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## We will be known by the tracks we leave behind: Exotic lithic raw materials, mobility and social networking among the Côa Valley foragers (Portugal)

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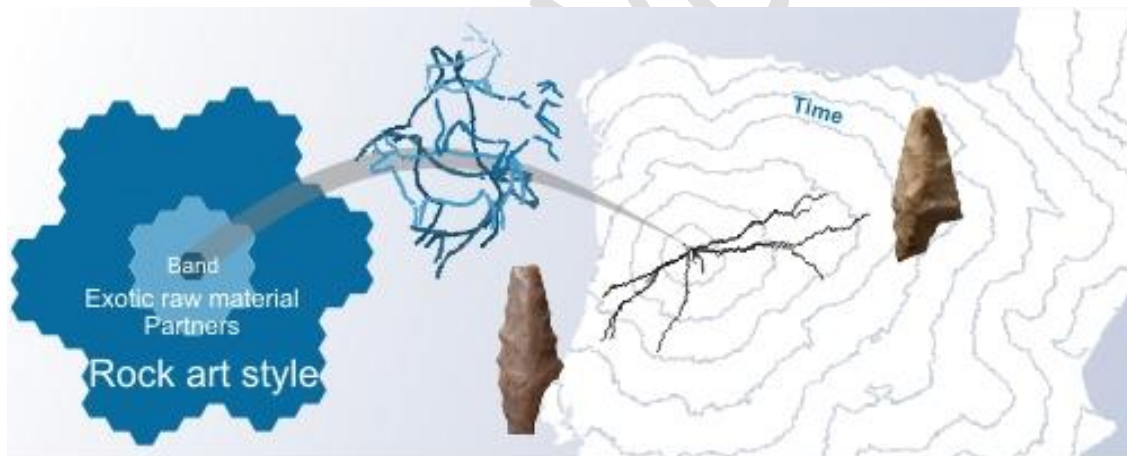
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### Graphical abstract



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## Highlights

- ▶ Toolstone sourcing indicates systematic long-distance transport of flint.
- ▶ GIS analysis provides a measure of range mobility and least-cost paths over time.
- ▶ Raw material is used to assess hunter–gatherers’ mobility and social network.
- ▶ Côa Valley Palaeolithic rock art is interpreted as defining a cultural boundary.

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## Abstract

The aim of this study is to establish different socio-cultural models based on lithic raw material sourcing integrated with regional rock art distributions to infer social behaviours within the context of central Iberian Upper Palaeolithic societies. Specifically, we focus on Upper Palaeolithic hunter-gatherer mobility and social interaction in the Côa Valley. This study relies on a knowledge of regional geology and field work to identify the sources of the lithic raw material found at Côa Valley Upper Palaeolithic sites. We expose the context of use and discard of exotic flint, which is naturally absent from the region, and other local materials. From this, we present a GIS based analysis concerning space, time and least-cost paths travelled. This analysis, along with the environmental data available, forms a baseline to evaluate different anthropological models on hunter-gatherer lithic use, mobility, and social networks. We conclude with a three-level model for social interaction, in the context of aggregation activities between different social meta-groups, which involves embedded procurement, long-distance raw material exchange, and symbolic community, reflected in the largest known open-air Upper Palaeolithic rock art concentration.

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## Keywords

Toolstone sources; Upper Palaeolithic; Iberia; Land-use; Mobility; Open-air Rock Art.

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## **1. Introduction**

The interpretation of the spatial of lithic raw material sources used to reconstruct hunter-gatherer landscapes is still a matter of debate among many researchers and multiple interpretations of the same data are often advanced. Moreover, when stressing the importance of raw materials, one should never forget that they reflect a small, even if well preserved, part of the foraging activities of past hunter-gatherer groups. Other resources, namely biotic, that may have played an even bigger role than lithic raw materials, have since been subjected to taphonomic filters, and are inaccessible in our analysis.

In an ecological perspective, lithic raw material sourcing can be used to determine past demography, since, the exploited space should reflect environmental resource supply and forager needs (Winterhalder, 2001; Hamilton et al., 2007). Besides being informative of prehistoric population size and territories, raw material studies can also inform us of changes in pattern of resource exploitation through time - a reflection of forager economic and seasonal variability (Demars, 1982; Féblot-Augustins, 1997). With this approach the distances of displacement, raw material quality and quantities present at a site, and the documentation of different lithic reduction phases leading to artefact abandonment (Geneste, 1985) are of the essence to reconstruct forager's mobility. This approach has not only been applied to Anatomically Modern Humans but also to Neanderthal populations (Féblot-Augustins, 1999; Fernandes et al., 2008).

However, when dealing with an eminently social species, territory use, notably reflected in long-distance lithic raw material sources may express non-utilitarian purposes. The raw materials in an archaeological assemblage can therefore be the result, not only of

direct procurement (Binford, 1980), but also exchange (Gamble, 1999). This is the case of long-distance raw materials, which have been used to define social networks fundamental for human survival (Whallon, 2006). In this case, lithic raw material could be the expression of immaterial behaviours, such as information exchange.

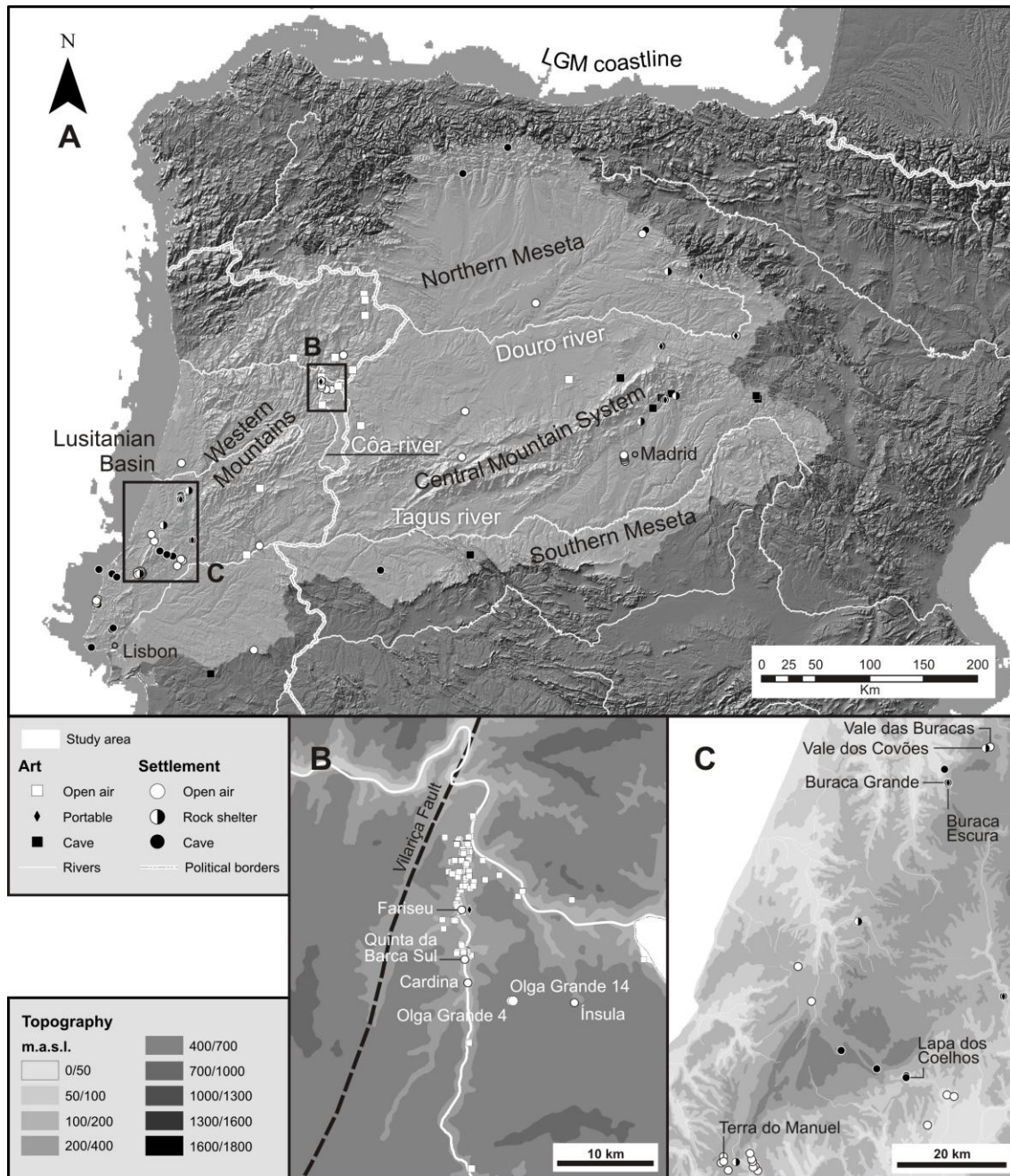
The aim of this study is to establish different sociocultural models from lithic raw material sourcing and to infer social behaviours within the context of central Iberian Upper Palaeolithic societies, integrating it with rock art distribution. We analyse the role of cultural vs. lithic resource constraints in the choice of reduction sequences, the mobility patterns of these peoples and their cultural geography. For this purpose we have conducted field surveys to define a raw material data set, macroscopic and microscopic observations were performed to better characterise the geological sources, and a Geographic Information Systems (GIS) approach was used to analyse distances and paths to the lithic sources used. Finally, we compared the Côa Valley toolstone supply with settlement data from sedimentary areas where flint is naturally present, some of which also are used in the Côa Valley, and interpreted the observed archaeological reality in the light of ethnographic data.

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## **2. Material and methods**

### **2.1 Côa Valley Upper Palaeolithic setting and occupation sequence**

Geomorphologically the core of the Iberian Peninsula corresponds to a large plateau, the Meseta, a Cenozoic peneplanation structural surface (Ferreira, 1978), which is divided in two by the Central Mountain System (**Fig. 1a**). To the west, the Northern plateau is limited by the SSW/NNE Manteigas-Vilarica-Bragança fault system, separating it from the Portuguese Western Mountains (Ferreira, 1978). Conditioned by this tectonic



**Fig. 1.** Upper Palaeolithic settlement, rock art and mobile art sites in the study area (a) with detailed vision for the Cõa Valley (b) and Portuguese Estremadura (c).

structure (Aubry et al., 2012), the Cõa river runs deeply gorged a few km east of this limit (**Fig. 1b**).

It was in this area, notably in the last 17 kilometres of the Cõa Valley, that, during the 1990s, stylistically Upper Palaeolithic open-air rock art was discovered (**Fig. 1b**), in a region where no evidence of Upper Palaeolithic human occupation had ever been reported before (Zilhão et al., 1995). Subsequently, the discovery and study of an

archaeological context for the rock art has enabled us to establish a significant occupation in this region of Iberia, during several periods of the Upper Palaeolithic (Zilhão, 1997; Aubry, 2001; 2002, 2009), partially contradicting the accepted logistic hunting sites model for the Iberian hinterland's scarce occurrences (Davidson, 1986). More than 15 archaeological sites have since been identified in the Côa Valley (10 of which were tested or excavated) for these periods over less than 400 km<sup>2</sup> along the river's nine last kilometres on both margins of the valley bottom, and on the granitic bedrock of the surrounding plateau (Aubry et al., 2002; Aubry and Sampaio, 2008a; Aubry et al., 2010).

In Portugal, Upper Palaeolithic remains present some peculiarities when compared to central and northern European contexts, in terms of animal species exploited, bone and lithic tool categories, as well as operative schemes (Zilhão, 1997; Bicho, 2000; Almeida, 2000; Aubry, 2009). Contrarily to most of European Upper Palaeolithic lithic stone-tool assemblages all the Portuguese series show systematic and profuse use of quartzite (Pereira, 2010) and quartz. Nevertheless, the typology of diagnostically Solutrean lithic points and of the retouched bladelets recovered on the Côa Valley sites has permitted, by comparison with other dated Portuguese lithic series, the establishment of a chronostratigraphic framework of the Upper Palaeolithic sequence of occupation, confirmed by radiometric ages obtained at four sites, by luminescence on burnt quartz and quartzite pebbles and sediments (Valladas et al., 2001; Mercier et al., 2001, 2006) and by <sup>14</sup>C (Aubry, 2009) (**Table 1**).

These sites reveal the discard of small quantities of raw materials formed in a sedimentary environment absent from the regional geological context (Mangado Llach, 2002, 2004; Aubry and Mangado Llach, 2003a, 2003b, 2006; Aubry et al., 2002, 2003, 2004). This environmental constraint to the Upper Palaeolithic settlement in the area

provides us an unique opportunity to study the origin and displacement of these materials, which attest long-distance connections with other areas of the Iberian Peninsula, namely Central Spain and Central Portugal, that hint at mobility patterns and long-distance social relations.

A relative chronology of the different phases of the Côa Valley Upper Palaeolithic occupation sequence was established from stratigraphic sequences identified at 5 sites, where a geoarchaeological approach was applied (Aubry et al., 2010). Radiometric ages were obtained at four Côa Valley sites, by luminescence applied on burnt quartz and quartzite pebbles and by Optically Stimulated Luminescence on sediments, at Cardina 1, Olga Grande 4, Quinta da Barca Sul and Fariseu (Valladas et al., 2001; Mercier et al., 2001, 2006) (**Table 1**). The acid soils developed on schist and granite bedrock of the region do not favour the preservation of macro organic remains. However, Upper Palaeolithic radiocarbon ages were obtained on bones and teeth recovered in stratigraphic level 4 of Fariseu (Aubry et al., 2007; Aubry and Sampaio, 2008b, Aubry, 2009), where faunal remains are unusually preserved (Gabriel and Béarez, 2009). Stratigraphic level 9 of this site, bearing a charcoal fragment dated to  $19,020 \pm 80$  <sup>14</sup>C years BP (GrA-40167; 22,581-23,174 cal years BP) by AMS demonstrates the potential conservation of Last Glacial Maximum (LGM) macro organic materials preserved in alluvial deposits. The ages obtained at the 4 sites have confirmed the typological attribution of the stone tool assemblages found therein and indicate human presence during several phases in the 31,000-12,000 BP interval (**Table 1**).

**Table 1.** Upper Palaeolithic archaeological lithic series of the Côa Valley and Portuguese Estremadura considered in this study.

Site	Environment	Latitude (N)	Longitude (W)	m.a.s.l.	Layer	Age (yrs BP)	<sup>14</sup> C Calibrated Age (cal yr BP) <sup>a</sup>	Lab code	Dating method	Cultural attribution	Reference
Olga Grande 4	Open air	40°58'10.44"	7°03'23.43"	510	3	26,800 ± 2300	-	GYF-OG4 no.4	TL	Gravettian	Valladas et al., 2001
					3	27,200 ± 2300	-	GYF-OG4 no.1	TL	Gravettian	Valladas et al., 2001
					3	28,500 ± 2300	-	GYF-OG4 no.3	TL	Gravettian	Valladas et al., 2001
					3	30,000 ± 2400	-	GYF-OG4 no.2	TL	Gravettian	Valladas et al., 2001
					3	31,000 ± 2500	-	GYF-OG4 no.5	TL	Gravettian	Valladas et al., 2001
Olga Grande 14	Open air	40°58'10.19"	7°03'17.99"	510	2c	-	-	-	Typology	Proto-Solutrean	Aubry, 2009
					3	-	-	-	-	Typology	Gravettian
Cardina 1	Open air	40°58'46.11"	7°03'23.43"	165	4,6	-	-	-	Typology	Upper Magdalenian	Aubry, 2009
					4,7	-	-	-	Typology	Upper Magdalenian	Aubry, 2009
					4,8	-	-	-	Typology	Magdalenian/Solutrean	Aubry, 2009
					4,9	-	-	-	Typology	Magdalenian/Solutrean	Aubry, 2009
					4,10	20,700 ± 1300	-	GYF-Card no.5	TL	Solutrean	Valladas et al., 2001
					4,10	23,400 ± 1500	-	GYF-Card no.8	TL	Proto-Solutrean	Valladas et al., 2001
					4,10	26,500 ± 1800	-	GYF-Card no.10	TL	Recent Gravettian	Valladas et al., 2001
					4,10	27,000 ± 1800	-	GYF-Card no.9	TL	Recent Gravettian	Valladas et al., 2001
					4,10	27,800 ± 1500	-	GYF-Card no.3	TL	Recent Gravettian	Valladas et al., 2001
					4,10	28,000 ± 2100	-	GYF-Card no.4	TL	Recent Gravettian	Valladas et al., 2001
4,10	30,100 ± 1500	-	GYF-Card no.7	TL	Recent Gravettian	Valladas et al., 2001					
4,11	-	-	-	Typology	Recent Gravettian	Aubry, 2009					
Ínsula	Open air	40°58'10.23"	6°59'28.99"	310	2	-	-	-	Typology	Recent Gravettian	Aubry, 2009
Quinta da Barca Sul	Open air	40°59'54.01"	7°06'14.09"	143	3	11,600 ± 1200	-	GYF-QBS no.3	TL	Final Magdalenian	Valladas et al., 2001
					3	11,900 ± 1100	-	GYF-QBS no.4	TL	Final Magdalenian	Valladas et al., 2001
					3	12,700 ± 1000	-	GYF-QBS no.2	TL	Final Magdalenian	Valladas et al., 2001
Fariseu	Open air	41°02'16.64"	7°06'36.53"	125	4	9830 ± 130	11,096-11,539	Ua-32645	<sup>14</sup> C AMS	Final Magdalenian	Aubry, 2009
					4	11,800 ± 900	-	GYF-FAR no.8	TL/OSL	Final Magdalenian	Merciel et al. 2006
					4	11,000 ± 1100	-	GYF-FAR no.17	TL/OSL	Final Magdalenian	Merciel et al. 2006
					4	10,800 ± 1700	-	GYF-FAR no.2	TL	Final Magdalenian	Merciel et al. 2006
					4	10,510 ± 40	12,287-12,621	Beta-213130	<sup>14</sup> C AMS	Final Magdalenian	Aubry, 2009

					9	19,020 ± 80	22,581- 23,174	GrA- 40167	<sup>14</sup> C AMS	Solutrean	Aubry, 2009
					10	-	-	-	Typology	Gravettian/Solutrean	Aubry, 2009
Buraca Grande	Cave	39°58'51.59"	8°33'0.69"	256	8c/9a	-	-	-	Typology	Solutrean	Aubry et al. 1997
					9b	23,920 ± 300	28,355- 29,255	GifA- 93048	<sup>14</sup> C AMS	Gravettian	Aubry et al. 1997
Buraca Escura	Cave	39°58'47.55"	8°33'7.65"	223	2ab	21,820 ± 200	25,582- 26,634	OxA- 5524	<sup>14</sup> C AMS	Recent Gravettian	Aubry et al. 2001
Vale das Buracas	Open air	40°2'46.01"	8°29'45.10"	290	3b, 3/4	-	-	-	Typology	Gravettian	Aubry et al. 2008
Vale dos Covões	Rock shelter	40°2'51.74"	8°29'57.83"	275	3	-	-	-	Typology	Upper Magdalenian	Aubry et al. 2008
					4	-	-	-	Typology	Upper Magdalenian	Aubry et al. 2008
					5	10,540 ± 95	12,251- 12,643	Ua- 33479	<sup>14</sup> C AMS	Upper Magdalenian	Klaric et al. 2009
					5	12,340 ± 50	14,174- 14,853	Beta- 201013	<sup>14</sup> C AMS	Upper Magdalenian	Klaric et al. 2009
Lapa dos Coelhos	Cave	39°30'17.41"	8°36'55.19"	85	3	11,660 ± 60	13,409- 13,683	GrN- 18376	<sup>14</sup> C AMS	Upper Magdalenian	Almeida et al., 2004
Terra do Manuel	Open air	39°20'41.72"	8° 59' 30.77"	110	2s	21,770 ± 210	25,456- 26,594	ETH- 6038	<sup>14</sup> C AMS	Proto-Solutrean	Zilhão, 1997
					2s1	-	-	-	Typology	Proto-Solutrean	Almeida et al., 2010
					2s2	-	-	-	Typology	Recent Gravettian	Almeida et al., 2010

Portuguese Estremadura

<sup>a</sup> Calibration used CalPal with the Calcurve CalPal\_2007\_HULU ([www.calpal-online.de](http://www.calpal-online.de)). All the errors are 1-sigma.

## 2.2. Raw material characterisation and technological analysis

The study of lithic raw material procurement was based on systematic descriptions and comparisons of archaeological and geological samples. The latter were collected specifically for this study during field work based on geological data provided by the Instituto Geológico e Mineiro de Portugal (Carta Geológica de Portugal, Scale 1:50,000) and Instituto Geológico y Minero de España (Mapa Geológico de España, Scale 1:50,000) (see **Table 2**). The geological data set was established during surveys undertaken by the authors, with the collaboration of Jorge Davide Sampaio and André Santos, between 1997 and 2011.

Archaeological and geological samples were described at different scales of analysis (macroscopic with stereomicroscope and microscopic thin sections) (Mangado Llach, 2002, 2004; Aubry and Mangado Llach, 2006). A total of 93,010 lithic artefact remains recovered at 11 sites were studied and data by C. Gameiro from the Lapa dos Coelhos cave (3,932 lithic artefact remains) were also examined (**Table 1, 3 and 4**). The geological samples from the Duero/Douro and Tagus basins were studied in terms of

texture and structure, mineralogical and palaeontological content, defining 59 categories (Mangado Llach, 2002, 2004, Aubry and Mangado Llach, 2003a, 2003b, 2006, **Table 2**), following the genetic and gytological description proposed by Fernandes et al. (2010). The preliminary systematic macroscopic examination was complemented by a petrographic analysis (mineralogy, texture and fossil content) of archaeological samples as well as geological ones collected from the different sedimentary basins analyzed (Mangado Llach, 2002, 2004).

Lithic assemblages were classified into lithological types and technological classes corresponding to reduction sequences starting with blocks, fragments from veins of siliceous rock, nodules or pebbles, in order to establish the production processes represented for each different raw material, their techniques and purposes and blank selection for retouched tools (Leroi-Gourhan and Brézillon, 1966). An economical interpretation of the data is proposed, based on the production sequences present and absent for each lithological category, as well as on the reconstruction of the techno-morphological objectives underlying the deliberate production of some flake blanks not designed for retouch (Aubry, 2009). The litho-technological information was complemented by use-wear analysis of a selected sample, representative of the retouched tools and blanks (Aubry and Araújo Igreja, 2009).

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### **2.3. Geographical approach**

Since resources are sparse and unequally distributed over the landscape, mobility is an essential feature of ancient and present-day hunter-gatherer societies. Used in association with archaeological data, GIS tools, notably cost and time surface analysis, are probably one of the most objective ways to determine routes and tracks that may have structured past hunter-gatherer landscapes.

These tools can determine the effort to travel across a certain landscape and optimal paths between two locations, taking into account physical obstacles to movement, namely topography and rivers (Wheatley and Gillings, 2002; van Leusen, 2002). Nevertheless, they present several limitations, connected with the different algorithms used (isotropic or anisotropic, energy or time models, etc.), that may not accurately translate the reality of human movement, but mainly connected with the fact that they are not suited to account for cultural or social constraints to movement, such as liminal areas. These analyses are also strongly dependent on the accuracy and resolution of the Digital Elevation Model (DEM) in which they are based (Wheatley and Gillings, 2002). Therefore, cost surface analysis should be taken not as an absolute but instead as a probabilistic approach to the time and space travelled between two locations (van Leusen, 2002).

Despite its limitations, cost surface analysis represents a major breakthrough, freeing spatial analysis from Cartesian space. It recognizes the fact that a straight line is not always the shortest distance between two points. After determining that certain objects travelled from known sources to the Côa Valley, our goal was to probabilistically assess the routes they may have travelled, and the time it would take to effect their transportation. This approach could get us closer to the perception of the landscape held by the human groups involved in this transport.

In our analysis we've used the Shuttle Radar Topographic Mission (SRTM) 30 arc-second elevation data (Farr et al., 2007) in order to build our DEM. To reconstruct Last Glacial Maximum coastlines, which were 120 meters lower than present day sea level (Lambeck and Chappell, 2001), we've also used bathymetry data from ETOPO1 (Amante and Eakins, 2009). Elevation data was projected into a metric coordinate system (ETRS 1989 UTM Zone 30N).

From this DEM we've estimated anisotropic distances to each settlement site analyzed, using ArcGIS's PathDistance function, where the vertical factor was determined using Tobler's (1993) hiking function, as proposed by Tripcevich (2007, 2009). This function converts space into time. Therefore, our distances are always determined in minimum time spent, not kilometres walked, thus closer to cognitive space. In our analysis we have not accounted for vegetation or watercourses as an obstacle to movement. Tobler's hiking function is based on empirical data provided by Imhof (1950). Therefore, it does not account for vegetation obstacles to displacement, which, nevertheless we consider negligible during the LGM, when herbaceous scrublands dominated (Zilhão, 1997; Haws, 2011). Although crossing rivers can be a limitation, they must nevertheless be crossed, and no model at the scale we've worked could account for natural fording places. A problem could arise if the least-cost paths would follow mainly stream lines, since they tend to be gently sloped lines (Fábrega Álvarez and Parceró Oubiña, 2007), but, once the least costs were produced, careful examination showed that was not the case. From these anisotropic cost surfaces, least-cost paths were generated from each site to each source presented in each archaeological layer. In order to calculate used resource areas, polygons were produced with ET Geowizards function, having the raw material sources location used as vertices.

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### **3. Results**

#### **3.1. Geological setting and differential toolstone sources potential**

The Duero/Douro and Tagus River Basins cover one third of the total Iberian Peninsula area, integrating a Mesozoic marine basin (Lusitanian), a Cenozoic basin in the continental crust (Duero, Madrid and Lower Tagus), and structural uplifts in the continental crust (Central Mountain System and Western Mountains) (Ribeiro et al., 1979; Kullberg et al., 2006; de Vicente et al., 2011).

Direct sampling and macroscopic analysis of siliceous rocks collected at 79 locations, and the microscopic petrographic and palaeontological description of siliceous rocks from 27 more outcrops of the Duero/Douro and Tagus basins allowed us to establish a precise and representative data set of the potential lithic raw material sources available in primary and secondary deposits (**Table 2 and Fig. 2**). A long-term survey has shown there are geographical dense clusters of outcrops where siliceous rocks nodules are abundant, available in large sizes and homogeneously spread through the landscape, but there are other regions where usable sources are restricted spatially or scarce among siliceous rocks not as suitable for knapping. Experimental knapping on the different siliceous rocks collected allowed us to establish the quality range of each source in terms of its adaptation to produce bladelets (evaluated from 1 [low quality] to 10 [high quality] in **Table 2**). The geographical distribution of each petrologic variety enabled us to identify raw material sources, and the systematic macroscopic and microscopic analyses in thin section of selected archaeological pieces permitted us to establish the ones used in the Côa Valley Upper Palaeolithic sites (Mangado Llach, 2002; Aubry, 2009).

Coarse-grain Armorican metaquartzites (Lower Ordovician) are ubiquitous rocks in the Central-Iberian Zone of the Iberian Massif (McDougall et al., 1987) found as narrow crests. These erosion resistant rocks are one of the most common materials in the composition of the coarse-grained Duero/Douro and Tagus fluvial deposits. Conglomerates, sandstones, and sandy mudstone varieties are less frequent but exist as consolidated fluvial deposits, dating from the Final Cretaceous to the Palaeocene in the

**Table 2.** Fine-grained siliceous rocks sources sampled and described in the Douro and Tagus basins.

Code	Genetic	Gytologic	Sedimentary	Constituents						
	type <sup>a</sup>	types <sup>b</sup>	Structure <sup>c</sup>	Texture <sup>d</sup>	Mineralogy <sup>e</sup>	Skeletal grain/bioclasts <sup>f</sup>	Porosity and non-skeletal <sup>g</sup>	Environment <sup>h</sup>	Quality <sup>i</sup>	Refs. <sup>j</sup>
L1	Ca-1	1	LAM	MUD	mQ, MQ	NOTS	NOTS	MAR	4	1, 2
A1	TJ-1	1	-	MUD	CQ-mQ (70%),MQ (10%), CAL-LF (10%)	-	MOL, OF, FEL, MOS, Q-TER	MAR-CS	4	1, 2, 3
A2	TJ-2	1	-	MUD	CQ-mQ (80%),MQ (10%), CAL-LF (5%)	-	MOL, CaCO <sub>3</sub> , OF	MAR-CS	5	1, 2, 3
B1	J1-1	1	BRE	MUD	NOTS	NOTS	NOTS	MAR	4	1, 2
C1	J2-1	0	LCR	MUD	CQ (70%-90), mQ, CAL-LF	FOR, ESP-T, BIV	FEN, CaCO <sub>3</sub> , Q-TER	MAR	5	1, 2
C2	J2-1	1, 2, 3, 4	LCR	MUD	CQ (90%), mQ, CAL-LF	FOR, ESP-T, BIV	FEN, CaCO <sub>3</sub> , Q-TER	MAR	6	1, 2
C3	J2-2	0	LCR, PER	MUD	CQ-mQ (70%), MQ, CAL-LF (10%)	ESP-M, FOR, GAS (?), INS	FEN, MOL, OF, CaCO <sub>3</sub>	MAR	5	1, 2
C3	J2-2	1, 2	LCR, PER	MUD	CQ-mQ (70%), MQ, CAL-LF (10%)	ESP-M, FOR, GAS (?), INS	FEN, MOL, OF, CaCO <sub>3</sub>	MAR	5	
C3	J2-2	4	LCR	MUD	CQ-mQ (70%), MQ, CAL-LF (10%)	ESP-M, FOR, GAS (?), INS	FEN, MOL, OF, CaCO <sub>3</sub>	MAR	5	
C3	J2-3	0, 1	PER	WAC	CQ-mQ (65%), MQ (5%), CAL-LF (10%)	ESP-T, FOR, CHA-S (?), GAS (?), INS (?)	FEN, MOL, OF, CaCO <sub>3</sub>	MAR	5	1, 2
C4	J2-3	0, 1	MLR, PER	MUD, WAC	CQ-mQ (75%), MQ (5%), CAL-LF (5%)	ESP-M, FOR (?)	FEN, MOL (?), OF, CaCO <sub>3</sub>	MAR	5	1, 2
C4	J2-3	1, 2, 3, 4	MLR, PER	MUD, WAC	CQ-mQ (75%), MQ (5%), CAL-LF (5%)	ESP-M, FOR (?)	FEN, MOL (?), OF, CaCO <sub>3</sub>	MAR	5	
D1	J3-1	0	LCR	MUD	CQ-mQ (90%), CAL-LF (<5%), MQ (<5%)	GAS	CaCO <sub>3</sub> , OF	MAR-CS	5	1, 2
D3	J3-1	4	LAM	MUD	CQ-mQ (90%), CAL-LF (<5%), MQ (<5%)	CHA-O (?), CHA-S (?)	OF	MAR-CS	8	1, 2
D4	J3-2	0	LAM, PER	WAC, PAC	CQ-mQ (70%), CAL-LF (5%)	BIV, ESP-M, OST, GAS, CHA-S	CaCO <sub>3</sub> , MOL, OF	MAR-CS	6	1, 2
D2	J3-3	0, 1	PER	WAC	NOTS	NOTS	NOTS	MAR-CS	6	
D2	J3-3	0, 1, 2, 3	PER, BRE, LAM	MUD, GRN	CQ-mQ (60-90%), CAL-LS (10-5%), MQ (<5%)	GAS, CHA-S, BIV	MOL, FEN, INT, PEO, OF, MO, CaCO <sub>3</sub> , Q-TER	MAR-CS	7	1, 2
D3	J3-3	4	PER, BRE, LAM	WAC	CQ (55%), mQ(30%), MQ, CAL-LF(5%)	BIV	OF	MAR-CS	8	1, 2
D5	J3-4	0	LCR, PER	PAC, GRN	CQ-mQ (50%), mQ (5%), CAL-LF (5%)	ESP-T, FOR (?), GAS	MOL, OF, PEO, Q-TER, MOS, CaCO <sub>3</sub>	MAR-CS	5	
E1	C2s-1	1	LAM	MUD, PAC	mQ-cQ, CAL-LF, CAL-LS, OP	BIV, OST, CHA-S	PEO, PEL, OOI, Q-TER, OF	MAR	5	1, 2
E2	C2s-2	0, 1	LAM	MUD, PAC	CQ (95%), mQ, CAL	FOR, ESP-M, BIV, OST, RAD	PEO, PEL, OOI?, Q-TER, OF	MAR	6	1, 2

<b>E2</b>	C2s-2	4	LAM	MUD, PAC	CQ, mQ, CAL-LF	FOR, ESP-M, BIV, OST, RAD	PEO, PEL, OOI?, Q-TER, OF	MAR	6	1, 2
<b>E3</b>	C2s-3	0, 1	LAM	MUD, PAC	CQ, MQ, CAL, OP	FOR, ESP-M, BIV	PEO, PEL, OOI?, Q-TER, MOS, OF	MAR	6	1, 2
<b>E4</b>	C2s-4	4	LAM, PER	MUD, PAC	CQ, MQ, CAL-LF	OST, CHA-S, BIV	Q-TER	MAR	7	1, 2
<b>E5</b>	C2s-5	1	LAM, PER	MUD	CQ-mQ (70-90%), CAL-LF	FOR, ESP-M, BIV, OST	CaCO <sub>3</sub>	MAR	6	1, 2
<b>E6</b>	C2s-6	4	LAM	MUD	CQ, mQ, CAL	FOR, ESP-M, BIV, OST	NOTS	MAR	9	1, 2
<b>E7</b>	C2s-7	4	LAM	MUD	CQ, mQ, CAL	FOR, ESP-M, BIV, OST	NOTS	MAR	8	1, 2
<b>F1</b>	?	3	BRE	-	NOTS	NOTS	NOTS	CONT	6	
<b>F2</b>	O-MC-1	1	-	MUD	CQ, CAL-LS, OP	NOTS	Q-TER	CONT	6	1, 2
<b>G1</b>	Eo-1	0, 1	BRE	MUD	OP	NOTS	NOTS	CONT-LAC	6	1, 2
<b>G2</b>	Eo-2	0, 1	BRE	MUD	CAL	NOTS	NOTS	CONT-LAC	6	1, 2
<b>G3</b>	Eo-3	4	BRE	MUD	CAL	NOTS	NOTS	CONT-LAC (?)	6	
<b>H1</b>	C-Pε-1	0, 1	-	CNG, SAN	OP-CT, ALU, CAL-LF, KAO, SME	-	Q-TER, FEL, OF	CONT	4	4
<b>H2</b>	C-Pε-2	0, 1	-	MUD-san	OP-CT, ALU, CAL-LF, KAO, SME	-	Q-TER, FEL	CONT	6	4, 5
<b>H3</b>	C-Pε-2	0, 1	-	SAN, MUD-san	NOTS	NOTS	NOTS	CONT	4	
<b>I1</b>	MC-1	0, 1, 2, 3, 4						CONT-LAC	6	1, 2
<b>I2</b>	MC-2	0, 1	-	MUD	MQ, CAL	GAS, CHA-O	OF, CaCO <sub>3</sub> , MO	CONT-LAC	6	
<b>I2</b>	MC-2	2, 3, 4	-	MUD	MQ, CAL	GAS, CHA-O	-	CONT-LAC	6	
<b>I3</b>	MC-3	0, 1	BRE, LAM	WAC, PAC	MQ, mQ, CAL	CHA-S, CHA-O, GAS,	FEN, CaCO <sub>3</sub> , Q-TER	CONT-LAC	6	
<b>I3</b>	MC-3	2, 3, 4	BRE, LAM	WAC, PAC	MQ, mQ, CAL	CHA-S, CHA-O, GAS,	-	CONT-LAC	6	
<b>I5</b>	MC-4	0, 1	BRE	MUD	CQ, CAL-LS	-	FEN, CaCO <sub>3</sub> , OF, Q-TER	CONT-LAC	6	6
<b>I6</b>	MC-5	0, 1	-	MUD	CQ, MQ, CAL-LS, OP	-	CaCO <sub>3</sub> , OF, Q-TER	CONT-LAC	6	6
<b>I7</b>	MC-6	3, 4	-	MUD, WAC	CQ, mQ, CAL-LF,	-	OF	CONT (?)	6	1, 2
<b>I8</b>	MC-7	0, 1	-	MUD, WAC	MQ, mQ, CAL-LF, CAL-LS	-	-	CONT	6	7
<b>I11</b>	MC-7	4	-	MUD, WAC	MQ, mQ, CAL-LF,	-	-	CONT	5	1, 2
<b>I9</b>	MC-8	0, 1	-	MUD	OP-CT, SME	-	-	CONT	6	7
<b>I10</b>	MC-9	0, 1	-	MUD	MQ, mQ, OP-CT, SME	-	-	CONT	6	7
<b>J1</b>	q-1	0, 1	-	-	MQ, CAL	NOTS	OF	CONT-HYD	4	1, 2

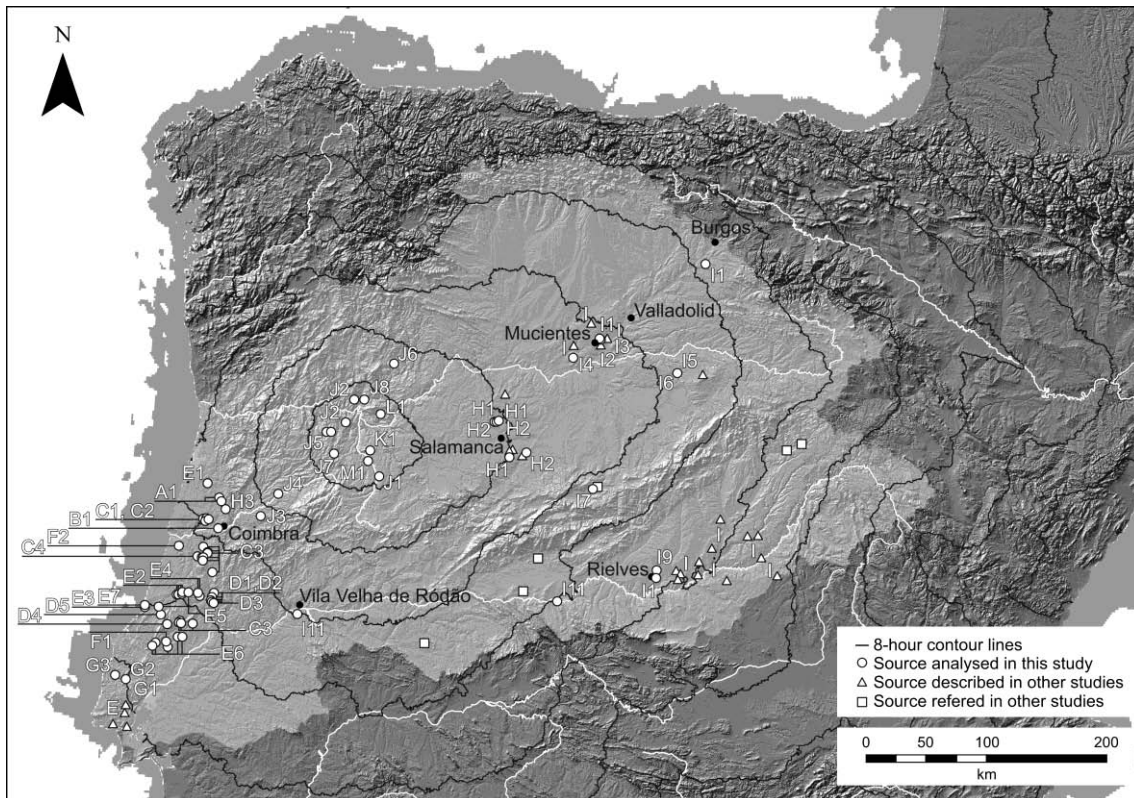
<b>J1</b>	q-1	5	-	-	MQ, CAL	<i>NOTS</i>	OF	CONT-HYD	6	1, 2
<b>J2</b>	q-2	0, 1	-	-	Q	<i>NOTS</i>	<i>NOTS</i>	CONT-HYD	5	1, 2
<b>J3</b>	q-3	4	-	-	MQ	<i>NOTS</i>	<i>NOTS</i>	CONT-HYD	4	1, 2
<b>J4</b>	q-4	0, 1	-	-	CAL, mQ	<i>NOTS</i>	OF, Q-TER (?)	CONT-HYD	4	8
<b>J5</b>	q-5	0, 1	-	-	MQ	<i>NOTS</i>	Q-TER	CONT-HYD	4	1, 2
<b>J6</b>	q-6	3, 4	-	-	OP	<i>NOTS</i>	<i>NOTS</i>	CONT-HYD	5	1, 2
<b>J7</b>	q-7	0, 1	-	-	OP	<i>NOTS</i>	MOS	CONT-HYD	4	8
<b>J8</b>	q-8	0, 1	-	-	Q	<i>NOTS</i>	<i>NOTS</i>	CONT-HYD	4	1, 2
<b>J9</b>	q-9	0, 1	-	-	Q	<i>NOTS</i>	<i>NOTS</i>	CONT-HYD	2	8
<b>K1</b>	Opc	0, 1	LAM	-	mQ	<i>NOTS</i>	OF	MAR	5	1, 2
<b>M1</b>	Rp	0, 1, 2, 3	-	-	Q, TUR	<i>NOTS</i>	<i>NOTS</i>	MAR	5	1, 2

<sup>a</sup> Types follow geologic map convention code and a sequential number; <sup>b</sup> 0 (in situ outcrop), 1 (subprimary outcrops), 2 (colluvial gathering), 3 (recent river deposits), 4 (old alluvial deposits), and 5 (only observed in archaeological sample); <sup>c</sup> BRE (brechoidal), LAM (lamination), LCR (liesegang concentric rings), MLR (multiple liesegang rings), PER (peloidal relict); <sup>d</sup> CNG (conglomerate), GRN (grainstone), MUD (mudstone), MUD-san (sandy mudstone), PAC (packstone), SAN (sandstone), WAC (wackstone); <sup>e</sup> ALU (alunite), BIO (biotite), CAL (undetermined chalcedony), CAL-LF (chalcedony length-fast), CAL-LS (chalcedony length-slow), CQ (criptoquartz), CQ-mQ (criptoquartz/microquartz), DOL (dolomite), KAO (kaolinite), MQ (macroquartz), mQ (microquartz), OP (opal), OP-CT (opal-CT), Q (alpha-quartz), SME (smectite), TUR (turmaline); <sup>f</sup> BIV (bivalve), BRA (brachiopod), BRY (Bryozoa), CHA-O (Charophyta gyrogonite), CHA-S (Charophyta stem), CRI (crinoids), DIA (diatom), ECH (echinoid), ESP-M (monoaxone spicule), ESP-T (triaxone spicule), FOR (foraminifer), GAS (gastropod), INS (*insertae sedis*), OST (ostracod), RAD (radiolarian); <sup>g</sup> CaCO<sub>3</sub> (calcite), FEL (feldspar), FEN (fenestral porosity), INP (intraparticle porosity), INT (intraclast), MO (organic material), MOL (moldic porosity), MOS (moscovite) OF (iron oxide), OOI (ooid), PEL (pellet), PEO (peloid), PIS (pisoid), Q-TER (terrigeneous quartz), SOF (secondary oxide); <sup>h</sup> CONT (continental), CONT-AL (alluvial), CONT-HYD (hydrothermal), CONT-Lac (lacustrine), MAR (marine), MAR-CS (marine continental shelf); <sup>i</sup> Experimental evaluation of knapping quality (1/10); <sup>j</sup> 1 (Mangado Llach, 2002), 2 (Aubry, 2009), 3 (Carvalho, 1946), 4 (Molina Ballesteros et al., 1997), 5 (Blanco et al., 2008) 6 (Armenteros, 2000), 7 (Bustillo and Jiménez, 2005), 8 (Cerveira, 1951); *NOTS* (not observed in thin section).

Duero/Douro basin (Mediavilla and Dabrio, 1986; Blanco et al., 2008). Quartz is present in its different mineralogical forms, as hydrothermal vein fillings, in the joint/fractures resulting from Variscan tectonic events, and in secondary position in detrital deposits.

Within this area, flint occurs in three main depositional environments. The first consists of syn-diagenetic siliceous precipitations formed in open or barrier reef continental shelf environments identified along the stratigraphic Mesozoic sequence of the Lusitanian basin. The evolution of the western Iberian margin, closely associated with the first opening phases of the North Atlantic, ranges from the Late Triassic to the Early Cretaceous, and its evolution was conditioned by inherited structures from the Variscan basement (Kullberg et al., 2006). The second, more circumscribed, flint source type appears in Miocene lacustrine environment of the Central Mountain System's northern and southern margins (Bustillo, 1976; Bustillo and Pérez-Jiménez, 2005; Armenteros, 2000). Finally, silcrete composed by amorphous silica in origin, evolving to opal-CT, occurs in dispersed and restrict outcrops of the northern and southern Meseta (Molina Ballesteros et al., 1997; Blanco et al., 2008), and in the Lusitanian basin (Proença Cunha, 2000).

Most of these sources are geographically located and geologically well defined by their sedimentary facies, detrital and palaeontological content (**Table 2 and Fig. 2**). However, several source locations could provide the same raw material type. In this case, we've used the most parsimonious hypothesis and assumed the closest source to the site. In most cases this choice was not complicated once most of the raw materials share the same limited coterminous regional distribution with the exceptions of type I11 and mostly type I1 (see **Table 2**). Type I11 corresponds to lacustrine Miocene flint available in primary position outcrops and in secondary position in the Tagus terraces,



**Fig. 2.** Siliceous raw materials available between the Douro and Tagus basins with time costs estimated from a mean centre in the Côa Valley area.

detected from El Puente de Arzobispo to Vila Velha de Ródão, along more than 200 km of the river basin. Type I1 is a ubiquitous siliceous type of rocks that can be found on both sides of the Iberian Central Mountain System, either on the Southern side at Rielves (Bustillo, 1976) or the Northern Plateau near Valladolid and Burgos (Armenteros, 2000; IGME, 1982). Once more, we have decided to use the closest source to the sites in calculating regional source use.

### 3.2. Lithic raw material origins in the Côa Valley

The Côa Valley data reveals the use of raw materials from four different areas of origin. Schist, granite, quartzite, quartz and rock crystal are available locally, in primary or secondary position in the areas surrounding each site, depending on local geology, but all within 1 hour radius. Veins of fine-grained siliceous rocks (J1, J2, K1 and M1), are present in very circumscribed sources, corresponding to less than 7 hours of walking.

Walking away from the Côa Valley, certain raw material sources are located at about 14 to 15 hours, in two opposing directions, to the south-westwards (J4) and eastwards (H1 and H2). Finally, in these same directions, the most distant flint sources are located between 21 and 31 hours walking (A1/2, C1/4, D2/3, E2/7 south-westwards; I1, I2/3, I5/6 and I7 eastwards) (**Fig. 2**).

The data obtained for the Côa Valley reveal that, during all Upper Palaeolithic occupation phases, lithic series are clearly dominated by local quartzite and quartz, but also include a small proportion of regional fine-grained siliceous rocks, as well as flint and other fine-grained siliceous rocks from distant sources (**Fig. 2, Table 3**). However, despite being suitable for knapping, some regional lithic raw materials detected to the north of the Douro valley were not used in any of the Upper Palaeolithic series studied (**Fig. 2**), including the regional sources of spatially localized Precambrian chert (L1), and volcanic opal (J6).

Overall, the occurrences of different local or regional raw materials used from the Gravettian to the Final Magdalenian in the Côa Valley, do not reveal significant differences in their sourcing.

All the raw material sources, be they regional or distant, South-western or Eastern, continue to be exploited along the Upper Palaeolithic sequence in the Côa Valley.

However, one can detect a diachronic trend. Gravettian assemblages from Olga Grande 4 (Layer 3), Olga Grande 14 (Layer 3), Cardina 1 (Layers 4, 10 and 4, 11), and Ínsula (Layer 2), have revealed a better representation of quartzite relatively to quartz, when compared to Final Magdalenian occupations, such as Fariseu and Quinta da Barca Sul assemblages, in spite of the local availability of both materials (**Table 3**).

In terms of regional and distant fine-grained sources, one also notes some differences. Generally, the same sources continue to be present throughout the entire sequence.

**Table 3.** Effectives of raw material categories defined in Table 2 used in the Côa Valley.

Raw material <sup>a</sup>	Sites <sup>b</sup>													Distance <sup>c</sup>		Origin	Range		
	OG4		OG14		CAR					INS	QBS		FAR		km <sup>d</sup>			hrs <sup>e</sup>	
	3	2c	3	4,6	4,7	4,8	4,9	4,10	4,11	2	3	4	9/10						
Fine-grained rocks	Flint	A1/2	-	2	-	1	5	4	2	8	2	-	1	-	-	130	21	SW (Portuguese Estremadura)	Long-distance
		C1/4	8	6	2	42	73	48	60	45	24	4	2	-	5	149	24		
		D2/3	31	17	-	4	5	4	8	16	9	-	-	3	-	180	30		
		E2/7	14	8	5	21	22	21	18	96	81	11	3	19	-	202	31		
		F1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
		F2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	I1	144	16	16	41	85	59	89	402	331	15	6	10	2	212	23	East (Northern Meseta)	Long-distance	
	I2/3	18	4	5	10	19	13	29	134	85	2	7	-	-	212	23			
	I5/6	-	-	-	1	1	4	2	32	9	-	-	-	-	268	26			
	I7	7	3	4	8	8	15	4	49	30	9	2	-	-	197	26			
	I11	-	1	-	3	1	4	2	-	-	-	2	4	-	159	24			
	Not determined	-	2	-	-	-	-	-	96	62	-	-	-	-	-	-			
	Burnt	-	2	-	-	-	-	-	20	81	2	-	7	-	-	-			
Coarse-grained rocks	Hydrothermal veins	J3/4	-	-	-	-	-	-	11	9	1	-	15	-	86	14	SW	Intermediate	
		H1	2	-	-	4	1	3	1	1	-	-	-	-	111	15	E		
		H2	6	2	-	5	11	9	8	22	10	-	-	-	2	109	15		
		J1	21	-	8	12	26	24	14	11	12	-	32	-	-	38	7		
		J2	3	-	-	5	4	7	2	5	-	1	22	26	-	28	5		
	Meta-	K1	26	16	5	2	5	8	3	7	3	2	-	-	-	15	3	Local	
		M1	1	25	3	-	-	-	-	2	6	1	8	2	-	23	5		
		Rhyolite	19	19	1	-	-	-	-	-	-	3	3	2	-	-1	-1		
		Quartz	7557	1316	25	x	x	x	x	9817	5967	836	774	4974	195	-1	-1		
		Rock crystal	968	92	108	x	x	x	x	5564	3411	142	16	237	-	-1/25	-1/25		
Quartzite	971	71	174	x	x	x	x	11875	8251	242	118	825	156	-1	-1				

<sup>a</sup> See Table 2 for raw material description; <sup>b</sup> Olga Grande 4 (OG4), Olga Grande 14 (OG14), Cardina 1 (CAR), Ínsula (INS), Quinta da Barca Sul (QBS), Fariseu (FAR); <sup>c</sup> Determined from the six sites' mean centre; <sup>d</sup> Straight-line Euclidean distances; <sup>e</sup> Cost distances using Tobler's (1993) hiking function (see text for details); x Present but unrecorded.

However, during the Proto-Solutrean and Final Magdalenian, regional sources tend to overcome distant ones.

Cardina 1, which is the best example for detecting a diachronic trend due to the long stratigraphy and large assemblage, shows that the relative amount of exotic raw material from beyond 197 km (the median of the exotic raw material distances present; **Table 3**) decreases through time in the site sequence, as opposed to the raw materials below that distance.

In terms of the two geographic areas, after LGM, the ratio of Eastern sources decreases in favour of South-western flint (**Fig. 3**).

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### **3.3. Differential raw material use**

As noted earlier, all the lithic assemblages have been studied technologically and selected bladelet and flake tools, as well as non-retouched blanks, were submitted to use-wear analysis (Aubry and Araújo Igreja, 2009). Each piece was classified into a technological scheme: from block, nodule or pebble, to retouched flakes and tools, in order to establish the production processes for each different lithological group, their techniques and purposes (**Fig. 4**).

Our interpretation of the different production processes, hammer types and techniques (Pelegrin, 2000) used to remove blanks in the Côa Valley series has resulted in an ascription to seven categories. Each sequence was evaluated in terms of its effective representation at each site and layer. An example of technological description by raw material is presented in **Fig. 4**. Gravettian assemblages reveal quite complete local quartzite pebble reduction sequences, which are basically represented by the production of flakes. These short and thick flakes were probably used un-retouched or slightly retouched as end-scrapers and side-scrapers (Aubry and Araújo Igreja, 2009). Some

pebbles, blocks and cores from such productions were also used as heat accumulators on fire-pits, either in the form of pebbles or discarded cores.

Throughout the Côa Upper Palaeolithic, quartz reduction sequences show the greatest diversity in technical processes of production, which is probably related to the variety of petrographic characteristics (crystal, fine grain to coarse quartz, milky to translucent), in relation to the origin of the material and the type of blocks used (pebbles, vein fragments). In the oldest Upper Palaeolithic occupation of the region attested in the layers 3 of Olga Grande 4 and 14 the morphology of blanks and numerous refitting reveals that fragments of local large vein quartz were used to produce thick flakes. At Cardina 1, a large range of quartz materials was used, revealing several reduction sequences to produce flakes and bladelets. At this site, the module of the scrapers made on milky quartz blanks, when compared to by-products of the quartz series, clearly indicates that the blanks were not produced in the excavated area. During the Final Magdalenian, at Fariseu, technological analysis has revealed the same situation: retouched tools made on cortical flakes produced from large quartz pebbles (more than 10 cm of diameter) were not produced on site (Gameiro et al., 2008).

With some exceptions in the numerically small series, the third most common raw material category is rock crystal (**Table 3**). Translucent rock crystals (from 1 to 3 cm in diameter) were available locally or regionally, while exceptionally large specimens (> 5 cm in diameter) and smoked varieties associated to uranium mineralisation are present as veins in local schist and granite bedrock. They were used as blanks for bladelet and small flake production, with two distinct operative schemes (**Fig. 4**). The most common operative scheme is based on anvil bipolar percussion, applied directly on the crystal or on a flake, recognised by the stigmata observed on the products and cores. The second one, less represented, depends on an unidirectional production sequence, where

bladelets are removed either by soft hammer direct percussion, using the longer axis and the intersection of the natural faces of the rock crystals, or by burin-type cores. Experimentation with this reduction sequence revealed that the anvil bipolar percussion reduction sequence, when applied on prepared flakes, allows the production of bladelets and a more intensive exploration of volumes smaller than 1 cm (Klaric et al., 2009). Based on the technological data available, the possible function of these pieces as intermediary pieces (“pièce esquillées”) (Le Brun Ricalens, 2006) cannot be entirely excluded. However, the reduced module, the morphology and the exclusive use of fine-grained raw material to produce them, argue in favour of the interpretation of these pieces as cores for bladelet and small flake production, and not as intermediary tools. Singularly, at Olga Grande 4, rock crystal is the raw material preferentially used for on-site production of blanks for microgravettes and retouched bladelets, by direct soft hammer removal, as well as bladelet and small flake productions, attested by numerous by-products probably used without transformation as cutting edge elements of composite projectile points (**Fig. 4**).

The next category of raw materials by number is composed of several regional fine-grained vein quartz and exogenous flint categories discarded at all the sites (~5% of the total raw material used, on average). The technological study reveals the use of these raw materials to produce blanks for retouched bladelets, following the same reduction sequence as described for rock crystal. However, part of the regional fine-grained siliceous rocks arrived on site in the form of blocks or prepared cores (**Fig. 4**), differently from the exogenous flints, which show reduction sequences that correspond essentially to the final phases of bladelet production and the reuse of blanks, flakes or blade-tools (**Fig. 4**). We could establish some differences between flint productions. In the Gravettian layers of the granitic plateau sites (Olga Grande 4 and 14), they

correspond basically to fragments of retouched bladelets, showing diagnostic fractures due to their use as projectiles and damaged tools (e.g., notches, scrapers), discarded or reused as blanks for the preparation of cores by bipolar percussion on anvil. At Cardina 1, a site located in the valley bottom, the Gravettian layers (4, 10 and 4, 11) present extremely reduced cores and core preparation and rejuvenation flakes, like tablets, indicating the on-site production of bladelets by soft hammer percussion on prismatic cores. However, the production of bladelets is essentially related to anvil bipolar percussion on flakes, or on small, fragmented retouched blades. These blades, retouched or not, were introduced in the Côa Valley as part of the tool-kit, and were reused after breakage.

During the Final Magdalenian, at Quinta da Barca Sul and Fariseu, the curved backed points and retouched bladelets were mainly produced from regional fine grain siliceous vein rocks and some southern flint sources (Gameiro et al., 2008). The lithological diversity observed for the local and non local raw materials of the retouched bladelet tools and the identification of typical fractures suggest discard after use as projectile implements, which were replaced by tools made from regional fine-grained siliceous sources.

Despite these differences in the operative scheme of local and long-distance raw materials, no noticeable technological distinction can be made between materials coming from the East and the Southwest, namely in the Gravettian layers of Cardina 1 and Olga Grande 4, where these materials are numerically important and statistically relevant.

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### 3.4. Comparison with Upper Palaeolithic raw material procurement in Central Portugal (Sicó Massif and Serra d'Aire e Candeeiros)

Of the six Upper Palaeolithic archaeological sites considered for comparison, four are located south of Coimbra, in the northern sector of the Meso-Cenozoic deposits of the Western Iberia margin (Wilson et al., 1989) (**Fig. 1c** and **Table 1**), including marine, littoral and continental sediments, often carbonates, covering the Iberian Hercynian crystalline basement (Ribeiro et al., 1979). Since 1991, a research project allowed us to recognize Middle and Upper Palaeolithic lithic assemblages preserved in occupation layers of caves and rock-shelters formed in the Middle Jurassic geological formations of the Sicó Massif (Aubry et al., 1994, 1997, 2001, 2008, 2010; Almeida et al., 2003), a geological formation bearing poor quality flint nodules (Aubry et al., 2001; Aubry, 2009). This limestone plateau rises to less than 600 m above sea level and is presently located 40 km east of the Atlantic (Cunha, 1990).

The sites considered (Buraca Escura, Buraca Grande, Vale das Buracas and Abrigo do Vale do Covões) are caves or rock-shelters located in two fluviokarstic canyons cut in the Middle Jurassic carbonate formations of the western belt of the Sicó Massif (Cunha, 1990), all yielding flint nodules in limestone outcrops or in continental Cretaceous and Cenozoic deposits covering depression in the bedrock. The cultural attribution of each archaeological assemblage is based on typological evidence, ages obtained by absolute dating, palaeoenvironmental conditions inferred from the features of sediment and soil formation and its disconformities. This data allow us to propose a correlative framework (**Table 1**) for the stratigraphical and archaeological sequence of these four sites preserving Middle and Upper Palaeolithic (Gravettian, Solutrean and Magdalenian) occupation levels (Aubry et al., 2010).

The archaeological assemblages of the Sicó massif sites were analyzed using the same protocol applied to the Côa Valley series, including systematic survey for locally available primary and secondary sources of lithic raw materials and their comparison with the archaeological record, completed by technological and use-wear analysis on a sample of retouched tools and blanks (Aubry et al., 2001, 2008; Gameiro et al., 2008; Aubry and Araújo Igreja, 2009).

Raw material procurement patterns revealed the use of the local quartz and quartzite pebbles, in all the series, despite the prevalence of a local poor quality flint, available at less than 1 hour of walking distance. The data also show a systematic use of exogenous fine-grained flint from Upper Cretaceous (E2/7) and Upper Jurassic (D2/3) sources available at less than a 8 hour walk distance southwards (Aubry et al., 2001; Gameiro et al., 2008) (**Table 4**). Technological study reveals that these fine-grained flint categories, having better qualities for knapping and for use in projectile technology than the local Middle Jurassic flint, were preferentially used to produce retouched bladelets. Other tool types were made on by-products of the bladelet production sequence on prismatic or burin-cores, or via independent flake production schemes.

The two other sites used for comparison with the Côa Valley series are also located in the Portuguese Estremadura, or Lusitanian basin, towards the South, in the Serra dos Candeeiros area. Terra do Manuel is an open-air site, firstly excavated in the 1940s and continued in the 1990s (Zilhão, 1997), which identified two Final Gravettian occupation levels (2s1 and 2s2), very similar to Cardina 1 (4, 10 and 4, 11), confirmed by salvage excavation in the 2000s (Almeida et al., 2010).

This site is located very close to several major Cenomanian secondary flint sources in the Rio Maior region. Like the Sicó sites, Terra do Manuel occupations rely mainly on local flint (less than 1 hour). The raw material types are roughly the same as the ones

used in the Sicó sites, however, considerable effort was made to obtain the Upper Jurassic flint (D2/3, 13 hours) (**Table 4**).

Two very different typo-technological systems could be identified. The lower level presents a small number of flint cores when compared with the amount of flint debris, as opposed to quartz and quartzite, where pebble cores and flakes are present. These flakes were used differently according to raw material, quartz was retouched and quartzite used unretouched. The absent flint cores were probably prepared on-site for the production of backed and truncated bladelets, partially explored and then exported. In the upper level non-retouched bladelets and the other bladelet forms were produced from prismatic and thick carinated scraper cores.

Finally, Lapa dos Coelhos is a small cave open in the lower portion of the Almonda karstic system (Angelucci and Zilhão, 2009), which was excavated between 1995 and 2007 under the direction of F. Almeida (Almeida et al., 2004). The archaeological sequence, beginning during the Middle Palaeolithic, comprises Solutrean and Upper Magdalenian occupations (Almeida et al., 2004). The lithic assemblage from layer 3 (**Table 1**) was studied by C. Gameiro from a lithological and technical perspective (Gameiro et al., 2008). Raw material sources used in this site are generally the same as Terra do Manuel's, with the advantage of being closer to Middle (C3/4) and Upper Jurassic (D2/3) sources (all within 5 hour walks) (**Table 4**). The different flint sources were used for the on-site production of small convergent bladelets extracted from prismatic, thick-scraper and burin cores (Gameiro et al., 2008). The blanks for thumbnail and on-flake scrapers consist of sub-products of this bladelet tool production. Quartz and quartzite pebbles were used to produce short flakes following a unidirectional or opposed platform reduction scheme.

**Table 4.** Effectives of raw material categories defined Table 2 used in the Portuguese Estremadura lithic assemblages studied.

Raw material <sup>a</sup>	Sites <sup>b</sup>																								
	BG		BE	BG/BE Dist		VB	VC						VB/VC Dist		LCO	LCO Dist		TMA			TMA Dist <sup>f</sup>				
	8c/9a	9b	2ab	km <sup>c</sup>	hrs <sup>e</sup>	3b, 3/4	3	4	5	6	6/7	7	8b	km <sup>c</sup>	hrs <sup>e</sup>	3	km <sup>c</sup>	hrs <sup>e</sup>	2s1	2s2	Total <sup>d</sup>	km <sup>c</sup>	hrs <sup>e</sup>		
Fine-grained rocks	A1/2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	C1/2	4	-	-	36	4	7	32	59	55	9	1	4	-	29	4	-	-	-	-	-	-	-		
	C3/4	83	95	14	3	-1	x	511	828	648	679	27	826	190	1	-1	7	-1/11	-1/3	1	1	5	29	7	
	D2/3	4	10	3	28	5	24	15	37	29	39	1	39	8	34	5	452	25	5	2	-	10	60	13	
	E2/7	20	32	6	35	5	54	100	261	303	367	16	432	6	44	5	3120	12	3	1310	844	9129	2	-1	
	F1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	73	12	3	40	11	205	2	-1	
	F2	-	3	-	23	3	1	6	4	4	1	-	-	-	25	4	-	-	-	-	-	-	-	-	
	I1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	I2/4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	I5/6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	I7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	I11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Not determined	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	280	-	-	-	-	-	-	-	
	Burnt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Coarse-grained rocks	Hydrothermal veins	J3/4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H1			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
J1			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
J2			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K1			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M1			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhyolite			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quartz			x	x	48	3	-1	125	213	394	259	327	21	497	4	4	-1	x	1	-1	844	967	5998	2	-
Rock crystal			-	-	-	-	-	-	-	2	-	-	-	-	-	?	?	-	-	-	x	x	x	-	-
Meta-sediment	Quartzite	-	x	5	3	-1	73	40	138	86	194	-	202	3	4	-1	x	1	-1	156	391	1139	2	-	

<sup>a</sup> See Table 2 for raw material description; <sup>b</sup> Buraca Grande (BG), Buraca Escura (BE), Vale das Buracas (VB), Vale dos Covões (VC), Lapa dos Coelho (LCO), Terra do Manuel (TMA); <sup>c</sup> Straight-line Euclidean distances; <sup>d</sup> Total sums layers 2, 2s1 and 2s2; <sup>e</sup> Cost distances using Tobler's (1993) hiking function (see text for details); x Present but unrecorded.

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## 4. Discussion

### 4.1. Palaeoenvironmental forcing

When interpreting the data presented above, a first variable to consider is the impact of climatic variation in ecosystems and resource distribution and availability just before and after the LGM.

Global climatic fluctuations during the Upper Palaeolithic sequence are well-known from the data established on the Portuguese continental margin (Lebreiro et al., 1995; Zahn et al., 1997; Bard et al., 2000; Shackleton et al., 2000; Thouveny et al., 2000; de Abreu et al., 2003; Skinner and Elderfield, 2007). The study of the last glacial period's record revealed various events of abrupt change associated with severe changes in surface water temperatures ( $\sim 7^{\circ}\text{C}$  in decades; de Abreu et al., 2003) and a periodicity of 1,500 years (Bond et al., 1997; Grootes and Stuiver, 1997; Debret et al., 2007). Several stadial/intestadial cycles have resulted in massive ice-discharges from the Northern Hemisphere ice sheets (Heinrich, 1988), every 7,000-10,000 years, known as Heinrich Events (Bond et al., 1993), that have been described in cores along the Portuguese continental margin (Lebreiro et al., 1995, 2009; Cayre et al., 1999; Sánchez Goñi et al., 2000; Roucoux et al., 2001; d'Errico and Sánchez Goñi, 2003; de Abreu et al., 2003; Roucoux et al., 2005; Sánchez Goñi et al., 2008).

From deep-sea pollen records and forest macroremains occurring along the NW Iberia coast in northern Portugal, Zilhão (1997) has proposed a general picture for the Portuguese Estremadura where scot pine forest is mixed with open herbaceous scrublands and patches of temperate deciduous and Mediterranean forest. At the time of Heinrich Events, correlations between marine and continental proxy data evidence a large development of dry climate-type vegetation in western Iberia, with low percentages of arboreal pollen during cold events and herb and shrub vegetation with

steppe species dominating. Lowered temperatures and precipitation were also accompanied by intensified winds leading to increased upwelling (Combourieu Nebout et al., 2002; Sánchez Goñi et al., 2002; Turon et al., 2003).

In central Portugal, faunal remains of Upper Palaeolithic age are known from cave and rock-shelter sites only, and data concerning Late Pleistocene fauna are scarce for all of the Northern Meseta. As a result of acid soils formed on metasediments and granites of the Côa Valley, as stated earlier, this kind of record is only available for layer 4 of the Fariseu site, an occupation dated by TL, OSL and  $^{14}\text{C}$  AMS between 11 and 12,000 BP and assigned to the Younger Dryas (Aubry et al., 2010). Wild boar (*Sus scrofa*), red deer (*Cervus elaphus*), chamois (*Rupicapra rupicapra*), rabbit (*Oryctolagus cuniculus*), squirrel (*Sciurus vulgaris*), undetermined cyprinid and shad (*Alosa alosa*) were identified (Gabriel and Béarez, 2009). Comparison with species presence/absence and dating of layers I to VI of Peña de Estebanvela (~11 to 14,000  $^{14}\text{C}$  years BP) (Cacho Quesada et al., 2007), a sequence preserved in a rock-shelter located at the eastern limit of the Northern Meseta (**Fig. 1a**), reveals the same large mammal species, along with Equidae (*Equus caballus* and *hydruntinus*) and few carnivore remains (*Felix silvestres*, *Lynx pardina*, *Canis lupus* and *Vulpes vulpes*), with rabbit being the most represented species in all layers, despite a better representation of the Equidae remains in layers III and IV.

The faunal record for the Upper Palaeolithic sequence preserved in caves and rock-shelters of Central Portugal is slightly better known (Zilhão, 1997; Aubry 2001; Davis, 2002; Hockett and Haws, 2009; Haws, 2011). Studies have revealed that rabbit remains show intentional cut marks and breakage patterns (Hockett and Bicho 2000) and that the ratio of rabbit to ungulate increases from the Mousterian to the Magdalenian (Davis, 2002), which is explained as the result of a gradual increase of hunting pressure on the

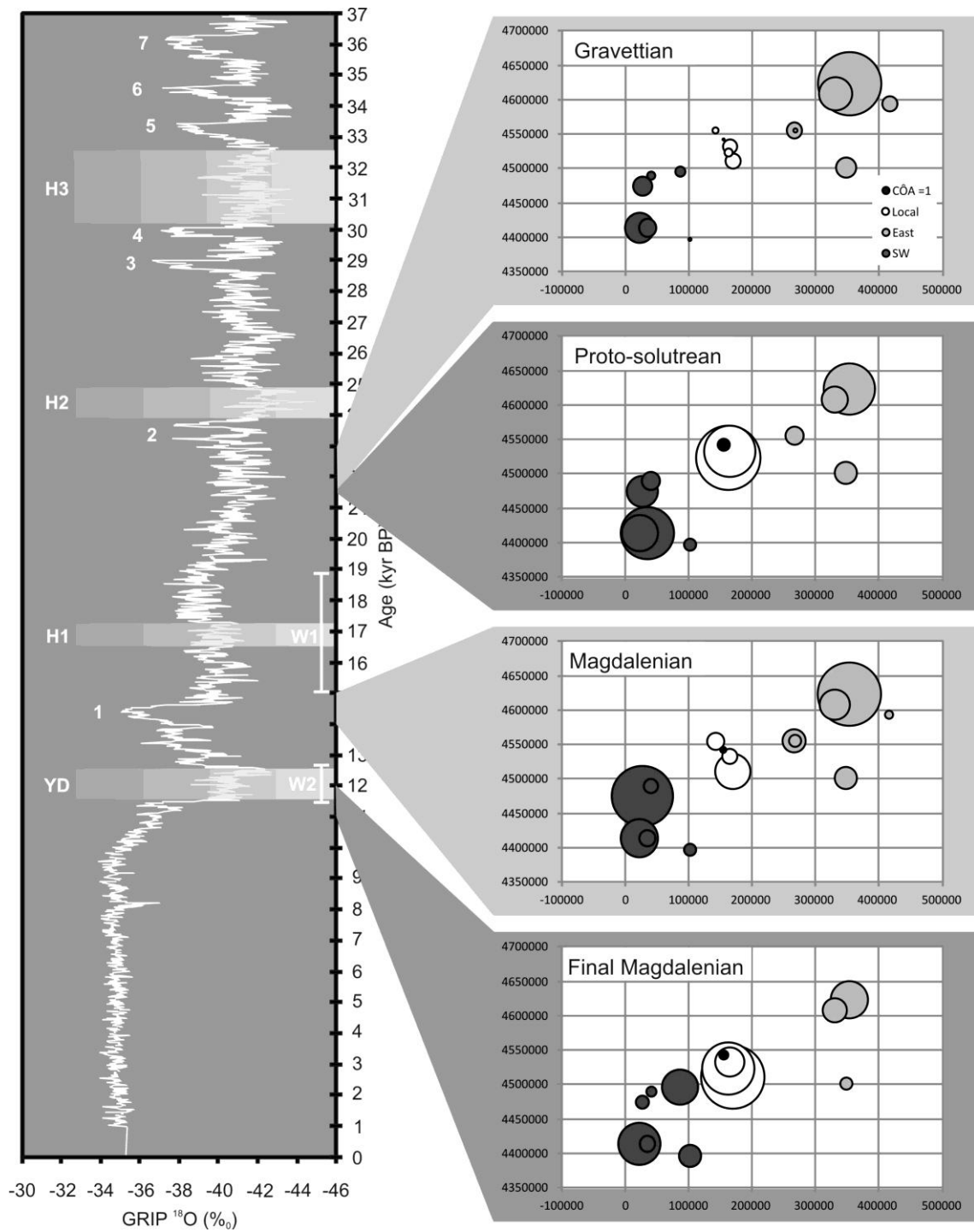
environment, probably due to higher human density. Red deer and wild boar dominate during the Lateglacial as opposed to a better representation of Equidae, ibex, chamois and aurochs before and during the LGM (Zilhão, 1997; Davis, 2002; Aubry et al., 2001, Haws, 2011). Thus, both in the Meseta and along the Atlantic coastline, the variation in animal resources reveals the same ecological trends from the end of the LGM to the Lateglacial.

Apparently, biotic resource forcing cannot be directly correlated with changes in the procurement of stone tool raw material over time, since it does not reveal clearly different origins from the Gravettian to Final Magdalenian/Azilian assemblages (**Fig. 3**). In the Côa Valley sites, local raw materials tend to gain importance over long-distance ones during the Proto-solutrean and the Final Magdalenian/Azilian (**Fig. 3**) and the predominance of Meseta sources over those from Portuguese Estremadura gradually decreases. But, despite these differences, all the raw material sources (local, eastern or south-western) were used, which, despite differences over time in their relative importance, implies the existence of a similar spatial organisation and social network throughout the Upper Palaeolithic. In the current state of knowledge, no correlation can be clearly established between palaeoenvironment and changes in the procurement of raw materials (**Fig. 3**), so other explanations must be found.

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#### **4.2. Functional forcing**




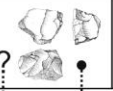

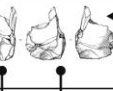
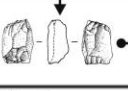
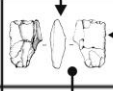


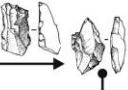

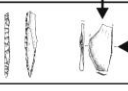

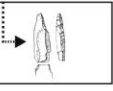
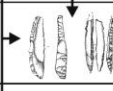
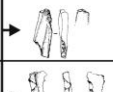

Functional and technological arguments have been advanced as explanation for the presence of exotics in Central Australian sites, where they present more efficient edge-holding properties (Gould and Saggers, 1985).



**Fig. 3.** Representation of Lusitanian basin and Northern plateau lithic raw material sources in the Côa valley Upper Palaeolithic sequence. The x and y-axis refer to Lisbon Hayford Gauss IGeoE coordinates, and relative abundance is indicated by the size of the circles. For scale purposes the Côa Valley circle size equals to 1.

In the Upper Palaeolithic of the Côa Valley, rock crystal, regional fine-grained vein quartz sources and long-distance flint sources were used to produce the same types of retouched bladelets in all the assemblages and with similar technological solutions (anvil bipolar percussion, associated with prismatic core reduction) (**Fig. 4**). Other raw materials, which were available locally, less than 50 km away, were used to produce the same specialized tools made on flint coming from distant sources. This fact is a strong argument against a strictly functional interpretation of the use of flint, independently of cultural factors.

Comparison between Final Gravettian reduction sequences from Cardina 1 and Terra do Manuel reveals that the production of the same truncated retouched bladelet on flint are the result of different reduction sequences (Klaric et al., 2009). This flexibility is interpreted as an adaptation to low resource availability. The anvil bipolar percussion

Operative scheme		Raw material		Rock Cristal	H1 H2	J1	J2	Flint
		Quartz	Quartzite					
Cores	Hard-stone hammer hammer flake-cores							?
	Soft-hammer percussion bladelet cores				?			
	Anvil bladelet and small flake cores				?			
Retouched tools	Flake tools					?		
	Bladelet tools <i>fractured during use</i>							
	Bladelet tools <i>fractured during fabric</i>						?	
	Blade tools							

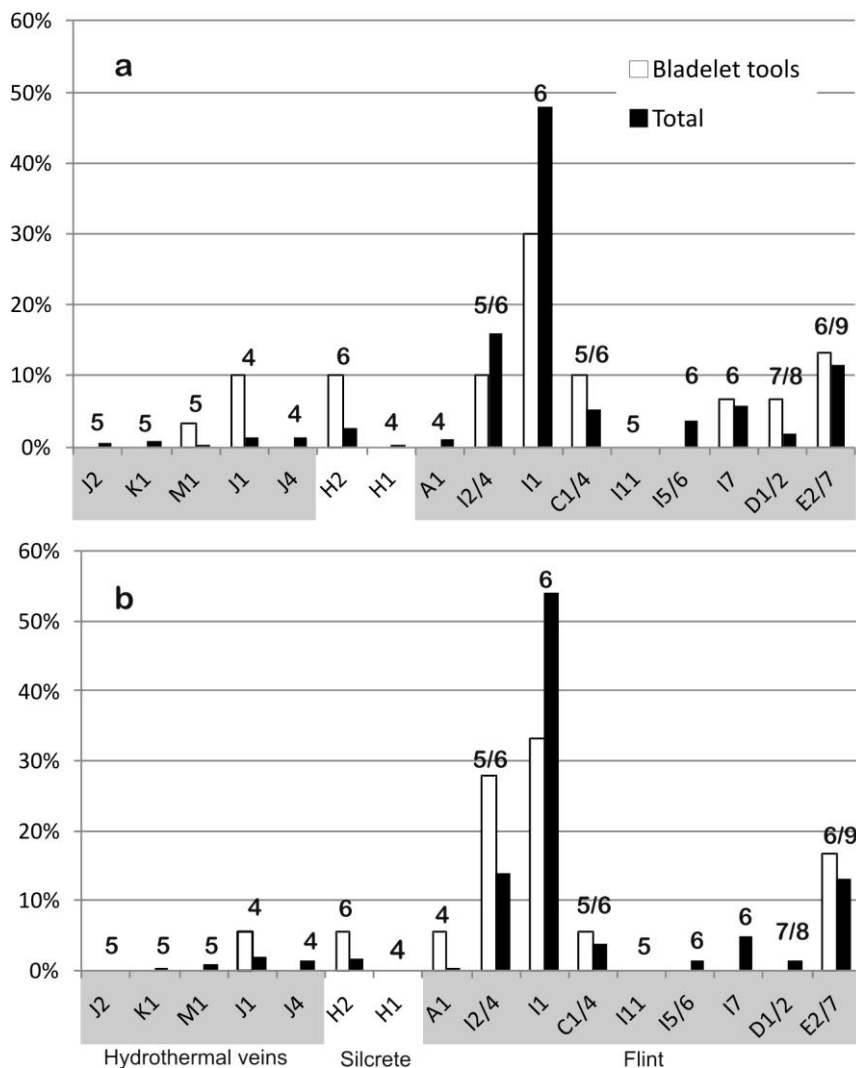
**Fig. 4.** Operative schemes and on-site representation of their different phases, by raw material type, in the Gravettian occupation layer 3 at Olga Grande 4. (See Table 2 for raw material categories description).

used in the Côa Valley, away from flint sources, allows maximal exploitation of core volumes (Aubry, 2009). Terra do Manuel, close to large Cenomanian flint sources, features classical unipolar prismatic bladelet cores, as is also seen at the same time in sedimentary basin sites of Southern France (Klaric et al., 2009).

In the logistical Gravettian occupation of Olga Grande 4, most of the bladelet tools produced on-site are on rock crystal, although on-site reduction of exotic flints is also documented (**Fig. 4**). This fact strongly suggests that such exotic raw materials were not indispensable for this specific type of tool production. Two different Final Gravettian layers from Cardina 1 (layers 4, 10 and 4, 11) reveal the same general pattern in the ratio between the total of the fine-grained remains from different sources and the proportion of these sources in bladelet tools (**Fig. 5**). With few exceptions, namely I1, part of the bladelet tools arrived as retouched bladelets, integrated or not in composite hunting tools, while a few nodule volumes, tools or flakes were introduced alongside and re-used on-site to produce bladelets or small flakes by anvil percussion (**Fig. 4**).

By itself, technology doesn't clearly explain the context of exotic raw material discard in the area. It is clear that some of the exotic raw materials, but also regional ones, arrived at the sites as blanks or finished products throughout the Upper Palaeolithic sequence. Even though flint is always present in the Côa Valley, its reduction sequence is one adapted to scarcity, having a clearly distinguishable *chaîne opératoire* from contemporary and similar tools in areas with abundance of this type of raw material.

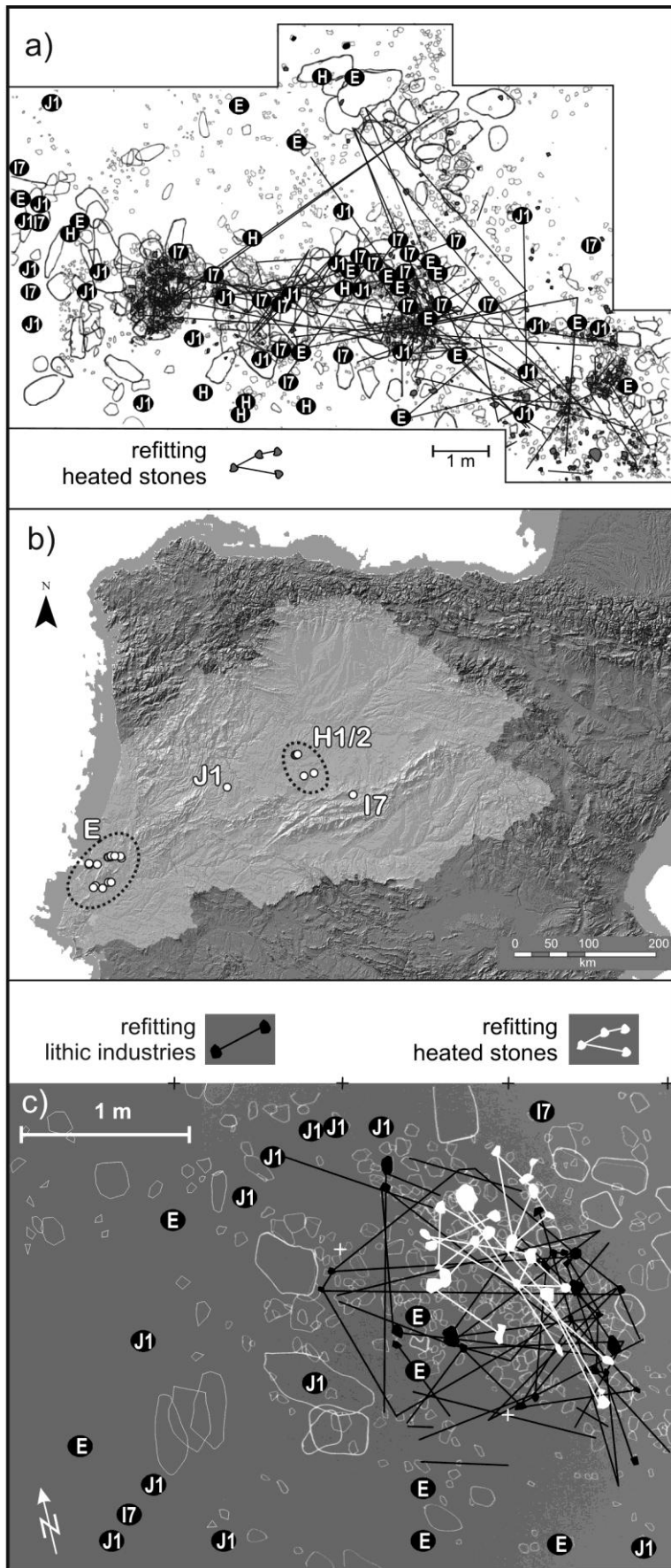
This data proves that flint was not indispensable for the production of tools, since local raw materials were also used. However it was used because it was better suited for knapping, more efficient for use without curation, and more appropriate for manufacturing the lithic components of hunting tools.



**Fig. 5.** Comparison between the proportion of all the fine-grained raw material found in Cardina's Final Gravettian layers 4, 10 (a) and 4, 11 (b) (including subproducts of tool manufacture), and the proportion of its use in bladelet tools. (See Table 2 for raw material categories description and quality).

### 4.3. Sociocultural models for the Côa Valley Upper Palaeolithic data

Theoretically, the Côa Valley lithic assemblages could be the result of the gradual accumulation of remains discarded by distinct cultural groups, originating from the Northern Meseta and the Portuguese Estremadura, during successive, unrelated occupations that exploited the same local biotic resources (Bailey, 2007; Hertell and Tallavaara, 2011). The successive reutilization of the exact same open-air sites by distinct human groups is highly improbable and is refuted by the archaeological data from two logistical hunting occupations on the granitic plateau. Refitting of stones used



**Fig. 6.** Spatial distribution of refitted heated stones used in fire pits and of lithic raw material categories in the Gravettian layers of Olga Grande 4 (a) and Olga Grande 14 (c), with location of the fine-grained siliceous sources represented at both sites (b).

to structure large fire pits and between knapped lithic debris in the Gravettian occupations of Olga Grande 4 and 14 shows that the Eastern and South-western raw material sources of bladelet tools present the same spatial patterns and were both used and discarded during short, specialized hunting occupations (Aubry, 2009; **Fig. 6**). Thus, the occupation of the same area on separated moments by different human groups from distinct regions cannot be advanced as an explanation for the origins and diversity of stone tool raw material sources used on-site.

Classically, other explanations of hunter-gatherer lithic raw material procurement involve two

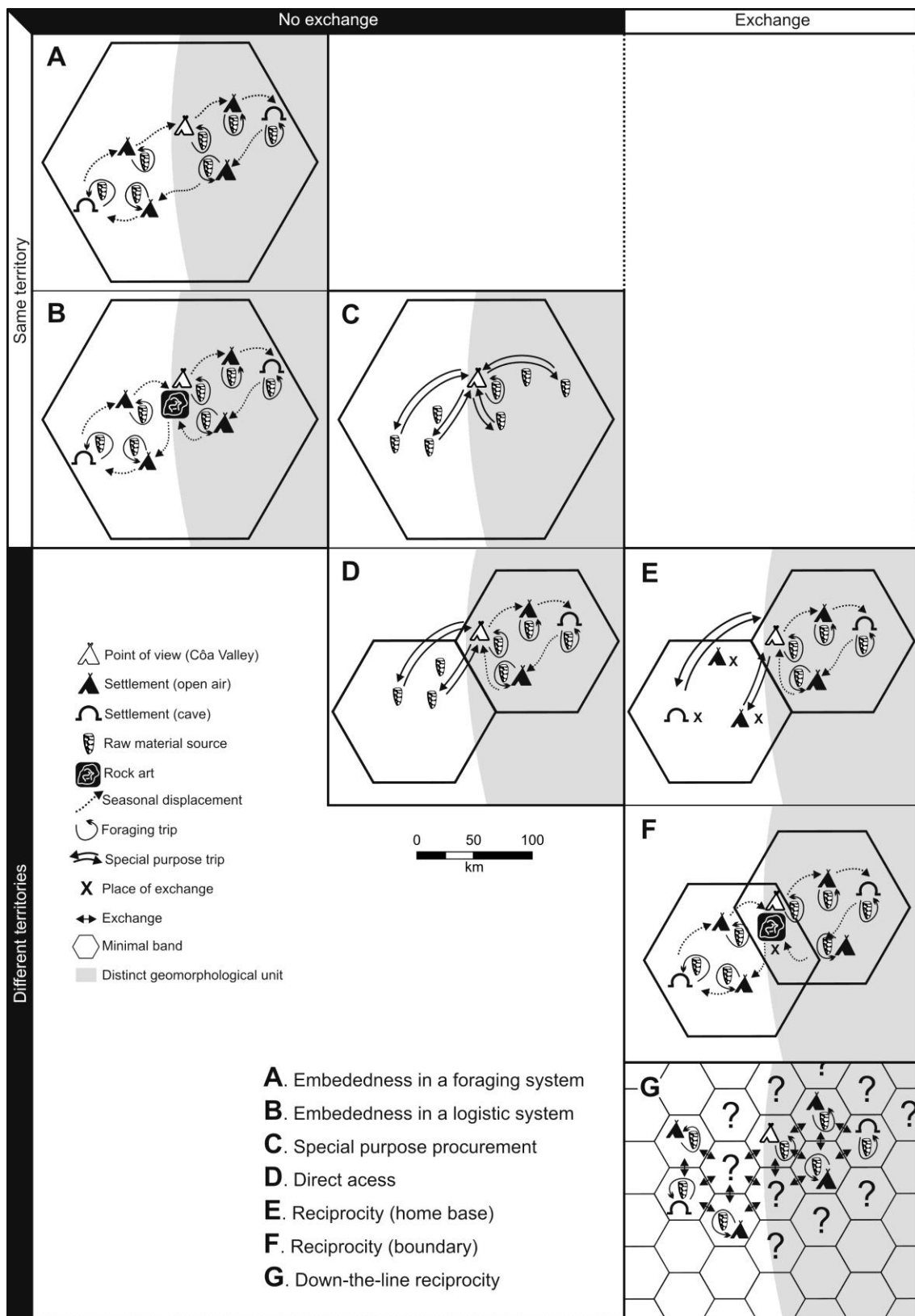
apparently colliding positions. One considers that raw material procurement is essentially embedded in daily subsistence activities (Binford, 1979), while the other argues, based on the long-distance displacement observed among present-day hunter-gatherer groups (Féblot-Augustins and Perlès, 1992), that some raw materials can also be interpreted as direct procurement from a site to one or more specific sources (Gould and Saggars, 1985), or the exchange of raw materials or tools between groups (Gamble, 1999).

Lithic raw materials, and especially so the fine-grained siliceous rocks, are not evenly distributed across the landscape and, as it depends on specific geological variables, the location of certain kinds of lithic raw materials may not coincide with that of other resources used by foragers. A number of ethnographic and archaeological examples show that raw materials can be introduced from distant sources. This fact can be explained by a utilitarian reason, as stated previously, but also by a broader adaptive reason. The presence of these exotic raw materials could be seen as evidence for the creation and maintenance of long-distance social networks. These social networks meet the regular needs of widely scattered groups (resources, partners) and can also function as a “safety net” in exceptional situations of resource scarcity (Gould and Saggars, 1985; Whallon, 2006). These exchange networks can be perceived as adaptive strategies, but they function also as cultural and ideological markers. Even though this type of exchange might be perceived as the opposite of embedded procurement, since it involves resources outside the landscape of habit or the strict home range, object transfers, namely raw materials, are in fact embedded in the activities groups perform (Polanyi, 1957, Gamble, 1999).

Thus, a variety of theoretical possibilities could account for the reality identified in the Côa Valley archaeological record (**Fig. 7**). In a first interpretative model, toolstone

sources located in the Portuguese Estremadura, the Meseta regions and intermediary regions would correspond to parts of a large territory exploited at different times by the same human group in what could be defined as embeddedness in a foraging system (Binford, 1980) (**Fig. 7a**). A different scenario would be embeddedness in a collector/logistical system (Binford, 1980) or a pattern of concentration and dispersion (Lee and Daly, 1999), where groups are seasonally reunited in one aggregation area, after being separated for most of the year (**Fig. 7b**).

Compilation of ethnological literature of the annual land-use range of present-day hunter-gatherers (Kelly 1995: table 4-1) reveals that only the extreme case of subarctic Baffinland Inuit approaches the maximum area defined by the procurement of lithic raw materials discarded on each occupation of the Côa Valley (over 27,000 km<sup>2</sup> in its maximal extension) (**Fig. 8b**). Except for equestrian (Crow Apsáalooke) and maritime cases, there are no hunter-gatherers known to cover an annual territory of such magnitude (Ellis, 2011). However, such extent can be observed in long-term mobility or lifetime ranges, notably among the Nunamiut (Binford, 1983) and the Montagnais (Hertell and Tallavaara, 2011). The areas defined by regional fine-grained siliceous rocks, in the Côa sites and for non local flint of the Portuguese Estremadura sites fall, however, within the limits of the annual land-use range of this type of groups (**Fig. 8a**). Still within the one territory hypothesis, a simplistic view would be to consider that the Côa Valley group undertook special-purpose trips to gather those raw materials from sources inside its own territory (**Fig. 7c**). Besides the territory size problem, this hypothesis would ignore the existence of settlement in the areas where such sources are located, especially in the Portuguese Estremadura area, and the fact that the known data for special purpose trips in the Australian Western Desert indicate that they do not exceed 45 km, travelled by motor vehicle (Gould and Saggars, 1985, table 1), whereas



**Fig. 7.** Theoretical framework of cultural processes behind siliceous raw material long-distance displacements.

the Côa Valley data implicates travel distances of 150 to 250 km. However, the same Australian case-study identifies the existence of male-only trips of almost 300 km to neighbouring territories to gather raw material and visit sacred places. This case-study is an illustration of the fact that some territorially distinct hunter-gatherer groups often have direct access to resources outside their home ground (e.g. Renfrew, 1975) (**Fig. 7d**), because resources are not owned by individuals or groups and land tenure is based on a common property regime (Lee and Daly, 1999). Even though land can be held by a kinship group, reciprocal access is the rule. This hypothesis obviates what seems an excessively vast territory, but the distances travelled within a single year continue to seem very long.

The longest documented straight-line distances covered during an annual range vary between 150 and 250 km (Labrador Innu, Baffin Island Inuit, Labrador Inuit, pre-1885 Nunamiut), with one extreme case of 400 km (Ethen-eldèli Chipewyan) (Ellis, 2011). These examples all have in common its subarctic environment, the use of means of transportation, such as watercraft and dog sled (except for the Ethen-eldèli Chipewyan) and its purpose, caribou hunting.

Several reasons can justify frequent long-distance travels: low density population, extreme climatic conditions, high dependence of seasonal resources and colonization processes. Archaeologically, some of the longest raw material displacements occurred during colonization processes, such as early Clovis settlement (Ellis, 2011) and the Finnish Mesolithic (Hertell and Tallavaara, 2011). Such a context would only be acceptable for the earliest Upper Palaeolithic settlement in the Côa Valley and not for the 20,000 years sequence of stable raw material procurement structure observed, also revealing a perfect knowledge of spatially restricted local raw materials. As stated previously, a palaeoenvironmental forcing is not supported by existing data.

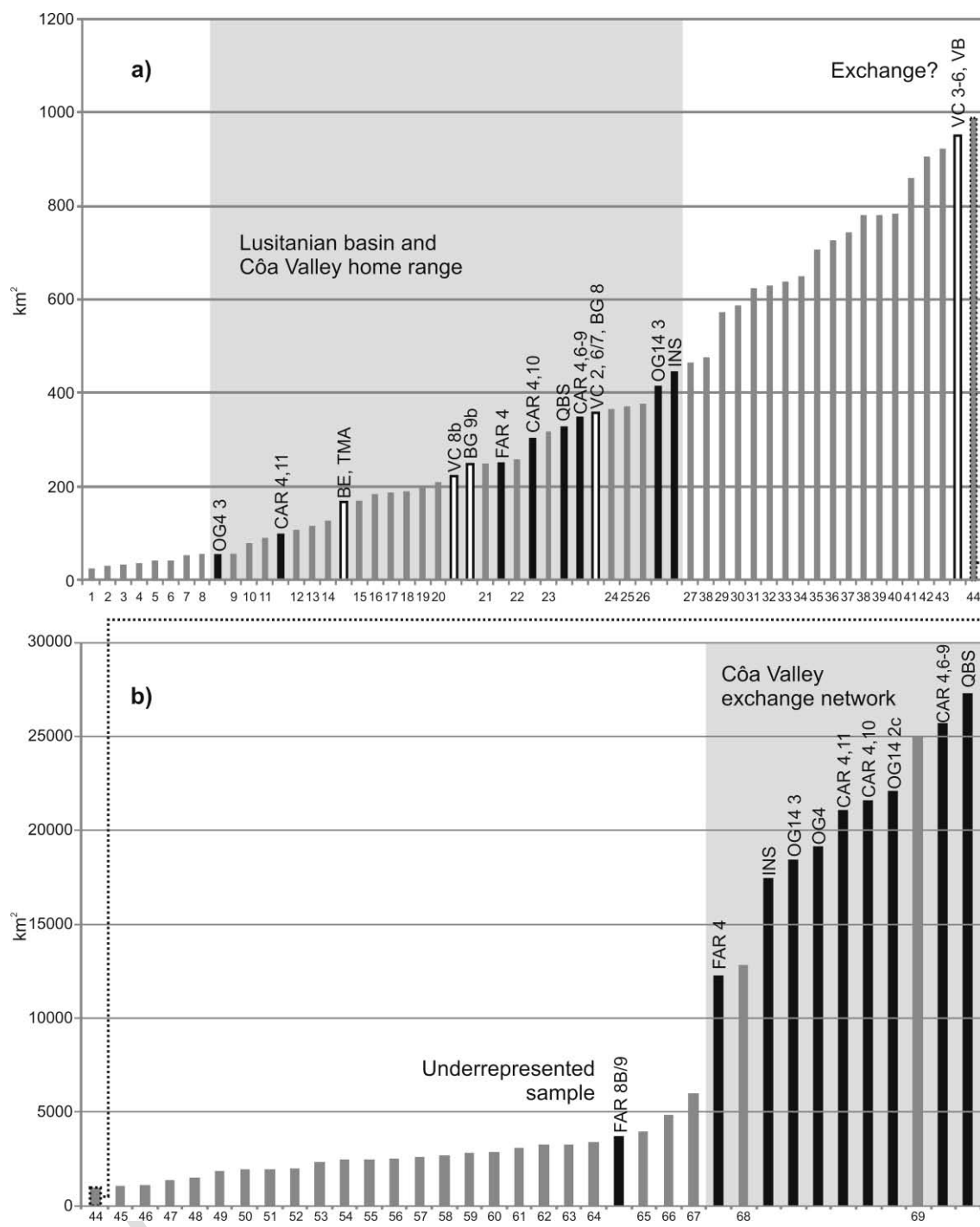
The direct access hypothesis implies one approach the evidence as representing different groups or different territories. In this context we must also consider hypotheses involving exchange. Among egalitarian hunter-gatherers exchange has a completely different meaning than among societies with private property, since goods are shared in what has been defined as generalised reciprocity (Sahlins, 1972) or demand sharing (Peterson, 1993). With this in mind, a fifth scenario would be that, instead of having direct access to the sources, groups would reciprocally exchange raw materials. This exchange would either be made at the home bases of each other (**Fig. 7e**) or at territorial boundaries (**Fig. 7f**) (Renfrew, 1975). Several ethnographic examples of this kind of boundary exchanges can be pointed out, notably amongst the Central Eskimo (Maus and Beuchat, 1905), !Kung (Lee, 1972) and North Andamanese (Kelly, 2005).

Finally, one can suppose that the studied area was homogeneously occupied by different bands practicing down-the-line exchange (Renfrew, 1975) (**Fig. 7g**). Thus, to arrive to the Côa Valley band, the different raw materials would have passed through different hands. This scenario presents some problems, mainly related to the fact that, despite systematic surveys in the Portuguese area, there are no known Upper Palaeolithic settlements in intermediate areas, even where raw material sources used in the Côa Valley are found (**Fig. 1a**). This result could be a product of a data bias due to the present state of research, as illustrated by the fact that prior to 1995 sites were completely unknown in the Côa Valley, but it could also equate with an Upper Palaeolithic reality. Moreover, if it was down-the-line exchange, the resulting raw material percentages would differ from the Côa Valley reality, predictably with closer sources better represented than distant ones.

The hypotheses presented are not necessarily mutually exclusive. One assumes that embeddedness and seasonal displacement are always part of the economic structure of

hunter-gatherers. Special-purpose trips can exist in an embedded reality, and so can exchange.

The data suggest that direct procurement is most probable for the local and regional fine-grained siliceous rocks used in the Côa sites and for the high quality flint discarded systematically on the Portuguese Estremadura sites. The spatial range of flint displacement in the sites located near flint sources of the Estremadura is similar to that defined by the hydrothermal micro-quartz vein varieties exploited in the Côa Valley (**Fig. 8a, Table 3**). The Côa Valley exotic raw material data point to a different scenario. Territory sizes, distances travelled, the archaeological record, and the presence of rock art in this natural geomorphological boundary suggest that the Côa Valley could have been an aggregation area, where dispersed bands would seasonally come together to fulfil their economic, social and cultural needs (**Fig. 7f**). The absence of sites between distant flint sources and the Côa Valley cannot be considered as definitive. A mixed hypothesis, such as the existence of intermediate bands that would acquire these raw materials via exchange, and bring it to the Côa Valley in the context of aggregation or other, cannot be discarded. Like the Australian example previously exposed (Gould and Saggars, 1985), the exotic raw material could also have arrived in the context sporadic traveller's transit, for religious or marriage purposes. Marriage can be an important variable in this analysis. Dispersed and low density population require long-distance marriage networks needed for biological survival (Wobst, 1974), and so, mobility can be regarded as a reproductive strategy (Macdonald, 1998). Beyond a certain threshold, the percentage of marriages decreases with distance, since it ceases to be advantageous (Hertell and Tallavaara, 2011). This marriage or kinship network has been defined as a maximum band (meta-group), which integrates several minimum bands (residential groups) (Wobst, 1974). The regulated exchange of mates and resources among hunter-



**Fig. 8.** Comparison between modern foragers' exploitation areas (Kelly, 1995: table 4-1) and the areas defined by lithic raw material sources. a) Location of all lithic raw material sources represented in the Lusitanian Basin sites and of regional raw materials in the Côa Valley assemblages. b) Areas defined by exotic raw materials in the Côa Valley. Numbers in the x-axis correspond to the different groups: Andamanese (coastal) (1), Karok (2), Wiyot (3), Yurok (4), Andamanese (Onge, inland) (5), Vedda (6), Nesbitt R. (Cape York) (7), Anbarra (8), Straits Salish (E. Saanich) (9), Hill Pandaram (10), Tolowa (11), Quinault (12), Chinook (13), Birhor (14), Ainu (15), Quileute (16), Makah (17), Puyallup-Nisqually (18), Upper Skagit (19), Twana (20), Aka (21), Aranda (22), Berens River Ojibwa (23), Nooksack (24), Nuuchahnulth (Nootka) (25), Tasmanians, N.W. (26), Mbuti (27), Tasmanians, S.W. (28), Tasmanians, Oyster Bay (29), Walapai (30), Bella Voola (Nuxalk) (31), Other Gulf Salish (32), Owikeno Kwakiutl (33), Pikangikum (Ojibwa) (34), Kaiab (S. Paiute) (35), S. Kwakiutl (Ft. Rupert) (36), Worora (37), Guayaki (38),

Siriono (39), G/wi (40), Penan (41), ≠Kade G/wi (42), Haida (43), Kua (mobile) (44), Klamath (45), Tasmanians, Big River (46), Ju/'hoansi (Dobe) (47), Alyawara (48), Maidu (49), S. Tlingit (50), Paiute (51), Nez Perce (52), Washo (53), Semang (54), N. Tlingit (55), Hadza (56), Ngadajara (57), Montagnais (58), Mlabari (59), Grand L. Victoria Cree (60), Micmac (61), Shasta (62), Aeta (63), Mistassini Cree (64), Haisla (65), Waswanipi Cree (66), Netsilingmiut (67), Nunamiut (68), Baffinland Inuit (69). Values for groups 7, 27, 49, 61 and 68 correspond to mean areas.

gatherers, as well as co-residence patterns have been recently identified as keys for the genetic variability of residential communities and the complexity of human social structure through the promotion of coalitions and alliances (Hill et al., 2011; Walker et al., 2011). The existence of marriages among an endogamous maximal band and other rites of passage may occur in aggregation contexts. However, this cannot be understood on a sporadic basis. The fact that exotic raw materials are constantly present in non negligible quantities and respond to permanent needs is also an argument against casual traveller's transit.

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#### **4.4. An aggregation model for the Côa Valley**

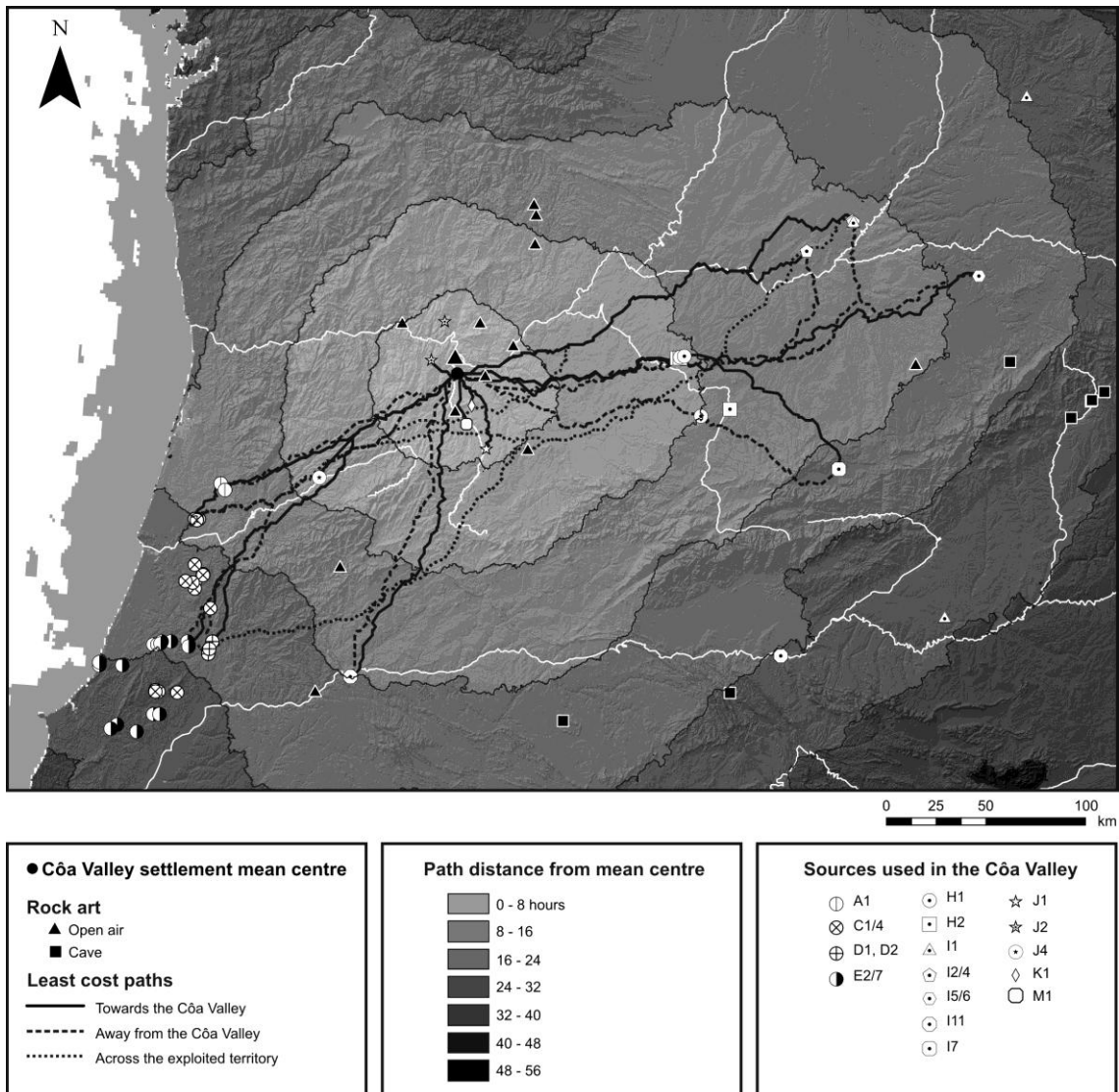
Applying a central place model to our study (Wobst, 1974; Whallon, 2006), the smallest spatial level of the local band would correspond to the local sources ranges documented by lithic raw material displacement in the Portuguese Estremadura and the Côa Valley. The permanent settlement of the Côa area is justified by the knowledge evident in the use of all local raw material types, even those with very restricted sources (J1, J2, M1 and K1).

Ethnographic data and heuristic modelling postulate that such minimum bands in low-population-density areas are not self-sufficient and cannot survive in the long-term (Whallon, 2006). Demography, but also variation in the availability of resources, requires the existence of "safety nets" composed of maximum or regional bands grouping several adjacent minimum or local bands (Whallon, 2006). Based on the raw materials found in the Côa assemblages we propose that, in this case, the Côa Valley

maximum band included Portuguese Estremadura and Northern Meseta local groups and that these areas were part of the same social network of exchange. In such an interpretation, we suggest that the displacement of flint from the Meseta and Portuguese Estremadura was realized by two or more different bands, and toolstone was exchanged and used in the Côa region.

The orographic characteristics of the Côa region suggest its classification as an ecotone area (Farina, 2006): from East to West, it corresponds to the end of the Meseta plateau (~600 m), with several quartzitic residual reliefs (~900 m) and cut by the deeply incised Douro and Côa valley river bottoms (~115 m), bounded to the West by the rugged Western Mountains, with a 200 meter elevation difference.

Among mobile foragers, other than blocks of land, territories can be defined by paths, as exemplified by Mbuti pygmies, whose territories are characterised by narrow paths which connect several hunting camps (Ichikawa, 1978). Least-cost paths from and to exotic raw material sources allowed us to better understand land-use and mobility in the study area. With one exception, paths from and to Eastern flint sources run through the exact area where the outcrops yielding silcrete sources (H1 and H2) are located (Fig. 9). The exact same scenario is verified with South-western flint sources, where the paths defined pass in the vicinities of hydrothermal fine-grained quartz veins (J4). These sources were used in the Côa Valley throughout the entire Upper Palaeolithic sequence, and are located at ~16 hours distance, and in the same direction as the flint sources located at ~32 hours. These results derived from GIS analysis locate these lesser quality sources (H1, H2 and J4) used in the Côa Valley approximately halfway along the least-cost path between this area and the flint sources. This fact is consistent with a scenario in which flint arrived in the Côa Valley in the context of long-distance displacement by



**Fig. 9.** Least-cost paths between raw material sources and settlement destinations.

distinct human groups coming from two, large, outside areas. Nevertheless, one cannot completely discard a second hypothesis, where groups originating from this intermediate area could have brought flint from the Northern Meseta and the Portuguese Estremadura, after obtaining it through exchange. This cost time analysis also reveals that, even though the distance between the Estremadura sources and the Côa Valley is smaller as the crow flies, topographic constraints to movement facilitate displacement towards the Northern Meseta, therefore making it closer.

To test the hypothesis that the Côa Valley could have been a natural crossing point between the Northern Meseta and Portuguese Estremadura, least-cost paths between

two extreme sources from the Meseta, and two others from Estremadura, were produced. Even though these origin and destiny points are arbitrary, since there is no evidence of Northern Meseta raw material in the Estremadura Upper Palaeolithic sites, and vice-versa, the least-cost paths show that, when moving between these two large regions, the Côa Valley is a natural passageway. All of the defined paths run less than 50 km south of the rock art area. Only one is farther out, even though it runs through the neighbouring Upper Palaeolithic rock art site of Siega Verde.

The Côa Valley region is located between two large geographical entities, the Northern Meseta and the Western Mountains (Ferreira, 1978). Historically, the Côa River defined the border between the kingdoms of Portugal and Castile-Leon until 1297, when a treaty incorporated the Ribacoa area, its right bank, in the Portuguese territory. This area, which integrated Meseta land in the Portuguese borders, was an historical pathway between the Atlantic coast of Iberia and the rest of Europe via the Iberian hinterland. In 1282, Elisabeth of Aragon crossed it to marry Denis of Portugal in Trancoso. In 1551, an elephant, offered as a wedding present by John III of Portugal to Archduke Maximilian, passed through Castelo Rodrigo on its way to Austria. In 1810, during the third Napoleonic invasion, the French forces entered Portugal through here, with fighting taking place in the Côa river banks.

Based on the raw material sourcing data and the geographical specificity of this area, we propose that the Côa Valley corresponded to a natural geographical transition zone that can be recognised from the Upper Palaeolithic settlement. This area would be an inclusive one that corresponded to the phase of aggregation or “public life” (Mauss and Beuchat, 1905; Lee, 1972) in a land-use pattern of fusion-fission (**Fig. 7f**). These moments of aggregation can be promoted by ecological factors (Steward, 1936), such as seasonal resource concentration, but present major opportunities social and ritual

activities (Lee, 1972). These moments are particularly important for the exchange of long-distance products, marriage brokering and adoption, but also for rites of passage and other collective rituals based on singing and dancing (Lee, 1972, Kelly, 2005). These are moments of intensified social life, that will end inevitably due to the increasing difficulty in obtaining resources for a large number of people, and the increasing potential conflict (Lee, 1972), even though they can also be seen as a means to prevent intergroupal violence, in the case of territorial disputes (Kelly, 2005).

The fact that the Côa Valley presents the largest concentration of open-air Palaeolithic rock art known today is of crucial importance in our interpretation. Firstly, it is located along the Meseta's western limit, as is a significant proportion of Iberian open-air rock art (**Fig. 1a**). Secondly, several authors have highlighted the social nature of rock art, as a record of exchanges between bands, namely via the exchange of partners or the formation of coalitions (Laming-Emperaire, 1972), the evidence of rites of passage (Owens and Hayden, 1997), and the materialization of aggregation sites (Conkey, 1980). The outside nature of open-air rock art sites, such as in the Côa Valley, makes this interpretation even more evident, as has already been proposed (Baptista and García Díez, 2002; Baptista et al., 2009, Santos, in press). The identification of this complex of rock art sites has shed new light on the Pleistocene artistic phenomenon, which nowadays can be seen an eminently open-air phenomenon, even though, until recently, it was perceived as cave art because of differential preservation (Bahn, 1995).

The lithic raw material sourcing data add to the interpretation of this area's rock art. If raw materials circulate primarily among maximum bands, other symbolic items, such as shells, may prove even wider contacts between adjacent maximum bands (Whallon, 2006). The nature of the Côa Valley archaeological record isn't amenable to the assessment of this type of contacts, but its rock art is different. The different phases of

the Côa Valley rock art attest stylistic commonalities with distant regions implying contacts at an even broader scale than that suggested by the lithic raw material evidence (Zilhão, 2003). The pre-Magdalenian phase, dated archaeologically at Fariseu (Aubry and Sampaio, 2008a, b; Aubry, 2009), is stylistically close to examples from North-eastern France to Southern Spain (Guy, 2002; Santos, in press). Also dated archaeologically, a Final Magdalenian/Azilian phase, present not only in rock panels but also on portable art recovered in a dated context (11,000-12,000 BP) at the Fariseu site (Aubry, 2009; Aubry et al., 2010), shows stylistic affinities with Peña de Estebanvela in the Northern Meseta as well as with sites in South-eastern Spain and Southern France (García Díez and Aubry, 2002; Baptista and Santos, 2010). An intermediate, still archaeologically undated, Middle/Upper Magdalenian phase also presents long-distance stylistic relations with the Northern Meseta (Domingo García) and the North of Spain (Santos, in press).

Stylistic affinities are not coincidences and indicate contacts outside the immediate safety nets. They are beyond the threshold of economic reason and attest the symbolic dimension of human relations. As social networks enlarge, emotional and material exchange and reciprocity diminishes, but symbol and style gain importance for communication and identification purposes (Wobst, 1977).

The Côa Valley lithic tools system integrating systematically exotic raw materials reveals a broad social network of Upper Palaeolithic hunter-gatherer societies. These societies produced and used rock art, which due to its symbolic nature puts in evidence a second and largest level of social networking.

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## **5. Conclusion**

Data obtained from the study of the Côa Valley lithic raw material procurement throughout the Upper Palaeolithic, its technological use, and comparisons with

contemporary occupation in cave, rock-shelter and open-air sites in central Portugal allow us to assess hunter-gatherer mobility and to reconstruct a large scale three level social network.

The first level corresponds to the home ranges of minimum bands, testified by the embedded supply of local and regional lithic raw materials, identified both on the Côa Valley and the Portuguese Estremadura sites.

The second level is attested by the presence of exotic raw material in the Côa Valley. The geological characterization and identification of the sources represented in the Côa Valley assemblages, and the differential use of the lithic raw materials, indicate that this region was the destiny of exotic materials arriving from two geographically opposed regions, the Northern Meseta and Portuguese Estremadura. Regional geomorphology and GIS least-cost paths place the Côa Valley in a transition zone between the Iberian Plateau and the rugged Western Mountains that reach the Atlantic (**fig. 9**), and show that it is a natural pathway between the Atlantic coast and the Iberian hinterland, as otherwise historically documented. The presence in the area of the largest concentration of Upper Palaeolithic open-air rock art currently known led us towards a sociocultural model, which interprets the exotic raw materials as the product of use and exchange between members of one endogamous maximum band (Wobst, 1974) in the context of aggregation events. We perceive the raw material data and the rock art as the materialization of complex social and cultural behaviours that should have also included the exchange of other goods and mates, but also group activities. Finally, the presence of rock art in the area, contemporary with the long duration Upper Palaeolithic settlement, and its stylistic links with sites from an even wider area, puts in evidence the existence of a third level, beyond the maximum group, related to symbolic items (Whallon, 2006).

From the long duration of the rock art tradition and the constant representation of the same basic lithic raw material sources we could infer a stable system, lasting from before the LGM to the Lateglacial. However, fine-grained analysis argues for dynamic changes within this general structure, as observed through an increase in the ratios of sources below the median of the exotic raw material distances (197 km) and procured from the South-west. The network seems to be constrained. This fact could be interpreted as a result of population growth, which is also suggested by an increase in the rabbit to ungulate ratio, as previously mentioned. Moreover, the Côa Valley social network shifts focus, with Eastern inland losing its relative significance in favour of South-western coastal areas. This fact could account for the increased exploitation of aquatic resources during the Magdalenian in Estremadura (Bicho et al., 2003). Territorial constriction, population increase and climate change all point to subsistence stress and a path towards sedentism and land tenure (Kelly, 1992).

Changes in the Côa Valley rock art are concurrent with the changes identified in lithic raw material. Lateglacial art is much more private and discrete than the pre-Magdalenian phase, in terms of size, techniques, placement and overall visibility (Aubry and Luís, 2012; Santos, in press).

Except for Portugal, where site counts are heavily dominated by open-air localities in all periods (Zilhão, 1997), Upper Palaeolithic research in Iberia has basically followed the cave and flint paradigm, focusing mainly on carbonate rocks formed in a marine environment (Northern, Western, South and South-eastern coasts). In this respect, the Côa Valley opens new avenues for the study of Upper Palaeolithic land use in the Iberian hinterland, far away from flint sources. This natural constraint and the cultural choices in stone tool production enable us to study long-distance relations with areas where this fundamental raw material was naturally available, and to integrate it in a

cultural system where rock art was produced and used. However, a geoarchaeological approach has shown that site formation and preservation throughout the Upper Palaeolithic is not homogenous and highly dependent on environment changes and sedimentary processes (Zilhão, 2003, Aubry et al., 2010, 2012). The Côa Valley Upper Palaeolithic settlement still remains an isolated island in the sea of the Iberian inland. Additional research, namely in the Northern Meseta and in Central Portugal, where no settlement is known, despite the existence of raw material sources used in the Côa Valley, is needed to obtain a sharper image of the variability in the exploration of abiotic resources and in social networking patterns over the 20,000 years' duration of the regional Upper Palaeolithic.

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