Stones in Motion: Cost units to understand flint procurement strategies during the Upper Palaeolithic in the south-western Pyrenees using GIS

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Abstract:

Studies on lithic resource management –mainly flint– by prehistoric groups south of the western Pyrenees have significantly increased during the past decades. These studies usually focus on identifying outcrops and characterising the different varieties found at archaeological sites. However, the understanding of mobility and territorial management patterns based on raw materials is still very limited and has only been tackled in terms of lineal distance.

This paper proposes a methodological approach for the territorial analysis of flint distribution with the three following aims: 1) to determine the expansion ranges of each variety of flint from its outcrop; 2) to spatially relate these outcrops with archaeological sites; and 3) to improve our knowledge on the catchment strategies of Upper Palaeolithic groups.

The methodological tool chosen to fulfil these objectives is the Geographic Information System (GIS), because it allows to relate spatially the flint outcrops and flint varieties identified at archaeological sites based on: 1) isocost maps showing the cost of expansion for each variety of flint across the territory built on topography; 2) the quantification of the cost of expansion using Cost Units (CU); and 3) the relationship between the percentage of each variety of flint at each archaeological site and the cost of accessing its outcrop. In order to demonstrate that cost is a powerful way to relate spatially raw material distribution and archaeological sites with outcrops, we contrasted its results with the ones obtained by more classic means (Euclidean distance and distance across the most optimal route). It was therefore shown that cost is better at explaining the spatial relationship between flint outcrops and archaeological sites, which, in turn, provides new data on catchment strategies, mobility patterns and territorial management of Upper Palaeolithic groups.

Keywords: Upper Palaeolithic; South-Western Pyrenees; flint procurement; GIS; cost; territorial management; mobility patterns

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1. Introduction

Despite the progress made in recent years, only a few aspects of the macrospatial behaviour of Palaeolithic societies are known and information about the decisions and determining factors that led these groups to settle or move across the landscape is still scarce. Fortunately, the increasing interest in palaeogeographic analyses, the development of new theoretical models, the application of new techniques (*e.g.*, palaeoenvironmental, stable isotope or archaeopetrological studies) and the progressive addition of new computational tools to process geographic information, have enabled new perspectives on Palaeolithic territorial patterns to emerge as a result (Kelly 1995; Binford 2001; Burke 2004; Vialou 2005; Whallon 2006; Hamilton *et al.* 2007; Geneste *et al.* 2008; Grove 2009).

Following this trend, the study of lithic raw materials has attracted most of the efforts of archaeologists seeking to characterize the procurement and management of lithic raw resources, the articulation of economic territories and the mobility patterns of Palaeolithic groups (Sarabia 1995; Terradas 2002; Mangado 2006; Djindjian 2009). The precise location and petrological characterisation of the main procurement sources (mostly flint) has recently taken a great step forward. This has enabled the identification of long-distance economic links between settlement and outcrops (Geneste & Rigaud 1977; Demars 1982; Arias 1992; Close 1996; Simonnet 1996; Bernabeu *et al.* 1998; Djindjian *et al.* 1999; Bourguignon & Turq 2008; Corchón *et al.* 2009). On the southern slope of the western Pyrenees, the area on which this study focuses on, research carried out by A. Tarriño over the past several years has been especially important (Tarriño 2006; Tarriño *et al.* 2007a; Tarriño *et al.* 2007b; Tarriño 2011a; b; Tarriño *et al.* 2013; Tarriño & Elorrieta 2013; Tarriño *et al.* 2015).

As a result of these studies, there is an increasingly bigger “map of dots and arrows”, where these connections are shown linearly, sometimes categorized according to the percentages of the different flint varieties found. In our opinion, these analyses do not adequately address the geographic constraints that conditioned Palaeolithic groups and they do not represent the actual possible routes taken by them. Therefore, this classic approach cannot explain the reasons behind the variations observed in the types of flint used.

The use of Geographic Information Systems (henceforth GIS) to model the mobility of human groups has a long tradition in the archaeological research of the Iberian Peninsula, with a special focus on the Holocene (Fairén 2004; Fábrega & Parcero 2007; Murrieta-Flores *et al.* 2009; Parcero *et al.* 2009; Murrieta-Flores 2010; Llobera *et al.* 2011; Güimil-Fariña & Parcero-Oubiña 2015). This tool is not commonly used in Palaeolithic studies, either because research has focused on other topics, or because of the difficulty of adapting this methodology to a much less visible record on a macro scale. Nevertheless, excellent studies integrating this tool (using optimal routes) with concepts such as accessibility or cost and applied to the study of settlement patterns (García 2010; Turrero *et al.* 2013) or the management of faunal resources (Coward 2004; Marín 2008) have recently been published for the Cantabrian Region.

In the case of lithic resource procurement, its application is even more innovative, as shown by the pilot studies carried out on the Portuguese valley of Foz Côa (Aubry *et al.* 2012), the valleys of the Trubia river in Asturias (Fernández 2010) or the Asón in Cantabria (Rissetto 2009; 2012). These works, pioneers in our area of study, deepen into the modelling of operational mobility based on optimal routes and have allowed us to obtain highly interesting, yet provisional, conclusions on the management of lithic resources by Palaeolithic groups. However, optimal route approaches (*e.g.*, Least Cost Path analyses) are usually limited to determine the shortest line between two places, ignoring the fact that multiple paths can actually connect two spots and that choosing one or another will depend on several factors different from linear distance.

The present study makes a case for the usefulness of the ‘cost’ concept in the analysis and interpretation of raw material provisioning/sourcing by prehistoric human groups as an alternative to Euclidean distance or the identification of optimal routes. In order to do so, we suggest an approach based on orography and developed using digital cartographic analysis tools such as GIS (van Leusen 2002; Wheatley & Gillings 2002; Connolly & Lake 2006; White & Surface-Evans 2012). As a first case study, this paper focuses on the Upper Palaeolithic of the southern region of the western Pyrenees and seeks to fulfil the following objectives:

- To determinate and compare the ranges of expansion of the three main flint types, using three different measurement sets, obtained from the application of Least Cost Analysis (LCA) through GIS.
- To determinate which of these three measurement suggestions best fits the archaeological record.
- To bring back orography as a key factor to understanding Palaeolithic mobility. In this way, we may be able to identify constraining transit areas or high-mobility transit zones that affected the movement of Palaeolithic societies.

2. Context and materials

The geographic framework chosen for this case study are the south western foothills of the Pyrenees, delimited by the Cantabrian Sea to the north, the Ebro Basin to the south, the estuary of Bilbao to the west and the Bidasoa valley to the east. This area corresponds to the current Spanish Autonomous Regions of Euskadi, Navarre and a small part of the province of Burgos. This area is part of the natural corridor formed by the foothills of the western Pyrenees (Figure 1) and is an appropriate geographical framework for the present research for the following reasons:

1. It is a natural crossing area between the European continent and the Iberian Peninsula, where intense mobility of Upper Palaeolithic groups has already been noted (Arrizabalaga 2007; 2009; Arrizabalaga & Iriarte-Chiapusso 2010a; b; Arrizabalaga *et al.* 2013; Arrizabalaga *et al.* 2014).
2. Both watersheds of the western Pyrenees show a significantly high density of high-quality flint outcrops extensively exploited during the Palaeolithic.
3. This is a region with a highly variable orography.
4. Detailed digital cartographic information is available for the study region.

Within this framework, we chose the three outcrops corresponding to the most common flint varieties known for the Upper Palaeolithic (Tarriño 2006). These are:

1. Kurtzia Flysch flint (Barrika, Bizkaia**):** This variety outcrops in an olistostrome 40 metres deep pertaining to the Eibar Formation (Mathey 1982). The nature of this type of outcrop allows weathering agents to easily free flint blocks from it, placing them in the marine influence area. This variety is bioclastic with many sponge spicules, detrital quartz and moldic microporosity from the dissolution of dolomite crystals (Tarriño 2006: 64-67).
2. Treviño flint (Treviño, Burgos): This variety outcrops in the Araico-Cucho mountain range, which is formed by Miocene lacustrine-palustrine limestone and contains plenty of nodular and stratiform silicifications. There are four main varieties: two bioclastic nodular (gastropods and ostracods) –one of them micritic, with liesegang rings, and the other rich in organic content–, and two stratiform –a brecciated silcrete with ooidal texture and siliceous cementations and a micritic one with algal lamination- (Tarriño 2006: 86-92).
3. Urbasa flint (Urbasa, Navarra): These are Thanetian (Paleocene) silicifications located in the SD-6 depositional sequence of the Urbasa mountain range (Baceta 1996: 120-133). This flint is composed of microquartz, benthic foraminifera (*Nummulites heberti* and

Discocyclina seunesi) and fragments of echinoderms. Its colour is dark and morphology nodular, sometimes slightly botryoidal (Tarriño *et al.* 2007b).

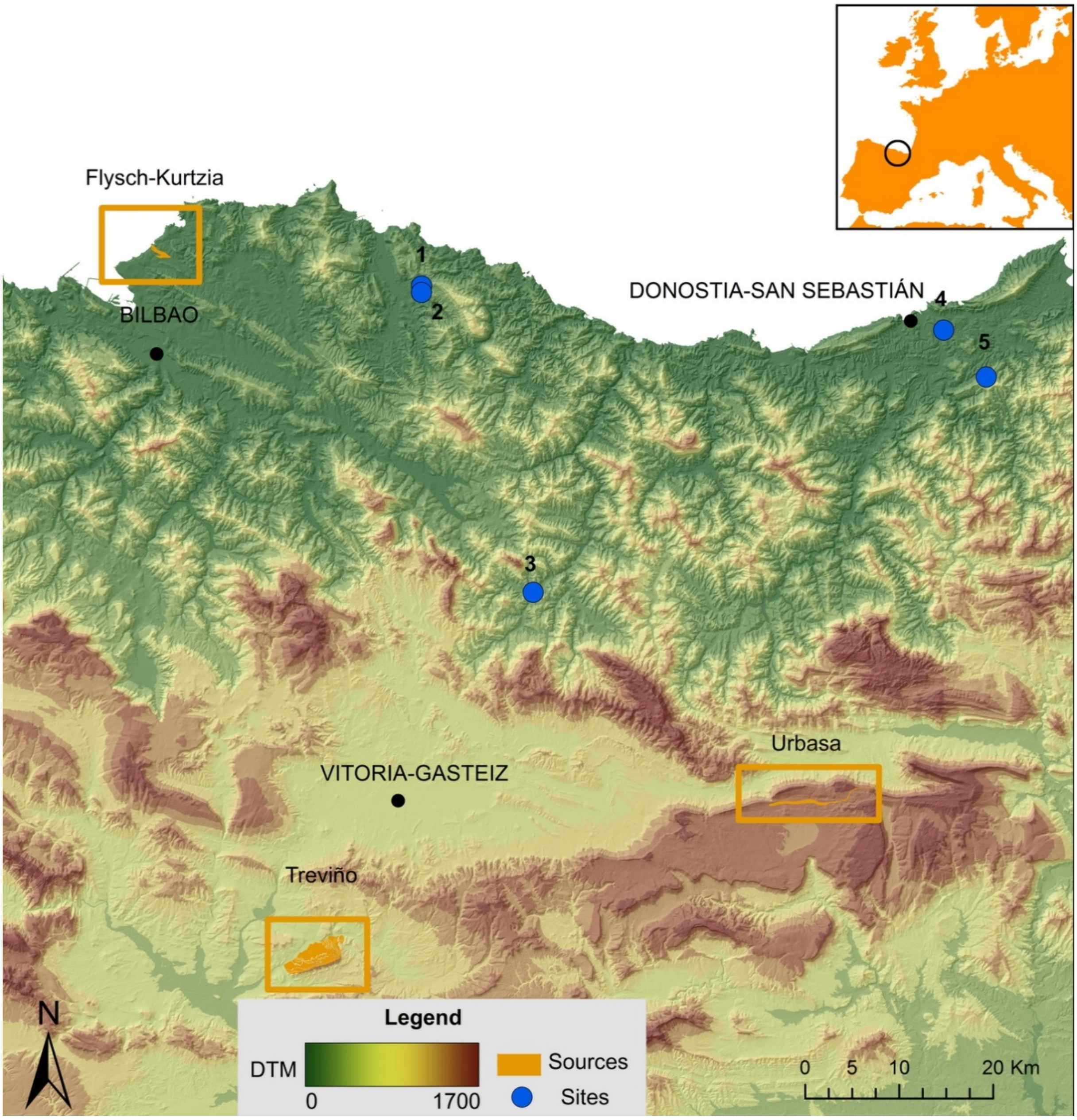

Figure 1. Digital elevation model showing the location of the archaeological sites and geological outcrops in the area of study. Archaeological sites: 1. Antoliñako Koba, 2. Santimamiñe, 3. Labeko Koba, 4. Ametzagaina and 5. Aitzbitarte III.

Likewise, for the present study we chose Upper Palaeolithic archaeological sites in the region that had already been studied in terms of the origin of the lithic raw materials and where the flint varieties mentioned above had been identified. The sites are:

1. Aitzbitarte III (Rentería, Gipuzkoa): This cave was excavated by J. M. de Barandiarán from 1961 to 1965 and re-excavated by J. Altuna between 1986 and 2002. It has an important sequence running from the Early Upper Palaeolithic. It presents a level with Aurignacoid and Mousteroid industries (Vb base) at the bottom, on which there is an Evolved Aurignacian level (Vb central) and four Gravettian levels (Vb superior, Va, IV and III), from both the early

and late phases. At the top, a level between the Gravettian and the Middle Solutrean (II) and a level attributed to an indeterminate Upper Palaeolithic (I) were noted (Altuna *et al.* 2011).

2. Ametzagaina (Donostia-San Sebastián, Gipuzkoa): This open-air campsite was excavated by J. Tapia between 2007 and 2009. Two main lithic assemblages (East and West) were recovered. A large part of them was found on the surface. The East assemblage was entirely attributed to the Gravettian, whereas the West assemblage, being also Gravettian, probably has intrusions from the Evolved Aurignacian. One of the pits excavated (Pit 7) revealed the existence of a stratigraphic relict, where a level with industry from the same Gravettian facies was recorded (Tapia et al. 2009; Calvo 2012; Calvo et al. 2013).

3. Antoliñako Koba (Gauteguiz-Arteaga, Bizkaia): This cave, initially explored by J. M. de Barandiarán in 1923, was excavated by M. Aguirre between 1995 and 2008. It contains a deep stratigraphy covering the whole of the Upper Palaeolithic; from the Evolved Aurignacian level at the base (Lmbk inf/Smk), to the Upper Magdalenian/Azilian (Lanc) at the top. The intermediate section of the sequence is noteworthy, especially the levels dated back to the Early (Lmbk sup) and Late (Lab) Gravettian and to the Upper Solutrean (Lmc). Above this level there is another modest one pertaining to the Evolved Lower Magdalenian (Lgc sup) (Aguirre 2000; 2012).

4. Labeko Koba (Arrasate, Gipuzkoa): This cave, now destroyed, was completely excavated during a rescue archaeological excavation in 1988, under the direction of A. Arrizabalaga. The site preserved one of the most important stratigraphies in the Iberian Peninsula for the beginning of the Upper Palaeolithic. The sequence comprised, from bottom to top, a Châtelperronian level (IX inferior), a Protoaurignacian one (VII), three levels pertaining to the Early Aurignacian (VI, V and IV) and a last level of uncertain nature, maybe related to the final episodes of the Aurignacian (III) (Arrizabalaga & Altuna 2000).

5. Santimamiñe (Kortezubi, Bizkaia): This famous rock art sanctuary from the Middle Magdalenian underwent three main excavations: from 1918 to 1926 by J. M. de Barandiarán, T. Aranzadi and E. Eguren; from 1960 to 1962 by J. M. de Barandiarán; and, finally, from 2004 to 2012 by J. C. López Quintana. According to the data obtained during its first excavation, the deep stratigraphic sequence spans, without interruption, from the Early Upper Palaeolithic (level IX, Aurignacian) to the Roman period (level 1a). The Palaeolithic occupation is represented by the aforementioned Aurignacian level at the bottom and by successive Gravettian (VIII), Solutrean (VII) and Magdalenian (VI) levels (Barandiarán 1976). The last excavation of the innermost sector of the entrance revealed the existence of a Late Lower Magdalenian (Csn-Camr), a Middle/Upper Magdalenian? (Almp), a Final Upper Magdalenian (Slnc) and an Azilian levels (Arcp) (López Quintana 2011).

The data on the raw material distribution at these sites are shown in the following table (Table 1). The percentage of each flint variety was obtained from the bibliography available. Total number of stone pieces is shown in the table, including other raw materials and flint varieties not considered in this paper, as well as unknown flint varieties. Percentage were calculated taking into account the total number of stone pieces from each archaeological level and the quantity of each flint variety.

3. Methodology

For this research study we used the spatial analysis tools offered by the ArcGIS 10.2 software and the Digital Elevation Model (MDT25, following the Spanish acronym) developed by the Spanish National Institute of Geography (IGN 2014). All the data included in this study were georeferenced following the UTM-ETRS89 (zone 30N) system of projected coordinates.

We did not consider bathymetry due its limitations when applied to the past, although we know it could have provided very interesting data on currently submerged Palaeolithic shore and lowlands. The main problem in this respect is access to data, the fluctuations of the sea-level and the differential erosion of its surfaces, which could distort the results of this study. The fact that our spatial analysis deals with current landscape features instead of actual Palaeolithic orography is another limitation, but we consider high-resolution digital cartography is still the best source for our approach. Finally, we are also aware effort or cost cannot only be quantified through geographic variables, but we consider these are the only ones based on consistent data we have access to nowadays. Factors such as vegetation, lithology, the river system or climate constraints could have greatly influenced the mobility of Palaeolithic groups, but being unable to know their exact impact at each period prevents us from including them systematically. Bearing these biases in mind, these are the steps we followed:

Table 1. Raw data of the sites and the archaeological levels included in the study. An asterisk indicates the identification is only probable, since it was not easy to distinguish the Flysch variety of Kurtzia from the other Flysch varieties available in the region. Only cases where the Flysch flint identification is specified in the bibliography are listed.

Site	Level	Chrono-cultural attribution	No. stone pieces	Flint varieties (%) Flysch Kurtzia	Urbasa	Treviño	References
Aitzbitarte III	Vb base	Mousterian-Aurignacian	46	0*	0	0	Tarriño 2011
	Vb	Evolved Aurignacian	850	0*	6.4	0.8	Tarriño 2011
	Vb sup	Early Gravettian	165	0*	9.1	1.8	Tarriño 2011
	Va	Early Gravettian	358	0*	10.9	0.6	Tarriño 2011
	IV	Early Gravettian	222	0*	19.8	0.5	Tarriño 2011
	III	Recent Gravettian	356	0*	16.3	0.6	Tarriño 2011
Antoliñako koba	Lab/Lmbk sup/Lmbk inf	Gravettian	224	75	10.3	4.9	Tarriño 2006 (137-144)
	Lmc	Solutrean	415	58.3	9.9	20.7	Tarriño 2006 (137-144)
	Lgc/Lamc/Lanc	Magdalenian	77	79.2	6.5	9.1	Tarriño 2006 (137-144)
Labeko Koba	IX inf	Chatelperronian	68	36.8	26.5	19.1	Tarriño 2000
	VII	Proto-Aurignacian	1.422	7	65.5	23.3	Tarriño 2000
	VI	Early Aurignacian	95	8.5	35.1	42.6	Tarriño 2000
	V	Early Aurignacian	1.358	1.5	51.8	36.5	Tarriño 2000
	IV	Early Aurignacian	875	1.8	33.7	43	Tarriño 2000
	III	Early Aurignacian?	51	90.2	3.9	5.9	Tarriño 2000
Santimamiñe	Csn-Camr	Lower Magdalenian	92	68.5	5.4	3.3	Tarriño 2011
	Arcp	Azilian	144	82.6	4.2	0	Tarriño 2011
Ametzagaina	Eastern Assemblage	Gravettian	2.029	1	4	0	Arrizabalaga *et al.* 2014
	Western Assemblage	Evolved Aurignacian-Gravettian	932	0*	1	0	Arrizabalaga *et al.* 2014

First, after having merged all the MDT25 sheets covering the territory under study, we created a slope map, measured in degrees, using the *Slope tool* (Figure 2.a). Next, this map was reclassified with the *Reclass tool*. The values of the cells of the new raster output were calculated by assigning average subunits of cost to the movement between specific slope ranges (Figure 2.b). This calculation was based on the model developed by M. Llobera (2000) after A. E. Minnetti’s experiments (Minnetti 1995) (see also López Romero, (2005)).

However, it is worth mentioning there are other valid approaches to calculate the cost of moving, such as those of Pandolf (1977), Langmuir (1984: 35) or Tobler (1993), whose most recent adaptations (Marín 2009; Kramer 2010) are currently being debated (Kantner 2012). The method chosen for this study defines the unitary value of cost as the effort generated by moving at a constant speed of 5 km/h on a 0º slope (Figure 2.c). As a result, we obtained a new surface friction map where each pixel contains information on the effort required to cross it, expressed in subunits of cost (Figure 2.d).

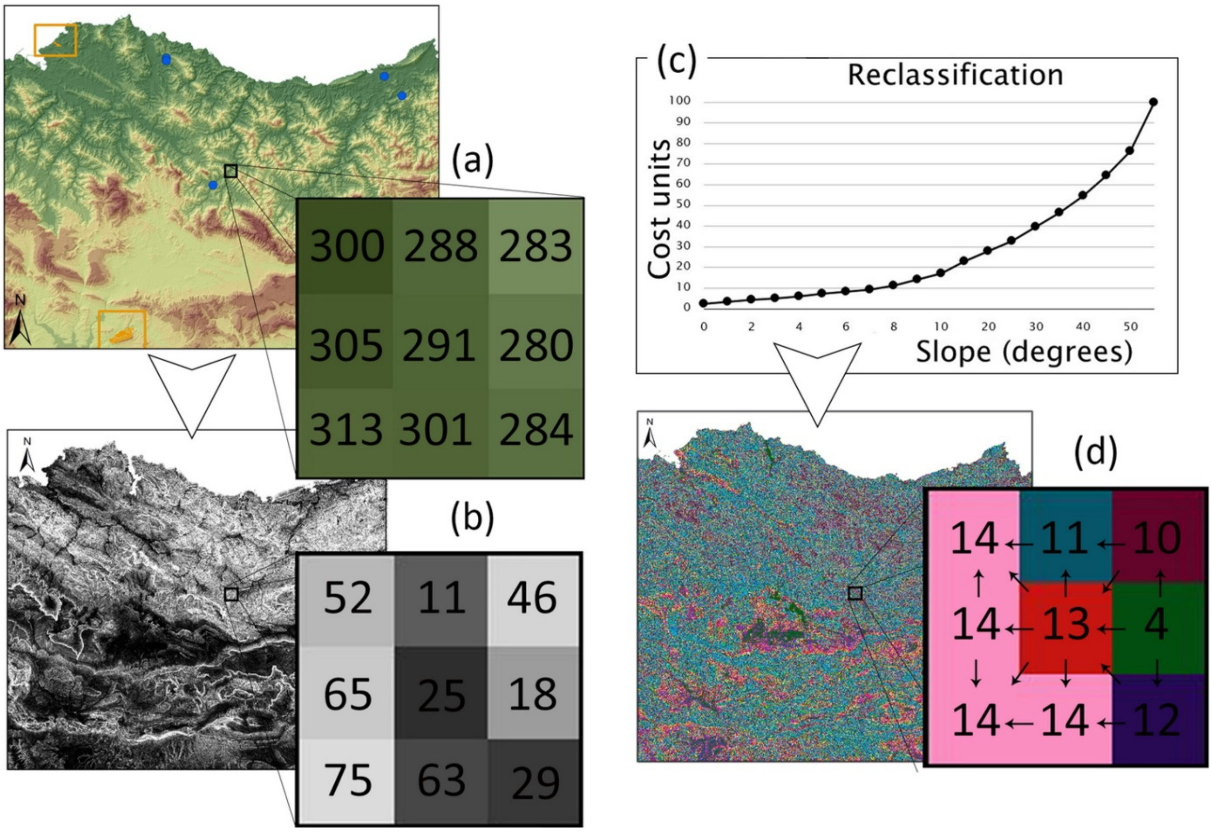

Figure 2. Methodological diagram showing the first four steps of the procedure for getting cost maps: a) digital elevation model showing the location of the archaeological sites and flint outcrops, with detail of the elevation value of each pixel; b) slope map, with detail of the slope value of each pixel; c) reclassification curve; d) slope map reclassified according to the reclassification curve.

The locations of the flint outcrops on the map were represented based on the geological units they belong to, as defined by the geological maps from the MAGNA 1:50.000 series provided by the Spanish Institute of Geology and Mining (IGME 2010c; a; b). In order to overcome the problem of identifying the precise location of the flint procurement places used by the Upper Palaeolithic societies, we decided to work with the centroid of the polygon drawn along the borders of each flint outcrop as a standardised procedure (Coordinates: Kurtzia Flysch UTM: 30T X:501638 Y:4803640; Treviño UTM: 30T X:518292 Y:4729046; Urbasa 30T X:570791 Y:4745451) (Figure 3.a). Once these points were located on the friction surface map (slope reclassified), we performed the geoprocess *Cost distance tool* (Figure 3.b). The resulting map shows, through a gradient of colours, the accumulated cost of carrying each variety of flint to any given point in the territory. Then we reclassified this map in ranges of 15,000 subunits (Figure 3.c). Each of these ranges was considered a Cost Unit (CU from now on). This step was performed in order to make representation and management of the data clearer and easier. (Figure 2.c). Finally, and with the aim of simplifying the visualization, we grouped the resulting values in groups of four CU by colour (Figure 3.c).

Accessibility from the outcrops to each site is another research question to be considered in order to understand flint mobility networks. We used the same methodology to address it (Figure 4). We repeated the geoprocess *Cost-distance tool*, but in this case, obtaining two maps: an accumulated cost map originating from the outcrop under study (Figure 4.b), and a new one, the direction map (Figure 4.c). Combining both through the geoprocess *Cost path tool*, we obtained the optimal routes between the procurement areas and the sites: the paths of least accumulated cost between them and their length (Figure 4.d). In addition, we calculated the Euclidian distance between the centroids of the flint outcrops and the archaeological sites. All in all, we applied three different methodological approaches and, as a result, we obtained three different quantitative datasets to evaluate the same issue.

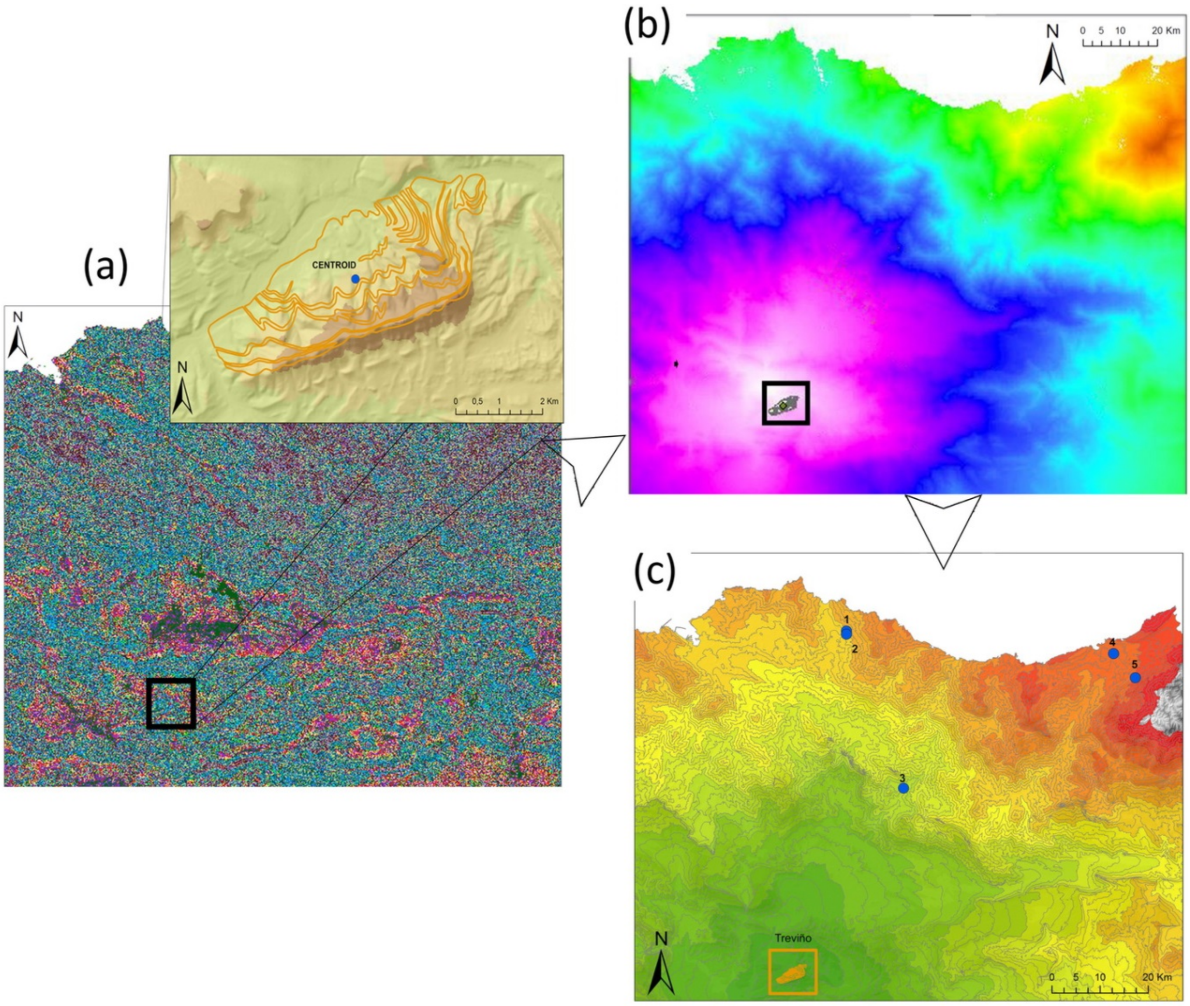

Figure 3. Methodological diagram showing the procedure for getting accumulated cost maps from a given outcrop: a) slope map reclassified according to the reclassification curve, with detail of the centroid of the outcrop of Treviño; b) accumulated cost map from the outcrop of Treviño; c) accumulated cost map from the outcrop of Treviño reclassified in CU. Scale bar in maps a to c is 20 km, and is 2 km in the inset map.

Additionally, we used some statistical procedures to understand and observe the differences between these three datasets. The results were described and compared with the archaeological record –primarily the percentages of raw materials at each site and the clusters of points on biplot graphs.

Finally, and regarding the final goal stated, we would like to compare the different expansion ranges and the theoretical spread of the different flint varieties. To do so, we visually compared the expansion of each flint variety through two box plots.

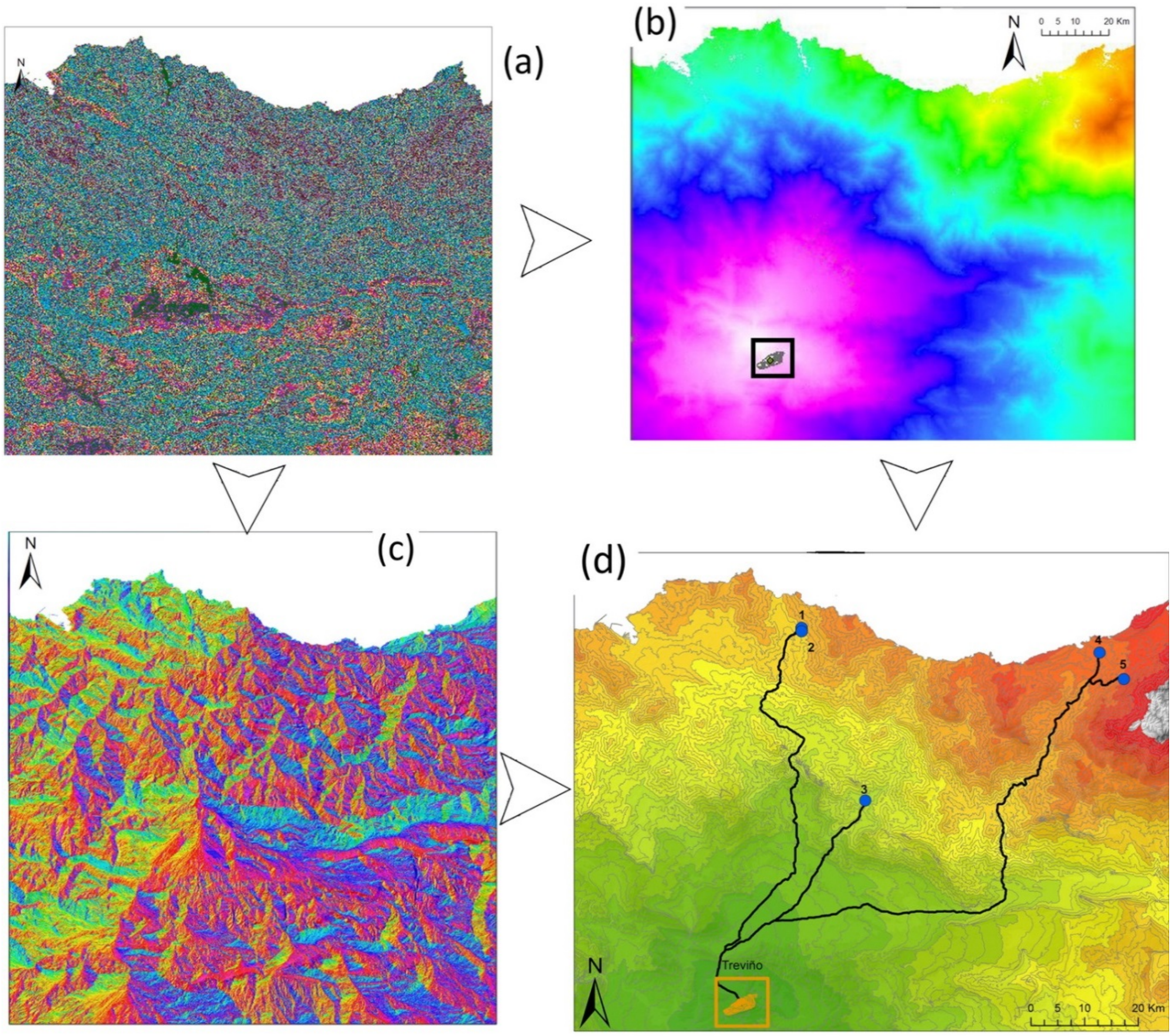

Figure 4. Methodological diagram showing the procedure for getting optimal routes and its comparison with CU and Euclidean distance: a) slope map reclassified according to the reclassification curve; b) accumulated cost map from the outcrop of Treviño; c) movement directionality map based on the cost map; d) map integrating CU and the linear magnitudes (Euclidean distance and optimal route).

4. Results

Traditionally the two approaches used to link flint outcrops and archaeological sites have been linear distance and distance through the optimal route. We also wanted to test these methodologies, so we produced three maps, one departing from each outcrop, with the objective of comparing these two traditional measurements with the one proposed in this paper: cost (Figure 5, 6 and 7). These figures represent the isocost lines from each of the three flint outcrops, showing the cost of a specific flint towards different sites and determining what the equivalent cost is. These maps also show the most relevant geographic units for human transit –such as plains, plateaus and valleys- represented by broad areas of the same colour. In addition, each map depicts, on the one hand, optimal routes, which show curvilinear shapes that adapt themselves to favourable passing zones, and, on the other, the Euclidean distances, which cross different geographic units regardless of their topography.

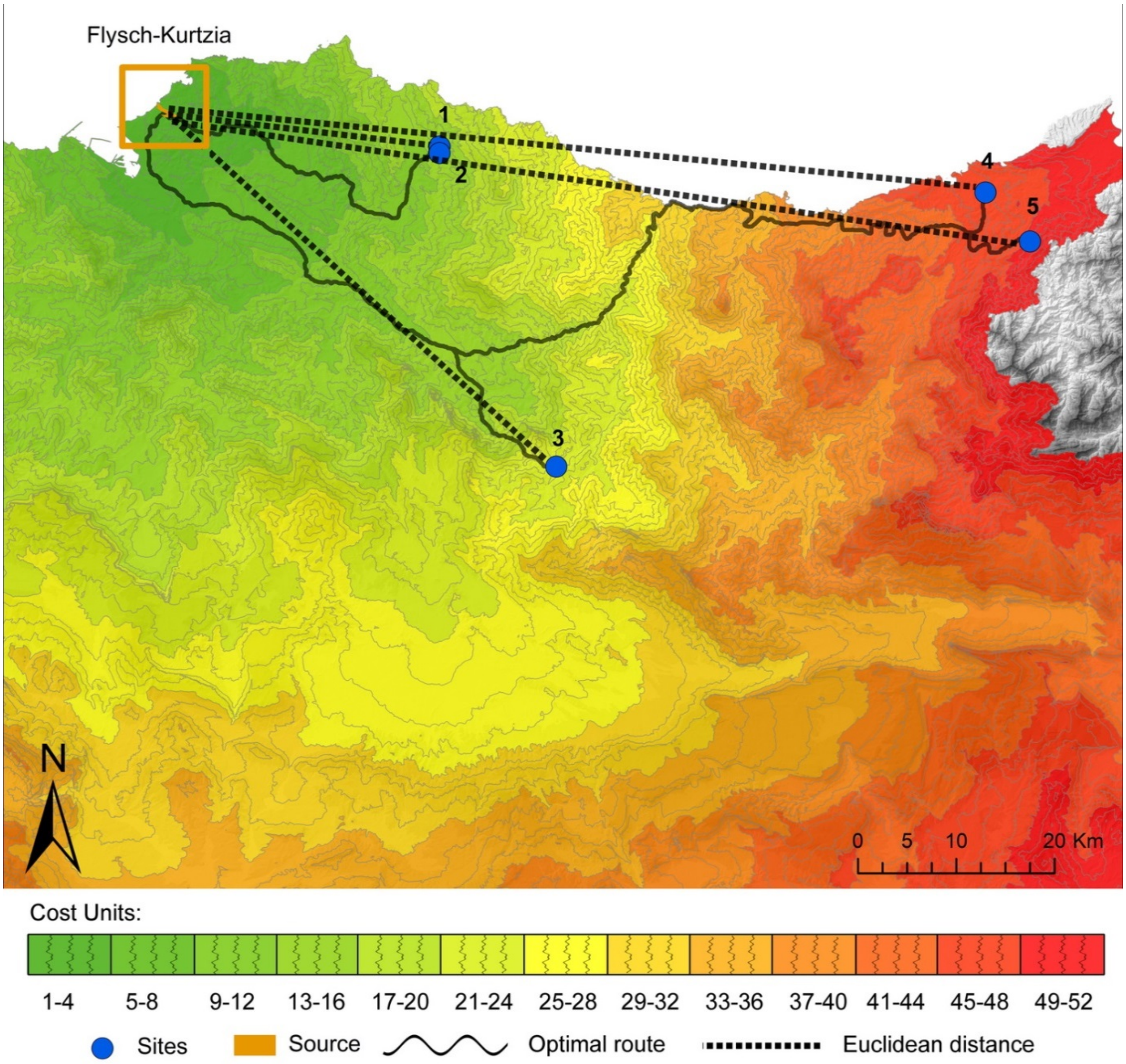

Figure 5. Map of the expansion of the Flysch Kurtzia flint representing the three types of measurement evaluated in this paper: Euclidean distance, the distance through the optimal route and cost. Legend: 1. Antoliñako Koba, 2. Santimamiñe, 3. Labeko Koba, 4. Ametzagaina and 5. Aitzbitarte III.

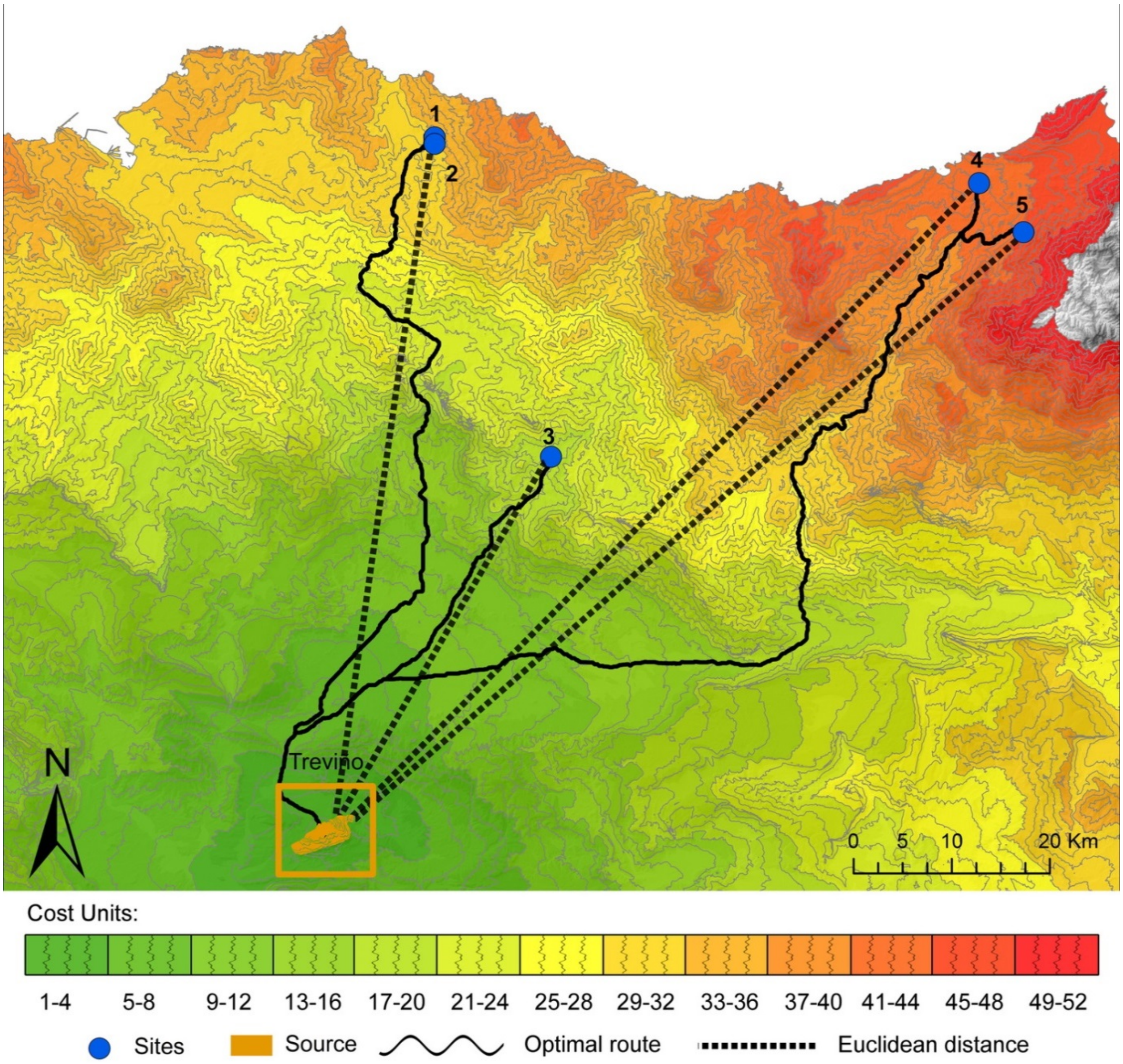

Figure 6. Map of the expansion of the Treviño flint representing the three types of measurement evaluated in this paper: Euclidean distance, the distance through the optimal route and cost. Legend: 1. Antoliñako Koba, 2. Santimamiñe, 3. Labeko Koba, 4. Ametzagaina and 5. Aitzbitarte III.

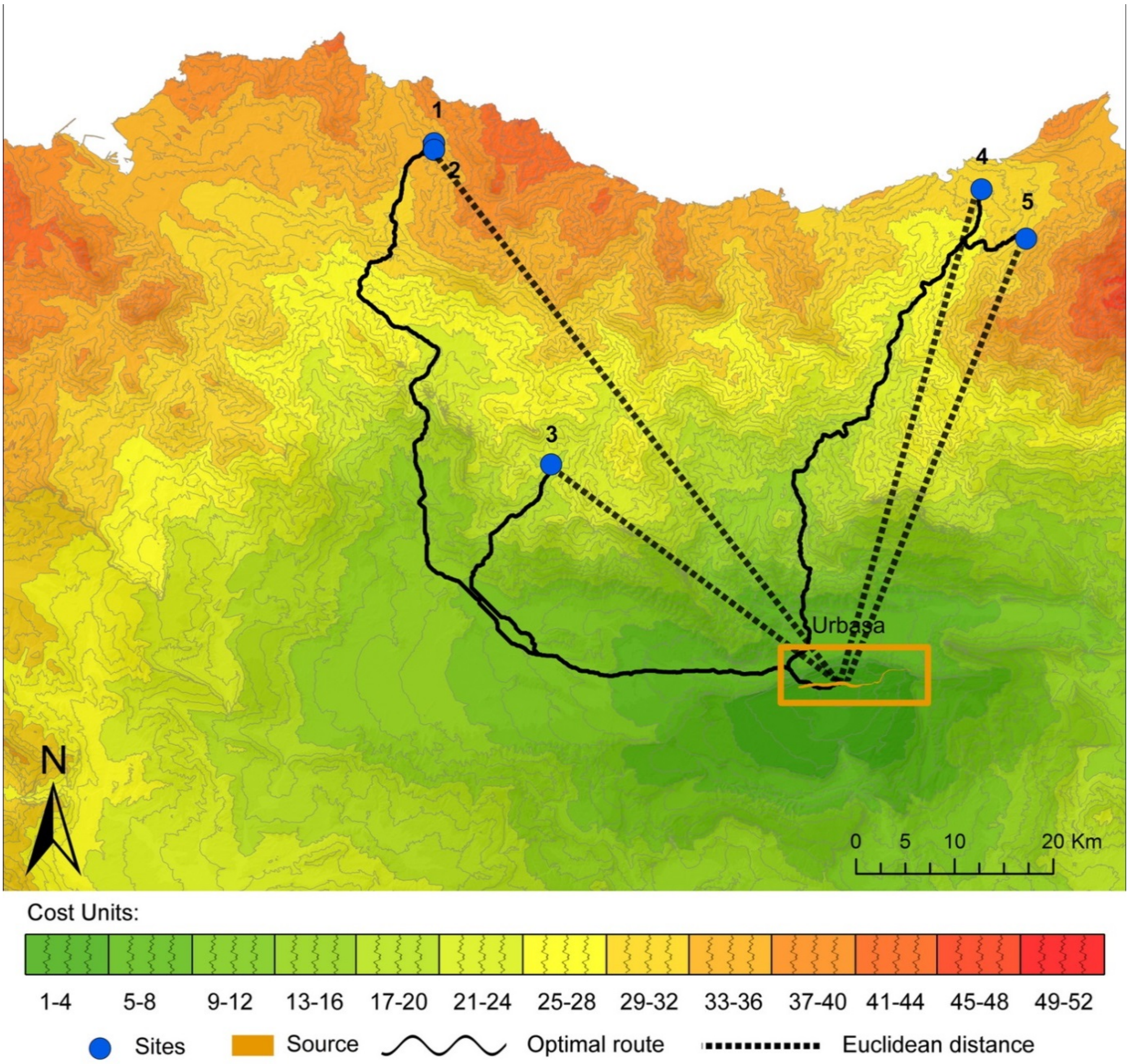

Figure 7. Map of the expansion of the Urbasa flint representing the three types of measurement evaluated in this paper: Euclidean distance, the distance through the optimal route and cost. Legend: 1. Antoliñako Koba, 2. Santimamiñe, 3. Labeko Koba, 4. Ametzagaina and 5. Aitzbitarte III.

Using the data derived from this analysis, we put together a table that contains the Euclidean distance, the distance through the optimal route and the cost between each outcrop-site combination (Table 2). The first two are expressed in metric units (kilometres) while cost is expressed in CU.

Table 2. Value of each possible site-outcrop route according to the three measurement methods proposed

Routes	Euclidean distance (km)	Optimal route (km)	Cost (Cost units)
Aitzbitarte III-Flysch Kurtzia (Ait-F)	88.96	133.88	49
Aitzbitarte III-Treviño (Ait-T)	94.22	137.73	44
Aitzbitarte III-Urbasa (Ait-U)	49.05	75.43	31
Ametzagaina-Flysch Kurtzia (Ame-F)	83.87	129.33	47
Ametzagaina-Treviño (Ame-T)	94.32	134.78	42
Ametzagaina-Urbasa (Ame-U)	52.08	72.5	29
Antoliñako Koba-Flysch Kurtzia (Ant-F)	28.24	42.06	15
Antoliñako Koba-Treviño (Ant-T)	72.27	96.7	32
Antoliñako Koba-Urbasa (Ant-U)	68.77	106.98	35
Labeko Koba-Flysch Kurtzia (Lab-F)	54	66.55	25
Labeko Koba-Treviño (Lab-T)	45.12	56.65	21
Labeko Koba-Urbasa (Lab-U)	36.9	61.42	23
Santimamiñe-Flysch Kurtzia (San-F)	28.25	41.1	14
Santimamiñe-Treviño (San-T)	71.52	95.63	32
Santimamiñe-Urbasa (San-U)	68.11	105.9	35

The resulting dataset is composed of 4 variables and 57 cases (one case for each route and archaeological level). All the variables are scales and they provide two different kinds of information: a) the percentage of flint from a specific flint outcrop identified at a specific archaeological site; and b) the measurements obtained through the three different methods that link flint outcrops with archaeological sites. We used statistical analysis in order to explore this dataset. The first step was to describe the data so as to select the most suitable test for the characteristics of our samples. The general description for the four variables is the following: Raw material distribution (M = 18.3, SD = 25.03), Euclidean Distance (M = 61.64; SD = 22), Optimal Route (M = 89,22; SD = 33.35) and Cost Units (M = 31; SD = 10.63). Kolmogorov-Smirnov test showed none of them follows normal distribution.

The second step was to represent this information using biplot charts (Figure 8), comparing the percentages of raw material distribution and the three different measurements obtained. The distribution of the plots seems to be guided by a linear regression, which is very similar in the three graphs. This line describes a clear inverse relation between the distance variables and the raw material percentages. That is to say, longer distance or higher CU are linked to a smaller quantity of the raw material under study in the corresponding archaeological levels, and *vice versa*. R^2 is reported in each plot and shows good agreement with the regression line suggested for all cases. However, it also shows a ranking, with Cost Units being the measurement that better fits it. Spearman's Rho Coefficient presents a similar pattern and points out a stronger inverse dependence in the relationship Cost Unit measurement/Percentage of raw materials. The coefficients are the following: Euclidean distance $\rho(55) = -.802$, $P < .001$; optimal route $\rho(55) = -.798$, $P < .001$; CU $\rho(55) = -.822$, $P < .001$. These statistical results demonstrate again a slightly better agreement between the archaeological percentages of raw materials and the data obtained from the Cost Units.

Finally, in all three graphs the presence of three distinct groups can be noted: a first cluster, situated in the lower right area of the plot, a second cluster in the centre of the chart, and a third one in the upper left angle.

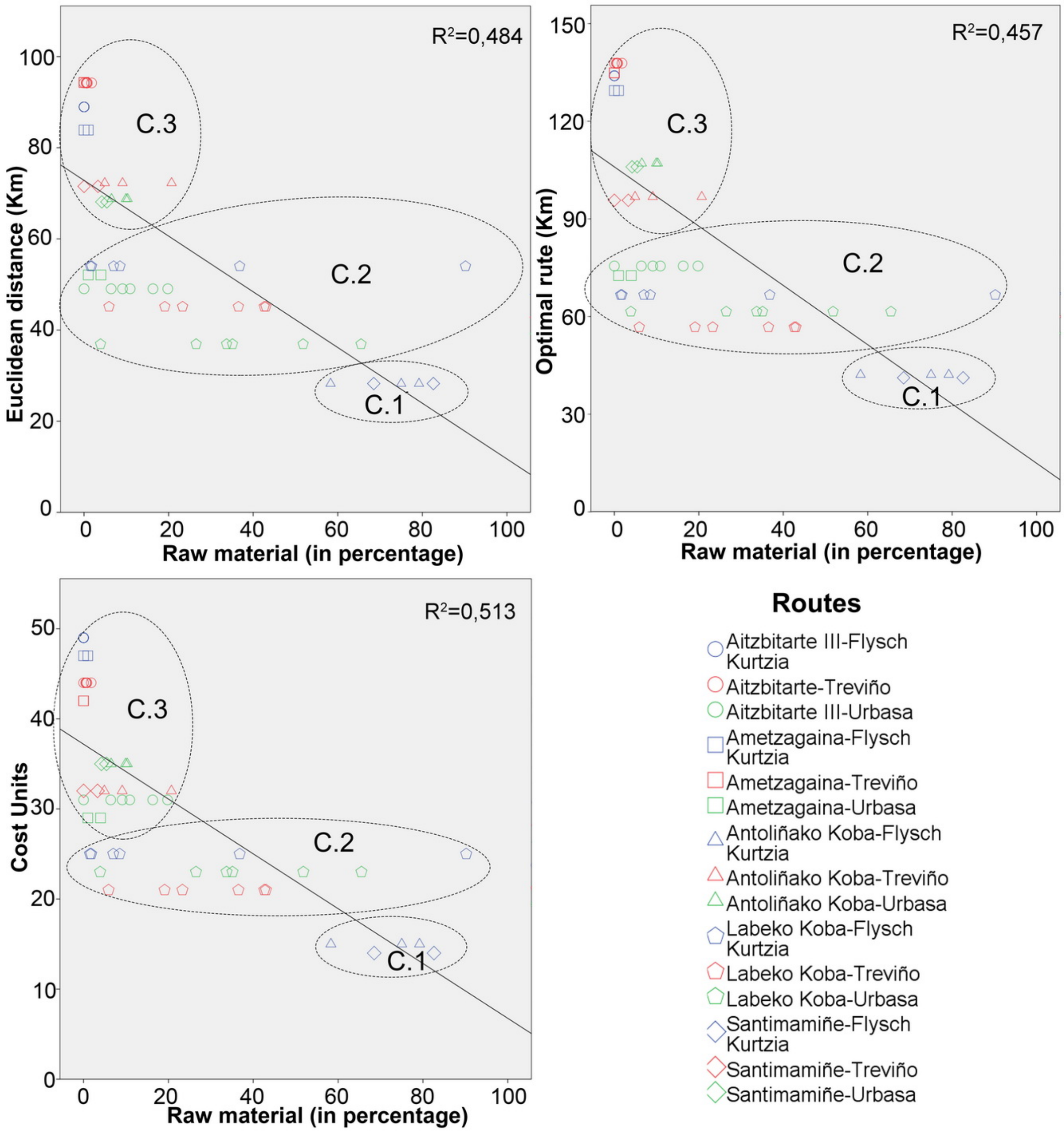

Figure 8. Triple biplot chart with the three clusters proposed for each type of measurement. Each chart shows the percentage of raw material on the horizontal axis and the value of the measurement of each methodological proposal on the vertical axis. The two first are expressed in Km and the last one in Cost Units. It must be noted the points which compose each cluster are different depending on the measurement applied. Abbreviations: C.1 - Cluster 1; C.2 - Cluster 2; C.3 - Cluster 3.

The next issue we faced was the detailed analysis of the relationship between raw material percentages and the data derived from the Cost Units measurements, in order to understand the different use of each flint outcrop. For this purpose, and excluding the archaeological levels with no presence of a specific raw material, we created a double boxplot to look at the different ranges of expansion from each outcrop more closely (Figure 9). This graph represents the differences in the expansion ranks from each outcrop and the percentage of flint carried to each of the archaeological sites. Urbasa and Treviño flints seem similar, but Kurtzia Flysch shows a different behaviour.

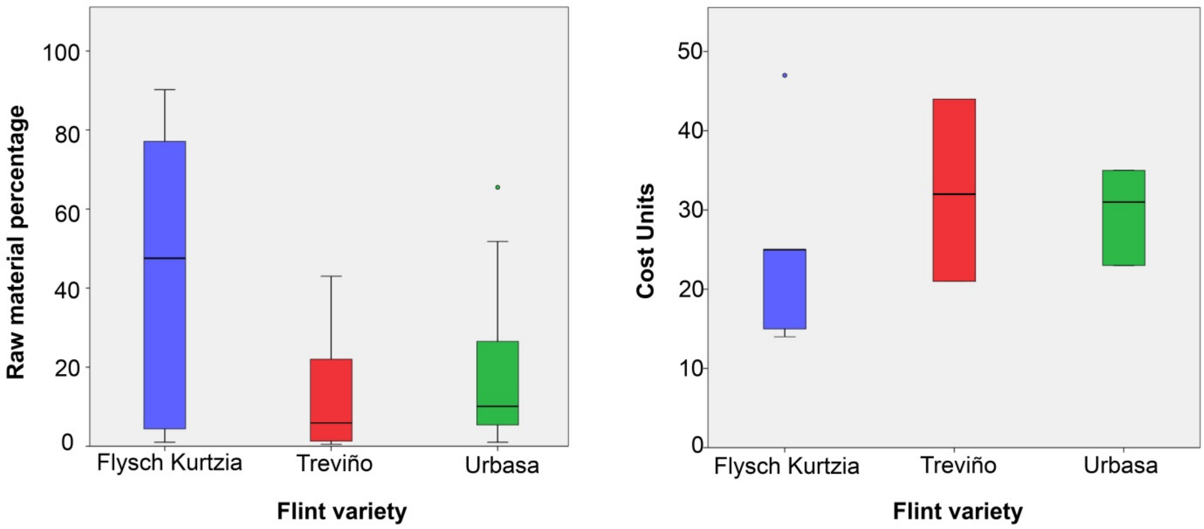

Figure 9. Double boxplot. The first plot shows the different varieties of flint on the horizontal axis and the Cost Units needed to reach each archaeological site with presence of that variety on the vertical axis. The second plot displays the percentage of flint from each outcrop identified in the all the archaeological sites under study.

5. Discussion

First, we would like to underline that this methodology is just a tool to model distance and orography and, therefore, to link this information to the archaeological record based on the percentages of raw material. Cost alone cannot explain the variability of the raw material distribution, but it is a good tool to make it visible and to start outlining some patterns. The raw material percentages in isolation cannot achieve this either; but, by combining both factors we can begin to understand raw material acquisition behaviour in this territory and overcome this long-lasting research bias. We are also aware of the existence of other socio-economic and cultural factors that affect or determine hunter-gatherer mobility, which lead us to be cautious with our conclusions (*e.g.*, Kelly 1992). Other physical constraints could also modify the results obtained here, but, as was already noted, we could not integrate them into this study due to the limited research/data available on them.

5.1. Cost as an analysis and interpretation tool for lithic raw material procurement patterns

For our purposes the concept cost can be defined as the energy spent by humans while traveling on rugged terrain (Surface-Evans and White 2012). The introduction of this idea diverges from previous studies on this topic, which only considered distance –Euclidean– between sites and outcrops. The incorporation of topography is essential here, especially in mountainous areas and regions with highly variable altitudes, since it was a determining factor for moving back and forth across the landscape. All this leads us to introduce the new magnitude presented in the methodology: CU. Nevertheless, as we showed above, there is already extensive scientific literature that demonstrates the importance of LCA in order to understand the mobility of Palaeolithic groups.

As shown in the results, each approach tested gave us different interpretations of the distribution of the percentages of the raw materials from the different archaeological levels. Spearman’s Rho Coefficient and R^2 correlation show that the three methods of measurement point to the economic rule of cost, but each one points out slight differences. The biplot chart

(Figure 8) makes these variations visible in the distribution of the points, which group into three clusters. The archaeological explanation for these groupings is determined by the theoretical approach stated above:

- The first cluster is comprised by the same points in all three charts. The correspondence of the cluster with the correlation line is clear and demonstrates the basic economic concept that a high quantity of raw material is associated with less effort. This cluster reflects the widespread idea derived from the archaeological literature of a direct and continuous exploitation of local lithic resources.
- The third cluster reflects the opposite idea: less quantity of raw material is associated with more effort to obtain it. This relationship shows a sporadic exploitation of the lithic resources within long-distance mobility. The points that make up this group are different in each plot since some of the points move between the second and third clusters depending on the measurement used.
- The second cluster is well distinguished from the others, but its archaeological interpretation is not clear. In the first (Euclidean distance) and second measurement methods (optimal route) the cluster is made up of all the archaeological levels from Labeko Koba, plus some from Aitzbitarte III and Ametzagaina. Instead, following the third approach (Cost Units) it turns out to be exclusively made up of Labeko Koba levels.

Focusing just on the last measurement (CU), the raw material distribution of the clusters derived from it shows high variability -among the analysed sites and within some of them- (Figure 10). The CU needed to arrive at Labeko Koba from all three flint outcrops under study is similar. This means that raw material acquisition was based on a direct and continuous exploitation of a medium-to-long distance, variable over time. However, if we considered Euclidean distance or the optimal route, there would be no clear explanation since clusters 2 and 3 overlap. This demonstrates that these two traditional suggestions/explanations do not fit with the raw material distribution and the geographic constraints of the region.

To try to understand the origin of these differences, we graphically represented each of the 15 possible site-outcrop combinations analysed (Figure 11). Each figure shows one of the measurements in increasing order and compares it to the remaining two. It is clear that the sequence of the cases and the shape of the reference curve change greatly depending on the ordering criterion chosen. The first two cases are always the same, but after that, the sequence changes completely. These arguments demonstrate that linear distance and distance through the optimal route are not appropriate means to understand raw lithic material catchment by Palaeolithic groups. Considering this, in the following section we will analyse the relationship between the quantitative distribution of the different types of raw materials found at each site and the CU.

5.2. Understanding variability in the movement and exploitation of flint during the Upper Palaeolithic in the south-western Pyrenees through Cost Units

As was already mentioned, the Upper Palaeolithic of the western Pyrenees is an especially appropriate framework to illustrate the interest and value of this new methodological perspective. During this period, and particularly in the geographic area defined by the southern slope of the western Pyrenees, high mobility has already been observed. One of the main bodies of evidence is raw material procurement itself. From the beginning of the Upper Palaeolithic an intensive and systematic use of the three varieties of flint considered in this paper has been demonstrated (Tarriño 2006). On a broader scale, procurement frequently also included varieties located on the northern side of the Pyrenees (*e.g.*, Tarriño 2011a; b; Arrizabalaga *et al.* 2014). Extraordinarily certain types, coming from up to 300 kilometres away, have been identified (Corchón *et al.* 2009). In general terms, throughout this period a northeast-southwest flint procurement axis crossing the Pyrenees predominated. Therefore, sites north of the Pyrenees have southern flint varieties in different percentages and *vice versa* (*e.g.*, Tarriño & Normand 2002). These long-distance contacts between both sides of the Pyrenean mountain range have also been noted for other material culture elements, such as for the bone industry, as exemplified by the Gravettian Isturitz-type bone points (Foucher & San Juan-Foucher 2008). In addition, there is evidence of other long-distance contacts through different routes such as the one crossing the Ebro valley, as proven by a fragment of *Spondylus sp.* found in the Aurignacian level of Lezetxiki (Arrizabalaga *et al.* 2011).

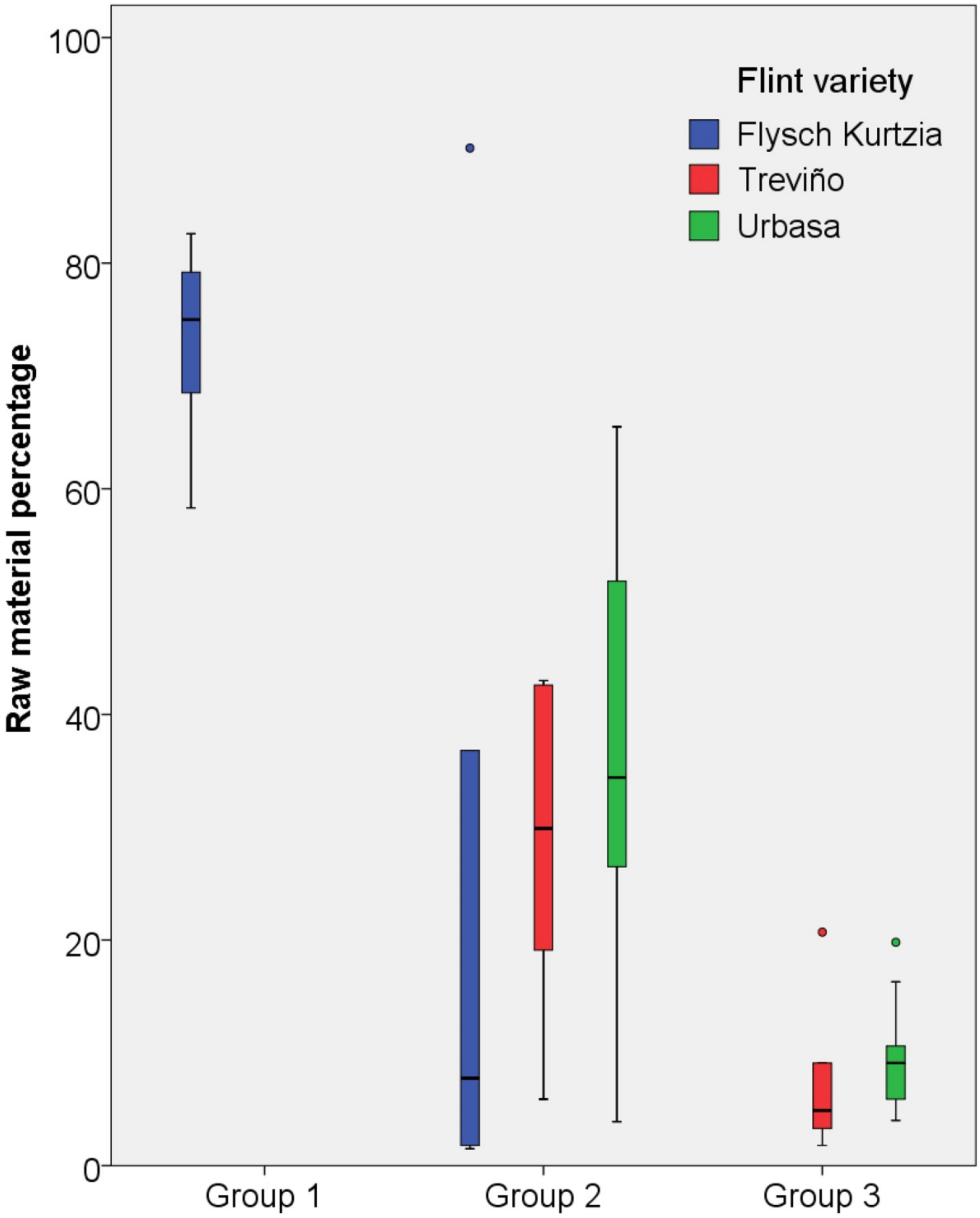

Figure 10. Boxplot which compares the variability of raw material percentages of each flint variety within each group proposed, using Cost Units.

We used the costs maps for each outcrop, where the dispersion of each type of flint is represented, to evaluate the relationship between distance and orography. In the case of the

Kurtzia Flysch outcrop, the isocost lines are wider in a north-south direction (Figure 5). Instead, from Urbasa the lines follow both an east-west axis and a north-south one through the Oria basin (Figure 7). Meanwhile, the configuration of the isocost lines around the Treviño outcrop is more homogeneous, though slightly wider to the north-east (Figure 6).

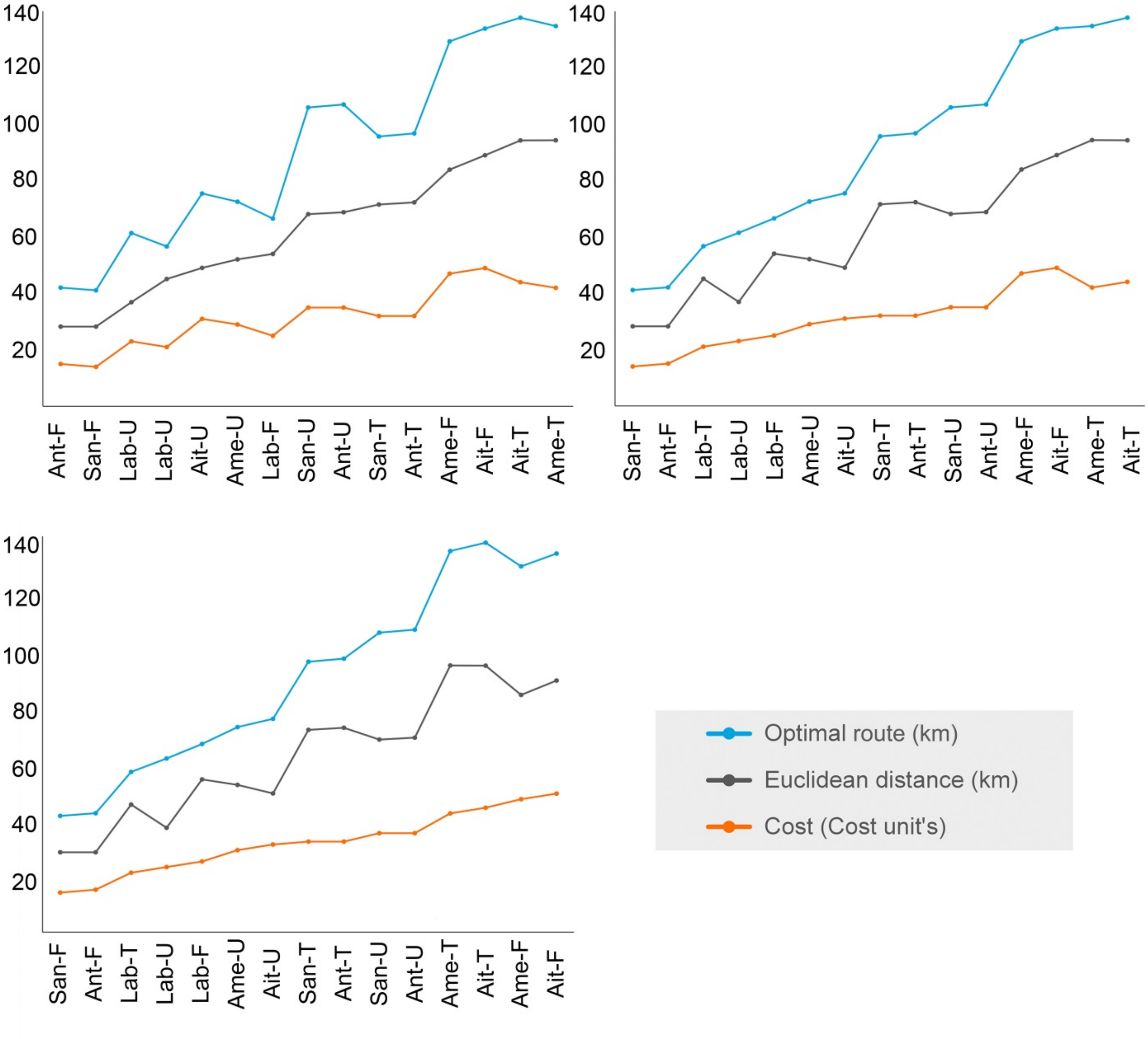

Figure 11. Triple graphic showing, on the horizontal axis, all the possible routes between archaeological sites and geological outcrops, ordered incrementally according to the three types of measurement used. The first one is ordered based on Euclidian distance, the second based on optimal route and the third is based on cost. The vertical axis represents two types of units of measurement contemporaneously on the same scale: kilometres, for Euclidian distance and optimal route, and CU, for cost. Variations in the order of the routes and the curves generated are observed.

Unequal behaviours for each outcrop can be noted when these are compared. The distribution area of Treviño is bigger than that of Kurtzia Flysch because it covers a broader area for the same cost. This is so because the density of the isocosts increases in the narrow coastal valleys due to the greater effort needed to cross them. Urbasa presents a wide spread, similar to that of Treviño. These conclusions are also supported by Figure 9, which represents the geographic spread of the different flint types. In this way, it is easy to identify the long-tracer varieties: Urbasa and Treviño (Tarriño *et al.* 2015). Both flint types show extraordinary knapping properties and are widely distributed. Their overall percentages at the archaeological sites are low (except Labeko Koba), but they are nonetheless present in all of them. These two varieties seem to have slighter different areas of distribution: Urbasa flint has a higher presence in the eastern area and Treviño flint, on the contrary, in the western part. Nevertheless, both varieties first spread through the Alava plateau and later move to the north following the main fluvial valleys. Meanwhile, the outcrop of Kurtzia Flysch seems to have a restricted area of influence and a narrower distribution, clearly conditioned by the north-south mountainous ridges. The high percentages of this kind of flint at the archaeological sites in the western area of the Basque Country make this flint a low-medium scale tracer.

These reasonings lead us to establish three main types of flint procurement strategies by Upper Palaeolithic societies based on the cost of covering the routes between the outcrops and the sites. The first one is characterised by a primary and very frequent input of raw material from just one flint outcrop situated at less than 15 CU, showing a clear relation of autochthony. In the second case, the cost of the procurement routes is higher than 25 CU and the proportion of raw material obtained is under 20%. These types of flint are considered allochthonous and may reflect occasional catchment strategies inserted in territorial or long-distance mobility patterns (Binford 1982; 1983). These two types of flint procurement strategies overlap in most of the archaeological sites. Finally, the third type of catchment strategy is defined by routes between 21 and 25 CU. The raw material composition of this long-distance flint assemblages varies significantly between and inside the different archaeological sites. These changes are due to the similar cost involved to arrive at different outcrops and are linked to modifications in the mobility patterns or changes in the direct management of the territory. Within this type of procurement strategy, cost does not explain the changes in the preference for a specific flint variety.

Summing up, we consider that cost can be a powerful indicator to understand the distribution of different varieties of flint and to explain the configuration of the archaeological assemblages. It can also be a tool to approach the nature and evolution of accessibility to outcrops and, indirectly, to Upper Palaeolithic territoriality and mobility.

6. Conclusions

The main conclusions of the present study can be divided into two groups. At the methodological level, the use of GIS allowed us to consider topography as an important variable when measuring accessibility to lithic resources. In addition, thanks to the concepts cost and CU, we overcame the limitation imposed by linear distances in kilometres, whether through Euclidean distance or optimal routes. This is due to two reasons:

- Linear measurements (Euclidean distance or distance through an optimal route) do not consider topographic variations.
- Cost, and its measuring unit CU, is a magnitude applicable to any territory, not being exclusively determined by distance or a precise itinerary.

In terms of the results, this study interrelated accessibility to outcrops with the quantitative distribution of the different varieties of flint identified in the archaeological assemblages, thereby providing insights into the procurement strategies of raw materials of western Pyrenean Upper Palaeolithic groups. Thus, it was possible to identify patterns and strategies of territorial management, as well as to detect some of the variables behind them. The dichotomy of a primary and recurrent raw material acquisition below 15 CU and a scarce or occasional catchment strategy over 25 CU appeared clearly. Within the geographic area analysed, the differential spread of lithic resources was mainly conditioned by the accessibility to outcrops, even though in some cases this was not the most determining factor (*e.g.*, Labeko Koba). Each flint variety showed different distribution patterns and CU let us identify the geographic opening and constraining areas. Although this relationship seemed clear, we must be cautious with our conclusions, because other types of socio-cultural and environmental factors not considered in this paper may have also played a major role in this equation.

The implementation of more precise and standardised protocols for the geological characterization of lithic assemblages could also improve and let us deepen into this line of research. Typological and technological studies, typometry or use-wear analyses could provide useful information too. In addition, the increase in the number of studies about on raw material characterisation from other archaeological sites could let us widen our framework, offering different perspectives on geographical and chronological variability. Finally, the combination of this approach with other sources, such as the catchment analysis of biological resources or the distribution of bone implements and mobile art, could offer us different perspectives and help us to better explain the mobility of Upper Palaeolithic groups.

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