Quantitative stone tools intra-site point and orientation patterns of a Middle Palaeolithic living floor: A GIS multi-scalar spatial and temporal approach

Quantitative Analyse von Verteilungsmustern von Steinartefakten eines mittelpaläolithischen Begehungshorizonts: Ein GIS multi-skalarer räumlicher und zeitlicher Ansatz

Francesca Romagnoli[1, 2]* & Manuel Vaquero[1, 2]

[1] IPHES, Institut Català de Paleoecologia Humana i Evolució Social, Campus Sescelades URV (Edifici W3), E-43007 Tarragona
[2] Area de Prehistoria, Universitat Rovira i Virgili (URV), Avinguda de Catalunya 35, E-43002 Tarragona

Abstract - Analysis of intra-site spatial patterns helps to characterise the social organisation of the human group that lived at the site. Variability in stone tool intensity and spatial distribution on the living floor reflects variability within each activity area in number of individuals, duration of occupation, and number of superimposed events. Specifying the value of these three parameters is usually highly difficult, due to the low resolution and temporal uncertainty that characterise archaeological records. Furthermore, natural processes could have affected the spatial distribution of artefacts and the formation of the archaeological assemblage. In this paper, we investigated taphonomic processes and cluster distribution of lithic remains using, for the first time, quantitative point-pattern modelling and statistical measure of density on a living floor at the Abric Romaní Middle Palaeolithic site. A quantitative approach has been applied to high-resolution lithic assemblage, previously empirically processed for Raw Material Unit and refits to identify single technical events. Multi-scalar horizontal analysis and vertical dispersion of artefacts within the activity areas exhibited different occupational patterns between the inner area of the rock-shelter closely located to the wall and the external area. The external area was well-preserved by water flows also outside from the drip line with almost unspoiled knapping areas. Different occupational patterns have been identified between interior and exterior area. The latter could be related to short events, spatially and temporarily well-delimited and, most likely, to the last phase of occupation of the site, as also discussed in comparison with other categories of archaeological material. In contrast, the inner part located close to the wall and the most protected, have been repeatedly occupied, most likely by small Neanderthal groups that maintained similar occupational patterns during time and generated a horizontal palimpsest. The results demonstrated that the quantitative approach, associated with previous empirical processing of data, is a useful and effective method for approaching temporal uncertainty in point patterns.

Zusammenfassung - *Die Analyse der Verteilungsmuster von archäologischen Funden innerhalb einer räumlich abgrenzbaren Fundstelle wird als eine Möglichkeit angesehen, die Organisation sozialer Strukturen einer Gruppe von Menschen an dieser Stelle zu untersuchen. Die Dichte und die Verteilung der Steinartefakte auf dem zu untersuchenden Begehungshorizont gelten als Anzeiger der jeweiligen Gruppengröße, Nutzungsdauer und Häufigkeit. Die Angabe eines Wertes für diese drei Parameter ist in der Regel aufgrund der geringen Auflösung und der unsicheren zeitlichen Tiefe der Befunde sehr schwierig. Darüber hinaus können natürliche Prozesse die räumliche Verteilung der Funde und die Bildung der archäologischen Einheiten beeinflusst haben. Im vorliegenden Beitrag werden taphonomische Prozesse und die Clusterverteilung von Steinartefakten mit Hilfe der quantitativen Punktwolkenmodellierung und des statistischen Maßes der Dichte an einem mittelpaläolithischen Begehungshorizont des Abric Romaní erstmalig durchgeführt. Der quantitative Ansatz wurde bei einem hochauflösenden Inventar von Steinarten angewendet, bei dem zuvor Rohmaterial-Einheiten gebildet wurden und mittels Zusammensetzung einzelne technologische Ereignisse identifiziert werden konnten. Die multi-skalare horizontale und vertikale Verteilung der Steinartefakte zeigt, dass innerhalb der Tätigkeitsbereiche unterschiedliche Arbeiten zwischen dem inneren Bereich des Abris nahe der Felswand und dem Außenbereich durchgeführt wurden. Auch der Außenbereich außerhalb der Traufkante war gut vor Erosion durch Wasser geschützt. Hier haben sich einige Schlagplätze erhalten. Verschiedene Aktivitäten konnten zwischen Innen-und Außenbereich identifiziert werden. Der Außenbereich kann mit kurzen räumlich und zeitlich gut abgrenzbaren Ereignissen, und wahrscheinlich mit der letzten Begehungsphase in Zusammenhang gebracht werden. Dies wird unterstützt durch das Fundmaterial anderer Kategorien. Im Gegensatz dazu wurde der innere Bereich, gut geschützt nahe der Abriwand, wiederholt genutzt. Es ist anzunehmen, dass hier kleine Gruppen von Neanderthalern ähnliche Arbeiten wiederholt an denselben Stellen durchgeführt haben und sich so ein horizontales Palimpsest bilden konnte. Die Ergebnisse zeigen, dass der quantitative Ansatz zusammen mit vorhergehenden empirischen Untersuchungen, ein nützlicher und effektiver Ansatz ist, um zeitliche Unschärfen in Punktwolken analysieren zu können.*

Keywords - Neanderthal, lithic refits, Monte Carlo simulation, spatial analysis, geo-statistics, taphonomy
Neandertaler, lithische Refits, Monte-Carlo-Simulation, Raumanalyse, Geostatistik, Taphonomie

*corresponding author: f.romagnoli2@gmail.com

Introduction

The intra-site spatial patterns of stone tools and their density on the living floor are traditionally used in archaeology as proxies for activity areas and social organisation of the human group that lived at the site (e.g., Jöris et al. 2011; Wright 2014; Gaudzinski-Windheuser 2015; Roda Gilabert et al. 2016). To understand human behaviour through the analysis of the spatial association of their remains, there are two main aspects that have to be primarily investigated and that are not systematically taken into consideration in archaeology. First, the type of patterns must be defined to identify the presence and the intensity of interaction between points and the spatial variability of processes underlying aggregation and segregations (effects external or internal to the human group, such as social structure and economic organisation). Second, site formation processes must be analysed to understand the degree of integrity in spatial patterns and how natural phenomena could have disturbed the spatial arrangement of anthropic activities.

Point-pattern data, in which the point locations of objects or classes of objects defined according to their attributes is of prime interest (Orton 2004), can be distributed in space in different ways: randomly (following a spatial Poisson process), regularly, or clustered (Bevan et al. 2013). In the last years, point pattern statistical analysis has been applied in archaeology to assess distribution of sites (Bevan & Connolly 2006), surface materials collected by regional surveys (Crema & Bianchi 2013), intra-site features (Crema et al. 2010), and artefacts (Orton 2004) but its application is still rare especially in intra-site analysis. The characterisation of point patterns in more formal, and quantitative ways allows us to construct a strong reference for comparisons and to attain a deeper understanding of spatial variability. The retrieval of quantitative spatial patterns is indeed the basis of investigation into spatial dependency (Bailey & Gatrell 1995). Human individuals are social agents that carry out activities in their living spaces. The spatial patterns of archaeological records that archaeologists investigate reflects the social phenomena of past human groups. An understanding of the reasons, modalities, and variability of the type of human aggregations or repulsion in past lived space permits to understand long-term cultural processes.

Neanderthal spatial organisation of technology at Abric Romaní, a Middle Palaeolithic campsite in northeast Iberia, is a central topic in the investigation of human behaviour at the end of MIS 3 and has been shown to have a great interpretative potential thanks to fieldwork methodologies aimed at excavating large surfaces (more than 200 m^2) with a high spatial detail in data recording (Carbonell i Roura 2012). Spatial patterns have been deeply investigated to understand the temporal resolution of the assemblages (Vaquero 2008), economic strategies (Vaquero 2011), the role of 'secondary' raw material (Bargalló et al. 2014), spatial relationships between hearths and activity areas (Vaquero & Pastó 2001; Vaquero et al. 2004), intra-site anthropic movements of toolkits (Vaquero 1999; Vaquero et al. 2015), length of site occupation (Vallverdú et al. 2005), and archaeostratigraphy (Bargalló et al. 2016). Previously, a quantitative approach to the definition of spatial patterns was performed for some layers in which a K-means cluster analysis was carried out to identify archaeological accumulations (Vaquero 1999). However, additional analyses to define point-pattern intensity are needed to define spatial patterns, make reliable comparisons along the sequence, and interpret changes in socio-economic human behaviour.

Although a living floor was the space where humans carried out their daily activities, individuals were not the only agents that contributed to the formation of the archaeological assemblages. Post-depositional disturbances could have affected the spatial distribution and the concentrations of artefacts at different degrees and by different biotic and abiotic agents, including water. Every archaeological context has been somewhat affected by post-depositional disturbances, including the living floor and the delimited aggregations of bones and lithics accumulated on them by humans (Schiffer 1983). According to Potts (1988), six indicators might show the effects of water flow disturbance: sedimentology, palaeogeography, artefact size classes, preferred orientation, edge abrasion, and bone hydraulic transport. Statistics of artefacts orientation (i.e., azimuth and inclination) have usually been used as a powerful proxy to address water flow disturbances in an archaeological context (Benito-Calvo & de la Torre 2011 and references therein). However, orientation data directly measured during excavations have been showed to be the only valid indicators of hydric effects (Domínguez-Rodrigo et al. 2012).

Abric Romaní is located on the Cinglera del Capelló, a travertine cliff associated with a waterfall system actually inactive (Vaquero et al. 2013). Due to sedimentary dynamics, water flows had the potential to have been the main agent responsible for taphonomic disturbances. At Abric Romaní taphonomy has been investigated in several studies from the faunal perspective (Fernández-Laso 2010; Cáceres et al. 2012; Rosell et al. 2012; Gabucio et al. 2014; Gabucio et al. 2016). These studies have shown the general low impact of water flows characterised by low energy and usually locally affecting delimited areas, as attested by water abrasion and manganese oxide pigmentation. However, neither a systematic study of azimuth and inclination of bones nor applications for lithic assemblages have ever been performed. Orientation data are directly registered during excavation prior to item collections, and this makes the archaeological materials highly suitable for taphonomic analysis (Domínguez-Rodrigo et al. 2012). Bones and stones have different physical and chemical characteristics and could have been differently affected by hydraulic phenomena. Furthermore, using spatial patterns of stone tools as a proxy for Neanderthal social organisation is of prime importance to test hypotheses about the intra-site anthropic origin of accumulations and to exclude possibly disturbed areas affected by paleo channels.

A variable that must be taken into account when investigating these topics is the scale of analysis. While multi-scalar GIS applications are quite common in regional studies (Francovich & Patterson 2000; Banning 2002; Van Leusen 2002; Hill 2004; Lock & Molyneaux 2006), the issue of the scale of analysis is rarely contemplated in intra-site applications. Phenomena that affected spatial patterns may have different trends at the large or small scale and that is true independently of the extension of the study area, both considering large territories or the living floor of a single site. The concept of spatial dependence (also known as heterogeneity) expresses the complexity underlying variation of point density over space (Bevan & Connolly 2009). This variation is related to different intensity in acting phenomena and to the possibility that in some areas of the living floor they were completely different. Furthermore, measurements of a given phenomenon may not vary equally in all directions of the space (spatial anisotropy; Rosenberg 2004). To further complicate this scenario, it must to be provided for palimpsest characteristic of every archaeological context (Bailey 2007; Machado et al. 2015). This means that living floors are the result of an unknown number of superimposed events carried out by an unknown number of individuals. Technical events are analysed in stone tools assemblage (import, production, export, use and discard events). Phenomena that affected spatial patterns may also have different trends, intensity, and vary during time. Several studies have shown the great informative potential of stone tools refits in high-resolution analysis. Refits allow us to detect single technical episodes, making it possible to (i) understand processes involved in the formation of the lithic assemblage from a behavioural perspective (Delagnes et al. 2006; Vaquero 2008; Turq et al. 2013; Romagnoli et al. in press), and (ii) investigate intra-site settlement dynamics (Vaquero et al. 2004, 2015; Folgado & Brenet 2010; Machado et al. 2015, 2016; Bargalló et al. 2016, among others). Furthermore, being refit the shortest temporal scale of analysis in technology, spatial analysis of refits permits us to discuss spatial variability across time.

In this paper, we address for the first time two questions aimed at explaining the spatial patterns of lithic assemblage at Abric Romaní site, and we test hypotheses about point pattern models using specific point-pattern statistics:

1) To what degree are the lithic remains spatially clustered?

2) To what degree did natural processes affect the spatial distribution of anthropic activities?

We analysed layer M. More specifically, through the application of Ripley's K function with Monte-Carlo simulations, we provided a statistical measure to test the Complete Spatial Randomness hypothesis. Then, through the study of lithic orientation (both azimuth and inclination) and the analysis of artefacts size classes, we discussed the role of water flow post-depositional disturbances in the formation of stone tools assemblage. The study of density was used to delimitate activity areas and we performed a multi-scalar spatial analysis both at layer and each single activity area scale of analysis. To perceive spatial and temporal variations of phenomena with the highest possible detail, we used Raw Material Unit (RMU) (Roebroeks 1988; Larson & Kornfeld 1997) and refits dataset (Vaquero et al. 2015; Romagnoli et al. in press). In this way we were able to identify single technical events and reduce as much as possible the temporal scale of analysis of the assemblage. Spatial variability of phenomena at different temporal scales are also discussed.

Abric Romaní site, layer M.

Abric Romaní is a rock shelter placed at 280 m above sea level and located approximately 50 km west of Barcelona, in the town of Capellades (Fig. 1). The site covers a chronology between 40 kyr and 110 kyr (Vaquero et al. 2013; Sharp et al. 2016) and is characterised by high temporal resolution, with archaeological levels vertically well-delimited and layers separated by travertine sterile platforms (Carbonell i Roura 2012). Each archaeological layer allowed us to collect well-preserved and very rich assemblages, including faunal remains, lithic items, woody rests (Solé et al. 2013), and several hearths (Cabanes et al., 2007; Vallverdú et al. 2012) associated with butchery, productive, and sleeping areas (Vallverdú et al. 2010; Vaquero et al. 2015; Gabucio et al. 2016).

Layer M has been excavated at approximately 250 m^2 yielding 18'946 archaeological elements: 7'614 faunal remains, 6'084 lithic remains, 114 wood imprints, and 260 charcoals. The entire assemblages, including bones over than 20 mm long and lithics over than 10 mm long, have been spatially recorded in a 3D Cartesian coordinate system using a square grid of 1 m. The travertine platforms covering and underlying the layer have been dated at 51.8 ± 1.4 kyr BP and 54.6 ± 2.3 kyr BP, respectively (Bischoff et al. 1988). The pollen record registered a predominance of *Pinus* and gramineae (*Artemisia* and *Poaceae*) associated with meso- and thermophilic taxa, indicating climatic oscillation within pollen zone 3 (Burjachs et al. 2012). Anthracological data show the predominance of *Pinus silvestris* (Burjachs et al. 2012). Human activity was mainly responsible for the accumulation of animal

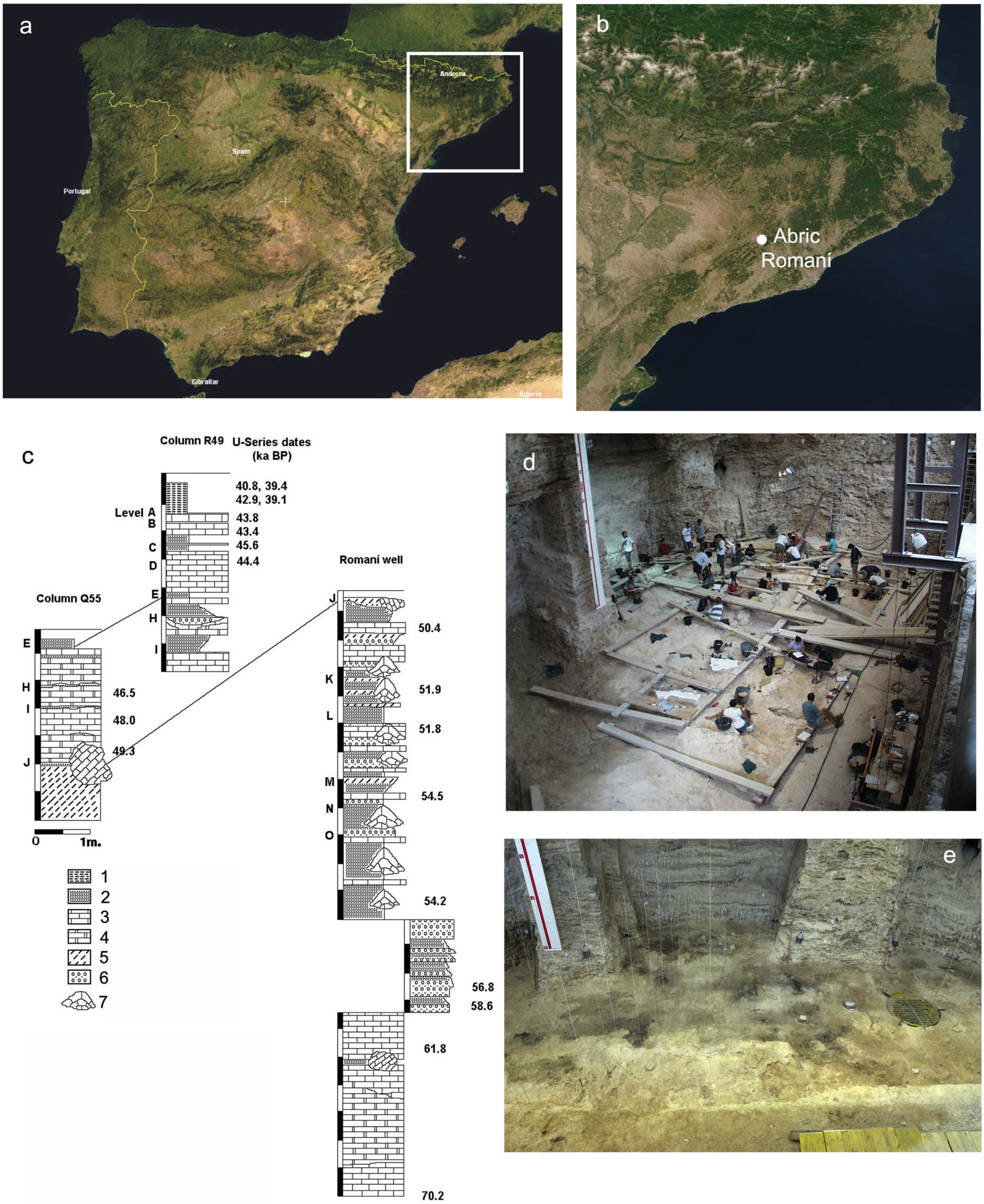


Fig. 1. a, b. Geographic location of Abric Romaní in Northeastern Iberia; c. Synthetic lithostratigraphic column; d, e. Images of Abric Romaní during the excavation of level M. Legend for the lithological column: 1. Red sands; 2. Carbonatic sands; 3. Filiform travertines; 4. Tubular travertines; 5. Carbonatic slabs; 6. Oncolithic gravels; 7. Travertine blocks.

Abb. 1. *a, b. Geografische Lage des Abric Romaní im Nordosten Iberias; c. Synthetisches lithostratigraphisches Profil; d, e. Fotos des Abric Romaní während der Ausgrabung der Ebene M. Legende für die lithologische Säule: 1. Rote Sande; 2. Kohlenstoffsande; 3. Fadenförmige Travertine; 4. Röhrenförmige Travertine; 5. Kohlenstoffbrammen; 6. Onkolithischer Kies; 7. Travertinblöcke.*

bones (carnivores' damages 0.3 %; Fernández-Laso 2010; Chacón et al. 2014). Hunting activity mainly focused on red deer, horses and aurochs; macro-mammal remains showed intense bone processing and a high level of bone fragmentation related to Neanderthal subsistence (Fernández-Laso et al. 2011). Chert was the main exploited raw material mostly collected in primary and sub-primary position at

15 - 20 km north-west of the site, followed by limestone and quartz locally collected in the form of cobbles (Gómez de Soler 2016). Production was mainly aimed at obtaining asymmetric flakes applying discoid and informal, expedient recurrent centripetal and orthogonal sequences with variable degree of surface resharpening and frequently included ramification (core-on-flakes); the lithic assemblage has short dimensions mostly comprising between 10 and 30 mm, shows a high morphological variability of flakes and a high fragmentation rate due to the general bad quality of raw material exploited and the use of knapping methods with low control on the geometric construction of the core (Vaquero et al. 2008; Chacón et al. 2013; Vaquero et al. 2015; Romagnoli et al. in press). Retouched tools were underrepresented and were mainly denticulates, notches and scrapers. Macrofaunal dental wear analysis suggested that in this phase the site was occupied during autumn and early winter (Fernández-Laso et al. 2010).

Materials and Methods

RMUs and refits data of the whole assemblage (including elements shorter than 10 mm; Vaquero et al. 2015; Romagnoli et al. in press) were processed to obtain a dataset, including single technical events organised in several categories (Fig. 2). We included in the analysis (i) refitting elements related to production events, (ii) refitting elements related to fractured pieces, (iii) RMUs identified on the basis of macroscopic characteristics of raw material and comparison with geological samples (type of cortex; degree of roughness of the chert surface; transparency; type of sedimentary structures; presence of fissures and joints; presence and characteristics of geodes, mineral inclusions, and others impurities; and colour; Soto et al. 2014; Gómez de Soler 2016), and (iv) single elements that were each imported into the site as finished tools ready to be used and were most likely part of the personal toolkit. The dataset includes 51 % of the whole chert assemblage from layer M that comprised by 5'033 pieces in total.

Technological dimensions were measured with a precision calibre and expressed in mm. Length was measured along the debitage axis while width reflects the maximum measurement orthogonal to the length.

Category	Number of elements	%
Production refits	726	*28.2*
Refitted fragments	85	*3.3*
RMUs elements	1682	*65.3*
Single elements	81	*3.1*
Total	**2574**	*100*

Fig. 2. Elements included into point and orientation patterns analysis.

Abb. 2. *In der Punkt- und Orientierungsmusteranalyse enthaltene Elemente.*

The analyses presented in the paper have been performed with Open Source resources, mostly in R environment (R Core Development Team 2011), with some processing in QGIS (Q GIS Development Team 2016).

Spatial distribution

One of the most robust point pattern analyses for characterising spatial aggregations and segregations between artefacts is Ripley's K function (Ripley 1976). In this analysis a series of buffers are set up around every point. Then, the mean number of observed points falling within each buffer radius is calculated (K value). The computation of the K function involves the computation of edge correction which calibrates the falsified data derived by points located near the edge of the study area. We used Ripley's 'isotropic' edge correction that was developed for irregular polygons, as is the case of layer M excavation limits (Ripley 1977). To test Ripley's K function, we checked if K value was deviated with respect to the expected theoretical K value for random point pattern (Complete Spatial Randomness; Diggle 1983) applying Monte-Carlo simulation (Robert & Casella 2004). This consists in generating a series of sets of artificial points with the same density as the observed points but with random spatial locations. The computation of the K value of each set of random points allows us to produce an envelope of expected values for the null hypothesis. If the observed K value falls below the envelope, then the point pattern is regular; if it falls within the envelope, it is random; and if it is above, it is clustered. We ran 999 Monte Carlo simulations and generated an envelope containing 95 % of random dataset. K function with Monte Carlo simulations is done by analysing the increasing buffer radius size to identify the presence of different spatial distribution at different scales of analysis.

Activity areas and taphonomic analysis

To identify the areas with the highest intensity of points we combined several methods. Our study was aimed at investigating spatial phenomena at different scales of analysis and we were deeply interested in delimitating the maximum number of accumulations and enlarging details in taphonomic analysis. The visualisation of these areas with just one method was not possible, especially for the extended concentration of materials located near the rock shelter wall where the high density of remains determined the drawing of a single extended buffer radius. We solved the problem by combining Kernel density estimation (Baxter et al. 1997), Kernel density plot implemented in spatstat R package by the function density.ppp (perspective and contour plots; Baddeley et al. 2016), and the calculation of k-nearest neighbour distances, calculating the average distance of each point to its nearest neighbour irrespective of the direction, and determining the optimal parameter of distance and minimum number of points falling within this distance radius (DBSCAN).

The areas delimitated in this way were used as proxies for activity areas and social lived spaces, and were used as a minimum spatial scale of analysis for orientation patterns. During fieldwork, orientation data of each remain were recorded previously to the removal of the items. Azimuth and inclination were recorded according to absolute value of length, irrespective of technological measurements and integrity. For lithic remains, every piece over than 10 mm long is usually recorded. In the paper, North (N) expressed the conventional reference direction during excavation, corresponding to the y-axis of the Cartesian coordinate system. It was beyond the geographic North axis of approximately 180° south, corresponding to the geographic South-West (SW; Fig. 3). For azimuth analysis, pieces with almost equivalent length and width have been excluded.

Results

Multi-scalar Ripley's K function clearly showed that point patterns were strongly clustered both at the layer scale and at the smallest scale of analysis considering low buffer radius (Fig. 4). The analysis rejected the null hypothesis of Complete Spatial Randomness and suggested the presence of attraction between points due to internal effects to the human group rather than being the consequence of external phenomena. However, water flows could have affected the distribution and displaced lithic remains in clustered distribution.

To test this hypothesis, we performed an orientation pattern analysis first considering the whole surface of layer M as a study area (Fig. 5). The results showed the lack of preferred azimuth and similar values for the eight orientations analysed. Does the result remain unchanged when reducing the study area and analysing each single accumulation?

Analysis of intensity in point pattern showed a spatial variability with four adjacent concentrations of remains near the wall of the rock shelter and seven other discrete areas mostly distributed in the central part of the site, with variable degree of intensity among them, and separated by empty spaces or areas with very low density (Fig. 6). Analysis of azimuth orientation showed comparable percentage in the different areas, with a general predominance of NS and EW orientations (Fig. 7).

Analysis of the inclination of each remain and, more specifically, of its surface touching the soil, showed a clear predominance of materials positioned

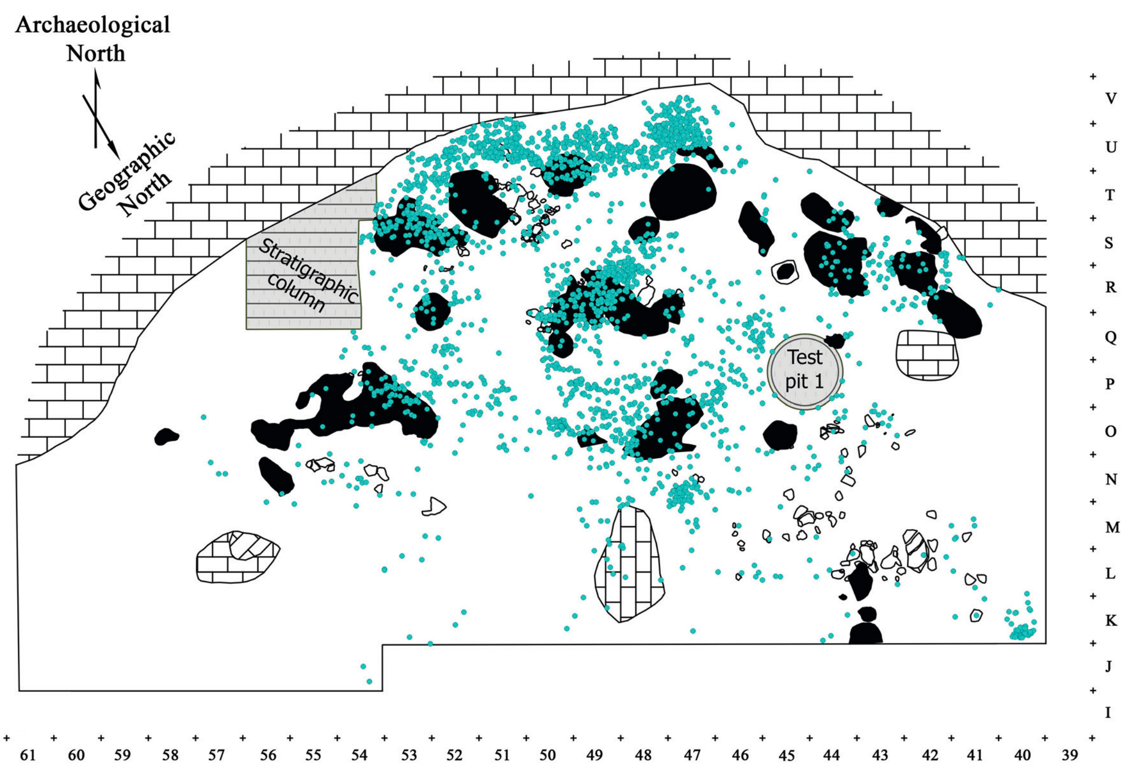


Fig. 3. Abric Romaní, layer M. Distribution map of analysed high-resolution chert dataset. Directions in the paper are expressed with respect to Archaeological North. Hearths are depicted in black, natural stones and blocks are black and white drawn.

Abb. 3. *Abric Romaní, Schicht M. Verteilungsplan des analysierten hochauflösenden Chert-Datensatzes. Die Richtungen in der Zeichnung beziehen sich auf den archäologischen Norden. Feuerstellen sind in schwarz, Natursteine und Blöcke sind schwarz/weiß gezeichnet dargestellt.*

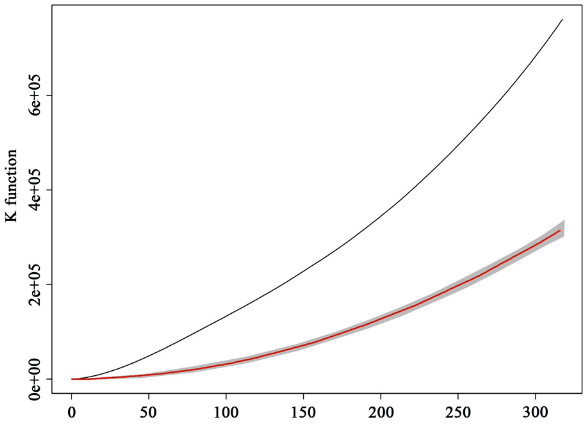


Fig. 4. Univariate K function for the analysed set of stone tools with isotropic edge correction. The x - axis represents increasing value of buffer radius. The grey area is the envelope generated for the null hypothesis of a theoretical random point pattern generated running 999 Monte Carlo simulations and it encloses 95% of random dataset. The black line represents the observed K function and its location above the grey envelope irrespective of the dimension of the study area shows a significant (with p - value < 0.05) clustered pattern.

Abb. 4. *Univariate K-Funktion für den analysierten Satz von Steinwerkzeugen mit isotroper Kantenkorrektur. Die x-Achse repräsentiert einen ansteigenden Wert des Pufferradius. Der graue Bereich ist die Hüllkurve, die für die Nullhypothese eines theoretischen Zufallspunktmusters erzeugt wird, das 999 Monte-Carlo-Simulationen erzeugt, und es umschließt 95% des zufälligen Datensatzes. Die schwarze Linie repräsentiert die beobachtete K-Funktion und ihre Lage oberhalb der grauen Hüllkurve unabhängig von der Dimension des Untersuchungsbereichs zeigt ein signifikantes Clustermuster (mit p - Wert <0,05).*

horizontally in every accumulation, with the percentage usually being over 50 % (Fig. 8). Vertical inclination was usually less than 10 %, except for accumulations M9 and M10, where the value was 10 % and 16 %, respectively. In these cases, other inclinations exhibited similar values: S and SW in accumulation M9, and N in accumulation M10. However, these values were always substantially below horizontal inclinations (43 % and 38 %, respectively).

Looking at artefact size classes in each accumulation (Fig. 9), it is possible to notice a general predominance of artefacts under 30 mm long, coherent with the general characteristics of the lithic assemblage, albeit with some fluctuations in the values. Remains with lengths between 10 and 20 mm were abundantly preserved in every accumulation, but variations could be highlighted on the proportion of this class, especially in areas M5, M8, and M11, where it reached values of 58 %, 57 %, and 83 %, respectively.

Discussion

Point pattern analysis showed a highly clustered intrasite distribution of chert remains with 11 areas characterised by high intensity of materials spatially related with hearths, except for area M11, which was isolated from the combustion structure. However, area M11 is located just at the limit of the excavated surface and we cannot therefore discard the possibility that a

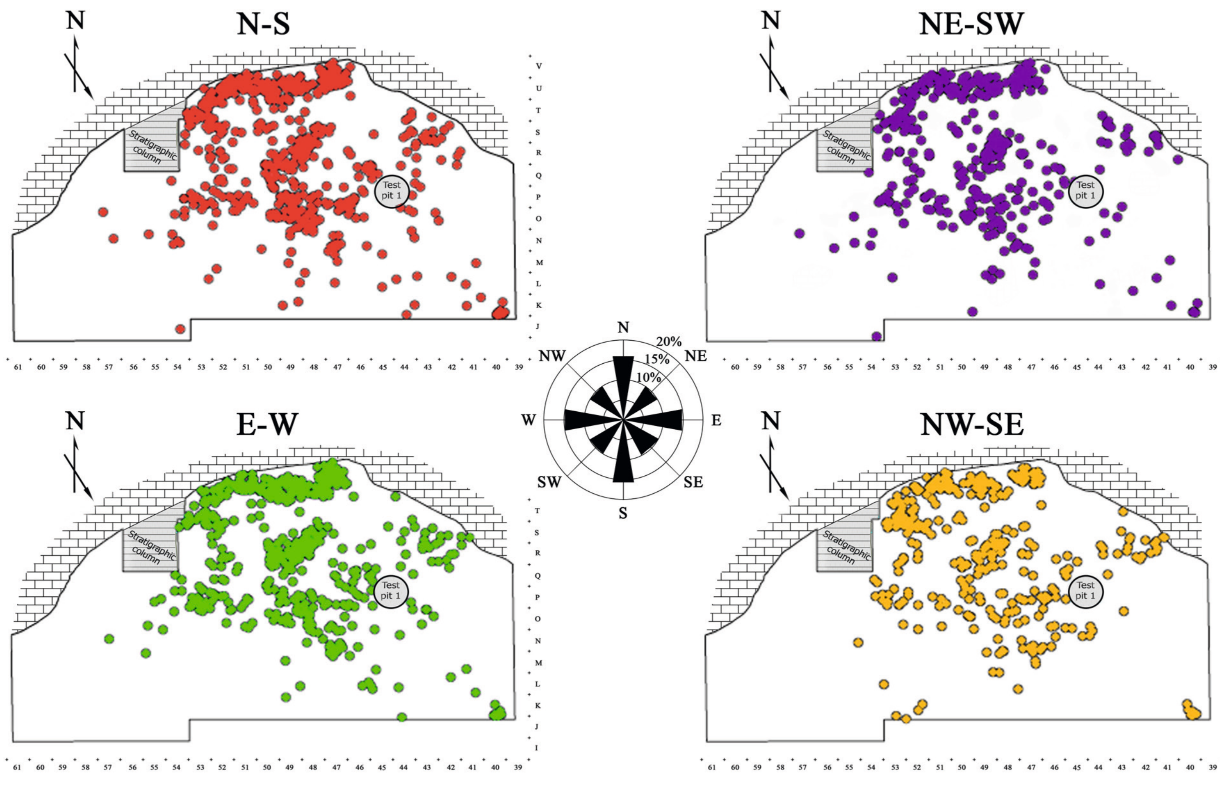
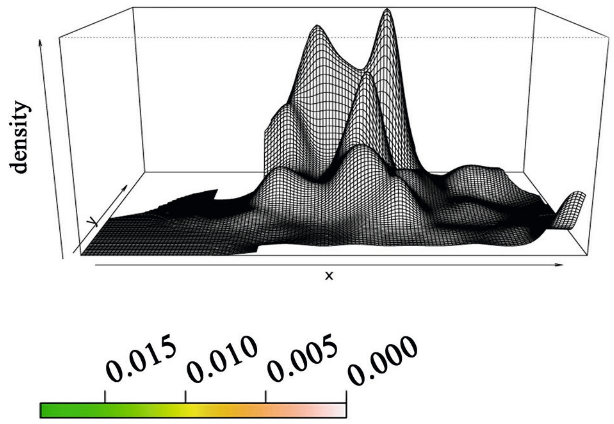


Fig. 5. Distribution maps and angular histogram of azimuth orientation in layer M.

Abb. 5. *Verteilungspläne und Winkelhistogramm der Azimutausrichtung in Schicht M.*



Accumulation	Average intensity	Area
M1	0.00492	39451.6
M2	0.01098	19129.9
M3	0.00667	29250.4
M4	0.01101	18791.6
M5	0.00655	42603.5
M6	0.00165	44929.1
M7	0.00214	44292.4
M8	0.00235	20816.1
M9	0.00549	21653.7
M10	0.00280	29649.7
M11	0.00239	12117.7

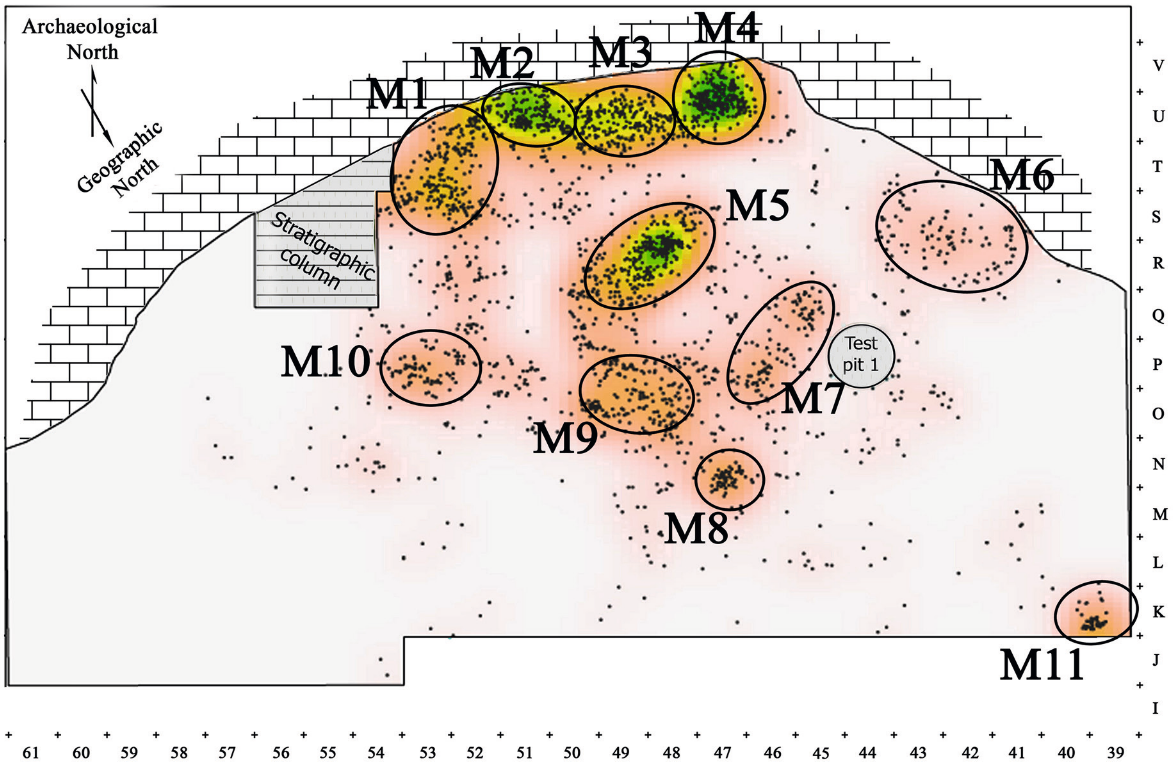


Fig. 6. Density plot, distribution map and values of average intensity of the 11 accumulations in layer M.

Abb. 6. *Dichteplot, Verteilungsplan und Werte der mittleren Intensität der 11 Konzentrationen in Schicht M.*

hearth was present in the nearby unexcavated area. This clustering differs from a previously published one (Vaquero et al. 2015) in which only six accumulations were differentiated. Differences can be explained taking into account that point intensity has been quantitatively analysed for the first time in the present paper, and only the artefacts included in refits and RMU have been considered here. Four areas with

	M1		M2		M3		M4		M5		M6		M7		M8		M9		M10		M11	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
NS	59	*30*	60	*29*	57	*29*	69	*33*	87	*31*	19	*26*	34	*36*	11	*22*	50	*42*	25	*30*	9	*31*
NESW	39	*20*	39	*20*	42	*22*	35	*17*	54	*19*	18	*24*	17	*18*	7	*15*	21	*18*	15	*18*	4	*14*
EW	45	*24*	63	*30*	63	*32*	69	*33*	91	*33*	19	*29*	24	*25*	20	*41*	34	*28*	28	*34*	10	*34*
NWSE	51	*26*	48	*23*	33	*17*	34	*17*	47	*17*	18	*24*	20	*21*	11	*22*	14	*12*	15	*18*	6	*21*
Total	**194**	*100*	**210**	*100*	**195**	*100*	**207**	*100*	**279**	*100*	**74**	*100*	**95**	*100*	**49**	*100*	**119**	*100*	**83**	*100*	**29**	*100*

Fig. 7. Frequency and proportion of orientation in each accumulation. Minimum length 10 mm. Chert remains with similar length and width have been excluded.

Abb. 7. *Häufigkeit und Orientierungsanteil in jeder Konzentration. Mindestlänge 10 mm. Chertreste mit ähnlicher Länge und Breite wurden ausgeschlossen.*

	M1		M2		M3		M4		M5		M6		M7		M8		M9		M10		M11	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
P	137	*67*	122	*54*	117	*53*	130	*56*	163	*56*	60	*76*	66	*58*	27	*46*	56	*43*	35	*38*	12	*42*
N	10	*5*	15	*7*	15	*7*	15	*6*	16	*5*	2	*2.5*	7	*6*	5	*8*	3	*2*	9	*10*	5	*17*
NE	4	*2*	7	*3*	8	*4*	14	*6*	8	*3*	2	*2.5*	3	*3*	1	*2*	3	*2*	1	*1*	1	*3*
E	11	*5*	14	*6*	8	*4*	4	*2*	10	*3*	3	*4*	10	*9*	3	*5*	7	*6*	6	*6*	0	*0*
SE	6	*3*	9	*4*	8	*4*	13	*6*	10	*3*	1	*1*	2	*2*	6	*10*	3	*2*	5	*5*	0	*0*
SE	11	*5*	17	*8*	25	*11*	16	*7*	33	*11*	3	*4*	12	*11*	2	*3*	19	*15*	6	*6*	3	*10*
SW	6	*3*	4	*2*	9	*4*	10	*4*	14	*5*	3	*4*	5	*4*	8	*14*	13	*10*	6	*6*	2	*7*
W	5	*2*	10	*4*	13	*6*	14	*6*	13	*5*	4	*5*	5	*4*	4	*7*	9	*7*	7	*7*	6	*21*
NW	8	*4*	8	*4*	6	*3*	9	*4*	12	*4*	1	*1*	1	*1*	2	*3*	3	*2*	2	*2*	0	*0*
V	9	*4*	18	*8*	10	*4*	7	*3*	13	*5*	0	*0*	2	*2*	1	*2*	13	*10*	15	*16*	0	*0*
Total	**207**	*100*	**224**	*100*	**219**	*100*	**232**	*100*	**292**	*100*	**79**	*100*	**113**	*100*	**59**	*100*	**129**	*100*	**92**	*100*	**29**	*100*

Fig. 8. Frequency and proportion of inclination in each accumulation. P = plane surface, absence of inclination. V = vertical.
Abb. 8. *Häufigkeit und Proportion der Neigung in jeder Konzentration. P = ebene Fläche, fehlende Neigung. V = vertikal.*

the highest intensity were located in the inner part of the rock shelter near the wall and were spatially adjacent between them. The other seven areas have a discrete distribution in the central and inner part of the site and only area M6 was located near the wall, laterally with respect to the main accumulations (Fig. 6). Each of these 'external areas' was characterised by variations in their extension and the intensity of the remains. The study of orientation patterns has highlighted a well-preserved archaeological context, essentially with no water flow disturbances within any areas. In several areas, NS and EW orientations prevailed on the others. Their opposite orientation suggests that we rule out taphonomic phenomena related to water disturbances. Their predominance could probably be explained by the fact that they are the easiest and most immediate orientation to be identified during excavation, including a case of slightly off-axis distribution. The low impact of taphonomic processes on lithic distribution was also shown by the predominant horizontal positioning of remains in each area. Areas with the highest value of vertical remains were M9 and M10. Here, vertical inclination was always under 16 % and well below horizontal remains. In these areas no evidence of important taphonomic processes has been highlighted on faunal assemblage with several anthropic cut-marks, fire alterations, and faunal refits associated with hearths (Fernández-Laso 2010: 542-570). Areas M11 and M8 were located outside from the drip line (Fig. 10). Despite their location in a part of the site where we expected an increased risk of disturbances, these two areas were well preserved, as attested not only by orientation and inclination patterns but also by the dimensions of remains preserved there (Fig. 9). This evidence was not underlined by taphonomic analysis of faunal assemblage. While low taphonomic modifications have been identified on bones surface, especially in relation to water disturbances, trampling, and carnivore activity (Fernández-Laso et al. 2011; Chacón et al. 2014), spatial distribution of macromammals remains showed the absence of clear accumulations outside the drip line where materials were more dispersed and probably more affected by

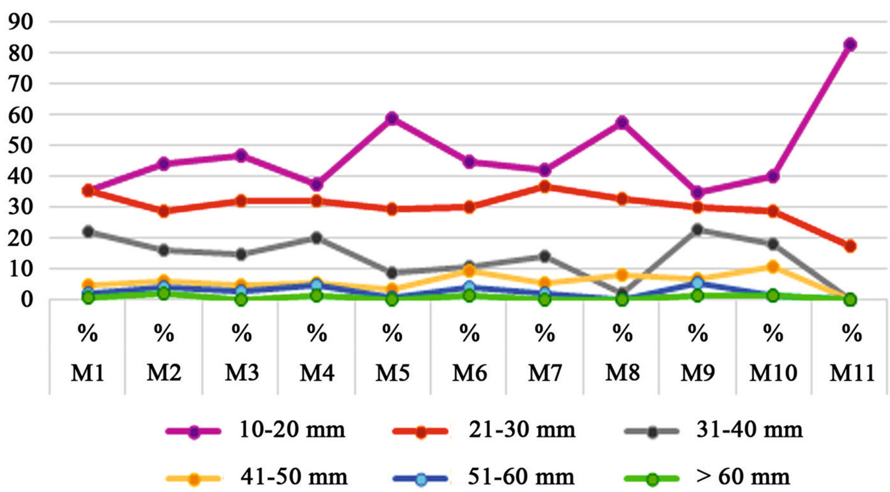


Fig. 9. Line charts representing proportion of artefact size classes in each accumulation.
Abb. 9. *Liniendiagramme, die den Anteil der Artefaktgrößenklassen in jeder Konzentration darstellen.*

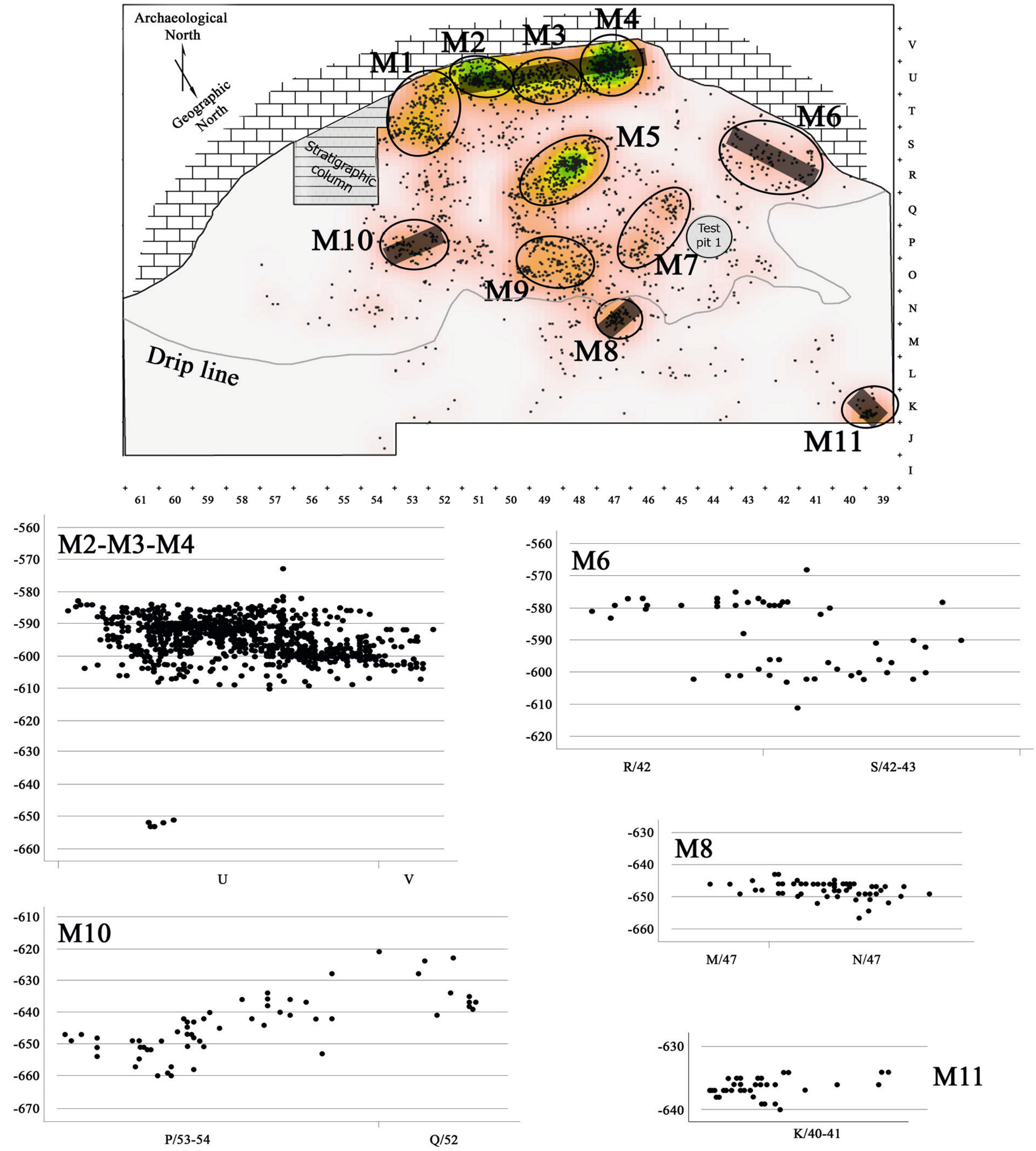


Fig. 10. Abric Romaní, layer M. Distribution map of high-resolution chert dataset and activity areas analysed in the paper. Drip line is drawn in grey. Vertical projections of accumulations M8, M9, M10, and M11. The exact positioning of projection on the map is shown by dark grey lines.

Abb. 10. *Abric Romaní, Schicht M. Verteilungsplan des hochauflösenden Chert-Datensatzes und Aktivitätsfelder, die in dem Papier analysiert wurden. Die Traufkante ist grau eingezeichnet. Vertikale Ansätze der Ansammlungen M8, M9, M10 und M11. Die genaue Positionierung der Projektion auf der Karte wird durch dunkelgraue Linien dargestellt.*

post-depositional processes related to the high exposure to climatic agents (Fernández-Laso 2010: 443). Therefore, taphonomic analysis of technology suggested that cluster distribution of lithic remains was due by anthropic activity and that spatial patterns were not related to external phenomena, including the extension of the rock shelter covering, but rather to social organisation and Neanderthal behaviour.

Variation in point density over space, that is, spatial dependence, could be related to variation in intensity of social phenomena. This variation could concern number of individuals and/or duration of activity. In the inner part of the site, the high density could be due to more numerous human groups, while in the other areas the groups carrying out technical activities could have been reduced in the number of individuals and/or in their composition (selection of age, gender, active individuals, etc.). It should be noted that the area close to the wall is the most protected and therefore a higher degree of reoccupation can be expected. Looking at the assemblage in this perspective, it is interesting to notice that micro-debris related to knapping activity were preserved in each accumulation suggesting that these areas were independent from one another, at least in relation to productive activities. However, connections between these clusters are attested by the mobility of lithic artefacts. Connection lines of stone tool refits showed several anthropic movements within the site attesting spatial internal fragmentation of knapping processes and of activities involving movements of tools and/or individuals (Vaquero et al. 2015). Fragmentation of processes is a phenomenon that involves both spatial and temporal discontinuity (Delagnes et al. 2006; Vaquero 2008; Turq et al. 2013; Romagnoli 2015; Romagnoli et al., 2016; Romagnoli et al. in press). What occurs when one introduces time as a variable?

According to point intensity, it is possible to organise activity areas in three categories: with (i) low intensity and medium extension, (ii) medium intensity and small extension, and (iii) high intensity. Accumulations M8 and M11, possessing the smallest extension (20'816.1 and 12'117.7 square units, respectively), correspond quite exclusively to a single event. In M8 were located almost exclusively elements of refitted RMU Sil017, and in M11 of refitted RMU Sil016. These were not the only examples of RMUs spatially located within a single activity area but were the unique cases where almost a complete single RMU constituted an activity area identified according to point intensity. Additionally, vertical dispersion of remains in these areas clearly showed technical events temporarily well delimited (Fig. 10). The short duration of these is coherent with the lack of combustion structure in area M11. It is possible to interpret these events as knapping episodes, as showed by the high percentage of micro-debris. Most likely these events were the last actions carried out at the site before the formation of the sterile travertine platform overlapping layer M. Otherwise time span, climatic agents, and human movements had produced a dispersion of remains on a biggest extension. M1, M6, M7, M9, and M10 showed a greater spatial extension associated with average intensity comprising between 0.003 and 0.005. In these areas were preserved tools related to several technical events, partially directly produced in situ and partially associated with intra-site mobility of technology, identified within each of these accumulations, and recycling behaviour, that have been identified in M6 and in the extended areas of M10 and M7 (Vaquero et al., 2015). The vertical distribution of materials within each of these areas usually showed a clear hiatus between two different series of events both characterised by reduced number of pieces (Fig. 10). The third group is composed of accumulations characterised by high density of rests, with average values comprising between 0.006 and 0.011 (M2, M3, M4, and M5). Here, were preserved many rich and different technical events with refit connection lines between the different clusters (Vaquero et al., 2015). The vertical projections showed an almost continuous vertical dispersion of remains, with no evident hiatus in different phases of occupation in these areas or a clear quantitative predominance of the upper one. In every areas technological behaviour is homogeneous and Neanderthal applied similar knapping methods exploiting similar resources. Some slight differences can be highlighted in the central areas where mostly of recycled toolkit is displaced and were raw material provisioning strategies also include the use of the inner part of the rock shelter as raw material catchment area (Vaquero et al., 2015). These data suggest that, beyond the complex temporal relations between activity areas, the humans that spent time at the site were sharing the same technological knowledge.

The presence in layer M of different occupation patterns related to variations in time span of events can be compared with variations in the degree of transformation of fuel in the same layer. According to Solé el al. (2013), the inner part of the site was characterised by a high degree of transformation and shortening of small wooden branches used as fuel, with a high density of charred wood and no evidence of wood remains. In the central part of the rock-shelter, moving towards the drip line, in association with charred wood, wood remains have been found spatially correlated with hearths and were characterised by homogeneous sizes. Finally, the outer part of the site was characterised by a lack of charred wood and a great variability in wood sizes. These data could be explained by a differential use of space but also by differences in the intensity of use of fire for specific time constraints. The exterior areas, where we have identified (i) lower and less standardised use of fuel and variations in the phase of hearth abandonment, (ii) recycling of lithic artefacts, and (iii) well-preserved isolated technical events, could be related to the shortest events and most likely to the last phases of occupation of the site. In contrast, in the inner part (i) the high transformation of fuel, (ii) lithic point patterns, and (iii) the rich archaeological assemblage could be related to a higher reoccupation most likely by small groups that settled in this area through a continuous succession of events, leading to the formation of a horizontal palimpsest. During this undefined spread of time these groups maintained similar behaviours in relations with technology, spatial patterns, and activity areas.

Conclusions

Taphonomy and spatial patterns exhibited differences in faunal and lithic remains, with lithic clustered and well-preserved by post-depositional displacements in the whole layer, including outside of the drip line. Social behaviour was the main cause for spatial patterns of stone tool remains, determining aggregation and segregation phenomena. Spatial patterns where not only related to variations in spatial intensity of phenomena but also to temporal discontinuity of events. It was possible to identify three main categories in spatial patterns: (1) inner activity areas characterised by high intensity (0.006 - 0.011), strong interconnections, numerically rich assemblages, and the continuous observance of homogeneous behaviour across time since the first entrance of Neanderthals in the site; (2) activity areas with medium extension and medium density (0.003 - 0.005) related to two series of several technical events each interrupted by a temporal hiatus and generally characterised by low concentration of materials. In these areas have been often identified recycling of stone blanks displaced by humans from the inner areas; and (3) two activity areas with low extension and medium density (0.002) related to a single technical event and located in the external part of the rock-shelter out from the drip line. They correspond to two ephemeral events that took place at the end of the occupation of the layer. The results showed that variability of social phenomena across time could affect archaeological setting, including in high-resolution contexts, and must be factored into behavioural analysis. This research showed that quantitative approach associated with previous empirical processing of data is a useful and effective method for approaching such temporal uncertainty in point patterns.

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