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Ground stone tools and spatial organization at the Mesolithic site of font del Ros (southeastern Pre-Pyrenees, Spain)

Xavier Roda Gilabert *, Jorge Martínez-Moreno, Rafael Mora Torcal

Centre d'Estudis del Patrimoni Arqueològic de la Prehistoria (CEPAP-UAB), Facultat de Lletres, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain

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ABSTRACT

Used cobbles (ground stone tools) help identify a range of tasks related to basic domestic activities associated with subsistence. Here, we combine techno-morphological analysis and the study of use-wear patterns with intra-site spatial analysis of tool distribution at the Font del Ros SG unit (southeastern Pre-Pyrenees, Spain). Successive occupations during the Boreal climatic phase characterize this site. We have identified areas that may correlate with specific activities that could represent internal diachronic events on surfaces with little vertical dispersion. In this approach, ground stone tools are key artifacts that define domestic activities usually considered as having little archeological visibility, and help identify activities undertaken across different parts of the site. Intra-site spatial patterns help us define the domestic aspect of Mesolithic hunter-gatherer lifestyle in the northeastern Iberian Peninsula.

1. Introduction

Ground stone tools form an assemblage of artifacts associated with activities of human groups in the past. Various techno-typological, experimental, and ethnographic studies (e.g. Leroi-Gourhan, 1971; Yellen, 1977; Chavaillon, 1979; Hayden, 1987; Adams, 1989; Wright, 1991; de Beaune, 1989) have highlighted their use in making and retouching lithics, as well as in pounding, grinding, and milling organic and inorganic materials. In recent years, studies of ground stone tools (also called percussion tools) have enabled us to define the functional nature of these tools that were essential to a hunter-gatherer lifestyle (de Beaune, 2000a, 2004; Procopiou and Treuil, 2002; Adams, 2002; Adams et al., 2009; Revedin et al., 2010; Cristiani et al., 2012; de la Torre et al., 2013; Dubreuil and Savage, 2014; Dubreuil et al., 2015).

Traces on these cobbles and fragments allow us to connect them with the type of percussion used and the materials worked, thus making them diagnostic elements in identifying subsistence tasks (Adams, 1988, 1989; de Beaune, 2002). Tools associated with percussion activities on hard materials are often mentioned in the literature (e.g., de Beaune, 1997; Goren-Inbar et al., 2002; Chavaillon and Piperno, 2004; Mora and de la Torre, 2005; Donnart et al., 2009; de la Torre et al., 2013; Harmand et al., 2015). There have been advances in the characterization of ground stone tools related to plant-processing and other abrasive activities (Hayden, 1987; Adams, 1988, 1989; Dubreuil, 2002, 2004; Hamon, 2003, 2008; Dubreuil and Nadel, 2015). Nonetheless, there remains a substantial lack of information about these artifacts for the Paleolithic and Mesolithic periods. Usually studies of ground stone tools have concentrated on description of their technical attributes. Although spatial analyses have increased in recent years (Wright, 2000; Hamon, 2004; Weiss et al., 2008; Cristiani et al., 2012; Nadel et al., 2012; Wright, 2014), those that also include statistical analyses are less common.

Discussion of living floors and palimpsests (e.g. Leroi-Gourhan and Brezillon, 1973; Bordes, 1975; Villa, 2004; Bailey, 2007; Malinsky-Buller et al., 2011) has hindered consideration of the technical and functional significance of ground stone tools in certain contexts. Such interpretative constraints focus on the difficulty of identifying occupational time spans and defining activity areas. We argue that spatial associations provide information about activity areas and functional differences (Binford, 1978), and the social organization of activities (Leroi-Gourhan and Brezillon, 1973; Yellen, 1977).

Our aim here is to present the results of a multidisciplinary study that combines techno-morphological analysis and use-wear patterns with intra-site spatial analysis of tool distribution at the site of Font del Ros (Berga, Spain). In sector SG, 43 ground stone tools have wear traces that suggest different activities; we believe that these artifacts indicate spatial patterning of activities performed at the

* Corresponding author.
E-mail address: javier.roda@uab.cat (X. Roda Gilabert).

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site (de Beaune, 2000a, 2000b). Our study has enabled us to reconstruct Holocene hunter-gatherer subsistence activities and, in addition, to determine general trends in spatial organization during the Mesolithic.

2. Archeological context

Font del Ros is located on a shelf of Quaternary colluvial deposits in the contact zone between the Catalan Central Depression and the lower foothills of the Pre-Pyrenees of Barcelona (Serra de Queralt). The Llobregat River facilitates communication between the Catalan Central Depression and the interior of the Pyrenees (Fig. 1a, b). Construction work in the municipality of Berga (Barcelona, Spain) exposed materials in stratigraphic position. Excavation revealed two Mesolithic levels (SGA and SG) and more recent occupation attributed to the early Neolithic (N) (Pallarés et al., 1997; Pallarés, 1999; Pallarés and Mora, 1999; Martínez-Moreno and Mora, 2011).

The Mesolithic unit SG (Fig. 1c) covered an area of approximately 1200 m^2 from which 27,800 lithics, bones, and burned plant remains (charcoal and seeds) were recovered (Pallarés, 1999; Martínez-Moreno and Mora, 2011). In this paper, we concentrate on the central zone that extends over an area of approximately 510^2 m in which the discrete distribution of the low density of materials aids in determining patterns of spatial organization. The more than 3200 coordinated pieces taken from the area included bones, plants and lithic tools. Among the lithic artifacts were chipped stones indicating use of both freehand and bipolar knapping (Roda Gilabert et al., 2015), and ground stone tools (43) with use-wear traces related to function (Fig. 2). A single feature has been identified in this area, a flat hearth (hearth VIII) with a significant accumulation of charcoal, burned bones, and thermo-altered fragments of sedimentary rocks (Pallarés, 1999).

Currently, there are 10 radiocarbon dates (calibrated at 2σ) based on the IntCal09 model (Reimer et al., 2009). Although some dates are very imprecise (Table 1), the series places the settlement in the Boreal chrono-climatic phase of the Early Holocene (Martínez-Moreno and Mora, 2011) and indicates an indeterminate number of occupation phases between 10,250 and 8450 cal BP (Fig. 3).

There are three direct AMS dates for this area: one on charcoal, two on burned hazelnut shells, one of which has recovered directly from hearth VIII. The dates seem to represent the first phases of settlement and could correspond to a single occupation event between 10,150 and 9925 cal BP (Fig. 2). However, we suspect that at least two different occupational phases cannot be discounted; one is suggested by radiocarbon sample #1 (Beta 231,728), and a second by samples #2 (Beta 231,727) and #3 (Beta 231,720) which are practically identical (Fig. 3, Table 1). New radiometric dating should help determine whether or not the area was formed by different overlapping occupations separated by a limited time span.

Level SG is embedded in a soil formed of silt and sand and showing features indicating bioturbation. Occupation occurred at the time of soil formation following a period of low energy deposition. The relative abundance of organic matter is a result of the juxtaposition of edaphic and anthropogenic processes (Jordá et al., 1992).

Sedimentary conditions have affected the faunal material; bones are poorly preserved and almost all the assemblage consists of fragments of <2 cm, which are difficult to identify. Nevertheless, *Cervus elaphus*, *Capra pyrenaica*, *Sus scrofa*, *Bos* sp., and *Oryctolagus cuniculus* have been determined, which may correspond to a mosaic landscape in the immediate vicinity of the site (Martínez-Moreno and Mora, 2011) (Fig. 1a), as indicated by macrovegetal proxis.

Charcoal analysis provides evidence of temperate taxa, such as *Quercus* sp., *Buxus sempervirens*, *Corylus avellana*, *Ulmus* sp., *Salix* sp., and *Sambucus* sp., associated with wet conditions suggest dense, deciduous woodland (Jordá et al., 1992). Such plant associations are characteristic of forest expansion and concur with the radiocarbon dates for the site. A similar ecological pattern, present during the Boreal climatic phase, has been detected in other archeological sites in northeastern Iberia (Allué et al., 2012).

The Font del Ros SG unit revealed horizontal and vertical accumulations of lithic, bone and plant remains with distinct spatial boundaries. Transversal (E–W) and longitudinal (N–S) sections show a very limited vertical dispersion of coordinates, forming a layer 5 cm thick followed by a sterile layer (Fig. 2). The vertical dispersion

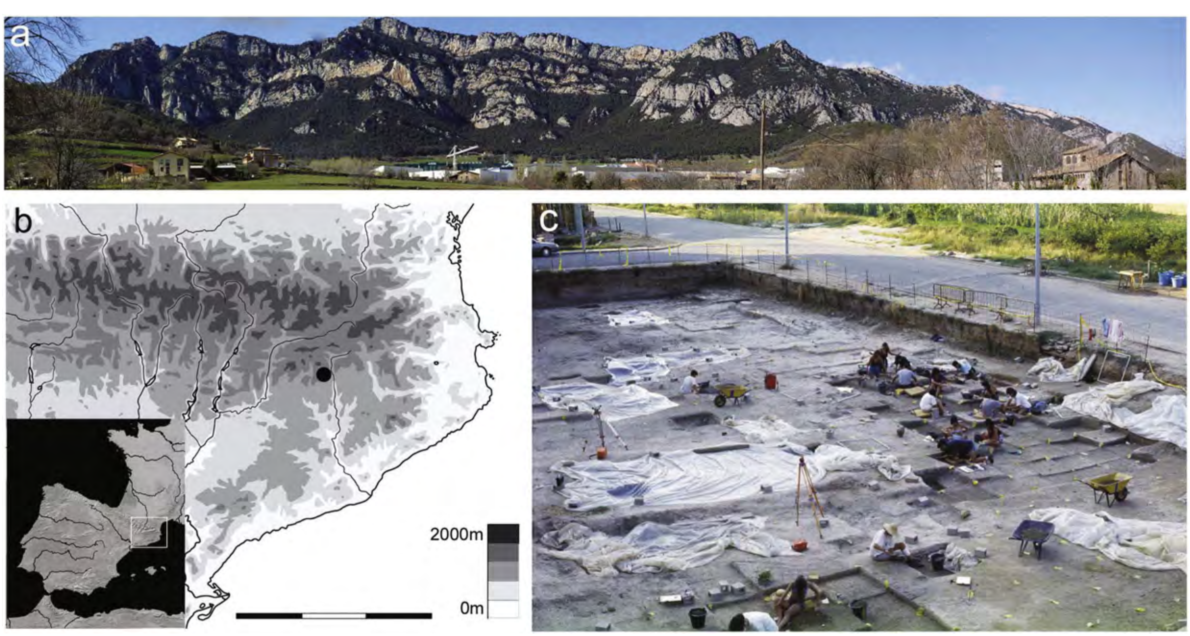

Fig. 1. Location of Font del Ros site. a) General view of the contact zone between the Catalan Central Depression and the western Pre-Pyrenees of Barcelona; b) Geographical location of the site; c) Level SG during excavation.

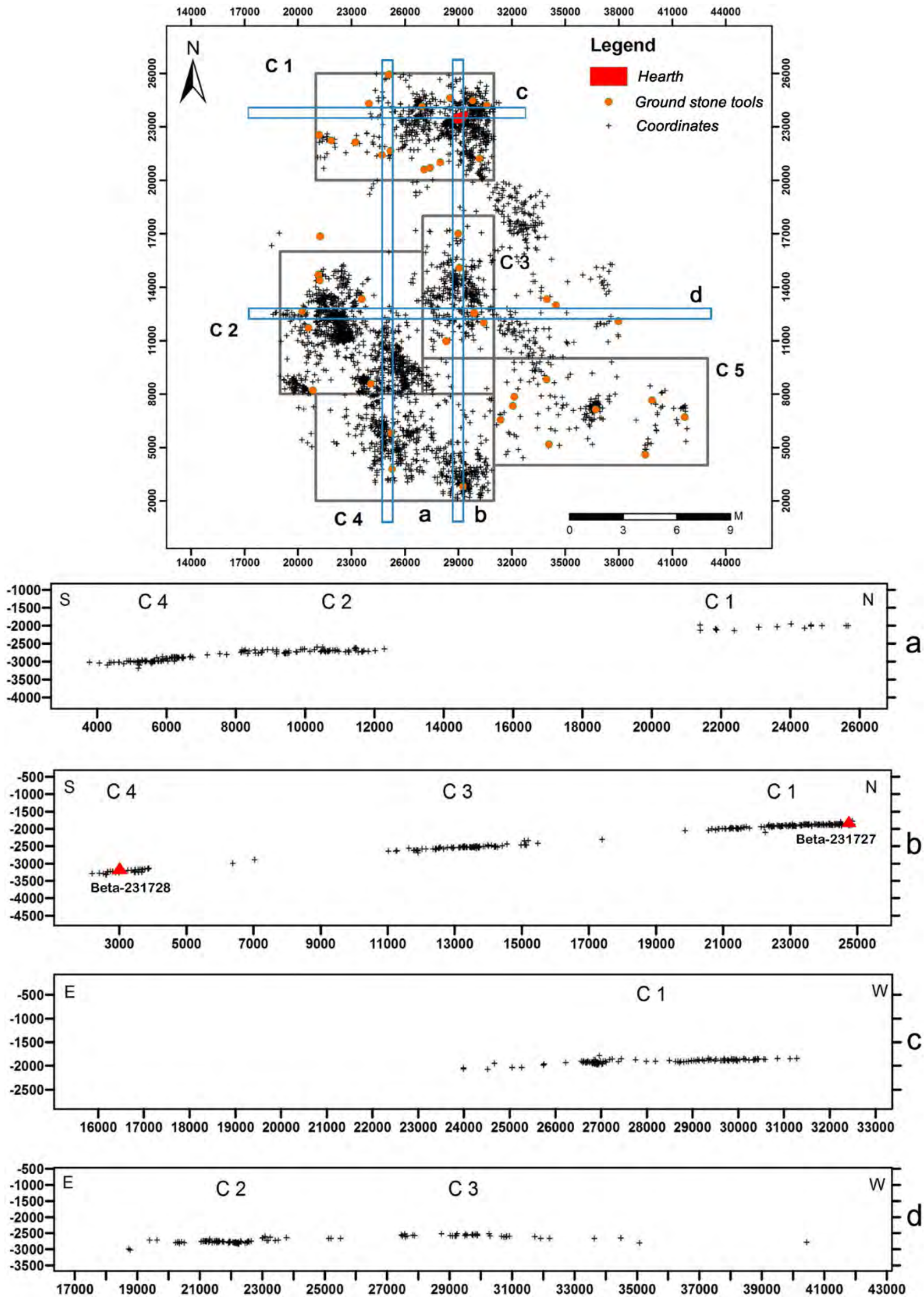

Fig. 2. Plan view of part of the Font del Ros site showing C1–C5 clusters (top). Circles indicate the ground stone tools analyzed in this study. Below, four sections (a, b, c, d) show the vertical dispersion of materials in clusters. The vertical plan b indicates the spatial location of the ^{14}C dates from C4 (Beta-231,728) and Hearth VIII on C1 (Beta-231,727).

of associated materials could correspond to a single event which, on an analytical level, allows us to consider them as living floors (sensu Villa, 2004; Malinsky-Buller et al., 2011). Nevertheless, we support the hypothesis that these coordinates may represent more than one event, which would correspond with the radiometric dates obtained for this sector (Fig. 3), as well as with the spatial separation of different clusters considered in the study (Fig. 2), that will be defined in the following section.

Table 1
Radiocarbon dates from Font del Ros. Shaded areas correspond to samples from the study area. Two sigma calibrations follow the IntCal09 model (Reimer et al., 2009).

#	context	# laboratory	Sample	method	BP	δ	^{13}C‰	Cal BP p (95%)
1	charred charcoal	Beta-231728	Charcoal	AMS	9000	50	-23,3	10246-9925
2	Hearth VIII	Beta-231727	*Corylus* shell	AMS	8820	50	-23,2	10156-9687
3	charred charcoal	Beta-231720	*Corylus* shell	AMS	8810	50	-22,2	10155-9671
4	charred charcoal	UBAR 345	Charcoal	CON	8800	360	-26,3	11068-9012
5	Hearth VII	Beta-210732	*Corylus*	AMS	8690	60	-24,2	9888-9539
6	charred charcoal	UBAR-397	Charcoal	CON	8400	180	-26,2	9906-8808
8	Hearth IX	UBAR-329	Charcoal	CON	8270	200	-23,4	9626-8633
7	Hearth V	UBAR-165	Charcoal	CON	8150	590	-	10707-7582
6	Hearth IV	UBAR-185	Charcoal	CON	8050	150	-	9402-8559
10	Hearth IV	Beta-210733	*Corylus* shell	AMS	7800	50	-24,6	8717-8434

3. Materials and methods

3.1. Intra-site spatial analysis

Due to the volume of remains, it was difficult to interpret the spatial distribution of materials and place them on thematic maps. An alternative way to determine spatial patterns and artifact associations was to apply geo-statistical and non-parametric statistical tests (d'Andrea et al., 2002; Alperson-Afil et al., 2009).

Five clusters (C1 to C5) or discrete artifact concentrations, separated by areas with few coordinated items, were identified (Fig. 2; Supplementary Information 1). The sedimentary context and materials recovered from unit SG do not appear to have been greatly affected by syn/post-depositional processes (Jordá et al., 1992). Similarly, a general reorganization of artifacts disturbed by depositional agents can be rejected according to the results of previous spatial analysis (Pallarés, 1999). Consequently, we assume that because of their weight, ground stone tools probably remained in primary position within the clusters. Differences in elevation seen in sections are due to surface topography within this large area of more than 1200 m^2.

There are striking differences in the composition of the archeological accumulations (Table 2). Given the incidence of taphonomic and anthropogenic processes, the causes of such differences are not obvious. Poor bone preservation, or the fact that different activities do not necessarily leave similar patterns in the archeological record, are factors that hinder characterization of clusters, creating a "fuzzy" image of tasks conducted in the settlement.

Analysis of the distribution of specific classes of material was undertaken using scatter plots and kernel density maps (Alperson-Afil et al., 2009; Supplementary Information 1, 2). In addition, inferential statistics were used to determine statistical significant differences in the composition of lithics and other archeological materials (bone, plant remains, and minerals). Once the different artifact categories in each of the defined clusters had been counted, we applied chi-squared (χ^2) and Lien non-parametric tests that can detect statistically significant differences in assemblage composition. The Lien test is a derivation of χ^2 that assesses category weight and on a statistical level provides more information in contingency tables (Laplace, 1980; Volle, 1981; Simek and Leslie, 1983; Supplementary Information 1). Significant statistical differences serve to test hypotheses about the function and activities of clusters.

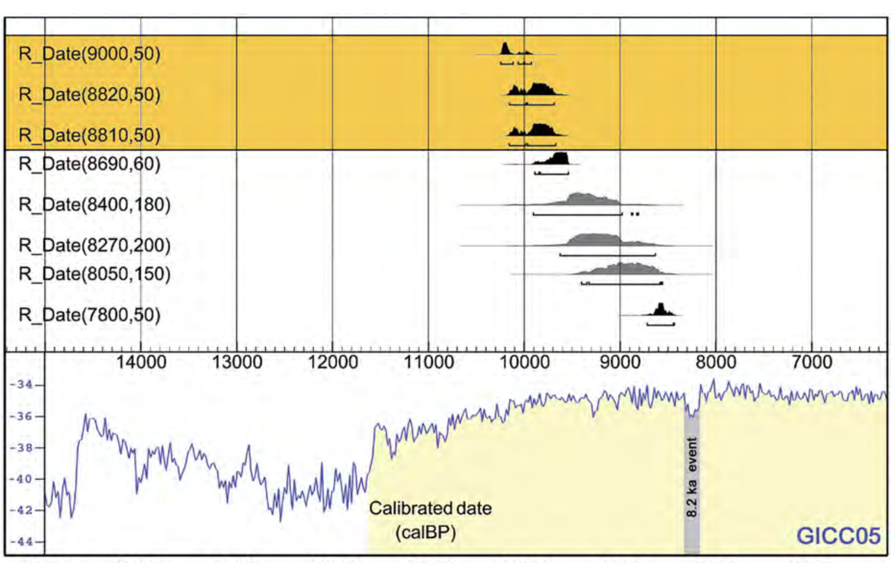

Fig. 3. Probability distributions of modeled radiocarbon dates from Font del Ros SG Unit. Shaded areas correspond to samples from the study area. Results have been processed and graphically expressed by Oxcal v4.17 (Bronk Ramsey, 2009). Dates with $\sigma > 200$ years have been excluded because of their poor temporal resolution.

Table 2
Artifact categories recovered from defined clusters.

	Ground stone tools	Flakes	Retouched pieces	Cores	Fragments	Chunks	Unused cobbles	Microdebitage	Bones	Mineral/pigments	Molluscs	Seeds	Σ
C 1	15 (1.97)	30 (3.98)	17 (2.23)	12 (1.57)	126 (16.54)	73 (9.58)	9 (1.18)	250 (32.81)	225 (29.53)	4 (0.52)	0 (0)	1 (0.13)	762 (25.18)
C 2	7 (0.57)	37 (3.01)	21 (1.71)	8 (0.65)	166 (13.51)	172 (13.20)	12 (0.98)	645 (52.48)	154 (12.53)	3 (0.24)	4 (0.33)	0 (0)	1229 (40.61)
C 3	5 (1.54)	24 (7.41)	9 (2.78)	3 (0.93)	74 (22.84)	48 (14.81)	6 (1.85)	136 (41.98)	14 (4.32)	4 (1.23)	1 (0.31)	0 (0)	324 (10.71)
C 4	3 (0.53)	30 (5.31)	11 (1.95)	6 (1.06)	101 (17.88)	100 (17.70)	4 (0.71)	244 (43.19)	39 (6.90)	10 (1.77)	0 (0)	17 (3.01)	565 (18.67)
C 5	9 (6.16)	6 (4.11)	4 (2.74)	1 (0.68)	24 (16.44)	24 (16.44)	8 (5.48)	58 (39.73)	5 (3.42)	2 (1.37)	0 (0)	5 (3.42)	146 (4.82)
Σ	39 (1.29)	127 (4.20)	62 (2.05)	30 (0.99)	491 (16.23)	417 (13.78)	39 (1.29)	1333 (44.05)	437 (14.44)	23 (0.76)	5 (0.17)	23 (0.76)	3026 (100)

Patterns detected (Table 3) allowed us to establish inferential hypotheses between qualitative information on ground stone and data derived from geo-statistical tests.

From an analytical perspective, these accumulations may be considered as events generated from unrelated temporal occupations despite the spatial proximity of their components. Alternatively, the abundance of activities or spatial isolation of some tasks can help clarify whether they form an interdependent network of activities at a structured campsite where different, but concurrent, domestic activities took place.

3.2. General analysis of ground stone tools

The development of wear on ground stone tools results from damage produced by the interaction of surfaces (Shizhu and Ping, 2012). The precise determination of use-wear relies on changes in texture or grain arrangement (fabric) of the mineralogical composition of the cobbles (Adams et al., 2009; Dubreuil et al., 2015). It is also important to consider tool kinematics in order to identify the active zones of the tool. In this sense we discuss “thrusting percussion” and “resting percussion” (*percussion lancée* and *percussion posée* respectively, sensu Leroi-Gourhan, 1971; de Beaune, 2000a, 2004) or simply “percussion” and “abrasion” (Stroulia, 2010). A stereoscopic microscope (Olympus SZ-11) was used to study use-wear traces identifiable on cobble surfaces (10×–80× magnifications), following protocols described in other studies (Adams, 1989; Dubreuil, 2002, 2004; Hamon, 2003, 2008; Adams, 2002; Adams et al., 2009; Dubreuil and Savage, 2014; Dubreuil et al., 2015).

Table 3
Relational hypotheses extracted from nonparametric tests.

		Proposed functional hypotheses arising from statistical tests
Cluster 1	χ^2	• Significant presence of bones • Significant differences in the layout of ground stone tools
	Lien	• Most important cluster on a statistical level • A priori, a range of activities are combined in this cluster • Overrepresentation of faunal remains in this area
Cluster 2	χ^2	• Significant presence of microdebitage: possibly a knapping area • A very heterogeneous zone
	Lien	• Important representation of knapping waste
Cluster 3	χ^2	• Significant difference in the presence of ground stone tools
	Lien	• Limited presence of bone remains • Important occurrence of knapping products • Significant presence of iron oxides
Cluster 4	χ^2	• Significant presence of plant macro-remains • Important presence of iron oxides
	Lien	• High representation of plant macro-remains • Limited presence of bone remains
Cluster 5	χ^2	• Significant presence of unused cobles and ground stone tools • Low informative weight of cores and retouched tools • Important presence of plant macro-remains
	Lien	• Elevated weight of information inside ground stone tools category • Prominent informative weight of plant macro-remains

Cobbles associated with thrusting percussion activities have battering traces on their surfaces; use-wear recorded on the active surfaces depends on the properties of the raw materials used. These tools are associated with knapping, bone-breaking, and the processing of hard materials, and function either as hammerstones or anvils (Dubreuil et al., 2015 and references therein). Low-power microscopic analysis of use-wear traces helps detect the pounding and pulverizing of cobble grains. Compression generated by impact produces alterations such as cracks, pits, splinters and a frosted appearance (Adams, 1989, 2002; Adams et al., 2009). Equally, bone-breaking causes scars with crushed ridges; such cobbles are known as pounding or *concassage* hammerstones (de Beaune, 1993a, 2000a), or hammerstones with fracture angles (Mora and de la Torre, 2005).

Cobbles associated with resting percussion are identified by abrasive wear traces that regularize the blank topography (sensu Adams, 2002). Linear traces, leveling and rounding of grain edges, and development of a glossy sheen (polish) are the main features related to this type of wear (Adams et al., 2009). Various experimental studies link these traces with hide-working, plant-processing activities, and the crushing and grinding of ochre (Adams, 1988, 1989, 1999; Dubreuil, 2002, 2004; Rodríguez Ramos, 2005; Hamon, 2003, 2008; Dubreuil and Grosman, 2009; Dubreuil and Savage, 2014; Dubreuil et al., 2015).

Previous experiments (Roda Gilabert et al., 2012) have enabled us to characterize use-wear traces on pitted stones and activities linked to this tool-type. Pit formation seems to be clearly associated with bipolar knapping or other bipolar pounding on hard materials. While hazelnut cracking presents problems when defining diagnostic attributes, pit formation linked to hazelnut cracking can be rejected. The pounding and grinding of hazelnuts can be associated with the appearance of flat and convex facets, a glossy sheen, and linear traces (see below). It should be noted that features identified on archeological pitted stones show a certain degree of variability that may relate to the multifunctional nature of these tools.

4. Ground stone tools and activities

4.1. Morphometric features

Forty-three ground stone tools were identified from the selected area: 13 complete cobbles and 30 fragments. The assemblage is dominated by limestone (33%, 14 pieces), quartzite (23%, 10 pieces), and sandstone (14%, 6 pieces); other raw materials such as granite (3), gneiss (2), ignimbrite (2) and andesite (1) are present in very small percentages. Quartz (3) and flint (chert) (2), used to produce blanks and retouched pieces, were occasionally used as ground stone tools. All the rocks are from local sources, coming from the terraces of the Llobregat River located about 10 km away from the site and from other nearby outcrops. The percentages of materials exploited at the site correspond with the composition of rocks at the source areas, suggesting little selection of materials (Terradas, 1995; Pallarés and Mora, 1999).

Cobbles are oval and semicircular in cross section with average dimensions of 75 mm in length, 55 mm in width and 37 mm in thickness, with a mean weight of around 400 g. (Fig. 4). They are generally convex (70%) and have wide, flat, active use surfaces (97%). Such characteristics imply a selection of cobbles that facilitated handling for various activities. The high percentage of broken cobbles (70%) does not match studies of the natural fracture of riverbed cobbles which is generally very low (Fallet, 1982). When added to the lack of taphonomic alteration observed in the lithic raw material, this fact indicates that breaks were made by humans. Indeed, angled side fractures, which are very common on percussion tools, are one attribute that could be connected with thrusting percussion (de Beaune, 1997, see below). Cobbles show use on several surfaces, and a third of the stones in the assemblage have use-wear traces over most of their surfaces. Such indicators imply the repeated use of cobbles.

Inferential and descriptive statistics show that ground stone tools form 29% of the total weight of all lithic materials, thus demonstrating their importance in the assemblage (Supplementary Information 3). The Lien test indicates that, although numerically few, cobbles are important in defining activities at the site (Supplementary Information 4). The morphometric characteristics and use-wear traces allow us to infer a group of identifiable tasks for ground stone tools. Confirmation is based on the results of our own experimental program (Roda Gilabert et al., 2012) and patterns established in other studies, summarized in Table 4. The association between different raw materials and activities identified on ground stone tools can be seen in Table 5.

4.2. Ground stone tools associated with thrusting percussion

Thirty-two of the 43 cobbles are associated with thrusting activities on stone (Table 5). Use-wear traces on their surfaces link this set to free-hand and bipolar stone knapping activities and the processing of bones. These cobbles are hammerstones that show impact fractures and modifications in areas of convexity (de Beaune, 2002; Mora and de la Torre, 2005; de la Torre et al., 2013; Dubreuil et al., 2015) (Fig. 5). Seven of the remaining cobbles are anvil fragments (Table 5).

Two ground stone tools have flake removals and step scars around their perimeters. We believe that this pattern of damage could have resulted from pounding to break bones. Marks observed on active dihedral angles are similar to those described on tools suggested as having been used to process animal carcasses (Thiébaut et al., 2010; Casanova et al., 2014). Such tools can be placed in the category of *concassage* hammerstones (de Beaune, 1993a, 2000a; Mora and de la Torre, 2005; Daulny and Dachary, 2009) (Table 4) (Fig. 6a).

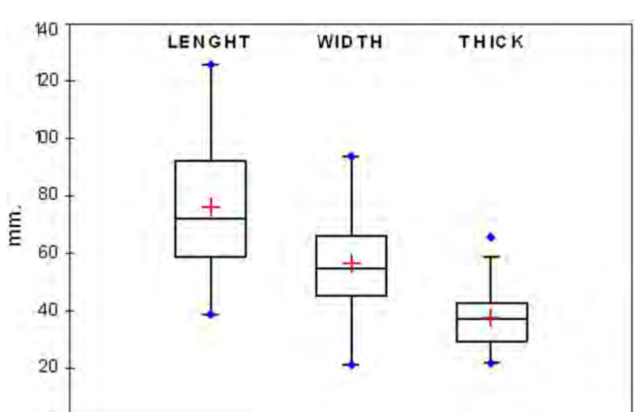

Fig. 4. Box plots of length, width and thickness of the ground stone assemblage.

Anvil fragments are mainly broken limestone blocks (Fig. 6b, c) (Table 5). The plasticity of limestone absorbs shock and prevents early breakage. Surface traces indicate that they may have been used to break bones – an activity associated with forceful percussion and identified by marks on the flat surface of the tool and on the perimeter (Alimen, 1963; Moura and Prous, 1989; Mora and de la Torre, 2005; de la Torre et al., 2013; Goren-Inbar et al., 2015). These fragments are from much larger, elongated, thick cobbles used as anvils (Fig. 6b). Several attempts were made to refit fragments but without success. It is possible that when they were no longer useful for their primary purposes, these fragments were transported to other places or used in other activities. The differences between hammerstones and anvils are subtle, and they may have been used interchangeably (Donnart et al., 2009).

Finally, use-wear depressions in the centre of six cobbles are characteristic of *pierres à cupules* or pitted stones (e.g. Chavaillon, 1979; de Beaune, 1989, 1993a, 2000a), and may be associated with bipolar battering (Le Brun-Ricalens, 1989; Jones, 1994; Donnart et al., 2009; Roda Gilabert et al., 2012) (Figs. 7, 8) (Table 5). Bipolar knapping has been identified on fragments and chunks, indicating that they are by-products of thrusting percussion. Furthermore, the assemblage includes scaled pieces in flint and quartz showing significant morphological variation, suggesting complex patterns of use. Together, these attributes highlight bipolar knapping as an important method of lithic reduction in the Pyrenean Mesolithic (Martínez-Moreno et al., 2006a; Roda Gilabert et al., 2015).

4.3. Ground stone tools associated with resting percussion activities

Ten cobbles have use-wear traces associated with resting percussion activities. All cobbles with traces of grinding also had marks characteristic of thrusting percussion, implying that they may have been used for several activities or were used at different stages of a task requiring a combination of different types of percussion. These artifacts are related to tasks such as mineral processing, hide-working, and the pounding of plant materials.

In addition to ochre fragments recovered during excavation, some complete and broken cobbles bearing mineral residues were found. Three pieces have use-wear traces and residues suggestive of the grinding and crushing of minerals (Dubreuil, 2002, 2004) (Table 5).

Three quartzite pieces show active working areas and polish with attributes suggesting hide-working (Adams, 1988; Dubreuil, 2002, 2004; Hamon, 2008; Dubreuil and Grosman, 2009) (Table 5). Of these, two flat quartzite cobbles are morphologically similar to ground stone tools on which hide-working has been identified (Roux, 1985; González Urquijo and Ibáñez, 2002) (Fig. 7c).

Four ground stone cobbles have convex facets on their flat surfaces and lateral edges that could be associated with pounding and grinding plants (Table 5). Such scars indicate a type of repeated resting percussion that produces polish on surfaces. Leveling of grains and parallel striations have been identified together with reflective sheen on these cobbles (see Roda Gilabert et al., 2013). Given that hazelnut (*Corylus avellana*) shells and seeds have been recovered from the level, we suggest that the traces on these cobbles may be related to nut-processing (Dubreuil, 2002, 2004; Rodríguez Ramos, 2005; Roda Gilabert et al., 2012, 2013) (Figs. 7b, 8).

It has been documented ethnographically that cobbles with centralized pitting are intentionally shaped to facilitate activities such as the opening of fleshy fruits (de Beaune, 2000a). One gneiss cobble has a regular surface with clearly defined pits similar to those experimentally produced by pecking (de Beaune, 1993b; see Roda Gilabert et al., 2012).

The identification of organic and inorganic residues is a further indicator of function. Some cobbles preserve oxide residues on their surfaces that can be observed with the naked eye (Fig. 7a). In addition, a preliminary study of several ground stone tools identified starch from edible plants and bone collagen residues, linking these cobbles with plant-processing and bone-breaking tasks (Pallarés, 1999).

Table 4
Functional assumptions of percussion tools.

Functional assumptions	Type of Percussion	Features	Use-wear traces	Main tribological mechanism
Hammerstones	Direct thrusting percussion on hard materials	Impact fractures, removals and modifications of convex areas, concentrated pitting derived from compression stress (Adams, 2002; de Beaune, 2002; Mora and de la Torre, 2005)	Fractures, cracks, pits, frosted appearance (Adams, 2002; de la Torre et al., 2013; Dubreuil et al., 2015)	Fatigue wear
Anvil/Anvil fragments	Indirect thrusting percussion on medium/hard materials	Battered edges, impact fractures in the contact between horizontal and transversal planes, plunging scars (Alimen, 1963; Moura and Prous, 1989; Mora and de la Torre, 2005; de la Torre et al., 2013; Goren-Inbar et al., 2015)	Cracks, pits, linear traces, frosted appearance (Moura and Prous, 1989; Adams, 2002; Donnart et al., 2009; de la Torre et al., 2013)	Fatigue wear, abrasive wear
Concassage cobble	Direct/Indirect thrusting percussion on medium/hard materials	Battering in active cortical/non cortical orthogonal planes, irregular edges with step and convex angles of detachment (de Beaune, 1993a, de Beaune, 2000a; Mora and de la Torre, 2005; de la Torre et al., 2013)	Fractures, frosted appearance, cracks, chipping of the ridges (Thiébaut et al., 2010; Casanova et al., 2014)	Fatigue wear
Bipolar knapping	Indirect thrusting percussion on hard materials	Developed pits with irregular section, step and impact fractures, breaking and crushing of grains (Donnart et al., 2009; de la Peña, 2011; Roda Gilabert et al., 2012)	Frosted appearance, crushing of grains, cracks, pits, fractures (Roda Gilabert et al., 2012)	Fatigue wear
Mineral pounding/grinding	Indirect thrusting percussion and resting percussion	Isolated impact fractures, surface regularization, visible, colored strias (Dubreuil, 2002, 2004; Hamon, 2008; Dubreuil and Savage, 2014; Dubreuil et al., 2015)	Grain extraction, striations, leveling, crushing of grains (Dubreuil, 2002, 2004; Hamon, 2008; Dubreuil and Savage, 2014)	Abrasive and fatigue wear
Plant pounding/grinding	Indirect thrusting percussion and resting percussion	Development of flat and convex facets, polish areas (Adams, 1989, 2002; Dubreuil, 2002; Hamon, 2008; Rodríguez Ramos, 2005; Roda Gilabert et al., 2012; Dubreuil and Savage, 2014; Dubreuil et al., 2015)	Highly reflective gloss, leveling, edge rounding, colored striations, (Adams, 1988; Dubreuil, 2002, 2004; Hamon, 2008; Dubreuil and Savage, 2014; Dubreuil et al., 2015)	Abrasive and fatigue wear, tribochemical wear
Hide-working	Resting percussion with possible intermediate elements	Development of convex facets, lustrous sheen, striations linked to addition of intermediate elements (Adams, 2002; Dubreuil, 2002; González Urquijo and Ibáñez, 2002; Hamon, 2008; Dubreuil and Savage, 2014; Dubreuil et al., 2015)	Leveling, dark reflective sheen, grain rounding, linear traces (Adams, 1988, 1989, 2002; Dubreuil, 2002, 2004; Hamon, 2008; Dubreuil and Grosman, 2009)	Adhesive and tribological wear, abrasive wear

4.4. Multipurpose nature of the assemblage

Cobbles are embedded in different parts of a knapping *chaine opératoire*, functioning as hammerstones, as cores for the production of blanks, and finally reused or recycled as ground stone tools. It is not unusual to see several active zones on a cobble and use-wear traces indicating prolonged reuse for the same task (Figs. 7b, 8). Of particular interest are traces that suggest different types of percussion on the same artifact, indicating a combination of different tasks (Fig. 8) (de Beaune, 1994). This mix of use-wear traces indicates the multipurpose nature of these tools (Martínez-Moreno et al., 2006a; Roda Gilabert et al., 2013).

5. From ground stone tools to identification of activity areas

The combination of functional inferences with the spatial position of ground stone tools can aid identification of patterns in the arrangement of the activities undertaken (de Beaune, 2000a, 2000b). Such inferences may confirm the spatial-functional pattern of the site (Pallarés, 1999; Martínez-Moreno and Mora, 2011).

We use the number of activities recorded as units of analysis. This differs from a count of cobbles as cobbles may be used for more than one activity (Fig. 9). Comparison of qualitative observations on cobbles along with hypotheses resulting from statistical tests allows us to establish functional inferences for the different clusters identified.

5.1. Stone knapping: a ubiquitous activity

The spatial distribution of ground stone tools identified as hammerstones which have traces associated with stone knapping, suggests that this activity was undertaken in all clusters – an observation that concurs with the abundance of microdebitage in all areas (Pallarés, 1999; Supplementary Information 2, 3). Microdebitage is not randomly distributed on the surface, and at least seven patches can be detected by geo-statistical analyses (Fig. 10). At the same time, there are numerous chunks and broken flakes associated with hammerstones in some patches; such a combination can be observed in clusters C1, C2, and C3. In C5, a concentration of microdebitage (debris) centered on a hammerstone was detected (Fig. 10). Spatial distributions suggest widespread knapping over the entire surface, but segregated in specific spots. Moreover, in some cases, we cannot ignore areas where lithic refuse from knapping activities was discarded.

Pitted cobbles associated with knapping by-products (broken flakes and chunks) support our interpretation of knapping activities (Roda

Table 5
Distribution of ground stone tools according to raw material and assumed functions.

	Andesite	Sandstone	Limestone	Quartzite	Quartz	Gneiss	Granite	Ignimbrite	Flint	Σ
Hammerstones	1	6	9	8	3	2	1	2		32
Anvil		5					2			7
Concassage coble			1	1						2
Bipolar Knapping			3	2		1				6
Mineral pounding/grinding			1	1				1		3
Plant pounding/grinding			1	2		1				4
Hide working				3						3
Indeterminate			5	2					1	8
Σ	1	11	20	19	3	4	3	3	1	65

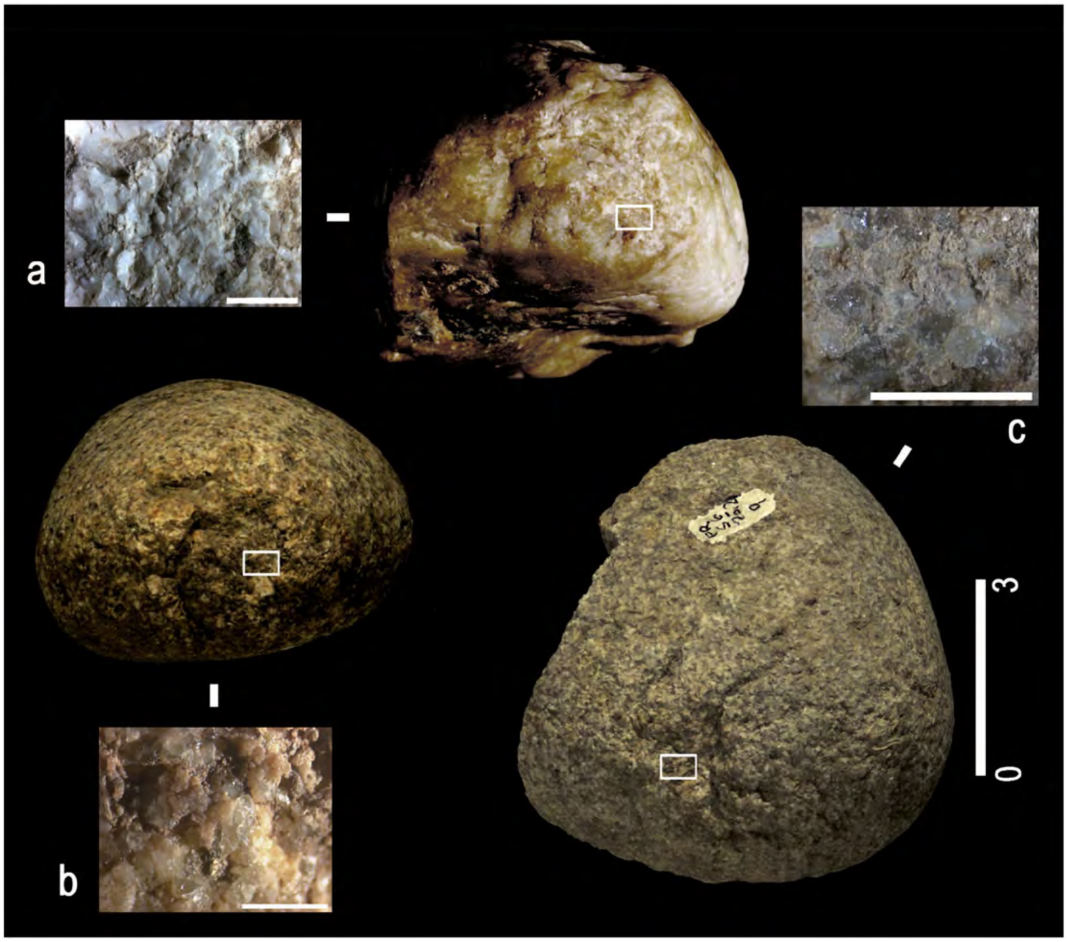

Fig. 5. Hammerstones. Areas of use were identified by impact cracks, micro-removals, and the crushing of grains. a) Quartz cobble fragment (49 × 48 × 37 mm) (graphic scale detail: 5 mm); b) Granite cobble (60 × 50 × 31 mm) (graphic scale detail: 2 mm); c) Granite cobble fragment (66 × 50 × 43 mm) (graphic scale detail: 3 mm).

Gilabert et al., 2012). Further support for bipolar knapping is found in C2 and C3, where hammerstones with punctiform traces (from thrusting percussion) and a blank with several pits were recovered. Additionally, scaled pieces and four cobbles bearing traces associated with bipolar knapping were found in C1.

Such associations emphasize the need for focused studies on the morpho-typological variability of scaled pieces (pieces esquillées). Results obtained in the Font del Ros SG unit indicate that scaled pieces should be considered exhausted bipolar cores and highlight the importance of this tool type in understanding bipolar knapping (Roda Gilabert et al., 2015).

5.2. Clusters and the identification of spatially segregated activities

Analysis of the five accumulations has allowed us to identify spatial distribution patterns that correspond with segregated activities in space, providing information about domestic activities during occupation of the site.

5.2.1. Cluster 1: a multipurpose domestic area

In C1, all activities suggested by ground stone tools indicate that they took place around hearth VIII (Fig. 2). Near this feature, we found three anvils and nine cobbles with scars associated with freehand knapping, and four cobbles used in bipolar knapping. Despite the general poor preservation of bones on the surface of the site, there were abundant small bone chips (mostly burned) around the hearth, suggesting activities associated with animal processing/consumption (Supplementary Information 3). In addition, two *concassage* hammerstones (sensu de Beaune, 1993a) were identified in the area. Given the importance of faunal remains in this cluster, these tools could be associated with bone-breaking and possibly with meat-pounding, the latter activity generating a pattern of modification with translucent gloss and striations recorded on one limestone cobble (Dubreuil, 2002, 2004). Although few plant remains were recorded, two cobbles with polished facets related to plant-processing were identified (Fig. 11; Supplementary Information 2).

The group of activities identified around the hearth in C1 corresponds with the Lien test results, indicating that this cluster has the highest level of information of the contingency tables (Supplementary Information 3). Multifunctional activities around hearths form a spatial pattern well documented in both ethno-archeological (Yellen, 1977; Kroll and Price, 1991; Kelly, 1995) and archeological studies (Leroi-Gourhan and Brezillon, 1973). Activities undertaken at C1 suggest tasks related to regular knapping, retouching of tools, bipolar production of blanks, and use of minerals that could be related to the preparation or production of composite tools (Audouin and Plisson, 1982) (Figs. 10, 11). All these activities are combined with tasks associated with subsistence, such as animal- and plant-processing (Fig. 11). C1 demonstrates the convergence of the main domestic activities around hearths (Pallarés, 1999; Roda Gilabert et al., 2013). Similarly, although no architectural elements have been identified at Font del Ros, the accumulation of tasks around this hearth could indicate the presence of a potential hut around which subsistence activities and other daily maintenance tasks were organized in this area of the site (Martínez-Moreno and Mora, 2011).

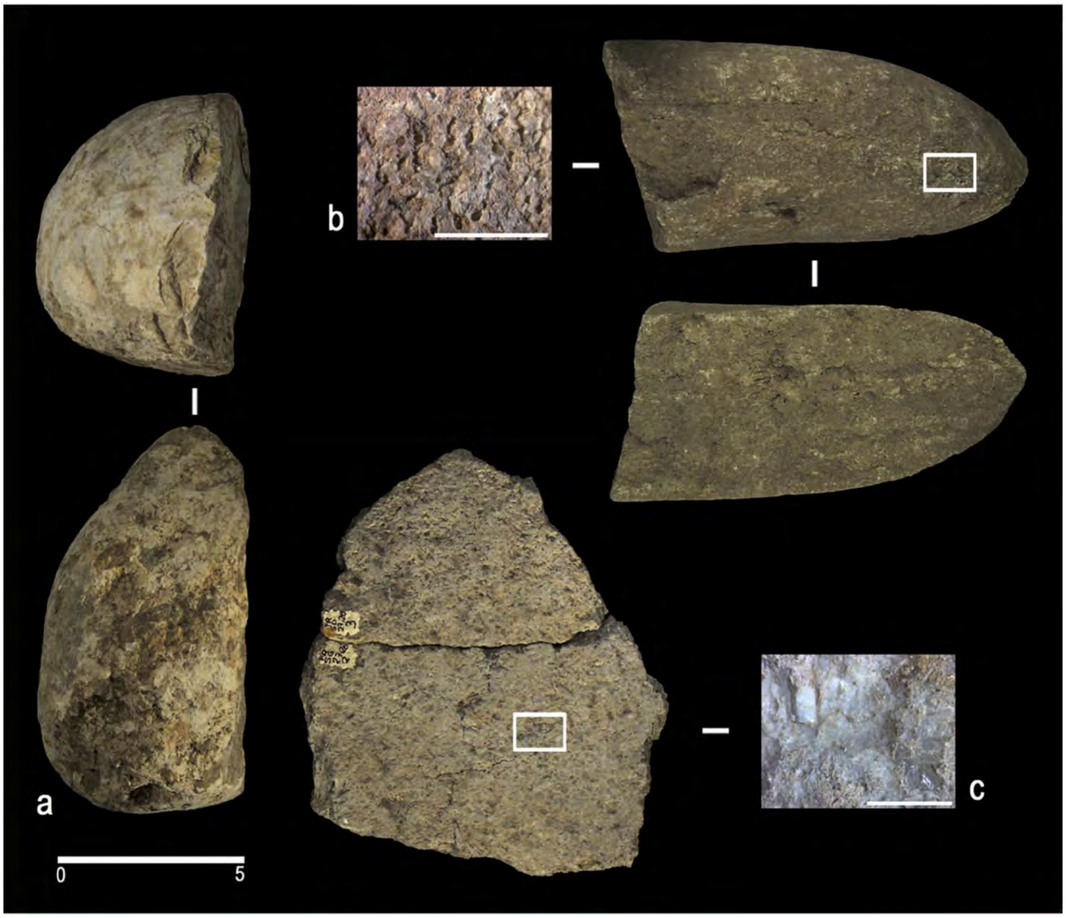

Fig. 6. a) C*oncassage* limestone hammerstone (126 × 86 × 65 mm) with conchoidal flake removals at one end produced by repeated percussion on this area of the tool, and numerous step scars on both sides of the ridge. The convex removals are not associated with knapping. The lateral zone shows intense percussion that has modified the original surface; b) Limestone anvil fragment (117 × 52 × 59 mm) and section of cobble indicating its possible origin from a large, thick cobble (graphic scale detail: 5 mm); c) Granite anvil fragment (177 × 79 × 54 mm) with the use surface modified by percussion (graphic scale detail: 3 mm).

5.2.2. Cluster 2: stone knapping and tool production

In contrast to the wide range of activities in C1, wear traces on ground stone tools from C2 suggest intensive production and modification of lithic artifacts. Our observation concurs with statistical inferences, indicating the importance of microdebitage in this group. In comparison with the general dynamic of the other clusters, the C2 attributes suggest bipolar knapping and retouching were the main activities in this area. Two separate locations identified in C2 correspond to two different knapping sequences which, while not linked by lithic refits, could be part of the same occupation (Table 2; Fig. 10).

5.2.3. Cluster 3: hide-working area

The scenario seen in C3 is different. Here, three ground stone tools in close spatial proximity are linked with an accumulation of iron oxide (Fig. 11). Statistically, the mineral distinguishes C3 from other areas (Table 3) (Pallarés, 1999; Supplementary Information 3), while the association of cobbles and iron oxide may indicate both a pigment-processing (Audouin and Plisson, 1982; Couraud, 1983, 1988, 1991) and a hide-preparation zone (Adams, 1988; González Urquijo and Ibáñez, 2002; Dubreuil and Grosman, 2009). It is possible that such tasks were undertaken in a larger area, including parts of C3 and C5, and an area extending along the perimeter of these clusters. Low artifact density in C3 indicates an empty space (or a space with few artifacts) that may correspond to a hide-working area (Fig. 11; Supplementary Informations 2, 3). Ethnoarchaeological studies suggest that from an archeological perspective, a characteristic attribute of hide-working is the presence of empty zones, that constrains positive identification of such tasks (Beyries et al., 2002).

5.2.4. Cluster 4: plant-processing area

Contextual data obtained during excavation indicates an abundance of plant macro-remains in C4 and C5 (Fig. 11; Pallarés, 1999; Supplementary Informations 2, 3). Nevertheless, it is important to stress that C4 is located at the edge of the excavated area, which makes it difficult to identify activities undertaken there. The presence of hazelnut shell residues associated with nut processing emphasizes the relevance of this activity on the site and is a significant indicator of spatial task patterns at Font del Ros (Pallarés, 1999; Martínez-Moreno and Mora, 2011; Roda Gilabert et al., 2013), However, use-wear traces identified on the pebbles in this area are not diagnostic of plant-processing.

5.2.5. Cluster 5: a "fuzzy" pattern task area

In contrast to C2, C3, and C4, a range of activities can be identified in C5, but the spatial pattern is imprecise, and materials appear dispersed. Nevertheless, ground stone tools here indicate a combination of tasks, including freehand knapping, bipolar knapping, the processing of plants, and hide-working. Our observation matches the statistical importance of used cobbles in C5, and despite the lack of functional resolution, the combination of activities is interesting (Table 6).

Although only one ground stone tool in C5 has traces indicating plant-processing (Fig. 11), we suggest that some cobbles in this area, whose precise functions remain unclear, may be associated with short-term plant-processing. Similar use-wear patterns have been

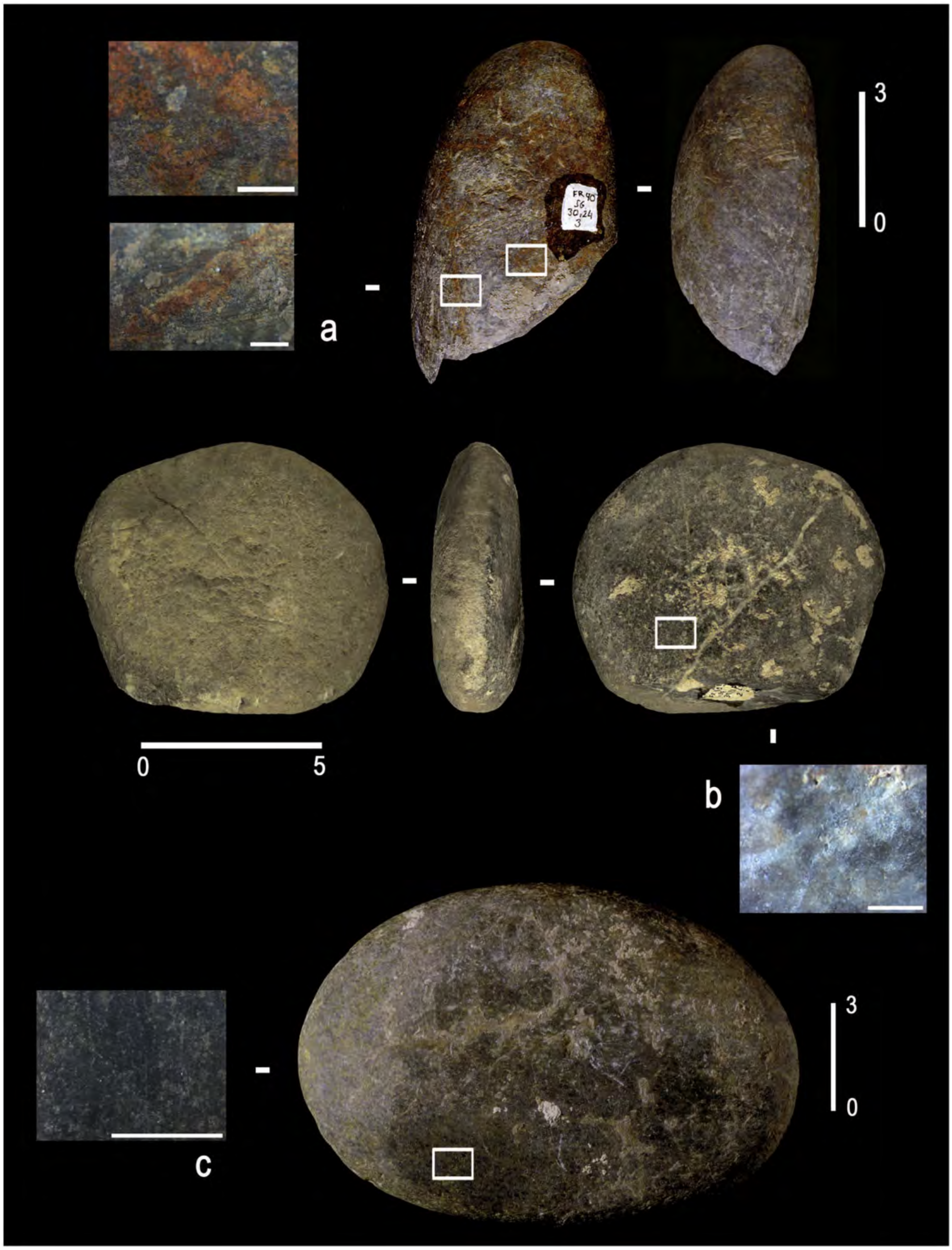

Fig. 7. Resting percussion. a) Ignimbrite fragment (80 × 48 × 37 mm) with pitting and striations impregnated with iron oxides (scale details of linear traces and residues: 2 mm); b) Limestone cobble (57 × 46 × 30 mm) with central pitting associated with bipolar knapping and a use-wear facet caused by friction on its edge (edge-ground cobble). Detail of the central pitting associated with linear traces (graphic scale detail: 1 mm).c) Flat quartzite pebble (126 × 88 × 32 mm) used in hide-working that shows a lustrous, dark gloss and light striations caused by abrasive activities (graphic scale detail: 5 mm).

observed on experimental cobbles used for cracking hazelnuts (Roda Gilabert et al., 2012).

C5 may be connected to adjacent concentrations, especially C4. Or, alternatively, it could represent an area where ground stone tools were preferentially used for specific activities, some of which were undertaken at the periphery of the central domestic unit, implying use of a large surface area. Such a possibility would be recorded by ^{14}C dates which suggest a greater radiometric age for C4 than C1 (Fig. 2).

6. Discussion

This study underlines the importance of ground stone tools as technical and spatial indicators of activities undertaken at Font del Ros (Pallarés and Mora, 1999; Martínez-Moreno and Mora, 2011; Roda Gilabert et al., 2013). Spatial analysis enabled the identification of five artifact segregated clusters in a part of level SG. This sector extends for about 500 m^2 and represents 30% of the excavated surface of this

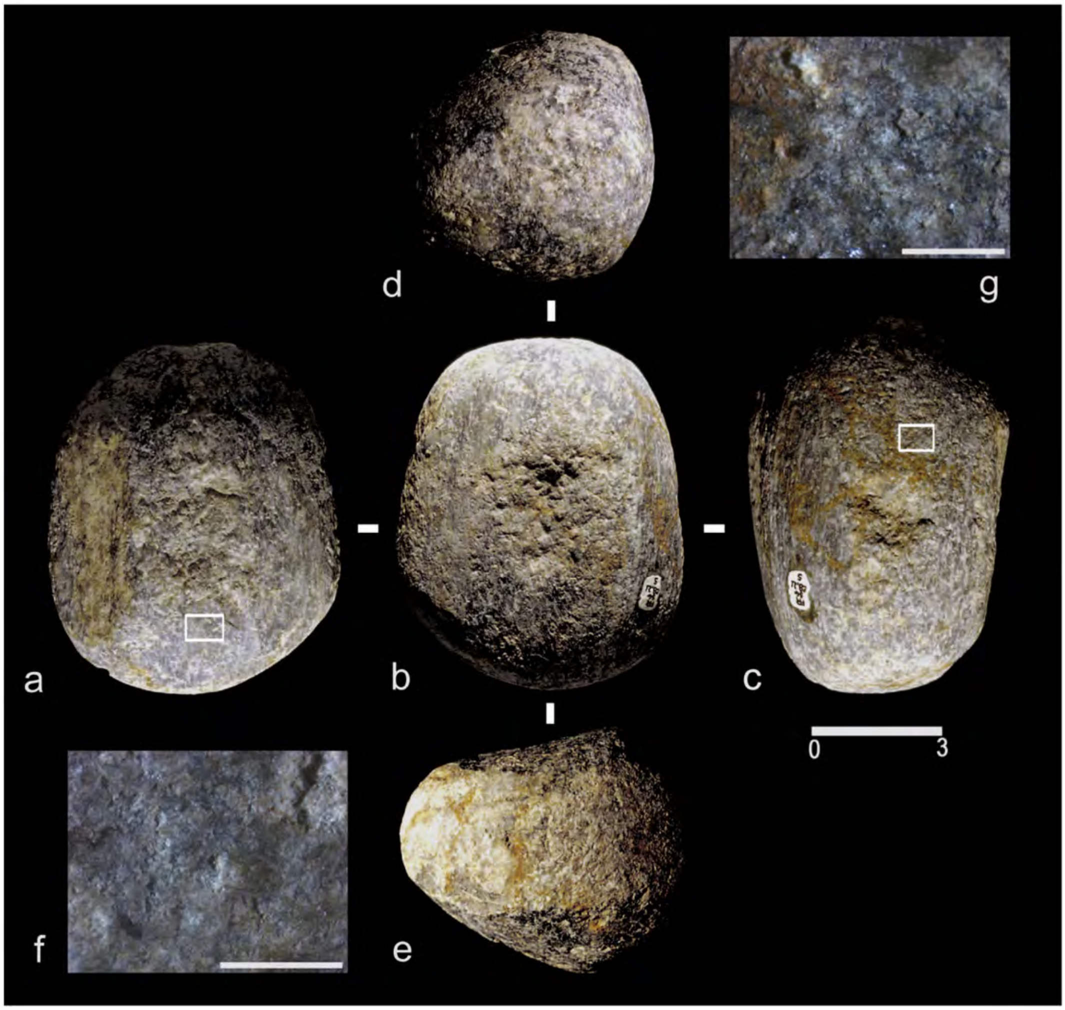

Fig. 8. Multipurpose quartzite cobble (74 × 63 × 38 mm) with several traces of thrusting and resting percussion. a, b, c) Depressions, irregular in section, with traces of polish on three surfaces; d) Pitting caused by thrusting percussion; e) Convex use-wear facet caused by friction; f) Detail of the area of polish (graphic scale detail: 2 mm); g) Center of the depression (b) showing frosting and compression points (graphic scale detail: 2 mm).

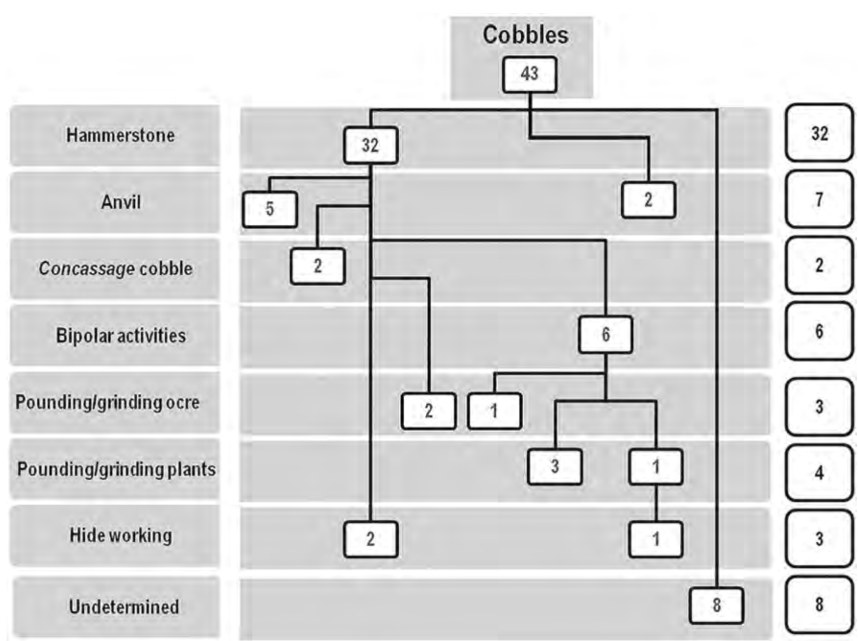

Fig. 9. Suggested distribution of ground stone tools according to their assumed functions (based on the model proposed by de Beaune, 1997: 81]). Numbers of artifacts are indicated.

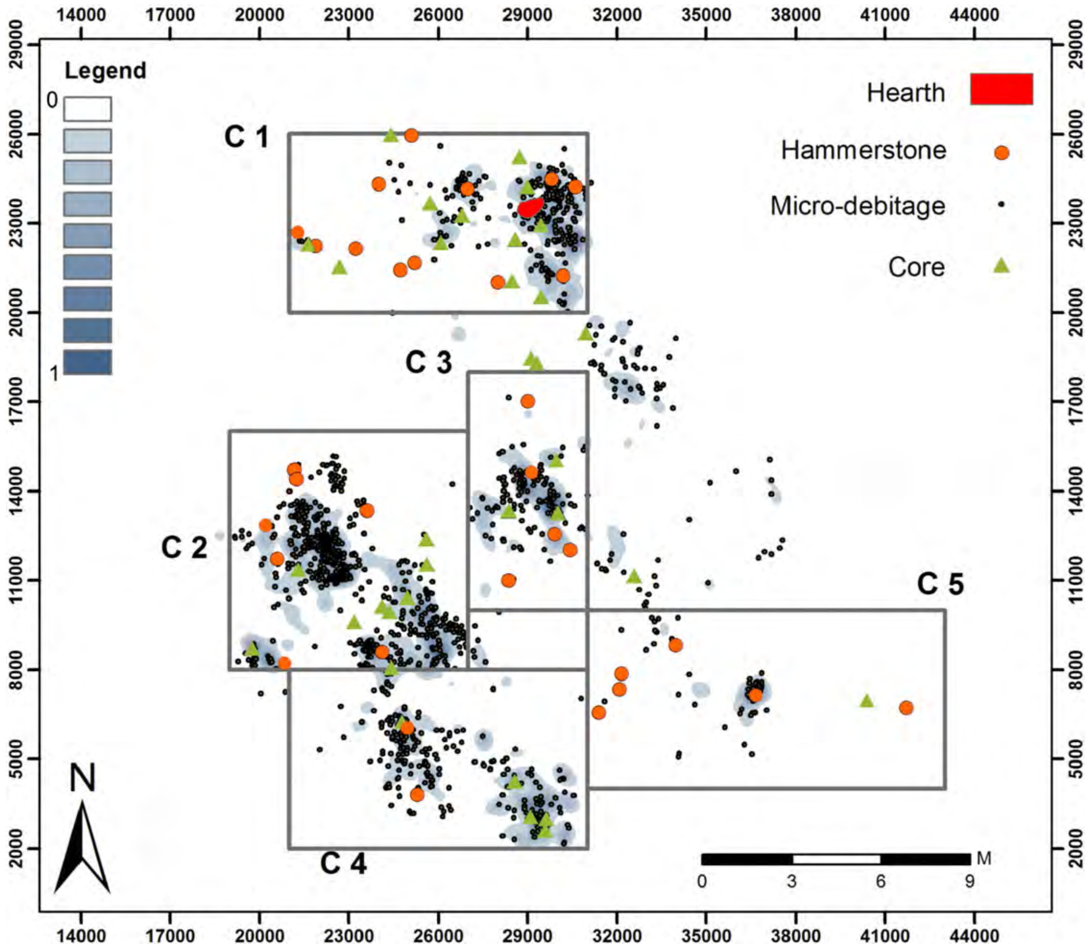

Fig. 10. Kernel density map of cores, microdebitage, and hammerstones from knapping activities. C1–C5 are clusters.

archeological level. Some indicators, such as radiometric dates and the spatial distribution of remains, suggest these accumulations were the result of successive and distinct occupation events, superimposed over a period of time which was not necessarily long.

The interrelationship between clusters allowed us to address functional and organizational questions. The tasks identified are domestic activities, including knapping and retouching of lithic artifacts, processing of fauna (bone-breaking and possibly meat-pounding), gathering and processing of nuts and fresh fruits, mineral-grinding and hide-working. These spheres of activity enable construction of the subsistence and social organization of Mesolithic hunter-gatherer lifestyle at Font del Ros during the Boreal crono-zone (Martínez-Moreno and Mora, 2011).

Our analysis of ground stone tools identified multiple use and recycling events (sensu de Beaune, 1994; Adams, 2002; Dubreuil et al., 2015), indicating a non-specialized tool assemblage in which raw material properties do not seem to be important (Table 5). Apart from sandstone, which is primarily associated with anvil fragments, and quartzite linked to hide-working, there does not seem to be a selection of raw materials according to the task to be undertaken. This characteristic is particularly interesting when one considers that tools used in activities involving resting percussion, such as pounding and grinding plants and minerals, are not those which have the greatest abrasive capability. It would seem, then, that concepts such as tool efficiency and productivity did not play an important role for the human groups at Font del Ros (Delgado-Raack et al., 2009).

These attributes agree with results from statistical tests and geostatistical analysis. Far from identifying specialized clusters or specific tasks zones, ground stone tools define a system that we call "multipurpose areas" (Pallarés, 1995; Martínez-Moreno and Mora, 2011). Cobbles may have use-wear traces connected with various technical processes applied to different subsistence activities.

One such activity is the cracking and pounding of hazelnuts (Roda Gilabert et al., 2012, 2013). The dense concentration of fresh fruit and nut trees in the Font del Ros area, suggested by charcoal analysis, could also have made it an attractive place on the regular foraging routes by post-glacial hunter-gatherers of the southern Pyrenees. Hazelnut shells and seeds of *Malus*, *Prunus spinosa*, and *Pyrus pyraster* have been identified at the site. These remains suggest that reliable and nutritious resources were available whose acquisition did not require significant investment of time and energy, thus promoting repeated visits leading to recurrent settlement (Pallarés and Mora, 1999; Roda Gilabert et al., 2013). Intensive plant-gathering has been proposed as a key attribute of Mesolithic subsistence in Western Europe (Clarke, 1976; Zvelebil, 1994; Mason and Hather, 2002). However, problems related to organic preservation and the scarcity of plant-processing tools have hindered assessment of the role of such resources (Marinval, 1988; Cane, 1989; Valdeyron, 2014).

Ground stone tools linked to food preparation tasks are known in Natufian contexts in the Near East (Dubreuil, 2004; Dubreuil et al., 2015), and particularly in the European Neolithic (Hamon, 2008; Stroulia, 2010). Nevertheless, there is little available information about such tools in Pleistocene hunter-gatherer contexts (Piperno et al., 2004; Aranguren et al., 2007; Revedin et al., 2010; Nadel et al., 2012). As such, the ground stone tools recovered from Font del Ros are clearly relevant because of their association with the processing of oily plants. Furthermore, throughout the entire excavated surface of Level SG, the spatial distribution of macro plant remains covaries with archeological

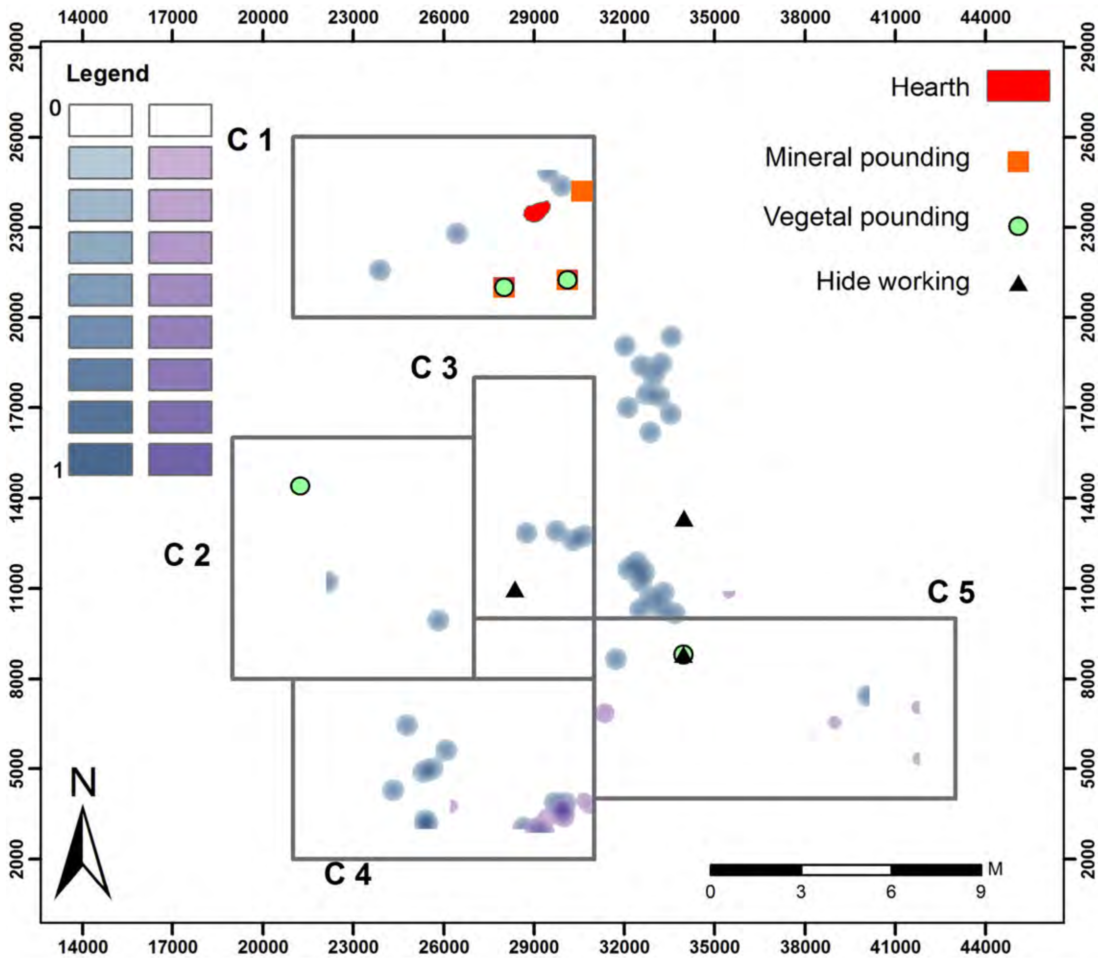

Fig. 11. Kernel density maps of mineral pigments (blue) and plant remains (purple) with superimposed spatial distribution of ground stone tools related to hide-working, mineral-pounding, and plant-processing. C1–C5 are clusters.

features and identifies plant food processing areas next to hearths (Roda Gilabert et al., 2013).

It has been shown that roasting and grinding/crushing of nuts aids absorption of nutrients and facilitates storage for later consumption (Stahl, 1989; Wandsnider, 1997; Score and Mithen, 2000). Such a scenario has been proposed for Staosnaig (Mithen et al., 2001), Verrebroek Dok 1 (Sergant et al., 2006), Wohnplatz 6 and 8 of Duvensee (Holst, 2011); Lough Boora (Mc Comb and Simpson, 1999) and Ertbølle (Robinson and Harild, 2002), where roasting and processing of hazelnuts would have been a strategic activity. In such cases, it is suggested that nuts form a substantial portion of nutritional requirements, providing a concentrated food source, easy to shelve, transport, or store throughout the year (Holst, 2010).

It is difficult to assess the importance of the consumption of nuts and plants in general for Font del Ros people because of factors associated with conservation of vegetal remains and in general the difficulties of identifying small scale storage systems which Upper Paleolithic and Mesolithic hunter-gatherers are assumed to have developed (Cunningham, 2011; Valdeyron, 2014). Nonetheless, it should be noted that there were concentrations of burned hazelnuts in all accumulations found at Font del Ros indicating periodic management of hazelnuts in the different clusters of this area over a long period (Roda Gilabert et al., 2013).

We emphasize the need to apply use-wear analysis along with protocols for the analysis of inorganic (phytoliths) and organic (starch) residues (Aranguren et al., 2007; Buonasera, 2007; Field et al., 2009; Revedin et al., 2010; Liu et al., 2010; Portillo et al., 2013). Such an approach enables a more precise characterization of the tasks for which artifacts were used that will provide information essential in establishing the organization of, and activities undertaken at the site.

The data presented here highlight the structure of an organizational system in which the gathering and processing of nuts and fresh fruits was a subsistence activity of increasing importance in the Mesolithic. These new behaviors are detected through seeds and husks, but also by the recovery, identification and study of ground stone tools linked to their processing.

Table 6
Functional assumptions detected on cobbles from each of the defined clusters.

	C1	C2	C3	C4	C5	Σ
Hammerstones	12	7	5	2	6	32
Anvil	2	2		1	2	7
Concassage cobble	2					2
Bipolar knapping	4	1			1	6
Mineral pounding/grinding	3					3
Plant pounding/grinding	2	1			1	4
Hide-working			1		1	3
Indeterminate		1	2	1	4	8
Total	25	12	8	4	15	65

7. Conclusions

In summary, concentrations of artifacts suggest a large range of tasks in the SG unit of Font del Ros. Usually these tasks cannot be detected through a straightforward reading of the archeological record. The present study has shown that ground stone tools are key to the identification of such activities (Dubreuil et al., 2015). The combination of qualitative information supplied by use-wear in cobbles, with intra-site spatial analysis and nonparametric statistical techniques, provided valuable information about the activities undertaken by past human groups (de Beaune, 2000a, 2000b).

The assignment of particular functions to ground stone tools in turn suggests certain domestic activities, among them the processing and consumption of plants, and other tasks such as lithic production, processing of fauna, hide-working and preparation of pigments, all of which are essential for the production and maintenance of subsistence and the social life of these hunter-gatherers. Cluster analysis identified the spatial dimension of tasks undertaken, and the results suggest a scenario that combines multipurpose activity areas with other activity areas segregated in space.

Likewise, artifacts with similar features have been described for sites of the same temporal and geographic range such as Balma Margineda (Guilaine and Martzluff, 1995), Balma Guilanya or Sota Palou (Martínez-Moreno et al., 2006b).

Ground stone tools have also been noted in several Mesolithic sites on the slopes of the Pyrenees, although it is not known what they were used for (Alday, 2006).Therefore, the presence of ground stone tools in the technical tool-kit is not an isolated phenomenon exclusive to Font del Ros. The study of these artifacts will enable us to characterize post-glacial hunter-gatherer adaptations on the south face of the Pyrenees and the Ebro basin. An extensive geographic environment with significant ecological contrasts and a wide biodiversity of plants, tubers and nuts (Zapata, 2000; Allué et al., 2012), easy to obtain, and providing high-energy returns, the processing of which was mediated by a ubiquitous tool such as a river cobble.

This conclusion indicates the need to recover and analyze such tools which often go by unnoticed, or are assigned to tasks related to knapping, and considered only as hammerstones. The cobble assemblage recovered at Font del Ros corroborates such activities, while also allowing us to tackle other tasks related to the maintenance of essential technological elements, among them hide-working, the preparation of mineral pigments and the processing of plants and animals that provide basic nutrients for the biological and social sustenance of prehistoric hunter-gatherers.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jasrep.2015.11.023.

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