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RESEARCH ARTICLE

Hjarnø Sund – all year, all inclusive. A submerged Late Mesolithic coastal site with organic remains

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ABSTRACT
Between 2009 and 2016, a series of investigations were undertaken at a submerged settlement of the island of Hjarnø in Horsens Fjord, Denmark. The work was prompted by the discovery in 2008 that heavy erosion of a gyttja deposit containing archaeological remains had resulted in artefacts of bone, antler and, not least, wood becoming exposed on the seabed. The investigations revealed that occupation of the site, with a few exceptions, dates to the first half of the Ertebølle culture (5400–4700 BC). In addition to numerous well-preserved artefacts made of organic materials, several areas were found to contain intact shell layers from submerged kitchen middens. Deposits of this kind have not previously been demonstrated in Denmark.

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1. Introduction

Marine archaeological investigations of Mesolithic settlements have been undertaken in Denmark and northern Germany since the 1970s (Andersen 1985, 2009, 2013, Skaarup and Grøn 2004, Lübke *et al.* 2011, Glykou 2016). Due to the exceptionally favourable conditions for the preservation of organic materials, these investigations have resulted in a broader and more nuanced picture of Mesolithic society. For example, through the discovery of new tool and implement types made of organic materials (Skaarup and Grøn 2004, Andersen 2009, 2013, Kloos 2015), as well as the aspects of the contemporaneous diet that are reflected in preserved seeds, fruits and other plant remains. The investigations at the 'Hjarnø Sund' settlement are the latest in this series of marine archaeological investigations in Denmark.

The Hjarnø Sund settlement is situated in shallow water on the southwestern side of the small island of Hjarnø at the mouth of Horsens Fjord (Figure 1). Due to its richness in finds, the locality has for many years attracted amateur archaeologists from both Denmark and abroad.

The finds collected from the sandy seabed at Hjarnø over the years mainly comprise flint tools, but artefacts of bone and antler have also occasionally been encountered. In 2008 it was observed that, in an area previously covered by sand, a layer of dark gyttja had become exposed, and from this, numerous wooden artefacts, several antler axes and the skull of a dog were recovered (Skriver *et al.* 2017). The finds were, in the first instance, handed over to Horsens Museum, but they subsequently formed the basis for a research collaboration between Moesgaard Museum, Horsens Museum and Aarhus University. In 2010 this partnership received funding from the Danish Agency for Culture and Palaces for a minor investigation at Hjarnø. The results from this led to five further minor excavations, funded by the same authority; the last of which was undertaken in 2016.[1] In parallel with these investigations, diver reconnaissance was undertaken during the entire period, aimed at picking up the artefacts that were continuously being eroded out of the gyttja by the sea.

As at many other submerged prehistoric settlements, favourable conditions for the preservation of organic materials have resulted in the 'dump' deposits at Hjarnø having a substantial content of

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Figure 1. Horsens Fjord with the islands of Hjarnø, Alrø and Vorsø.

worked and unworked objects of bone, antler and wood (Skriver and Borup, 2012). It was therefore clear from the outset that the site had major scientific research potential, and this was further underlined by the finds of completely new tool types and large assemblages of preserved faunal and botanical remains. One of the project's major aims was therefore to collect and preserve a selection of the organic objects that were being continually eroded out from their original context on the seabed (Skriver *et al.* 2018, p. 126). During successive site visits, several areas were observed where dense shell layers (possible shell mounds) were suffering heavy erosion. There was therefore a need to clarify whether these shell deposits represented natural shell banks or human refuse dumps, or whether they could be the remains of actual kitchen middens formed along the contemporaneous shoreline. A further major task was to evaluate the level of threat to the various areas of the settlement in relation to marine erosion and, at the same time, attempt to find ways to protect these areas in the future.

The aim of this paper is to present the preliminary results of these investigations which, due primarily to the exceptional preservation of organic materials at the site, have provided new information on the characteristic coastal settlement of the Ertebølle culture.[2]

After outlining the formation history of Horsens Fjord, the objectives and methods employed in the investigations are described. Then, based on the investigation findings, a picture is drawn of the local coastal environment and its development during Atlantic times. This includes an evaluation of the contemporaneous sea level, with direct reference to the archaeological evidence. There then follows a description of the investigated shell deposits which, together with the substantial faunal assemblage and the various tool types made of organic materials, provide the basis for a preliminary insight into the subsistence economy of the settlement. The paper concludes with a short description of the methods involved in the planned future protection of the locality.

2. The formation and development of the fjord in prehistoric times

Horsens Fjord is a predominantly shallow fjord, with a length of *c.* 20 km and a width that increases from *c.* 2 km at its head to 6–7 km at its mouth. At its entrance lie the two largest of the fjord's three islands – Alrø and Hjarnø – from where there is a clear view inland to the head of the fjord. The third and smallest island – Vorsø – lies about halfway along the fjord, close to its northern shore (Figure 1). The date of formation of Horsens Fjord is still unclear, but the sea probably penetrated a pre-existing valley in Early Atlantic times (Borup 2003). This took place via a deep old river channel running through the strait of Hjarnø Sund, from where there was unhindered access to the innermost part of the valley. The sea relatively quickly flooded the entire valley, which at the beginning of the High Atlantic transgression became transformed into a fjord with a fully developed marine environment and a water level that lay close to that of the present day (see later).

Information on the development of the sea level through both the remainder of the Atlantic period and in subsequent Subboreal times is still limited, and current knowledge is based primarily on some archaeological investigations (Borup 1993, 2003). The position of the coastal settlements of the time suggests that the sea level remained below that of the present until the end of the Atlantic period (*c.* 4000 BC), when it apparently fluctuated with an overall amplitude of only about 1 m. Consequently, all the settlements from the Ertebølle culture in Horsens Fjord lie between 1 and 0.5 m below current mean sea level. At the end of the Ertebølle culture, there was apparently a marked rise in sea level such that, for the first time, it exceeded that of today, and here it remained throughout the Subboreal. This explains why all the Neolithic coastal settlements are found today up in the fields, often directly above the submerged settlements of the Ertebølle culture. Investigations of fossil beach ridges in the area show that a Postglacial maximum of 1–1.5 m above mean sea level was reached in Subboreal times (Mertz 1924).

3. Methods

Between 2008 and 2018, a large number of methods have been employed in the investigations at the Hjarnø Sund settlement. The choice of methods was influenced to a major extent by the rapid degradation of the exposed dump deposit: There was a special focus on regular recording of the changes in the gyttja layer, as well as collecting and recording the finds eroded out from it. The deposit lies today in the littoral zone, extending out to a depth of 1–1.5 m, which gave various advantages and disadvantages with respect to the investigation.

Even though the actual excavation was undertaken by divers, it was sometimes necessary to carry out the work in such shallow water that the divers lay virtually on the seabed with their air tanks above water (Figure 2). Conversely, the shallow water also made it possible for a person wearing waders to take core samples and undertake survey work using a high-precision GPS.

3.1. Excavation techniques

The excavations were carried out using an ejector pump (Figure 3). In technical terms, this was accomplished as follows: A Honda pump fitted with a suction dredge was installed on the work dinghy and a net with a mesh size of 10 mm was fitted over the exit port. The drawn-up sediment passed through the net, which was subsequently examined for artefacts and plant macro-remains such as hazelnut shells, buds and charcoal. Sorting took place partly on the boat and partly on land, where amateur archaeologists provided assistance (Figure 4).[3] This method resulted in the recovery of a diverse and representative archaeological

Figure 2. Divers working in shallow water. Photo: M. Hamberg.

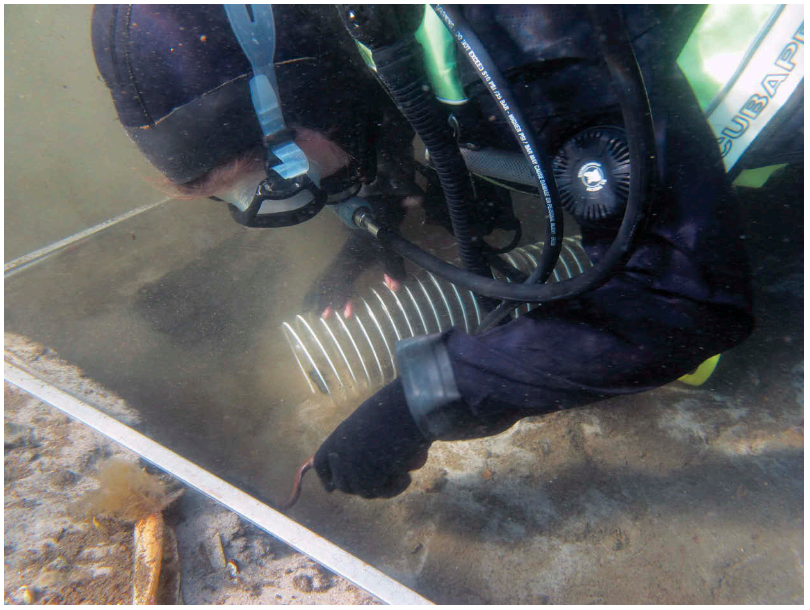


Figure 3. Excavating with an ejector pump and a straightedge. Photo: C. Skriver.

Figure 4. Some of the sorting work was undertaken by enthusiastic amateur archaeologists. Photo: C. Skriver.

assemblage consisting of bones, charcoal, plant macro-remains and flint from the individual excavated squares.

The gyttja was first carefully excavated with a trowel and then directed into the inlet of the ejector pump. The aim was to excavate the trenches in 25 cm layers. Each suction bag was marked with the layer from which its contents came, so there is a precise stratigraphic 'address' for all the artefacts recovered in this way. Larger finds and all wooden artefacts were surveyed and drawn in the field as follows: Ranging rods were used to mark each corner of an excavated square and an excavating frame measuring 1 × 1 m was lowered over these, so the 1 m^2 square was clearly marked. A holder on which a straightedge could be laid was then mounted on the ranging rods, and the level of this holder was determined by GPS. A spirit level could then be laid out across the square from the straightedge so that the level of the surface and the recovered finds could be measured. These levels were then transferred to drawings on plastic foil sheets. The finds were given x-numbers with prenumbered labels and

Figure 5. Overview of the Hjarnø settlement showing the locations of the excavated squares (white) and the core samples (red stars).

taken up into the boat, where the boatman entered them on the finds forms.

In the case of special finds (such as bows, paddles and fish weirs), photos were taken for 3D recording. This method, whereby the artefact is photographed from different angles with defined coordinates, made it possible subsequently to recreate detailed 3D scale georeferenced models of complex artefacts on the computer.

During the first excavation campaign, 1 × 1 m squares were excavated to a depth of up to 60 cm. This gave a good understanding of the individual layers and their contents but was, however, very time-consuming and meant that only very few square metres could be excavated during a season. In 2014 it was decided to excavate a surface of 18 m^2 to a reduced depth of 20 cm, with the aim of obtaining a better overview of the gyttja layer and making it possible to excavate a larger part of the area, which would otherwise be eroded away within a relatively short time. Based on the good results obtained in this way, it was decided to employ the same approach in the following year, when a shell mound was similarly excavated over an 18 m^2 area. Using this method, two divers could excavate side by side, each in their own square, while working together in setting up the excavation grid, surveying, etc. A total area of 48 m^2 has been excavated across the entire settlement area, and the distribution of the excavated squares is shown in Figure 5.

3.2. Reconnaissance

In parallel with the archaeological and geological investigations, regular reconnaissance surveys were also undertaken of the seabed. The aim was to do these surveys on a monthly basis, through the involvement of a local scuba (sports) diver. The finds recovered as a result included numerous wooden artefacts, several of which represented previously unknown types of tools and implements. All the finds were plotted in by the finder using a handheld GPS and then covered with sandbags until they could be excavated and recovered in cooperation with Moesgaard Museum.

3.3. Coring

In parallel with the excavations, a series of cores were taken in the area. The aim was, in the first instance, to obtain an overview of the extent of the exposed gyttja deposit and an idea of the depth of the sand cover in the areas where the gyttja was not visible. The latter was to evaluate the degree to which further areas were potentially threatened by future marine erosion. As new questions and problems arose during the excavation, the aims and

Figure 6. Core sample with alternating layers of dark organic gyttja, sterile pale gyttja and coarse sand. Photo: P. Borup.

objectives of the coring activities were adjusted accordingly to give a better understanding of the overall settlement area, the contemporaneous coastal environment and the influence of sea-level change upon this.

Initially, 42 core samples were taken, all 20 m apart, on a grid system. A so-called Russian corer with a diameter of 5 cm was used to take the samples. The cores were photographed and described on specially produced sample sheets (Figure 6). A few cores were retained for later analysis at Moesgaard Museum's Department of Environmental Archaeology and Conservation. In subsequent years, the network of core samples was refined and the spacing between the individual sampling points was reduced to only 2 m. At the same time, the diameter of the corer employed was reduced to 3 cm, making it possible to take a greater number of cores and to a greater depth. A total of 259 core samples were taken during the entire period of the investigation (see Figure 5).

As it was important to be able to fix the positions of all the recorded finds and levels precisely, all cores, sections recorded in the excavated squares holes, fix points and significant finds were surveyed and plotted using RTK precision GPS.

3.4. Sampling and scientific analysis

A large number of scientific analyses have so far been performed on material recovered from the site. These include a total of 50 radiocarbon dates for finds and samples taken from sections, identification of the wood used for almost all the wooden artefacts, analysis of plant macro-remains and faunal remains and identification of various species of molluscs. In addition, ongoing lipid analyses of samples taken from potsherds are expected to reveal the composition of some conspicuous food crusts. Unless otherwise stated, all the radiocarbon dates listed in the text are presented as calibrated using OxCal V 4.3 and are quoted with two standard deviations (2 σ). Marine samples have been corrected for the reservoir effect using the Marine 13 calibration dataset (Reimer *et al.* 2013) (see also the description in Table 1).

4. Results of the investigations

Based partly on the excavation and core samples, and partly on the observations that were possible on the seabed, a general impression can be gained of the stratigraphy within the excavated area. Erosion in modern times has apparently resulted in cultural deposits from the later part of the Ertebølle culture being completely removed from the area. A general picture of the stratigraphy in the northern part of the area is shown in Figure 8. From this it is evident that over the subsoil there was a layer of oyster shells (K19), which was overlain by a layer of cockle shells (K18) and a sand layer containing finds (K17). Gyttja layer K1 was formed on top of the latter.

4.1. Dates and cultural environments

About 50 radiocarbon dates are available from the Hjarnø locality. Those mentioned in this paper are shown in Table 1. The dates have helped to fix the habitations in absolute calendar years.

Table 1. Radiocarbon dating of samples from the Hjarnø midden site. Results are presented in stratigraphic sequence for each of the 2013, 2015 and 2016 excavations. Radiocarbon ages were calibrated using OxCal 4.3 (Bronk Ramsey 2009). Shell samples were calibrated using the Marine13 calibration dataset (Reimer *et al.* 2013). Charcoal and bone samples were calibrated with the IntCal13 calibration dataset (Reimer *et al.* 2013). All calibrated ages are quoted at the 95.4% probability range.

Lab No.	Trench–Sample–Layer	Material	Species	^{14}C Age (years BP)	Calibrated Age BC	Median Calibrated Age BC
AAR-16958	2013–X119–K10	Charcoal	?	6396 ± 27	5468–5320‡	5379
AAR-16959	2013–X112–K10	Bone	Roe deer	6426 ± 28	5474–5340	5414
AAR-24753	2015–P4–K1	Charcoal	Hazel	6130 ± 48	5214–4947	5077
AAR-24756	2015–P7–K21	Shell	Cockle	6515 ± 34	5275–4955	5116
AAR-24751	2015–P2–K21	Shell	Cockle	6538 ± 39	5296–4976	5140
AAR-24754	2015–P5–K19	Shell	Oyster	6588 ± 38	5341–5022	5200
AAR-24755	2015–P6–K19	Shell	Oyster	6492 ± 48	5270–4910	5090
AAR-24750	2015–P1–K19	Shell	Oyster	6617 ± 36	5367–5051	5233
AAR-24752	2015–P3–K20	Charcoal	Hazel	6162 ± 34	5215–5011	5122
AAR-26593	2016–P1–K22	Charcoal	Hazel	6390 ± 49	5477–5299	5378
AAR-26592	2016–P2–K23	Shell	Cockle	6515 ± 27	5271–4961	5116
AAR-26591	2016–P3–K19	Shell	Oyster	6637 ± 35	5395–5072	5254
AAR-26594	2016–P4–K9	Charcoal	Hazel	6285 ± 40	5365–5082	5266
AAR-16090	Bow – X144 – K1	Wood	Elm	6136 ± 30	5209–4998	5089
AAR-12641	Brakør	Wood	Stump	6225 ± 55	5315–5040	5177
AAR-23271	K1	Wood	Hazel	5691 ± 27	4593–4458	4520
K-1222	Stensballe Sund	Shell	Oyster	6340 ± 130	5557–5003	5319

Most of the archaeological finds encountered at Hjarnø are types that are familiar from many other Ertebølle settlements in southern Scandinavia and northern Germany (Skaarup and Grøn 2004, Andersen 2009, 2013, Klooss 2015): Flint flakes, blades and both flake and core axes have been found in large numbers scattered across the seabed. The abundance of finds reflects long-term occupation, and the initial radiocarbon dates show that there was activity at the site from around 5400 BC until some time after 4600 BC. This time frame is underlined by the typological dating of the artefacts, although the majority of these fall primarily within the first half of the Ertebølle culture. Most of the collected and excavated artefacts come from well-defined and well-dated shell mounds and gyttja layers, representing the settlement's kitchen midden and dump deposits. Many of the finds can consequently also be assigned to specific phases or 'cultural environments' within this particular period.

The earliest traces of human activity at the site were found in a shell deposit (Figure 9, section 2013), which contained a very small, but culturally well-delimited, finds assemblage, including a good number of arrowheads that are all of the oblique transverse type. This shell mound has been radiocarbon dated to the very earliest part of the Ertebølle culture 5474–5340 cal BC (AAR-16959) and 5468–5320 (AAR-16958).

The majority of the finds derive from the exposed gyttja layer (K1) which, despite a degree of homogeneity and a generally modest thickness, has been radiocarbon dated to an extended period of several hundred years (from 5214–4947 cal BC (AAR-24753) to 4593–4458 cal BC (AAR-23271)). It could therefore have been formed during horizontal displacement. Characteristic finds from K1 include several antler axes, all of the type with the shaft hole by the burr, which is normally diagnostic for the early part of the Ertebølle culture (Andersen 2001, p. 168). However, the gyttja was also found to contain large sherds of Ertebølle pottery, normally dated to the later part of the period, after *c.* 4600 BC (Andersen 2013). Overall, the gyttja layer must, in archaeological terms, be seen as representing both the Early and the beginning of the Late Ertebølle culture.

4.2. Shell mounds – natural or man-made?

As mentioned above, the remains of several shell heaps were found during the investigations. Denmark has a long tradition of investigating shell mounds and kitchen middens which extends back to the mid-nineteenth century (Madsen *et al.* 1900, Andersen and Johansen 1986, Andersen 1995). Most middens have been encountered in northern parts of the country, where they all lie above present sea level. It therefore aroused considerable interest when oyster shells were found in several of the core samples at Hjarnø in 2012 (Figure 9). These could represent the first submerged kitchen midden ever found in Denmark. A small investigation was launched in the following year (2013) to establish whether the layer had been formed naturally or could possibly represent an inundated, perhaps redeposited, kitchen midden. A small trench of 2 m^2 was excavated, and in this it could be seen that the shell layer was 10–12 cm thick and consisted predominantly of oyster shells. It also contained large quantities of charcoal, flint, fishbones and other bones, including whales and roe deer (Figure 7). More than *c.* 4600 fishbones were recorded during the excavation, as well as 600 fragments of mammal bones and *c.* 2500 pieces of worked flint. Given the quantity of cultural remains, and the fact that the shells did not lie in pairs, it was concluded that the shell layer had not formed naturally. It was less certain whether the layer had been formed as a kitchen midden on the contemporaneous shore or whether the shells and the cultural remains were embedded in a submarine dump deposit. A sample from the top of the shell layer has been radiocarbon dated to 5469–5319 cal BC (AAR-16958), while a sample from the base (x119) gave a date of 5474–5341 cal BC (AAR-16959). The shell layer can therefore be said to be coeval with the earliest shell layers in southern Scandinavia, for example, that at Brovst in northern Jutland (Andersen 1969). The feature lies relatively well protected and has therefore been given a lower archaeological priority in favour of more exposed areas that are suffering rapid degradation.

A new area containing shells was discovered in 2015, but here they were freely exposed on the seabed and, like the gyttja layer, were subject to heavy erosion (Figure 9). An investigation was therefore launched to clarify whether this shell deposit could also represent a kitchen midden. A 9 × 2 m N-S trench was excavated on the seabed where the shells lay exposed. The excavation revealed that a compact shell layer, comprised

Figure 7. Whale bone under excavation in the shell layer. Photo: J. Frederiksen.

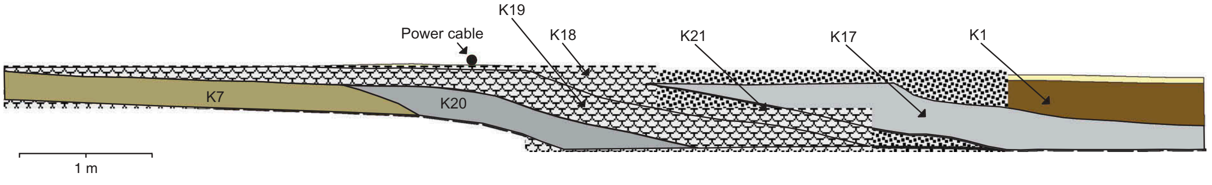


Figure 8. Section through shell heap 2 excavated in 2015. K1: brown gyttja, K7: subsoil, K17: grey sand, K18: modern sand layer, K19: compact layer of oyster shells, K20: grey gyttja, K21: cockle shells (*Cerastoderma edule*). Digitalisation: P.M. Astrup.

Figure 9. Reconstruction of the local environment, gyttja deposits (dark brown), coastline (light brown), shell midden (grey), core with shells (green stars) core with gyttja (red stars) and excavated squares (white). The dates mark the area excavated in that particular year. Photo: Geodatastyrelsen, orto_foraar, WMS-tjeneste. Drawing: Ea Rasmussen.

mostly of oysters but with a minor content of cockles, lay partly over the subsoil (sand and glacial sediments) K7 and partly over gyttja layer K20 (Figure 8). The presence of terrestrial snails among the marine shells indicates that at least parts of the shell heap developed on dry land and should therefore be seen as a result of human activity, i.e. a shell midden. The shell deposit had undoubtedly been larger – both horizontally and vertically – extending up towards the former shore, until it was exposed to erosion by the sea.

The compact layer of oyster shells (K19) was directly overlain by another shell layer consisting primarily of cockle shells (K21). Even though the two shell layers appeared clearly discrete and separate, they both contained large quantities of charcoal, flint and fishbones resulting from human activities. In the cockle layer (K21), a large proportion of the shells also showed signs of having been exposed to heat, and there were charcoal remains on their inner surfaces. This not only indicates that the shells were deposited after having been on a fire, but also that this took place without subsequent redeposition by the sea. The cockle layer (K21) probably originally extended over a larger part of the oyster layer (K19), before it subsequently became inundated and covered by sand (K17) due to a rise in sea level. The sand layer similarly contained large quantities of cultural remains in the form of bones and flint.

Final clarification of the origins of the shell deposits came in 2016, when a 4 × 1 m trench was dug at right angles to the trench cut in 2015. In the resulting section, remains were observed of an *in-situ* hearth with fire-brittled stones and charcoal fragments. Several lines of evidence therefore suggest that the two shell layers, K19 and K21, represent a kitchen midden formed above the contemporaneous shoreline.

The shell deposits that were investigated possibly constitute only a minor part of a much larger shell midden, the existence of which was demonstrated in a series of cores taken along the contemporaneous coast to the north. The shell layers here had a thickness of up to 40 cm. However, the degree to which they represent a single large shell midden, with a length of at least 80 m, or several smaller discrete shell deposits, remains to be clarified.

Samples were taken for radiocarbon dating from all the layers in section 2015, and the resulting dates are rather surprising as they show that the sequence of deposits was formed over less than 50–100 years. With reservations for the uncertainty inherent in radiocarbon dates, the ages of the lowest (oldest) and the uppermost samples in trench 2015 are almost identical: Like the intervening stratigraphy, they are dated to the time around 5100 BC. The fact that the gyttja overlies the shell midden indicates that there was a marked rise in sea level around 5100 BC. It is unclear why an almost homogeneous layer of cockle shells was deposited on top of an almost equally homogeneous layer of oyster shells. It could reflect changes in the local marine environment towards poorer conditions for oysters but could also simply be due to a change in human behaviour (Larsen et al. 2018).

4.3. *Reconstruction of the local environment in Ertebølle times*

Hjarnø is surrounded by channels with a minimum depth of 4–5 m, and it was probably cut off from the mainland, i.e. became an island, as early as some time in the Atlantic period. The investigations have shown that Hjarnø achieved its current approximate size and extent at the beginning of the Ertebølle culture. The largest channel follows the former course of a late glacial river, which now constitutes the major part of the *c.* 700 m wide and up to more than 20 m deep Hjarnø Sund, running between Hjarnø and the mainland at Snaptun. Like the archaeological investigations, the geological investigations were undertaken at depths of less than 1 m below current sea level – limited by the length of the coring equipment. Consequently, this depth also marks the lower chronological boundary for the investigations of the contemporaneous sea level. The results of the various investigations have enabled a picture to be drawn of some contemporaneous cultural and coastal environments, whereby the relationship between well-dated cultural layers and coeval coastal formations has formed the basis for an evaluation of the contemporaneous sea level. Whereas the marine deposits are, in this respect, able to give a minimum value for the contemporaneous sea level, some of the terrestrial cultural layers define a maximum level. It has also been possible in several cases to undertake an evaluation based on several different deposits and events. The investigations have, furthermore, shown how the rise in sea level in the later part of the Atlantic period created variable and, at times, complicated sedimentary conditions at one of the coastal settlements of this time.

During the Atlantic transgression phases, the coast was subjected to major marine influences and, as a consequence, apparently changed character over a very short time span. This is reflected in core samples taken from the seabed offshore from the contemporaneous coastline. These contained alternating and, at times, sharply delineated layers of marine sediments, which varied from thick uniform deposits to horizons of only a few centimetres (Figure 6). Some striking boundaries are evident between layers of coarse sand and fine clay gyttja: two sediment types that normally reflect widely differing sedimentary conditions.

Fine gyttja is deposited in calm waters, which explains why this kind of sediment is not found on the exposed present-day coasts, where wave action deposits sand and forms beach ridges instead.

The gyttja deposits therefore reveal a coastal morphology which, at the time of their formation, was very different to that of today. Only the uppermost and partially exposed gyttja layer K1 has been securely dated at present, but other thick gyttja deposits below this suggest that the area was characterised by calm depositional conditions, not only during most of the Early Ertebølle culture but also in earlier periods.

The gyttja layers are not homogeneous but vary in both consistency and colour. Greyish, virtually sterile layers, with no conspicuous content of organic material, are, accordingly, found embedded between dark-brown layers of detritus gyttja with a major content of worked and unworked wood. These variations reflect changes in the contemporaneous sedimentary conditions and in the vegetation and cultural environment of the immediate surroundings.

The archaeological remains encountered at Hjarnø cover a period of just less than 1000 years (*c.* 5400–4600 BC), corresponding to the Early and Middle Ertebølle culture. At the beginning of this period, the area around the central gyttja deposit K1 was occupied by a small bay which extended more than 60 m inland from the contemporaneous coastline to a position close to the present-day shore. A small, *c.* 20 m wide point formed the southern boundary of the bay, which had a *c.* 40 m opening out towards the sea.

There was a steep-sided basin here in which gyttja could accumulate in deep water. Already at the beginning of the Ertebølle culture, the bay appears to have been completely levelled and, at this time, a minor shell midden (shell midden 1) was formed on the small point to the south (Figure 9). The finds from here show that the shell deposit was formed as a kitchen midden close to the contemporaneous shoreline and, consequently, some of the shells became embedded in dark-green gyttja. The shell deposit has been dated to 5470–5330 BC cal BC (AAR-16958) and 5474–5340 cal BC (AAR-16959), and its position indicates a contemporaneous sea level about 1 m below that of the present. An almost completely identical situation is evident at Brakør, on the north side of the fjord, where a tree stump was inundated at 0.9 m below mean sea level this has been radiocarbon dated to 5315–5040 cal BC (AAR-12641).

Shell midden 1 represents not only one of the earliest known kitchen middens in Denmark, but also the earliest evidence so far of the presence of oysters in Horsens Fjord. Some oyster shells from the lower layers of an up to 9 m thick shell deposit in the narrow Stensballe Sund, innermost in the fjord, have previously been radiocarbon dated to *c.* 5557–5003 cal BC (K-1222; Tauber 1968). Given the special conditions required in the local marine environment for oysters to thrive (Aaris-Sørensen 1988), the shell deposit at Hjarnø shows that there was already both a relatively strong water flow and high salinity here prior to the Ertebølle culture.

Like the kitchen midden, most of the actual point itself was subsequently inundated by a transgression which also removed the final remnants of the small bay. This could be the same rise in sea level that deposited the greyish gyttja layer K20 on the north side of the former bay and which is dated to 5215–5011 BC (AAR-24752). Around this time, a new kitchen midden was formed here (shell midden 2), comprised of two different shell layers, K19 and K21 (see later). It lay on the contemporaneous shore around 0.6–0.8 m below current mean sea level, and over older marine deposits (K20) in the apparently earlier seabed beyond this. There were no indications of redeposition of the shells, suggesting that the sea had receded somewhat by this time.

In the excavated longitudinal section in midden 2 (Figure 8), the shell layers were overlain first by the thick sand layer K17, then by the dark-brown gyttja layer K1, which here constitutes the northern edge of this gyttja deposit. These two sediments were laid down under widely differing conditions, but during the same transgression, when the sea reached a level that then appears to have remained relatively constant in subsequent centuries. The height of this sea level is uncertain, but it probably did not exceed 0.5 m below current mean sea level. Virtually identical dates for the earliest gyttja layer K20, the latest layer K1 and the intervening shell layers K19 and K21 to *c.* 5200–5000 BC reflect repeated and significant changes in the local coastal environment within this relatively short period of time. Collectively, the heterogeneous sequence of sediments probably represents various phases of the same transgression, i.e. the High Atlantic transgression, which characterised the shores of the fjord in Early Ertebølle times at the beginning of the 6th millennium BC. When sand layer K17 was deposited, this took place on an open coast, where the former bay was also exposed to marine wave action. During the phases of the Atlantic transgression, the advancing sea caused heavy coastal erosion, and some of the sand removed from the coastal slopes was redeposited close by as extended reefs and spits along the coast. Small sand spits could, with time, develop into large curved spits or enclosed lagoons, within which fine sand and clay particles could be deposited in a calm environment, shielded from marine waves. With continued sedimentation, the further development of the lagoon could lead to the formation of a new shore meadow, that is if a new transgression had not already flooded and eroded away the protective sand spits. These fossil sand formations can rarely be demonstrated directly, but sand layer K17 shows that the conditions necessary for the spit formation existed here at this time.

The process that led to the formation of sand spits can also be observed today along the shallow coasts of the fjord, where new sand formations continue to display the various phases in the development of new lagoons (Borup 2015). Some fine examples of these large developed lagoons are found on both the southern and northern coasts of Hjarnø, where only a narrow opening now hinders complete exclusion of the sea. A small lagoon has been formed in a similar fashion in recent years by some exposed sand spits on the northwest coast of the island (Figure 10).

It was presumably the development of a protective curved spit that enabled the accumulation of brown detritus gyttja layer K1 at Hjarnø, and the extent of this layer suggests that the size of the lagoon was at times considerable. But the protective sand barriers were not permanent features, and the core samples revealed thick sand layers embedded in the gyttja, showing that it had been inundated on several occasions and perhaps also partially eroded by the sea. Several thinner sand layers are presumably the result of brief transgressions caused by local weather phenomena.

During both Late Atlantic and Subboreal times, further rises in sea level led to not only the lagoon but also the activity areas on the nearby shore being inundated and exposed to incipient erosion. The reason we do not find preserved cultural layers from the Late Ertebølle culture at the site today could therefore be because the original cultural layers from this period have been removed by erosion in

Figure 10. An example of a developed lagoon as formed in many places in Horsens Fjord today. This lagoon is on the south coast of Alrø. Photo: Geodatastyrelsen, orto_foraar, WMS-tjeneste.

more recent times. Numerous artefacts dating from this period have been collected in the area previously.

4.4. Subsistence economy

4.4.1. Hunting

The subsistence economy of the Ertebølle culture was characterised by hunting, fishing and gathering and, as testified by various categories of finds recovered from the site, the Hjarnø Sund settlement was no different in this respect.

The faunal remains constitute an important component of the finds assemblage. From these it is evident that large game animals were commonly hunted for their meat. Analyses of the bones show that red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), elk (*Alces alces*), aurochs (*Bos primigenius*) and wild boar (*Sus scrofa*) were all killed. In addition, both cast and sawn-off antlers of red deer and a single sawn-off antler of roe deer have been found. Large terrestrial game was probably not hunted on Hjarnø itself, as the island's area was too small to support a population of these animals. We must therefore imagine that the hunters travelled the short distance to the mainland by boat to hunt in the extensive forests there. Water transport on the fjord has been demonstrated at Hjarnø by the finding of a fragmented dug-out boat in the seabed just offshore from the settlement. The dimensions of this boat are unknown, as it remains '*in situ*' just below the surface of the seabed, covered by sand. An analysis of the wood shows – very characteristically for Late Mesolithic dug-out boats – that it is made of lime wood (Andersen 2011). Propulsion was by paddle, of which four more or less preserved examples have been found at Hjarnø (see Section 'Wooden Artefacts').

Hunting of large game animals was undertaken primarily with bows and arrows, and fragments of a total of seven bows have been found, all in the settlement's dump deposit. None is complete, but five are so well preserved that it is possible to calculate their approximate original length, which varies from 123 to 166 cm. This variation could be due to the bows being intended for different kinds of hunting, but it is also possible that the smaller examples were used by children. S.H. Andersen reports that the characteristic bows from Funen were between 150 and 160 cm in length (1985, p. 64, 2009, p. 102), though one found at Tybrind Vig had a length of 167 cm (2013, p. 142).

Two main bow types can be identified at Hjarnø: (1) examples with flattened oval limbs, (2) flatbows which taper from the grip towards the ends. The first type has a possible parallel in the form of a bow fragment found at the settlement at Møllegabet (Skaarup and Grøn 2004, p. 89). This type is represented at Hjarnø by two relatively well-preserved examples (Figure 11). The longest of the bows measured 135 cm on recovery but had originally had a length of *c.* 166 cm. The grip measures *c.* 12 cm, and the bow has *c.* 5.5 cm wide flattened oval limbs, which terminate in 26 cm long tips. There is no trace of an attachment or nock for the bowstring.

Figure 11. Examples of well-preserved bows with flattened oval limbs. Photos: D. Butler and J.G. Due, Photo/media Moesgaard museum.

The bow has been radiocarbon dated to *c.* 5209–4998 cal BC (AAR-16090). The second bow of this type had an original length of *c.* 140 cm, of which only a few centimetres were missing when it was recovered. The other five bows are of the more common flatbow type, with limbs tapering evenly towards each end. Common to both bow types is that they are made of elm wood (*Ulmus*).

No definite examples of wooden arrow shafts have been found at Hjarnø, but a total of 30 transverse arrowheads were recovered. A possibly unique find from the Danish Mesolithic is a harpoon-like implement made of wood of Pomoideae (apple, hawthorn, Rowan etc. subfamily) (Figure 12). The implement has a preserved length of 27 cm, but the tip has been broken off and its original length is estimated to have been *c.* 30 cm. About 7 cm from the tip there is a 2.5 cm long barb, and in the middle a small groove has been carved – possibly so a stone weight could be lashed in place. The side from which the barb projects is a few centimetres wide and carved flat. It is unlikely that the implement functioned as a harpoon as these are normally made of antler or bone, because a wooden version would break more easily when impacting large animals. The implement could possibly be a so-called 'atlatl' or spear-thrower, as known both from ethnographic parallels, including the Greenland Inuit, where it is known as 'norsaq' (Jensen 1975, Petersen 1997), from Palaeo-Eskimo contexts (Gotfredsen and Møbjerg 2004) and from Palaeolithic contexts in Europe (Stodiek 1993). S.H. Andersen, in his publication of the Ronæs Skov settlement (2009), has suggested that spear-like objects found there could have been launched with 'atlatls' of this kind.

In addition to hunting large terrestrial game animals, seal bones (*phocidea*) in the faunal assemblage show that marine mammals were also hunted. Seal bones are very common archaeological finds in Horsens Fjord, where seal hunting appears to have played a particularly important role at coastal settlements. A whale rib bone (Figure 13) and the tooth of a killer whale could similarly result from marine hunting. These large whales are, however, more likely to have stranded in the shallow fjord, after which they would have been butchered so their bones could be used for tools and their blubber for small oil lamps. Hunting of marine mammals was presumably undertaken with some of the same hunting weapons used for large terrestrial mammals, including 'atlatls': The latter are known to have been employed in this way by the Greenland Inuit (Petersen 1997). We know from many other settlements that harpoons were used to hunt marine mammals, but only one harpoon was found during the present investigations. Another example has though been found in the area previously (Andersen 1997), and harpoons have also been recorded at other settlements on the fjord. Pieces of antler with burin furrows are interpreted as characteristic waste products from harpoon manufacture (Andersen 2009), and antler artefacts of this kind have been found during the investigations at Hjarnø.

Figure 12. Possible spear-thrower ('atlatl'). Photo: R.N. Johansen, Photo/media Moesgaard museum.

Hunting of fur animals is indicated by bones of animals such as otter (*Lutra lutra*), water rat (*Arvicola terrestris*), fox (*Vulpes vulpes*) and wild

Figure 13. Whale bone found during reconnaissance on the settlement area. Photo: C. Skriver.

cat (*Felis sylvestris*). These four species were also found at the settlements of Ronæs Skov (Andersen 2009) and Tybrind Vig (Andersen 2013). Birds are represented at Hjarnø by a few bones of large waterfowl, such as mute swan (*Cygnus olor*), cormorant (*Phalacrocorax carbo*) and red-necked grebe (*Podiceps grisegena*).

4.4.2. Fishing

Fish made up a very large part of the diet, and it was presumably fishing that had the crucial role in determining the settlement's almost permanent location close to the channel. The archaeozoological analyses reveal that a wide variety of species were fished for, including cod family (*Gadidae*), flatfish (*Pleuronectidae)* and mackerel (*Scomber scombrus*) as well as eel (*Anguilla anguilla*), herring (*Clupea harengus*), bull-rout (*Myoxocephalus scorpius*), spiny dogfish (*Squalus acanthias*) and garfish (*Belone belone*). Viviparous eelpout (*Zoarces viviparus*) and salmon family (Salmonidae) also feature in the assemblage, but only to a limited extent. No remains have been found of freshwater fish, and all the species represented appear to have been caught close to the actual settlement.

The archaeological finds show that two kinds of fishing were practised:

(1) Active fishing with hook/line and leister

(2) Passive fishing with fish weir and fish trap

The active fishing is documented by finds of fragments of leisters and a single fish hook. Fragments were found of a total of nine leister prongs (Figure 14). These occur as two variants: one consists of a single complete piece of wood, while the other type was made by cleaving a piece of wood to produce two exact mirror images for the two wooden leister prongs.

A fish hook of bone was found during reconnaissance near the settlement area (Figure 15).

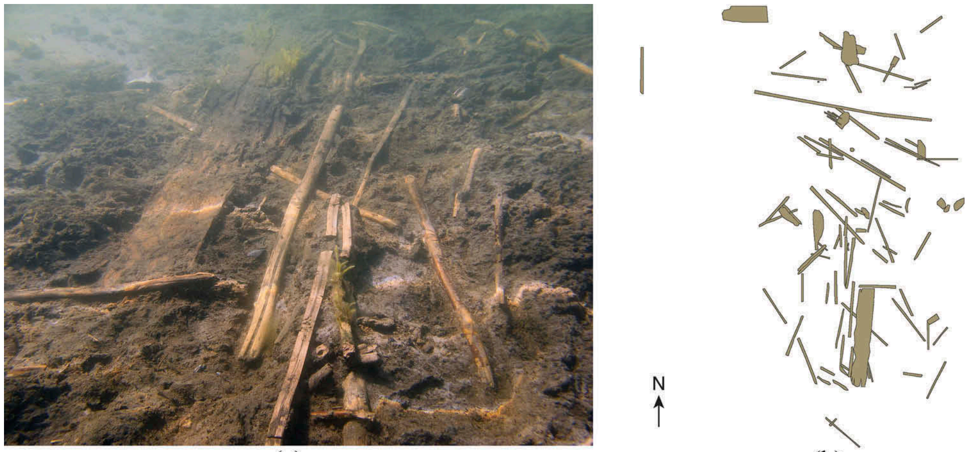
Passive fishing is documented by the widespread occurrence in the gyttja layer of hazel rods and stakes with sharpened ends, the latter in some cases still standing in a vertical position. Similar rods and stakes have been found at sites such as Tybrind Vig (Andersen 2013, p. 59–62) and Ronæs Skov (Andersen 2009, p. 42–44). It is usually assumed that sharpened rods and stakes of this kind, which occur very frequently in the dump deposits associated with the settlements, constitute remains of fish weirs, which had the function of directing fish into a fish trap (Andersen 2013). A damaged panel presumed to be from a fish weir was encountered in 2014, during the establishment of the coordinate system (grid) for the site. The panel's orientation was approximately N-S, and a section of measuring 6 × 2.8 m was visible.

(a) (b)

Figure 14. (a-b). Examples of leister prongs. Photos: R.N. Johansen, Photo/media Moesgaard museum.

Figure 15. Bone fish hook found during reconnaissance. Photo: R.N. Johansen, Photo/media Moesgaard museum.

The fish weir was made of hazel rods of various sizes, with and without bark, as well as some sheets of bark which lay approximately across the longitudinal orientation of the rods (Figure 16). Even though this structure was not intact, it was evident that several of the long stakes that had originally stood vertically in the weir now lay on the seabed, parallel to the rods which originally were at right angles to them, i.e. they ran horizontally in the panel. In addition, several vertical stakes were recorded around the structure. It is still unclear, however, whether the latter were part of the fish weir or whether the current had carried the preserved part of the fish weir away from its original position more or less intact. The individual stakes had lengths of up to 2.7 m, and the average diameter of the vertical stakes was 2.65 cm (11.5 years/tree rings), while the average for the horizontal examples was 1.96 cm (7.8 years/tree rings). Of the 15 rods that have been identified to species, 12 are of hazel, while the other 3 are of elm, willow and oak, respectively. Based on the cessation of tree-ring formation, it seems the hazel rods



(a) (b)

Figure 16. (a) Underwater photograph of part of a fish weir under excavation. Photo: P.M. Astrup. (b) Plan of the structure. Drawing: P.M. Astrup.

were cut in the middle or at the end of the growing season.

4.4.3 Gathering

Gathering of food is reflected by the presence of hazelnut shell fragments, as well as the previously mentioned shell layers containing oysters and cockles with an admixture of other marine molluscs, which show that this food source also constituted an excellent supplement to meat and fish. From other sites with preserved organic materials, we know that sea beet (*Beta vulgaris* ssp. *maritima*) and acorns (*Quercus* sp.) were also gathered during this period (Andersen 2013).

4.5 Archaeological finds

4.5.1 Artefacts of antler, bone and tooth/tusk

Ten antler axes have been found at the site. In all cases, the shaft hole is located at one end of the axe, near the burr, which dates the axes typologically to the early part of the Ertebølle culture (Andersen 2001). Several of them have a length of 25–30 cm, and they are therefore relatively large compared to the modest diameter of their shafts. Four of the axes were found with an intact wooden (hazel) shaft. A conically shaped shaft hole prevented the axe's head from falling off during use. The shafts are just less than 50 cm in length (Figure 17).

Just like several of the paddles, four (i.e. almost half) of the antler axes are ornamented (Figure 18). Two of them have some quite small areas on their sides with a few fine incised criss-cross lines. On the third, fine lines form a larger and more regular pattern resembling a chequered motif. On the fourth axe, traces are evident of a more finely composed pattern incised with broader and deeper lines. Unfortunately, this is only preserved as a large fragment. Two of the axes also have parallel lines running around the shaft hole and the place where a tine has been sawn off. None of the ornamented objects has been radiocarbon dated, but their finds contexts indicate that they all date from an early part of the Ertebølle culture, corresponding to the picture previously presented for ornamented artefacts (Andersen 1981).

In terms of artefact type, given the widely varying nature and extent of their motifs, the ornamented artefacts constitute a very heterogeneous group. In some cases, these objects appear to have had a special symbolic or prestigious value, being the preserve of the few, while others seem more ordinary and could represent everyday objects. Frequent examples of edge damage suggest that the ornamented antler axes were also used as working tools. More exquisitely composed, almost surface-covering patterns are, for example, evident on some special, long antler shafts that were presumably only owned by a select few members of society. Three ornamented shafts of this type have

Figure 17. Antler axe head with wooden shaft, lying on the gyttja layer. Photo: P.M. Astrup.

Figure 18. Example of ornamented antler axe. Photo: M. Johansen, Photo/media Moesgaard museum.

been found previously in Horsens Fjord: one on the beach at Hjarnø, the second at Snaptun on the opposite side of the sound and the third at a locality innermost in the fjord (Andersen 1981).

In general, there appears to have been a special predilection at the settlements in Horsens Fjord during this period for decorating or ornamenting personal artefacts. Numerous ornamented objects of this kind have been found, primarily of bone and antler (Andersen 1981), but there are also some of amber, a single piece of limestone (Borup 2008) and now also some of wood.

4.5.2 Wooden artefacts

A total of 75 wooden artefacts have been recovered, in addition to the artefacts already mentioned above in the section on hunting and gathering (4.4.1 and 4.4.3). They include axe handles and other types of shafts, as well as various rods and stakes, etc. Special mention should be made of 'axe sockets', of which a total of six have been found. Some of these are very finely shaped, while others appear simpler and without 'finish'. The species of wood used has been identified in five cases: Four are of Pomoideae (apple, hawthorn, rowan, etc. subfamily), while one is of oak. This artefact type has also been found at Ronæs Skov and Flynderhage (Andersen 2009, 2013), as well as at Margrethes Næs (Myrhøj and Willemoes 1997); a single example was recorded in each case. The socket from Ronæs Skov is, like the majority of those from Hjarnø, made of wood of Pomoideae (Andersen 2009), while the socket from Margrethes Næs is of hazel (Myrhøj and Willemoes 1997). These sockets have previously been described as being hafts or mounts for a flint axe on a shaft, where the shaft comprised the lower part and the socket the upper part of the composite hafting (Myrhøj and Willemoes 1997, Andersen 2009). A rare find of a hafted core axe shows, however, that there may also be two socket pieces forming the actual haft, which was then mounted on a shaft (Figure 19). This suggests, in turn, that there were two types of hafting devices or sockets, one of which has a knob at one end, while the other is more pointed oval or rounded. The knobbed examples are possibly associated with the latter type of hafting, as seen in the axes from Hjarnø.

Four fragments of paddles were found during the investigations, and paddles have also been found previously at Tybrind Vig (Andersen 2013). Even though the number of paddles found at Ertebølle sites remains modest relative to other artefact types, they are now seen as one of the characteristic implements at the coastal settlements. They are typically made of ash wood and this is also the case for the examples found at Hjarnø. Of the four fragments recovered there, two stand out, because, despite some degradation of the wood, traces of preserved paint are evident on the actual blades. The applied motifs on the two paddles are not quite identical, but in general terms they represent the same composition. Both have a surface-covering black substance (pigment) on the lower half of the blade, and above this are three parallel, horizontal lines. On one paddle, these lines are 6 mm wide and curve upwards in the middle from both sides, while the other blade appears to have three separate distinct groups of *c.* 1.3 cm wide bands (Figure 20). The painted pattern has only been demonstrated on one side of the paddle blades, but this could be because the other side is, in both instances, less well preserved. It is consequently unclear whether the paddles were originally painted on both sides. Interestingly, a paddle found next to a kitchen midden some years ago at Flynderhage in Norsminde Fjord, just less than 25 km north of Horsens Fjord, has decoration which is very similar to that evident on one of the paddles from Horsens Fjord (Andersen 2013, p. 182, fig. 3.83). On the Flynderhage example, black paint has been

Figure 19. Hafting device consisting of two socket components between which a core axe was placed. Photo: R.N. Johansen, Photo/media Moesgaard museum.

(a) (b)

Figure 20. (a-b). Painted paddle blades. Photo: M. Dalegaard, Photo/media Moesgaard museum.

used to draw four narrow lines, arched in the middle, over a similarly fully blackened lower half. The two motifs therefore show a close resemblance. Only the number of lines appears to vary in the motifs on the two paddles. This could indicate a certain degree of symbolic symbiosis and consequently a relationship between the populations of the two areas.

Ornamented paddles have also been found at a very few other Danish Ertebølle settlements. The best known of these are the ornamented paddle blades from Tybrind Vig in western Funen, mentioned above, where 4 of the 13 paddle components recovered were decorated in various ways (Andersen 2013 p. 175–184). The motifs comprise exquisite patterns formed of dots and lines executed in sunken relief; the presence of black pigment has also been demonstrated here. Clear differences are though evident between the paddles from Horsens Fjord and those from Tybrind Vig, both with respect to their motifs and the technique employed.

4.5.3 Flint artefacts

An actual analysis of the flint assemblage recovered from Hjarnø has not yet been undertaken. As for the total numbers of flint artefacts, it must be noted that only actual tools were picked up from the seabed and recorded, while this was not the case for the many waste flakes, because this would have rendered the flint assemblage almost unmanageably large. Conversely, all the flakes encountered during the excavations on the seabed were retained, including those from all the excavated squares.

The flint assemblage comprises both patinated flint from the seabed and unpatinated flint recovered during the excavations. Microscopic examination of a handful of the tools shows that the unpatinated flint is well suited to wear-trace analysis.

A total of 4435 pieces of flint were recovered during the investigations, of which 4213 are flakes. The remainder comprises axes, unmodified blades and blade tools such as scrapers, knives, truncated pieces, etc. A total of 33 flake and core axes were found. The flake axes are in the majority with 20 examples, or rather more than 60% of the total number. Thirty-one transverse arrowheads were recovered. These vary typologically from oblique examples of varying size to transverse examples with a flared edge; there are also a few with a narrow edge and parallel sides. During the investigation of the earliest shell mound (K10) in 2013, 11 oblique transverse arrowheads were recovered from a trench of only 2 m^2 in area. This presumably represents a specialised functional area.

4.5.4 Artefacts of other stone types

4.5.4.1 Greenstone axes. Three greenstone (diabase) axes were recovered. Two were located in the dump layer, while the third was found washed up on the beach (Figure 21). One of the axes is virtually round in cross-section with a maximum diameter of 4 cm, while another is more oval and has a maximum diameter of 4.5 cm. Two of the

Figure 21. Greenstone axe found on the shore at low tide. Photo: P.M. Astrup.

axes are broken in the edge region but have had a ground/polished facet on one side, running towards the edge.

4.5.4.2 Flat stones. Three special stones were found which differ in several ways from all the natural stones evident on the seabed. They are completely flat and have one or both sides smoothly polished. One is fragmented and probably only represents a quarter of its original size. It consists of a 1.5 cm thick slab of sandstone, the edge of which has also clearly been rounded or polished. The other is an intact, approximately oval stone slab measuring 14 × 11 cm. The stone itself is almost black with a shiny black residue over a large part of one side. It also has a ground rounded edge. The third stone has one flat side too, a small part of which appears to be covered with black 'paint' or 'pigment'. The function of these three stone objects remains unknown, but one cautious interpretation could be that they were used as 'palette stones' employed in the painting of special objects, for example, the paddle blades found at Hjarnø.

5. The future

An important reason for the Hjarnø settlement being subjected to heavy erosion today is that the eelgrass which previously covered large areas of the seabed has disappeared from the site. Eelgrass normally forms a carpet of roots which protects the underlying sediments. With the disappearance of eelgrass from the area, the site's cultural deposits are no longer protected from wave erosion and the destructive activities of marine organisms such as crabs, piddocks (*Barnea candida*) and shipworms (*Terodo navalis*), which bore deep into the wood to reach the cellulose. As early as 1936, a school teacher from Hjarnø reported that: In recent years, as the seaweed disappeared from the waters, the sea has washed a quantity of stone tools up, and more than 20 a day can be found. This suggests that there has been habitation out where there now is sand. The seaweed referred to here is eelgrass which, due to a global epidemic – or 'wasting disease' (Rasmussen 1977) – had disappeared from major parts of inner Danish waters a few years previously. The submarine cultural layers at Hjarnø appear therefore to have been subject to erosion, presumably to a varying extent, for more than 80 years.

In 2016 the Hjarnø project received funding from the Danish Agency for Culture and Palaces to facilitate protective covering of the locality. An application was approved by the Danish Coastal Authority that permitted covering of the area in 2017, after which the site's scientific potential will hopefully be secured for posterity. Protection will be achieved by adding a protective layer of sand. Seeds of eelgrass will then be sown in this sand, and eelgrass plants will also be planted. The expectation is that eelgrass will again form a mat of roots which will be able to protect the underlying deposits against erosion.

6. Conclusion

The investigations in Hjarnø Sund have yielded several new and exciting results. For example, the numerous artefacts of organic materials include completely new types, as well new variants of already known tools and implements, thereby shedding important light on their use and function. The 75 wooden artefacts recovered from the site also demonstrate the great archaeological potential of submerged early prehistoric settlements, as well as the importance of undertaking investigations and of preserving these localities. Ornamented artefacts constitute a special and important element of the archaeological finds assemblage from Hjarnø. The ornamentation on the paddle blades, in particular, is interesting, seen in relation to that on the paddle blades from other Ertebølle sites. It is possible that these can form the foundation for future studies of the territories of the Ertebølle culture (Skriver *et al.* 2017).

The discovery of several submerged shell mounds is also intriguing, not least because these include the first recorded example of a submerged kitchen midden in Denmark. Moreover, the intact cultural deposits are much better able to fix and date the levels of the coeval coastlines than corresponding marine dump deposits. The oldest shell mound also represents one of the earliest known kitchen middens yet found in Denmark.

The broad nature of the settlement's subsistence economy is evident from the bones found in both the shell mounds and the dump deposits. Given the presence of a range of seasonal indicators which collectively cover the entire year (catching of mackerel and garfish, gathering of shed antlers, hunting fur animals, presence of hazelnuts, etc.), the site was probably occupied all year round. Its position was likely determined primarily by fishing, such that this could be undertaken using both active and passive techniques.

In addition to the purely archaeological observations, the investigations have made it possible to draw up a picture of the relationship between well-dated cultural deposits and the contemporaneous coastal topography. They have also enabled an assessment of the contemporaneous sea level and provided an insight into the local sedimentary conditions associated with the various phases of the Atlantic transgression.

Notes

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2. The plant macro-remains were analysed by Marianne H. Andersen; the wood identifications were undertaken by Janni K. Larsen and Karen V. Salvig, and the zoological analyses were performed by Kenneth Ritchie, Susanne Østergaard and Jacob Kveiborg, all from the Department of Environmental Archaeology and Conservation, Moesgaard Museum.
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