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ABSTRACT: Berenike Troglodytica was one of the key harbours on the Red Sea coast during the Ptolemaic and Roman periods and was a major trade and exchange hub connecting the Indian Ocean and the Mediterranean. Berenike's geographical position was extraordinarily propitious owing partly to its natural harbours, protected against the prevailing northern winds, as well as its location in the vicinity of an ancient viewshed, the large peninsula of Ras Benas. This paper discusses how multifaceted geoarchaeological approaches to the study of ancient ports can contribute to a better understanding of the mechanisms and logistics of maritime trade, as well as fluctuations in its quality and quantity. It also sheds new light on the significance of the effect that local and regional palaeoclimatic, landscape, seascape and environmental changes had on the development and decline of the port, and its changing role within the Red Sea–Indian Ocean maritime network.

KEYWORDS: Greco-Roman, ancient harbour, port of trade, geoarchaeology, Red Sea, Indo-Roman trade, maritime trade

الملخص: لقد كان مرفأ برنيكا تروجوديتيكا واحداً من الموانئ الرئيسية على ساحل البحر الأحمر خلال العصرين البطلمي والروماني، وكان كذلك مركزاً رئيسياً للتجارة ومحطة هامة للتبادل التجاري الذي يربط بين المحيط الهندي وبين البحر الأبيض المتوسط. لقد كان الموقع الجغرافي المتميز لبرنيكا مناسباً بشكل غير عادي ويعود ذلك بشكل جزئي بسبب مرافئها الطبيعية المحمية من الرياح الشمالية السائدة، وكذلك من أسباب تميز هذا الميناء أيضاً هو وقوعه على مسافة قريبة من منطقة رؤية قديمة، وتحديداً، شبه الجزيرة الكبيرة المسماة راس بناس. وهذه الورقة تناقش كيف تتمكن النهج الجغرافية-الأثرية متعددة الأوجه و الأساليب من دراسة الموانئ القديمة و كيف تُتسهم هذه الدراسات وطرق البحث في فهم أفضل لآليات التجارة البحرية وتقنياتها، بالإضافة إلى التقلبات التجارية من حيث نوعيتها وكميتها. كما أن هذا البحث يلقي ضوءاً جديداً على أهمية تأثير تغير المناخ محلياً وإقليمياً، وكذلك المناظر الطبيعية، المشاهد البحرية وأيضاً أهمية التغيرات البيئية التي قد حدثت نتيجة التطوير وتناقص مساحة الميناء ودورها المتغير خلال الشبكة البحرية للبحر الأحمر-المحيط الهندي.

الكلمات الدالة : يوناني- روماني، المرفأ القديم، ميناء للتجارة، علم الجغرافيا الأثرية، البحر الأحمر، التجارة الهندية- الرومانية، التجارة البحرية.

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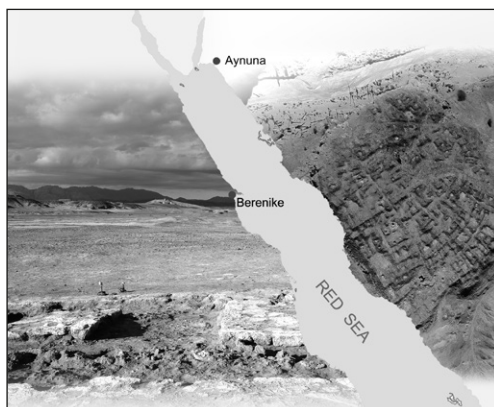
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SPECIAL STUDIES

RESEARCH ON THE RED SEA



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ABBREVIATIONS

<i>AJA</i>	<i>American Journal of Archaeology</i> (Boston)
<i>ASAE</i>	<i>Annales du Service des Antiquités de l'Égypte</i> (Cairo)
<i>BAR IS</i>	<i>British Archaeology Reports International Series</i> (Oxford)
<i>BIFAO</i>	<i>Bulletin de l'Institut français d'archéologie orientale</i> (Cairo)
<i>FIFAO</i>	<i>Fouilles de l'Institut français d'archéologie orientale</i> (Cairo)
<i>GAMAR</i>	<i>Gdańsk Archaeological Museum African Reports</i> (Gdańsk)
<i>JARCE</i>	<i>Journal of the American Research Center in Egypt</i> (Boston et al.)
<i>JEJ</i>	<i>Journal of Egyptian Archaeology</i> (London)
<i>JGS</i>	<i>Journal of Glass Studies</i> (Corning, NY)
<i>JJP</i>	<i>Journal of Juristic Papyrology</i> (Warsaw)
<i>JRA</i>	<i>Journal of Roman Archaeology</i> (Portsmouth, RI)
<i>MDAIK</i>	<i>Mitteilungen des Deutschen Archäologischen Instituts, Abteilung Kairo</i> (Wiesbaden)
<i>OLA</i>	<i>Orientalia lovaniensia analecta</i> (Louvain)
<i>PAM</i>	<i>Polish Archaeology in the Mediterranean</i> (Warsaw)
<i>SAOC</i>	<i>Studies in Ancient Oriental Civilisation</i> (Chicago)

Port town and its harbours: sedimentary proxies for landscape and seascape reconstruction of the Greco-Roman site of Berenike on the Red Sea coast of Egypt

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Abstract: Berenike Troglodytica was one of the key harbours on the Red Sea coast during the Ptolemaic and Roman periods and was a major trade and exchange hub connecting the Indian Ocean and the Mediterranean. Berenike's geographical position was extraordinarily propitious owing partly to its natural harbours, protected against the prevailing northern winds, as well as its location in the vicinity of an ancient viewshed, the large peninsula of Ras Benas. This paper discusses how multifaceted geoarchaeological approaches to the study of ancient ports can contribute to a better understanding of the mechanisms and logistics of maritime trade, as well as fluctuations in its quality and quantity. It also sheds new light on the significance of the effect that local and regional palaeoclimatic, landscape, seascape and environmental changes had on the development and decline of the port, and its changing role within the Red Sea–Indian Ocean maritime network.

Keywords: Greco-Roman, ancient harbour, port of trade, geoarchaeology, Red Sea, Indo-Roman trade, maritime trade

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

John Keay, *The Spice Route* (2005)

The archaeological site of Berenike Troglodytica (275 BC–6th century AD), located on the Egyptian Red Sea coast, served as a port on the spice and incense routes that linked the Mediterranean world (specifically the Roman Empire) to India, Southern Arabia and East Africa (e.g. Sidebotham 2011). In the Greco-Roman period the site was at the cutting edge of what was then the embryonic global economy, ideally situated as a key node connecting Indian Ocean and Mediterranean trade for almost 800 years. It is now located in an arid, marginal, hostile

environment but the situation must have been very different 2300 years ago.

Given the importance of the port town over such a long period of time, it is perhaps surprising that very little is known about the foundation, evolution, heyday and subsequent decline of this city, or the size, shape, and capacity of its harbour/s. The intention of this paper is to briefly address this shortfall in our knowledge and to examine the drivers behind the rise and fall of this port city, and to explore the extent to which the dynamics of physical landscape were integral to its story.

THE SITE AND ITS HISTORY

Berenike Troglodytica, ancient port of trade on the western coast of the Red Sea, was situated in a prime geographic position at the distal end of the influence of the monsoon wind. It was located some 300 km upwind from the Roman Red Sea port of Myos Hormos¹ and 825 km south of Arsinoe and Clysma (near Suez),² as well as 260 km east overland from Syēnē (Aswan) and 12 days by the Eastern Desert caravan route to Coptos (Quft), both riverine ports on the Nile. The city of Berenike was sited just south of the large peninsula of Ras Benas, which offered protection from the elements. During the Roman period it was strategically connected with Alexandria on the Mediterranean, the

capital of Roman Egypt, by three separate routes: across the Eastern Desert, along the Nile, and to the north up the Red Sea.

The geographic location and landscape setting of Berenike—the starting point of the *Periplus Maris Erythraei* (Schoff 1912/2010; Casson 1989)—was well-suited for a commercial port, even taking into consideration the difficulties in developing a large trading enterprise in the marginal hinterlands of the Empire. These difficulties included restricted access to fresh water, food and other essential resources. Therefore, it is fair to say that the demand for exotic goods would have been a leading factor in sustaining the site's growth and popularity, with the wealth

¹ The passage from Berenike to Myos Hormos (approximately just over 200 nautical miles allowing for tacking) could take up to 5.5 days with VMG of 1.5 knots (Velocity Made Good – describes the relative speed of the vessel directly to windward and was observed as a good measure of sailing capabilities of vessels during replica trials in Scandinavia [Englert 2006: 39; Whitewright 2007: 84]), and a minimum of 32 h; with a high average long distance speed of 6.2 knots (Whitewright 2007: 85).

² Contrary to conventional belief, Whitewright proves (2011: 14–15) that the sophisticated and efficient rigs fitted on Mediterranean vessels of the Imperial period were capable of sailing upwind (i.e., using brails for reefing and changing the shape of the sails, and the use of a new sail type, the *artemon*, to stabilise the vessel on an upwind course; cf. Arnaud 2011), equating them in performance, if not marginally superior, compared with the lateen/settee rig. This means that such vessels could have been capable of sailing upwind towards the Northern Red Sea sites ports as Clysma and Arsinoe.

of archaeological material recovered from Berenike confirming the cosmopolitan character of the city. This transitory space, situated at the crossroads linking the Indian Ocean and the Mediterranean with East Africa, Arabia, and India, brought together country folk, merchants, sailors, priests, officials, soldiers, quarry workers and slaves

from across the world. Inscriptions found at the site show the use of at least 12 languages (Sidebotham 2011: 74–76) and coexistence of a number of different cults and religions (Rądkowska et al. 2013). Taken together, it is vivid testimony to the international and multicultural character of the city.

ANCIENT SOURCES AND PORT LOCATIONS

An extensive body of ancient literature testifies to commercial and seafaring activities around the rims of the Red Sea and the Indian Ocean, proving maritime contacts between these disparate lands and continents. The most complete collection of work available consists mainly of Classical Mediterranean writings of Greco-Roman tradition, such as Herodotus, Strabo, Pliny, Ptolemy, Aelian, Plutarch, Diodorus, Megasthenes and others (discussed in e.g. Majumdar 1960; McCrindle 1901/1991; Young 2001). The best known of these accounts include the *Periplus Maris Erythraei*—hereinafter referred to as the *PME* (Schoff 1912/2010; Palmer 1951; Huntingford 1980; Casson 1989), Ptolemy's *Geographike Hyphegesis* (Berggren and Jones 2000; Curry 2005), Strabo's *Geographica* (Dueck 2010; 2011), Pliny's *Naturalis Historia* (Healey 2004), and accounts by Cosmas Indicopleustes in his *Topographia* (McCrindle 1897/2010).

Only a few descriptions of Berenike's harbour have been preserved in ancient texts. For example, at around AD 22 Strabo indicated that 'convenient landing-places' (καταγωγὰς ἐπιτηδείους) existed in Berenike, suggesting that the site then had an anchorage or roadstead, rather than a port with a significant harbour (he refers to the city as being ἀλίμενον – harbourless).

He recorded: "thence one crosses an isthmus, which extends to the Red Sea, near a city Berenicê. The city has no harbour, but on account of the favourable lay of the isthmus has convenient landing-places" [Ἐντεῦθεν ἐστὶν ἰσθμὸς εἰς τὴν Ἐρυθρὰν κατὰ πόλιν Βερενίκην, ἀλίμενον μὲν τῇ δ' εὐκαιρίᾳ τοῦ ἰσθμοῦ καταγωγὰς ἐπιτηδείους ἔχουσιν] (*Geogr.* 17.1.45, emphasis added).

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

Some 50 years after Strabo's comment, around AD 77, Pliny the Elder wrote that Berenike had by that time a proper harbour, noting: "from the city of Berenice, situated upon a harbour of the Red Sea, ... and distant from Coptos by 12 days" [*inde Berenice oppidum, ubi portus Rubri maris, ... totum a Copto Berenicem iter duodecimo die*

peragitur] (NH 6.26.103, emphasis added). Pliny does not mention anything specific or special about the location of this port city (*oppidum*), and so one can only speculate whether he realised that it had a 'typical' harbour (*portus*) such as those that he, as a well-travelled military and public officer, would have been more accustomed to.

EXCAVATIONS IN THE HARBOUR AREA

One of the major objectives of the renewed Polish–American excavations at Berenike was to investigate the area believed to have been Berenike's southwestern port (Sidebotham and Zych 2011). A geo-physical magnetic survey and targeted test excavations were carried out in this area prior to the augering and georadar survey work as part of the geoarchaeological programme undertaken by the author in 2011–2013 seasons.

Initial excavations in the harbour area were aimed at testing the hypothesis that the 'Crescent-shaped Ridge' was a harbour jetty or a wharf in the early Roman period (see Fig. 2 top for location). Trenches BE09-55 and BE10-67, which crossed the top of the ridge, did not, at this stage of excavations, provide any direct evidence to support their definite connection with the early port. However, evidence from trenches BE09-54, at the northern edge of the ridge (Sidebotham and Zych 2011:

27–43), and its extensions BE10-62/64 and BE11-78, as well as later fieldwork in BE11-71 and BE11-72, as well as BE14-100 and BE14-101 (Sidebotham and Zych 2017a; forthcoming), suggest the presence of an area with features dated to the 2nd century AD and resembling a ship repair workshop (see 'Ship Maintenance Area' in Fig. 2 top), which could have been located in the vicinity of the 'Southern Port' investigated in the 2011 season.

The 6,600 m² area around what is believed to have been the 'Northern Anchorage' was targeted for further investigation, including augerhole and geo-physical surveys in the 2012 season. This was based on data derived from excavations in trenches BE98-23 and BE99-32 (located to the southwest), and BE97/98-17, BE96-7, BE95-4 (to the southeast) with purported evidence of the wharf (for further references, see Sidebotham 2007: 74–75).

LANDSCAPE AND GEOMORPHOLOGICAL SETTING

Berenike is situated on top of Quaternary sediments only ~9.5 km east of the foothills of predominantly metamorphic mountains, incised by numerous east-west run-ning wadis that drain to the Red Sea

[Fig. 1]. The site is located in the catchment area of three wadis, which also serve as major sources of sediment transported to the site: Wadi Mandit, Wadi Umm Salim al-Mandit and the northern branch

of Wadi Kalalat to the west; with a large Wadi Abu Greyah, connecting from the north-northwest (Harrell 1996: 100–101) [Fig. 3]. These wadis have a significant effect on the environment of Berenike, serving as the main source of material in-flux to the site and forming transport routes connecting the site to the hinterland. Tidal *sabkha*³ surrounds the site from the east and south, adjoining the lagoon on the east and southeast [see Fig. 3].

Local seascape at Berenike comprises a wide range of geomorphic features, such as coastal shelf and coral reef, the 'Lagoon', the 'Southern Promontory' (an uplifted reef outcrop joined to the mainland

by a tombolo⁴), and the 'Southwestern Embayment' (also known as the 'Southern Port') [Fig. 2 bottom].

Since the mid 1990s, pioneering geological work by James A. Harrell from the University of Toledo was carried out at Berenike and in its hinterland. Subsurface coring of natural deposits around the site in the *sabkha* area (see Fig. 4, transects in pink) was supplemented with a survey in the mountains and around the quarries, as well as detailed study of the mineralogical assemblages (Harrell 1996; 1998; 2001; 2007; Harrell and Storemyr 2009). Harrell's works laid the foundation for this geoarchaeological research.

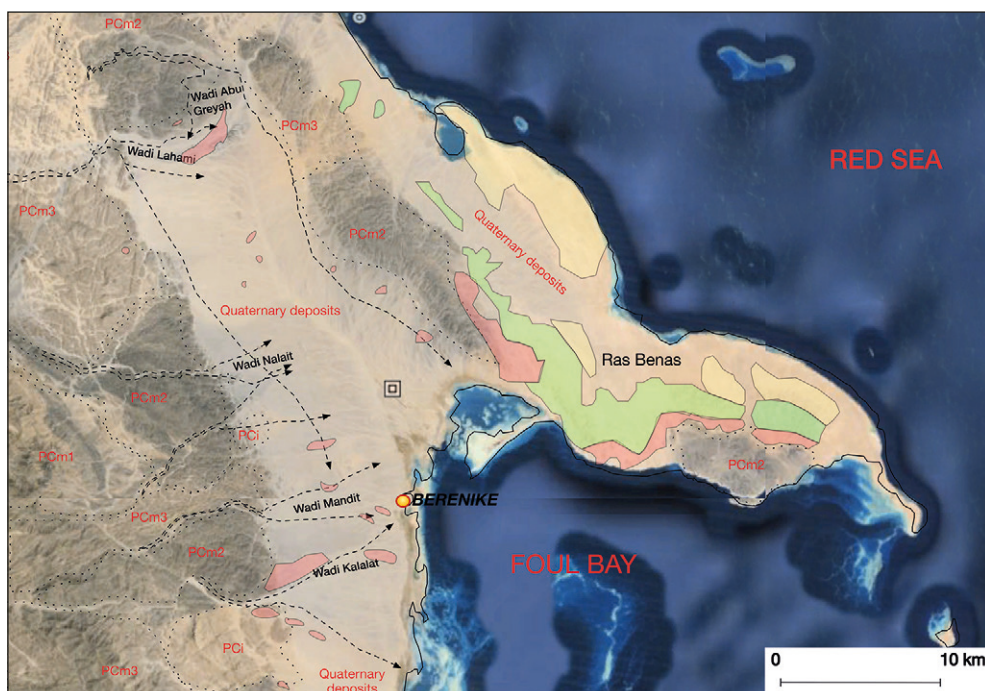
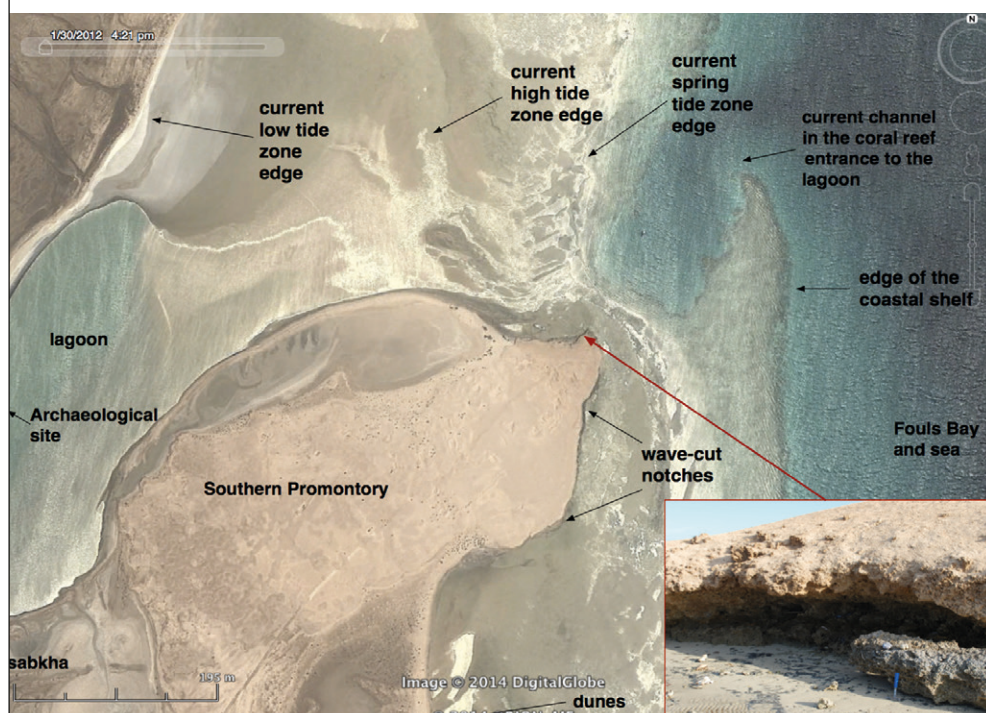


Fig. 1. The regional geological context of the location of Berenike, showing rock formations and wadis (Drawing A.M. Kotarba-Morley 2013, after Harrell 1996)

³ It is essentially a supratidal salt flat characterised by evaporite-carbonate deposits with some siliciclastics.

⁴ A depositional landform in which an island is attached to the mainland by a narrow piece of land such as a spit or a bar.



AIMS OF THE RESEARCH

Despite Berenike playing such a significant role in maritime trade during the Ptolemaic and Roman periods and the transshipment of African and Eastern goods to the Mediterranean, the Red Sea and the Indian Ocean regions, only very limited focused research was undertaken prior to the fieldwork in 2011 in order to elucidate

the location, size and capacity of its harbour basins, and the processes involved in the inception, evolution and eventual decline of the port town that developed around it. Based on field observations it became clear that changes in the local landscape and regional climate, however minor, must have played a crucial role in the rise and fall

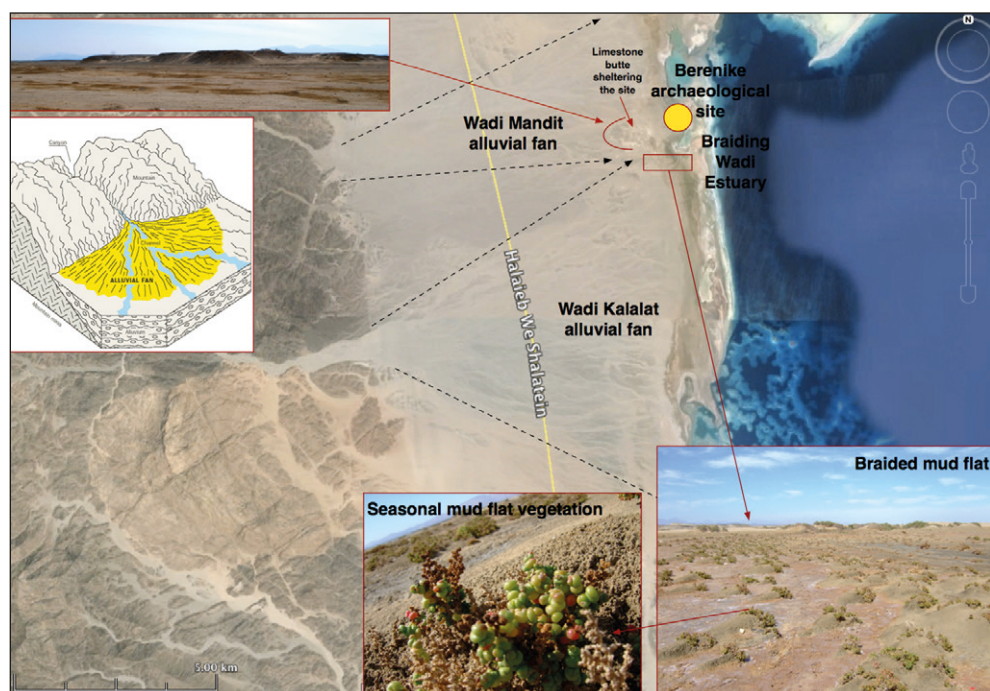


Fig. 3. Satellite image of alluvial fans of Wadi Kalalat and Wadi Mandit that feed into Berenike. Insets: (anti-clockwise from top left) view of limestone buttes from the east; model of a braided alluvial fan; seasonal mud flat vegetation in the estuary of one of the wadi delta channels; braided mud flat just south of the Southwestern Embayment, separated from it by the Crescent-shaped Ridge (Modified from Google Earth; inset photos A.M. Kotarba-Morley 2013)

- ◀ Fig. 2. Satellite image showing location shot of the current entrance to the lagoon and tidal zones; inset, mid-holocene highstand wave-cut notch; top, satellite image of the setting of the port, marking the extent of the Ptolemaic and early Roman harbor lagoons and location of major parts of the town (Modified from Google Earth; processing and inset photo A.M. Kotarba-Morley 2012)

of this port, situated in such a dynamic, marginal environment. This variability would have also dictated the levels of maintenance and adaptation required to keep the port of Berenike operational. Therefore, a systematic geoarchaeological survey on site was deemed necessary.

Palaeoenvironmental and palaeoland-scape data from geomorphological surveys, augering and sedimentological analyses, recovered from the site between 2011 and 2013, served to reconstruct the dynamics of the site in its landscape setting during Ptolemaic and Roman occupation. This research intended to elucidate the landscape and site formation processes that shaped Berenike, providing information about how its inhabitants responded to environmental changes. The final palaeo-environmental reconstruction used both cultural (historical) and scientific (archaeological, geoarchaeological) data sets to assess the correlation—if any—between environmental change and socio-political events.

Ascertaining how the past coastlines were shaped, and whether this was by horizontal (deposition or erosion) or vertical (uplift or subsidence) movements, or via anthropogenic processes, is extremely important to enhance our understanding of archaeological visibility and the issue of presence or absence of a port in any given location. As the actual existence

and the exact location of an alleged harbour at Berenike was a debatable issue at the start of this research, the research programme developed by the author was aimed at establishing the ancient port location. Moreover, it was aimed at developing a better understanding and appreciation of Berenike's landscape setting through the study of subsurface sediment composition and their vertical stratigraphy. This component of the research was designed to situate the site within the dynamics of the local landscape whilst complementing the ongoing archaeological excavations.

Therefore, the augering (coring) was designed with a number of aims in mind:

- i. to locate the southern Ptolemaic and early Roman harbour basin of Berenike, and to establish whether the assumed 'Northern Anchorage' actually existed;
- ii. to establish where the late-period port could have been located;
- iii. to delineate the boundaries and spatial extent of this/these ancient harbour/s;
- iv. to demarcate their shape, size, depth and aspect (including understanding of relative sea level (RSL) change);
- v. to understand the sedimentological history of this area, and use the changes in sediment delivery to the site as a proxy for studying environmental changes in Berenike (Kotarba-Morley 2015a; 2015b).

METHODS

Altogether ten transects, with 89 auger-holes, were cored, sampled and analysed during the 2011 and 2012 seasons. In 2011, a series of six inter-crossing transects, BE11-T01–06, were augered. Augerhole (AH) transects BE11-T05 and BE11-T06

were roughly aligned west-southwest–east-northeast (west–east according to the site grid). Transects BE11-T01, BE11-T02, and BE11-T04 were oriented generally north–south, whilst BE11-T03 followed the northeast–southwest direction [Fig. 4].

These transects were drilled to:

- i. locate the purported infilled Ptolemaic and early Roman 'harbour basin' (AH36, AH37 and others to the north);
- ii. delineate the braided channels of the alluvial fan of Wadi Kalalat (AH52, AH53) in order to establish the depth of sedimentation caused by fluvial influx over time;
- iii. delineate the crescent-shaped coral reef ridge that was thought to have been the wharf of the 'harbour basin' (AH2-4, 43, 54) and to establish its origin; and also to understand whether it was originally a natural structure adapted for use by harbour facilities or whether it remained a natural feature

of the landscape throughout the use of the port;

- iv. define and delineate the so-called 'island' in the middle of this possible basin (AH20-24 and AH31-34) on which a *temenos* with late 5th-6th century AD temple (also called the Lotus Temple in early reports) is located.

Geoarchaeological sampling of archaeological trench sections was undertaken in trench BE11-71 due to its significance for understanding changes in the palaeoshoreline (see trench bottom in *Fig. 5*). Each context (cultural and natural) was sampled after cleaning and drawing the profile. About 100 g of sediment was

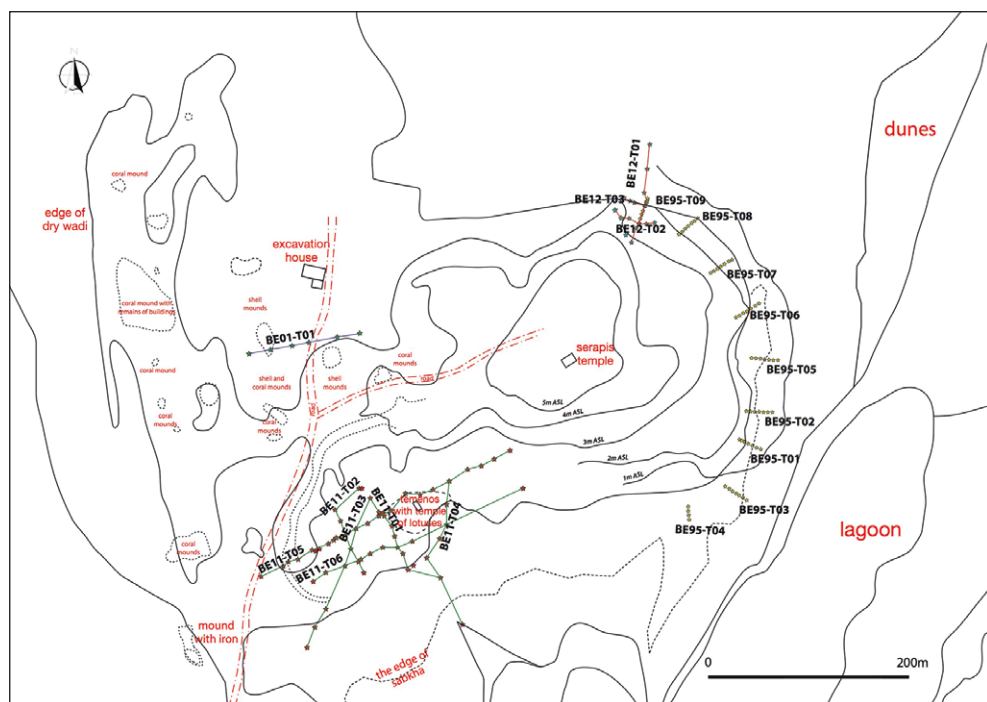


Fig. 4. Map of the site showing baseline plan and coring transects from Harrell's 1995 and 2001 surveys and the author's 2011 and 2012 surveys (PCMA-University of Delaware Berenike Project/ drawing A.M. Kotarba-Morley 2013)

sampled and analysed from each context. After sampling from the section, a small test-pit was excavated at the base of the trench through the laminated beach deposits, and this material was sampled at high-resolution (every 2 cm). An auger-

hole was cored at the bottom of this trench to extend the vertical sedimentological profile. Geomorphological, GPR and pedogenic surveys were also conducted on site and those will be published separately.

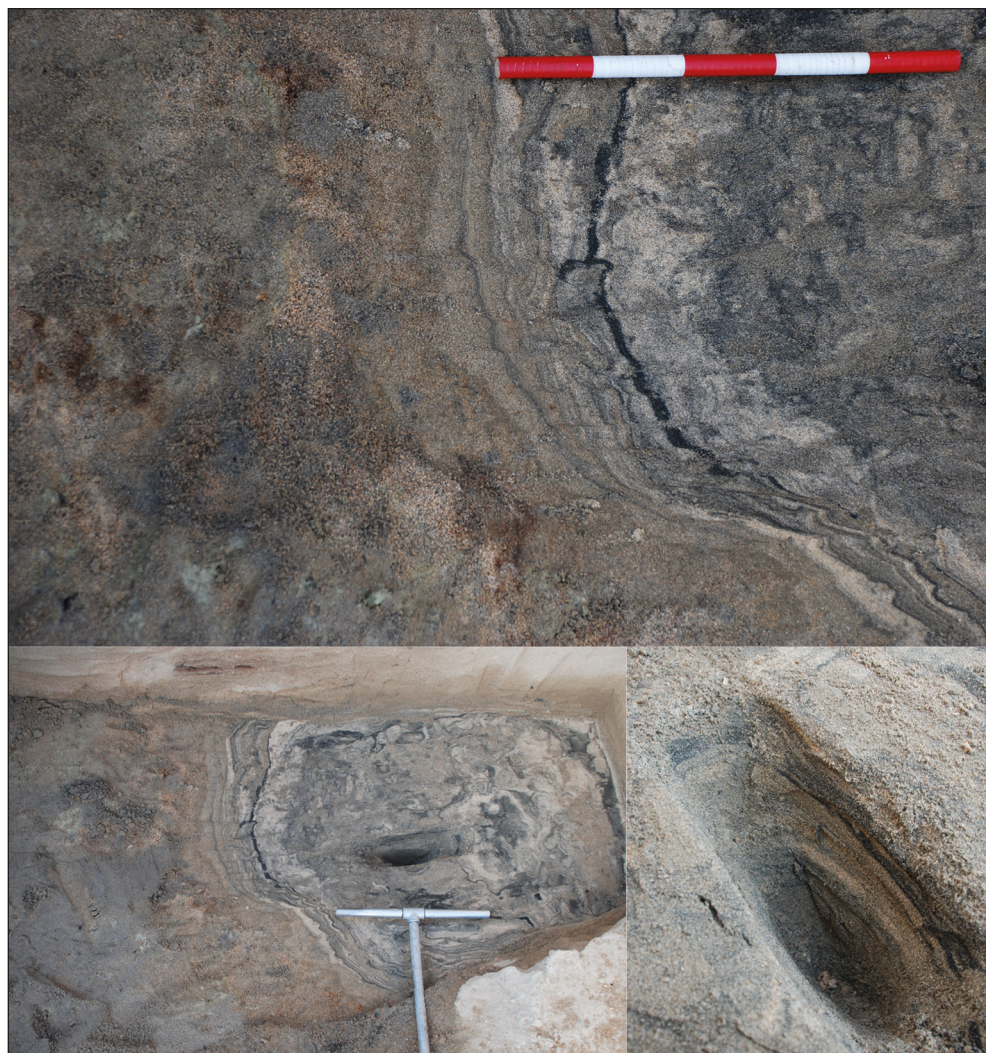


Fig. 5. Remains of a laminated tidal beach underlying hearths uncovered in trench BE11-71; top and bottom right, detailed views (PCMA–University of Delaware Berenike Project/photo A.M. Kotarba-Morley 2011)

Table 1. Groups of facies and their descriptions.

Colour code on transect	Group	Name	Description	Includes facies
	I	Modern (natural)	The most recent period of sedimentation at the site and its environs. These processes may be ongoing, relating primarily to windblown sedimentation, but with exposures of colluvial sequences in some areas.	A: modern dune sand (orange brown, oxidised, loose, very poorly-sorted, coarse sand; occurs in BE11: AH1, 2, 4–21, 25, 26, 29, 30, 42, 43, 48, and 51) J: modern inter-tidal sands/inter-stratified fine (yellowish, loose, very clean and homogenous, well-sorted, medium to fine sand; occurs in BE11: AH2, 3, 36) U: modern dune/aeolian deposition (light to olive brown, very loose, fine sand with coarser grains inclusions; occurs in BE11: AH29 and 31–33) W: modern colluvium (pale brown, organic, medium to fine silty sands; occurs in AH1) V: sub-recent windblown/dune sand (very pale brown to light yellowish-brown, loose, fine to medium silty sand with some clay; occurs in BE11: AH1) A2: modern windblown (greyish, poorly-sorted, compressed but friable to loose, calcareous, fine silty material with coarse quartz inclusions; occurs in BE12: AH1–10, 12–15, and 18–20) E: pottery layer and E1: burnt pottery and hearths; early Prolemaic(?) layer with burnt and water-abraded pottery and hearths (dark to rusty brown, densely packed and slightly compacted, organic silty sand; occurs in BE11: AH5? 6? 7–14, 16, 17?; 18–20, 39–41, 46–47) AA-AM: archaeological layers (occur in BE11: AH2–6, 42, 43, 49, 50)
	II	Archaeological levels	Direct evidence of human exploitation of the landscape and the port city.	
	III	Exposed stable ground surface (occasional background archaeological signal)	Facies likely to be broadly equivalent chronologically to archaeological levels. These facies represent periods of stability, with gradually accreting ground surfaces. This group acts as a part of the landscape surrounding Berenike, but not necessarily as part of the archaeological landscape of the city.	D: terrestrial windblown sand mixed with anthropogenic detritus and occasional colluvium (light grey to brownish-grey, extremely friable but moderately compact, homogenous but very-poorly sorted, laminated, medium to coarse sands and fine silty sands; occurs in BE11: AH5?; 16–18, and 20) P: wadi influx but transitional/relic land surface with aeolian and colluvial influence and occasional wadi influx (dark greyish- to olive-brown or light grey, poorly-sorted, fine to coarse silty sand; occurs in BE11: AH4?, 8–14, 41–43, 46, 51–54) R: mixed transitional (dark greyish-brown, loose to friable, medium sand; occurs in BE11: AH38–41, 46, 47, 51) B2: colluvium and sporadic human activity (olive brown, consolidated but friable, poorly-sorted, medium silty sand; occurs in BE12: AH1–7, 10, 12–14, 19, and 20) G2: transitional silty colluvium on margins of high ground (greyish, loose to friable, poorly-sorted, silty material frequent gravel, broken shells and very occasional calcified granules; occurs in BE12: AH7, 19, 20)

Table 1. (continued)

Colour code on transect	Group	Name	Description	Includes facies
	IV	Fluvial (wadi systems, marginal and proximal)	Interaction with the fluvial systems in close association with the site. Three main wadi systems drain the mountain ranges to the west, and it is likely that there was variable input of these fluvial systems to the basins and low lying areas around Berenike.	T: fluvial into <i>sabkha</i> system/marginal <i>sabkha</i> -wadi interface (pale olive, loose but friable and brittle, highly oxidised, coarse sand; occurs in BE1: AH53) C2: ferruginous transitional (olive brown, compressed but friable, organic and ironised, medium silty sand; occurs in BE12: AH1-3, 6, and 14-17) H2: ferruginous wadi material (reddish-brown, ironised layer of very organic silty sand; occurs in BE12: AH3, 6, 13, and 14) J2: distal wadi sands (grey, dense, fine sand; occurs in BE12: AH16, and 17) M2: inwashed wadi material with ferruginous clay and mica (reddish-brown, iron-rich, ferruginous silty sand with clay lenses and with mica inclusions; occurs in BE12: AH3)
	V	Flood event (pooling)	Unusual facies, a category unto itself. The fine-grained sediments of this facies bear witness to a time when large quantities of standing water were present at various locations on the site. It is not possible to say whether this relates to a period of higher sea level (and ultimate regression), a period of increased precipitation, or is indicative of large flash flood events. The latter is thought most likely.	F: flood event and water pooling (greenish, compacted, pure, homogenous, well-sorted, clay; occurs in BE1: AH17, 18, and 21) Modern analogue middle facies from BE12-T04
	VI	<i>Sabkha</i> (infilled embayment, gypsiferous)	Associated with <i>sabkha</i> formation. Infilling of the low-lying areas around the site, and subsequent surface gypsum formation (via tidal or capillary action) provide large, levelled areas of potentially periodically inundated salt and gypsum flats.	B: relict <i>sabkha</i> surface (light grey to light brownish-grey, loose, poorly sorted, fine to medium silty sand with salt; occurs in BE1: AH4, 11, 14, 16-18, 42-45, 51, and 53-54) N: evaporitic/calcareous gypsiferous surface (white, moderately compressed and friable, very well-sorted, clean and homogenous, chalky calcareous layer of silt with clay; occurs in BE1: AH33, 34, 38-41, 46, and 48) O: calcareous fine aeolian sand possibly with marine influences (light grey, loose and calcareous, clean and homogenous, fine sand with some silt and high content of heavier minerals (black manganese grains); occurs in BE1: AH9, 10, 12-15, 19, 20, 25-30, 41, 46, and 48)

Fig. 6. Transects with radiocarbon dates location. The distance between each augerhole or section is presented on the horizontal axis (and above its interpretative allocation to a particular functional zone of the site), and on the vertical axis represents the depth of the interventions. The 0 – meeting point of X- and Y-axis has been established as the current MSL. Note that the vertical scale on each transect is exaggerated to allow a more legible representation of stratigraphic logs in each augerhole and to pick up topographic changes in transects (Design, drawing and digitizing A.M. Kotarba-Morley)

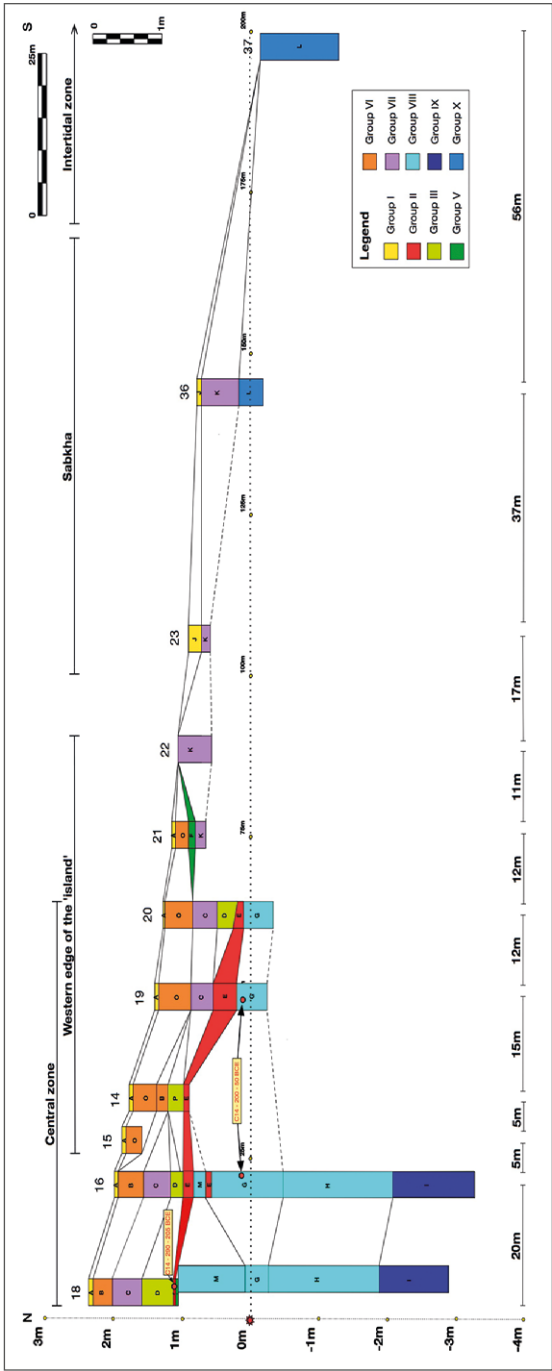


Fig. 6.A. Transect BE11-T01 (for location, see Fig. 4)

Table 1. (continued)

Colour code on transect	Group	Name	Description	Includes facies
	VII	Beach facies (not inundated)	Sediment facies that lie above the high water mark and are indicative of beach sediments. As such they are largely stable and potentially useful for human exploitation in the form of careening/beaching/landing areas. These areas are prone to marine influence and could sporadically flood during exceptionally high tides or storm surges.	C: beach sands at margins of the <i>sabkha</i> (brown, loose to friable, poorly sorted, medium silty sands with marine inclusions; occurs in BE11: AH4; 16–20, and 44–45) K: beach sands (dark grey to yellowish, clean and homogenous, well-sorted, medium sand; occurs in BE11: AH21–23, 33, 34, and 36) S: relic ground surface with notable marine activity (light olive to light yellowish-brown, loose, poorly-sorted, medium to coarse sand with shells; occurs in BE11: AH12, and 47) I2: modern beach sand (pure white, compressed but loose, clean and homogenous, very organic medium sand; occurs in BE12: AH16)
	VIII	Inter-tidal (tidally inundated, stratified)	The facies of this group were inundated on a regular (probably daily) basis and therefore display a much stronger marine influence. Waxing and waning of the tides often produces finely stratified sediments, such as recorded in facies of this group, which are caused by the winnowing of lighter material due to wave action.	G: inter-tidal, intermittent inundation (dark olive brown/very dark grey to black, loose/friable to waterlogged, fine to medium silty sand; occurs in BE11: AH7–13, 16–20, 39–41, 46, 47, and 53) H: inter-tidal environment with proximal backwater influences (dark grey to very dark grey, waterlogged, medium to fine silty sands often fining upwards; occurs in BE11: AH9–11, 13, 16, 18, 39, 40, and 46) M: laminated dark and light beach sands/deposits (dark blackish and light yellowish, interstratified and laminated layers, well-sorted, fine to medium sand; occurs in BE11: AH10, 11, and 16–18) D2: shallow marine/inter-tidal <i>sabkha</i> modern analogue top facies from BE12-T04 (dark greyish to brownish, dense, fine to medium silty sand; occurs in BE12: AH1, 2, 6–7, 12–17, and 20)
	IX	Lagoonal/backwater (low-energy)	Low-energy, shallow to moderate depth deposition in a backwater or lagoonal environment. Lagoons such as these are present near the site today, close to the present day coastline.	G: inter-tidal, intermittent inundation (dark olive brown/very dark grey to black, loose/friable to waterlogged, fine to medium silty sand; occurs in BE11: AH7–13, 16–20, 39–41, 46, 47, and 53) H: inter-tidal environment with proximal backwater influences (dark grey to very dark grey, waterlogged, medium to fine silty sands often fining upwards; occurs in BE11: AH9–11, 13, 16, 18, 39, 40, and 46) M: laminated dark and light beach sands/deposits (dark blackish and light yellowish, interstratified and laminated layers, well-sorted, fine to medium sand; occurs in BE11: AH10, 11, and 16–18) D2: shallow marine/inter-tidal <i>sabkha</i> modern analogue top facies from BE12-T04 (dark greyish to brownish, dense, fine to medium silty sand; occurs in BE12: AH1, 2, 6–7, 12–17, and 20)

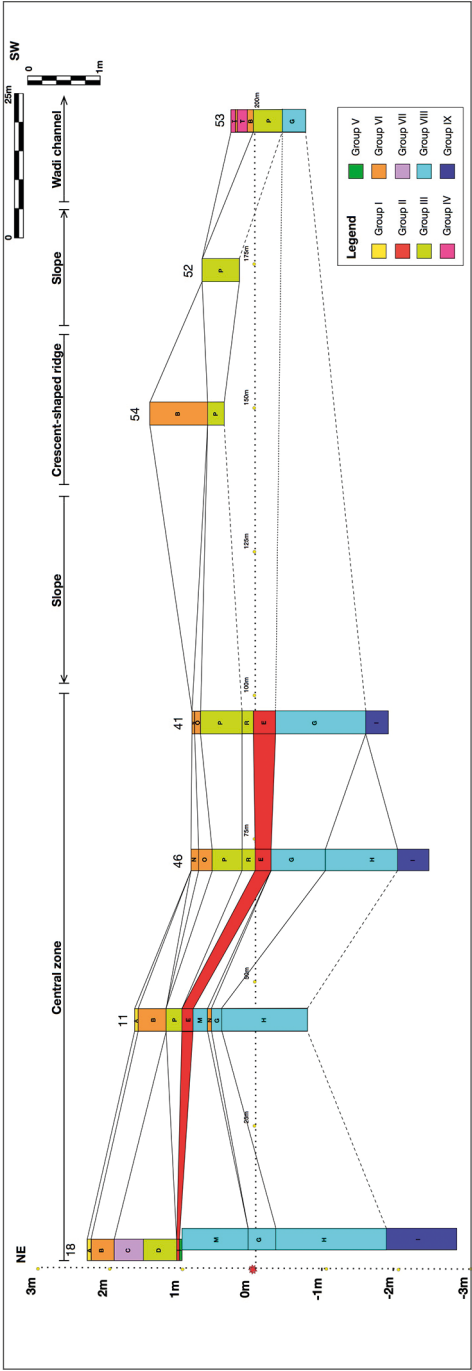


Fig 6B. Transect BE11-T03 (for location, see Fig 4)

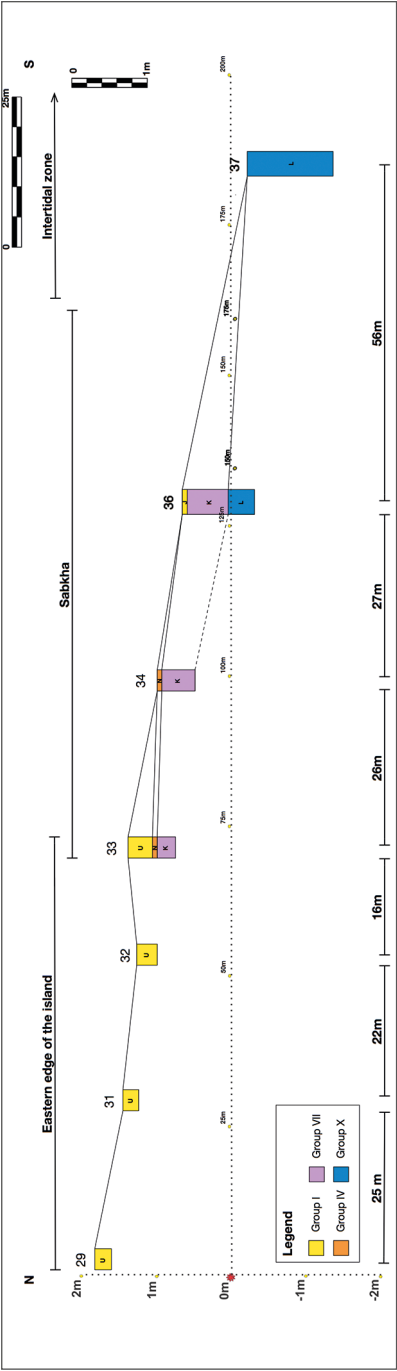


Fig 6C. Transect BE11-T04 (for location, see Fig 4)

Table 1. (continued)

Colour code on transect	Group Name	Description	Includes facies
	X	Near shore marine (shallow)	Sedimentation in a marine environment, close to the shore, and just outside the influence of the inter-tidal zone. The depth of the water and the lack of wave action (compared to the inter-tidal zone) mean that there is a lack of free oxygen and a closer link to the marine biological ecosystem.
	XI	Offshore marine (moderate)	Sediments very similar to the near-shore group, but laid down at an even greater depth of water, slightly further offshore.

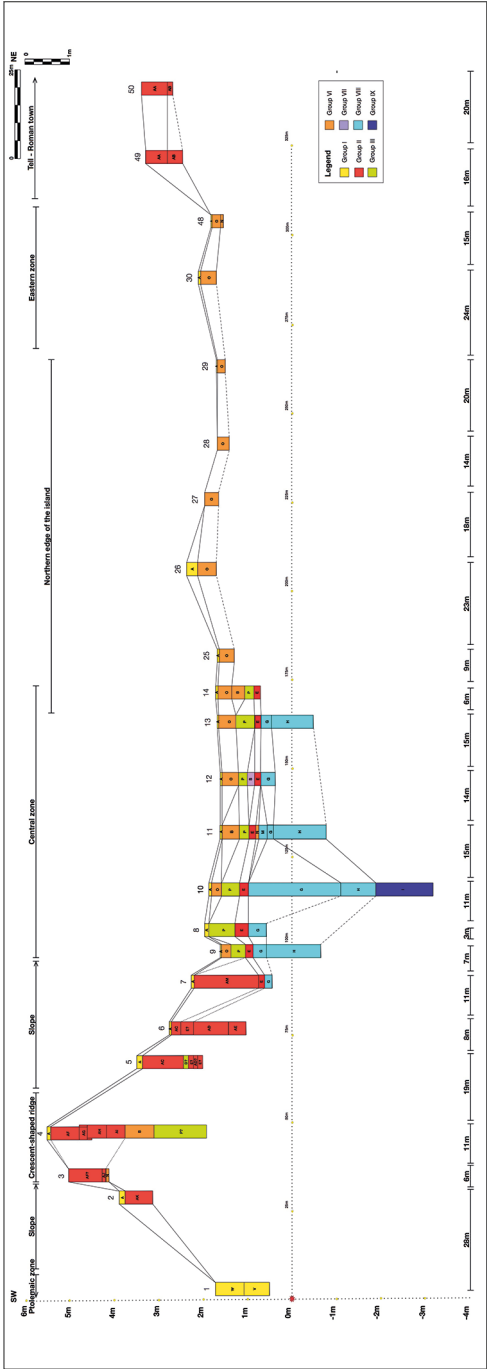


Fig. 6D. Transect BE11-T05 (for location, see Fig. 4)

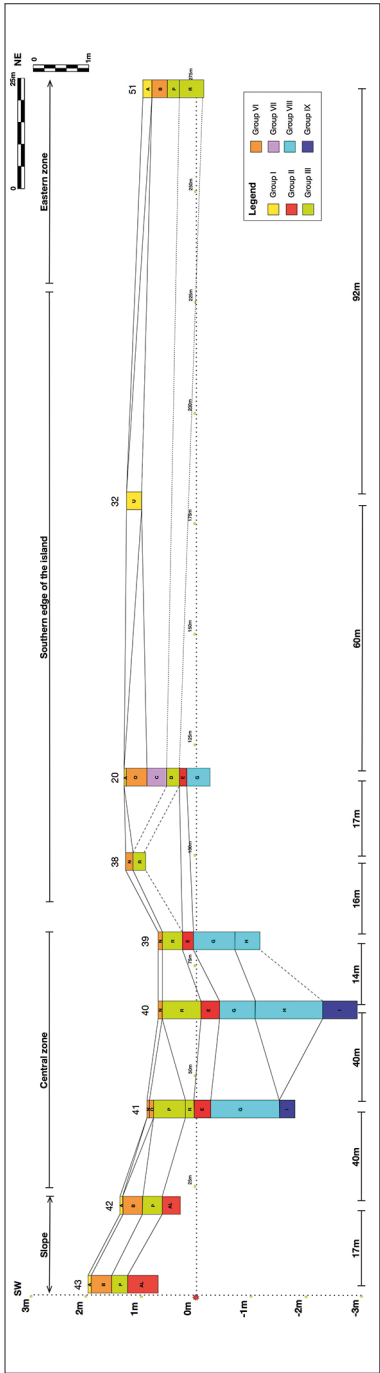


Fig 6E. Transect BE11-T06 (for location, see Fig 4)

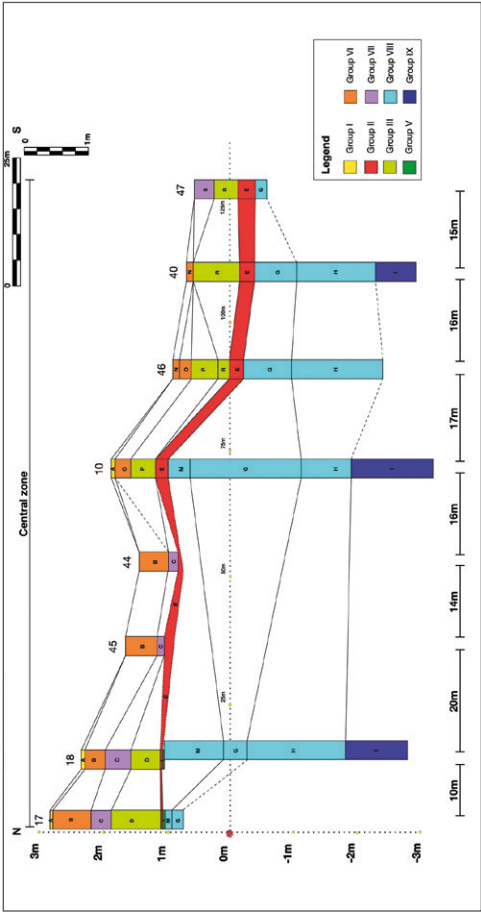


Fig 6F. Transect BE11-T02 (for location, see Fig 4)

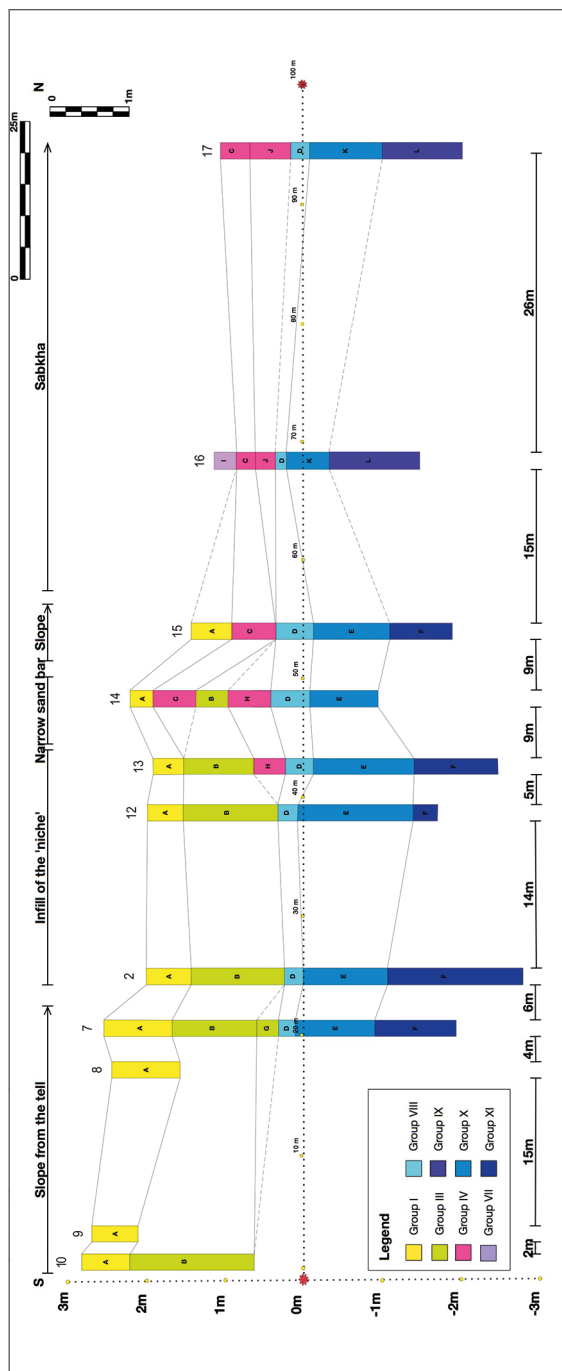


Fig 7A. Transect BE12-T01 (for location, see Fig 4)

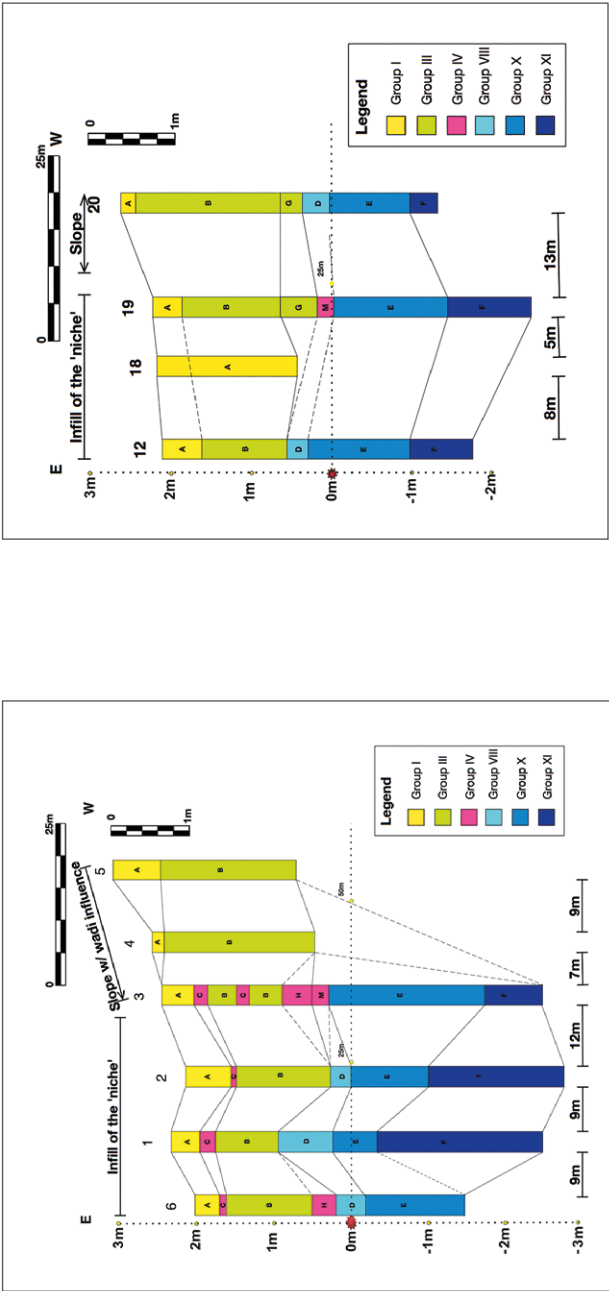


Fig. 7C. Transect BE12-T03 (for location, see Fig. 4)

Fig. 7B. Transect BE12-T02 (for location, see Fig. 4)

RESULTS

Results of augerhole surveys in Berenike revealed highly distinctive and environmentally diagnostic sedimentary sequences beneath the present site and its immediate environs. They also allowed observation of the changes in sedimentology that reflect marked fluctuations in landscape dynamics at the site through time.

For a better understanding of the sub-surface stratigraphy across the site, and for the convenience of the reader, descriptions of the sedimentological units (Facies) recorded across all transects are grouped in tabular form and represented visually (for a detailed description and analysis, see Kotarba-Morley 2017) [*Table 1; Figs 6–7*].

LANDSCAPE RECONSTRUCTION

Results of geoarchaeological analyses demonstrated that Berenike has a very well preserved subsurface stratigraphy that could be used to reconstruct changing coastal environment. This stratigraphic record has been investigated not only with respect to the existing archaeological evidence, but also in relation to the present-day above-ground geomorphology [*Fig. 7B*]. Coastal geomorphological surveys around the site and its hinterland linked contemporary landscape features with the reconstructed ancient landscape, allowing for a far greater appreciation of the ‘Parameters of Attractiveness’ (Kotarba-Morley forthcoming), a theoretical framework designed by the author to statistically quantify and qualify the most important factors that ancient prospectors, settlers, and traders would have considered when founding a new port.

Using the sedimentological, geochemical and geochronological data derived from the analysis of core sediment samples, and the relative age determination of diagnostic ceramic fragments in conjunction with absolute AMS radiocarbon dates, a chronology for landscape change has been developed and is presented below.

Early landscape (Prehistoric and Pharaonic)

Geomorphological and sedimentological features recorded around the site indicate that the entire site of Berenike was inundated in the Pleistocene. A small and undiagnostic stone tool assemblage was found on top of the limestone buttes/terraces to the southwest of the site (see *Fig. 1* top left) during a survey conducted by the author and Piotr Osypiński, a Palaeolithic specialist. It confirms the ephemeral presence of prehistoric human groups in this landscape already in the Middle Pleistocene, when this area of the coast would have looked strikingly different.

Wave-cut notches recorded at the base of these limestone outcrops, at an elevation of ~12 m above the ground surface [see *Fig. 3* inset], indicate higher sea levels during, possibly, the Marine Isotope Stage (MIS) 11.⁵ This is supported by the subsurface stratigraphy recorded in geoarchaeological transects indicating the base of the lagoon at a much higher elevation towards the ‘Crescent-shaped Ridge’. Following a lowering of the sea level in the terminal Pleistocene during the Last Glacial Maximum (LGM),⁶ and what seems to be significant changes in the coastline at

⁵ MIS 11 that occurred 424–374 kya was the longest and warmest interglacial interval of the last 500 ky. It corresponds with the geological Hoxnian Stage.

⁶ LGM occurred between 26.5 kya and 19–20 kya.

the mid-Holocene high stand,⁷ the land around Berenike became viable for human exploitation as a port site, opening up possibilities for a proto-Berenike to emerge and for human occupation of the site to begin.

‘Proto-Berenike’/Ptolemaic settlement

The early Ptolemaic town may have been preceded by a small fishing village or a coastal settlement (maybe seasonal), although no traces of such dwelling have been identified to date. Therefore, the Ptolemaic settlers and elephant-carriers of the 3rd century BC were probably the first to use the area of what is currently the archaeological site of Berenike. Most likely this used to be a relatively small-scale venture prior to becoming a formalised part of the maritime trade infrastructure, gaining a fort, city walls and a gate.⁸ At this time the foreshore area would have been used for seafaring activities such as loading and unloading of boats, vessel repairs and maintenance, and temporary storage of goods. The prograding backbeach environment and the shore, from the ‘Central Zone’ of the ‘Southwestern Embayment’ (‘inner’ + ‘outer’ harbour)—in most times the city harbour—towards the narrow sandbank in the ‘Northern Anchorage’, would have been particularly responsive to the relative sea level lowering thereby conducive to such port activities (see *Fig. 3* top).

Based on current knowledge regarding the site and its buried stratigraphy, it can now be suggested, with reasonable confidence, that the pottery layer (Facies E and E1, see *Table 1*) correlates with the bed of the Ptolemaic harbour basin and indicates a lowering of the sea level by ~0.85 m since

that time to the present. Charred pottery from Facies E1, dated to the early Ptolemaic period, formed a component of hearth structures from the time when the beach-front (observed in trench BE11-71, see *Fig. 5*) was utilised for maritime activities. However, pottery recovered from Facies E in augerholes further east is heavily water-abraded and the layer angles downwards at a gradient and in a pattern similar to that of the intertidal zone of the contemporary lagoon (see transects: BE11-T01, *Fig. 6A*; BE11-T02, *Fig. 6D*; BE11-T03, *Fig. 6B*).

Roman Berenike (early)

Following the Ptolemaic period, the harbour basin and lagoon areas began to infill with silt and other fine sediments. The exact mechanism of this process is currently unclear, but natural factors such as coastal progradation and wadi discharge would have certainly contributed, possibly also with an influx of windblown fine sands. Human modification of the landscape, with practices such as overgrazing of live-stock (especially caprine, available in abundance in the archaeozoological record) causing landscape destabilisation and a marked increase in sediment availability, would have exacerbated the situation.

The siltation could well have been initiated during the main occupation phase at Berenike, with pulses of wadi sediment discharged during heavy rains and flash flood events (potentially linked with an increase in local precipitation or increased seasonal floods, for example). An instance of increase in sediment flux to the coast most likely occurred between the late Ptolemaic/early Roman and the late period

⁷ 0.5–2 m difference noted at around 5 kya (Hein et al. 2011).

⁸ The Ptolemaic city walls and gate were uncovered during the 2013 and 2014 field seasons (M. Woźniak, personal communication; Sidebotham and Zych forthcoming).

(late 4th–early 6th century AD), as seen through the approximate limits of coastal progradation marked by the ‘Harbor temenos’.

Sedimentology indicates that prior to this phase of siltation, in the Ptolemaic and, probably, in much of the Early Roman periods, the harbour extended right through the ‘Central Zone’ of the South-western Embayment to the ‘Lagoon’. It is at this time, when the ‘Lagoon’ achieved its greatest extent, that it was exploited for international maritime trade. Intensive commercial activity would have most likely necessitated regular dredging that, however, could have been performed only episodically.

Evidence of dredging is often detectable only in very subtle stratigraphic changes (e.g., Morhange and Marriner 2010), and as such was not directly identified during the augering of the Berenike’s South-western Embayment. This could be due to the limitations of the equipment and/or the lack of a robust geochronological framework with which to identify gaps and inverse relations in the stratigraphic record associated with dredging events, or the relocation of the harbour further into the ‘Lagoon’, where augerhole coring was impossible. Alternatively, it might be related to the lateral shift of the functional area of the port, such as moving from the ‘Central Zone’ favoured by the Ptolemies, further into the Southwestern Embayment and the ‘Lagoon’ during Roman use, when the ‘Central Zone’ may have already partly silted up.

Roman Berenike

(late 4th–6th century AD)

During the late period Berenike witnessed a slow decline. The extent of Roman con-

trol over this area of Egypt from the late 3rd century AD is unclear, but a reduced trade with the East and the overall decline of maritime trade in the Mediterranean—part of a general economic pattern—had a severe impact on the port (Wilson 2015). A detectable gradual deterioration of living conditions in the city (e.g., architecture, richness of the diet) seems to be mirrored in the decline of the functionality of the port. This may have been influenced not only by geopolitical factors, but also by subtle changes in the geomorphology of the catchment area leading to enhanced siltation to the coast and harbour basin. Processes such as increased wadi sediment discharge and gradual lowering of the sea level would have hindered port operations and required ever-increasing costly and time-consuming maintenance, making, most likely, the areas such as the ‘Central Zone’ and ‘Northern Anchorage’ non-operational at this time.

Increasing sediment flux and subsequent silting up of the basin, caused by a combination of natural and anthropogenic factors, would have necessitated either extensive dredging at the entrance to the harbour/lagoon, or partial reconfiguration of functional areas of the port and associated infrastructure. If such were not performed, the port could soon become unusable. Additionally, even though events such as an epidemic (e.g., the Justinianic Plague of plausible Indian or Ethiopian origin; Sarris 2002: 171–172 was deemed to have prompted the final decline of the city) are undetectable in the geoarchaeological record (although, in the archaeological record, some pathological evidence for such causes of death can be identified in the human skeletal record and a large number of contemporaneous burials could

be seen in the cemeteries) they could have had an impact on the decline of the city. Minor climatic changes, contributing to the site's diminishing role in trade and eventual decline, could have also occurred at this time, although none can be unequivocally confirmed nor dated at this stage.

Arabic times and the East India trade

Because of a lack of historical or archaeological evidence for the continued use of Berenike during the Islamic period, when most of its trade had been moved to the port of Myos Hormos (Quseir al-Qadim, some 260 km to the north), it is important to ask why the site, after its initial decline in the 6th century AD, was not revitalised by the Arabic caliphates and, later on, by the Portuguese traders. It seems likely that extensive modification or even refurbishment of the already abandoned port of Berenike, with a partly or wholly silted up lagoon at this time, may have surpassed efforts and expenses connected with transferring its operations to another port in the region such as Quseir. This was of much greater significance at the time as it lay directly on the *hajj* (pilgrimage route) to Mecca.

The East India trade since the 16th century AD onwards, passing through this area, is known not only from the historical records but also from the engravings in the Eastern Desert (such as those of ships; Blue, Whitewright, and Thomas 2011). However, the geoarchaeological evidence from Berenike shows that the South-western Embayment would have been, by that time, almost totally silted up and therefore probably unsuitable for Portuguese or English ships of the 16th century AD and later.

Modern

Although the present-day coastal landscape of Berenike is not viable as a shipping port, a major naval and air force base—Baranis—is located some 10 km north of the site. It is equipped with a naval harbour proving that this area of the coast still possesses the 'Parameters of Attractiveness' (Kotarba-Morley forthcoming) for modern maritime activity. It is currently unknown why the original Ptolemaic and early Roman port was not situated in this location and whether the activities would have moved there in the late period and/or early Islamic period (and if not, why) as this military area is inaccessible to research.

INTERPRETATION

Berenike was founded in a harsh, marginal environment where relatively minor environmental changes (e.g., fluctuations in sea level, changes in coastal geomorphology, increase in seasonal floods) might have had a dramatic effect on the short- and long-term viability of the site. The results of this research show that:

- i. There has been a drop in relative sea level of ~0.85 m since the Ptolemaic period.
- ii. The role of the 'Southern Promontory' was both as an ancient viewpoint (with a potential beacon to guide vessels), and as a barrier against the waves and sheltering of the bay. It also acted as a trap for alluvial sediments resulting in the silting-up of the lagoon, most likely contributing to the decline of the harbour.
- iii. The extent of the harbour in Ptolemaic times was outlined and limited to the 'Central Zone' of the Southwestern

- Embayment, with at least one of the harbour floor levels identified.
- iv. Previous interpretations regarding the role of the Crescent-shaped Ridge as a harbour wharf with piers are suspect. Location of the 'Ship Maintenance Area' and interpretation of the function of a wooden bollard as a mooring device have also been reevaluated.
 - v. New data have been generated providing clues as to the location of the 'Temenos of Temples' and the 'Northern Anchorage' (the 'Niche').
 - vi. Attractiveness of the location of the Ptolemaic fort and the 'Ptolemaic Industrial Zone' have been reinterpreted in light of the potential environmental marginality of the location.

The coastal location of Berenike benefits from at least two basins (the 'Lagoon' and the Southwestern Embayment, including purported inner and outer harbours), 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.

Whilst the current coastal situation of the site does not seem propitious for hosting a large volume of maritime traffic, the design and construction techniques of ancient merchantmen, navigational and mooring techniques available at the time (e.g., using oars or tug boats for entering and exiting ports, unloading on the roadstead with lighters and entering the port without the cargo), location of the Red Sea at the crossroads of the Indian Ocean and Mediterranean commerce, as well as the configuration of natural features of the coastal landscape, all meant that Berenike must have possessed a sheltered harbour with water depth sufficient to accommodate high volumes of incoming and outgoing merchant vessels.

DISCUSSION 1: SCENARIOS TO RECONSTRUCT THE PORT CITY OF BERENIKE

In order to articulate different site narratives, specifically to better understand the form, function and configuration of Berenike's harbour basins, alternative scenarios for potential reconstructions of the port city of Berenike are presented below. These scenarios are based on results of the geoarchaeological and archaeological interpretations and they emphasise different aspects of interpretation of the ancient lagoon and embayment topography [see *Fig. 3* top]. Furthermore, they allow for examining how the port might

have functioned given small changes to the environment (possibly in different periods of utilisation).

The scenarios below show that Berenike was most likely a natural haven that might have been altered over time (maybe even extensively, although this proves difficult to determine with the limited dataset available to date) to accommodate the changing volume of traffic, types of boats and the needs of the local population. Some modifications might also have been necessitated by the dynamic landscape

changes such as siltation, and local changes in the sea level.

SCENARIO 1

Most traffic located in the inner harbour (including smaller and large vessels); overflow in the outer harbour; potential seasonal use of the roadstead

Scenario 1 assumes that the sea level reconstruction recorded in trench BE11-71 at ± 0.85 m means that the inner harbour was deep enough to accommodate (at least in the Ptolemaic period and the beginning of Roman occupation) large sea-going ships with a draught of up to 3 m.⁹ This 'inner harbour' was located within the 'Central Zone' of the Southwestern Embayment, attaining a depth of around 0.85–1.4 m at the margins, and at least 3 m in its deepest part (according to the topographic reconstruction), with smaller vessels beached or moored in shallower parts of the basin.

Whilst most of the traffic is accommodated in the 'inner harbour', the overflow is directed to the 'outer harbour' or 'Lagoon'. The 'outer harbour' would have either been a single basin comprising only the southwestern part of the 'Lagoon', or, dependent upon the size of the first basin and the amount of traffic, would have comprised two outer harbours. In the second case, the northeastern sector of the 'Lagoon' would also have been adapted to accommodate vessels and would be treated as another 'overflow basin'.

Assuming all marine traffic to have been accommodated within the inner and outer harbours (west of the Southern Promontory), maximum vessel draught would be limited by the depth of the

channel leading to the 'Lagoon' through the coral reef. Additionally, the roadstead to the east of the Promontory and the entrance to the 'Lagoon' would only need to be used seasonally, if at all. The 'Northern Anchorage' would not need to be utilised in this scenario.

SCENARIO 2

All traffic accommodated between the inner and the outer harbours; roadstead used episodically

Contrary to Scenario 1, in which vessels of all sizes would be accommodated in the inner harbour, Scenario 2 assumes that the inner harbour catered to the smaller coastal and ancillary vessels. Along with the outer harbour including the 'Lagoon', accommodating larger, ocean-going ships, they catered to all marine traffic. The roadstead on the northeastern side of the 'Southern Promontory' could be either episodically or permanently used for mooring long-distance merchantmen and navy vessels passing through Berenike on their way south or north. The 'Northern Anchorage' would not have been utilised in this scenario.

Furthermore, this scenario assumes that the remaining large vessels would have been moored even further east or north in Foul Bay (and loaded/unloaded via lighters), i.e., in the roadstead located in the bay, some 1.5 km north of the ancient city. Despite the sheltered, back-reef setting, the coast of Foul Bay is persistently exposed to the action of waves and storm surges posing potential risks to vessels. Therefore, the more exposed roadstead northwest of the 'Southern Promontory' might have only been used in favourable weather conditions

⁹ Similar to that of the Madrague de Giens merchantman shipwreck (Pomey and Tchernia 1978), as well as military vessels that we know were stationed at the port.

whilst the northern extension would have been more propitious.

SCENARIO 3

All traffic accommodated in the inner and outer harbours; potential usage of the roadstead and/or Northern Anchorage

In Scenario 3, both the 'inner' and 'outer' harbours, to their maximum possible extent, were used jointly to accommodate marine traffic, forming a single basin. The 'Northern Anchorage' was also connected with the single basin and used to house important and/or prestigious, smaller vessels such as those used by governmental officials or those belonging to visiting dignitaries or rich merchants from the south. The roadstead may have also been used to accommodate overflow of the traffic, but it is unlikely to have been essential.

In this scenario, taking into account the high sedimentation rates in the northern

area of the site (at least 1 m recorded in the northern part of the site), and the subsequent lowering of the relative sea level by some 0.85 m, it is possible that the depth would have been sufficient, even at a low tide, for small to medium vessels to access this part of the shoreline and take advantage of its sheltered location.

SCENARIO 4

Most traffic located within the outer harbour; probable second outer harbour

Scenario 4 assumes that most of the maritime traffic, including small and large vessels, is accommodated only within the outer harbour ('Lagoon'), and in the absence of any visible remains of direct port infrastructure (waterfront, jetties, etc.), that beaching on the eastern slope of the city mound would have been the most likely way of housing ancillary vessels. The roadstead would have been used only sporadically.

DISCUSSION 2: ESTIMATING THE CAPACITY OF BERENIKE'S HARBOUR

Whilst the calculations of the capacity of ancient ports put forward by de Graauw (2014) and Boetto (2010) are useful for estimating the volume of traffic in the Mediterranean harbours (both man-made and natural), they are based on the assumption that vessels were moored stern or side on to the quay. However, as we have seen from the reconstructed topography of the 'Lagoon' and the lack of any port infrastructure in the archaeological record to date, the style of mooring at Berenike is likely to have been very different. Based on a new reconstruction of site conditions, types of vessels that could have moored in this port (Kotarba-Morley 2017), and

personal experience of navigating into and out of small- and medium-size harbours under sail, some new estimates have been calculated as part of this research.

Calculating 'comfortable' capacity of the 'Southern Port' of Berenike (including both the 'inner' and the 'outer' harbours) is based on a series of assumptions expanded below, and some modern analogue mooring experiments undertaken by the author in small- and medium-size harbours (chiefly Shellharbour and Wollongong, NSW, Australia) during different phases of the tidal cycle. It assumes that:

- i. Most larger merchant ships moored at Berenike were an average 25 m by

7 m in size (with a 250–350 tonnes deadweight tonnage; but vessels of up to 625-tonne, such as *Hermapollon*, are recorded as well, Kotarba-Morley 2015b; 2017).

- ii. The ships under investigation would have had an average draught of 3.5 m, but no less than 2 m (Kotarba-Morley 2015b; 2017), meaning that, accounting for the average tidal range of approximately 0.50 m on the Red Sea (but note: spring tides¹⁰), it would not be possible to moor them comfortably anywhere shallower than +1–1.50 m of their draught at high tide.
- iii. A large number of ancillary and fishing vessels of various sizes and draughts could be moored at the edges of the embayment and the lagoon, in their own area of the harbour, or simply beached (these vessels are not taken into consideration in the estimate as they were most probably indirectly linked with the Indian Ocean trade, i.e., did not contribute to its overall quantity).
- iv. Based on the results of geoarchaeological analyses, a ballpark figure was calculated for the capacity of different functional areas of the site. The ‘Southern Port’ (including ‘inner’ and ‘outer’ harbours from the scenarios mentioned above) was likely to be approximately 17.3 hectares, and the alleged ‘Northern Anchorage’ approximately 0.48 hectares.¹¹
- v. Our understanding of the bathymetry of the ‘Lagoon’ and the Southwestern Embayment makes it clear that the entire 17.3 hectare basin could not have been used to moor large merchant vessels. The available data show that the near-shore part of the ‘Central Zone’ would have a depth of approximately 0.85–1.40 m, whilst the Southwestern Embayment would range from 2.85 m to 3.35 m and deeper. It is assumed that little over a half of this body of water would have attained a depth of 5 m or deeper. The other half could accommodate shallower-draught fishing and ancillary crafts and mid-size merchant vessels. For the sake of this calculation and based on the above assumptions, merchant ships can be accommodated only in some 9 hectares of the harbour.
- vi. Taking into account the tidal range, directions and strength of the offshore winds, and the experiments conducted in similar size harbours on board vessels of various sizes and capacities, the space between the boats on ‘swing’ moorings or on anchor should be at least 1.5–2 times their width side to side, and at least 1 time their length stern-to-bow to allow for safe manoeuvring and passing space for other vessels.

With the above in mind, a medium-size merchant ship of 25 m by 7 m would take up an area of 175 m² (based on assumption i.; but using a square area rather than a circle for easy calculation¹²). As mentioned above, a vessel would also need sufficient

¹⁰ A tide offering just after new and full moon with the greatest difference between low and high water.

¹¹ For comparison, the town on the elevated reef outcrop was approximately 6.2 hectares in size, whilst the island with the ‘Temenos of Temples’ was approximately 0.16 hectares.

¹² This could also be calculated by using the long axis (length of a vessel) and the length of the anchor chain (at least twice or three times the length of the vessel) as the radius of a circle that the vessel could swing around on its mooring, i.e., 25 m vessel + 50 m anchor chain = a circle with a radius of 75 m. This sort of calculation would be used in a harbour with a high tidal range and where the vessels would moor using anchors only on the bow/or stern rather than a number of anchors dropped from different points of the vessel.

space between it and any adjacent vessel, and a channel between the rows of moored ships through which to travel. This creates a requirement of 850–1,050 m² per vessel (based on assumption vi.) to accommodate a merchant ship comfortably in the harbour, meaning that an area of 90,000 m² (based on assumption v.) would accommodate 85–105 medium to large ships at maximum, although it is unlikely that such a large number of vessels would have been moored at Berenike at any one time. Additionally, Berenike would accommodate a much larger number of smaller ancillary and fishing vessels that would be

located in shallower waters and beached.

Whilst there are obvious limitations to this estimation, and there is an apparent need for much more data derived from interdisciplinary research to further enhance these calculations, the figure of 85–105 medium to large vessels has been presented to allow us to imagine how the port of Berenike might have looked and what its potential capacity and maximum occupancy might have been. Despite very general assumptions used to calculate this figure, they still reflect a fair estimate of Berenike's capacity on the basis of the current state of knowledge.

DISCUSSION 3: THE PORT AND ITS FUNCTIONALITY

Archaeological excavations at Berenike, yielding an abundance of high-quality imported material and ancient textual evidence for trade and contacts with the outer world (Sidebotham 2011), demonstrate that the site was of great importance as a seaport during late Ptolemaic and early Roman times. During that time, environmental conditions and the size of the 'Lagoon' were optimal for the operation of this international port and harbour. Results of sedimentological analyses and the geoarchaeological component of this research have provided an understanding of the dynamics of the 'Lagoon' at Berenike and its changing viability as a harbour, as well as giving some estimates of its size, depth and capacity.

Although only limited information regarding port infrastructure is available from archaeological excavations and ancient texts recovered to date, the environ-

mental conditions during peak periods of occupation of the site were highly conducive to establishing a port. The site would have been attractive for human settlement as it was located relatively close to some fresh water sources in the foothills of the mountains (some 8 km) and to the wadi corridors, through which a 12-day caravan route to the Nile Valley¹³ was marked out. The Roman infrastructure in the Eastern Desert seems to have developed in unison with the rise of maritime trade at the Red Sea, with state-sponsored provisions for establishing roads, wells, security posts and alike on the ground, and support for private entrepreneurship. It should also be noted that in the Roman period, it was within easy reach of a large complex of mines and quarries, and therefore represented a very good location not only for a commercial port town, but also a regional administrative centre.

¹³ Compared to the six-day route from the more northerly port of Myos Hormos, sailing time to which may have been much longer than a week, depending on conditions.

At present, despite new data available regarding the changing landscapes and coastal seascapes of Berenike, there remains insufficient archaeological data pertaining to the definite delineation of the harbour and its functional zones, and the mechanisms of its operation. What can be said with reasonable certainty is that the harbour's heyday was in the Ptolemaic and early Roman periods, with the +0.85 m sea level providing at least 2.85 m water depth in the 'Lagoon'. High sedimentation rates (potentially connected with a slightly wetter climate, as attested by the 'flooding' layers in trench BE11-71, Facies F, see *Table 1*) could have instigated a slow decline of the harbour. The basins would have started contracting already in the early Roman period unless dredging was undertaken. If dredging had indeed been performed—and it is likely that it was, despite the lack of hard evidence to date—it probably occurred in the early Roman period when maritime trade was at its peak, and could have been repeated later on, when required.

The late port from the 4th through 6th century AD appears to have been much smaller, without the use of the 'Central Zone' or the 'Northern Anchorage'. The location of the late 'Temenos of Temples' suggests that much of the 'Central Zone'

would have already been infilled at this stage. The gradual lowering of sea level over about 500–600 years, combined with the high sedimentation rates, would have also impacted the depth of the 'Lagoon', which may have diminished even by 2 m (or more) in some places.

Considering archaeological evidence alone it appears that during the early Ptolemaic period vessels, especially the famous, flat-bottomed *elephantagoi*, could have simply been beached or anchored in the 'Central Zone'. This may also have been the case during later periods in some parts of the city and for some types of boats, as no jetties or wharf structures have been found. By the late period, as the 'Lagoon' began to choke with silts, the roadstead could have been used more commonly, with small boats loading and unloading their cargo outside the old main harbour, or anchoring and using a boarding ramp to unload directly into the shallows, the goods then being carried ashore.

The geoarchaeological survey has led to a clearer understanding of local environmental dynamics. However, what is lacking to take this research further is a high-resolution geochronological framework and robust palaeoenvironmental context on which to hang this palaeogeographical reconstruction.

CONCLUSIONS

During its 800-year operational lifespan, the port city of Berenike was located in a somewhat inhospitable, marginal environment at the edge of an arid coastal plain adjacent to the Red Sea. Based on the results of this study, it is clear that even though the reason for Berenike's inception was partly political and strategic, the physical configuration of the coastal

landscape was also important in the choice of its location, whilst a key factor in its subsequent decline was the political shift and the changing dynamics of its environment. The presence of a natural lagoon and favourable prevailing winds constituted such an attractive location for a port that neither the proximity of four large wadi systems, prone to deliver silt to

the harbour basin, nor the scarcity of fresh water or food for humans and animals, could act as a deterrent to the city's development and continuous occupation. Clearly, political and economic requirements for a port outweighed potential disadvantages of its location.

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