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The silence of the layers: Archaeological site visibility in the Pleistocene-Holocene transition at the Ebro Basin

Alfonso Alday [a], Rafael Domingo [b,*], María Sebastián [c], Adriana Soto [d], Josu Aranbarri [e], Penélope González-Sampériz [f], María Marta Sampietro-Vattuone [g], Pilar Utrilla [b], Lourdes Montes [b], José Luis Peña-Monné [h]

[a] Universidad del País Vasco/EHU, Área Prehistoria, C/ Tomás y Valiente s/n, 01006 Vitoria, Spain
[b] Universidad de Zaragoza, Área Prehistoria, C/Pedro Cerbuna 12, 50009, Zaragoza, Spain
[c] Universidad de Zaragoza, Área Didáctica Ciencias Sociales, C/Pedro Cerbuna 12, 50009, Zaragoza, Spain
[d] Université Toulouse-Jean Jaurès. UMR TRACES, 5 allées A. Machado, 31058 Toulouse Cedex 9, France
[e] Universidad del País Vasco/EHU. Área Geografía Humana, C/ Tomás y Valiente s/n, 01006 Vitoria, Spain
[f] Instituto Pirenaico de Ecología / CSIC, Campus de Aula Dei, Avda. Montañana 1005, CP 50159 Zaragoza, Spain
[g] Univ Nacional de Tucumán-CONICET, Lab. de Geoarqueología, Miguel Lillo 205, 4000 San Miguel de Tucumán, Tucumán, Argentina
[h] Universidad de Zaragoza, Área Geografía Física, C/Pedro Cerbuna 12, 50009, Zaragoza, Spain

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ABSTRACT

The Ebro Basin constitutes one of the most representative territories in SW Europe for the study of prehistoric societies during the Pleistocene-Holocene transition. The correlation of palaeoenvironmental and geomorphological proxies obtained from sedimentary records with chronologically well-constrained reference archaeological sites has allowed defining this time frame precisely, such that three main pilot areas haven been broadly depicted: the Alavese region, the Pre-Pyrenees and the Bajo Aragón.

Overall, the human imprint in the Ebro Basin was rare during the Upper Palaeolithic, but more visible from the Upper Magdalenian (14500–13500 cal BP) to Neolithic times (up to 5500 cal BP). Local environmental resources were continuously managed by the prehistoric communities in the different areas of study. In fact, the Ebro Basin acted during those millennia as a whole, developing the same cultural trends, industrial techniques and settlement patterns in parallel throughout the territory.

However, some gaps exist in the ^{14}C frequency curve (SCDPD curve). This is partially related to prehistoric sites in particular lithologies and geological structures that could have partly been lost by erosional processes, especially during the Early Holocene. In addition, this gap also parallels the reconstructed climate trend for the Pre-Pyrenean and the Bajo Aragón areas, which are defined by high frequencies of xerophilous flora until ca. 9500 cal BP, suggesting that continental climate features could have hampered the presence of well-established human communities in inland regions.

The interdisciplinary research (archaeology, geomorphology and palaeoclimatology) discussed in this paper offers clues to understand the existence of fills and gaps in the archaeological record of the Ebro Basin, and can be applied in other territories with similar geographic and climate patterns.

1. Introduction

Interest in, scientific literature and projects, and meetings related to climate-human interactions have notably increased in recent years. Reconstruction of population distributions and/or analysis of occupation patterns and cultural changes in their environmental context have emerged as a major research interest (Aura et al., 2011; Banks et al., 2013; Bar-Yosef, 2015; Binford, 1999; González-Sampériz et al., 2009; Sánchez Goñi, 1997; Starkovich and

* Corresponding author.
E-mail addresses: a.alday@ehu.eus (A. Alday), rdomingo@unizar.es (R. Domingo), msebas@unizar.es (M. Sebastián), asoto.sebastian@yahoo.es (A. Soto), aranbarri.josu@gmail.com (J. Aranbarri), pgonzal@ipe.csic.es (P. González-Sampériz), sampietro@tucbbs.com.ar (M.M. Sampietro-Vattuone), utrilla@unizar.es (P. Utrilla), lmontes@unizar.es (L. Montes), jlpena@unizar.es (J.L. Peña-Monné).

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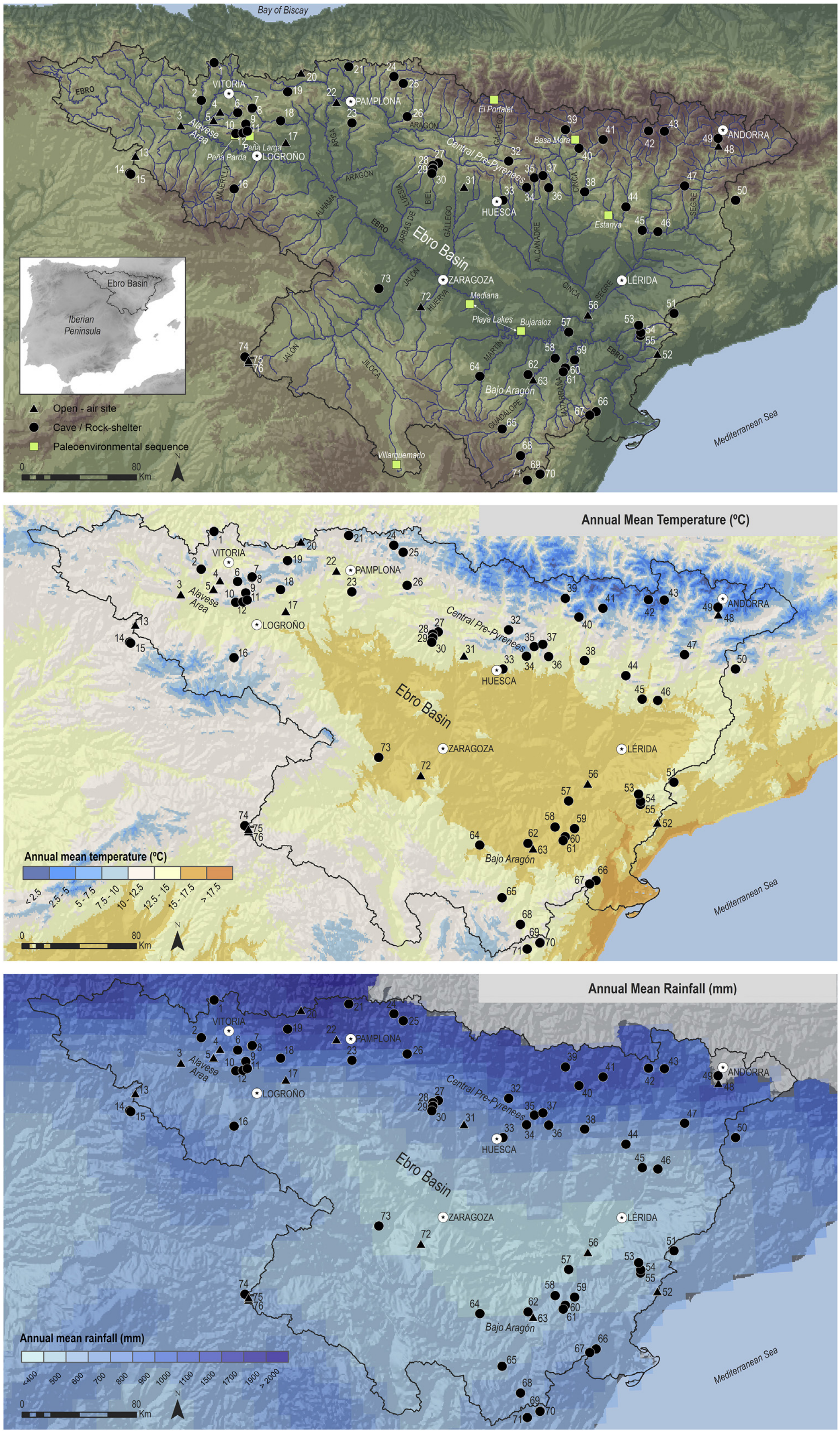

Fig. 1. Location of the archaeological sites (open air/cave or rockshelter) and paleoenvironmental records discussed in the text. 1 Urratxa-III. 2 Socuevas. 3 El Prado. 4 Araico. 5 Larrenke N. 6 Mendandia. 7 Kanpanoste and Kanpanoste Goikoa. 8 Atxoste. 9 Martinarri. 10 San Cristóbal. 11 Husos-I and Husos-II. 12 Peña Larga. 13 Alto de Rodilla. 14 Portalón. 15 Mirador. 16 Cueva Lóbrega. 17 Cascajos. 18 Orcillas. 19 Portugain. 20 Artegieta. 21 Abauntz. 22 Paternanbidea. 23 Artusia. 24 Aizpea. 25 Zatoya. 26 Padre Areso. 27 Paco Pons. 28 Peña-14. 29. Legunova and Rambla de Legunova. 30 Valcervera. 31 Samitiel. 32 Esplugón. 33 Espantalobos. 34 Chaves. 35 Pacencia. 36 Huerto Raso. 37 Drólica. 38 Forcas-I and Forcas-II. 39 Coro Trasito. 40 Puyascada. 41 Trocs. 42 Sardo. 43 Estany de la Coveta. 44 Colomera. 45 Cova Gran. 46 Parco. 47 Montanissell. 48 Camp Colomer. 49 Balma Margineda. 50 Balma

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Ntinou, 2015; Van der Plicht et al., 2011). However, most of these studies minimize the absence of archaeological evidence (both layers and materials), which should be considered as important as their dated or undated presence. Only the combination of lacks and fills would allow the construction of realistic scenarios.

Mediterranean regions are recognized as sensitive environments because of their particular climatic and geomorphological features, such as macro-scale erosive processes that might have destroyed and/or hidden some prehistoric sites (Fullola et al., 1987; Peña-Monné et al., 2011, 1996). In this sense, the Ebro Basin can be proposed as a good research area (Fig. 1), reproducing at a microscale the whole panoply of environmental varieties found in the Mediterranean realm, from the Atlantic-influenced landscapes to semi-arid territories, where the present-day environment is completely different to those of the Late glacial and the Early Holocene (González-Sampériz et al., 2008, 2004, Valero-Garcés et al., 2004, 2000) or even Roman times (Pérez-Lambán et al., 2014). Hence, the basin-scale holistic analysis allows us to compare how contemporary prehistoric human occupations responded to different climatic and geomorphologic drivers.

The Ebro Basin epitomizes a perfect case study to test how and why the potential role and the existence of open-air sites are usually misrepresented during the end of the Pleistocene and the onset of the Holocene. Data gathered only at caves and rockshelters shows only a partial image of the prehistoric occupation patterns.

In the last decades, systematic archaeological research focused on the transition from the Upper Pleistocene to the consolidation of the farming communities in the Ebro Basin has considerably enlarged our knowledge of those societies (Alday, 2006; Alday et al., in press; Montes et al., 2015; Montes and Alday, 2012; Soto et al., 2015; Utrilla et al., 2012; Utrilla and Domingo, 2014; Utrilla and Montes, 2009). The descriptions of the successive cultural units and their economic patterns (raw materials exploitation and hunting and gathering, among other practices) and the amount of data related to palaeoenvironmental issues (Aranbarri et al., 2014; González-Sampériz et al., 2008, 2017) allow the depiction of the basin as a cultural ensemble with well-defined characteristics that is constantly evolving, even if we can glimpse the existence of inner regional nuances.

To provide a more detailed analysis of the Ebro Basin, this work focuses on three pilot areas where the concentration of sites related to the studied chronological frame is especially relevant and linked to particular environmental trajectories (Fig. 2). The Alavese area in the NW belongs to a region dominated by an Atlantic climate influence; the Central Pre-Pyrenean ranges are characterised by Mediterranean montane climatic conditions; and the Bajo Aragón area close to the Central Depression has a marked aridity index and extreme summer temperatures. The study of all these pilot areas has been built upon a basic similar process but considering some differences through time, which can be summarized in three main stages.

1. In the first stage (between the 70's and 90's), the main research goal was the holistic understanding of the excavated sites: identification and nesting of the sedimentary fillings, analytics of the collections, and faunal and palaeobotanical studies (e.g. Botiquería, Costalena, Forcas I and II, Fuente Hoz, Kanpanoste-Kanpanoste Goikoa, Peña de Marañón, Pontet, Secans).
2. Around the turn of the century, new sites (Ángel, Atxoste, Baños, Legunova, Mendandia, Peña-14) were discovered in nearby areas, allowing a new research stage focused on interrelations between the sites in order to establish the cultural sequence (Alday, 2002; Cava, 2004a; Utrilla et al., 2003, 1998).
3. The last stage of our research included recent multidisciplinary studies of new sites (Espantalobos, Esplugón, Martinarri, Plano del Pulido, Rambla de Legunova, Socuevas, Valcervera and Valmayor-XI) that have enlarged the known record both cultural and geographically. The identification of different exploitation networks at local, supra-local and regional scales has enhanced our understanding of the relationships of the human groups and at the same time, the characteristics of each industrial phase. In addition, the multidisciplinary research includes the detailed study of palaeobotanical proxies (both anthracological and carpological remains), technological and functional analyses, and genetic studies.

This information allows an acceptable reconstruction of many aspects of the prehistoric past. Nevertheless, a critical revision of the available data points out some deficiencies and repetitions mainly derived from the research process, but also related to: i) The interpretation of the absence *vs.* the presence of archaeological layers, and ii) the lack/occurrence/imprecision of radiocarbon dating as well as its recent use as a demographic indicator, despite its intrinsic incoherencies.

Our hypothesis and the ultimate motivation of this paper is that the archaeological record, no matter how wide, cannot completely express the cultural situations of the past. We face a noteworthy loss of information that hampers advancement and that perhaps should encourage us to design new actions to obtain solutions. In any case, our consciousness of this situation can be the basis for a new look at prehistoric processes, a perception that must be rather different to the current one.

Consequently, this paper proposes a more realistic valorisation of prehistoric occupation patterns by exploring a multi-proxy approach to this central research issue: the description of the processes (and their possible origin; i.e., climate, humans, natural hazards) that played a major role in the settlement and abandonment of the dwelling places and the later natural evolution that have unearthed, masked, destroyed or hidden those archaeological sites, depending on the region. For this objective, we consider the Ebro Basin and the three model areas within (Alavese, Central Pre-Pyrenees and Bajo Aragón) because they represent different biogeographical regions with a common cultural pattern within the 16000–5500 cal BP chronological frame.

2. Regional settings

The Ebro River, which runs from the Cantabrian Ranges to the Mediterranean across the NE Iberian Peninsula, constitutes a huge basin whose surface exceeds 80,000 sq. km. It is closed off to the N by the Pyrenees, to the SW and S by the Iberian Range and to the E by the Catalonian Ranges (Fig. 1). It was formed by Alpine tectonic shifts that pushed up the outlying mountain chains and formed the sedimentary foreland depression. During the Tertiary, it was gradually filled with sediments as an endorheic continental basin. After the Late Miocene-Pliocene, as it became exoreic, it gained an outflow to the Mediterranean and the sediment moved to its bottom (200–300 m a.s.l.). This was the start of the growth of the Ebro River system and of sediments draining from the basin to the sea, which still continues today.

Guilanyà. 51 Molí del Salt. 52 Collet Puiggrós. 53 Colls. 54 Hort de la Boquera. 55 Filador. 56 Riols. 57 Valmayor-XI. 58 Plano del Pulido. 59 Costalena. 60 Pontet. 61 Botiquería. 62 Torrazas. 63 Alonso Norte. 64 Baños. 65 Ángel-1 and Ángel-2. 66 Clot del Hospital. 67 Vidre. 68 Mas Cremat. 69 Cova Fosca. 70 Mas Nou. 71 Cingle de l'Aigua. 72 Cabezo de la Cruz. 73 Cueva del Gato-2. 74 Carlos Álvarez. 75 Lámpara. 76 Revilla. Source: Confederación Hidrográfica del Ebro (http://www.chebro.es). Below, average annual precipitation (González-Hidalgo et al., 2011) and temperature (González-Hidalgo et al., 2015) maps.

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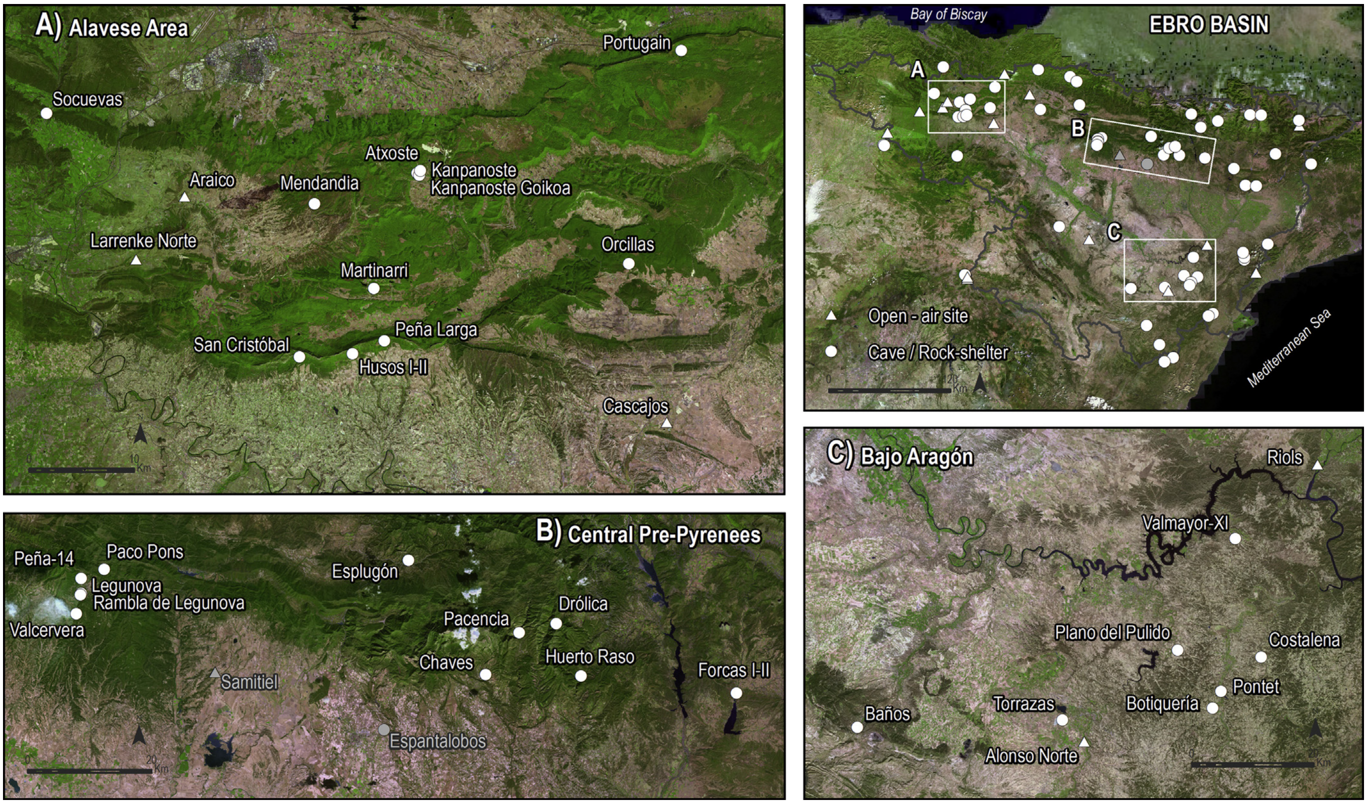

Fig. 2. Archaeological sites studied in each pilot area (PNOA Orthophotos, 2016). In grey, archaeological sites not included in the pilot areas.

Several climate types can be found in this territory. The NW corner is defined by an Atlantic climate regime, while the mountain ranges are defined by high- and mid-mountain climate features. In contrast, the bottom of the depression is characterized by semi-arid Mediterranean conditions. Overall, annual rainfall values oscillate between 2500 mm and barely 350 mm, whereas temperatures depend on the height, exposition and orientation, with the highest values measured in the central and Eastern sector of the basin. The vegetation communities are well distributed according to these climatic drivers, being defined by the typical broadleaved forests in the Atlantic region and by dry steppes in the semiarid Mediterranean realm. The main characteristics of the three pilot areas can be summarized as follows.

1. The Alavese area is placed Northwest of the Basin at approximately 600 m a.s.l. It presents a mesothermal climate, moderate in temperature and with abundant precipitation (*ca.* 1000 mm of annual rainfall). Vegetation communities in this area are dominated by mesophytes, mainly deciduous (*Quercus robur*, *Q. petraea*) and semi-deciduous oaks (*Quercus faginea*) in the lowlands, while beech (*Fagus sylvatica*) and pine communities (*Pinus sylvestris*) spread at higher elevations.
2. The central Pre-Pyrenees are located North of the Ebro Basin. This region has an average altitude of 1000 m a.s.l. The climate is continental, with a 760 mm mean annual rainfall, mostly occurring between October and June. The vegetation composition is essentially mixed, dominated by pines (*Pinus sylvestris*) and both evergreen and semi-deciduous oaks (*Quercus ilex ssp. rotundifolia*, *Q. faginea*).
3. Bajo Aragón is located Southeast of the Basin and close to the Mediterranean coast. These lowlands, at an altitude lower than 400 m, are defined by a semi-arid climate with the highest potential evapotranspiration levels of all of Iberia. Annual rainfall barely reaches 300 mm. The natural vegetation cover is open and dominated by scattered pines (*Pinus halepensis*), junipers (*Juniperus thurifera*, *J. phoenicea*, *J. oxycedrus*) and thermophilous shrubs (*Quercus coccifera, Rhamnus alaternus, Pistacia lentiscus, Phyllirea angustifolia, Rosmarinus officinalis, Lavandula latifolia*), among others.

3. Materials and methods

Archaeological work carried out at 80 sites from the Ebro Basin and very close areas allows us to draw an accurate picture of the prehistoric communities that lived in the region from the Late Pleistocene to Neolithic times. Their cultural phases have been characterized by means of lithic typology, as well as their economic basis (subsistence practices and resource exploitation). In total, 425 ^{14}C dates (maximum standard deviation allowed $\leq$ 100) sustain this dataset (Table 1; Appendix A). Archaeological sequences and ^{14}C dates reveals the continuity and discontinuity processes in the occupation patterns. As extreme examples, Atxoste (Alday, 2014) offers a stratigraphy 6 m deep that was almost continuously occupied from the Late Palaeolithic to the Neolithic, dated by 23 14C dates, and Botiquería (Barandiarán, 1978) has a sequence of fertile and sterile layers from the Mesolithic and Neolithic periods of barely 1.5 m with only 4 14C dates. Among this set, the 35 sites (30 caves/rockshelters, 5 open-air locations) from the three detailed areas (43.75% of the basin sites) are the basis for the current analysis. Most of them (approximately 80%) have been excavated by the authors of this paper so their archaeological records and materials are known in detail, which assures a homogeneous treatment of data.

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Table 1
Synthesis of sites and available dates from the Ebro Basin and the 3 pilot areas. The whole basin dataset already includes sites and dates from the pilot areas.

PERIOD (Date cal BP)	TOTAL EBRO BASIN 80 sites	SITES/ 100 YEARS	PILOT AREAS (35 sites; 186 14C) ALAVESE AREA 14 sites	 CENTRAL PRE-PYRENEES 12 sites	 BAJO ARAGÓN 9 sites
NEOLITHIC	54 SITES	2,70	Araico	Chaves	Alonso Norte
	(41 caves and rockshelters		Atxoste	Drólica	Botiquería
ca. 7500-5500	13 open-air)		Cascajos	Esplugón	Costalena
			Husos I – I	Forcas II	Plano del Pulido
			Larrenke N	Huerto Raso	Pontet
			Mendandia	Pacencia	Riols
			Peña Larga	Paco Pons	Torrazas
			San Cristóbal	Rambla Legunova	Valmayor XI
	254 14C		(45 14C)	(33 14C)	(13 14C)
GEOMETRIC	27 SITES	2,25	Atxoste	Esplugón	Baños
MESOLITHIC	(26 caves and rockshelters		Kanpanoste G	Forcas II	Botiquería
	1 open-air)		Martinarri	Peña-14	Costalena
ca. 8700-7500			Mendandia	Rambla Legunova	Pontet
			Socuevas	Valcervera	
			Urratxa III		
	55 14C		(11 14C)	(13 14C)	(8 14C)
DENTICULATE	17 SITES	1,31	Atxoste	Esplugón	Baños
MESOLITHIC	(16 caves and rockshelters		Kanpanoste	Forcas II	Pontet
	1 open-air)		Kanpanoste G	Legunova	
ca. 10000-8700			Martinarri	Peña-14	
			Mendandia		
	32 14C				
			(11 14C)	(9 14C)	(4 14C)
SAUVETERRIAN/	20 SITES	0,57	Atxoste	Forcas I	
AZILIAN/	(20 caves and rockshelters)		Martinarri	Legunova	
MICROLAMINAR			Mendandia	Peña-14	
			Portugain		
ca. 13500-10000			Socuevas		
			Urratxa III		
	46 14C				
			(11 14C)	(4 14C)	
LATE MAGDALENIAN	20 SITES	1,33	Atxoste	Chaves	–
	(20 caves and rockshelters)		Martinarri	Forcas I	
ca. 15000-13500			Socuevas	Legunova	
	38 14C		(13 14C)	(11 14C)	
TOTAL 14C	425	0,84	91	70	25

In addition, geomorphological field projects have been carried out in the three study areas. Detailed morphological descriptions of each site have been performed in order to identify the main drivers that determined their formation and degradation. These micro-analyses are completed by the characterisation of the palaeoenvironmental records and other geomorphological proxies from the surrounding areas. The aim of the geomorphological analysis of the rockshelters lies in determining the varied origins and the evolutionary processes of their deposits, as well as establishing a basic typology and the extent to which their conservation and visibility is possible. These data are important to determine the distortion that the conservation/disappearance of deposits can create in the available information.

As well as in archaeology, an important effort in the study of palaeoenvironmental sequences covering the Late glacial and the Early-Mid Holocene has been performed for the Ebro Basin and the Pyrenees during the last decades (Aranbarri et al., 2014; González-Sampériz et al., 2008, 2006; Iriarte-Chiapusso, 2009; Iriarte-Chiapusso et al., 2008; Pérez-Díaz et al., 2016, 2015; Valero-Garcés et al., 2000). Although most of the studies have been focused on archaeological sites (see the compilation for the Central Ebro Basin in González-Sampériz, 2004), lacustrine records have increased exponentially in the last years. Thus, it is possible to correlate chronologically well-constrained regional palaeoenvironmental and palaeoclimatic proxies with both patterns of human occupation and geomorphological evolution of sites. For this work, the two longest continuous lacustrine sequences from both the Northern and Southern Ebro Basin (Estanya and Villarquemado records) have been selected, together with the El Portalet record from a high altitude location in the Central Pyrenees, in order to show the climate history of the Atlantic-influenced areas. These sequences cover all the different biogeographical regions within the study area.

The chronological evaluation analysis has been performed using a reference database including 425 ^{14}C dates that span from 5000 to 13000 BP (5650–15750 cal BP) from 80 archaeological sites. It has been compiled by means of an exhaustive bibliographical search. The only selection criterion considers their accuracy: a standard deviation of less than a century was required. Despite the lack of anthracological determination for most of the dated samples in our database, we believe that the debate surrounding short life *vs.* long life samples is no longer relevant in this case (Barceló, 2008; Williams, 2012; Drake et al., 2016). The correlation coefficient of charcoal vs. other material samples in our database is 0.92. On this basis, and accepting the “old wood effect” for some of the samples, we cannot exclude around 190 charcoal radiocarbon references (almost a 45% of the available dataset). Traditionally, ^{14}C dates have been analysed using a wide set of methods, each of them with different possibilities and limits (Attenbrow and Hiscock, 2015; Barceló, 2008; Blaauw, 2010; Contreras and Meadows, 2014; Crombé and Robinson, 2014; Gkiasta et al., 2003; Guilderson et al., 2005; Michczynski et al., 2007; Riede et al., 2009; Riede and Edinborough, 2012; Surovell and Brantingham, 2007; Torfing, 2015; Wicks et al., 2014; Williams, 2012). A consensus is established by presenting the dates in calendar years (preferentially cal BP, as shown here) rather than in their isotopic format.

The varied software specifically designed to create chronological models from a long series of ^{14}C, if analysed in detail (i.e., when looking at the cultural transitions), can be read in very different ways. Those differences may pass unnoticed or are minimised when a large number of dates are compiled, as in this paper. Nevertheless, they should be considered when working from a historical perspective. In summary, the compilation of a long series of ^{14}C dates is always problematic because different statistical solutions are available, such as Bayesian analysis or SCDPD curves, and the results are always diverse.

In this paper, the evolutionary spectrum of the ^{14}C series has been constructed following the protocols of the Summed Calibrated radiocarbon Date Probability Distribution (SCDPD) (Balsera et al., 2015; Bernabeu et al., 2015; Bocquet-Appel et al., 2012; Drake et al., 2016; Pardo et al., 2015; Shennan et al., 2013). In addition, we have included some variations for improving resolution. First, dates have been calibrated with Oxcal V4.2 (IntCal13 curve) (Bronk Ramsey, 2009; Reimer et al., 2013). Then, their graphic representation was obtained following Evin's recommendations (Evin et al., 1995) to guarantee that the dates contribute equally regardless of their chronological span (paradoxically, in traditional systems the most imprecise samples are better represented). Next, we have considered the standardized value for every subdivision (50 years long) within the studied temporal lapse. In order to avoid over-representation of the most repeatedly dated contexts, we have only included the highest weighed value from each context in every section. Finally, we have summed the values of each 50-year period (see Appendix B for further explanation). The benefits of this procedure can be summarized as follows: i) all the registered values are taken into account, and ii) a previous selection of the repeated values from a context is unnecessary because the system selects the best suited for each moment. Thus, all the laboratory results are respected. We have to be conscious that the available software (OxCal, Calpal, etc.) calibrates the dates and draws the frequency graphs disregarding their origin, such that each chronologic value is related to a laboratory reference but not to its site of provenance. Consequently, for this software there is no difference if a hundred dates are obtained from only one site or from a hundred different sites; on the contrary, our procedure establishes a dialogue between the date and its archaeological context.

However, there are some previous remarks that we have to bear in mind before analysing the results. Usually, SCDPD has been employed as a demographic proxy (Balsera et al., 2015; Pardo et al., 2015; Riede et al., 2009; Shennan et al., 2013) based on the premise that "the bigger the population, the greater the archaeological record". This proposition equates ^{14}C date frequency and population growth. But in recent years, many studies have pointed out many factors that influence the final value of the SCDPD, highlighting: i) procedural or methodological factors (Bamforth and Grund, 2012; Contreras and Meadows, 2014; Steele, 2010; Weninger et al., 2015; Williams, 2012); ii) factors related to the reality of prehistoric societies (Naudinot et al., 2014; Torfing, 2015); and iii) factors related to the nature and entity of the archaeological data (Attenbrow and Hiscock, 2015; Crombé and Robinson, 2014; Surovell et al., 2009; Surovell and Brantingham, 2007; Torfing, 2015). In relation to the latter we emphasise that:

1. Databases composed by ^{14}C references may only partially reflect the archaeological reality found by archaeologists, distinct from the historic or cultural reality.
2. Databases are composed of very different archaeological contexts in terms of entity (i.e. major sites *vs.* temporary campsites), functionality (i.e. settlement *vs.* funerary), knowledge degree (i.e. whole site excavated *vs.* partial test-pit), and cultural representativeness. The only common nexus for all the considered sites is their temporal convergence. Likewise, every type of human settlement offers different conservation patterns that, logically, interfere in the database construction (for example, dating funerary contexts is usually easier than dating habitation levels).
3. Databases are not independent of several problems inherent to the archaeological discipline, such as taphonomy, post-depositional processes or history of the research.

For these reasons, we believe that dating frequency curves never can be seen as a faithful reflect of the actual peopling. In this sense, in this paper we analyse SCDPD focusing on the nature of the known archaeological record −which in our territory is heavily conditioned by the geomorphic evolution typical of soft lithological environments-, especially in the lack of information from taphonomic processes and its influence in the interpretation of prehistoric dynamics.

4. Results

Within the broad context of the Ebro Basin, the three pilot areas (Alavese, Central Pre-Pyrenean and Bajo Aragón regions) have provided enough data to build a first draft of their prehistoric settlements, establishing a multi-proxy approach that includes archaeological, geomorphological and palaeoenvironmental analyses.

4.1. Archaeological records and SCDPD

The SCDPD curve of the Ebro Basin compiled as explained in Methods has a general profile that follows the same trends observed for the entire Iberian Peninsula (Fig. 3). The particular nuances should be related as much as to the regional peopling dynamics as to the record opportunities, the research rhythms and the Holocene sedimentary processes.

Both the Iberian and the Ebro Basin SCDPD curves (Fig. 3) show a sustained growth of dating frequency from 15000 to 14000 cal BP and onwards (i.e., during the Late/Upper Magdalenian). There is a short drop during the GI-1b and a general abrupt and short increase at approximately 13000 cal BP. After this rise and fall, the GS-1 episode maintains a low frequency of radiocarbon dates during the whole period, and a general stability persists until *ca.* 10000 cal BP in both curves. As the Holocene advances, it is possible to observe: i) a frequency growth around 9500 cal BP (more noticeable in the Iberian curve than in the Ebro Basin), followed by an abrupt and striking decrease; ii) an accelerated and persistent rise from *ca.* 8500 cal BP, much more intense in the Iberian curve, which reaches its maximum at approximately 7500 cal BP; iii) the incorporation of dates from open-air sites since *ca.* 8000 cal BP; and iv) the sudden fall following an erratic profile from 7300 cal BP onwards, showing in this case that the Ebro Basin curve has a higher stability than the SCDPD of the Iberian Peninsula. Punctual peaks in the SCDPD curves, also detected in other parts of the world, have been related to calibration curve perturbations for the considered timeframe, *ca.* 12600 cal BP (Michczynski et al., 2007; Williams,

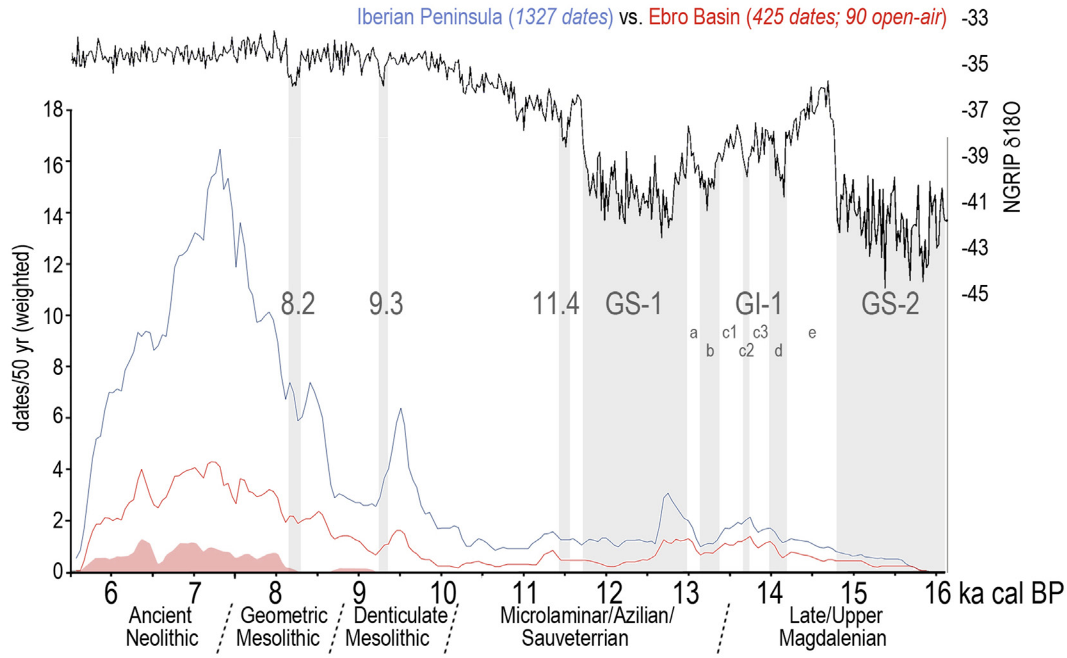

Fig. 3. Compared SCDPD curves from Iberia and Ebro Basin between 16000 and 5500 cal BP. Reddish area under Ebro line points out the 90 dates from the open-air sites.

2012) and *ca.* 9500 cal BP (Zahid et al., 2016). In our opinion, the abrupt decrease in dates *ca.* 6700-6600 cal BP could be explained by the same reasons: it affects all the regions despite their particular environmental features and it is extremely brief.

In archaeological terms, the beginning of the timeframe is characterised by a progressive increase in dates and sites, in parallel to the tendency documented in the classic Franco-Cantabrian Late Magdalenian and Azilian periods (see Straus et al., 2012 and papers in the same volume). The generalised scarcity of sites that follows it is also part of a wider trend. As commented, the abrupt rise and fall *ca.* 13000-12500 cal BP may be related to the calibration curve stability and not to a real archaeological event (there are only five sites and seven dates for this interval). The low frequency in the Ebro curve between 11000 and 10000 cal BP can be related to the scarce number of dates and sites. The diffuse transit between the old Mesolithic industries and the Denticulate period occurs during that low-profile moment (*ca.* 10000 cal BP). Around the noticeable peak of *ca.* 9500 cal BP, several sites with a long future lifespan were occupied for the first time (Ángel 2, Artusia, Esplugón, Kanpanoste, Mendandia and Forcas II: Fig. 1, Table 1). Almost the same could be said for Martinarri, Legunova or Peña-14 (Fig. 1, Table 1), given the gap between their preceding Late Pleistocene occupations and this one, and Las Orcillas (as well as other undated locations). A short time before 8500 cal BP, a notable rise in frequencies can be seen until *ca.* 7400 cal BP; in some long-time occupied sites like Peña-14 or Socuevas this is the last dwelling period. On the contrary, new locations are first inhabited (Cova del Vidre, Rambla de Legunova or Cova Fosca). The final decrease cannot be explained even if we apply the taphonomic bias formula (Surovell et al., 2009).

If the Ebro Basin and the three pilot area curves are analysed in detail (Fig. 4), it is possible to observe similar general trends but also interesting regional differences that could be explained by the archaeological context, as follows.

- In the Alavese Area and the neighbouring Western Pyrenees (Fig. 4A), the SCDPD reproduces the Ebro Basin curve, although its first growth begins later (*ca.* 14000 cal BP). A more intense drop is recorded at the end of the GS-1 and the beginning of the Holocene, when as described there is a decline in dated sites, whereas a stability of accumulated dates is observed between 7500 and 5500 cal BP, in agreement with the frequencies of dates from open air sites (the highest of the three pilot areas).

Archaeologically, the end of the Upper Magdalenian (ca 14500 to 13500 cal BP) is well represented in various archaeological sequences (Table 1), whose development during the first part of the GI-1 shows a progressive evolution towards Azilian and Mesolithic industries. This is the case at the Atxoste, Martinarri and Socuevas sites (Fig. 2, Table 1) (Barandiarán et al., 2006; Soto et al., 2015). Along the GS-1 (12900 - 11700 cal BP), this progressive transformation culminates in the Azilian ensembles (Portugain, Urratxa III) (Barandiarán and Cava, 2008; Barandiarán et al., 2006) with others attached to Microlaminar and Sauveterrian traditions (Socuevas, Atxoste), lasting until *ca.* 10500 cal BP (Soto, 2015). However, some contexts suggest a longer timespan (*ca.* 9500) (Mendandia, Martinarri, Las Orcillas) (Soto et al., 2016). Around 10000 cal BP, a large technological transformation appears: the Denticulate Mesolithic (Atxoste, Mendandia, Kanpanoste, Kanpanoste Goikoa) (Alday and Cava, 2006). In some cases, these assemblages are the beginning of new stratigraphic sequences. These industries dominate until 8700-8500 cal BP, when the triggering of the Mesolithic Geometric tradition marks the last technological change of the hunter-gatherer societies (Atxoste, Mendandia, Kanpanoste Goikoa, Socuevas) (Alday and Cava, 2009). Triangle-shaped microliths gradually replace trapeze forms during this period (Fig. 5). With regional and chronological evolution, this tradition is upset at *ca.* 7500 cal BP by the arrival of the Neolithic transformation, which includes new economic patterns, as shown by diverse biological markers (pollen, charred seeds, domestic animal bones, for example). The new forms replaced old ones in several of the ancient sites, with the appearance of new occupation typologies like villages and animal enclosures (Mendandia, Atxoste, Peña Larga, Los Cascajos). The development of Betey microlithic elements connects this territory with Aquitaine, while a common ceramic decoration mode (Boquique type: Fig. 5) is related to the inner Iberian Peninsula.

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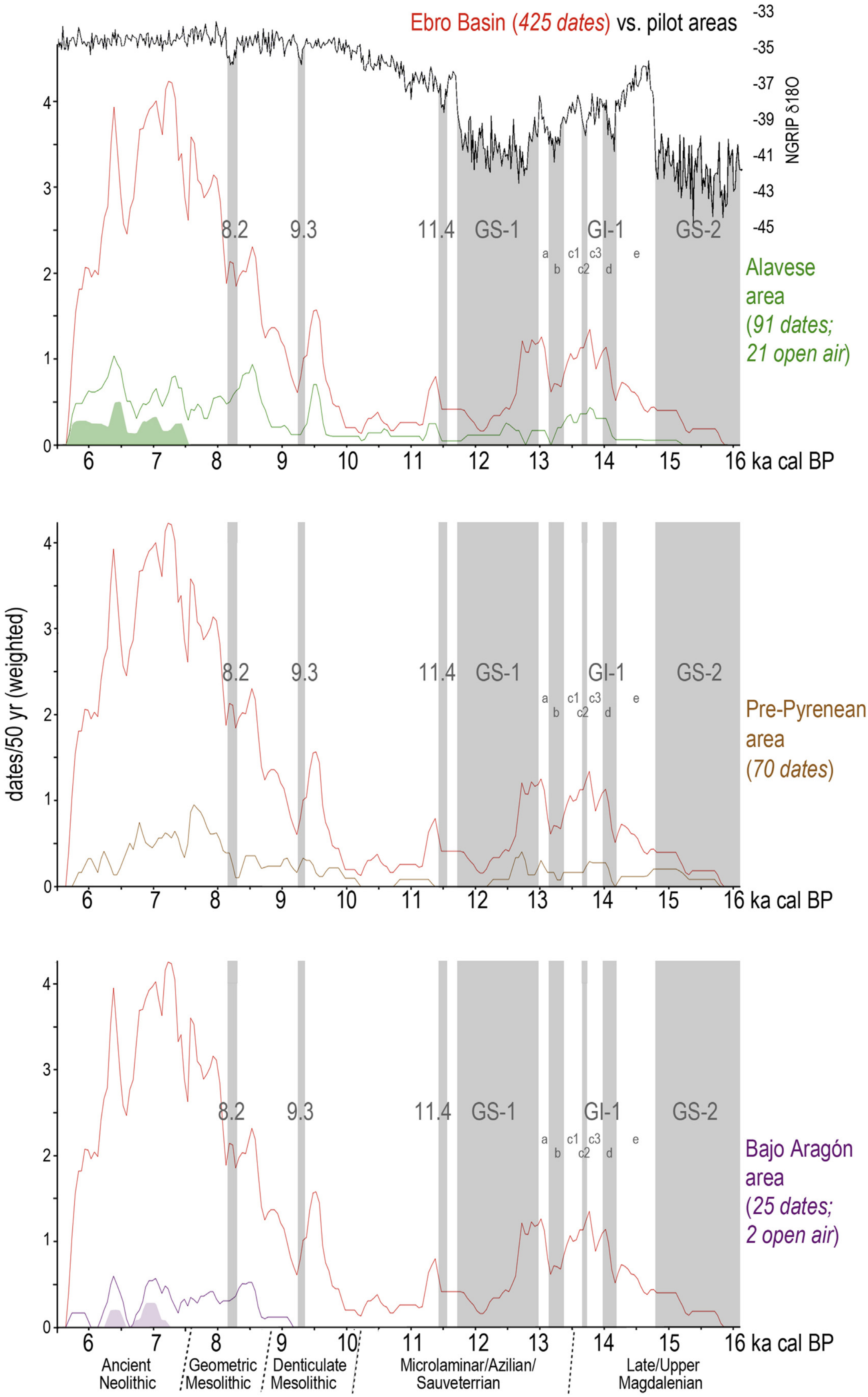

Fig. 4. Ebro Basin *vs.* Alavese (A), Pre-Pyrenean (B) and Bajo Aragón (C) pilot areas. Red line shows the SCDPD from the whole basin compared to each area curve. Green and blue zones under Alavese and Bajo Aragón lines reflect its open-air sites (absents in Pre-Pyrenean area). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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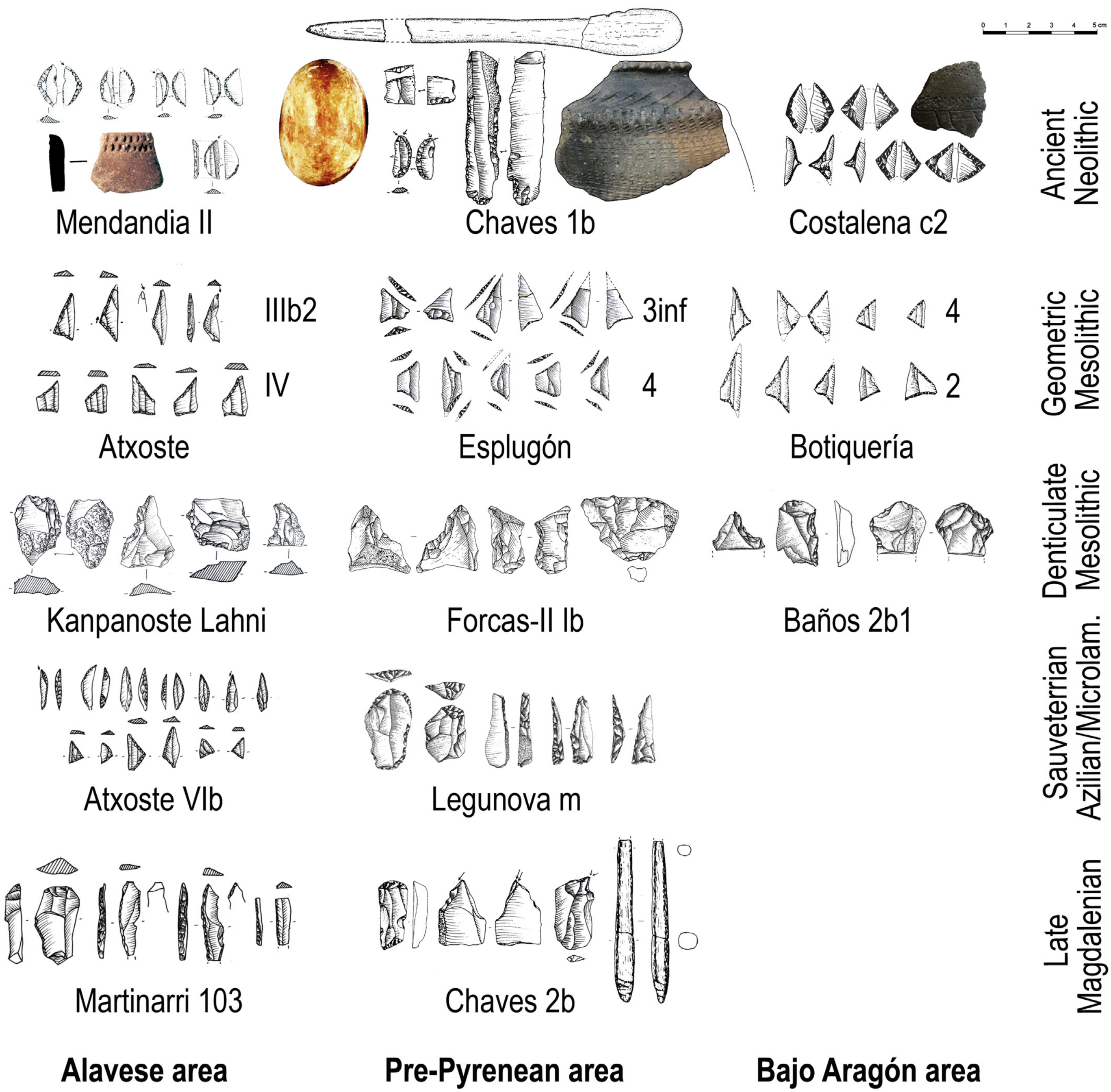

Fig. 5. Representative archaeological materials from sites within the three pilot areas of the Ebro Basin. Magdalenian: Martinarri level 103 (Alday et al., 2012); Chaves level 2b (Utrilla and Baldellou, 1994). Sauveterrian/Azilian/Microlaminar: Atxoste level VIb (Soto, 2015); Legunova level m (Montes et al., 2016). Denticulate Mesolithic: Kanpanoste level Lahni (Cava, 2004b); Forcas-II level Ib (Utrilla and Mazo, 2014); Baños level 2b1 (Utrilla and Rodanés, 2004). Geometric Mesolithic: Atxoste levels IV and IIIb2 (Soto, 2015); Esplugón levels 4 and 3inf (Utrilla et al., 2015); Botiquería levels 2 and 4 (Barandiarán, 1978). Neolithic: Mendandia level II (Alday, 2005); Chaves level 1b (Cava, 2000) (Utrilla and Baldellou, 2001) (Baldellou, 2011); Costalena level c2 (Barandiarán and Cava, 1989).

In the Central Pre-Pyrenean area (Fig. 4B), the SCDPD curve fits well with the regional one, excepting for a long drop from the second half of the GS-1 (from 12200 to 11500 cal BP and again from 10800 to 10200 cal BP). In addition, the intense peak recorded at 9500 cal BP in the Ebro curve is not observed in the region and the general growth of the accumulation curve begins later, *ca.* 8200 cal BP instead of *ca.* 9000 cal BP as in the Ebro Basin. It is worth mentioning that open-air sites in the Pre-Pyrenees pilot area have not been found.

In the archaeological record, a well-developed Upper-Late Magdalenian dated *ca.* 14000-13000 cal BP (Legunova, Chaves, Forcas-I) is followed by the Microlaminar, Azilian or Sauveterrian levels until *ca.* 10800 cal BP in almost the same locations (Alday et al., 2014; Aura et al., 2011; Soto et al., 2015; Utrilla et al., 2012). Later, there seems to be an archaeological gap, with some true sterile layers; i.e., in the Arba de Biel area, Legunova and Peña-14 sites (Fig. 2 and Table 1) (Montes et al., 2016), or even definitive abandonment of some sites (Forcas-I: Utrilla and Mazo, 2014). After this gap, the Denticulate Mesolithic occurs between 10200 and 8800 cal BP (Montes et al., 2006). It appears in thick archaeological layers at the previously mentioned Arba de Biel area, somewhat later at Esplugón (Fig. 2b, Table 1) and inaugurating the archaeological sequence at Forcas-II (Figs. 2b and 5, Table 1). Immediately after 8800-8200 cal BP, the Geometric Mesolithic trapeze phase appears, with Peña-14, Rambla de Legunova, Valcervera or Esplugón and the nearby Espantalobos located in the lowlands as some examples (Fig. 2b, Table 1). Later, the second phase, characterised by triangles, develops *ca.* between 8200 and 7700 cal BP (Forcas-II, Esplugón). Its main feature is the dominance or equality of triangles *vs.* trapezes (Fig. 5) and the posterior incorporation of some abrupt-retouched pieces of the North Pyrenean tradition (Utrilla et al., 2009). Then, the first Neolithic-related elements appear without a break. The most prominent Pre-Pyrenean Ancient Neolithic site is Chaves, a true village inside a cave (Baldellou, 2011), where a fully agricultural human occupation took place between 7500 and 7000 cal BP (Fig. 2b and Table 1). This site may have triggered the regional neolithisation process. The other site locations determine their economic basis. Most are in remote areas where traditional hunting-gathering practices coexist with pioneering husbandry, with the incorporation of material novelties such as double-bevelled lithic retouch or pottery (Fig. 5). Clear examples would be the Arba de Biel ensemble, Forcas-II and Esplugón (Montes et al., 2016; Utrilla et al., 2015; Utrilla and Mazo, 2014).

Finally, the SCDPD of the Bajo Aragón pilot area (Fig. 4C) shows a different evolution because the earliest documented archaeological levels -and hence the first radiocarbon dates-begin at approximately 9200 cal BP and follow a similar trend to the Ebro Basin, although the pilot area accumulation curve almost disappears at *ca.* 6600 and 6100 cal BP.

Therefore, the first human occupation in this area belongs to the Denticulate Mesolithic (Montes et al., 2006), found in sites like Los Baños, Pontet, Costalena, Plano del Pulido and Ángel located in the nearby Maestrazgo area (Fig. 2, Table 1). Between 8800 and 8200 cal BP, the Geometric Mesolithic is the dominant horizon, starting with the traditional trapeze phase (Fig. 5) at some of the mentioned sites (Barandiarán and Cava, 2000; Utrilla et al., 2009). In some of them, an evolution of the trapezes can be observed, starting with a dominance of wide and short elements, followed by small types and ending with big long specimens. The triangle B-phase, well represented North of the Ebro River, is absent from the Bajo Aragón and is rare in the nearby Maestrazgo-Els Ports area (i.e., Ángel 2 and Vidre sites: Fig. 1, Table 1). The transition to the Early Neolithic (7700-7300 cal BP) remains marked by the dominance of triangles *vs.* trapezes; to this we can add the appearance of the double-bevelled retouch and the first pottery examples -Cardial, impressed or incised-that begin to generalise (Montes and Alday, 2012; Utrilla and Domingo, 2014). Sadly, the poor conservation of biological markers in this region hampers this type of analytics and thus the characterization of economic strategies.

4.2. Geomorphological processes and representative data

Geomorphological studies carried out in the three pilot areas across the Ebro Basin show a generalisation of changes in landscape features during the Late Pleistocene and the Holocene due to climate fluctuations. This dynamic acquired special relevance from the Middle Holocene onwards, when human intervention on the environment begins to be recognisable. For example, sediment records at the bottom of secondary valleys in the centre of the Ebro Depression show that the erosion triggered by human activities started in the Neolithic (ca. 6500 cal BP) and sped up from the Bronze Age, becoming even faster during Iberian and Roman times (Constante et al., 2010, 2011; Peña-Monné et al., 2004, 2014; 2005, 2011).

The influence of environmental changes on the preservation of ancient prehistoric sites has been analysed in detail in the mid-section of the Segre River, Northeast of the Ebro Basin (Fig. 1). Processes involved in the destruction of rockshelters (weathering of the sandstones and erosion in the bottom clay basis) have been dated to the Bronze and Iron Ages (4000-2500 cal BP) (Peña-Monné et al., 2005). To date, there are no models explaining rockshelter evolution in the Ebro Basin prior to the Bronze Age. A first morphological classification of the sites occupied by prehistoric groups from 16000 to 5500 cal BP allows us to distinguish three typologies according to the lithological characteristics, the layout of the structure and the type of response to increased erosion (Table 2, Figs. 6 and 7).

1. Rockshelters and cavities in marginal and middle mountains, in detrital and calcareous rocks (limestone, dolomite, sandstones, chalk conglomerates), formed by fluvial and/or karstic activity mainly in river canyons (Table 2, type 1.1) or shelters found in slope faces due to differential erosion and weathering (Table 2, type 1.2), or cavities in river canyons formed by fluvial and karstic erosion. In several cases the lithological factor is reinforced by the structural position, taking advantage of the shelters located in the front of the cuestas (Table 2, types 1.2 and 1.3). Only a shelter located in a big tafoni was found, which was the result of old formation processes (Table 2, type 1.3, Martinarri). The evolution of these typologies (Fig. 6), mainly due to collapsing overhangs, fillings by fluvial or karstic action, or fossilisation related to slope dynamics, is slow and their archaeological deposits have the highest chance of being preserved completely or partially. Type 1 is frequent in the mountain ranges of the Northern sector of the Basin (i.e. Forcas and Martinarri: Figs. 6 and 7, type 1.3), the Basque Mountains (i.e. Atxoste: Figs. 6 and 7, type 1.2) and some valleys in the Iberian Range (i.e. Ángel: Figs. 6 and 7, type 1.1).
2. Rockshelters formed in durable sandstone layers from the continental Neogene period, in a horizontal or sub-horizontal layout and, in most cases, containing a palaeochannel structure (Table 2, Figs. 6 and 7, type 2.1). They evolve relatively fast because erosive processes dismantle soft sediments and the overhanging rock fractures and falls (Fig. 6). In addition, slope movements displace both the fallen blocks and the sediments. Rock weathering sometimes helps in their destruction. The processes become even faster when the palaeochannels are totally exposed, as erosion can advance on several fronts at once (type 2.2 in Table 2 and Figs. 6 and 7). Frequently, fallen blocks partially protect the ancient deposits. They are characteristic of the SE basin (Bajo Aragón) and the central-western area (Arba de Biel River), although this type is also found in the NE sector of the basin (middle valleys of the Segre and Cinca Rivers, with more recent archaeological deposits). Eventually, ancient tafonis caused by different climatic stages in more resistant sandstone formations were occupied by prehistoric groups, like Rambla de Legunova and El Pontet (type 2.3 in Table 2, Figs. 6 and 7) (Domingo and Montes, 2009; Mazo and Montes, 1992). Their degradation is slower than other sandstone sites.
3. Open-air campsites, which sometimes are an expansion of the living space next to the rockshelters (Arias et al., 2015; García-Diez and Vaquero, 2015), but also occur as isolated settlements, are totally unconnected with the presence of parietal protection. The known deposits are in flat zones, near to riverbeds, like the Cabezo de la Cruz campsite (type 3 in Table 2, Fig. 7) (Rodanés and Picazo, 2013) and the Cascajos and Paternanbidea villages (García-Gazólaz, 1999, 2007; Sesma, 2007). This type of deposit may have been dismantled by erosion and human activities and they are often some meters underground,

Table 2
Revised archaeological sites according to lithological characteristics, the layout of the structure and the type of response to erosional processes (see location of the sites in Fig. 1).

TYPE AND REPRESENTATIVE SITE		LITHOLOGY AND GEOMORPHOLOGY	GENESIS	ALTERATION PROCESSES
1. SHELTERS AND CAVES IN MARGINAL MIDDLE MOUNTAIN	**1.1 ÁNGEL 1** Chaves C. Drólica Huerto Raso Los Husos Peña Larga Portugain S. Cristóbal Urratxa III	Mesozoic and Eocene limestones, dolomites and conglomerates Cavity in fluvio-karstic canyon	Fluvial and/or karstic activity	Slow erosion
	1.2 ATXOSTE Los Baños Esplugón Forcas Kanpanoste Kanpanoste Goikoa Paco Pons Socuevas	Mesozoic and Eocene limestones and detrital rocks Small shelther in front of the structural cuesta	Differential erosion and rock weathering	Slow erosion
	1.3 MARTINARRI	Paleogene detrital sediments Taffoni in monocline sandstones	Ancient stages of rock weathering	Slow weathering
2. SHELTERS IN LOWLANDS EBRO BASIN	**2.1 PLANO DEL PULIDO** Botiquería Costalena Espantalobos Legunova Peña-14 Valmayor-XI	Horizontal Neogene sandstones Shelter in the cliffs of the paleochannel reliefs and mesas	Differential erosion and rock weathering	Fast weathering + rock falls
	2.2 VALCERVERA Torrazas	Horizontal Neogene sandstones Shelter in narrow and exempt paleochannel relief	Differential erosion and rock weathering	Very fast weathering + rock falls
	2.3 EL PONTET Rambla de Legunova	Horizontal Neogene sandstones Large taffoni in paleochannel relief	Ancient stages of rock weathering	Slow weathering + rock falls
3. OPEN AIR	**CABEZO DE LA CRUZ** Alonso N. Cascajos Larrenke N. Riols	Valley bottoms, fluvial terraces, alluvial cones and other flat quaternary forms	No specific	Fast accumulation + slow erosion

covered by sediments of various origins (i.e. Samitiel, Montes et al., 2000). There is little chance of finding them except when cut by watercourses or when they are uncovered by anthropogenic activities (Cabezo de la Cruz, Cascajos). This type had to be the most common; however, it is the one we know the least about.

In summary, the preservation of most of the documented sites has been accidental: accumulations of fallen roof fragments, sedimentary fills or slope slides have protected the archaeological remains. Their current visibility is also hazardous: natural erosion and/or infrastructure projects have unearthed the archaeological sediments. This dependence on visibility leads us to conclude that we only know a small portion of the potential sites that were occupied in the Basin in prehistory.

4.3. *Regional palaeoenvironmental records*

As we have mentioned before, the increased amount of both palynological and sedimentological records coming from the Ebro Basin allow decoding the environmental impact of the climate phases during the Upper Pleistocene and the Holocene time frames (Aranbarri et al., 2014, 2016; González-Sampériz et al., 2008, 2009, 2017). Overall, there is a major spatial cluster in terms of available environmental studies between the Atlantic-influenced regions and those found in the dry, Central Ebro Basin (Fig. 1b and c).

In the Alavese region, there is no master palaeoenvironmental sequence spanning the entire Late Pleistocene/Holocene period, and those available are obtained from caves and rockshelters without high-resolution analyses. In any case, relatively close regional sequences show that the vegetation landscape during the Late glacial (prior to 12900 cal BP) was defined by the progressive substitution of conifers by *Betula*-deciduous *Quercus-Corylus* communities, as recorded in Eurosiberian pollen profiles both from the Pyrenees (Gil-Romera et al., 2014; González-Sampériz et al., 2006) and the Cantabrian sector (Iriarte-Chiapusso et al., 2016; Moreno et al., 2011). The GS-1 represents a clear biostratigraphic marker in this region, shaping a treeless landscape with low lake levels (Moreno et al., 2011) and glacier readvances (García-Ruiz et al., 2016). In contrast, the onset of the Holocene is defined by the maximum spread of the broadleaved woodland regionally (Pérez-Díaz et al., 2016, 2015) in response to the climate/hydrological system adjustment (Moreno et al., 2010).

For the Central Pre-Pyrenees, the Estanya multiproxy sequence (González-Sampériz et al., 2017; Morellón et al., 2009; Vegas-Vilarrúbia et al., 2013) reveals the regional hydrological and vegetation response to millennial-scale climate variability since the Last Glacial Maximum. The GI-1 or Bølling/Allerød interstadial (14500-12900 cal BP) is defined by a conifer landscape with reduced meso-thermophilous flora and thus points to continental climate features in the Mediterranean realm. Hydrological proxies suggest similar arid conditions until approximately 13500 cal BP (Morellón et al., 2009; Pellicer et al., 2016). The vegetation snapshot of the GS-1 or Younger Dryas is not usual because refuge areas show unexpected palynological spectra for this period. During the onset of the Holocene, a parkland landscape dominated by junipers and steppe herbs reflect a resilient environment. Since *ca.* 9500 cal BP, *Corylus*, and after 8000-7000 cal BP, both deciduous and evergreen oaks, spread regionally, highlighting the establishment of a milder climate in the Mediterranean setting.

Regarding the environmental history of the Central Ebro Depression and the surrounding territories, the lack of chronologically well-ascribed records continues defining this region, especially during Pleistocene times. The potential of playa-lakes to draw the environmental history of this land has been widely recognized (Luzón et al., 2007; Valero-Garcés et al., 2004, 2000), although all of

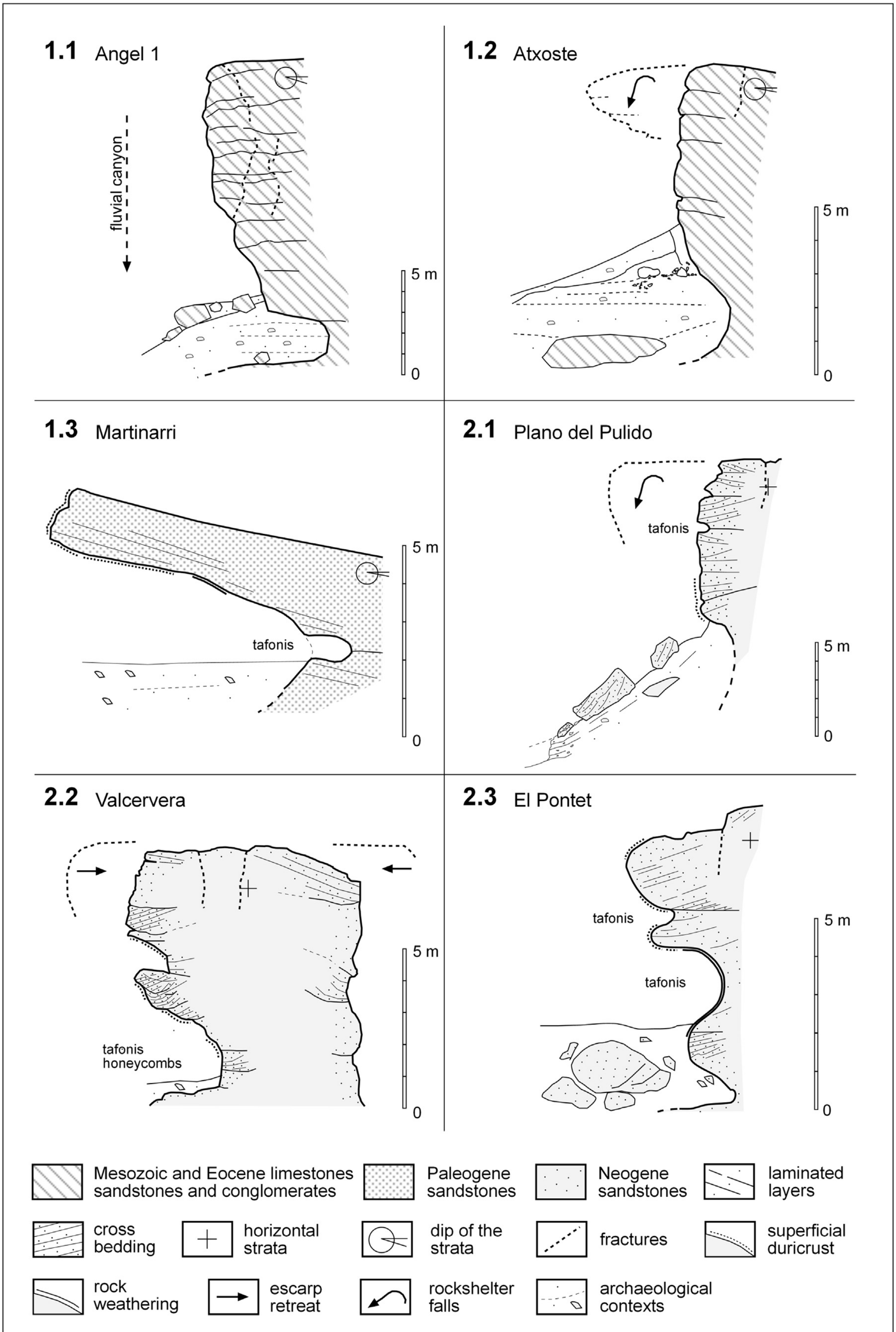

Fig. 6. Archaeological sites types and rockshelter subtypes described in Table 2.

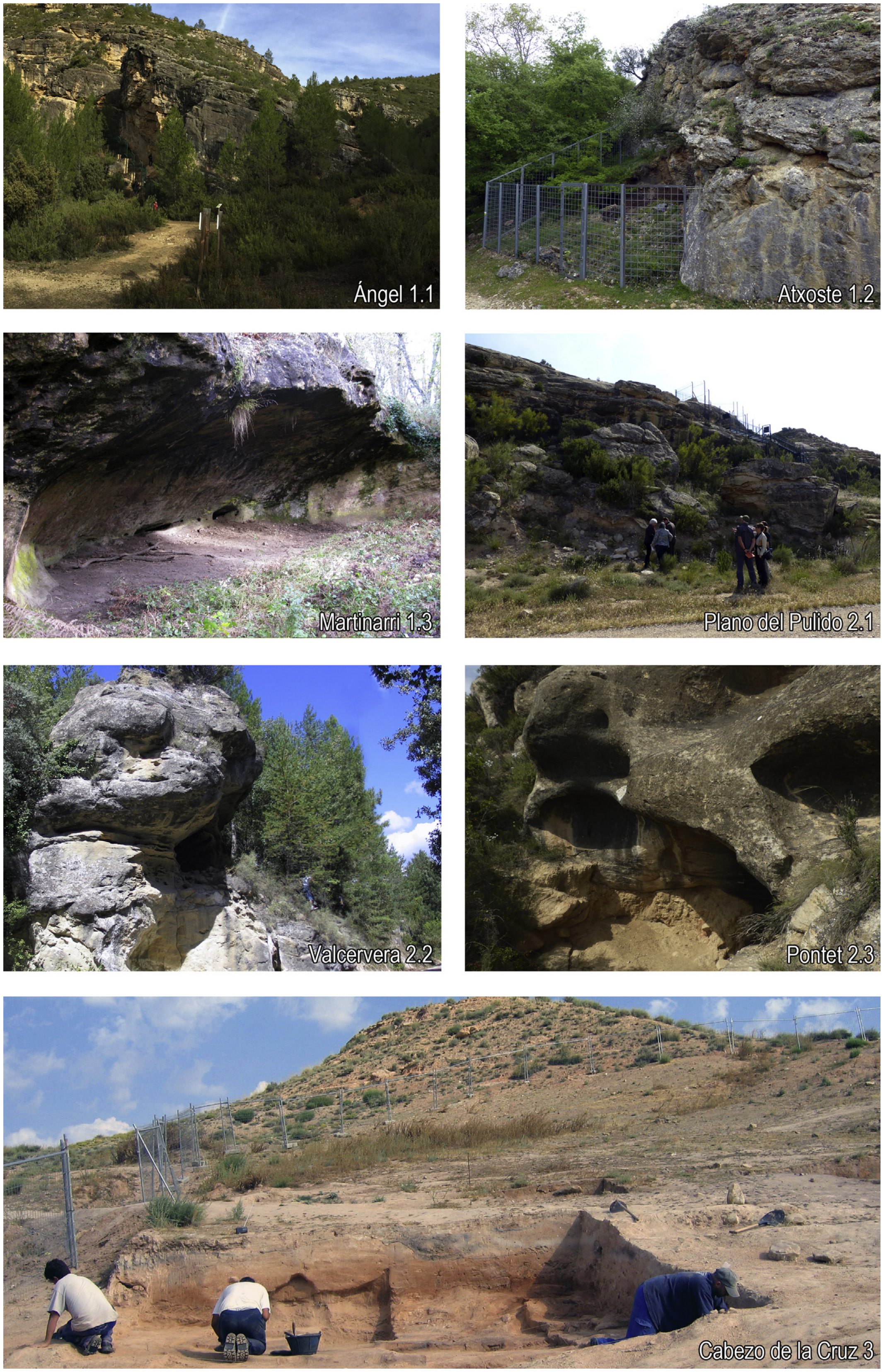

Fig. 7. General views of the archaeological site types schemed in Fig. 6 and detailed in Table 2.

them have difficulty in establishing precise radiocarbon chronologies (González-Sampériz et al., 2008). Some archaeological records have partially reconstructed the vegetation landscape (Alcolea, 2014; González-Sampériz et al., 2004; Iriarte-Chiapusso et al., 2008). However, most of them show uncompleted palaeobotanical information caused by poor preservation related to dry conditions, resulting in the oxidation and mechanical destruction of pollen grains.

With respect to the nearby Bajo Aragón pilot area, the Villarquemado palaeolake sequence (Aranbarri et al., 2014) is the best available record to decode the main phases of climate variability in the region since Late glacial times. Montane pinewoods and junipers are the landscape components during the second half of the GI-1 (13500-12900 cal BP) and the GS-1 or YD, a trend that continues during the onset of the Holocene, with the resilience of conifers against arid and cold climate spells one of the environmental distinctions of the continental Mediterranean ecosystems in the Southern (Aranbarri et al., 2014) and Northern areas of the Ebro Basin (González-Sampériz et al., 2017). The sclerophyllous forest expansion in Inner Iberia occurs once humid and thermal climate conditions takes place *ca.* 9500 cal BP and especially during the Mid Holocene (8200-4200 cal BP), in contrast with the more precocious appearance of mesophytes in Mediterranean contexts such as Estanya.

5. Discussion

After establishing the cultural dynamics and a holistic understanding of every archaeological site and their typological features within the palaeoenvironmental frame, it is possible to understand the site ensemble as an evolving regional network. Contemporary occupations were interdependent and followed integral exploitation strategies. The pilot areas we propose in the present study are good examples of this pattern. Those networks controlled raw lithic materials outcrops, hunting spots or specialised activity areas (butchery, meat or hide smoking). These places were exploited on a long-term basis, mainly as the Neolithic arrived.

This archaeological record shows some particular features: a) the almost complete lack of open-air settlements, the frequent employment of rockshelters and the surprising absence of Mesolithic cave occupations, even if easily available. The enormous cave of Chaves, densely occupied during the Magdalenian and not inhabited again until the Early Neolithic, could be the most noteworthy example; b) the site concentration in some areas and the existence of wide regions with no archaeological sites at all; and c) the contemporary and lineal development of successive cultural units in the whole Basin during the studied time frame, which suggests that the territory largely functioned as a continuum, despite the wrong modern-day image of disarticulated minor regions that is due to a combination of research and taphonomic biases.

Nevertheless, we must be aware that the conserved record is hazardous from the geomorphological point of view and unsystematic if we consider the archaeological research. For example, in the Upper Arba de Biel Basin, fieldwork began in 1999 at Peña-14 and three years later, by 2002, the five currently known archaeological sites had been located (Fig. 1 and Table 1). The presence of archaeologists in the area stimulated local people to find similar rockshelters that could host fertile layers. A similar story can be told for the Atxoste-Kanpanostes ensemble and the neighbouring sites of Mendandia and Martinarri. Moreover, the development of modern archaeological schools in the Ebro Basin can be traced to forty years ago to the activity of I. Barandiarán, who formed present-day research teams at the Universities of Zaragoza and Basque Country. This circumstance has conditioned investigation interests and methods (Alday and Cava, 2008).

5.1. Geological and climate constraints

Considering the pattern of prehistoric site locations, the frequent rockshelter and cave settlements can be related to the abundance of particular lithologies and geological structures conducive to the formation of these features suitable for human occupation in the Ebro Basin. Another factor to be considered is the local climate conditions that can be gained from appropriate orientation at not too high altitude. Obviously, natural resources for subsistence, raw materials, and especially water are required, but they are easily available throughout the Basin. Therefore, there are several essential factors that promote the presence of groups of humans in certain places such as rockshelters and open-air camps, plus mixed occupation sites.

Specifically, some rockshelters are particularly appropriate for recurrent occupation where the presence or absence of humans can be clearly identified. Geological structures associated with cave-rockshelter formation facilitate criteria for searching out and finding these types of favourable environments. Moreover, their geomorphological features and the greater resistance to erosion of their lithology enable records to last longer, so that most of the deposits analysed belong to this type of occupations.

However, we have to bear in mind that most of the Ebro Basin rockshelters would hardly have been big enough to shelter a group of more than 20–30 people. Sandstone palaeochannels, particularly, suffer a continuous geomorphological evolution that prevents large roofed areas. Dwelling solutions like the annexed open-air campsites proposed for Molí del Salt (García-Diez and Vaquero, 2015) or Atxoste (Perales et al., 2016) should have been common, although their archaeological imprint is very difficult to find. Many of the rockshelter sites have been exposed and found after being cut away by roads or gravel quarries that have destroyed the outer sedimentary zones. In the early Holocene occupation of Martinarri, up to three carefully arranged functional areas have been located, one of them under the roof and the other two outside it.

Moreover, open-air campsites would rarely be reoccupied (Cabezo de la Cruz), leaving a weaker archaeological imprint, so their records are not equally useful for analysing long stratigraphic sequences. On the other hand, well-established villages dating from the Neolithic offer recurrent occupational phases that last for some centuries (Cascajos, La Lámpara). Compared to rockshelters, it is usually more difficult to predict where campsites and villages lie. Frequently they are mere hut floors, postholes and negative pits (that may reflect a long lifespan through their use as garbage dumps), so they are more exposed to erosion or sediment covering, and their record visibility is much less. Therefore, this study contains very few examples of these sites.

The characteristics of the various types of rockshelter determine their state of preservation and ease of discovery. Type 1.1, 1.2 and 1.3 shelters (Ángel 1, Atxoste and Martinarri, respectively: Table 2, Figs. 6 and 7), composed of limestone, sandstone or conglomerates, are more able to withstand changes in the rock and retain their original form better. The most important evolutionary process is rock-falls, which may seal the surface and protect the underlying archaeological record. In the case of shelters inside river canyons, records can be protected by flooding that covers the cavity (Ángel 1: type 1.1 in Table 2, Figs. 6 and 7). Therefore, well-preserved archaeological records are more likely to be found at these shelters.

Types 2.1 (Plano del Pulido) and 2.2 (Valcervera), shown in Table 2 and Figs. 6 and 7, evolve the most rapidly, since they consist of sandstone outcrops more susceptible to weathering, worsened by the S/SE orientation of the rock cliffs containing the shelters. This sandstone was formed by palaeochannels in several planes of

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stratification that led to water penetration, wet-dry sequences, and haloclastic processes giving rise to microform alterations, such as tafoni and honeycombs in the rock wall. In addition, there are fractures from decompressed rock causing the rock-falls that protect the archaeological record. Type 2.2 (Valcervera type), with a narrow palaeochannel morphology, evolved even faster, since it has two erosion faces that could cause the whole palaeochannel to disappear, hiding the original location of the settlement (Fig. 7).

Sandstone shelters types 1.3 and 2.3 (Martinarri and El Pontet, respectively) evolve more slowly than the others, although their composition, structure, and age are very similar. In these cases, large tafoni were developed and covered by a duricrust, a legacy of warmer and moister climates than today. To a large extent, such hardening prevented changes (flaking, spalling) in the rock surface. Nevertheless, rock-falls are the most active process.

Finally, open-air settlements (type 3, Cabezo de la Cruz: Table 2, Fig. 7) are subject to many different geomorphological processes that could lead to either partial or total erosion, or to perfect preservation under accumulations from several origins (fluvial, slopes, etc.). Likely, those processes have buried the campsites that undoubtedly should have been the basis of the human occupation system in the floodplains of the central Ebro Basin. Their current visibility depends on natural incisions or human interventions that bring them to the surface.

5.2. Site concentrations versus gaps

All across the Ebro Basin the prehistoric cultural patterns were very similar, which means that the human groups that lived there were well connected. Demographic and social needs encouraged the relationships. However, the population cartography reveals wide documental gaps, which interferes with the previous assumption. The difficulty in concretizing the existence of those interregional links confirms the current insufficiency of archaeological records and the need for further surveying programs.

With this in mind, the study of the BP ^{14}C frequency curves offers nuanced and partial readings concerning human populations for every pilot area and for the whole Basin compared to the Iberian Peninsula, with a total of 1327 dates (Figs. 3 and 4). For example, in the Alavese area, the frequency peak at approximately 9500 cal BP converges with the end of the Microlaminar episode at some sites (i.e., Atxoste, Martinarri and Mendandia: Table 1) and the early Denticulate Mesolithic (i.e., Kanpanoste: Table 1). In the same period, the curve is more stable in the Pre-Pyrenees, while in the Bajo Aragón the first human occupations appear later, near 9000 cal BP, with the poor Denticulate Mesolithic layers at Los Baños and Pontet (Table 1). A probably contemporary (but yet undated) occupation at Costalena (Fig. 1) exists in the same pilot area; however, it does not contribute to the curve, as no dates are available. In the Bajo Aragón area, the almost complete lack of settlements previous to the Geometric phase (8700-7500 cal BP) should be highlighted: is this a consequence of the ancient erosive dismantlement of sandstone palaeochannels? Or was the extreme continentality the main driver hampering the existence of suitable habitats for hunter-gatherer groups at the beginning of the Holocene (Fig. 8)?

If we consider the erosive processes as a hypothesis, and taking into account the current situation of most of the known rockshelter prehistoric sites, we can imagine that early Holocene (and perhaps Late Pleistocene) sites could have passed unnoticed due to the total disappearance of the palaeochannels that protected (and landmarked) the archaeological sites.

Concerning the second hypothesis, lacustrine sequences from inner Mediterranean continental environments such as the nearby Bajo Aragón areas and the sunny slopes of the Pre-Pyrenean lowlands (Fig. 8) show an intense climatic seasonality and the persistence of arid features until at least 9500 cal BP, when more humid conditions expand in the whole Mediterranean region (Aranbarri et al., 2014; González-Sampériz et al., 2017). Consequently, it is suggestive to relate the onset of moister conditions recorded since *ca.* 9500 cal BP with the first remarkable Holocene peak of the Ebro Basin SCDPD curve (Fig. 3). However, this peak it is not synchronous in the three pilot areas: while it is clearly observed in the Alavese one, it is less evident in the Pre-Pyrenees and does not apply to the Bajo Aragón since human occupation begins later. Similarly, it would be very suggestive to relate the decrease of the SCDPD curve from the Pre-Pyrenees with the coetaneous increase in the xerophyte component of the Estanya sequence between *ca.* 12500 and 10500. This trend of the palaeoenvironmental proxy is interpreted as increasing arid and probably cold-cool conditions during the GS-1 and the beginning of the Holocene and, perhaps, less suitable habitats for human communities. Again, we cannot observe the same trend in the other two pilot areas because available data are incomplete. Likely, only a combination of the two hypotheses may explain the archaeological record of this pilot area.

Therefore, there are no certainties concerning whether the climate variability affected the prehistoric populations, as the palaeoenvironmental and archaeological records are partial, and opposite trends have been recorded in the region with respect to the potential impact of, for example, the well-known 8.2 event (González-Sampériz et al., 2009; García-Martínez de Lagrán et al., 2016; Montes et al., 2016). Similarly, we do not know how climatic features have an essential role concerning the conservation of the archaeological sites. We only know some of them. Thus, the ^{14}C frequency variability of the Ebro Basin and, probably, most of the SCDPD curves, can be related to different potential circumstances.

In the Pre-Pyrenees, there seems to be a direct relationship between the ^{14}C dates growth and the development of the second episode of the Geometric Mesolithic (8000-7500 cal BP). The rising SCDPD curve (Fig. 4B) could lead us to think of population growth. But the explanation lies in the behaviour of the archaeologists. That is, following an understandable desire to refine knowledge of the Mesolithic-Neolithic transition, intensification of research has implied an increase in dating key human occupations (such as Forcas-II or Rambla levels for the Late Mesolithic and the Ancient Neolithic). This abundance of sites and radiocarbon dates for such a short period of time may offer the false image of population growth, at least in sites like the ones cited above, where the economy did not change at all from Mesolithic to Neolithic times, despite the incorporation of sparse material novelties (double-bevelled retouched microliths, pottery). From *ca.* 7500 onwards, the radiocarbon dates from the cave of Chaves Ancient Neolithic (Baldellou, 2011) nourish the Pre-Pyrenean curve for more than 500 years. In this case archaeology, not the dates, tells us that a large human group intensely occupied the huge cavity throughout that time.

From 7000 cal BP, a loss of information —both radiocarbon chronologies and sites-occurs in the Ebro Basin and the entire Iberian Peninsula (Fig. 3). The coincidence with the consolidation of the Neolithic economic patterns is evident. Should we think of a population decrease linked to causes such as diseases or bad crops that are invisible to the archaeology? A partial answer can be obtained from the analysis of the three pilot areas. A new occupation system based on stable villages near the farmlands -whose archaeological imprint is weak, as previously said-is reflected in the Alavese area, mainly by the occupation persistence of Cascajos and irregularly in the Bajo Aragón, where the curves are partially sustained by only two dates from the open-air sites of Alonso Norte and Riols. On the contrary, in the mountainous Pre-Pyrenees, the

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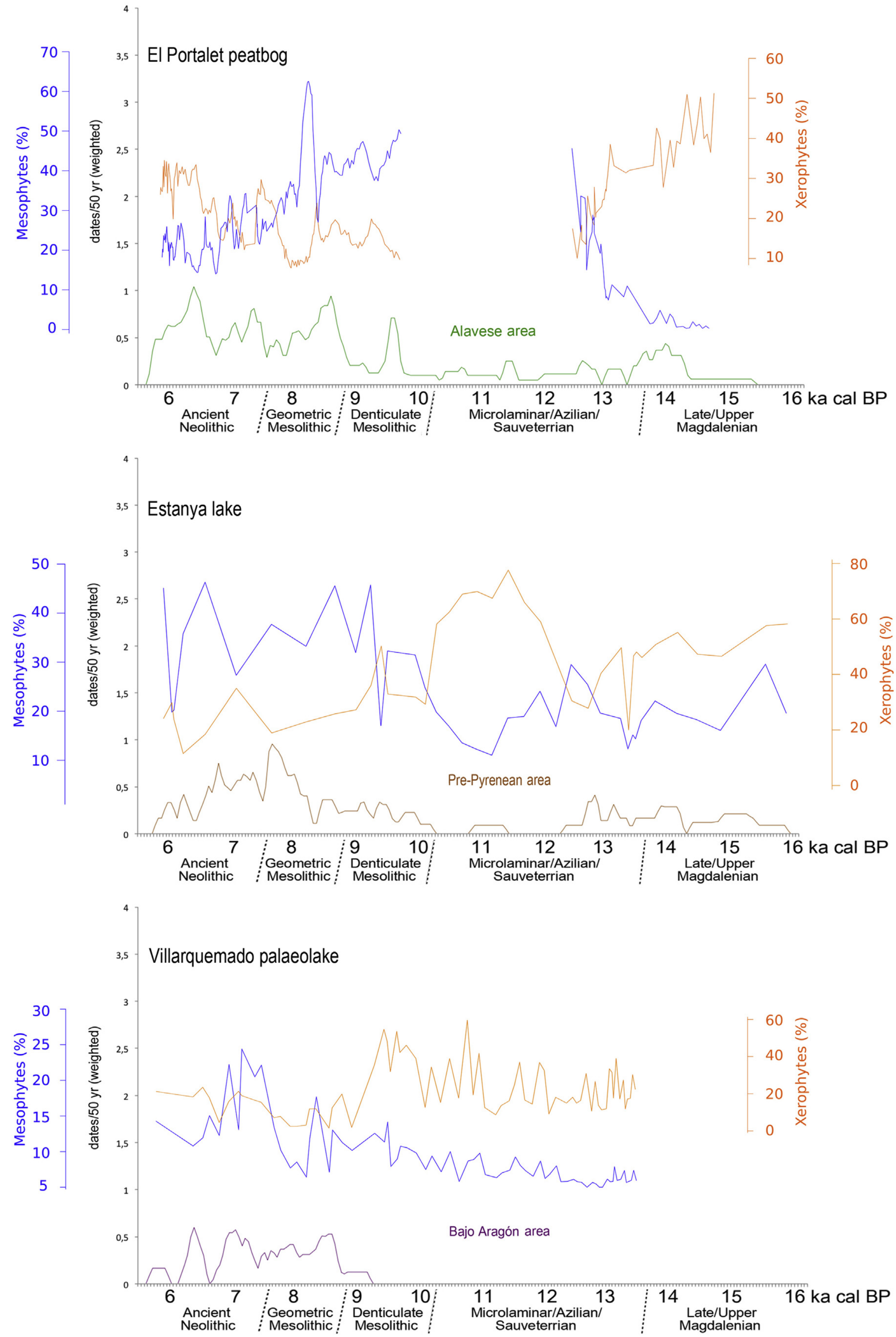
El Portalet peatbog
Mesophytes (%)
dates/50 yr (weighted)
Xerophytes (%)
Alavese area
Estanya lake
Pre-Pyrenean area
Villarquemado palaeolake
Bajo Aragón area
6 7 8 9 10 11 12 13 14 15 16 ka cal BP
Ancient Neolithic
Geometric Mesolithic
Denticulate Mesolithic
Microlaminar/Azilian/ Sauveterrian
Late/Upper Magdalenian

current lack of those villages replicates the whole declining profile of the Ebro Basin (Table 2, Fig. 4). Obviously, there should have existed many more dwelling places across the Basin in Neolithic times: such an empty panorama is economically and socially untenable. Actually, this situation continues for several millennia: there is a striking lack of human settlement during the rest of the Neolithic and Chalcolithic, even in areas where their funerary megalithic constructions are common. Again, open-air villages are almost invisible to archaeologists. Therefore, local divergences point to difficult climate-SCDPD curves relationships. We have to bear in mind the provisional character of those SCDPD curves when reading them. For example, in 2009, available radiocarbon dates suggested a lack of population in the same area of the Bajo Aragón related to the 8.2 event (González-Sampériz et al., 2009). Barely eight years later, new dates obtained from the sites of Costalena and Pontet have drawn a new curve (Fig. 4C) that apparently removes that supposed gap.

Another deficit of the SCDPD curves as a direct population reflection is the absence in them of sterile layers sandwiched between archaeological levels. These layers offer us valuable information concerning the rhythms of occupation/abandon of a site. Those human presences/absences may be related to cultural decisions (the hinterland occupation system) as well as to geomorphological and climate events (collapses, floods, erosion).

In the Ebro Basin, there are territories with many known prehistoric sites, non-excavated and therefore undated, that stay mute in reviews such as this. Fig. 9 shows a non-exhaustive display of undated or inaccurately dated sites from the studied periods in the Ebro Basin, coupled with some representative materials that allow us to place them in a restricted time window. If we focus the research excessively to accurately radiocarbon dated sites or levels, an enormous fraction of the available evidence is silenced; for example, some of the gaps detected in Fig. 1. Also, Fig. 9 reinforces the vision of the prehistoric investigation as an addition of unsystematic efforts that tend to focus in some regions for a series of reasons that go from being the homeland of the researcher to public works research projects. Although some of the empty territories in Fig. 1 are not such in Fig. 9, wide areas remain completely unknown.

The most extreme example of underrepresented territories can be found next to the well-known Arba de Biel area, in the neighbouring Arba de Luesia, Onsella and other small river basins (Fig. 9), where the archaeological surveys described in the Ph.D. thesis of J. Cabello (2005) have documented at least 12 sites of Mesolithic-Neolithic chronology based on lithic and ceramic remains. The same is true for the Urbasa Range, where archaeological surveys detected more than twenty undated sites that fit industrially to the analysed period (Barandiarán and Vegas, 1990). A similar situation is the “archaeological silence” of undated or inaccurately dated levels or sites (often because they were excavated a long time ago). When rejected by our frequency curves, they completely disappear if we restrict our research strategy to the radiocarbon data. There are well-known sites that we cannot include in well-documented areas: Fuente Hoz, Peña del Castillo, Bardallo and Montico de Charratu in the Alavese area (Baldeón et al., 1983), and several sites in the Bajo Aragón. Here, in the Matarraña-Algás basin alone we can list up to thirteen Mesolithic and/or Neolithic sites (Mazo et al., 1987), but only three (Costalena, Pontet and Botiquería) fit in this work. The reason for this “no consideration” is related to methodological features: i.e., deposits excavated in the fifties such as Serdá and Sol de la Piñera; sites with no datable remains such as Secans or Cova del Llop; or unexcavated sites such as Cueva Ahumada or Era de Rayos. Thus, the Denticulate Mesolithic presence at the Bajo Aragón -archaeologically documented in Pontet, Los Baños, Plano del Pulido and Costalena but only dated in Pontet and Los Baños- almost disappears in a radiocarbon-restricted discussion.

The previous sites are examples of prehistoric sites or layers excluded from the research discourse because they lack ^{14}C dates, although their archaeological materials undoubtedly fit them in the respective contexts. In this way, archaeologists mute sites, levels and materials. Despite this, it is frequent to use the radiocarbon graphics to shape an accurate image of the population evolution.

Therefore, we think that perhaps the study of the increase in sites or activities therein (not only of dates) could reflect a minimum population growth in the hunter-gatherer groups or in the pioneer farmers (Table 1). This image is the same no matter if the focus is centred in each of the pilot areas or in the whole Ebro Basin: the number of sites shows a slow and progressive yet irregular increase from the Late Magdalenian onwards, which accelerates intensely in Late Mesolithic and Early Neolithic times. Thus, it seems that the site typology and visibility matter. The only exception to this image is the Azilian/Sauveterrian/Microlaminar period, when the index of sites every 100 years (Table 1) is by far the lowest of the whole series. Some possible explanations arise: apart from being the longest period that coincides with a notable paucity of known sites, it might mark the onset of a new occupational system, mostly based on open-air settlements. The new climate conditions allowed human groups to abandon the caves, lessening their archaeological imprint.

If only the number of dates and dated levels for each cultural period were considered and treated as a mere demographic reflection without any archaeological criticism at all, it could be concluded that Neolithic innovations were brought by an important human contingent: from 8000 cal BP to 7000 cal BP the number of dates almost triples (Fig. 3). If the *dates* = *population* equation were correct, this supposed demographic growth could not be explained only in internal terms (Bocquet-Appel et al., 2012). But if other significant data are analysed, such as the type of site and its visibility, the reading is different. In Neolithic times, large cavities unoccupied until then (or only inhabited during Palaeolithic times) are used to shelter people and livestock. This is the case of Los Husos I-II, Peña Larga, Cueva Lóbrega, Chaves, Olvena, Coro Trasito, Puyascada, Colomera and Cova Gran (Fig. 1). As we have discussed before, caves and large rockshelters are very easy to find. Besides, dates from open-air sites are common for another reason. On the one hand, the number of sites is far greater now than in previous periods (Table 1). On the other hand, their features (no clear levels and negative structures like hearths and grain pits) oblige us to obtain copious dates that show prolonged occupations along several centuries. Significantly, the average quantity of dates by site remains stable until Neolithic times, when it doubles.

In this sense, we could consider that only agricultural practices demand villages to be built. But we should also consider that pottery fragments are much easier to find in archaeological surveys -highlighting the existence of a possible village-than the small lithic armatures characteristic of previous stages. Perhaps this greater visibility of the material remains can explain the location of Neolithic −but not previous-villages. Some of these villages may have started as smaller dwelling places in Mesolithic times, but if

Fig. 8. Selected paleoenvironmental sequences compared to SCDPD curves to illustrate main trends and particularities of each pilot area considered in this work. From top to bottom: a) Mesophtyte (in blue) and Xerophyte component (in orange) of El Portalet record (González-Sampériz et al., 2006; Gil-Romera et al., 2014) compared to the SCDPD from the Alavese pilot area (in green); b) Mesophtyte (in blue) and Xerophyte component (in orange) of Estanya Lake (González-Sampériz et al., 2017) compared to SCDPD from the Pre-Pyrenean pilot area (in brown); c) Mesophtyte (in blue) and Xerophyte component (in orange) of Villarquemado palaeolake (Aranbarri et al., 2014) compared to SCDPD from the Bajo Aragón pilot area (in purple). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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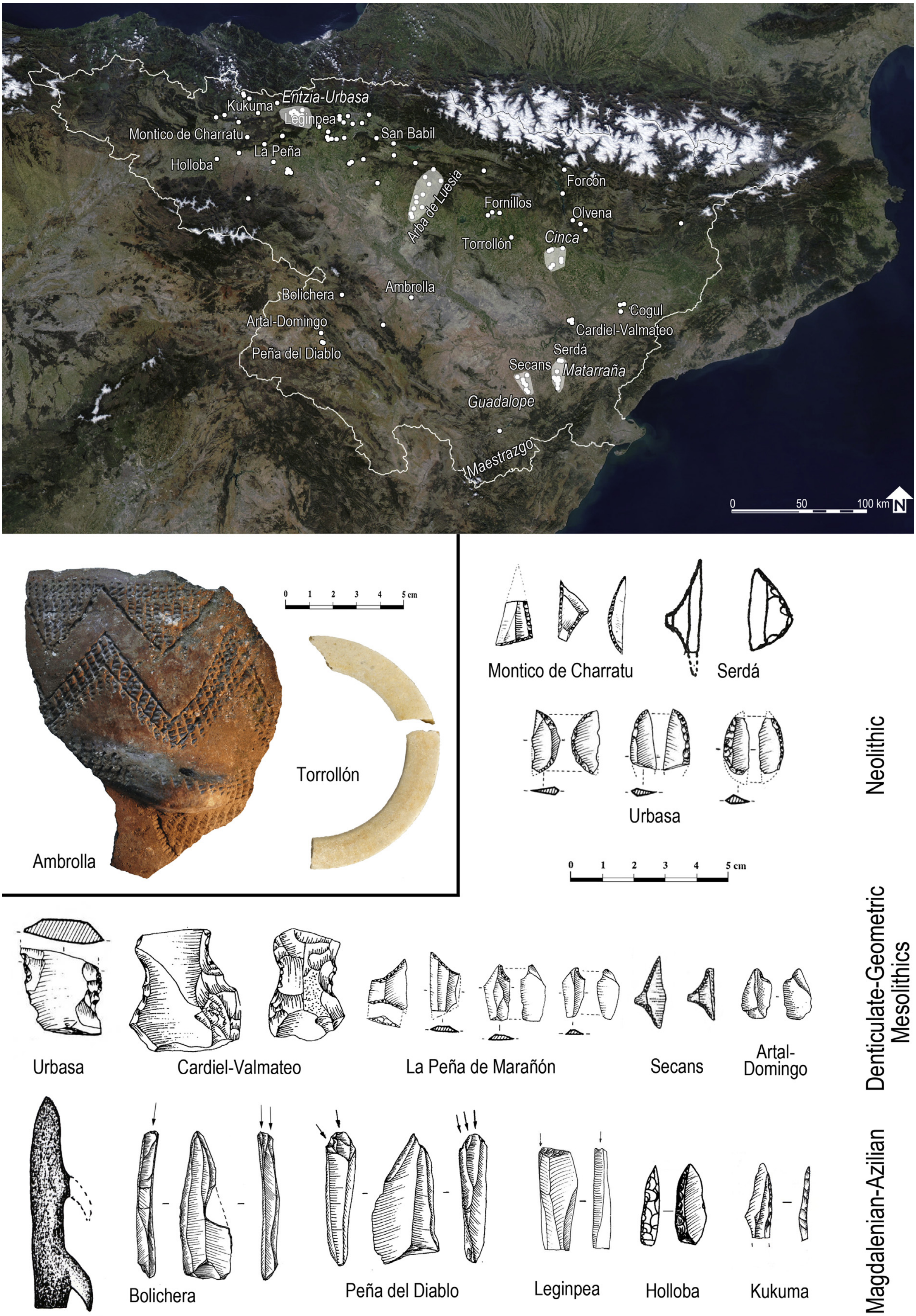

Fig. 9. Representative archaeological materials from undated or inaccurately dated sites within the Ebro Basin. Magdalenian/Azilian: Bolichera (Utrilla et al., 2012); Peña del Diablo (Utrilla and Domingo, 2003); Leginpea (Nuin, 1988); Holloba (Barrios and Porres, 2006); Kukuma (Baldeón and Berganza, 1996). Denticulate & Geometric Mesolithic: Urbasa 11 (Cava, 1986); Cardiel-Valmateo (Tilo, 1991); La Peña de Marañón (Cava and Beguiristáin, 1992); Secans (Rodanés et al., 1996); Artal-Domingo (Utrilla and Domingo, 2003). Neolithic: Ambrolla (Bea et al., 2011); Torrollón (photo: Museo de Huesca); Montico de Charratu (Baldeón et al., 1983); Serdá (Vallespí, 1960); Urbasa 11 (Cava, 1986).

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we only date short-life elements undoubtedly linked to the agricultural economy (cereal seeds, domestic fauna) we will never know if their occupation started earlier. The "old wood" effect, proposed to explain some ancient charcoal dates from the Ambrona Valley sites (Rojo et al., 2008), is questioned by several authors (Barceló, 2008; Williams, 2012; Drake et al., 2016) and can be partially denied by dendrochronological studies from La Draga (Tarrus, 2008), where most of the oak trunks that served as posts were obtained from young trees less than 35 years old. It is also hard to think that prehistoric people used on a common basis very aged fallen trunks for their fires. As a matter of fact, ethnographic evidence points to a universal preference for small branches as fuel.

Could these ancient dates, almost always obtained from the bottom of the structures and some of the associated non-significant remains belong to a previous Mesolithic occupation? Again, the archaeologists mute archaeological documents after the inaccurate premise that all open-air villages were of Neolithic foundation. If we only date the undoubtedly Neolithic materials (domestic fauna, seeds) we will only obtain Neolithic dates. It seems a tautology, but it is not.

6. Final remarks

The ideas discussed here concerning the limits of radiocarbon dates as a reflection of prehistoric populations may seem discouraging for our discipline. But on the contrary, the construction of radiochronological big data is forcing us to better understanding the significance of archaeological contexts, instead of just accepting mechanistic explanations. More than forty years of fieldwork experience at the Ebro Basin have taught us that SCDPD on its own cannot be taken as a direct reflection of the population evolution, but only as an indication of human presence in the territory. Thus, the gaps in the SCDPD curves do not imply an absence of people, but only a lack of one type of archaeological information: radiocarbon dating. If, as we have seen, we have other prehistoric information sources (scattered lithic remains, undated stratified sites), we must use them in our historic explanation as a very valuable resource. Therefore, we are obliged to think about the methods and objectives of our discipline. We must be aware that our concern as prehistorians is the understanding of a very remote human ecumene and we must accept that this comprehension cannot be restricted to a mere quantification of ciphers (whether obtained from the tool assemblage or from radiochronological statistics). Our methods imply a continuous exchange of data between all the information sources. Radiochronology is only one of them (a very important one, indeed), but its capacities are very limited if we isolate the samples from their contexts and if our thought is limited to the dated archaeological record. The understanding of archaeological gaps and fills can be envisaged only by means of interdisciplinary research.

The typology of the sites that make up the database, their geologic structures, and geomorphologic evolution since the Late Pleistocene and along the Holocene reinforces our arguments on the severe loss of archaeological information. This degradation effect can be extended to similar environments in terms of its geomorphological characteristics and Holocene environmental evolution, as for example the Eastern and central part of the Iberian Peninsula and other Mediterranean areas.

Authorship contributions

Archaeological data: A. Alday, R. Domingo, L. Montes, A. Soto and P. Utrilla.

Geological and geomorphological data: J. L. Peña-Monné, M. M. Sampietro-Vattuone and M. Sebastián.

Paleoenvironmental data: J. Aranbarri and P. González-Sampériz.

Discussion and final remarks have been agreed by all authors.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.quascirev.2017.11.006.

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