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RESEARCH

# Knapping… Sleeping and Consuming? Spatial Variability in the High-Resolution Neanderthal Context of Abric del Pastor (Alcoi, Eastern Iberia)

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**Abstract**

Sequencing and characterising high-resolution units in which both natural and anthropogenic records can be examined on comparable scales is essential for understanding spatial behaviour and site formation processes. This requires a multidisciplinary approach that has previously been applied to the Neanderthal site of Abric del Pastor (Alcoi, eastern Iberia), revealing short-term occupations with high spatiotemporal resolution in stratigraphic unit IV, particularly focused on the lithic assemblages. In this study, we extend this methodological framework to stratigraphic unit V, investigating lithic record formation processes by applying archaeostratigraphic and spatial analyses, incorporating raw materials, technical attributes, and refits. Additionally, this research integrates soil micromorphology and sedimentary *n*-alkane analysis to explore critical aspects of sedimentary formation processes. Specifically, these techniques were used to corroborate the presence of in sitv hearths and rule out the possibility of erosional processes in the western sector of the rockshelter, where no archaeological materials were recorded. Our results, with refits as a benchmark, reveal at least two distinct stages of anthropogenic formation, characterised by recurring knapping activities primarily concentrated in the northern zone. These activities display internal variability in terms of flint type usage and activity intensity. Moreover, this knapping area is spatially segregated from three other zones: one containing a single hearth, close to the rockshelter wall, with no associated archaeological materials, possibly aligned with sleeping/resting purposes; another with a diachronic accumulation of faunal remains; and a third with an absence of archaeological record, in which postdepositional processes have not been detected. By identifying discrete formation events, we provide a detailed example of Neanderthal spatial variability, highlighting the deliberate use of certain zones for similar activities over time. This pattern contrasts with the spatial organisation of stratigraphic unit IV and other Neanderthal contexts, reflecting shifting strategies in the arrangement and use of space.

**Keywords** Neanderthal behaviour · Palimpsest · Lithic refitting · Archaeostratigraphy · Spatial analyses

## Introduction

Middle Palaeolithic spatial units play a pivotal role in deciphering Neanderthal behaviour (Vaquero, 2022), as they offer a valuable framework for interpreting the organisation of activities and interactions within sites with different types of records (e.g. lithic, faunal, charcoal remains) (e.g. Vaquero et al., 2012; Vaquero, 2022; Vidal-Matutano, 2017; Rosell et al., 2019; Bargalló et al., 2020; Sánchez-Romero et al., 2020, 2024; Moclán et al., 2023). In this sense, the *hearth-related assemblage* (*sensu* Vaquero & Pastó, 2001) is the most widely recognised spatial unit within Middle and Upper Palaeolithic sites with combustion evidence, where fire acts as a focal point around which humans carried out their activities (Binford, 1978; Stevenson, 1991), at least since the Middle Palaeolithic onwards. Furthermore, other spatial units have been identified in Neanderthal contexts, exhibiting notable variability, including secondary refuse areas of faunal remains (e.g. Gabucio et al., 2018; Speth, 2006; Starkovich et al., 2020) or lithic products (e.g. Sossa-Ríos et al., 2024; Spagnolo et al., 2019), sleeping zones (e.g. Henry et al., 2004; Spagnolo et al., 2019, 2020; Vallverdú et al., 2010), or storage places (e.g. Uthmeier et al., 2020).

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However, the understanding of spatial organisation remains incomplete without addressing its interplay with the temporal dimension, particularly because the palimpsest effect is inherent in nearly all archaeological sites (Bailey, 1983, 2007, 2008; Lucas, 2008; Stern, 2008; Vaquero, 2012). The accumulation of overlapping and/or interweaved events, either human or natural, hampers the process of isolating discrete spatial units within larger assemblages. As a result, it may produce a homogeneous and misleading picture of the archaeological space–time, where all activities appear to have occurred everywhere and at all times. Additionally, palimpsests can obscure spatial units with scarce material records and hinder comparisons with ethnographic data, which often operates on a human timescale. These challenges make the reconstruction of the diachronic history of archaeological deposits, and thus of the human groups that generate them, a particularly demanding task.

Specifically, when studying lithic assemblages, these temporal challenges are even more evident. We must acknowledge from the outset that their formation likely involved multiple depositional episodes, mostly represented by single products (Dibble et al., 2017; Turq et al., 2013; Vaquero, 2008). This awareness implies that any behavioural interpretations are constrained by the limitations of temporal resolution (Vaquero, 2001, 2008). Therefore, it becomes essential to search for diachrony markers within the assemblage that might help differentiate and contextualise events, or groups of events, across time and space.

But does this mean that we must only be interested in isolated events to understand past behaviour? Our recent research argues otherwise (Sossa-Ríos et al., 2024): the goal is not merely to isolate events, but to order and sequence them. This sequential understanding—determining what occurred first and what followed—is fundamental not only for capturing the nuances of human behavioural variability but also for detecting the continuity of certain behavioural patterns or the emergence of new behavioural dynamics. The process of analysis remains the same for both questions, offering insights into both change and persistence across time and space. For example, while one type of flint may constitute 80% of an assemblage, this does not imply that it was introduced uniformly over time. In fact, this flint could have been massively transported in only one or a few events, becoming a high but biased percentage of the total of human actions, as De Lange (2008: 155) showed in her model for faunal assemblages and Vaquero et al. (2012) for lithic assemblages. Thus, from being the constant pattern, it would become the indicator of variability. Both behavioural continuity/staticity and variability/dynamism require testing, and any hypothesis of time averaging must be carefully scrutinised and, if possible, rejected.

Delving into more detail, when examining time within a lithic assemblage, two information flows are ideally encountered: direct and indirect diachrony indicators. The former are particularly valuable as they allow time to be observed as empirical data: several centimetres of sedimentation separate two events of human activity, one below, the other above, with those centimetres representing a temporal lapse between groups of events. However, indirect markers offer a different perspective, especially as they tend to be horizontally shaped: Does a cluster of artefacts constitute a different temporal unit from a cluster positioned two metres away? Or does a concentration of a flint type signify a distinct timeframe compared to another dispersed flint assemblage? There is no empirical basis to confirm these temporal distinctions directly. Behavioural aspects can be tentatively inferred and compared with experimental or ethnoarchaeological studies, and formation models can provide additional context (e.g. Stevenson, 1985; Sullivan, 1992), but there is no straightforward relationship between time and the observed archaeological data. However, these indirect indicators can be highly informative, particularly in cases where direct markers are scarce or absent, enabling archaeologists to develop and test hypotheses about assemblage formation, such as bidirectional movements of refitted artefacts to test contemporaneity (Vaquero et al., 2017, 2019). Thus, both direct and indirect flows of information are essential when reconstructing the formation processes of lithic assemblages, with one important nuance: not all movements within an assemblage are the result of human action.

In this regard, archaeostratigraphy has proven useful in determining these sequences by identifying material gaps within vertical point-patterns (Bargalló et al., 2016; Canals et al., 2003; Galobart & Canals, 2003; Machado et al., 2017; Sánchez-Romero et al., 2017; Sossa-Ríos et al., 2024; Spagnolo et al., 2020). However, using point-patterns alone without considering archaeological information can be problematic for the definition of units of analysis that may have undergone postdepositional alterations. To address this issue, one of the most common solutions in lithic studies is to link remains through refit connections (López-Ortega et al., 2019; Romagnoli & Vaquero, 2019; Vaquero et al., 2012, 2019). This approach has not only refined the isolation of higher resolution units but has also helped to detect vertical movements, such as refit connections between different material beds (e.g. Hofman, 1986; Morrow, 1996; Villa, 1982). While refits are instrumental in identifying movements, other variables can further explain them. For instance, size and weight can help to assess whether remains have been sorted by size or weight, which would vary based on factors like the type of matrix or surface topography (e.g. Baker, 1978; Gifford-González et al., 1985; Marwick et al., 2017; McPherron et al., 2014; Villa & Courtin, 1983).

As we stated before, even within an archaeostratigraphic unit, the spatial dimension of lithic assemblages remains temporally ambiguous, with different human and non-human agents acting during the period of surface exposure, sometimes reaching more than centuries (e.g. Herrejón-Lagunilla et al., 2024). In the case of space, there have been a growth of contributions investigating not only the distribution of activities and their interrelationships (e.g. López-Ortega et al., 2011; Sánchez-Romero et al., 2020, 2024; Spagnolo et al., 2019, 2020; Vaquero et al., 2017) but also the postdepositional processes that may have occurred horizontally. Here, lithic orientation, size, and weight, when correlated with more general factors such as palaeosurface reconstructions, can be useful for assessing the taphonomy of the record involved (e.g. Bertran et al., 2012, 2019; Sánchez-Romero et al., 2023). On the other hand, we have seen that hearths are the most common focus for human activities. However, fire can also act as a spatial modifier, as fire activity is capable of displacing lithics up to 3 m from their original location when they are on the surface at the time of combustion (Dorta et al., 2010; Nieto-Márquez & Baena, 2015; Frank & Baridón, 2021).

These advances have significantly improved our understanding of how hunter-gatherers managed the site, shedding light on the variability between areas and activities developed within them over time. Additionally, they have highlighted that both vertical and horizontal distributions are influenced by non-human factors, which can be recognised and isolated through lithic and spatial taphonomy. However, this is not always enough. Other alterations affecting the record must also be considered when analysing and interpreting lithic assemblages. Both macroscopic and microscopic geoarchaeological observations are critical for evaluating the general and specific sedimentary contexts in which lithics are found (Karkanas & Goldberg, 2018). This approach has gained much attention, for instance, by warning of the possibility of vertical movements not only from top to bottom (e.g. Canti, 2003; Araujo, 2013) but also from bottom to top (e.g. Luria et al., 2020).

Even with the aforementioned advances, few lithic studies have successfully integrated the human-generated record with the sedimentary context in which it is embedded (e.g. Machado et al., 2013; Sánchez-Romero et al., 2022; Spagnolo et al., 2019). This task is essential before exploring any behavioural insights occurring at the site (Bertran et al., 2019; Sánchez-Romero et al., 2022), especially when lithic data alone may offer limited information. Moreover, tracing the dynamic composition and spatiotemporal dimension of the lithic record requires specific contextual conditions that mitigate the intrinsic uncertainties of archaeological assemblages. In this regard, two factors are particularly advantageous. First, sites where nearly complete surfaces have been excavated enable us to reconstruct more reliable scenarios, such as the intrasite movement of artefacts connecting different areas. Second, assemblages characterised by low material density inherently reduce the degree of time averaging, thus facilitating the isolation of high-resolution units. Together, these conditions allow for a more accurate integration of lithic data with its spatiotemporal context, building a robust foundation for exploring behavioural patterns.

The Middle Palaeolithic site of Abric del Pastor (Alcoi, eastern Iberia) meets these essential criteria, making it particularly well-suited for tackling the challenges posed by the palimpsest effect. In previous studies, SU IV was defined as an example of low-density assemblages in which high-resolution units were isolated and characterised using various methods, at different scales, over a representative area (Machado et al., 2013, 2019; Mallol et al., 2019; Sossa-Ríos et al., 2022). In this study, we present a multidisciplinary investigation focusing on the formation processes of the lithic assemblages of SU V. This includes the analysis of lithic attributes, raw material sourcing, refitting, archaeostratigraphy, and spatial distribution.

Additionally, we have incorporated geoarchaeological techniques: soil micromorphology and sedimentary *n*-alkane analysis. The application of these multiscale methods is critical for accurately interpreting the formation and distribution of lithic assemblages and particularly for assessing specific key field questions. First, the western part of the surface displays an apparently homogeneous deposit, primarily composed of massive, calcitic yellow sand and calcareous gravel. This area showed no evidence of anthropogenic activity, with only a few isolated archaeological materials recorded over the 2018–2023 excavation seasons (*ca.* 20 cm depth). Thus, understanding the geoarchaeological genesis of this deposit is essential for exploring the possible reasons behind the lack of anthropogenic activity in this area. By disentangling the main sedimentary formation processes, we could gain a clearer understanding of the actual agency/role played by human groups that occupied the site (Schiffer, 1972, 1983, 1985). Second, fire activity was only recognised in a limited area near the wall, where a clear combustion structure consisting of black and red layers (i.e. H19) was documented during excavation. However, additional traces of combustion were detected above and below this hearth (i.e. H18 and H20), although these were less well-defined. Therefore, determining the number of fire episodes within the SU V is crucial for two main purposes: (1) associating specific lithic assemblages with one or more fire events, both vertically and horizontally, and (2) evaluating the possibility of multiple hearths existing in the same space, but linked with different moments. Investigating fire, known as the primary spatial organiser of hunter-gatherer groups (e.g. Binford, 1978; Stevenson, 1991; Vaquero & Pastó, 2001), through its sedimentary record can help complement and refine the scale offered by the vertical point-pattern and the features of associated materials.

By addressing the challenges posed by the temporal and spatial dimensions of lithic assemblages, alongside the complexities of the sedimentary record, this study seeks to advance the interpretative frameworks for understanding Neanderthal spatial behaviour and the formation processes of archaeological assemblages.

## The Abric del Pastor Middle Palaeolithic Site

The Abric del Pastor site is located within the Serra de Mariola natural park, in the municipality of Alcoi (eastern Iberia) (Fig. 1). Positioned at an elevation of 820 m.a.s.l., this rockshelter lies on an escarpment within the eastern foothills of the Mariola mountain range. It is situated on the left side of the El Cint ravine, which links to the upper and middle courses of the Benissaidó river (Galván et al., 2009; Machado et al., 2013, 2019). From a geomorphological perspective, the rockshelter is a partially eroded karstic tube generated during the Tortonian Miocene, characterised by alternating layers of Cretaceous dolomitic limestone and Serravallian Miocene limestone-cobble conglomerates (Molina et al., 2010). The erosion process that

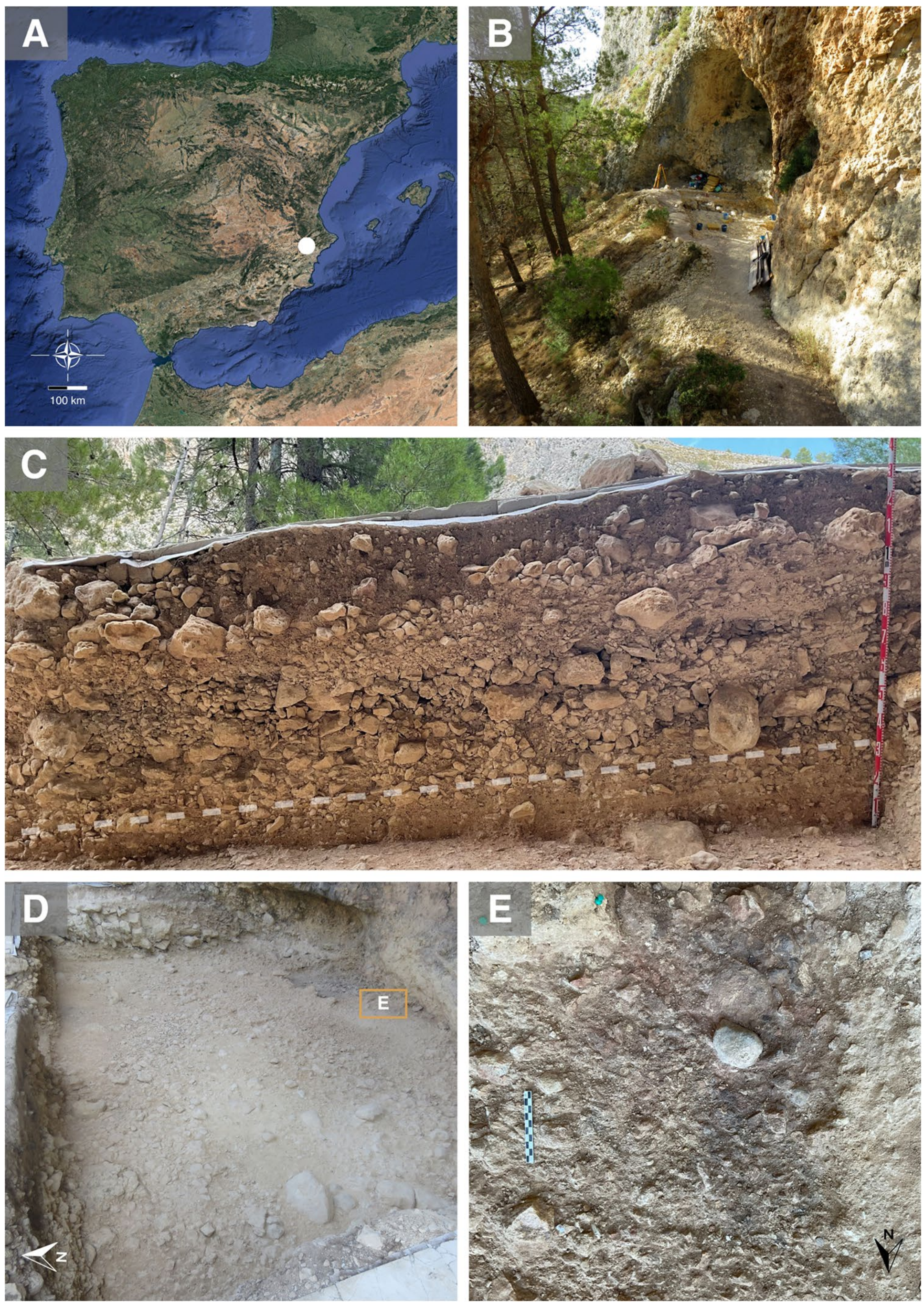


**Fig. 1** Location of the Abric del Pastor site in the Iberian Peninsula (**A**), general view of the rockshelter from the west (**B**), view of the north profile. SU V is the brown, finer grained layer at the bottom (**C**), 2022 excavation surface (**D**), dark grey area classified as H19 (**E**)

led to the formation of the rockshelter took place during the Pleistocene, associated with the incision and phreatic activities of the Benissaidó river.

The first intervention was conducted by M. Brotons, who excavated the site in 1951 and 1953. These excavations, restricted to a few square metres, revealed several Middle Palaeolithic remains coming from the SU I, a reworked Holocene unit that partially eroded the upper sections of SUs II and III (Galván et al., 2009). After this, two other interventions were carried out with the aim of contextualising the work previously developed by Brotons, the excavation of A. Seguí in 1967 and that of J.M. Segura and E. Cortell in 1972 by the Museu Arqueològic Municipal Camilo Visedo Moltó. In 2005, the excavations were restarted by B. Galván, C.M. Hernández, and C. Mallol covering the current area. Since that time, the site has been excavated every year so far by the University of La Laguna and national and international researchers.

The site offers a potential occupation surface of 60 $m^2$, with 40 $m^2$ currently under excavation. Up to now, the stratigraphic sequence measures 1.6 m thick and is divided into six stratigraphic units (SUs), labelled VI-I from bottom to top, with a chronometric range for the Pleistocene sequence (SU VI to II) of 63 $\pm$ 5 to 48 $\pm$ 5 ky BP (see Connolly et al., 2019 and Mallol et al., 2019 for a detailed description of each unit).

SU V was excavated between the 2018 and 2023 field seasons. Although SU V lacks direct chronometric data, it is presumably older than the OSL date from SU IVd (63 $\pm$ 5 ky BP). With a thickness varying from 15 to 30 cm, this unit consists of matrix-supported blocks, gravels, and reddish calcareous sands in the southeastern and central zones, with gravels and reddish sands in the northern and southern parts, while the western zone is composed of calcareous, yellowish massive sands. Previous micromorphological analysis on a thin section from the test pit showed that SU V is composed of a calcitic matrix, with the occasional presence of iron oxides and clay coatings. On the other hand, this unit presents the lowest organic content of the archaeological sequence, based on the concentration of *n*-alkanes and the total organic carbon index (TOC) (Connolly et al., 2019).

At the time of formation of this unit, the site featured, inside the main 6.95-m-high shelter covering almost the entire surface (i.e. drip line in Fig. 2), a limestone ledge in the east (1.5 m high), which collapsed during the early stages of SU IV formation (i.e. collapsed ledge in Fig. 2 and Fig. S1). From the latter, a small sheltered zone is still preserved in the southeast (3 $m^2$).

## Materials and Methods

For this work, we analysed the lithic assemblage from SU V, consisting of 147 products. Additionally, we considered the X, Y, Z coordinates of the lithic ($n$ = 147) and faunal ($n$ = 300) assemblages, as well as the potential combustion structures for archaeostratigraphic and spatial analyses, recorded using Sokkia iM-50 Series and Leica Geosystems FlexLine TS02 total stations. While our objective was to record all lithic artefacts regardless of their size, some pieces were recovered through water screening. None of these pieces exceeds 20 mm, and despite conducting two separate refitting attempts, none could be linked to the established refitting sequences. Moreover, given that this study focuses primarily on the temporal dimension provided by the Z coordinate, we decided not to include these materials in the analysis.

On the other hand, five sediment blocks were taken for soil micromorphology, and six sediment samples were collected for *n*-alkane analysis.

### Lithic Record

#### Raw Material Analysis

The entire lithic assemblage was analysed both macroscopically and by means of a Euromex DZ 1600 and a Euromex EduBlue 1802-S stereomicroscope, both visualised using the Euromex ImageFocus Plus software, version 2.4.9.0. The first step involved examining the primary genetic traits exhibited by each lithic element (*sensu* Fernandes & Raynal, 2006). For the limestone, these characteristics were just described. For the flint, these traits allowed us to identify the specific lithotypes to which the lithic specimens belonged. These siliceous lithotypes had been previously recognised, described, and defined in studies conducted in the eastern Prebaetic System and associated Neogene basins, such as the Serpis or the Vinalopó river valleys (Molina, 2016; Molina et al., 2010, 2014, 2016). Additionally, we have also observed the postgenetic traits, that is, those produced by alterations that occurred after the flint release from the host-rock, in order to use them in the identification of raw material units (i.e. RMU), as explained below.

In this vein, the genetic features used to identify the flint lithotypes within the assemblage included matrix colour and texture; cortex colour, texture, and thickness; subcortical and endocortical halos; inclusions (e.g. fossils and microfossils, biogenic structures, megaquartz). The characteristics of the siliceous lithotypes appearing in this paper (i.e. Serreta, Mariola, Beniaia, and Catamarruc) have already been published, as mentioned earlier (see Machado et al., 2017; Mayor et al., 2022; Molina et al., 2016).

Additionally, we focused on two types of alterations observed in some flint elements: thermal alteration and white patina formation. On the one hand, thermoalterations were identified based on macroscopic indicators that had been previously defined through experimental studies, compared with the archaeological record, and published

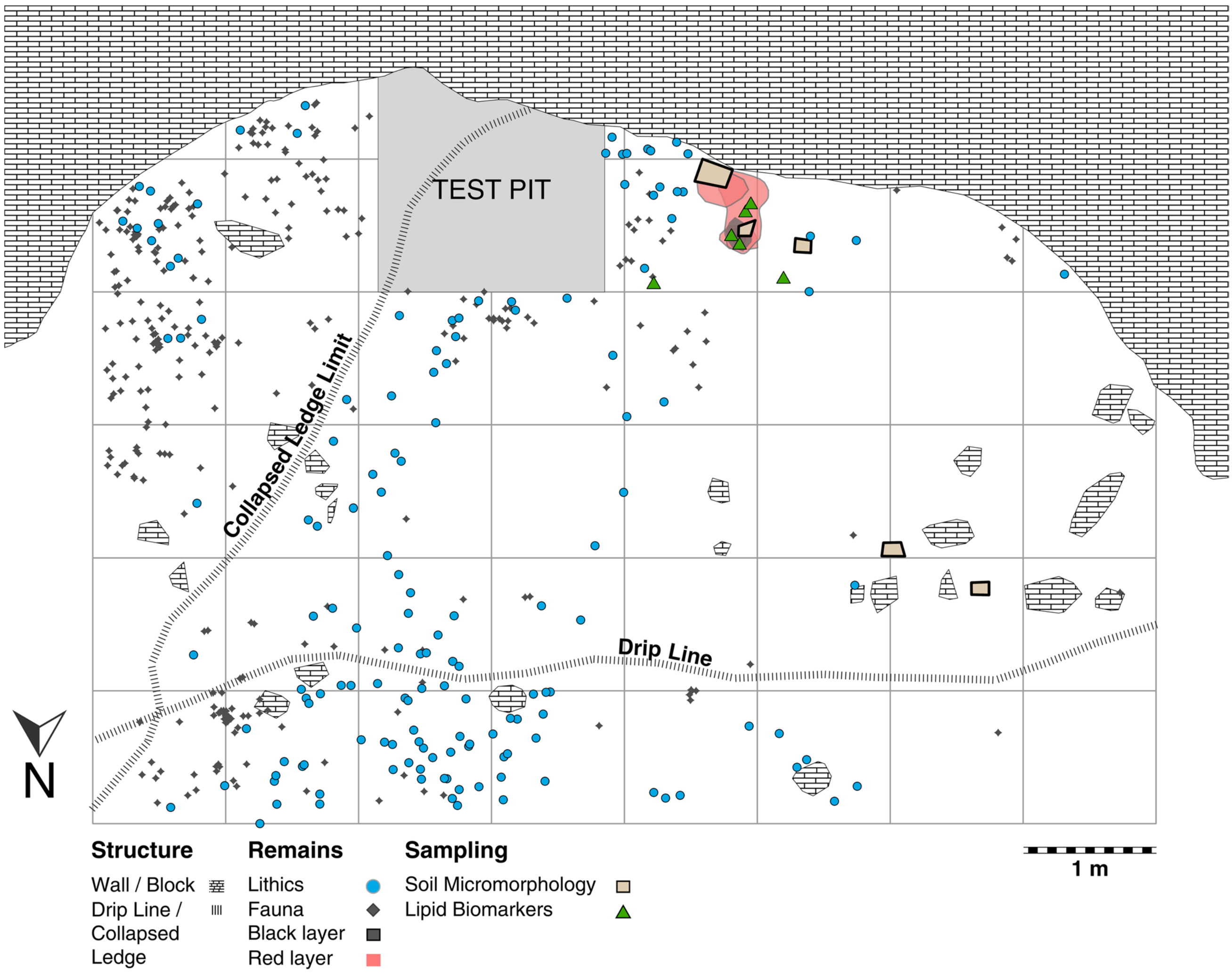


**Fig. 2** Plan of the site showing the position of structural elements, archaeological remains, and sediment samples

(Dorta et al., 2010). These features include chromatic and textural changes, reticular fissures, thermal domes, irregular fractures, and glossy surfaces. On the other hand, the formation of white patina has been associated with the exposure of flint to weathering processes (Fiers et al., 2018; Thiry et al., 2014), as well as its presence in acidic, calcite-rich deposits (Rottländer, 1975). In the Serpis river basin, this phenomenon has been notably observed in flint that has redeposited in colluvial environments, where it occurs with particular intensity (Mayor et al., 2024; Molina & Mayor, 2023; Molina et al., 2015).

Once the genetic traits and the aforementioned signs of alteration were described, we proceeded with the RMU identification (Roebroeks, 1988; for minimum analytical nodule, see Larson & Kornfeld, 1997). Each element was compared to the rest of the assemblage to recognise matches in their traits, whether geogenic or postgenetic. When two or more flint artefacts exhibited a high degree of similarity and coincidence, they were grouped together as a set RMU (i.e. S-RMU). Since an RMU represents the outcome of knapping a single raw material nodule, any element that did not match with others was classified as a single-element RMU (i.e. SE-RMU) and thus considered the potentially sole product of a single raw material nodule (Sossa-Ríos et al., 2022, 2024).

## Lithic Attribute Analysis

The lithic assemblage was analysed based on specific qualitative and quantitative attributes. First, each lithic element was classified according to artefact type (i.e. flake, retouched product, core, fragment, or unmodified nodule).

The next step involved acquiring metric data from the artefacts. For flakes, maximum length, width, and thickness were measured, considering their technical axes. For the remaining elements, the maximum possible dimension was recorded as the length. Taking this axis as reference, the widest horizontally transversal line was considered the width, and the thickest vertically transversal measure was taken as the thickness. These measurements allowed us to establish different typometric groups based on the product of length and width: very small (i.e. < 500 $mm^2$), small (i.e. 500–1000 $mm^2$), medium-sized (i.e. > 1000–1500 $mm^2$), large (i.e. > 1500–2000 $mm^2$), and very large (i.e. > 2000 $mm^2$), following the criteria outlined by one of us (Vaquero, 2008).

Additionally, each element was weighed and grouped according to the results of the Jenks natural breaks classification method, which identifies groups in the data by maximising the differences between classes and minimising the variance within them (Jenks, 1967). Weight has proven to be a more appropriate variable to investigate changes in mass introduction (Sossa-Ríos et al., 2024).

Subsequently, the approximate proportion of cortex present on flakes was estimated. These percentages were grouped into ranges based on quarters: 0%, > 0 to 25%, > 25 to 50%, > 50 to 75%, > 75 to < 100%, and 100% (Mayor et al., 2022).

In the case of cores and flakes, we followed established technological approaches aimed at reconstructing knapping methods, strategies, and modalities (Boëda et al., 1990; Pelegrin, 1990; Boëda, 1995). For flakes, the analysis focused on variables such as the number and orientation of dorsal scars and platform and bulb characteristics. Cores underwent a more detailed evaluation, considering the organisation and hierarchy of surfaces, the type and preparation of striking platforms, and the number and orientation of removals. This analytical framework enabled the general identification of knapping systems, including the presence and variability of Levallois and non-Levallois methods, as well as the degree of fragmentation in the operative sequences.

#### Lithic Refitting Analysis

Once the assemblage was separated into SE-RMUs and S-RMUs, we undertook the task of connecting lithic products. This process is critical not only to gain confidence in the identification of S-RMUs by physical joining but also to increase our knowledge of technical and technological aspects, as well as the vertical and horizontal distribution of knapping activities (Baena et al., 2019; Cziesla, 1990; Machado et al., 2019; Martínez-Moreno et al., 2019; Romagnoli & Vaquero, 2019; Vaquero et al., 2017, 2019).

We distinguish between two types of connections: refits, which are considered to be links associated with production sequences, and conjoins, understood as product joints resulting from either syndepositional or postdepositional fractures. We generated connection lines for both refits and conjoins and calculated the number of elements involved, the number of connections by lines, and their lengths (minimum, maximum, mean, and standard deviation) for each flint type and R-RMU (i.e. products physically connected within an S-RMU, whether refits or conjoins).

The connection lines were drawn based on the chronological sequence of removal events for refits and on the artefact surface contact for conjoins. All this information may provide clues, for example, to the movement of certain products between activity areas, the position of the knapper (e.g. standing or sitting) or postdepositional disturbances (e.g. Arilla et al., 2020; Bertran et al., 2012; Kwamme, 1997; Newcomer & Sieveking, 1980; Vaquero et al., 2017).

For the refitting task, we spent 2 months, the first at Universitat de València and the second at the Interdisciplinary Centre of Archaeology and the Evolution of Human Behaviour (i.e. ICArEHB), with different attempts for each product and involving different people.

#### Archaeostratigraphic Analysis

The archaeostratigraphic analysis was applied with the aim of detecting possible material hiatuses that can separate the entire assemblage into higher resolution units of analysis (e.g. Arteaga-Brieba et al., 2023; Martínez-Moreno et al., 2004, 2016; Sánchez-Romero et al., 2017, 2023; Spagnolo et al., 2020). All the following steps were performed using ArcGIS Pro 3.1.0.

First, the entire assemblage was plotted in 3D for visualising the overall and specific point-pattern, since 2D analysis implies a serious lack of perspective (Roy-Sunyer, 2015; Sánchez-Romero et al., 2017). This process continues throughout the entire vertical examination, as each cross-section is constantly visualised and subjected to a qualitative analysis in this manner (Machado et al., 2013; Sossa-Ríos et al., 2024). Second, kernel density estimation (KDE) (see the "Spatial analyses" section for further explanation) was horizontally conducted for lithic and faunal assemblages in order to observe the areas where most materials were involved and thus placing the 2D cross-sections. Taking into account the areas of major accumulation of artefacts, we selected the profiles and applied a thickness of 0.50 m due to the low density of the assemblage, in order to represent the largest possible number of materials without losing perspective. For the lithic assemblage, we combined the visualisation of RMUs, both single and refitted, with weight, patina, and edge damage within the 2D cross-sections, for compositional and taphonomic assessments (Baker, 1978; Gifford-González et al., 1985; Rose et al., 2024; Stevenson, 1985; Villa, 1982). For analysing the vertical relationships of R-RMUs, the connecting lines were also displayed in 3D, as this visualisation saves the need to generate many 2D cross-sections when including all the refitted sets (e.g. Sánchez-Romero et al., 2024).

Finally, we applied the ordinary Kriging interpolation method to generate a palaeosurface that enhances the understanding of the archaeostratigraphic cross-sections (e.g. Arteaga-Brieba, 2024; Hageman & Bennett, 1999; Oliver & Webster, 1990; Sánchez-Romero et al., 2020, 2023). This method estimates values at unsampled points by considering spatial autocorrelation, using both the coordinates of the archaeological remains and the coordinates obtained to control the topography of the surface, recorded horizontally at 0.5 m intervals.

### Spatial Analyses

The spatial analyses were applied to determine the distribution patterns of the lithic record and establish units of analysis that can offer insights into spatial assemblage variability (Arteaga-Brieba et al., 2023; Clark, 2017, 2019; Sánchez-Romero et al., 2022, 2024). All the following tests were performed using Esri ArcGIS Pro, version 3.1.0.

First, average nearest neighbour (ANN) was applied to the lithic assemblages considering the excavated area (i.e. 40 $m^2$). This test shows the general spatial pattern exhibited by the X–Y points, discerning between clustered, random, or dispersed (Romagnoli & Vaquero, 2016; Sánchez-Romero et al., 2022; Whallon, 1974). The homogeneous Ripley *L*-function was then applied to the lithic record to identify the spatial scale, in terms of distance, at which clustering or dispersion occurs (Besag, 1977). This transformation of the *K*-function (Ripley, 1977) linearised the results, making it easier to detect deviations from randomness. The observed $L(d)$ values are compared against an envelope created by simulating random spatial distributions. This provides a more comprehensive view of clustering and dispersion across different spatial scales, allowing the identification of statistically significant patterns (Lee, 2023). Third, KDE was conducted with Euclidean distance with a search radius of 0.9 m. This method estimates the distribution of archaeological remains over a defined space, creating a continuous raster that highlights areas with higher and lower concentrations of materials (Sánchez-Romero et al., 2022; Spagnolo et al., 2019, 2020; Zilio et al., 2021). We applied this not only for lithics but also for faunal remains, since their analysis was necessary for placing the archaeostratigraphic cross-sections, and also for allowing comparisons in the use of space.

Two additional tests were applied to detect spatial clusters with the aim of exploring in depth the composition of the lithic assemblages. On the one hand, density-based clustering (DBSCAN) was performed using the self-adjustment clustering method (HDBSCAN) and considering a minimum of 10 points for clustering. This analysis identifies both clusters and "noise" (i.e. artefacts located in areas where local point density is too low to meet the clustering criteria) by evaluating the spatial distribution of the dataset without predefining the number of clusters (Díaz-Rodríguez & Fábregas-Valcarce, 2022; Mikhailova et al., 2019; Murugesan et al., 2021). The probability threshold for clustering was set at $\geq 0.66$, considering the need to balance inclusivity and precision in identifying significant clusters within this low-density assemblage. This threshold provides a moderate level of stringency that captures a substantial number of points while minimising the inclusion of "noise". On the other hand, optimised hot spot analysis (Getis-Ord Gi*) was applied to calculate the number of artefacts by square, considering a fishnet composed of 0.74 $m^2$ squares. This grid measure was calculated following the quadrat method, in which the size of each of the quadrants is calculated based on the extent of the area and the number of artefacts (Getis, 1964; Lee & Wong, 2001; Sánchez-Romero, 2019). This method was also applied to the weight variable to detect possible sorting by mass. The optimised Getis-Ord Gi* offers a high statistical confidence in the identification of spatial clustering also without having to define the radius and the number of clusters in advance (Arteaga-Brieba, 2024; Sánchez-Romero et al., 2022).

Moreover, we conducted a Chi-square, Fisher exact, and Cramer's *V* tests to explore the interdependence between the archaeological remains (both lithics and fauna) and their positioning in certain areas of the site. These tests were conducted to assess whether the observed distribution of materials was significantly different from what would be expected by chance.

Finally, several variables were displayed for qualitative analyses: white patina and edge damage, weight, raw material, type of product, and thermal alteration. Furthermore, we applied the Jenks natural breaks classification method to categorise lithic artefacts by weight, forming groups that minimise variance within each class, while maximising variance between classes, based on the dataset itself (e.g. Benito-Calvo et al., 2015; Jenks, 1967; Sánchez-Romero et al., 2021).

## Sedimentary Record

### Soil Micromorphology

Five undisturbed, oriented sediment blocks were collected from two different locations of the rockshelter (Fig. 2). Three blocks were collected from the combustion area, in order to assess the presence of a single or multiple combustion structures (H18, H19, and H20). Two other blocks were sampled from the massive sandy deposit located at the western area of the site, with the aim of assessing its main formation processes and integrity. This selection of sampling areas was specifically designed to address these targeted field questions. Broader geoarchaeological data regarding the general formation processes at SU V have already been published by Connolly et al. (2019).

The micromorphology blocks were processed at the Archaeological Micromorphology and Biomarkers Lab

(AMBILAB, University of La Laguna, Tenerife, Spain). First, the blocks were dried for 48 h at 60 °C and then impregnated with a 7:3:0.1 v/v/v/ratio mixture of polyester resin (palatal cast resin UN1866, TNK compounds), styrene (styrene monomer (CAS: 100–42–5) UN2055, TNK compounds), and catalyst (methyl ethyl ketone (Luperox, CAS: 78–93–3), TNK compounds). The hardened blocks were cut into 1-cm-thick slabs using a Euro-Shatal M31100 radial saw. These slabs were then transformed into eight thin Sects. (7 cm × 4 cm × 30 μm) at Spectrum Petrographics (Vancouver, Washington, USA).

For micromorphological analysis, petrographic microscopes Nikon E600 POL and Nikon AZ100 were used, both located at AMBILAB. The samples were analysed under plane-polarised light (PPL) and cross-polarised light (XPL). Microphotographs were taken using a Basler acA2400 camera. Thin sections were analysed and described following the standard guidelines provided by Stoops (2003) and Nicosia and Stoops (2017).

#### *n*-Alkanes

Bulk sediment samples were collected from the black layer (BL) and red layer (RL) of H19. For H20, a blackish sediment beneath H19 was identified and sampled as a possible black layer, with the underlying sediment sampled as a potential red layer. Control samples were also collected from the natural substrates of the potential combustion structures. No samples were collected from H18 due to insufficient sediment with signs of combustion for analysis. All the samples were recovered with solvent-washed metal tools using nitrile gloves, packed in aluminium foil, and stored at − 20 °C until further processing.

Sediment samples were oven-dried at 60 °C for 48 h and homogenised using an agate mortar and pestle. Lipids were extracted from 10 g of sediment using a dichloromethane and methanol mixture (DCM:MeOH, 3:1, v/v, 40 mL) through ultrasound-assisted extraction in three cycles of 30 min each. The total lipid extract was fractionated into three different polarity fractions through a silica gel column (1 g activated silica 70–230 mesh, 0.1 g sand 50–70 mesh, and glass wool in a Pasteur pipette) using several mobile phases. In this study, we present results of fraction 1 (F1: *n*-alkanes), which was eluted with 3/8 of the dead volume (~ 1.5 mL) in hexane. The fraction extracts were subsequently evaporated under a stream of $N_2$ at 40 °C and re-dissolved in 50 μL of hexane. Prior to measurement, 1 μL of 5α-androstane (8 mg/L in DCM) was added as an internal standard (IS). The extracts were analysed by gas chromatography–mass spectrometry (GC–MS) (see Supplementary material). Even/odd numbered *n*-alkanes distribution was evaluated by calculating the carbon preference index (CPI) (see Supplementary material).

## Results

### The Assemblage as a Whole: A Simple Lie

The lithic assemblage comprises four flint types alongside a single limestone artefact. Thirteen S-RMUs were identified, six of which include almost complete or partial refits. When counted by RMUs rather than by individual artefacts, Mariola flint emerges as the most represented, followed by Serreta, Beniaia, and a minor presence of Catamarruc flint. Technologically, the assemblage is dominated by Levallois production, with a preference for recurrent centripetal modalities. Additionally, a smaller proportion of the assemblage reflects unidirectional and bidirectional reduction patterns not strictly following Levallois principles. Flakes are generally very small and small sized with a low amount of cortex, suggesting that most of the core exploitation and initial decortication occurred elsewhere. Retouched products are scarce, and all correspond to sidescrapers, only one of which is associated with an R-RMU, suggesting that most were likely introduced to the site already fully knapped and modified.

Spatially, lithic materials are concentrated in the northern sector, which also contains all refitted sequences. This distribution contrasts with the faunal remains, primarily located in the southeast, and a combustion area to the south, where a single hearth lacks associated materials and only a few remains are found nearby. The western sector remains empty, with no evidence of either human activity or natural disturbance.

While this summary offers a useful overview, it reflects only the apparent pattern at the stratigraphic unit level. To fully understand the formation of this assemblage and the behavioural variability it captures, it is essential to move beyond this static view and explore the diachronic relationships between discrete formation events.

### Lithic Record

#### Archaeostratigraphic Results

Based on KDE results, lithic products are concentrated in the north, while faunal remains are primarily located in the northeast and southeast, with a noticeable absence of archaeological materials in the west and certain central areas (Fig. 3A). Consequently, the 50-cm-thick cross-sections illustrating vertical distribution are focused on these zones where most material is concentrated. Given that the point-pattern exhibits a concave morphology from north to south (Fig. 3B), cross-sections were oriented along this axis, except for one 35-cm-thick oblique cross-section, which was used to analyse the relationship between H19 and archaeological remains (Fig. 3G).

The SU V point-pattern is well organised, with vertical gaps of materials identified, including differences of up to 10 cm between material beds in the southeast (Fig. 3C) and 1 to 3 cm between Serreta and Mariola R-RMU line sets in the north (Fig. 4). Additionally, the refitting line sets show similar slopes, with no line crossings between vertically separated refitted products (Fig. 4). Similarly, there is no evidence of vertical weight sorting. Lightweight classes (W1 and W2) are evenly distributed, especially in the central and northern zones, where these classes predominate (Fig. 3E). Furthermore, considering the Kriging results (Fig. 3B), most of these lightweight products are positioned in the higher parts, decreasing in number as the surface becomes more concave. On the other hand, although the presence of some heavy materials at the bottom is noticeable in the east (Fig. 3C), lighter materials are found on top of the assemblage in the same profile. Regarding other taphonomic features, such as patina and edge damage, both conditions are observed particularly at the bottom of the assemblage (Fig. 3F), with some exceptions such as a product with patina and edge damage situated at the top (Fig. 3D).

Despite the absence of major vertical movements, we were unable to subdivide the assemblage into distinct archaeostratigraphic units for several reasons. First, there are horizontal gaps in the central zone, hampering the association of material beds across different areas of the site. Second, these material beds are not continuous, with certain materials bridging existing gaps after 10 to 20 cm horizontally. Finally, the compaction of the record, which spans a short vertical range, particularly in the north where most materials are concentrated, hinders any reliable archaeostratigraphic correlation.

In the case of H19, the only identified combustion structure (see the "Discussion" section, "A Possible Resting Area?" subsection), it was not possible to establish an archaeostratigraphic correlation between any of its layers (black or red) and the point-pattern. This is due to the *ca*. 25 cm horizontal gap between the hearth and the lithic and faunal record (Fig. 3G).

### Spatial Results

The ANN (Table S1) and homogeneous Ripley's *L*-function (Fig. S2) analyses indicate a clustering pattern for the lithic assemblage. Both methods also show clustering for the Serreta and Mariola flint types. However, for the Beniaia flint type, ANN suggests a clustering pattern but with a higher *p* value (0.23), indicating weaker statistical significance due to the low sample size. Additionally, the *L*-function did not produce reliable results for the Beniaia flint, as the test requires at least 30 points for robust analysis.

In the case of KDE (Fig. 5A), the lithic products exhibit a major concentration in the northern area. Other zones with lower densities were identified in the southeast and in the south, near the wall and H19. However, there is a notable absence of archaeological materials in the western part of the site, where no concentrations are observed. HDBSCAN identified clusters in the same three areas (Fig. 5A), resulting in three clusters and a "noise" assemblage with varying numbers of lithic products. Thus, Cluster 1 (C1) has been identified in the southeast ($n = 9$), Cluster 2 (C2) in the north ($n = 42$), and Cluster 3 (C3) in the south ($n = 14$). In addition to these, there are scattered materials ("noise") across the surface ($n = 82$) that were not classified within any cluster by HDBSCAN. While Clusters 1 and 3 aligned with their respective KDE density ranges, Cluster 2 encompassed the lithic products extending into the fourth most dense range of values. Considering both the KDE ranges and the HDBSCAN cluster boundaries, the sizes of the clusters were similar for Cluster 1 (0.87 × 0.68 m) and Cluster 3 (0.87 × 0.79 m), while Cluster 2 (1.81 × 1.66 m) was approximately double their dimensions.

On the other hand, optimised hot spot analysis only identified one hot-spot cluster in the northern area, with eight quadrats showing a 99% confidence level and one quadrat 95% confidence (Fig. 5B). No cold-spot clusters were detected. In the case of weight, optimised hot spot analysis shows a clustering pattern of heavyweight products with 95% confidence in the southeastern area, all under the ledge (Fig. S4).

The Chi-square test revealed a statistically significant relationship between the distribution of lithic and faunal remains in relation to the ledge ($Chi^2 = 87.67$, $p < 0.0001$). Similarly, Fisher's exact test further confirmed this association ($p < 0.0001$), with Cramer's *V* indicating a moderately strong effect size ($V = 0.44$) (Table S2).

Finally, the KDE analysis of faunal remains shows concentrations in areas distinct from the lithic distributions (Fig. 5C). These concentrations are particularly high in the southeast and the northeast, with smaller concentrations in the south. Again, the western part of the site exhibits a notable absence of faunal remains, consistent with the pattern observed for lithic materials.

### Raw Material Results

The lithological data obtained will be presented here by distinguishing between the material record associated with each cluster (i.e. C1, C2, and C3) and the scattered assemblage (i.e. "noise") (Fig. 7). Lithic artefacts that fall outside any cluster but belong to an S-RMU included in any of them will be incorporated in the analysis of the corresponding cluster (Fig. 5A). Furthermore, this is supported by the spatial distribution of flint types (Fig. 6) and recognised alterations (Fig. S3b).

C1 consists of ten lithic artefacts, all made of flint. Three are made of Beniaia flint, while seven, including one

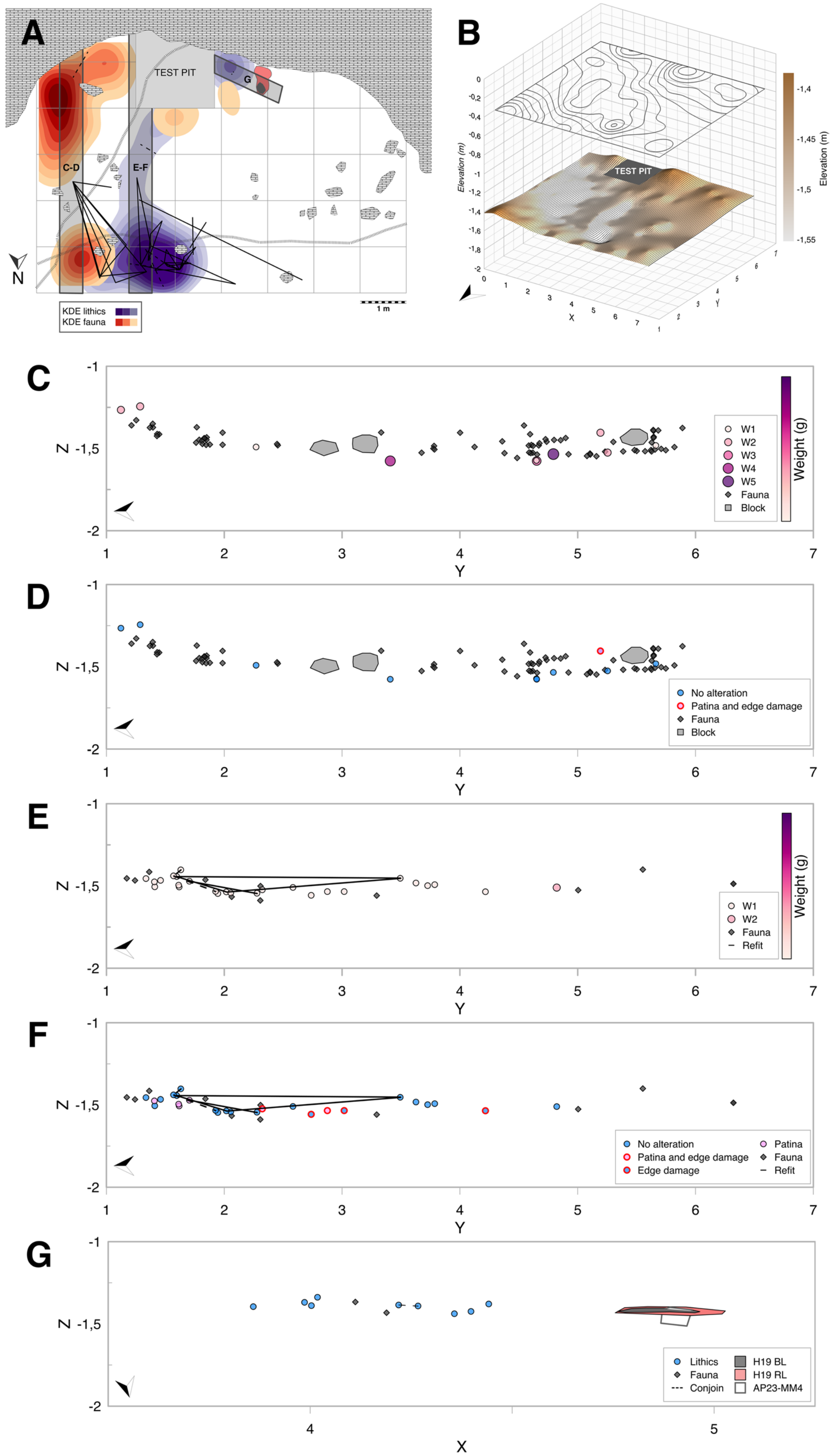


**Fig. 3** Site plan indicating the most dense concentrations of lithic and faunal remains, and the location of the cross-sections (**A**), palaeotopographic reconstruction of SU V (**B**), north-to-south C cross-section by weight class (**C**), north-to-south D cross-section by taphonomy (**D**), north-to-south E cross-section by weight class (**E**), north-to-south F cross-section by taphonomy (**F**), and northeast-to-southeast cross-section (**G**). Weight classes in grammes: W1 = 0–3.58; W2 = 3.59–18.62; W3 = 18.63–46.40; W4 = 46.41–88.93; W5 = 88.94–1239

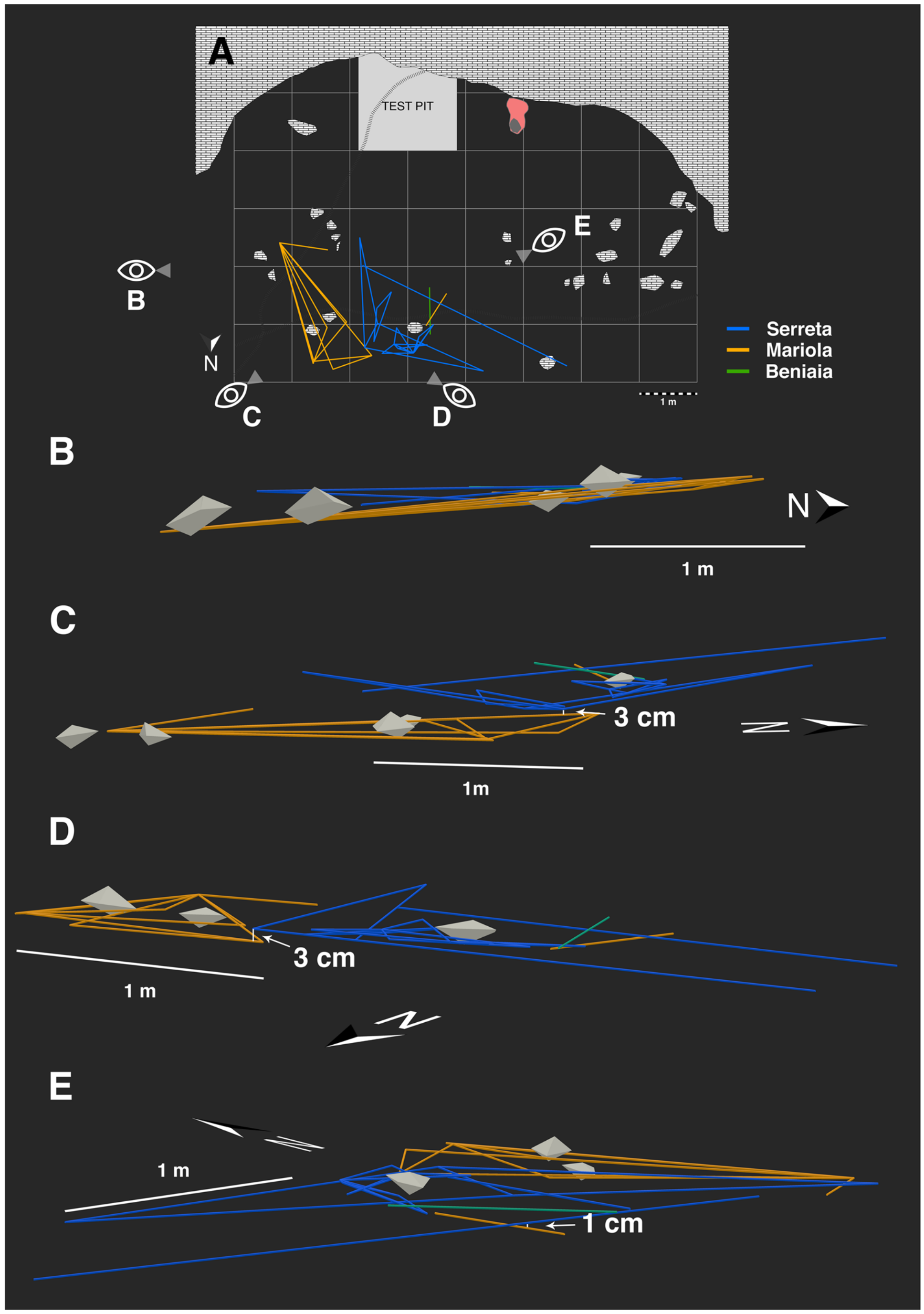


**Fig. 4** Site plan showing refitting lines by flint type (**A**) and 3D visualisation of the refitting lines from different perspectives and angles (**B**–**E**)

outside the cluster, are made of Mariola flint (Fig. 7). The only S-RMU identified (V-M6) is made of Mariola flint and includes two elements, one located outside the cluster. This reduces the total number of anthropogenic inputs in C1 from ten to nine. In the Beniaia flint assemblage, none of the artefacts shows thermal alterations, but one artefact has initial stages of white patina and edge damage. The Mariola flint set lacks signs of thermal alteration, with two artefacts showing white patina in advanced stages on natural surfaces and one artefact (from V-M6) displaying edge damage.

C2 contains 67 flint artefacts, with Serreta being the most represented ($n = 40$), followed by Mariola ($n = 21$), and Beniaia ($n = 4$), and two undetermined products. Six S-RMUs were identified: three made of Mariola flint (V-M3, V-M5, and V-M7) and three of Serreta flint (V-S1, V-S2, and V-S4). These S-RMUs comprise 53 products (79% of C2), reducing the potential anthropogenic inputs from 67 to 20. Although this cluster is dominated by both Serreta and Mariola, they exhibit a slight spatial differentiation, with minimal overlap between the two flint types

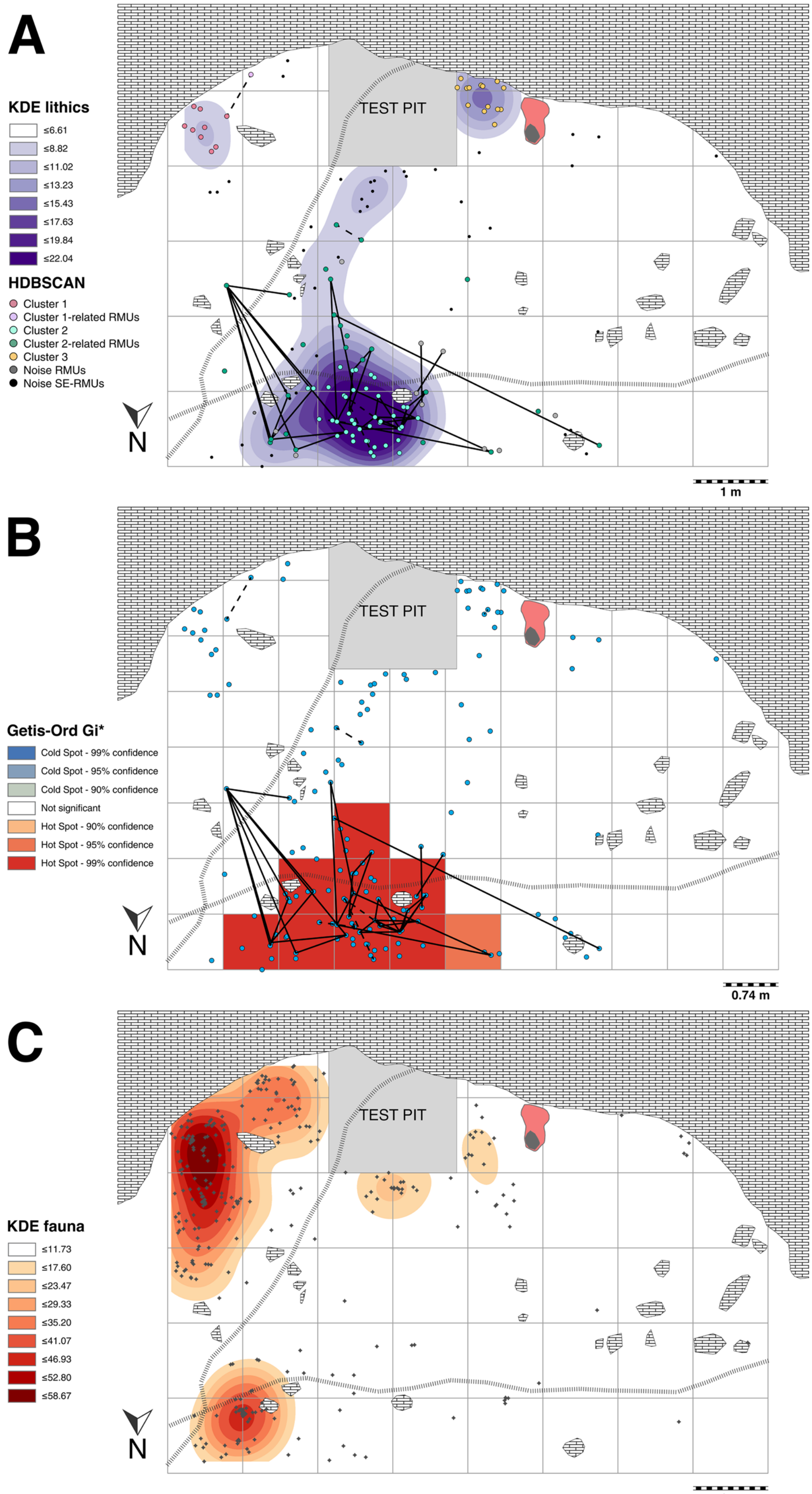


**Fig. 5** KDE and HDBSCAN results of the lithic assemblage (**A**), Getis-Ord Gi* results of the lithic assemblage by 0.74 m.$^2$ squares using the Quadrat method (**B**), and KDE results of the faunal assemblage (**C**)

(Fig. 6B). In the Beniaia assemblage, none of the artefacts shows thermal alteration, but three have white patina and one has edge damage. In the Mariola assemblage, no thermal alteration was observed, but three artefacts show advanced white patina and no edge damage. The Serreta assemblage has one thermally altered artefact and 11 products with white patina, mostly at early stages. It also has the most artefacts with edge damage ($n = 11$). Spatially, the KDE concentrations of both patina and edge damage coincide with the C2 perimeter (Fig. S3b).

C3 comprises 14 flint artefacts, predominantly of Mariola flint ($n = 10$), with three made of Serreta and one of Beniaia flint. One S-RMU (V-M1) was identified in C3, consisting of five Mariola flint artefacts, reducing the number of potential anthropogenic inputs from 14 to 10. None of the artefacts shows thermal alteration or edge damage, although one Mariola product exhibits white patina development in the subcortical area (Fig. 7).

The scattered assemblage includes 56 artefacts, with one made of limestone (bioclastic calcarenite) and the remaining 55 of flint. Among the flint assemblage, 20 products were made on Mariola flint, 17 on Serreta, 10 on Beniaia, and only 1 on Catamarruc lithotype. Seven artefacts remain undetermined. Five S-RMUs were identified: two made of Mariola (V-M2 and V-M4), two of Serreta (V-S3 and V-S5), and one of Beniaia (V-B1), accounting for 17.85% of the total scattered assemblage. The Beniaia assemblage shows one thermally altered artefact and two with white patina formation. In the Mariola assemblage, one element is thermally altered, and three display white patina. The Serreta assemblage has two thermally altered artefacts and six with white patina, mostly at advanced stages. One artefact shows edge damage. Finally, the single Catamarruc product shows no postgenetic alterations.

## Lithic Attributes

Following the results presentation scheme of raw materials, the lithic attributes will be described by differentiating between the artefacts linked to each cluster (i.e. C1, C2, and C3) and the dispersed products (i.e. "noise") (Tables 1, 2, 3, and 4) (Fig. 8). Likewise, any lithic artefact that lies outside a cluster but is part of an S-RMU included in one of them will be analysed as part of the corresponding cluster (Fig. 5A). This is further supported by the spatial representation of type of products (Fig. 6A) and weight classification (Fig. S3a).

C1 contains ten lithic artefacts (Table 1), with a combined weight of 35.92 g. The Mariola artefacts ($n = 7$) mainly consist of very small to small non-cortical flakes. The S-RMU V-M1 includes one flake (located outside the cluster) and one fragment that conjoins. The Beniaia products ($n = 3$) are also very small to small flakes and fragments, with a low amount of cortex.

C2 includes 67 artefacts weighing 247.06 g (Table 2). Among them, 25 artefacts (37%) belong to S-RMUs outside the cluster, although most are found within 1 m of it. C2 is dominated by S-RMU related products (79%, $n = 53$), with 34 artefacts refitted (64%). Only 14 products were identified as single elements.

The Mariola assemblage within C2 ($n = 21$) consists largely of very small to small flakes with a low amount of cortex. These include several flakes that belong to RMU V-M3, which refit with a core (88 g) located to the east. One small fragmented retouched artefact forms RMU V-M5 ($n = 4$), and another larger retouched product is present. Single elements are primarily small flakes with 0–25% of cortex.

The Serreta flint assemblage ($n = 40$) is mainly distributed within S-RMUs ($n = 37$), with only three being single products (two flakes and one very small non-cortical retouched product). The general trend within S-RMUs is very small to small flakes ($n = 34$), with 0–25% of cortex. The only documented core is linked with RMU V-S1, which is refitted with seven flakes and a fragment with a medium to high percentage of cortex. RMU V-S2 and V-S4 consist of very small to small flakes, non-cortical in the first case and with a non-cortical to medium cortical proportion in the second. Beniaia flint type is represented by three very small flakes and a fragment with a low amount of cortex.

C3 contains 14 artefacts weighing 76.4 g (Table 3). Mariola artefacts ($n = 10$) are mainly very small to small flakes with a low to medium amount of cortex. Within these, RMU V-M1 ($n = 5$) is composed of very small to small products with a low amount of cortex (four flakes and one fragment). From these, two artefacts conjoin, being one flake and one fragment. The Serreta assemblage ($n = 3$) includes two very small flakes and a small, retouched product with low cortical proportions, while the Beniaia flint type is represented by a single small non-cortical flake.

"Noise" or dispersed materials show a more heterogeneous composition (Table 4). It consists of 56 products, weighing 1671.02 g. Mariola products ($n = 20$) include mostly flakes ($n = 16$), predominantly very small to small with varying cortex (up to 75–100%). Some exceptions include two large flakes, one large core, one medium-sized retouched artefact, and a medium-sized nodule with no evidence of technical exploitation. S-RMU V-M2 is integrated by one large core and one small flake that refit, and V-M4 is composed by two very small non-cortical flakes.

The Serreta assemblage ($n = 17$) exhibits primarily flakes ($n = 8$), although there is a relevant presence of retouched artefacts ($n = 6$). The flakes are very small to small products with a low amount of cortex, while the retouched products tend to be larger and have higher cortical proportions.

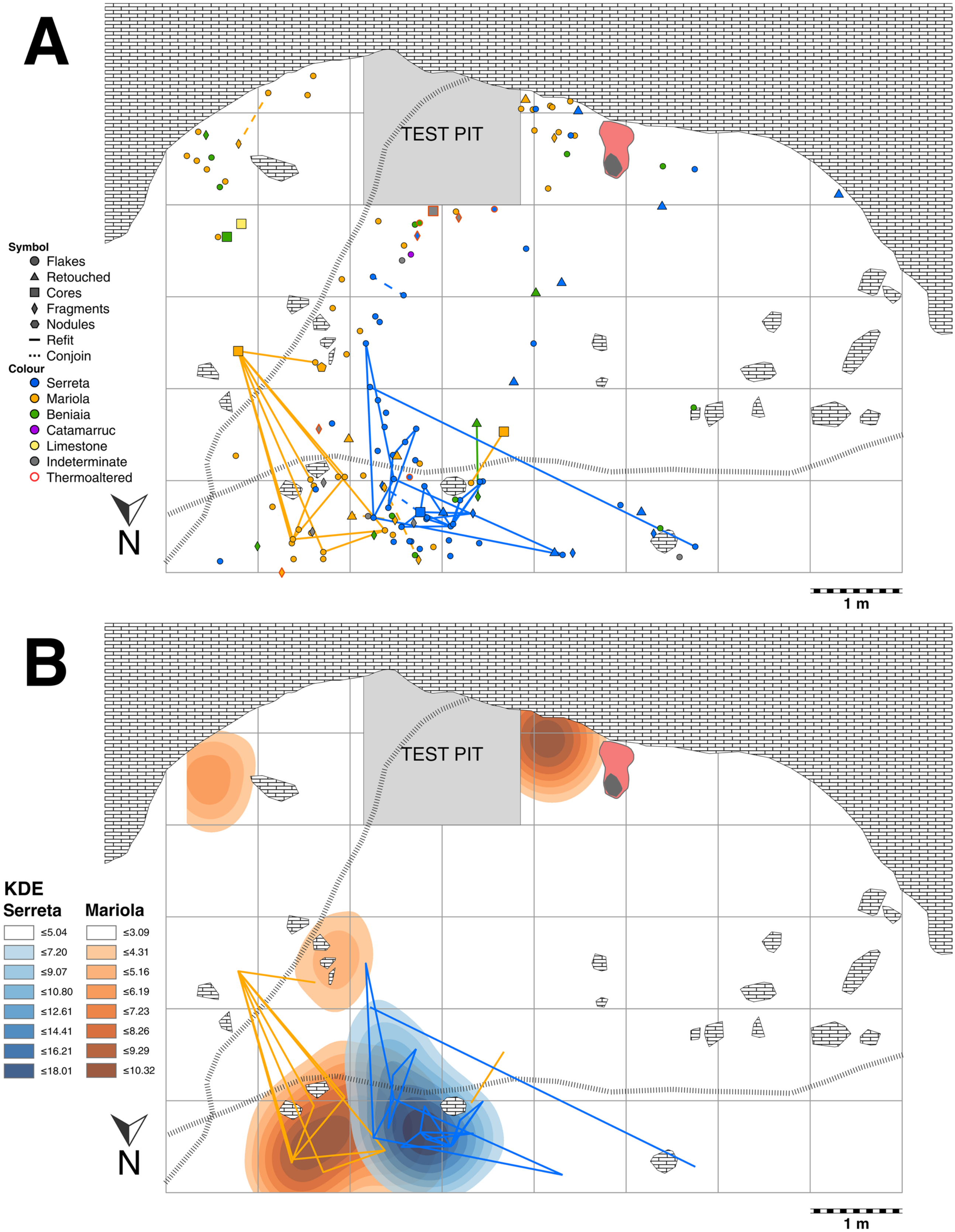


**Fig. 6** Spatial distribution of the SU V lithic assemblage by product type (symbol), flint type (colour), and thermoalteration (red contour) (**A**) and KDE results of Serreta and Mariola flint types (**B**)

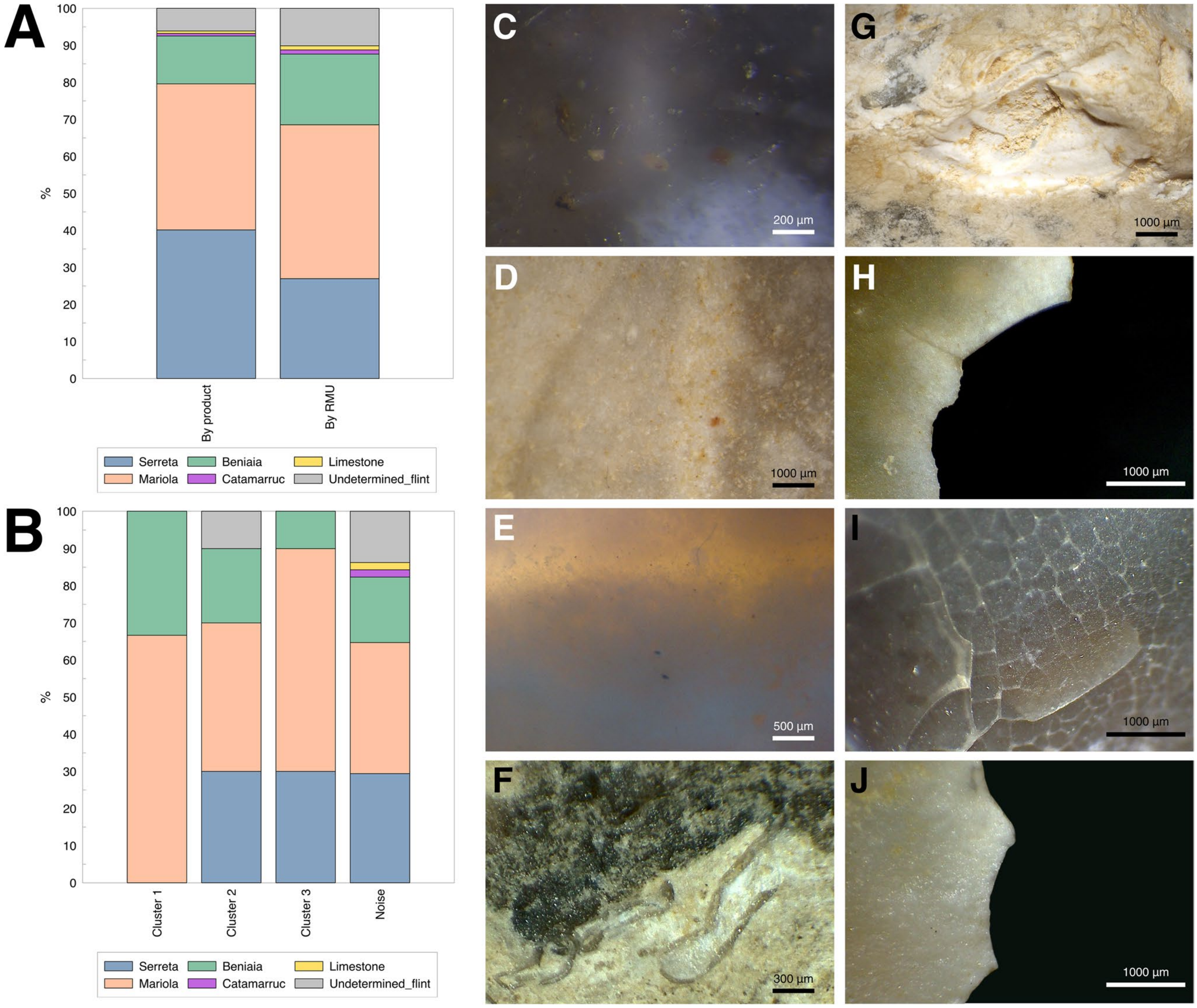


**Fig. 7** Bar graph showing the representation of raw materials by product type and RMU (**A**) and by clusters (**B**); microphotograph of the Serreta flint matrix, displaying figured elements and texture (**C**); microphotograph of the Mariola flint matrix, which contains carbonate inclusions (**D**); photograph of the a Beniaia flint surface displaying a biogenic structure using light contrast (**E**); photograph of a Catamarruc flint flake surface, including a subcortical area (i.e. upper black part) with biogenic structures and recrystallised fossils (**F**); photograph showing the presence of white patina on natural crash-marks (**G**); photograph of the patinated edge of a flint flake (**H**); photograph of the surface of a flint flake showing reticular fissures as sign of thermal alteration (**I**); and edge fractures on a flint flake (**J**)

**Table 1** Type of products of Cluster 1 by raw material

| | Mariola | | Serreta | | Beniaia | |
|---|---|---|---|---|---|---|
| | ***n*** | % | ***n*** | % | ***n*** | % |
| Flakes | 6 | 86 | | | 2 | 67 |
| Retouched | | | | | | |
| Cores | | | | | | |
| Fragments | 1 | 14 | | | 1 | 33 |
| Nodules | | | | | | |
| Total | 7 | 100 | | | 3 | 100 |

**Table 2** Type of products of Cluster 2 according to raw material

| | Mariola | | Serreta | | Beniaia | |
|---|---|---|---|---|---|---|
| | ***n*** | % | ***n*** | % | ***n*** | % |
| Flakes | 15 | 71 | 36 | 90 | 3 | 75 |
| Retouched | 2 | 10 | 1 | 2.5 | | |
| Cores | 1 | 5 | 1 | 2.5 | | |
| Fragments | 3 | 14 | 2 | 5 | 1 | 25 |
| Nodules | | | | | | |
| Total | 21 | 100 | 40 | 100 | 4 | 100 |

**Table 3** Type of products of Cluster 3 according to raw material

| | Mariola | | Serreta | | Beniaia | |
|---|---|---|---|---|---|---|
| | ***n*** | % | ***n*** | % | ***n*** | % |
| Flakes | 8 | 80 | 2 | 67 | 1 | 100 |
| Retouched | 1 | 10 | 1 | 33 | | |
| Cores | | | | | | |
| Fragments | 1 | 10 | | | | |
| Nodules | | | | | | |
| Total | 10 | 100 | 3 | 100 | 1 | 100 |

**Table 4** Type of products of the “noise” assemblage according to raw material

| | Mariola | | Serreta | | Beniaia | | Catamarruc | | Limestone | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ***n*** | % | ***n*** | % | ***n*** | % | ***n*** | % | ***n*** | % |
| Flakes | 16 | 80 | 8 | 47 | 5 | 50 | 1 | 100 | | |
| Retouched | 1 | 5 | 6 | 35 | 2 | 20 | | | | |
| Cores | 1 | 5 | | | 1 | 10 | | | 1 | 100 |
| Fragments | 1 | 5 | 3 | 18 | 2 | 20 | | | | |
| Nodules | 1 | 5 | | | | | | | | |
| Total | 20 | 100 | 17 | 100 | 10 | 100 | 1 | 100 | 1 | 100 |

S-RMU V-S3 includes a small flake and one very small fragment with medium proportion of cortex, and V-S5 consists of two very small fragmented retouched products with no cortex.

Beniaia flint type ($n = 10$) includes small non-cortical flakes ($n = 4$), a large full cortical flake, a large core, fragments, and two retouched artefacts. Of these, one small, retouched product and a very small fragment refit (V-B1). Lastly, there is one medium-sized Catamarruc flake with no cortex and a very large limestone core weighing 1239 g, which significantly contributes to the overall weight of the dispersed materials (Fig. 6A and Fig. S3a).

## Refitting Results

The 28.57% of the lithic assemblage is refitted, comprising 42 products (Table 5). Of these, 71.43% are technical refits, while 28.57% are conjoins. In total, seven technical refits within six R-RMUs were identified, involving 30 lithic products and creating 37 lines (Fig. 9). The average distance between refitted artefacts is 1.01 m, with a standard deviation of 0.87 m. The shortest distance recorded is 0.03 m, while the longest is 3.94 m.

Following on technical refits, Serreta flint type exhibits four refits within three R-RMUs, involving 18 products that form 24 refitting lines. The average distance for these lines is 0.80 m, with a maximum of 3.94 m, a minimum of 0.03 m, and a standard deviation of 0.89 m. The R-RMU V-S1 ($n = 9$), located in C2, represents a core reduction sequence progressing from initial to full production, following a recurrent centripetal Levallois modality. The sequence is distributed over a small area in the northern sector (1.01 ×0.51 m) (Fig. 9F). The R-RMU V-S2 contains two separate refits, both related to C2, and reflecting advanced stages in the knapping sequence: one composed of two centripetal flakes located 3.94 m apart (Fig. 9C) and the other comprising three flakes from a centripetal knapping sequence, with distances of 0.91, 0.58, and 0.38 m between them (Fig. 9D). R-RMU V-S4, linked with C2,

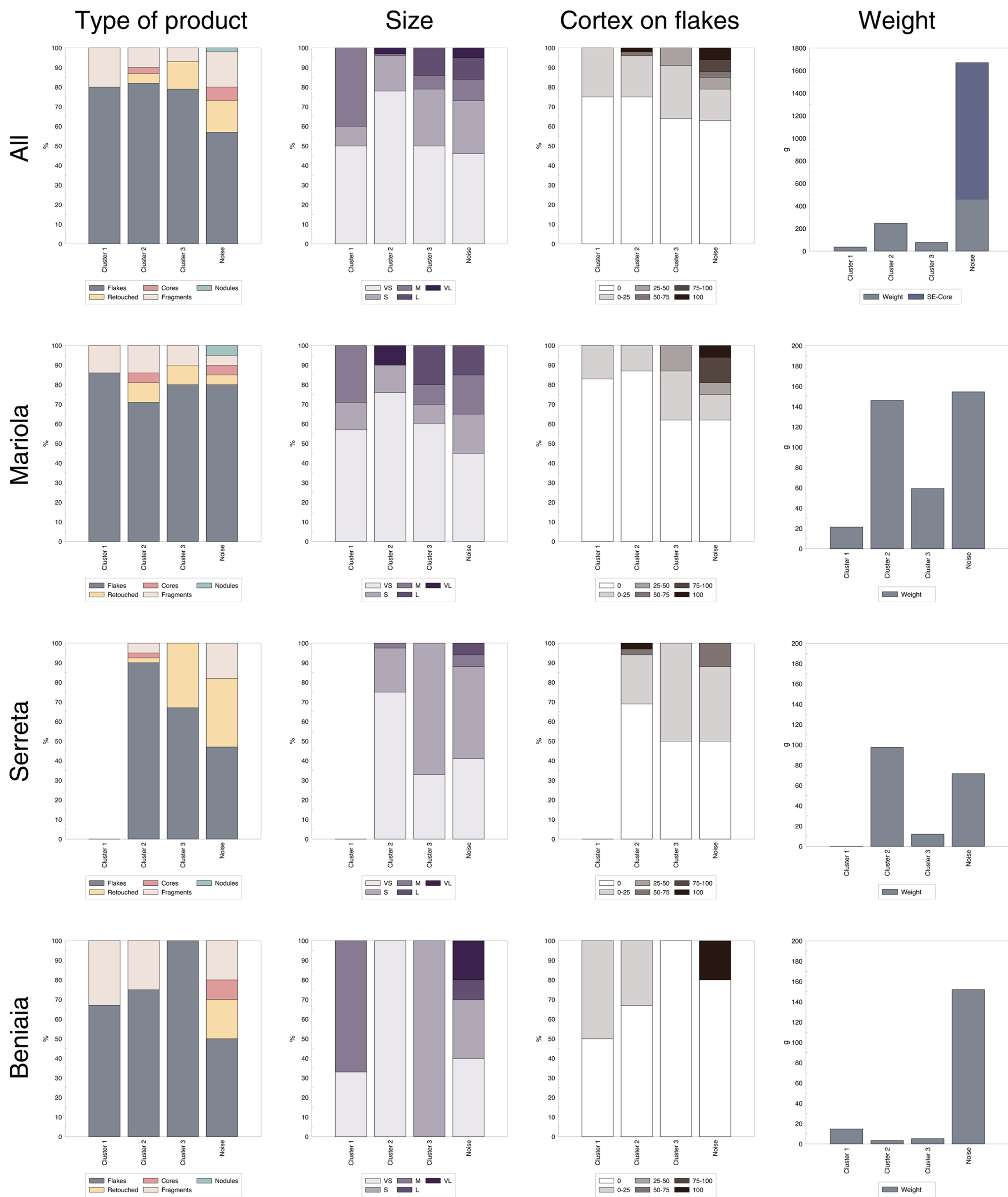


**Fig. 8** Bar charts showing flint type presence within the spatial units, based on type of product, size-class, amount of cortex, and weight

**Table 5** Refitting composition and distances according to flint type

| | Flint type | Refits | R-RMU (*n*) | Products (*n*) | Lines (*n*) | Average distance (m) | Minimum distance (m) | Maximum distance (m) | Standard deviation |
|---|---|---|---|---|---|---|---|---|---|
| Refits | All | 7 | 6 | 30 | 37 | 1.01 | 0.03 | 3.94 | 0.87 |
| | Serreta | 4 | 3 | 18 | 24 | 0.80 | 0.03 | 3.94 | 0.89 |
| | Mariola | 2 | 2 | 10 | 12 | 1.45 | 0.66 | 2.52 | 0.72 |
| | Beniaia | 1 | 1 | 2 | 1 | 0.81 | 0.81 | 0.81 | - |
| Conjoins | All | 5 | 5 | 12 | 7 | 0.49 | 0.08 | 0.87 | 0.25 |

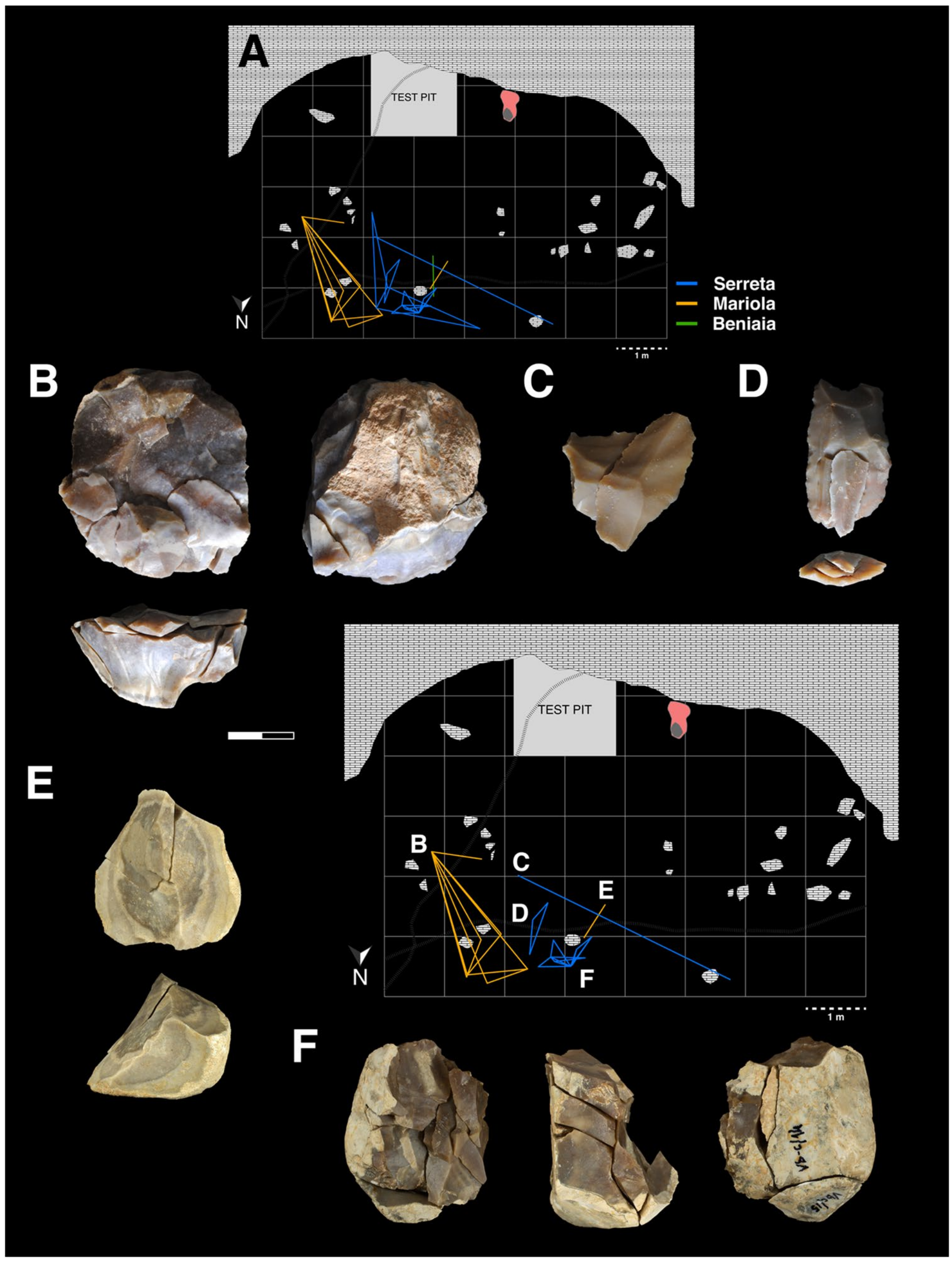


**Fig. 9** Site plan showing refitting lines by flint type (**A**), R-RMU v_M3 (**B**), refit 1 from RMU v_S2 (**C**), refit 2 from RMU v_S2 (**D**), R-RMU v_M2 (**E**), and R-RMU v_S1 (**F**)

consists of an advanced knapping sequence of four centripetal flakes distributed across an area of 1.93 m.

Mariola flint type shows two R-RMUs comprising 10 products, generating 12 refitting lines. The average distance of these lines is 1.45 m, with a standard deviation of 0.72 m. The minimum distance recorded is 0.66 m, while the maximum distance reaches 2.52 m. R-RMU V-M2, located in the "noise" assemblage, consists of a core and a flake, separated by 0.66 m, which together display a bidirectional reduction pattern (Fig. 9E). In contrast, R-RMU V-M3, related to C2, reflects a recurrent centripetal Levallois sequence that includes one core and seven flakes, covering both full production and the preparation of striking platforms (Fig. 9B). From these artefacts, six flakes are located within a small area (0.88 × 0.74 m) in the northeast, while the core and the remaining flake are spaced further apart, with distances ranging from 1.3 to 2.5–2 m towards the east, and the core positioned under the ledge.

Beniaia flint type shows one R-RMU (V-B1), located in the "noise" assemblage, consisting of two products that form a single refitting line over a distance of 0.81 m. These artefacts reflect a brief orthogonal knapping episode and consist of one retouched product and one fragment.

The 12 conjoined products form seven lines, distributed within five R-RMUs (two from Serreta and three from Mariola flint type). These exhibit a smaller spatial spread than technical refits, with an average distance of 0.49 m, a minimum of 0.08 m, a maximum of 0.87 m, and a lower standard deviation of 0.25 m.

## Sedimentary Record

### Soil Micromorphology

The micromorphological samples from the combustion and western areas of the rockshelter (Fig. 10, Fig. S5) exhibit a stratified sequence of alternating beds of loose, clast-supported sediment, and slightly compact, matrix-supported sediment. Throughout the samples, the coarse fraction is composed of frequent (~ 30–40%), unsorted, subrounded, and subangular fossiliferous limestone sand and gravel and minor amounts of quartz (< 5%). The micromass is composed of micritic calcite and clay, and it is predominantly arranged in a loose, granular, and/or crumbly microstructure with vughs, simple and compound packing voids. A porphyric c/f related distribution has also been occasionally documented. Iron mottles and iron staining (< 5%) have been detected. For a more detailed description of the micromorphological features documented in each sample, see Table 6.

The micromorphological samples from the possible combustion structures show few microscopic combustion residues at the top part of sample AP-23–4 and the bottom part of AP-23–3, a segment stratigraphically associated with H19 (Fig. 10). The combustion residues comprise (1) scatters of unidentified, rounded silt-to-fine sand-sized charred plant matter; (2) few subrounded, fissured, sand-sized charcoal fragments; and (3) few subrounded, fissured, rubified limestone gravel.

### *n*-Alkanes

The natural substrate of the combustion structures, collected as control samples, was characterised by the prevalence of odd-numbered, long-chain *n*-alkanes (i.e. $C_{27}$, $C_{29}$, and $C_{31}$), although mid-chain compounds lacking an odd-over-even predominance were also present (Fig. 11A, Table S3). Similar results were observed in the sediment sampled as the potential red layer of H20, and to a lesser extent, in the sediment identified in the field as its black layer (Fig. 11A, Table S3). The control samples yielded CPI values of 3.2 and 3.0, while H20 samples returned values of 3.9 for the red layer (RL) and 2.5 for the black layer (BL) (Fig. 11B, Table S3).

In contrast, in both BL and RL of H19, mid-chain *n*-alkanes without an odd-over-even predominance (maximising at $C_{21}$, $C_{22}$, and $C_{20}$) dominated, with a minimal presence of long-chain, odd-numbered compounds (Fig. 11A, Table S3). This is reflected in CPI values below 2 for both samples (Fig. 11B, Table S3).

## Discussion

Our results reveal the presence of four distinct archaeological areas in Abric del Pastor SU V, as determined through spatial analyses. The northern area is predominantly composed of lithic products, with multiple refits. These refitting sequences show a vertical discontinuity, separating distinct episodes of different flint type exploitations. In contrast, the southeastern area features a diachronic accumulation of faunal remains under the ledge. The southern zone, situated near the wall, presents the single combustion structure of SU V (i.e. H19), as evidenced by micromorphological and *n*-alkane data, with limited anthropogenic activity in its surroundings. Lastly, for the western area, where no archaeological remains were detected, geoarchaeological data show the absence of severe postdepositional disturbances that may have affected the integrity of the deposit.

In the following paragraphs, we address the taphonomic aspects of the lithic assemblage to assess its potential for building behavioural interpretations, and subsequently, the temporal and spatial formation dynamics are evaluated.

### Lithic Taphonomy

With the aim of evaluating the integrity of SU V lithic assemblage, three variables could provide valuable

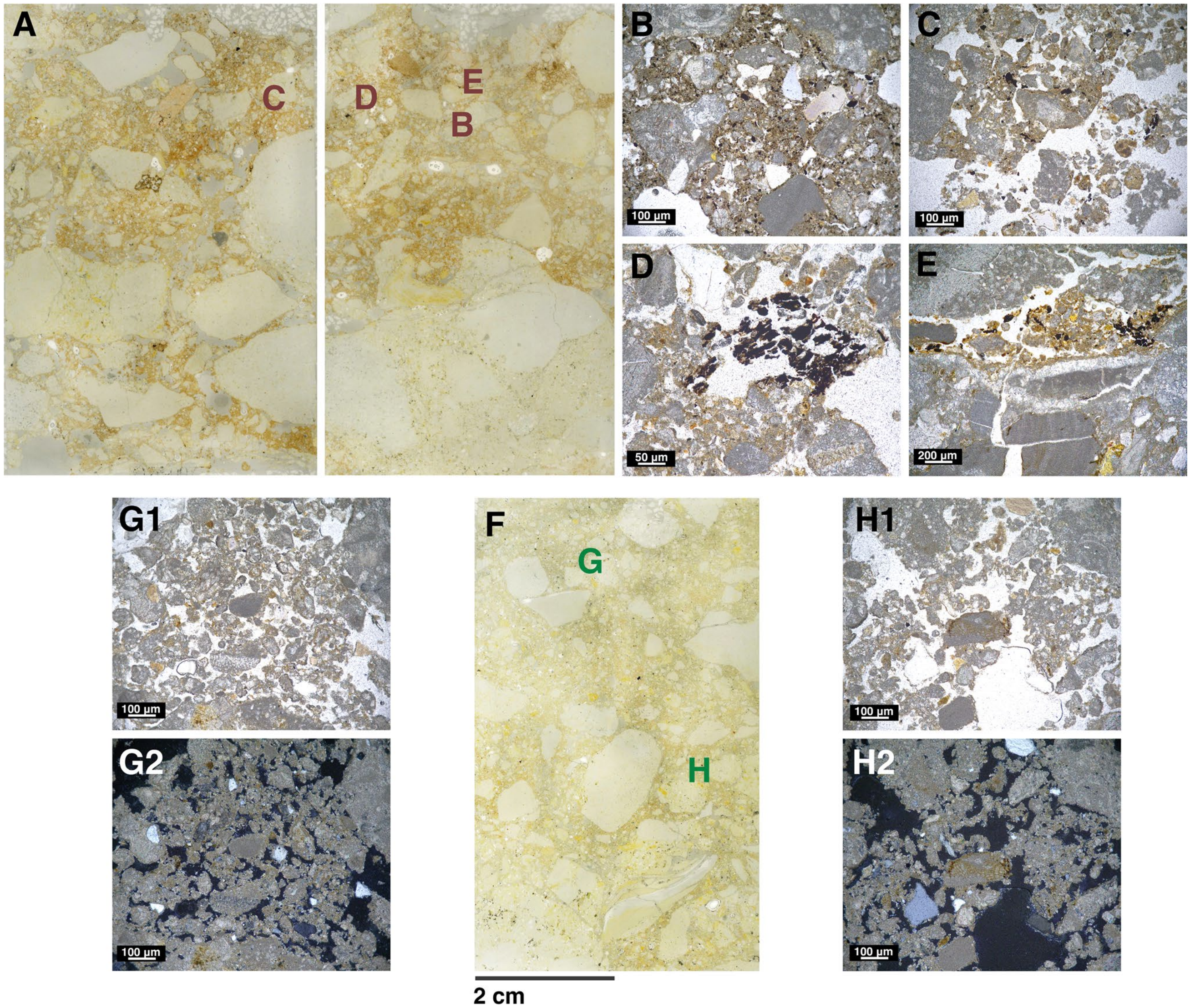


**Fig. 10** Micromorphological scans of thin sections from sample AP-23–4, representing the H19 combustion structure (**A**) and sample AP-23–1, representing the archaeologically sterile zone at the western area of the rockshelter (**F**). The location of selected microphotographs for each sample is labelled with capital letters. **B** PPL (plane-polarised light). Accumulation of silt-to-fine sand-sized unidentified charred matter in a single-spaced porphyric, vughy, calcitic clay matrix with subangular subrounded limestone sand and gravel. **C** PPL. Similar matrix as **B** and presence of silt-to-sand-sized charred matter and charcoal but more loose, with a granular crumbly microstructure. **D** PPL. Sand-sized fissured charcoal. **E** PPL. Silt and sand-sized charred matter between two limestone clasts. (G) PPL (**G1**) and XPL (cross-polarised light) (**G2**) microphotographs displaying loose, granular sediment with vughs and packing voids, composed of unsorted limestone clasts and calcitic clay cement. (H) PPL (**H1**) and XPL (**H2**) similar to **G1**. Here, some of the limestone clasts are iron-stained

insights: white patina on edges, edge damage, and refitting connections. White patina on edges is concentrated in the northern part of the site, beyond the drip line. This position likely increases exposure to water and moisture, which, along with mechanical stress in coarse-grained deposits such as Abric del Pastor, may cause and accelerate patina formation (Berruti & Arzarello, 2020; Burroni et al., 2002; Caux et al., 2018; Rottländer, 1975). For edge damage, while it is possible that different fractions (sand, pebbles, blocks) falling from the roof of the shelter could naturally contribute to this alteration, the concentration of artefacts with damaged edges and its coincidence with Cluster 2, where most of the human activity has been identified, suggests that trampling is the most plausible factor (McBrearty et al., 1998; Weitzel & Sánchez, 2021). Furthermore, both factors may be correlated. Experimental work by McPherron et al. (2014) indicates a significant difference in trampling damage between fine-grained and coarse-grained deposits, with damage being more pronounced in the latter.

**Table 6** Summary of the lithological composition and main micromorphological features documented in each sample

| Sample ID | Location | Lithology | Micromass | Microstructure | Porosity | Anthropogenic components | Other relevant features |
|---|---|---|---|---|---|---|---|
| AP-23–1 | Massive sands | Subangular, subrounded, and angular silt, sand and gravel-sized fossiliferous limestone (~ 40–45%), quartz fine sand (< 5%) | Micritic calcite with iron mottles (< 5%) and iron staining | Medium compaction, crumb/granular | Vughs, simple, and compound packing voids | | Very scarce fresh root tissue |
| AP-23–2 | Massive sands | Subangular, subrounded, and angular silt, sand and gravel-sized fossiliferous limestone (~ 50–55%), quartz fine sand (< 5%) | Micritic calcite with iron mottles (< 5%) and iron staining | Upper section: compact, crumb, porphyric<br>Lower section: medium compaction, crumb/granular | Vughs, simple, and compound packing voids | | |
| AP-23–3 | Combustion area (H18, H19) | Subangular and angular silt, sand and gravel-sized fossiliferous limestone (~ 30–40%), fossiliferous limestone subangular and subrounded coarse gravel and clasts (~ 15–20%), quartz fine sand (< 5%) | Micritic calcite with iron mottles (< 5%) and iron staining | Upper section: compact, subangular blocky, porphyric<br>Lower section: loose, crumb/granular | Vughs, simple, and compound packing voids | Lower section: rubified limestone gravel and clast | Weakly developed iron coating around a gravel-sized limestone |
| AP-23–4 | Combustion area (H19, H20) | Subangular and angular silt, sand and gravel-sized fossiliferous limestone (~ 30–40%), fossiliferous limestone subangular clasts (~ 10–15%), quartz fine sand (< 5%) | Micritic calcite with iron mottles (< 5%) and iron staining | Upper section: loose, crumb/granular. Gefuric<br>Middle-lower section: compact, porphyric | Vughs, simple, and compound packing voids, few channels | Upper section:<br>Sand-sized subrounded, fissured charcoal<br>Silt-to-fine sand-sized, rounded charred plant matter<br>Rubified, fissured limestone gravel | |
| AP-23–5 | Combustion area (control sample) | Subangular and angular silt, sand and coarse gravel-sized fossiliferous limestone (~ 55–60%), quartz fine sand (< 5%) | Micritic calcite with iron mottles (< 5%) and iron staining | Loose crumb/granular | Vughs, simple, and compound packing voids | | Scarce fresh root tissue |

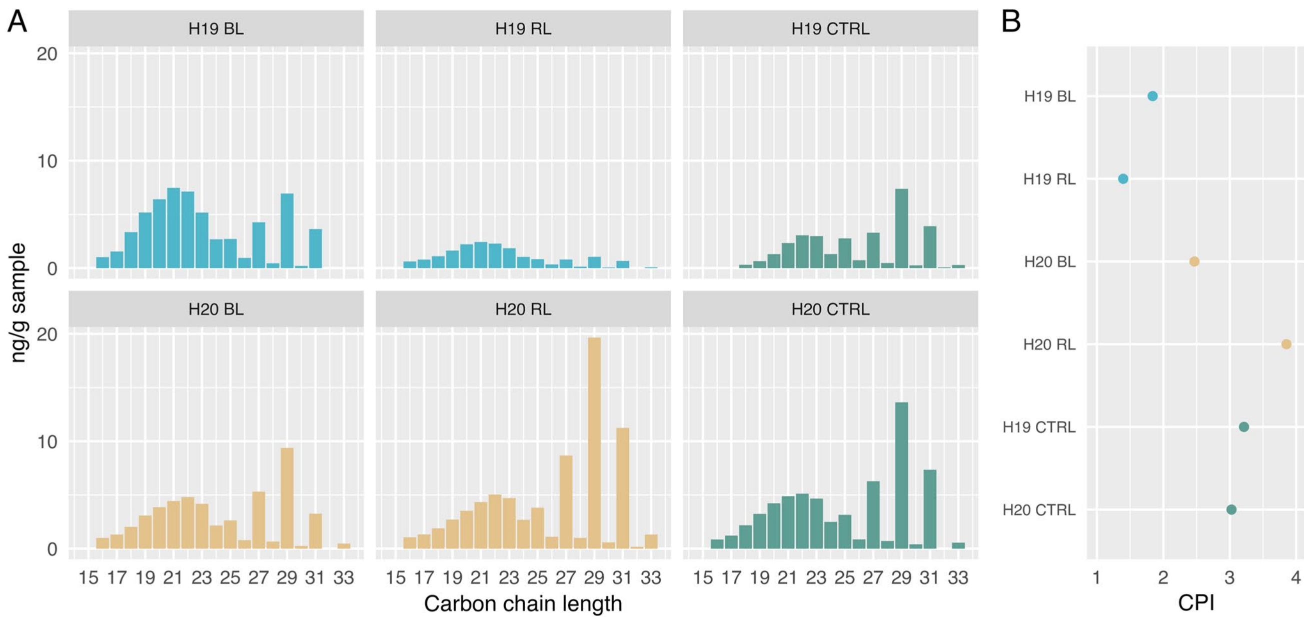


**Fig. 11** Bar charts showing the distribution and abundance of the *n*-alkanes identified in the sedimentary samples (**A**), CPI (carbon preference index) values of *n*-alkanes ($C_{19}$ to $C_{33}$) from the sedimentary samples (**B**). BL: potential black layer; RL: potential red layer; CTRL: control sample

Both trampling and exposure could have caused minor vertical or horizontal movements, although such slight displacements could remain undetected in our study. In the archaeostratigraphic profiles crossing the northern area, point-pattern analysis did not reveal any significant movement. Refitted sets exhibit minimal vertical separation, spanning no more than 1 to 4 cm, a much lower range than in other sites where refitted pieces display vertical displacements of up to 20–40 cm (e.g. Hofman, 1986; Morrow, 1996; Villa, 1982). Furthermore, our refits generally show horizontal connections of short distance (average 1.01 m), suggesting a low incidence of any of such postdepositional processes. In fact, in some cases, they are concentrated in very small areas of less than 1 m$^2$, as in the case of V-S1. However, we cannot entirely rule out vertical displacement. Experimental studies on trampling, such as Villa and Courtin (1983), demonstrate that assemblages initially separated by 3 cm can converge within a short vertical span due to small downward and upward movements of 0.9 to 2.9 cm. Similar short-range vertical displacements have also been observed by Marwick et al. (2017), within timeframes much shorter (5 to 15 min) than those used by Villa and Courtin (1983) of 21 to 38 days or Driscoll et al. (2016) of 12 days.

In experimental works, the influence of artefact size/weight on vertical displacement due to trampling remains debated. Some experiments suggest that small products tend to move downward, preserving their original horizontal positions, while medium to large artefacts exhibit more horizontal than vertical displacement (Nielsen, 1991; Stockton, 1973). Conversely, other studies report no correlation between size/weight and vertical movement (e.g. Gifford-González et al., 1985; Marwick et al., 2017) or note preferential movement of larger products over smaller ones (Moeyersons, 1978). In our case, the densest lithic area (Cluster 2), where edge damage is observed, does not show evidence of weight sorting. However, this area is predominantly composed of lightweight products in weight class 1 (0–3.58 g). While it is possible that some differences exist within class 1, experimental data suggest that artefacts up to 9 g exhibit similar behaviours (Villa & Courtin, 1983). Finally, a greater concentration of these lightweight products towards the centre of the deposit is also not observed as a function of slope, which is also a key variable in identifying postdepositional movements (Bertran et al., 2012).

Having considered the taphonomy and composition, we consider that it is feasible to interpret the archaeological record of SU V in terms of human behavioural variability.

## Squeezing the Time Out

While the identification of the distinct events contributing to the formation of the entire assemblage is often possible due to the distinction of clear vertical gaps between material beds, the situation in SU V is challenging. Although material hiatuses are indeed present, they lack lateral continuity and are predominantly observed in the southeast area, where the highest concentration of faunal remains is located. Thus, without a detailed taxonomic and taphonomic analysis of the faunal assemblage, relying solely on these vertical gaps as indicators of diachronic events would be premature and potentially misleading.

Therefore, in cases like this, where clear stratigraphic separations involving the entire record are ambiguous, a more in-depth analysis that includes the study of raw materials, RMUs, and lithic refits can provide valuable insights. The event-based approach has proven valuable in isolating discrete formation episodes in the absence of general archaeostratigraphic gaps. At Abric del Pastor SU IV, even archaeostratigraphic units were initially established based on homogeneous vertical hiatuses, yet further refinement was achieved through RMUs and refits (Machado et al., 2013, 2019; Sossa-Ríos et al., 2022). Multiple refitted sequences from distinct RMUs and flint types enabled the identification of three depositional events within a single AU (i.e. AU IVb), establishing spatial associations between specific knapping events and certain hearths (Machado et al., 2019).

Comparable examples from other Palaeolithic sites further validate this approach. At Abric Romaní level J, three diachronic events linked to the introduction and exploitation of different chert types have been documented, revealing distinct technical behaviours and spatial distributions (Vaquero et al., 2012). Similarly, at Cova Gran level 497D, spatial clustering of refitted chalcedony RMUs within a 3 $m^2$ area (i.e. cluster HL1) contrasted with the broader distribution of chert RMUs, suggesting diachronic inputs and knapping activities (Mora et al., 2020; Sánchez-Romero et al., 2024). At Abri du Maras level 4.1, comparing RMUs of different raw materials revealed that, even in the northern part of the site where most lithic activities occurred, flint and quartz RMUs show different spatial distributions (Guillemot et al., 2023). The archaeostratigraphic analysis of RMUs and refits has also been instrumental at El Salt, where distinct formation events have been recognised within SUs Xa and Xb, enabling the linkage of each knapping episode with different hearth layers (Machado et al., 2017; Mayor et al., 2020; Sossa-Ríos et al., 2024).

Following this approach, our analysis of SU V reveals similar diachronic patterns. The most compelling evidence lies in the vertical differentiation between the refitting sequences of Mariola and Serreta flint types. Although both refitting sets are largely associated with Cluster 2, their knapping sequences are vertically distinct, with Mariola refits placed at the bottom and those of Serreta positioned above (Fig. 4). Furthermore, this remark is also evident spatially: while both refitting sets are concentrated in the same general area, they do not completely overlap but are instead slightly separated. Beyond the refits, the overall assemblage, when examined by flint types, also reveals spatial variability. Mariola flint type is predominantly found in the eastern area, where Serreta is absent. This spatial segregation provides further indirect evidence of diachrony within SU V, supporting the hypothesis of at least two formation stages as indicated by both direct (i.e. vertical separation of refits) and indirect (i.e. distinct flint types with different spatial distributions) temporal markers.

Accepting this hypothesis implies a recurrent pattern in activities that warrants spatial examination. The spatial distribution of SU V is characterised by distinct separations between clusters and a lack of interconnections among them. In the northern area, despite the presence of numerous refits, these connections do not extend beyond two metres from Cluster 2, and they do not reach the perimeters of Clusters 1 or 3. For the latter clusters, there is no evidence to suggest any association, either with each other or with Cluster 2. Given this spatial segmentation, we must examine the behavioural patterns within each zone separately.

## Knapping Here… Again

So far, our data indicate that the northern zone was repeatedly selected for knapping at different times, with Mariola flint knapped first and Serreta flint later. However, does separating these two events reveal other variations beyond the use of different raw materials? In fact, there is a noticeable distinction between the two assemblages. While both flint types were knapped, Serreta appears more prominently in recent knapping events, suggesting an intensification of activity over time. This shift is evident in the change of raw material percentages, with Serreta dominating when counted by artefact, but being surpassed by Mariola when counted by RMU. A similar trend continues in the overlying AUs IVfH17 and IVc2, which also show a dominance of Mariola flint (Machado et al., 2013, 2019; Sossa-Ríos et al., 2022). In contrast, later units such as AU IVb1 and El Salt SU VIII—both dated to around 48 ka—display a marked shift, with Beniaia flint becoming the principal introduced raw material (Machado et al., 2013, 2019; see Mayor et al., 2022, for further discussion).

Therefore, the zone where Cluster 2 is located appears to function as a recurring knapping area. This idea is principally based on the vertical relations of the refitting sets and reinforced by the raw material changes between upper and lower segments of the sequence, which strengthen the diachrony interpretation by representing the different visits to potentially distinguishable lithic provisioning areas.

This use of specific areas for knapping at different moments has also been documented in other Neanderthal contexts, such as the northeastern zone of Oscurusciuto in SUs 11a, 11b, and 13 (Spagnolo et al., 2019, 2020); the M2 accumulation in sublevel M or the A accumulation in archaeolevel Oa at Abric Romaní (Bargalló et al., 2020; Vaquero et al., 2015); the Cluster HL1 of level 497D at Cova Gran (Mora et al., 2020; Sánchez-Romero et al., 2024); the northern area of level 4.1 and Area 1 of level 4.2 at Abri du Maras site (Guillemot et al., 2023; Moncel et al., 2021); or the inner area of El Salt (Machado et al., 2017; Mayor et al., 2020; Sossa-Ríos et al., 2024).

However, there are several aspects in which our case diverges from these examples. On the one hand, our knapping events are not associated with any combustion structure, which contrasts with the hearth-related assemblage model frequently observed where knapping activity is recurrent (Brooks & Yellen, 1987; Stevenson, 1991; Vaquero & Pastó, 2001; Yellen, 1976), including SU IV at Abric del Pastor (Machado et al., 2013, 2019). On the other hand, our refitting sets display shorter connection distances (average of 1.01 m) compared to, for example, almost all levels of Abric Romaní, except for levels H and N (Vaquero et al., 2019). Moreover, although there are examples where the averages are even lower such as those from levels H and N, or the present at Cova Gran 497D (0.85 m; Sánchez-Romero et al., 2024), they all show refit connections that reach 5 m or more. In general, our case exhibits minimal intrasite movement. While some of our connections extend 3 to 4 m, there are limitations to their interpretation.

Firstly, medium-to-long distance refitting lines are scarce. In some cases, such as R-RMU_vM3, the core is located the farthest from refitted artefacts, standing alone underneath the ledge in the northeast. This reminds us of similar cases at Abric del Pastor SU IV where cores within refits R12 and R14b appear isolated, possibly indicating discard after knapping rather than intentional movement between areas (Machado et al., 2019). Secondly, our maximum refit distances of around 4 m could result from the natural scattering effect of knapping when standing upright (i.e. Newcomer & Sieveking, 1980), which complicates the identification of spatiotemporal relationships that typically require at least a 5 m threshold (Vaquero et al., 2017, 2019). Lastly, artefacts found outside Cluster 2 but related to it are not associated with any specific activity areas but rather appear mixed with other dispersed material.

This recurrent and concentrated lithic production, spatially unrelated to other activities, also exhibits a high degree of fragmentation. Although a detailed technological analysis of SU V is ongoing, refits further highlight that aspect. The predominance of small products with a low amount of cortex in both flint types suggests advanced stages of the knapping sequence, as both product size and cortex percentage typically diminish with reduction progress (Ahler, 1989; Kvamme, 1997; Vaquero, 2008; Bertran et al., 2012). These features point to significant fragmentation of the operative chains (Turq et al., 2013), contrasting sharply with the almost complete sequences frequently observed in some of the abovementioned sites. The only exception to this pattern is R-RMU-vS1, which shows evidence of earlier stages in the reduction sequence. Moreover, the procurement of lithic resources identified in this case points to mobility from the Serpis valley towards the ravine. This would indicate different knapping events carried out across the territory, beginning with raw material acquisition from at least 3 km away for Serreta and Mariola flints and from at least 35 km for Beniaia and Catamarruc (Molina et al., 2016).

Taking all these attributes into consideration, our findings seem more consistent with anticipatory lithic production for use in activities carried out elsewhere, fitting with Kent's (1991) concept of "anticipated mobility" or the "What I will have to do in terms of the goals of the expedition" notion of Binford (1977). Therefore, this pattern may reflect the time before resource gathering typical of this environment during SU IV, such as the collection of juniper (*Juniperus* sp.) (Vidal-Matutano et al., 2015) or goat hunting in the steep terrain of the Cint ravine (Connolly et al., 2019).

This repetition of knapping in the northern area, coupled with the hearth positioned near the shelter wall, could give us a pristine image of a "special-purpose camp" (*sensu* Bartram et al., 1991: 90) or a "work camp" (*sensu* Binford & Binford, 1966: 269), very similar to the "Alyawara men's bush camp" described by Binford (1986: 558). However, the persistent palimpsest effect and the lack of spatiotemporal relationships between this zone and others, where hearths and faunal remains are present, advise caution in drawing definitive, and illusory, behavioural conclusions. In this case, it is necessary to continue the discussion area by area.

### A Possible Resting Area?

The southern part of the site, close to the rockshelter wall, exhibited lower material density than either the north and southeast areas. In this context, our proxies for detecting anthropogenic combustion in SU V yielded positive results for H19. Micromorphological analysis revealed the absence of anthropogenic components in association with H18 or H20. These were exclusively documented within the stratigraphic section associated with H19 (Fig. 10), specifically in the lower part of sample AP-23–3 and the upper part of sample AP-23–4. These components, which include silt-to-fine sand-sized charred plant remains, fragmented charcoal, and fissured, rubified limestone gravel, are indicative of combustion (Mallol et al., 2017; Mentzer, 2014), and likely represent the burnt substrate—the black/red layer—on which the fire was lit (Mallol et al., 2013a, 2017). The absence of distinct, well-defined black layers in combustion structures at Abric del Pastor is a recurrent feature, which is likely associated with the scarcity of organic matter present on the surface prior to ignition (Mallol et al., 2013b) and the overall poor preservation of organic matter at the site and particularly at SU V (Connolly et al., 2019). On the other hand, calcitic wood ash—typically stratigraphically associated with a white layer, corresponding to fuel *input* (Mallol et al., 2017)—was not detected, aligning with findings from other combustion structures at Abric del Pastor SU IV (Mallol et al., 2019). The absence of an ash layer may be attributed to wind erosion, due to its volatility, and/or moisture-induced dissolution. Human activities, such as trampling, may have also contributed to its disappearance (Mallol et al., 2013b, 2017), as previously suggested for other combustion structures at Abric del Pastor SU IV (Mallol et al., 2019).

*n*-Alkane data provide additional evidence that H19 represents a combustion structure and that this is the sole evidence of anthropogenic fire within Abric del Pastor SU V. Control samples representing the natural sediment of SU V showed a predominance of odd-numbered, long-chain *n*-alkanes (Fig. 11A). This pattern indicates that waxes derived from terrestrial higher plants are the primary source of sedimentary *n*-alkanes in Abric del Pastor SU V (Bush & McInerney, 2013; Eglinton & Hamilton, 1967; Ficken et al., 2000). CPI values above two in these samples (Fig. 11B) suggest relatively well-preserved sedimentary organic matter (Ortiz et al., 2013), although the presence of mid-chain compounds lacking an odd-over-even predominance suggests some degradation, likely from bacterial activity in which longer hydrocarbons are broken down, resulting in a restructured distribution that lacks odd-over-even predominance (Brittingham et al., 2017; Grimalt et al., 1988; Zech et al., 2011). Similar results have been previously found in the sediments of Abric del Pastor SU IV (Mallol et al., 2019). This pattern is also observed in H20 RL and, to a lesser extent, in the H20 BL (Fig. 11A, B). Together with the soil micromorphology data, these findings allow us to exclude H20 as a combustion structure. In contrast, the red and black layers from H19 exhibited a pronounced dominance of mid-chain *n*-alkanes without an odd-over-even predominance, while long-chain, odd-numbered compounds were present only minimally in this case (Fig. 11A). This *n*-alkane profile with CPI values lower than two indicates a significantly more intense degradation process (Ortiz et al., 2013) (Fig. 11B), which more likely aligns with the occurrence of a combustion event, i.e. H19, and the consequent thermal breakdown of the molecules (Diefendorf et al., 2015; Knicker et al., 2013; Leierer et al., 2019; Tomé et al., 2022, 2024; Wiesenberg et al., 2009).

The marginal *n*-alkane degradation observed in H20 BL can be explained not as an individual combustion structure, as noted above, but rather as a result of heat transfer from H19, since the H20 BL sample was located beneath H19 RL. In fact, micromorphological observations identified silt and fine sand-sized charred plant material slightly below H19, supporting this interpretation. Therefore, both micromorphological and molecular data underscore H19 as the only Neanderthal combustion structure documented at Abric del Pastor SU V.

Macroscopically, this combustion structure (i.e. H19) is placed just 5 cm from the wall, with no archaeological materials documented in its red and black layers. The archaeological record was found about 25 cm to the east of the hearth, consisting of a S-RMU ($n = 5$) and nine single elements, but there is no evidence of archaeostratigraphic correlation with H19, nor any evidence of thermally altered artefacts. This example diverges from most Palaeolithic contexts, where hearths and their perimeters commonly contain different and abundant burnt remains (e.g. bones, lithic fragments) (e.g. Barkai et al., 2017; Blasco et al., 2016; Fernández-Peris et al., 2012; Machado & Pérez, 2016; Pérez et al., 2017a; Spagnolo et al., 2016), consistent with the hearth-related assemblage model (*sensu* Vaquero & Pastó, 2001). This model works independently from the palimpsest effect, being always archaeologically visible, since it has been verified in high-resolution examples, such as AU IVc1 or IVfH17 of Abric del Pastor SU IV (Machado et al., 2019; Sossa-Ríos et al., 2022) or Horizon A of Wallertheim (Adler et al., 2003), as well as in time-averaged contexts like the H50 hearth-related assemblage from El Salt SU Xb (Sossa-Ríos et al., 2024).

As discussed above, micromorphological data showed that silt-sized charred plant matter, few sand-sized charcoal fragments, and burnt limestone gravel are the solely anthropogenic components associated with H19. Experimental and archaeological studies suggest that human activities around a fire, such as production or consumption, would likely leave more abundant microscopic anthropogenic residues, even if the hearth area has been trampled, dumped, or swept (Goldberg et al., 2009; Mallol et al., 2013b; Marcazzan et al., 2022; Miller et al., 2010; Starkovich et al., 2020).

This set of evidence aligns with some of the characteristics commonly associated with resting/sleeping zones, as identified in ethnoarchaeological, archaeological, and experimental studies (Galanidou, 2000; Henry et al., 2004; Mallol et al., 2007; Goldberg et al., 2009; Vallverdú et al., 2010; Wadley et al., 2011; Bargalló et al., 2020; Spagnolo et al., 2020). The recent state of the art on this topic, provided by Spagnolo et al. (2019), proposes the evaluation of certain parameters to infer the existence of such spaces: (1) spatial segregation from high-activity areas, (2) spatial proximity to the wall, (3) presence of hearths at roughly equal distance intervals, and (4) potential traces of bedding. In addition, recent investigations on smoke density simulation indicate that fires positioned within 0.5 m from the wall generate a smoke-free space, providing ideal conditions for resting activities rather than domestic tasks (Kedar et al., 2024). Our case fulfils the first two requirements: a microscopic absence of archaeological remains, similar to Spagnolo et al. (2019) soil micromorphology sample 172; a low concentration of unburnt macroscopic remains around the hearth, with the uncertainty about their correlation with the fire; and the proximity of the hearth to the wall (< 0.5 m). However, it lacks multiple hearths and evidence of bedding. While the presence of multiple hearths can be ruled out, bedding, if present, would be very difficult to identify considering the grain size and overall composition of the deposit (Connolly et al., 2019; Mallol et al., 2019), and the poor preservation of phytoliths in SU V (D. Papavasiliou, comm. pers.).

Ultimately, whether this area was used for sleeping, resting, or for some other purpose, it seems clear that this example does not fit the hearth-related assemblage model, showcasing a distinct form of variability within Abric del Pastor, as well as potentially within broader Palaeolithic contexts.

## More Areas, Less Evidence

Once we have reviewed the southern and northern zones, the remaining areas within the site should be addressed. The southeastern sector, covering everything under the ledge, is an area dominated by faunal remains, with no detected hearths and scarce lithic artefacts, forming what we refer to as Cluster 1. This composition stands in contrast to Cluster 2 and, indeed, to the entirety of the site surface. Statistical tests, including Chi-square, Fisher, and Cramer's *V*, underscore this distinctiveness, highlighting a significant disparity between the record within the area sheltered by the ledge and the record outside of it. Moreover, it is worth noting that the roof of the ledge was positioned approximately 1.5 m above the ground level, potentially restricting the range of activities that could be carried out within this confined space.

The current data concerning Cluster 1 and artefacts under the ledge include predominantly small to medium-sized flakes, two cores (one medium-sized and one very large), and a notable absence of retouched products and refitting sets. The statistically significant presence of heavyweight products was also noted. However, due to the small number of lithic remains, this information can only support the inference of limited or absent knapping activities, while the potential interaction between these artefacts and the faunal remains requires a use-wear analysis to confirm or refute this hypothesis. This being the case, we must shift our focus to the faunal assemblage.

The observed concentration of faunal remains in this manner, spatially differentiated from domestic activities, mirrors patterns noted in other Neanderthal contexts (e.g. Gabucio et al., 2018; Spagnolo et al., 2019; Speth, 2006; Starkovich et al., 2020). This pattern has often been interpreted as a secondary refuse zone, with size sorting favouring the accumulation of larger bones away from activity areas, which in this case would be reinforced by the presence of heavyweight lithic products. Such "cleaning behaviour" is ethnoarchaeologically associated with extended occupations in residential contexts, where domestic tasks are concentrated around the hearth and the perimeter needs a continuous refurbishment (Bartram et al., 1991; Binford, 1978; Galanidou, 2000; O'Connell, 1987). However, intriguing questions arise in our case: If H19 shows no evidence of domestic activity, were these bones cooked? If they were cooked, from what central focus were they displaced? Further zooarchaeological analyses could provide crucial insights on this matter.

While this area could align with a designated refuse disposal zone, our data remains limited, constrained by the lack of taxonomic and taphonomic analyses on the faunal assemblage. This gap prevents us from ruling out alternative explanations, such as the deposition of bones by carnivores, a phenomenon documented in other Middle Palaeolithic sites (e.g. Sánchez-Romero et al., 2020; Spagnolo et al., 2020, 2024; Zilio et al., 2021), despite there is no previous evidence of carnivore activity in the analysed sequence (Connolly et al., 2019; Pérez et al., 2017b; Sanchis et al., 2015; Sossa-Ríos et al., 2022).

On the other hand, micromorphological data offer valuable insights into the depositional dynamics of the western area of the site, where no archaeological remains were identified. Micromorphological observations revealed that what appeared to be a massive sandy-gravelly deposit in the field consists of a crudely bedded sequence of sandy-gravelly layers with variable micritic calcite cement (Fig. 10). The coarse fraction is unsorted, and there are no signs of lamination, sharp contacts, or any other feature indicative of surface transport or erosion. The lithology and fabric at this part of the rockshelter is similar to what was observed in the micromorphological samples from the combustion area (AP-23–3, AP-23–4, and AP-23–5) and to previously documented samples from SU V and SU IV (Connolly et al., 2019; Mallol et al., 2019) and suggest a gravitational, accretional depositional dynamic, a pattern typical of rockshelter environments (Mentzer, 2017).

Therefore, severe postdepositional processes affecting the archaeological record can be ruled out. This implies that this area was not used for performing any of the activities detected in other zones of the rockshelter (e.g. knapping, fire use) and that this choice was consistent over time, creating a *non-activity* palimpsest. Similar cases have been reported at Abric Romaní level N (Vallverdú et al., 2010), Oscurusciuto unit 13 (Spagnolo et al., 2019), Tor Faraj (e.g., floor II; Henry et al., 2004), and Roca dels Bous level 10 (Martínez-Moreno et al., 2004). However, in these examples, the empty spaces are typically located near the wall with aligned fires and have been interpreted as sleeping or resting areas; in the case of Roca dels Bous, the empty zone lies between hearth-related assemblages. To our knowledge, no previously documented cases exist in which almost half of a rockshelter surface lacks archaeological remains, as observed in the western sector of Abric del Pastor, where the persistence of an unused space suggests a deliberate and recurrent spatial decision. In this sense, the reasons why Neanderthals did not leave any record in this area remain ambiguous. Various possibilities could be considered, including structural/environmental factors, such as exposure to wind or rain in this less sheltered part of the site, or cultural factors, like the preference for reoccupying the same spaces previously used by earlier groups.

## Conclusions

By adopting an event-based approach, we have shifted the unit of analysis from broad stratigraphic containers to discrete, temporally constrained episodes of activity. Events, as the minimal components of the assemblage, provide the most precise window into human behaviour. Their identification and the study of their interrelationships have clarified the diachronic organisation of space, resource management, and behavioural variability. This approach also offers a methodological reference for interpreting more complex palimpsests where such high spatiotemporal resolution cannot be fully achieved. Through refitting analysis and the principle of diachrony, we were able to separate certain events, thereby reducing the spatiotemporal uncertainty that typically characterises stratigraphic units. This allowed us not only to demonstrate that certain areas were used for the same purpose at different times but also to refute the hypothesis of a singular, extensive knapping episode involving distinct flint types in the same zone.

Nevertheless, this study also highlights that even in high-resolution contexts, the issue of palimpsests remains prevalent. The temporally separated activity events may represent multiple occupation events, potentially linked with materials whose association with the same temporal context cannot be proven, as in the case of single products. Thus, time, understood as an emergent property, continues to pose challenges, regardless of the resolution of archaeological assemblages, making it difficult to assume contemporaneity. While some degree of time averaging persists, albeit in a reduced form, the methodological framework applied here has significantly improved our understanding of the temporal and spatial structuring of Neanderthal behaviours.

Similarly, our interpretations have also been refined thanks to the integration of geoarchaeological techniques, enabling us to avoid potential inferential errors, such as the misinterpretation of repeated fires in the southern area, and to rule out geogenic/biogenic postdepositional factors as an explanation for the absence of materials in the western sector.

On the other hand, the spatial units examined notably lack the typical hearth-related assemblages. This discrepancy may indicate a positive correlation between temporal resolution and behavioural variability, suggesting that finer temporal distinctions allow for a more nuanced understanding of diverse site use patterns. In other words, these cases accentuate the differences, making common behaviours less apparent. However, we also observed continuity in spatial organisation, exemplified by the repeated knapping activity in the northern sector. This highlights that palimpsest dissection is essential not only for detecting short-term changes but also for identifying persistent and structural behaviours. While explaining this recurrence will require additional examples and, consequently, a more robust hypothesis, this study establishes a valuable precedent.

Furthermore, the low degree of interaction observed between the distinct areas suggests that activities were short term, likely more aimed at planning economic tasks than at fully executing them on site, which reinforces the notion of spatial fragmentation of activities within the landscape. However, this limited interaction also restricts the temporal linkage across areas, compelling us to interpret each area as a discrete behavioural unit without assuming direct/indirect connections. Precisely for this reason, identifying discrete events allows us to move beyond conceiving space as a uniform whole, thus avoiding hasty or inaccurate interpretations that fail to align with the temporal scale of the data.

In this sense, zooarchaeological analysis will be crucial for examining potential spatiotemporal inferences, particularly concerning refitting links between zones, and the possible presence of a secondary waste deposit in the southern area. Such deposits are generally associated with long-term residential contexts, and any contradictions here, interpreted as a short-term context, could open possibilities for more complex site formation processes. Lastly, a more detailed technological analysis of the lithic record will provide further insights into spatiotemporal variability, allowing us, for instance, to test the differences between the Mariola and Serreta assemblages or to assess the role of the minor flint types and limestone.

Finally, this case highlights the limitations of applying uniformitarianism as an interpretative framework in archaeology. When confronted with archaeological cases that lack robust ethnoarchaeological parallels, our explanatory capacity becomes significantly constrained, diminishing what Bailey (1983: 173) describes as the "creative role" of our discipline. The issue is not merely the challenge of reconciling different temporal scales, but also the limited capacity to address research questions without forcing our data to fit existing examples. More data from high-resolution Palaeolithic contexts are required in order to build strong hypotheses about Neanderthal spatial behaviour.

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**Data Availability** Data is provided within the manuscript or supplementary material file.

## Declarations

**Competing interests** The authors declare no competing interests.

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