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SPATIOTEMPORAL PATTERNS ON THE APPEARANCE OF THE FIRST TRAPEZE INDUSTRIES IN THE LATE MESOLITHIC OF THE IBERIAN PENINSULA

Magdalena Gómez-Puche* • Javier Fernández-López de Pablo

Instituto Universitario de Investigación en Arqueología y Patrimonio Histórico (INAPH), University of Alicante, Carretera de San Vicente del Raspeig s/n, 03690, San Vicente del Raspeig, Alicante, Spain

ABSTRACT. The spread of trapeze industries (the creation of trapeze-shaped flint tips) during Late Mesolithic is one of the most disruptive phenomena of technological change documented in the European Prehistory. Understanding the chronological patterns of this process requires (i) a critical evaluation of stratigraphic relationship between trapeze assemblages and radiocarbon samples, and (ii) considering different levels of chronological uncertainty according to the inbuilt age of the samples and the calibration process. In this paper, we critically evaluate and analyze the radiocarbon record of the first trapeze industries in the Iberian Peninsula. A dataset of 181 radiocarbon dates from 67 sites dated to 8800–8200 cal BP was collected and evaluated following a strict data quality control protocol, from which 135 dates of 53 sites were retained and classified according to a reliability index. Then, three different phase Bayesian chronological models were created to estimate the duration of the first spread of trapezes across Iberia, considering different levels of chrono-stratigraphic resolution. We find that trapeze industries appeared in the eastern half of Iberia, over an area of 330,000 km^2 between 8505–8390 and 8425–8338 cal BP, spanning 0–85 yr (95.4% CI). When the oldest evidence of trapezes from Portugal are considered, the probability distribution expands (8943–8457 and 8686–7688 cal BP), due to the chronological uncertainty of human samples with marine diet and regional ΔR values applied. For the eastern half of Iberia, the current evidence indicates a very rapid spread of trapeze industries initiated in the Central-Western Pyrenees, suggesting cultural diffusion within Mesolithic social networks as the main driving mechanism.

KEYWORDS: Iberian Peninsula, Late Mesolithic, radiocarbon, trapeze industries, trapeze-shaped flint tips.

1. INTRODUCTION

1.1. Historical Background of the Late Mesolithic at European Scale

The Mesolithic of trapezes also known as the Late Mesolithic of trapezes, the second Mesolithic or Geometric Mesolithic is characterized by lithic assemblages of regular blades and bladelets produced by pressure and/or indirect percussion, notched blades and trapeze microliths (Binder et al. 2012; Perrin and Binder 2014; Marchand and Perrin 2017). This specific type of trapeze-shaped flint tip entailed a novel mode of manufacturing projectiles for hunting tools. Such a technological system widely spread out in Central and Western Europe, as well as the north of the Maghreb region, at the end of the Early Holocene (8600–8200 cal BP). Where found in stratigraphic position, the Mesolithic of trapezes always overly different technocomplexes the Notched and Denticulated Mesolithic in Iberia (Utrilla and Montes 2009), the Typical Capsian in Tunisia (Rahmani 2003) and the Upper Sauveterrian in Italy and France (Valdeyron 2008) whose debitage systems and microlith technology were radically different.

The wide geographic distribution of this cultural phenomenon has brought the attention of archaeologists for decades (e.g., Clark 1958; Perrin et al. 2009; Perrin et al. 2010; Marchand and Perrin 2017). Grahame Clark proposed that the spread of the Mesolithic of trapezes across Europe was driven by different human dispersal processes prior to the Neolithic colonization (Clark 1958). Since then, different hypotheses have been proposed about its geographic provenance: the Crimean Peninsula (Biagi and Starnini 2016), and, more recently, eastern Maghreb (see below, Perrin et al. 2009, 2010; Marchand and Perrin 2017).

*Corresponding author. Email: magdalena.gomez@ua.es

Over the past years, works by Perrin et al. (Perrin 2019; Perrin et al. 2009, 2010), and Marchand and Perrin (2017) have set the methodological grounds to this debate by conducting large-scale critical evaluation of both the techno-typological and radiocarbon evidence. Adopting a macro-regional approach considering North Africa, the central and Western Mediterranean basin, Western Europe, and the Iberian Peninsula, Marchand and Perrin (2017) explored the spatio-temporal patterns of the first appearance of the trapeze industries. These authors suggested a North African origin in Tunisia and eastern Algeria related with the Upper Capsian techno complex, from which jumped to Sicily to reach the southern of the Italian Peninsula, and from there, to spread northwards to reach Northern Italy, Southern France, and the Iberian Mediterranean region (Perrin et al. 2009, 2010; Marchand and Perrin 2017). More recently, Perrin and colleagues have thoroughly evaluated a database of more than 600 archaeological sites from North Africa, to conclude that the precedence of trapeze industries in Maghreb over Europe cannot be demonstrated considering the significant degree of chronological overlapping, suggesting a co-evolution of trapeze industries between both geographic areas (Perrin et al. 2020: 47).

The Iberian Peninsula plays a major role on the understanding of the tempo and diffusion modalities of trapeze industries in Europe. Its cul-de-sac position at the southwestern tip of the Eurasian continent, and bridge condition with respect to North African regions, allow to test different hypothesis regarding its geographic origin. In addition, its wide extension with relevant physical barriers and interregional corridors allow to explore the role of physical geography in all processes involving the movements of people and ideas. Finally, in the Iberian Peninsula, the Mesolithic of trapezes taxonomically related with the so-called Geometric Mesolithic, has been intensively investigated over the past two decades (Utrilla and Montes 2009 and references therein), producing a significant body of chronostratigraphic and lithic technological information to discuss the tempo of appearance and spreading dynamics of trapeze industries.

In the Iberian Peninsula, the Mesolithic of trapezes signifies a major break in lithic technical systems regarding the previous Notched and Denticulated Mesolithic. The selection of high-quality flint from local raw material sources has been consistently reported in different studies (Cava et al. 2008; Jover et al. 2012; Soto et al. 2016) and related with the new requirements resulting from the reintroduction of the micro-blade production. Where core bladelets and diacritic analyses of *plein debitage* bladelets have been performed (Fernández-López de Pablo 2001; García Puchol 2005; García-Puchol and Juan-Cabanilles 2012; Soto 2014), unipolar knapping strategies are dominant, following a frontal exploitation pattern for the laminar table, with debitage exploitation rhythms of (1-2-3 or 3-2-1). Regarding the debitage technique, different studies have reported the use of indirect percussion in Portugal (Marchand 2001) and the Upper Ebro Valley (Soto 2014), while others consider the coexistence of indirect percussion with the pressure (Perrin and Binder 2014). The production of notched blades and bladelets and the use of the microburin technique to segment blades/bladelets blanks is well documented in most of the Mesolithic of trapeze assemblages. Finally, the trapeze microliths with abrupt retouch display a certain degree of morphological variability whose chronological significance, in terms of seriation, has been discussed by different authors (Utrilla and Rodanés 2004; Utrilla et al. 2009).

The present study aims to evaluate the stratigraphic and radiocarbon record associated to the first appearance of Mesolithic trapeze industries in the Iberian Peninsula in order to discuss different hypothesis about its geographic origin and diffusion mechanisms. To this end, in this study we have adopted a data-driven, bottom-up perspective, evaluating both the stratigraphic and radiocarbon record associated to each lithic assemblages with trapezes across Iberia.

2. MATERIALS AND METHODS

2.1. Data Collection

An extensive compilation of radiocarbon dates from Iberian Mesolithic lithic assemblages dated to between 7900 and 7400 BP (8800–8200 cal BP) was conducted for this study using gray literature. The data set is composed of 67 archaeological sites and 181 radiocarbon dates from Spain and Portugal. Dates from closed sites represent almost 70.1% of the total (rockshelters = 37.3%, caves = 32.8%), whereas open-air sites the 29.9%. For each dated assemblage, we have also collected information about the presence or absence of specific techno-typological categories related to the Mesolithic of trapeze lithic industries: trapezes, notched blade/bladelets, and microburins.

Radiocarbon dates obtained by the AMS method represent almost 80% of the collection. Charcoal samples represent the largest group of the whole radiocarbon dates collected (35.4%), raising issues of chronological uncertainty due to the "old wood effect" problem (Pettit et al. 2003; Wood 2015). This matter is more recurrent in radiocarbon dates obtained from bulk charcoal samples scattered in the archaeological layers whereas individual charcoal samples, clearly associated to combustion features show a consistent degree of reliability. In addition, the inbuilt age of aggregated samples associated to hearths in Mesolithic contexts has been proved few significant. The most evident example is radiocarbon date Ly-1198:7550 ± 200, from Botiquería level 2, obtained over an aggregated charcoal sample associated to a hearth, but statistically similar to another radiocarbon date on a bone collagen sample, GrA-13265: 7600 ± 50 from the same level.

Also in a significant percentage, marine shells are the 34.3% of samples at the current data set, being especially abundant in the Cantabrian and Atlantic regions (most of them produced in the context of shell midden-oriented research). Marine shells are affected by local marine reservoir effects (MRE) that are variable throughout space and time (Soares 1993; Soares and Dias 2006; Soares et al. 2016).

Bone samples represent the third group of the whole radiocarbon data set (28,1%). This type of material is currently considered one of the most reliable samples for radiocarbon dating (Higham 2011), if information about the bone collagen data quality control (bone collagen yield and C:N ratios) is published along (DeNiro 1985). In the case of human bone samples, which conform the 6.6% of the analyzed data set, it is crucial to take into consideration both, the percentage of marine diet derived from $d^{13}C$ and $d^{15}N$ palaeodietary reconstruction, who might be affected by an artificial carbon enrichment (Lanting and Van Der Plicht 1998), and the local marine reservoir effect (Peyroteo 2016: 101). We will refer to these fundamental issues in subsequent sections.

2.2. Radiocarbon Calibration Procedures

Radiocarbon dates were calibrated with OxCal (Bronk Ramsey 2009a) version 4.4, using the IntCal20 atmospheric calibration curve (Reimer et al. 2020), and the Marine20 curve (Heaton et al. 2020), employing a Mix_curves() function (mixed atmospheric-marine curves), when radiocarbon dates came from human bone samples with a certain contribution of marine diet.

Table 1 Reference record of Iberian Peninsula reservoir ages used in this work.

Regions in Iberia	ID Site	ΔR in ^{14}C years	Reference
Mediterranean Coast	124. El Collado	−175 ± 36	Siani et al. 2000
Algarve region	165. Montes de Baixo. 167. Armação Nova.	−146 ± 78	Soares 1993
Tagus valley (Muge)	129. Moita do Sebastião	−48 ± 143	Martins et al. 2008
Alentejo (Sado)	160. Vale Romeiras	−323 ± 127	Soares and Dias 2006

Accordingly, samples affected by MRE have been calibrated applying different regional offset ΔR values to correct the mixed-source of carbon (Table 1). The use of IntCal20 and Marine20 calibration curves requires a recalculation of the reservoir age corrections ΔR previously applied (Heaton et al. 2020: 784). To this end, we have used the ΔR calculator built into the Marine Reservoir Correction section of Calib.org (Reimer and Reimer 2017), considering different options, whether knowing the calendar year of the marine sample (in the case of mollusk shell used for correcting El Collado radiocarbon dates), or comparing contemporaneous marine and terrestrial samples from archaeological sites (as in Portuguese cases). More details are provided in Supplementary Material, section S2.

2.3. Data Quality Control and Data Aggregation

After calibration, we excluded for further analysis those dates whose calibrated median were older of 8800 cal BP or younger to 8200 cal BP. In addition, we filtered out those anomalous radiocarbon dates with unreliable stratigraphic or industrial information. As a result of this first filter process, a dataset with 53 archaeological sites and 135 radiocarbon dates from Spain and Portugal was retained for further analysis (Figure 1).

A limitation of any study analyzing the stratigraphic relationship between inorganic artifacts and radiocarbon samples is the, very often, coarse resolution of the Early Holocene archaeological record. In most archaeological sites reviewed in this work, the archaeological levels in which trapeze microliths are associated with radiocarbon samples can be considered as cumulative palimpsests (Bailey 2007), formed by successive episodes of deposition that became mixed together. Therefore, it was necessary to follow a ranking protocol to evaluate if the relationship between the dated radiocarbon samples and the trapezes can be reliably established within a single archaeological level, or, on the contrary, resulted from a spurious association of materials from different occupation layers mixed by post-depositional processes.

Following the work of Marchand and Perrin (2017), we ranked the radiocarbon record in three different groups according to three criteria: (i) the presence or absence of diagnostic techno-typological categories commonly accepted when defining the Late Mesolithic industries (i.e., notched blades, trapezes, and microburins); (ii) the integrity of both, the stratigraphic context and the association between radiocarbon dates and lithic assemblages; and (iii), the accuracy of the radiocarbon measurements considering the radiocarbon method (conventional or AMS), the laboratory error measurements and the inbuilt age of the samples (Waterbolk 1971; Petit et al. 2003).

According to these criteria, we established a “reliability index” to rank the reliability of the relationship between radiocarbon record and archaeological contexts into three groups. The first group (code 1) corresponds to lithic assemblages from the most reliable Late Mesolithic

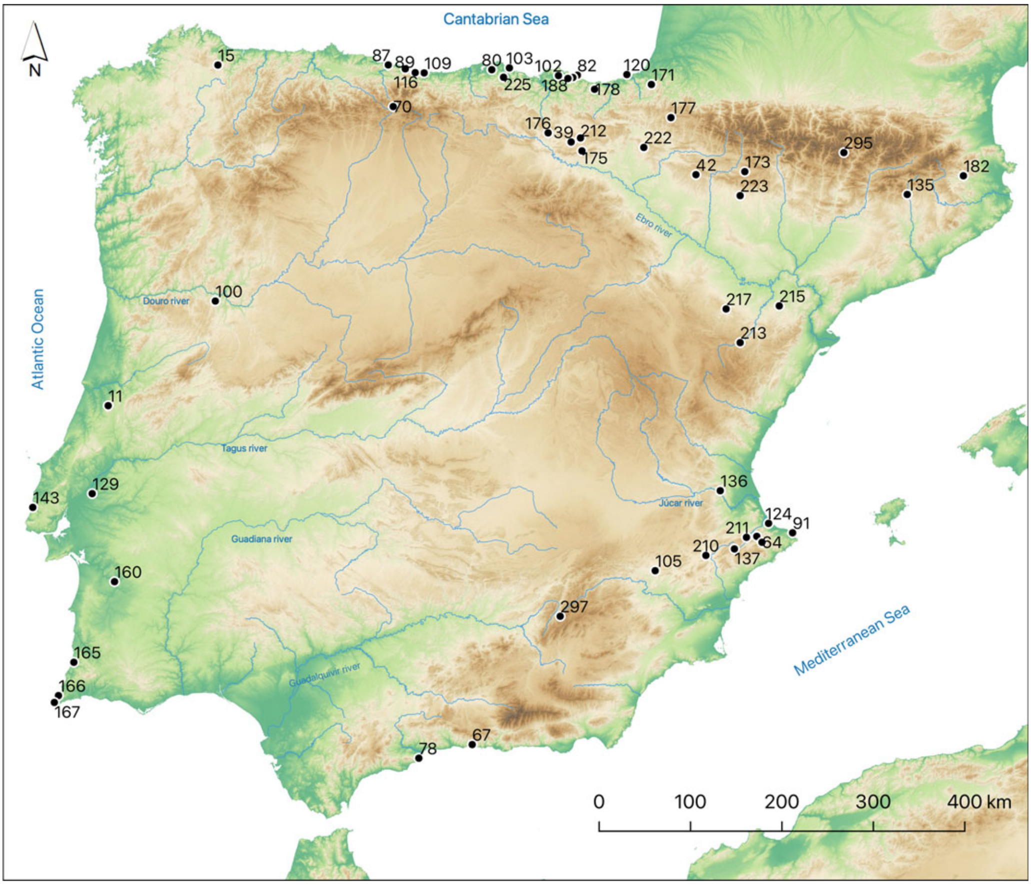

Figure 1 Spatial distribution map of archaeological sites between 8800 and 8200 cal BP analyzed in this work.

archaeological contexts, and a well-characterized Late Mesolithic lithic assemblages, along with accurate radiocarbon dates showing coherent results with their position into the stratigraphic sequences and the regional context. The second group (code 2) consists of those lithic assemblages that provided in the same layer, diagnostic Late Mesolithic artifacts, and accurate radiocarbon dates, however the association between them is problematic. This could be the result of two main problems: first, the chronological accuracy of radiocarbon ages is subjected to any sort of uncertainty, i.e., old wood effect, marine calibration, aggregated sample, etc.; and second, the presence of site taphonomy processes affecting the assemblage integrity (e.g., palimpsest formation, partial mixing of trapezes with artifacts from other periods due to percolation etc.). Finally, a third group (code 3) has also been differentiated, to include those archaeological levels that have radiocarbon dates from this chronological interval (8800–8200 cal BP) but lack trapezoids microliths.

The period of interest has been divided in three temporal windows: Temporal slice 1 (TS1), from 8800–8600 cal BP; Temporal slice 2 (TS2), from 8600–8400 cal BP; and Temporal slice 3 (TS3), from 8400–8200 cal BP. Tables 2, 3, and 4, show the unmodeled probability distribution of selected radiocarbon dates for each time slice at 95% C.I., ranked by the “reliability index” of the archaeological assemblages and the calibrated median date. We are aware of issues using

Table 2 Conventional and AMS ^{14}C radiocarbon dates from 8800–8600 cal BP calibrated in OxCal 4.4. and expressed as unmodeled chronological range at the 95% CI. Sample code: Ch/ch—individual/aggregated charcoal; B/b—individual/aggregated bone; Bc—bone collagen; Hh—human bone; S—fruit/seed; Sh—individual shell. Column "Rank" refers to "reliability index". References: 122. Arias et al. 2018; 212. González-Sampériz et al. 2009; 136. García-Puchol et al. 2018; 173. Utrilla et al. 2012; 70. Neira and Fuertes 2009; 166. Soares and Tavares da Silva, 2003; 218. Domingo et al. 2018; 176. Alday and Cava,2009; 223. Montes et al. 2015; 295. Gassiot et al. 2014; 210. Fernández et al. 2023; 143. Bicho 2009; 82. Berganza and Arribas, 2014; 124. Gibaja et al. 2015; 165. Soares and Tavares da Silva, 2003; 175. Alday and Cava 2009; 217. González-Sampériz et al. 2009. OxCal v4.4 (Bronk Ramsey 2009a).

ID_Site	Name	Unit	Lab.code	Sample	Species	Age BP	SD	Cal BP 2s	Median cal BP	C:N	Yield	ΔR	Rank
122	Alloru	UE104	OxA-29115	B	*Rupicabra pyrenaica*	7979	38	8995-8650	8853	nd	nd	nd	3
166	Castelejo	lower levels	ICEN-211	Ch	nd	7970	60	9000-8638	8830	nd	nd	nd	3
218	Pontet	g	D-AMS-020211	Ch	*Pinus halepensis*	7941	65	8992-8602	8797	nd	nd	nd	3
212	Kanpanoste	Lanhi base	GrN-22442	b	nd	7920	100	9020-8484	8773	nd	nd	nd	3
165	Montes de Baixo	c.4B	ICEN-720	Sh	nd	7910	60	8816-8595	8754	nd	nd	−146 ± 78	3
176	Fuente Hoz	III (23)	I-13496	Ch	nd	7880	120	9007-8429	8731	nd	nd	nd	3
223	Espantalobos	Nivel e	Beta-361625	Ch	*Juniperus sp.*	7900	50	8984-8593	8729	nd	nd	nd	3
136	Cueva de la Cocina	Layer 13-1941	UCIAMS-147348	B	*Capra pyrenaica*	7905	40	8981-8596	8724	3.24	nd	nd	3
124	El Collado	Burial 13	CNA-1628	Hh	*H. sapiens*	7976	33	8928-8551	8668	3.3	0.57	−175 ± 36	3
173	El Esplugón	5	Beta-306725	Bc	nd	7860	40	8972-8543	8645	nd	nd	nd	3
295	Estany de la Coveta	5A1	KIA-29818	Ch	*Pinus sp.*	7845	45	8974-8487	8629	nd	nd	nd	3
210	Arenal de la Virgen	625	Beta-473944	Ch	*Quercus sp. evergreen*	7850	30	8765-8546	8624	nd	nd	nd	3

Table 2 (*Continued*)

ID_Site	Name	Unit	Lab.code	Sample	Species	Age BP	SD	Cal BP 2s	Median cal BP	C:N	Yield	ΔR	Rank
143	S. Juliao	nd	ICEN-76	Ch	nd	7810	90	8981-8413	8610	nd	nd	nd	3
70	El Espertín	Level II	GIF-10053	b	nd	7790	120	8984-8388	8604	nd	nd	nd	3
82	Santa Catalina	Level I	Ua-2036	Ch	nd	7800	100	8983-8405	8602	nd	nd	nd	3
175	La Peña	d	BM-2363	B	herbivorous	7890	120	9012-8429	8743	nd	nd	nd	2
217	Los Baños	2b1	GrN-24299	Ch	nd	7840	100	8985-8430	8670	nd	nd	nd	2

Table 3 Conventional and AMS ^{14}C radiocarbon dates from 8600–8400 cal BP calibrated in OxCal 4.4. and expressed as unmodeled chronological range at the 95% CI. Sample code: Ch/ch—individual/aggregated charcoal; B/b—individual/aggregated bone; Bc—bone collagen; Hh—human bone; S—fruit/seed; Sh—individual shell. Column "Rank" refers to "reliability index". References: 26. Alday 2006; 135. Martínez and Mora 2011; 225. Pérez et al. 2016; 100. Monteiro-Rodrigues 2012; 91. Casabó 2014; 182. Alcalde and Saña 2017; 120. Iriarte et al. 2010; 109. Monge Soares et al. 2016; 210. Fernández-López De Pablo et al. 2023; 15. Villar 2007; 80. Arias and Ontañón 2000; 118. López Quintana 1999; 171. Barandiarán 1993; 178. González Sainz 2005; 174. Alday 1997; 143. Bicho 2009; 177. Alday and Cava 2009; 39. Alday 2006; 217. González-Sampériz et al. 2009; 63. Jordá and Cacho 2008; 297. Rodríguez 1979; 212. González-Sampériz et al. 2009; 67. Jordá and Aura 2008; 105. Uzquiano et al. 2016; 222. García-Martínez de Lagrán et al. 2014; 42. Utrilla et al. 2009; 124. Fernández López de Pablo 2016: 100; 89. Gutiérrez et al. 2014; 173. Utrilla et al. 2016; 136. García-Puchol et al. 2018; 215. Barandiarán and Cava, 2000. OxCal v4.4 (Bronk Ramsey 2009a).

ID_Site	Name	Unit	Lab.code	Sample	Species	Age BP	SD	Cal BP 2s	Median cal BP	C:N	Yield	ΔR	Rank
26	Atxoste	V	GrA-13447	B	nd	7810	40	8716-8454	8581	nd	nd	nd	3
135	Font del Ros	SG-6	Beta-210733	S	*Corylus avellana*	7800	50	8720-8425	8571	nd	nd	nd	3
225	Carabion	C5_N1	Poz-32691	B	nd	7800	50	8720-8425	8571	nd	nd	nd	3
100	Prazo	U4a/MF	OxA-24779	ch	nd	7792	34	8638-8456	8565	nd	nd	nd	3
118	Kobeaga II	Amck-h	GrN-24780	Ch	nd	7690	270	9265-7977	8550	nd	nd	nd	3
91	Cova Foradada	II	Beta-167654	B	*Homo sapiens*	7770	50	8608-8424	8541	nd	nd	nd	3
120	J3	D (top)	GrA-25774	Ch	nd	7770	50	8636-8424	8541	nd	nd	nd	3
182	Serrat del Pont	IV.2	Beta-212541	Ch	nd	7770	50	8636-8424	8541	nd	nd	nd	3
109	Mazaculos II	Level 1.3	OxA-26953	B	*Capreolus capreolus*	7755	38	8596-8430	8526	nd	nd	nd	3
210	Arenal de la Virgen	IV hearth	Beta-243772	Ch	*Q. evergreen*	7750	40	8595-8426	8520	nd	nd	nd	3
15	C. Rei Cintolo	Camarín S3	Lyon-2731	B	nd	7735	60	8603-8405	8507	nd	nd	nd	3
80	La Garma A	Q	OxA-7495	B	nd	7710	90	8723-8343	8500	nd	nd	nd	3
171	Berroberria	B	GrN-16511	b	nd	7640	190	8986-8086	8463	nd	nd	nd	3

Table 3 (*Continued*)

ID_Site	Name	Unit	Lab.code	Sample	Species	Age BP	SD	Cal BP 2s	Median cal BP	C:N	Yield	ΔR	Rank
178	Ekain	Charcoal from horse II-45	Gif-95228	Ch	nd	7630	80	8595-8215	8432	nd	nd	nd	3
174	Kanpanoste Goikoa	III inf	GrN-20215	b	nd	7620	80	8592-8212	8421	nd	nd	nd	3
143	S. Juliao A	nd	ICEN-73	Ch	nd	7610	80	8589-8207	8411	nd	nd	nd	3
177	Aizpea	Level I	GrN-16620	b	nd	7790	70	8929-8409	8566	nd	nd	nd	2
39	Mendandia	IV	GrN-22745	b	nd	7780	40	8637-8447	8554	nd	nd	nd	2
217	Los Baños	2b1	GrA-21552	Ch	nd	7740	50	8598-8416	8510	nd	nd	nd	2
63	Tossal de la Roca	level I ext	Gif-6898	b	nd	7660	60	8588-8370	8455	nd	nd	nd	2
124	El Collado	C-1	UBA-27478	B	*Cervus elaphus*	7660	44	8542-8383	8448	nd	nd	nd	2
297	Cueva del Nacimiento	Layer 3	Gif-3471	Ch	nd	7620	140	8854-8039	8426	nd	nd	nd	2
212	Kanpanoste	Lanhs	GrN-22440	B	nd	7620	70	8589-8219	8420	nd	nd	nd	2
67	Nerja	NV 3 (IIIc)	GifA-102010	S	*Pinus pinea*	7610	90	8590-8202	8412	nd	nd	nd	2
105	Cueva Blanca	level Ib	Beta-288287	Ch	*Pinus halepensis*	7610	40	8519-8345	8403	nd	nd	nd	2
222	Artusia	SU20 (Unit III)	Beta-374431	Ch	*Corylus avellana*	7680	40	8546-8390	8466	nd	nd	nd	1
42	Peña 14	a	GrN-25094	Ch	nd	7660	90	8638-8217	8462	nd	nd	nd	1
89	El Mazo	105	UGAMS-5408	Ch	nd	7640	30	8520-8376	8419	nd	nd	nd	1
173	El Esplugón	4	GrA-59632	Ch	*Pinus sylvestris*	7620	40	8520-8361	8409	nd	nd	nd	1
136	Cueva de la Cocina	Layer 17 (1945)	Beta-267440	B	*Capra pyrenaica*	7610	40	8519-8345	8403	nd	nd	nd	1
215	Botiquería dels Moros	2	GrA-13265	B	*Cervus elaphus*	7600	50	8537-8330	8399	nd	nd	nd	1

Table 4 Conventional and AMS ^{14}C radiocarbon dates from 8400–8200 cal BP calibrated in OxCal 4.4. and expressed as unmodeled chronological range at the 95% CI. Sample code: Ch/ch—individual/aggregated charcoal; B/b—individual/aggregated bone; Bc—bone collagen; Hh—human bone; S—fruit/seed; Sh—individual shell. Column "Rank" refers to "reliability index". References: 11. Aubry et al. 2011; 188. López Quintana and Guenaga 2011; 143. Bicho 2009; 116. Fano 2004; 103. Straus et al. 2002; 167. Soares and Tavares da Silva, 2003; 102. López Quintana 2005; 210. Fernández et al. 2023; 87. Balbín et al. 2014; 166. Carvalho 2009; 160. Peyroteo 2016; 63. Jordá and Cacho 2008; 124. This work; 78. Cortés 2007; 213. Utrilla et al. 2017; 129. Peyroteo 2016; 217. Utrilla and Rodanés 2004; 215. Barandiarán and Cava, 2000; 137. García-Puchol et al. 2006; 211. Torregrosa et al. 2011; 26. Alday and Cava 2009; 136. García-Puchol et al. 2018; 89. Soares et al. 2016. OxCal v4.4 (Bronk Ramsey 2009a).

ID_Site	Name	Unit	Lab.code	Sample	Species	Age BP	SD	Cal BP 2s	Median cal BP	C:N	Yield	ΔR	Rank
11	Buraca Grande	8c	Gif-9707	Ch	nd	7580	30	8420-8346	8387	nd	nd	nd	3
188	Santimamiñe	H-Sln	Beta-240899	Ch	nd	7580	50	8518-8211	8385	nd	nd	nd	3
143	S. Juliao A	nd	ICEN-77	Ch	nd	7580	70	8538-8202	8383	nd	nd	nd	3
116	Sierra Plana	IC	UGRA-209	Ch	nd	7550	190	8973-7969	8356	nd	nd	nd	3
103	La Fragua	1inf	GrN-20965	Ch	nd	7530	70	8446-8182	8334	nd	nd	nd	3
167	Armaçao Nova	4b	ICEN-1228	Sh	nd	8120	60	8513-8141	8318	nd	nd	nd	3
102	Pareko Landa	l-Smk (h2)	GrN-24782	Ch	nd	7510	100	8520-8039	8306	nd	nd	nd	3
210	Arenal de la Virgen	615	Beta-493224	Ch	Conifer	7480	30	8365-8193	8279	nd	nd	nd	3
87	Tito Bustillo	Rock art	GifA-96097	Ch	nd	7440	60	8383-8043	8262	nd	nd	nd	3
166	Castelejo	middle levels	Beta-2908	Ch	nd	7450	90	8405-8036	8259	nd	nd	nd	3
160	Vale Romeiras	SK19	Ua-46972	Hh	*Homo sapiens*	7640	55	8542-8225	8400	3.2	nd	*−323 ± 127*	2
63	Tossal de la Roca	level I ext	Gif-6897	b	nd	7560	60	8512-8194	8367	nd	nd	nd	2
124	El Collado	Surface level	Ua-72903	B	*Cervus elaphus*	7484	38	8375-8194	8295	3.3	nd	nd	2

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Table 4 (*Continued*)

ID_Site	Name	Unit	Lab.code	Sample	Species	Age BP	SD	Cal BP 2s	Median cal BP	C: N	Yield	ΔR	Rank
78	Bajondillo	3	Ua-18269	Ch	nd	7475	80	8418-8040	8279	nd	nd	nd	2
213	Angel 1	8c (U28)	Gra-27274	Ch	nd	7435	45	8366-8175	8263	nd	nd	nd	2
129	Moita do Sebastião	Sk 9	Ua-46264	Hh	*Homo sapiens*	7621	50	8342-7977	8152	3.2	nd	*−48 ± 143*	2
217	Los Baños	2b3inf	GrA-21551	Ch	nd	7550	50	8424-8200	8362	nd	nd	nd	1
215	Botiquería dels Moros	2	Ly-1198	Ch	nd	7550	200	8978-7966	8359	nd	nd	nd	1
137	Falguera	VIII	AA-59519	S	Pine cone scale	7526	44	8409-8200	8345	nd	nd	nd	1
211	Benamer	UE 2578	Beta-287331	Ch	*Arbutus unedo*	7480	40	8374-8192	8290	nd	nd	nd	1
26	Atxoste	IV	GrA-13418	B	nd	7480	50	8378-8188	8288	nd	nd	nd	1
136	Cueva de la Cocina	Layer 8 (1941)	UCIAMS-145195	B	*Capra pyrenaica*	7475	25	8368-8195	8287	3.18	nd	nd	1
89	El Mazo	105	OxA-30535	S	*Corylus avellana*	7380	55	8330-8035	8195	nd	nd	nd	1

a single point estimate of a calibrated ^{14}C date to present results of calibration (Michczyński 2007), however, in this paper, the value of the calibrated median is merely used to order probabilistically the dataset in different chronological subsets, nor to raise statistical assumptions of the distribution.

Data from TS1 (Table 2) corresponds to 17 archaeological assemblages. Radiocarbon dates are quite homogeneous regarding the type of sample dated, single charcoal or bone, although barely half of the samples were taxonomically identified. Most of them have been ranked as group 3, because during this temporal slice, Geometric Mesolithic industries have not been detected. The two cases ranked 2, will be commented on later.

In the Iberian Peninsula, trapeze industries appear in the archaeological record during the TS2, so the analysis of radiocarbon data is crucial to identify the first appearance and follow subsequent diffusion dynamics. A total of 31 archaeological assemblages have been considered. Table 3 shows the calibrated radiocarbon dates ranked (from the less to the more reliable lithic assemblages) and ordered by the calibrated median (from the older to the younger calibrated dates). Radiocarbon dates from TS2 are also very accurate, although 65% of the samples are not taxonomically identified, 81% of the global data correspond to individual samples with a standard deviation lower than 100 years (90.4%), or even lower than 50 years (58.1%).

Lithic assemblages from TS3 come from 23 archaeological sites. Table 4 shows the calibrated radiocarbon dates ranked (also from the less to the more reliable lithic assemblages) and ordered by the calibrated median (also from the older to the younger calibrated dates). At this chronological range (8400–8200 cal BP), blade and trapeze industries have virtually spread and consolidated across the Iberian Peninsula (see Results, section 3.1.). Interestingly, the onset of the 8.2 kya cal BP abrupt climate event occurred at the end of TS3. As it can observed in Table 4, the radiocarbon dates of some archaeological assemblages overlap with this climatic event (Rasmussen et al. 2014).

2.4. Spatiotemporal Analysis

To explore the spatiotemporal patterns on the spread of trapeze industries in the Iberian Peninsula we have produced three maps dividing the period of interest according to the three temporal bins previously stated: Temporal slice 1 (TS1), from 8800–8600 cal BP, corresponding to the Notched and Denticulated Mesolithic (NDM) industries; Temporal slice 2 (TS2), from 8600–8400 cal BP, with the first appearance and expansion of Late Mesolithic trapeze industries; and Temporal slice 3 (TS3), from 8400–8200 cal BP, period where consolidation and evolution of blade industries took place reaching the Atlantic coast of Portugal. All dated assemblages are included at each temporal slice considering the median of the calibrated radiocarbon probability distributions without prior stratigraphic or spatial probability constraints. Then, we have plotted archaeological sites at each temporal window, selecting only one radiocarbon date representative per site among the rest, i.e., the oldest one or/and the most reliable, related to trapeze industries. The resulting dataset is composed of 53 sites and 71 calibrated radiocarbon dates, because some archaeological sites have occupation episodes at more than one temporal slice (data file S1).

2.5. Bayesian Chronological Modeling

Radiocarbon dates from archaeological contexts with trapezes in TS2 (8600–8400 cal BP) were further analyzed using three different Bayesian phase chronological models (named A, B, and

C) to group the posterior probability distributions and estimate the duration of the first spread of blade and trapeze industries across Iberia. In doing so, our goal is not to model the duration of the Mesolithic taxonomic units or phases adopting a bottom-up strategy, from Bayesian chronological models of individual sites to regional phases (e.g., Marín-Arroyo et al. 2018). Instead, we used a conservative single-phase Bayesian model in A and B cases, assuming uniform distribution in the relative order of the dated events across most of the Iberian Peninsula, and two overlapping phases in the case of Bayesian model C, accounting Portuguese sites.

The first one Model A comprises the six radiocarbon dates from sites ranked as group 1 in TS2 (8600–8400 cal BP). A second Bayesian phase model—Model B—was built in order to consider 15 radiocarbon dates from sites ranked in groups 1 and 2 in TS2. However, the spatial distribution of sites considered in models A and B does not include any site from Portugal, whose calibrated medians fall within the TS3 (8400–8200 cal BP). In order to address the dynamic of the process considering the whole Iberian Peninsula as a geographic scale of analysis, a third Bayesian model model C was implemented to include the radiocarbon dates from model A, plus the oldest radiocarbon dates from Portugal during TS3 (8400–8200 cal BP) (See Results section 3.1.3). Each Bayesian phase model was implemented in OxCal 4.4 software (Bronk Ramsey 2009a), employing IntCal20 atmospheric (Reimer et al. 2020) and Marine20 (Heaton et al. 2020) calibration curves as it has been previously explained (Section 2.2). For each model we have reported both the span () and interval () queries, to probabilistically estimate the duration of each phase, and its chronological boundaries.

3. RESULTS

3.1. Spatiotemporal Patterns

3.1.1. Temporal Slice 1: 8800–8600 cal BP. Early Mesolithic Industries

The geographic distribution of archaeological sites dated to the first temporal bin (TS1: 8800–8600 cal BP) is shown in Figure 2. A total of 17 radiocarbon dated lithic assemblages are found at the coastal regions of Iberian Central Mediterranean coast, east of Cantabrian façade and south-central coast of Portugal, as well as in the inland territories of the Lower-Aragón (in the central-south Ebro Valley), the Central Pyrenean and pre-Pyrenean mountain ranges and the Upper Ebro Valley (in the Álava province). It should be stressed the lack of dated assemblages from the northwestern section of Iberia (Galicia and northern Portugal), the northeastern sector, Andalusia and the Iberian interior (northern and southern plateau).

All the lithic assemblages considered in this temporal slice are technologically characterized by flake debitage systems, and reduced typological repertoires clearly dominated by notched and denticulated tools. These industries have been assigned to different taxonomic units according to different historiographic traditions (Asturian in the Cantabrian fringe or Macrolithic Epipalaleolithic). Since 2006, the Mediterranean and Ebro valley regions are taxonomically termed as 'Notched and Denticulated Mesolithic' technocomplex (Alday 2006).

No archaeological deposit has provided reliable dated industries with trapezes within this temporal bin. Just two sites located in the Ebro Valley—La Peña de Marañón and Los Baños—have provided lithic assemblages with trapezes and radiocarbon dates falling within TS1. However, the critical evaluation of the microlithic component and radiocarbon record of both assemblages cast doubts on the stratigraphic association between the first trapezes documented in the stratigraphic sequence and the radiocarbon dated samples.

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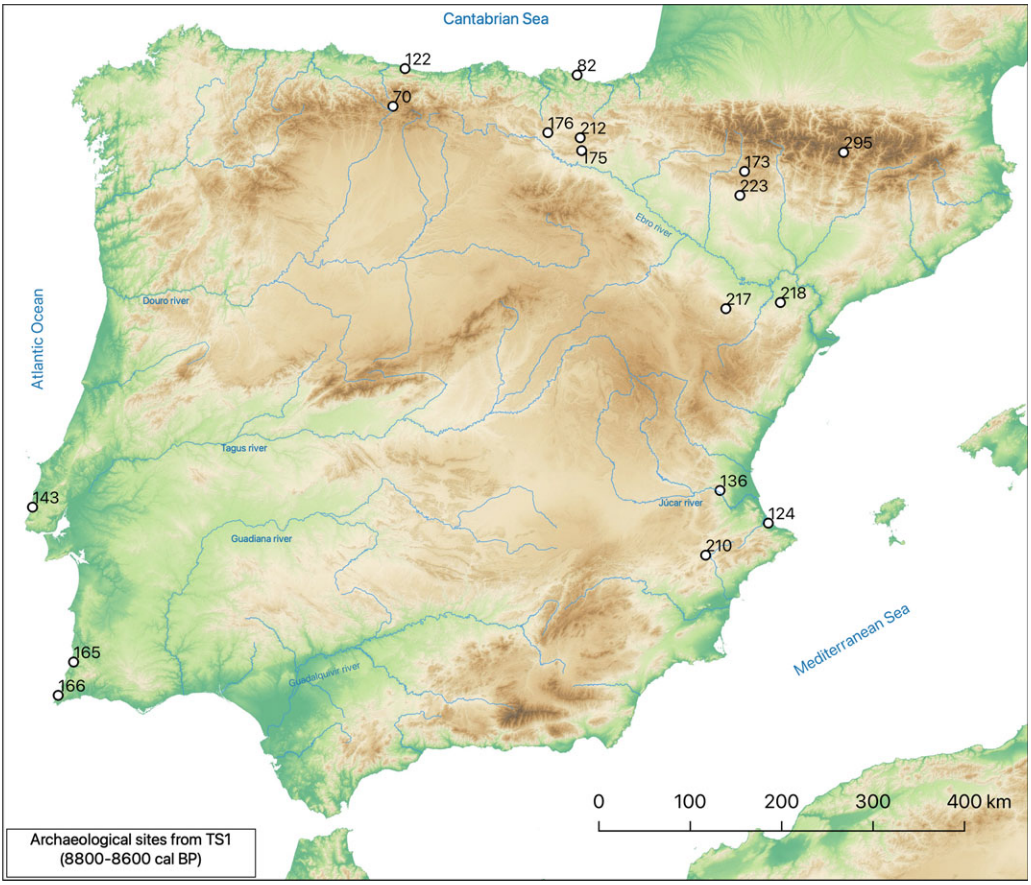

Figure 2 Spatial distribution of archaeological sites in temporal slice 1 (TS1). 70: El Espertín. 82: Santa Catalina. 122: Alloru. 124: El Collado. 136: Cocina. 143: São Julião. 165: Montes de Baixo. 166: Castelejo. 173: El Esplugón. 175: La Peña. 176: Fuente Hoz. 210: Arenal de la Virgen. 212: Kanpanoste. 217: Los Baños. 218: Pontet. 223: Espantalobos. 295: Estany de la Coveta.

At the Upper Ebro Valley, two assemblages, levels d and dsup from La Peña de Marañón site (ID175) (hereafter La Peña), have yielded a relative rich collection of 22 trapezes, microburins (30) and notched blades (18) (Cava y Beguiristain 1991: 84). The only radiocarbon date available for the Late Mesolithic occupation of this site, BM-2363 7890 ± 120 BP (9012–8429 cal BP; 8743 median cal BP), was obtained using the conventional ^{14}C method on a single bone sample (classified as herbivorous) recovered in level d. This level d has a maximum thickness of 95 cm and has also provided younger archaeological materials such as early neolithic pottery in its upper section (Cava y Beguiristain 1991: 76).

A closer view of the detailed publication allows to evaluate the stratigraphic relationship between the dated sample and the trapezes from level d found in the bands A/B. It shows how the radiocarbon dated sample was recovered at approximately depth –375 cm (Cava and Beguiristain 1991: 114, Figure 28), whereas the vertical distribution of trapezes shows the highest representation of trapezes come from the spits at depths –350–360 cm (Cava and Beguiristain 1991: 103, Figure 26), 25–15 cm above the depth of the dated sample. According

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to this, the relationship between the dated sample and the trapezes found at the same depth, which follows a clear decreasing pattern, opens the possibility that the second ones were associated to the radiocarbon sample by percolation. Supporting this hypothesis, it must be noted that other close sites such as Kanpanoste (ID212) have provided a statistically similar radiocarbon age for the lithic assemblage of Lanhi base level 7920 ± 100 (9020–8484 cal BP), which typologically corresponds to the Notched and Denticulates Mesolithic.

Therefore, the single radiocarbon date from the basal level d in La Peña site, considering the stratigraphic association of the sample with the trapeze microliths discussed above, overestimates the age of the first trapeze industries.

The second possible occurrence of trapezes falling within the TS1 is found at Los Baños site (ID217), in the central Ebro valley. Here, trapeze microliths appear in level 2b1 (Utrilla y Rodanés 2004: 31–40), a transitional level of only 15 cm depth, containing both Early Mesolithic artifacts (endscrapers, denticulated flakes, outils écaillées) and a reduced set of 10 geometric microliths composed by small and short trapezes with abrupt retouch (or tranchets) (Utrilla and Rodanés 2004: 37). This level has three radiocarbon dates on individual charcoal samples with unknown taxonomic identification, retrieved from different squares of the excavation area during different fieldwork campaigns. Two are AMS radiocarbon dates (GrA-21556: 8080 ± 50 BP and GrA-21552: 7740 ± 50 BP), and one was obtained by ^{14}C conventional method (GrN-24299: 7840 ± 100 BP). This radiocarbon evidence indicates a wide chronological range for the formation of the archaeological level 2b1, composed by different occupation episodes within the same level without stratigraphic differentiation (Utrilla and Rodanés 2004: 93). However, while the stratigraphic association of *tranchets* or short trapezes (whose length < to width) to the radiocarbon dated samples is uncontestable, the position of the oldest dated sample (GrA-21556: 8080 ± 50 BP), at the base of level 2b1 in square 4A, barely 10 cm above of the underlying level 1b, from the Notches and Denticulates Mesolithic, suggests the presence of older inherited material from this level 1b into the level 2b1. Also, in square 1A, the oldest radiocarbon date—GrN-24299: 7840 ± 100 BP—has a broad probability distribution (see Table 2). Only the most recent radiocarbon date (GrA-21552: 7740 ± 50 BP; 8510 median cal BP), found in square 1A without any other overlying archaeological level, can provide the most accurate chronology for this level 2b1 referring to the middle of IX millennium cal BP for the appearance of trapeze industries at Los Baños rockshelter.

3.1.2. Temporal Slice 2: 8600–8400 cal BP. First Appearance and Rapid Expansion of the Late Mesolithic Trapeze Industries

Regarding TS1, on TS2, both the number of archaeological sites and archaeological assemblages, increases from 17 to 31 sites, and from 27 to 71 assemblages (Figure 3). Fifteen assemblages have provided lithic industries with trapezes, with a geographic distribution that covers the Western Pyrenees, the Ebro Valley, the southern and eastern Mediterranean provinces of Valencia, Alicante, Jaén, Murcia and Málaga, and the Western area of Cantabrian façade.

The stratigraphic sequences of archaeological sites included TS2 present two different cases: stratigraphic sequences with previous occupations associated to the Notched and Denticulated Mesolithic; and archaeological sites whose stratigraphic sequences began during Geometric Mesolithic. In comparison to TS1, the Late Mesolithic geographic distribution continues located in the same regions inhabited before, becoming denser in some particular areas, especially in the western Pre-Pyrenees sector and the central Mediterranean area. In recent

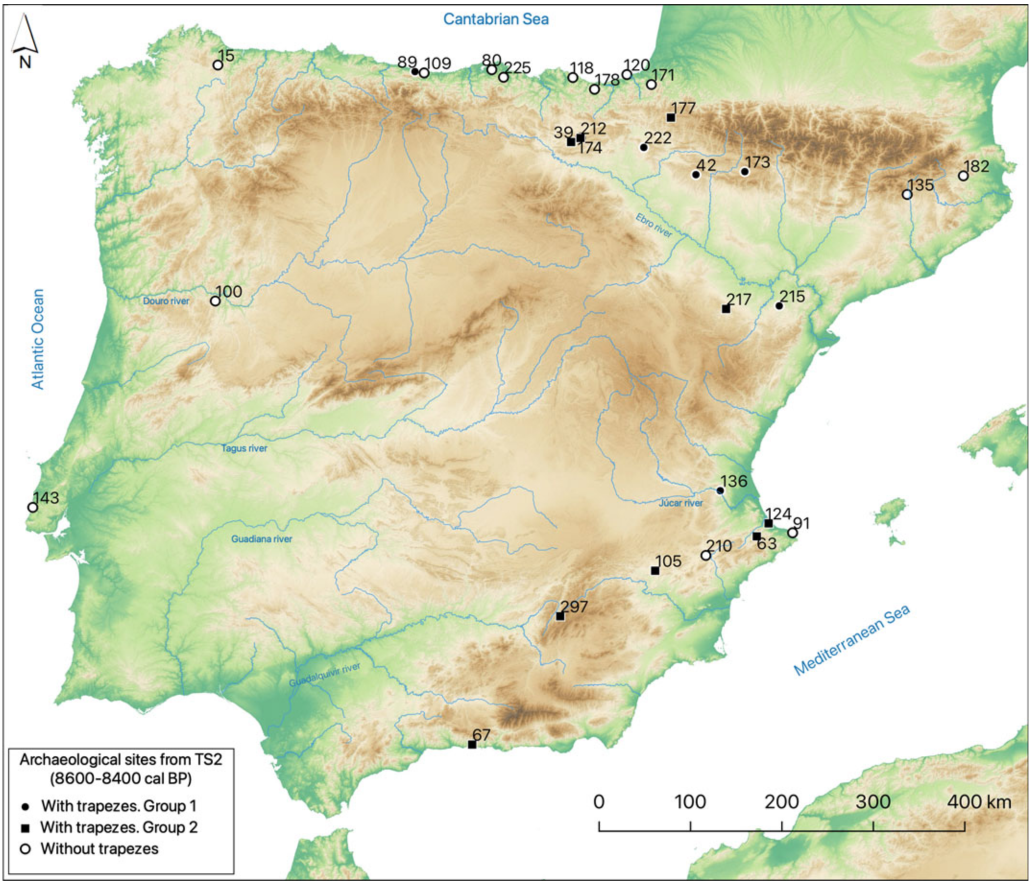

Figure 3 Spatial distribution of archaeological sites in temporal slice 2 (TS2). Archaeological sites with trapezes, group 1: 42. Peña 14. 89: El Mazo. 136: Cocina. 173: El Esplugón. 215: Botiquería. 222: Artusia. Archaeological sites with trapezes, group 2: 39: Mendandia. 124: El Collado. 63: Tossal de la Roca. 67: Nerja. 105: Cueva Blanca. 177: Aizpea. 217: Los Baños. 297: Cueva del Nacimiento. Archaeological sites without trapezes, group 3: 15. Rei Cintolo. 26. Atxoste. 80: La Garma. 91: Cova Foradada. 100: Prazo. 109: Mazaculos II. 118: Kobeaga II. 120: J3. 135: Font del Ros. 143: São Julião. 171: Berroberría. 174. Kanpanoste Goikoa. 178: Ekain. 182: Serrat del Pont. 210: Arenal de la Virgen. 212: Kanpanoste. 225: Carabión.

years, western Cantabrian façade shell middens are providing relevant information, as exemplified by El Mazo site (ID89) shell midden. In other areas such as Andalusia, the re-evaluation of radiocarbon dates and lithic materials from old excavations of Cueva del Nacimiento (ID 295), in the Subbaetic system, and Nerja cave (ID 167) in the Malaga coast, provide chronometric evidence of the first appearance of trapeze industries in southern Iberian Peninsula.

The most reliable chronological evidence (group 1) dated to the TS2 (8600–8400 cal BP) (Table 3) is limited to 6 assemblages, which have provided statistically similar radiocarbon ages. Below, we describe them according to the representativeness and/or the size of lithic assemblage and following a northeastern-southwestern geographic gradient.

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In the Pre-Pyrenees area, three rockshelters, El Esplugón (ID173), Artusia (ID222) and Peña 14 (ID42), have yielded lithic assemblages with trapezes (Utrilla et al. 2016; García-Martínez et al. 2014; Montes 2001). El Esplugón (Unit III), has contributed with the most numerous dataset (47 trapezes), whereas Artusia (unit III) and Peña 14 (level a), have yielded a very modest collection of trapezes (4 and 2, respectively).

The Geometric Mesolithic has been recognized at El Esplugón archaeological phase III (ID173), composed by level 3 inferior and level 4. The typological analysis of lithic assemblages from these levels has led researchers to identify two phases in the Geometric Mesolithic occupation: phase A of trapezes in level 4 and phase B of triangles in level 3 inferior (Utrilla et al. 2016: 95). We focus on level 4, where there is a predominance of trapezes (n = 17), versus a testimonial and minority presence of triangles (n = 6). The high percentage of microburins (n = 30) (Obón et al. 2019) should also be mentioned. Short trapezes with one or two concave sides are the most common type (Utrilla et al. 2016: 84). The oldest ^{14}C AMS radiocarbon date available for Level 4, on a single charcoal sample of *Pinus sylvestris*, around a hearth or combustion area (Alcolea 2017: 41–42), provides a consistent chronology for this Mesolithic phase of trapezes (GrA-59632: 7620 ± 40 BP, 8409 median cal BP).

Farther west, in the Upper Ebro Valley, the unit III from Artusia rockshelter (ID222) and level a from Peña 14 (ID42), have yielded a discrete but noteworthy representation of trapezes: n = 4 in the former (García-Martínez et al. 2014: 34; 2016: 159), and n = 2 in the latter (Montes 2001: 294 and 302). Levels from both sites are associated with two radiocarbon dates on single charcoal samples, the one from Artusia III (Beta-374431: 7680 ± 40 BP, 8466 median cal BP) comes from a short-lived sample (*Corylus avellana*) on a hearth context, whereas the one from Peña 14 comes from one single charcoal in level a, taxonomically unidentified (GrN-25094: 7660 ± 90 BP, 8462 median cal BP).

In the North Atlantic coast of Iberia, in eastern Asturias, El Mazo shell-midden (ID89) has provided new evidence about the presence of trapeze industries in the Cantabrian Mesolithic. Although lithic analyses have just been preliminary reported and the assemblage size is discrete (Fuertes et al. 2021: 474), two trapezes and two microburins have been recovered in SU105 associated to a radiocarbon date on a single charcoal sample (UGAMS-5408:7640 ± 30 BP, 8419 median cal BP).

In the lower Ebro Valley, Botiquería de los Moros rockshelter (ID215) (hereafter Botiquería), is a key archaeological site of the Geometric Mesolithic of the Iberian Peninsula for its prolific lithic assemblage and the rigorous excavation methodology (Barandiarán 1978). The oldest fertile archaeological level, Level 2, has provided a rich lithic assemblage dominated by notched blades (82), geometric microliths (74), and microburins (29). From a typological point of view, trapezes (57) predominate over triangles (10) that will be more abundant in subsequent level 4 (Barandirán 1978: 71–73). Interestingly, the most represented type corresponds to short trapezes with abrupt retouch and one concave side, followed by symmetric trapezes, asymmetric trapezes and trapezes with two concave sides, in descending order of cases. Level 2 has provided two radiocarbon dates: the oldest one, comes from an aggregate sample of charcoals recovered from a combustion feature and dated by the conventional ^{14}C method (Ly-1198:7550 ± 200). The most reliable radiocarbon date stratigraphically associated with trapeze industries was obtained by AMS, and corresponds to an individual sample, a red deer metapodium fragment found at depth –178/173 cm. (GrA-13265:7600 ± 50; 8399 median cal BP) (Barandiarán and Cava, 2000: 297). According to the depth distribution of retouched lithic

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pieces published, the abruptly retouched trapezoids are almost exclusively ascribed to the lower half of Level 2 stratigraphic deposit, reaching their maximum concentration between the spits –190/–185 and –160/–155, which is consistent with the depth where radiocarbon sample was recovered (Barandiarán 1978: 121–122).

Further south, in the central Mediterranean area of the Iberian Peninsula, one site has provided significant information about the Mesolithic period: Cueva de la Cocina (ID136) (hereafter Cocina). First excavated in the 40's of the XXth century, the study of lithic assemblages from Cocina (ID136) established a first correlation with the Mesolithic of Castelnovian tradition (Pericot 1945).

Lithic assemblages of Cocina have been analyzed by Fortea (1971), Sectors E I and E II, excavated by Pericot in 1945, and García-Puchol (2005), Sectors D1, D2, C1 and C2, excavated by Pericot in 1943, to establish the techno-typological evolutionary trends in the stratigraphic sequence. More recently, radiocarbon studies based on extensive sampling, and Bayesian chronological modeling have been undertaken to define the chronological boundaries of each Mesolithic phase (García-Puchol et al. 2018; 2023) and discuss site formation processes for the Mesolithic-Neolithic transition (Pardo-Gordó et al. 2018).

The new radiocarbon studies focused on the Pericot's excavations, sectors excavated in 1941 and 1945, have differentiated two phases (García-Puchol et al. 2018): Phase A/ Cocina I, characterized by the predominance of trapezes (Subphases A1 and A2 in the Bayesian models); and Phase B/ Cocina II (Subphases B1 and B2), where triangles are the most common geometric type over trapezes and abruptly retouched segments (García et al. 2018: 266). According to these models, phase A1 (Phase A of trapezes) is represented by the radiocarbon dates from the 1941 sector, layer 11 (UCIAMS-14734: 7415 ± 35 BP; 8259 calibrated median), and 1945 layer 17 (Beta-267440: 7610 ± 40 BP; 8403 calibrated median). Since Bayesian models were built assuming a contiguous order, the transition between Sub-phase A0, the first evidence of human occupation in the cavity according to current radiocarbon dates and sub-phaseA1, with predominance of trapezes, is situated between 8614–8400 cal BP (García-Puchol et al. 2018: 268). The new studies have reported that asymmetrical trapezes with abrupt and concave edges are dominant in the initial phase (García-Puchol et al. 2014).

Nine assemblages have been ranked in group 2 for the TS2 (8600–8400 cal BP): 177: Aizpea. 39: Mendandia. 212: Kanpanoste. 217: Los Baños. 124: El Collado. 63: Tossal de la Roca. 67: Nerja. 105: Cueva Blanca. 297: Cueva del Nacimiento.

In the Upper Ebro Valley, Aizpea I, Mendandia levels IV and IIIinf, and Kanpanoste level Lanhs, have provided geometrics (Alday and Cava 2006: 290). The site of Aizpea (ID177) has been considered as a paradigmatic site to define chronological evolution between the two geometric industrial horizons, trapezes and triangles phases (Alday and Cava 2009: 118), given its rich collection of geometric microliths (48), trapezes with abrupt retouch included. The trapeze microliths have been recovered from level I of 80 cm depth (named level b in previous publications c.f. Cava 1994), which has been radiocarbon dated in its upper and lower section.

A careful review of Aizpea publication shows that the geometric microliths are absent in the lower section of Aizpea I, and on the contrary, the flake debitage and denticulates are of relative importance. Furthermore, the oldest radiocarbon date for Aizpea I (GrN-16620: 7790 ± 70BP) corresponds to an aggregated sample, composed by bones gathered from layers between 135–100 cm depth below datum, that encompassed the lower part of the sequence—without geometrics, but with some backed bladelets (Alday and Cava 2006: 293), providing a wide range of chronological uncertainty. The upper section of Level I has provided an important set of trapezes (n = 32) and it is dated to 7190 ± 140 (GrN-16621), by a radiocarbon sample composed by different bone fragments recovered at 80–90 cm depth below datum. Therefore, the evidence of Aizpea clearly shows a diagnostic component of trapeze microliths with notched blades and microburins, recovered in the upper section of the cultural horizon Aizpea I, but cannot be directly associated to the oldest radiocarbon date of Aizpea I, within TS2.

Mendandia level IIIinf has provided a very diagnostic assemblage of trapezes with abrupt retouch: 22 trapezes (symmetric, asymmetric and with concave sides), 9 notched blades and 20 microburins (Alday 2005: 71), that have been radiocarbon dated to 7620 ± 50 BP (GrA-22743; 8413 median cal BP) from an aggregate sample of bones (Alday 2002: 41; Alday 2005: 106). Despite the aggregated nature of this radiocarbon sample, its age is consistent with the chronology of other assemblages from nearby sites such as Artusia and indicates the first appearance of trapeze industries at the end of TS2. However, the three trapeze microliths documented in the underlying level IV, with two radiocarbon dates GrA-22744: 7810 ± 50 BP and GrA-22745: 7780 ± 50 BP), should be considered with caution considering the overwhelming dominance of notched and denticulated tools and the aggregated nature of the radiocarbon samples. While the median of both radiocarbon dates falls within our TS2 (8583 cal BP and 8554 cal BP, respectively), the intrusive character of the three trapezes documented in level IV migrating from level IIIinf cannot be completely ruled out, especially considering the depth of this level (25–30 cm) (Alday 2005:68).

A similar argument could be raised in the case of Kanpanoste Lanhs level (GrN-22440: 7620 ± 70BP, 8589–8219 cal BP), where the lithic industry presents a majority component of typological groups from the Notched and Denticulates Mesolithic (Alday and Cava 2006: 229–232), and the scarce geometrics (3 trapezes), could have migrated from the contact with the upper level Clag. The possibility of a partial removal of the archaeological deposits has been pondered by researchers (Cava 2004: 103), although they finally validate the integrity of Lanhs lithic assemblage, arguing that laminar knapping has been also documented in the same level, and trapezes are completely different from the ones found in the upper Clag level. Ultimately, researchers compare level Lanhs from Kanpanoste with Los Baños level 2b1, where trapezes are small and short, representing an initial glimpse of the Geometric Mesolithic phase (Cava 2004: 103).

In any case, the low representativity of trapezes on these assemblages, the wide chronological range on radiocarbon dates provided by samples composed by bone aggregates and the application of the conventional ^{14}C method, does not allow to account them as an accurate archaeological context to assess the first appearance of trapeze-based industries like those archaeological sites from group 1.

In the central Ebro Valley, there is an occurrence of trapeze-based industries at Los Baños site (ID217). As we have mentioned in TS1, techno-typological categories related to trapeze-based industries appear in level 2b1 (Utrilla y Rodanés 2004: 31–40). The fact that this level contains both Early Mesolithic artifacts (endscrapers, denticulated flakes, outils écaillées) and a reduced set of geometric microliths composed by small and short trapezes with abrupt retouch (or tranchets) (Utrilla and Rodanés 2004: 37), has led us to rank the reliability of the archaeological context in group 2. However, the youngest radiocarbon date of level 2b1

(GrA-21552: 7740 ± 50 BP; 8510 median cal BP), can provide the most consistent chronology for the appearance of trapeze industries at Los Baños.

In the central Mediterranean area of the Iberian Peninsula two sites have provided trapezes in archaeological levels dated in TS2 (8600–8400 cal BP): El Collado (ID124) and Tossal de la Roca (ID63). El Collado site holds one of the most important Mesolithic necropolises in the Western Mediterranean area and also presents lithic assemblages with trapezes whose chronological position within TS2 is discussed for the first time in the present study. In the monographic volume of El Collado site, Aparicio just provides a very summary description of the lithic assemblages, referring to a generic classification of "Geometrics" among other typological groups (Aparicio 2008: table on p. 53). More recently, a new study focused on the radiocarbon dating of faunal remains of El Collado associated to different layers established a preliminary chrono-stratigraphic sequence of the archaeological deposit (Fernández-López de Pablo 2016). A close examination of the lithic assemblages' illustrations allows a tentative correlation with the radiocarbon record of the site stratigraphy (Fernández-López de Pablo 2016). From top to bottom, trapezes are present in the Surface Level (n = 4) (Aparicio 2008: 58–60, Figs. 27–29), in layer C-1 from Level 1 (n = 4) (Aparicio 2008: 68, Fig. 37; 71, Fig. 40; 73, Fig. 42), and layer C-2 from Level II (n = 1) (Aparicio 2008: 81, Fig. 50). The vertical distribution shows that trapezes with concave sides are concentrated in the Surface Level, whereas from Layer C-1, Level I we find symmetric and asymmetric trapezes. The isolated trapeze found at layer C-2 of Level II has a clear intrusive character (Vertical distribution is presented in Supplementary Figure S3). Therefore, the radiocarbon date on a bone fragment (*Cervus elaphus)* from layer C1, Level I (UBA-27478: 7660 ± 44 BP, 8542–8383 cal BP) should be considered a maximum age for the first trapeze industries at the site. This chrono-stratigraphic attribution is fully consistent with that of the underlying Level II with the Notched and Denticulated Mesolithic (Aura et al. 2006; Gibaja et al. 2015; Fernández-López de Pablo 2016).

Level I from the exterior sector of Tossal de la Roca (ID63) has yielded a lithic assemblage composed by trapezes with abrupt retouch, also abundant flakes with notches and denticulates, endscrapers and backed bladelets, but any microburins (Cacho et al. 1995: 83). There is one radiocarbon date for this level on aggregate bone sample whose calibrated median falls at the end of TS2 (Gif-6898: 7660 ± 60 BP, 8588–8370 cal BP 2σ, 8455 median cal BP). Considering the variable thickness of level I, from 50 cm to 110 cm in different sectors, and its sedimentological characteristics, a high presence of cobbles in a silty-clayish matrix with a stepped tilt, the stratigraphic relationship between trapezes and this radiocarbon date with a wide probability distribution, cannot be establish in an unambiguous way.

Besides, Cueva Blanca rockshelter (ID105) is situated in the foothills of an interior middle altitude mountain range, in Albacete province. Level Ib has been considered from the Geometric Mesolithic period because of the identification of blade knapping and 3 trapezes with abrupt retouch (Mingo et al. 2012). Two radiocarbon dates on individual charcoal and statistically different, correspond to level Ib (Beta-288287: 7610 ± 40 BP, 8403 median cal BP, and Beta-288288: 6730 ± 40 BP) provided a wide chronological interval for the formation of this level. Moreover, researchers admit the chronocultural interpretation of level Ib is problematic because two fragments of pottery were found in its upper part, and researchers did not detect intrusions from more recent periods into it (Mingo et al. 2012: 71). In summary, even though the conditions of synchrony and archaeological association could have been fulfilled (Uzquiano et al. 2016), the fact that the lithic assemblage is not quantitatively significant, and

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the radiocarbon dates associated display a broad chronological range, led us to consider this assemblage in group 2.

Further south, in the Jaén province, eastern Andalusia, Cueva del Nacimiento (ID295) provides evidence of trapeze industries that come from late 70's excavations. The stratigraphic sequence was originally published by Rodríguez (1979) and subsequently revised by Asquerino and López (1981) (see correlation in Supplementary Table S4). In the first publication, the stratigraphic sequence of El Nacimiento was divided in three levels, with different layers included (Rodríguez 1979, 34): Level A. Layer 1 and Layer 2; Level B. Layer III; Level D. Layer V. This stratigraphy was associated to 3 radiocarbon dates, all obtained from charcoal associated with hearths, and dated by the conventional ^{14}C method: GIF-1368:6780 ± 130 (layer 2); GIF-3471: 7620 ± 140 (layer III) and GIF-3472:11200 ± 200 (layer V).

Later, Asquerino and López renamed archaeological levels and subdivided former Layer 2 into five sublevels, due to its thickness (50 cm). Before that, the stratigraphic sequence merged Layer 2 and Layer III from Rodríguez's publication, and correlated it with Level II (sublevels 2A, 2B, 2C, 2D and 3), from Asquerino and López's publication (1981). Then, this Level II was associated with two radiocarbon dates, GIF-1368:6780 ± 130 and GIF-3471: 7620 ± 140, originally circumscribed only to Layer 2 (Rodríguez 1979). Level II in Asquerino and López (1981: 116), was associated with trapezes and microburins from level B in a subsequent publication (Rodríguez 1997: 407). The geometric microliths of the lithic assemblage published in Asquerino and López (1981) are reproduced in Supplementary Figure S5. From a techno-typological perspective, the lithic assemblage of Level II is very diverse and lacks any internal chronological consistency: a clear Early Neolithic trapeze with a Jean Cross retouch is found at the bottom of Level II (sublevel 3) whereas trapezes of concave sides and abrupt retouch (supposedly Geometric Mesolithic) are documented in all layers except from sublevel 2c.

In summary, the data from Nacimiento provides typological evidence of trapezes whose typology could be related with the trapezes phase of the Geometric Mesolithic. Even though the lithic assemblage integrity remains low, with a clear mixed component of Neolithic materials throughout the sublayers, the radiocarbon age retrieved from a combustion feature must be considered as maximum age for presence of trapezes in this site (Rodríguez 1979; 1997).

Finally, in the southern Iberian coast, in the Malaga coast near to the Gibraltar Strait Nerja Cave (ID67) has also provided lithic assemblages with trapezes. This paradigmatic prehistoric site presents several areas or rooms (Vestibule, Torca, and Mina). The study of lithic assemblages from Mesolithic occupations are still in progress, for example, no studies are still available for the Torca room. In levels NM12, NM11 from Mina room, and level NV3 from Vestibule room, 6 trapezes with abrupt retouch, some microburins and notched blades have been classified (Aura et al. 2013: 60). The identification of blade knapping with Montbani blades have allowed to propose the presence of Geometric Mesolithic trapeze-based industries at Nerja Cave. The most reliable radiocarbon date from a Geometric Mesolithic occupation comes from level NV3(IIIc) of the Vestibule room that corresponds to a pinecone scale (GifA-102010: 7610 ± 90 BP, 8412 median cal BP). Nevertheless, as the researchers have cautiously admitted, it has not been possible to stratigraphically individualize a Mesolithic horizon in NV3, due to the lateral discontinuities, and Neolithic intrusions that resulted in a mixed multicomponent layer with Epipaleolithic and Neolithic materials (Aura et al. 2009: 349–350). Therefore, the association of these lithic assemblages with a precise radiocarbon framework still needs to be evaluated, but in any case, situates the trapeze industries at the end of TS2.

Ultimately, there is a group of lithic assemblages whose radiocarbon calibrated median falls into the TS2 (8600–8400 cal BP), nevertheless they have not provided trapeze microliths. These are sites classified at group 3 (see Figure 3): Rei Cintolo, camarín S3 (ID15). Atxoste, level V (ID26). La Garma, level Q (ID80). Cova Foradada, level II (ID91). Prazo, U4a/MF (ID100). Mazaculos II, level 1.3 (ID109). Kobeaga II, level Amck-h (ID118). J3, level D (top) (ID120). Font del Ros, SG-6 (ID135). São Julião (ID143). Berroberría, unit B (ID171). Kanpanoste Goikoa, level IIIinf (ID174). Ekain, charcoal from horse II-45 (ID178). Serrat del Pont, unit IV.2 (ID182). Arenal de la Virgen, SU604-hearth (ID210). Carabión, C5_N1 (ID225). Most of them correspond to lithic assemblages from Notched and Denticulates tecno-complex (Atxoste—level V, Font del Ros—unit SG-6, Berroberría—unit B, Kanpanoste Goikoa-level III inf, Serrat del Pont—unit IV.2, or Arenal de la Virgen—SU604), or flake industries sensu lato (Mazaculos II—level 1.3). Others have some microliths, not trapezes, with a doubtful stratigraphic association (Kobeaga II—unit Amck-h, Carabión-C5_N1). In the remaining sites (C. Rei Cintolo, La Garma, Cova Foradada, J3, Prazo, São Julião, Ekain), the Mesolithic radiocarbon date has no relationship with any lithic assemblages.

In short, the chronostratigraphic data previously presented and analyzed enable us to build a more accurate radiocarbon framework fundamental to trace the first appearance of Late Mesolithic blade and trapeze industries. First, we can point out that radiocarbon signal of archaeological assemblages with trapezes cannot be traced back beyond 8550–8450 median cal BP (depending on whether we considered sites ranked in group 2 or 1). From a typological point of view, short trapezes with abrupt retouch and one or two concave sides are the majority, as in the case of Esplugón, level 4, Artusia, level III, Botiquería, level 2, or Cocina, layers 12 to 9 (1941 trench), to name a few between the most quantitatively representative.

Likewise, a quick glance at the generic typological data available for archaeological assemblages of this TS2, brings to light the scarcity of detailed technological studies which hampers intersite comparisons.

3.1.3. Temporal Slice 3: 8400–8200 cal BP. Consolidation of Late Mesolithic Industries

Within the chronological interval of TS3 3 (8400–8200 cal BP), we find a slight decline in the number of lithic assemblages ($n = 23$). The main geographic distribution of archaeological sites shows a continuity pattern regarding the TS2, however we observe few changes such as the nucleation of Mesolithic settlements around the Atlantic rich estuarine areas of Portugal (Bicho et al. 2010; McLaughlin et al. 2021), and the coast of eastern Asturias (García-Escárzaga et al. 2022). The most significant change of TS3 is the first documentation of trapeze industries in Portugal (Figure 4).

Most of the archaeological assemblages in group 3, are not relevant in the assessment of the consolidation of trapeze industries in TS3, because they correspond either to collections without techno-typological categories related to trapeze-based lithic industries: Buraca Grande, unit 8c (ID11); Tito Bustillo, rock art pigment (ID87); Pareko Landa, l-Smk(h2) (ID102); Sierra Plana, level IC (ID116); São Julião (ID143), Santimamiñe, H-Sln (ID188); or archaeological sites where the information is not available: La Fragua, level 1 inf (ID103); Castelejo, middle levels (ID166); Armação Nova, level 4b (ID167). However, Arenal de la Virgen, SU615 (ID210) deserves a special mention, since a recent detailed technological analysis has characterized the most recent Notched Mesolithic lithic assemblage of the eastern Iberian Peninsula, contemporaneous to the first trapeze industries from archaeological sites in

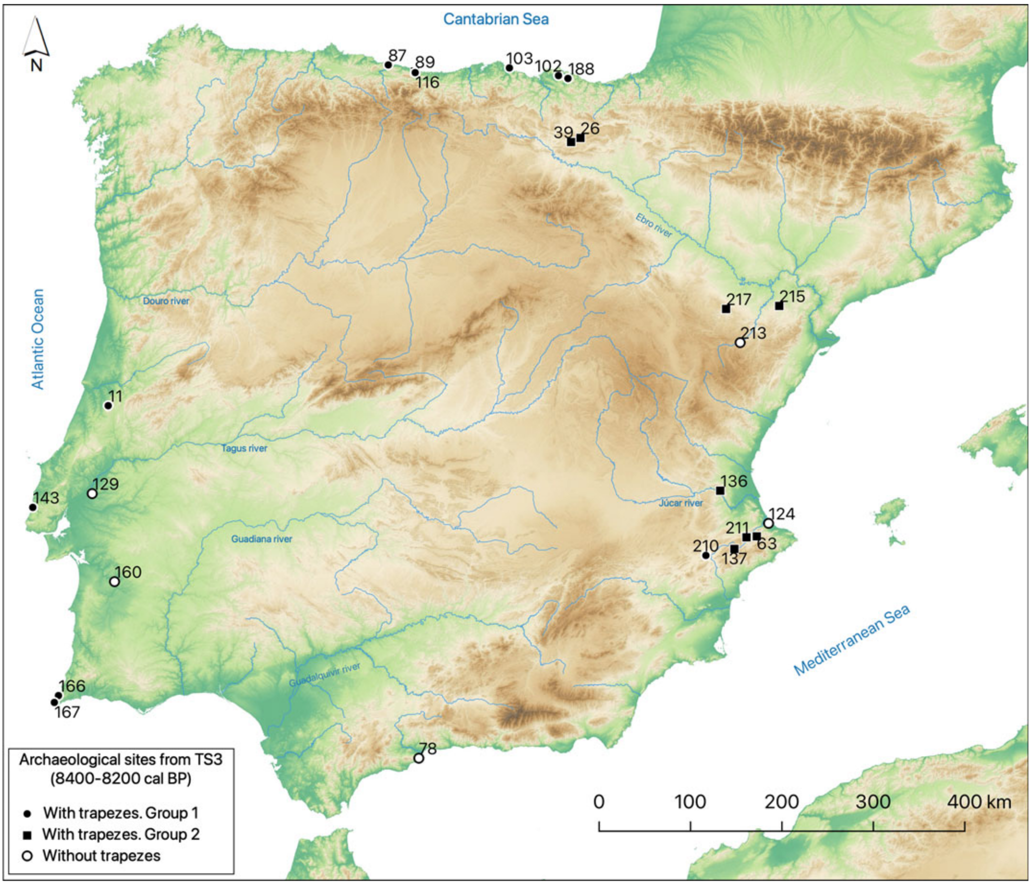

Figure 4 Spatial distribution of archaeological sites in temporal slice 3 (TS3). Archaeological sites with trapezes, group 1: 26. Atxoste. 78: Bajondillo Cave. 89: El Mazo. 136: Cocina. 137: Falguera. 211: Benàmer. 215: Botiquería. 217: Los Baños. Archaeological sites with trapezes, group 2: 63: Tossal de la Roca. 124: El Collado. 129: Moita do Sebastião. 160: Vale Romeiras. 213: Ángel 1. Archaeological sites without trapezes, group 3: 11. Buraca Grande. 87: Tito Bustillo. 102: Pareko Landa. 103: La Fragua. 116: Sierra Plana. 143: São Julião. 166: Castelejo. 167: Armação Nova. 188: Santimamiñe. 210: Arenal de la Virgen.

the regional context such as Cocina, Falguera, El Collado or Tossal de la Roca (Rabuñal 2021).

According to the assemblage reliability index followed in this study, the assemblages displaying the most reliable relationship of trapeze industries with accurate radiocarbon dates are, from north to south: El Mazo, SU105 (ID89); Atxoste, level IV (ID26); Los Baños, level 2b3inf (ID217); Botiquería, level 2 (ID215); Cocina, layer 8 (1941) (ID136); Falguera, layer VIII (ID137); and Benàmer, SU2578 (ID211).

In the eastern coast of Asturias, the SU105 from El Mazo shell midden (ID89) has provided a short collection of geometric armatures, limited to two trapezes (Fuertes et al. 2021: 473). However, this archaeological level corresponding to the central section of a shell midden deposit, concentrates the majority of the lithic artifacts and trapezoidal microlith armatures (Fuertes et al. 2021: 472). All the geometric microliths were produced with abrupt retouch and

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the microburin technique. A radiocarbon date on a short-lived sample bounds the chronology of this level to the end of the ninth millennium cal BP (OxA-30535: 7380 ± 55 BP, 8195 cal BP calibrated median).

In the Upper Ebro Basin, Level IV from Atxoste rockshelter (ID26), with 88 geometric microliths, most of them trapezes (n = 66), is one of the main lithic assemblages of the TS3. The detailed analysis of the lithic collections (Soto 2014: 705–707) shows the prevalence of asymmetric trapezes with one or two concave sides. Four radiocarbon dates have been published for this level: two of them, GrA-13470: 8080 ± 50 BP, and GrA-13419: 6970 ± 40 BP, have been dismissed by the researchers because they are the result from a single sample, evaluated by the laboratory according to two different procedures, providing anomalous results separated by a millennium (Alday and Cava 2006: 293); the other two radiocarbon dates were also produced on a single bone collagen sample, recovered at the same depth as the highest density of geometric microliths (Alday 2002: 39; Soto 2014: 730; Pérez et al. 2020: 4), are GrA-13469: 7480 ± 50 BP and GrA-13418: 7340 ± 50 BP. Since both dates come from the same sample (Alday 2002: 40), we have considered the oldest one, GrA-13469: 7480 ± 50 BP (8288 calibrated median), as representative of the beginning of the trapeze phase in Atxoste. In any case, both dates, statistically similar (χ^2-test: df = 1 T = 2.6, 5% 3.8) forward to the end of TS3, around the 8.2 ka climatic event.

In the lower Ebro Valley, the occupation at Los Baños rockshelter (ID217), documented in TS1 and TS2, continues during the TS3. Level 2b3 has provided a lithic assemblage of 5 notched blades, 8 microburins and 17 trapezes, of short size and mostly asymmetric and with one or two concave sides (Utrilla and Rodanés 2004: 22, 34–35; Utrilla et al. 2009: 156–160). As the Level 2b3 is difficult to detect in the whole excavated area, the researchers opted to subdivide it into 3 sublevels: 2b3 inferior, medium and upper, being 2b3medium archaeologically sterile. The stratigraphic association between trapezes and radiocarbon dates can be established in both level 2b3 inferior and 2b3 upper. We consider the oldest radiocarbon date from level 2b3inf (square 4A') indicates a consolidated presence of trapeze industries at this site in TS3 (GrA-21551: 7550 ± 55BP, 8362 median cal BP), confirmed by another radiocarbon date statistically similar (χ^2-test: df=1 T=0.0, 5% 3.8) from level 2b3 generic (GrA-24300: 7570 ± 100BP), retrieved from another sector (square 1A) and associated to short size and asymmetric trapezes.

Trapeze industries can also be considered consolidated in Level 2 of Botiquería (ID215) during TS3. The radiocarbon date Ly-1198:7550 ± 200 BP (8359 median cal BP) (Barandiarán 1976: 184; Barandiarán 1978: 132), can be regarded as a *terminus ante quem* expanding the occurrence of trapezes up to the end of IX millennium cal BP, when the rockshelter occupation was interrupted as evidenced by the superimposed level 3, barely sterile from the archaeological point of view (Barandiarán 1978: 62).

In the central sector of the Iberian Mediterranean region, Geometric Mesolithic occupation of Cocina (ID136) within 8400–8200 cal BP, is associated to lithic industry from layer 8, 1941 trench, that has a predominance of trapezes, but also a few Cocina type triangles documented for the first time in the archaeological sequence (García-Puchol et al. 2018: 262). There is one radiocarbon date from an individual *Capra pyrenaica* bone sample on that layer 8 (UCIAMS-145195: 7475 ± 25 BP, 8287 calibrated median).

In the southeastern Mediterranean region of Iberia, two Late Mesolithic archeological sites in the interior valleys of Polop and Serpis rivers–Falguera rockshelter (ID137), and open-air site of Benàmer (ID211)– have provided lithic assemblages with trapezes dated during the TS3. The

Falguera rockshelter (ID137), excavated between 1998 and 2001, has provided interesting data for reconstructing the dynamics of phase A or trapeze phase of the Geometric Mesolithic. The archaeological sequence starts with level VIII. The lithic assemblage from this level has 4 trapezes with abrupt retouch, two of them correspond to short asymmetric trapezoids of small size, whereas the other two respond to an asymmetrical trapezoid with a concave side, and a fragment of trapeze (García et al. 2006: 130–131). Notched blades are also present (Martí et al. 2009: 223). However, the microburin technique has not been documented. Level VIII is associated with a radiocarbon dated on a short-lived sample (pinecone scale) (AA-59519: 7526 ± 44 BP, 8345 calibrated median), which is fully consistent with the Geometric Mesolithic in the regional context.

Finally, the open-air site of Benàmer (ID211) has provided data from the Geometric Mesolithic in this southeastern Mediterranean region of Iberia (Torregrosa et al. 2011). The Geometric Mesolithic Phase A of trapezes has been identified in the occupation phase Benàmer I. Notched blades predominate, followed by trapezes with abrupt retouch particularly with one concave side and to a lesser extent, with two concave sides. Few short size trapezes have also been documented. The microburin technique seems little representative (Jover et al. 2012: 117, 122). There is one radiocarbon date on a short-lived wood charcoal from SU2578 is stratigraphically associated with 3 trapezes of one concave side (Jover et al. 2011: 163), that dates trapeze industries during the TS3 (Beta-287331: 7480 ± 40 BP, 8290 calibrated median).

Six additional assemblages should be mentioned within the chronological range of TS3, although ranked in group 2. These assemblages are Ángel 1, level 8c (ID213); El Collado (ID124); Tossal de la Roca, level I (ID63); and Bajondillo Cave, level 3 (ID68), in the Ebro valley and the Mediterranean coast, and two Portuguese shell middens, Moita do Sebastião (ID129), and Vale de Romeiras (ID160). In the Ángel 1 rockshelter (ID213), the lithic assemblage of Level 8c is characterized by trapezoids with abrupt retouch, both short and elongated and microburins. Triangles are less numerous, being more abundant the segments and the small-curved backed bladelets or elongated crescents (Utrilla et al. 2003: 303). However, the relationship between the trapeze microliths and the radiocarbon record requires to be discussed. This site was excavated by different research teams during several fieldwork campaigns (Utrilla et al. 2017). The most updated archaeological sequence is the result of the correlation between different levels and contexts previously differentiated to which the lithic assemblages were attributed. From this Level 8c two radiocarbon dates are available, both on a single charcoal sample. The oldest one, GrA-27278: 7955 ± 45 BP, entirely falls within the chronological boundaries of the Notches and Denticulates Mesolithic, hence we have taken the most recent one as valid, for the beginning of trapeze phase at Ángel 1 rockshelter during TS3: GrA-27274: 7435 ± 45 BP, 8263 calibrated median.

In the central Mediterranean coast, a new radiocarbon date on a *Cervus elaphus* bone with anthropic fractures from the Surface Level of the open-air site of El Collado (ID124), has recently confirmed the continuity of Geometric Mesolithic trapeze-based industries, already detected in TS2, during TS3 (Ua-72903: 7484±38 BP, 8295 median cal BP). The provenance of the sample from the Surface level, is associated to the presence of trapezes with concave sides (see Figure S3), however we rank this case at group 2 because the limited information about the stratigraphic sequence.

Also, in the central Mediterranean region of Iberia, the lithic assemblage from level I (exterior sector) at Tossal de la Roca rockshelter (ID63), has been ascribed to the Geometric Mesolithic, Phase A or trapezes phase (Martí et al. 2009: 222). Level I (exterior sector) has yielded trapezes of abrupt retouch but also abundant notches and denticulates pieces, although no microburins have been recovered (Cacho et al. 1995: 83). This level has two radiocarbon dates on aggregate bones sample: Gif-6898: 7660 ± 60 BP; 8455 calibrated median date, that was in the chronological span of TS2, and Gif-6897: 7560 ± 60 BP; 8367 calibrated median, in the chronological limits of TS3. Considering the wide probability distribution of the calibrated radiocarbon date, derived from an aggregate sample, we ranked this assemblage in our group 2.

Finally, in the coast of Málaga (Andalucía, south Spain), within the long stratigraphic sequence of Bajondillo Cave (ID68), the Holocene level Bj3, has provided one trapeze without any other contextual information (Cortés 2007: 454). Although researchers have admitted that the material culture is very scant (Cortés et al. 2007: 494), the trapeze is associated to a radiocarbon date on a single charcoal sample that gives a chronological signal for trapeze-based industries in TS3 (Ua-18269: 7475 ± 80 BP, 8279 calibrated median), and complete regional data in the southern sector of the Iberian Peninsula.

As mentioned before, during the TS3 we find the first occurrence of trapezes in Portugal, mainly associated with the open air shell middens of the Muge and Sado rivers (Bicho et al. 2010). Here, determining the timing of appearance of blade and trapeze industries and its evolutionary patterns in this kind of archaeological deposits remains more difficult than in rockshelter stratigraphic sequences for several reasons: First, because the low stratigraphic resolution of the assemblages from old fieldwork campaigns (19th century), on the basis of differentiating artificial layers inside thick archaeological levels (mainly, lower, medium and upper levels); second, the abundance of radiocarbon dates made on marine shells or human bone collagen samples with significant proportions of marine diet, which requires radiocarbon calibration with the marine and mixed marine-atmospheric calibration curves with different local reservoir effects (Carvalho 2009: 46; Peyroteo 2016; Soares et al. 2016); third, the difficulty in establishing stratigraphic association between lithic assemblages with radiocarbon dates in shell matrix deposits affected by postdepositional disturbance due to the recurrent funerary activity (Roche 1966: 19; Arnaud 1989); and fourth, the partial publication of lithic assemblages and lack of detailed coupled chronostratigraphic-typological studies does not allow direct comparison.

Up to now, the most complete techno-typological systematization for the appearance and evolution of the trapeze industries in Portugal has been established by G. Marchand more than two decades ago (Marchand 2001). This author proposed three phases in the evolution of the Late Mesolithic lithic industries in Portugal, relying on the revision of old excavations from the Muge shell middens. According to this proposal, the oldest phase would be represented by the shell midden of Moita do Sebastião, where asymmetric trapezes predominate (trapezes with one large rectilinear truncation and a small concave truncation and those trapezes with two concave truncations). This stage would be also represented in Sado shell middens of Vale de Romeiras and Arapouco, with an abundance of trapezes (Marchand 2001: 71). A second phase characterized by a major presence of triangles of central spine—Muge or Cocina type—would be represented at the lithic assemblages of Cabeço da Amoreira. The most recent phase, where segments and trapezes are more numerous in detriment of triangles, would be detected both in Muge (Moita do Sebastião, Cabeço da Arruda) and Sado shell middens (Poças de S. Bento, Cabeço do Rebolador, Várzea da Mó, Amoreiras), as well as in the Alentejo coast (Fiais, Vidigal) (Marchand 2001: 71–73).

Since 2013, new works based on extensive radiocarbon sampling have assessed the chronometric framework for Late Mesolithic in the centre and south of Portugal (Bicho et al. 2010; 2013; Monteiro et al. 2017), including new ones focused on bone collagen samples from Mesolithic burials (Peyroteo 2016, 2021). In this context, archaeological sites with the oldest radiocarbon evidence of trapeze industries are Moita do Sebastião (ID129), and Vale de Romeiras (ID160), both classified in group 2, because the problematic relationship between the lithic assemblages and radiocarbon dates from human interments.

Moita do Sebastião (ID129), partially razed in 1952, provided the first absolute radiocarbon date from the Portuguese Mesolithic (Roche 1957). The direct analysis of Moita do Sebastião lithic collections by Marchand, led this research to consider this site representative of the first phase of the trapeze industries (Marchand 2001: 71 and 94; Fig. 19). The main problem is to establish the correlation between the oldest funerary activity in this site and the lithic assemblages of the basal levels from Roche's collection. New radiocarbon dates on fourteen human samples from Roche's 1952–1954 excavations, have provided ages that could date the appearance of trapezes during the TS3 (Peyroteo 2016: 166). The oldest one is radiocarbon date from Sk. 9 Ua-46264: 7621 ± 50 BP, 8152 median cal BP, which has been calibrated, considering the 42.9% of marine origin diet according to recent palaeodietary evidence (Peyroteo 2016: 269), and a local reservoir offset for the Tagus paleostuary of $\Delta R = -48 \pm 143$ (recalculated from Martins et al. 2008: 79). This radiocarbon date included in the Bayesian chronological model built for the whole funerary activity in Moita do Sebastião, led Peyroteo to estimate that the earliest burials at the site occurred between ca. 8300–7900 cal BP (Peyroteo 2021: 276). The use of an updated $\Delta R = -48 \pm 143$ applied in this work does not significantly affect the probability distribution of the earliest funerary activity on the site and the main issue regarding lack of correlation still remains. Several attempts to reconstruct Moita do Sebastião stratigraphy have been carried out (Jackes and Alvim 2006; Alvim 2010), but since the site was partially razed to the ground and just 20 cm of archaeological deposits were left (Roche 1965: 132), we can just reconstruct a tentative relationship between asymmetric trapezes with one or two concave sides, the most abundant type of geometric microliths (Roche 1972: 65–95), and the oldest skeleton (Skeleton 9) found during Roche fieldwork campaigns (1952–1954), both at basal level (see plans of the site in the Supplementary materials, Supporting graphic material S9). To retain this information in Bayesian model C, we have used the Before () function.

Finally, Vale de Romeiras (ID160) is a small open-air shell midden located in the Sado valley. The archaeological excavations were undertaken during 1959 and 1960 of XXth century under the supervision of Professor Manuel Heleno, director of the Museu Nacional de Arquelogia e Etnologia in Lisbon, over an area of 54 m^2 (Arnaud 1989: 614; Marchand 2001: 51; Peyroteo 2016: 292). Archaeological methods at that time only differentiated one or two layers of brown soil covering shell middens deposits that overlaid yellowish sands (upper, middle, and lower levels) (Arnaud 2000: 34, Fig. 9).

More detailed stratigraphic data, based on the digitalization of the graphic documentation available, has been later resumed (Peyroteo 2016: 293–295). According to this, the archaeological deposit of Vale de Romeiras has a maximum depth of 84 cm whose stratigraphic sequence is composed of 6 layers. Thirteen samples of human bones were selected for ^{14}C analysis, however only three fulfilled the laboratory quality control parameters (Peyroteo 2016: 298). The oldest valid radiocarbon date corresponds to a bone collagen sample from the skeleton 19 (Ua-46972: 7640 ± 55 BP). Most of the burials were found lying on the soft bedrock or layer 6 (Peyroteo 2016: 293, Fig. 4.45), but burial 19 was found in layer 5, penultimate layer over the bedrock, at 60 cm depth (Peyroteo 2016: 295) (See plans of the site in the Supplementary Materials, supporting graphic material S9).

Researchers acknowledged that the recovery of findings was intensive, though there is no precise stratigraphic attribution for the lithic assemblages (Arnaud 1989: 616). Trapeze microliths were described by Arnaud (1989: 621–624) for the entire archaeological deposit and not for each layer. Arnaud identified a predominance of asymmetric trapezes at Vale de Romeiras (Arnaud 1989: 621 and 623). This type of trapezes led Marchand to include the site in the oldest phase of the Late Mesolithic in Portugal (Marchand 2001: 71).

We have calibrated radiocarbon date from skeleton 19 (Ua-46972: 7640 ±55 BP, 8395 median cal BP), considering 12% of marine diet estimate (Peyroteo 2016: 298), and the updated local reservoir offset for the Sado river ΔR value = –323 ± 127 (recalculated from Soares and Dias 2006).

According to the current evidence, we assume that the first trapezes of Vale de Romeiras might be as old or postdate the age of the skeleton 19. Consequently, as in the previous case of Moita do Sebastião, this date has been considered as a "Terminus Ante Quem" in the two overlapping phases of Bayesian model C to probabilistically establish the beginning of trapezes phase at Vale de Romeiras between TS2 and TS3 (see below section 3.2).

3.2. Bayesian Model Results

The results of the Bayesian chronological Model A, built on the six most reliable dates (classified in group 1) from TS2 (8600–8400 cal BP) (Supplementary text S6) are presented in Figure 5 and Table 5. Model A plot (Figure 5), shows a model agreement index ($A_{model} = 161$) greater than 60, indicating consistency of the proposed model (Bronk Ramsey 1995: 427–428). All the individual values also display a good agreement with the model (Table 5).

According to model A, the start of blade and trapeze industries is situated between 8505–8390 cal BP and the end between 8425 –8338 cal BP. These probability distributions partly overlap, revealing the narrow interval of the process. The Span () query confirms this, yielding a probabilistic estimation between 0–85 years (95.4% CI) for the duration of the initial diffusion of trapeze industries during the TS2.

For the Bayesian phase model B, the one with 15 radiocarbon dates ranked in groups 1 and 2 according to the reliability index, we find very similar results (Supplementary text S7). The model also displays a good agreement index ($A_{model} = 109$) indicating the consistency of the model and the radiocarbon dates (Figure 6; Table 6). Only the radiocarbon date of Mendandia—level IV (GrA-22745: 7780 ± 50 BP) was detected as an outlier (A = 31). This outlier corresponds to a sample composed by several bone fragments, whose radiocarbon measurement is likely merging materials from different occupation events. However, this date has little impact in the general agreement index of the individual dates ($A_{overall} = 106.6$) and does not affect the assessment of the quality of this Bayesian model (Bronk Ramsey 2009b: 1025; Bayliss 2015). The Span () function shows a probabilistic estimation between 0–147 years (95.4% CI) for the duration of the initial diffusion of trapeze industries during the TS2, demonstrating that the inclusion of radiocarbon dates from archaeological contexts affected by a palimpsest-like structure, almost double the estimated duration of the spread of trapezes in comparison to model A.

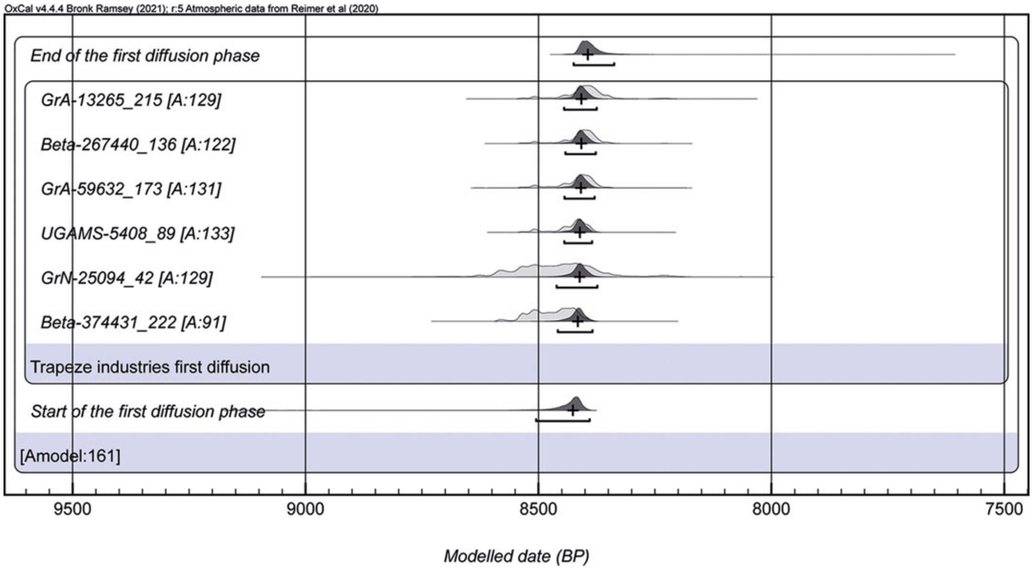

Figure 5 Plot of the single-phase Bayesian model A with the most reliable archaeological contexts to establish the beginning of trapeze industries, TS2 (8600–8400 cal BP). N = 6. Prior distributions (unmodeled calibrations) are shown in light gray and posterior distributions (modeled) in dark gray. OxCal v4.4 (Bronk Ramsey 2009a). 222: Artusia. 42: Peña 14. 89: El Mazo. 173: El Esplugón. 136: Cocina. 215: Botiquería.

The third Bayesian chronological model—Model C—comprises the six most reliable archaeological assemblages for TS 2 (8600–8400 cal BP), and the oldest Portuguese Mesolithic sites—Moita do Sebastião and Vale de Romeiras—with trapeze industries, documented during TS3 (8400–8200 cal BP) (Table 7, Figure 7) (Supplementary text S8). Model C is a two overlapping phases chronological model aimed at keeping both phases independent in an overall phase, i.e., the diffusion process of trapeze industries.

In Portuguese sites, the radiocarbon dates were obtained on human bone samples, partially affected by the “marine reservoir effect” (MRE), which implies a degree of chronological uncertainty in the calibration process. The percentage of marine diet estimated for these sites ranges between 43% for Skeleton 9 from Moita do Sebastião (Peyroteo 2016: 169, Table 4.4), and 12% for Skeleton 19 from Vale de Romeiras (Peyroteo 2016: 298, Table 4.50). Moreover, in this model C, we have introduced a TAQ ()/Before (), to constrain the appearance of trapeze industries after the radiocarbon date of Skeleton 9, in Moita do Sebastião, and Skeleton 19, in Vale Romeiras, representing both the earliest funerary activity in these shellmiddens prior to the appearance of trapeze industry.

Constraining the uncertainty to the radiocarbon dates from Portuguese archaeological sites and differentiating the chronological span of the diffusion process in the two areas in model C yielded a model agreement index ($A_{model} = 145$) (Figure 7). However, in this model, the chronological boundaries for the spread of trapezes are considerably wider (8943–8457 and 8686–7688 cal BP), than in the eastern half of Iberia, spanning between 0 and 1250 years (95.4% CI). These broad ranges are result of the chronological uncertainties of the current radiocarbon record available in shellmidden sites.

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Table 5 Table of results from Model A. Radiocarbon posterior probabilities and model agreement indexes of the most reliable archaeological contexts (classified in group 1) from TS2 (8600–8400 cal BP). A = OxCal Agreement index value (should be above 60 if data agree with model), C = OxCal Convergence value (should be ≥95). OxCal v4.4 (Bronk Ramsey 2009a).

Sample ID	Site	Level	^{14}C BP age	Modeled 95.4%		Median	A	C
Boundary	*End*			8425	8338	8394		97.9
Interval				0	139	31		97
Span				0	85	21		98.9
GrA-13265	Botiquería	2	7600 ± 50	8445	8375	8408	128.8	99.4
Beta-267440	Cocina	layer 17(1945)	7610 ± 40	8442	8377	8408	121.1	99.4
GrA-59632	El Esplugón	4	7620 ± 40	8444	8380	8409	130.9	99.5
UGAMS-5408	El Mazo	SU105	7640 ± 30	8445	8385	8411	132.8	99.5
GrN-25094	Peña 14	a	7660 ± 90	8461	8374	8412	128.7	99.4
Beta-374431	Artusia	SU20	7680 ± 40	8459	8384	8416	91.2	99.3
Boundary	*Start*			8505	8390	8426		97.4

4. DISCUSSION

We aimed to review the radiocarbon evidence of the first trapeze industries in the Iberian Peninsula between 8800–8200 cal BP and discuss the spatiotemporal patterns of appearance. Our work provides a baseline based on the critical evaluation of the radiocarbon record of the first trapeze industries and the stratigraphic association between radiocarbon samples with trapeze industries. Our results show solid evidence for the appearance of trapeze industries in most of the Iberian Peninsula during the TS2 (8600–8400 cal BP) except for Portugal and Galicia, where it is dated during the TS3 (8400–8200 cal BP) or later (Ramil et al. 2021). Other regions where the Mesolithic evidence has not been documented for the time range under analysis are northern and southern Iberian Plateau and Cataluña.

Possible older occurrences of trapezes, during the TS1 (8800–8600 cal BP), have been discussed for the assemblages "d" of La Peña de Marañón and "2b1" of Los Baños. However, in the case of La Peña, the dated sample is 15 cm below the first trapezes, whereas for the case of the Level 2b1 of Los Baños, the presence of old inherited charcoal from previous Mesolithic occupations seem the most parsimonious explanation for such early occurrences, especially if we consider the recent chronometric evidence provided by other well dated sites of the Upper Ebro Valley and the central Pre-Pyrenean area such as El Esplugón or Artusia rockshelters.

Beyond the Ebro valley, the publication of new assemblages in Cantabria (El Mazo), new radiocarbon analyses in relevant Mesolithic sites of the central Mediterranean area (Cocina and El Collado) and the revaluation of the chronometric evidence in Andalusia (Nacimiento cave and Nerja) advocate for a wider spread diffusion of trapeze industries in Iberia during the TS2, than that envisaged just few years ago (Marchand and Perrin 2017: Fig. 3).

As mentioned in the introduction section, the geographic position of the Iberian Peninsula makes this area an ideal scenario for testing different hypothesis about the geographic origin of and diffusion dynamics of trapeze industries in Western Europe. As far as the spatiotemporal patterns derived from the present study are concerned, we do not find solid chronometric evidence supporting a diffusion related to the Upper Capsian from the Maghreb region to the

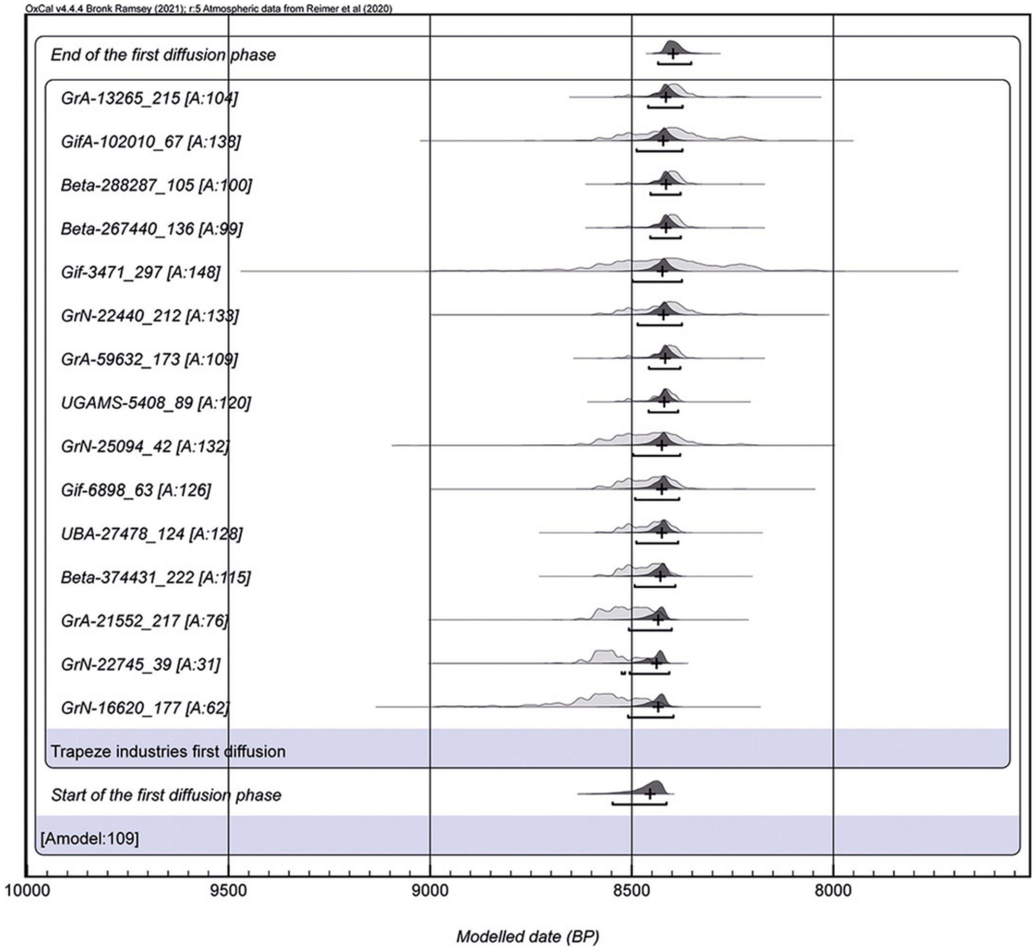

Figure 6 Plot of the single-phase Bayesian model B with radiocarbon dates from sites in TS2 (8600–8400 cal BP), classified in groups 1 and 2. N = 15. Prior distributions (unmodeled calibrations) are shown in light gray and posterior distributions (modeled) in dark gray. OxCal v4.4 (Bronk Ramsey 2009a). 177: Aizpea. 39: Mendandia. 217: Los Baños. 222: Artusia. 124: El Collado. 63: Tossal de la Roca. 42: Peña 14. 89: El Mazo. 173: El Esplugón. 212: Kanpanoste. 297: Cueva del Nacimiento.136: Cocina. 105: Cueva Blanca. 67: Nerja. 215: Botiquería.

south of the Iberian Peninsula during the TS2 (8600–8400 cal BP). This does not preclude future possible occurrences, because some undated open-air sites such as Embarcadero del Río Palmones, in the Algeciras Bay (Ramos 2005) have provided lithic assemblages with trapezes, triangles, notched blades and microburins. However, such a techno-typological structure can equally correspond to the TS3 (8400–8200 cal BP). Therefore, the north African origin hypothesis still remains to be demonstrated, especially if we consider the significant distance between the Gibraltar strait and the core area of the Upper Capsian technocomplex (Perrin et al. 2020), in eastern Algeria and Tunisia. Recent studies from the northern Morocco sites of Ifri Oudadane (Linstädter et al. 2015) and Ifri n'Etsedda (Broich et al. 2021) have reported assemblages with few trapezes and microburins, among other kind of armatures such as triangles of backed bladelets within thick sedimentary deposits considered "Epipalaeolithic."

Table 6 Table of results from Model B. Radiocarbon posterior probabilities and Model agreement indexes of radiocarbon dates from sites in TS2 (8600–8400 cal BP), classified in groups 1 and 2. A = OxCal Agreement index value (should be above 60 if data agree with model), C = OxCal Convergence value (should be ≥95). OxCal v4.4 (Bronk Ramsey 2009a).

Sample ID	Site	Level	^{14}C BP age	Modeled 95.4%		Median	A	C
Boundary End				8435	8353	8398		98.6
Interval				0	177	58		97.5
Span				0	147	50		98.3
GrA-13265	Botiquería	2	7600 ± 50	8459	8374	8416	103.9	99.6
GifA-102010	Nerja	NV3 (IIIc)	7610 ± 90	8488	8375	8422	137.8	99.7
Beta-288287	Cueva Blanca	level Ib	7610 ± 40	8454	8379	8415	99.5	99.7
Beta-267440	Cocina	Layer 17 (1945)	7610 ± 40	8454	8379	8415	99.4	99.7
Gif-3471	Cueva del Nacimiento	layer 3	7620 ± 140	8499	8376	8424	147.6	99.6
GrN-22440	Kampanoste	Lanhs	7620 ± 70	8486	8376	8422	132.8	99.8
GrA-59632	El Esplugón	4	7620 ± 40	8457	8380	8417	108.8	99.7
UGAMS-5408	El Mazo	105	7640 ± 30	8458	8385	8420	120	99.8
GrN-25094	Peña 14	a	7660 ± 90	8497	8380	8426	131.8	99.7
Gif-6898	Tossal de la Roca	level I ext	7660 ± 60	8492	8383	8426	126.1	99.8
UBA-27478	El Collado	C-1	7660 ± 44	8489	8385	8426	127.6	99.9
Beta-374431	Artusia	SU20 (Unit III)	7680 ± 40	8493	8392	8429	115.4	99.8
GrA-21552	Los Baños	2b1	7740 ± 50	8507	8401	8435	76.1	99.6
GrN-22745	Mendandia	IV	7780 ± 40	8525	8407	8439	30.6	99.5
GrN-16620	Aizpea	I	7790 ± 70	8509	8397	8435	61.8	99.6
Boundary Start				8548	8414	8455		

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Table 7 Table of results from Model C. Radiocarbon posterior probabilities and Model agreement indexes of radiocarbon dates from the most reliable sites in TS2 (8600–8400 cal BP), classified in group 1 and, the oldest Mesolithic sites with trapeze industries from Portugal, documented during TS3 (8400–8200 cal BP). A = OxCal Agreement index value (should be above 60 if data agree with model), C = OxCal Convergence value (should be ≥95). OxCal v4.4 (Bronk Ramsey 2009a).

Sample ID	Site	Level	^{14}C BP age	Modeled 95.4%		Median	A	C
Portuguese dataset								
Boundary End				8686	7688	7982		99.1
Interval				0	1250	718		98.4
Ua-46264	Moita do Sebastião	Skeleton 9	7621 ± 50	8390	8025	8239	100.7	99.5
Ua-46972	Vale Romeiras	Skeleton 19	7640 ± 55	8548	8222	8411	99	99.7
Boundary Start				8943	8457	8774		99.4
Spanish dataset								
Boundary End				8425	8343	8394		99.1
Interval				0	138	31		98.4
Span					86	21		99.5
GrA-13265	Botiquería	2	7600 ± 50	8445	8375	8408	128.9	99.7
Beta-267440	Cocina	layer 17(1945)	7610 ± 40	8442	8377	8408	122.2	99.8
GrA-59632	El Esplugón	4	7620 ± 40	8444	8380	8409	130.9	99.7
UGAMS-5408	El Mazo	SU105	7640 ± 30	8445	8385	8411	132.6	99.8
GrN-25094	Peña 14	a	7660 ± 90	8460	8374	8412	128.7	99.7
Beta-374431	Artusia	SU20	7680 ± 40	8459	8384	8416	90.9	99.7
Boundary Start				8504	8390	8426		98.6

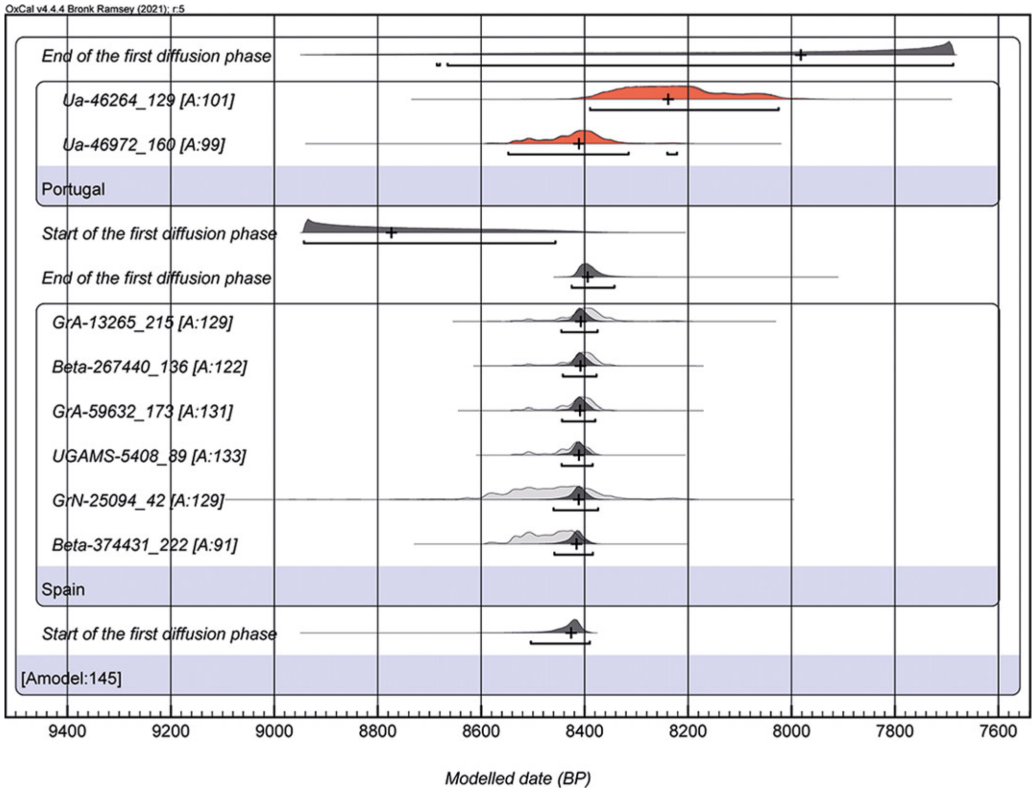

Figure 7 Plot of the single-phase Bayesian model C with the most reliable archaeological TS 2 assemblages and the oldest Mesolithic sites with trapeze industries from Portugal, documented during TS3 (8400–8200 cal BP). N = 8. Prior distributions (unmodeled calibrations) are shown in light gray and posterior distributions (modeled) in dark gray, when IntCal20 has been used. In the case of using a mixed calibration curve Intcal20 and Marine20, prior distributions (unmodeled calibrations) are shown in light red and posterior distributions (modeled) in dark red. OxCal v4.4 (Bronk Ramsey 2009a). 222: Artusia. 42: Peña 14. 89: El Mazo. 173: El Esplugón. 136: Cocina. 215: Botiquería.160: Vale Romeiras. 129: Moita do Sebastião.

However, nowadays such evidence remains inconclusive to establish a clear link with the Mesolithic of trapezes documented in the south of the Iberian Peninsula.

In contrast, the Southern Central and Western Pyrenees have provided strong chrono-metric and techno-typological evidence supporting a diffusion in the Iberian Peninsula from southern France, as initially proposed by other authors (Marchand and Perrin 2017). Our results, however, indicate a very wide and rapid diffusion process during the TS2 (8600–8400 cal BP) that, once reached the Ebro valley, would have spread to more distant regions of the Iberian Mediterranean rim, to the east and the south, and the Cantabrian region up to the eastern Asturias to the north. In sum, the whole area covered for the trapezes is close to 330000 km^2. Under the premises of our Bayesian Phase model A, the most conservative and restrictive one on the model assumptions and the data quality control respectively, the span of such a spread could have taken place between in just few generations (0–85 years at a 95.4% CI). When the current evidence of the oldest occurrences of trapeze microliths in Portugal is considered (Model C), the spreading process for the whole Iberian Peninsula expands (0–1250 years), here the current resolution of the chronostratigraphic framework might be improved with new fieldwork on stratified sites (especially in the rockshelter's stratigraphic sequences).

While our work has a clear regional focus on the Iberian Peninsula, understanding the diffusion mechanisms of trapeze industries necessarily requires new cross-regional comparisons of the radiocarbon record over larger geographic scales (Western Mediterranean and beyond). With the current data, at least for the TS2 and the eastern half of the Iberian Peninsula, the broad spread of trapeze industries in such a narrow chronological span allows to propose the cultural diffusion of technologies within Mesolithic socio-spatial structures as the main driving mechanism. An important argument in favour of such hypothesis, is the geographic distribution of Mesolithic sites reported during our TS1 and the fact that a significant number of them show trapeze assemblages during the TS2. New studies adopting a social network approach can be used to test such a hypothesis (Lozano et al. 2020; Romano et al. 2021; Fernández-López de Pablo et al. 2022). Other suite of novel statistical techniques such as Bayesian Computation Analysis (Cortell-Nicolau et al. 2021) and Bayesian hierarchical Gaussian Process Quantum Regression can equally shed light on the spatio-temporal patterns by comparing different origin points, diffusion mechanisms, dispersal routes and diffusion rates (Crema et al. 2022).

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2024.6

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AUTHOR CONTRIBUTIONS

Both authors have equally contributed to conceptualization, methodology, investigation, writing original draft and editing.

DECLARATION OF COMPETING INTERESTS

The authors declare no conflicts or competing interests.

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