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Shell midden research in Atlantic Europe: State of the art, research problems and perspectives for the future

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ABSTRACT

The formation of shell middens by hunter-gatherers and research into them has been a common field of study in different parts of Atlantic Europe. Although evidence of marine resource exploitation has been identified since the Middle Palaeolithic, and an increase can be seen during the Upper Palaeolithic, it is during the Mesolithic when true shell middens have been identified, apparently showing an increase in the exploitation of coastal areas. This paper summarizes the available information about the formation of shell middens and the exploitation of the coast in several regions of Atlantic Europe, and discusses the main research problems, as the differences in availability of information, the definition and characteristics of shell middens, the relation between shell middens and molluscan exploitation and the problems regarding the chronology of the sites. Finally, the paper proposes the main approaches that should be pursued by future research into this topic.

1. Introduction

The formation of archaeological shell middens by hunter-gatherers societies in Atlantic Europe is a relatively well-known phenomenon and a subject of research since the 19th century (Du Chatellier, 1881; Ribeiro, 1884; Madsen et al., 1900). Although similar methods and theoretical frameworks have been used to study shell middens along Atlantic Europe, great differences are seen between those used in the late nineteenth and early twentieth centuries (Cultural History, using old methods for constructing regional chronological sequences and identifying cultural areas), and those employed from the second half of the twentieth century onwards (Processualism, using modern methods from an economic and ecological perspective).

Regarding the chronology of this phenomenon amongst the hunter-gatherers, while the first evidence of molluscan exploitation has been dated to the Middle Palaeolithic followed by an increase during the Upper Palaeolithic, it is in the Mesolithic that a large number of shell middens have been documented. From the geographical point of view, shell deposits have been identified from Norway to the south of Spain, taking in southern Scandinavia, the British Isles, Ireland, France, Spain and Portugal. In other areas, such as northern Norway, Sweden, Germany, Netherlands and Belgium, gaps in research mean that no information (or very little) is currently available, and therefore these areas are not included in the present paper (Fig. 1).

In recent years, a number of publications have examined the formation of shell middens by hunter-gatherers, and these have tended to present the results of very localised research, of particular sites, regions or chronologies (e.g. Andersen, 2007; Araújo, 2011; Dupont, 2006; Milner et al., 2007; Milner and Woodman, 2007; Gutiérrez-Zugasti, 2009; Milner and Craig, 2009), with a focus in the Mesolithic period and from an ecological and economic perspective. However, no studies have synthesized the main characteristics of this phenomenon as a general overview. Therefore,

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Fig. 1. Distribution of Mesolithic shell middens and shell-bearing sites along Atlantic Europe (Map: C. Dupont).

the available information from the Middle Palaeolithic to the start of the Neolithic still needs to be brought together, in order to compare the situation of the research in different regions of Atlantic Europe. This paper reviews the available information regarding the characteristics of the sites and their chronology, the composition of the shell middens, the settlement patterns and the main research problems in Denmark, Britain, Ireland, France, northern Spain and Portugal. On one hand, the climatic and environmental differences of every region and their influence in the hunter-gatherer subsistence strategies; and on the other hand, the peculiarities regarding social, economic and political aspects, have led to the organization of the information by countries. The paper

also discusses some general research problems, as the differences and biases in the availability of information and research intensity, the definition and characteristics of shell middens, the peculiarities regarding molluscan exploitation and the problems involved with the chronological data. Finally, and taking into account the available information, it establishes future avenues for research into this phenomenon from an ecological and economic perspective but it also aims to reconstruct social aspects. In short, this paper aims to act as a starting point for future research into the study of this particular aspect of European archaeology; the appearance and formation of shell midden sites.

2. Shell middens in Atlantic Europe: the regional evidence

2.1. Denmark

2.1.1. Research history and theoretical frameworks

Research on Danish shell middens (the so-called *"Køkkenmøddinger"*) goes back to ca. 1828–1831, when the first shell midden (Krabbesholm site) was recognized. This discovery gave rise to a discussion as to whether such sites were natural phenomena or humanly created settlement sites. To solve this question a multidisciplinary group comprising an archaeologist, a zoologist, a botanist and an expert on molluscs was established (*The First Kitchen Midden Commission*). This initiative formed the starting point of a tradition which has always been a very characteristic aspect of Danish *Køkkenmødding* research. In 1851 these findings were placed in their correct context as settlement remains (Meilgård site). Later, *The Second Kitchen Midden Commission* worked at the Ertebølle site (1893–97) with the purpose of recovering a large artefact assemblage from one site and, to date the shell middens in relation to the Postglacial forest succession (Madsen et al., 1900). Besides it was also demonstrated that shell middens were not only a Mesolithic phenomena, but that many sites also belonged to the Neolithic period. Since the Ertebølle excavation, larger interdisciplinary investigations involving both archaeologists and scientists, were not resumed until the 1970s and 1980s. The development in Danish shell midden research could be described as a trend from objects to contexts and from chronology to site formation and function. Today, the main trend is oriented towards ecological and economic aspects, and the excavation technique has changed from investigation of sections and small areas to whole middens in order to expose and investigate habitation surfaces in the cultural layers. Finally, there is also a growing recognition of using ethnographic information for the interpretation of the Danish middens.

2.1.2. Site type and chronology

A Danish shell midden (*Køkkenmødding*) is defined as a special type of coastal settlement with a cultural deposit in which at least ca. 50% of the volume consists of marine shells, and the cultural layer forms a continuous horizon exceeding more than 10 m^2; if this is not the case the site is called "a shell-bearing site" (Andersen, 2000) (Fig. 2). Denmark is the northern European region with the highest number of *Køkkenmøddinger* of which ca. 500–550 sites have been recorded. Additionally, there are also a number of

Fig. 2. Excavations at the shell midden of Ertebølle (Denmark) in 1980. The picture shows how the midden is build up by several, individual and smaller shell deposits – dominated by oysters. Here the shell midden is ca. 25 m wide and 1.20 m thick and stretches along the Late Mesolithic coastline.

"natural" mollusc banks from the Stone Age, which provide essential information/clues into the variation of the number and frequency of marine molluscs and snails and thereby also the marine environment. Such banks are important as reference points to what species were available and which ones were favoured and collected by the Stone Age population.

The oldest Danish kitchen middens date back to ca. 5600 cal BC. The majority of the *Køkkenmøddinger* and the largest and most famous sites all belong to the Ertebølle culture (5400–4000 cal BC), but a substantial number of middens also have layers from later periods – especially the Early Neolithic Funnel Beaker Culture (ca. 4000–3600 cal BC). The radiocarbon dates show that the kitchen middens reflect an extraordinarily stable pattern of coastal habitation system during long periods and the larger sites were used over a surprising long span of time, ca. 1000–1200 radiocarbon years, e.g. the Ertebølle shell midden was in use from ca. 5100 cal BC to ca. 4100 cal BC (Andersen and Johansen, 1987). The Danish dates are all calibrated using a reservoir age of ca. 400 years.

The shell middens generally have an oblong outline and vary in size from small up to very large (ca. 30 × 700 m) and with a thickness of ca. 0.10–1.80 m. The cubic content varies from 10 to 5000 m^3. The form of the middens is a product of depositional and post-depositional processes. Horizontal as well as vertical series of radiocarbon dates combined with stratigraphical analysis demonstrate that the oblong outline and size of the Danish middens is a direct function of the duration of occupation at the same location and of a both vertical and horizontal growth along the coastline as a function of time. The dates reflect a gradual, chronological movement – mainly in a horizontal but also in a vertical manner along the prehistoric coast, thereby creating the characteristic form. Contemporary inland sites along rivers and freshwater lake shores are also known, but are far less in number and size.

2.1.3. Composition of shell middens

The Mesolithic middens are characterized by layers containing a mixture of different species of shellfish and cultural debris, including flint debris and artefacts, animal bones – especially fish bones (very often forming regular layers), antler, charcoal, pot-boilers and pottery. The Danish *Køkkenmøddinger* are generally very "compact" in their structure and shells and shell fragments normally make up to 70–80% of the cubic content.

The range and variation of some marine species is very restricted (compared to the natural banks); the dominant species is oysters (*Ostrea edulis),* followed by cockles (*Cerastoderma edulis*), mussels (*Mytilus edulis*) and periwinkles (*Littorina littorea*). Limpets (*Patella* sp.), which are the dominant species in other European shell middens are not found in Denmark; this is also the case with crustaceans and sea urchins, which are absent. The dominance of oysters is a characteristic aspect of the Danish, Mesolithic middens. In contrast to the Mesolithic middens, the Early Neolithic *Køkkenmøddinger* are dominated by cockle.

The faunal remains include ca. 48 fish species, ca. 44 bird species and ca. 26 species of mammals. The dominant fish species are eel (*Anguilla anguilla*), cod (*Gadus morhua*) and flatfish such as plaice and flounder (*Heterosomata*) (Enghoff, 1987, 1994). Red deer (*Cervus elaphus*), wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*) are the main exploited land mammals.

It is still difficult to ascertain the relative importance of shellfish as a subsistence resource. Primarily, the marine molluscs seem to have been used as a food resource, but one must not underestimate the importance of this food type as a supply of minerals such as zinc, iodine and iron compounds (Møhl, 1979). Another use for some of the shellfish could have been as fish bait. Shells have never been used as a raw material for artefacts and only sporadically for beads, although two types are known (Andersen, 2008). Fish, seals and small whales contributed an essential part of the diet, and indicate the importance of marine resources in the diet – a fact which is also supported by analysis of human bones.

The shell matrix also contains scattered human bones and a range of settlement structures, mainly hearths of different types, some pits and stake-holes. In contrast to other European shell middens graves of humans and dogs are few in the Danish ones. Modern excavations have also demonstrated the presence of "living floors" covering several m^2 within the midden deposits – especially around the hearths. However, constructions of well defined dwellings are still absent. Modern excavations have also documented that these sites are not just "middens", but that they display a deliberate internal "layout" concerning the position of fireplaces, areas for food and artefact production, discard-areas for shellfish and positions for flint knapping. This internal organization has been constant through long periods of time.

2.1.4. Settlement patterns

In Denmark the shell middens are only known from the north/northeastern part of the country – only in this part of the country was the Atlantic Sea warm, saline, and rich enough in nutrients to permit the formation of mollusc banks which could be exploited.

Ertebølle middens always lie directly on, and along, prehistoric shorelines, close to natural shell banks and at good "fishing-localities". The preferred positions are in estuaries, sheltered bays, fjords and lagoons. In limited regions such as fjords, bays etc, only one of the middens will be large and there is a tendency that this site will be centrally positioned in the region or close to the mouth of the inlet and surrounded by smaller sites.

The zoological analysis points to a year-round occupation (Madsen et al., 1900) – at least on the large midden sites, while smaller sites reflect more specialized, seasonal food activities, e.g. fowling of whooper swans (*Cygnus cygnus*) (Andersen, 1979; Møhl, 1979) and whaling (Andersen, 2009). Oysters were predominantly collected in March–April (Milner, 2002).

2.1.5. Research problems

An important research problem in Danish shell midden research is the lack of well defined dwellings. Technically it is necessary to direct future excavations towards exposing large areas of the middens, as these areas give the most promising and important data about site layout and function. Besides, ethnographic analogies must be used much more frequently for the interpretation of such living floors.

On the other hand, several research questions should be answered for a better understanding of the shell midden phenomena in Denmark, such as, what was the function of the shell middens in the total coastal settlement pattern? Did the middens have a "special" social and/or ritual importance, and what was their economic importance? Is it possible to observe a sort of "ranking" among the middens in a restricted area, e.g. a fjord or bay? How much of the *Køkkenmødding* was in use at the same time? How often did people change living places on the shell heap?

2.2. Britain and Ireland

2.2.1. Research history and theoretical frameworks

Investigations into shell middens in the British Isles began in the 19th century. In Ireland, shell middens were being discovered in Donegal by Harte, the County Surveyor, and analogies were made to the Danish kitchen middens (Milner and Woodman, 2007). In Scotland, the shell middens on the island of Oronsay are perhaps the most well known and were first investigated in 1881 by Grieve. He visited the island due to his interest in the natural history, but he found what appeared to be an artificial mound, which he assumed

was a burial monument (Mellars, 1987). As in Denmark, these early investigations established that these middens dated from a pre-Christian period, containing unusual artifacts such as bone and red deer antler artifacts such as "harpoons". Other important shell midden discoveries were made in the 1890s around the town of Oban, but unlike the open air shell middens of Oronsay these were all located in caves (Mackay Cave, Gasworks Cave, MacArthur Cave, Druimvargie Cave) (Saville, 2004).

In the 20th century, investigations into shell middens continued and some sites were revisited, e.g. the shell middens on Oronsay were further investigated between 1910 and 1913 by Buchanan and Henderson and again in the 1970s by Mellars (1987). Since the 1960s, an increasing number of shell midden sites with Mesolithic dates have been excavated in Scotland (e.g. An Corran, Ulva Cave and West Voe amongst others: see Wickham-Jones, 2010); Ireland (Baylet, Dalkey Island and Ferriter's Cove amongst others: see Milner and Woodman, 2007); England (Westward Ho! (Balaam et al., 1987), and Culverwell (Palmer, 1999)) and Wales (Prestatyn (Armour-Chelu et al., 2007)). The investigations have mainly focused on environmental and economic issues, and since the 1980s there have been increasing applications of seasonality studies, particularly on shellfish (see Milner et al., 2007 for examples).

2.2.2. Site type and chronology

These middens are found in a number of locations, but many are open air sites with the exception of the majority on the west coast of Scotland which are usually located within caves or beneath rock shelters. Size varies considerably and the largest shell middens are similar to the Danish kitchen middens such as those on the Firth of Forth which date to the Late Mesolithic/Early Neolithic and can extend 150 m. However, there is some debate about whether these are natural shell accumulations or midden sites because of the lack of cultural material found within them (Saville, 2004). The Scottish middens tend to date from the 8th millennium BC and continue in use beyond the end of the Mesolithic up to historical times. Some of the Irish shell middens around Inch Island in Donegal are also relatively large, or certainly were according to 19th century accounts (Milner and Woodman, 2007). However, there are also many very small shell middens, e.g. Ferriter's Cove, Ireland, which with a total MNI of 29,120 shells could arguably be classified as small shell dumps (Woodman et al., 1999). The Mesolithic middens in Ireland tend to date to the 6th and 5th millennium BC, and many more of the middens in this country date to later prehistory and historical times.

2.2.3. Composition of shell middens

The west coast Scottish shell middens tend to be composed predominantly of limpet shell (*Patella* sp.) which tends to create quite a loose structure which can be difficult to excavate stratigraphically. There is usually a large range of other food remains in these middens including large quantities of fish and animal bone, and cultural material including harpoon points, bevel ended tools and worked stone (see e.g. Sand: Hardy and Wickham-Jones, 2009). Sites on the east coast are different: at Morton, there was a predominance of cockles (*C. edule*); the sites around the Firth of Forth are mainly composed of oysters (*O. edulis*).

In Ireland, the middens vary: at Baylet in Donegal the midden was composed of oyster (*O. edulis*) at the base, but the main species above this were mussel (*M. edulis*) and periwinkle (*Littorina* sp.). In contrast to the Scottish middens, there were very few animal bones, some small concentrations of fish, and almost no artefacts at all (Milner and Woodman, 2007). In Wales at Prestatyn, the Late Mesolithic middens are composed of mussels (*M. edulis*) but the Early Neolithic middens are composed of cockles (*C. edule*) suggesting some change in the environment at that time, and both included some bone and lithics (Armour-Chelu et al., 2007). At Portland the main shells are limpet (*Patella* sp.), periwinkle (*L. littorea*) and topshell (*Osilinus lineatus*) (Mannino and Thomas, 2001). The range of fish species varies from site to site but in Scotland saithe and pollack are usually the most prevalent species (e.g. Hardy and Wickham-Jones, 2009). Further work is currently being carried out on fish remains from Mesolithic middens by Rachel Parks.

Overall, there is no consistency to the shell composition in the middens and it can vary considerably from site to site, largely due to what is locally available and the nature of the shore, i.e. rocky or sandy.

2.2.4. Settlement patterns

The size and location of most of these middens suggests that the sites were probably used for temporary occupation though interpretations vary and rely quite heavily on seasonality studies using incremental analysis of shellfish or fish otoliths. For Oronsay, it has been suggested that people visited the island only intermittently (Mithen and Finlayson, 1991). An alternative view is that groups could have been resident on this island for most if not all of the year: fish otolith seasonality data suggests exploitation in different seasons at different sites, and stable isotope data indicates marine foods were a major component of the diet (Richards and Mellars, 1998). At Morton, through analysis of cockle seasonality, it has been suggested that people visited the site primarily for other reasons such as stone collecting, and cockle gathering was a way of gathering food at the same time (Deith, 1986). At Culverwell, it has been demonstrated that there was a marked seasonal pattern to collection and that this human foraging was intensive enough to have a significant impact on the natural shell population (Mannino and Thomas, 2001).

2.2.5. Research problems

Shell middens vary considerably in this part of Europe, but the label of "shell midden" often masks that variability. In Scotland they are even perceived as a "defining characteristic" of the Mesolithic and yet they are still relatively rare (Wickham-Jones, 2010). This is a problem in that there might be the perception that everything is already known about them, and yet very little is actually known! There are still important economic and social questions to be explored and the question of regional differences and changing activities through time are only beginning to be investigated. In addition, new approaches such as surveys of the area can help put Mesolithic shell middens into the wider landscape context, as has been done for Sand, as part of the Scotland's First Settler's Project (Hardy and Wickham-Jones, 2009).

Another key problem is that in many parts of the British Isles, Mesolithic shell middens have been lost, especially due to coastal erosion. This is particularly the case in parts of Wales, England and Ireland which appears to have very small numbers overall. Those in Scotland survive partly due to isostatic uplift.

A further problem is that the data is incredibly patchy. Many sites have not been excavated under rigorous scientific conditions due to the nature of their discovery, often through building works. Very few sites have been extensively excavated and even fewer have been fully published. Consequently, there is little data that is easily accessible concerning faunal remains, ecofacts and sometimes even shellfish composition. There is no doubt that Mesolithic shell middens are an incredibly important resource but sadly they have been much neglected and further scientific approaches are needed which would not only provide information on Mesolithic lifeways but also allow better comparisons to be made with other sites in Europe.

2.3. France

2.3.1. Research history and theoretical frameworks

The oldest shell middens known in France are Late Mesolithic ones, dated from the 7–6th millennium BC. This is simply a consequence of sea-level variations: some shell middens, either Mesolithic or from previous periods, may be submerged but may also be covered by sediments. This phenomenon also explains why all the Mesolithic shell middens known in France are from Brittany on rocky coasts.

The first descriptions of shell middens in France are known at the end of the 19th century (Du Châtellier, 1881). Excavations increased during the first half of the 20th century with the development of research into the Mesolithic period. These excavations were due to association between shell middens and burials: Téviec and Hoedic were the first ones (Péquart et al., 1937; Péquart and Péquart, 1954). Sieving was applied, but mainly for burial components. Other smaller shell middens, called Saint-Gildas, were described south of the Loire estuary by G. Reffe in 1984 (Bellancourt, 1980).

During the 20th century, new excavations were carried out on shell middens devoid of burials: Beg-an-Dorchenn and Beg-er-Vil (Kayser, 1985). In spite of the sieving of sediments for lithic analyses during these excavations, few remains of fauna have been kept due to the fact that there was a lack of specialists dedicated to the study of faunal remains.

At the end of the 20th century French projects focused research on the process of neolithisation and subsistence and settlement became central themes for these last hunter-gatherers populations. Studies of all faunal remains became a fundamental part of the process and were improved by more exhaustive methods applied during excavation (Dupont et al., 2009, 2010). They allowed excluding the presence of domestic mammals in these Mesolithic assemblages (Tresset, 2000) and because of sieving and sorting, Beg-an-Dorchenn and Beg-er-Vil are better documented. Through exposure through erosion, a small accumulation of shells similar to Saint-Gildas has also been excavated in 2001 at Porteau Ouest (Dupont, 2006).

The Early Neolithic is poor on data for marine exploitation. Only one small accumulation is actually known at the Ouchettes (Laporte, 2002). This hiatus represents a topical question in the French archaeological community: is the rarity of marine resources during the Neolithic a reality and a consequence of the adoption of new resources linked to the agriculture, or is it the result of archeologists' bias associated with site visibility?

2.3.2. Site type and chronology

Observation and definition of these shell accumulations are not easy. They all are covered by a sand dune (Dupont et al., 2007) and are not visible in relief in the landscape. Taphonomy seems to have an important impact on the size of these sites and since their first descriptions they are constantly eroded by the sea and digested by the acidity of the soil. For example, the thickness of the Beg-an-Dorchenn site seems to decrease daily: 1.60 m (Bénard Le Pontois, 1929), 1 m (Du Châtellier, 1881), 0.35–0.45 m (Kayser, 1985) and 0.30 m in 2001 (Dupont, 2006). This evolution can be an obstacle in defining the function of a shell midden.

The diversity of material analyses and the constant evolution of calibration methods makes these shell middens difficult to be exactly dated (Marchand et al., 2009). In taking in account the reservoir effect and only dates on material identified, Saint-Gildas 1b seems to be the oldest one (ca. 7000–6600 cal BC), and that is corroborated by the lithic industries. The dates of other shell middens overlap: Beg-er-Vil (ca. 6400–4500 cal BC), Hoedic (ca. 6200–4360 cal BC), Beg-an-Dorchenn (ca. 5900–5400 cal BC) and Téviec (ca. 5700–5080 cal BC).

First descriptions of Téviec, Hoedic, Beg-er-Vil, Beg-an-Dorchenn and Saint-Gildas 1b describe large shell middens of 100 m^2 with a thickness from 0.5 to 1 m. Saint-Gilas 1c is only 2 m^2 but has been described for the first time in 1984 by Tessier when it was eroded by tides. They are all in the form of a brown layer mainly composed by shells. Téviec and Hoedic are the only ones that include burials inside the shell middens. These, alongside Beg-er-Vil and Beg-an-Dorchenn possess hearths and paved surfaces. The Saint-Gildas sites are only composed of shell middens and no other anthropic structures have been detected.

2.3.3. Composition of shell middens

Hoedic, Téviec, Beg-an-Dorchenn and Beg-er-Vil correspond to a wide exploitation of close environments (Schulting et al., 2004; Dupont et al., 2009, 2010). Though present, the terrestrial mammals (wild boar *Sus scrofa scrofa*, roe deer *C. capreolus*, red deer *C. elaphus* and aurochs *Bos primigenius*) seem to be the minority. The main shells eaten are limpets *Patella* sp., flat oysters *O. edulis*, thick topped shells *O. lineatus*, periwinkles *L. littorea*, cockles *C. edule*, peppery furrow shells *Scrobicularia plana* and carpet shell *Ruditapes decussatus*. The marine environment is also represented by marine mammals (grey seal *Halichoerus grypus*), a variety of marine birds (atlantic puffin *Fratercula arctica*, great auk *Pinguinus impennis*, guillemot *Uria aalge* and ducks *Anas* sp.…), fishes (bream *Sparus* sp., ballan wrasse *Labrus bergylta*, pageot, bogue Boops boops, hake *Merluccius merluccius*, poor cod *Trisopterus minutus*, thornback *Raja clavata*, pollack *Pollachius* sp. and tope *Galeorhinus galeus*.…) and crabs (edible crab *Cancer pagurus*, warty crab *Eriphia spinifrons*, furrowed crab *Xantho* sp. and shore crab *Carcinus maenas*.…). All these marine resources indicate the exploitation of varied coastal environments. Some of these components are witnesses of palaeoenvironment modifications, such as the peppery furrow shells found at Beg-an-Dorchenn that are no longer present there today. Diversities and quantities of marine resources seem to indicate a diet based on marine components, like the isotopic analyses carried out on human bones at Téviec and Hoedic (Schulting et al., 2004).

The Saint-Gildas and Porteau Ouest middens are totally different. They are only composed of shells. Peppery furrow shells *S. plana* and limpets *Patella* sp. are the main species. These sites seem to correspond to more punctuated occupation. The peppery furrow shells indicate the presence of a large estuary during the Mesolithic, which has now disappeared (Dupont, 2006).

The impact of marine environments on these Mesolithic populations is also known thanks to numerous shell ornaments (mainly *Littorina obtusata*, *Trivia monacha* and *Nassarius reticulatus*). Shells are perforated on the last spire (*L. obtusata* and *N. reticulatus)* and two holes are found on the dorsal area of *T. monacha*. They are associated with burials at Téviec and Hoedic and are also loose finds in fewer number at Beg-an-Dorchenn, Beg-er-Vil and Saint-Gildas.

2.3.4. Settlement patterns

The difference observed between shell middens with broad and restricted variety of components is interesting. Téviec, Hoedic, Beg-er-Vil and Beg-an-Dorchenn show a wider exploitation of environments, fauna and species with varied activities (common lithic tools, habitat structures). Some of these animal resources may have been present and collected year-round (shellfish, crabs and some fishes). However, a few species do provide access to more detailed information concerning the season of their exploitation: sclerochronology on carpet shells, breeding time of birds, approach near the coast by fishes and availability of fruits (Dupont et al., 2009). The combination of availability times of the different resources shows that Mesolithic people could have had a stable

subsistence economy in time. If a year-round occupation of these settlements is difficult to prove, this can be interpreted from the evidence of residential settlement.

Unlike these four shell middens, the Saint-Gildas sites are only composed of shells. Lithic tools are less varied and the authors do not know of any habitation structures. The low diversity of shell species and animal resources exploited seems to correspond to a more sporadic settlement. Unfortunately, there are no precise data on the seasonal residence of Mesolithic population.

The two kind of shell middens described here are in agreement with the economic models based on lithic analyses. Some residential base-camps more or less extended in time were occupied, with specialized short expeditions to other sites.

2.3.5. Research problems

There is a lack of definition of shell middens in France. A first attempt has been made (Dupont, 2006) but the constant evolution of such accumulations can make their classification more difficult.

The Holocene transgression and all the associated phenomena (erosion, sedimentation) must be taken into account because they modify the vision of the position of settlements linked to coastal environments and only give access to snippets of Prehistoric coastal occupation.

The bulkier shell middens (Téviec and Hoedic) provide few data on subsistence and residence of the last Mesolithic populations because of unsuitable methods of sampling during excavations around 1950. All the excavations carried out on French shell middens have focused on the areas of food refuse and the cemeteries: the shell midden. The nearest areas, next to the middens, may preserve habitation structures or specialized areas and this is one of the objectives of French researchers.

Developments of sclerochronological and isotopic analyses on modern shells are promising. This aspect of the Mesolithic has poorly been explored in France and should be improved in the following years. These methodological developments should have important impacts on the understanding of climate change.

Most dates on French shell middens have been made on charcoal but preliminary tests have also calculated the marine reservoir effect at Beg-an-Dorchenn. A twig of wood stratigraphically close to different species of shells was dated (Marchand et al., 2009). The value obtained is a delta *R* of -260 ± 65 but this work needs to be taken further to understand the values, variations linked to shell species, and the location of the sites.

2.4. Spain

2.4.1. Research history and theoretical frameworks

Although the first shell layers were found at Altamira cave at the end of the 19th century (Sanz de Sautuola, 1880), research on shell middens began properly in the first years of the 20th century when the Count Vega del Sella excavated several sites in the western part of the region, as El Penicial and Cueto La Mina (Vega del Sella, 1923). Until the 1970s, shell middens research was conducted within Normative Thinking and it was focused on the Mesolithic and its position in relation to the Palaeolithic and the Neolithic. Since that date, the introduction of processualism by North American researchers (Straus, 1979; Clark, 1983) changed the focus to ecology and economy, and several shell middens were excavated from this perspective. The most important research project was that of the La Riera (Straus and Clark, 1986) but excavations were also carried out at other sites including Balmori, Coberizas, and Arnero. In the 1980s, shell midden research was conducted by a new generation of Spanish researchers influenced by processualism but more concerned with the historical perspective and processes of change (González Morales, 1982; Arias, 1991). Following this perspective, many other sites have been dug (El Perro, La Fragua, Poza l'Egua) during the last 30 years, providing abundant information about shell midden formation by Upper Palaeolithic and Mesolithic hunter-gatherers and their environment.

2.4.2. Site type and chronology

The earliest evidence of mollusc exploitation dates back to the Middle Palaeolithic, although no shell middens as such were formed, and only a few remains are known in strata where other kinds of materials predominate (e.g. at the sites of Morín, El Castillo and Amalda) so, their use as food is not clear. The first evidence of the systematic exploitation of the shore is seen in the Upper Palaeolithic (ca. 38,000–8900 cal BC), at sites like El Cuco (Aurignacian and Gravettian), El Salín (Gravettian), La Riera (Solutrean, Magalenian and Azilian) or El Perro (Magdalenian and Azilian). However, the accumulations of shells do not form true middens and comprise strata with shells (often quite abundant) together with the remains of the other resources being exploited. It was in the Mesolithic (ca. 8900–4900 cal BC) when large accumulations of shells built up, filling cave entrances to the roof and forming true shell middens. The phenomenon of large accumulations is restricted to the western part of Cantabrian Spain, and constitutes what has been called the Asturian culture (González Morales, 1982; Clark, 1983). A large number of settlements are known (e.g. Mazaculos II, La Riera, El Toral III among others) and the size of the middens indicates the importance of marine resources in the diet, with a smaller frequency of land mammals and other resources. On the other hand, shell deposits are found in the eastern part of the region too, but these are generally layers with shells rather than middens (e.g. La Fragua, La Chora, Kobeaga II and Santimamiñe, among others) although some sites show a considerable amount of shells, similar to those of Asturian sites (e.g. El Perro, La Trecha and J3). In the Early Neolithic (ca. 4900–3700 cal BC), the exploitation of coastal resources continued in a very similar way to that of the Mesolithic, although the shell accumulations are smaller (e.g. Arenillas, Pico Ramos, Kobaederra).

2.4.3. Composition of shell middens

A diversification in the exploited resources has been identified in the region during the Upper Paleolithic. Thus, the main molluscs species being consumed were limpets (*Patella vulgata*) and periwinkles (*L. littorea*), which are found together with other resources, particularly mammals like red deer (*C. elaphus*) and ibex (*Capra pyrenaica*). At this time river fish, mainly salmonids, were the most exploited, although some estuarine fishing was carried out at the end of the Upper Paleolithic (Fano et al., in press). There are also a lot of lithic and osseous artifacts, hearths and a few structures. During the Mesolithic, diversification become greater and intensification has been identified in the exploitation of coastal resources (Gutiérrez-Zugasti, 2009). The main mollusc species found in both parts of the region are the limpets *Patella intermedia* and *P. vulgata*, the topshell *O. lineatus* and the mussel *Mytilus galloprovincialis*. Regarding the mammals, although red deer can be considered the main exploited species, certain diversification can be seen, with an increase in the presence of roe deer (*C. capreolus*) and wild boar (*Sus scropha*), in comparison with the Upper Palaeolithic. In the same way, marine fish, as sardine (*Sardina pilchardus*), anchovy (*Engraulis mordax*), horse mackerel (*Trachurus trachurus*), sea bass (*Dicentrarchus labrax*) and some of the Labridae and the Sparidae families are also very common in the mesolithic shell middens (Fano et al., in press), as well as crustaceans (mainly crabs and goose barnacles) and sea urchins (*Paracentrotus lividus*). However, there is a notable reduction in the lithic and osseous assemblages, and at most of the sites habitation areas have not been identified. Another characteristic of Mesolithic middens is the presence of human remains

within them, both at some Asturian middens (e.g. Mazaculos II, El Toral III, Poza l'Egua and Colomba – Arias, 2007; González Morales, 1995) and at the eastern part of the region (e.g. J3 – Iriarte et al., 2005). Although the record is quite fragmentary, palaeodietary information suggests that marine and terrestrial proteins each made up 50% of the diet (Arias, 2006). During the Early Neolithic, the use of estuaries, and the species found in them (*O. edulis*, *R. decussatus*, *S. plana*), increases, while the open coast continues to be exploited as during the Mesolithic. The contexts are very similar to that of the Mesolithic.

2.4.4. Settlement patterns

Shell middens in northern Spain are always located in caves and rock shelters. While during the Upper Paleolithic both coast and inland were widely occupied, during the Mesolithic, occupation is focused in coastal sites, mainly located less than 5 km from the coastline (Bailey and Craighead, 2003; Fano, 2007). These sites are usually located in good places to exploit not only the coast itself but also the coastal plain. This is probably related with a restriction in mobility in comparison with the Upper Paleolithic, so reduced catchment areas were exploited with more intensity. On the other hand, a debate on the occupation time of these sites is still ongoing in northern Spain. On one hand, some shell midden sites, with good conditions and large size are proposed to be year-round sites, while small sites with evidence of small occupations are considered seasonal sites. However, few seasonality studies have been made to confirm this argument. In the case of molluscs, some data for the Upper Palaeolithic indicate that *P. vulgata* were gathered in the summer/autumn, and *P. intermedia* in the autumn/winter (Bailey and Craighead, 2003). During the Mesolithic, seasonality studies indicate that *P. intermedia* was gathered in autumn/winter (Bailey and Craighead, 2003) and *O. lineatus* in winter (Deith, 1983). During the Early Neolithic, growth line analysis on the flat oyster *O. edulis* show that they were collected mainly in spring (Zapata et al., 2007; Gutiérrez-Zugasti, 2009) which seems to reflect a change in the collection patterns if compared with previous times. In the case of mammals, the only information for Mesolithic and Early Neolithic times come from the site of Mazaculos II, showing that hunting took place from spring to autumn (Marín-Arroyo and González-Morales, 2009). However, the range of data, both for molluscs and other species is very limited, and this is true for the Upper Paleolithic and the Mesolithic.

2.4.5. Research problems

Finally, there are some research questions and problems that should be mentioned. On one hand, the definition of shell midden has not been fully established in the region. As described above, two types of shell accumulation have been proposed under morphological criteria: layers with shells and shell middens. The differences between both types are mainly the size and the shape and they seem to indicate two different settlement patterns and/or ways of coastal exploitation. However, there are not detailed analyses on these questions, either from the morphological point of view or from the range of activities carried out in the sites.

Archaeological visibility is a key research problem. On the one hand, the rise in sea level makes it difficult to find coastal Palaeolithic sites and, therefore their comparison with the Mesolithic ones is very difficult. On the other hand, probably due to karstic processes, most of the shell middens show erosion, which makes the interpretation of the sites difficult. In the same way, the characteristics of the region regarding geology and vegetation make it especially difficult to identify open air shell midden sites.

During the Mesolithic, there are also some differences between the western and eastern parts of the region (Fano, 2007). While in the western part, the formation of shell middens is very common, it is not the same in the eastern part. These differences could be related with archaeological visibility or research traditions but also with cultural behaviour. On the other hand, the relation between coastal and inland occupations should be studied in a more detailed way. Some differences have been identified regarding the funerary ritual and palaeodiets, which support the occurrence of diverse human groups and a concern for the occupation of the territory.

Another important research problem is the lack of habitation areas in the shell middens, mainly in Mesolithic ones. So far, living floors have only been identified at Mazaculos II, while the rest of the shell middens do not have an inner spatial organization and they look like disposal garbage dumps. The previously mentioned problem of erosion makes it even more difficult to obtain information on this topic.

Finally, although shell midden research has had a long tradition in the region, much more work should be conducted on shell midden formation, settlement, mobility, archaeozoology, seasonality, palaeodiet and DNA to answer all these research questions and to establish the real character of shell midden sites and their evolution in northern Spain.

2.5. Portugal

2.5.1. Research history and theoretical frameworks

In 1880, during the Ninth International Congress of Anthropology and Prehistoric Archaeology held in Lisbon, Carlos Ribeiro, of the Geological Survey, described for the first time the "*kjoekkenmoeddings*" in the Tagus Valley, discovered and excavated since 1863 (Ribeiro, 1884). Until the 1940s, researchers focused mainly on the anthropological remains. During the 1950s, Veiga Ferreira and Jean Roche resumed investigations at Muge, carrying out salvage excavations at Moita do Sebastião. The focus of their subsequent studies was on the stratigraphy of the sites and their lithic industries, supported by radiocarbon dates (synthesized in Roche, 1972b). Roughly at the same time and entering the following decade, Manuel Heleno, Director of the National Museum of Archaeology, initiated a large program of survey and excavations in a second cluster of shell middens located in the Sado Valley. Unfortunately, Heleno never published his results.

From the 1980s onwards, several shell middens were discovered and excavated, and the Muge and Sado sites were revisited. These investigations, supported by new and accurate radiocarbon dates, address palaeoeconomic, palaeoenvironmental and bioanthropological questions. Based on the shell midden archaeological record, three main research avenues have been developed: i) evolution of hunter-gatherer adaptations during the Pleistocene–Holocene transition (Bicho, 1994; Bicho and Haws, 2008; Araújo, 2009); ii) the appearance of food production economies, and the possible role of Mesolithic communities in this process (synthesized in Carvalho, 2008); finally, crossing both research topics, iii) the determination and variability of the marine reservoir effect and its application on radiocarbon dating (Soares, 2004; Martins et al., 2008).

2.5.2. Site type and chronology

In Portugal, the earlier evidence of a shell midden site dates back to the Middle Palaeolithic (ca. 32,300 cal BC). It is a cave (Figueira Brava) located not far from the present coastline which documents several remains related with the exploitation of both marine and terrestrial faunas. Shell midden sites of the Upper Palaeolithic are still unknown, but the consumption of molluscs is testified in a few contexts (the site of Vale Boi, for example, Bicho et al., 2010a). At present, around 50 Mesolithic shell middens are known. The large majority are open air sites, although some Early Mesolithic shell middens/dumps have been found in caves and rock shelter sites (Fig. 3, right).

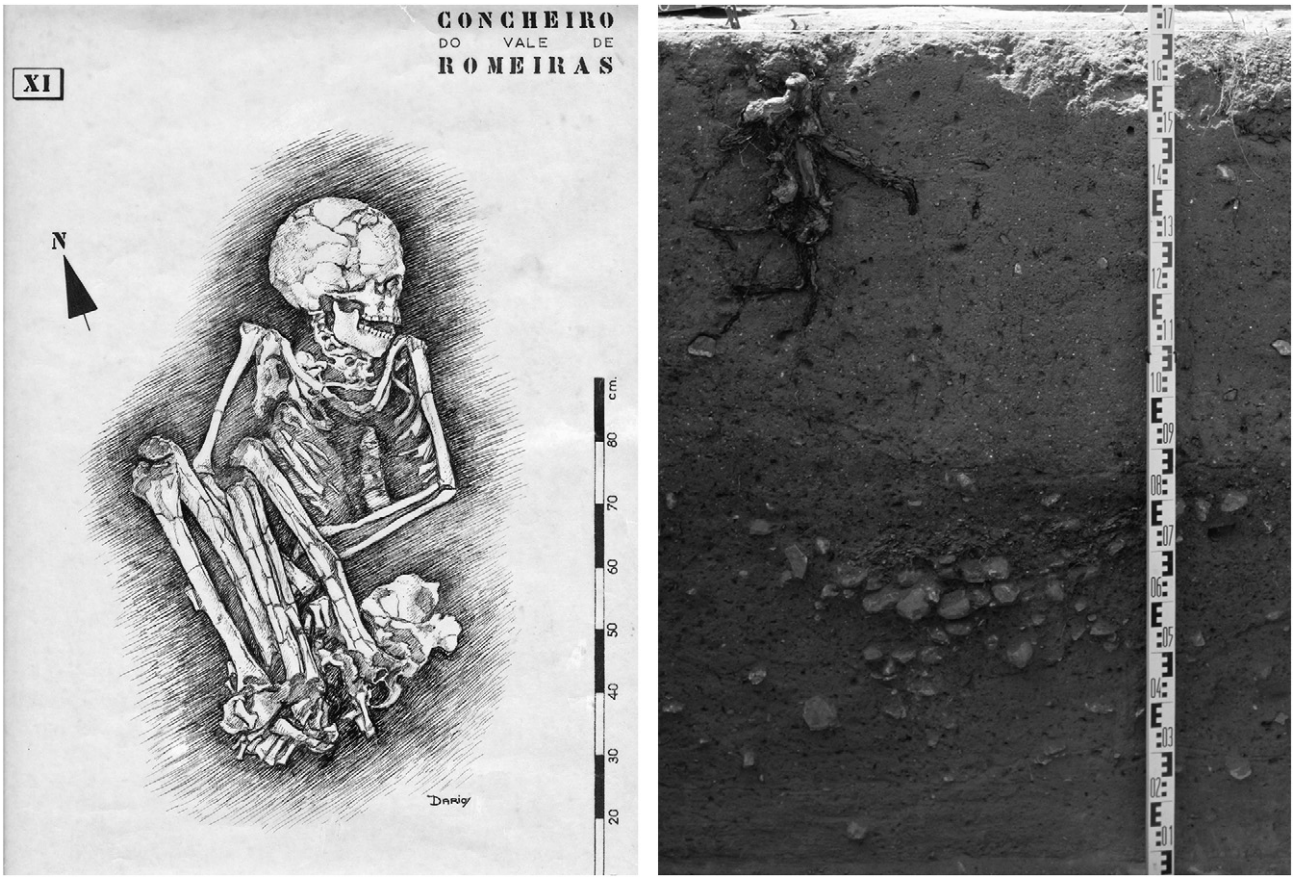

Fig. 3. Left side: Field drawing of a human skeleton recovered at Vale de Romeiras shell midden (Sado Valley), in the 1950s, in a foetal position (courtesy of the National Museum of Archeology, Lisbon). Right side: structure preserved in the profile west of the Early Mesolithic shell midden of Toledo related to the processing of molluscs (mainly *Cerastoderma edule* and *Solen marginatus*).

Several shell middens represent repeated and short episodic occupations, probably of a seasonal nature, related to the gathering and consumption of shellfish (mainly molluscs). They tend to be small in both size and thickness, particularly those dated from the Early Mesolithic (ca. 9500–6800 cal BC), and have been described as logistical sites (Araújo, 2009; Valente and Carvalho, 2009).

The largest shell middens known in Portugal date to the Late Mesolithic (ca. 6500–5200 cal BC); their areas can reach 8000 m^2 (Poças de São Bento, in Sado; Arnaud, 2000) and their levels can attain 5 m in thickness (Cabeço da Arruda, in Muge; Roche, 1972b). They have been interpreted as base-camps of a residential nature, which were occupied in a more permanent way (year-round) and where different kinds of activities took place. They have, in some cases, associated burials, and therefore, their habitat functionality is not exclusive. The best examples of such extensive sites were found in the inner parts of the estuaries of the Tagus, Sado and Mira rivers (Roche, 1972b; Arnaud, 1989; Soares, 1996; Lubell et al., 2007). The exploitation of shellfish banks, with the resulting formation/reoccupation of Mesolithic shell midden sites, continued to play some role in the daily life of Neolithic people (synthesized in Carvalho, 2008).

2.5.3. Composition of shell middens

The representation of marine invertebrates naturally varies from site to site according to geographical settings and chronology. In the coast of Estremadura (Dupont, 2011), species of sedimentary facies of a marked estuarine influence dominate the faunal assemblages of shell middens: cockle (*C. edule*), peppery furrow clam (*S. plana*), clams (*R. decussatus*) and razor-shells (*Solen marginatus*). The Alentejo and Algarve coasts show an inverse situation, with a clear preponderance of species associated with rocky habitats (synthesized in Valente, 2008): limpets (*Patella* sp.), mussels (*Mytilus* sp.), topshells (*O. lineatus*), and rock shells (*Thais haemastoma*). Due to the rise in sea level, large estuaries were formed in the inner parts of the Tagus and Sado rivers; cockle and peppery furrow clam, species very well adapted to brackish waters, dominate shell middens in these locations.

Defined by the gathering and consumption of molluscs, numerous shell middens do not present other cultural remains. According to site type, however, composition may vary.

Those of residential nature, mostly dated to the Late Mesolithic, present a wide range of animal remains, domestic features, burials and lithic industries. Red deer (*C. elaphus*), wild boar (*Sus scrofa*), and Leporidae are the most predominant mammal prey, with a lesser representation of roe deer (*C. capreolus*) and aurochs (*Bos primigenius*) (Lentacker, 1986; Le Gall et al., 1994; Arnaud, 2000; Detry, 2007; Moreno, 2011). Several families of fish are also documented: seabreams (Sparidae), houndsharks (Triakidae), mullets (Mugilidae), sea bass (Moronidae), and croakers (Sciaenidae) (Lentacker, 1994; Le Gall et al., 1994; Arnaud, 2000; Gabriel, 2011). In addition, crustaceans and sea urchins were also exploited as food supply.

Post-holes, pavements, fireplaces and two possible huts at Moita do Sebastião, in Muge, have been recorded in sites of residential nature (Roche, 1972b; Arnaud, 2000). Lithic technology of Early Mesolithic shell middens is generally limited to the production of

non-standardized flakes and heavy-duty tools (Araújo, 2009, 2011), while geometric armatures dominate the tool assemblages of the latest phase (Vierra, 1995; Marchand, 2005; Lubell et al., 2007; Carvalho, 2009).

Finally, the most prominent feature of Late Mesolithic shell middens is related with their funerary character (Fig. 3, left). About 400 human burials were already recovered in the Tagus and Sado valleys (synthesized in Umbelino, 2006). Although the majority of the dead were buried on the base of the shell midden deposits, within sterile sands, some were found inside the middens. At Moita do Sebastião, in Muge, infants and adults were inhumated in differentiated areas, with the formers placed in semicircle. This site also documents double and multiple burials (Roche, 1972a; Ferembach, 1974). The dorsal decubitus position predominates at Muge, while in Sado is the foetal. Personal adornments made on shell accompanied the dead at Muge; in Sado, information lacks about other funerary practices and offerings (some perforated shells were found but their association with the dead is uncertain). In Vale de Romeiras, however, 25 individuals were placed in a semicircle, facing the Sado River, suggesting a contemporaneous deposition (Arnaud, 2000).

2.5.4. Settlement patterns

Shell middens of the Early Mesolithic show a relatively uniform distribution pattern. They are located in or near the present coastline and in areas corresponding to ancient estuaries of small rivers, which allowed for the exploitation of both marine and fluvial-estuarine ecosystems. The identification of shell deposits in caves and rock shelters located at a considerable distance from the ancient coastline (ca. 60 km) shows, on the other hand, a considerable reliance on aquatic resources in the subsistence economy of inland human populations. The presence of molluscs in these locations is not a result of sporadic contacts or exchanges between groups but the product of a highly mobile social system (Araújo, 2009, 2011).

At the beginning of the Atlantic, a major reorganisation of human settlement occurred, which has been hypothesized to be related to the 8.2 ka cold event (Zilhão, 2003; Carvalho, 2009). Shell middens of the Late Mesolithic are now mainly concentrated on the inner parts of the major estuaries of the Tagus, Sado and Mira rivers, in ecotone areas. They represent, even today, the ultimate examples of human adaptation to the large and very productive estuaries of the Atlantic. Analyses of skeletons buried at Muge and Sado (Lubell et al., 1994; Umbelino, 2006) demonstrate a diet strongly dependent upon marine resources (50%, at Muge, and 30%, at Sado). While some shell middens show clear indicators of their residential nature, others seem to be more logistical, and exclusively related to mollusc processing activities.

Little can be said about seasonality of site occupation. Data on the issue has been tentatively provided using faunal remains as seasonal indicators (Gabriel, 2011; Lentacker, 1986; Le Gall et al., 1992; Lubell et al., 2007; Moreno, 2011).

2.5.5. Research problems

There are numerous research problems when dealing with shell middens. These tend to be complex. Many have suffered from varying degrees of destruction by nature or modern anthropic pressure and others were deficiently excavated and published. The main composition of these sites, the shell itself, still tends to be studied in a somewhat superficial manner, mainly due to the scarcity of Portuguese specialists dedicated to archaeomalacology. Seasonality studies based on mollusc growth have been ignored. A shell midden is a very complex type of site, frequently resulting from several episodes of shell accumulation. Site formation processes, supported by geoarchaeological analyses and accurate radiocarbon dating constitute one of the major lacunae in the understanding of shell middens.

Although the enormous and important scientific investment made by different interdisciplinary teams to rehabilitate and restore much of the material culture recovered during excavations in the Tagus and Sado shell middens, such as ^{14}C dates, anthropology, isotope and element analyses of human bone collagen, zooarchaeology, lithic technology, serious problems persist and several questions need systematic addressing. Most of these investigations were not supported by accurate stratigraphic and spatial information. This lack prevents an understanding of patterns of occupation of sites, their functional differentiation, demography, mobility of the inhabitants, their subsistence and technology, across both space and time.

At present, new excavations on shell midden sites are under way in both Sado and Tagus clusters. These, hopefully, will allow correction of many of the mistakes derived from former works. Models concerning subsistence and settlement patterns previously established will also be tested and revaluated in the light of these new digs.

A second problem is the absence of true shell midden sites in the Upper Palaeolithic. Whether or not this lack results from taphonomy, due to the rise in sea level, or past human activities is a matter of debate and one of the most promising research avenues.

3. Shell middens in Atlantic Europe: research problems

3.1. Biases in the availability of information

Several factors are biasing knowledge of the shell midden phenomena in Atlantic Europe. In terms of the availability of information, it is interesting to point out the differences in the extent of the excavations. Thus, in most of the regions, shell middens have been partially excavated due to a variety of reasons. In Denmark, some middens have been excavated totally, mainly the smaller ones (e.g. Aggersund), although the majority were excavated over a reduced area and combined with information from sections (e.g. Ertebølle). In many cases, the only available information is from the sections (e.g. Havnø). In Britain and Ireland the middens are only sampled, not completely excavated, although the excavations at Cnoc Coig on Oronsay were fairly extensive and produced some interesting information on hearths and spatial variation. In France, Téviec and Hoedic middens have been excavated over a large area but excavations have been concentrated on burials. Small shell middens, such as Saint-Gildas and Porteau Ouest, have been excavated in their entirety but only after their preservation was already compromised. Several sections were excavated at Beg-er-Vil and Beg-an-Dorchenn. In the same way, in northern Spain and Portugal, the majority of shell middens were only partially excavated, although some of them were excavated in several sections, producing interesting results (e.g. Muge shell middens in Portugal, and El Toral III in northern Spain). This scarcity in large scale excavations in Atlantic Europe is the result of multiple factors: 1) ploughing and sea/river/karst-erosion, which have been responsible for the partial or even total mutilation of a considerable number of sites (see Fig. 4 for an example of eroded shell midden); 2) old excavations, which were mainly focused on the stratigraphy of the sites rather than their spatial extension or internal organization; 3) reduced funding of the archaeological activity; 4) large scale excavations take a long time and produce vast quantities of material.

Some other factors condition the preservation and visibility of the shell middens and therefore the availability of information and the research intensity in some areas. For example, areas of northern Europe, such as Scandinavia and part of the British Isles and Ireland were covered by ice during the last glaciation, and therefore

Fig. 4. Shells cemented to the walls at the Mesolithic site of El Mazo cave (Asturias, Northern Spain) after the shell midden was eroded.

information is only available for the Mesolithic onwards. In addition, in some countries such as Denmark, the Netherlands, Belgium, France and England, sea-level rise during the Holocene has had a considerable adverse effect due to the greater width of the continental shelf: this is not always the case in Scotland because of the isostatic uplift. Thus, no coastal Upper Palaeolithic settlements remain above the current sea level and to a certain extent this is also true of Mesolithic sites, which are also affected by erosion and/or sedimentation. On the contrary, in northern Spain, with a narrower coastal platform, the impact has not been so great, and Upper Palaeolithic sites which were relatively near to the shore have been preserved, although only in just a few cases (e.g. Tito Bustillo and Santa Catalina shell midden site) less than 5 km away to the present coastline. In Portugal, the absence of shell midden sites dated to the Upper Palaeolithic is also possibly related with complex sea-level fluctuations across time. Therefore, the impact of sea-level rise in the archaeological record is biasing knowledge about shell midden formation and their evolution through time.

In other countries, such as Norway or Sweden, the effect of the isostatic rebound has allowed the preservation of Early Mesolithic shorelines. However, only a few shell middens have been identified and they are not similar to those of Denmark and so should be considered shell layers rather than shell middens (Bjerck, 2007; Schaller Åhrberg, 2007). Although several arguments have been stated to account for this scarcity of shell middens, the more probable explanation is related to the ecological and topographical conditions that could have resulted in a scarcity of intertidal mudflats and rocky shores suitable for the development of molluscs. The Danish environment and topographical conditions are very different from the Norwegian and Swedish areas, because Denmark is only made up of hilly areas of clay, gravel and sand, and with a rather low relief (below 200 m). On the other hand, the absence of middens in Norway and Sweden might also purely be a question of representativity. The rocky, open coasts have been subject to heavy erosion since the Stone Age, while most of the Danish fjord-areas are much more protected; e.g. most Norwegian shell deposits (and not proper middens) are all found in protected caves.

3.2. Problems in the definition and characteristics of shell middens

Among the problems related with this research is how to define a shell midden. Great differences are seen in the size and shape of the shell deposits, which range from large accumulations covering up to 6000 m^2, to small layers or pits with a greater or lesser number of shells. Differences have also been seen in the position and features (e.g. shape and outline) of middens. However, in many areas a detailed analysis on the morphology and characteristics of the different shell middens has not been carried out. Thus, in France, shell middens have been classified in three types according to the morphology and the volume: *Amas coquillier* is a mound bigger than 2 m^3, while the smaller ones are called *Dépôt coquillier*. *Lit coquillier* should be used for horizontal shell layers (Dupont, 2006). In Spain, a simple distinction has been made between shell middens (big mounds) and shell horizontal layers (synthesized in Gutiérrez-Zugasti, 2009). In Britain, Ireland and Portugal a clear definition of a shell midden is lacking probably because much of the information comes from old excavations and the deficiency in publication prevents such comparisons. In contrast, in the case of Denmark, where all the middens have the same characteristics (oblong in shape and following the coastline), differences have been established between shell midden and shell bearing depending on the size of the deposit (larger or lesser than 10 m^2) (Andersen, 2000).

There are also differences in relation to the internal characteristics of the shell middens, mainly in the question of identifying activity/habitation areas. Thus, in Denmark, internal organization including hearths, post-holes and graves have been identified within the shell middens, while there are no signs of habitation to the rear of the middens. On the other hand, in Portugal, the same kind of structures have been documented in some sites of residential nature, but also pavements and two possible huts at Moita do Sebastião (Roche, 1972b; Arnaud, 2000). Recent excavations in the shell midden of Cabeço da Amoreira, in Muge, are also concerned with the study of shell midden formation and internal organization (Bicho et al., 2010b). In France the clearer structures are the graves at Téviec and Hoedic. A paved area and hearths are also described at Hoedic, (Péquart and Péquart, 1954) and some hearths at Téviec (Péquart et al., 1937). Kayser also described in 1985 a structure of 8 m^2 with stones associated with burning marks. In northern Spain, some living floors were found at Mazaculos II, including hearths but not dwellings or other kind of structures (González Morales, 1982). The recent excavations at El Toral III showed the existence of possible post-holes, but not other structures. Ongoing excavations at El Mazo shell midden site have allowed identification of the remains of hearths inside the shell matrix, and lithic remains have been documented to the rear of the midden, but other structures are still lacking.

Some of these differences are related with the functionality of the sites inside the subsistence-settlement system (residential vs seasonal). Although in general shell middens always include materials other than shells, which seem to be related with a large range of activities carried out in the sites, in some cases, shell middens were just composed of shells (e.g. Saint-Gildas in France or the Early Mesolithic occupations identified at Magoito and Montes de Baixo in Portugal). However, other factors may be biasing knowledge of the real size, volume and form of the accumulations, and also of their internal characteristics: 1) most of the shell middens have been affected by erosion and ploughing; 2) in many cases, sites were just partially excavated consequently preventing a good comprehension of the real extent of the midden; 3) the complexity involved in the excavation of a shell midden was not always considered and this has led to an incomplete understanding of these sites.

Thus, the information on this issue is limited and uneven, which makes it very difficult to compare between regions and, in some cases, even between shell accumulations in the same region. Establishing a classification on shell middens, based not only on size, volume and form but also in their internal characteristics,

would help to understand formation processes, use of space, length of occupation and identify regional differences. In any case, much more work on this topic should be conducted in the future, taking into account as many of these variables as possible.

3.3. Shell middens, diets and molluscs exploitation

Regarding the marine resources in general, the few palaeodietary analyses that are available show that in the Mesolithic, marine resources made up as much as 50% of the proteins consumed by hunter-gatherers in Denmark, France, Britain (at Oronsay it may have been ca. 90%), Ireland, northern Spain and Portugal (although this is only true for Muge shell middens, as in the Sado valley the contribution of marine resources is ca. 30%), which seems to show the significance of these resources in human diet. This statement is also supported by other kind of data, as the large accumulation of molluscs across Atlantic Europe or, for instance, the 48 different species of fishes documented in the Danish middens (Enghoff, 1994) and the 50 recognized within Portuguese middens (Gabriel, in prep.). However, it is important to keep in mind that the percentages in marine proteins consumed may have varied taking into account the temporal extent of the Mesolithic occupation in most of the cases. Thus, more data is needed to address the evolution of marine resources in the diet, not only during the Mesolithic, but also during the Upper Palaeolithic, and to corroborate the current data.

One of the most frequently discussed issues in shell midden research concerns the importance of molluscs for human populations. On the one hand, the low value of molluscs as food has been highlighted, due to their small energy value and nutritional contribution to the diet (Parmalee and Klippel, 1974). However, other authors have stated quite the contrary; that their energy value is not so low, and they may be the ideal complement for a diet rich in meat (Chenorkian, 1988; Erlandson, 1988). In addition, other advantages have been put forward. As they are a stationary resource, their profitability increases due to the low risk and small amount of energy spent in their gathering (Perlman, 1980; Yesner, 1980; Erlandson, 2001).

According to the archaeological record in Atlantic Europe, molluscs have been used as a food resource since the Middle Palaeolithic, although the data for this period is very scarce, so it is difficult to know if this is due to erosion/lack of visibility or a low reliance on these resources as food. For later periods, one of the most common debates is that of the occurrence of intensification in the exploitation of molluscs in the Pleistocene–Holocene transition. The biases related with sea-level rise prevent achieving a clear assessment of their real importance and evolution in the hunter-gatherers diet through time, since data on coastal sites for the Upper Palaeolithic are lacking. However, the hypothesis has been tested in northern Spain, where a relatively good archaeological record exists for the Upper Palaeolithic and the Mesolithic, and the occurrence of intensification starting during the Azilian has been proposed (Straus and Clark, 1986; Gutiérrez-Zugasti, 2009), although some authors do not agree (Bailey and Craighead, 2003). However, the appearance of shell middens across Atlantic Europe during the Mesolithic seems to support the existence of this intensification and a great reliance on these resources as food. The impact of this intensification can be seen in the overexploitation of the main collected species. For example, in Denmark a decrease in the size of the oysters have been recorded between the start and the end of the Ertebølle period (Andersen, 2007), and the same process has been identified in northern Spain, where limpets and topshells were intensively harvested, presenting very small sizes during the late Mesolithic and the Early Neolithic (Gutiérrez Zugasti, 2009). In Portugal, the systematic accumulation of molluscs in Early Mesolithic sites located very far from the coast (e.g. Gruta do Casal Papagaio, Abrigo Grande das Bocas, Pena de Mira) also supports the hypothesis of intensification. However, the best example of this intensification is shown by the large accumulations of shells present within Late Mesolithic shell middens (as is the case of both Muge and Sado sites). The case of molluscs is addressed here, but in general, in the most of the counties, there are indications that intensification of marine resources exploitation (not only molluscs) took place.

In terms of species and environment, hunter-gatherers' subsistence strategies involved the exploitation of similar species of molluscs in all areas and times (Table 1), although with differences between the use of open rocky coasts (*P. vulgata* and *intermedia*, *O. lineatus*) and soft-bottom estuaries (*C. edule*, *O. edulis*, *S. plana*, *R. decussatus*). This use depends on the morphology of the coastline in each area and other factors such as salinity, temperature, nutritional value of the sea and cultural behaviour. The large estuaries in France and Portugal favoured the occupation and exploitation of these areas, although some open coast exploitation has also been detected. In Denmark, although all areas (fjords and more open coasts) were occupied, the environmental constraints favoured the exploitation of estuarine species. In northern Spain, the exploitation was concentrated on open coasts, although small estuaries were also used in certain cases, mainly during the Early Neolithic. As well as molluscs, the shell middens usually contain the remains of both land and sea mammals, fish, crustaceans, echinoderms and plants, except in Denmark where crustaceans and echinoderms have not been identified. This absence of echinoderms and crustaceans might be

Table 1
The most important species of molluscs represented in shell middens and shell layers of the Atlantic Façade of Europe by country and chronological period. Those of Denmark are ranked by importance.

	Upper Paleolithic	Mesolithic	Early Neolithic
Denmark	No middens	*Ostrea edulis* *Cerastoderma edule* *Mytilus edulis* *Littorina littorea*	*Cerastoderma edule* *Ostrea edulis* *Mytilus edulis* *Littorina littorea*
Britain and Ireland	No middens	**Scotland** *Patella vulgata*, *Littorina littorea* **Ireland**, *Ostrea edulis*, *Mytilus edulis*, *Littorina littorea*	**Scotland** *Patella vulgata*, *Littorina littorea* **Ireland**, *Ostrea edulis*, *Mytilus edulis*, *Littorina littorea*
France	No middens	*Patella vulgata* *Patella intermedia* *Cerastoderma edule* *Mytilus edulis* *Ostrea edulis* *Scrobicularia plana*	*Patella vulgata* *Patella intermedia* *Osilinus lineatus* *Cerastoderma edule* *Mytilus edulis* *Ostrea edulis* *Ruditapes decussatus* *Scrobicularia plana*
Northern Spain	*Littorina littorea* *Patella vulgata*	*Patella vulgata* *Patella intermedia* *Osilinus lineatus* *Mytilus galloprovincialis*	*Patella vulgata* *Patella intermedia* *Osilinus lineatus* *Mytilus galloprovincialis* *Ostrea edulis* *Ruditapes decussatus* *Scrobicularia plana*
Portugal	*Patella vulgata* *Littorina littorea* *Mytilus* sp.	**Littoral Centre**: *Cerastoderma edule* *Scrobicularia plana* *Ruditapes decussatus* *Solen marginatus* **Littoral South**: *Patella*, sp. *Mytilus* sp. *Osilinus lineatus* *Thais haemastoma*	*Patella* sp. *Thais haemastoma* *Mytilus* sp. *Ruditapes decussatus*

a question of a lower salinity or human preferences, as these resources prefer rocky beaches and live in deeper waters than might have been accessible for the Stone Age population. On the other hand, it is interesting to note the absence of limpets in the Danish shell middens, as this is one of the main exploited species in the rest of the countries. This absence can probably explained as a function of at least two environmental factors: the absence of rocky surfaces and the lower levels of salinity in Danish-South Scandinavian waters, in contrast to other areas of the Atlantic.

3.4. Chronology in shell midden research

The scarcity of radiocarbon dates is another problem which needs addressing. Whilst at many sites there are several radiocarbon dates, what matters is the range of the dates and the occupation length at the same locality, and this is not available for many sites, particularly those from older excavations. For example, in Denmark there are ca. 200–250 ^{14}C dates (using different materials such as charcoal, bones and shells) from many middens, out of which the main part are stratigraphical series through the middens sequence. The main part of the Danish middens have been in use for several hundreds of years, many up to 1000–1200 years, covering the last part of the Mesolithic and chronologically going far into the Neolithic. Although with not so many dates as in Denmark, the dates in the rest of the Atlantic Europe cover a similar range of time and the same periods. In Scotland and Ireland some of the middens have been well dated using a variety of different materials (animal and human bone, shell and charcoal), but others are in need of redating. The case is very similar in Portugal where almost all Mesolithic shell middens are ^{14}C dated (using charcoal, shells, bones and human bones), establishing the length of the occupation. In northern Spain, most of the sites (both Upper Palaeolithic and Mesolithic) have several dates on different materials, although just a few are covering all the stratigraphic sequence. The high level of erosion of many middens prevents knowing the length of occupation in some of them. In the case of France, although just a few shell middens have been dug, they have several dates (also on different materials), giving the duration of the occupations, as occurs in Beg-an-Dorchenn or Beg-er-Vil (Dupont et al., 2010; Marchand et al., 2009). On the other hand, the complexity of dating middens via human bones must be pointed out. Thus, in Portugal and northern Spain, dates obtained on human bone collagen and other materials recovered within the shell midden sites show a good correlation between the burials and the middens. However, in Denmark and Scotland, in some cases the dates of the human bone, although within the middens, are later in date and are arguably intrusive or secondary. To prevent this problem, when possible shell middens should be dated using other materials, such as charcoal, bone or shells and not only human bones.

Another interesting research topic related with dates is that of the marine radiocarbon reservoir effect. As molluscs are the most usual resource in the shell middens, they are the best material to establish the range and length of occupations, as they can be dated throughout the stratigraphic sequence. However, to set up chronologies for a particular area using marine shell samples prior research concerning the oceanographic conditions and the marine ^{14}C reservoir effect (ΔR) of that area is needed in order to obtain accurate results (Stuiver et al., 1986; Stuiver and Braziunas, 1993). Several studies have provided values of regional marine ^{14}C reservoir effect of coastal waters off Atlantic Europe and have also indicated some variability during the Holocene. For example, in Scotland research has demonstrated a lot of variability in time and space and related to different marine species (Ascough et al., 2005; Cage et al., 2006; Russell et al., 2010). In Denmark this variability has been attributed to local factors (Heier-Nielsen et al., 1995; Olsen et al., 2009) whilst in Atlantic Iberia, the variability have been correlated with the upwelling phenomenon (Soares, 1993, 2010; Soares and Dias, 2006a, b, 2007; Soares and Martins, 2009, 2010). The information on the reservoir effect for the Mesolithic in the Atlantic façade is still very limited (and non-existent for the Palaeolithic), but it supports the variability seen in the data for the Holocene in different parts of Atlantic Europe. Thus, there are both temporal and spatial variations in the marine reservoir effect during the Mesolithic. This means that in order to obtain a good chronological resolution when dating shells, it is necessary to have information on the reservoir effect, which in some cases suggests obtaining a high number of radiocarbon dates using several different materials (usually charcoal or bone, as well as the marine shells). In Denmark a standard mean of 0 ^{14}C *y* is used as ΔR, which corresponds to a reservoir age of 400 ^{14}C (Heier-Nielsen et al., 1995), although recently it has been stated that modern reservoir ages cannot simply be applied back in time (Olsen et al., 2009). In France, the only information comes from the site of Beg-an-Dorchenn and the value obtained is a ΔR of -260 ± 65 (Marchand et al., 2007). In northern Spain there are two preliminary results from the sites of La Garma A ($\Delta R = 220$) and Colomba ($\Delta R = 85$) (synthesized in Fano, 2007). However, these positive results should be negative and similar to that from Beg-an-Dorchenn if the oceanographic conditions of northern Spain are taken into account. In Portugal, recent archaeological excavations at Cabeço da Amoreira allowed the determination of an accurate ΔR value for the Muge estuarine region. A value of 140 ± 40 ^{14}C *y* for ΔR was then calculated (Martins et al., 2008).

4. Final considerations and perspectives for the future

First, and taking into account the research problems in every region, several avenues for future research can be put forward. From the point of view of fieldwork, in most of these countries it is necessary to undertake more detailed excavations with a larger number of radiocarbon dates. As the expense of radiocarbon dating and the problems dealing with the reservoir effect could make difficult to use radiocarbon techniques, other dating methods can be used to have large numbers of dates. Among them, Amino Acid Racemization is probably the technique showing the biggest potential, as has been demonstrated in the last few years (Demarchi et al., 2011; Ortíz et al., 2009). However, much more work should be conducted on this technique to achieve more precise results, because currently when D/L ratios are converted to dates, the standard deviation is much higher than that of the ^{14}C.

At the same time, it is also necessary to obtain more information on shell midden formation, carrying out micro-stratigraphic studies, in order to ascertain the true significance of accumulations and their chronology. The research should also aim to define habitation areas during the excavations in order to obtain a better understanding of the layout and organization of the shell middens and also to do comparative studies with ethnographic material/information from regions where the collecting and disposal of marine molluscs have taken place up to modern times. In addition, the causes for the gaps in the data for some regions and some periods should be clarified and attempts made to fill those gaps.

It is also necessary to make advances in the methodologies used, not only in terms of the molluscs, but also in the other kinds of materials. In this way, care should be taken to extract all the information that shells can give (species representation, gathering areas, fragmentation rates, biometrics, seasonality etc.), as they are the most abundant resource (see Dupont, 2006 and Gutiérrez-Zugasti, 2009 for examples of utilization of these methods). This

should use new recovery techniques, especially using at least 2 mm mesh screen size, so much more information can be obtained.

More studies should be conducted in order to obtain information on the environments where humans carried out their subsistence activities. For example, a new approach in Danish shell midden research is the application of analysis of the relative frequencies of small snail species in order to obtain further information on the micro-fauna and the environmental reconstruction (Nielsen, 2007). In the same way, biostratigraphic studies on marine molluscs can provide important information on the climate and the type of exploited environments. Other source of information can be the analysis of natural shell banks contemporary to the shell middens, so it can be determined if the middens contain the whole faunal range of the surrounding marine environment or just a selection. In some countries, mainly those with open air shell middens close to the coastline (e.g. Denmark), attempts should investigate how much of the content of the middens is a result of human collecting of different foods and how much is a function of natural sea sediments/deposits. In addition, new techniques as sclerochronology have been used to answer questions related with the nature of the occupation (year-round vs seasonal) (Milner, 2002; Mannino et al., 2003). However, in recent years, sclerochronological studies using oxygen isotope analysis on molluscs species, such as *P. vulgata* (Fenger et al., 2007), have demonstrated that these organisms can also be used for high resolution palaeoclimatic reconstruction.

It is also necessary to develop further the analysis of the human remains that have been found in middens (trace elements, stable isotopes), with the aim of obtaining more information about the diet of these groups and the role that molluscs and other marine resources played in their nutrition. These analyses can provide insights or even new research questions on many other topics related to the social and economic systems, and mainly with those about settlement and mobility patterns. Are the shell middens part of a more complex organisational system that includes other types of settlements where the exploitation of terrestrial resources took place, as seems to be the case in the Mesolithic of Portugal or in the Upper Palaeolithic of northern Spain? Is the existence of contemporary settlements without shells related to the existence of different cultural groups and some kind of territoriality, as seems to be the case in the Mesolithic of northern Spain? (Arias, 2006). Thus, it is essential in understanding/explaining the coastal shell middens, that these be compared with contemporary coastal or inland settlements without shell accumulations, and it would also be necessary to establish differences between shell midden sites within smaller, well defined regions, and see what the differences in size, content, etc. mean.

Using DNA analysis, information would also be obtained about the relationships between the populations of Atlantic Europe and their mobility, which can provide information on social questions. The presence of human remains has usually been interpreted from the subsistence point of view (palaeodiet), but it is important to understand what they mean from the social and symbolic perspective. In some cases (Téviec and Hoedic in France and sites from Muge and Sado Valleys in Portugal) it is possible to talk about cemeteries, which are related to the residential nature of these sites. However, in other areas, like Denmark or Spain, usually only scattered remains are found. However, are these differences related with post-depositional or with cultural processes? Is the occurrence of shell middens without human remains related with more sporadic occupations?

Thus, despite the long tradition in shell midden research in Atlantic Europe, many questions remain unanswered. Hopefully, the ongoing projects and the application of new analytical techniques will provide, enough data to answer them within the next few years.

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