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There and back again: Late Mesolithic technological change in the northeast of the Iberian Peninsula

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ABSTRACT

A profound change took place in the lithic technology of the last hunter-gatherer societies in Western Europe and North Africa at the end of the Early Holocene. In a short period, several technological innovations were adopted in geographically, socially and culturally different contexts; a situation that raises many questions about the mechanisms that enabled this successful expansion and acceptance.

In this paper, we propose a regional approach to the phenomenon. In the northeast of Iberia, the Ebro valley is one of the areas with the most records from the Late Mesolithic (Geometric Mesolithic or GM) as well as from the immediately previous phase (Notched and Denticulate Mesolithic or NDM). This study explores on exploring the main technological characteristics of both phases, as well as their chronological development, to analyse when and how the change occurred. For this purpose, we have reviewed the lithic industry, the stratigraphic sequences and the chronology of more than fifty archaeological levels.

The results obtained highlight the technological distance between the two industrial traditions, where the GM innovations burst into the Ebro valley when the NDM technology was still active. However, we consider that the adoption of the new technology would take place through the socio-territorial structures of the NDM. This hypothesis is based on the recognition of continuity in the territorial occupation, as well as the identification of technological practices typical of the NDM that persist in GM lithic assemblages.

1. Introduction

At the end of the Early Holocene a remarkable technological change took place in the lithic systems of the last hunter-gatherer societies. In most of Western Europe and North Africa, the development of lithic industries was characterized by regular and standardized laminar knapping, associated with the use of indirect percussion and pressure, and the generalization of new tools such as geometric trapezoid-shaped microliths and notched or/and denticulated blades (Binder et al., 2012; Marchand and Perrin, 2017). The rapid expansion of these technological novelties has been highlighted in recent years, with the first evidence around 8800–8600 cal BP in Sicily and southern Italy, and immediate recognition in northern Italy, southern France, Iberian Peninsula and North Africa by 8600–8400 cal BP (Perrin et al., 2009; Marchand and Perrin, 2017). This implies a successful expansion, acceptance and adoption of the new technology across wide geographical territories with very different social, cultural and environmental realities. In this sense, its diffusion cannot be explained by particular ecological or economic casuistries, but necessarily alludes to social processes still not determined. Population movements and the transmission of knowledge via social networks are often adduced as explanatory engines of the speed and procedures of expansion. These are not mutually exclusive proposals, and it would be interesting to reflect on the weight given to each of them. Thus Perrin et al. (2020: 2) propose a first phase characterized by migratory dynamics followed by another of adoption, integration and redistribution that slows down the process, while generating technological diversification practices, with perhaps local particularities.

These approaches make it possible to analyse the mechanisms of diffusion of the phenomenon, but their assessment also requires

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attention to and explanation of the contexts of implementation. How did previous technological practices become dismantled? What motivates societies that have been successfully employing a particular technology for generations to abandon it and replace it with a new one?

We know that mere contact with an innovation, even in cases where it is a substantial improvement, does not necessarily imply its adoption. In other contexts, the importance of social factors, such as the valorisation of the new technology, the context of transmission, the learning process, and even social dynamics of resistance to change, have been revealed to be important in the success or failure of the diffusion of an innovation (e.g., Roux, 2013). In this sense, we believe that a regional approach to this phenomenon can facilitate the analysis of the mechanisms of both technological dislocation and adoption.

This new Late Mesolithic technology corresponds to the Geometric Mesolithic (GM) in the Iberian Peninsula. Its development becomes widespread around the middle of the 9th millennium cal BP and can be traced over wide geographical areas, including the Cantabrian coast, the Ebro basin, the Mediterranean area, and different regions of Portugal (Utrilla and Montes, 2009). As in other European regions, it represents a profound technological change, a situation that is particularly striking in the Iberian Peninsula, given its rupture with the industrial tradition that preceded it: the Mesolithic of notches and denticulates (NDM) (Alday, 2006a; Araújo, 2009), which had thrived for circa two millennia. Although the technological distance between the two ways of organising and managing lithic systems is evident, it is less clear whether the process was progressive or disruptive. We will address the question in this paper, taking into account its social implications.

For this purpose, we focus on the Ebro Valley, one of the richest regions in the Iberian Peninsula in terms of archaeological records of the NDM and the GM, including situations in which features of both traditions seem to coexist (Cava, 2001, 2006; Utrilla and Rodanés, 2004a; Utrilla et al., 2014; Alday and Cava, 2006). This allows us to consider the existence of a possible transition phase. In these circumstances: a) we characterise the industries of both traditions; b) we analyse the entity of these “transition” contexts; and c) we identify the time frame of these dynamics. The ultimate goal is to characterise, technologically and chronologically, the contexts of NDM disarticulation and the adoption of the new lithic tradition, tracing possible processes of technological persistence that allow the mechanisms of this change (progressive or disruptive) to be defined.

2. The archaeological record

The Ebro basin, located in the NE of the Iberian Peninsula, runs parallel to the Pyrenees, in a triangular tectonic trench that leaves the Pyrenees to the N, the Iberian Range to the SW and the Catalonian Ranges to the E. It forms a natural route that communicates the Mediterranean world, the Cantabrian area and the Pyrenees.

With a large number of Mesolithic archaeological sites, research carried out in recent years has shown that this region functioned as a territorial and cultural unit (see bibliography in Alday et al., 2018). In this paper, we focus on the areas with NDM and GM archaeological sites. The part of the Ebro valley corresponding to the current territory of Catalonia has been excluded due to its specific development in the Late Mesolithic (see Vaquero and García-Argüelles, 2009; Oms et al., 2018).

The archaeological record comprising the GM and its predecessor, the NDM, has been recognised in 28 sites in the Upper and Middle Ebro Basin (Fig. 1 and Supplementary material Table 1), adding up to 41 GM levels and 26 NDM levels. Of those considered, all except the open-air settlement at Cabezo de la Cruz (Rodanés and Picazo, 2013) are rock shelters of varying sizes that would form socio-economic networks (Montes and Alday, 2012). It has already been noted (Alday et al., 2018) that, in all likelihood, taphonomic problems have prevented the conservation and current visibility of more open-air settlements, including, for example, those in the vicinity of the well-known outcrops where they obtained the raw materials. Therefore, the geographic distribution that we currently identify, with clusters in certain areas, derives from geomorphological possibilities, taphonomic processes and field research policies.

The stratigraphic continuity between the NDM and the GM is particularly significant in many cases. Indeed, almost all the settlements active during the NDM were also occupied during the GM. The NDM levels close the stratigraphy in only three cases (Kanpanoste, Legunova and Plano del Pulido) but in the first two examples their abandonment is

Fig. 1. Notched and Denticulate Mesolithic and Geometric Mesolithic sites from the studied area (Ebro Basin, Spain).

Table 1
Typological characterization from some NDM lithic ensembles synthesized in different categories (% among the total retouched pieces). (ND: notches and denticulate; Gm: geometric armatures; PD: backed points; G: endscrapers; R: scrapers; T: truncations; B: burins; SP: splintered pieces; Other: rest of types). Bold: dominant type. In the case of Ángel 1 we have only considered materials linked to clear NDM contexts (see Utrilla et al., 2017).

Site and level	ND	Gm	PD	G	R	T	B	SP	Other	Total
Atxoste VI	**52,1**	0,0	1,2	4,8	17,0	0,6	3,6	17,0	3,6	165
Atxoste IV	**70,0**	1,8	0,0	5,9	19,4	1,8	0,0	0,0	1,2	170
Mendandia IV	**65,1**	1,1	0,9	9,9	14,5	1,7	3,1	1,4	2,3	352
Kanpanoste Goikoa IIIinf	**56,8**	0,0	0,0	24,3	5,4	0,0	0,0	0,0	13,5	37
Kanpanoste Lanhi	**50,8**	0,0	0,0	10,2	23,7	4,2	3,4	7,6	0,0	118
Kanpanoste Lanhs	**48,0**	4,9	2,0	7,8	26,5	4,9	2,0	3,9	0,0	102
Costalena d	**29,3**	5,2	6,9	13,8	6,9	6,9	0,0	5,2	25,9	58
Ángel 1 8d	**35,7**	0,0	0,0	17,9	0,0	10,7	3,6	21,4	10,7	28

linked to the occupation of very close sites. In others, there is evidence of phases of abandonment between episodes, either because of the presence of sterile levels or because of the chronological dating results. In any case, the data point to an increase in the number of records from the GM, including settlements that were inaugurated at that time (La Peña, Padre Areso, Valcervera, Espantalobos, Botiquería dels Moros, Cabezo de la Cruz…) or that had been abandoned for millennia (Socuevas and Montico de Charratu).

3. Characterization of lithic industries from the NDM and the GM in the Ebro basin

3.1. NDM lithic industries

Despite the significant number of NDM assemblages, few technological studies are available that allow a detailed characterisation of the lithic complex. Most of the information comes from sites in the upper Ebro: Kanpanoste (Cava, 2004a); Kanpanoste Goikoa (Alday, 1998); Mendandia (Alday, 2006a); Atxoste (Soto, 2014), plus some annotations for Costalena (Barandiarán and Cava, 1989); Forcas II (Utrilla and Mazo, 2014) and Ángel 1 and 2 (Utrilla et al., 2017), as well as collective works (Alday and Cava, 2006; Montes et al., 2006). In other cases the available information is still provisional –Fuente Hoz and Aizpea (Alday and Cava, 2006); Artusia (García-Martínez de Lagrán, 2014); Legunova and Peña-14 (Montes et al., 2016) and El Pontet (Montes et al., 2006)-. A synthesis of the data highlights:

a. Use of local raw materials, even if this means using siliceous rocks of mediocre knapping qualities. In the upper Ebro, in sites such as Kanpanoste, Mendandia (Cava et al., 2007–2008) or Atxoste (Soto et al., 2015), they recurred to flints of the Urbasa and Treviño types (20–30 km away), two varieties from the eastern sector of the Basque-Cantabrian basin of good quality and widely exploited throughout Prehistory (Tarriño, 2006; Tarriño et al., 2015). However, they also quarried, and preferentially despite its mediocre attributes, Thanetian flint, included in the Loza type variety (Ibid.), whose outcrops are closer to the settlements (10–20 km). The preference for local sources translates into a decrease in materials of supra-regional origin (>60 km).

b. Technology centred on the production of flakes, by means of discoid, multipolar and occasionally bipolar exploitations on anvil. Generally, no preparation work is identified in the cores, and maintenance actions are scarce. In the Upper Ebro, there is a notable interest in the production of small-sized flakes (around 20 mm long), whose functionality has yet to be determined (Soto, 2014).

Laminar products account for 10–15% in most collections (Alday, 1998, 2006a; Cava, 2004b; Utrilla and Rodanés, 2004b; Soto, 2014), characterised by their short average dimensions (25 × 10 mm) and their irregular morphology: they could better be classified as laminar flakes. They are produced using unipolar prismatic cores, with no notable preparation or maintenance actions.

c. The retouched toolkit is dominated by notches and denticulated pieces, together with a variable number of sidescrapers, endscrapers and, occasionally, splintered pieces (Table 1). The absence of projectiles is very notable: backed elements and geometric microliths of previous traditions have now disappeared (the few specimens counted are clear intrusions from contiguous levels, see the explanation below).

This NDM toolkit has compositional characteristics that make it easily recognisable. First, the use of flakes of various sizes is common, but also the use/recycling of conditioning products and exhausted cores (Cava, 2006; Soto, 2014). Second, the combination of various retouched edges on the same piece is common. Thus, in some sites multiple-tools make up 25–50 % of the retouched tools in NDM levels, linked to processes of reworking and recycling (e.g., Mendandia and Atxoste: Soto, 2014). Third, retouching is more or less invasive (simple retouch according to Analytical Typology: Laplace, 1972), and often with the retouch negatives slightly hinged. It usually affects both surfaces (dorsal and ventral), with frequent stepped formations (Fig. 2).

The combination of these features results in pieces which, although relatively homogeneous in general terms, offer little morphological standardisation, so that they do not fit in with the morphotypes of the most common typologies. Traceological analyses, for example at Mendandia (Mazo 2006), link many of these tools to the processing of organic hard materials.

It is necessary to add two observations about this industrial tradition:

It is characterised by a relatively simple and technically undemanding technological organisation. Thus, the exploitation of the cores is usually not very productive and does not require conditioning actions, as reduction-schemes adapts to the original morphology of the selected material. On the other hand, the configuration of the retouched toolkit does not respond to rigid techno-morphological standards looking for specific morphotypes. It is precisely both features that favour a versatile and flexible management of the entire lithic production. Under this dynamic, we can understand the use of low-quality local raw materials (reducing the investment in their procurement); the use of secondary products (cores and conditioning elements) for retouching; or the habitual presence of recycling and reuse processes among the retouched products, subject to intense reduction-sequences. Therefore, the dynamic management of the entire production compensates for the low productivity of the knapping schemes and the generally limited technological investment.

The origin of some of these NDM-defining characteristics can be traced back to Late Glacial technologies. Issues such as the progressive reduction in the raw material supply territory, the simplification of the knapping schemes and the loss of blade production in Azilian assemblages and, more evidently, in the Sauveterrian (Alday et al., 2020; Soto et al., 2020), foretell the mutation in techno-cultural patterns. This is a process of simplification/flexibility that started in the late Upper Magdalenian as seen in different Iberian regions (Cava, 2004c; Martínez-Moreno et al., 2006–2007; Roman et al., 2020) and was sustained by social interests and new ecological scenarios. However, the question remains as to why this process derives in some regions in the development of the NDM and in other neighbouring regions, such as the North-Pyrenees with respect to the Ebro Valley (Soto et al., 2018), in very different technological strategies.

The second observation refers to the absence of lithic projectiles in

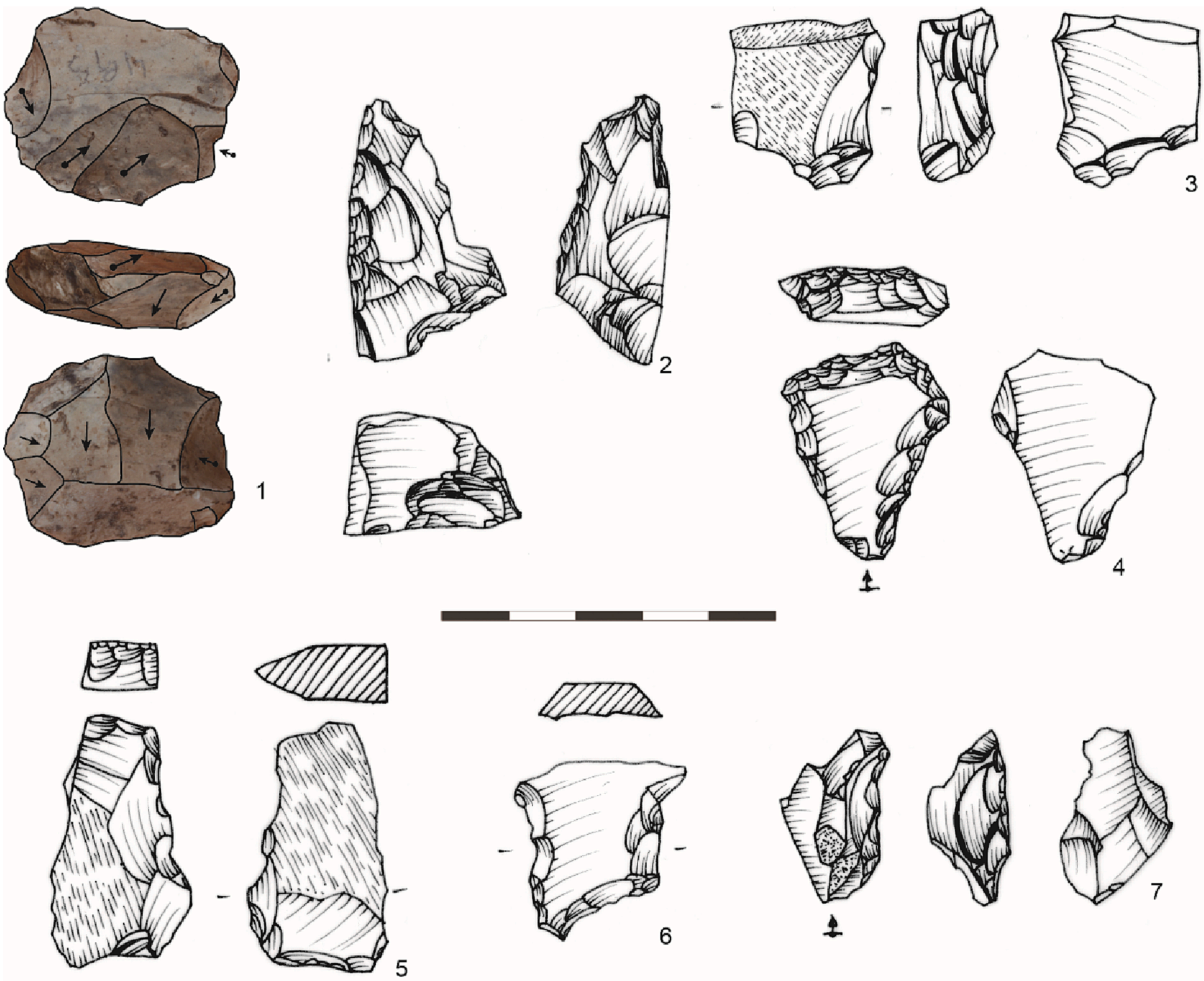

Fig. 2. Lithic industry of NDM levels (VI and V) from the site of Atxoste: 1 Flakes core; 2–7 retouched tools with different reductions-sequences.

the NDM. The main hypothesis is their replacement by weaponry made of organic material, taking into account that traceology indicates that NDM retouched tools were mainly employed on hard organic materials, presumably wood, in the absence of bone industry (Utrilla and Rodanés, 2004a; Alday, 2006b). Circumstantially, the use of flakes or small parageometric pieces in composite tools has been suggested (Martínez-Moreno et al., 2006–2007; Aura et al., 2006; Fernández-López De Pablo et al., 2023), an issue that should not be overlooked. In any case, what stands out is the change in the objectives and functions of the lithic system: before and after the NDM, part of the effort was aimed at obtaining a precise and effective hunting toolkit, but at that time the purposes were different.

3.2. GM lithic industries

The publication of complete reports or advances on various sites provides us with detailed information about GM lithic industries in the area of study – Kanpanoste Goikoa and Mendandia (Alday, 1998, 2006a); Atxose (Soto, 2014); Socuevas (Alday and Cava, 2009); Aizpea (Barandiarán and Cava, 2001); La Peña (Cava and Beguiristáin, 1991–1992); Botiquería dels Moros (Barandiarán, 1978); Costalena (Barandiarán and Cava, 1989, 2001; Els Secans (Rodanés et al., 1996); Cabezo de la Cruz (Rodanés and Picazo, 2013); Los Baños (Utrilla and Rodanés, 2004a); Las Forcas (Utrilla and Mazo, 2014); Ángel (Utrilla et al., 2017); collective works (Utrilla and Montes, 2009) and preliminary reports in Artusia (García-Martínez de Lagrán, 2014), El Pontet (Utrilla et al., 2009), Rambla de Legunova and Valcervera (Montes et al., 2016); Espantalobos (Montes et al., 2015), and El Esplugón (Obón et al., 2019)-. In this way, its basic characters are:

a. A procurement strategy that takes advantage of regional resources by selecting the best quality siliceous varieties available, in those geographical contexts where it is possible. The abandonment or little use of flint with mediocre knapping possibilities is a differential fact in comparison with the NDM. In addition, the use of distant raw materials has again been identified, although these have little weight in the assemblages. As an example of these changes in the raw material supply strategies, we note that, in the Pre-Pyrenean region during the NDM, the use of local flint, despite its poor quality, is very usual, while in the GM its presence drops by half in favour of better quality regional flints (50–70 km away) (see for example, Peña-14 and Valcervera: García-Simón et al., 2016). The requirements of the laminar technology typical of the GM would call for a more demanding selection of raw materials.

b. Development of blade technology, the main objective of lithic production. In fact, at sites such as Espantalobos or Atxoste, blades account for more than half of the knapping products, although in the rest of the Ebro sites the percentages are between 20 and 35% (Alday and Cava, 2009). Standardized products, with parallel edges and arrises, are sought; preferred dimensions fall between 25 and 35 mm in length and around 10 mm in width (Alday and Cava, 2009; Soto, 2014), although in some cases they are narrower, probably linked to restrictions derived from the raw material, as for example at Aizpea (Cava, 2001).

Given that most of the recovered cores appear exhausted, it is not easy to reconstruct the blade knapping schemes. In general terms, they are articulated in pyramidal or prismatic-rectangular cores of semi-tournant unipolar management, with occasional utilization of an opposite percussion platform for maintenance actions. Depending on the context and the raw materials, unequal attention is paid to the preparation phase (see Atxoste in Soto, 2014; Espantalobos in Montes and Domingo, in press; and Aizpea in Cava, 2001). Also in some cases, flake-edge exploitation has been evidenced (Montes and Domingo, in press). Regarding the knapping technique, several sites suggest the use of indirect percussion: Atxoste (Soto, 2014), Espantalobos (Montes and Domingo, in press), and perhaps in Artusia (García-Martínez de Lagrán et al., 2014), Mendandia (Cava, 2006) and La Peña (Cava and Beguiristáin, 1991–1992).

Finally, small-sized flake production with discoid-like cores and multipolar exploitation continues, together with bipolar on anvil knapping (Alday, 1998; Cava, 2002; Alday and Cava, 2009; Soto, 2014; Utrilla et al., 2014).

c. Among the retouched tools, the most representative novelty is the generalization of geometric microliths (trapezes and triangles), linked almost exclusively to hunting activity as projectiles. Occasionally, they were intensely employed (use wear appearing in one out of three or even one out of two pieces), but most commonly they seem to conform a surplus of knapped microliths, perhaps intended as a stock for maintenance/repairing of damaged arrows, that were left behind when the occupation was abandoned (Domingo, 2009). The relative weight of geometric microliths among the retouched objects is variable (Table 2): less than 20% in some sites (e.g., Mendandia or Atxoste IV) and close to 50% in others (La Peña de Marañón and Forcas II Level IV). In their production, narrower blades are preferred to those used in the configuration of other retouched or unretouched tools (Perales et al., 2016). They are worked by a combination of abrupt retouching and microburin technique.

The typological variability of geometric microliths has been interpreted in terms of a combination of temporal evolution and regional preferences (Alday and Cava, 2009; Utrilla et al., 2009):

a) Trapezes are more numerous than triangles and backed points in the initial phase of the GM. Certainly, all sites with a high proportion of trapezes are dated in the second half of the 9th millennium cal BP (e.g., Mendandia IIIinf, Atxoste IV, Aizpea I, El Esplugón 4, Espantalobos, Botiquería dels Moros 2, Pontet e, Ángel 1 8c and Los Baños -see Supplementary material Table2 and Figs. 1 and 2). In Bajo Aragon this phase includes short trapezes (about 12–13 mm long) that will become widespread later (Utrilla et al., 2014); this trend may also be valid for the NW sector (Soto, 2014).
b) In a second stage, there is a significant increase in the proportion of triangles, which will be dominant in the SE sector and better balanced with trapezes in the rest of the Ebro basin. In this dynamic, backed points become more prominent, especially in the most northerly sites (e.g., Atxoste IIIb2, Kanpanoste Goikoa III and Aizpea II – see Supplementary material Table2 and Figs. 1 and 2), even surpassing the geometric microliths: those with a stylized and curved morphology, sometimes classified as elongated segments, stand out. The contexts with these characteristics date from the first half of the 8th millennium BP (see Supplementary material Fig. 2). Interestingly, triangles with concave truncations and a central spine ("Cocina type" triangles according to Fortea, 1973) are found in these final moments of the GM. Although they always appear in small numbers, their presence links the Ebro Basin with both the Mediterranean coast and the Portuguese Atlantic coast.

The common trends between distant geographical areas and the transmission of specific types are a reflection of the networks of contacts that the Mesolithic communities of the Ebro basin weaved among themselves and with other more distant communities (Montes and Alday, 2012). In contrast to this commonality, armature models with a more restricted spatial implantation add personality to the assemblages. A good example are the occlusal trapezes and triangles of the NW area (Alday and Cava, 2009), or those displaying flat-inverse retouches complementary to the basal truncations in territories closer to the Pyrenees (Alday and Cava, 2009; Utrilla et al., 2009).

Besides the projectiles, notches and denticulates continue to be present, reaching almost 40% of the retouched tools (Table 2). In this category of tools, examples made on blades now stand out (Fig. 3), generally with a wider module (12–14 mm) than those used in the manufacture of projectiles (11–10 mm), and shaped by simple direct retouching (Soto, 2014; Perales, 2015). Traceological studies indicate that they were used in occasional scraping and brushing (finishing, repairing, etc.) of plant materials (woody and non-woody), but also of bone and skins (Mazo, 2006; García Martínez de Lagrán et al., 2014; Perales, 2015; Mazzucco et al., 2016; Laborda-Martínez, 2020). Wear

Table 2
Typological characterization from some GM lithic ensembles synthesized in different categories (% among the total retouched pieces). (ND: notches and denticulate; Gm: geometric armatures; PD: backed points; G: endscrapers; R: scrapers; T: truncations; P: drills; Other: rest of types). **Bold**: dominant type.

Site and level	ND	Gm	PD	G	R	T	P	Other	Total
Atxoste IV	**37,9**	23,0	4,4	10,4	11,7	3,7	4,4	4,4	383
Atxoste IIIb2	13,9	16,9	**25,9**	13,9	20,9	2,0	2,5	4,0	201
Mendandia IIIinf	**38,7**	15,2	5,1	6,9	24,4	0,9	6,9	1,8	217
Kanpanoste Goikoa III	**38,9**	19,8	12,7	15,9	5,6	1,6	4,0	1,6	126
La Peña d	21,5	**47,3**	4,3	9,7	2,2	4,3	2,2	8,6	93
Aizpea I	28,9	**32,2**	10,1	5,4	6,7	4,0	2,7	10,1	149
Aizpea II	16,9	**31,5**	26,4	3,9	2,8	5,6	2,8	10,1	178
Espantalobos e	23,2	23,2	0,0	7,1	**42,9**	1,8	1,8	0,0	56
Espantalobos c	15,8	33,7	0,0	6,9	**36,6**	4,0	2,0	1,0	101
Forcas-II II	20,8	**34,0**	7,5	9,4	0,0	3,8	0,0	24,5	53
Forcas-II IV	10,5	**48,7**	7,9	2,6	0,0	5,3	0,0	25,0	76
El Pontet e	27,9	**32,8**	4,9	13,1	4,9	3,3	1,6	11,5	61
Costalena c3	**31,1**	23,4	6,0	13,0	3,2	4,6	3,2	15,3	431
Ángel 1 8c	5,5	**34,2**	13,7	26,0	0,0	8,2	4,1	8,2	73
Botiquería 2	**34,0**	28,5	7,0	7,4	4,3	7,0	1,2	10,5	256
Botiquería 4	**28,7**	24,1	13,8	14,9	0,0	4,6	3,4	10,3	87
Los Baños 2b3inf	16,3	16,3	2,3	0,0	4,7	11,6	0,0	48,8	43
Los Baños 2b3med-sup	26,1	**30,4**	0,0	8,7	0,0	13,0	0,0	21,7	23
Ángel 2 2a3	**41,7**	37,5	16,7	20,8	0,0	4,2	0,0	16,7	24
Ángel 2 2a2	7,9	**36,0**	19,1	12,4	0,0	7,9	0,0	16,9	89

Fig. 3. Lithic industry of GM level (c) from the site of Espantalobos: 1 Blades core; 2–7 microlithic geometrics; 8–9 retouched blades.

traces linked to the scraping of dry hide or cutting actions have sometimes been identified on the unretouched edges of these pieces (García-Martínez de Lagrán et al., 2014; Perales, 2015; Mazzucco et al., 2016).

Similarly in terms of their functionality, the role of unretouched blades cannot be neglected either. When they have been analyzed, their repeated use has been proven, once again, in different tasks and on different materials (Perales, 2015). Finally, our brief summary would be incomplete without mentioning the endscrapers, generally short and made on flakes, present in all the sites in a noteworthy but unequal manner.

4. Is there a transitional phase between the NDM/GM?

A simple reading of the description of the industrial characteristics of the NDM and GM assemblages reveals the distance between the two technological traditions. In short: a technology based on the production of flakes and their flexible management is abandoned in favor of a laminar one, more rigorous in its methods and linked in part to the shaping of projectiles. The question is whether we should think of this change in terms of rupture from both a technological and a social perspective, or as a progressive transformation or adaptation.

In this debate, we should consider the studies that suspect a transitional phase between traditions (Utrilla et al., 2004, 2014) or, if we prefer, a progressive adoption of blade production that will coexist for a certain period with the previous technology (Cava, 2002, 2006; Alday and Cava, 2006). The two positions take into account the presence of contexts that provide elements of both traditions. Depending on the proportion of one or the other, the stratigraphic positions of the examples and the absolute chronology obtained, two archaeological situations are discriminated: a) an early evidence of GM technology in NDM assemblages (Table 3 – in italics); and/or b) a continuation of some NDM tradition practices in the GM assemblages (Table 3 – in grey). It is necessary to assess to what extent these situations are a sufficient argument to support a progressive transition between the two traditions

Table 3
Stratigraphic continuities and discontinuities between NDM and GM archaeological levels (numbers represents the stratigraphic position). // - steril level; *italics* – NMD levels with some evidences of GM lithic industry; dark grey – strong evidences of NDM industry in GM levels; light grey – weak evidences of NDM industry in GM levels. The attribution of the archaeological levels to the NMD or GM is based on the technological characterisation of the lithic assemblages (for more details see Supplementary material Table 1).

	Archaeological levels			
Sites	**NDM1**	**NDM2**	**GM1**	**GM2**
Kanpanoste	Lanhi	*Lanhs*		
Legunova	1	2		
Plano del Pulido		cm		
Fuente Hoz		IV (?)	III	
Mendandia		*IV*	IIIinf	
Atxoste	VI	*V*	IV	IIIb2
Kanpanoste Goikoa		IIIinf	III	
Artusia	I	II	III	IV
Aizpea		I Base (?)	I	II
Peña-14		b	a	
El Pontet	i	g	e	cinf
Costalena		*d*	c3	
Ángel 1		8d	8c	
Ángel 2		2b	2a3	2a2
Socuevas			II	
Montico de Charratu			II	
La Peña			d	
Padre Areso			IV	V
Rambla Legunova			2	
Valcervera			b	
El Esplugón			4	3inf
Espantalobos			e	c
Forcas II		Ib //	//II	IV
Los Baños		*2b1//2b2*	2b2//2b3inf	2b3med-sup
Cabezo de la Cruz			UE	
Botiquería dels Moros			2	4
Els Secans			IIb	

and in what sense.

4.1. *Evidence of GM technology in NDM assemblages. An initial evaluation*

In the Ebro valley there are five NDM sites (Table 3- in italics) that contain some GM industrial elements (e.g., some geometric microliths) (Table 1). The chronological situation of these occupations in the first half of the 9th millennium cal. BP has led to their interpretation as the first evidence of the introduction/development of the geometrism in the territory (Cava, 2001, 2006; Utrilla et al., 2004, 2014). However, these are levels directly overlain by GM occupations, and therefore possible percolation of materials has also been alluded to as an explanatory factor (Cava, 2001).

This seems to be the case in three of the deposits: Lanhs level in Kanpanoste (Cava, 2004a:171-176), V in Atxoste (Soto, 2014:560) and d in Costalena (Barandiarán and Cava, 1989: 33). The number of retouched tools or products related to blade knapping identified in these levels is very low (less than10 items) and their presence is easily explained by their stratigraphic location on the boundary between the two levels. However, in the other two cases, Mendandia and Los Baños, the situation is somewhat different.

In the southernmost region of the Ebro valley, a more complex situation has been described in level 2b1 at Los Baños. In this level 15/25 cm thick, several sublevels were identified as a result of occupation/abandonment dynamics of the shelter. Between this level and 2b3inf, linked to the GM, a sterile layer was isolated (Rodanés and Utrilla, 2004:15) which individualizes the contents of the strata it separates. In 2b1, the lithic material is scarce (53 retouched pieces and about 1,500 knapping remains), combining the usual products in the NDM and geometric microliths, retouched backed pieces and retouched blades, amounting to 30% of the retouched material (Utrilla and Rodanés, 2004a: 36). However, in this case "it is possible to think that we are including in the same level, without the possibility of stratigraphic separation, several moments of occupation" (Utrilla and Rodanés, 2004a: 95). Thus, its industrial composition may respond to different phases and not to a transition context as such.

At the opposite end of the Ebro valley, in the case of Mendandia rockshelter, the situation is somewhat different. Level IV offers a dense sedimentary structure with a lithic assemblage of about 350 retouched pieces and more than 10,000 knapping products (Alday, 2006a). The technology fits the parameters of the NDM; in fact, it constitutes one of the best examples of this industrial tradition in the region. With flake production being the norm, 21 pieces retouched on blades have been identified, whose spatial distribution coincides with that of the rest of the material, ruling out the possibility of possible filtrations from higher levels (Cava, 2006: 234). Certainly, the recovery of 271 blades, some cores and conditioning products linked to a blade production are hardly compatible with such a possibility.

In conclusion, in the absence of more detailed spatial analyses, the case of Mendandia is the only one in which the incorporation of GM technology into fully NDM industrial complexes could be considered. However, it is an issue that requires future work.

4.2. Is there a persistence of NDM technological practices?

As indicated above (Table 3 – in grey), it is common for the GM records, with a fully developed blade and trapezes technology, to show a high percentage of notches and denticulates. Within this typological category, there is a coexistence of two different modalities: notches/denticulates on blade, following the morphotype of this period (Fig. 4); and pieces which, in terms of both the blanks (flakes, conditioning products and exhausted cores) and the type of configuration (highly invasive simple retouching, with a high proportion of inverses, multiple retouched edges), respond to NDM patterns (Fig. 4). A good example is Level IV at Atxoste, where there are notches and multiple denticulates with reduction-sequences identical to those of the NDM (Fig. 4) (Soto, 2014).

This combination has been noted expressly in sites such as Mendandia (Cava, 2006), Level I at Aizpea (Cava, 2001), in some examples from La Peña (Cava and Beguiristáin, 1991–1992), in Costalena (Barandiarán and Cava, 1989), in Layers 2 at Botiquería dels Moros (Barandiarán, 1978) and in 2a3 at Ángel 2 (Utrilla et al. 2017).

This toolkit, often considered as common background, has not been the subject of detailed techno-typological analysis, and it is not easy to calibrate its representation in the GM. Here we shall approach the question by evaluating the type of blank used in the notches and denticulate typological group (Table 4). The situation is very unequal between cases: a) In the rockshelters in the NW area (Álava territory and the Navarrese pre-Pyrenees) only 15–30% of the notches and denticulates are made on blades; b) In the Aragonese pre-Pyrenees, on the other hand, they are in the majority (greater than70%); c) in the sites on the right bank of the Ebro the situation is different: never exceeding 66% of the total, and never falling below 35%.

This approach is certainly elementary, but it can be reinforced by

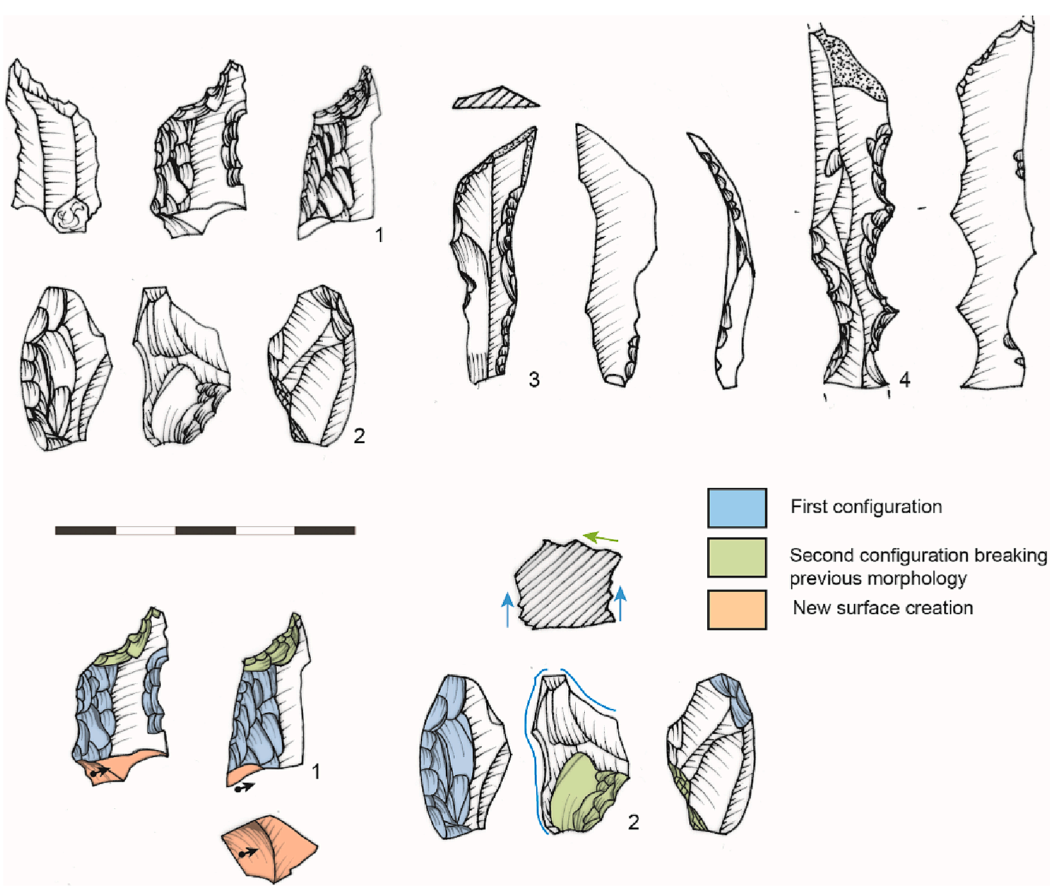

Fig. 4. Retouched tools of MG level (IV) from the site of Atxoste: 1–2 retouched tools with NDM like reduction-sequences; 3–4 denticulated blades.

Table 4
Type of support (blade or flake/other) in notches and denticulates retouched tools of GM levels. Sites with few pieces have been discarded. **Bold**: dominant values.

Site and level	Flake/other	Blade	Total
Atxoste IV	**70,7**	29,3	133
Atxoste IIIb2	**85,2**	14,8	27
Mendandia IIIinf	**84,8**	15,2	79
Kanpanoste Goikoa III	**84,8**	15,2	46
La Peña d	22,2	**77,8**	18
Aizpea I	**53,7**	46,3	41
Aizpea II	45,0	**55,0**	20
Espantalobos e	25,0	**75,0**	12
Espantalobos c	31,3	**68,8**	16
Forcas-II II	0,0	**100,0**	11
El Pontet e	**64,7**	35,3	17
Costalena c3	**51,6**	48,4	128
Els Secans IIb	**64,7**	35,3	17
Botiquería dels Moros 2	41,5	**58,5**	82
Botiquería dels Moros 4	44,0	**56,0**	25

resorting to other data, such as similar configurations and reduction-sequences in other tools (mainly sidescrapers and drills). These dynamics affect between 35% and 11% of the toolkit in Levels IV and IIIb2 at Atxoste (Soto, 2014), in Mendandia and Aizpea it would be at a minimum of 17% and in Kanpanoste Goikoa 23% (Cava, 2001, 2006, Alday, 1998). Although there are no similar calculations for the Lower Aragon sites, the presence of those tools is significant according to the drawings of their published materials (Utrilla and Rodanés, 2004a: fig.19; Rodanés et al., 1996: fig.15, 16 and 20; Barandiarán, 1978: fig.16.3 and 4, fig.21.4 and Barandiarán and Cava, 1989: fig.14 and 17 respectively).

The superimposition of these assemblages on previous levels of the NDM makes it necessary to consider, once again, whether this situation could derive from the difficulty of identifying different episodes of occupation within a stratigraphic level. In a first spatial approximation to the Atxoste and Mendandia cases (Alday, 2006a, Soto, 2014), there is a homogeneous distribution, a clear coexistence of tools from both traditions. Nevertheless, we have yet to carry out more detailed analyses that will allow us to test this first interpretation.

Despite these observations, it should be remembered that this situation also occurs in sites occupied for the first time in the GM, without previous levels of the NDM or with sterile sedimentary layers between the two: Botiquería dels Moros or Els Secans, or the Navarrese shelter of La Peña.

5. Chronology

To evaluate the chronology of the NDM/GM transition we have 108 radiocarbon dates belonging to 51 archaeological levels (Supplementary material Table 1). However, based on the following criteria we withdrew 42 dates from our analyses:

a. Those with standard deviations greater than 100 years;
b. Those derived, according to complementary laboratory information, from samples with low collagen content, and duplicates of the same sample, taking into consideration the collagen fraction versus carbonaceous residues or bioapatite;
c. Those from contexts whose categorization requires more detailed analysis.

Our objective is to explore the temporality of both technological traditions and to evaluate to what extent the dismantling of the NDM coincides in time with the process of implantation of the GM. To this end, we have determined the start and end boundaries of the two uniform phases and calculated their difference, assuming their complete independence (Buck et al., 1992; Bronk Ramsey, 2009a), using the OxCal v4.4 program (Bronk Ramsey, 2009a; Reimer et al., 2020). From this assumption we developed three models, from least to most conservative:

- Model A. The 66 dates previously filtered (22 from the NDM and 44 from the GM) are considered;
- Model B. Three dates considered outliers (Bronk Ramsey, 2009b) are removed, which constitute the oldest references for both periods: 63 dates (21 from the NDM and 42 from the GM);
- Model C. Dates on bone are selected from the filtered ones and a new one is removed that the model considers an outlier: 30 dates (10 NDM and 20 GM).

Model A (Fig. 5 and Table 5) suggests an early irruption of GM technology (GM Start 8774–8603 cal BP), preceding the onset of NDM decline (NDM End 8516–8220 cal BP). In fact, both events would differ by between 490 and 135 years (according to the values of the Difference function at 95.4% probability). This approximation would imply that the implementation of the GM occurs in a context in which the NDM technology is still in full force.

Model B (Fig. 5 and Table 5) rejuvenates the beginnings of both complexes (NDM Start 9893–9560 cal BP; GM Start 8594–8436 cal BP). The approximation now offers a possible coincidence between the beginning of the end of the NDM and the first indications of the GM: the Difference function indicates that, although small, there is some probability that both events were contemporaneous. Finally, Model C (Fig. 5 and Table 5) affects the probability of the contemporaneity of the events by generating similar parameters (NDM End 8508–8013 cal BP and GM Start 8570–8378 cal BP), but its reading must take into account the smaller number of dates used, which blurs the NDM considerably.

In short, the three exercises refer us to a scenario in which the technological novelties of the GM seem to emerge in a context of full validity of the NDM. The differences lie in: a) the chronology of the implementation of the GM, older in the first (8774–8603 cal BP), and somewhat more recent in the more conservative models (8594–8436 cal BP and 8570–8378 cal BP); and b) the greater or lesser distance between the two events (NDM End - GM Start). In the first model, the end of the NDM does not occur until one or several centuries after the implantation of the GM, while in the other two, a certain synchrony between the two events cannot be ruled out, although the probability is low.

6. Discussion

As we have explained throughout this work, the technological parameters of the lithic systems of the NDM and the GM follow very different dynamics in the procedures, techniques and management of the materials. The former opts for relatively simple schemes: production of flakes without great technical investment, and few formal requirements in the retouched tools, facilitating a flexible management of resources in terms of their supply and use, which includes reuse and recycling.

In contrast to this model, the GM develops a much more technologically demanding program. Laminar knapping and, especially, the use of indirect percussion, require greater care in the selection of raw materials, and the application of more demanding knapping schemes. Retouched tools, especially the projectiles, show notable dimensional and formal standardization: a specialized management that leaves less room for recycling processes.

These features show that the distance between the two traditions is not only technological, but also organizational, with an impact on other techno-economic and social spheres and activities. The most obvious implications concern raw material sourcing strategies and, together with that, the mobility of those populations. The change of perspective on what is useful or usable and what is not would determine not only the selection of siliceous varieties, but also the management of “lithic waste”, and therefore the “demand” for raw materials.

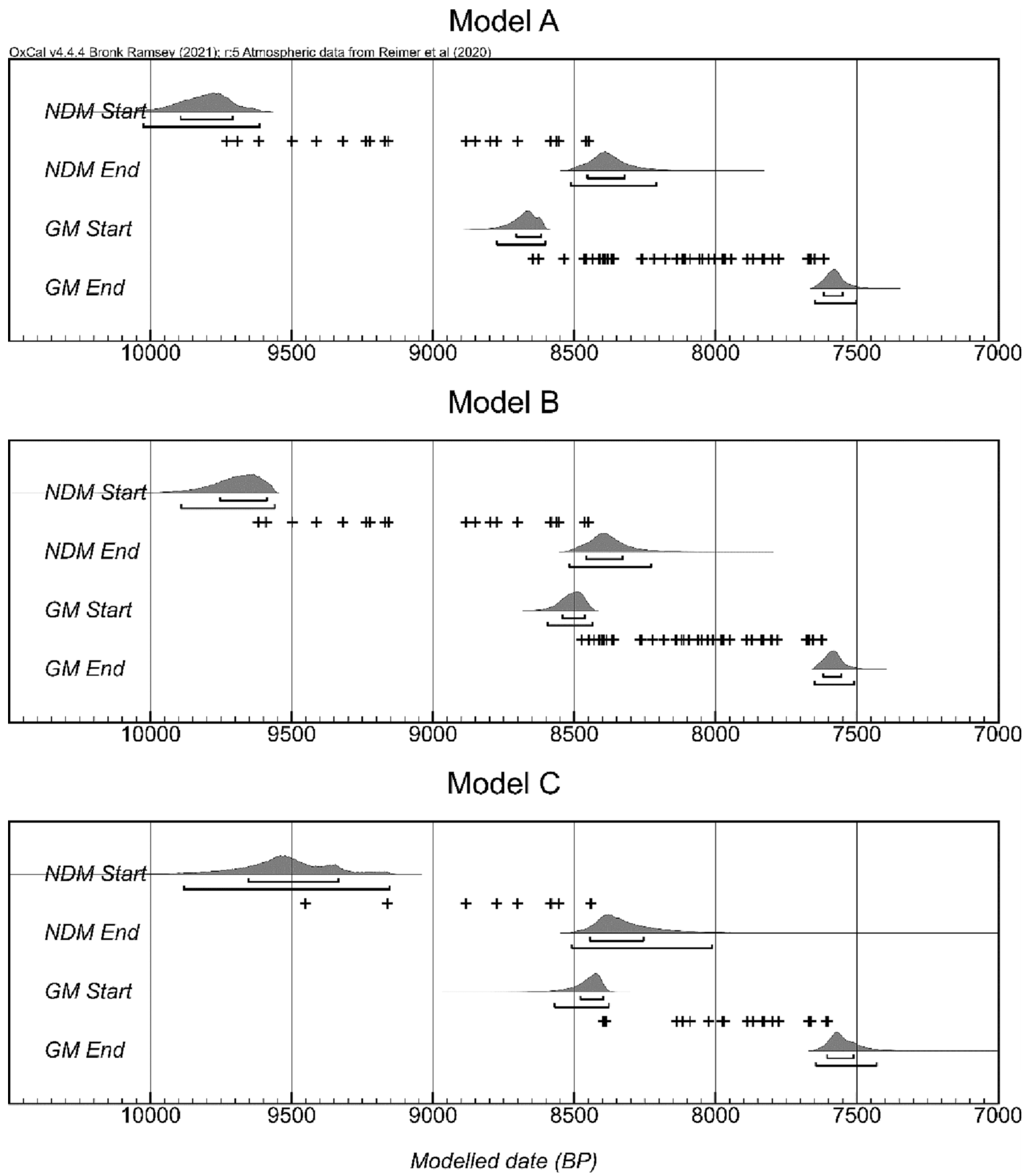

Fig. 5. Chronological models for start and end boundaries of NDM and GM phases derived from Bayesian modelling performed with OxCal 4.4 (Bronk Ramsey, 2009a; Reimer et al. 2020). Black crosses for the medians of the marginal posterior distributions for the individual dates.

Table 5
Numerical values (cal BP) for chronological models for NDM and GM phases derived from Bayesian modelling performed with OxCal 4.4 (Bronk Ramsey, 2009a; Reimer et al., 2020).

	NDM Start	NDM End	GM Start	GM End	Diff. GM Start-NDM End	
68.3%					from	to
Model A	9891–9708	8455–8324	8705–8620	7618–7551	−368	−207
Model B	9753–9589	8458–8330	8542–8462	7620–7555	−193	−39
Model C	9653–9335	8445–8256	8478–8398	7605–7513	−213	8
95.4%						
Model A	10011–9616	8516–8220	8774–8603	7648–7502	−490	−135
Model B	9893–9560	8517–8228	8594–8436	7650–7509	−306	31
Model C	9881–9154	8508–8013	8570–8378	7644–7431	−471	78

At the same time, it is logical to think that there was also a change in the composition and conformation of weaponry, and perhaps in hunting practice. The use of bows and arrows is taken for granted in earlier periods, while the appearance of “short” trapezes in some of the earliest GM levels (such as in Los Baños or Botiquería dels Moros; Utrilla and Rodanés, 2004a) implies the generalization of transverse arrows (Domingo, 2009) although an earlier date has recently been suggested (Jacquier et al., 2020). The absence of lithic projectiles in the NDM, although striking, must be seen as part of the usual mutations that occur in this type of tool. The possible use of small flakes or parageometric microliths (Aura et al., 2006; Fernández-López de Pablo et al., 2023), as mentioned above, needs to be considered, as does the use of wooden projectiles, based on their recognition at ethnographic level (see references in: Ellis, 1997, Greaves, 1997, Waguespack et al., 2009). In any case, it is necessary to consider the development of work processes and know-how (e.g., selection of types of wood), which would not necessarily disappear with the arrival of the GM. In the context of this debate, it is interesting to reflect on the possibility that these wooden projectiles were also used beyond the NDM “even when the geometric microliths had already become widespread” (Cava, 2006:219).

As for their impact on hunting practice itself, more detailed taphonomic research would be necessary, largely limited by the high fracturing of the bone remains in these Mesolithic deposits, but considering the spectrum of animals hunted, no substantial changes seem to be observed between the NDM and the GM (Alday, 2006b; Montes et al., 2016).

Finally, we cannot forget the possible implications for the learning and socialization dynamics of lithic technology. The technical skills and the learning process required for the use of direct percussion and those required for indirect percussion are not the same (Gallet, 1998), as with the observed knapping schemes. Although complex to assess, it is not unreasonable to think that these factors had some impact on the social organization of knapping activities.

For all these reasons, we consider that the NDM and the GM societies approached their needs for lithic tools from very different technological logics, schemes and practices. From this reading, it is not difficult to consider that the GM innovations do not derive from an internal mutation or transformation of the NDM tradition. In the study carried out, we have not identified elements that allow us to think of an emergence of more regular and standardized schemes, or of new knapping techniques. In this sense, apart from some cases that need to be carefully evaluated, the presence of GM diagnostic elements in assemblages with a clear NDM technology can be explained by the stratigraphic continuity of these assemblages, where the limits between levels are never easy to establish. In short, the GM technology would appear as a novelty, with no apparent antecedents in the territory.

This reading is in accordance with the image returned by the chronology. The three models we have tested refer us to a scenario of the irruption of the GM at a time when NDM sites are still active in the Ebro valley. It is not certain when this phenomenon took place -between circa 8800–8600 cal BP or circa 8600–8350 cal BP in the most conservative models-, and what is more relevant, how long the coexistence of both traditions lasted: extended in time in the first case, and shorter, with a certain probability of synchrony in the last one.

The interpretative implications of both proposals for how the transition took place are important. The first scenario assumes the coexistence of the two technological traditions for a fairly short time (between 490 and 135 calibrated years, depending on the Difference values). Considering the novel nature of the GM in the territory, one of the possible explanations would allude to social dynamics. These could range from specific migratory processes –we lack evidence- to different rates of adoption of the new technology by the local population depending on the territories -different communities of technological practice based on the greater or lesser degree of contact with the innovations, and their greater or lesser degree of acceptance-. In any case, they would reflect a duality that is difficult to explain based on the regional interactions that are recognized for this period (Montes and Alday, 2012; Cucart-Mora et al., 2022), and which depict the Ebro valley as a territory of contacts.

The second scenario envisages a more time-limited period of coexistence, where the dismantling of the NDM technology would take place shortly after the new practices are implemented or adopted. This eliminates the problem of prolonged technological duality. From this approach, it is possible to think of an introduction or adoption of the new technology through the mechanisms of mobility and regional/supra-regional interaction common among those communities, and which the archaeological record reflects (Ibid.). In this sense, the appearance of the GM before the decline of the NDM would fit within the logical processes of diffusion/adoption of technological innovations. These are usually adopted in the first instance by a small number of people, applied in a limited way, and then generalized to the rest of the social group and to all associated activities (Roux, 2013).

There is little doubt that the social structures of local NDM population played a vital role in the technological diffusion of GM. On the one hand, this is evidenced by the occupational continuity observed in most of the sites. Those spaces occupied during the NDM continue to be occupied during the GM, demonstrating a shared/transmitted knowledge of the territory between both phases. On the other hand, it is seen in the possible persistence of technological practices from the NDM. Certainly, there are many GM contexts in which retouched tools share similar reduction sequences to those observed in the NDM. Can we interpret this reality as evidence of technological survival?

First, it is a fact that the adoption of technological novelties does not necessarily imply a radical break with previous practices. The phenomena of persistence can also respond to different reasons, ranging from a greater/lesser degree of social resistance to change (ibid.) to the maintenance of practices whose scope of application is not directly affected by the new technology.

In our specific case, and taking the denticulated pieces as a point of discussion, it is striking to note the maintenance of the previous configuration-use-reconfiguration schemes, adopting, in turn, the laminar morphotypes so characteristic of the GM. Especially when, according to the functional studies available, both types of pieces are linked to a very similar range of activities: mainly scraping hard materials in finishing actions (Mazo, 2006; García-Martínez de Lagrán et al., 2014; Perales, 2015; Mazzucco et al., 2016; Gibaja et al., 2018; Laborda-Martínez, 2020).

This common functionality would derive more from the characteristics of the active zones (morphology and angle) than from the general format of the pieces (Mazo, 2006; Gassin et al., 2013, 2014). However, the kinematics of the tool, in terms of ergonomics and/or gripping system, can hardly be the same. It is difficult to imagine the way of gripping the NDM type pieces given their morphodimensional variability and the carinated and multiple-tool character of many of them. However, in the case of denticulated and notched blades, which are so standardized, the hafting would be relatively simple, as well as the actual replacement of the piece if necessary. Moreover, the former have reached us after different configuration phases, the result of a versatile and dynamic management, which we understand could be operated within the same work sequence, or more flexibly, integrated into different processes (Soto, 2014). Although the latter, the laminar tools, would not be excluded from these dynamics (García-Martínez de Lagrán et al., 2014; Perales, 2015; Mazzucco et al., 2016), recycling processes have less impact on the formatting of the tool. Ultimately, the question is whether the durability of some constants is linked to the preservation of specific working processes. To answer this question, it is necessary to undertake new technological and traceological studies that will allow us to reconstruct in more detail the so-called domestic tools, traditionally forgotten by researchers, but with valuable information in the reconstruction of the operational chains of lithic systems.

Second, we cannot rule out the fact that the levels in which this circumstance is best reflected are those which overlap with previous occupations of the NDM. The formative complexity of any archaeological context recommends caution in this respect, but it is necessary to bear in mind that: a) neither in their stratigraphic sequences, nor in the spatial distribution of the materials, do we find incongruities or anomalies that require us to reconsider the integrity of these assemblages; and b) this technological "coexistence" also takes place in assemblages where the GM inaugurates the site, without previous levels of the NDM. These sites are of great interest, since they would ratify the technological durability and, consequently, a diffusion of innovations through the social structures of the NDM. Finally, in other regions of the Iberian Peninsula they seem to share a similar situation (Martí et al., 2009). This fact highlights the need to address and trace these processes of technological persistence in other regions, which allow us to explain, starting from the local, the mechanisms of technological transmission between Mesolithic communities.

In any case, a more detailed analysis of the stratigraphic and technological contexts will be necessary, incorporating other variables of interest not addressed here. Likewise, and with respect to chronology, it would be advisable to test other types of modelling, such as trapezoidal (Lee and Ramsey, 2012), perhaps with a better fit to the phenomena analyzed here, to increase the number of dates for the NDM and thus reduce the uncertainty in its end boundary (Holland-Lulewicz & Ritchison, 2021), as well as to evaluate the archaeological reality behind the outliers.

7. Final remarks

Holocene hunter-gatherer societies developed different technological strategies in the production of their lithic industry, materializing in complexes that are easily recognizable to archaeologists. In the Ebro Valley, the NDM and the GM stand out the latter being enormously successful in Western Europe and North Africa, with definite social implications in its diffusion. In our region, its development meant a break with the previous industrial tradition, and we reflect here on whether this was a progressive or disruptive process, and the mechanisms of disarticulation/adoption linked to it. To address this debate, we have gathered information from more than 60 archaeological levels and almost a hundred radiocarbon references. The derived reflections can be summarized as follows:

1. The NDM and the GM constitute two very different technological traditions, which respond to technical and organizational parameters that are very dissimilar from each other. From this perspective, the GM is a novelty that does not seem to have its technological roots in the lithic structures of the NDM.
2. Despite the technological rupture it represents, its introduction into the Ebro basin seems to be based on the technological and territorial foundations of the NDM communities. The occupational continuity of the sites and the persistence of technological practices, also evident in the ex novo settlements, support this hypothesis.
3. The chronological modelling leads us to a scenario consistent with the technological and stratigraphic analyses: an early GM irruption in one case, and a later one in the other two. Both options have important implications in terms of historical processes (mechanisms of adoption and integration of innovations, processes of disarticulation of previous practices, dynamics of resistance/conservation, etc.) that will have to be evaluated in future studies.

Finally, it is interesting to note that the technological changes addressed here affected issues such as mobility patterns or hunting techniques, but took place in an environment of apparent stability in terms of the selection of places to be occupied, interoperability between sites, the capture and consumption of animals and plants, the establishment of social networks, and so on. The combination of all these factors is a complex issue, but it shows the true nature and scope of this technological change in the Late Mesolithic.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2023.104086.

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