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Salt production by ignition during the prehistory in the Iberian Peninsula with special focus on the archaeological site of Espartinas (Ciempozuelos, Spain)

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ABSTRACT
One of the prehistoric techniques of salt production consisted of using ceramic vessels, known as briquetage, for the artificial evaporation of salt water. This paper summarizes all the archaeological sites throughout the Iberian Peninsula where briquetage has been described to date, with special focus on the well-studied archaeological site of Espartinas saltworks. At Espartinas we found the use of two different kinds of ceramics, which points to a two-step process also involving halfish or esparto grass, which may well have been used for transport or/and as an insulating layer between the vessels walls and the mass of salt to facilitate the extraction of whole salt cakes. Palaeoenvironmental conditions at Espartinas have also been described based on local and regional pollen records and compared with the dry conditions associated to the so-called “4.2 cal kyr BP abrupt climatic event”. Despite the reduced amount of radiocarbon dating, the briquetage appears have been present in the studied region from the Late Neolithic to at least the Bronze Age. However, we cannot discard the fact that it might have reached the early Roman period, when salt evaporation ponds replaced this laborious technique. Moreover, briquetage distribution has been compared with evaporite outcrops throughout the Iberian Peninsula and it has been observed a characteristic pattern with a preference for peripheral, near to coast regions, with the exception of from Aranjuez-Getafe lower-Miocene lacustrine evaporites in central Iberia. Briquetage spread also shows a marked correlation with sites characterized by the presence of Atlantic halberds the first true metal weapon ever made in Western Europe and part of the warrior panoply of Late Copper Age/Early Bronze Age elites. At least during this period, these findings suggest that briquetage was used to obtain solid salt cakes easily transportable to medium and large distances by Atlantic and intra-Iberian trade exchange networks, which confirms previous studies that associate Bell Beaker phenomenon with salt circulation.

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Key points

- A review of evidence of briquetage in the Iberian Peninsula Prehistory is described
- Factors that appear to have affected the distribution of briquetage are described
- During the Late Copper Age/Early Bronze Age a marked correlation between briquetage sites and Atlantic halberds is described
- Salt pans appear to have been highly demanded by prehistoric communities during environmental conditions associated with the 4.2 cal kyr BP climatic event

1. Introduction

Salt in prehistoric times was a vital product as it had many uses ranging from nutritional to symbolic (Harding, 2013). Apart from being a flavour enhancing substance, most importantly, it could be used for preserving, and curing meat, fish and cheese products. For this reason, salt was employed, both for domestic and industrial uses, notably for the preservation of foodstuffs, being one of the most efficient ways to do so before the invention of refrigerating systems in the second half of the 19th century (Shachman, 2000). As a consequence, salt intake and utilization became integral to community’s daily activities, and those residing in salt-rich regions would have harnessed salt for their needs, possibly even trading it with areas lacking their own salt sources (Erdogu et al., 2003). After the Neolithic, when exchange networks began to consolidate and livestock farming became more important in the subsistence and economy, salt seems to have gained greater importance (Weller, 2015). Livestock farming requires a significant contribution of salt to make cattle gain weight and keep them healthy (~20 kg per year; Cifani, 2020), and meat and fish products required to be salted in order to be preserved or exported by long distance trade networks in temperate areas of the ancient world. Consequently, it is not surprising that early prehistoric salt extraction has been recognized in diverse regions of Europe (e.g., Weller, 2000; Harding, 2013), as evidenced by activities such as salt mining, boiling saline brines, or employing salt pans employment. As sedentarism increased, the interest in methods of food preservation for longer periods would have grown, and salt probably played a significant role in this.

In prehistoric technology, among the most peculiar ways to obtain salt from sea water or brine springs, we can distinguish the method called briquetage, based in the use of ceramic vessels and artificial evaporation of salt water. This method is recognized in prehistoric archaeological records by numerous fragments of poorly fired ceramic vessels made by hand, clay pellets, charcoal and ashes layers. In addition, soils colour modification (rubefaction) corresponding to oven pits or cookers floor’s, pedestal vessels (ceramic or stone) should be identified. This technique is worldwide attested and field experiments confirm that is quite complex and laborious (Daire, 1994; Tencariu et al., 2015). The aim of this method was to produce compact salt cakes that were easily transportable, likely intended for trading purposes (Monah, 1991). Salt production using briquetage has been identified as early as in the Neolithic and Chalcolithic in Britain (France, Saile, 2000, 2012), Poland (e.g., Frań, 2001), Germany (Saille, 2000), Spain (Abarquero Moras et al., 2010), and the Balkans (e.g., Tasić, 2000; Weller and Dumitroaia, 2005; Nikolov, 2008; Nikolov, 2012), continued and expanded during the middle Bronze and late Iron ages to other regions like Italy (Alessandri et al., 2021).

In the Iberian Peninsula briquetage was described for the first time in the Late Neolithic (La Marismilla site (Seville), Fuente Camacho (Granada), Monte da Quinta (Santarém), dating approx. to the second half of the 4th millennium BC (Terrán Manrique and Morgado, 2011; Valera, 2017; Escacena Carrasco and García Rivera, 2019) (Fig. 1). In contrast to what was found in the rest of Europe (Harding, 2013, 2021), here Middle/Late Bronze and Iron Age salt production related artefacts are rare (e.g., Santistoste site (Abarquero Moras et al., 2012)) and scarce evidence of mining or processing salt has been found. Instead, most of the clear evidence for salt exploitation in Iberia dates back to the Chalcolithic and Bell Beaker period, when indications of salt production by evaporation, are found both inland and along coastal lagoons. Nonetheless, description and level of knowledge of these sites is very uneven and radiocarbon dates are only available in few of them (Table 1) with archaeological campaigns only completed at some locations. While individual and regional studies have been conducted (e.g., Ramos Muñoz et al., 2013; Valera, 2017; Guerra-Doce et al., 2023) comprehensive analysis of the salt production phenomenon considering the Iberian Peninsula scale including geological, environmental, climatic and cultural factors is lacking and only some summarizing attempts have been made (e.g. Morère, 2002).

To have a better understanding of briquetage in the Iberian Peninsula, we are going to carry out the first compilation of these deposits following a multidisciplinary approach that will enable us to reach a better understanding of this salt works technology distribution and cultural connections. We selected the archaeological site of Espartinas (Madrid) as a case study, reviewing previous data and recovering new unpublished images and figures. Finally, we conduct a thorough comparison involving cultural elements, environmental factors, and geological reconstructions. This comprehensive analysis aids in gaining a deeper understanding of the significance of this technology in prehistoric times.

2. Regional setting

The Iberian Peninsula is located at the western end of the Himalayan-Alpine collision zone (Rosenbaum et al., 2002), a territory rich in evaporite rocks outcrops with ages that range from early Mesozoic to Quaternary (Gonzalez-Esverti et al., 2023). Mesozoic evaporite deposits are frequently deformed in the Iberian Peninsula with structures that correspond to anticline cores, detachment horizons and allochthonous bodies (e.g., Martínez del Olmo et al., 2015; Vergés et al., 2020). On the other hand, Neogene and Quaternary deposits within the Cenozoic foreland basins have practically been unaffected by deformation. The Iberian Peninsula uplifting formed many endorheic drainage conditions during the Paleogene and Neogene and coupled with intense evaporation favoured evaporite deposition in Douro, Ebro and High Tagus foreland basins (Escavy et al., 2012). This geography led to the term “Salado” (salty) being a common name for many streams in the peninsula.

Additionally, the Iberian Peninsula has about 7000 km of coastline from a Mediterranean facade with no tidal changes and to the Atlantic side with strong tidal currents. In coastal salt marshes with tidal influence and high potential evapotranspiration salt can precipitate in solid form (Shen et al., 2018). A high spatial variation in precipitation and evapotranspiration is another key feature of the Iberian Peninsula. Highest precipitation values exceeding 2200 mm are observed in the mountainous areas of north-eastern Continental Portugal (Serra do Gerês), in the northeast of Navarra and in some areas of the southwestern Galicia, close to the “Rías Baixas” in Spain. The lowest values were recorded in the southeast of Spain with an annual rainfall average below 300 mm, dropping to less than 200 mm in some areas. Regarding the potential evapotranspiration, it oscillates between 600 and 1400 mm, with the highest values in the Guadalquivir valley and southeast of...
First evidence of intense alterations of the landscape by humans dated back to the Copper/Bronze Age (~4.2 kyr) and mining pollution (García-Alix et al., 2013; Alba-Sánchez et al., 2021). This region played a key role in both Atlantic and Mediterranean social and exchange networks during prehistory, as evidenced since at least the Upper Palaeolithic period (Cortes et al., 2020). Additionally, there are indications of longstanding maritime connections dating back to the Middle/Late Neolithic, as seen in findings such as obsidian (Terradas et al., 2014) and Baltic amber (Murillo-Barroso et al., 2023).

For the Iberian Peninsula the current state of knowledge on salt extraction deposits by ignition with traces of briquetage is still in an incipient state, despite major efforts of different research groups. The first description dates back to the early 21st century and, up to now, a total number of 16 locations with different emplacements have been described (Fig. 1) to different extents (Table 1). We believe that this number will increase in the future as long as the interest of research groups in this topic grows in this region. Despite these limitations, a few general observations can be obtained based on the compilation of recent publications.

We selected the Espartinas briquetage deposits (Figs. 2–10) as a case study since it constitutes one of the peninsular and European references in obtaining salt by means of ignition (Weller, 2015). At this location, situated in the south of the municipality of Ciempozuelos (Madrid), a series of excavations were carried out in 2001, 2002 and 2003, primarily focusing on a prehistoric waste dump deposit, reaching a height of ~9 m (Fig. 6) and mainly composed of briquette materials. Abundant ceramic remains were extracted (Fig. 9), including pedestals (Fig. 7), and some of which of the Bell Beaker type (Fig. 8), ashes (Fig. 6), abundant rubefacted materials and small rafts made of clay were extracted. Recently, vestiges of a fortified settlement with a moat, which is in the process of study, have been located barely 1 km from the Espartinas waste dump (Figs. 2 and 3, green area).

3. Methodology

3.1. Pollen analysis

During the 2001 excavation season, four sediment samples of 10 square cm for pollen analysis were extracted from profile 3C-E (levels IX, level VI right, level VI center, level VI left), located in a prehistoric waste...
Summary of briquetage sites radiocarbon and ceramic based dates and periods. All dates have been calibrated with CALIB 8.2 (Stuiver and Reimer, 1993) using the most recent calibration curve INTCAL20 for continental samples and MARINE20 for shell based radiocarbon dates. Briquetage sites active during the Late Chalcolithic/Early Bronze Age are marked in bold and underlined.

<table>
<thead>
<tr>
<th>Area</th>
<th>Site and Laboratory code</th>
<th>Sample</th>
<th>Radiocarbon age (yr BP)</th>
<th>Calibrated age BP (95.4% confidence interval, 2 sigma) INTCAL20/MARINE20</th>
<th>Median age (cal yr BP) INTCAL20/MARINE20</th>
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<th>Estimated Age Ceramics</th>
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<td>–</td>
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<td>–</td>
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<td>–</td>
<td>–</td>
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<td>Abundant Bell Beaker ceramic among others</td>
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Table 1 (continued)

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</table>

Fig. 2. Espartinas (Ciempozuelos, Madrid) briquetage site landscape during the 2002/03 archaeological excavations. On the right side the brine spring can be observed, white color corresponds to salt crusts. Image taken by the authors of this study.
following standardized techniques for archaeological sites as described in López-Sáez et al. (2003). Sample preparation was carried out at the CSIC labs (Madrid) using standard HCl sieving, HF and density separation techniques (solution density 1.9) outlined in Burjachs et al. (2003). After processing, the samples were suspended in glycerine prior to being mounted on slides. Counting was undertaken using a Nikon Eclipse 50i light microscope until a sum of 250 total land pollen (TLP) had been achieved, excluding indeterminable pollen grains (i.e., those that were broken, concealed, corroded, crumpled or degraded), as well as Cardueae and Cichorioideae with possible zoophily (López-Sáez et al., 2003). Palynomorphs were identified at 400× and 1000× magnification to the lowest taxonomic level possible. Identification was based on the European and North African Atlas (Reille, 1999), and the pollen reference collection at the Institute of History (CSIC-Madrid). Olea pollen type was discriminated according to Renault-Miskovsky et al. (1976). The pollen diagram was constructed using TILIA 2.0 and TGView software (Grimm, 1993) and percentages were based upon the TLP (Fig. 11).

### 3.2. Age estimation in briquetage deposits

The entire set of ceramic remains (briquetage) found in different strata, are mixed with pieces of mud or rubefied clays, ashes, remains of combusted plant material, allowing the application of different absolute chronology systems (i.e., C14, thermoluminescence, etc). The abundance of handcrafted ceramic fragments, each displaying a typology distinctive to specific cultural chronological periods, holds the potential for precise temporal and cultural attribution of these deposits (e.g., Terán Manrique and Morgado, 2011; Ayarzagüena Sanz, 2019). Basing on the ceramic typology characteristics of each of the chronological periods, authors can attribute briquetage deposits to Late Neolithic, Chalcolithic, Early, Middle and Late Bronze and Early and Late Iron Age at least (Table 1).

A total of 39 radiocarbon dates between ~7.2 and ~3.6 cal kyr BP from 8 areas with evidence of briquetage have been summarized
Arqueológico y Paleontológico de la Comunidad de Madrid (Alcalá de Henares, Madrid).

These dates were reviewed from previous publications and a new date presented from Arcos de las Salinas (Teruel). All dates have been calibrated or re-calibrated with CALIB 8.2 (Stuiver and Reimer, 1993) using the most recent calibration curve INTCAL20 for continental samples and MARINE20 for shell based radiocarbon dates. The marine reservoir correction in dated marine samples was calculated based on the 20 nearest samples from the Iberian margin close to Lisbon (38.50°N, 9.44°W). The weighted mean ΔR = 25 ± 140 yrs.

5. Discussion

5.1. Briquetage sites in the Iberian Peninsula and the case study of Espartinas site

Espartinas site is located on a hillock plain formed by gypsum and clayey marl materials dating back to the Miocene, originated from the ancient Tertiary Depression of the Tagus River (Fig. 1). These hills are crossed by small streams that have created numerous runoffs between the gypsum cliffs, opening springs and brackish water surges (Figs. 2 and 3) which have created an area with important brackish outcrops that have been exploited since prehistory. In the cases of Espartinas, Valdelascasas-Sotomayor and Arcos de las Salinas (Fig. 1), prehistoric brine extraction was carried out on the Miocene hills and outcrops through open mine shafts over mid-slope springs. Extraction from wells has been verified in the salt flats of Villafáfila (Fig. 12), derived from brackish wetlands where salt extraction has persisted until modern periods (Delibes de Castro et al., 2020). In other inland sites, salt springs have been described (i.e., Agrina, Gerri de la Sal and Loja) (See Table 1 for references) as well. In coastal regions, former lagoons, salt lakes, or coastal lagoons, it is highly probable that brine extraction took place through wells, which retrieved it from a specific depth in the sand or possibly by washing of very fine sand. (i.e., Cultura de los Silos de Baja Andalucía, Cassen et al., 2004; Cassen et al., 2008), also using rock or removable sinks (Bettencourt et al., 2021) or other undescribed methods to date.

Archaeological findings at Espartinas, coupled with experimental approaches (Tencariu et al., 2015), enable us to reconstruct the process of obtaining salt by ignition. In a very simplified manner, we can interpret the existence of settling ponds (Fig. 5) and open-air bonfires used as cookers (Fig. 4), where the vessels containing brine content were heated using a base (Fig. 7). At Espartinas we found various types of vessels of different sizes, generally characterized by very open rims. The overall process involved a complex transformation from brine to a salt slurry with diverse concentrations (Abarquero Moras et al., 2012; Ayarzagüena Sanz, 2019). The study of 21 ceramic sherds with plant impressions by silicone molds confirms the use of basketry textiles in the vessel and/or salt processing, and they geometrically
Fig. 9. Top: Large ceramic vessel reconstruction from fragments recovered at Espartinas during archaeological campaigns from 2001/02 at Museo Arqueológico y Paleontológico de la Comunidad de Madrid (Alcalá de Henares, Madrid). Bottom: Reconstruction drawings of large and small ceramic vessels from fragments recovered from Level X Section 3C-E at Espartinas.

Fig. 10. Pot fragments with imprints of basketry impressions from level X at Espartinas, at Museo Arqueológico y Paleontológico de la Comunidad de Madrid (Alcalá de Henares, Madrid).
decoration is congruent with the use of esparto grass (*Stipa tenacissima*) (Valiente Cánovas et al., 2003). The site name “Espartinas” means “related with esparto” in Spanish and expert craftworks in esparto grass (*S. tenacissima*) has been in Iberia at least since the Neolithic (Martínez-Sevilla et al., 2023). These impressions mainly appears to occur in vessel exterior and only a few in the interior. Exterior plant imprints could point to the use of basketry or wickerwork for ceramic transport or hanging. It is has been hypothesised that ceramic containers might also have tried to imitate the organic sachets in which salt was distributed (Guerra-Doce et al., 2023). These impressions mainly appears to occur in vessel exterior and only a few in the interior. Exterior plant imprints could point to the use of basketry or wickerwork for ceramic transport or hanging. It is has been hypothesised that ceramic containers might also have tried to imitate the organic sachets in which salt was distributed (Guerra-Doce et al., 2023). On the other hand, interior imprints are aligned with field experiments that recognize the value of an insulating layer used for the intact recovery of the salt block, consistent with ethnographic observations (Reina and Monaghan, 1981). Coherently, sherds showing basketry impressions were also observed at Villafáfila (Guerra-Doce et al., 2023; Delibes de Castro et al., 2020). Once the brine precipitated in these prehistoric ceramics, the salt remained inside. Subsequently, the containers were broken and thus the salt cakes extracted. Accumulation of ash, sediments and broken containers originated thick anthropic deposits reaching 9 m thickness in the case of Espartinas (Fig. 6). All of the above-described elements have been retrieved from the referred briquetage sites, with excellent preservation in the case of Villafáfila (Delibes de Castro et al., 2020) among others. One exception is the site of Marismillas, where briquetage deposits are not accompanied by ash or charcoal remains (Escacena Carrasco and García Rivero, 2019).

Near Espartinas, numerous hut floor sites close to these sources have been excavated and documented (Valiente and Ramos, 2009). Important vestiges of Bell Beaker pottery of the so-called “Ciempozuelos style”, have been documented in the area near this site. The most well-known example is the cemetery of Cuesta de la Reina (Ciempozuelos, Madrid), where several tombs with outstanding metal, ceramic grave goods and exotic ornamental objects were discovered in the late XIX century (Riaño et al., 1894). These important discoveries named a new type of pottery, since then known as the “Ciempozuelos style”, which appears in most of the interior of Iberia (Garrido-Pena, 2000). This particular pottery type and its commonly associated objects, such as ivory buttons and beads, copper weapons and tools, stone wrist-guards, and gold jewellery, are typically found in both domestic and funerary...
contexts. Nonetheless, while in domestic settings, these ritual sets are frequently represented by scattered potsherds, always a minority amongst the total repertoire of ceramics of the site (Garrido-Pena, 2019), in the burial sphere, the most spectacular examples can be found. In the last years very interesting findings and research have been published about salt production centres directly related with Bell Beaker pottery, such as the site of Molino Sanchón II, near the lagoons of Villalafáila (Zamora) (Abarquero Moras et al., 2012; Guerra-Doce et al., 2015; Delibes de Castro et al., 2020). Interestingly, the contexts where most well preserved Beaker pottery has been found are ritual deposits (Delibes de Castro et al., 2016), which points to ceremonials being directly related with the exploitation of the salt as a key resource. Moreover, it seems that the control of salt could have been one of the means by which emergent leaders could reach and maintain power (Delibes de Castro and Val Recio, 2008), together with the accumulation of surpluses to acquire these prestigious products (Ayarragüena Sanz and Carvajal García, 2005).

The radiocarbon dating of Espartinas offers a radiocarbon age of 3731 ± 32 yrs BP (3979–4224 cal yr BP), suggesting that this saltworks were in use during the transition to the Early Bronze age (~4200-3500 cal yr BP) in the Iberian Peninsula (Valiente et al., 2009). The briquetage age compilation (Table 1) indicate that briquetage deposits appear during the Late Neolithic and persisted at least until the Late Iron Ages, becoming especially abundant in the studied area during the Early Bronze Age (Fig. 2).

5.2. The “4.2 cal kyr BP event” in the Iberian Plateau

Pollen assemblages from Espartinas site associated to the briquetage layers are characterised by low tree cover and high values of xerophytic taxa (Fig. 11), which suggests a dehesa-like landscape and the advent of a markedly arid phase, during which riparian forests would have been greatly reduced, while elements associated with drier conditions would have expanded. These facts could be associated to the so-called “4.2 cal kyr BP event” (Magny, 2004), an abrupt climate episode characterized by a marked aridification phase in the Mediterranean Iberian region (Jalut et al., 2009; Carrión et al., 2010). In the Iberian Peninsula recent studies show that this event present a characteristic double-peak centered at ~4.5 and ~4.2 cal kyr BP recognized in both pollen stacks (e.g., pollen stack based on 107 pollen records from Iberia and Morocco of the arid-adapted Artemisia, Camuera et al., 2023) and speleothem data (e.g., Thatcher et al., 2020) (Fig. 13). This dry pulse has been associated to North Atlantic Oscillation positive index conditions (Olsen et al., 2012). This abrupt climatic event is broadly coincident with the Bell Beaker phenomenon onset (Fig. 13) and also had an significant impact on the Iberian prehistory in the Chalcolithic-Bronze Age transition from a cultural, demographic and palaeoenvironmental point of view, particularly on both the northern and southern plateaus (Fabián et al., 2006; Delibes et al., 2015; Lillios et al., 2016; Blanco-González et al., 2018; Pérez-Díaz et al., 2019).

The 4.2 cal kyr BP abrupt climatic event has been also detected from the pollen record of some archaeological sites in La Mancha (southern Iberian Plateau) such as Motilla del Azuer or Castillejo del Bonete where it had a significant impact on the settlement patterns and palaeoecological practices (López-Sáez et al., 2014b, 2017a; Benítez de Lugo et al., 2014, 2015). Furthermore, it has been proposed that the origins of social inequality in the Bronze Age in La Mancha could be traced back to rituals and monuments designed to regulate wealth during this period (Benítez de Lugo et al., 2020). Interestingly, in the eastern part of La Mancha region, many archaeological sites belonging to the ‘Motillas culture’ (Bronze Age), are characterized by deep wells excavated to capture groundwater (e.g. the Motilla del Azuer is the oldest well in Europe with a masonry lining), which were built precisely between ~4150 and 4000 cal yr BP and it is significative that all of them collapsed after the end of the event (Mejías et al., 2015, 2020). Meanwhile, on the northern plateau, the pollen record of the Villalafáila lagoon complex (López-Sáez et al., 2017b), where salt exploitation has been documented since the Bell Beaker period around ~2450 cal yr BC (Abarquero et al., 2017), provides irrefutable evidence of salt exploitation during the Chalcolithic period. This coincides with the findings at the Espartinas site, where extremely intense human impact coincides with an extremely arid phase between ~2300 and 2000 cal yr BC, which was marked by the development of anthropic-nitrophilous grasslands and xerohalophilous herbs (Valiente et al., 2007).

5.3. Key factors for briquetage sites distribution in the Iberian Peninsula

Although the described briquetage sites are not contemporary and considering that the number of discovered locations with briquetage will most probably increase in the near future, we can still make a series of observations regarding the spatial distribution of the said sites in the Iberian Peninsula.

Firstly, the presence of evaporite outcrops where salt and brines are present is not the main control for the briquetage distribution in the Iberian Peninsula (Fig. 1). Up to date, major evaporite outcrops, especially in the Mediterranean basins, do not show common evidence of briquetage with the exception of Arcos de las Salinas (Teruel). This lack of direct correlation could be linked to several factors: (1) the diverse nature and quality of brines potentially obtained from these outcrops; (2) the accessibility of locations in remote or challenging areas; (3) the possible lack of briquetage preservation or access to areas like plains or past marshland, presently buried or other highly erosive locations (river bank, hilltops, etc) where archaeological evidence would have not been preserved and/or (4) other geological factors like the presence of rock salt that could have been exploited and simplified the extraction of salt (NE Iberian Peninsula, in Cardona, a salt mountain has been mined since the Neolithic (Weller, 2002)).

Second, in a diachronic approach briquetage appears as an Atlantic, and central Iberian and South Pyrenean phenomenon (Fig. 1). During the Neolithic and Early/Middle Chalcolithic we observe a preponderance of sites placed in Atlantic estuaries like Tagus, Sado, and Guadalquivir (the site of Marisimillas was placed in the Guadalquivir estuary during reviewer comments.
the Late Neolithic, Escacena Carrasco and García Rivero, 2019). Nevertheless, during the Late Chalcolithic/Early Bronze Age, inland sites were more abundant (Fig. 14).

Third, when compared with the archaeological elements, a striking correlation appears with those sites where Atlantic halberds were described (Figs. 1 and 14). The Atlantic halberds are a peculiar type of copper weapon (Fig. 15), made and used during a relatively short time (Garrido-Pena et al., 2022). Considering the amount of copper employed in their fabrication, they could have functioned even as a sort of ingots or accumulation of metal, and their presence is also documented in rock art and stelae (Garrido-Pena et al., 2022). Available lead isotope analysis indicate that Humanejos halberd has different sources as well as other metallic weapons for this period, but more copper mines from Iberia must be sampled to find the possible distant or local sources (Montero and García, 2019). Nevertheless, we know that these were intensely used and, in fact, they could be considered the first true metal weapons in Western Europe, given that the previous daggers/knives or axes were both tools and weapons. Atlantic halberds were only used for interpersonal violence, as part of the Beaker male “warrior” paraphernalia, as they are found especially in well-furnished elite male grave goods as in the tomb 1 of Humanejos (Garrido-Pena et al., 2022). For all these reasons, they were certainly a prized and exclusive possession and perhaps this is the reason why their geographic distribution is so similar to that of salt exploitation centres, mainly those of Beaker chronology. A parallel close spatial correlation was observed in Germany between salt springs and the distribution of greenstones long alpine axis, which possibly suggests that salt could have played a key role in the acquisition of these exclusive and ceremonial objects (Weller, 2002).

Fourth, climate conditions appear to have played a significant role in the distribution of briquetage sites in the Iberian Peninsula. All described sites are placed in locations where precipitation is lower than evaporation (Fig. 1, red line), although evaporite outcrops are present in northern areas as well. Briquetage sites along the coast were not active during the Late Chalcolithic/Early Bronze Age and we agree with previous authors that this probably indicates that they were abandoned because they could not contend with the arrival of inland salts (Valera, 2017). Likely it was easier to concentrate salt from brines containing up to 35 times more salt than sea water, placed in easily accessible slope springs (with the exception of Villafáfila) under dry atmospheric conditions, than from coastal sites, but we cannot discard other socio-cultural or economic factors. Additionally, salt heating could provide high quality and dry salt pans were very suitable for transport in long-lasting communication networks in a period with high demand and with the conditions associated to the so called “4.2 cal kyr BP climatic event”. This high demand could be related with the agricultural crisis linked with the aridity of this climatic event in the Iberian Peninsula (Schirrmacher et al., 2020). Despite the generalized name of “4.2 cal kyr BP event”, in the Iberian Peninsula the latter is characterized by two marked arid peaks dated at 4.5 and 4.2 cal kyr BP based on the stack of 107 palynological records from Iberian Peninsula and Morocco (Camuera et al., 2023) and speleothems (Thatcher et al., 2020) (Fig. 13), as well as in the Mediterranean basin (Di Rita et al., 2022). In addition, recent studies indicate that during this event the lowest sea surface temperatures were reached in the South Iberian margin (e.g., Català et al., 2019), torrential precipitation and floodings in the Tagus River occurred (Benito et al., 2023), while the driest conditions of the entire Holocene were observed in the Saharan region (van der Meer et al., 2022). This event also had a heterogeneous spatial impact since it was
almost absent in the British Isles and in the North European climate records (Bradley and Bakke, 2019) but extremely marked in central Europe (e.g., Magny et al., 2009; Zanchetta et al., 2016). Likely these regions faced an agricultural crisis that increased the relevance of cattle rising and, consequently, the demand for high amounts of salt for meat preservation and dairy products, a hard period for lactase non-persistent populations (Gamba et al., 2014; Evershed et al., 2022). During the Bell Beaker period some human groups may have controlled the exploitation and distribution of salt (Guerra-Doce, 2023) and salt demand could have been one of the reasons not only for the Bell Beaker Phenomenon expansion but also for its demise. Climate amelioration after the “4.2 kyr event” likely reduced the demand of salt, after agricultural recovery, and could be the reason for the chronological correlation between the Bell Beaker Phenomenon and the “4.2 kyr event” noticed in previous studies (Fig. 13) (López-Sáez et al., 2017b; Vander Linden, 2024). If certain groups or individuals during the Bell Beaker period controlled the circulation of salt, could a reduction of the relevance of salt trading have affected them? This question requires further studies.

Fifth, if only briquetage sites active during the Late Chalcolithic/Early Bronze Age are considered, together with their link to the Atlantic halberds distribution, we can observe a pattern that can be interpreted as the presence of three Atlantic salt distribution networks (Fig. 14).

i) From Villafáfila saltworks to the Douro estuary and Atlantic maritime networks (Fig. 14). This route is really clear and appears as a dotted pathway of sites with Atlantic halberds up to and through the Douro valley in most of the cases. Halberds had been described also in major Atlantic network hubs, like the region of Vigo (Fig. 14, Beluso, Leiro) where gold began to be exported in the Early Bronze (Armbruster and Comendador Rey, 2015). In this area, the Carreço beach camp-site (Viana do Castelo) near to the Limia river estuary, dated from 4230 to 3400 cal yr BP, also appears to have been active as an ignition saltwork (Bettencourt et al., 2021), but does not have the distinctive attributes of briquetage. Additional evidence of this well-known connection and richness of Villafáfila area is the presence of a girl’s burial pit containing exotic elements as silver and ivory dated (4415 - 4157 cal yr BP) in Santioste and, close to it, the votive offering of a complete calf (Abarquero Moras et al., 2012).

ii) From Central Iberia salt works to the Tagus/Sado estuaries: even though, up to date, the number of sites with halberds is limited in these regions, the Tagus valley or even through the Middle Guadiana area could be a region to explore in future works (Fig. 14).

iii) In Southern Iberia the connection between Atlantic halberds and briquetage is restricted to the site of Fuente Camacho (Loja), dated by ceramics from Late Chalcolithic to Bronze Age with abundant Bell Beaker remains and considered coetaneous to Espartinas and Villafáfila sites (Terán Manrique and Morgado, 2011). Nevertheless, it is remarkable that the distribution of the sites with Atlantic halberds is only found on the southern side of the Guadalquivir valley, close to the evaporitic outcrops (Fig. 1),
and in the routes to the Atlantic estuaries (Lacus Ligustinus) and to the southern Iberian Plateau (Fig. 14, Peñalosa). The Atlantic halberds are also not described to date in the southwest Iberia where Chalcolithic major archaeological sites and their “way of life” collapsed at the beginning of the Bronze Age at ~4.2 cal kyr BP (Soares and Tavares da Silva, 1998; Garcia Sanjuan et al., 2018). Their absence is surprising in the extremely rich copper, lead and silver mineral areas in the northern side of the Guadalquivir valley and the Tinto-Odiel estuary. Copper metallurgy in South Iberia has been dated to the Middle Neolithic (7th millenium BP) (Rovira and Montero-Ruiz, 2013) and they are widespread occurrences of copper mineralization in Spain and Portugal but the distribution of Atlantic halberds does not appear to fit with copper production sites. The only exception could be Cueva del Canaveralejo (Córdoba) dated from 4.5 to 4.2 cal kyr BP where new smelting techniques, similar to those from France and beyond were used (Bourgarit, 2007; La Duc et al., 2022). Atlantic halberds from Lebrilla and Arcos de la Frontera (Fig. 14) could connect to the Lacus Liguustrinus with the historic inland saltworks site of Iptuci (Valiente Canovas et al., 2016), but no evidence of briquetage has been found to date. Maybe in the Guadalquivir basin, with extreme evaporation rates, especially during summer, combustion heat was not required and used other techniques that did not generate ceramics were used, as open clay or wood recipients exposed to heating sunlight/wind, burning salted plants and collecting the salt grans from the ashes (e.g., New Guinea, Gouletquer and Weller, 2015) or discrete halite outcrops were being mined along the chaotic olistostromic Triassic Unit in South Iberia. In this sense, in the Late Neolithic site of Marismillas, briquetage layers are not accompanied by ash or charcoal remains (Escacena Carrasco and García Rivero, 2019), and in the Cádiz area only minor archaeological evidences of saltworks has been described (Aloino et al., 2003), despite the major role that salt should have played in the Neolithic and Chalcolithic communities (Ramos Muñoz et al., 2013). For this reason, previous authors point to different production techniques in this high evaporation region during prehistory, including the washing of sand (e.g., Cultura de los silos de Baja Andalucía, Cassen et al., 2004; 2008). This Southern Iberia saltworks “anomaly” also appears during the Roman period, when this region dominated the export of garum and salted fish products with many factories (Andrews et al., 2022), but coastal evaporite saltworks are rare, in opposition to northern-western Iberia with many coastal brine or saltwork sites (Currais, 2017). In any case the distribution of the Atlantic halberds in Southern Iberia also points to a mainly Atlantic character connecting evaporite sites with Atlantic estuaries (Fig. 1), but could also represent an inland route between the estuaries and the Southern Plateau, where the Motillas culture developed in association with the 4.2 event (Mejias et al., 2020) just in the way to Central Iberia saltworks.

The Atlantic character of the three suggested routes also emerges when compared with other Iberian Late Prehistoric networks. It is the case of the tin associated network active during the Bronze Age, where a marked North-South (Vía de la Plata route) connection appeared (Rodríguez-Corral and Rodríguez-Reyll, 2023), differing from the one present for salt transport. An equivalent to the described Atlantic saltwork site of Iptuci (Valiente Canovas et al., 2016) could connect the Lacus Liguustrinus with the historic inland saltworks site of Iptuci (Valiente Canovas et al., 2016), but no evidence of briquetage has been found to date. Maybe in the Guadalquivir basin, with extreme evaporation rates, especially during summer, combustion heat was not required and used other techniques that did not generate ceramics were used, as open clay or wood recipients exposed to heating sunlight/wind, burning salted plants and collecting the salt grans from the ashes (e.g., New Guinea, Gouletquer and Weller, 2015) or discrete halite outcrops were being mined along the chaotic olistostromic Triassic Unit in South Iberia. In this sense, in the Late Neolithic site of Marismillas, briquetage layers are not accompanied by ash or charcoal remains (Escacena Carrasco and García Rivero, 2019), and in the Cádiz area only minor archaeological evidences of saltworks has been described (Aloino et al., 2003), despite the major role that salt should have played in the Neolithic and Chalcolithic communities (Ramos Muñoz et al., 2013). For this reason, previous authors point to different production techniques in this high evaporation region during prehistory, including the washing of sand (e.g., Cultura de los silos de Baja Andalucía, Cassen et al., 2004; 2008). This Southern Iberia saltworks “anomaly” also appears during the Roman period, when this region dominated the export of garum and salted fish products with many factories (Andrews et al., 2022), but coastal evaporite saltworks are rare, in opposition to northern-western Iberia with many coastal brine or saltwork sites (Currais, 2017). In any case the distribution of the Atlantic halberds in Southern Iberia also points to a mainly Atlantic character connecting evaporite sites with Atlantic estuaries (Fig. 1), but could also represent an inland route between the estuaries and the Southern Plateau, where the Motillas culture developed in association with the 4.2 event (Mejias et al., 2020) just in the way to Central Iberia saltworks.

The halberd that appeared in the Southern Pyrenees region (Fig. 14, Gerona) is coincident with the network route proposed for Cardona salt rocks by Weller and Figuls (2012), where salt and other goods such as flint, variscite, jade, etc. were exchanged with Europe. The presence of these routes does not exclude the fact that ignition saltworks were also able to satisfy local and regional demands or that they could have been used for other products as amber or marine shells (Buono Ramirez et al., 2012).

Finally, our data are in agreement with previous studies suggesting that the communities of the Bell Beaker period may have controlled the exploitation and distribution of salt in Iberia (Guerra-Doce, 2017, 2023), the presence of Atlantic long-distance exchanges (Liesau et al., 2016) and that salt trade was one of the great sources of communication between people (Saile, 2012). The spread of Bell Beaker pottery is also related with very significant changes in the genetic evolution of the Iberian Peninsula, because it is when the Pontic-Caspian steppe-related ancestry first arrived in Iberia (Valdiosera et al., 2018) and when a major Y-chromosome turnover began (Olalde, 2019).

5.4. Comparison between briquetage in the Iberian Peninsula and Europe

In Central and Western Europe brine evaporation from ceramic vessels emerged during the Chalcolithic period, particularly in the mid-5th millennium BC (Weller, 2015). This development coincided with the appearance of the first copper objects. Nevertheless, there is scarce evidence from the rest of Europe, albeit, a fragment of a furnace discovered in southern Poland (Little Poland), together with small conical vessels and pits, interpreted as settling tanks that have been identified at Barycz VII site Krakow (Bukowski, 1985). Some similar examples of large-scale salt production, from the Middle Chalcolithic period and dated between 6700 and 6200 cal yr BP, can be found in the briquetage site of Provadia-Solnitsata (Bulgaria) where analogous elements, including pits and huge amounts of potsherds, have been identified (Nikolov, 2008, 2012). Apart from the common features, these sites are always found in the immediate proximity of the salt springs even though the exact exploitation technique remains largely unknown.

It was during the Bronze Age that Western Europe saw the emergence of combustion structures, and it took until the Iron Age for salt production facilities, in the true sense of the term, to be fully established (Weller, 2015). In contrast with the rest of Europe, where briquetage become widespread during the Bronze and Iron Age, the evidence for salt exploitation in Iberia seems to be particularly abundant in the Chalcolithic and Beaker periods (Weller, 2015), sharing still common features with European sites, notably the presence of scorched soil near salt springs or lagoons, along with a substantial quantity of pottery fragments that are identified as briquetage, pedestals to hold the pots over the open fire and artificially dug pits (Harding, 2013, 2021). We must keep in mind that Bell Beakers had different duration in different areas of Europe and even inside Iberia. Bell Beakers developed from 4.600/4.500 cal yr BP (earlier chronologies are dubious) across western Europe (Brunner et al., 2020; Vander Linden, M., 2024), but in Iberia disappeared from the southeast Iberian Peninsula by 4.300–4.200 cal yr BP, when the Argar Group emerged, as it happened in other European regions such as central Europe, when Unetice culture began (Moucha, 1963). Nevertheless, in the interior of Iberia we have outstanding examples of Bell Beaker tombs until around 4.000 cal yr BP (Garrido-Pena, 2000, 2014). Therefore, Bell Beakers occupied part of the Chalcolithic (the second half) and the beginning of the Bronze Age. It seems that the duration of Bell Beakers in any given region is the measure of the process of social change developing there. Beakers seem to have occupied a transitional position between the first signs of social ranking to the fully hierarchical societies of the Bronze Age. When this process was quick and strong Beaker period was shorter, when it was weaker and slower their presence was prolonged, as in the interior and other regions to the north of Iberia (Garrido-Pena, 2006, 2014).

During the early Bronze Age, salt-production by means of briquetage became increasingly prominent especially in the region along the Saale
River (east-central Germany) where a large quantity of ceramic vessels, trays and pedestals have been recovered (e.g., Riehm, 1962; Matthias, 1976), while in Breña a pottery kiln with numerous oval trays has been found (von Rauchhaupt and Schunke, 2010) in agreement with the pattern observed in the Iberian Peninsula. In Pisa (Italy), salt production through brine evaporation, in this case sea water, appeared in the early/middle Bronze Age, with the earliest sites being Isola di Coltano (Pasquinucci and Menchelli, 2002) and some along the Tyrrenian coast of Lazio like Caprolace (Alessandri et al., 2019). These sites are also characterized by high abundance of pottery. On Isola di Coltano, cy

Visualization. J.A.L.-S. Investigation, Writing- Review, Methodology, Conclusions. J.M.C. Investigation, Writing- Review

4. Conclusions

The reviewed spatial-temporal distribution of briquetage sites in the Iberian Peninsula to date has allowed us to reconstruct the use of this peculiar technology to obtain salt during Late Prehistory. The distribution of briquetage sites is not only influenced by the presence of evaporites or sea water, but also by climate conditions, exchange networks or the presence of other salt sources as salt rocks.

The summarized new information from archaeological excavations at Espartinas briquetage site allowed us to identify the common features of this technology in Iberia. This site highlights the complexity of this technique involving the use of two different containers and likely boiling processes, probably to reduce salt Mg content, and the use of plants/ plant material as covet, decoration or insulating layers in ceramics.

During the Bell Beaker temporal horizon (Garrido-Pena et al., 2005), active briquetage saltworks show a striking correlation with those sites with presence of Atlantic halberds summarized in Fig. 14. This comparison allowed us to infer new Atlantic long-lasting communication networks where briquetage sites appear to have had a key position. We also linked the relevance of salt consumption to the extreme arid conditions established in certain areas of Western and Central Europe during the so called “4.2 kyr event”, which in Iberia appears as two differentiate pulses at ~4.2 and ~4.2 kyr (Cámara et al., 2019). Our study is in agreement with previous works showing that Bell Beaker human groups may have controlled the exploitation and distribution of salt (Guerra-Doce, 2023). We hypothesize, in order to explain the chronological link between the Bell Beaker Phenomenon and the “4.2 kyr event” in the studied region, that the drop in salt demand after climate amelioration could have affected its development and/or their symbolic expressions. The briquetage phenomenon in the Iberian Peninsula shows certain similarities with this technology from other European sites during the Chalcolithic and early Bronze Age, but it appears to have declined during the Late Bronze and Iron Ages compared with the European trends.

We hope that this study will stimulate the briquetage saltwork research and the discovery of new briquetage and Atlantic halberds sites, allowing to either validate or refute our observations and conclusions.

Author statement


Declaration of competing interest

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

Data availability

Data will be made available on request.

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