Ancient Ports of Trade on the Red Sea Coasts—The 'Parameters of Attractiveness' of Site Locations and Human Adaptations to Fluctuating Land- and Sea-Scapes. Case Study Berenike Tro…

Chapter · January 2019

DOI: 10.1007/978-3-319-99408-6_34

CITATIONS
0

READS
60

1 author:

Ania Kotarba-Morley
Flinders University
14 PUBLICATIONS **73** CITATIONS

SEE PROFILE

Najeeb M. A. Rasul · Ian C. F. Stewart *Editors*

Geological Setting, Palaeoenvironment and Archaeology of the Red Sea

هيئة المساحة الجيولوجية السعودية
SAUDI GEOLOGICAL SURVEY
www.sgs.org.sa

Springer

Najeeb M. A. Rasul • Ian C. F. Stewart
Editors

Geological Setting, Palaeoenvironment and Archaeology of the Red Sea

هيئة المساحة الجيولوجية السعودية
SAUDI GEOLOGICAL SURVEY
www.sgs.org.sa

Springer

Editors
Najeeb M. A. Rasul
Center for Marine Geology
Saudi Geological Survey
Jeddah, Saudi Arabia

Ian C. F. Stewart
Stewart Geophysical Consultants Pty. Ltd.
College Park, SA, Australia

ISBN 978-3-319-99407-9 ISBN 978-3-319-99408-6 (eBook)
https://doi.org/10.1007/978-3-319-99408-6

Library of Congress Control Number: 2018952604

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Ancient Ports of Trade on the Red Sea Coasts —The 'Parameters of Attractiveness' of Site Locations and Human Adaptations to Fluctuating Land- and Sea-Scapes. Case Study *Berenike Troglodytica*, Southeastern Egypt

Anna M. Kotarba-Morley

Abstract

The Red Sea region is unfavourable for long-shore nautical activity as it lacks natural topographic features that could be used as harbours; there are only a few suitable bays for landing along its coasts, where wadi mouths allow for a break in the reef. However, experiencing seasonally variable winds and currents, parts of the Red Sea constituted favourable marine environments for sea voyaging, contact and trade for millennia. This paper focuses on the influence that the local environmental and climatic context (including land- and sea-scape), had on the location, development, and ultimate success or decline of key Classical (Greco-Roman) ports of trade on the Red Sea coast, most pertinently those involved in exchange on the Spice, Incense and Maritime Silk Routes. The importance of changes in geomorphological, climatic, landscape and sea level configurations that led to the alternation of these human-adapted landscapes will be discussed within the new theoretical framework of 'Parameters of Attractiveness' developed whilst focusing on a case study, the Greco-Roman port town of *Berenike Troglodytica* on the southern Red Sea coast of Egypt. These parameters—grouped into 4 main categories: Sea, Land, Resources, and Socio-Economic and Political—were designed in order to statistically quantify the attractiveness of particular sites along the rims of the Red Sea for use as trade ports.

A. M. Kotarba-Morley (✉)
Department of Ancient History, Faculty of Arts, Macquarie University, Sydney, NSW, Australia
e-mail: ania.kotarba@mq.edu.au

A. M. Kotarba-Morley
School of Archaeology, Oxford Centre for Maritime Archaeology, University of Qxford, Oxford, UK

A. M. Kotarba-Morley
Centre for Archaeological Science, School of Earth, Athmospheric and Life Sciences, University of Wollongong, Wollongong, Australia

N. M. A. Rasul and I. C. F. Stewart (eds.), *Geological Setting, Palaeoenvironment and Archaeology of the Red Sea*,
https://doi.org/10.1007/978-3-319-99408-6_34

1 Introduction

Ports and harbours can be located in extremely diverse political, landscape and geomorphological settings, forming hubs that not only connect different environments and cultures, but also act as centres of social and cultural diversity and the hybridisation of ideas. Owing to their favoured positions in the coastal, riverine or lacustrine landscape, and the functional and cultural sub-divisions within them, ports constitute excellent study areas for understanding past landscapes 'of the shores', geomorphological dynamics, and —in the case of sea ports—sea level changes, as well as ancient marine technologies, cultural interactions and large-scale geographic networks. It is therefore important to understand what drives the choice of location of these sites since cursory examination appears to reveal an unpredictable, non-linear pattern for the distribution of these important infrastructural nodes. It is also crucial to develop a methodology through which we can attain a deeper understanding of the land- and sea-scape settings, the contemporary environmental context, and the availability of natural resources (to build and maintain them as well as for trade) for these ancient commercial harbours. Defining and understanding their physical configuration and the level of human adaptation required to utilise and maintain the ports over long periods of time also remain key research issues.

Due to the location of ports and harbours on the dynamic intersection between the waterscape (sea, lake or river) and the terrestrial landscape, prograding and regressing coastlines provide excellent areas for the study of temporal changes in settlement patterns and the degree of adaptation and modification required from the people using and occupying them. It is therefore necessary to develop a deeper understanding of the environmental context and the landscape setting of ancient ports in order to fully appreciate the reasoning behind the choice of their particular locale on the Red Sea coast (our study region) as well as the level of geomorphological and environmental change within these littoral 'coast-scapes'.

The near constant adaptation to geomorphologically dynamic shorelines in ports such as *Berenike Troglodytica* on the southern Egyptian coast emphasises the impact that natural factors such as sea level change, coastal erosion and sedimentation, and climate change had on the viability of these settlements and towns (e.g., Kotarba-Morley 2015, 2018).

The theoretical concept including a suite of variables, called the 'Parameters of Attractiveness' (PoA), developed for the purposes of this research, will allow 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. 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, the Greco-Roman port of trade *Berenike Troglodytica* on the southern Red Sea coast of Egypt. 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 (hereinafter SPE), and were identified in order to determine the extent to which the landscape and physical environment dictated locations of Hellenistic or Roman provincial ports of trade (or their trading counterparts) on the Red Sea, and whether other variables (e.g., geopolitical location, proximity to existing trade routes) were equally, or more, important.

The Berenike case study (Kotarba-Morley 2015, 2018) demonstrated the utility of the PoA approach for quantifying and evaluating many competing factors that were likely to have influenced the choice of ancient port location. 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 at 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. The results from the pilot study also suggest 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 and how it changed through time.

This is particularly important since very little is known to date about Classical (Greco-Roman) ports on the Red Sea beyond brief references in classical texts (see de Romanis 2009; Wilson 2015; Kotarba-Morley 2015). Since over 100 years ago, when Couyat (1910) calculated the potential locations of five important Red Sea ports, primarily using Ptolemy's *Geography* (Berggren and Jones 2000), very little progress has been made to locate any 'missing' sites. Aside from Myos Hormos, Adulis and Berenike, no other exact and unequivocally confirmed location of an actual harbour within a Classical port town is known. Although ancient authors mention 49 ports situated on the Red Sea, only 9 of them have ever been successfully located (see Table 1 and Fig. 1). The remaining 39 are divided between 34 port towns provisionally identified or with a probable location, and 5 that have not been identified at all. Additionally, six locations have been identified that have not yet been correlated with any harbours mentioned in the ancient texts, but which, according to the 'Parameters of Attractiveness', discussed further in this paper, have great potential for accommodating a significant port and/or have yielded archaeological material relevant to the study period. A similar situation can be observed in the Gulf of Aden, the Arabian Gulf and the Indian Ocean, where most site locations from this period are still yet to be confirmed.

Even though, as we will see below, the paucity of archaeological and 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 coastlines of the Red Sea are generally sparsely inhabited and often rather inhospitable in terms of climate and the shortage of modern infrastructure. In many regions, there is a lack of facilities and resources meaning that scientists hoping to work there find that the logistics are too difficult to overcome. Moreover, the relatively unstable political situation and harsh climate can similarly hamper research in the region. 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 A Brief Introduction to Greco-Roman Ports of the Red Sea

As mentioned above, very little research has been undertaken in the Red Sea region, with studies mainly concentrated on the Pharaonic ports of the Egyptian Red Sea coast (e.g., Tallet 2009, 2012a; Tallet and Mahfouz 2012), including Ayn Soukhna (Abdel-Raziq et al. 2012; Tallet 2010, 2012b, c, 2013), Wadi Gawasis (Sayed 1977; Bard and Fattovich 2003; Fattovich 2005; Bard et al. 2007; Hein et al. 2008, 2011; Fattovich and Bard 2012) and Wadi El-Jarf (Tallet 2012c; Tallet and Marouard 2012, 2014; Tallet et al. 2012). However, some interesting research has been undertaken on a number of Greco-Roman sites, mostly in Egypt and some recent excavations in Saudi Arabia (see below).

Although the northernmost Late Roman and Islamic Red Sea port of Aila (Aela/Aelana/modern Aqaba) is never

Table 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
1	Aelana, Aila, Elaea, Berenice, Ezion Geber	Aqaba	Gulf of Aqaba
2	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
3	Saba	Near Eilat (?)	Gulf of Aqaba
4	Ankale	Near Haql	Gulf of Aqaba
1.1	*Potential port location*	Nuweiba	Gulf of Aqaba
1.2	*Potential port location*	Tayyib al Ism	Gulf of Aqaba
1.3	*Potential port location*	Tell el Mashraba, near Dahab	Gulf of Aqaba
5	Makna	Near Magna	Gulf of Aqaba
6	Isle of sea-calves (dugongs?)	Tiran and Sanafir Islands, at the entrance of the Gulf of Aqaba (?)	Gulf of Aqaba
7	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
8	Modiana (?)	Al Muwalih	Saudi Arabia
9	Dabba, Modiana (?)	Dhuba at 27°21'N, 35°41'E	Saudi Arabia
10	Hippos Kome	Unidentified	Saudi Arabia
11	Egra and Phoinikon Kome	Al Wajh/Wedjh? Recognised as Egra since at least the 19th c. However, no associated archaeological evidence has ever been recovered from the site	Saudi Arabia
12	Ampelone, Akra (?)	At the outlet of Wadi al Hamd South of Al Wajh (?)	Saudi Arabia
13	Raunathou Kome	Near Khurayyim Said	Saudi Arabia
1.4	*Potential port locations*	Al Haura and Umm Lajj	Saudi Arabia
14	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
15	Farasan Islands	Roman naval base in front of Jizan (Van Hecke et al. 1861, p 747; Phillips et al. 2004, pp 244–245; Adams 2007, p 35; Cooper and Zazzaro 2012, p 408)	Saudi Arabia
16	Arsinoe, Cleopatris, Port Daneon, Klysma, Clysma, Clysina	Suez	Egypt
17	Phoinikon	Unidentified	Egypt
18	Marah	Near Ras Matarma	Egypt
19	Rhaithou	El Tor	Egypt
1.5	*Potential port location*	Tell el Raya	Egypt
20	Abu Shar	Roman fort at the end of the Via Hadriana, between El Gouna and Hurghada	Egypt
1.6	*Potential port location*	Wadi Safaga	Egypt

(continued)

Table 1 (continued)

	Ancient port	Modern location	Country
21	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
22	Arsinoe Troglodytika	Unidentified but somewhere between Philotera and Myos Hormos, perhaps near Kalawy Imperial Resort or Hamrawein (?)	Egypt
23	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 lie near Safaga. However, the location of the site is agreed upon 8 km north of Quseir	Egypt
24	Nechesia	Potentially Marsa Nakari, 18 km south of Marsa Alam	Egypt
25	Berenike Troglodytika, Berenike with ancient lighthouse	Pliny indicates that there is no shadow at noon on the day of the 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
26	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 olivine stone in this area	Egypt
27	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
28	Dioscuror	Dungunab (?) Ptolemy locates Dioscuror at the same place as Bathus, perhaps on the west side of Mukawwar Island	Sudan
29	Theon Soterum, Deorum Salutarium, Sotira	Suakin (?) Ptolemy situates Theon Soterum at 1° N of Ptolemais, potentially corresponding with Suakin at 19°08'N	Sudan
30	Evangeliorum, Evangelon	Protected bay of the island Saqir, near Trinkitat (?) Ptolemy situates Evangelon at 30' N latitude of Ptolemais, at 18°44'N	Sudan
31	Port Elaea	Ptolemy's Evangelon (?)	Sudan
32	Ptolemais (Epi) Theron, Ptolemais of Hunters, Epitherias	Probably Aqiq Kebir or Adobona village and the nearby island of Badhur	Sudan
33	Port Melinus	Unidentified	Sudan
34	Port of Colobônalsos, Cape Colobon	Ptolemy locates Colobon at 2° N of Adulis, which does not correspond with any prominent cape or promontory	Sudan
35	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
36	Ery	Large bay of the Isle of Dahlak, Isle of Disset, Isle of Deses (?)	Eritrea
37	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; it lies near Assab or Beilul, 400 km further south. It may be 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	Eritrea
38	Isle of Diodore	Island located in the bay of Zula and now joined with land as 'Galala Hills' 6 km south of Zula	Eritrea
39	Port of Eumene	Port of Eumène (?)	Eritrea

(continued)

Table 1 (continued)

	Ancient port	Modern location	Country
40	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
41	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
42	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 lies to the south of the Bab el Mandeb Strait	Djibouti
43	Port of Isis	Djibouti (?). The Port of Isis is at ten days rowing (500–1000 km) from Adulis according to Pliny, which lies near the coast of Djibouti (at 660 km) with its two islands located just in front of the port (as indicated by Pliny)	Djibouti
44	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
45	Burnt Island	Volcanic island Jabal al-Tair northwest of Hodeida (?)	Yemen
46	Bolicas	Mokha (?). Port of the Omerits, in front of Adulis, on the Arabian side.	Yemen
47	Masala, port of Mouza, Muza	Mokha (?)	Yemen
48	Sosippi	Dhubab seems to be the only natural shelter between Murad/Océlis and Mokha/Mouza	Yemen
49	Acila, Ocelis, Artemidore	Murad (?), south of Mokha and in front of Ras Siyan	Yemen

actually referred to as a harbour (Ward 2007, p 163), Eusebius (*Onomasticon* 6.17–20 and 8.1) mentions 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 and Smith 1999; Niemi et al. 2006; Mansoor 2002; Mansoor et al. 2004; Al-Tarazi and Korjenov 2007) but more work will hopefully build on this in the future. Also in the north of the Red Sea some early surveys and excavations (e.g., Bourdon 1925) were undertaken at the important port of Clysma (Cleopatris/Arsinoë/Islamic Qolzoum) in the 1920s and 1930s (Bruyère 1966), and renewed fieldwork at the site is likely to start soon (Blackman, pers. comm.). The early studies suggested that the location of the ancient harbour was evidenced by concrete quays, a feature more common in the Mediterranean than the Red Sea. Recent work on the Nile–Red Sea canal (Cooper 2009, 2014) has brought into focus the importance of this port.

The shortest route between the River Nile and the Red Sea in the southern part of Egypt 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 (Zitterkopf and Sidebotham 1989). Myos Hormos has been studied in great detail (Peacock and Blue 2006, 2011), ascertaining the location and depth of the harbour in the Roman and Islamic periods. Blue (2011) also modelled the silting up of the harbour,[1] with the migration of a sandbar, originally in the inner reaches of the lagoon, gradually moving toward the entrance of the lagoon, closing off the channel, and ultimately disabling the harbour. The discovery of waterfronts constructed from empty amphorae proved extremely valuable in developing our understanding not only of Myos Hormos and its social context, but also of technological connectivity across the Empire (Blue 2011). This

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

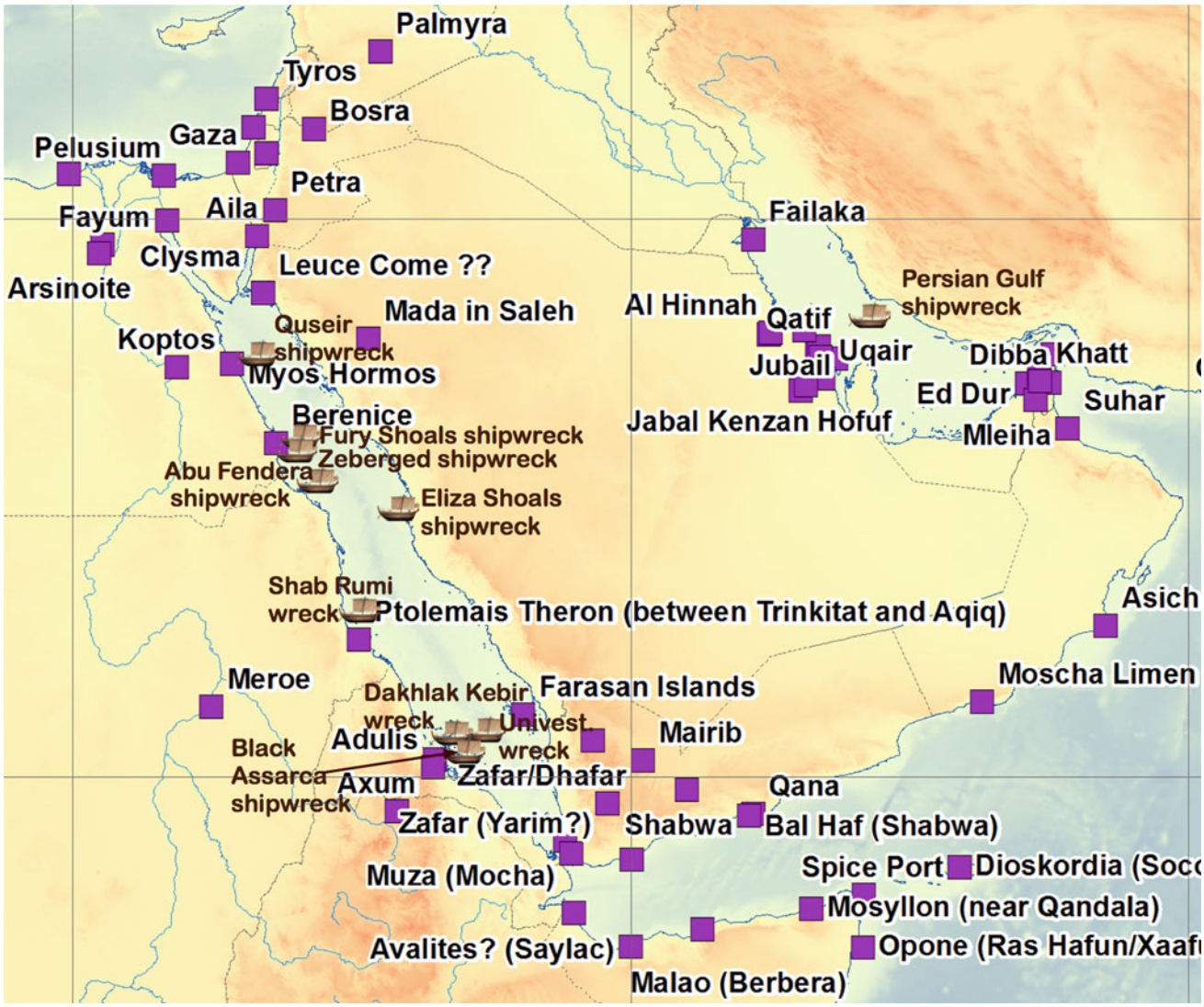

Fig. 1 Topographic and bathymetric view of the Red Sea with locations of Greco-Roman ports mentioned in Table 1 as well as known Roman-era shipwrecks in the area (drawn by AM Kotarba-Morley)

type of construction was used across the Mediterranean, for example, in Naukrais (Thomas et al. 2016), Cadiz on the Atlantic coast of Spain (Bernal et al. 2005) or in sites in northern Italy and southern France (Pessavento Mattioli 1998).

Berenike Troglodytica was one of the most important port cities on the Egyptian Red Sea coast during the Ptolemaic and Roman periods (Sidebotham 2011). The city intermittently prospered for eight centuries, from about 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). The port of Berenike was sited just south of the large peninsula of Ras Benas, which offered the site protection from the elements (Kotarba-Morley 2015, 2018). The 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. 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 (Kotarba-Morley 2015, 2018).

Recent excavations on the site of Aynuna by a Polish team from the University of Warsaw unearthed a significant Nabatean coastal city with an abundance of Roman pottery, coins and other evidence for trade in the Red Sea. Located some 2 km from the modern fishing village in the Aynuna Bay, which the excavators believe to be the location of an ancient port, the extensive ruins at Aynuna have only been

cursorily surveyed in the 1980s. Whilst it is still debatable whether the site is indeed the port of Petra, Leuke Kome (Albus Portus/Leukos Limen), the findings themselves seem to be of importance for understanding the trade connections of the region (e.g., Gawlikowski and Juchniewicz 2016).

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, p 186). Nor do we have any definite answers regarding the locations of Philoteras/Aenum (Sidebotham 2011, p 184), or Ptolemais (Epi)Theron (Seeger et al. 2006; Sidebotham 2011, p 186).

Further to the south, the city of Adulis on the Eritrean Red Sea coast was a key port of the Late Antiquity Axumite Empire, connected with the capital, Axum, by a meandering mountain passage, and has been subject to significant research effort (Peacock and Blue 2007). The two harbours of Adulis—Diodorus Island and Orienê—have been located and geoarchaeological research, including coring and a geomorphological survey, was initiated in 2004 in different areas of the site. The current location of the site, 7 km from the present shoreline, indicates considerable coastal change over the intervening years. While the results of coring were deemed inconclusive in terms of direct evidence for a marine environment (Peacock and Blue 2007, p 47), they did provide indications as to the location of the ancient shoreline. This work also helped to identify the seastack bisecting the Galala Hills in the southern part of the site as Diodorus Island, one of the harbours mentioned in the *Periplus Maris Erythraei* (PME4, Casson 1989), in whose lee ships could safely moor (Blue and Peacock 2007, p 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, p 137). Renewed excavation at the site by the Italian team (e.g., Zazzaro 2013; Zazzaro et al. 2014) might yield further detail regarding this port town.

The port towns and harbours described briefly here form only a part of the picture of coastal exchanges and commercial dynamics on the Red Sea in Greco-Roman times. As mentioned above many of these hugely important nodes of communication are yet to be discovered and studied, with some of them probably remaining under the desert sands for many years to come. What is important to keep in mind at this stage is that locations of those sites are not spread at random along the Red Sea rim and have been chosen with particular parameters in mind, due to their attractiveness to the settlers and sailors and with a clear understanding of the constraint and limitations of contemporary engineering, shipbuilding technologies, supply chains and political needs. With ancient landscape, climatic and environmental reconstructions available for this period we would be able to better imagine the relationships between the sites and the level of adaptation required from the settlers to tame their chosen locations.

3 Methodology

In order to assess the relative contribution of a series of social-political and environmental parameters to the choice of location of Greco-Roman ports of trade located on the Red Sea coast a case study site, *Berenike Troglodytica*, was selected. Previous research (Kotarba-Morley 2015, 2018) reconstructed the changing environment at the site over key stages of its development using geological and geoarchaeological datasets. This environmental dataset is additionally supplemented with existing historical data regarding political, social and economic factors that are of importance to produce a list of potential variables and links and relationships between them.

During the process of building up this model four main categories of so-called 'Parameters of Attractiveness' (PoA) have been distinguished, as mentioned above: (1) Sea, (2) Land, (3) Resources, and (4) Socio-Economic and Political. Each of these categories consists of between 3 and 5 parameters valued at 1–5. To carry out a semi-quantified assessment of the Parameters of Attractiveness a series of hierarchical sliding scales (1–5) is employed specific to each parameter in the four categories identified. In this model the higher the value, the more favourable the location. As can be seen, the highest score in each of the parameter groups represents 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.

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*. The final score of each category, as well as the final score for the whole site (calculated by: *sum of all total scores for each category/number of categories*) will then fall under a simple denomination of:

- 0–0.25—Not Attractive
- 0.25–0.50—Poorly to Reasonably Attractive given the circumstances
- 0.50–0.75—Moderately Attractive
- 0.75–1—Very Attractive

The pilot study site of Berenike has been subject to systematic analyses of the contemporary environmental characteristics of its port's/ports' location/s and in turn the assessment and quantification of social, political and economic aspects that also had an impact on the attractiveness of its location. Such 'port attractiveness' patterns emerging

from the assessment of the contemporary natural and political landscape will be presented as the main focus of this study. In the future, more advanced statistical analyses could be performed in order to assess the past landscapes and environments of known Greco-Roman and contemporary ports and harbours on both sides of the Red Sea and set them within an analytical and interpretative framework of 'Parameters of Attractiveness'.

4 Results: Parameters of Attractiveness

The concept of this theoretical framework of PoA was partly based on the 'landscape learning idea' (Rockman and Steele 2003), the 'common sense geography' approach (Geus and Thierling 2014), as well as the 'transaction cost theory' (Williamson 1989). Some of the questions listed below, originally part of a list posed by Rickman (1985) and discussed also by Karmon (1985) in a study of Mediterranean harbours, were also highly relevant to the development of the PoA framework 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 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. How would individual municipalities have financed the harbour maintenance? Was it from harbour taxes, loans, benefactions from local magnates, or merchant guilds, or was it always an external source such as a state treasury?
x. Can ancient harbour sediments provide information about human-environment interactions?

These have proven to be particularly important in the assessment of the pilot study site. The city of Berenike was founded in a harsh, marginal environment where relatively small environmental changes (e.g., fluctuations in sea level, changes in coastal geomorphology, an increase in seasonal floods) might have had a dramatic effect on the short- and long-term viability of the site. Whilst the current coastal situation of the site (see Fig. 2) 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 that was at least reasonably attractive (see Table 2) to settlers and sailors alike.

Below I present the results of the analyses conducted on the site set against the general Red Sea coast context. Each of the categories is briefly introduced and then followed by a description of a particular parameter and the results from the pilot study at Berenike. All of those results are also shown in Table 2 for the convenience of the reader.

5 Sea Parameters

Sea parameters are those variables that influence marine environments, such as winds, currents, waves, reefs and maritime resources. The achievements of ancient sailors and navigators reveal a deep knowledge of the marine environment and a near-symbiotic relationship with these variables (e.g., Facey 2004). Similarly, designs of ancient ships prove that ancient shipwrights had a deep understanding of the materials used to construct vessels that could operate in a diverse range of weather conditions (e.g. Kotarba-Morley 2017). The parameters used here were selected following a review of literature (ancient and modern) regarding the environmental conditions on the Red Sea and a detailed appraisal of ancient navigational techniques and ship designs on the ancient Red Sea and beyond (e.g., Kotarba-Morley 2017). It is hoped that they will allow for a better appreciation of the natural, physical and geographical characteristics of Hellenistic and Roman provincial harbours in this region. In turn, this will permit an establishment of possible navigation patterns on the Red Sea in this period and draw out the major factors that could have been influential in types of vessel steering in the region.

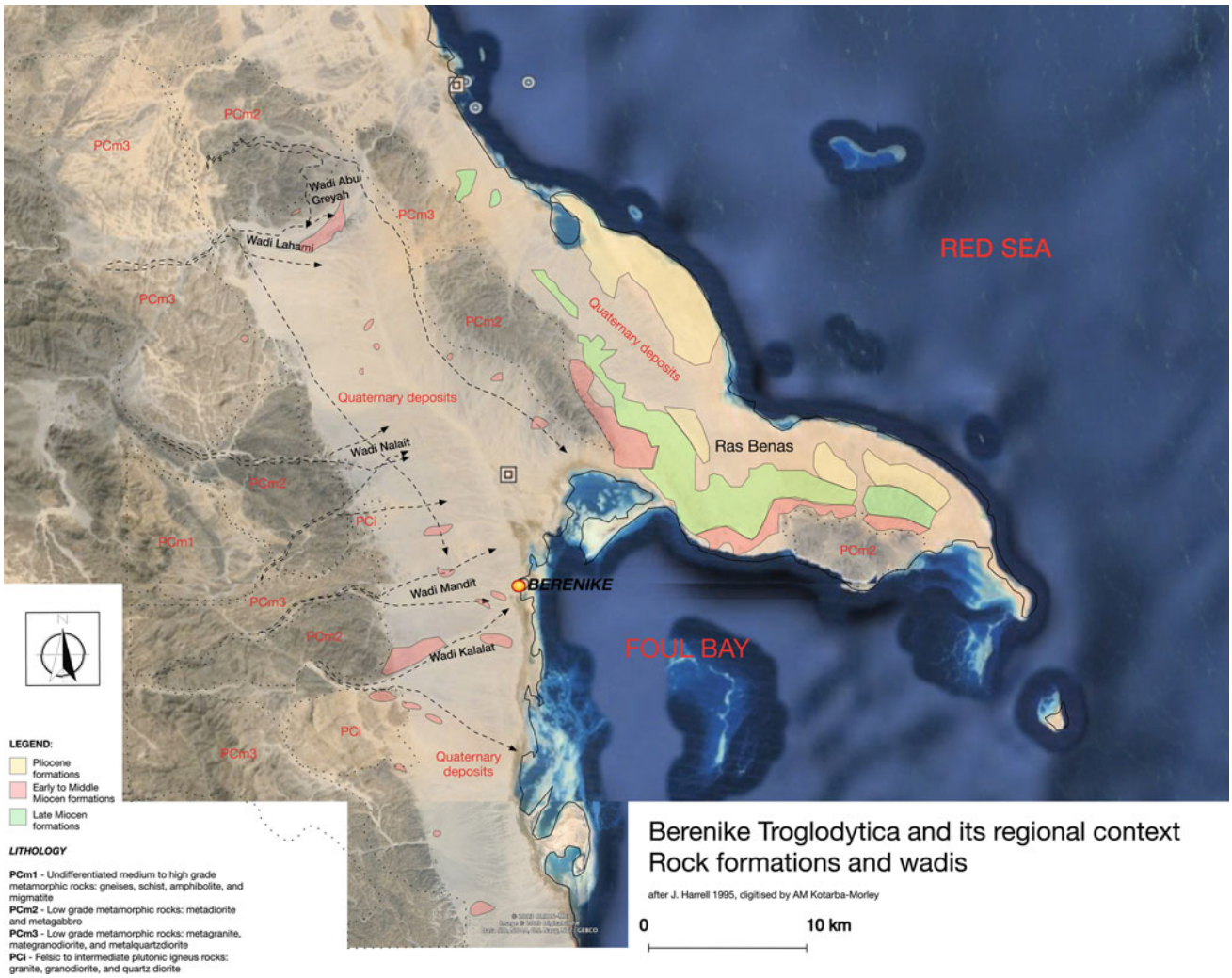

Fig. 2 Berenike Troglodytica and its regional context. Rock formations and wadis (drawn by AM Kotarba-Morley, based on Harrel 1996)

5.1 Winds: Seasonality, Strength and Direction (Also Ship Technology)

The prevailing forces propelling ancient sailing vessels along trade routes were atmospheric winds, and merchant vessels plying the Red Sea and the 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 on board). The Red Sea circulation is dominated by winds, evaporation and the monsoon system, with northerly–northeasterly winds dominating (see Fig. 3). The prevailing northerlies in the northern part of the Red Sea (where 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 (as a result of trough pattern anomalies promoting Sub-Tropical Westerly Jets (STWJ) over the Red Sea (Williams 2011, p 36). 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, pp 29–30). The strong seasonal currents (0.5 knot) follow the directions of winds aiding the northward journeys (Whitewright 2007, p 85). During the northern hemisphere summer, intertropical fronts move northward 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, p 99). 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 (e.g., Edwards and Head 1987; Davies and Morgan 1995, p 29). 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, b, 1974; Edwards and Head 1987; Stenchikov 2011).

Table 2 Parameters of attractiveness of the site of Berenike Troglodytica (Kotarba-Morley 2015)

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		
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

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		

(continued)

Table 2 (continued)

Category: resource parameters			
Parameter	*Parameter characteristics*	*Berenike score*	*Berenike justification*
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 dependent		
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 fishproducts (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		
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		
Agriculture & pastures	*Quantity and distribution of cultivable land, crop production, animal power and transport. Quality, quantity, sustainability, seasonality of pastures*	1	Potentially, brackish water could have been used for horticulture or light agriculture. Macrobotanic 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		

(continued)

Table 2 (continued)

Category: resource parameters			
Parameter	*Parameter characteristics*	*Berenike score*	*Berenike justification*
Bldg. Mats.	*Level of availability of biotic (e.g., forests) and abiotic (e.g., building materials, ore) resources*	4	Abundance of gypsum anhydrite and coral, however of a very low quality
1	No building material available in the area; all materials have to be imported		
2	No suitable, good quality building material available in the immediate area		
3	Limited supply of decent building materials; need to transport		
4	Good source of building materials but either a limited supply and/or no maintenance facilities and/or skilled craftsman or some issues with transport/access		
5	Very good quality of local quarries for stone and ore; easily available good quality building materials		
Wood	*Level of availability of biotic (e.g., forests) and abiotic (e.g., building materials, ore) resources for ships and buildings*	1	Only acacia and mangrove wood and the rest of the wood has to be brought through the caravan route and Nile route from the Mediterranean or from the south/Indian Ocean
1	No decent quality wood available in the area. Only shrubs		
2	No suitable wood available for ship repairs; wood can be imported or collected (such as mangrove) for urgent ship repairs		
3	Limited supply of decent wood. Need to transport		
4	Good source of wood but either a limited supply and/or no maintenance facilities and/or skilled craftsman or some issues with transport/access		
5	Very good wood freely available, skilled craftsman, shipyard with dry docks		
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		
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 a manageable distance		
5	Abundant good quality natural resources that are easily accessible and in the vicinity of the site		
	Berenike Sea parameter total score	15/30	0.5
Category: socio-political-economic parameters			
Parameter	*Parameter characteristics*	*Berenike score*	*Berenike justification*
Demand	*Scale of 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

(continued)

Table 2 (continued)

Category: socio-political-economic parameters			
Parameter	*Parameter characteristics*	*Berenike score*	*Berenike justification*
1	No demand		
2	Low demand		
3	Sufficient demand		
4	Significant demand		
5	Strong demand		
Strategic position	*Connection with hinterland and provision of safety for the inhabitants in case of an attack*	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		
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 of 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		
Port facilities & infrastructure	*Accessibility of human expertise, administrative facilities, hospitality service and built infrastructure*	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

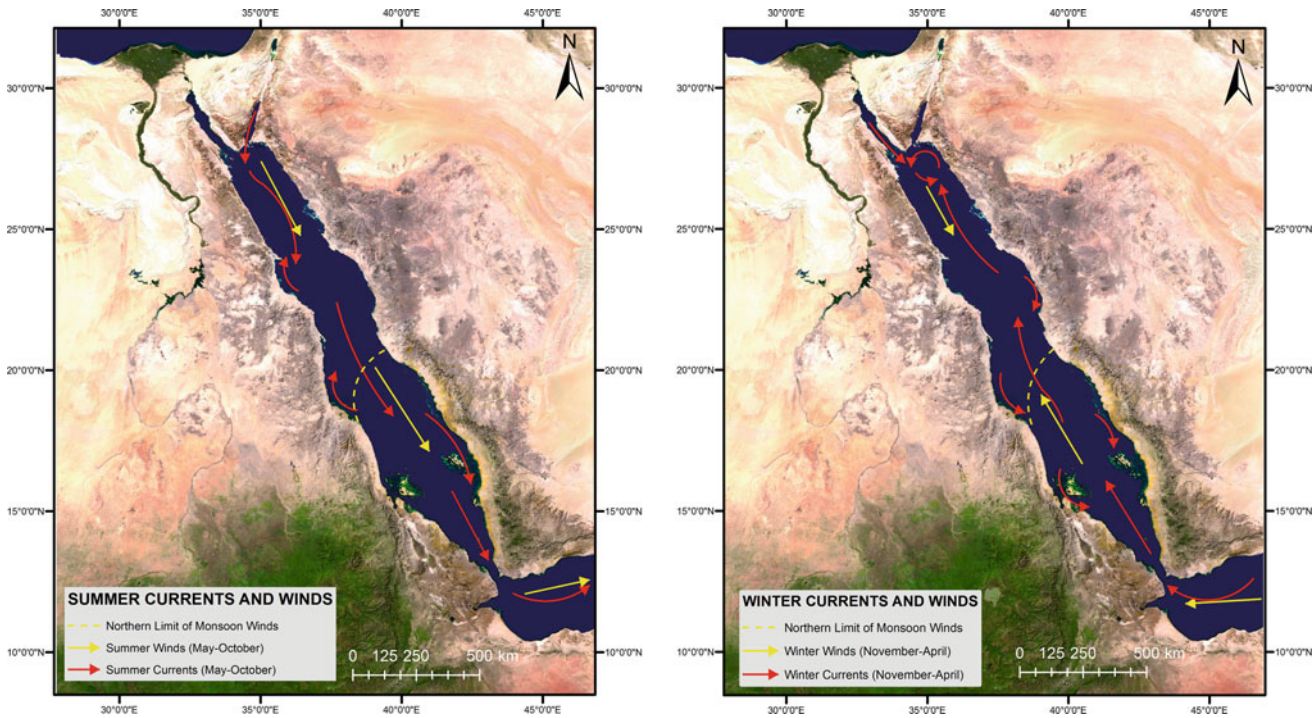

Fig. 3 Summer and winter currents and winds on the Red Sea (drawn by AM Kotarba-Morley)

In weak winds the course would be north-east by north and due west (Whitewright 2008, p 139), whilst in a strong wind, as Sulaimān al-Mahrī tells us, 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, p 327).

Traditionally, it is understood that vessels which left Egypt early enough (around August) arrived in India some time in September (Curtin 1984, p 99), and then set out for the return journey from India after three months of trading and ship maintenance, any time after the onset of the northeasterly monsoon around December and no later than mid-January (Pliny, *NH* 6.106; Whitewright 2007, p 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, pp 9–11; most northerly position of the ITCZ). This would enable the crews to exploit any 'decent' southerly and offshore (diurnal) wind that was experienced on the Red Sea (Whitewright 2007, p 78). After that, from April to December, northerly winds prevailed over the southern Red Sea making the passage very difficult if not impossible (de Romanis 2009; Seland 2011, p 401). The journey from India to Arabia could have been performed any time between late October and early March (Tibbetts 1971, p 231) with no 'closing' date of arrival in the Persian Gulf. However, according to the speed calculated by Seland (2011, p 401) if a vessel left the 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. The so-called southern passage to Africa was also available from July to August (Horsburgh 1841, p 484).

5.2 The Winds at Berenike

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 seasonality, and as such scores highly—*5*—in this PoA category. The wind patterns over 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 onward if arriving from the north (Facey 2004, pp 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. 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 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.

5.3 Currents: Strength, Direction, Seasonality and Predictability

Ocean currents are movements of water in response to prevailing wind patterns, variations in salinity, water temperature and water density that are important for seafaring and harbour location. 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, p 208), as is the case at the southern end of the Red Sea (Fig. 3) and, on a smaller scale, at the entrance to Berenike's 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 and making mooring extremely dangerous. 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* (e.g., *PME* 13, 25, 43, 46; Casson 1989). Their strength, direction, seasonality and predictability would have been important in prospecting for the site of a new port.

5.4 Sea Currents at Berenike

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. The other part of the justification for such a 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 (bringing in a requirement for tug boats and availability of oarsmen on trading vessels).

5.5 Wave Action: Strength, Size, Length, Seasonality

Waves are extremely efficient energy transporters and are important in navigation, with implications for sailing conditions and harbour location. Upon reaching the coast, waves change height and direction due to shoaling and the effects of refraction and diffraction (de Graauw 1986) and can be potentially devastating to vessels (see Casey 2011 on the subject of rogue waves). Assessing wave strength, size, length, and seasonality would have to therefore been 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, p 222); however, the Red Sea waves are recorded as being much lower. The ability to withstand large swells would have been one of the considerations of ship designers and even though capsizing a sailing vessel is difficult even in 'big seas' (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 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, p 13).

5.6 The Effect of Waves at Berenike

The coastal configuration at Berenike, when the harbour was operational, would have meant that waves broke on the southern promontory, which sheltered the lagoon (see Fig. 4). The approach to the harbour mouth 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 that 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 the harbour is well-sheltered and that the wave range at Berenike is generally low in this part of the Red Sea and does not disrupt the incoming or outgoing traffic on site.

5.7 Near-Shore Coastal Shelf Geomorphology and Bathymetry

The geomorphology includes shoals, reefs, rocky coast, as well as space to manoeuvre and to set out beacons at the entrance of the port. The configuration of the near-shore environment would have been an extremely influential coastscape parameter in the locating of a new port, most likely only second in importance to the presence of a natural sheltered harbour or a 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

Fig. 4 The site of Berenike Troglodytica with marked extents of Ptolemaic and Roman areas and supposed extent of port in different periods (drawn by AM Kotarba-Morley using Google Earth satellite image)

prevailing winds, currents, and tidal cycle, including submerged obstacles such as rocks, reefs and shoals, incline and depth of the coastal shelf, and space to manoeuvre (Figs. 2 and 4). 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 human 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 2000, 2006, 2008; Kirkland 2010, p 3). The technique of the sounding line was first reported by Poseidonius who calculated that the Mediterranean was a thousand fathoms deep (Strabo, *Geogr.* 1.1.37). This method was also 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, p 207).

5.8 Berenike's Coastal Geomorphology

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 near-shore geomorphological setting was only partially satisfactory. Firstly, 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 (Kotarba-Morley 2015, 2018) 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. Additionally, as Pedersen (2015, p 128) points out, 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[2] (Murray and Warmington 1967, p 25) was present due to the flow of fresh water precluding excessive 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

[2]Passage, usually between mountains.

it is today, whilst the overall width would have been in a range of 100 m (Kotarba-Morley 2015, 2018). 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 further creation of sabkha fields). 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.

5.9 Tidal Range: Range and Size

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). The tidal range of different basins, seas and oceans can be very diverse 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. 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 in planning shipping voyages.[3] 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, hence incorporating the occurrence of this natural phenomenon with the techno-culturally driven factors—vessel design and sailors' expertise.

5.10 Tides at Berenike

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 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.

6 Land Parameters

The Land parameters 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 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). 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 and their counterparts is essentially unknown. It is likely that already existing local harbours would have been utilised in the first instance, either modified to suit current needs or retained as already suitable. However, it is equally likely that there were so many of these small moorings along any given stretch of the coast that a sort of crude PoA would still be used by the prospectors to assess which of these would have been the best for larger-scale development.

The most obvious of these parameters 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, coastal geomorphology, as well as the speed and volume of siltation and the proximity of inland waterways such as rivers (including seasonal wadis), creeks and lakes. 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 a city's layout and connections with the hinterland. The exception to this rule is when the political or strategic position of a proposed port, or a market demand, is so critical that the port is ultimately founded in an otherwise unattractive location regardless of the configuration of the landscape.

6.1 Presence and Physical Configuration of a Natural Bay, Lagoon or Inlet

The spatial configuration of the site determines the level of availability of a natural bay or lagoon. One of the major prerequisites for the siting of the new facility, once the demand for a port serving a particular region was identified,

[3]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) only because of his exploitation of an extremely low tide (Tacitus, *Agricola* 14–15).

would have been the existence of a natural sheltered bay, lagoon or inlet that could be used to safely moor the required quantity of vessels. Exploitable basins could be either entirely natural or artificially manipulated landscape features, and ancient port prospectors and builders would have certainly favoured locations with reasonably deep 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 on the coast of Israel, Portus in Italy, or Carthage in Tunisia.[4] 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. However, in the contemporary context of the Red Sea and Indian Ocean littoral, it is unlikely that such costly endeavours would have been approved in areas where a large expense could not be justifiably explained. Specifically, even though we know of shipments of *opus signinum/pulvis puteolanus*[5] over 2,000 km distance from Italy for the purpose of building the port of Sebastos at Caesarea (Oleson and Branton 1992; Oleson et al. 2014), the availability of this material in marginal areas of the Empire, such as Berenike of even Myos Hormos (where stacked-up amphorae are used instead to build waterfronts), is unlikely.

Sometimes, the size and depth of the harbour basin could have been dictated by the type of facility needed for trade and other associated activities (e.g., large international trade hub or smaller regional stopping point) or additional military outpost. Therefore, it can be assumed that when a suitable natural location was identified, ancient engineers 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, to ascertain whether they were suitable to accommodate their certain needs as found or whether they needed to be expanded.

6.2 Natural Bay or Lagoon at Berenike

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 mooring of a significant number of vessels (approximately 85–105 medium to large merchantmen, Kotarba-Morley 2018) 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) as well as the associated waves and storm surges.

6.3 Siltation Rate and Regime

The siltation regime depends on the speed and volume of siltation and available dredging technology. Siltation, or sediment infilling, from terrestrial (rivers, wadis), marine (tides and currents), and atmospheric (windblown sand) sources, was, and is, one of the most significant problems faced by engineers, port builders and their maintenance teams (e.g., Blackman 1982; 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 (e.g., Rabān 1990, 2009; Pydyn 2011), and reached a peak of advancement in Roman times. 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 (Pedersen 2015, p 25), emphasising the importance of understanding siltation rates for the engineers planning new Red Sea ports. Whilst most known Red Sea and Indian Ocean harbours show no signs of major dredging activities to date, such a practice could have been undertaken using simple and relatively low-technology equipment when undertaken on a small scale (e.g., Hoyle 1989). 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. 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 (e.g., Giraudi et al. 2006, 2009; Bellotti et al. 2011; Goiran et al. 2012; 2014a, b; Salomon et al. 2012; Millet et al. 2014; Vittori et al. 2015).

6.4 Siltation at Berenike

Although harbour dredging was a routine activity in the Roman Mediterranean (e.g., Bini et al. 2009; Morhange and Marriner 2010, p 29; Mazzini et al. 2011), the level of maintenance and associated costs are little known for provincial cities such as Berenike, which, as mentioned above, would have necessitated at least occasional dredging to keep the harbour operational and accessible for large ships. Berenike's siltation rate is very high and so the site scores

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

[5]Hydraulic concrete was arguably used in harbour installations from at least the mid-1st century BCE (when it was used at the entrance channel to Portus Iulius in the Gulf of Pozzuoli; Oleson et al. 2004, 2014, Chap. 4) to build underwater structures as it sets subaquaeously (Vitruvius *De Archit*. 2.6.1, 5.12.2-3; Gazda 2001, pp 171–177; Lancaster 2005, p 58; Brandon et al. 2008).

low (2) in this category. Seasonal flash floods flowing through the wadis resulted in a large flux of fluvial sediments to the coast and harbour basin area each year. 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 by the local maintenance teams, and the harbour was eventually abandoned.

6.5 Rivers, Creeks and Backwaters

Factors affected by the existence of rivers, creaks or backwaters on the site include accessibility, size of an estuary, the degree of protection, depth and currents. 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 (Salway 2004). These backbeach or backwater environments represented excellent locations for founding a port town and viable fishing, farming and foraging communities, and were widely exploited in Europe (most Roman cities were located on floodplains), and also 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). 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. Propitious 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 is 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). Shifting sandbars, shaped in or near estuaries due to alluvial sedimentation debouching from the river and exposed at low tide, would create obstacles for incoming and outgoing shipping and 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.

6.6 River and Creek Access at Berenike

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.

7 Resource Parameters

Natural resources are understood here to be 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 can be divided into biotic resources, such as animals and animal products, plants and plant products, including timber for shipbuilding and building construction, as well as fossil fuels such as coal, and inorganic materials such as metal ores, rocks or sediments. They can be used as raw materials or as trade commodities. This section explores the major Resource parameters, including availability, quantity and quality of fresh water, marine and terrestrial food products, building materials, pasture and arable land, and evaluates their attractiveness in the Red Sea Classical ports. The accessibility of raw materials that represent trade commodities, including good quality wood, rock (e.g., marble), metal ore and luxury goods such as spices, frankincense, tortoise shell, emeralds and topaz are also taken into consideration. Ancient prospectors would likely have assessed the availability and proximity of their sources as well as the effort required to procure and safeguard them, their value on the open market, and 'portability' (i.e., different methods were required and different costs incurred to transport elephants or marble compared to spices or tortoise shell).

7.1 Availability and Proximity of Fresh Water

This includes fresh water availability, accessibility, proximity, quantity and quality. 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 it (either through 'manual or animal carriage' or via aqueducts or pipelines). Naturally, water is impossible to compromise

on and 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. Even with limited bathing and cooking, a human being comfortably needs about 15–20 L of water a day during a hot summer, especially in the desert, and a little less in a winter (Zitterkopf and Sidebotham 1989, p 164; Sidebotham 2011, p 89). 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 administration agenda to access, acquire, store, protect and distribute sufficient quantities of clean, fresh water (e.g., Sidebotham 2011, p 87).

The growth of ports imposed responsibility not only for supplying water to the town but also for both incoming and outgoing ships and inland merchants (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 with a requirement of around 8 L per person per day (Morrison and Coates 1986; Shaw 1993; Hattendorf and Unger 2003).[6] 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 L per day, a camel about 20 L per day (Schmidt-Nielsen 1964, pp 85–92, 1965),[7] similar to a horse. These animals would have to water well before, and after, a 2-week (or longer) journey across the deserts surrounding the Red Sea rim. 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 even three times the ordinary supply of the port's permanent population during the trading season. An estimate like this would have to have been kept in mind by the port prospectors when setting up a port in the area with scarce water supply.

7.2 Berenike's Fresh Water Access

The freshwater issue at Berenike was clearly significant. Not only was the site without a direct water source, but a number of wells, or *hydreumata*, located at the foothills of the mountains that were used, were quite distant, approximately 7.5 km away. A very rough estimate, assuming that 100 large ships visited Berenike throughout the seasons (Kotarba-Morley 2018) with crews of 6–10, with each crew member requiring 6.5–8 L of freshwater a day (average between the amount recorded for quarry workers and a galley crew in an Olympias trial) for a period of 2 weeks (approximate time required for unloading the cargo and re-provisioning) would amount to 150,000 L (to sustain crews visiting a port per season only). Additionally, ships would have to re-supply with water to last through their journey (depending on the direction, sometimes for the whole length of it). A rough calculation shows that a similar amount of water to that needed by ship crews would be required by a local population of 2,000 people (Steven Sidebotham, pers. comm. 2011) with each person consuming a ration of over 6.5 L (1 *keramion*) of freshwater per day. Similar amounts of water required for both incoming and outgoing caravans should also be added to this equation.

Berenike scores only 1 in this category, because the distance and effort of supplying large qualities of water to town—potentially up to 35,000 L a day[8] in the peak season—was a colossal undertaking and one that would require a constant flow of water ferried on the backs of pack animals such as donkeys. This would then need to be stored (although no cisterns have been found in Berenike to date) and distributed around town and into the harbour. It perhaps reveals the strategic importance of Berenike as a port when we consider that it is most likely that it did not have a direct fresh water source on site and had to rely on the transport of water from around 7–8 km away.

7.3 Availability of Food Resources

The food resources category includes here marine and terrestrial procurement (hunting and gathering), with the demand for marine species and game, availability of marine

[6]The Olympias and other trials have shown, for example, that a member of a galley crew would need a minimum of 8 L per day (approximately half of the 'comfortable' amount), including their main meal (e.g., Morrison and Coates 1986; Shaw 1993; Hattendorf and Unger 2003), substantially more than earlier estimates as low as 2.25 L (Sleeswyk and Meijer 1998). However, these approximations are for oarsmen who would have needed to drink more water than a regular sailor.

[7]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 L a day (pers. observ.).

[8]Calculated using rough estimates of water use for the local population (of approximately 2,000 inhabitants consuming a minimum of 6.5 L a day and comfortably 15–20 L), moored vessel crews for a period of approximately 1 month at a time (approximately 100 ships × 6–10 crew plus passengers), ships re-supplying for a lengthy journey to the Indian Ocean and the incoming, ongoing and resting caravans (humans and pack animals).

resources and game, available procurement technology, and the possibility of trade in seafood, fish and terrestrial animal products (if in surplus). The availability of marine resources, access to terrestrial game, and the availability of food that can be foraged must have hugely influenced the potential choice of a port location. Fishing and procurement of other marine resources (e.g., fish, molluscs, shellfish, seaweed, coral, marine mammals, birds, reptiles) provided a relatively comfortable subsistence strategy for coastal populations and people who worked on the sea. Seafood represented 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). The Red Sea is particularly renowned for the diversity of its coral reefs and its fish resources (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, the reef environments are active perennially, providing a wealth of resources, making them 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. Notably, recent zooarchaeological data confirms consumption of large quantities of fish (and even shark) endemic to Red Sea (only one fish bone belonging to the Nile riverine fish species) in the Eastern Desert forts such as *Mons Claudianus* and *Mons Porphyrites*, located 2-days camel ride away from the sea (Hamilton-Dyer 1990, pp 76–77, 2001; Marzano 2013). It is worth mentioning that the collection and 'cultivation' of seaweed and algae could have also been an important part of a subsistence strategy as well as a tradable commodity (e.g., Woodward 1951; Fleurence 1999) although not very likely to be performed along the Red Sea.

Hunting wild game would have been an important means of supporting or supplementing the seafood diet of the Red Sea inhabitants. 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 the diet possibly supplemented by smaller animals such as turtles, frogs, lizards and birds (Hughes 2014, p 93) and maybe even by beekeeping (Crane 1999, pp 203–211). Hunting with dogs was particularly popular, and indeed there were specially bred animals that were regularly exported to the Empire—maybe even ones that have been discovered in the unusual animal cemetery at Berenike (Osypińska 2016).

7.4 Availability of Food Resources Around Berenike

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. The availability of different strands of subsistence strategies means that Berenike scores 4 in the 'Food' category. Plentiful fish, attested by large quantities of fish bones in the archaeological record, especially in the 'port area', show the high level of exploitation of marine resources. However, it is possible that many of them could be just natural waste making it unambiguous whether all of the fish bone material was a part of post-consumption remains. On another hand, the rate of recovery of small fishbones is always a widely discussed issue even on excavations that employ strict sieving. Additionally, some evidence for hunting for game in the mountains is available, with domestic animal meat—such as of donkey, pig or a camel—also being often utilised for food. Bird and rodent bones are also present in the archaeozoological record, however, mostly in the trash dump deposits suggesting an unlikely food source (Osypińska 2011, 2017). Unusually 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 2016).

7.5 Agriculture—Cultivable Lands and Pastures

The agriculture aspects include here the quantity and distribution of cultivable land, crop production, animal power and transport, and quality, quantity, sustainability and seasonality of pastures. Ancient assessments of agricultural value must have considered the availability of cultivable land and the fertility of soils. Although access to local supplies would have been an important consideration, the ability for the port to at least partly sustain its population, or even create an agricultural surplus in order to feed visiting ship crews and land-based merchants, or for trade, is likely to have been important in the creation of a new harbour town. Port city populations would have also been dependent to some extent upon animals domesticated for power (plough oxen, pack animals such as donkeys, camels and horses), 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 the use of marine resources, such as was the case at Berenike. However, if secondary products such as dairy and hides were sought then they may have required pastureland to allow grazing of fodder, pack and work animals.

Although many attempts have been made to quantify the 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). At the peak of its development (Principate, 27 BCE–284 CE), the Roman agrarian system was diversified and well-developed, not only benefiting 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 making a development of small-scale agriculture or horticulture viable.

The significance of particular parameters for sites located in specific climatic and environmental zones is worth a comment. There is evidence from Myos Hormos, for example, that caravans would have supplied hay brought all the way from the Nile Valley for animals (Van der Veen 2011). This must have been a complex logistical issue and implies a lack of viable pasturelands. Even though some grasslands occur in warmer climates (30 °C) and with lower rainfalls (around 500–600 mm) (Woodward et al. 2004), 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 be seen as an added benefit. The most popular desert-crossing pack animal in the Eastern Desert and along the Red Sea coasts, the camel, requires approximately 10–20 kg of fresh food a day (or 5–10 kg of dry fodder) depending upon the size of the animal, but up to 30–50 kg when working. As camels eat mostly grasses, herbs, bushes, trees such as acacia, and salt-tolerant plants they are well-adapted to travelling around the Red Sea region. It should be noted, nevertheless, that 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). Additionally, some animals (such as pigs that were kept on sites in the hinterland of the Eastern Desert) could have been partially fed on human waste, this solving two problems with one solution.

7.6 Agriculture or Horticulture at Berenike

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 pastureland, horticulture or even light agriculture or oasis-like plantation (of, e.g., date palms), but to date there is no unequivocal evidence for any. Macrobotanical evidence appears to show, however, 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, if indeed in existence, it is possible that they could only be suitable for camels and donkeys.

7.7 Availability of Local Building Materials

Building materials under consideration are represented by the biotic (e.g., forests) and abiotic (e.g., building materials, ore) resources. 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 materials, in some cases, could be imported from 'outside' areas (such as *pozzolana* imported from up to 2,000 km away within the Mediterranean), it is likely that the availability of decent 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, including easily available sediments such as clay and sand, which could be fired or sun-dried to produce mud bricks, lime plaster, rubble, cement, gravel, as well as quarried rocks of various types ranging from perishable gypsum anhydrite, poor quality limestone or coral, to hard and extremely durable granites, marbles or basalts. 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 could have at least been a serious consideration when prospecting for new ports. The development of roads, aqueducts and other types of infrastructure, the foundations of new ports and cities, and the expansion of old ones, also necessitated extensive quarrying (Russell 2013, p 16).

Organic materials could also have been widely used for the construction of houses, administrative buildings, fences and enclosures, 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, coral, animal skins, leather, bone, and textile. An interesting example of the use of amphorae as the base for a wharf is also known from a couple of Roman port sites in Egypt including Myos Hormos on the Red Sea (Peacock and Blue 2006, pp 68–74) and Naukratis—a river port in the delta of the Nile next to its Kanopic branch (Thomas et al. 2016).

7.8 Building Materials Around Berenike

Three different types of stone were sourced in the area around Berenike: (i) ordinary stone for building and infrastructure such as gypsum anhydrite as well as hard coral, (ii) high-quality 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, also sourced for export. Since the landscapes around Berenike support an abundance of gypsum anhydrite and coral that can be used as low-quality building materials these were widely utilised on site for domestic edifices but also for more prestigious buildings such as temples. Large quantities of high-quality stone are also available from the mines exploited in Roman times in the area surrounding Berenike; however, there is no evidence, to date, for their use on site and it is envisaged that most of quarried high-quality material was exported to the Mediterranean. Berenike would therefore score 4 in this category.

7.9 Availability of Wood

The level of availability of forests and quality of wood for ship repairs, ship building and other production purposes would have been a very significant aspect in the siting of an ancient port. A growing population and rapid economic development would have resulted in an increased demand for fuel to produce light and heat in both domestic and industrial contexts, as well as in public buildings (such as baths) (Veal 2013). In an ancient urban context wood was not only used as fuel but also for industrial processes such as mining, smelting, and pottery making, as well as for military and domestic purposes. Most importantly for a port city, though, it was used for shipbuilding and for repair material.

Wood such as Indian teak, African blackwood or Lebanese cedar was ideal for ship construction, but many other species could have been used for a diverse range of repairs. 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 (Khalil 1994, p 126), which could sometimes be good locations for harbours (if not too shallow). An ethnohistorical study undertaken by Pierre Schneider (2017) 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) also mentioned using mangrove wood for building boats, and specifically *Avicennia maritima* or *Avicennia officinalis* (white mangrove) to repair them. Dionisius Agius (pers. comm. 2012) also remarks about sources from Djibouti corroborating the use of mangrove for shipbuilding, most likely for repairs. This 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.

7.10 Wood at Berenike

In terms of wood, only acacia and mangrove are locally available. Other wood species, recorded in the archaeological material, such as cedar, pine or oak were imported via the caravan route from the Nile valley and the Mediterranean. Those originating in Africa or India such as blackwood and teakwood, were imported through the maritime route. The availability and use of low-quality building materials local to Berenike and the great scarcity of wood scores the site only 1 in this category.

7.11 Accessibility of Raw Materials and Trade Commodities

The category of raw materials and trade commodities needs to be considered in light of their availability, portability, quality and types. As already discussed above 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. Apart from wood and building materials (see categories above), an economic boom during the early Principate and increased demand for tools, weapons, ornaments and jewellery (Craddock 1995) also amplified the need by the Roman Empire, and ore-deprived Central Italy, for heavy metals (gold, silver, copper, tin, lead, zinc, iron, mercury, arsenic, and antimony; Healy 1978). 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 metal ores to the State was so

huge that the army oversaw mining undertaken by locals and convicts condemned to the *metalla*,[9] some of them located in Roman Egypt. Some scholars even suggest an existence of a centralised bureau in Rome that was responsible for mining (Hirt 2010). Specific sediments such as clays were also required for pottery manufacture, and sand, with a high quartz (silica) content, was needed for glass production. Other trade goods such as gems and turtle shell, as well as luxury organic materials were available along the Red Sea coast and exploited by coastal port-dwelling communities for exchange with visiting merchant vessels.

7.12 Raw Materials and Trade Goods at and Around Berenike

Berenike scores highly (4) in this category as it is located in an area with plentiful raw materials. Gold, emeralds, olivine, topaz, and basalt, exploited in the area in the Ptolemaic and Roman times, 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. Although sand is certainly plentiful at Berenike and there is also some clay available in the area, there have been no production centres of glass or pottery production identified to date, and the high quantity of decent wood required for such manufacture would mean that it was not viable, on a large scale, at the site where wood resources were scarce (see previous parameter). Other raw materials such as metal ore, as well as non-essential foodstuffs and goods for elite consumers including spices, frankincense, tortoise shell, or ivory, 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, pp 278–280) subjected to import tax in Alexandria (Cappers 2006, p 3), whilst *Periplus Maris Erythraei* mentions all together 34 plant products, 18 of which were traded from Berenike (Casson 1989; 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.

8 Socio-Political-Economic Parameters

The social, political and economic parameters presented in this section, in contrast with the environmental (sea, land, resources) parameters set out in the sections above, relate to human decision-making and are used as a counter-balance for the factors such as the availability of raw materials and trade goods as well as the attractiveness of the local sea- and land-scape setting. Admittedly, these variables are not only 'archaeologically invisible' but also very difficult to quantify and if not approached rigorously, with enough historical data available to seek them, could create a circular argument. Since they could have also changed throughout the lifetime of the port, or have been quite short-lived, they should be used with the highest level of caution and with appropriate levels of analyses of historical sources. However, they should not be entirely excluded from consideration since not only would they affect the choice of location made by those who were setting up the new port, but they 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 ships' crews and cargo, would play an important role and would ultimately determine the popularity of the ports in respect of the expectations of sailors and merchants. Nevertheless, it is worth noting at this point that many or most of the parameters and criteria can be overridden if economic circumstances increase potential profit beyond a certain threshold.

8.1 Demand: Scale of 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 (including both market demand for a particular commodity or a range of them, as well as a potential local or regional need for a new port facility). Although this parameter is difficult to assess quantitatively and highly contextual and historically contingent it would have only been after the demand for a new port 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 in 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

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

Sātavāhana, Chola and Guptas dynasties in India, were highly developed civilisations that had similar luxurious 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 a similar need of luxury items. They were interested in taking part in the emerging global economy and pursuing its benefits.

Whilst in some contradiction to Wallerstein's World-system theory (Hopkins and Wallerstein 1982; Wallerstein 2009), Linder proposes (see discussions in: Frankel 1997, p 60, pp 133–134; Choi 2002) that 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, p 91). Analogously, the notion of 'opposite shores' developed through observation of the popularity of ports situated on the western shores of 19th-century Britain during the increased Atlantic trade (e.g. Harvie 2008) might be successfully applied to the Indo-Roman trade, with the Mediterranean representing Western Europe and the Indian Ocean region, especially India, representing North America and the Red Sea the transitional area in-between—that is, the Atlantic. It is an obvious point that the ends of the supply chain have a major impact on the development and growth of particular modes of transhipment—that is, ports during periods of intensified trade activity.

8.2 Demand for Berenike

The highest score of 5 in this category for Berenike may indicate that 'Demand' played a key role in siting of the site. 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.

8.3 Strategic Position

This factor includes the defendability of the site, and security of its connection with the 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 a particular location. The key factors that would have been taken into consideration by ancient port builders when thinking about good strategic positions would have therefore included:

i. Safety of the position in connection to the hinterland routes.
ii. Provision of safety for the inhabitants in case of an attack:
   - Location on a hill, uplifted terrace or other easily defendable elevated position (good visibility and good observation points).
   - Readily defended approach from the sea, possibly blocked by harbour chains or watched over by a fortified building.

The contact with the hinterland 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 pack animal, hauled by slaves (or by river-boat). 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 toward 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 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, in Alexandria on the Mediterranean or in Berenike

on the Red Sea). 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, pp 173–180). Some ports and landing places on the Red Sea were so strategically positioned that they also served, as in the Mediterranean, as naval bases (such as Jizan on the Farasan Islands; Phillips et al. 2004, pp 244–245; Adams 2007, p 35). These were usually located in a separate harbour basin from the commercial harbour (e.g., Carthage) but in smaller ports, such as Berenike, they might have only had a special delineated (or not) area.

8.4 Berenike's Strategic Position

The recently discovered Ptolemaic fort and substantial defensive city walls indicate conscious improvements in the defensibility of the site of Berenike 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 Bay and the entrance to a number of surrounding wadis, 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 well-positioned and well-defendable stations, forts and *praesidia* (Bagnall et al. 2001; Sidebotham and Zitterkopf 1995).

8.5 Political Stability and General Safety

Coastal sites are threatened from both the sea and hinterland, as Polanyi (1963, pp 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. The political stability of a region must have therefore played a crucial role in deciding which port to trade in. This included factors such as the political situation in a region, as well as a potential for civil strife, war and predictability of conflict (internal due to, for example, high taxes, social inequality or through slave revolt or external aggression). 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. Similarly to the case of 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 sea merchants and their agents.

8.6 Political Stability Around Berenike

Ten *praesidia*, part of a Roman early-warning system, were situated within a distance of 7–35 km from Berenike (Bagnall et al. 2001; Sidebotham and Zitterkopf 1995). 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.

8.7 Port Infrastructure and Facilities

The attractiveness of any given port to the merchants includes the accessibility of human expertise, administrative facilities, appropriate port infrastructure and hospitality services. It is also based on existing networks of kinship and faith as well as practicalities and journey times (e.g., Seland 2013), and is therefore often difficult to assess quantitatively. 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. Information about the particular types of human expertise in the area, such as specialist workshops, talented craftsman or artists, or a renowned and capable shipwright, a good brothel (see the Coptos Tariff for a tax paid for the transport of prostitutes from the Nile valley to Red Sea ports; Young 2001, p 44), bar, theatre, fighting arena or other form of entertainment, could potentially result in the modification of a route as the crew of the vessel chose a more attractive port for their needs, if one was available. Therefore, access to these 'human resources' and their 'willingness' to settle in a new port town would be a crucial consideration when assessing the attractiveness of a port. Whilst such facilities, as mentioned above, were unavailable prior to the setting of the harbour, the availability of human resources, the capacity of the port to develop such amenities, the availability of particular types of goods and a particular type of landscape and environmental setting, as well as the

location on a particular node of a trade network (e.g., Leidwanger et al. 2014; Seland 2016) with, for example, a pre-set taxes zone, would have been a crucial consideration.

Another influential factor would be the potential risk of queues to enter the harbour, and the level of taxes and custom duties,[10] which could have convinced the merchants to travel to other locations to trade. Customs duties were high in some areas of the ancient world and in many cases predestined the success or otherwise of a particular port, therefore this could, in the future, justify making custom duties and taxes a parameter on their own. 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). Nabatean ports such as Leuke Kome would have had their own rates of taxes. Usually the imported goods would be raw materials that were then sold in the cities like 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). 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, its size (and ability to accommodate vessels waiting to pay the levy on the roadstead) and how quickly merchants would be able to move the delivered goods making highest possible profit.

8.8 Berenike's Port Infrastructure and Facilities

The closest major port from Berenike was Myos Hormos but a number of other smaller anchorages were available en route. 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 they could have been in comparison with Berenike or Myos Hormos. Berenike attains 4 in this category based on the evidence from ostraca and papyri (Bagnall et al. 2000, 2005) and ancient texts such as *Periplus Maris Erythraei* attesting to the importation of variety of foodstuffs and wine to the town (Cappers 2006). There are both references to prostitutes and brothels (i.e., Muziris Papyrus), as well as temples and religious and cultic worship, serving a diverse array of creeds and interests, from explorer and 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.

9 Summary of Berenike's 'Parameters of Attractiveness'

The Parameters of Attractiveness (PoA) scored by Berenike for each of the categories can be seen in Table 2 and we can draw a number of conclusions from this semi-quantitative dataset. As can be seen from the tables the Sea parameters that score 0.72 (Moderately Attractive) and Socio-political-economic parameters that score a very high 0.85 (Very Attractive) put the site in the Moderately Attractive or Very Attractive. At the same time, values for both Land parameters and Resource parameters are low at 0.53 and 0.50 respectively and located at the border of Poorly to Reasonably Attractive and Moderately Attractive. Berenike scored a total of 2.60 out of 4 (0.65) overall making it a practical and a rather attractive location.

As we can see above, these data suggest that the decision behind the siting of Berenike was not entirely due to environmental parameters. 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 water supply. This seems counter-intuitive, although, in light of other very strong parameters (i.e., natural bay, winds, demand), can be explained. Despite this rather obvious hindrance, Berenike flourished in that challenging landscape for almost a millennium. This shows that political will, economic demand and marine setting 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 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 old

[10]Compare with establishing Delos as a freeport in 167 BCE to counterbalance Rhodes 2% harbour tax (Duncan-Jones 1990, p 37; Adams 2011). Within a year, trade immediately bypassed Rhodes in favour of Delos (Adams 2001, p 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).

Ptolemaic port 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? Whilst the site of the modern naval base of Baranis seems extremely propitious for locating a maritime port the inaccessibility of the site makes it difficult to assess whether there are any ancient remains and why the southern location, a potentially less attractive one, has been chosen instead.

The prevailing wind patterns reaching Berenike from the south, along with the natural harbour and lagoon system available at the current site must have nevertheless 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 stretch of coast within 100 km north and south of the site, Berenike's Parameters of Attractiveness—potentially those connected with strategic location or access to hinterland routes (i.e., the presence and proximity of a number of wadi systems)—must have tipped the balance.

We cannot know whether the initial decision to exploit the coast at Berenike in the Hellenistic period was made with haste, but the sudden need for war elephants in the time of Ptolemy's II struggles with the Seleucids may have added an element of urgency to the decision-making process. 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 developed infrastructure to connect it with the Nile and was a 'known' quantity rather than a totally new area to explore. It would also be the fastest port to utilise with the necessity to provide for the steadfast 'picking-up' of the trade networks.

As mentioned above, 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 rather hostile, 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.

10 Conclusions and Moving into the Future

The Berenike case study presented here demonstrates the utility of the Parameters of Attractiveness 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, would be examined in more detail and the 'Parameters' already employed at Berenike will be used to assess different aspects of their 'attractiveness'.

The possibility of performing such analyses on an enlarged dataset, discussed in brief in this paper, would allow for a more objective and hence robust evaluation of these parameters and a better confidence-scoring scheme of each variable with a greatly refined and enhanced system ready to observe patterns on a larger sample size. A 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. The enlarged dataset will include 'potential locations' as well as localities which do not host successful ports, or indeed settlements of any kind. Those randomly selected locations on the coast will allow for testing of the robustness of this approach and methodology.

Should larger sample sizes become available (more definite locations within Table 1 will be assessed during the upcoming fieldwork, led by the author and conducted in Saudi Arabia by the University of Wollongong and Saudi Geological Survey team) this simple scheme of semi-quantitative sliding scales would also allow for cross-checking of the viability of the models themselves (and links and relationships between them). An enlarged dataset will also allow for a more objective and hence more robust evaluation of each parameter and for setting up relevant connections between different groups and individual parameters. It would similarly allow for lists of relevant, irrelevant and neutral variables and the assessment of their relationships to be created (e.g., *presence of an active wadi* versus *availability of a good bay with a decent entrance*, but also *presence of an active wadi* versus *dormant wadi; a good bay with a narrow, shallow channel* versus a *good bay with a wide, deep channel*). It is anticipated that the evaluation and scoring 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 groups of 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.

The hypothesis that the attractiveness of the sites of harbours on the Red Sea was dependent primarily on landscape and environmental factors, with a strong influence of political will from Ptolemaic rulers in Alexandria, from Rome, Petra or Axum, or other dominating powers, can then be tested more robustly.

Acknowledgements The author would like to thank Dr. Damian Robinson and Prof. Andrew Wilson for unfailing support during this research, and Dr. Lucy Blue and Prof. Chris Gosden for invaluable comments. Thanks are also extended to Prof. Tom Hillard and two other anonymous reviewers for further insights and comments relating to Red Sea ports and ancient Roman port technologies, as well as very valuable comments regarding socio-economic and political parameters, especially in relation to demand and port infrastructure and facilities. This research has been so far carried out with generous support of The Griffith Egyptological Fund, a Polish Centre for Mediterranean Archaeology scholarship and Meyerstein Award from the University of Oxford.The deepest gratitude is also given to Saudi Geological Survey and Dr. Najeeb Rasul for the invitation to the Red Sea workshop in Jeddah in 2016 and SGS support for a 'Landscapes and Environments of late Holocene Red Sea ports of trade: Geomorphological and Geoarchaeological survey' and a planned fieldwork season of the 'Coastal Cultural Landscapes of the Saudi Red Sea', led by the author of this paper.

References

Abdel-Raziq MA, Castel G, Tallet P, Marouard G (2012) The pharaonic site of ayn soukhna in the Gulf of Suez 2001–2009 progress report. In: Tallet P, Mahfouz E-S (eds) The Red Sea in pharaonic times: recent discoveries along the Red Sea coast. Proceedings of the colloquium held in Cairo/Ayn Soukhna, 11–12th January 2009, Cairo. L'Institut Français d'Archéologie Orientale, pp 3–20

Adams C (2001) For good and evil: the impact of taxes on the course of civilization, 2nd edn. The Madison Books, Lanham, Maryland and Oxford

Adams C (2007) Land transport in Roman Egypt: a study of economics and administration in a Roman province. Oxford University Press, Oxford

Adams C (2011) Tax-haven tales: kooks, crooks, and con men in the offshore world. Laissez Faire Books, Baltimore, Maryland

Admirality, Great Britain Hydrographic (1995) Admiralty tide tables: Atlantic and Indian Oceans, vol 2. The Hydrographer of the Navy, Taunton, Somerset

Al-Tarazi EA, Korjenkov AM (2007) Archaeoseismological investigation of the ancient Ayla site in the city of Aqaba. Jordan Nat Hazards 42(1):47–66

Angelakis AN, Mays LW, Koutsoyiannis D, Mamassis N (2012) Evolution of water supply throughout the millennia. IWA Publishing, London

Bagnall RS, Bülow-Jacobsen A, Cuvigny H (2001) Security and water on the eastern desert roads: the prefect Iulius Ursus and the construction of praesidia under Vespasian. J Roman Archaeol 14:325–333

Bagnall RS, Helms C, Verhoogt AMFW (2000) Documents from Berenike: Greek ostraka from the 1996–1998 seasons, vol 1. Fondation Egyptologique Reine Elisabeth, Papyrologica Bruxellensia 31, Bruxelles

Bagnall RS, Helms C, Verhoogt AMFW (2005) Documents from Berenike: texts from the 1999–2001 seasons, vol 2. Association Egyptologique Reine Elisabeth, Papyrologica Bruxellensia, p 33

Bard KA, Fattovich R (2003) Mersa Gawasis: a pharaonic coastal site on the Red Sea. Bull Am Res Center Egypt 184:30–31

Bard KA, Fattovich R, Ward CA (2007) Sea port to Punt: New evidence from Marsa Gawasis, Red Sea (Egypt). In: Starkey JCM, Starkey P, Wilkinson TJ (eds) Natural resources and cultural connections of the Red Sea. Soc Arabian Studies Monographs No. 5. Archaeopress, Oxford pp 143–148

Bellotti P, Calderoni G, Di Rita F, D'Orefice M, D'Amico C, Esu D, Magri D, Preite Martinez M, Tortora P, Valeri P (2011) The Tiber river delta plain (central Italy): coastal evolution and implications for the ancient Ostia Roman settlement. The Holocene 21:1105–1116

Benedetti A (2007) The Littoral: an essential space for humanity. Special Issue: Endangered coastlines. CNRS International magazine 8. Editorial. http://www2.cnrs.fr/en/981.htm. Accessed 6 June 2014

Beresford J (2013) The ancient sailing season. History and archaeology of classical antiquity, vol 351. Brill, Leiden and Boston

Berggren JL, Jones A (2000) Ptolemy's geography: an annotated translation of the theoretical chapters. Princeton University Press

Bernal D, Sáez AM, Montero R, Díaz JJ, Sáez A, Moreno D, Toboso E (2005) Instalaciones fluvio-marítimas de drenaje con ánforas romanas: a propósito del embarcadero flavio del caño de Sancti Petri (San Fernando, Cádiz). Spal 14:179–230

Bini M, Chelli A, Durante AM, Gervasini L, Pappalardo M (2009) Geoarchaeological sea-level proxies from a silted up harbour: a case study of the Roman colony of Luni (northern Tyrrhenian Sea, Italy). Quatern Int 206(1/2):147–157

Blackman DJ (1982) Ancient harbours in the mediterranean. Part 2. Int J Naut Archaeol 11(3):185–211

Blue LK (2011) The Amphora Wharf: the context and construction of Roman amphora installations. In: Peacock DPS, Blue LK (eds) Myos Hormos—Quseir al-Qadim. Roman and Islamic ports on the Red Sea. Finds from excavations 1999–2003, vol 2. Archaeopress, Oxford, pp 35–42

Blue LK, Peacock DPS (2007) The ancient shoreline and maritime landscape. In: Peacock DPS, Blue LK (eds) The ancient Red Sea port of Adulis, Eritrea: results of the Erito-British expedition, 2004–2005. Oxbow Books, Oxford, pp 39–56

Bourdon C (1925) Anciens canaux, anciens sites et ports de Suez. Mémoires de la Société Royale de Géographie D'Égypte, vol 7. Imprimerie de L'Institut Français D'Archéologie Orientale, Cairo

Bowman A (2013) Quantifying Egyptian agriculture. In: Bowman A, Wilson AI (eds) Quantifying the Roman economy: methods and problems. Oxford Studies on the Roman Economy. Oxford University Press, Oxford, pp 177–204

Bowman A, Wilson AI (2013) Quantifying the Roman economy: integration, growth, decline? In: Bowman A, Wilson AI (eds) Quantifying the Roman economy: methods and problems. Oxford Studies on the Roman Economy. Oxford University Press, Oxford, pp 3–84

Brandon CJ, Hohlfelder RL, Oleson JP (2008) The concrete construction of the Roman harbours of Baiae and Portus Iulius, Italy: the ROMACONS 2006 field season. Int J Naut Archaeol 37(2):374–392

Bruyère B (1966) Fouilles de Clysma-Qolzoum (Suez) 1930–1932. Imprimerie de L'Institut Français d'Archéologie Orientale, Cairo

Cappers RTJ (2006) Roman food prints at Berenike. Monograph, vol 55. Cotsen Institute of Archaeology, Los Angeles

Carayon N (2005) Le cothon ou port artificiel creusé. Essai de définition. Méditerranée 104:5–13

Casey S (2011) The wave: in pursuit of the rogues, freaks, and giants of the ocean. Anchor

Casson L (1974) Travel in the ancient world. Hakkert, Amsterdam

Casson L (1989) The Periplus Maris Erythraei: text with introduction, translation, and commentary. Princeton University Press, Princeton

Cherian JP, Prasad GVR, Dutta K, Ray DK, Selvakumar V, Shajan KP (2009) Chronology of Pattanam: a multi-cultural port site on the Malabar coast. Current Sci 97(2):236–240

Choi C (2002) Linder hypothesis revisited. Appl Econ Lett 9(9):601–605

Cooper JP (2009) Egypt's Nile-Red Sea canals: chronology, location, seasonality and function. In: Blue LK, Cooper JP, Thomas R, Whitewright J (eds) Connected hinterlands. In: Proceedings of Red

Sea project IV held at the University of Southampton September 2008. Soc Arabian Studies Monographs, vol 8. Archaeopress, Oxford, pp 195–210
Cooper JP (2014) The Medieval Nile: route, navigation, and landscape in Islamic Egypt. The American University in Cairo Press, 392 p
Cooper JP, Zazzaro C (2012) A stone anchor from the Farasan Islands Saudi Arabia. Int J Naut Archaeol 41(2):407–411
Cottier M (2005) The organisation of customs duties in Ptolemaic and Roman Egypt (circa 332 BC–AD 284). Unpublished PhD thesis, University of Oxford
Cottier M (2010) The customs districts of Roman Egypt. In: Gagos Y (ed) Proceedings twenty-fifth international congress of papyrology, Ann Arbor 2007. American Studies in Papyrology. Scholarly Publishing Office, University of Michigan Press, Ann Arbor, pp 141–148
Couyat J (1910) Ports gréco-romains de la Mer Rouge et grandes routes du Désert Arabique. CRAI 54(6):525–542
Craddock PT (1995) Early metal mining and production. Edinburgh University Press, Edinburgh
Crane EE (1999) The world history of beekeeping and honey hunting. Routledge, New York
Crouch DP (1993) Water management in ancient Greek cities. Oxford University Press, New York
Crouch DP (2004) Geology and settlement: Greco-Roman patterns. Oxford University Press, New York
Curtin PD (1984) Cross cultural trade in world history. Cambridge University Press, New York
Davies S, Morgan E (1995) Red Sea pilot. Imray Laurie Norie & Wilson Ltd, London
de Graauw A (1986) Wave statistics based on ship's observations. Coastal Eng 10:105–118
de Graauw A (2014) Ancient ports and harbours, the catalogue, 4th ed., Port Revel. Potential ancient harbours. Ancientportsantiques.com. https://www.academia.edu/7628768/Potential_Ancient_Harbours. Accessed 4 August 2014
de Romanis F (2009) Patterns of trade in the Red Sea during the age of the Periplus Maris Erythraei. In: Blue LK, Cooper JP, Thomas RI, Whitewright J (eds) Connected hinterlands. In: Proceedings of Red Sea Project IV held at the Unversity of Southampton September 2008. Soc Arabian Studies Monographs. Archaeopress, Oxford, pp 31–36
Dulvy NK, Polunin NV (2004) Using informal knowledge to infer human-induced rarity of a conspicuous reef fish. Animal Conserv 7 (4):365–374
Duncan-Jones RD (1990) Structure and scale in the Roman economy. Cambridge University Press, Cambridge
Edwards AMC, Head SM (1987) Red Sea (key environments). Pergamon Press, Oxford
Facey W (2004) The Red Sea: the wind regime and location of ports. In: Lunde P, Porter A (eds) Trade and travel in the Red Sea region. In: Proceedings of the Red Sea project I held in the British Museum October 2002, vol 2. Soc Arabian Studies Monographs. Archaeopress, Oxford, pp 7–17
Fattovich R (2005) Marsa Gawasis: a Pharaonic coastal settlement by the Red Sea in Egypt. In: Starkey JCM (ed) People of the Red Sea. Proceedings of the Red Sea project II held in the British museum October 2004. Archaeopress, Oxford
Fattovich R, Bard KA (2012) Archaeological investigations at Wadi/Mersa Gawasis, Egypt: 2006–2007, 2007–2008 and 2009 field seasons. In: Tallet P, Mahfouz E-S (eds) The Red Sea in pharaonic times: recent discoveries along the Red Sea coast. Proceedings of the colloquium held in Cairo/Ayn Soukhna, 11–12th January 2009. L'Institut Français d'Archéologie Orientale, Bibliotheque d'Étude, Cairo, 155, pp 21–26
Fitzpatrick MP (2011) Provincializing Rome: the Indian Ocean trade network and Roman imperialism. J World Hist 22(1):27–54
Flemming BW (1995) Tidal signatures in modern and ancient sediments. Spec Publ Int Assoc Sedimentologists. Blackwell Science Ltd, Oxford
Fleurence J (1999) Seaweed proteins: biochemical, nutritional aspects and potential uses. Trends Food Sci Technol 10(1):25–28
Frankel J (1997) Regional trading blocs in the world economic system. Institute for International Economics, Washington, DC
Friedman HA (2008) Industry and empire: administration of the Roman and Byzantine Faynan. Unpublished PhD thesis, University of Leicester
Gawlikowski M, Juchniewicz K (2016) Aynuna on the Red Sea. Soc Arabian Studies Conference 2016 poster
Gazda EK (2001) Cosa's contribution to the study of Roman hydraulic concrete: an historiographic commentary. In: Goldman NW (ed) New light from ancient cosa: classical mediterranean studies in Honor of Cleo Rickman Fitch. Hermeutics of art, vol 10. University of Michigan Press, New York, pp 145–177
Geus K, Thiering M (2014) Features of common sense geography: implicit knowledge structures in ancient geographical texts, vol 16. LIT Verlag, Münster, Antike Kultur und Geschichte
Giraudi C, Paroli L, Ricci G, Tata C (2006) Portus (Fiumicino—Roma) Il colmamento sedimentario dei bacini del Porto di Claudio e Traiano nell'ambito dell'evoluzione ambientale tardo-antica e medievale del delta del Tevere. Archeologia Medievale 33:49–60
Giraudi C, Tata C, Paroli L (2009) Late Holocene evolution of Tiber river delta and geoarchaeology of Claudius and Trajan Harbor, Rome. Geoarchaeology—an International J 24(3):371–382
Goiran J-P, Salomon F, Pleuger E, Vittori C, Mazzini I, Boetto G, Arnaud P, Pellegrino A (2012) Port antique d'Ostie. Résultats préliminaires de la première campagne de carottages. Chronique Des Activités Archéologiques De l'École Française De Rome
Goiran J-P, Salomon F, Mazzini I, Bravard J-P, Pleuger E, Vittori C et al (2014a) Géoarchéologie du delta du Tibre: évolution géomorphologique holocène et contraintes hydrosédimentaires dans le système Ostie-Portus (Italie). J Archaeol Sci 41(8):389–398
Goiran J-P, Salomon F, Mazzini I, Bravard J-P, Pleuger E, Vittori C, Boetto G, Christiansen J, Arnaud P, Pellegrino A, Pepe C, Sadori L (2014b) Geoarchaeology confirms location of the ancient harbour basin of Ostia (Italy). J Archaeol Sci 41:389–398
Hamilton-Dyer S (1990) The animal remains. In: Bingen J (ed) Quatrième Campagne de Fouille au Mons Claudianus, Rapport préliminaire. Bulletin de l'Institut Français d'Archéologie Orientale 90. Cairo
Hamilton-Dyer S (2001) The faunal remains. In: Peacock DPS, Maxfield VA (eds) Survey and excavation Mons Claudianus, vol 2, pp 251–312
Hansen RD (1983) Water and wastewater systems in imperial Rome. J Am Water Res Assoc 19(2):263–269
Harrell JA (1996) Geology. In: Sidebotham SE, Wendrich WZ (eds) Berenike'95, Preliminary report of the excavations at Berenike (Egyptian Red Sea Coast) and the survey of the eastern desert. Special Series, vol 2. Research School of Asian, African and Amerindian Studies (CNWS), Leiden, pp 99–126
Harvie C (2008) A floating Commonwealth: Politics, culture, and technology on Britain's Atlantic coast, 1860–1930. Oxford University Press, New York
Hattendorf JB, Unger RW (eds) (2003) War at sea in the Middle Ages and the Renaissance. Boydell Press, Woodbridge
Healy JF (1978) Mining and metallurgy in the Greek and Roman world. Thames and Hudson, London
Hein CJ, Fitzgerald DM, Bard KA, Fattovich R, Zazzaro C (2008) Geological investigations of a Middle Kingdom harbor: Wadi Gawasis, Egypt. In: 2008 joint meeting of the Geological Society of America, Soil Science society of America, American Society of Agronomy, Crop Science Society of America, Gulf Coast

Association of Geological Societies with the Gulf Coast Section of SEPM, Session No. 255, Archaeological Geology, Houston. Geological Society of America
Hein CJ, FitzGerald DM, Milne GA, Bard K, Fattovich R (2011) Evolution of a Pharaonic harbor on the Red Sea: implications for coastal response to changes in sea level and climate. Geology 39 (7):687–690
Hirt AM (2010) Imperial mines and quarries in the Roman world: organizational aspects 27 BC–AD 235. Oxford Classical Monographs. Oxford University Press, New York
Hopkins TK, Wallerstein IM (1982) World-systems analysis: theory and methodology, vol 1. Sage Publications Inc
Horsburgh J (1841) The India directory, or directions for sailing to and from the East Indies, China, Australia, and the adjacent ports of Africa and South America: Comp. chiefly from original journals of the honourable company's ships, and from observations and remarks, resulting from the experience of twenty-one years in the navigation of those seas, 5th ed. W. H. Allen and Co, London
Hoyle BS (1989) The port–city interface: trends, problems and examples. Geoforum 20(4):429–435
Hughes JD (2014) Environmental problems of the Greeks and Romans: ecology in the ancient mediterranean. Johns Hopkins University Press, Baltimore
Karmon Y (1985) Geographical components in the study of Ancient Mediterranean ports. In: Rabān A (ed) Harbour Archaeology. In: Proceedings of first international workshop on Ancient Mediterranean harbours, Caesarea Maritima. Archaeopress, Oxford, pp 1–6
Khalil ASM (1994) Fishes in the mangrove ecosystem of Egypt and the Suakin area, Sudanese Red Sea: Population ecology, community structure and species diversity. Unpublished M.Sc. thesis, University of Khartoum
Kirkland K (2010) Marine sciences: notable research and discoveries. Infobase Publishing, New York
Kotarba-Morley AM (2015) 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. PhD thesis, University of Oxford
Kotarba-Morley AM (2017) The Maritime context of the trans-Mediterranean–Indian Ocean trade: Critical review of the Roman era vessels of the Red Sea. In: Agius DA, Khalil E, Scerri E, Williams A (eds) Proceedings of Red Sea VI conference, Tabuk, Saudi Arabia. University of Exeter, Brill, pp 171–206
Kotarba-Morley AM (2018) Port town and its harbours: sedimentary proxies for landscape and seascape reconstruction of the Greco-Roman site of Berenike Troglodytica, Red Sea coast of Egypt. Polish Archaeology in the mediterranean (PAM 25) Special Issue: 'Studies' from the Red Sea to the Gulf
Kron G (2012) Roman agriculture. In: Bagnall RS, Broderson K, Erskine A, Heubner S (eds) The encyclopedia of ancient history. Blackwell, Oxford, pp 217–222
Lancaster LC (2005) Concrete vaulted construction in imperial Rome: innovations in context. Cambridge University Press, New York
Leidwanger J, Knappett C, Arnaud P, Arthur P, Blake E, Broodbank C, Brughmans T, Evans T, Graham S, Greene ES, Kowalzig B, Mills B, Rivers R, Tartaron TF, Van de Noort R (2014) A manifesto for the study of ancient Mediterranean maritime networks. Antiquity 342 online, pp 1–5
Linder SB (1961) An essay in trade and transformation. Wiley, New York
Luttwak E (1976) The grand strategy of the Roman empire: from the first century A.D. to the third. John Hopkins University Press, Baltimore, Maryland
Manguin P-Y, Mani A, Wade G (2011) Early interactions between south and southeast Asia: reflections on cross-cultural exchange. Institute of Southeast Asian Studies
Mannino MA, Thomas KD (2002) Depletion of a resource? The impact of prehistoric human foraging on intertidal mollusc communities and its significance for human settlement, mobility and dispersal. World Archaeol 33(3):452–474
Mansoor NM (2002) A GIS-based assessment of active faults and liquefaction potential of the city of Aqaba, Jordan. M.S. Thesis, Geosciences Department, UMKC
Mansoor NM, Niemi TM, Misra A (2004) A GIS-based assessment of liquefaction potential of the city of Aqaba. Jordan Environ Eng Geosci 10(4):297–320
Marzano A (2013) Harvesting the sea: the exploitation of marine resources in the Roman Mediterranean. Oxford Studies on the Roman Economy. Oxford University Press, Oxford
Mazzini I, Faranda C, Giardini M, Giraudi C, Sadori L (2011) Late holocene palaeoenvironmental evolution of the Roman harbour of Portus. Italy J Paleolimnol 46(2):243–256
Miller JI (1969) The spice trade of the Roman Empire 29 B.C.–A.D. 641. Clarendon Press, Oxford
Millet B, Tronchère H, Goiran J-P (2014) Hydrodynamic modeling of the Roman harbor of Portus in the Tiber Delta: the impact of the north-eastern channel on current and sediment dynamics. Geoarchaeol Int J 29(5):357–370
Morgan G (2004) Review of the state of world marine capture fisheries management: Indian Ocean. Country review: Egypt (Red Sea coast). Fisheries Aquaculture Dept. http://www.fao.org/docrep/009/a0477e/a0477e0i.htm. Accessed 9 June 2014
Morhange C, Marriner N (2010) Mind the (stratigraphic) gap, Roman dredging in ancient Mediterranean harbours. Portus, Ostia and the ports of the Roman Mediterranean. Contributions from archaeology and history. Bolletino Di Archeologia on Line. Edizione Speciale. In: Roma 2008—International Conference of Classical Archaeology Meetings Between Cultures in the Ancient Mediterranean, pp 23–32
Morrison JS, Coates JF (1986) The Athenian trireme: the history and reconstruction of an ancient Greek warship. Cambridge University Press, Cambridge
Morton J (2001) The role of the physical environment in ancient Greek seafaring. Brill, Leiden, Boston and Koln
Murray GW, Warmington EH (1967) Troglodytica: the Red Sea littoral in Ptolemaic times. Geograph J 133(1):24–33
Nappo D (2010) On the location of Leuke Kome. J Roman Archaeol 23:335–348
Niemi TM, Smith AM (1999) Initial results of the southeastern Wadi Araba, Jordan geoarchaeological study: implications for shifts in Late Quaternary aridity. Geoarchaeol Int J 14(8):791–820
Niemi TM, Thomas R, Parker ST (2006) A 2nd century earthquake at the time of the Roman annexation of Nabataea? Geol Soc America. In: 2006 Philadelphia annual meeting (22–25 October 2006). Abstracts with Programs 38(7):178
Oleson JP (2000) Ancient sounding-weights: a contribution to the history of Mediterranean navigation. J Roman Archaeol 13:293–310
Oleson JP (2006) Herodotus, Aristotle, and sounding weights: the deep sea as a frontier in the classical world. In: Tassios TP, Palyvou C (eds) Ancient Greek technology: proceedings 2nd international congress. Technical Chamber of Greece, Athens, pp 32–48
Oleson JP (2008) Testing the waters: the role of sounding-weights in ancient Mediterranean navigation. In: Hohlfelder RL (ed) The maritime world of Ancient Rome. Memoirs American Academy in Rome, Suppl. 6. University of Michigan Press, Ann Arbor, pp 119–176
Oleson JP, Branton G (1992) The technology of King Herod's harbour. In: Vann RL (ed) Caesarea papers: Straton's tower, Herod's harbour, and Roman and Byzantine Caesarea. JRA Supplementary Series, vol 5. Ann Arbor, pp 49–67
Oleson JP, Brandon C, Cramer SM, Cucitore R, Gotti E, Hohlfelder RL (2004) The ROMACONS project: a contribution to the historical

and engineering analysis of hydraulic concrete in Roman maritime structures. Int J Naut Archaeol 33(2):199–229
Oleson JP, Brandon CJ, Hohlfelder RL, Jackson MD (2014) Building for eternity. The history and technology of Roman concrete engineering in the sea. Oxbow Books, Oxford and Philadelphia
Osypińska M (2011) Archaeozoological remains. In: Sidebotham SE, Zych I (eds) Berenike 2008–2009. Report on the excavations at Berenike, including a survey in the eastern desert. Polish Centre of Mediterranean Archaeology, University of Warsaw, pp 67–76
Osypińska M (2016) Pet cats at the early Roman Red Sea port of Berenike, Egypt. Antiquity 90(354)
Osypińska M (2017) Archaeozoological remains. In: Sidebotham SE, Zych I (eds) Berenike 2010–2011: report on the excavations at Berenike, including a survey in the eastern desert. PCMA Excavation Series. Polish Centre for Mediterranean Archaeology, University of Warsaw
Patzert WC (1972a) Seasonal reversal in Red Sea circulation. L'Oceanographie physique de la mar Rouge: symposium de l'Association Internationale des Sciences Physique de l'Ocean, Paris, 9–10 Octobre 1972. Centre National pour l'Exploitation des Océans, Paris, pp 55–89
Patzert WC (1972b) Seasonal variations in structure and circulation in the Red Sea. Hawaii Inst Geophys Reports. Hawaii Institute of Geophysics, University of Hawaii, Honolulu
Patzert WC (1974) Wind-induced reversal in Red Sea circulation. Deep Sea Res Oceanogr Abstr 21(2):109–121
Peacock DPS, Blue LK (2006) Myos Hormos—Quseir al-Qadim, Roman and Islamic ports on the Red Sea, Volume 1: the survey and report on the excavations 1999–2003. Oxbow Books, Oxford
Peacock DPS, Blue LK (2007) The ancient Red Sea port of Adulis, Eritrea. Report of the Eritro-British expedition, 2004–5. Oxbow Books, Oxford
Peacock DPS, Blue LK (2011) Myos Hormos—Quseir al-Qadim Roman and Islamic ports on the Red Sea, Volume 2: finds from the excavations 1999–2003. University of Southampton Monograph Series in Archaeology, vol 6. Archaeopress, Oxford
Pedersen RK (2015) A preliminary report on a coastal and underwater survey in the area of Jeddah. Saudi Arabia Am J Archaeol 119 (1):125–136
Pessavento Mattioli S (ed) (1998) Bonifiche e drenaggi con anfore in epoca romana: aspetti tecnici e topografici. Materiali d'archeologia, 3. Módena
Pethick J (1995) An introduction to coastal geomorphology. Wiley, Chichester
Phillips C, Villeneuve F, Facey W (2004) A Latin inscription from South Arabia. In: Kennet D (ed) Papers from the thirty-seventh meeting of the seminar for Arabian studies held in London, 17–19 July 2003. Proceedings of seminar for Arabian studies, vol 34. Archaeopress, Oxford, pp 85–100
Polanyi K (1963) Ports of trade in early societies. J Econ Hist 23(1):30–45
Pydyn A (2011) Argonauci epoki kamienia, Wczesna aktywność morska od pierwszych migracji z Afryki do końca neolitu. Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń
Rabān A (1990) Medieval anchors from the Red Sea. Int J Naut Archaeol 19(4):299–306
Rabān A (2009) The harbour of Sebastos (Caesarea Maritima) in its Roman Mediterranean context. In: Artzy M, Goodman B (eds) Gal Z. Archaeopress, Oxford
Rathbone D (2001) The 'Muziris' papyrus (SB XVIII 13167): financing Roman trade with India. Alexandrian Studies II in Honor of Mostafa el Abbadi. Bulletin de la Societe Archeologique d'Alexandrie, Alexandria 46:39–50
Ray HP, Salles J-F (eds) (2012) Tradition and archaeology. Early maritime contacts in the Indian Ocean. The Nalanda-Sriwijaya Series. Institute of Southeast Asian Studies, New Delhi
Rickman GE (1985) Towards a study of Roman ports. In: Rabān A (ed) Harbour archaeology. proceedings of first international workshop on ancient mediterranean harbours, Caesarea Maritima. Archaeopress, Oxford, pp 105–114
Rockman M, Steele J (2003) Colonization of unfamiliar landscapes: the archaeology of adaptation. Psychology Press
Russell B (2012) Shipwrecks and stone cargoes: some observations. In: Gutierrez A, Lapuente P, Roda I (eds) Interdisciplinary studies on ancient stone. ICAC, Tarragona, pp 533–539
Russell B (2013) The economics of the Roman stone trade. Oxford Studies on the Roman Economy. Oxford University Press, Oxford
Russell KW (1980) The earthquake of May 19, A.D. 363. Bull Am School Oriental Res 238:47–64
Salomon F, Delile H, Goiran J-P, Bravard J-P, Keay SJ (2012) The Canale di Comunicazione Traverso in Portus: The Roman sea harbour under river influence (Tiber delta, Italy). Géomorphologie: Relief, Processus, Environnement 1:75–90
Salway RWB (2004) Sea and river travel in the Roman itinerary literature. In: Brodersen K, Talbert RJA (eds) Space in the Roman world: its perception and presentation. Lit Verlag, Münster, pp 43–96
Sayed AM (1977) Discovery of the site of the 12th Dynasty port at Wadi Gawasis on the Red Sea shore. Revue d'Égyptologie 29:140–178
Schmidt-Nielsen K (1964) Terrestrial animals in dry heat: desert rodents. Clarendon Press, Oxford
Schmidt-Nielsen K (1965) Desert animals. Physiological problems of heat and water. Oxford University Press, New York
Schneider P (2017) 'On the Red Sea (…) the trees are of a remarkable nature' (Pliny the Elder): The Red Sea mangroves from the Greco-Roman perspective. In: Agius DA, Khalil E, Scerri E, Williams A (eds) Proceedings of Red Sea VI conference, Tabuk, Saudi Arabia. Brill, University of Exeter
Seeger JA, Sidebotham SE, Harrell JA, Pons M (2006) A brief archaeological survey of the Aqiq region (Red Sea Coast) Sudan. Sahara 17:7–18
Seland EH (2011) The Persian Gulf or the Red Sea? Two axes in ancient Indian ocean trade, where to go and why. World Archaeology 43(3):398–409
Seland EH (2013) Networks and social cohesion in ancient Indian Ocean trade: geography, ethnicity, religion. J Global Hist 8(3):373–390
Seland EH (2016) The Periplus of the Erythraean Sea: a network approach. Asian Rev World Hist 4(2):191–205
Selvakumar V, Shajan KP, Tomber R (2009) Archaeological investigations at Pattanam, Kerala: new evidence for the location of ancient Muziris. In: Tomber R, Blue L, Abraham S (eds) Migration, trade and peoples. British Academy, London, pp 29–41
Shajan KP, Tomber R, Selvakumar V, Cherian PJ (2004) Locating the ancient port of Muziris: fresh findings from Pattanam. J Roman Archaeol 17:312–320
Shaw T (1993) The trireme project: operational experience 1987–90, lessons learnt. Oxbow Books, Oxford
Sidebotham SE (2011) Berenike and the ancient maritime spice route. University of California Press, Berkeley and Los Angeles
Sidebotham SE, Zitterkopf RE (1995) Routes through the eastern desert of Egypt. Bull University Museum University of Pennsylvania 37 (2):39–52
Sleeswyk AW, Meijer F (1998) The water supply of the ARGO and other oared ships. Mariner's Mirror 84(2):131–138
Srinivasan DM (ed) (2007) On the cusp of an era: art in the Pre-Kuṣāṇa world. Brill's Inner Asian Library. Brill, Leiden
Stenchikov G (2011) Modeling of regional climate over Red Sea and Arabian Peninsula. In: Red Sea Research Center Symposium April 2011. King Abdullah University of Science and Technology (KAUST), Jeddah

Tallet P (2009) Les Égyptiens et le littoral de la mer Rouge à l'époque pharaonique. CRAI 153(2):687–719
Tallet P (2010) Prendre la mer à Ayn Soukhna au temps du roi Isési. BSFE 177–178, pp 18–22
Tallet P (2012a) The Red Sea in Pharaonic Egypt. Assessment and prospects. In: Tallet P, Mahfouz E-S (eds) The Red Sea in Pharaonic times: recent discoveries along the Red Sea coast. Proceedings of colloquium held in Cairo/Ayn Soukhna 11–12th January 2009. L'Institut Français d'Archéologie Orientale, Cairo, pp 171–174
Tallet P (2012b) A new Pharaonic harbour in Ayn Sokhna (Gulf of Suez). In: Agius DA, Cooper JP, Trakadas A, Zazzaro C (eds) Navigated spaces, connected places: proceedings of Red Sea project V held at the University of Exeter, 16–19 September 2010. British Foundation for the Study of Arabia Monographs, vol 12. Archaeopress, Oxford
Tallet P (2012b) Ayn Sukhna and Wadi el-Jarf: two newly discovered Pharaonic harbours on the Suez Gulf. Br Mus Stud Anc Egypt Sudan 18:147–168
Tallet P (2013) Deux notes sur les expéditions au Pays de Pount à la lumière de nouvelles données archéologiques. Revue d'Ègyptologie 64:189–209
Tallet P, Mahfouz E-S (2012) The Red Sea in Pharaonic times: recent discoveries along the Red Sea coast. In: Proceeding of the colloquium held in Cairo/Ayn Soukhna 11th–12th January 2009. L'Institut Français d'Archéologie Orientale, Bibliotheque d'Étude, Cairo 155
Tallet P, Marouard G (2012) Wadi al-Jarf—an early Pharaonic harbour on the Red Sea coast. Egypt Archaeol 40:40–43
Tallet P, Marouard G (2014) The harbor of Khufu on the Red Sea coast at Wadi al-Jarf. Egypt Near East Archaeol 77(1):4–14
Tallet P, Marouard G, Laisney D (2012) Un port de la IVe dynastie au Ouadi al-Jarf (mer Rouge). Bull De L'institut Français D'archéologie Orientale 112:399–446
Temin P (2004) Financial Intermediation in the Early Roman Empire. J Econ Hist 64(3):705–733
Thomas R (2010) Fishing equipment from Myos Hormos and fishing techniques on the Red Sea in the Roman period. In: Bekker-Nielsen T, Casasola DB (eds) Ancient nets and fishing gear. Proc international workshop on "nets and fishing gear in classical antiquity: a first approach" Cadiz, 15–17 November 2007. Monographs of the SAGENA Project, vol 2. Universidad de Cádiz, Servicio de Publicaciones, Cadiz, Aarhus University Press, pp 139–159
Thomas R, Pennington B, Villing A (2016) Naukratis in its riverine setting. In: IKUWA 6 conference presentation
Thurman HV, Trujillo AP, Abel DC, McConnell R (1999) Essentials of oceanography. Prentice Hall
Tibbetts GR (1961) Arab navigation in the Red Sea. Geograph J 127 (3):322–334
Tibbetts GR (1971) Arab navigation in the Indian Ocean before the coming of the Portuguese: Being a translation of Kitab al-Fawa'id fi usul al-bahr wa'lqawa'id of Ahmad b. Majid Al-Najdi, together with an introduction on the history of Arab navigation, notes on the navigational techniques and the topography of Indian Ocean, and a glossary of navigational terms. Oriental Translation Fund Series, vol 42. Routledge, Royal Asiatic Society of Great Britain and Ireland, London
Van der Veen M (2011) Consumption, trade and innovation: Exploring the botanical remains from the Roman and Islamic ports at Quseir al-Qadim, Egypt. Africa Magna Verlag, Frankfurt
Van Hecke J, Bossue B, De Buck V, Carpentier E (eds) (1861) Acta Sanctorum Octobris, ex Latinis & Græcis, aliarumque gentium Monumentis, servata primigenia veterum Scriptorum phrasi, Collecta, Digesta, Commentariisque & Observationibus Illustrata a J. van Hecke, B. Bossue, V. de Buck et E. Carpentier, e Societate Jesu Presbyteris Theologis. Tomus X, quo dies vigesimus tertius et quartus continentur. Typis Henrici Goemaere, Brussels
Veal RJ (2013) Fuelling ancient Mediterranean cities: a framework for charcoal research. In: Harris WV (ed) The mediterranean environment in ancient history. Brill, Leiden and Boston, pp 37–58
Vittori C, Mazzini I, Salomon F, Goiran J-P, Pannuzi S, Rosa C, Pellegrino A (2015) Palaeoenvironmental evolution of the ancient lagoon of Ostia Antica (Tiber delta, Italy). J Archaeol Sci 54:374–384
Wallerstein I (2009) World system analysis. In: Modelski G, Denemark RA (eds) World system history (Vol. 1 of Encyclopaedia of life support systems). EOLSS Publications, Oxford
Ward W (2007) Aila and Clysma: The rise of northern ports in the Red Sea in late antiquity. In: Starkey J, Starkey P, Wilkinson T (eds) Natural resources and cultural connections of the Red Sea. Archaeopress, Oxford, pp 161–171
Whitewright J (2007) How fast is fast? Technology, trade and speed under sail in the Roman Red Sea. In: Starkey JCM, Starkey P, Wilkinson TJ (eds) Natural resources and cultural connections of the Red Sea. Soc Arabian Studies Monographs, vol 12. Archaeopress, Oxford, pp 77–88
Whitewright J (2008) Maritime technological change in the ancient mediterranean: the invention of the lateen sail. Unpublished PhD thesis, University of Southampton
Williams CJR (2011) African climate and climate change: physical, social and political perspectives. Springer, London and New York
Williamson OE (1989) Transaction cost economics. Handbook of industrial organization, vol 1, pp 135–182
Wilson AI (2002) Marine resource exploitation in the cities of coastal Tripolitania. In: Khanoussi M, Ruggeri P, Vismara C (eds) L'Africa Romana XIV. Carocci di Roma, Roma volume 1. Rome, pp 429–436
Wilson AI (2015) Red Sea trade and the state. In: de Romanis F, Maiuro M (eds) Across the ocean: nine essays on Indo-Mediterranean trade. Brill, Leiden and Boston, pp 13–32
Woodward FI, Lomas MR, Kelly CK (2004) Global climate and the distribution of plant biomes. Phil Trans Roy Soc B 359:1465–1476
Woodward N (1951) Seaweeds as a source of chemicals and stock feed. J Sci Food Agric 2(11):477–487
Yin J, Falconer RA, Chen Y, Probert SD (2000) Water and sediment movements in harbours. Appl Energy 67(3):341–352
Young GK (2001) Rome's Eastern Trade: International commerce and imperial policy 31 BC–AD 305. Routledge, London and New York
Zazzaro C (2013) The ancient Red Sea port of Adulis and the Eritrean coastal region. Previous investigations and museum collections. Cambridge Monographs in African Archaeology, vol 85. Archaeopress, Oxford
Zazzaro C, Manzo A, Cocca E (2014) Towards a chronology of the Eritrean Red Sea port of Adulis (1st–Early 7th Century AD). J Afr Archaeol 12(1):43–73
Zieliński J (2011) Archaeobotanical remains. In: Sidebotham S, Zych I (eds) Berenike 2008–2009. report on the excavations at Berenike, including a survey in the eastern desert. PCMA Excavation Series, vol 1. Polish Centre for Mediterranean Archaeology, University of Warsaw, Warsaw, pp 59–66
Zitterkopf RE, Sidebotham SE (1989) Stations and towers on the Quseir Nile road. J Egyptian Archaeoly 75:155–189

Ancient Sources

Eusebius of Casearea (*Onomasticon* 2005) Translated by R.S. Notley and Z. Safari. *Onomasticon*. A Triglott Edition with Notes and Commentary. Brill, Leiden

Pausanias (*Perieg* 1918) Translated by W.H.S. Jones and H.A. Ormerod. *Periegesis Hellados*—Description of Greece. Loeb Classical Library, 188. Harvard University Press, Cambridge

Pliny (Plinius Secundus, Gaius, NH 1942) Translated by H. Rackham. Pliny. Natural History. Loeb Classical Library. Harvard University Press, Cambridge, MA

Seneca, Lucius Annaeus (*Nat. Quest.* 1972) Translated by T.H. Corcoran. *Naturales quaestiones*. University of Chicago Press, Chicago

Strabo from Amaseia (*Geogr*. 1917) Translated by H.L. Jones. The geography of Strabo, Vol. I. Books 1–2. William Heinemann Ltd, London

Tacitus, Publius Cornelius (*Agricola* 1914) Translated by M. Hutton and W. Peterson. Agricola. Germania. Dialogue on Oratory. Tacitus Vol. 1. Loeb Classical Library, 35. Harvard University Press, Cambridge

Theophrastus from Lesbos (*Hist. Plant*. 1916) Translated by A.F. Hort. Enquiry into plants (*Historia Plantarum*), vol I. Books 1–5. Loeb Classical Library, 70. Harvard University Press, Cambridge

Vitruvius, Marcus Pollio (*De Archit*. 1931) On architecture (*De Architectura*), vol I. Loeb Classical Library, 251. Harvard University Press, Cambridge