Journal of Archaeological Science: Reports 67 (2025) 105361

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Mining tools from the prehistoric quarries in Serra Llarga (NE Iberia): Preliminary results from lithological and techno-morphological approaches☆

Xavier Terradas [a,*], David Ortega [a], Clara Fernández [a], Arnau Minguell [b], Carlos Rodríguez-Rellán [c], Rafel Rosillo [d], Carles Roqué [e]

[a] Institute Milá y Fontanals of research on Humanities, CSIC, Barcelona, Spain
[b] Universitat Autònoma de Barcelona, Department of Prehistory, Spain
[c] Universidad de Granada, Department of Prehistory and Archaeology, Spain
[d] Independent Researcher, Spain
[e] Universitat de Girona, Department of Environmental Sciences, Spain

ARTICLE INFO

Keywords:
Quarries
Flint
Neolithic
NE Iberia
Mining tools

ABSTRACT

The Montvell quarries form an archaeological site specialized in the procurement of flint nodules for the production of knapped lithic tools. Excavations and studies carried out so far suggest exploitation based on the recurrence of discrete episodes throughout the Mesolithic and Neolithic. These quarries are not an isolated case, since the surveys carried out along the entire 12 km length of Serra Llarga mountain range have allowed us to record more than 100 quarry faces. The similarity of their formal characteristics and the type of associated mining tools lead us to propose a prehistoric chronology for the entire quarrying operation. All these discoveries highlight the importance of this mining complex in the supply of flint in the Iberian northeast throughout prehistory.

During a survey carried out in the 2020 fieldwork season we recovered a significant number of mining tools (n = 50), both on the surface and associated with quarry faces located within the area studied archaeologically. The blanks of these tools are cobbles, without any type of modification, obtained from alluvial deposits outcropping near the slopes of Serra Llarga. The choice of blanks was based on their lithology, weight and morphology. Their lithologies correspond to tenacious materials, mainly quartzite, as well as other metamorphic, igneous and sedimentary rocks.

A first morphotechnical approach reveals that there are no perceptible differences among the tools according to their shape and weight.

Although there is certain diversity in their weight, they are presented ordered, without significant groupings that would allow us to establish types of tools based on discontinuities. Bearing in mind the extremes, it could be established that some may be regarded as heavy sledgehammers linked to the hard work of dismantling the calcareous strata that contain the flint nodules, whereas others could correspond to hammerstones used to remove limestone remains adhering to the surface of flint nodules, to test them, or in preliminary knapping operations.

1. Introduction and objectives

Until a short time ago, research on the procurement of lithic raw materials in the Iberian Peninsula during prehistory was lacking in approaches focused on the production sites themselves; the places where their acquisition and initial transformation took place (Terradas and Ortega, 2017). This omission was a consequence of inertia in the research process, in which scientific studies on raw material sourcing

☆ This article is part of a special issue entitled: 'Exploring Human-Mineral Interactions' published in Journal of Archaeological Science: Reports.

* Corresponding author.
E-mail addresses: terradas@imf.csic.es (X. Terradas), ortega@imf.csic.es (D. Ortega), cefebe11@gmail.com (C. Fernández), arnau.minguell@uab.cat (A. Minguell), carlos.rellan@ugr.es (C. Rodríguez-Rellán), rafelrosillo@gmail.com (R. Rosillo), carles.roque@udg.edu (C. Roqué).

https://doi.org/10.1016/j.jasrep.2025.105361
Received 3 March 2025; Received in revised form 29 May 2025; Accepted 13 August 2025
Available online 15 August 2025

have developed later in Iberia compared with other parts of Europe. It is possible that this delay can be linked to the scarcity of mining sites like those documented in different European countries since the 19th century (see, for example, Lech, 1995; Pelegrin and Richard, 1995; Russell, 2000; Collet et al., 2008; Pereira et al., 2017; Collet and Hauzeur, 2019; Bostyn et al., 2023).

This pattern changed in the 1990 s, partly because the *VIth International Flint Symposium*, which was held in Madrid in 1991 (Ramos-Millán and Bustillo, 1998), roused interest in the topic among Spanish institutions and researchers. In the following years, lines of research were implemented from different places in Spain, focused on characterising the geological units that contained high-quality raw materials for the production of lithic implements (Lozano et al., 2010; Morgado et al., 2011; Tarriño et al., 2007, 2013, 2016; Fuertes-Prieto et al., 2014; García-Simón, 2016; Sánchez de la Torre and Mangado, 2016; Ortega et al., 2016, 2018; Herrero-Alonso et al., 2021; Belmiro et al., 2023).

With this background, the discovery and excavation of the Casa Montero flint mines near Madrid (Consuegra et al., 2018) was a turning point, as it was followed by new discoveries, such as the flint quarries at Pozarrate (Tarriño et al., 2022) and the flint operations at La Leandra (Picazo et al., 2023).

Similarly, the mining complex of Serra Llarga extends along the whole length of the range of hills of the same name, in the north-east of the Iberian Peninsula (province of Lleida, Spain). Numerous quarry faces have been documented on its hillsides. Of these the quarries at Montvell stand out, in the easternmost sector of the range (Terradas et al., 2017, 2023, in press). The present study will focus on the lithic tools found in surveys along the range and which, owing to their context and morphotechnic characteristics, are interpreted as tools used to quarry the limestone beds in the Castelltallat Unit and extract the flint nodules that were widely used and distributed across the region throughout Palaeolithic and Neolithic times. (Ortega et al., 2018).

2. The Serra Llarga mining complex

Serra Llarga is formed by an alignment of low hills that extend for 12 km from east to west, between the valleys of the Farfanya and the Noguera Ribagorçana Rivers (Figs. 1, 2 and 5). Even though the relief is

Fig. 2. Landscape of the Serra Llarga hills from their southern slope.

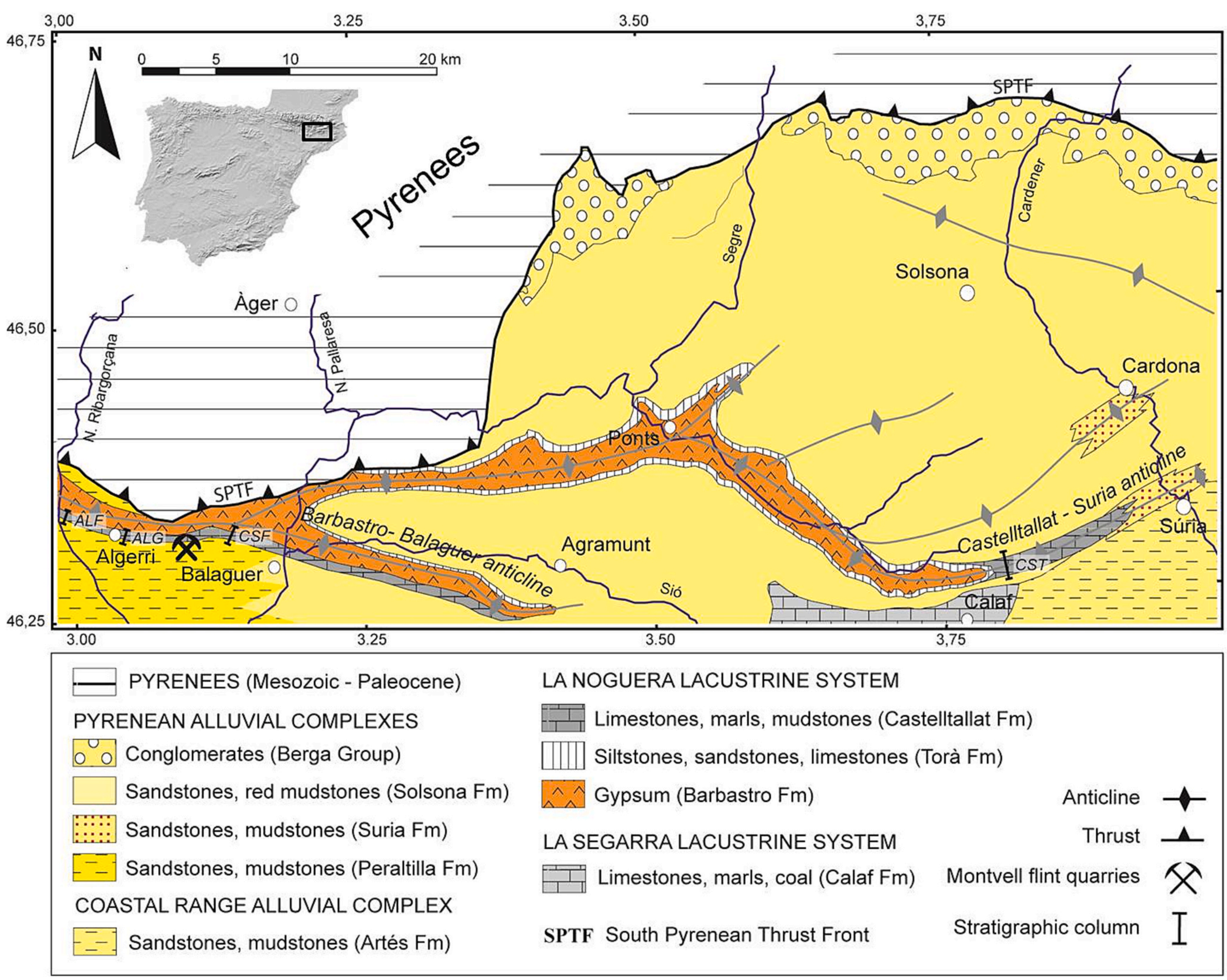

Fig. 1. Geological map showing central and western sectors of Castelltallat Formation (based on Sáez et al. 2007). The location of Montvell chert quarries is noted.

not very high, the hills form a historic and geographic boundary between two large geographic and ecological units: the plains of the central Catalan Depression, to the south, and the mountains of the Pre-Pyrenees and Pyrenees, to the north.

The range was formed by the development of an extensive tectonic fold, the Barbastro-Balaguer anticline, which, on the southern edge of the Pyrenean geological structures, buffered the compression forces in the last stages of the emergence of the cordillera (Martínez Peña and Pocoví, 1988). When the hills were uplifted, the folding brought to the surface sedimentary materials from the Ebro Tertiary basin: gypsum in the Barbastro formation, limestone in the Castelltallat formation and silts and sandstone in the Peraltilla formation (Senz and Zamorano, 1992), which are covered by more recent deposits towards the south, in the plain that extends at the foot of the range. Among these formations, flint nodules only appear in the Castelltallat limestone. Those beds outcrop almost vertically on the southern flank of the anticline, and are the rocks most resistant to erosion that form the nucleus of the Serra Llarga range (Fig. 2).

The relaxation of the tectonic forces that followed the formation of the anticline divided the range into smaller sections of more or less similar sizes. The surface drainage, with its headwaters in the north, made use of the fractures to cut stream channels deeply into the limestone and over time that process shaped the gentle relief of the hills.

The Castelltallat limestone formed in the bottom of a shallow freshwater lake that in the late Palaeogene (Oligocene) covered a large area in the eastern Ebro basin, which at that time still did not drain to the sea (Sáez et al., 2007). On the shores of the lake, colonised by palustrine vegetation and rich in organic matter, local chemical conditions favoured the precipitation of silica dissolved in the water, which originated the flint nodules. These formed by replacing the limestone but preserving its sedimentary structures, microfossils and any other detritic and mineral elements in it. This resulted in defining the textural and composition attributes that allow this type of flint to be identified in archaeological assemblages (Ortega et al., 2018).

The flint in the Castelltallat Unit is dark brown, opaque and finely-textured with occasional concentric bands (Fig. 3). It contains the characteristic fossils of the lacustrine environment in which it formed: shells of small gastropods and ostracods and stems and fructifications of charophyte algae. Moreover, its distinctive chemical composition enables it to be differentiated from other regional flint types of similar age and appearance. It is lodged in an extremely rigid limestone, and is affected by fissures that nonetheless did not hinder its use in prehistory.

In order to synthesise the diagnostic features of this type of flint, to differentiate it from other similar and to monitor its distribution throughout the regional geography, a multi-parametric analysis was carried out, allowing its characterisation in petrographic, mineralogical and geochemical terms (Ortega et al., 2018). A rough estimate indicates that this rock –either as raw material or knapped lithic products- was distributed mainly to the north of the outcrops, over an area of 6,000–8,000 km^2. The presence of this flint has been documented in numerous Middle and Upper Palaeolithic sites in the region, although it was during the Neolithic when it reached a wider distribution within the Ebro basin (see Ortega et al., 2018 for a list of sites and their geographical location).

Prehistoric quarrying activities took places at the outcrops, which led to the anthropic modification of their natural appearance and shape, while allochthonous objects were brought, in the form of mining tools, to extract the flint. The more intensive or repeated the quarrying was, the more evident its effects are, which allows its archaeological identification by creating a particular context linked to the quarrying of the raw material and its initial transformation (Ericson and Purdy, 1984; Costin, 1991; Terradas and Ortega, 2017).

Although the Castelltallat geological unit extends beyond Serra Llarga, towards both the west and the east, to date quarries have only been detected in the Serra Llarga sector. Evidence of quarrying activity were identified where the limestone beds were dismantled, where flint nodules outcropped most often and were most accessible, giving rise to geomorphologically distinctive anomalies. These irregularities are characterised by cropping the topography of the original rock slope associated with small platforms caused by the accumulation of rubble during quarrying. In addition to these alterations to the shape of the land, the presence of river cobbles, which are foreign to the limestone formation, indicated their deliberate introduction to be used in quarrying activity.

Fig. 3. Flint nodules occurring within limestone strata (left) and macroscopic detail of the Castelltallat Formation flint (right).

The presence of these sites suggested the likely existence of a large number of prehistoric quarries in the area. This hypothesis was tested by the excavation of several of these quarry faces in the Montvell area (Castelló de Farfanya, Lleida) in the eastern sector of Serra Llarga. We documented there a site with four stepped faces of old flint quarries dug into the side of the hill during the Neolithic (Terradas et al., 2017, 2023, in press) (Fig. 4).

Here we are carrying out a stratigraphic reconstruction of the entire hillside where the four quarry faces are, delimiting the stratigraphic units linked to the different quarrying episodes and specifying their chronological scope based on ^{14}C dating, as well as the reconstruction of the surrounding landscape and the footprint that the mining activity generated in it. These data allow us to situate this exploitation within the framework of the Early Neolithic of the region (*circa* 5600–4500 BCE). This work is now in preparation for a specific publication, so we are unable to provide further details.

In the absence of dating so far in other parts of Serra Llarga, the similarity of the morphology of the quarry faces, their grouping and distribution pattern, together with the characteristics of the archaeological artefacts documented on the surface, are the criteria that lead us to propose a prehistoric chronology for the quarries in the entire mountain range.

3. Surveying and documentation of quarry faces

The discovery of groups of quarries in several places in Serra Llarga led to specific fieldwork involving geoarchaeological surveys along the whole range of hills to delimit the spatial extent of the quarries and obtain more evidence to understand their diversity and complexity. The surveys were carried out in 2020 from the course of the River Farfanya

Fig. 4. Stepped quarry faces on the slope of a hill at Montvell area (Castelló de Farfanya, Lleida). The width of the limestone strata in the lowest quarry is almost 5 m.

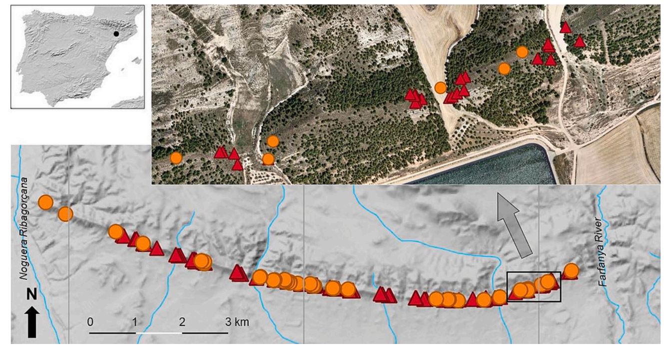

Fig. 5. Digital terrain map with the location of quarry faces (triangles) and mining tools (circles) documented in Serra Llarga hills (IGN source), and detail of Montvell quarries area.

in the east to the Noguera Ribagorçana valley in the west, over an area 12 km long and about 0.2 km wide (Fig. 5); i.e. an area of about 240 ha.

For the surveys, LiDAR (Light Detection and Ranging) techniques were applied with aerial sensors, in a data acquisition programme in collaboration with the *Institut Cartogràfic i Geològic de Catalunya*. Once the LiDAR data had been processed, the terrain was reconnoitred to document the structures revealed by LiDAR, ground truth them and identify others that might have gone unnoticed. The whole area was covered on foot and the quarry faces were georeferenced, recorded and documented, while remains of mining tools or any other artefacts were also recorded (Fig. 6).

This work identified as many as 106 anomalies in the narrow band of terrain where the Castelltallat formation outcrops (Fig. 5), so that together with the four quarry faces already known at Montvell, a total of 110 quarry faces are known in the area. They can all be interpreted as old quarries since exokarstic landforms, such as potholes and dolines, that cause relative lowering of the surface, do not occur in the Castelltallat limestone. Their spatial distribution repeats the pattern documented at Montvell, as the quarries are located in the low hillsides where a valley cuts into the hill and they are often arranged in small stepped groups.

The recognition of over a hundred quarries and their distribution along the whole Serra Llarga range has identified an extensive prehistoric complex that was unknown until recently.

4. Mining equipment

Lithic materials that are not native to the area were observed during the surveying to locate quarry faces. Owing to their lithology, different

Fig. 6. Mining tool associated with quarry rubbles found in Serra Llarga hills.

from the limestone in the Castelltallat Unit and the flint that appears in it, and to their morphology in the form of cobblestones, it may be supposed that they were brought to the area by human action. These stones were found on the surface of the surveyed areas, and no excavations or test pits were dug to obtain them.

This assemblage of 50 lithic tools was distributed unequally across the hills of Serra Llarga. They sometimes appeared in isolation and other times in small concentrations associated with a quarry face or with no apparent connection to one (Fig. 5). Because of their size and weight, it may be supposed that they were brought for quarry work, to dismantle the limestone beds and extract the flint nodules. They are sometimes complete, and display traces clearly caused by percussion activities, while others are fragments or flakes that broke during the percussion work. A full list of these artefacts, their lithology, condition, morphometric attributes, weight and active zones is given in Table 1.

4.1. Lithology of the quarrying tools and their provenance

The cobblestones that were used for quarrying work are of different rock lithologies, although with similar properties and from the same source.

Of the objects listed in Table 1, most of them are of metamorphic rocks (over a half: 58 % of the stones), rather than igneous (30 %) and sedimentary rocks (12 %). Their lithology is extremely variable (Fig. 7): as many as ten types in a relatively small sample of 50 stones. The igneous rocks include quartz, aplite, ophite, porphyry and granite, whereas the metamorphic (quartzite, hornfels and episyenite) and sedimentary lithologies (conglomerate and limestone) are less diverse. The most frequent raw material in the assemblage is quartzite, with 24 objects or 48 % of the sample.

Despite this apparent diversity, these are all tenacious rock types, capable of absorbing and/or accumulating the defects caused by mechanical stress before finally breaking by impacts or the sum of alterations. The shape, weight and density of the cobblestones brought to the

Table 1
Lithology, condition, morphometric attributes (in millimetres), weight (in grams) and active zones of the lithic implements recovered during surveying at Serra Llarga hills.

Record	Lithology	Condition	Length	Width	Thickness	Weight	Category	Active Zones
77	Quartz	Complete	164.00	106.00	79.50	1,834.50	Large	1
78	Granite	Complete	165.00	115.00	99.00	2,531.50	Very Large	1
84	Quartzite	Complete	201.00	100.00	98.00	3,144.00	Very Large	4
85	Porphyry	Fragmented	165.00	66.00	36.00	622.00	Medium	1
102	Episyenite	Complete	181.00	91.50	61.50	1,885.40	Large	0
983	Hornfels	Complete	110.00	82.00	60.00	757.10	Medium	1
984	Granite	Complete	66.00	54.00	31.00	174.40	Small	0
986	Quartzite	Fragmented	145.00	83.50	42.50	1,047.20	Medium	2
987	Ophite	Fragmented	73.00	133.00	88.00	1,060.20	Medium	1
989	Limestone	Complete	154.00	189.00	96.50	3,667.00	Very Large	3
990	Quartzite	Fragmented	143.00	131.00	49.00	1,533.80	Large	3
991	Quartzite	Fragment	81.00	57.00	24.00	100.90		1
992	Quartzite	Fragmented	134.50	90.50	71.50	1,156.70	Medium	1
993	Quartzite	Fragment	60.00	36.00	28.00	71.30		0
995	Quartz	Complete	123.00	96.00	60.00	1,038.00	Medium	1
996	Quartzite	Fragmented	171.00	122.50	92.50	2,918.80	Very Large	3
997	Quartzite	Fragmented	234.00	134.00	49.50	2,117.50	Large	0
998	Aplite	Fragmented	134.00	112.00	87.00	1,677.20	Large	1
1002	Quartzite	Fragmented	83.00	75.00	64.00	535.50	Small	0
1003	Porphyry	Fragment	11.50	79.00	54.00	606.60		3
1013	Quartzite	Fragment	60.50	54.5	12.00	37.20		0
1019	Quartz	Fragment	85.50	65.00	29.50	218.60		0
1020	Quartz	Fragment	47.00	38.00	28.00	60.20		0
1027	Quartzite	Fragment	65.00	47.00	21.00	311.10		0
1028	Hornfels	Fragment	36.00	40.00	12.00	25.40		0
1029	Quartzite	Fragment	43.50	73.00	14.00	52.60		1
1032	Quartzite	Fragment	65.5	41.00	7.00	21.40		0
1034	Conglomerate	Fragment	135.40	100.20	41.90	590.60		1
1035	Quartzite	Fragment	45.00	39.00	10.00	21.60		0
1036	Quartzite	Fragment	29.50	23.30	6.50	4.50		0
1038	Quartzite	Fragment	108.00	60.00	54.50	409.50		0
1040	Quartzite	Fragment	37.00	61.00	28.00	275.70		0
1042	Hornfels	Fragment	82.00	79.00	33.00	369.50		2
1045	Aplite	Fragmented	51.50	79.50	34.50	276.70	Small	3
1046	Limestone	Fragment	43.20	24.50	11.00	14.00		0
1048	Porphyry	Fragmented	117.00	101.00	92.00	1,130.40	Medium	3
1049	Aplite	Complete	142.00	134.50	130.00	3,701.00	Very Large	0
1051	Quartzite	Fragment	96.00	67.00	55.00	332.80		2
1052	Conglomerate	Fragmented	123.00	94.00	101.00	1,490.70	Large	2
1053	Quartzite	Fragmented	131.00	67.00	34.00	333.20	Small	0
1056	Quartzite	Fragment	59.00	43.00	15.50	37.80		2
1057	Quartzite	Fragment	93.00	86.00	15.00	126.70		2
1058	Conglomerate	Fragment	50.00	47.00	15.00	2.90		0
1059	Hornfels	Fragment	96.50	65.50	45.50	413.70		4
1060	Quartzite	Fragment	111.00	110.00	63.00	664.70		3
1061	Quartz	Fragment	172.00	150.00	60.50	1,510.30		0
1062	Quartz	Fragmented	135.00	118.00	73.00	1,907.10	Large	1
1063	Conglomerate	Fragmented	198.00	197.00	123.00	6,518.00	Very Large	0
1071	Quartzite	Fragmented	91.00	57.00	36.00	211.00	Small	1
1072	Quartzite	Fragmented	78.00	78.00	36.00	320.00	Small	1

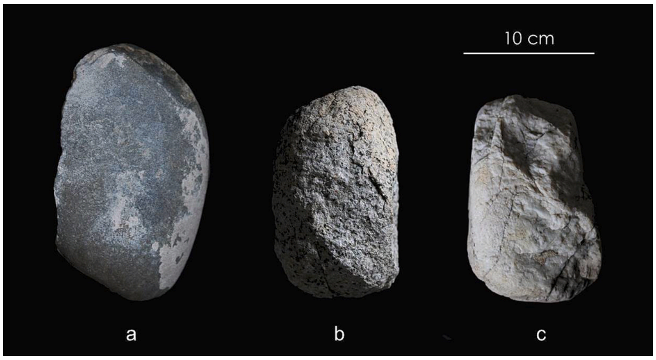

Fig. 7. Mining tools on different lithologies: a. Quartzite; b. granite; c. quartz.

hills of Serra Llarga further support those properties, making them efficient tools to be used in repeated percussion activity.

The igneous rocks are of Palaeozoic age and their original source area can be located in granitoid outcrops in the axial Pyrenees. The metamorphic rocks share the same Palaeozoic age and their origin would similarly be in the axial zone of the Pyrenees. It is more difficult to determine the age of the sedimentary rocks, although it is likely that the conglomerates are Mesozoic and the limestone is Cretaceous-Palaeogene, and they shared their source area in the Pre-Pyrenean ranges. All these areas are quite distant from Serra Llarga. However, the rounded shape of all the stones shows that the geological environments in which they were collected must have been sedimentary deposits; either fluvial terraces or alluvial fan deposits. These rock types indicate that the sedimentary deposit they come from is related to the river system over a large area encompassing the axial Pyrenees and the Pre-Pyrenean ranges. They are therefore compatible with the Quaternary terraces of the Rivers Noguera Ribagorçana and Segre, respectively to the west and east of Serra Llarga. The centre of the Serra is about 5 km from the River Noguera Ribagorçana and 7 or 8 km from the River Segre (Fig. 8).

Nonetheless, the most likely provenance of these Pyrenean cobblestones is an alluvial deposit dated in the Pliocene-Lower Pleistocene, and therefore older than those river terraces, which extensively outcrops *in situ*, approximately parallel to the hills of the Serra Llarga (Fig. 8). Although it is more important in the eastern half of Serra Llarga, it outcrops at very short or insignificant distances from the hills, at most a few hundred metres, and often adjoins them. It corresponds to the 'Serra Llarga Plio-Quaternary Level' (Peña, 1983) or the 'polygenetic conglomerates and ochre silts', that are represented on the Balaguer geological map (ITGE, 1998). The deposit is formed by rounded gravel and boulders that are hardly cemented or not at all, that can reach up to 40 cm in diameter, clast-supported and in a sandy matrix. The predominant lithologies are metamorphic (hornfels and quartzite) and magmatic rocks (quartz, granite, porphyry) from the axial Pyrenees, and also include some limestone clasts (limestone and dolomite), as well as ophite, sandstone and Mesozoic conglomerates from the Pre-Pyrenean ranges. The cobbles were probably picked up in the beds of the streams that cross and drain the areas between the Serra Llarga hills, as these deposits outcrop in their drainage basins.

4.2. *Morphotechnic characteristics of the tools*

The remains of the quarrying tools appear in different states of conservation. Some are complete, others are fragmented, and some fragments and flakes produced by their use have also been found.

Based on the whole implements or those that preserve a large part of their original volume, a preference is seen for ellipsoidal or oval cobblestones with blunt ends. Therefore, they are morphologies with low sphericity but well-rounded (Tucker, 1991) as a result of their intense transport over long distances within the dynamics of the alluvial deposit described above.

An initial examination of these remains shows that no modifications are visible on their surfaces apart from the fractures produced by their use in percussion activities and the micro-traces inherent to this type of activity. The marks are concentrated in the more prominent parts of the cobblestones, in the form of pecked surfaces, as a consequence of the deformations and removal of the mineral matrix of the rock during reiterated impacts (Fig. 9). It should be noted that these types of traces are substantially different from those that appear on the surfaces of the cobblestones that remain in their original deposits, which are the result of multiple punctual impacts, of lower intensity and with a random distribution.

Apart from this damage, the stones were not subject to technical shaping and therefore cannot be classified in conventional typologies, even though they may have been used in different tasks. In this sense, no evidence has been seen of notches, grooves or any other diagnostic marks that might indicate that these tools were hafted to improve their functionality.

Of the 50 items, 26 are complete or preserve much of their original morphology (Table 1). These are stones that preserve at least one of their two main axes, longitudinal or transversal, completely. The weight of this group of artefacts is quite variable, between 6,518 and 174 g, with an average of 1,676.50 g. Out of this sample, 11 were above the average weight and 15 were below it.

To approach their variability and establish whether the cobblestones were chosen in accordance with any preference about their weight, their distribution has been studied by categories, based on the quartiles (Fig. 10). It can be seen that the distribution between very large (6 artefacts), large (7), medium (7) and small (6) is very equal and therefore, although a large difference is seen between the extremes, there is continuity without any significant differences that allow tool types to be

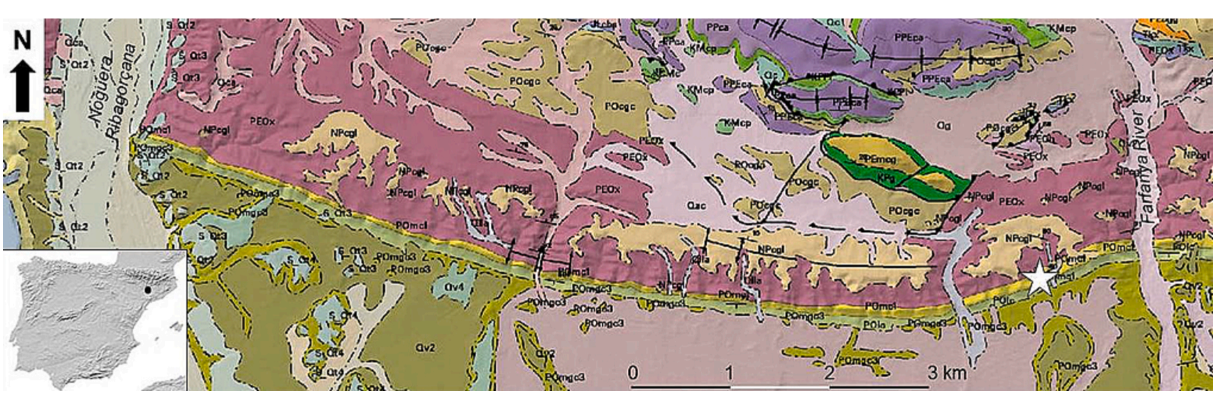

Fig. 8. Geological map of Serra Llarga (ICGC source). The Pliocene-Lower Pleistocene alluvial deposits are shown in cream colour (legend NPcgl) and the Oligocene limestone containing flint nodules are indicated in lime green (legend POmc1). The white star indicates the location of Montvell quarries.

Fig. 9. Percussion traces on the surface of a quartzite pebblestone used as a sledgehammer. They are located at one end (a) and in the centre of one side face (b). Scale in millimetres.

Category	Weight
Very Large	> 2,221 g
Large	2,221 to 1,324 g
Medium	1,324 to 600 g
Small	< 600 g

Fig. 10. Distribution of mining tools by categories based on quartiles established according to their weigh.

discriminated based on their weight.

As stated above, the only use-wear marks preserved on their surfaces are traces of pecking concentrated in specific areas and caused by reiterated intentional impacts during their use in percussion activities. These percussion marks are usually located on the most prominent parts of the stones, which are areas on the tools damaged or altered by their use. Active zones have been observed on 29 of the items and many of them display more than one zone (Fig. 9). Whereas some tools exhibit up to four active zones (2 items or 6.9 %), most of them are affected by a single active zone (14 items or 48.28 %). In any case, it can be seen that the tools were used repeatedly, often changing their orientation either to achieve greater efficacy or because of the deterioration of their active zones. This recurrence in the use of the tools could have occurred in a single quarrying episode or implements abandoned on the ground during previous work may have been reused.

To this end, we have developed an experimental program to obtain an experimental collection of macro- and microscopic use-wear traces derived from these percussion activities. Studying and comparing them with archaeological artefacts should allow us to test our hypotheses about the patterns of use of these tools. The study is currently being reviewed for publication.

Another characteristic trait of the surface of these tools is the presence of reddish zones, which usually affect all of one surface of the tool. This alteration has been observed on nine items (18 % of the sample). The most coherent explanation is that these surfaces were exposed to the effect of a thermal shock, i.e. a sudden change in temperature, as might occur during a fire. Additionally, the minerals in the rock absorb the heat in different ways, which causes variations in the tension and generates cracks and ultimately the disintegration of parts of the stone, as has been observed on the surfaces and edges of some of the artefacts.

5. Discussion

The number of quarries documented along the length of Serra Llarga shows that the area was worked repeatedly, rather than in occasional episodes. It may be supposed that, as in Montvell, the Serra Llarga quarries were worked for centuries and quarrying activity was a normal economic activity, albeit probably a temporary one, of the human communities settled in the area or those who visited frequently.

As in the Montvell area, the distribution pattern of the quarry faces denotes a model of prehistoric exploitation focused on the lower hillsides. The almost vertical position of the limestone beds would facilitate access to them along the stream channels cut into the hillside. The stepped appearance of several faces is the result of a strategy that aimed to minimise the management of rubble and quarrying waste. Once the work faces had become covered by the spoil heaps, a new quarry face was opened at a higher level, and this might be repeated several times resulting in this arrangement (Terradas et al., 2017, 2023, in press).

However, the distribution pattern of the quarrying tools is different, as these are found indistinctly along the range, on summits, slopes and cols between hills (Fig. 5). The presence of these implements on the hilltops may be explained by the existence of older superficial quarrying, during the Palaeolithic and later periods, without any excavations or noticeable alterations to the original topography of the limestone strata of the Castelltallat formation (Terradas et al. in press).

A striking issue is the low number of mining tools recovered (50) for the large surveyed area (240 ha) and the high number of quarry faces documented (110). This might be explained due to the lower visibility of the lithic remains and to the fact that they may be camouflaged by the vegetation cover. On the other hand, the explorations and excavations carried out in the sedimentary deposits associated to the 4 quarry faces in the Montvell area have allowed us to recover up to 39 remains of mining tools (Terradas et al., in press), which undoubtedly allows us to obtain a more realistic image of the representation that these implements could reach in the mining complex as a whole. In any case, new surveys will be carried out in a fieldwork session in October 2025, so it is possible that the number of recovered mining tools will increase.

The tools used for quarrying are easily identifiable because they are cobblestones whose lithology differs from that of exploited strata on the quarries. These stones, which were gathered in Plio-Pleistocene alluvial deposits near the hills in Serra Llarga, are of very diverse lithologies. They are mostly metamorphic rocks, especially quartzite, but also igneous and sedimentary types. Despite this variability, they share characteristics as dense and tough rocks, well suited to reiterated percussion actions on hard materials such as the limestone containing the flint nodules. Therefore, rather than choose a specific lithology, the groups who worked in the Serra Llarga quarries selected a series of rocks with similar properties that were optimal for the purpose they were gathered for.

The same is true of the size and shape of the cobblestones that were used. As described above, no preference for any particular morphology can be detected. Instead, stones of different format and weight were employed, depending on their properties, in different functions and intensity in percussion activity. The largest and heaviest cobblestones were probably used held in both hands to split the limestone. The fissures and cracks would make it easier to dismantle the strata either with wooden poles and wedges or directly by hand. Therefore, those tools would have been used like sledgehammers. Their characteristics resemble those described for quarrying rather than for underground mining (LaPorta et al., 2010; Capote, 2011; De Labriffe et al., 2019; Tarriño et al., 2022). For this latter purpose, more diverse and specialised equipment would be required, owing to the technical difficulty of digging underground and removing materials of different kinds. In this case, in addition to stone hammers, other types of implements tend to be found, such as picks mad from antler or knapped on flint (Clutton-Brock, 1984; Boguszewski, 1991; Bostyn and Lanchon, 1992; Russell, 2000; Galiberti, 2005; Collin and Collet, 2011; Weiner, 1995; among others). This is not at all the case for the Serra Llarga quarries. Neither have we found to date the use of flint nodules as percussion tools.

The abandonment of these hammers on the hillsides meant that they could be reused in later visits to the quarries, sometimes until the repetition of the work damaged them and they were no longer of use. The presence of alterations to the surface of some of the tools related to exposure to heat may indicate that fires were lit to burn the plant cover off the limestone beds before opening a new face. However, no evidence has been found so far to demonstrate that the fires were intentional or took place in prehistory, as they might have occurred at any time and for other reasons.

On the other hand, we propose that the lighter and smaller tools were held in one hand in percussion activities corresponding to lithic reduction, such as to free the nodules of remains of the host rock, test the quality of the nodules or remove parts that could not be used because of fissures and irregularities. Although these implements appear to be equivalent to the hammerstones normally used in lithic reduction, at the Montvell quarries, where the sedimentary fill of the adjoining platforms to several quarry faces have been excavated archaeologically, the practice of the knapping activities has not been documented. It may therefore be proposed that the selected nodules were transported in their raw state or with slight modifications for their later distribution or use elsewhere.

6. Conclusions

Based on the evidence described here, the Serra Llarga mining complex may be regarded as the largest group of flint quarries in the Iberian Peninsula, the exploitation of which dates back to the most remote times. The scale and scope of prehistoric quarrying and the possibility of dating and documenting the work carried out at them in detail signify an outstanding opportunity to face the study of this complex, its diversity and intensity from a diachronic viewpoint. However, in addition to the excavations already performed at the Montvell quarries, it is now necessary to carry out further excavations of the sedimentary fills associated with quarry faces in other parts of the range of hills.

The tools associated with the quarrying work form an assemblage of cobblestones of different rock types, although they are all dense, tenacious rocks. They are especially suited to percussion activities involved in dismantling the limestone beds that contain the flint nodules. The criteria applied by the prehistoric quarry workers to select them resulted in a set of tools that would be very effective in the different operations linked to their quarrying tasks. The strategies for the selection of lithologies and specific shapes and weight were carried out in the alluvial deposits containing the cobblestones, just a short distance from the limestone outcrops in Serra Llarga.

No shaping out nor knapping operations were carried out to adapt the shape of the cobblestones to the work in which they would be used. Similarly, no evidence has been recorded of diagnostic alterations or traces on the surfaces of the implements indicating the attachment of handles or hafts for their use. This might be explained by the simplicity of the actions in which the tools were employed and the facilities that the environment and context offered for their development; therefore, it was not necessary to improve their effectiveness.

It should be noted that the present assemblage concerns quarrying tools found on the ground surface and it is consequently difficult to link them to a particular quarry face. Excavations have been carried out at the Montvell group of quarries since 2015, in the eastern sector of Serra Llarga. This research is revealing a stratigraphic sequence that enables the finds to be attributed to well-contextualised stratigraphic units, dated in different times in the Neolithic. The continuation of this fieldwork and excavations in new sectors will contribute a better understanding of quarrying practices in Serra Llarga, their chronology, strategy and objectives.

At the same time, the finds of tools linked to well-documented quarrying contexts will generate new results as regards use-wear traces, refits, successive sequences of use, surface alterations, etc. that, all together, will allow the study of those implements from a more holistic perspective that can integrate them within the socioeconomic activities that generated them.

CRediT authorship contribution statement

Xavier Terradas: Methodology, Supervision, Validation, Conceptualization, Writing – review & editing, Funding acquisition, Investigation, Writing – original draft, Formal analysis, Visualization, Data curation. **David Ortega:** Visualization, Data curation, Writing – original draft, Formal analysis, Writing – review & editing, Funding acquisition, Supervision, Validation, Conceptualization, Methodology, Investigation. **Clara Fernández:** Methodology, Supervision, Writing – review & editing, Formal analysis, Investigation, Data curation, Conceptualization. **Arnau Minguell:** Supervision, Writing – review & editing, Investigation, Formal analysis. **Carlos Rodríguez-Rellán:** Data curation, Formal analysis, Investigation, Writing – review & editing, Supervision, Methodology. **Rafel Rosillo:** Investigation, Supervision, Writing – review & editing, Formal analysis. **Carles Roqué:** Methodology, Supervision, Writing – original draft, Formal analysis, Investigation, Data curation, Writing – review & editing, Conceptualization.

Declaration of competing interest

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

Acknowledgements

The archaeological fieldwork in the hills of Serra Llarga and the Montvell quarries is funded by a project authorised by the Culture Department in the Government of Catalonia (*'The Serra Llarga mining complex and flint quarrying activities in prehistory'*; ref. ARQ001SOL-134-2022). In addition to this programme, the research is framed in the project *'Territories, technical productions and technological innovation in the Mesolithic-Neolithic transition'* funded by the State Research Agency of the Spanish Ministry of Science, Innovation and Universities (ref. PID2019-109254 GB-C22). We have also been supported by the AGAUR (*Agència de Gestió d'Ajuts Universitaris i de Recerca*) from the Government of Catalonia (2021 SGR 00501) and the Palarq Foundation (2019) for the application of methodologies and techniques of experimental/analytical sciences in Archaeo-Palaeontology. Lastly, the authors wish to thank Castelló de Farfanya Town Hall for its support and collaboration.

The English translation of the original Spanish manuscript has been done by Peter Smith.

Data availability

The current data are contained in the manuscript, pending further ongoing studies. When the study is completed, all data will be uploaded to an institutional CSIC data repository.

References

Belmiro, J., Terradas, X., Cascalheira, J., 2023. Creating frames of reference for chert exploitation during the late pleistocene in southwesternmost iberia. PLoS One 18 (10), e0293223. https://doi.org/10.1371/journal.pone.0293223.

Boguszewski, A., 1991. Experimental use of antler tools in flint mines in Krzemionki, Poland. In: Archéologie Expérimentale (actes Du Colloque International 'expérimentation En Archéologie: Bilan et Perspectives'). Éditions Errance, Paris, pp. 46–48.

Bostyn, F., Lanchon, Y. (Eds.), 1992. Jablines, Le Haut Château. Une minière de sílex au Néolithique. Éditions de la Maison des Sciences de l'Homme (Documents d'Archéologie Française, 35), Paris.

Bostyn, F., Lech, J., Saville, A., Werra, D.H. (Eds.), 2023. Prehistoric Flint Mines in Europe. Archaeopress Publishing Ltd, Oxford.

Capote, M., 2011. In: Working in the Flint Mine: Percussion Tools and Labour Organisation at Casa Montero (spain). and Protohistoric Times. Archaeopress, Oxford, pp. 231–242.

Clutton-Brock, J., 1984. Neolithic antler picks from Grimes Graves, Norfolk, and Durrington Walls, Wiltshire: a biometrical analysis. British Museum Publications Limited, London.

Collet, H., Hauzeur, A., Lech, J. 2008. The prehistoric flint mining complex in Spiennes (Belgium) on the occasion of its discovery 140 years ago. In Allard, P., Bostyn, F., Giligny, F., Lech, J. (Eds.), Flint mining in Prehistoric Europe. Interpreting the archaeological records. Archaeopress (BAR IS 1891), Oxford, pp.41-77.

Collet, H., Hauzeur, A. (Eds.), 2019. Mining and quarrying. Geological characterisation, knapping processes and distribution networks during pre- and protohistoric times. Société royale belge d'Anthropologie et de Préhistoire (Anthropologica et Praehistorica, 128), Bruxelles.

Collin, J.P., Collet, H., 2011. Mode d'acquisition, stigmates d'utilisation et motifs d'abandon des outils d'extraction de la 'ST 20' de Petit-Spiennes, Spiennes (Hainaut, Belgique). Anthropologica et Praehistorica 122, 65–85.

Consuegra, S., Castañeda, N., Capdevila, E., Capote, M., Criado, C., Casas, C., Nieto, A., Díaz-del-Río, P., 2018. The Early Neolithic flint mine of Casa Montero (Madrid, Spain), 5350-5220 cal BC. Trab. Prehist. 75 (1), 52–66. https://doi.org/10.3989/tp.2018.12203.

Costin, C.L., 1991. Craft specialization: issues in defining, documenting and explaining the organization of production. Archaeol. Method Theory 3, 1–56.

De Labriffe, P.A., Reggio, A., André, P., 2019. Neolithic flint mines and quarries from Vaucluse (France). Assessment and review. In Collet, H., Hauzeur, A. (Eds.), Mining and quarrying. Geological characterisation, knapping processes and distribution networks during pre- and protohistoric times. Société royale belge d'Anthropologie et de Préhistoire (Anthropologica et Praehistorica, 128), Bruxelles, pp. 271-290.

Ericson, J.E., Purdy, B.A., 1984. Prehistoric quarries and lithic production. Cambridge University Press, Cambridge.

Fuertes-Prieto, M.N., Neira-Campos, A., Fernández-Martínez, E., Gómez-Fernández, F., Alonso-Herrero, E., 2014. Mucientes Chert in the Northern Iberian Plateau (Spain). J. Lithic. Stud. 1 (1), 117–135. https://doi.org/10.2218/jls.v1i1.785.

Galiberti, A. (Ed.), 2005. Defensola. Una miniera di selce di 7000 anni fa. Protagon Editori Toscani, Siena.

García-Simón, L.M., 2016. El sílex de Monegros y el evaporítico del Ebro: tipologías silíceas de la cuenca media del Ebro. In: CAPA (1er Congreso De Arqueología y Patrimonio Aragonés). Colegio Oficial de Doctores y Licenciados en Filosofía y Letras y en Ciencias de Aragón, Zaragoza, pp. 591–599.

Herrero-Alonso, D., Tarriño-Vinagre, A., Fernández-Martínez, E., Fuertes-Prieto, N., Neira-Campos, A., 2021. Black chert and radiolarite: knappable lithic raw materials in the prehistory of the Cantabrian Mountains (North Spain). Archaeol. Anthropol. Sci. 13, 113. https://doi.org/10.1007/s12520-021-01340-1.

ITGE 1998. Mapa Geológico de España. E. 1:50.000 - Hoja 359 – Balaguer. Instituto Geológico y Minero de España, Madrid.

LaPorta, P., Minchak, S.A., Brewer-LaPorta, M., 2010. The life and history of quarry extraction tolos excavated from the Skene Motion and workshop, Hartford Basin, Champlain Valley, New York, USA. In: Brewer-LaPorta, M., Burke, A., Field, D. (Eds.), Ancient Quarries and Mines: a Transatlantic Perspective. Oxbow Press, Oxford, pp. 109–119.

Lech, J. (Ed.), 1995. Flint mining. Polish Academy of Sciences - Institute of Archaeology and Ethnology (Archaeologia Polona 33), Warszawa.

Lozano, J.A., Morgado, A., Puga, E., Martín-Algarra, A., 2010. Explotaciones del sílex tipo 'Turón' (Málaga, España): localización y caracterización petrológica y geoquímica. Geogaceta 48, 163–166.

Martínez-Peña, M.B., Pocoví, A., 1988. El amortiguamiento frontal de la estructura de la cobertera surpirenaica y su relación con el anticlinal de Barbastro-Balaguer. Acta Geológica Hispánica 23 (2), 81–94.

Morgado, A., Lozano, J.A., Pelegrin, J., 2011. Las explotaciones prehistóricas del sílex de la Formación Milanos (Granada, España). Menga 2, 261–269.

Ortega, D., Terradas, X., Roqué, C., Ibáñez, J., Beamud, E., Larrasoaña, J.C., 2016. El sílex de la unidad de calizas de Montmaneu (sector oriental de la Cuenca del Ebro). Geogaceta 60, 95–98.

Ortega, D., Roqué, C., Ibáñez, J., Beamud, E., Larrasoaña, J.C., Sáez, A., Terradas, X., 2018. The chert from the castelltallat formation (south-central pyrenees): archaeometric characterization for archaeological research. Archaeol. Anthropol. Sci. 10, 1329–1346. https://doi.org/10.1007/s12520-016-0458-1.

Pelegrin, J., Richard, A. (Eds.), 1995. Les mines de silex au Néolithique en Europe: Avancées récentes. Comité des Travaux Historiques et Scientifiques (Documents préhistoriques, 7), Paris.

Peña, J.L., 1983. La Conca de Tremp y Sierras Prepirenaicas comprendidas entre los ríos Segre y Noguera Ribagorzana: estudio geomorfológico. Instituto de Estudios Ilerdenses, Lleida.

Pereira, T., Terradas, X., Bicho, N. (Eds.), 2017. Raw Materials Exploitation in Prehistory: Sourcing, Processing and Distribution. Cambridge Scholars Publishing, Cambridge.

Picazo-Millán, J.V., Pérez-Lambán, F., Fanlo-Loras, J., Sampietro-Vattuone, M.M., Peña-Monné, J.L., Pueyo-Anchuela, O., Pocoví-Juan, A., Tarriño-Vinagre, A., 2023. Explorando paisajes mineros prehistóricos. Estrategias de prospección para la documentación de las explotaciones de sílex de La Leandra (La Muela, Zaragoza). Munibe Antropologia-Arkeologia 74, online first. https://doi.org/10.21630/maa.2023.74.04.

Ramos-Millán, A., Bustillo, M.A. (Eds.), 1998. Siliceous rocks and culture. Universidad de Granada (Monográfica Arte y Arqueología, 42), Granada.

Russell, M., 2000. Flint Mines in Neolithic Britain. Tempus Publishing Ltd, Gloucestershire.

Sáez, A., Anadón, P., Herrero, M.H., Moscariello, A., 2007. Variable style of transition between Paleogene fluvial fan and lacustrine systems, southern Pyrenean foreland, NE Spain. Sedimentology 54, 367–390. https://doi.org/10.1111/j.1365-3091.2006.00840.x.

Sánchez de la Torre, M., Mangado, X., 2016. A new territorial marker in the Pyrenees: cherts from the Agua-Salenz formation. Munibe Antropologia-Arkeologia 67, 219–226. https://doi.org/10.21630/maa.2016.67.mis08.

Senz, J.G., Zamorano, M., 1992. Evolución tectónica y sedimentaria durante el priaboniense superior-mioceno inferior, en el frente de cabalgamiento de las sierras marginales occidentales. Acta Geologica Hispanica 27 (1-2), 195–209.

Tarriño, A., Olivares, M., Etxebarria, N., Baceta, J.I., Larrasoaña, J.C., Yusta, I., Pizarro, J.L., Cava, A., Barandiarán, I., Murelaga, M., 2007. El sílex de tipo 'Urbasa'. Caracterización petrológica y geoquímica de un marcador litológico en yacimientos arqueológicos del Suroeste europeo durante el Pleistoceno superior y Holoceno inicial. Geogaceta 43, 127–130.

Tarriño, A., Duarte, E., Santamaría, D., Martínez, L., Fernández de la Vega, J., Suárez, P., Rodríguez, V., Forcelledo, E., de la Rasilla, M., 2013. El Sílex de Piloña. Caracterización de una nueva fuente de materia prima lítica en la Prehistoria de Asturias. In de la Rasilla, M. (Ed.), F. Javier Fortea Pérez - Universitatis Ovetensis Magister (estudios en homenaje). Universidad de Oviedo, Oviedo, pp. 115-132.

Tarriño, A., López-Tascón, C., Hernández, H.H., Elorrieta, I., Herrero-Alonso, D., Aguirre, M., Larreina, D., Castañeda, N., Mujika, A., 2022. The neolithic flint quarry of pozarrate (treviño, northern spain). Open Archaeology 8, 273–286. https://doi.org/10.1515/opar-2022-0233.

Terradas, X., Ortega, D., 2017. Flint quarrying in north-eastern Iberia: quarry sites and the initial transformation of raw material. Antiquity 91/359, e5, 1–6. https://doi.org/10.15184/aqy.2017.167.

Terradas, X., Ortega, D., Marín, D., Masclans, A., Roqué, C., 2017. Neolithic flint quarries on montvell (catalan pre-pyrenees, NE Iberia). In: Pereira, T., Terradas, X., Bicho, N. (Eds.), Raw Materials Exploitation in Prehistory: Sourcing, Processing and Distribution. Cambridge Scholars Publishing, Cambridge, pp. 78–90.

Terradas, X., Marín, D., Masclans, A., Ortega, D., Rodríguez-Rellán, C., Roqué, C., Verdún, E., 2023. Las canteras de Montvell (Castelló de Farfanya, Lleida): una nueva modalidad de aprovisionamiento de sílex en el Neolítico del noreste peninsular. In: García-Rivero, D. (Ed.), Actas Del VII Congreso Sobre Neolítico En La Península Ibérica. Editorial Universidad de Sevilla, Sevilla, pp. 123–136.

Terradas, X., Ortega, D., Roqué, C., (in press). El complejo minero de Serra Llarga y las actividades extractivas de sílex en las canteras de Montvell (Castelló de Farfanya, Lleida). Boletín del Museo Arqueológico Nacional, Madrid.

Tucker, M.E., 1991. Sedimentary Petrology. An Introduction to the Origin of Sedimentary Rocks, Blackwell Science, Oxford.

Weiner, J., 1995. Les outils d'extraction à encoches en silex et pierre de la mine Néolithique Final du Lousberg, Aachen (Rhénanie septentrionale- Westphalie, Allemagne). In Pelegrin, J., Richard, A. (Eds.), Les mines de silex au Néolithique en Europe: Avancées récentes. Comité des Travaux Historiques et Scientifiques (Documents préhistoriques, 7), Paris, pp. 93-106.