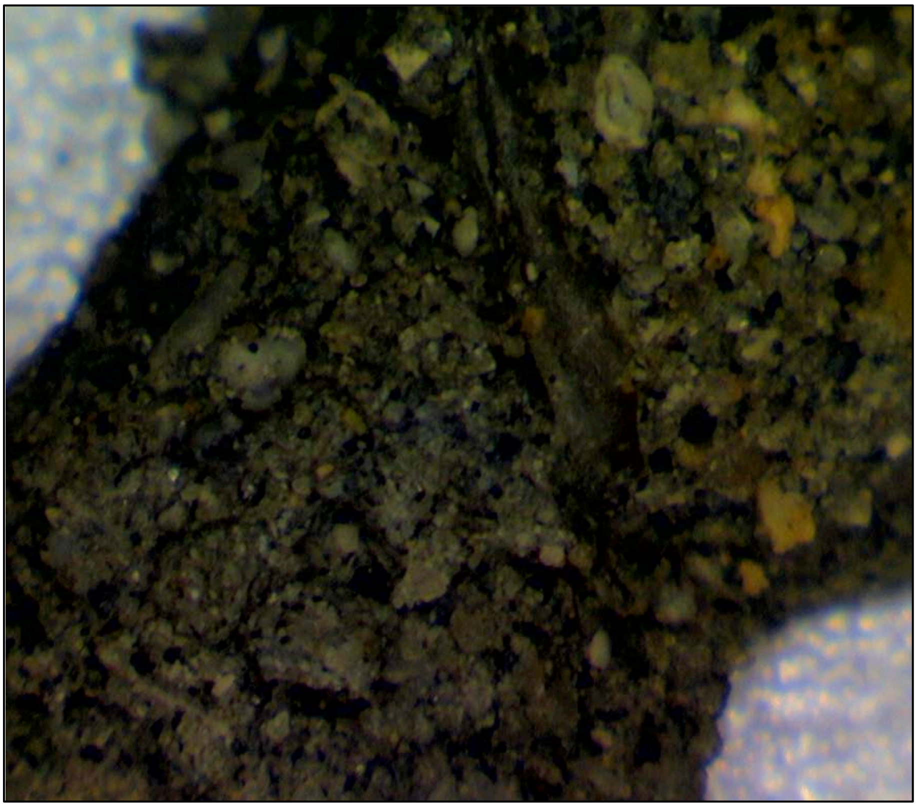


Figure 4.22 Microscopic photograph of Facies F^2 in $AH02^2$ (Photo: AM Kotarba-Morley 2012).

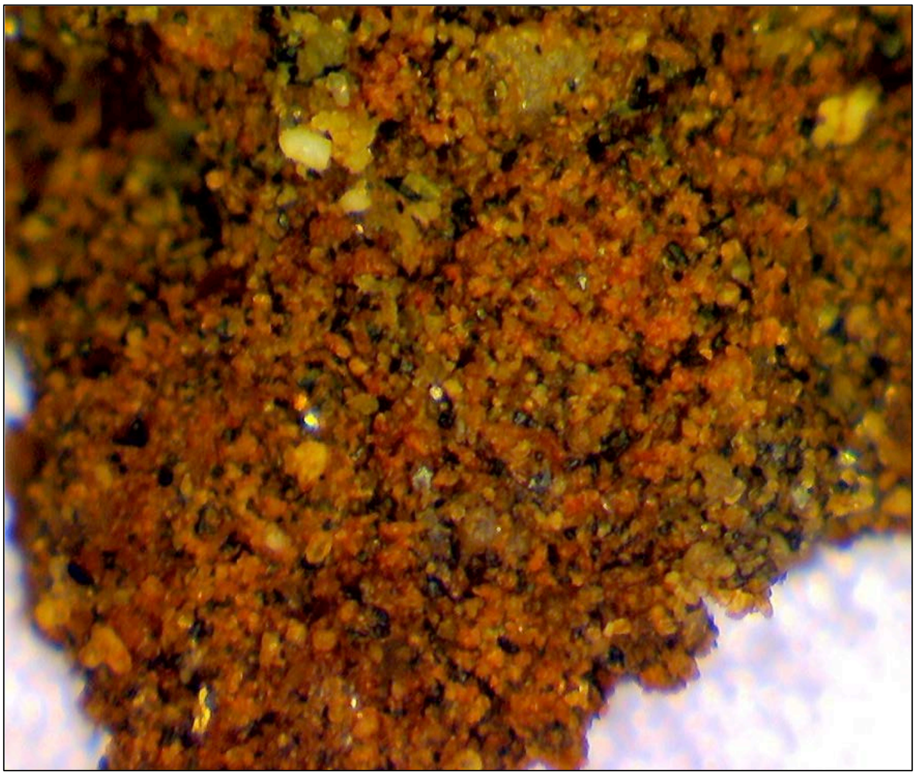


Figure 4.23 Microscopic photograph of Facies M^2 in $AH03^2$ (Photo: AM Kotarba-Morley 2012.

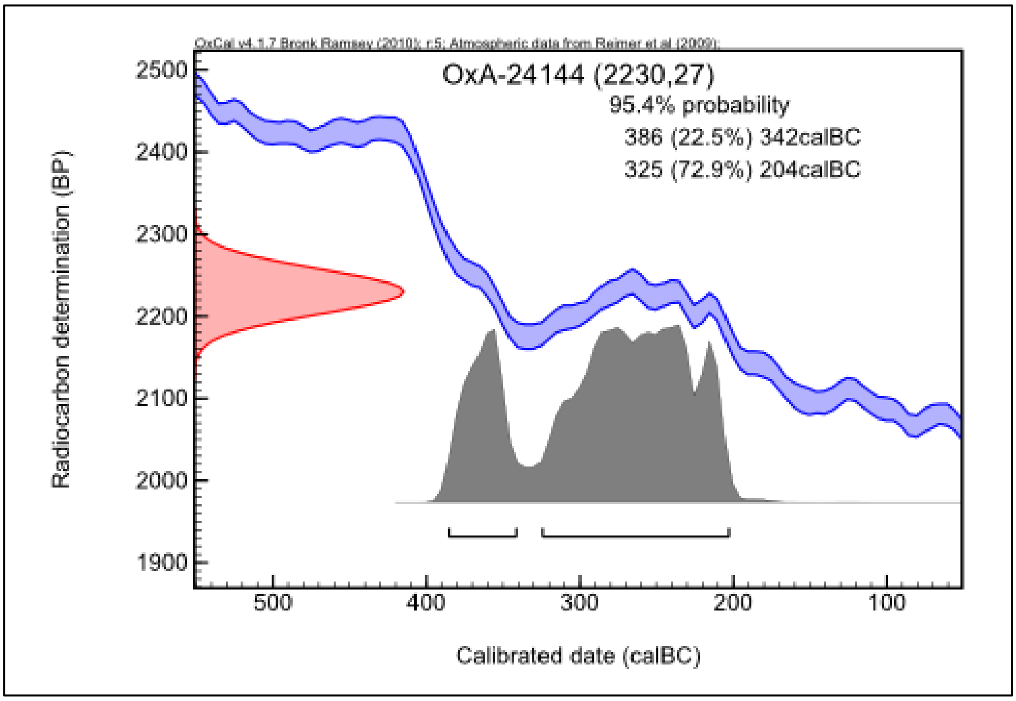


Figure 4.24 Calibrated date curve for sample OxA-24144 – AH17b, Facies E[1].

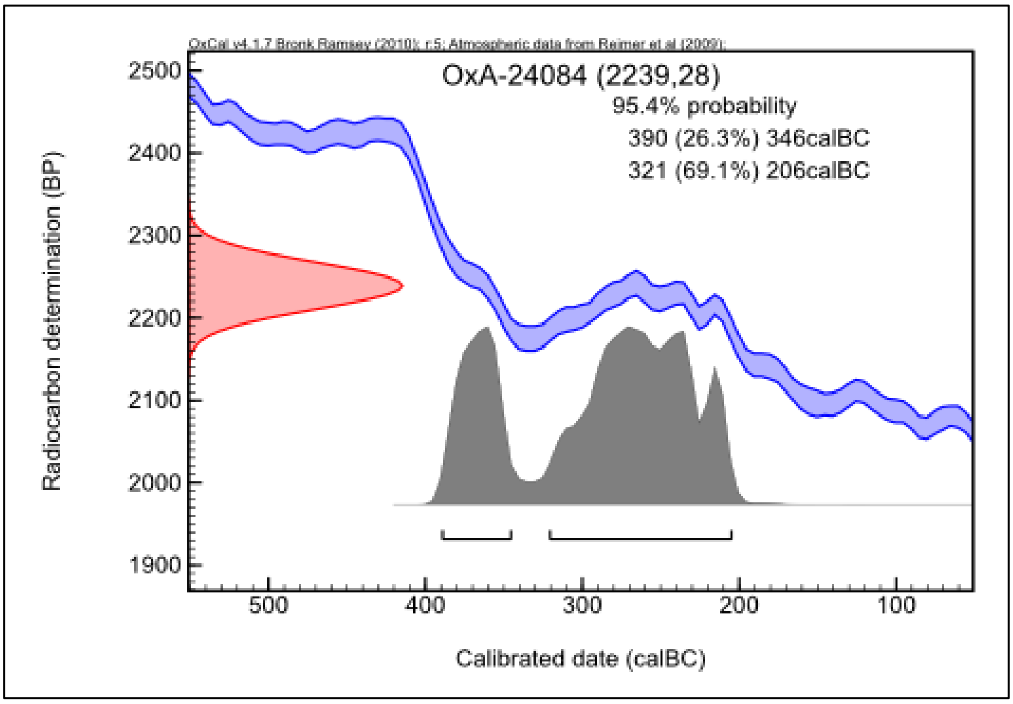


Figure 4.25 Calibrated date curve for sample OxA-24084 – AH17c, Facies E[1].

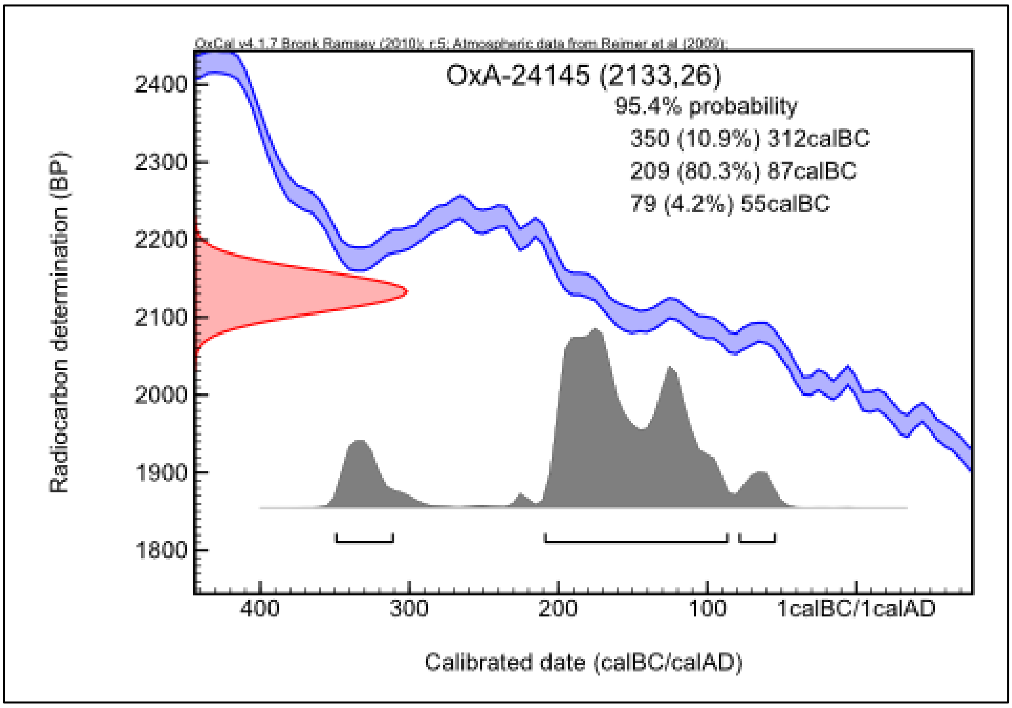


Figure 4.26 Calibrated date curve for sample OxA-24145 – AH16, Facies G.

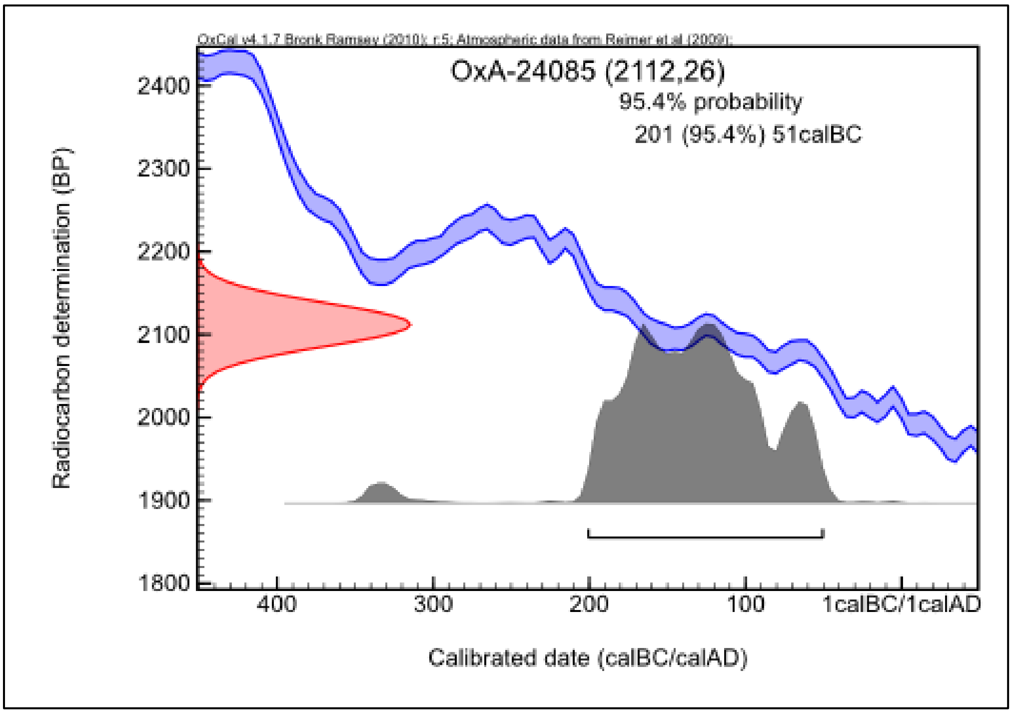


Figure 4.27 Calibrated date curve for sample OxA-24085 – AH16, Facies G.

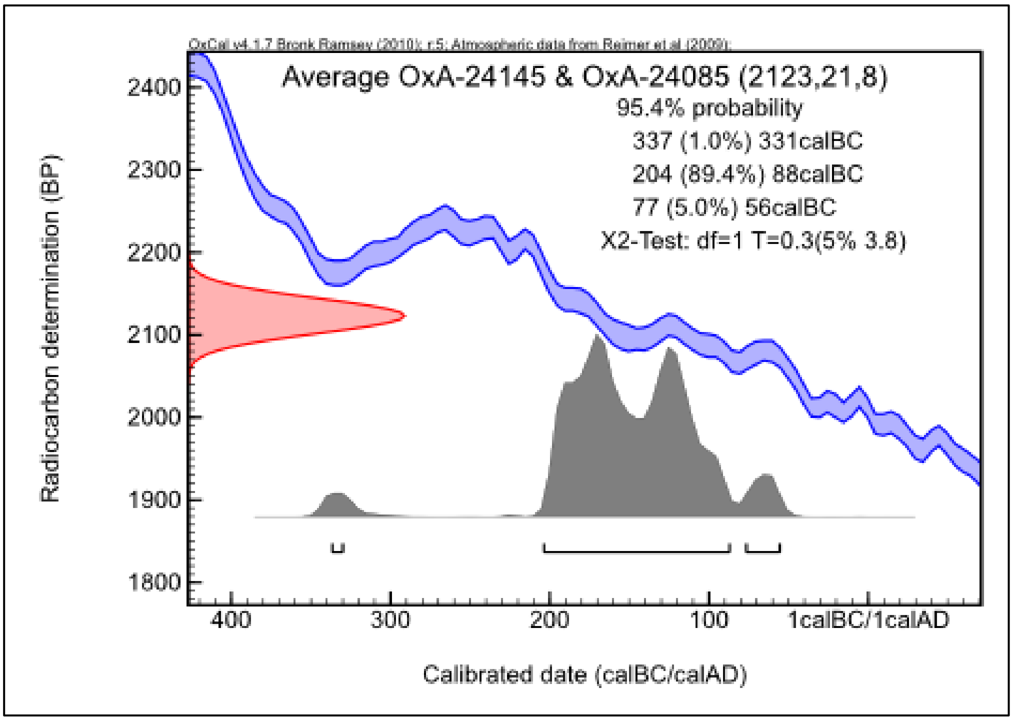


Figure 4.28 Calibrated date curve for both sample OxA-24145 and OxA-24085 – AH16, Facies G.

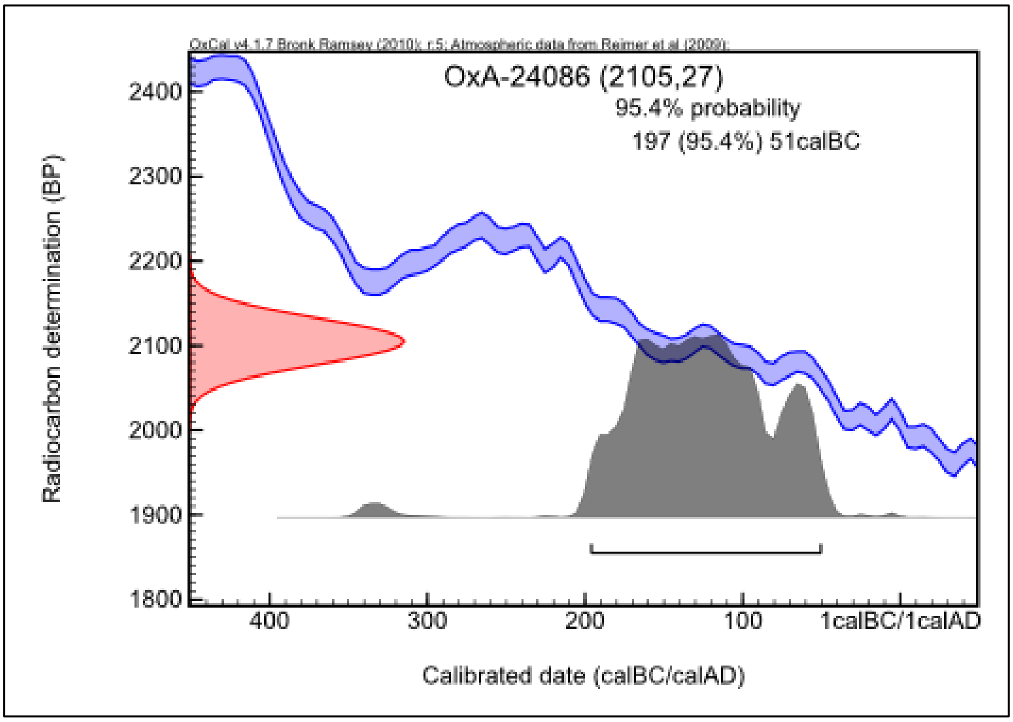
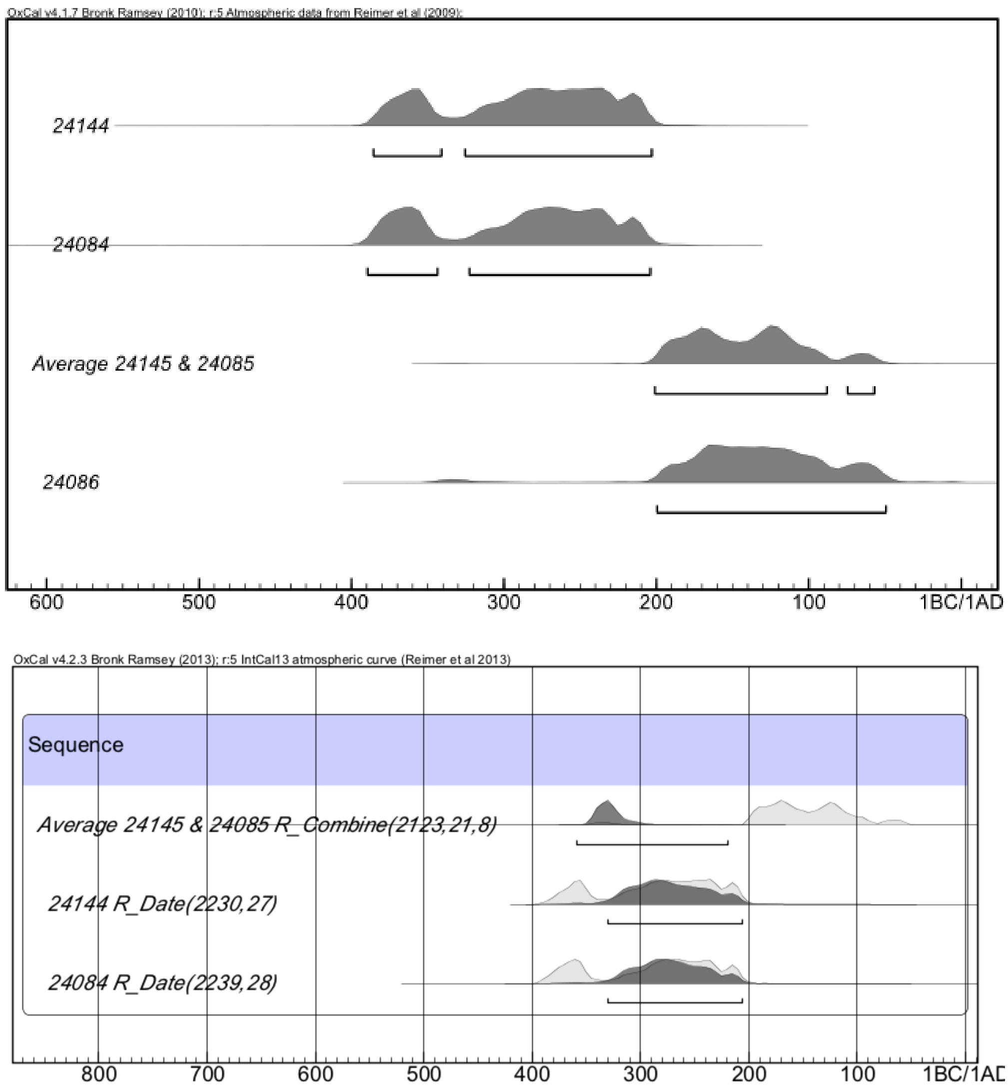


Figure 4.29 Calibrated date curve for sample OxA-24086 – AH19, Facies G.



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Name (Show all / Show structure)	Unmodelled (BC/AD) from	to	%	Modelled (BC/AD) from	to	%	Indices A_{model}=33.9 $A_{overall}$=34.1 A_{comb}	A	L	P	C	Select (All / Visible)	Page break
				Warning! Poor agreement - A= 34.1%(A'c= 60.0%) Warning! Poor agreement - A= 33.9%(A'c= 60.0%)									
▼ General Outlier_Model				-102	353	95.4					78.5	☑ 10	☐
T(5)	-2.65	2.65	95.4								48.8	☑ 11	☐
U(0,4)	3.98986e-17	4	95.4	5.37764e-17	3.744	95.4		100			94.7	☑ 2	☐
▼ Sequence												☑ 3	☐
Boundary				-703	-252	95.4					98.7	☑ 4	☐
Average 24145 & 24085 R_Combine(2123,21,8)	-335	-56	95.4	-360	-220	95.4		11		85.5	99.8	☑ 5	☐
				Warning! Poor agreement - A= 11.0%(A'c= 60.0%)									
▼ 2.84m Phase												☑ 6	☐
24144 R_Date(2230,27)	-384	-204	95.4	-331	-206	95.4		104.4		97	99.6	☑ 7	☐
24084 R_Date(2239,28)	-388	-206	95.4	-331	-206	95.4		100.9		96.9	99.4	☑ 8	☐
Boundary				-336	284	95.4					97.8	☑ 9	☐

Figure 4.30 Top: Plot of modelled calibrated dates in the 'passed' model. Middle: Plot of modelled calibrated dates in a 'failed' model. Bottom: 'Failed' model screen shot of data analyses from OxCal 4.2 (Courtesy of M Dee).

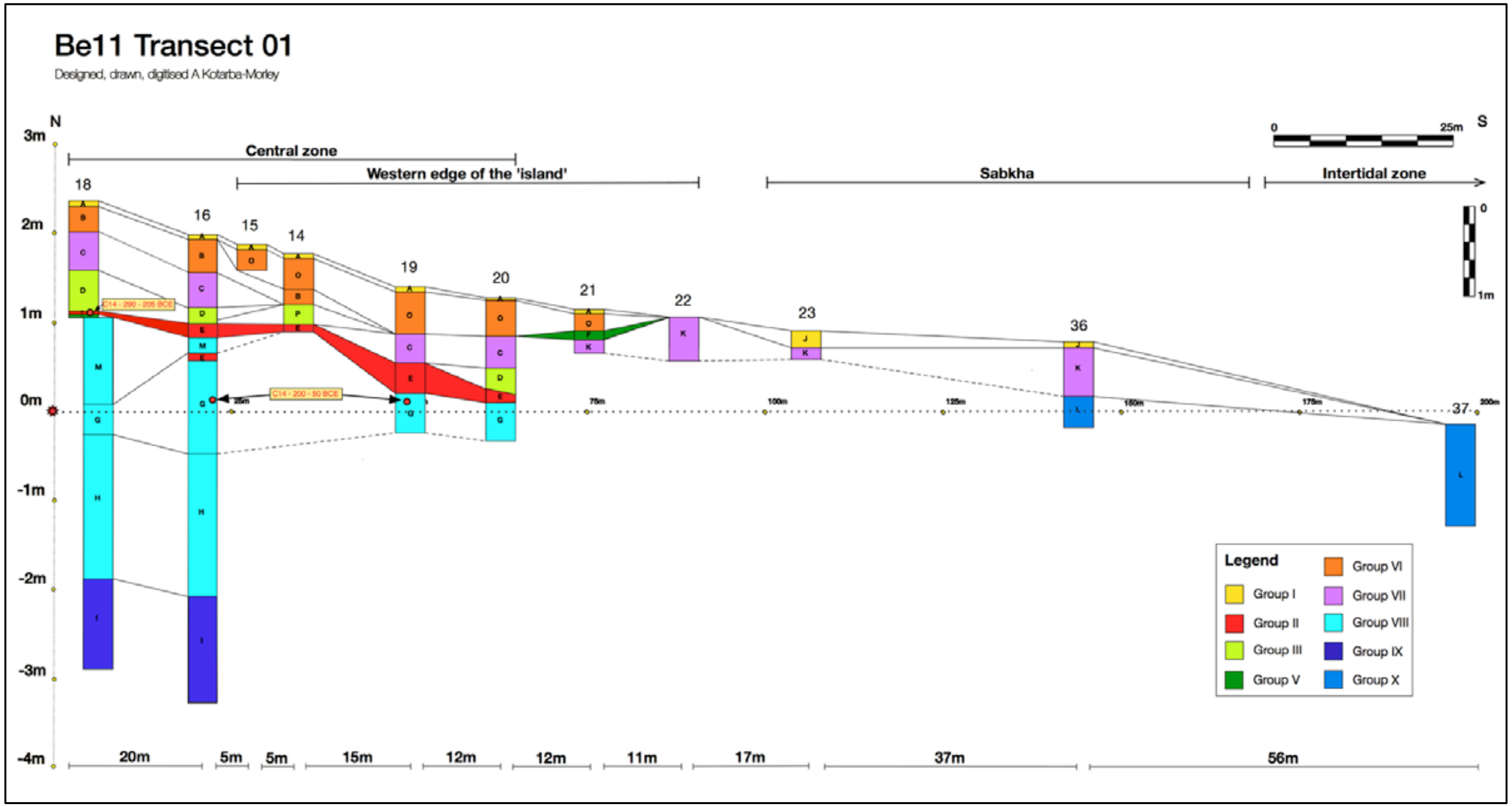


Figure 4.31 Transect BE11-T01 with radiocarbon dates location. The distance between each augerhole or section is presented on the horizontal axis (and above its interpretative allocation to a particular functional zone of the site), and on the vertical axis represents the depth of the interventions. The 0 – meeting point of X- and Y-axis has been established as the current MSL. Note that the vertical scale on each transect is exaggerated to allow a more legible representation of stratigraphic logs in each augerhole and to pick up topographic changes in transects. (Drawn by AM Kotarba-Morley).

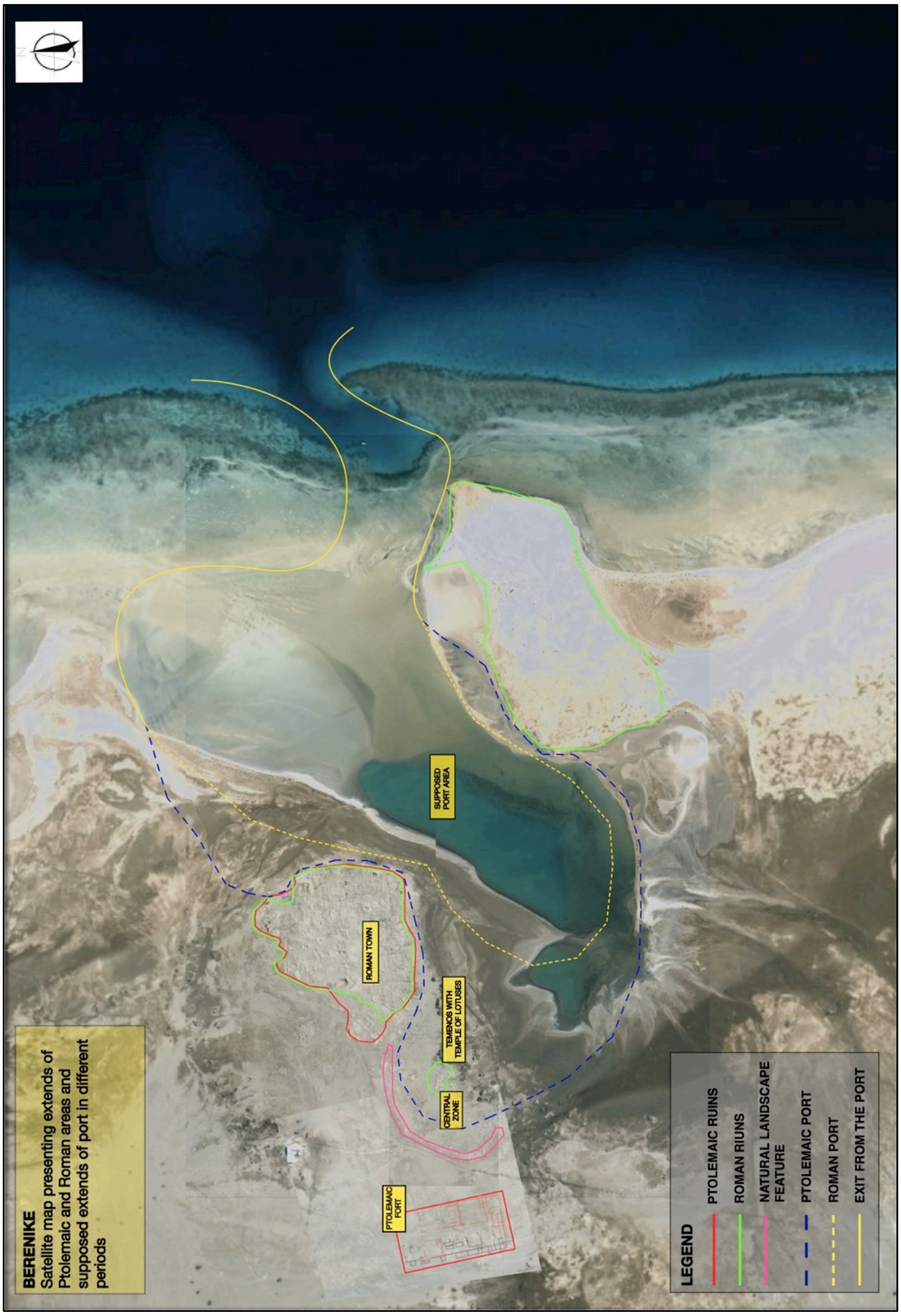


Figure 4.32 Google Earth illustration with a flooded landscape/beach moved towards BE11-71 (by AM Kotarba-Morley).

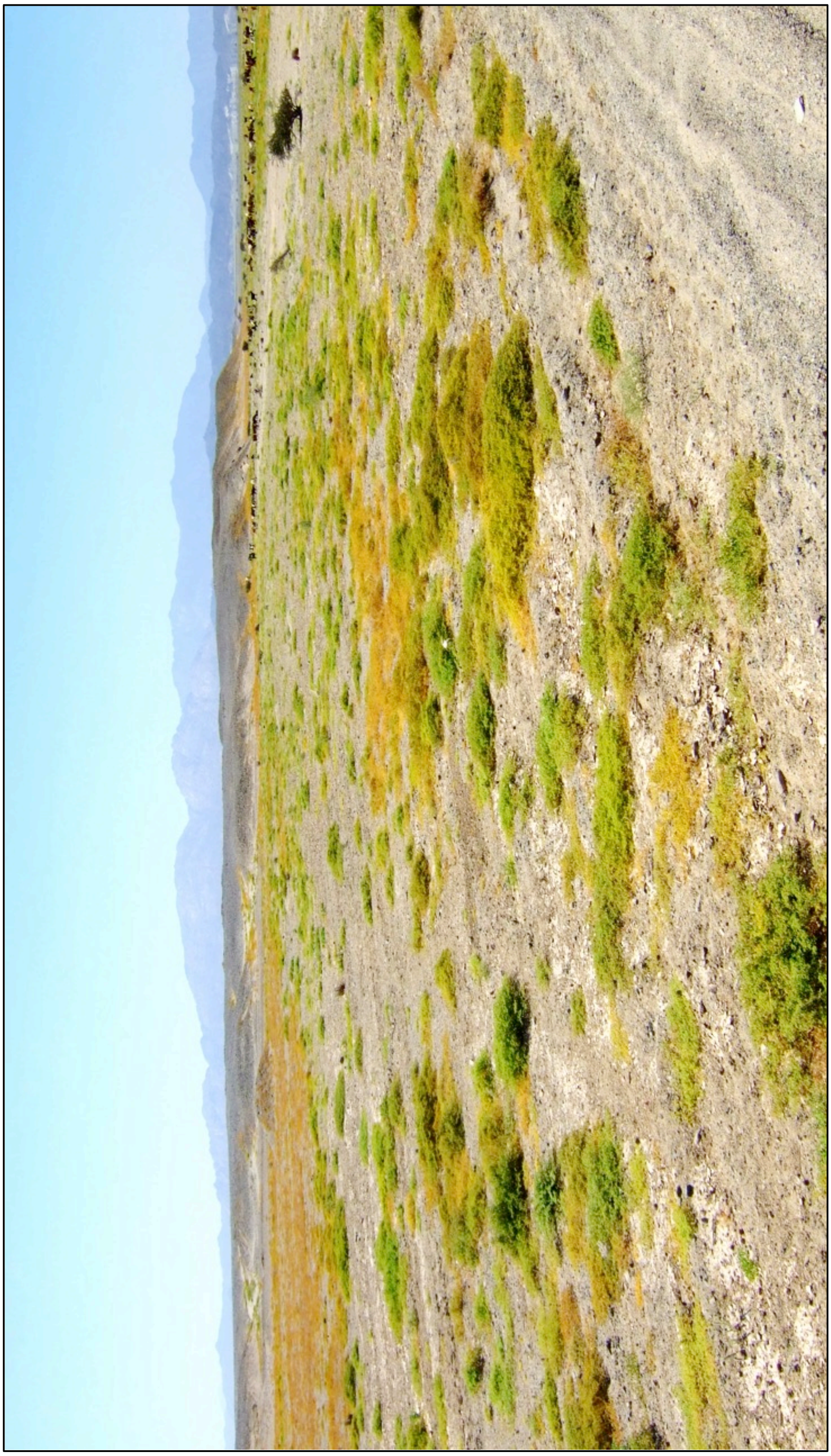


Figure 4.33 Southern part of Berenike after rains in winter 2013. Compare with Figure 2.11 showing the northern part of the site (Photo: AM Kotarba-Morley 2013).

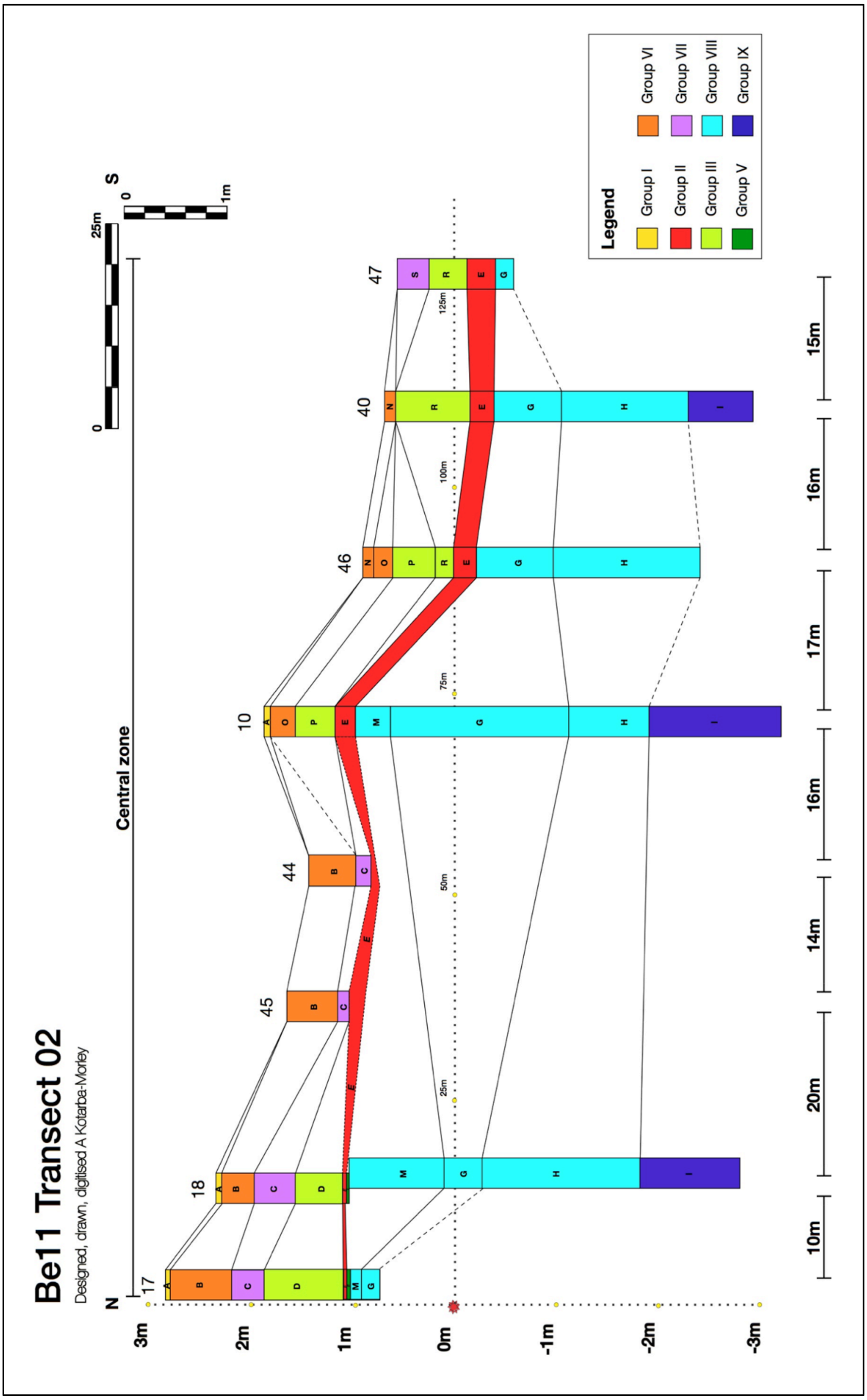


Figure 4.34 Transect BE11-T02 (Drawn by AM Kotarba-Morley).

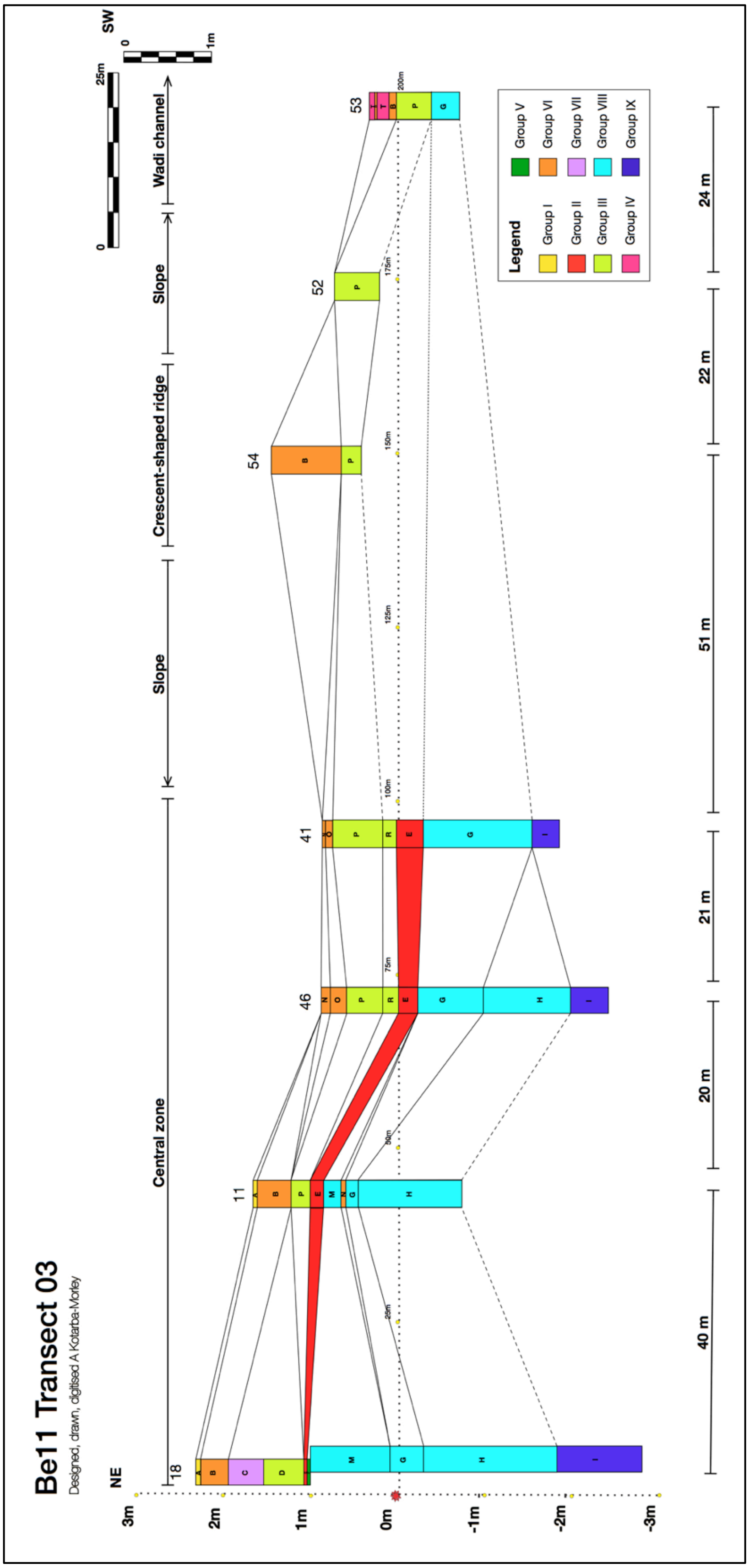


Figure 4.35 Transect BE11-T03 (Drawn by AM Kotarba-Morley).

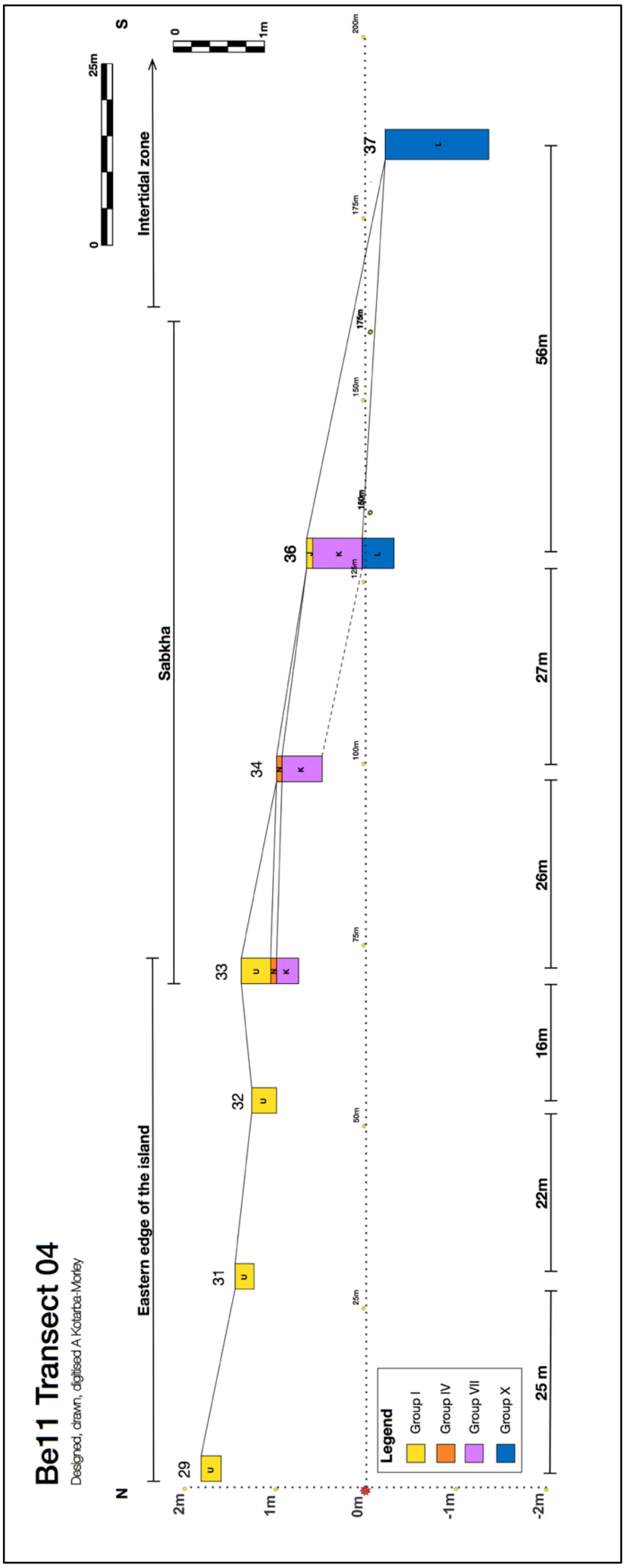


Figure 4.36 Transect BE11-T04 (Drawn by AM Kotarba-Morley).

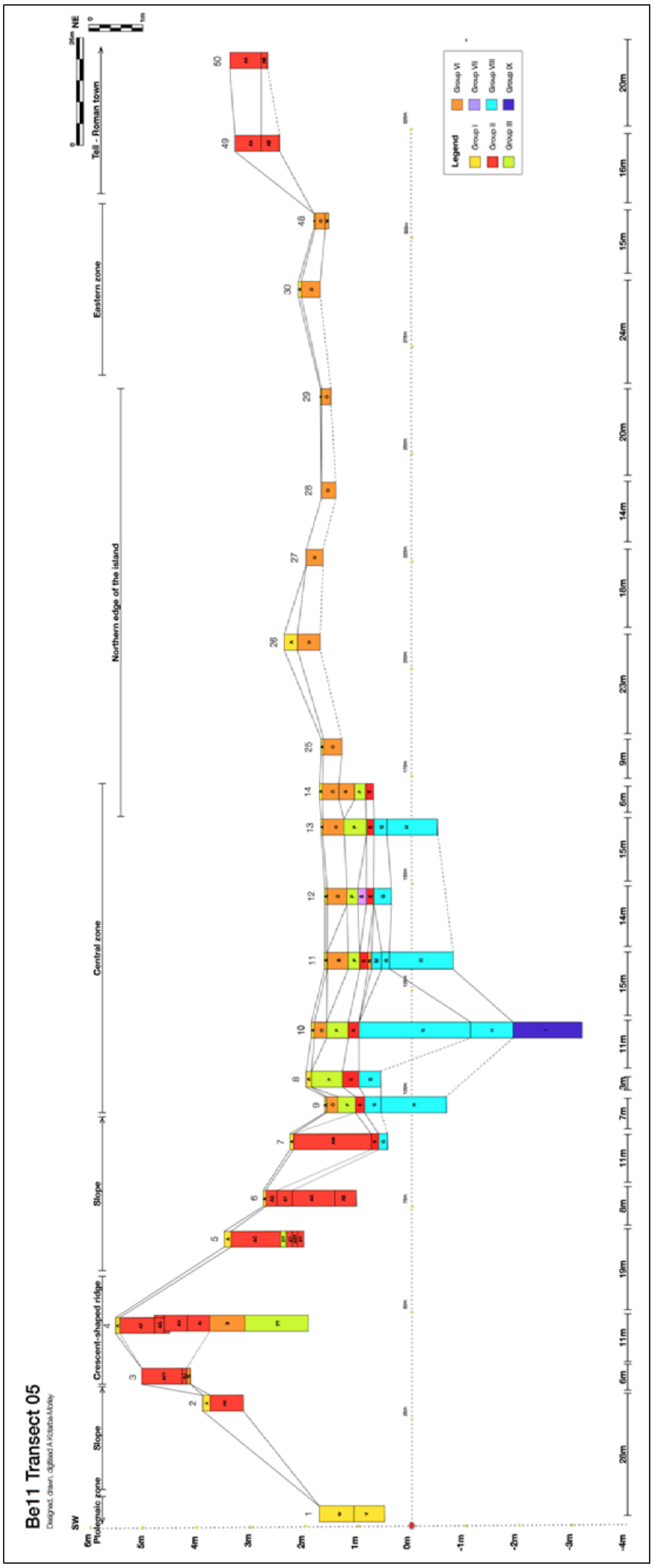


Figure 4.37 Transect BE11-T05 (Drawn by AM Kotarba-Morley).

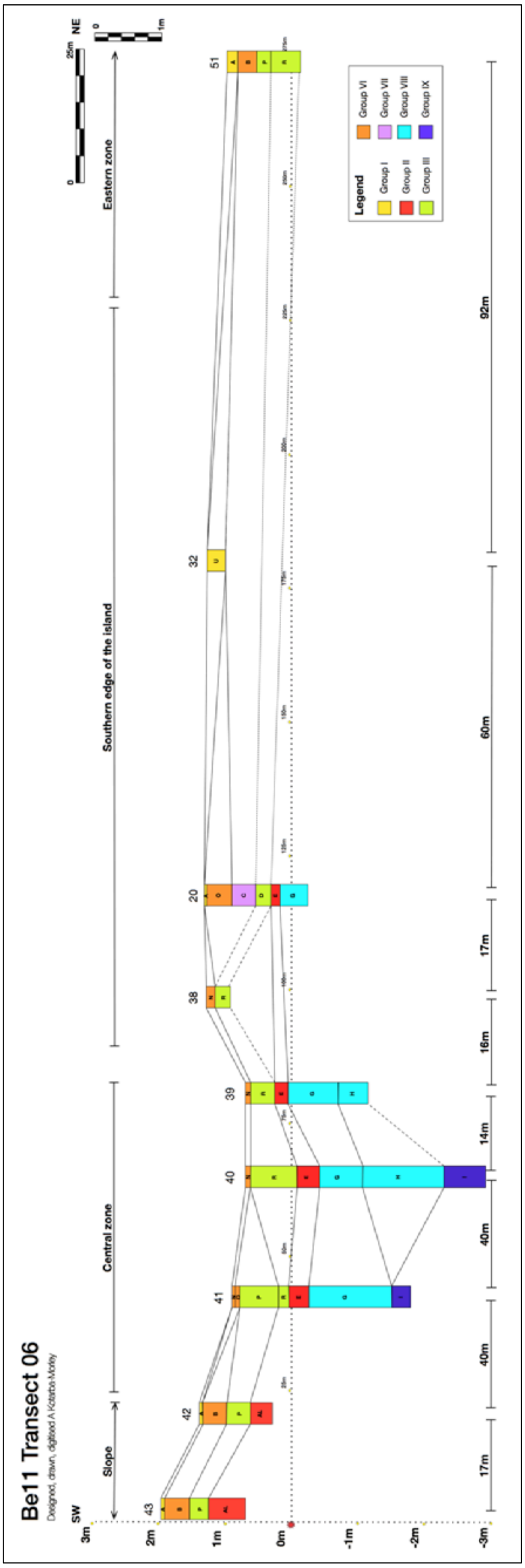


Figure 4.38 Transect BE11-T06 (Drawn by AM Kotarba-Morley).

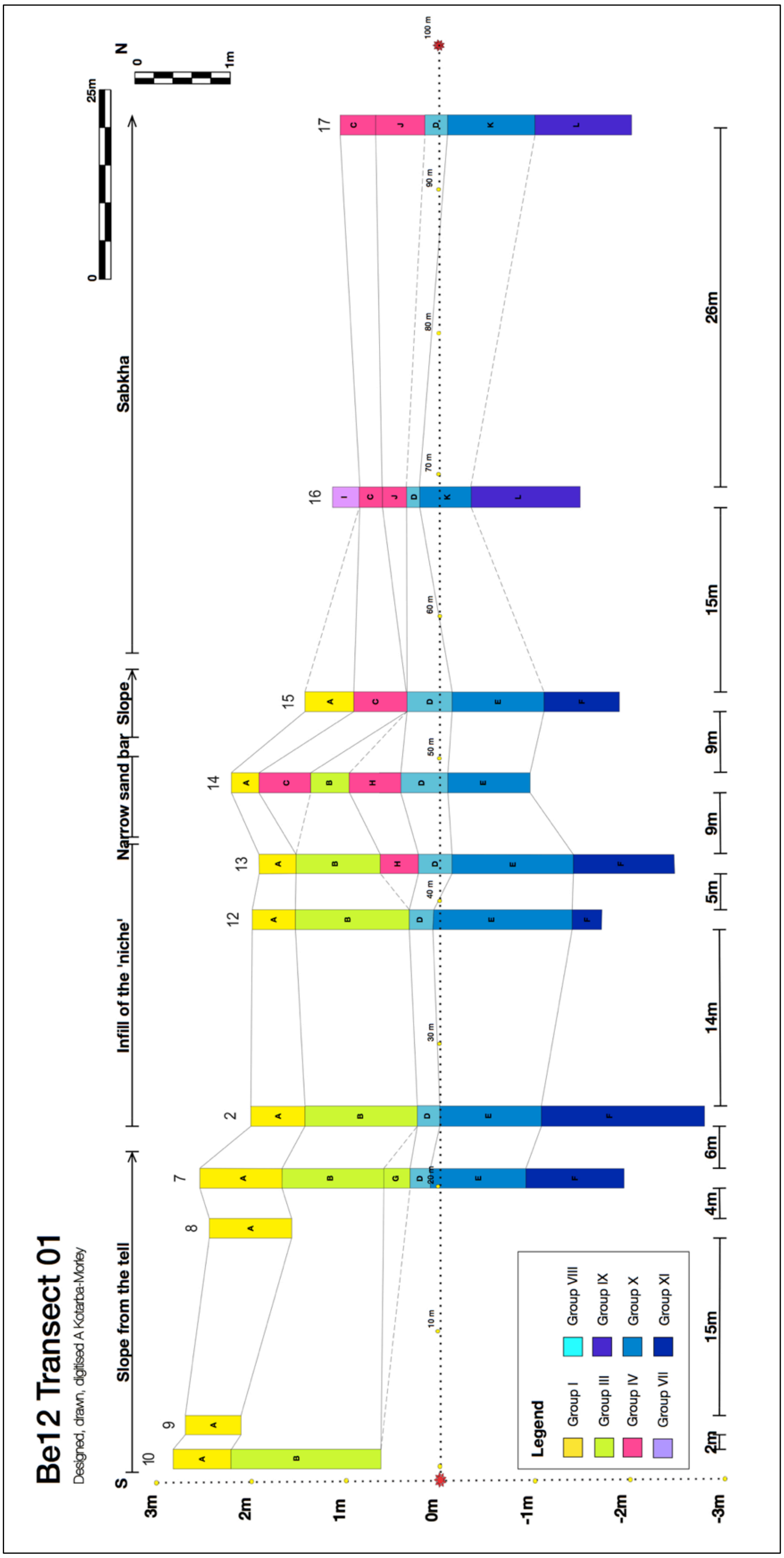


Figure 4.39 Transect BE12-T01 (Drawn by AM Kotarba-Morley).

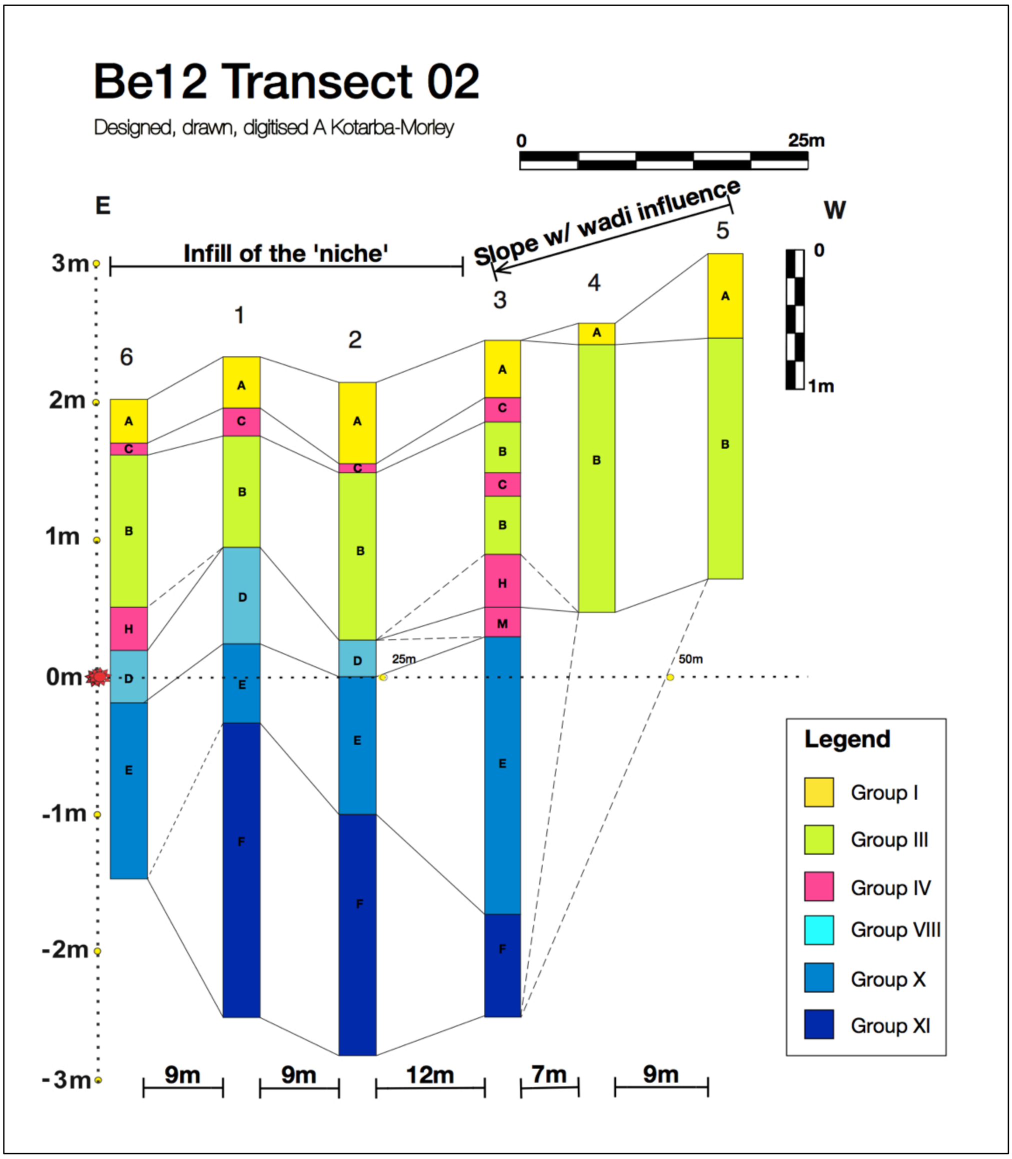


Figure 4.40 Transect BE12-T02 (Drawn by AM Kotarba-Morley).

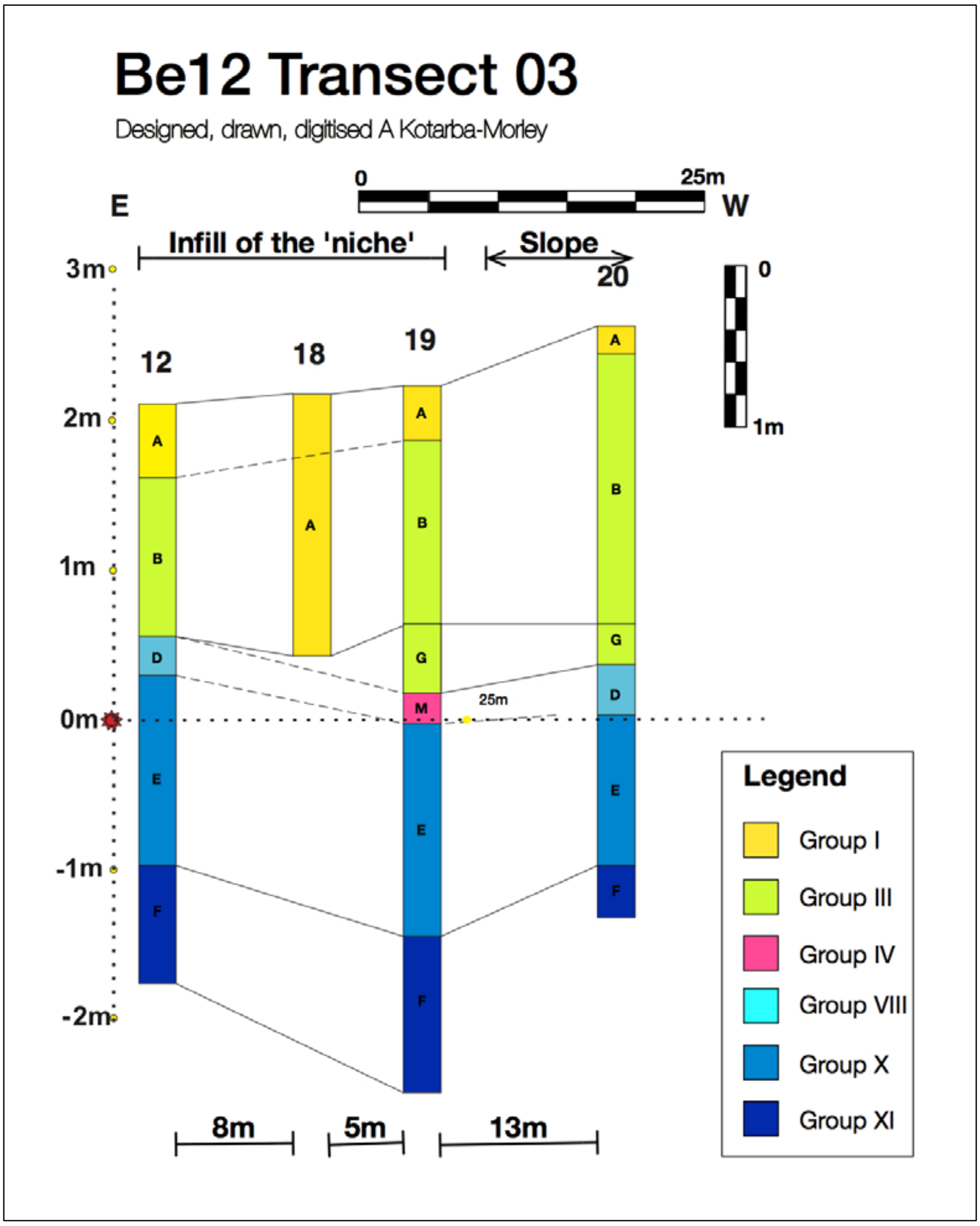


Figure 4.41 Transect BE12-T03 (Drawn by AM Kotarba-Morley).

FIGURES: CHAPTER 5

Figure 5.1 Sedimentation closing off the entrance to the lagoon at low tide (Photo: AM Kotarba-Morley 2013).

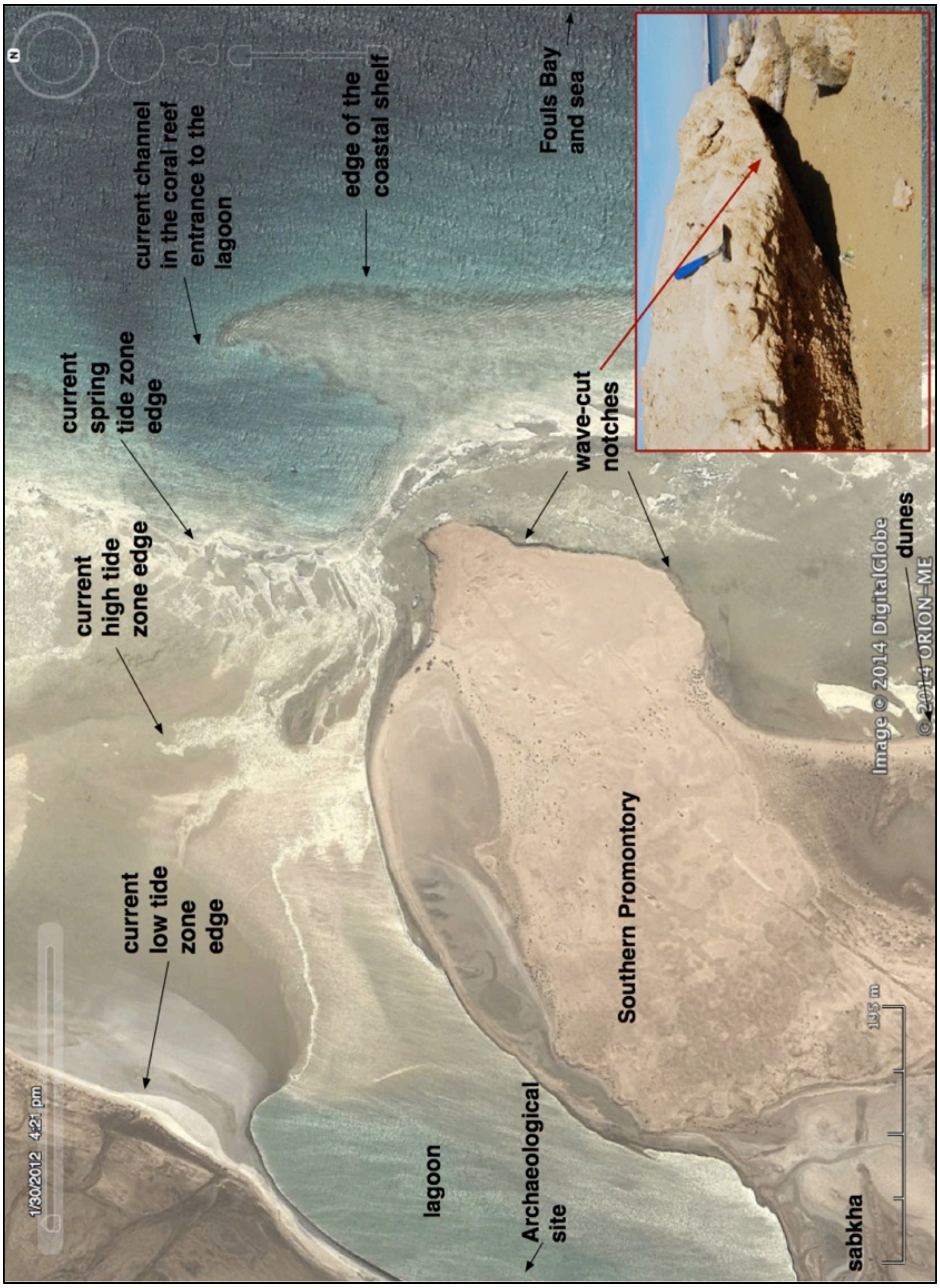


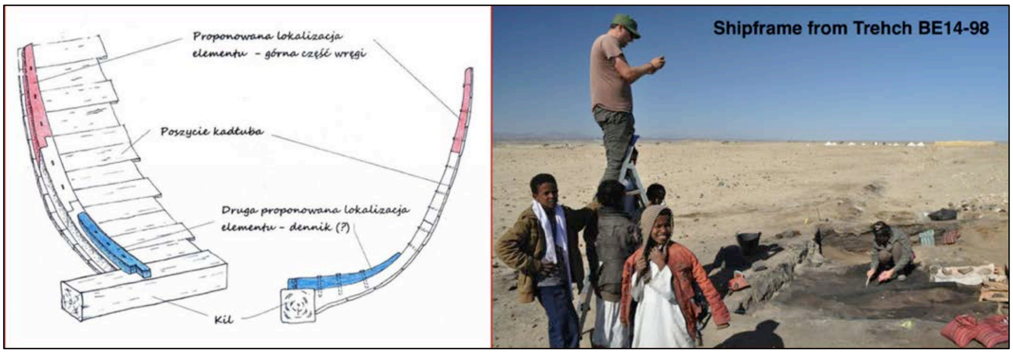
Figure 5.2 Satellite image showing location shot of the current entrance to the lagoon and tidal zones. Mid-holocene highstand wav-cut notch in an insert (Source: modified from Google Earth; drawn by AM Kotarba-Morley; Photo AM Kotarba-Morley 2012).

Figure 5.3 Inscription from Ostia mentioning the *collegium* of *urinatores* – salvage divers and potentially dredgers (Source: CIL XIV 303, supp. 4620).

Figure 5.4 Ababda Bedouin meeting at the Southern Promontory (Photo: AM Kotarba-Morley 2011).

Figure 5.5 Panorama of the lagoon from the Southern Promontory looking towards the north (Photo: AM Kotarba-Morley 2010).

Figure 5.6 Southwestern Embayment (SWE) area as viewed from the top of the highest *nebkha* towards the north-northwest (Photo: AM Kotarba-Morley 2012).



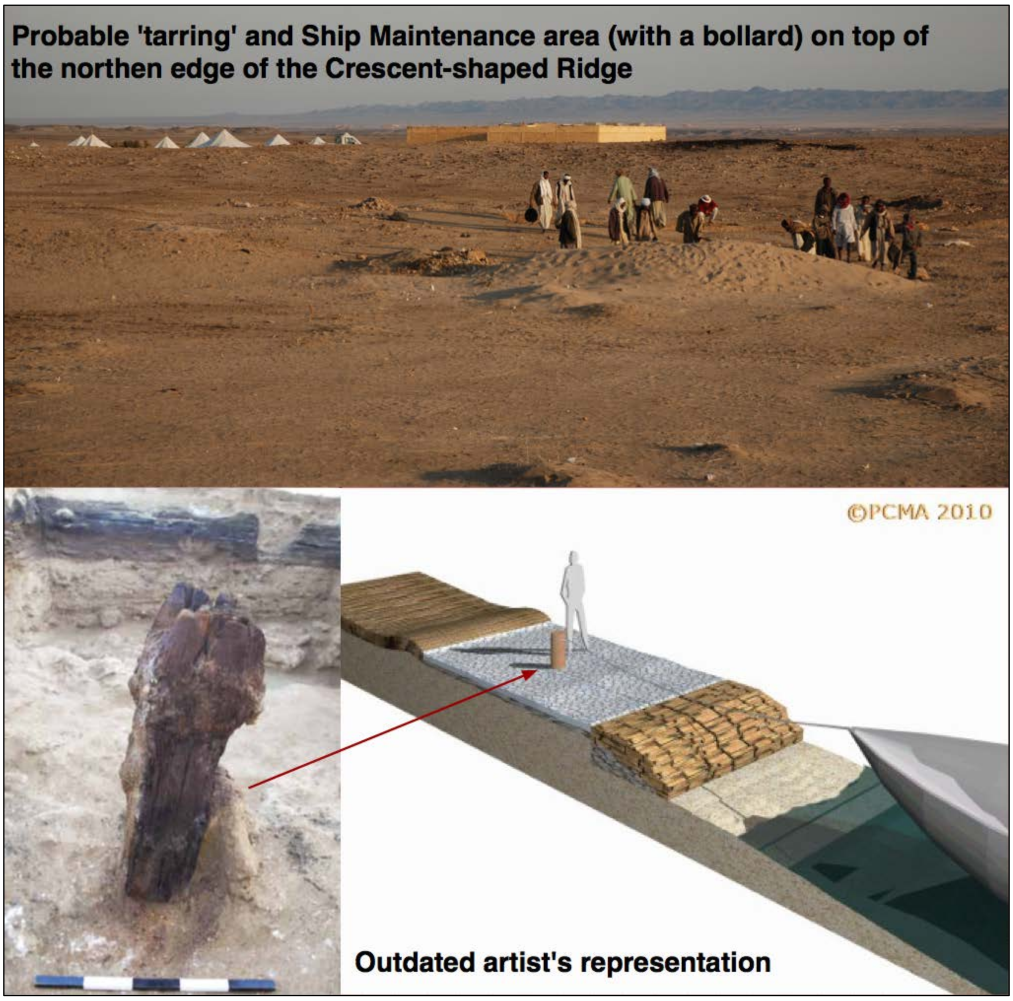


Figure 5.7 Top: Ship frame from trench BE14–98 and reconstruction of the hull (Reconstruction: J Rądkowska, Photo: S Sidebotham 2014). Bottom: Wooden bollard from trenches BE09–54 (Woźniak 2011: Fig. 4.7; Reconstruction: Woźniak 2011: Fig. 4.20).

Figure 5.8 Top left: Close-up of white evaporitic surface of Facies N; Bottom left: Satellite map showing the location of the *Temenos* with Temple of Lotuses (Source: Google Earth Image and a geomagnetic map by Herbich and Swiech from Berenike Excavation Project Archive); Top and bottom right: The *Temenos* with Temple of Lotuses (Photos: AM Kotarba-Morley 2012, 2013).

Figure 5.9 Large coral head deposit, probably connected to a maritime cult in the Temple of Lotuses (Top: Rądkowska et al. 2013: 217–218, Fig. 2B and 5, Bottom: Photo: AM Kotarba-Morley 2013).

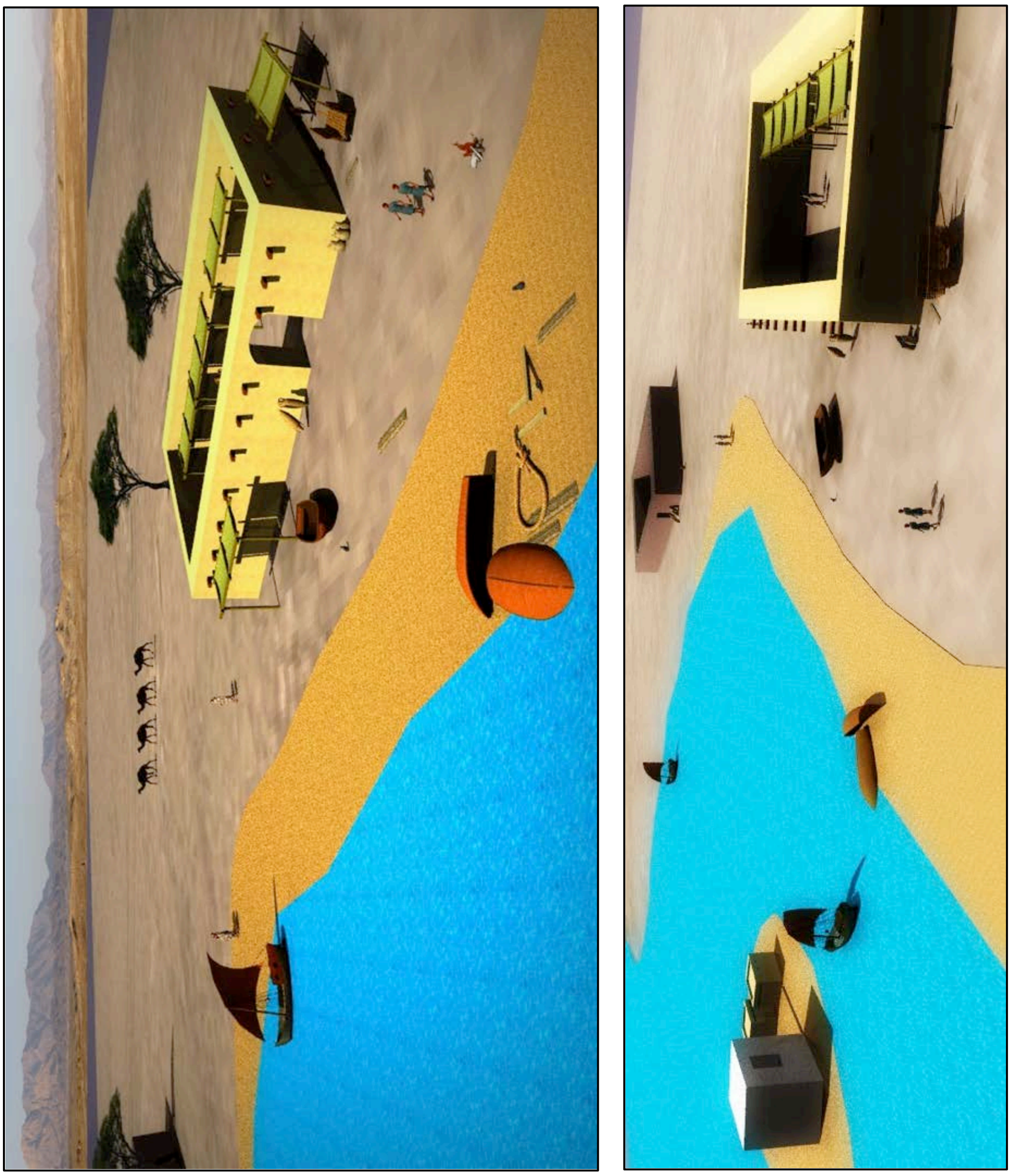


Figure 5.10 Artist's reconstruction of the 'Ship Maintenance Area' and the island with the Temenos. Note that the reconstruction does not accurately reflect the topography of the terrain nor of the potential design of the vessels (Source: The Berenike Excavations Project, Reconstruction: J Rądkowska 2012).

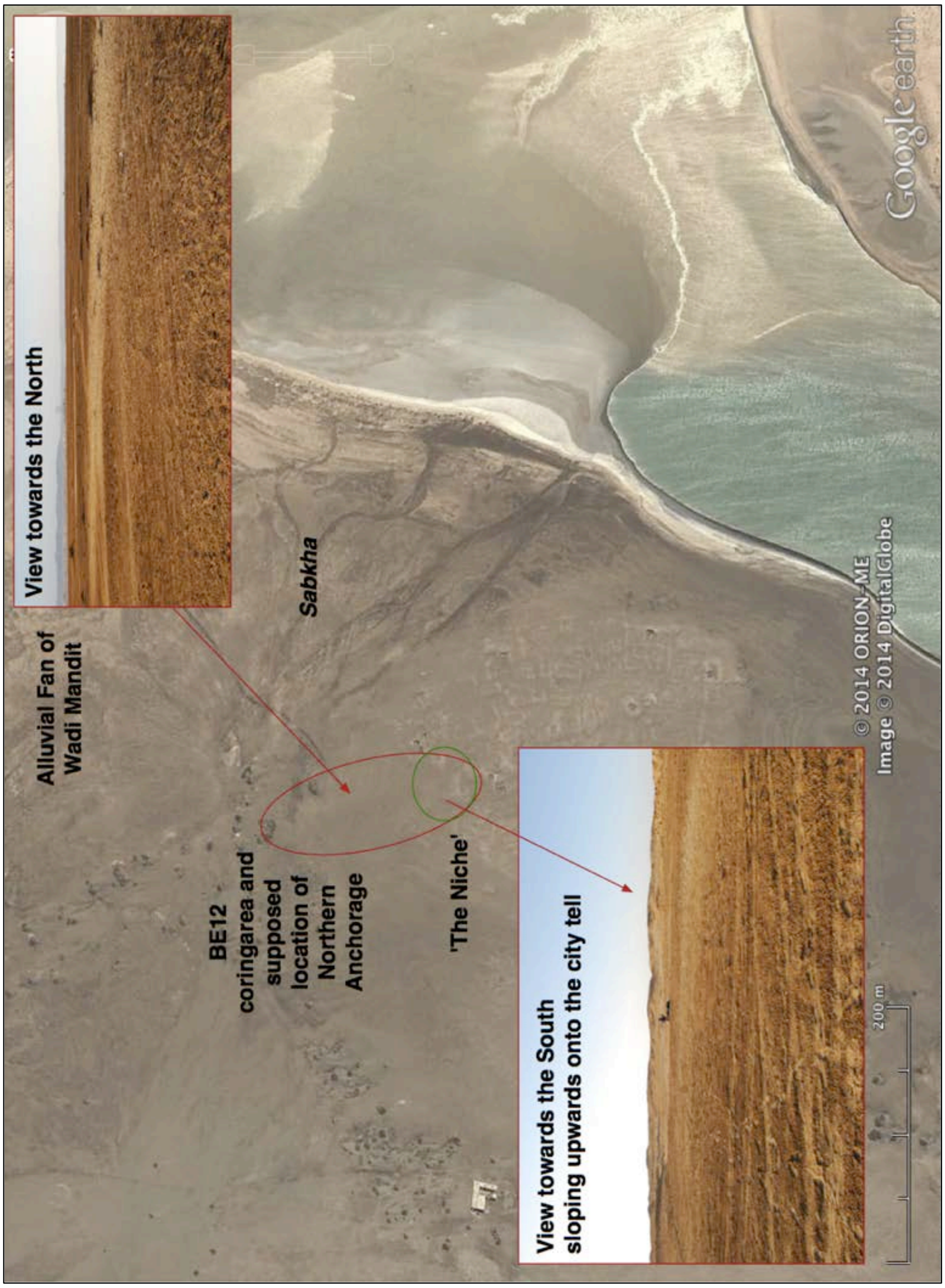


Figure 5.11 Area of the supposed Northern Anchorage, author's coring from 2012 and the 'niche' (Source: modified from Google Earth; Photo: AM Kotarba-Morley 2012).

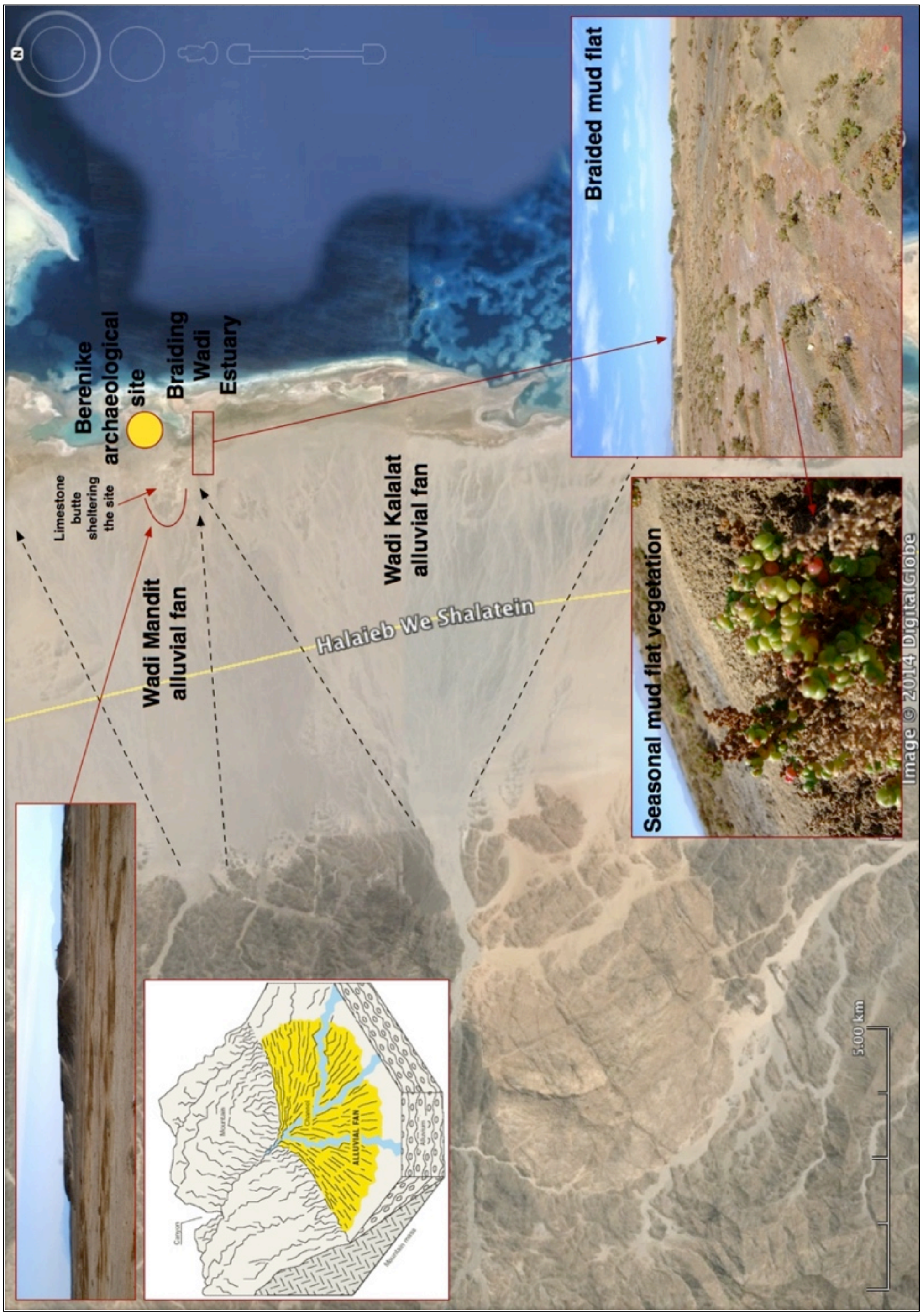


Figure 5.12 Satellite image of the alluvial fans of Wadi Kalalat and Wadi Mandit that feed into Berenike. Insets: (anti-clockwise from top left) View of limestone buttes from the east; Model of a braided alluvial fan; Seasonal mud flat vegetation in the estuary of one of the wadi delta channels; Braided mud flat just south of the Southwestern Embayment (SWE), separated from it by the Crescent-shaped Ridge (CSR) (Sources: modified from Google Earth; Photos: AM Kotarba-Morley 2013).

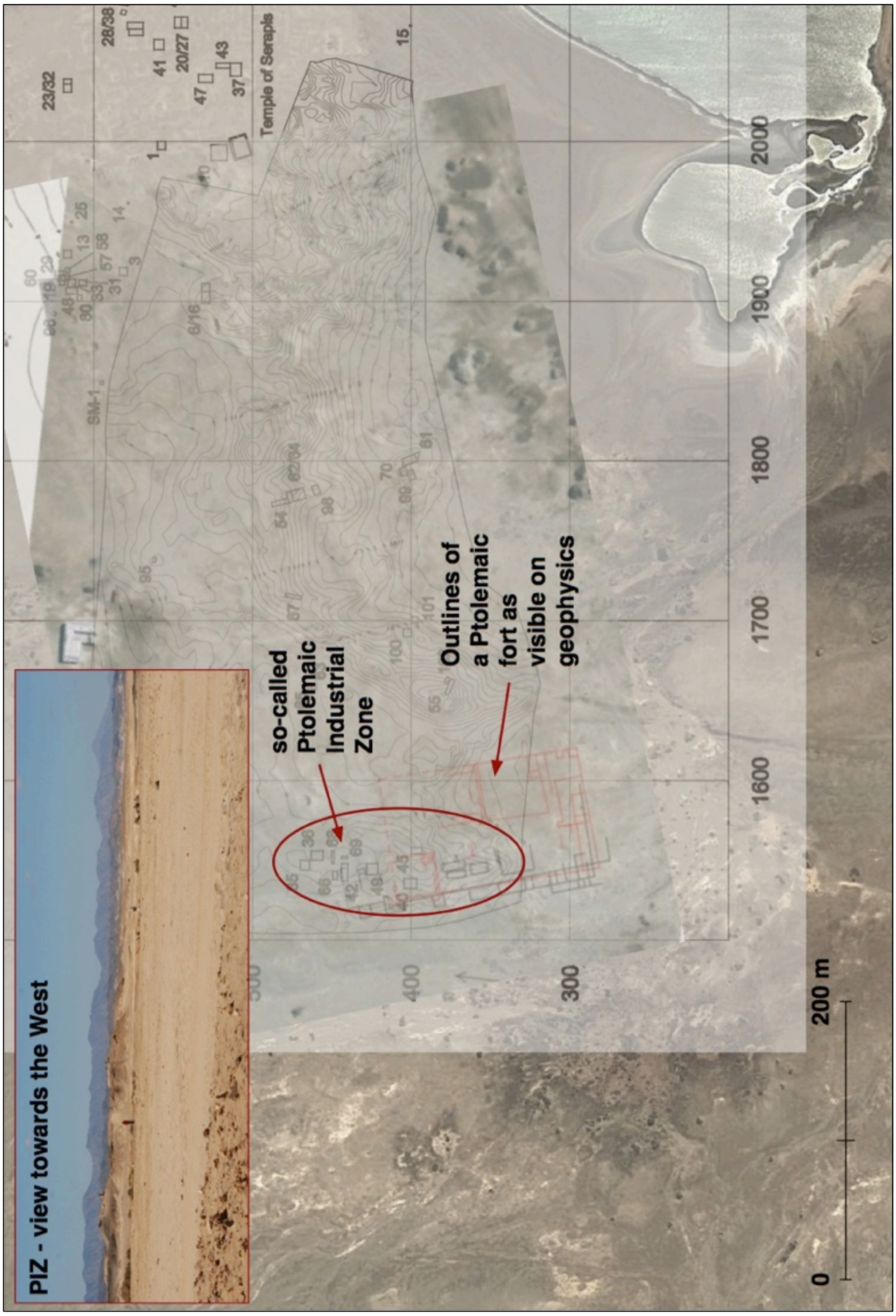


Figure 5.13 Satellite imagery and contour map showing the location of the so-called Ptolemaic Industrial Area (trenches excavated to date are marked) and the plan of a potential Ptolemaic fort as discerned by geophysics (Source: modified from Google Earth and Berenike Excavations Project Archive; Photo: AM Kotarba-Morley 2010).

FIGURES: CHAPTER 6

Figure 6.1 Waves approaching Zanzibar (Photo: AM Kotarba-Morley).

Figure 6.2 Pharos in Portus (Source: www.portusproject.org).

Figure 6.3 Artificial harbours of Sebastos (top left), Carthage (top right) and Portus (bottom) (Sources: Wikipedia).

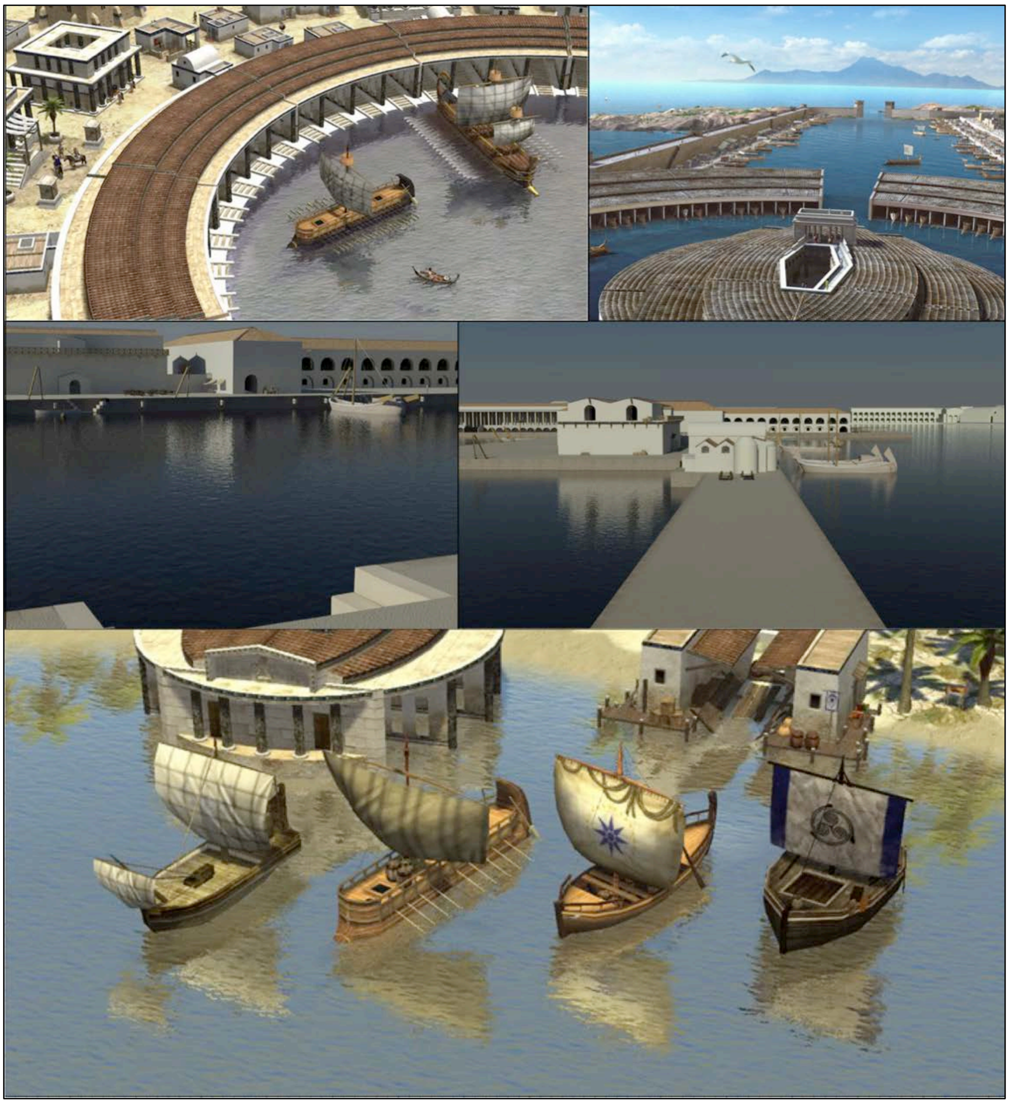


Figure 6.4 3D representations of different types of harbour installations in Roman ports of Carthage and Portus (Sources: Carthage – gaming forum www.historum.com, Portus – www.portusproject.org).

Figure 6.5 Malayalam people near Pattanam village involved in the de-silting of the canal. A canoe is seen just setting off to start de-silting in the middle of the canal (Photo: AM Kotarba-Morely 2011).

Figure 6.6 Idyllic life on the backwaters. Pattanam, Kerala, southern India (Photo: AM Kotarba-Morley 2011).

Figure 6.7 Large 'Chinese style' fishing nets on one of the backwaters in Kerala, southern India. Large-scale fishing is still performed in a traditional way (Photo: AM Kotarba-Morley 2011).

Figure 6.8 Small fishing outriggers moored at a beach in Kilifi Creek, Kenya (Photo: AM Kotarba-Morley 2011).

Figure 6.9 Delta of the Rufiji River, the possible location of the ancient port of Rhapta, Central Coast of Tanzania (Photo: AM Kotarba-Morley 2011).

Figure 6.10 Jama Taweel from Abu Greyah in one of the abandoned wells in the Eastern Desert, Egypt (Photo: AM Kotarba-Morley 2012).

Figure 6.11 Indian fishermen chatting and laughing whilst fixing their nets. Kerala, southern India (Photo: AM Kotarba-Morley 2011).

Figure 6.12 Women collecting seaweed on a beach on Zanzibar (Photo: AM Kotarba-Morley 2011).

Figure 6.13 Fish basket on a Lod mosaic (Source: http://helenmilesmosaics.org/mosaic-sites/lod-roman-mosaic/).

Figure 6.14 An example of surplus-creating coastal agriculture in Goa, southwestern India (Photo: AM Kotarba-Morley 2011).

Figure 6.15 Camels feeding on the desert in Kuwait (Photo: AM Kotarba-Morley 2009).

Figure 6.16 Author interviewing traditional boatbuilder during the coastal survey in Kerala, southern India (Photo: A Blair 2011).

Figure 6.17 Cedar woods on the coastal hills in Lebanon. Cedar wood was considered prime quality for use in shipbuilding and there are accounts of it being transported all the way to the Red Sea via the Nile and Eastern Desert caravan route (Photo: S Randall 2009).

Figure 6.18 Red Sea coastal mangrove forest in the area of Ras Benas (Photo courtesy of M Abdel Raziq).

Figure 6.19 Quarry in *Mons Claudianus*, Eastern Desert of Egypt (Photo: T Witkowska 2012).

Figure 6.20 Detail of a quarry in *Mons Claudianus*, Eastern Desert of Egypt (Photo: T Witkowska 2012).

Figure 6.21 A merchant selling chili, ginger, pepper and other spices at a spice market in Mysore, India (Photo: AM Kotarba-Morley 2011).

Figure 6.22 Author inspecting the building of a new sewn-hull vessel at the experimental workshop in Qantab, Oman, run by Tom Vosmer, where the *Jewel of Muscat* was built. Author inspecting building of a new dhow (Photo: E Scerri 2012).

FIGURES: CHAPTER 7

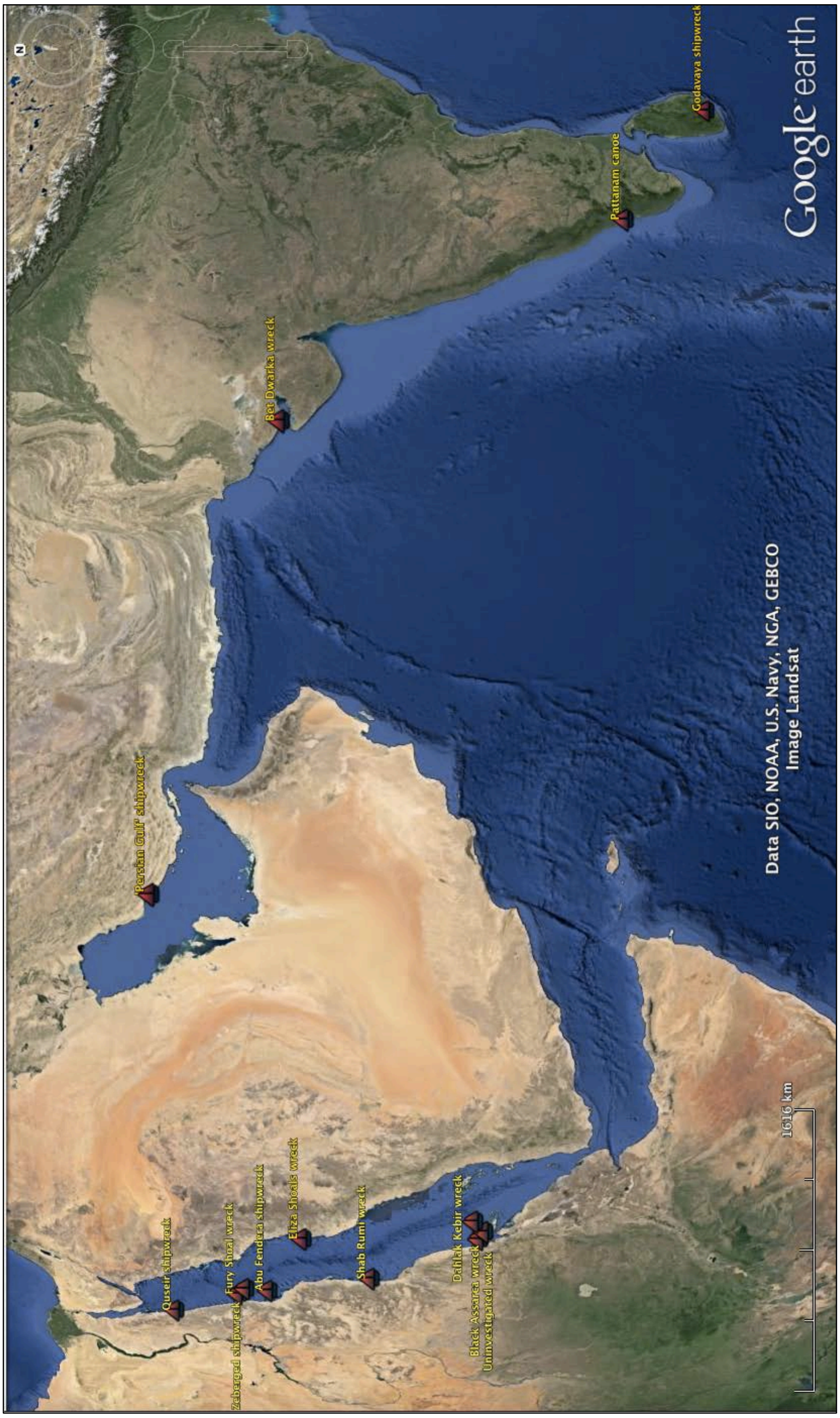


Figure 7.1 Map of distribution of known Roman era shipwrecks on the Red Sea and the Indian Ocean as described in Table 7.1 (Source of satellite image: Google Earth, modified by AM Kotarba-Morley).

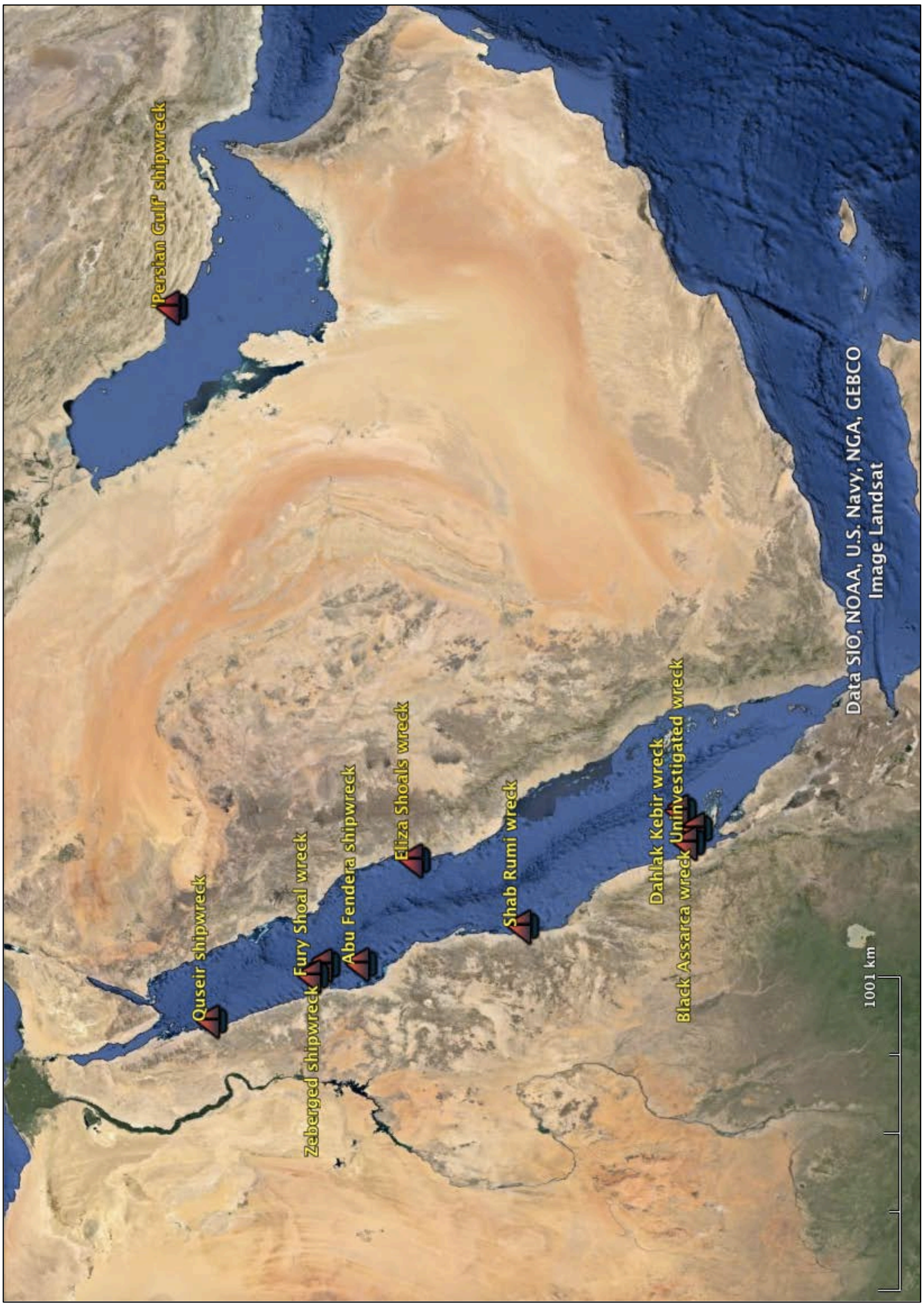


Figure 7.2 The map of distribution of known Roman-era shipwrecks on the Red Sea and the Persian Gulf (Source of satellite image: Google Earth, modified by AM Kotarba-Morley).

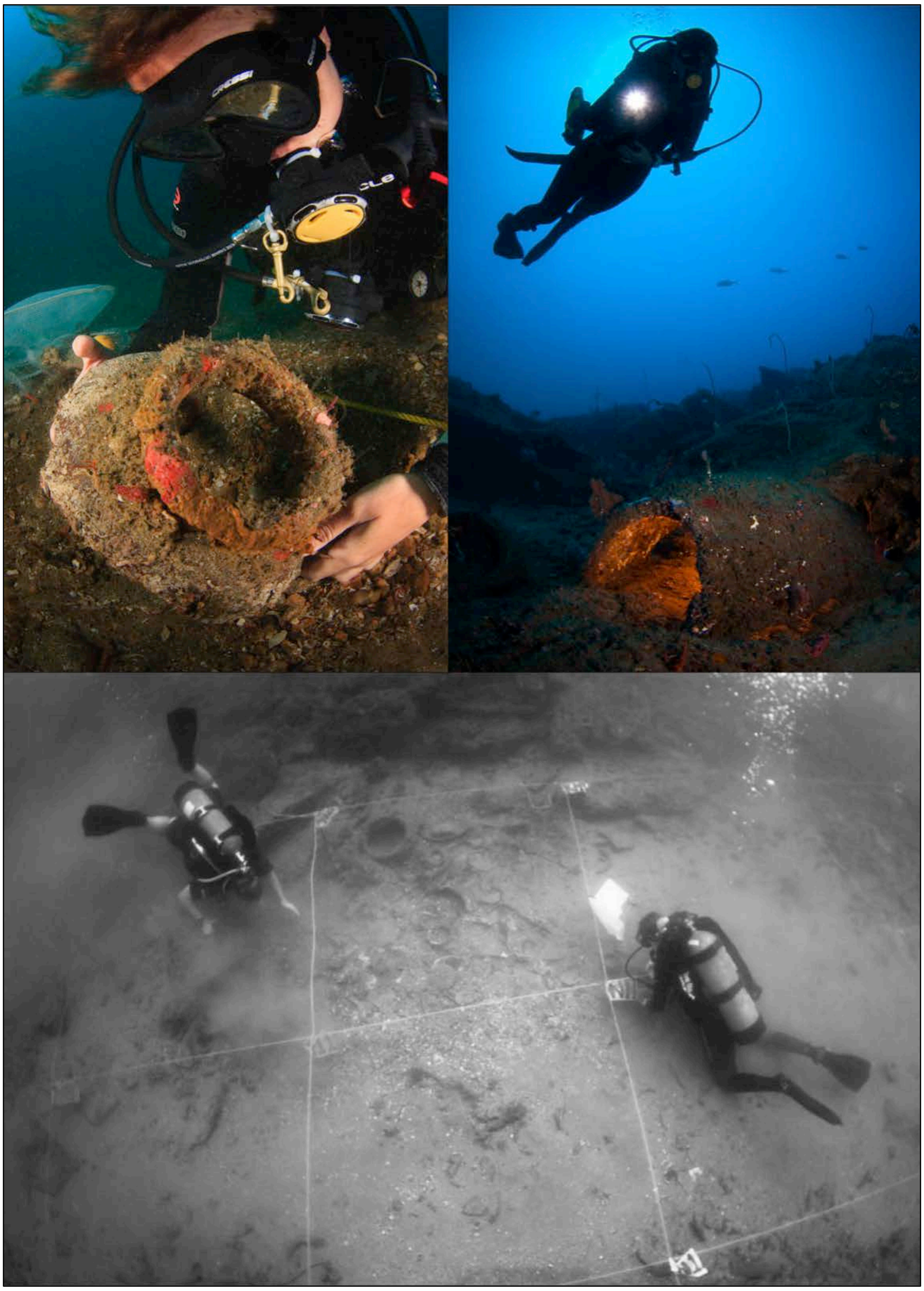


Figure 7.3 Godavaya shipwreck deemed to be the oldest discovered wreck on the Indian Ocean (Courtesy of © 2014 SUSANNAH H. SNOWDEN www.omniaphoto.com, for INA).

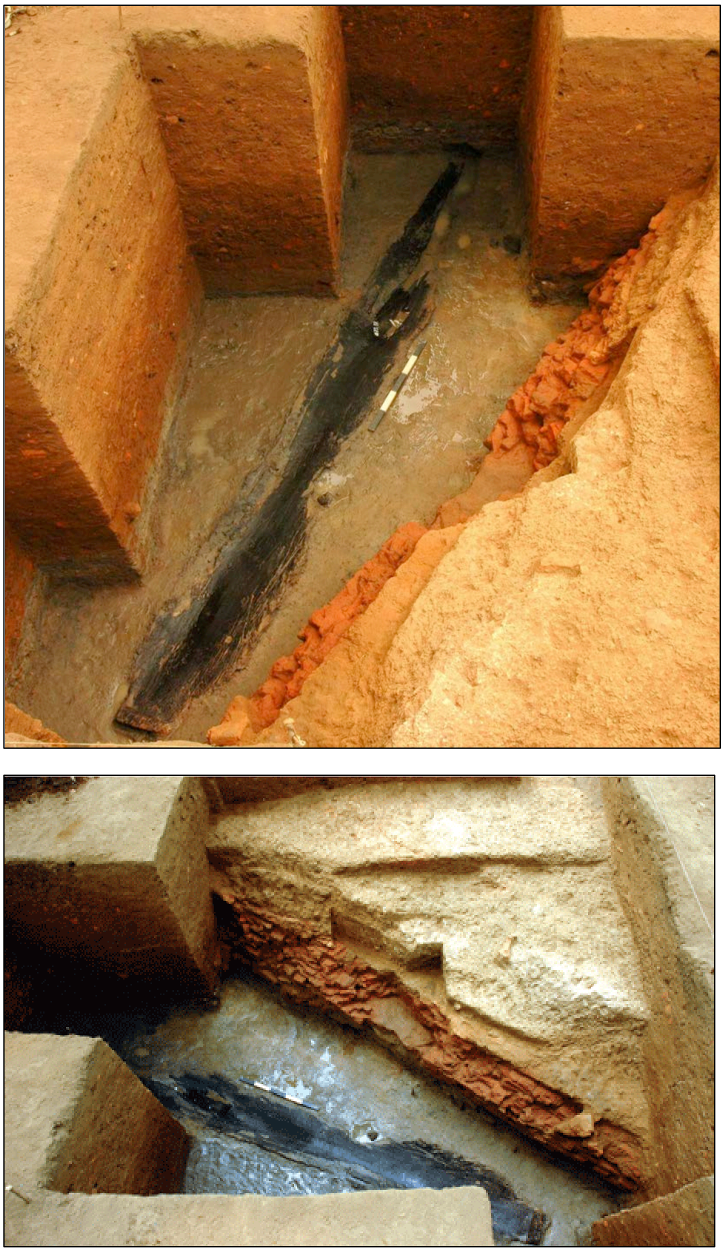


Figure 7.4 Top and bottom: Pattanam canoe (6 m long) and an adjacent wharf structure during the excavations (Photos courtesy of P J Cherian).

Figure 7.5 One-masted Roman merchantman from a relief on the tomb of Naevoleia Tyche at Pompeii (Photo courtesy of A Wilson).

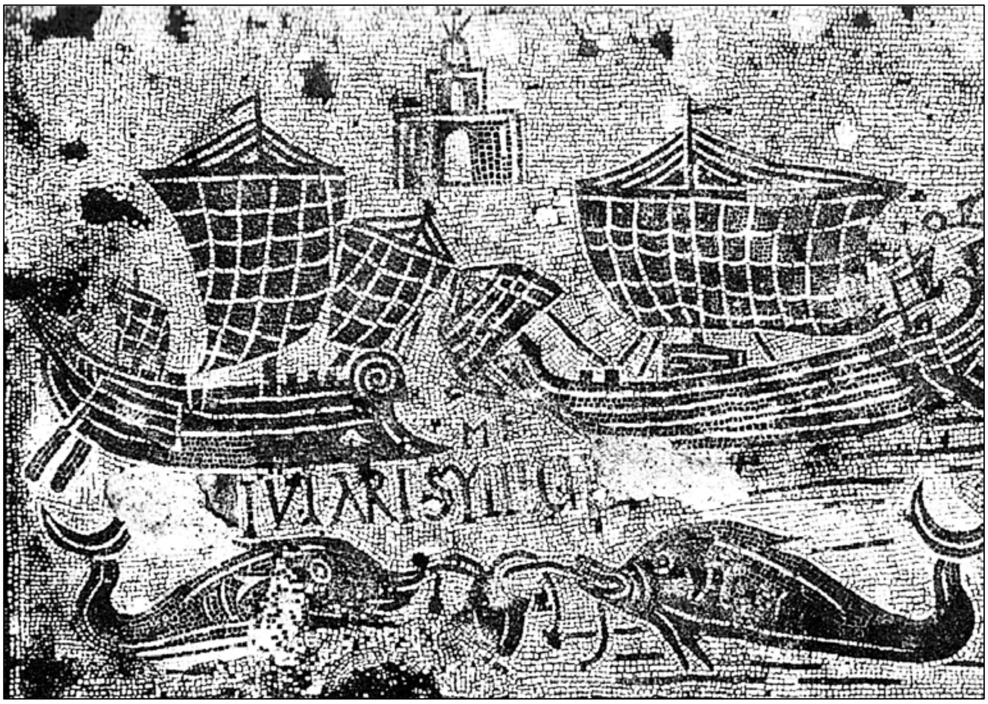


Figure 7.6 Roman merchantmen from a mosaic on Piazza della Corporazioni, Ostia, Italy – Station 23, Ships 1 and 2 showing different types of rigging (Source: Friedman 2011: 108, Fig. 3.7.20).

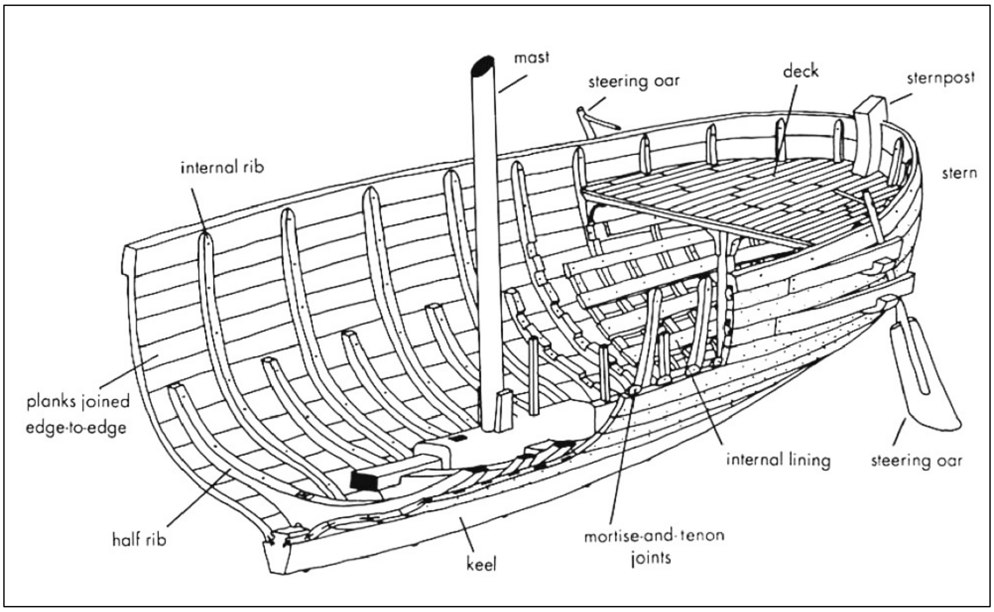


Figure 7.7 Cutaway of a Roman merchantman showing the details of construction (Source: Adkins and Adkins 1998: 205, Fig. 5.9).

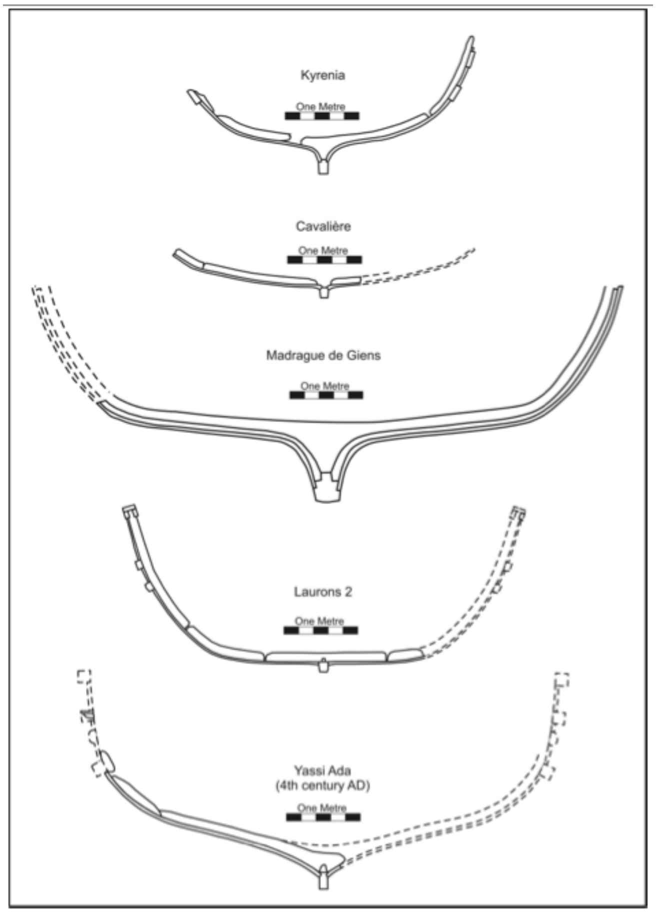


Figure 7.8 Sections through the hulls of five Mediterranean sailing vessels showing different sizes and different types of hull morphology, curvature and shape of keel (Source: Whitewright 2008: 131).

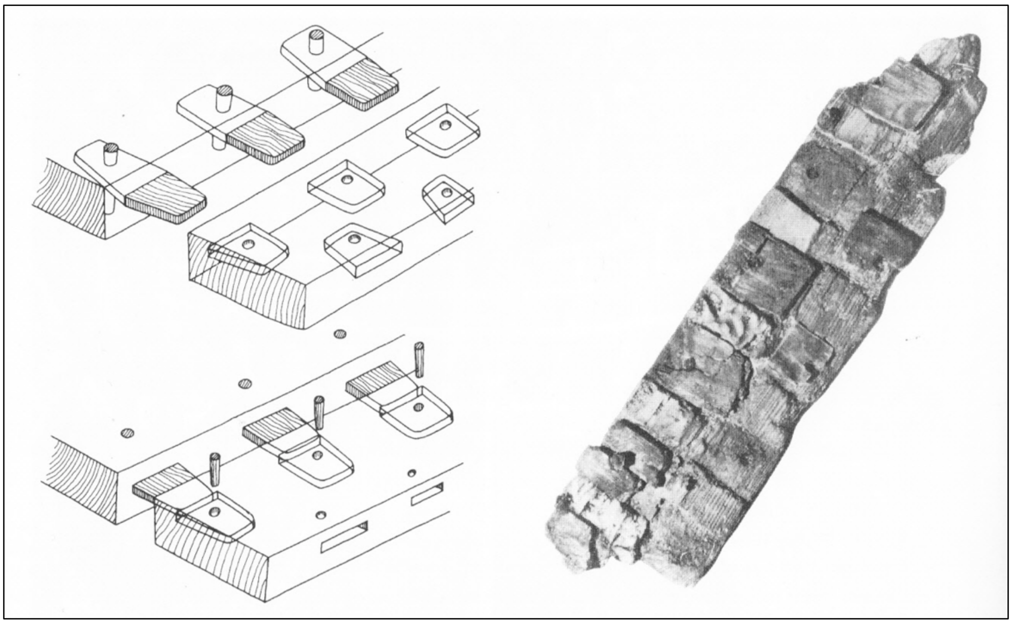


Figure 7.9 Mortise-and-tenon construction typical for the Mediterranean ships (Source: Gianfrotta and Pomey 1981: 238).

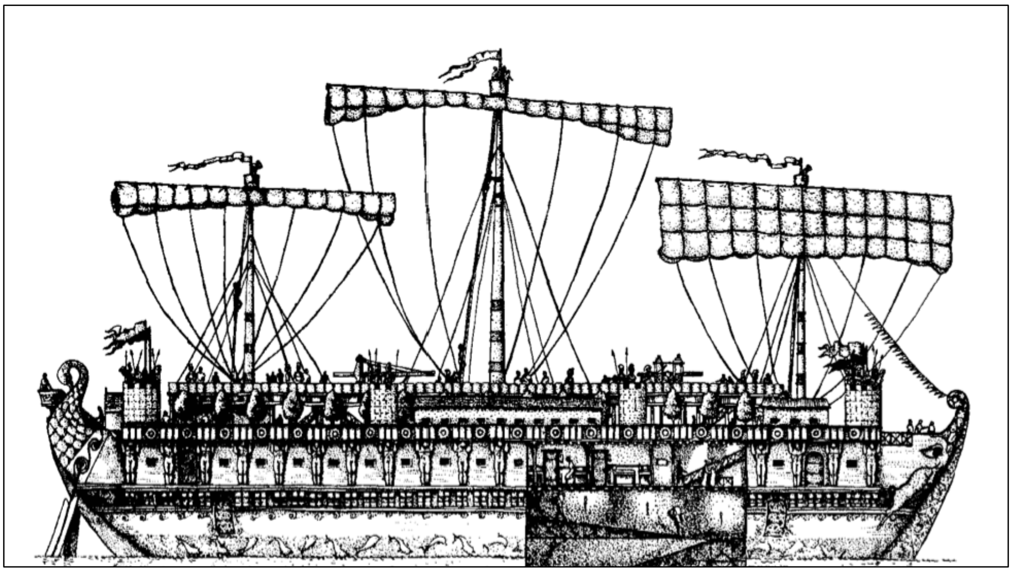


Figure 7.10 Artist's conception of a huge Hellenistic merchantman the *Syracusia* (Drawn by N. Holmes Kantzios; Source: Turfa and Steinmayer 1999: Fig. 3).

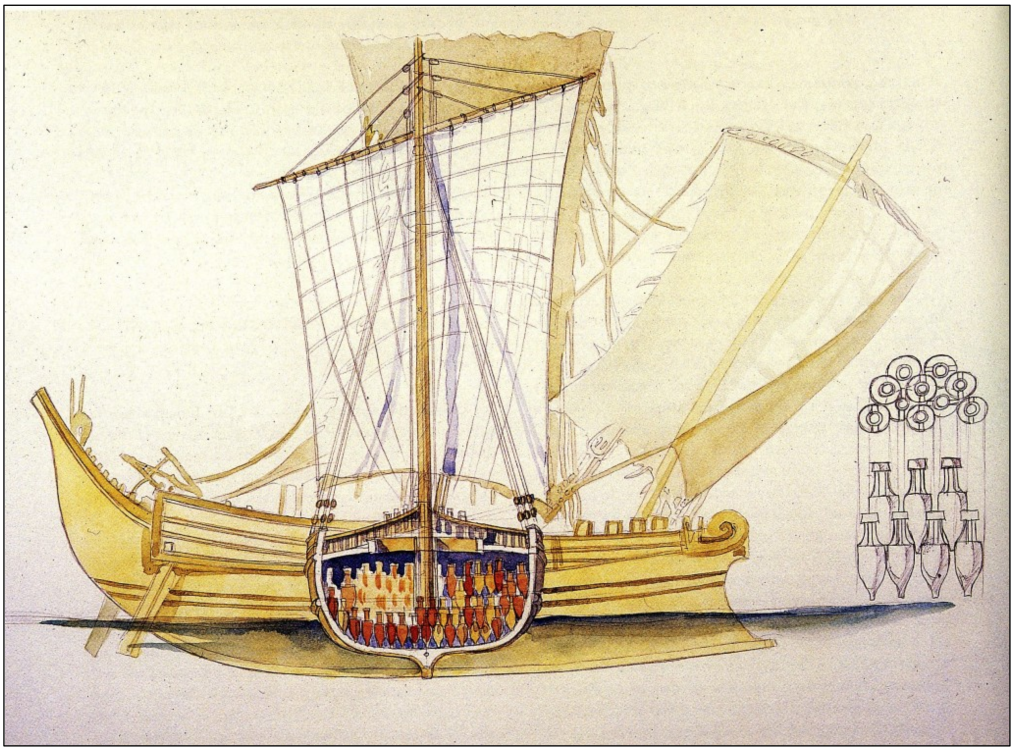


Figure 7.11 Artist's reconstruction showing the Roman ship the *Madgrague de Giens* and her cargo, *ca.* 75–60 BCE (Source: http://www.ancientportsantiques.com/ancient-ships/merchant-ships/navire-romain-gassend/; Drawn by Jean-Marie Gassend).

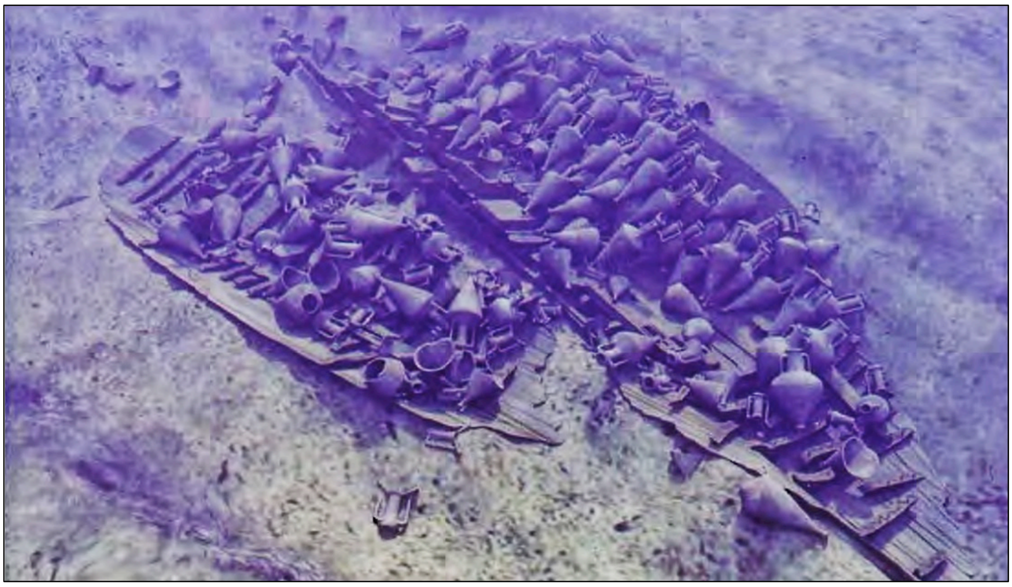


Figure 7.12 Underwater photograph of the shipwreck of *Kyrenia* showing the cargo and the hull (Source: Katzev 2008: 81).

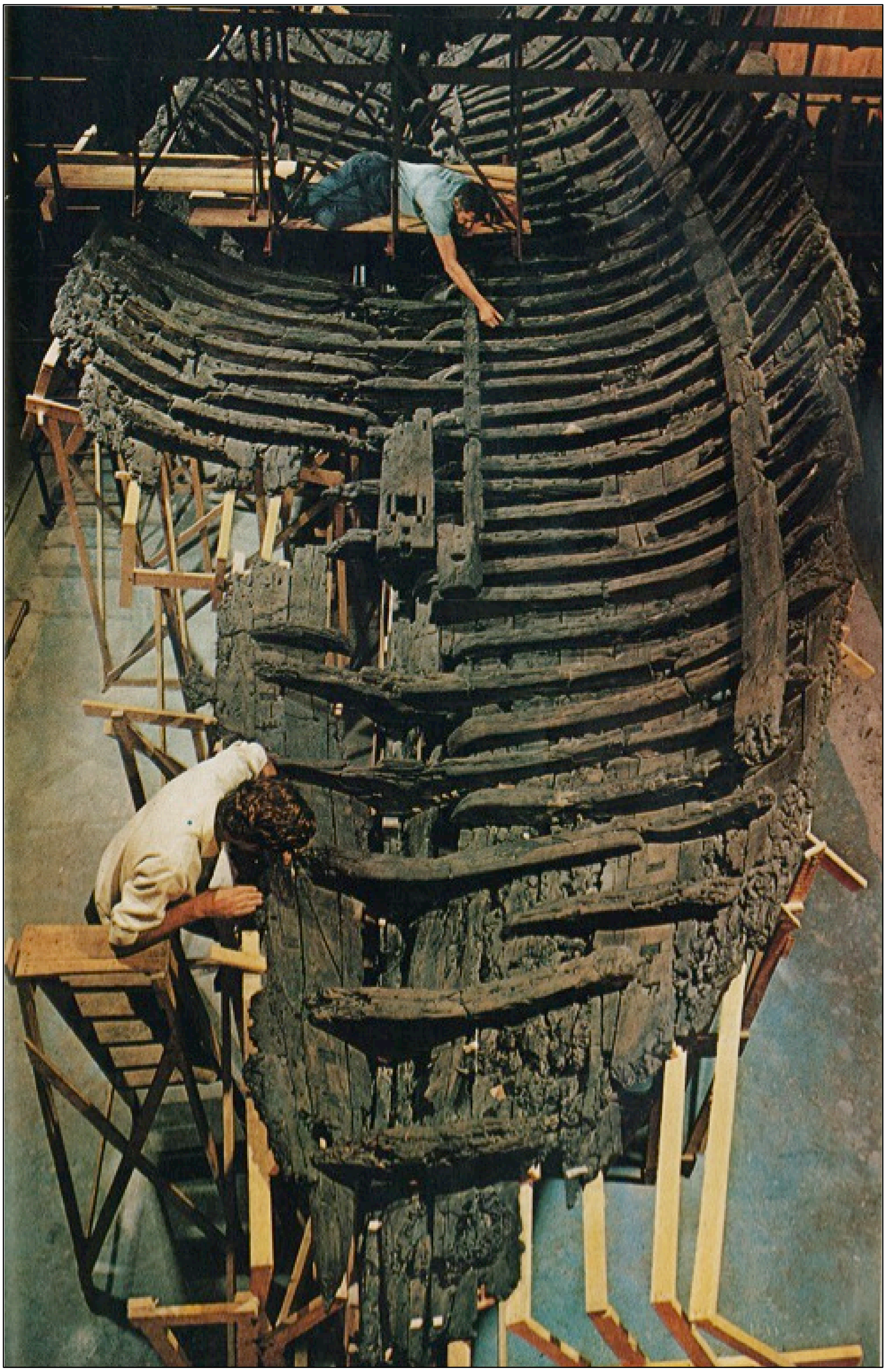


Figure 7.13 Reconstruction of the hull of the *Kyrenia* shipwreck (Source: Katzev and Katzev 1974: 621).

Figure 7.14 Replica of the 4th-century BCE merchantman, *Kyrenia II*, undertaking her voyage (Source: Katzev 2008: 77).

Figure 7.15 A find of a ship-frame in Berenike's tarring area (Source: Berenike Excavations Project; Photo: SE Sidebotham 2014).

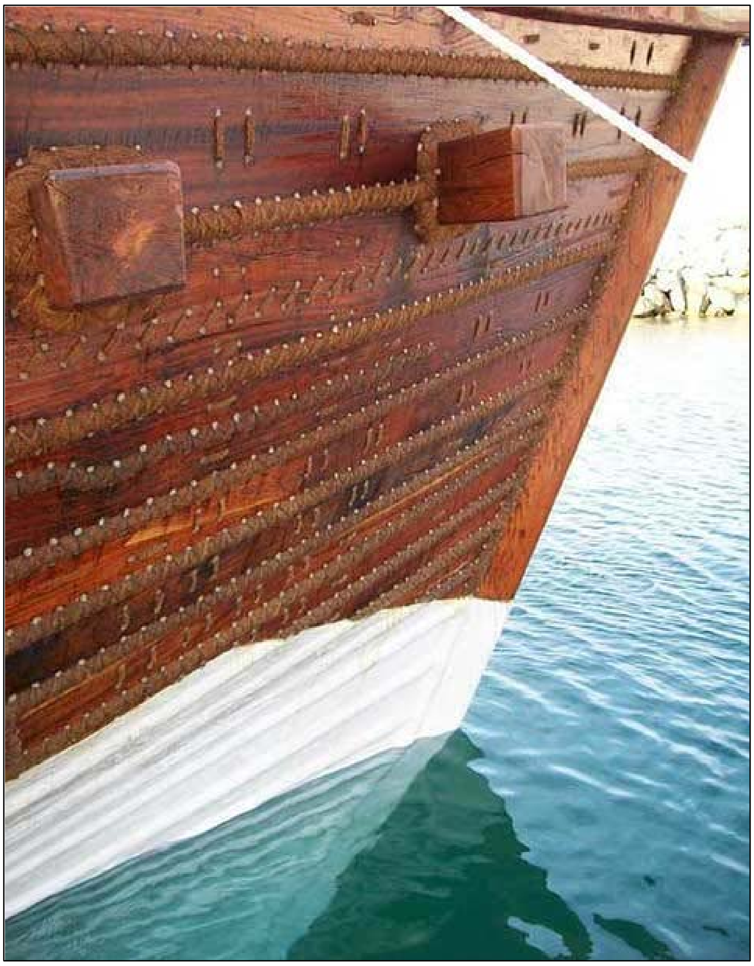


Figure 7.16 Sewn-hull construction and detail (Source: *'Oman et la mer'* on-line exhibition gallery http://omanetlamer.fr/_en/gallery_en.html).

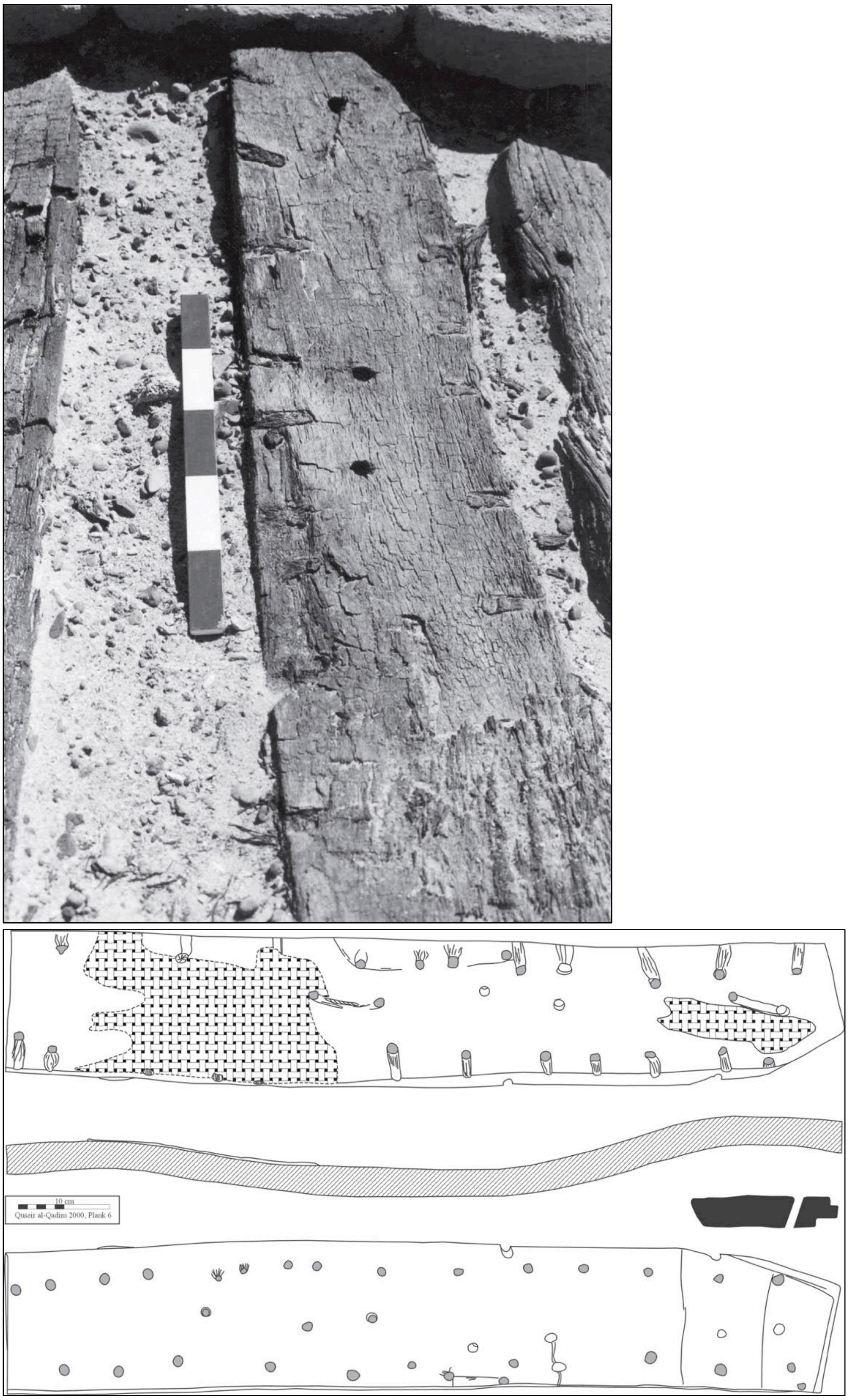


Figure 7.17 Sewn hull planking from Tomb 1 in the Islamic Cemetery (12th–15th c. CE) in Myos Hormos (Source: Blue et al. 2011: 183, Fig. 15.4 and Fig. 15.5).

Figure 7.18 Boats on the beach, Kilifi, Kenya (Photo: ACrowther 2010).

Figure 7.19 Careening of vessels on the shore. Top: Fishing boats in Berenike (Photo: AM Kotarba-Morley 2011). Bottom: Fishing dhows in Ra's al Hadd in Oman (Source: National Geographic July 2005).

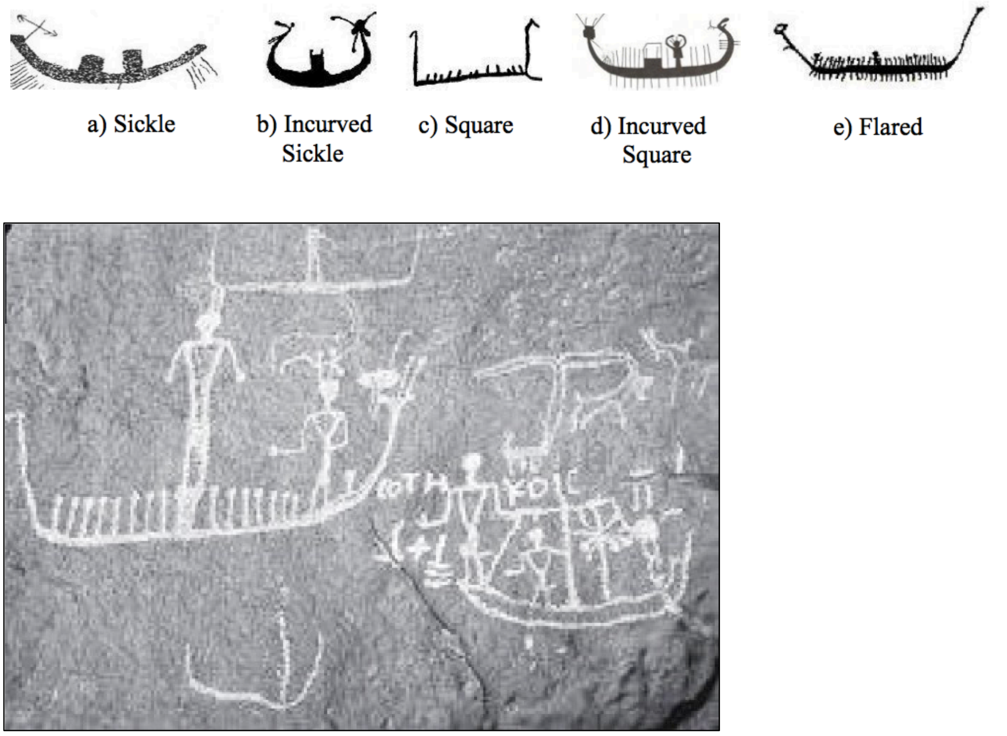


Figure 7.20 Types of boats distinguished by Lanester (2012: Fig. 6..1); Boats shown on rock art from Eastern Desert. Choice of engraving suggested by F. Lankester. Picture shows Late Plumed figures boat IA-10 (Photo after Lankester 2012a: 153).

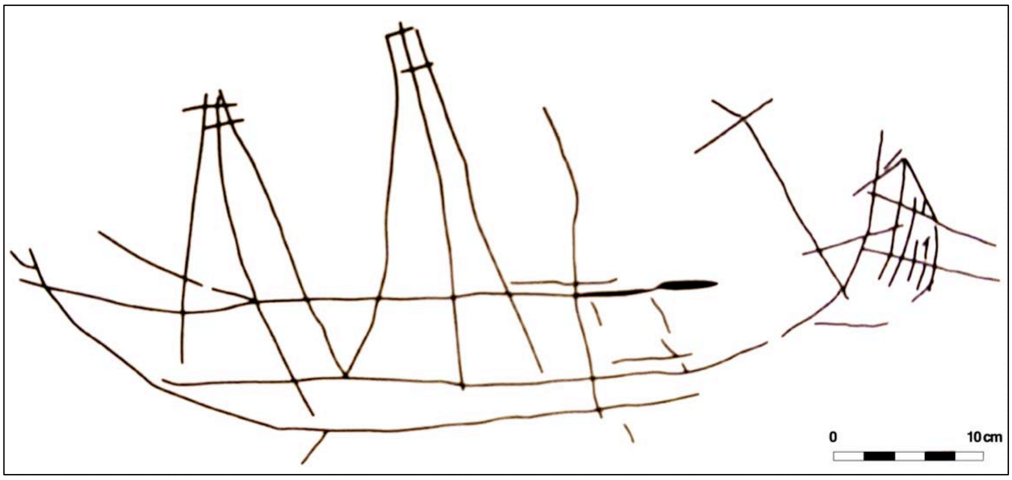


Figure 7.21 A vessel from Wadi Quseir (Myos Hormos) showing 2- or 3- masted ship with twin steering oars. According to van Rengen et al. 2006 it is Vessel 3 from location 3, whilst Blue et al. 2011 refer to it as Vessel 6 (Source: van Rengen et al. 2006: 18, Fig. 2.11 and Blue et al. 2011: 204, Fig. 15.21).

Figure 7.22 Ostracon from Berenike showing a depiction of a single-masted vessel with an *artemon* (Source: Sidebotham 2011: cover).

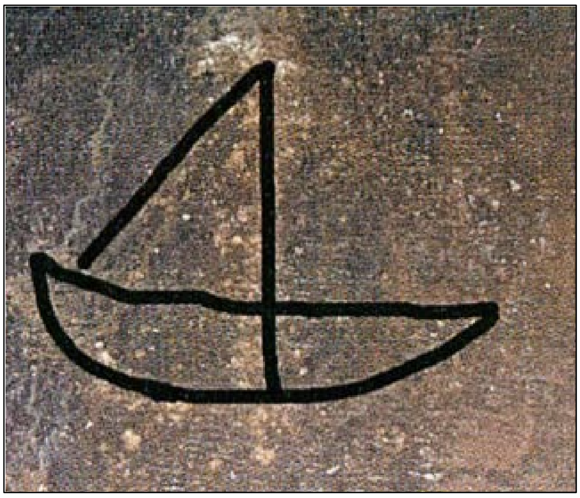


Figure 7.23 Traced engraving from Hoq cave, Socotra Island, Yemen showing a single-masted vessel either with only one yard (second one didn't preserved?) or with a lateen sail (?) (Source: Strauch 2012: 364, Fig. 2.16).

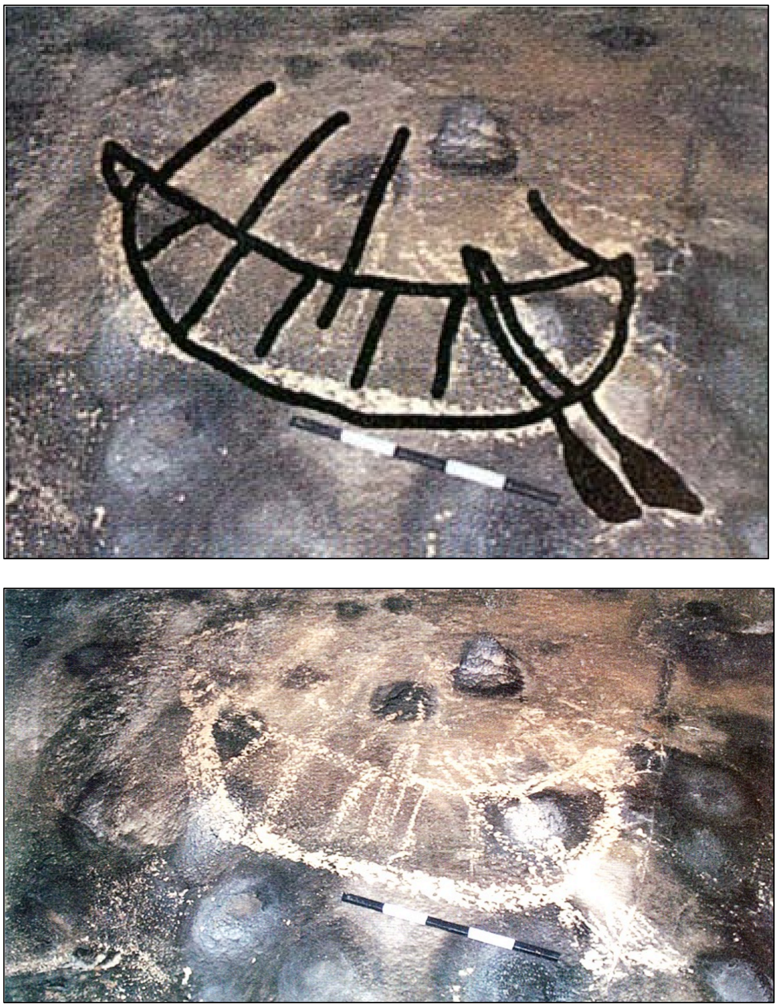
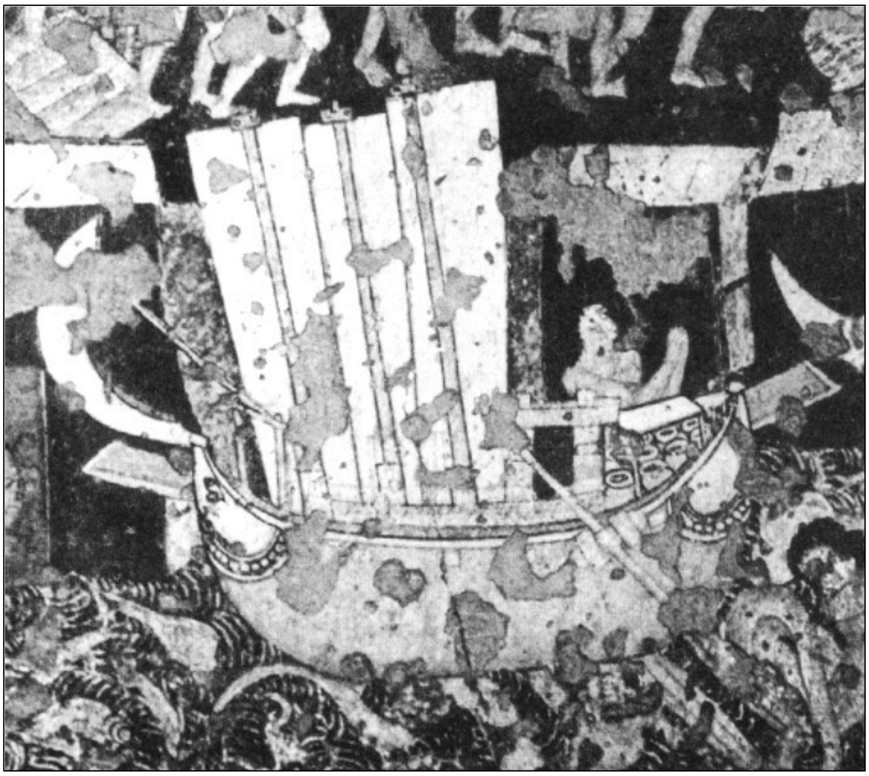
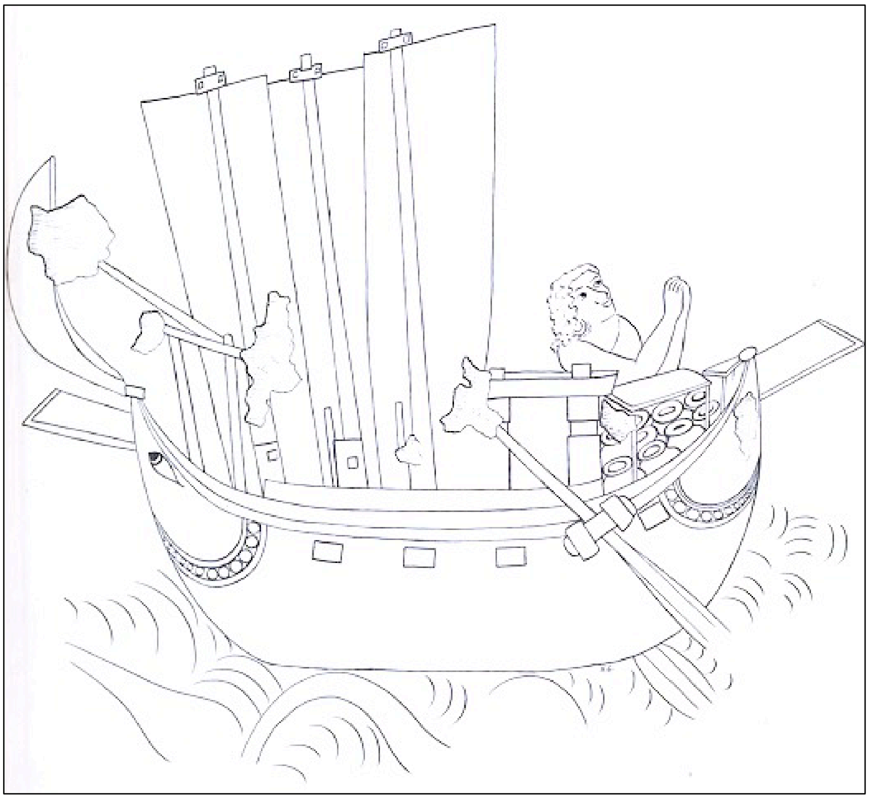


Figure 7.24 Engraving from Hoq cave, Socotra Island, Yemen showing a three-masted vessel with twin steering oars (Source: Strauch 2012: 364–365, Fig. 6.13; traced and original versions).





Figures 7.25 Photograph and a tracing of a painting 79(6) with a boat representation from Cave II in Ajanta, India dated to 4th–mid 7th c. CE (Sources: Hourani 1995: Pl. 4, Deloche 1996: 205, Fig. 3).

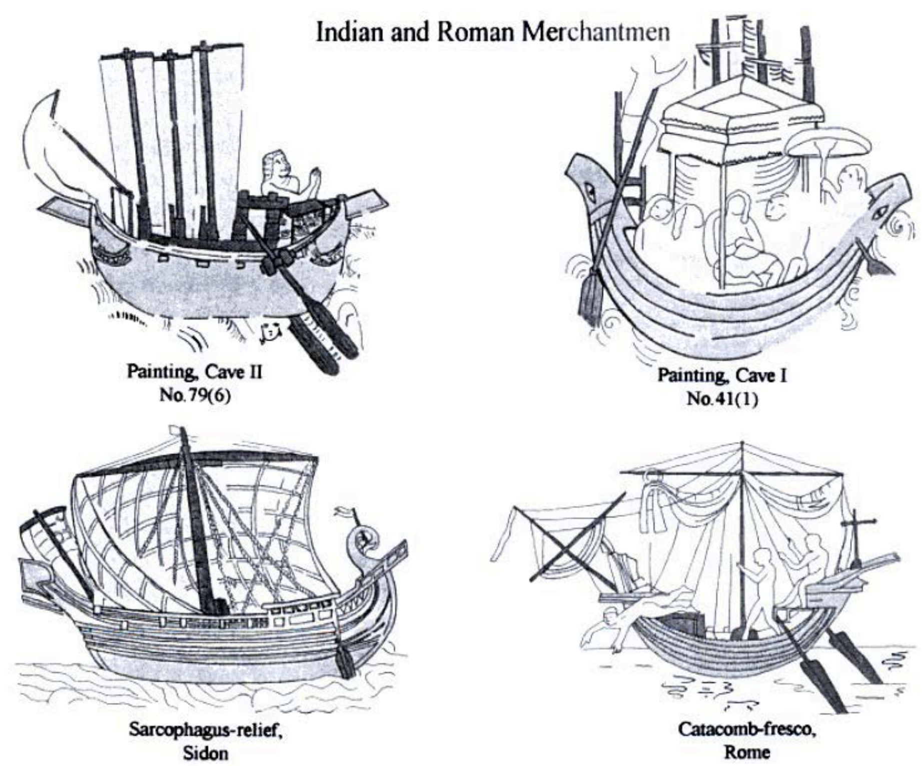


Figure 7.26 Comparison of Indian and Roman merchantman (Source: Schlingloff 2000: 451).

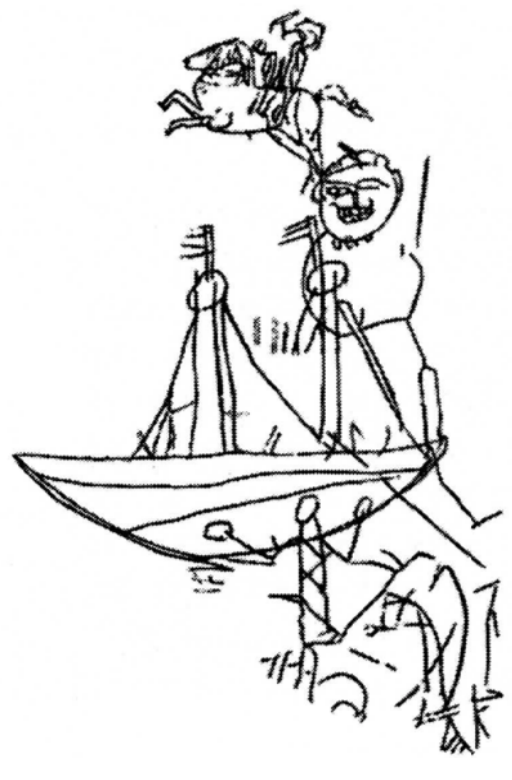


Figure 7.27 Graffito showing a two-masted vessel with back and fore yards from Khor Rori, Dhofar coasts, Oman (Source: Avanzini 2008: 616, Fig. 4).

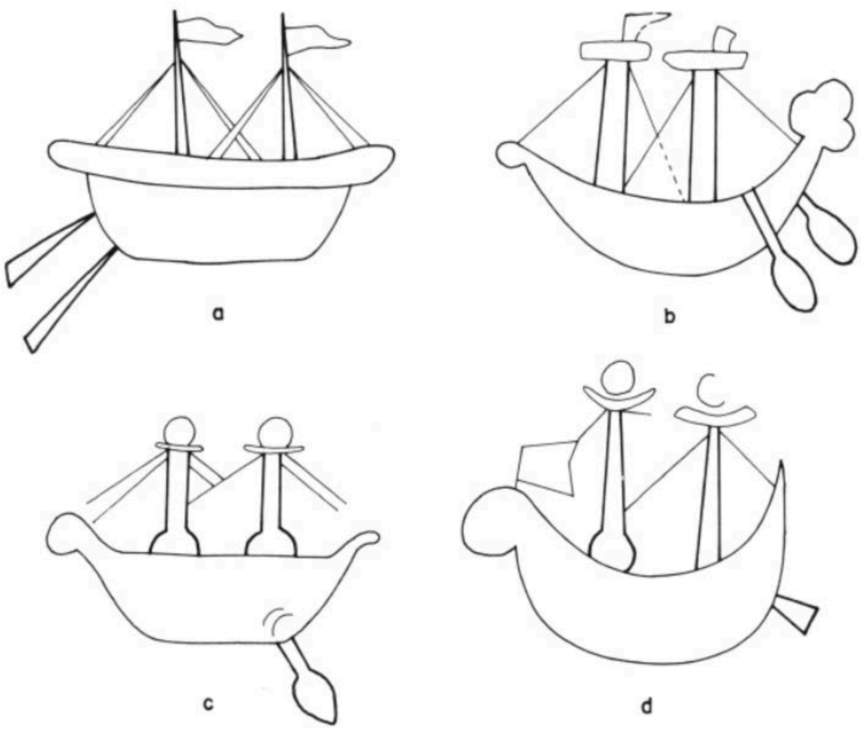


Figure 7.28 Representations of two-masted ships from the reverses of 2nd *c* CE Andhra-Sātavāhana coins (Source: Schlingloff 1976: 21).

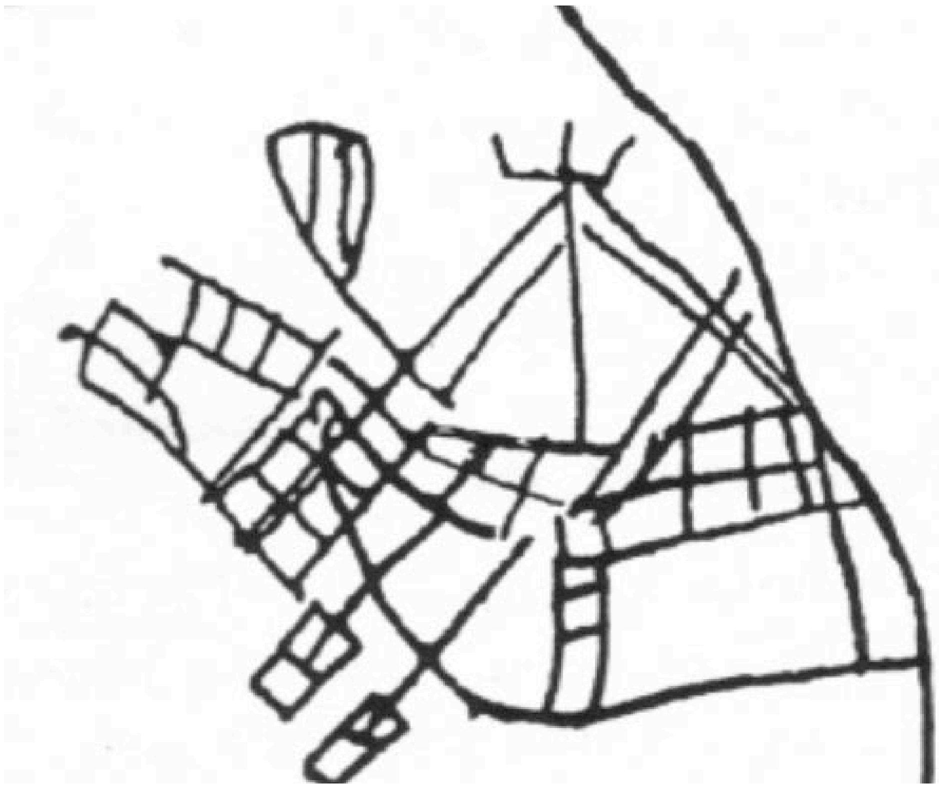


Figure 7.29 Graffito on a pot from Alagankulam, Tamil Nadu, India showing a vessel with twin steering oars (Source: Sridhar et al. 2005: 67–73).

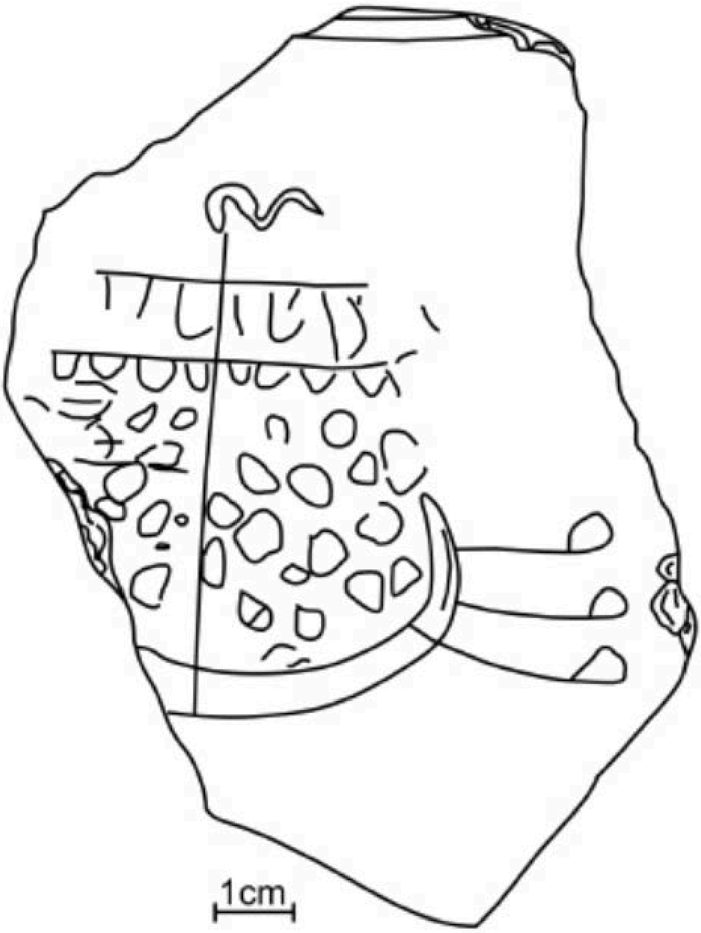


Figure 7.30 Graffito on a sherd from Alagankulam, India showing a ship with crescent-shaped hull and potentially three anchors (Source: Sridhar et al. 2005: 69–70).

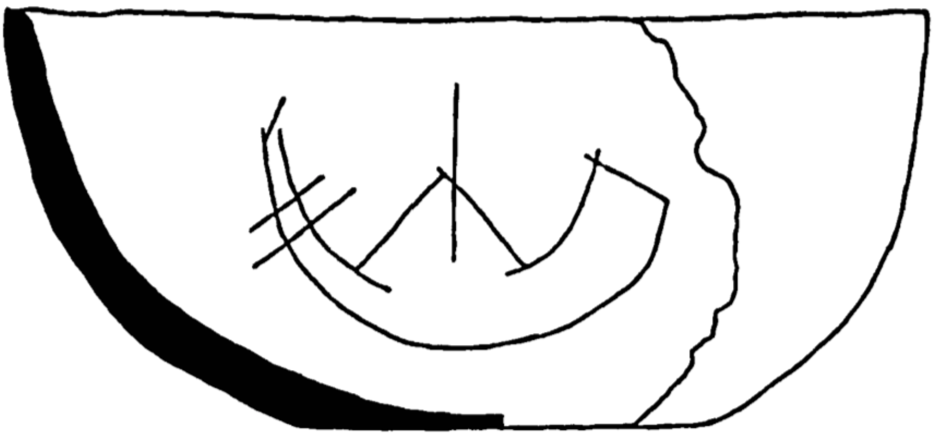


Figure 7.31 A pottery sherd fragment showing a single-masted vessel with back and fore yards and twin steering oars from Anuradhapura (Source: Coningham and Allchin 1999: 92 Fig. 16, SF 10,548).

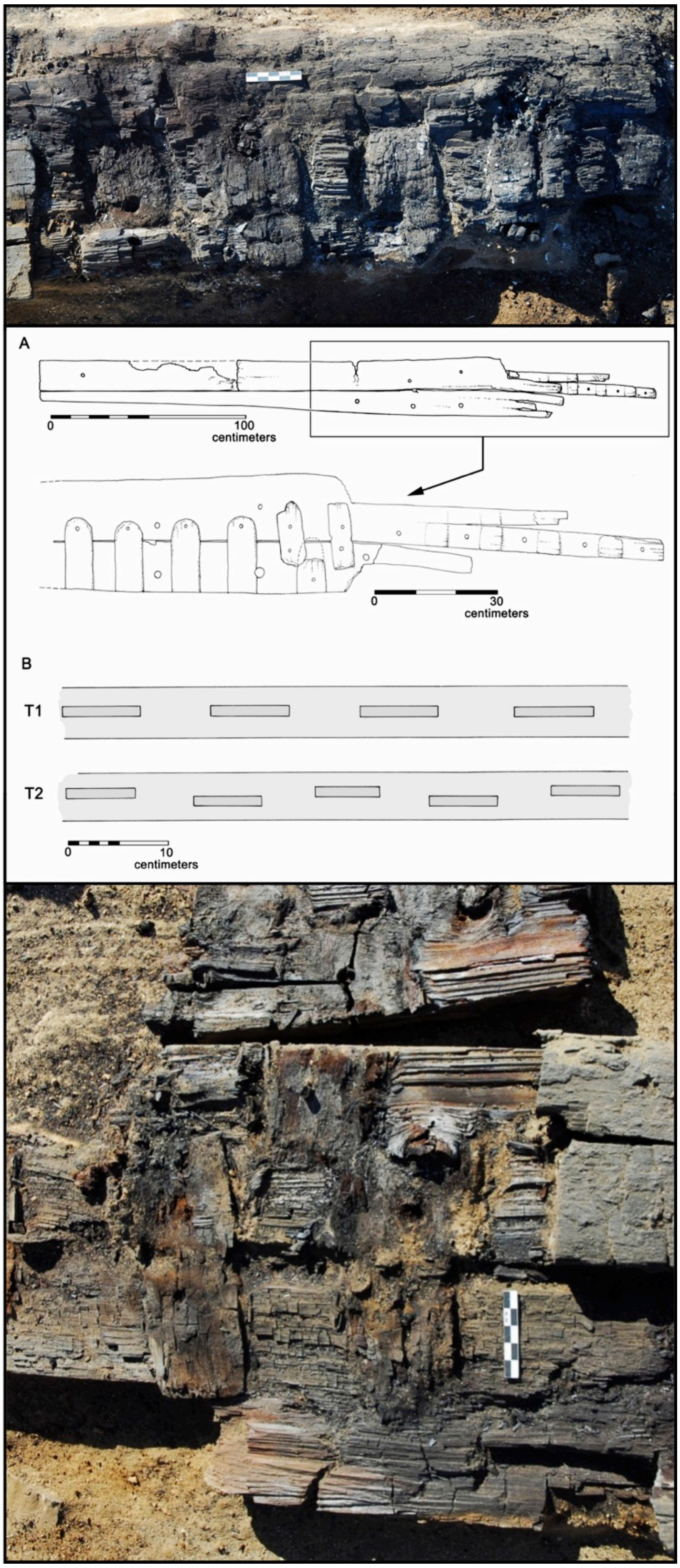


Figure 7.32 Mortise-and-tenon joints from excavations in Berenike's tarring area (Source: Berenike Excavations Project, Photograph by Steven E. Sidebotham).

Figure 7.33 Excavations in so-called 'tarring area' showing *in situ* remains of re-used ship timbers and ropes as well as signs of tarring (Source: Berenike Excavations Project; Photo above by Steven E. Sidebotham, below by AM Kotarba-Morley).

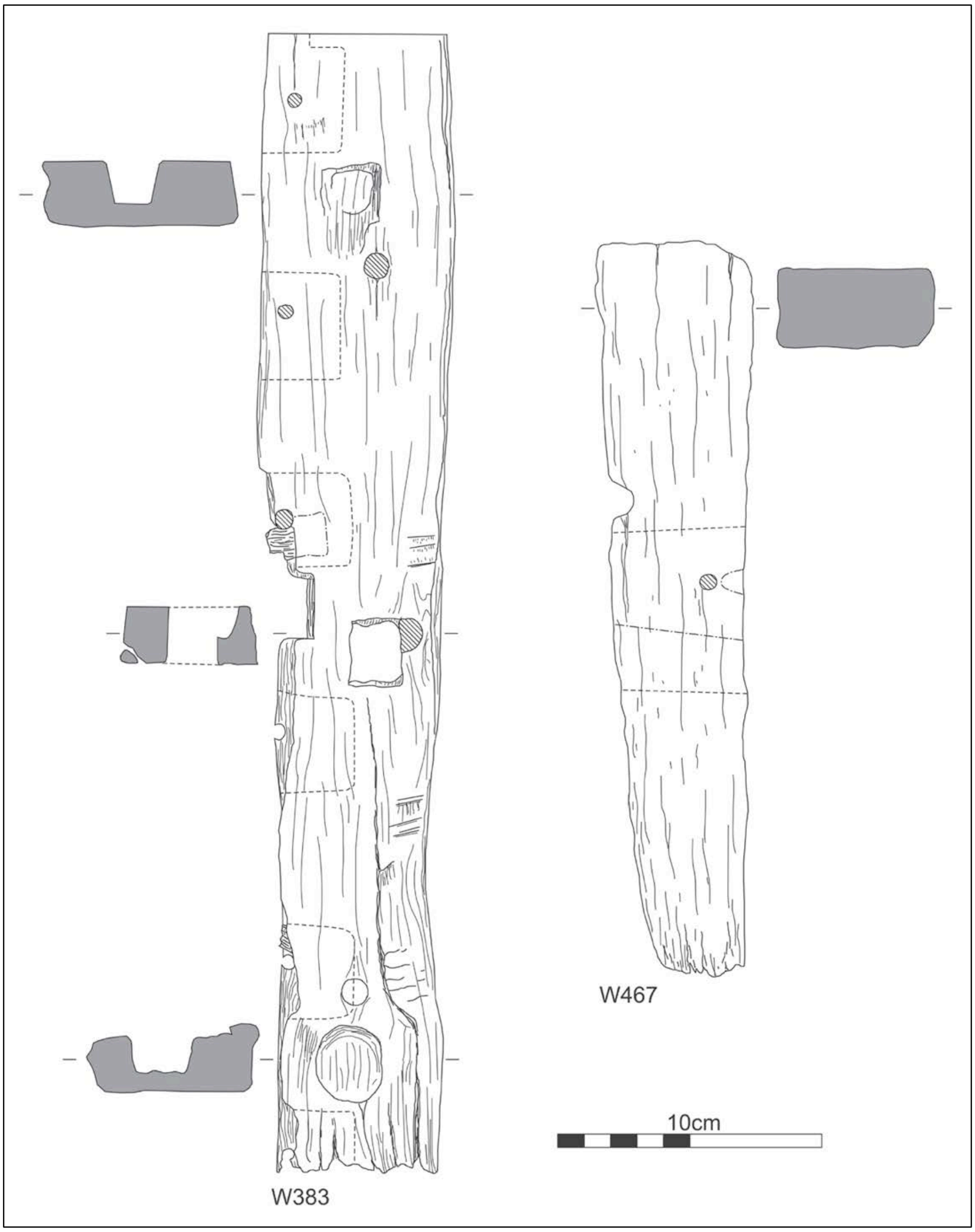


Figure 7.34 Two fragments of re-used mortise-and-tenon planking found from Trench 8A in Myos Hormos (Source: Blue et al. 2011: 180, Fig. 15.1).

Figure 7.35 Re-used Lebanese cedar ship timbers probably roofing from northeastern side of the Serapis temple. Some were as long as 2.33 m (Source: Sidebotham 2011: Fig. 10-2).

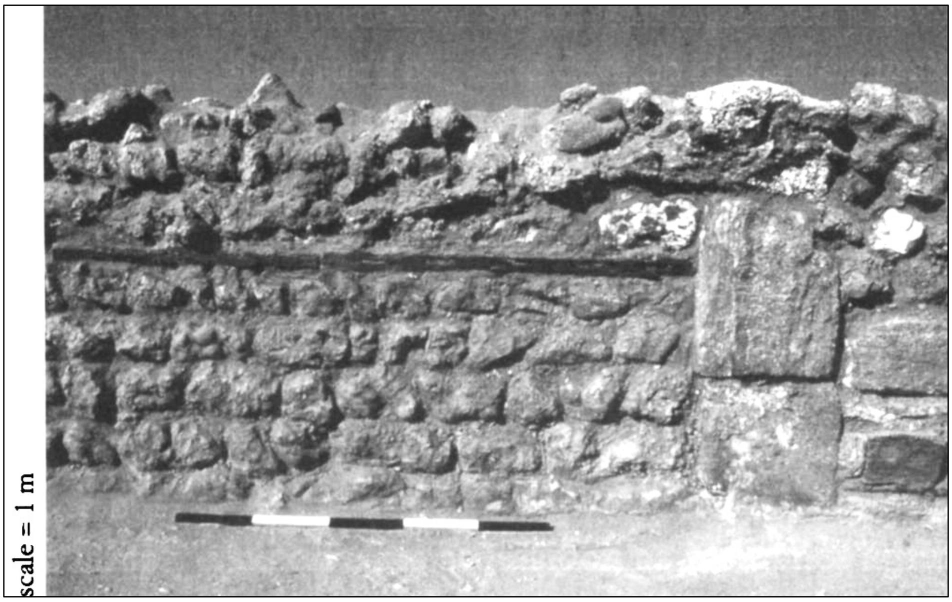


Figure 7.36 Teakwood reused as levelling course in late Roman wall in trench BE97/98-16. Photograph looking towards south (Source: Sidebotham 2008: 311, Fig. 9).

Figure 7.37 Re-used teakwood (over 3 m long) from a late Roman religious shrine in trench BE98/99-23. Photograph looking north (Source: Sidebotham 2008: 311, Fig. 11).

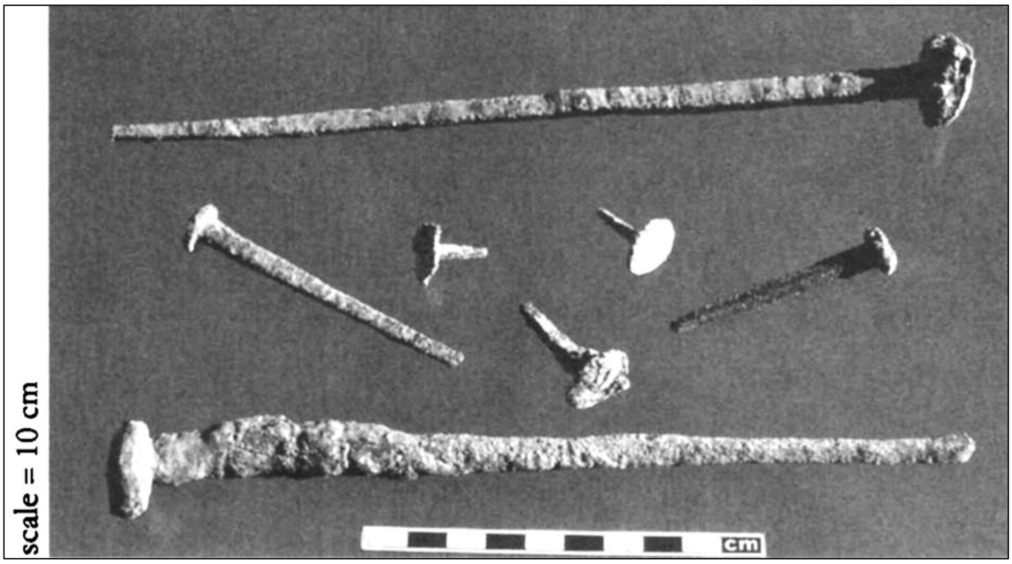


Figure 7.38 Copper nails and tacks from Berenike (Source: Sidebotham 2008: 307, Fig. 3).

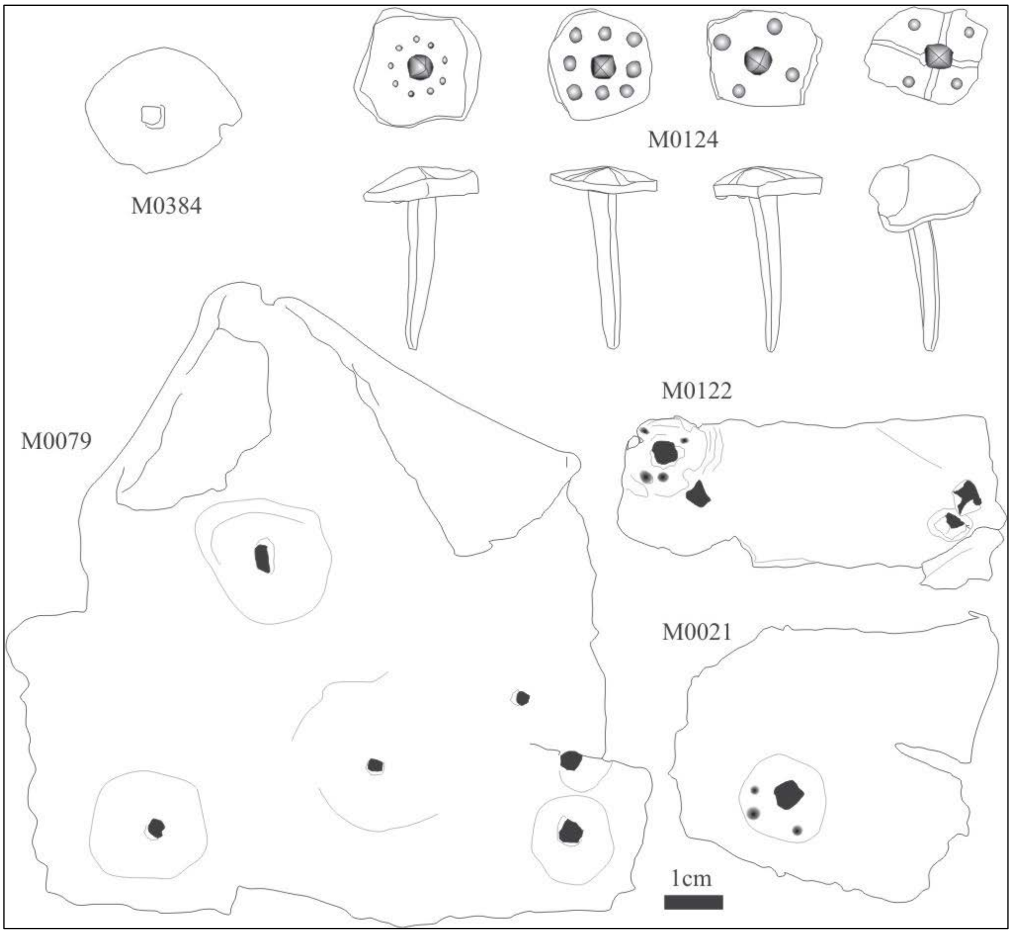


Figure 7.39 Copper alloy tacks and lead sheets from the harbour contexts (Trenches 7 and 7A) in Myos Hormos (Source: Blue et al. 2011: 187, Fig. 15.8).

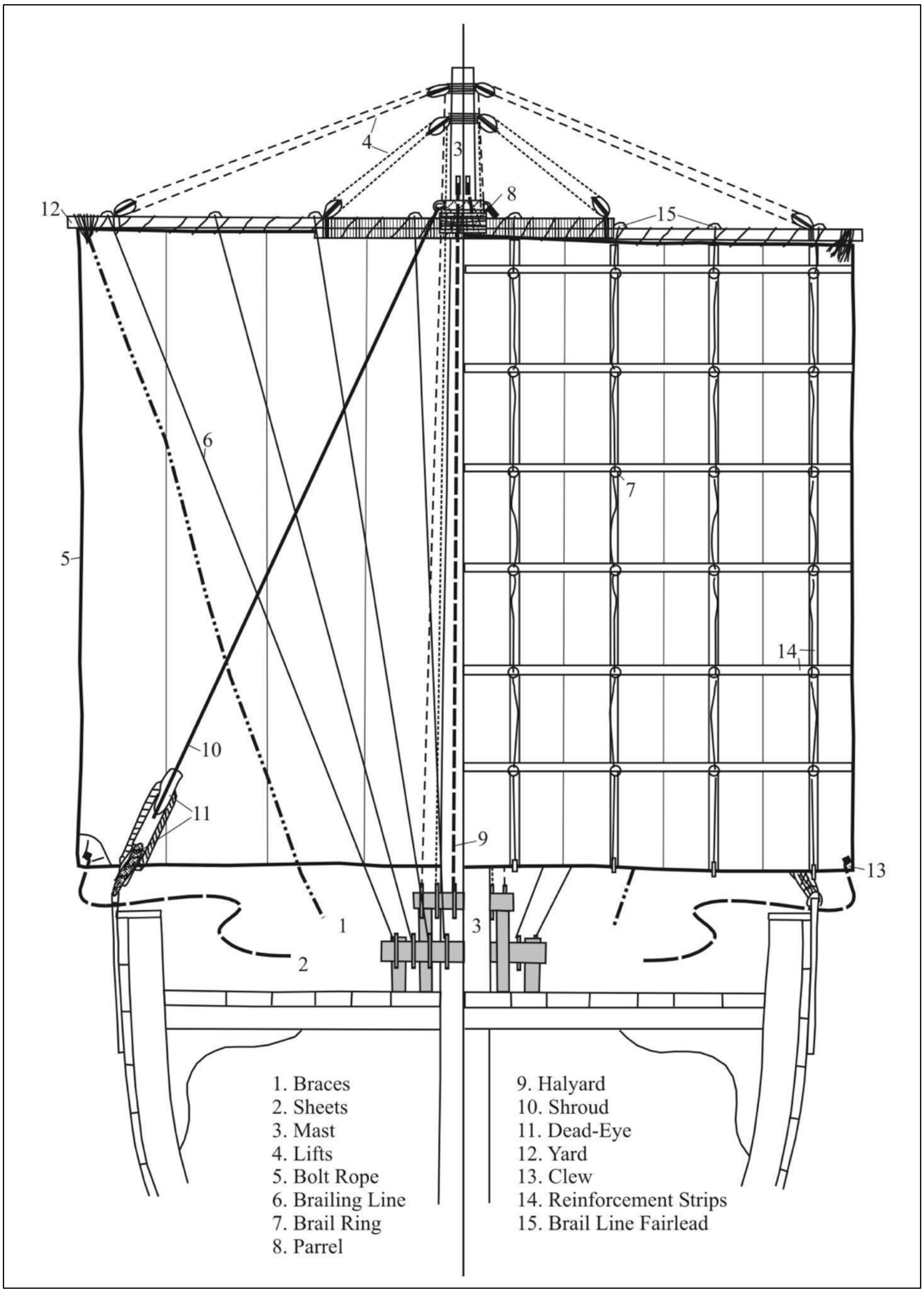


Figure 7.40 A schematic representation of a Mediterranean square-sail rigging (Source: Whitewright 2008: 75, Fig. 2.6).

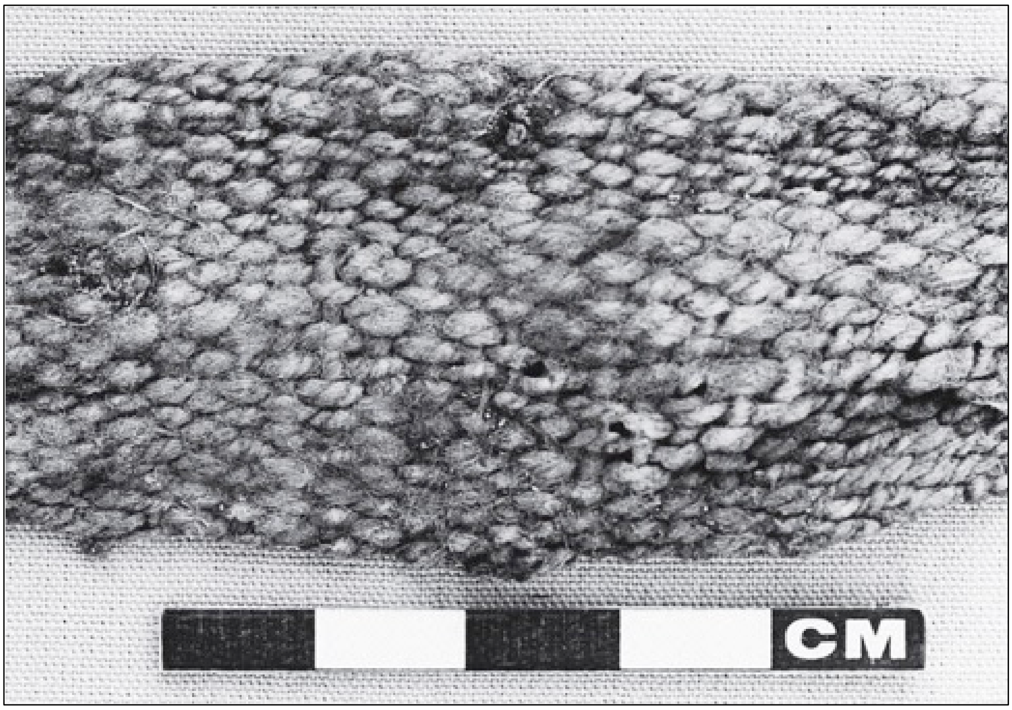


Figure 7.41 Z-spun (Indian tradition) piece of sail cloth from Berenike (Source: Wild and Wild 2001: 218, Fig. 6).

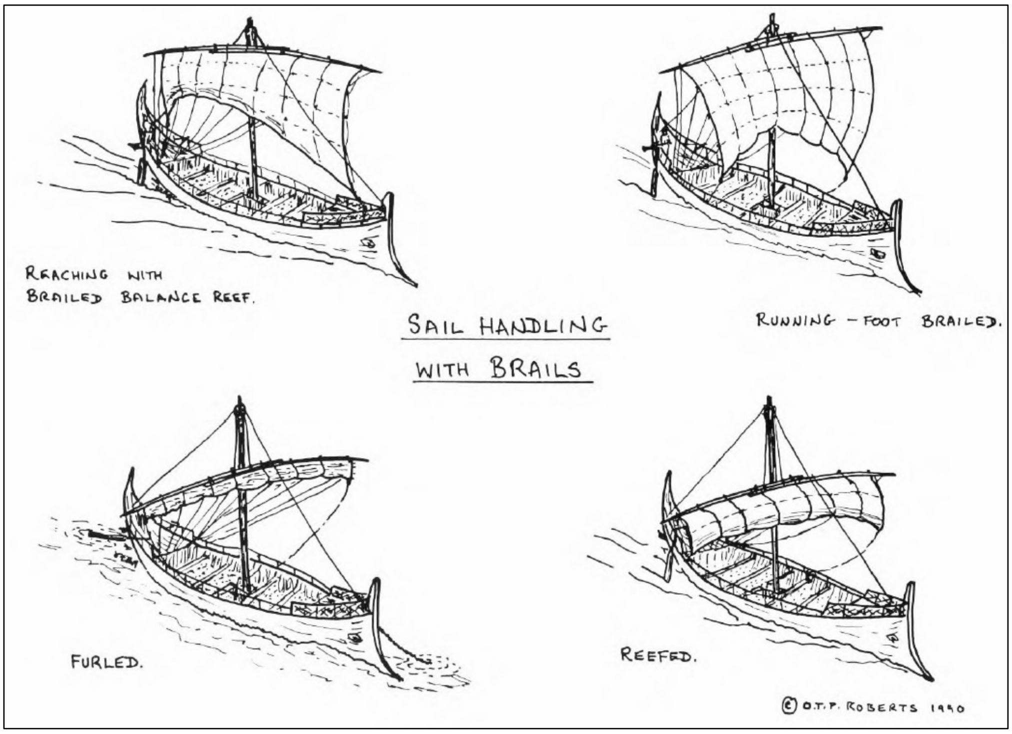


Figure 7.42 Reefing sail by the way of using brail rings (Source: Roberts 1991: XX).

Figure 7.43 Reinforcing strip (0758) and associated brailing rings (Source: Wild and Wild 2001: 215, Fig. 5).

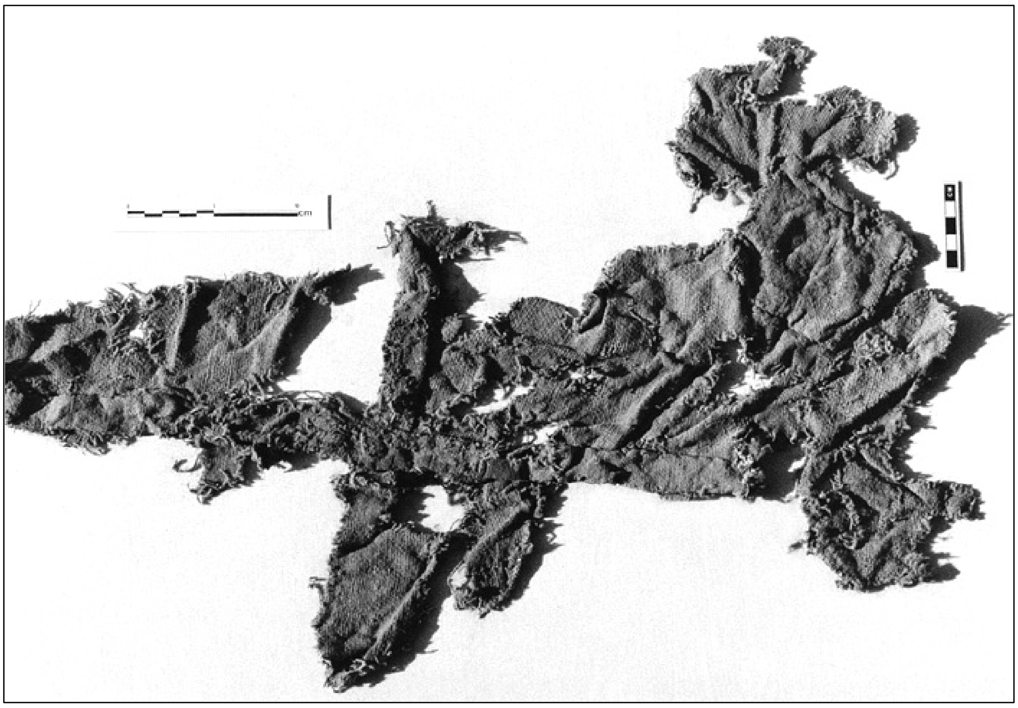


Figure 7.44 Sail fragment from Berenike (97.103) (Source: Wild and Wild 2001: 214, Fig. 2).

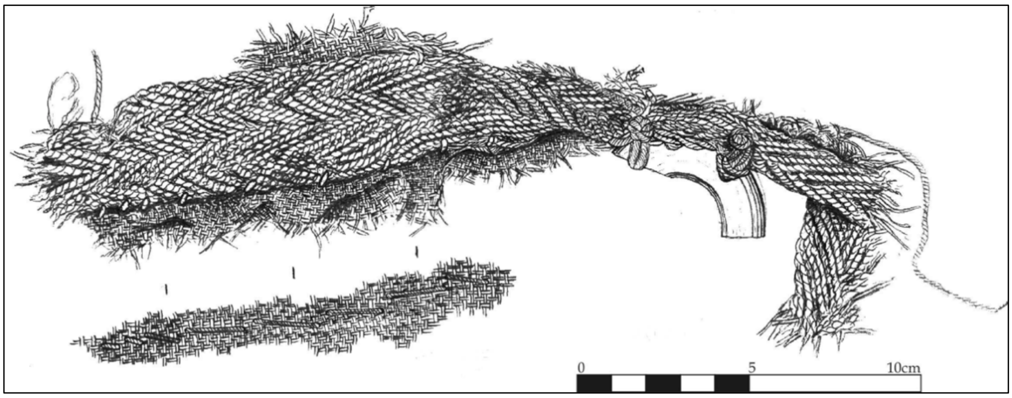


Figure 7.45 Sail fragment with a partly preserved brailing ring from Myos Hormos (Source: Whitewright 2008: 89, Fig.2.11).

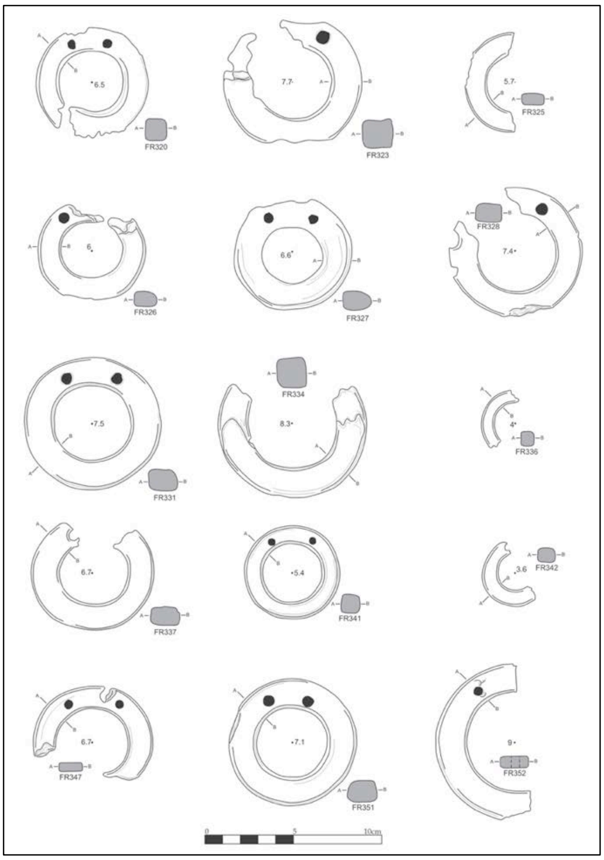


Figure 7.46 Brail rings made out of cattle horn from Berenike (top) and Myos Hormos (bottom) (Sources above: Sidebotham 2008: 309, Fig. 4; left: Blue et al. 2011: 193, Fig. 15.13).

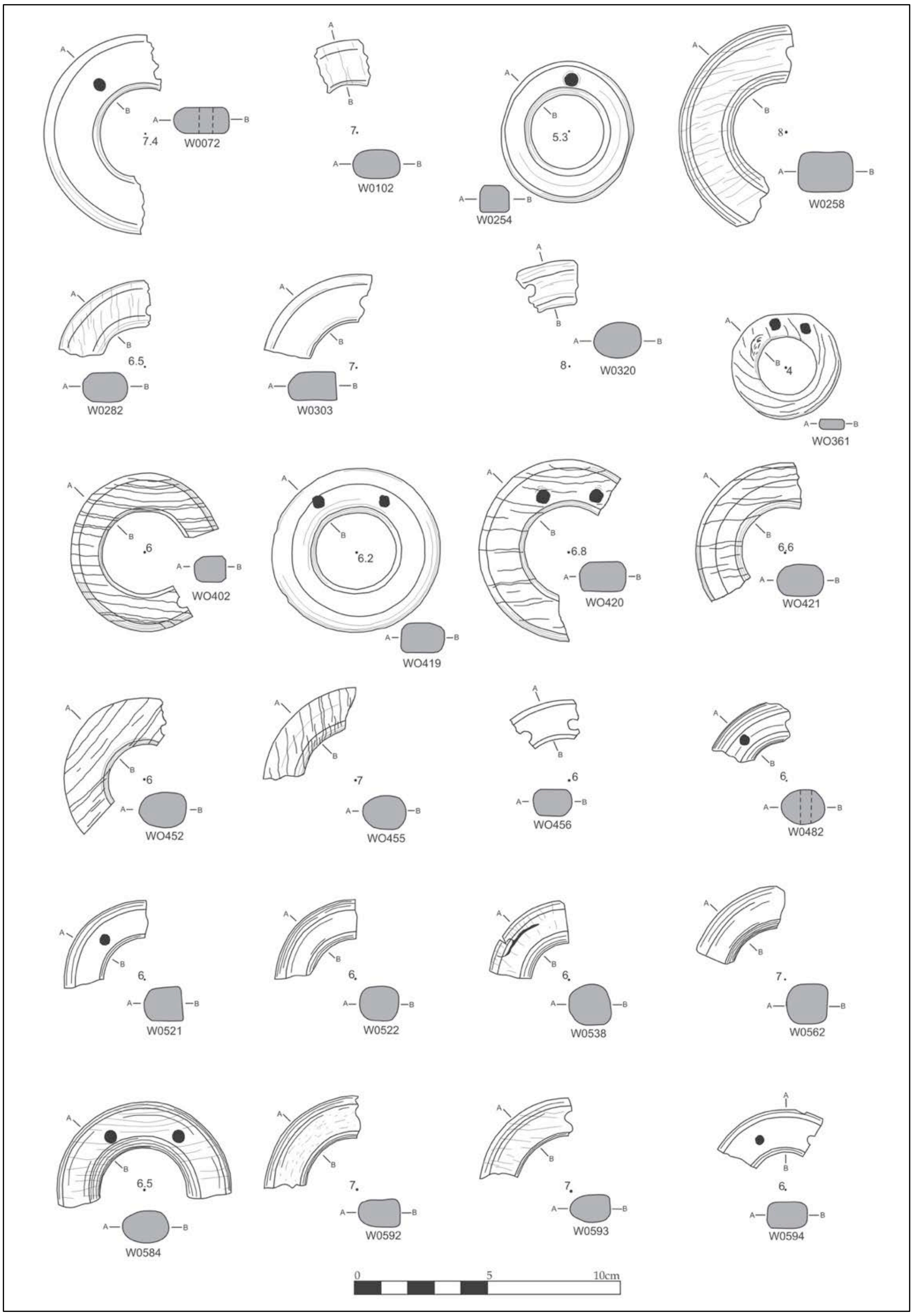


Figure 7.47 Wooden brail rings from Myos Hormos. They were produced from a variety of wood including Indian teak, blackwood, and alder (Source: Blue et al. 2011: 192, Fig. 15.12).

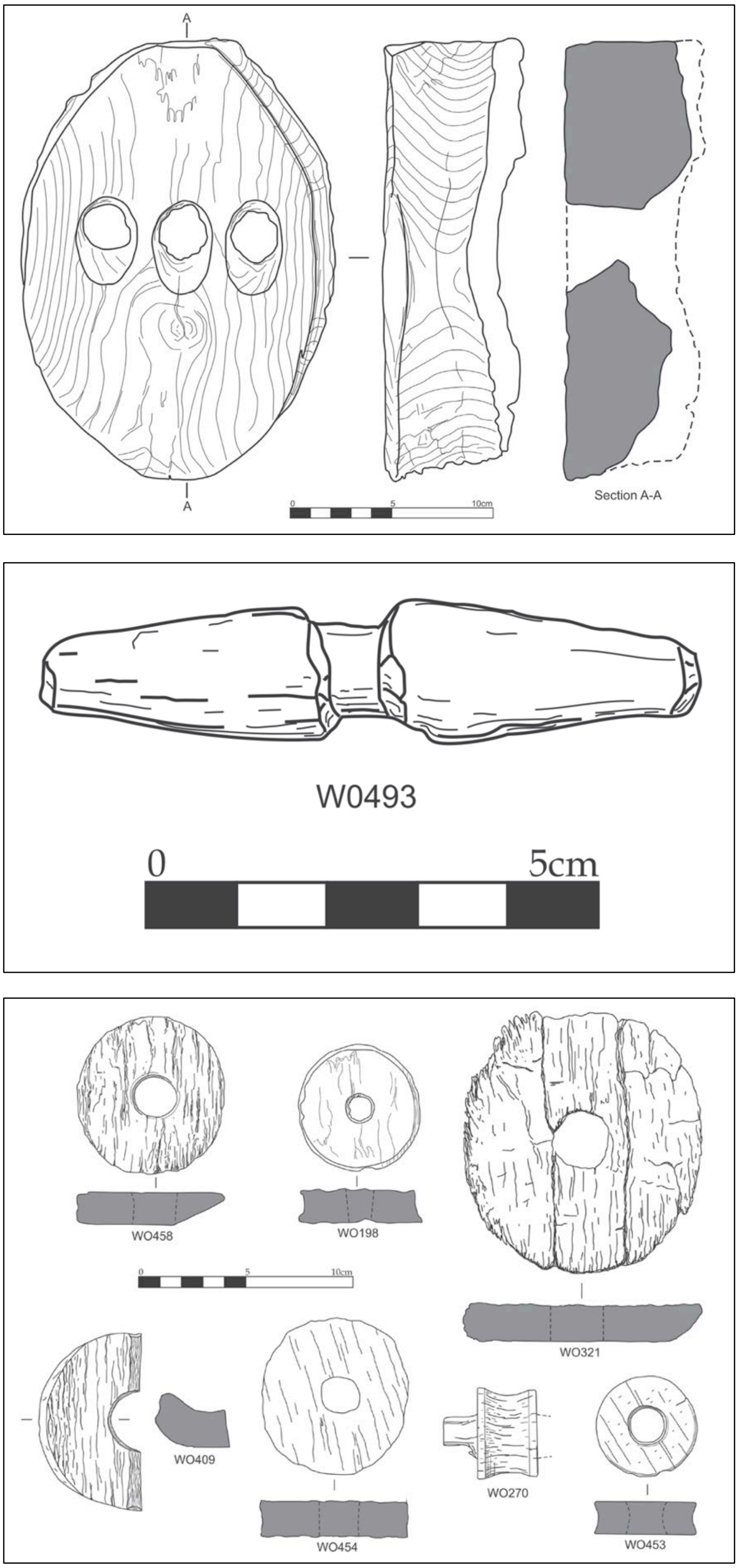


Figure 7.48 Elements of square-sail rigging from Myos Hormos. From the top a Roman deadeye, wooden toggle and block sheathes (Source: Blue et al. 2011: 189–191, Figs. 15.9–11).

Figure 7.49 Top: *In situ* ropes from the 'tarring area' in Berenike. Bottom: Detail of a thick rope braid (Source: The Berenike Excavations Project, Photos: SE Sidebotham).

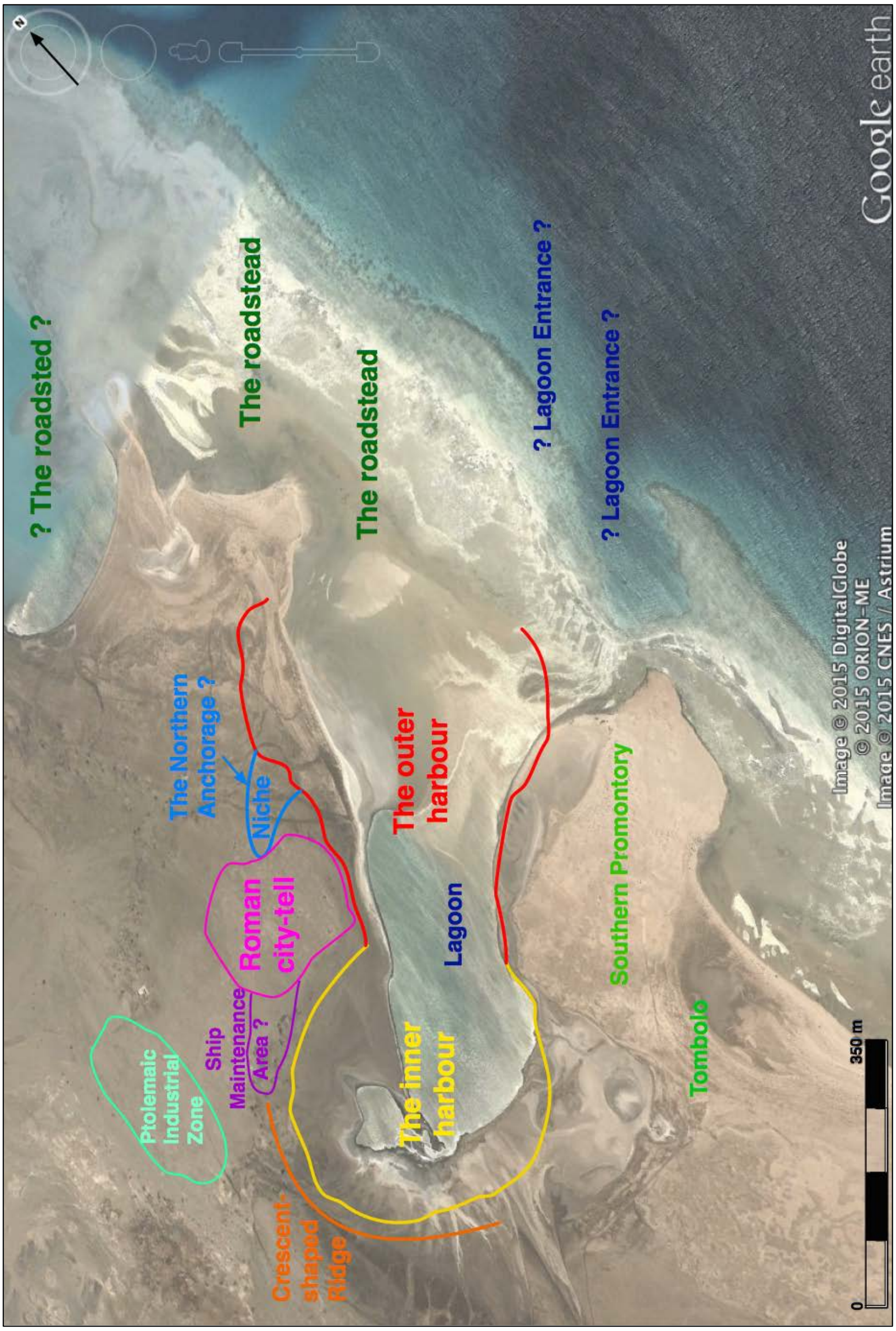


Figure 7.50 Division of functional zones within the port of Berenike that has been used to create the 'Scenarios' (Section 7.3) and to calculate the capacity of the harbour (Source of image: Google Earth 2015; Drawn by AM Kotarba-Morley).

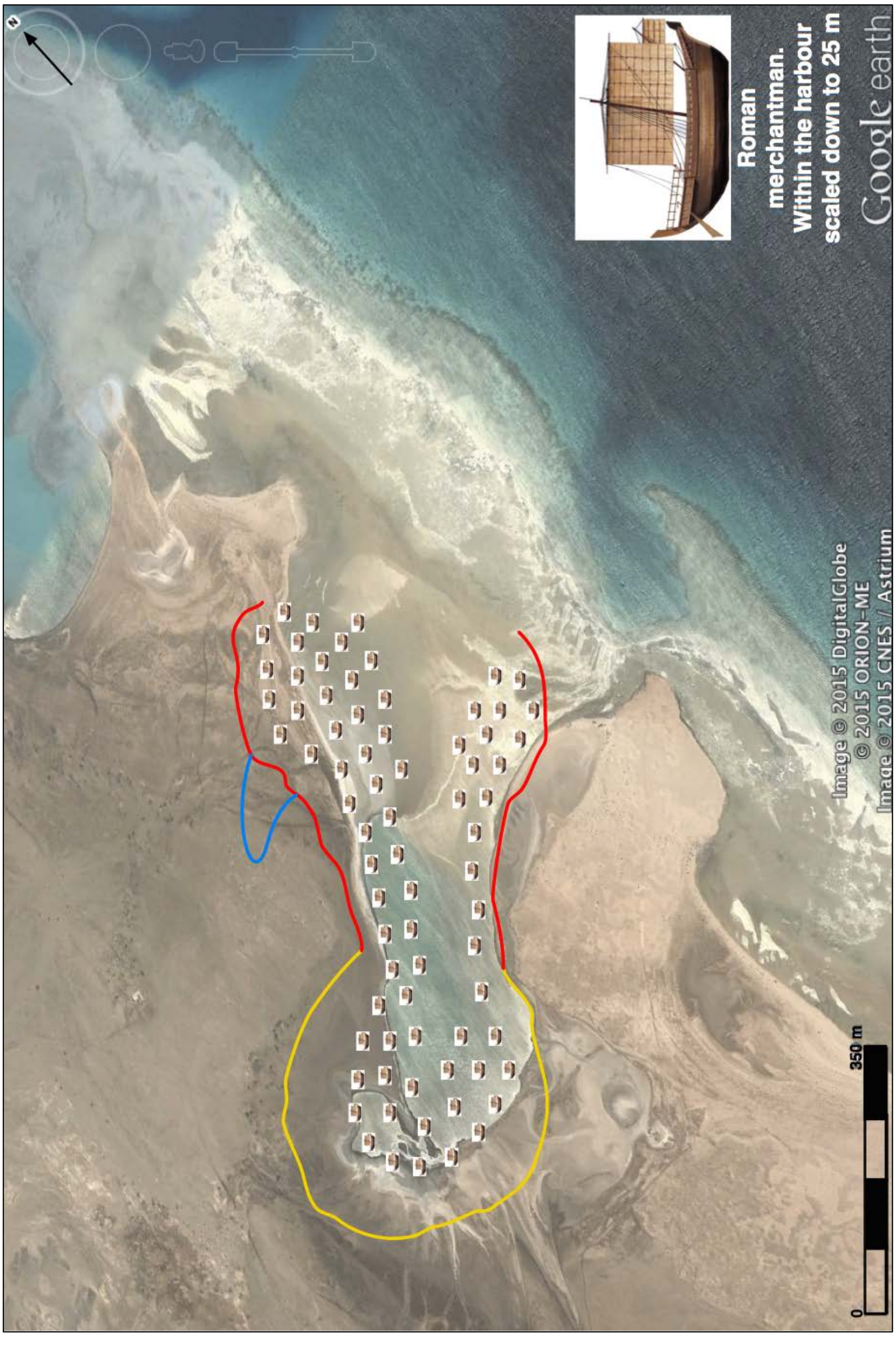


Figure 7.51 Representation of the estimate of 75 merchantmen of 25 m x 7 m in size located within Berenike's harbour (representation to scale) (Source of imagery: Google Earth; Drawn by AM Kotarba-Morley).

FIGURES: APPENDIX 1

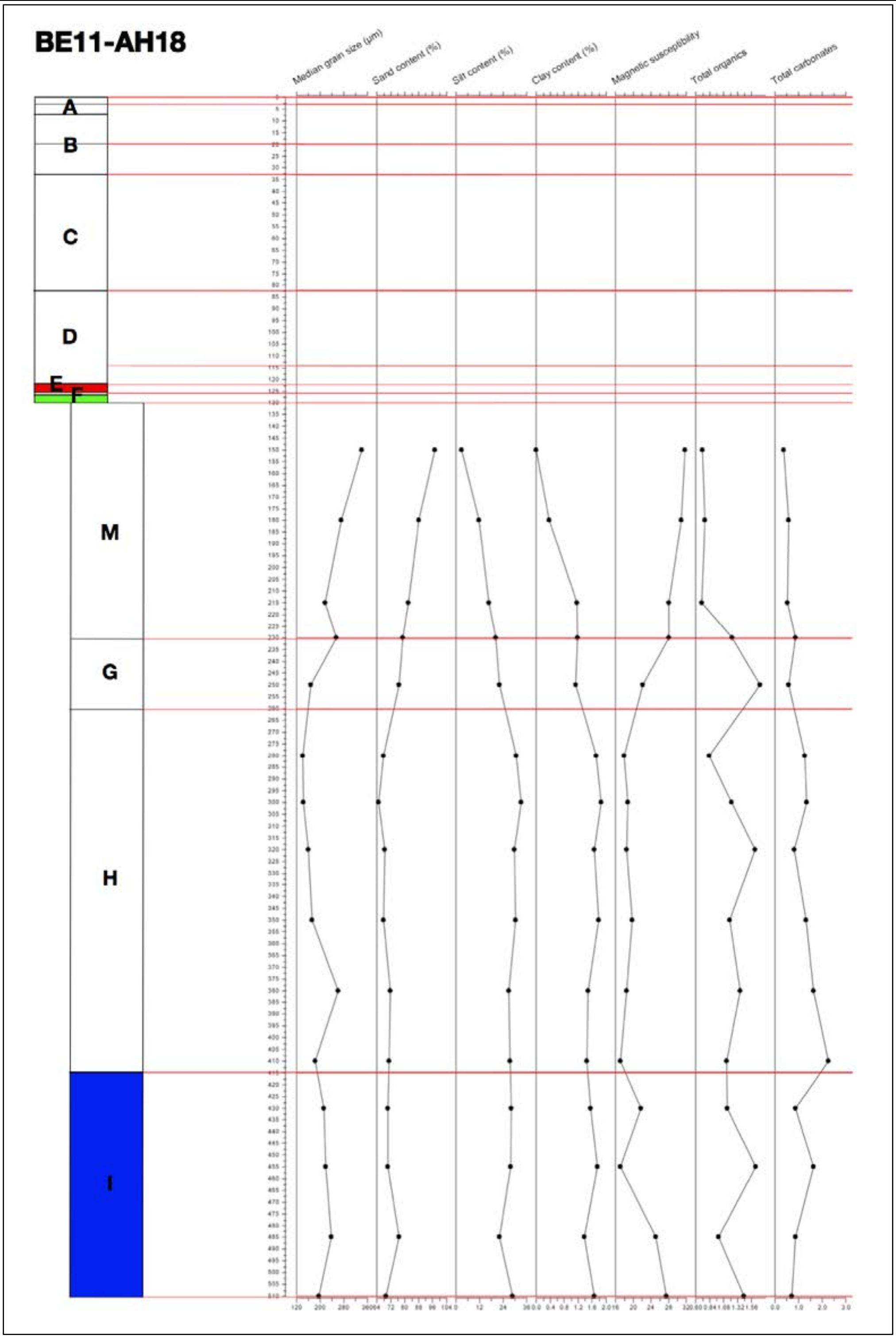


Figure A.1 Stratigraphic log of BE11-AH18 showing results from laboratory analyses (sedimentary log, median grain size, % of sand, % of silt, % of clay, magnetic susceptibility value, total organic matter in %, total carbonate content in %; Drawn by AM Kotarba-Morley, same as in all following figures of this kind).

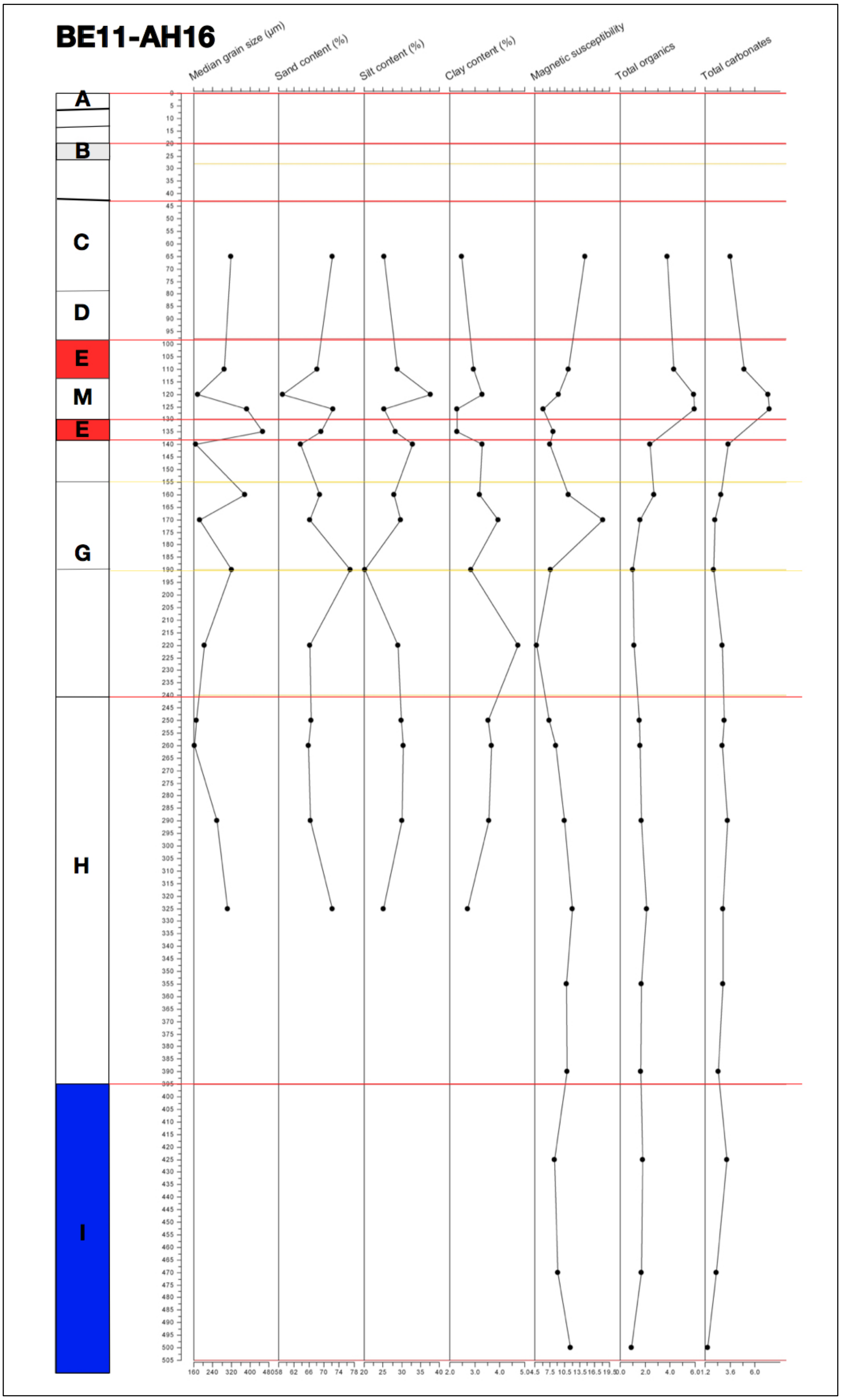


Figure A.2 Stratigraphic log of BE11-AH16.

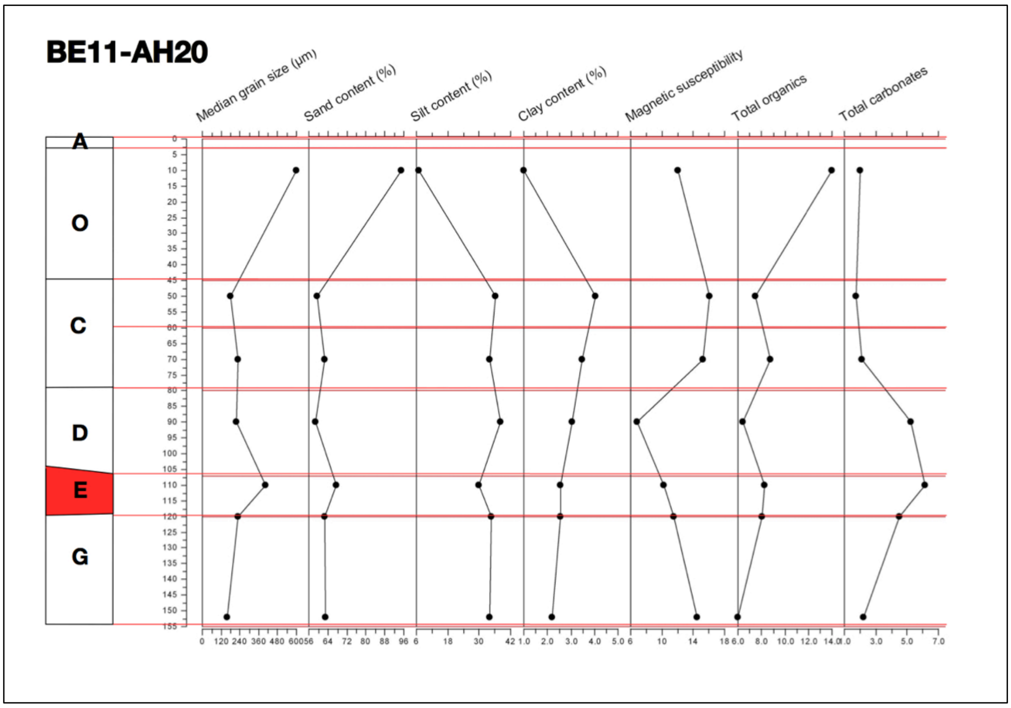


Figure A.3 Stratigraphic log of BE11-AH20.

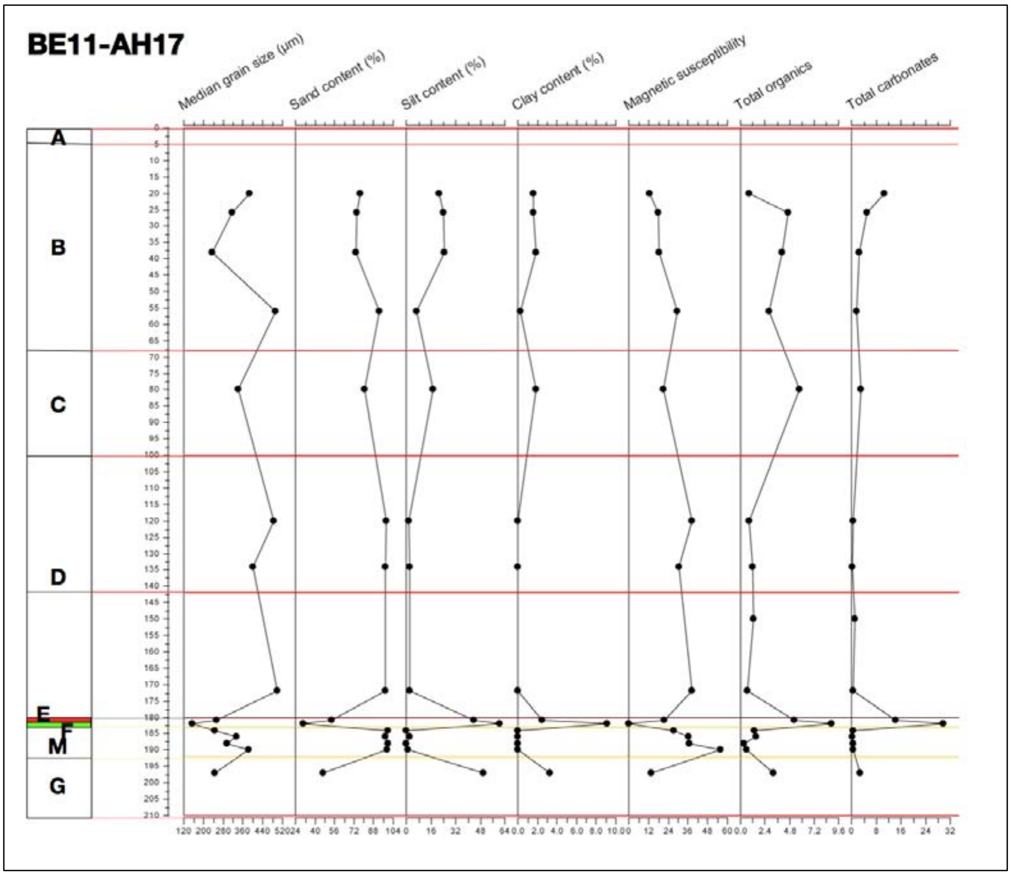


Figure A.4 Stratigraphic log of BE11-AH17.

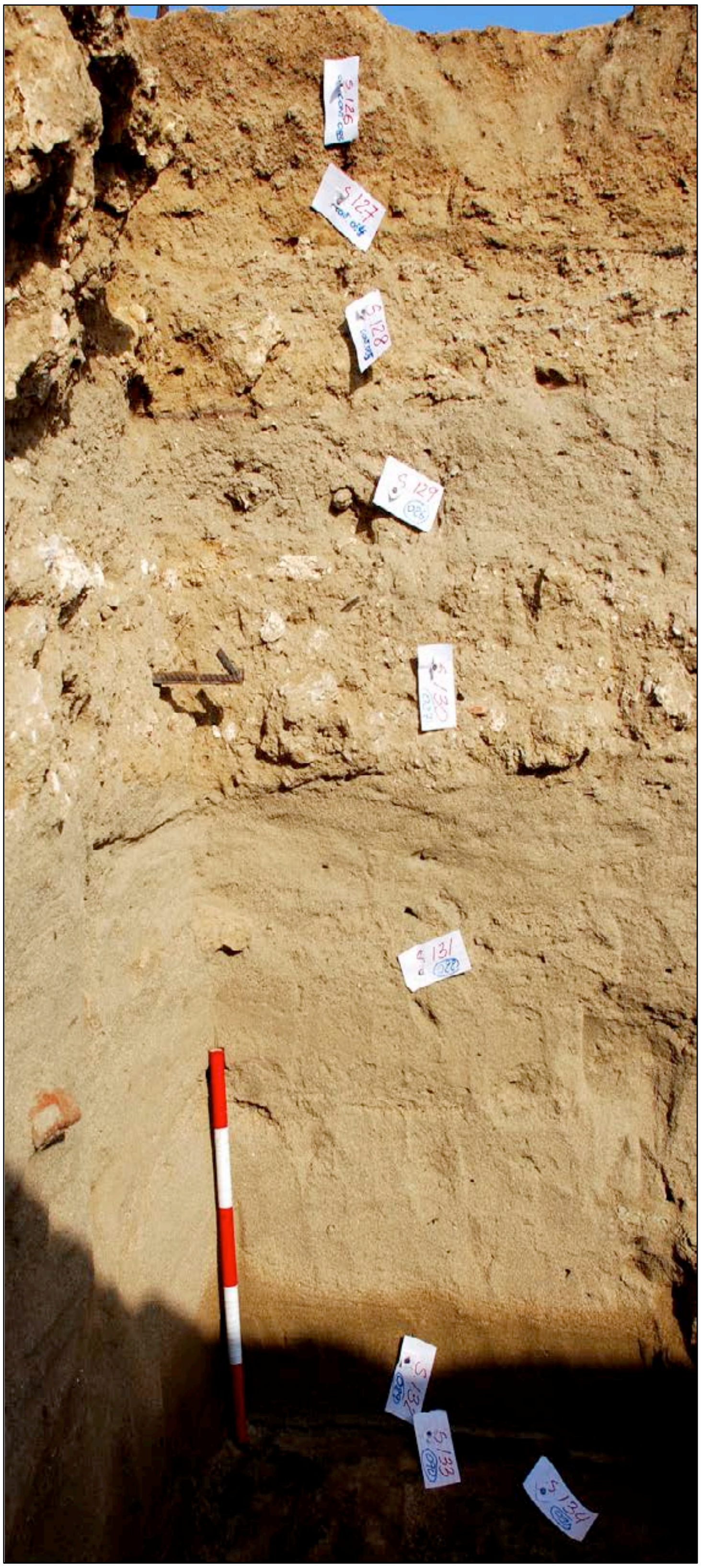


Figure A.5 Northern section of trench BE11-71 that has been sampled as AH17 (Photo AM Kotarba-Morley).

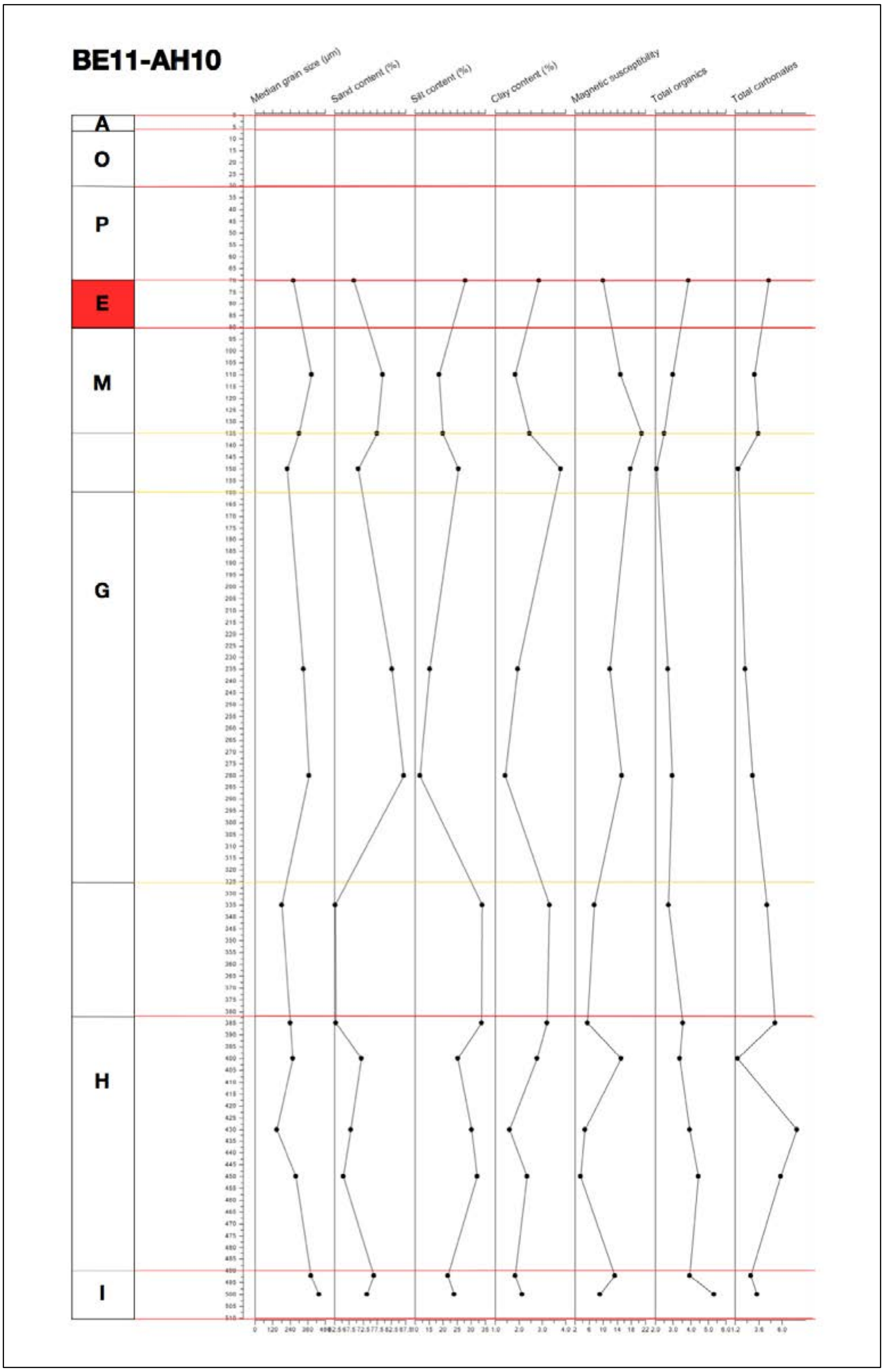


Figure A.6 Stratigraphic log of BE11-AH10.

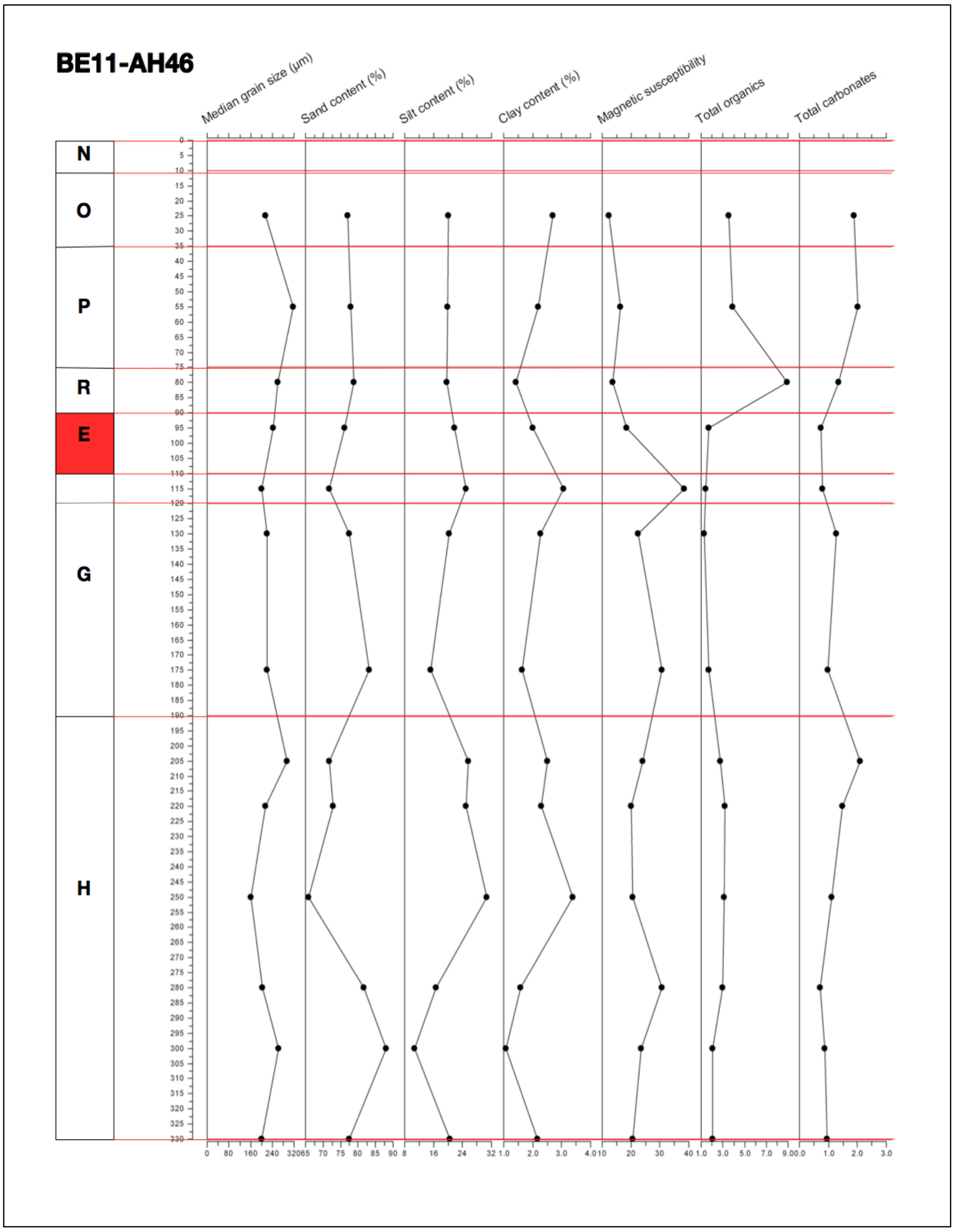


Figure A.7 Stratigraphic log of BE11-AH46.

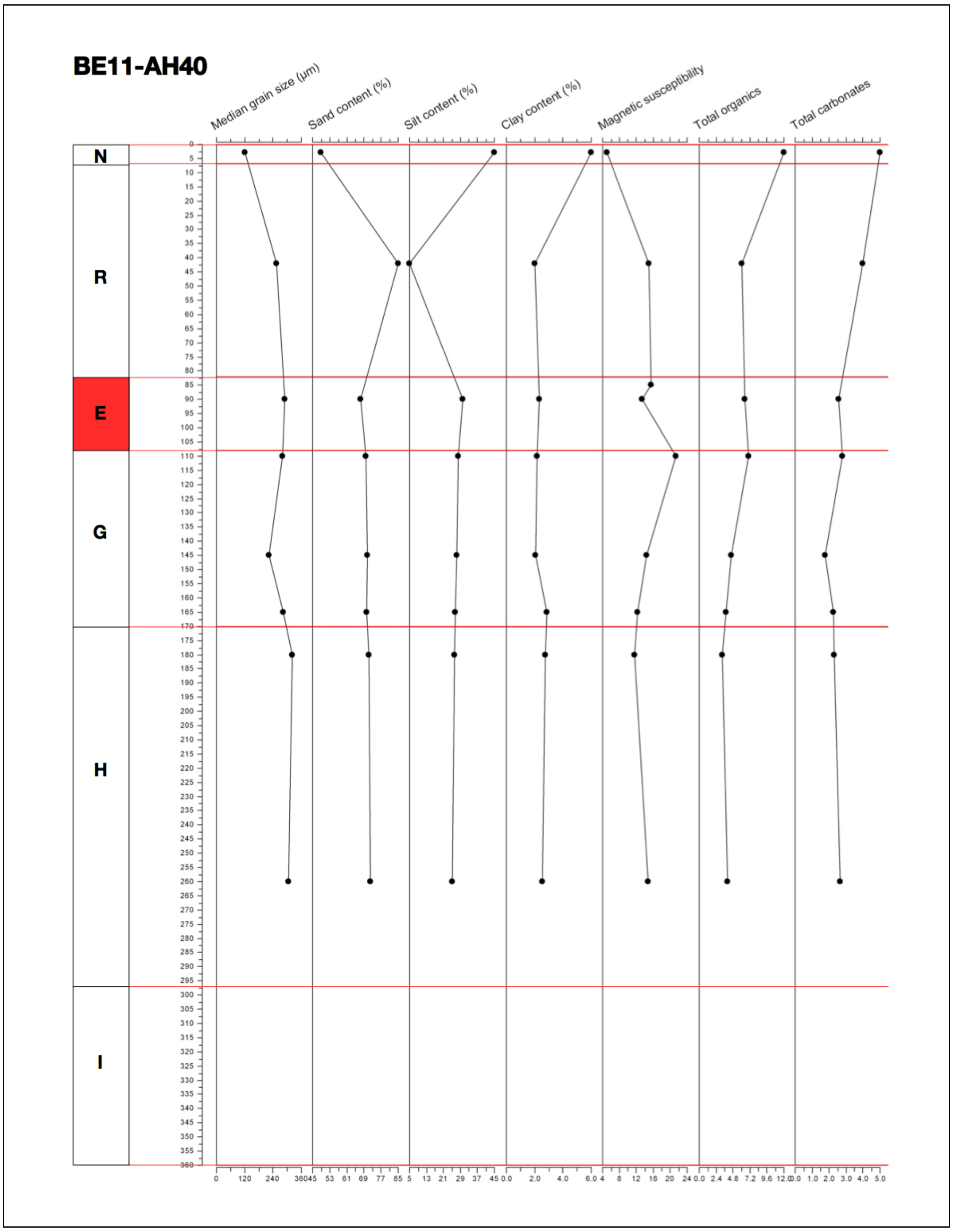


Figure A.8 Stratigraphic log of BE11-AH40.

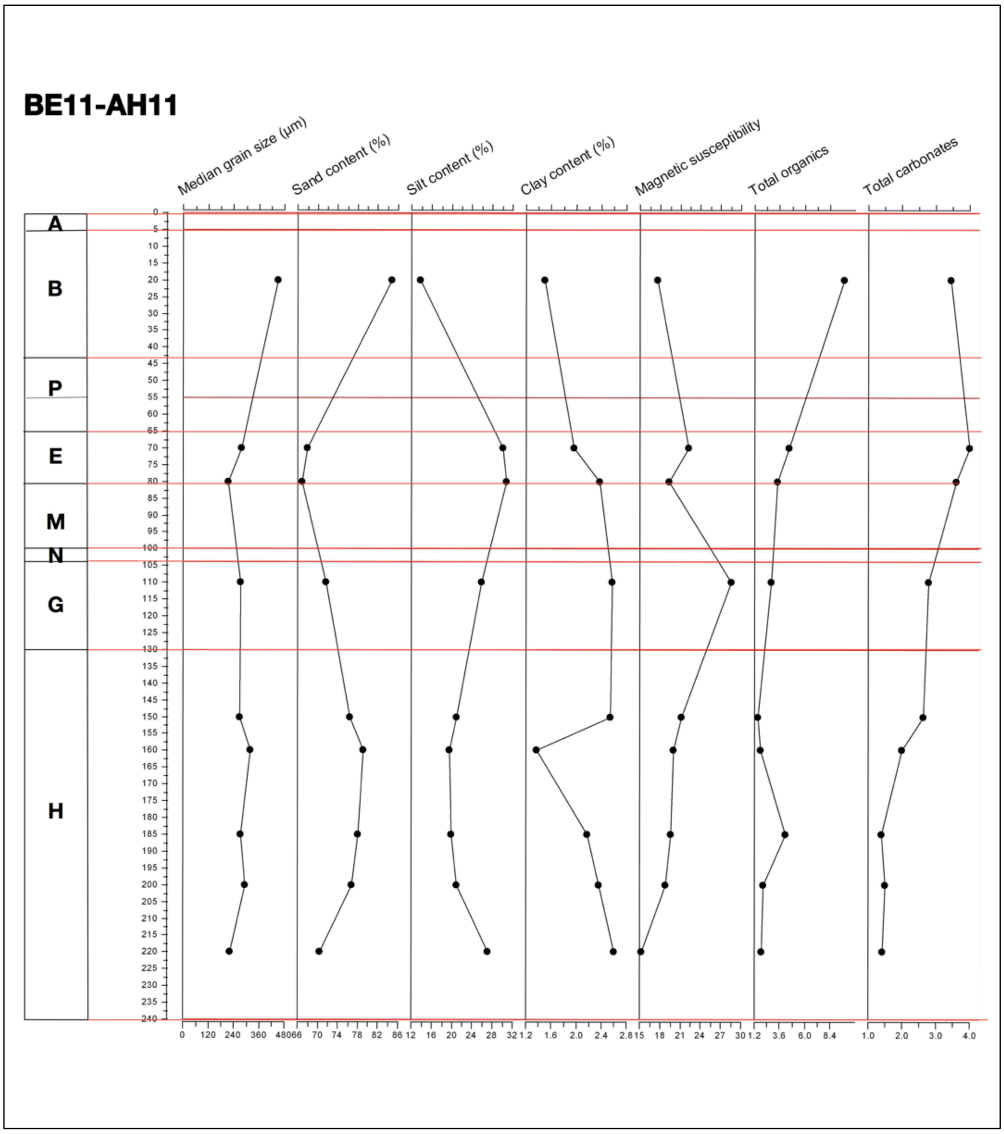


Figure A.9 Stratigraphic log of BE11-AH11.

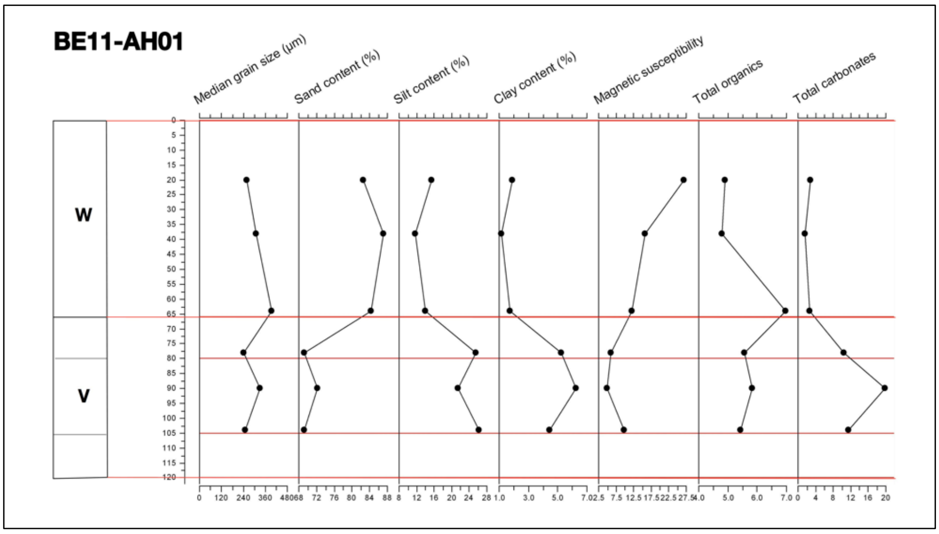


Figure A.10 Stratigraphic log of BE11-AH1.

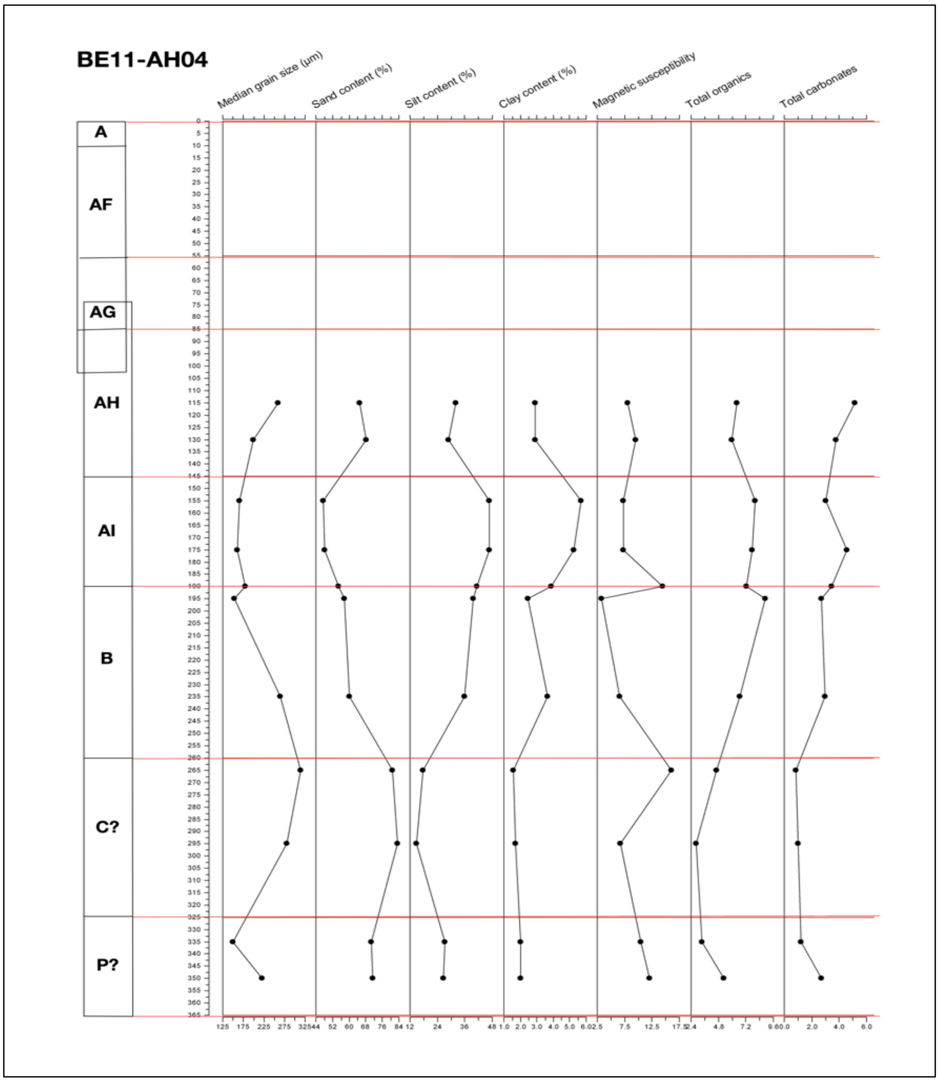


Figure A.11 Stratigraphic log of BE11-AH4.

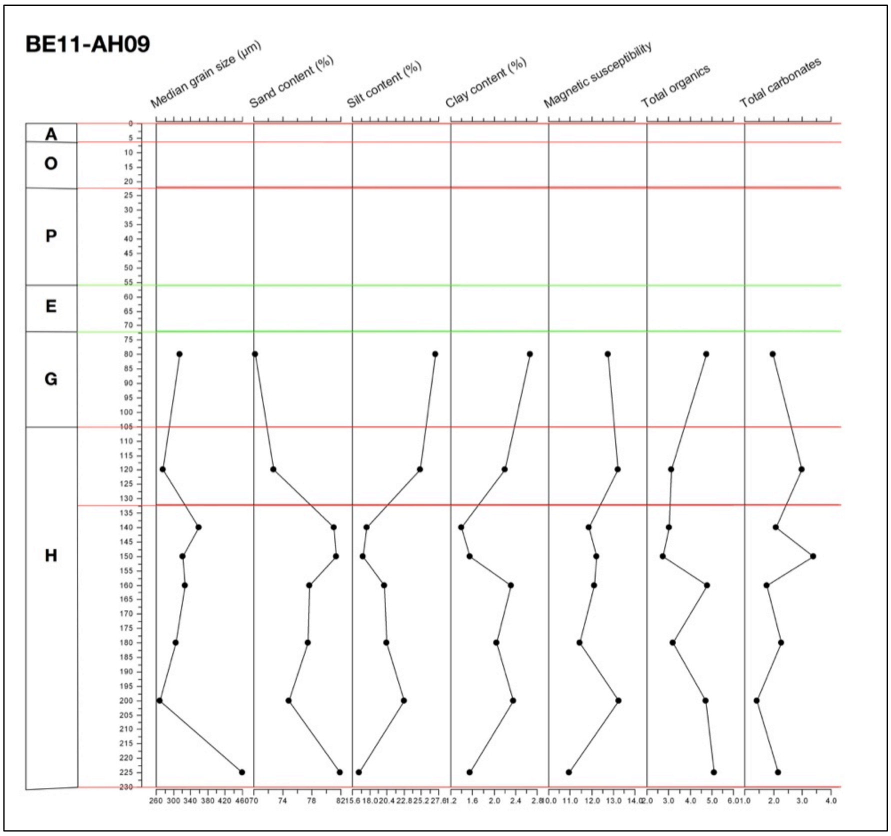


Figure A.12 Stratigraphic log of BE11-AH9.

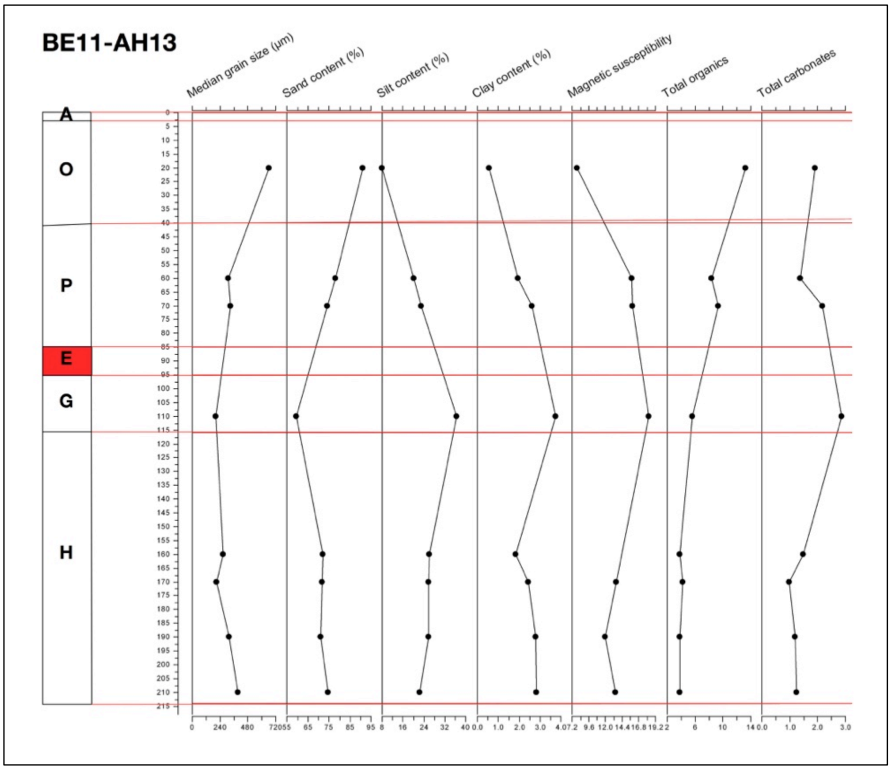


Figure A.13 Stratigraphic log of BE11-AH13.

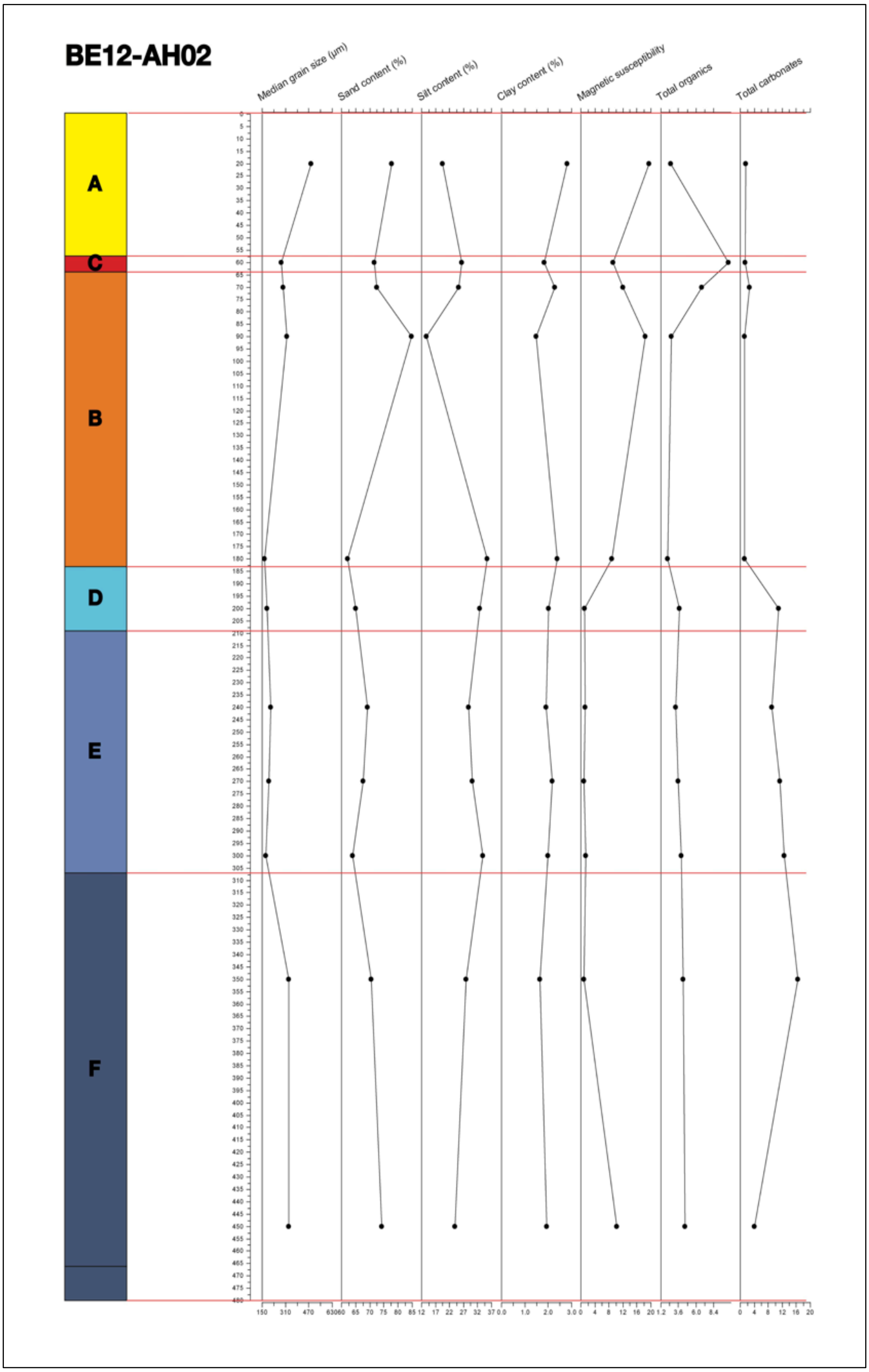


Figure A.14 Stratigraphic log of BE12-AH2.

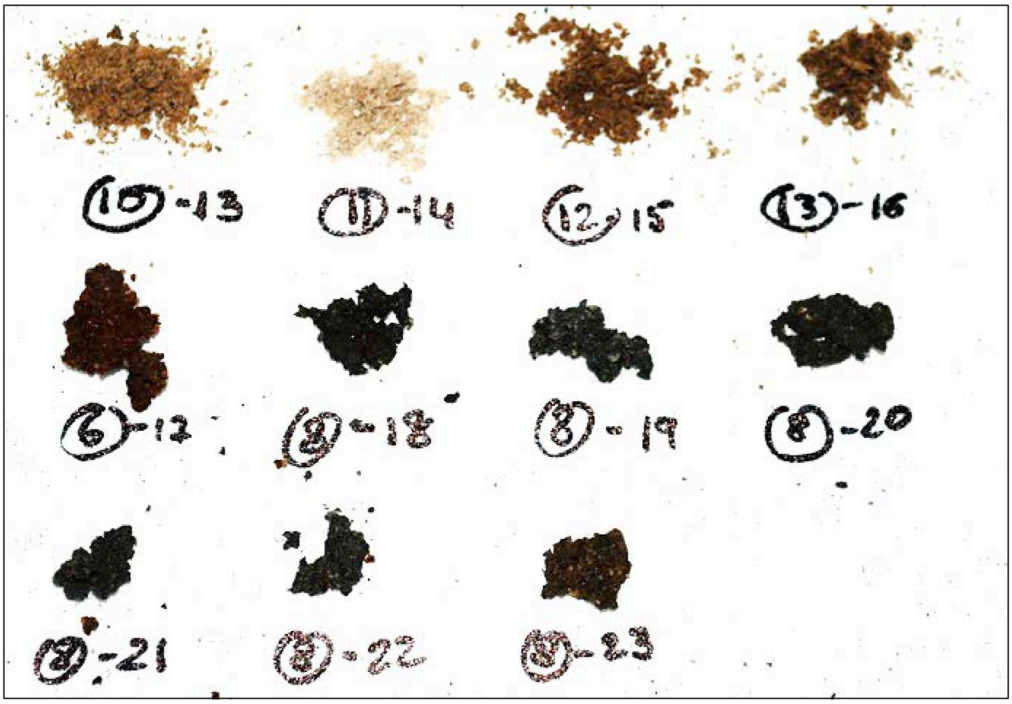


Figure A.15 Field photograph of samples collected from the BE12-AH02 (Photo: AM Kotarba-Morley 2012).

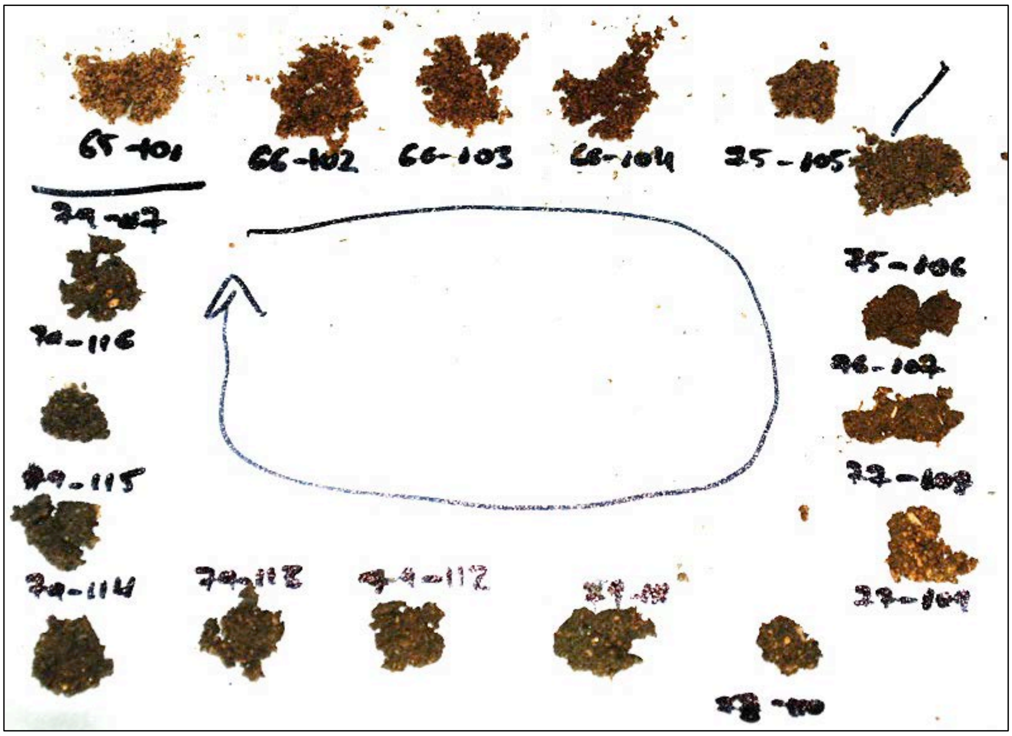


Figure A.16 Field photograph of samples collected from the augerhole BE12-AH13 (Photo: AM Kotarba-Morley 2012).

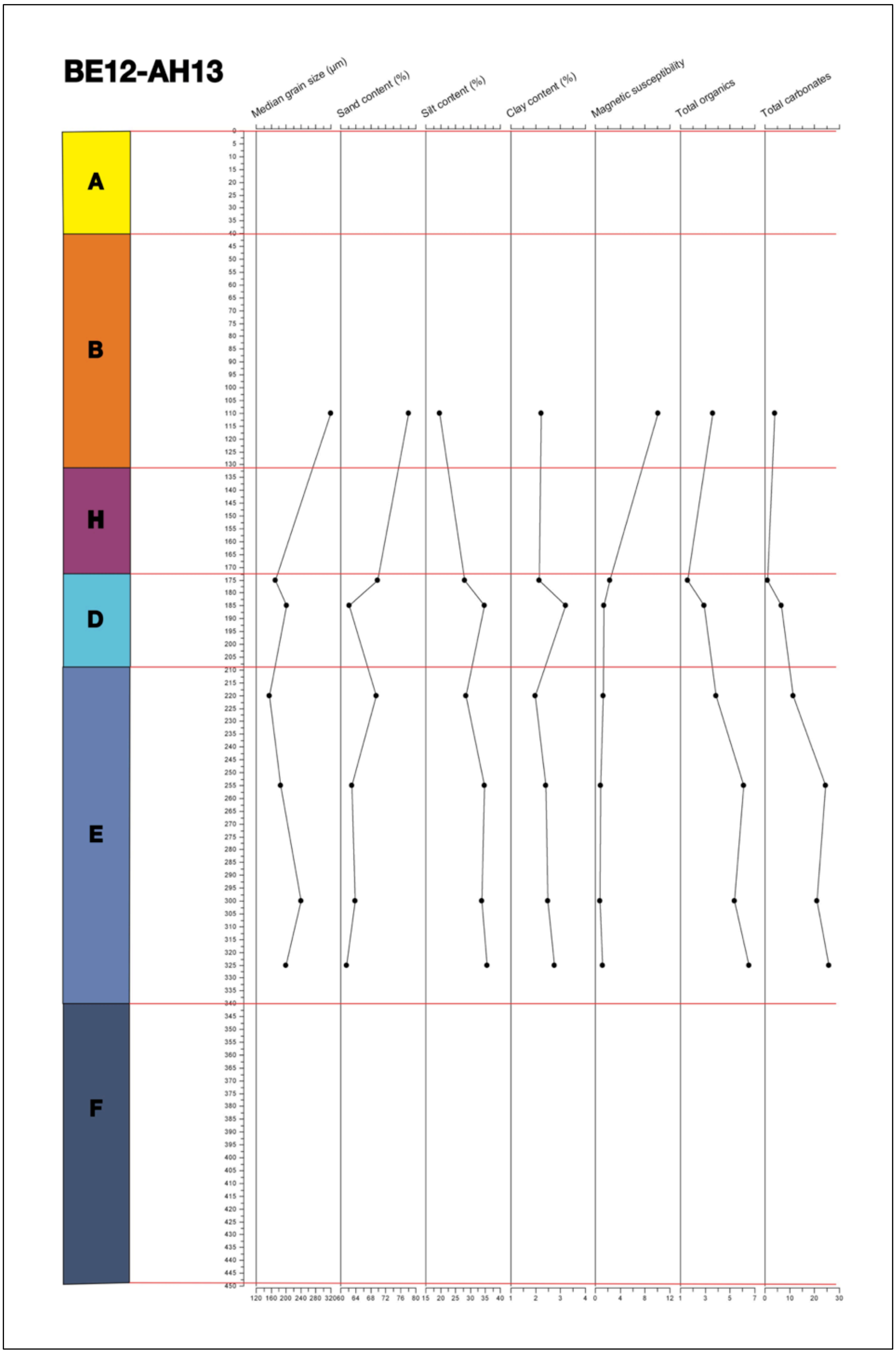


Figure A.17 Stratigraphic log of BE12-AH13.

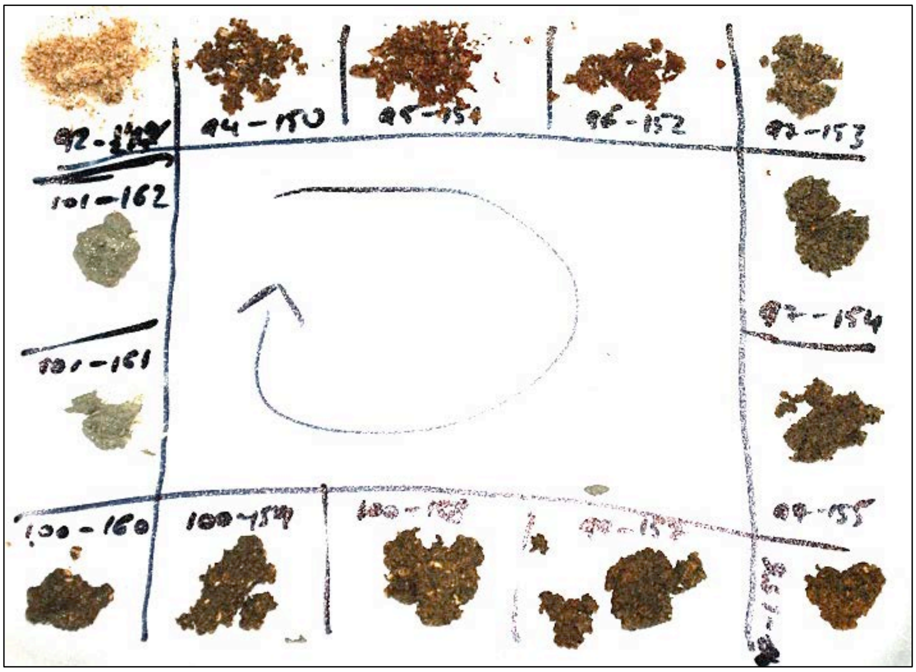


Figure A.18 Field photograph of samples collected from the augerhole BE12-AH16 (Photo: AM Kotarba-Morley 2012).

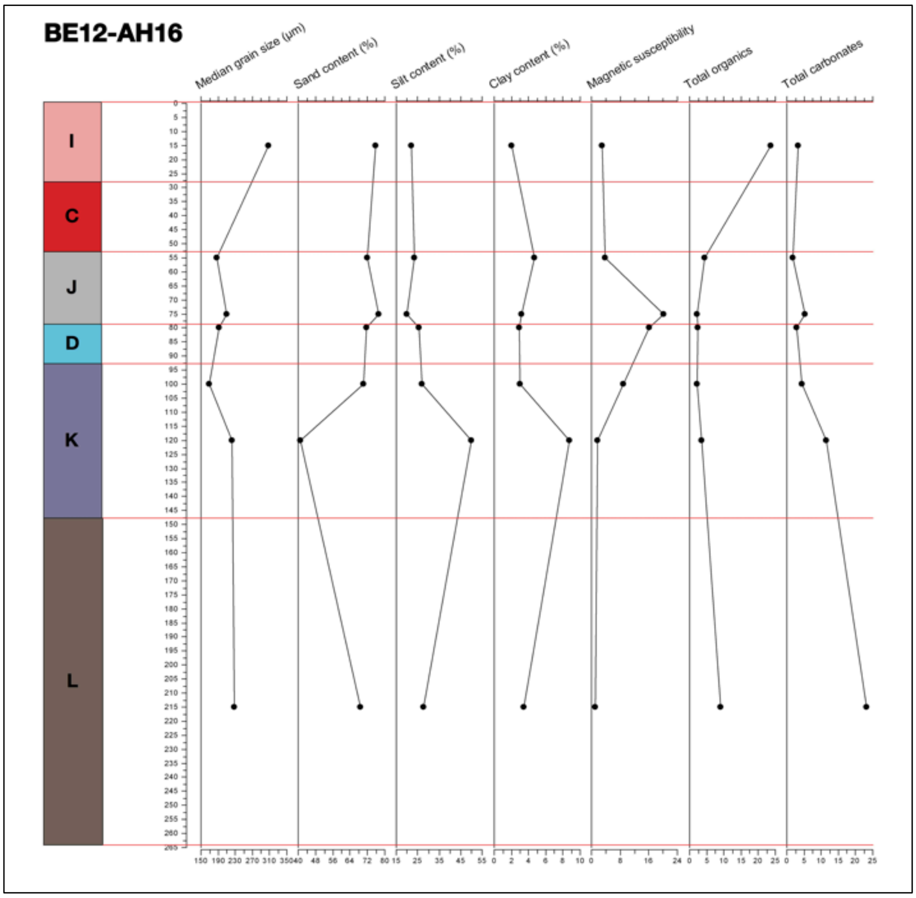


Figure A.19 Stratigraphic log of BE12-AH16.

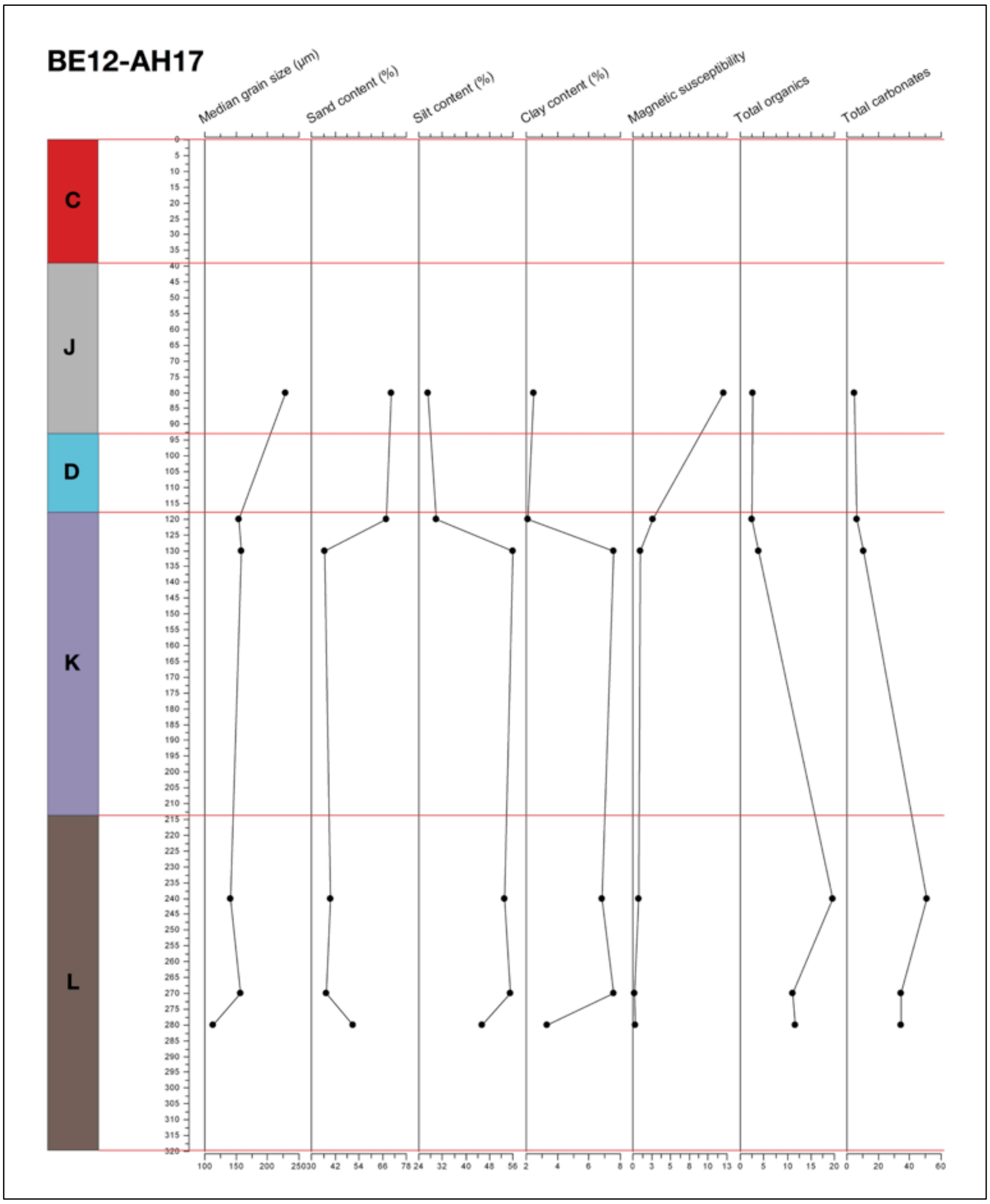


Figure A.20 Stratigraphic log of BE12-AH17.

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GLOSSARY OF TERMS USED

AH – Augerhole
ahtl – above current high tide level
AMS – radiocarbon dating method
amsl – above mean sea level
asl – above sea level

BCE – before Common Era = BC
BFT – Beaufort Scale
bgl – below ground level
bmsl – below mean sea level
BP – before present
bsl – below sea level

CE – of Common Era = AD
CSR – Crescent-shaped Ridge

kya – thousand years ago

LGM – last glacial maximum

MIS – Marine Isotope Stage
MSL – mean sea level

OSL – Optically Stimulated Luminesence

PIZ – Ptolemaic Industrial Zone
PoA – Paramterers of Attractiveness

rpm – rotations per minute
RSL – relative sea level

SWE – Southwestern Embayment