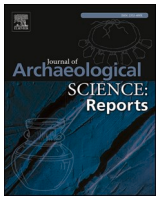
Journal of Archaeological Science: Reports 44 (2022) 103515

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep



More than just food from the sea: Exploitation of marine resources in Hellenistic Berenike on the Red Sea (Egypt)

Alfredo Carannante [a], Marek Adam Woźniak [b], Iwona Zych [c,*]

[a] Mediterranean Archaeology Department, International Research Institute for Archaeology and Ethnology (IRIAE), Italy
[b] Institute of Mediterranean and Oriental Cultures, Polish Academy of Sciences, Poland
[c] Polish Centre of Mediterranean Archaeology, University of Warsaw, Poland

ARTICLE INFO

Keywords:
Hellenistic Egypt
Red Sea
Archaeomalacology
Ancient food
Gastropod operculum
Incense
Shell containers

ABSTRACT

Hellenistic Berenike, a major harbour founded on the Red Sea coast of Egypt in the mid-3rd century BCE, was from the beginning dependent in part on the exploitation of its marine ecosystem to ensure a proper supply of food for the soldiers manning the fort as well as the population servicing the commercial harbour. The archaeomalacological assemblage from recent excavations (2009–2020) has provided material for redefining the relationship between the human population and the marine ecosystems. Remains associated with anthropic activity were separated from the malacological "background noise" by applying a taphonomic analysis and comparing results with a sedimentological study of core drillings from the site and the findings of a local geo-archaeological study carried out for the purposes of the Berenike Hellenistic subproject. Palaeoecological analyses identified the ecosystems exploited in fishing and mollusc gathering, while taphonomic examination revealed different food processing and cooking strategies used in fish and mollusc preparation, suggesting some interesting Hellenistic culinary practices. The study also demonstrated the other uses of marine resources: as decorated trays, pigment containers, censers or drinking cups, as personal ornaments and decoration of objects or furnishing, as raw resources for local handicrafts (tortoiseshell). Not the least, the earliest archaeological attestation of the use of gastropod operculum as an incense ingredient is of particular interest.

1. Introduction (MAW, IZ)

Recent multidisciplinary research into the Hellenistic layers at the Red Sea harbour of Berenike provided data on the marine resources exploited by the inhabitants of the site for a period of roughly 260 years from the port's founding (about the 270s BCE) through the coming of the Roman administration in 30 BC (for preliminary information on the results of the project see Woźniak et al., 2021). There is an extensive literature already on the transport of animals (elephants among others), as well as spices and other valuable goods from East Africa and South Arabia, and (especially in the middle and late-Hellenistic period) more widely the Indian Ocean basin, that passed through Berenike in this period (Cobb, 2018, 52–56; for a concise summary as well as history of discovery and excavations see Sidebotham, 2011). The origins, transport and exploitation of mammals and birds in Hellenistic Berenike have also been studied within the frame of recent research (Osypińska and Woźniak, 2019). However, the exploitation of marine resources on the Egyptian Red Sea coast and the Eastern Desert hinterland has been a neglected topic of research, with limited malacological data being published incidentally in a few site reports without extended analysis, especially in dated archaeological contexts (most recently malacological data from the Hellenistic period have been reported from a desert mining site at Samut Nord; Leguilloux, 2020).

The extensive new data from Berenike, collected over 14 fieldwork seasons of the Polish-American project (starting from 2009), coupled with preliminary insight into marine resources from the previous leg of the archaeological project, then American-Dutch, more than 20 years ago (Van Neer and Ervynck, 1998; 1999), provided grounds for investigating the following issues related to this aspect of the human ecosystem:

- fishing and mollusc gathering strategies at the site, which involved an identification of the marine habitats exploited by the local inhabitants in the vicinity of the port,

* Corresponding author.
E-mail address: i.zych@uw.edu.pl (I. Zych).

https://doi.org/10.1016/j.jasrep.2022.103515
Received 7 June 2021; Received in revised form 2 June 2022; Accepted 3 June 2022
Available online 20 June 2022

- relative role of fish and seafood in the diet and evidence of culinary practices, that is to say, preparation and cooking techniques observed for different marine species,
- importance of shells and other marine resources as ornaments, tools and raw material for the crafts industry,
- other uses of living molluscs.

A coastal centre of this kind is expected to yield massive amounts of shells and other marine remains but much of that is malacological "background noise", which should not be included in an analysis of the role of marine resources in the economy of the site, the food supply in particular. Being located on the border of two very different environments, Berenike suffered from the extremely limited resources of the Eastern Desert on the one hand, while benefitting from a biologically very rich sea on the other. A review of material from secure archaeological contexts aimed at establishing the fishing and mollusc-gathering strategies of the indigenous population, reflecting to a large extent their dietary preferences. Soldiers periodically stationed in the town and passing merchants and sailors would have learned these strategies from the local people or else applied their own, deriving from their presumed Mediterranean background. Attention was paid to archaeological evidence of culinary practices involving marine resources, contributing to the body of data on Hellenistic cuisine in coastal areas, not only in the Red Sea area.

Not the least, the collected assemblage yielded artifacts worked by human hand, exemplifying a shell-crafting tradition that includes tools, decorated objects, and personal adornments (the latter also made of tortoiseshell). These objects were studied as a reflection of the material culture of the inhabitants of Berenike, adding more examples to a still modest category of finds from secure Hellenistic contexts.

The significance of this material derives from this secure contextual attribution, both chronological and cultural. Hellenistic-period remains at Berenike, excavated between 2010 and 2018, were investigated in four clusters of trenches representing different sectors of the site. The extent of the fortified town from Hellenistic times was traced mainly on the basis of magnetic and traditional ground surveys, and tested archaeologically in selected locations. The first two clusters (areas 1 and 2) were located within a large fortified complex, measuring in its heyday 150 m by 80 m (Woźniak, 2017: 44–45) (Fig. 1: Areas 1 + 2). The "fort" stood on a rocky plateau in the western part of the site, by the edge of a wadi. It was a multi-phase structure built around three courtyards, of which the northern one, probably the oldest (located in the north-western corner of the architectural complex) was built in the form of a *tetrapyrgion* (Area 2). Two other courtyards to the south were adjoined on the west and south by rows of rooms that probably housed workshop and storage facilities (Woźniak and Rądkowska, 2014: 511–513). A V-shaped ditch (in Area 1) cut in bedrock west of the middle courtyard intimated the presence of a pen for the wild elephants that the Ptolemaic kings of Egypt imported from East Africa through this harbour (Sidebotham and Wendrich, 2001/2002: 26, Fig. 4, Sidebotham et al., 2008: 162–164, Fig. 7.13, Woźniak and Rądkowska, 2014: 511, Woźniak et al., 2021: 255–256). This pen, probably together with the *tetrapyrgion* courtyard (located directly north of it), belonged to the original fort from the end of the first half of the 3rd century BCE (the origins were conveniently dated by a stamped handle of a Rhodian amphora to about 270–240 BCE; Woźniak et al., 2021: 256, 259). Fairly soon the buildings were enlarged and developed substantially without changing the "military" character of the complex. Two phases of occupation, following closely one upon the other, were distinguished: the first in the second half of the 3rd century BCE and the next in the 2nd century BCE (probably after the 160s) (Woźniak and Rądkowska, 2014: 517; Woźniak et al., 2021: 255; Woźniak and Harrell, 2021).

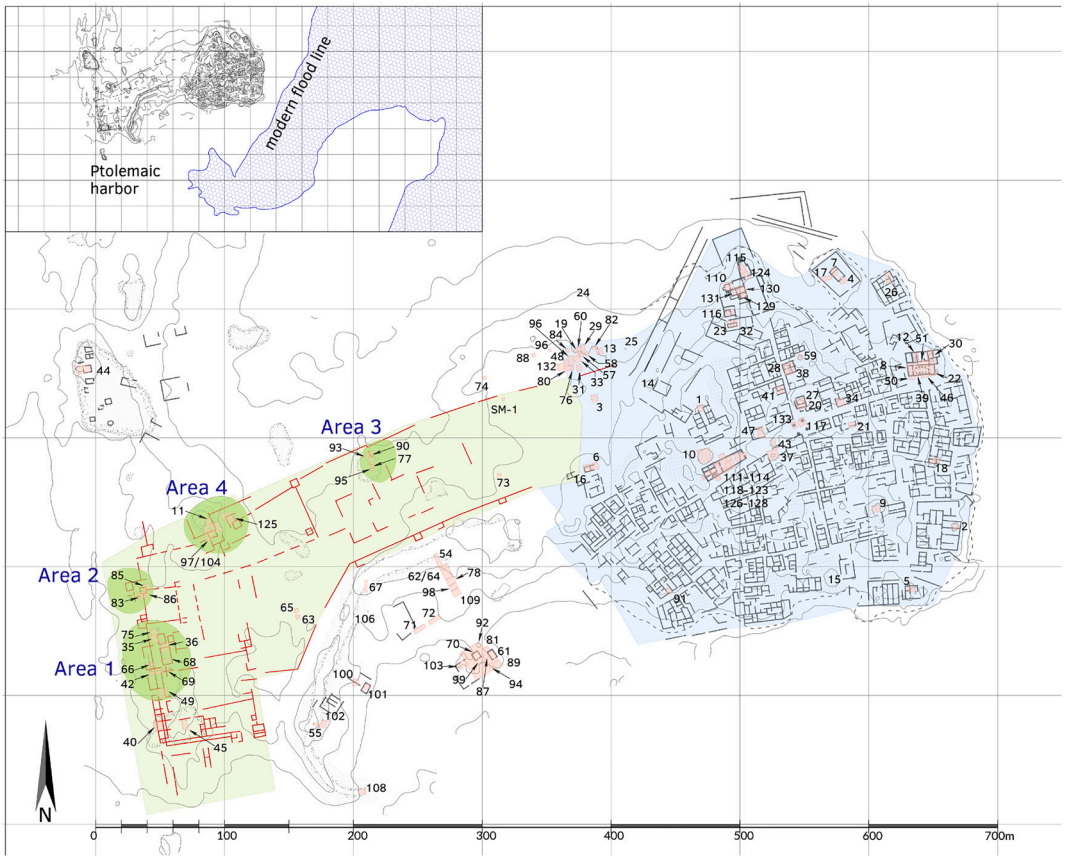


Fig. 1. Plan of Berenike archaeological site: Areas 1, 2, 3 and 4 indicate the location of trenches with Hellenistic material (PCMA UW–University of Delaware Berenike Project/processing M. A. Woźniak).

The next cluster of trenches (Fig. 1: Area 4) surrounds a fortified stone gate from the early Hellenistic period (mid-to-end 3rd century BCE–second half of the 2nd century BCE) located north of the "fort". Housed within the complex was a unique water-supply infrastructure consisting of a rock-cut well (Woźniak, 2019: 250) equipped with an extensive water storage and distribution system, including a subterranean structure acting as a cistern, a rock-cut tunnel evacuating water in the direction of the residential area of the town, and a series of tanks related to an early Hellenistic bathhouse (Woźniak, 2017: 53–59; Woźniak, 2019: 246–250; Woźniak et al., forthcoming). Water was brought to the well from a sandy aquifer, located probably in the Eastern Desert mountains. An interdisciplinary study of this complex has helped to shape views on the climate characteristic of the region in antiquity and the changes it underwent (Woźniak, 2019: 246–250, Woźniak and Harrell, 2021; Woźniak et al., 2021: 267–276).

Last but not least, a series of trenches (Fig. 1: Area 3) uncovered the remains of the northern line of Hellenistic defences, which started to be dismantled perhaps already in the 2nd century BCE, a process that was completed by the end of 1st century BCE. The rubbish dump revealed in this area yielded workshop-related waste mixed with largely decomposed organic rubbish, including processed semiprecious stones, tortoiseshell, ostrich eggshell etc. A diverse range of tableware and cooking ware found in this assemblage suggests a residential character, perhaps connected with the craftsmen employed in the workshops. Dumping of the rubbish peaked over a short period of time in the second half of the 2nd century BCE, with scarce 1st century BCE material lying on top (Woźniak, 2017: 47; Woźniak et al., 2021: 257–258; R. Hartmann, pers. comm.).

2. Material and methods (AC, MAW, IZ)

The material considered in this paper consists of archaeomalacological and marine vertebrate finds clearly pertaining to anthropic action, collected from archaeologically identified Hellenistic contexts described above, excluding from the analysis (as far as possible) assemblages that were potentially disturbed or contaminated by later material. The sampling strategy followed general site excavation rules, which can be broken down into a two-step collection process: hand-picking material from the trench complemented by sieving of all deposits (screens with mesh size 1 mm). Finds were pre-sorted manually, weighed and labelled with contextual data, registered in the project database, and stored for further study.

The identification and separation of the malacological "background noise" was a prerequisite for the study of the archaeomalacological assemblage from the excavation, this contrary to earlier findings by Van Neer and Ervynck (1998; 1999), who had excluded the presence of this factor, resulting in a misinterpretation of the data in the absence of an in-depth study of the geological framework of the site. A recent, extended sedimentological study (Harrell, 1998; 2019; Woźniak and Harrell, 2021: 351–353) coupled with a malacological/palaeontological analysis of the local bedrock oryctocoenosis revealed the complex origin of shell deposits in Berenike (for a detailed preliminary discussion, see Appendix 1). In effect, the preliminary results of this study enabled the isolation of the anthropic fraction in the huge mass of shell remains. Shells showing incipient diagenesis and/or the same features characterizing the Pleistocene and Mid-Holocene deposits were considered as pertaining to the "background noise" and excluded from further taxonomical and taphonomic analyses (Fig. 2). Only the differences in the "background noise" composition between the four considered areas of the site were recorded in order to check local depositional processes.

The process of excluding "background noise" from the rest of the assemblages has to take into account the fact that the same molluscs characterizing the "background noise" were sometimes exploited by man, as attested in many contexts by fresh shells mixed with sub-fossil ones of the same species. Sporadic use of fossil shells as containers or building elements is attested in other contexts. Furthermore, fossil shells

Fig. 2. Late Pleistocene–Mid Holocene outcrops: A – fossil reef overlooking the modern tidal flat; B – Pleistocene fossil coral and shell assemblage (*Tridacna, Anadara, Spondylus, Tricornis*); C – Mid-Holocene sub-fossil shell assemblage (mainly *Conomurex*); D – sample of "background noise" (PCMA UW–University of Delaware Berenike Project/photos A. Carannante).

in some contexts show traces of combustion because they were present in hearth areas or used as a pot stand.

Shells selected as anthropogenic deposits were thoroughly processed and the data recorded in a detailed Excel database reporting in each case the archaeological context, biological data and results of taphonomic analyses. Most of the specimens were taxonomically identified to the species level by comparing them with a personal reference collection and with published atlases (Sharabati, 1984; Vine, 1986; Graham Oliver, 1992; Bosch et al., 1995). Scientific names were updated according to MolluscaBase (www.molluscabase.org) and the World Register of Marine Species (https://www.marinespecies.org). These atlases and the study of the current distribution of molluscs in the different marine habitats along the coasts of Berenike provided the information on the biotope of the species identified as molluscs harvested during the Hellenistic period.

All the identified archaeomalacological remains were analysed in a taphonomical perspective: bryozoans, mollusc and *Serpulidae* internal biofouling, waterworn marks, sponge bioerosion, and gastropod predation holes were examined, including under magnification lens, in order to verify whether the shells were collected after the death of the mollusc. Anthropic holes and working marks were checked and studied in order to identify the craft processes and the operational chain needed to produce the shell objects or to open living bivalves. Burning marks, their nature and distributional patterns were also studied in order to verify some cooking processes. Weighing of the shell assemblage would have enabled the highlighting of species with significant nutritional contribution as opposed to those of little nutritional interest; however, this quantitative method could not be applied effectively in the short time available on site. Therefore, this useful estimate was deemed less essential than the data obtained from the analyses described here.

The identified *taxa* with the relative number of remains and minimum number of individuals are detailed in Table 1. The EDI and ECO columns in this table provide further information. The EDI column reports the Minimum Number of Individuals attesting possible use as food. This count obviously excludes species that are inedible because of size and rarity, and remains with taphonomically identified marks of bioerosion, biofouling and marine erosion, or predation holes. The ECO column reports the main habitats—type of substrate, depth, salinity—in which specific taxons are found in the Red Sea.

The findings were also studied in the context of Carannante's work at other Red Sea coastal sites outside of Egypt (Marsa Gawasis and Adulis) and a preliminary publication of the shell finds from Aynuna on the Arabian side of the Red Sea (Gawlikowska, 2021), searching for general trends in marine resource exploitation in the region.

3. Results (AC)

Archaeomalacological finds clearly pertaining to anthropic action were separated from the "background noise" (the method is described in detail in the Appendix). 5688 (4606 Minimum Number of Individuals, MNI) invertebrate remains were analysed: 30 echinoids (sea-urchin) spine fragments and 5658 mollusc remains pertaining to 65 identified species (Table 1). In terms of classes, 3291 (3190 MNI) specimens were identified as gastropods, 2351 (1364 MNI) as bivalves and only 14 as chitons (Polyplacophora, 5 MNI), in addition to two cuttlefish bones (Cephalopoda, 1 MNI) remains. The lack of crustacean remains is noteworthy.

The archaeoichthyological assemblage from the recent excavations is still under examination in order to better identify the exploited species, but preliminary identifications at Family level have corroborated earlier research by Van Neer and Ervynck (1998; 1999). Their analysis of 1823 fish bones from Hellenistic levels (trenches BE96-11 in Area 4 and BE 97-13 in Area 5) identified 617 remains at least to the Family level (Table 2). According to these findings, the most attested taxon were groupers (Serranidae) (30.3% of the identified fish remains), followed by parrotfish (Scaridae, 26.4%) and emperor breams (Lethrinidae,

Table 1
List of species identified in Berenike Hellenistic strata with the relative number of remains (NR), minimum number of individuals (MNI), MNI of edible specimens (EDI) and relative habitats (ECO). Habitats according to substrate: mud (===), sand (:::) and gravel (°°°) bottom; rocks (^^^); coral reef and flat (***); mangrove thickets (III). Habitats according to depth: intertidal and shoreface shallow waters (=); offshore deep waters (>>>).

TAXA	NR	MNI	EDI	ECO	
GASTROPODA	**3291**	**3190**	**2621**		
Cerithium spp.	3	3	1	:::^^^	=
Chicoreus spp.	1496	1492	1463	***	=
Conomurex fasciatus	405	405	82	***	=
Conus arenatus	1	1	–	***	=
Conus betulinus	1	1	–	:::	>>>
Conus pennaceus	2	2	–	^^^	=
Conus textile	2	2	–	^^^	=
(Cypraea) Monetaria annulus	9	9	–	^^^***	=
(Cypraea) Erronea caurica	2	2	–	^^^***	=
(Cypraea) Palmadusta lentiginosa	1	1	–	^^^***	=
(Cypraea) Monetaria moneta	1	1	–	^^^	=
(Cypraea) Naria nebrites	1	1	–	^^^	=
Cypraea pantherina	2	2	–	:::^^^***	=
Cypraea sp.	6	5	–		=
(Cypraea) Talostolida teres	1	1	–	***	=
(Cypraea) Naria turdus	1	1	–	^^^	=
Lambis truncata	8	6	6	:::^^^***	=
Malea pomum	2	2	–		>>>
Murex tribulus	11	11	11	===	=>>>
Nerita spp.	138	138	4	^^^***	=
Oliva bulbosa	4	4	–	:::	=
Oxymeris maculata	1	1	–	:::	>>>
Pleuroploca sp.	1	1	–	:::	=
Polinices mammilla	6	6	6	:::	=
Tectus dentatus	335	331	331	***	=
Terebralia palustris	308	308	279	III	=
Tricornis tricornis	381	297	297	:::	=
Trochus sp.	1	1	–	^^^	=
Turbo radiatus	133	127	127	^^^	=
Vasum turbinellus	1	1	1	^^^***	=
Volema pyrum	13	13	13	:::	=
Volvarina obscura	14	14	–	:::	=
POLYPLACOPHORA	**14**	**5**	**5**		
Acanthopleura vaillantii	14	5	5	^^^	=
BIVALVIA	**2351**	**1407**	**1356**		
Acrosterigma sp.	1	1	1		
Anadara antiquata	16	9	–	===:::	=
Anadara erythraeoensis	9	6	6	:::	>>>
Anadara sp.	3	3	–		
Arca sp.	4	4	2	^^^***	=
Asaphis violascens	2	2	2	°°°	=
Atactodea striata	250	141	140	:::	=
Barbatia setigera	46	33	28	^^^***	=
Brachidontes variabilis	5	5	5	^^^III	=
Callista sp.	1	1	1	===:::	>>>
Chama brassica	89	72	68	^^^	=
Mimachlamys varia	2	2	1	***	=
Circenita callipyga	1372	791	786	===	=
Gafrarium pectinatum	73	53	53	:::°°°	=
Glycymeris pectunculus	1	1	–	===:::	>>>
Hyotissa hyotis	6	5	5	^^^***	=>>>
Lima sp.	1	1	–	^^^	=>>>
Marcia cordata	16	10	10	:::	=
Modiolus auriculatus	195	105	105	:::^^^	=
Ostrea spp.	35	18	18	^^^	=
Paratapes undulatus	1	1	–		>>>
Periglypta reticulata	5	3	1	?	
Pinctada margaritifera	16	8	8	^^^	=>>>
Plagiocardium pseudolima	1	1	–	===:::	=>>>
Saccostrea cucullata	130	79	79	III	=
Scapharca sp.	1	1	–		
Semele sp.	5	3	3	===	
Spondylus marisrubri	26	19	13	^^^***	=>>>
Tivela sp.	1	1	1	:::	=
Tridacna spp.	38	28	20	***	=>>>
CEPHALOPODA	**2**	**1**	**1**		
Sepia sp.	2	1	1		
ECHINOIDEA	**30**	**3**	–		
Heterocentrotus mammillatus	30	3	–		

Table 2
List of fish species identified in Berenike Hellenistic strata with the relative number of remains (NR), according to Van Neer and Ervynck 1998 (*) and Van Neer and Ervynck, 1999 (**).

TAXA	*	**	TOTAL
Groupers and rockcods (Serranidae)	146	41	187
Parrotfish (Scaridae)	131	32	163
Emperors (Lethrinidae)	99	46	145
Seabreams (Sparidae)	11	21	32
Mullets (Mugilidae)	1	16	17
Triggerfish (Balistidae)	12	1	13
Snappers (Lutjanidae)	11	1	12
Unicornfish (Naso sp.)	12	0	12
Trevallies and jacks (Carangidae)	7	2	9
Squirrelfish (*Sargocentron* sp.)	6	1	7
Surgeonfish (Acanthurus sp.)	3	4	7
Wrasses (Labridae)	5	1	6
Boxfish (Ostraciidae)	1	1	2
Rabbitfish (Siganus sp.)	1	1	2
Porcupinefish (Diodontidae)	1	0	1
Pufferfish (Tetraodontidae)	1	0	1
Fish assemblage	448	168	616

23.5%). Sea breams (Sparidae, 5.2%) and mullet (Mugilidae, 2.7%) were less common. A requiem shark (Carcharinidae) was also present. Preliminary assessment of the new finds demonstrated a clear prevalence of the Serranidae and Scaridae remains, followed by Lethrinidae and Sparidae, thus confirming the previous data.

Complementing the analysed material were 26 remains of worked tortoiseshell from marine turtles (BE13-90 and BE14-95 in Area 3). No marine reptile bones were recorded. Neither is there any mention of bones among the 13 remains of marine turtle from previous excavations of Hellenistic layers in trench BE 96-11 as reported by Van Neer and Ervynck (1998, Table 17–8). There were no marine mammal remains from the Hellenistic layers, but rare dolphin and dugong bones are reported for later, Roman phases of the site (Van Neer and Ervynck, 1998: 368).

3.1. Shells/fish in a dietary context

A palaeoecological study of the Berenike surroundings resulted in the identification of the main habitats: gravel, sandy and muddy beaches, coral reef flats, rocky bottoms and mangrove forest. Relevant habitats were assigned to particular species based on their ecology. Specimens too small or species too rare to be utilized as food (e.g., Cypraeidae and Conidae) were excluded from the analysis, as were also specimens showing marks (waterworn, internal bryozoan, serpulid and mollusc biofouling, sponge bioerosion, mollusc predation holes) indicating that the shell had been collected after the death of the mollusc or for other purposes. The results are reported in Table 1: main habitats are indicated in column ECO, whereas column EDI reports the MNI for each species considered as possible food remains. 4912 remains (3983 MNI), or 86.3% of the invertebrate assemblage (86.5% in terms of MNI), were found to be compatible with food use (Chart 3).

While most of the shells presumed to be food remains did not show any cooking marks, a taphonomic study revealed some specimens with traces interpreted as evidence of preparation and cooking processes. These included forced opening marks made with a knife on the posterior edge; a few marks appear to belong to a fork-like tool with three prongs (spaced 4 mm) used to open living bivalves. Burning marks were observed on a number of edible specimens. Most were accidentally produced when fires were lit directly on the ground, but some are well recognizable as traces of intentional contact with hot embers or ash. Four lower valves—three *Chama* and one *Spondylus*—appeared to be burned only on the external surface. Ten examples of *Chicoreus* were reddened on the dorsal side, while black burning marks on the opposite side of the aperture were observed on six *Tricornis*, six *Chicoreus* and three *Terebralia* shells. A set of 28 *Circenita* remains (15 MNI), all found in the same context, showed a characteristic external reddening of the shells caused by contact with an overheated pan. *Tricornis* remains showed a very high degree of fragmentation despite having one of the most solid and massive shells in the Red Sea (Fig. 5b, c). 226 individuals out of 297 of this species (76.1%) were broken according to a set pattern: outer lip, spire, siphonal channel, columella, which is typical of percussion on the dorsal part of the shell to extract the mollusc. By contrast, *Chicoreus* (Fig. 5d) and other less solid and/or fragile shells (e.g., *Tectus,* Fig. 5e) in the same deposits have very low fragmentation degrees around zero, excluding any chance of post-depositional fragmentation of these shells.

A spatial distribution analysis of malacological remains has revealed a strangely complementary situation to that of fish remains: 89.6% of the molluscs (in terms of MNI) come from the rubbish dumps (Fig. 1: Area 3). Here, most of the Berenike large shells of *Chicoreus* (90.9%), *Tricornis* (95.3%), *Tectus* (98.5%) and *Terebralia* (99.3%) were found together with the other gastropod (*Turbo* 81.1%, *Volema* and *Conomurex* 100%) food remains. The bivalve food remains show the same distribution, as almost all of them come from this area: *Circenita* 94.2%, *Atactodea* 100%, *Modiolus* 95.2%, *Chama* 97.1%, *Gafrarium* 88.7%, *Barbatia* 85.7%, *Spondylus* and *Ostreidae* 100%. By contrast, no seafood remains have been reported from the complex of trenches in the western part of the site (Fig. 1: Area 2). The mass of small waterworn *Barbatia*, *Spondylus*, *Chama* valves intensely bioeroded by sponges, characterizing strata in this area, are treated as part of the natural fossil coral reef forming the substrate here.

Finally, a partial taphonomic analysis of fish remains recorded a sharp transverse cut on two vertebrae of a grouper and traces of combustion on two premaxillar and a dental of *Scarus*.

3.2. Shells showing evidence of utilitarian use

A search for evidence of utilitarian use of shells, both worked and unworked, revealed two large *Tridacna* and one waterworn *Plagiocardium* valves with a polished surface restricted to the posterior margin and the umbo, which obviously excludes natural sea action, arguing instead in favour of prolonged anthropic handling over time. They were found at the bottom of a basin in trench BE-97/104 (Area 4), in deposits well dated by a coin of Ptolemy III or IV and pottery finds to end of the 3rd–beginning of the 2nd century BCE. A worked and very worn (probably subfossil) *Pleuroploca* sp. (Fig. 6a) shell was found in the same context. Its opening external lip was removed by sawing and then abraded until it was polished. Its siphonal channel was also well worked (sawed and polished) to form a spout. The shell surface is waterworn but was probably also polished from prolonged handling.

Two small (137 and 205 mm) *Tridacna* valves, both from trench BE-

Fig. 3. Specimens of *Terebralia palustris* (two on the left) and *Saccostrea cucullata* (three on the right) from Hellenistic contexts; note the lower surface of the oysters with imprint of a mangrove root on which the bivalve grew (PCMA UW–University of Delaware Berenike Project/photos A. Carannante).

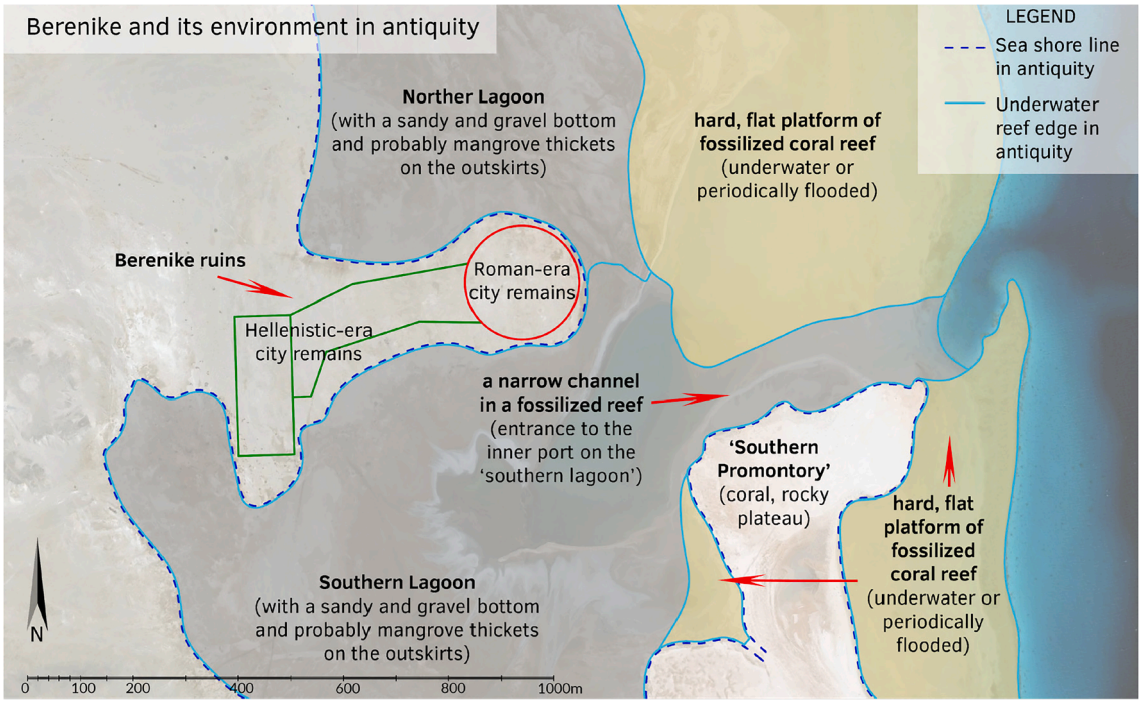


Fig. 4. Map of the ancient coastline in the area of Berenike with indication of ecosystems (Processing M. A. Woźniak).

95 (Area 3), show a lightly burnished internal surface, still encrusted with a patina of semi-combusted vegetable resins. The resinous residue (which further archaeometric analyses will better define) still emits an intense smell of incense, suggesting use as a censer. The most interesting example of an incense burner of this kind (Fig. 6b) is a small (102 mm) *Tridacna* valve from trench BE10-77 (also Area 3), the internal surface of which is encrusted with burnt vegetable resins incorporating a semi-combusted operculum of *Chicoreus ramosus.*

Two fragments of *Tridacna* valves, one incomplete specimen and one large fragment, from the rubbish dumps in area 3 (respectively, BE13-90 and BE14-95), were painted with radial, red-coloured bands along the ridges on the internal surface, and red dots on the edge. Three other identical, red-painted *Tridacna* fragments come from the same area (trench BE11-77). Other shell remains from the rubbish dump were found to contain abundant red ochre powder (Fig. 6c): a small (185 mm) *Tridacna* valve (trench BE14-93) and a fragment of *Lambis truncate*, the latter found in a mixed, late Hellenistic/early Roman deposit (trench BE11-77). So far, these finds are unique in the Berenike assemblage.

Last but not least, there is the *Chicoreus ramosus*, which is the most abundant species attested in the Berenike archaeomalacological assemblage. It belongs to the Muricidae Family: the *taxon* most exploited for purple-dye production in antiquity (Carannante, 2014). Nonetheless, *Chicoreus* remains found in Berenike are always mixed with other species of dietary significance and the shells are almost never broken or pierced, excluding any possibility of industrial exploitation of this species. However, the Hellenistic strata have yielded numerous chitinous opercula, which are another by-product of the *Chicoreus* species widely traded in the Middle East as a component of incense recipes.

3.3. *Shells as personal adornment/ornamentation*

Several shells from Hellenistic contexts show working marks suggestive of their use as personal adornments or decoration of objects and furnishings. *Volvarina obscura* was a most appreciated species, with nine shells from one of the trenches in the rubbish dump showing the dorsal part removed by chiselling. The second most appreciated species were cowries (two different species) with 10 worked specimens: two *Monetaria annulus* pierced on the dorsal-posterior part to turn them into a pendant; six other *Monetaria annulus* (14–22 mm) and one *Monetaria moneta* were worked by removing the dorsal part of the shell by sawing or chiselling. The latter kind of ornament is known to archaeomalacologist as 'cowry lips' and it is still widespread worldwide, while imbued with a special cultural role in Africa. A large *Cypraea pantherina* cowry (81 mm) from Area 4 (trench BE-97/104) was worked in a similar way. Two large (67 and 78 mm) *Conus textile* specimens (Fig. 7) from trench BE14-95 in the rubbish dump show an artificial hole on the apex of the shell, suggesting their use as pendants. A drilled hole on the apex also characterizes two *Malea pomum* shells from trenches BE14-95 (Area 3) and BE-97/104 (Area 4) and an *Oliva bulbosa* shell from trench BE15-104 (Area 4).

No other working marks were observed on any of the shells and neither were the 16 pearl-oyster (*Pinctada margaritifera*) remains worked. By contrast, the 26 worked pieces of tortoiseshell from the rubbish dump in Area 3 (trenches BE13-90 and BE14-95) (Gwiazda and Khan, forthcoming) demonstrate the importance of this raw material in Hellenistic Berenike. Most of the Hellenistic tortoiseshell remains are characterized by a translucent amber colour with scattered darker (brown/black) patches typical of the *Eretmochelys imbricata* (hawksbill turtle). All the tortoiseshell remains are clean and show striations on the flat surfaces. This attests to a preliminary operation of cleaning by removing the biofouling shells (bryozoans, barnacles, worms, molluscs) using a sharp blade. Small circular disks (15 mm of diameter) were cut using a crown drill; 14 pieces of this form were recorded. The other 12 pieces (all from trench BE14-95) are sub-triangular or sub-quadrangular and show circular concave margins cut with a crown drill, compatible with the disks, indicating that they represent waste from a disk production process. 28 other tortoiseshell remains, all worked, come from mixed late Hellenistic/early Roman contexts in the rubbish dump in Area 3 (trenches BE11-77 and BE14-95). Some of them are similar to the described pieces, whereas others demonstrate the *chaîne opératoire* of crafting tortoiseshell. Two pieces are pre-form rectangular platelets (36 × 29 and 36 × 39 mm), sawed at the edges. A third piece (36 × 24 mm) from the same context is sawed and drilled, showing a hole 15 mm wide. 19 fragments are small sub-triangular and sub-quadrangular elements which could be interpreted as workshop waste. Two disks, 15 mm in diameter are a good illustration of the final product.

Fig. 5. Sample of food remains from Hellenistic Berenike, found in a mixed late Hellenistic/early Roman deposit: A – *Spondylus* valves showing forced opening marks; B – *Tricornis tricornis*; C – shattered *Tricornis* shells; D – *Chicoreus ramosus;* E – *Tectus dentatus* (PCMA UW–University of Delaware Berenike Project/photos A. Carannante).

4. Discussion

A study of the collection of remains of marine organisms in an ecological context sheds light on the nature of the biological environment in which the Hellenistic fortified town functioned. In-depth analysis of the role of particular species in the human diet as well as craftwork (supported by archaeoethnographic observations of the relevant practical know-how of men from the Ababda tribe living in the vicinity of the site) has contributed information on their significance over time and with regard to particular occupational and social groups inhabiting Berenike between the late 3rd and 1st centuries BC.

4.1. Fishing and mollusc gathering strategies in the exploited habitats (AC)

Once the main habitats of particular species were established, it was possible to reconstruct fishing and mollusc gathering strategies. The Berenike study is the first such archaeomalacological research carried out for a Red Sea site.

The bulk of the assemblage was composed of intertidal or very shallow water species (82.2% in terms of MNI; [=] in Table 1). Most of these would have been gathered along the coast at low tide, in the intertidal zone or just below the low tide line (see Charts 1, 2). The few offshore specimens in the assemblage were waterworn, indicating collection of beached shells. Coral reef flats were the most exploited ecosystem (50% in terms of MNI). Intertidal species, such as *Chicoreus*, *Conomurex* and *Tectus*, occurred here as well. The most exploited fish *taxa* (Serranidae, Scaridae, Lethrinidae, Sparidae) were also typical of the coral reefs; other coral reef dwellers, Labridae and Lutjanidae, were represented in lesser numbers (Van Neer and Ervynck, 1998). A previous study by Van Neer and Ervynck (1998) found that open-water and sandy-bottom species were exploited during the Berenike Hellenistic phase (the numbers grow for the Roman period). The second most exploited habitat were the intertidal mud flats, where *Circenita* was gathered (16.6% MNI). This was followed by sandy beaches (10.4% in terms of MNI), where *Tricornis*, *Atactodea*, *Marcia* and *Volema* live. Rocky bottoms were exploited mainly for *Turbo*, *Modiolus*, *Chama* and oysters (8.8% in terms of MNI), although many of the recorded species could be found on the coral reef as well. Of particular interest are *Terebralia palustris* (Fig. 3, left), a species characteristic of a mangrove habitat, and *Saccostrea cucullata* or 'oysters' (8.7% in terms of MNI). One third of the lower valves of the latter species show the impression of mangrove roots on the external side (Fig. 3, right). These data strongly suggest that an intertidal flat covered by a dense mangrove ecosystem

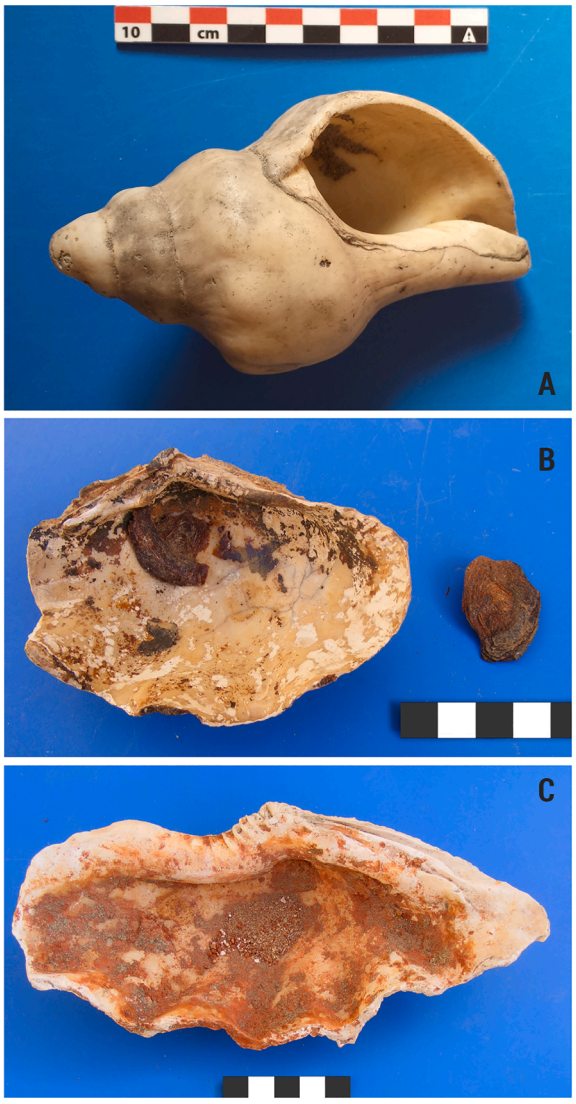


Fig. 6. Instrumental use of shells in Hellenistic Berenike: a – feeding cup made from a worked *Pleuroploca* sp. shell; B – *Tridacna* valve used as incense burner, still containing incense residue and *Chicoreus* operculum; C – *Tridacna* valve used as a red-pigment container (PCMA UW–University of Delaware Berenike Project/photos A. Carannante).

existed near the town during Hellenistic times, but has since disappeared. The relative abundance of these two species indicates the importance of dense Hellenistic mangrove thickets for the site economy. Gravel beaches, where *Gafrarium* and *Asaphis* (0.9% in terms of MNI) were gathered, seem to have been of lesser economic importance.

Some sessile mollusc lower valves (4 *Chama*, 2 *Spondylus* and 1 *Hyotissa*) from Area 3 of the site (trenches BE-77, BE-90, BE-95) show a smooth flat surface on the external side, revealing that they grew for many years on a smooth artificial submerged substrate (metallic or plaster surface) in open waters outside the Berenike lagoon (Fig. 4). This can suggest either the existence of an artificial construction related to the port or, more likely, that the shells fouled on the hull of a ship below the waterline.

The composition of the archaeomalacological assemblage reveals a generally low exploitation effort, with most of the specimens being gathered along the coast during low tide in the intertidal zone or just below the low tide line. Species like *Murex tribulus* and cuttlefish (*Sepia*), generally living offshore, migrate to shallow water lagoons during the reproductive period (Vine, 1986: 140). Most of the other species, such as *Spondylus*, *Chama*, *Ostrea* and *Pinctada*, live in the upper part of the shore

Fig. 7. Large *Conus textile* shells used as ornaments (PCMA UW–University of Delaware Berenike Project/photo A. Carannante).

environment and also just below the tide line. Fish *taxa* identified in the archaeological remains continue to be caught today by local fishermen using nets and lines, from small boats sailing along the coral reef or walking along the reef edge at low tide. Meat of molluscs gathered in place is generally used as bait when hooks are utilized. The waterworn offshore specimens would have been collected as beached shells. *Tricornis tricornis* is still common in the shallow sandy areas associated with seagrasses or coral rubble (Vine, 1986: 134). According to Nawata (2013), *Tricornis* is still collected along the Red Sea coast by walking at low tide in seagrass beds on the sandy flats of lagoons where the species is abundant. It is an important resource for local economies as it provides both meat in the diet and the operculum, commercialized as an incense ingredient (Nawata, 2013).

Evidence of specific ecosystems supplied by sedimentological analysis of cores from Berenike coastal transects (Kotarba-Morley, 2017) indicates the areas of the site where the gathering strategies were realized. The town overlooked a lagoon larger than the present one (Fig. 4). Much of the area currently occupied by the coastal *sabkha* flats near the site was an extensive muddy intertidal plain and the abundance of mud species can be correlated to this intertidal environment, whereas most of the reef and rock species were gathered on the reef flat just outside the southern promontory and also east and northeast of the town ruins. It is likely that sandy bottom species, especially *Tricornis*, could have been easily gathered on the intertidal flats and submerged beaches nearer to the entrance of the lagoon. Investigating the location of the mangrove thickets in the vicinity of the site was beyond the scope of the present research.

Last but not least, there are three possible scenarios for procuring the tortoiseshell found in the archaeological layers. First, as proposed already by Van Neer and Ervynk (1998), sea turtles are easily captured either when they are spawning on the sandy beaches around Berenike or approaching the beach during the mating and breeding season. Van Neer and Ervynk hypothesized the use of sea reptiles for food, however, it is equally possible that the carapaces alone were collected from the beaches as raw material for the crafts industry (even today turtle carcasses are found beached on the shore along the Berenike coast, this according to the Ababda). Finally, the *Periplus Maris Erythraei*, a navigational guide from the mid-1st century CE, mentions tortoiseshell among the imports traded up the Red Sea from the south (Casson, 1989).

4.2. Fish and seafood in the diet and local culinary practices (AC)

Chicoreus spp. (represented by both *C. ramosus* and *C. virgineus*) was the most exploited *taxon* with 36.7% in terms of MNI of the edible

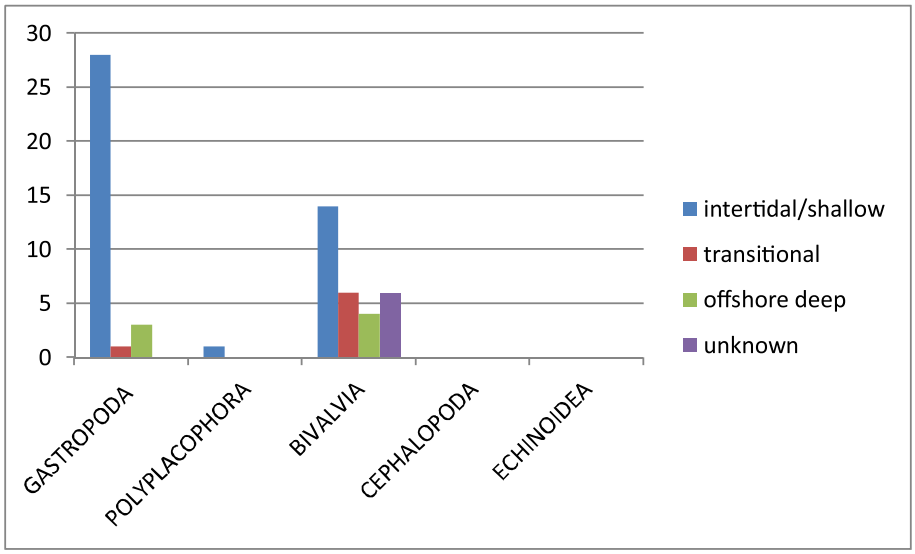


Chart 1. Habitats according to depth (number of species by class).

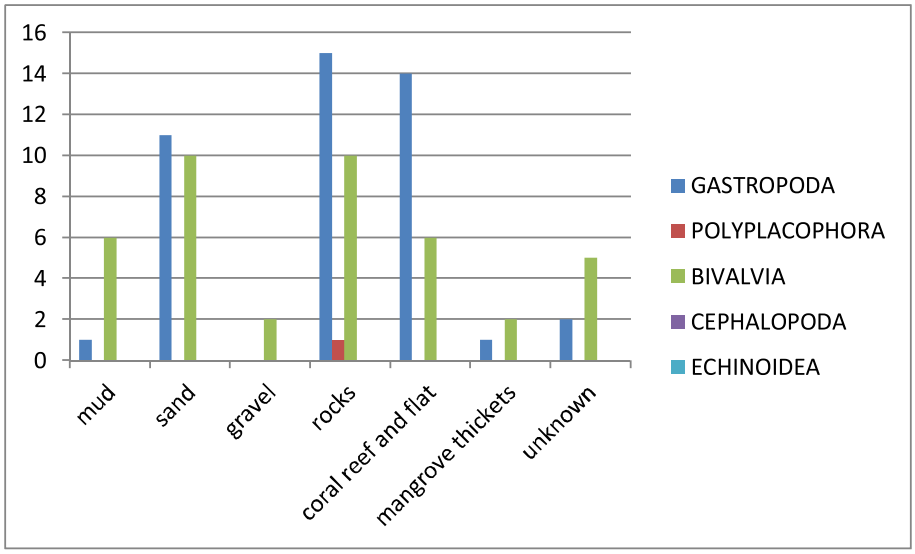


Chart 2. Habitats according to substrate (number of species by class).

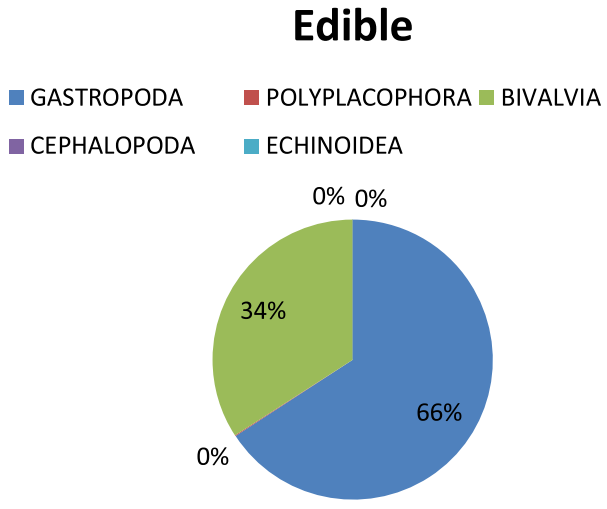


Chart 3. Share of edible species in the assemblage.

invertebrates. These species are very rich in meat (the shell may reach 160 mm), thus suggesting that *Chicoreus* provided much more than half of the mollusc meat in Hellenistic Berenike. The second most abundant species is the *Circenita* clam (19.7% MNI of the food remains), which was easily gathered on the mud intertidal flat just around the site, followed by the large gastropod species *Tectus* (8.3%) and *Tricornis* (7.5%). The 7.0% of *Terebralia* remains suggests that species gathered from the mangrove thickets were also important in the Berenike diet. Of the other species with a percentage share in the assemblages greater than 1%, *Atactodea* (3.5%), *Turbo* (3.2%), *Modiolus* (2.6%), *Saccostrea* (2.1%), *Conomurex* (2.1%) and *Chama* (1.7%), *Gafrarium* (1.3%) were also likely of some importance in the local diet. However, a mere quantitative study of the species does not imply a corresponding qualitative evaluation in the culture of the time. Species attested by less than 1%, like *Spondylus* for example, which required a greater effort to collect, could have been a prized resource intended for special occasions as was the case in later times. Fourteen plates of the large chiton *Acanthopleura vaillantii,* pertaining to five specimens among the food remains, attest that Polyplacophora molluscs were also part of the diet.

Just two fragments of cuttlefish bone attest to Cephalopoda fishing

but, considering the differential preservation of such fragile shells, we can assume this class is strongly underrepresented in the archaeological assemblage. The lack of crustacean remains and the few sub-fossil Echinodermata (sea-urchin) fragments suggest these invertebrates had no role in the Hellenistic diet.

The spatial distribution of shells as presented in this paper compares with that of the vertebrates, demonstrating a steady increase in the quantities of seafood consumed over time. This suggests a limited interest of the first colonizers of the site, contrary to the inhabitants of later phases, and could reflect a social and functional change accompanying the development of the harbor. In terms of spatial distribution, the absence of recorded seafood remains from the western trenches (Fig. 1: Area 2) confirms the archaeozoological findings, indicating that food consumption was probably not practiced regularly in this area. This change could also be explained by the different functionalities of the areas investigated so far at Berenike. The area of the early fort (area 2 + 1) has yet to deliver proof of any habitation within the walls, but it is conceivable that food prepared there for a larger workforce engaged in building the fort could have included a greater share of fish. By contrast, the rubbish dumps in Area 3 reveal some characteristics of waste coming from a residential zone, but so far no layers of ash associated with cooking. Food remains found in this waste could represent household operations, thus affecting the composition of the remains. A comparison of percentages of archaeozoological and archaeomalacological material from the different zones of Hellenistic Berenike, and the differences that such a comparison demonstrates, require further investigation.

The absence of bones in the assemblage make the use of marine turtles as food dubious. Tortoiseshell being a popular traded raw material for the crafts industry in the region, it is likely that just the carapaces were brought to the site for this purpose.

Berenike culinary practices as attested by traces found on some of the archaeomalacological remains could have been influenced by the indigenous population, but there is much to indicate that certain eating habits were universal in nature and not limited to the Red Sea coast. Forced opening marks on spiny oyster (*Spondylus*), *Chama* and *Gafrarium* valves, found amidst other food waste, show that these species were eaten raw or extracted from the shell before cooking. In later Roman Imperial gastronomy, the large spiny oyster in particular would be enormously appreciated (Carannante et al., 2014a). Large bivalves could also be opened over warm ash, and large gastropods (as attested by *Chicoreus, Tricornis*, *Tectus* and *Terebralia* remains) were sometime cooked by placing the mollusc, with the shell opening facing up, directly on the hot ash or embers. This method of preparation is still used today by the Ababda tribe living near Berenike.

Most of the bivalves exploited at Berenike, such as *Circenita* and *Atactodea*, were probably sautéed in a pan, albeit only a few of them show the characteristic traces of a typical cooking error when sautéing, that is, reddened shells when the oil in the pan is overheated.

Species like the *Murex, Tricornis*, *Tectus*, *Conomurex, Terebralia* and *Turbo,* whose meat cannot be extracted from the shell without breaking it, were most probably boiled. Even today local fishermen on the Red Sea will often cook the large *Chicoreus* molluscs (as still happens with other Muricidae in the Mediterranean) by placing them in cold sea water over a fire and simmering slowly at low temperature to extract the boiled meat of the mollusc from the shell. Or they will simply crack the shells to extract the meat, which they then cook in seawater.

More information on Hellenistic culinary practices can be inferred from the degree of shell fragmentation. The high degree of fragmentation of *Tricornis* remains compared to the less solid *Chicoreus* shells deserves note. The large *Tricornis* could have easily been extracted from the shell after a slow boiling, as was the case with the *Chicoreus,* and yet the degree of fragmentation of its shells is considerable. Based on the taphonomic evidence it is very likely that people at Berenike boiled or roasted the large *Chicoreus* in its shell, while breaking the large *Tricornis* shell to extract the mollusc before cooking in order to prepare the abundant meat of this mollusc in different ways, either by boiling in soup, stewing or frying.

According to Morand (2020), exotic oysters (*Pinctada* and *Saccostrea*) appear to have been imported to Hellenistic Alexandria from the northern Red Sea as a luxurious seafood. Hence, finds of these oysters in Berenike are proof of a good eating culture also on the spot.

Little information is currently available on fish processing and cooking; however, the ongoing taphonomic analysis has revealed several interesting pieces of evidence. Large groupers were occasionally portioned before cooking, as attested by taphonomic traces in at least two cases, where vertebrae showed evidence of sharp transverse cuts. Parrotfish was sometime roasted whole on embers as attested by a premaxillar and dental bones showing black burning marks. Both portioning and roasting are also methods known today to the Ababda people.

The spatial distribution of fish remains presented in a recent paper (Osypińska and Woźniak, 2019) highlighted a particularly interesting aspect of fish exploitation during the Hellenistic period: fish remains constituted 80–90% of the vertebrate assemblage in the earlier, western part of the site (especially in layers associated with the functioning of a kitchen in the presumed fort; trenches BE 96-11 and BE 14-97 in Area 4). This is identified as the location of the main industrial, ship repair and storage area of the early Hellenistic town, grouping the purely utilitarian and economic architectural features, such as the fort, gate, well and tower (Areas 1, 2 and 4). People would have worked here, while their homes would have been elsewhere on the site (most probably to the east of the rubbish dump). Archaeozoological analyses of the Hellenistic deposits discovered in this area, dating mostly from the second half of the 3rd century BCE (with some late 2nd century material), have identified goat, sheep and chicken bones beside the fish. Quantitatively, fish remains drop to just 8% of the assemblage coming from the late 2nd century BCE and later trash dumps in Area 3.[1] The vertebrate composition in this later set, demonstrating a predominance of both domesticated and wild mammal bones (caprines, donkey, cattle but also pig and gazelle), suggests a different socio-economic and probably functional situation.

4.3. Shells as material artifacts, ornamentation and personal adornment (AC)

Simple tools and vessels were made of shells, especially the large *Tridacna* valves. The specimens from the well, with their evidence of prolonged anthropic handling over time, were probably used as drinking cups. This interpretation is supported by finds of two valves of a *Plagiocardium* shell, which were found together with pottery sherds of drinking cups and an intentionally cut-off amphora bottom, as well as a small fine-ware *amphoriskos*, at the bottom of a basin in the vicinity of the well. The size of these valves and the context of the find suggest use as a drinking vessel. It has been suggested that feeding cups, like the *Pleuroploca* shell (Fig. 6a), could have been used for the application of medicaments or for nursing a baby.

Small *Tridacna* valves found in layers of rubbish at Berenike are encrusted with a residue that still exudes the smell of incense. They could not have been lighting devices because they show no trace of contact with an open flame or wick of the kind that is observed on *Tridacna* lamps from other Red Sea sites (Carannante et al., 2014b). They were evidently used as a censer, making use of *opercula* together with vegetal resins. Surviving evidence of a semi-combusted *operculum* from a *Chicoreus ramosus* demonstrates that the use of *opercula* from this species in the incense mix was known in Hellenistic times. *Tridacna* shells imported from the Red Sea were used as lamps and censers in sanctuary and funerary contexts at Saitic Naukratis (Morand, 2020:13).

[1] Import of Nilotic fish (*Bagrus, Synodontis*) from the Nile Valley has been attested for the early Roman period and for late Berenike in the 4th and 5th centuries, but not for the Hellenistic deposits (Van Neer and Ervynck 1998).

In this context, the discovery of a *Tridacna* valve tuned into a incense burner (Fig. 6b), with the internal surface of the shell still covered with a resinous material smelling of frankincense and a half-burned *Chicoreus* operculum stuck to the resin, is telling. Two other burned *Chicoreus* opercula were found in the Hellenistic deposits, suggesting that opercula were involved in the production of an incense mixture. The use of the *Chicoreus* operculum as an ingredient in a Hellenistic Berenike incense mix is clearly attested and noteworthy. Nonetheless, the topic of the production, use, trade and economic and cultural value of the *operculum* in the ancient world is beyond the scope of this paper.

The *Tridacna* valves from Berenike decorated with radial, red-painted bands along the ridges and red dots on the edge could have served as a tray, a ritual vessel or a decorative architectural element. Similar finds are reported from 2nd-century BCE deposits in Alexandria (Morand, 2020): two *Donax* valves with traces of red pigment (probably hematite) on the internal surface. According to Morand (2020), they were part of either a wall, or furnishings, or architectural decoration. Other shells from Alexandria, still bearing plaster residue, would have been part of a *rocaille*-style décor, a decoration technique attested elsewhere in the Hellenistic Mediterranean (Morand, 2020: 10). It is possible that some of the decorated shells from Berenike could have been part of a rocaille-style décor.

Shells were also handy pigment containers in Berenike. Similar pigment containers are attested in Alexandria from Late Roman and later contexts: a *Spondylus* valve filled with red ochre and an *Ostrea* valve with a copper green pigment inside it (Morand, 2020). Empereur and Nenna (2003: 523) reported several *Tridacna* valves used as cosmetic containers from burials in the necropoleis of Alexandria.

In a practice not unlike modern tourist behaviour, Red Sea shells, such as *Chicoreus ramosus*, *Tridacna maxima*, *Lambis truncata,* bearing no particular evidence of utilization, were probably imported to Hellenistic Alexandria (as well as being traded around the Mediterranean basin) as exotic items (Morand, 2020: 13).

Examples of personal adornment from the Hellenistic contexts include several pendants and beads, as well as the so-called 'cowry lips', which would have decorated objects or furnishings (for a recent discussion of the issue, see Then-Obłuska, 2018; see also Then-Obłuska, 2015). Interestingly, it does not seem that either shell or nacre were worked in the Hellenistic craft ateliers in Berenike, even though the material was an important resource for the Hellenistic handicraft in Alexandria and other contemporary sites (Morand, 2020: 14ff.). The most likely explanation is that in this case Berenike acted only as a transhipment site. Perhaps the material was too luxurious for local needs, which were satisfied by worked tortoiseshell. This raw material was an important commodity traded in the southern Red Sea and western Indian Ocean, e.g. Ptolemais Theron and ports of East Africa and India, mentioned in the 1st-century CE navigational guide for ship captains, the *Periplus Maris Erythraei* (3.1.15–16; 6.3–4; 7.3.20; 8.3.30; 17.6.18–20 etc.), among others (on this topic see also Trinquier, 2018). Tortoiseshell remained a favourite with the local craftsmen into the 4th–5th centuries AD as the excavations in Berenike have demonstrated. The pieces reveal traces of cleaning of the surfaces using a sharp blade and softening by heating on a fire to give the raw material the desired shape, as described in the written sources. It is also clear that the first operational step was to cut strips that were 36 mm wide (for an exhaustive discussion of this topic, including marks on tortoiseshell pieces and the *chaine d'operatoire*, as well as trade and archaeological attestation see Gwiazda and Khan, forthcoming). These actions are also attested in the Red Sea Middle Kingdom harbour of Mersa Gawasis (Carannante et al., 2014b).

The concentration of post-production waste in the area of the Hellenistic dumps (mainly in BE11-77 and BE14-95 in Area 3) suggests the existence of craft workshops processing a variety of raw materials: bone, tortoiseshell, and ostrich eggshell, as well as semiprecious stones (such as beryls, peridot and amethyst). These workshops have yet to be located archaeologically. Strangely, Red Sea shell and mother-of-pearl do not appear to have been raw materials worked in this area, although, already worked, they are attested in Alexandria and other contemporary sites. This suggests that these raw materials were exported prior to processing.

In addition, the mollusc shells that show evidence of possible fouling on a ship hull, also found in this area, constitute more proof of the workshop character of this part of the town where refuse from the cleaning of such ship hulls was discarded. In this area, perhaps also intended for boat storage, ships would be pulled ashore, cleaned of fouling organisms and repaired.

The small circular disks (15 mm of diameter) cut with a crown drill from tortoiseshell are proof of a crafts industry preparing inlay pieces for decorating furniture/furnishings. The local character of this industry is evinced by the quantities of waste products found on site. Many come from Area 3 trenches, demonstrating the *chaîne opératoire* of crafting tortoiseshell.

4.4. Significance of the research for site interpretation (AC, MAW, IZ)

The archaeological phasing of the excavated remains shows a chronological continuity from at least the mid-3rd through the end of the 1st century BCE, divided into three phases (Table 3). Functionally, the four clusters can be interpreted as representing a community of soldiers and workers/craftsmen associated with the military outpost. It seems that the well and bath located by a gate at the entrance to the harbour was a public zone of water storage and distribution for the entire community, whereas the complex in areas 1 + 2 served as the main storerooms and industrial zone. The rubbish dump in turn reflects a residential and small-crafts zone, which would have been located further east (Chart 4). The indigenous settlement, if one existed, has not been located as yet, and the port probably had a natural harbour without any artificial infrastructure. The population harvesting marine resources in this town consisted of non-native soldiers from the Mediterranean and hellenized Egyptians possibly from the Fayum (Wilcken, 1963, 534–535n. 452; for soldiers in an elephant hunting party, see *P. Petrie* 3.114; Desanges, 1978, 297–298) as well as, possibly, officers. The community would have included various ordinary craftsmen working for the army (including elephant caretakers in the early phase), doing repair work, servicing the ships. The most invisible in this context is the indigenous population that presumably lived on the coast in the area.

The present study found that, in the early phase of colonization at the site, in the mid to late 3rd century BCE, fish were the more exploited resource with molluscs playing a limited role in the diet. However, in view of the scarce evidence for this phase, which has not produced any trace of cooking facilities or consumption areas (even though indirect evidence exists in the form of kitchen waste), this does not really say much about the diet of the Hellenistic soldiers/contractors involved in the project. It is tenable that the area of the fort, which was a primarily industrial and warehousing activity zone, could not provide the kind of evidence needed to comprehensively trace all aspects of the diet and culinary behaviour of the people of Berenike at this time. One could speculate that large amounts of fish consumed in the area of the fort, probably with a small addition of poultry, reflected the operation of a makeshift kitchen supplying the workers and guards working on the construction.

The military lifestyle, which would have characterized the soldiers and contract workers of various specialties from early Hellenistic Berenike, would have affected culinary habits, most significantly by the limitations resulting from food supply logistics. In an outpost like Berenike, harvesting the local ecosystems would have rounded-off the supplies brought in from the Nile Valley, intended to satisfy the needs of a population coming largely (if not predominantly) from Greek and Hellenized Egyptian communities. The percentage share of marine resources in the diet at any given moment would have depended to a large extent on the preferences of the crew manning the fort and the frequency and extent to which preferred food supplies were replenished. This

Table 3
Phasing of the four areas of Hellenistic-period remains excavated at Berenike.

	Area I: elephant pen Trenches		Area 2: storage and industrial zone/fort Trenches		Area 3: rubbish dump/ residential Trenches				Area 4: water storage and distribution zone (gate and well) Trenches		
	66	69	83	85/86	77	90	93	95	97	104	125
Phase I (mid 3rd c. BCE)											
Phase II (second half 3rd c. BCE)											
Phase III (2nd c. BCE, esp. after 160s)											

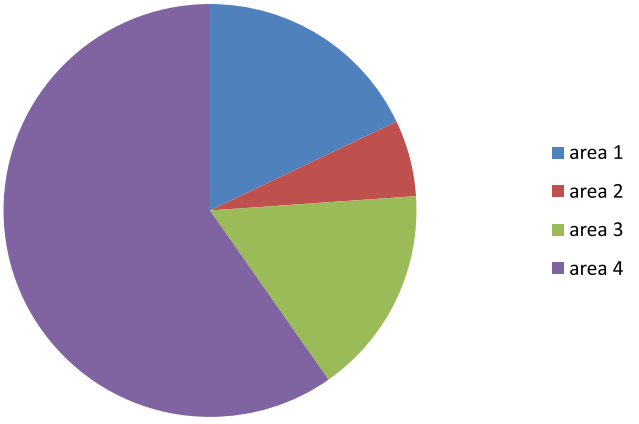


Chart 4. Share of particular areas (based on total cubic meters of excavated deposits) vs. the collective shell assemblage from trenches located in these four areas.

psychological aspect would have changed to some extent with the more settled and civilian way of life in later phases, but we still know too little about the ethnic diversity of the population over time, as well as the nature and intensity of contacts with the Nile Valley and other ports of the Red Sea in the Hellenistic period (Woźniak et al., 2021; Woźniak, 2022), to formulate more far-going conclusions. Judging by the content of the trash dumps from the later phases of Hellenistic Berenike (2nd through 1st centuries BC), the presumably already more 'civilian' population exploited shellfish more intensively. It can also be related to the changes in population size and urban character of Berenike in this period. Strikingly, judging merely by the form of architectural structures from this period, Berenike of the 2nd century BCE was similar in size to the early Hellenistic town, but much more makeshift in character, frequently reusing the ruins of older structures. The community living in late Hellenistic Berenike appears to have been much more diverse than its early Hellenistic predecessor, but was also apparently much less well organized and catered for. The conclusions are weighed with all the reservations voiced above, although we can be fairly certain that the dumps represent a residential quarter of Berenike in the vicinity of the harbour. Looking at this assemblage, we may be dealing with a reflection of culinary behaviour in a specific zone of the city, the pattern of which need not have been exactly the same in other sectors.

The specific combination of species identified in the archaeomalacological and archaeoichthyological assemblage demonstrates that fishing and harvesting of the molluscs took place mainly along the coral reef and in the muddy tidal plain that bordered the city. Mangrove thickets, now extinct, existed near Berenike where molluscs would have been collected as well. Little effort was needed for fishing and gathering activities, which were concentrated in the shallow coastal waters, probably on foot, at low tide. Some valves of open-sea fouling molluscs, bearing traces of a smooth artificial substrate on which they have grown for years, suggest that they were collected on some kind of submerged structures, wrecks outside the lagoon or the hull of ships that arrived in the port after a few years of navigation. In the latter case, their presence is proof of the expected hull-cleaning activities that would have taken place on the nearby beaches where such ships could have been dragged out of the water.

The taphonomic study revealed some interesting culinary practices. The most exploited molluscs, the large *Chicoreus*, were simmered in their shells as suggested by their very low degree of fragmentation. Clams, as well as other small bivalves, were sometimes sautéed. The large shells of *Tricornis* were smashed to free the meat before cooking, again attested by their, this time high, degree of fragmentation. More rarely, some molluscs were cooked by placing them directly on hot ashes or embers and some bivalves were opened alive to be eaten raw or cooked without the shell. Some large fish such as groupers were cut into pieces before cooking, whereas the parrotfish was sometimes roasted whole on a grill or in ash.

The finds from Hellenistic strata at Berenike demonstrated also a utilitarian use of the shells themselves. Large valves were used as decorated trays, cosmetic containers for pigments, censers or simple drinking cups at the well. A shell, found in the same well, was worked into a feeding cup, useful for individuals with physical impairments (Fig. 6a). Some of the painted shells could have been part of some form of architectural decor. Furthermore, pierced gastropod shells, mainly *Volvarina* and cowries, as well as the ubiquitous 'cowry lips', were almost certainly used as personal ornaments and decoration of furniture and personal objects made of other materials, possibly leather, as is still practiced today in the ethnic handicrafts of almost all of east Africa. Interestingly, only tortoiseshell appears to have been important for Berenike artisans and this is attested by, among others, a complete *chaîne opératoire* for the production of discoid inlays. Neither nacre or other shells seem to have drawn any attention in this respect.

Last but not least, the Hellenistic refuse dumps of the 2nd/1st century BCE have provided the earliest clear archaeological evidence of the use of *Chicoreus* operculum as an incense ingredient.

5. Conclusion (AC, MAW, IZ)

New material coming from recent archaeological explorations dedicated to the Hellenistic period at the Berenike site has enabled a redefinition of the relationship between the human population and the marine ecosystems. Remains related to anthropic activity were distinguished in the archaeomalacological assemblage by applying a taphonomic analysis and comparing results with a sedimentological study of core drillings from the site and the findings of a local geoarchaeological

study carried out for the purposes of the Berenike Hellenistic subproject. The malacological "background noise" taphonomy analysis, which has not been done on any other of the few Red Sea sites with archaeomalacological material reported, has proved crucial to a proper selection of material for study. This method should precede any analyses of archaeomalacological material from archaeological contexts where all of the deposits are sieved. Otherwise the results are quite skewed.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Archaeological fieldwork in Berenike was supported by the Polish Centre of Mediterranean Archaeology University of Warsaw and the University of Delaware. Alfredo Carannante's study of the archaeomalacological assemblage from ten seasons of Polish-American excavations at Berenike between 2009 and 2020 was supported in part by National Science Centre grant UMO-2014/14/M/HS3/00795, which also contributed to the participation of Iwona Zych in this research. Marek Woźniak's research on Hellenistic Berenike was supported by National Science Centre, Poland, grant UMO-2015/17/N/HS3/00163.

The authors would like to thank Prof. Steven E. Sidebotham (University of Delaware), Co-Director of the Berenike Project, for his kind assistance during the fieldwork and subsequent research. We are also grateful to the two anonymous reviewers and the editors, whose comments have contributed to the improvement of this paper.

Appendix

The Berenike geological setting and the malacological "background noise" taphonomy: A crucial problem

Alfredo Carannante

The malacological "background noise" in the Hellenistic layers represents from 57% to 100% of the malacological contexts from all of the trenches but there is a variation in terms of the faunal composition between the different areas of the site (see Fig. 1). The "background noise" in areas 1 and 2 is characterized by masses of very small *Arcidae*, mixed with shattered fragments of fossil *Tridacna* and some large isolated bioeroded and biofouled *Chama* and *Spondylus* valves, alternating with masses of small waterworn *Barbatia*, *Spondylus* and *Chama* valves intensely bioeroded by sponges and biofouled. In Area 3, the "background noise" is different, being characterized mainly by large amounts of waterworn *Conomurex fasciatus* shells associated with *Nerita* spp., Nassariidae, and a few large *Lambis truncata* portions which, in the author's opinion, were produced by the erosion of the Mid-Holocene tidal flat deposits. Although the state of preservation indicates their origin from the local subfossil assemblage, their prehistoric use as food or ornament cannot be excluded. Masses of mixed shell fragments, very small *Arcidae* valves and some isolated large waterworn *Periglypta*, *Turbo* and rare sea urchin spines characterize the "background noise" in contexts from trenches in area 4. The different composition of the "background noise" in the four areas examined is, to my mind, a reflection of the different coastal ecosystems in these particular areas during the Pleistocene and Mid-Holocene high-stand periods.

Massive quantities of mollusc remains, or fragments of them, come from all the layers excavated in Berenike. Most of them are represented by either altered shells or shells too small to have been intentionally collected and used by man. Because Berenike is a coastal site bordered by a lagoon and built upon an eroded fossil reef outcrop (Harrell 1998: 125–131), the greatest challenge is to distinguish and separate the anthropic deposit from the natural one in order to prevent analytical misinterpretations. The natural deposit was created mainly by a weathering erosion of the fossil substrate, but also by wind transport, storm and tsunami phenomena, as well as hermit crabs. Thus, in a preliminary step of the analysis, steps were taken to assess how much of the archaeomalacological assemblage is attributable to natural depositional processes. Working in 2019 with James A. Harrell, sedimentologist and *Professor Emeritus* of Geology at the Department of Environmental Sciences of the University of Toledo (Ohio USA), the author was able to define the geological setting of the site and to evaluate the role of local oryctocoenosis/taphocoenosis (natural fossil/buried organism remains) in the formation of the archaeomalacological assemblage found at the site.

The sedimentological study (Harrell 1998; 2019; Woźniak and Harrell 2021: 351–353) revealed that Berenike was built upon a 3.5 m thick (on average) bedrock consisting of 'reef limestone' (or 'limestone conglomerate'), composed of reef rubble with gravel-size fragments of coral heads and mollusc shells, plus other bioclasts, especially echinoids and calcareous algae, and occasional pebbles of igneous and metamorphic rocks from the Red Sea Hills. It is tightly cemented with calcite (as well as secondary gypsum and halite cements), making it hard and relatively impermeable. Harrell (2019) relates the origin of 'reef limestone' to the evolution of the Red Sea coastline in the last 120,000 years.

The maximum sea-level rise during the last interglacial period in the Late Pleistocene reached 6–7 m above current sea level (ACSL), which allowed for the growth of extensive coral barrier reefs at this level (Plaziat et al. 1995: 18; Pugh and Abualnaja 2015: 326). The sea level dropped during the next and final glacial period, reaching 125 m below current sea level at the glacial maximum about 18,000–20,000 years ago near the end of the Pleistocene. During this period, the Late Pleistocene coral reef was exposed on land and subjected to weathering action which created the present-day bedrock. Thereafter, the sea level rose again and by 6000–7000 years ago (in the Mid-Holocene) reached 1–2 m ACSL, cutting a marine terrace across it (Scott and Collins 1996; Harrell 2019). Ancient Berenike was built on top of this marine terrace, which is now completely covered with aeolian deposits, ruins and other anthropic deposits, including the shell deposits.

The next step in the research was a malacological/palaeontological analysis of local bedrock oryctocoenosis. This focused on the outcrops surrounding the site where human deposits were not attested, to avoid the interference of massive anthropic depositional processes. The outcrop exposed on the peninsula to the south of the site ('Southern promontory') turned out to be the place where the palaeontological/sedimentological frame is most clearly legible and interpretable (Fig. 2: a). Here, the Pleistocene fossil reef bedrock (Fig. 2:b) is characterized by early diagenized and often bioeroded valves of *Tridacna*, *Chama*, *Spondylus*, *Anadara* and other species typical of the coral reef. At the top of the fossil reef—and interspersed with it, where there is evidence of erosion—a typical reef, flat sub-fossil deposit crops out (Fig. 2:c). It is characterized by dense concentrations of *Conomurex fasciatus* mixed with small Cerithiidae, Arcidae, Nassaridae and Nerita shells, concentrated by the differential erosion of the substrate. Rare Veneridae, Muricidae, *Conus* spp. and giant *Lambis,* which demonstrate bioerosion and biofouling covering the inside, are sporadically attested. All these shells appear slightly altered and not diagenized. It is important to note that the top deposit species are still those characterizing the present-day coral reef tidal flat as attested by several biological surveys. Thus, the deposit at the top of the Pleistocene fossil reef is the taphocoenosis corresponding to the tidal flat reef during the Mid-Holocene high-stand which created the marine terrace later colonized by man.

The paleontological study of the bedrock thus revealed a complex origin of the shell deposits in Berenike. Throughout the area where the bedrock emerges, its original surface is covered with a mixture of Pleistocene shells that have undergone incipient diagenesis and slightly altered Mid-Holocene shells concentrated by differential erosion processes. This mixture constitutes the "background noise" (Fig. 2:d), to

which anthropic activities have added, over the centuries, the remains of molluscs used by man. Only the latter remains need to be the object of an archaeomalacological study. This preliminary analysis allowed, as far as possible, the isolation of the anthropic fraction in the huge mass of shell remains. The comparison between the altered shells released by the fossil outcrop and the assemblages from the trenches allowed for the exclusion of most of the specimens pertaining to these species from further taxonomical and taphonomic analyses. This also avoided the data misinterpretation present in previous studies which were done in the absence of an in-depth understanding of the geological framework of the site (see Van Neer and Ervynck 1998; 1999). Van Neer and Ervynck (1998: 369) explicitly excluded the possibility that a "background noise" existed because "a major part of the shells still had partly preserved colours and virtually none of them showed calcareous concretions, characteristics which distinguish them from the fossil material in the area". As a consequence, the scholars interpreted the "background noise" as food/bait remains, or hypothesized that it was produced by the transportation of salt contaminated with small molluscs from infratidal pools, "dumping of debris from dredging nets used for catching fish or the removal of the stomach of molluscivore fishes or cephalopods". However, the Mid-Holocene component of the "background noise" is not diagenized in fact, just slightly altered, without concretions and often with colouration residues, as attested by the outcrops now examined. To compare the results of the different archaeomalacological analysis approaches—considering or not the "background noise"—in order to illustrate the bias is beyond the scope of the present paper. It will be addressed in future research including also the results of archaeomalacological studies at other archaeological sites along the Red Sea.

The "background noise" in the assemblages from the trenches is generally characterized by masses of *Conomurex*, Arcidae, Cerithiidae or small Ostreidae in different proportions associated with Veneridae, Nassaridae, *Chama*, *Spondylus* and *Anadara* valves and shattered fragments of *Tridacna* bioeroded by sponges. The different composition of the deposits is not within the scope of this paper, but probably corresponds to the different Pleistocene and Mid-Holocene ecosystems in the area.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2022.103515.

References

Bosch, D., Dance, S.P., Moolenbeek, R.G., Oliver, P.G., 1995. Seashells of eastern Arabia. Motivate Publishing.

Carannante, A., 2014. Archaeomalacology and purple-dye. State of the art and new prospects of research. In: Cantillo, J.J., Bernal Casasola, D., Ramos, J. (Eds.), Moluscos y púrpura en contextos arqueológicos atlántico-mediterráneos: nuevos datos y reflexiones en clave de proceso histórico. Actas de la III Reunión Científica de Arqueomalacología de la Península Ibérica. Universidad de Cádiz, Servicio de Publicaciones, pp. 273–282.

Carannante, A., Chilardi, S., Rebbecchi, D., Del Santo, A., Vedovelli, R., 2014a. Oysters, pheasants and fine foods. High-class products in Alife (Campania, Italy) during and after the Roman Empire. In: Szabó, K., Dupont, C., Dimitrijević, V., Gómez Gastélum, L., Serrand, N. (Eds.), Archaeomalacology: Shells in the archaeological record. Archaeopress, pp. 181–194.

Carannante, A., Fattovich, R., Pepe, C., 2014b. Marine resource exploitation at Mersa/Wadi Gawasis (Red Sea, Egypt). The harbour of the pharaohs to the land of Punt. In: Szabó, K., Dupont, C., Dimitrijević, V., Gómez Gastélum, L., Serrand, N. (Eds.), Archaeomalacology: Shells in the archaeological record. Archaeopress, pp. 121–134.

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

Cobb, M.A. (2018). *Rome and the Indian Ocean trade from Augustus to the early third century CE*. Brill.

Desanges, J. 1978. *Recherches sur l'activité des méditerranéens aux confins de l'Afrique: VI^e^ siècle avant J.-C. – IV^e^ siècle après J.-C.* (Collections de L'École française de Rome 38). Rome: "L'Erma" di Bretschneider.

Empereur, J.-Y., Nenna, D. (2003). *Necropolis* 2, Institut Français d'Archéologie Orientale (*Etudes alexandrines* 7) Centre d'etudes alexandrines.

Gawlikowska, K. (2021). The shells. In M. Gawlikowski, K. Juchniewicz, and A. al-Zahrani (Eds.), *Aynuna. A Nabataean port on the Red Sea. Seven seasons of Saudi-Polish excavations (2014–2018)* (pp. 353-430). Polish Centre of Mediterranean Archaeology, University of Warsaw. https://depot.ceon.pl/handle/123456789/19983.

Gwiazda, M. and Khan, B. (forthcoming). Luxury craft production on the fringes of the Hellenistic-Roman world. Tortoiseshell production waste and objects from Berenike. In S.E. Sidebotham and I. Zych (Eds.), *Berenike 2010–2011. Report on two seasons of excavations at Berenike, including survey in the Eastern Desert and reports on earlier work*. Warsaw University Press–PCMA UW.

Harrell, J.A., 1998. Geology. In: Sidebotham, S.E., Wendrich, W.Z. (Eds.), Berenike 1996: Report of the 1996 excavations at Berenike (Egyptian Red Sea Coast) and the survey of the Eastern Desert. CNWS, pp. 121–148.

Harrell, J.A. (2019). Geological studies from the 2019 season at Berenike. Part A. The early Hellenistic well in trench BE15/18-104 and the Berenike bedrock [Unpubl. report].

Kotarba-Morley, A.M., 2017. Port town and its harbors: Sedimentary proxies for landscape and seascape reconstruction of the Greco-Roman site of Berenike Trogodytica on the Red Sea coast of Egypt. Polish Archaeol. Mediterranean 26 (2), 61–92.

Leguilloux, M. (2020). Utilisation et exploitation des animaux domestiques: les données archéozoologiques de Samut Nord. In B. Redon and T. Faucher (Eds.), *Samut Nord. L'exploitation del l'or du désert Oriental à l'époque ptolémaïque* (pp. 288–307). Institut Français d'Archéologie Orientale.

Morand, N., 2020. The exploitation of molluscs and other invertebrates in Alexandria (Egypt) from the Hellenistic period to Late Antiquity: Food, usage, and trade. Anthropozoologica 55 (1), 1–20.

Nawata, H., 2013. Relationship between humans and camels in arid tropical mangrove ecosystems on the Red Sea coast. Glob. Environ. Res. 17, 233–246.

Oliver, P.G., 1992. Bivalved seashells of the Red Sea. Hemmen.

Osypińska, M., Woźniak, M., 2019. Livestock economy at Berenike, a Hellenistic city on the Red Sea (Egypt). African Archaeol. Rev. 36 (3), 367–382. https://doi.org/10.1007/s10437-019-09346-w.

Plaziat, J.-C., Baltzer, F., Choukri, A., Conchon, O., Freytet, P., Orszag-Sperber, F., Purser, B., Raguideau, A., Reyss, J.-L., 1995. Quaternary changes in the Egyptian shoreline of the Northwestern Red Sea and Gulf of Suez. Quat. Int. 29, 11–22.

Pugh, D.T., Abualnaja, Y., 2015. Sea-level changes. In: Rasul, N.M.A., Stewart, I.C.F. (Eds.), The Red Sea: The formation, morphology, oceanography and environment of a young ocean basin. Springer, pp. 317–328.

Scott, D.B., Collins, E.S., 1996. Late mid-Holocene sea-level oscillation: a possible cause. Quat. Sci. Rev. 15 (8), 851–856. https://doi.org/10.1016/S0277-3791(96)00063-7.

Sharabati, D. (1984). *Red Sea shells*. KPI.

Sidebotham, S.E., 2011. Berenike and the Ancient Maritime Spice Route. University of California Press.

Sidebotham, S.E., Hense, M., Nouwens, H.M., 2008. The red land: The illustrated archaeology of Egypt's Eastern Desert. American University in Cairo Press.

Sidebotham, S. E. and Wendrich, W. (2001–2002). Berenike: Archaeological fieldwork at a Ptolemaic-Roman port on the Red Sea coast of Egypt 1999–2001. *Sahara*, *13*, 23–50.

Then-Obłuska, J., 2015. Cross-cultural bead encounters at the Red Sea port site of Berenike, Egypt. Preliminary assessment (seasons 2009–2012). Polish Archaeol. Mediterranean 24 (1), 735–777. https://doi.org/10.5604/01.3001.0010.0126.

Then-Obłuska, J. (2018). Beads and pendants from the Hellenistic to early Byzantine Red Sea port of Berenike, Egypt. Seasons 2014 and 2015. *Polish Archaeology in the Mediterranean*, *27/1*, 203–234. https://doi.org/10.5604/01.3001.0013.2001.

Trinquier, J., 2018. De la tortue marine à l'écaille. Un matériau 'indien' du luxe romain. Topoï 22 (1), 15–124.

Van Neer, W., Ervynck, A.M.H., 1998. The faunal remains. In: Sidebotham, S.E., Wendrich, W. (Eds.), Berenike 1996: Report of the 1996 excavations at Berenike (Egyptian Red Sea Coast) and the survey of the Eastern Desert. CNWS, pp. 349–388.

Van Neer, W., Ervynck, A. M. H. (1999). The faunal remains. In S. E. Sidebotham & W. Wendrich (Eds.), *Berenike 1997: Report of the 1997 excavations at Berenike and the survey of the Egyptian Eastern Desert, including excavations at Shenshef* (pp. 325–348). Research School of Asian, African, and Amerindian Studies (CNWS), Universiteit Leiden.

Vine, P. (1986). *Red Sea invertebrates*. Immel.

Wilcken, U. 1963. *Grundzüge und Chrestomathie der Papyruskunde.* Erster Band: Historischer Teil Zeite Hälfte: Chrestomathie. Hildersheim.

Woźniak, M., 2017. Shaping a city and its defenses: Fortifications of Hellenistic Berenike Trogodytika. In: Zych, I. (Ed.), Research on the Red Sea. University of Warsaw Press, pp. 43–60.

Woźniak, M. (2019). Berenike of the Ptolemies: A Hellenistic desert city/fortress. In M. P. Hlouchová, D. Belohoubková, J. Honzl, & V. Nováková (Eds.), *Current research in Egyptology 2018: Proceedings of the Nineteenth Annual Symposium, Czech Institute of Egyptology, Faculty of Arts, Charles University, Prague, 25–28 June 2018* (pp. 239–252). Archaeopress.

Woźniak, M., 2022. Berenice – why there; environmental, economic and logistic conditions of the Hellenistic port/base location, [in:] *Proceedings of the 9 Red Sea Conference; Networked spaces: the spatiality of networks in the Red Sea and Western Indian Ocean Archéologie(s)* 8, *MOM Éditions*, Lyon, 73–95.

Woźniak, M.A., Harrell, J.A., 2021. When the well runs dry: Climatic instability and the abandonment of early Hellenistic Berenike. Antiquity 95 (380), 349–366. https://doi.org/10.15184/aqy.2021.16.

Woźniak, M.A., Popławski, S., Sidebotham, S.E., forthcoming. Water and fire – the history of a mound of ash: Water management in Hellenistic Berenike, its environmental and logistical setting. Étude et Travaux. In preparation.
Woźniak, M., Rądkowska, J.K., 2014. In search of Berenike of the Ptolemies. The Hellenistic fort of Berenike Trogodytika, its localization, form and development (part one). *Polish Archaeology in the Mediterranean* 23, 505–526.
Woźniak, M.A., Sidebotham, S.E., Osypińska, M., Carannante, A., Rądkowska, J.K., 2021. Ptolemaic Berenike: Resources, logistics, and daily life in a Hellenistic fortress on the Red Sea coast of Egypt. Am. J. Archaeol. 125 (2), 247–281. https://doi.org/10.3764/aja.125.2.0247.