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Sedimentological and archaeological fabrics in Palaeolithic levels of the South-Eastern Pyrenees: Cova Gran and Roca dels Bous Sites (Lleida, Spain)

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The comparative study of sedimentary fabrics in relation to archaeological fabrics in various levels of the sites of Cova Gran de Santa Linya (Middle and Early Upper Palaeolithic) and the Roca dels Bous (Middle Palaeolithic) has made it possible to analyse the formation dynamics of the deposits and determine the extent of disturbance of the archaeological levels by natural processes. To achieve this, diagrams and two- and three-dimensional indices were calculated from the azimuth and dip angle of natural clasts and artefacts. The results indicate that the sedimentary levels were formed mainly by planar fabric shape gravitational processes (low depositional angles), which differ notably from the archaeological fabrics they contain, characterised by a greater degree of isotropy. This difference in the fabrics would reflect human activity and indicates that the archaeological levels both in Cova Gran and Roca dels Bous have not been subject to significant natural modifications, and are preserved *in situ*.

1. Introduction

The study of sedimentary fabrics, that is, the analysis of the orientation and dip angle of the clastic elements that make up the deposits, constitutes a useful methodology for interpreting depositional and post-depositional processes. Fabrics analysis has been applied in order to study the dynamics of various quaternary sedimentary materials (Mills, 1983; Benn, 1994; Bertran et al., 1997; Benn and Ringrose, 2001), and has been used recently for reconstructing formation processes of archaeological sites (Lenoble and Bertran, 2004; McPherron, 2005; Lenoble et al., 2008), thanks to improvements in data recording and statistical methods. One of the most commonly applied techniques is the study of fabric shapes, based on the relative values of the three eigenvalues calculated from the orientation and dip angle data (Bertran and Lenoble, 2002; Benn, 1994; Woodcock and Naylor, 1983; Woodcock, 1977).

In this study, the fabrics of several levels from two Upper Pleistocene sites (Cova Gran and Roca dels Bous) situated in the Pre-Pyrenees of Lleida (Northern Spain) have been analysed. Analysis of orientation diagrams and a number of two- and three dimensional indices has been conducted, in order to interpret the depositional and post-depositional processes of the Cova Gran (Late Middle Palaeolithic and Early Upper Palaeolithic), in conjunction with other sedimentological and mineralogical data.

Determining the influence of sedimentary and post-depositional processes in archaeological assemblages is essential for assessing site formation, especially in sites with levels corresponding to the Middle–Upper Palaeolithic interface, such as Cova Gran, where determining the primary position or degree of modification of the archaeological record is of particular importance. In this paper we have followed a new methodology in the analysis of fabrics, consisting of analysing the orientation and the dip angle of natural clasts and artefacts separately, with the aim of evaluating the differences between the sedimentary fabrics and the archaeological fabrics of each level. By following this procedure it was possible to establish that there was little or no reorganisation of

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archaeological assemblages due to natural processes in the late Middle Palaeolithic and the early Upper Palaeolithic in Cova Gran. The same techniques were applied in another Middle Palaeolithic level of the nearby rockshelter of Roca dels Bous, corroborating the results of Cova Gran with regard to the characteristics of the archaeological fabrics and their differences from the sedimentary fabrics.

2. Geoarchaeological context

The archaeological sites of Cova Gran de Santa Linya (X = 318635, Y = 4644081, UTM H31 N ED50) and Roca dels Bous (X = 321443, Y = 4638281 UTM H31 N ED50) are located in the Marginal Exterior Sierras of the South flank of the Pyrenees (Fig. 1A), close to the area where this range connects with the Tertiary Ebro Depression. The Roca dels Bous lies on the right bank of the river Segre (now the Sant Llorenç reservoir) at a height of 286 masl, while the Cova Gran de Santa Linya is located in a small tributary valley of the Noguera Pallaresa River (385 masl), at less than 5 km from Roca dels Bous (Fig. 1B).

2.1. Cova Gran site

Cova Gran is a large rockshelter with an area of 92 × 83 m at its widest part, semi-spherical in shape and facing south, formed of Upper Cretaceous bioclastic limestones (Bona Formation). In the Cova Gran, these limestones include brecchias associated with fractures, composed by subangular and subrounded limestone clasts. The rockshelter is situated on the left bank of the Sant Miquel ravine (Fig. 1B), which follows the area of weakness defined by

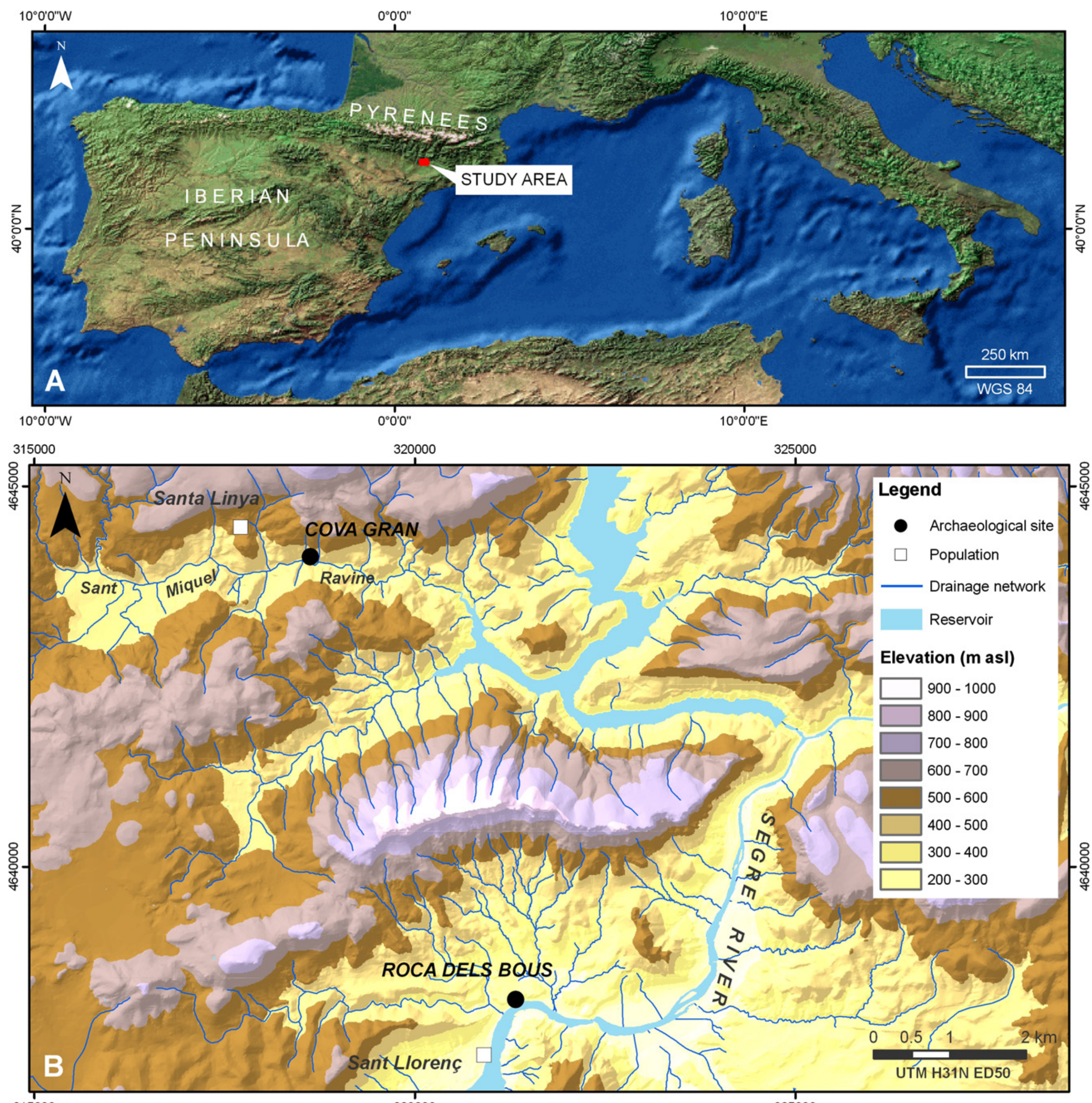

Fig. 1. Study area: A) Geographical location in the European context; B) Position of the sites of Cova Gran and Roca dels Bous in the Marginal Sierras of the southern Pyrenees.

mechanical contact between the Bona Formation and the clays and gypsums of the Upper Triassic (ICC, 2002). This E-W contact is displaced by transversal faults, causing minor variation in the valley direction, such as an incised meander, on the concave side of which is the Cova Gran.

Within the rockshelter there is a sedimentary infill situated +3–9 m from the stream bed (Fig. 2A), with two clearly differentiated morphological areas. On the east of the rockshelter there is a flat area a few metres above the stream (+3 m), in which there is a 2.5–9.6 m thick deposit, with recent alluvial sediments on the top (Fig. 2A). However, in the east of the shelter there is a slope which reaches +9 m above the stream, consisting of Pleistocene deposits shielded from the erosive action of the Sant Miquel stream by a rockfall of large blocks (Fig. 2A). The characteristics and morphology of these sediments suggest that it is a gravitational cone, 4–6 m thick (Fig. 2A). The thickness of the sedimentary infill was estimated using electric tomography, which indicated a discontinuous variation of the thickness, from 2.6 to 4.5 m at the wall of the rockshelter, to 7–9 m in the central part of the cavity.

The archaeological excavations carried out so far in the Pleistocene sediments yield a sequence with two main stratigraphic units (Fig. 2A and B). The lower unit (S1) has a depositional slope facing W-SW. Six levels have been identified in this unit, all of which contain archaeological material (497D and from S1B to S1E), and the bedrock has not yet been reached (Fig. 2B). The deposits are formed by poorly classified autochthonous blocks and clasts and a matrix of sands, silts and clays composed mainly of calcite and dolomite, some quartz and illite, and to a lesser extent, clinochore and gypsum. Above this sequence is the upper unit (497), which contains archaeological levels 497C and 497A. These levels are characterised by a N70°E depositional slope, dipping 12° towards the east (Fig. 2B). Levels 497C and 497A are formed by subangular limestone blocks and clasts in the lower and middle sections, and sub-rounded clasts in the upper stretch (Fig. 2B). The sand and clay matrix contains calcite, quartz, and smaller amounts of illite, albite and clinochlore. The deposits are the combined result of the action of gravitational and runoff processes, caused by cycles of freezing and thawing in cold periods alternating with temperate-warm episodes. As a result of these erosion and sedimentation processes, the deposit is a conical shape, resting against the wall of the rockshelter.

To date, the archaeological and sedimentological studies have concentrated on the western part of the site (Figs. 2A and 3A), where several archaeological levels have been extensively excavated (Fig. 3B). The most significant is the documentation of Middle Palaeolithic levels in the lower unit (S1), which also includes an Early Upper Palaeolithic level (497D). The archaeological levels are shaped in discrete, individual geometries which contain lithic (Fig. 4A–D), bone remains and hearths. In the lower unit, the archaeological levels have been excavated across a maximum of 53 m^2 for S1B and a minimum of 13 m^2 for S1D (Fig. 3B), the average thickness being 10-15 cm (Table 1). The upper unit (497C

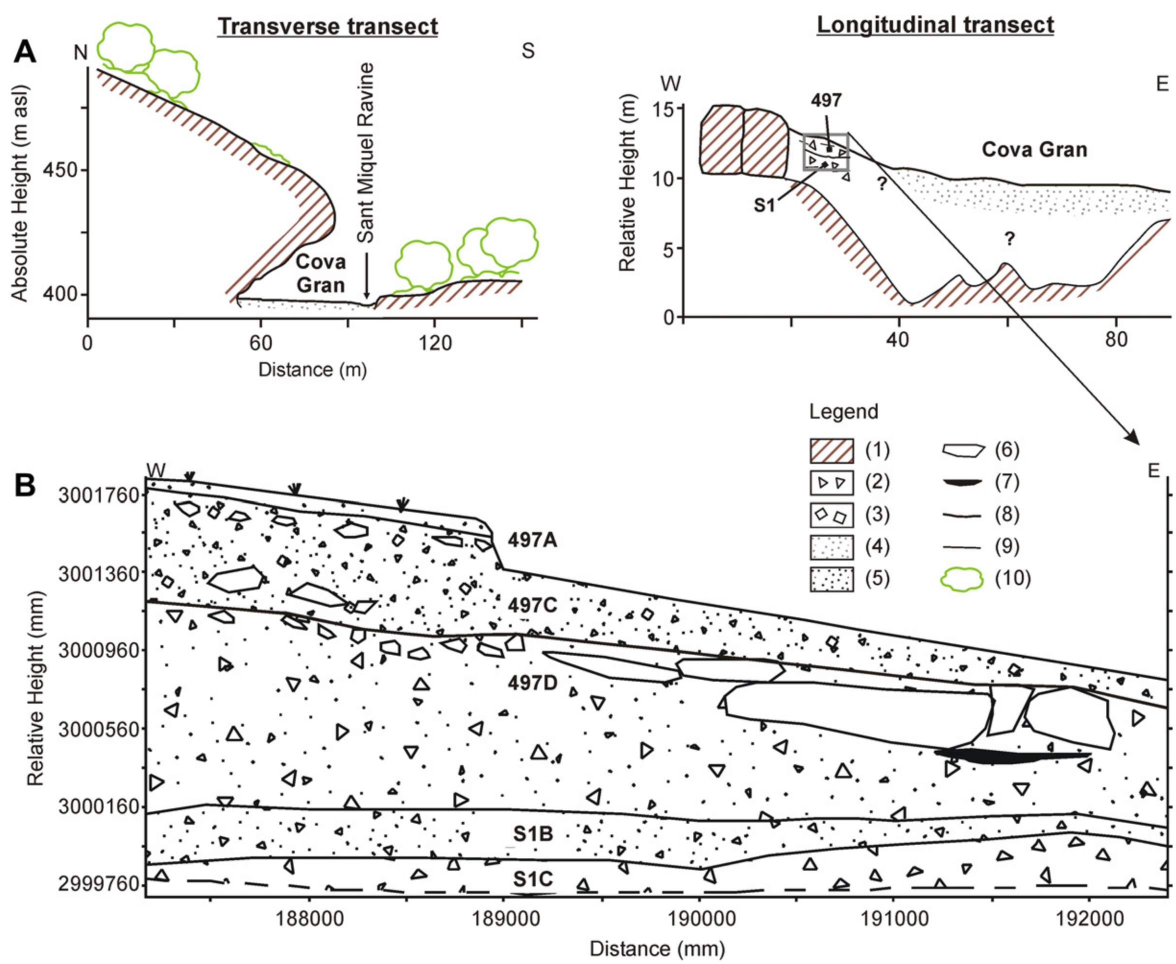

Fig. 2. Geomorphological transects (A) and stratigraphic section of the Cova Gran Site (B). Legend: (1) Bedrock (Upper Cretaceous limestones and brecchias); (2) Subangular clasts; (3) Subrounded clasts; (4) Recent alluvial deposits; (5) Matrix of sands, silts and clays; (6) Large blocks (7) Hearths; (8) Discontinuity?; (9) Stratification; (10) Vegetation; Cova Gran stratigraphic units: 497 (archaeological levels 497A and 497C), S1 (archaeological levels 497D and from S1B to S1E).

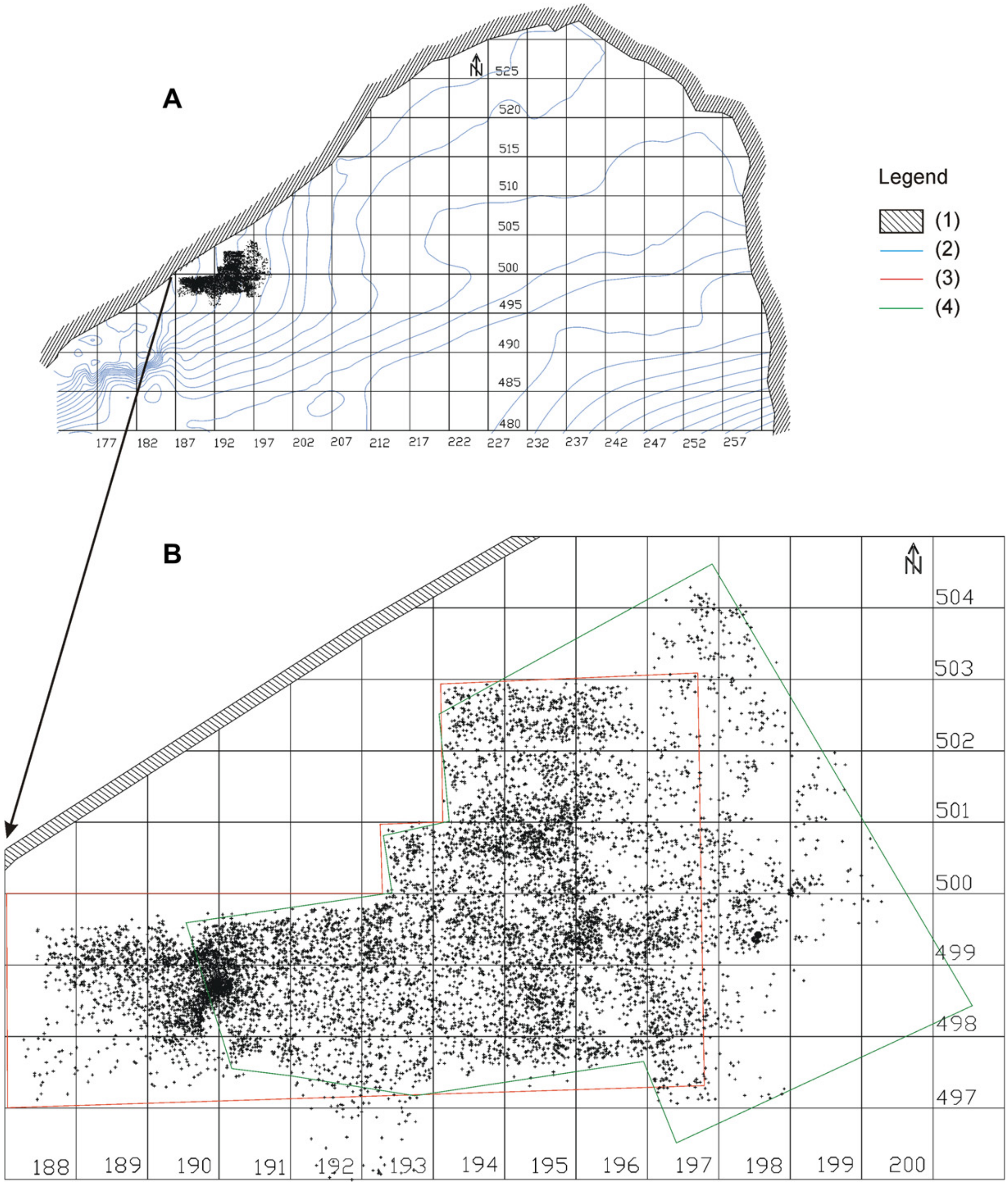

Fig. 3. Topographical map (A) and plotting of the archaeological remains excavated at Cova Gran (B). Legend: (1) Bedrock; (2) Topographical contours each 0.5 meters; (3) Area excavated in the Upper Palaeolithic units; (4) Area excavated in the Middle Palaeolithic units.

and 497D) has been excavated over an area of 40 m^2 (Fig. 3B), with levels 5–10 cm thick. The archaeological levels of both stratigraphic units (S1 and 497), are eroded towards the East by the slope.

The set of radiometric ^{14}C AMS dates (Martínez-Moreno et al., submitted for publication) puts the three levels of the Upper Palaeolithic between 21 and 34 kyr, while the Middle Palaeolithic levels extend between a minimum of 38–32 kyr (Fig. 2A). As can be observed in Table 1, the densities of archaeological materials vary from level to level, but in general the density of artefacts is greater in the Middle Palaeolithic units than in the Early Upper Palaeolithic assemblages.

2.2. Roca dels Bous

The Roca dels Bous rockshelter is located at the foot of a rocky outcrop formed by early Oligocene conglomerates and carbonated shales (Graus Formation; ICC, 2002; Figs. 1B and 2B). This site is located on the concave side of a large, narrowly incised meander of the river Segre that now forms a reservoir (Fig. 1B).

Archaeological levels at Roca dels Bous are dated to between 38 and $>$ 47 kyr, and are included in rock fall deposits with locally major cementations (Fig. 5), the sequence ending with a recrystallised speleothem (Martínez-Moreno et al., 2006). Next to the wall of

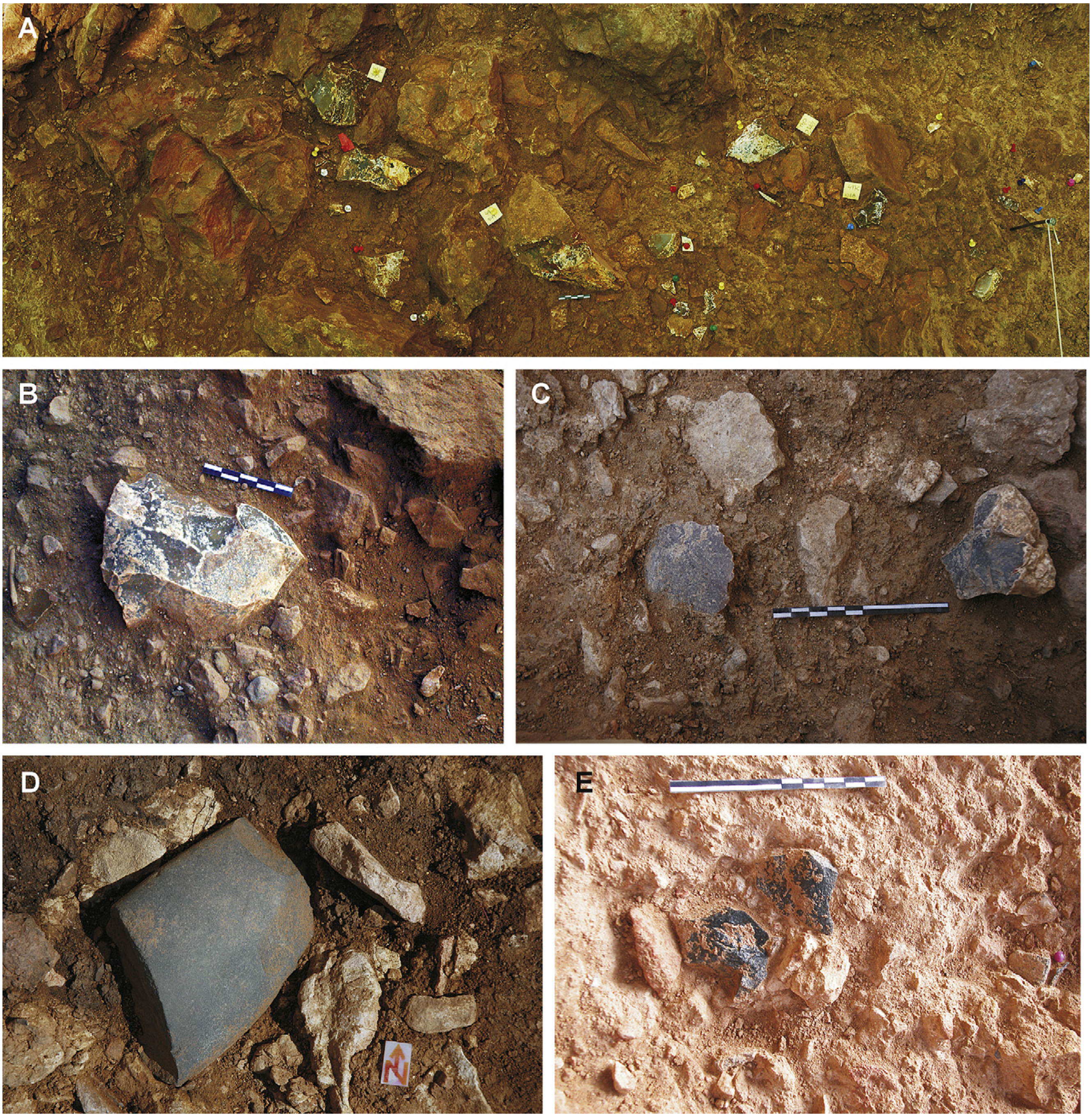

Fig. 4. Artefacts and clasts from the Cova Gran and Roca dels Bous Sites. Cova Gran: level 497C (A and B), and level S1B (C and D). Roca dels Bous: level N12 (E).

Table 1
Archaeological units in Cova Gran de Santa Linya (497A, 497C, 497D, S1B, S1C, S1D and S1E) and in Roca dels Bous (N12) described in this paper.

Level	Excavated surface (m^2)	Thickness (cm)	Total artefacts	Cores	Retouched tools	Cultural attribution
497A	21	5–10	1035	18	82	EUP
497C	35	5–10	1580	47	217	EUP
497D	39	10–15	2788	31	216	EUP
S1B	53	10–15	3047	34	181	LMP
S1C	21	10–15	2848	46	175	LMP
S1D	13	15	4546	56	349	LMP
S1E	7	10	2468	37	159	LMP
N12	37	15–20	12,048	158	331	LMP

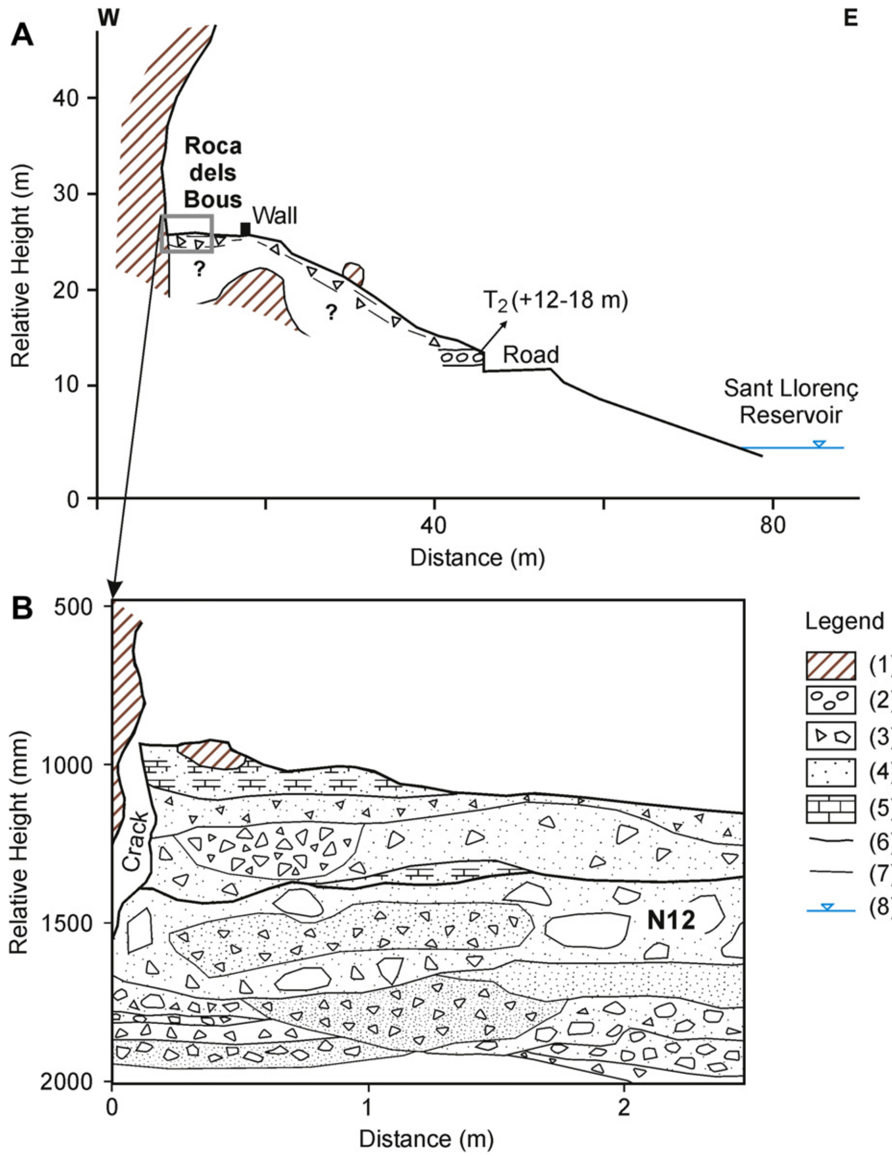

Fig. 5. Geomorphological transect (A) and stratigraphic section of the Roca dels Bous site. Legend: (1) Bedrock (Lower Oligocene conglomerates and shales); (2) Fluvial terrace (T_2 at +12–18 m); (3) Subangular and subrounded clasts; (4) Matrix of sands, silts and clays; (5) Carbonated cementations; (6) Discontinuity; (6) Stratification; (7) Reservoir.

sector E, the morphology of deposits is slightly convex, while towards the outside deposits tilt acutely southwards (34°, Fig. 5A), with sediments and some large blocks detached from the bedrock (Jordá Pardo et al., 1994; Jordá Pardo, 2005). Deposits in this slope are situated above the T_2 (+12–18 m) Segre river terrace (Fig. 5A), which is included by Peña Monne (1983) in the Upper Pleistocene.

In Roca dels Bous, azimuth and dip angle were recorded in level N12 of sector E (Fig. 5B). Its deposits consist of angular and subangular rounded clasts and autochthonous blocks, and a sandy-lutitic matrix in which calcite is the principal mineral, with illite and quartz as secondary components. Clasts increase towards the top of the level and a small proportion of feldspars and clinochlore are identified, while at the same time there is more quartz and less calcite (a major component of the bottom of the level). This sedimentation was caused by gravitational processes associated with weathering of the wall and roof of the rockshelter.

Roca dels Bous contains a Late Middle Palaeolithic sequence (Table 1), the upper levels of which have been described elsewhere (Martínez Moreno et al., 2004, 2006; Mora et al., 2004; de la Torre et al., 2005). The archaeological unit studied here (N12) has been excavated over an area of 37 m^2, is 10–20 cm thick, and contains abundant lithics (85% of the total, Fig. 4E), six hearths, and poorly preserved bone remains. Level N12 contains variable densities of archaeological items across the rockshelter, which have been tentatively interpreted as areas of differentiated activities.

3. Methodology

Fieldwork methodology in Cova Gran Roca dels Bous is based on open area excavation following natural rather than arbitrary levels. Archaeological units are defined by the three-dimensional position and vertical scatter of artefacts as well as their location within sedimentary levels. Three-dimensional recording of artefacts (bones and lithics), sedimentary features (i.e. rocks) and archaeological structures (i.e. hearths, pits, etc) is undertaken with a total station. All the sediment is screened with water through 0.5 mm sieves to recover microdebitage and microfaunal remains.

Fabric analyses focus on the study of the azimuth and dip angle of the major axis of clasts (A-axis). Other directions, such as the minor axes C and B, and the overlapping of planes A–B, are considered insufficient for obtaining valid conclusions and are rarely cited (Bertran et al., 1997). The final result of the fabric of the A-axes depends largely on the size and shape of the clasts (Drake, 1974; Kjaer and Krüger, 1998; Bertran and Lenoble, 2002), it being considered that the preferential orientation is better reflected in clasts of more than 2 cm (Kjaer and Krüger, 1998), and with elongation values greater than 1.6 (Lenoble and Bertran, 2004). In this way, the data used relate solely to the azimuth and dip angle of the A-axis (measured with compass and clinometer) of items displaying these characteristics of shape and size.

In Cova Gran and Roca dels Bous, the fabric analysis was conducted separately on clasts and artefacts, in order to evaluate the differences between sedimentary fabrics and archaeological fabrics. The statistical analysis was carried out on the levels with a high number of available measurements, n always being higher than 50. This number of measurements has been proposed by Lenoble and Bertran (2004) as a standard sample size. The spatial position of the elements was registered with a total station.

The measurements were represented in rose diagrams (strike or azimuth) and in stereographic projections (azimuth and dip angle). In the statistical study various two-dimensional and three-dimensional indices were used. An initial analysis was carried out by applying the Magnitude Vector L defined by Curray (1956). This two-dimensional index constitutes the magnitude of the resulting vector, calculated from the direction of the A-axes, varying between 0 and 180°. L is expressed as a %, and can vary from 0% (the direction of the axes presents maximum dispersion) and 100% (all the axes point in the same direction) The Curray index can be applied to estimate the probability p according to the Rayleigh test. These calculations are only significant when the distribution is not plurimodal and are applied to obtain the probability p of obtaining a value greater than L by pure chance combination of random phases (Curray, 1956; Bertran et al., 1997; Bertran and Lenoble, 2002; Lenoble and Bertran, 2004).

From a three-dimensional point of view, the sample was initially characterised by calculating the mean vector (azimuth, dip angle and module). The module of the mean vector also constitutes an index of dispersion, varying between maximum values when the dispersion is minimal and the vectors are added, and minimum values when the dispersion is maximum and the vectors cancel each other out. This module, normalised by the size of the sample and expressed as a %, constitutes an index of the degree of preferred orientation (*R%*).

The most widely used three-dimensional method is the Eigenvector Method (Benn, 1994, Benn and Ringrose, 2001; Lenoble and Bertran, 2004; McPherron, 2005; Lenoble et al., 2008). This method simplifies the set of measurements in a tensor of orientations, which defines the shape of the fabric and is made up of three eigenvectors (V_1, V_2 and V_3), orthogonal with each other. The dominant orientation is represented by vector V_1, which together with vector V_2 forms the preferred plane of the fabric, while V_3 is normal to such a plane. The degree of clustering of the population in relation to the eigenvectors is reflected by their modules (or eigenvalues), which are expressed in their normalised values: S_1, S_2 and S_3. The relationships of the eigenvalues make it possible to differentiate isotropic ($S_1 \approx S_2 \approx S_3$), planar ($S_1 \approx S_2 >> S_3$), and linear ($S_1 >> S_2 \approx S_3$) fabrics.

Various indices have been proposed using eigenvectors. Woodcock (1977) defines *eigenvalues ratios* $r_1 = \ln(S_1/S_2)$ and $r_2 = \ln(S_2/S_3)$, which are projected in a biaxial and orthogonal diagram, where the index $K = r_1/r_2$ represents the bisector that delimits the planar ($0 < K < 1$) from the linear ($1 < K < \infty$) fabrics. Using this method, Woodcock and Naylor (1983) also establish the fabric strength, defined as $C = \ln(S_1/S_3)$. The greater the C parameter, the further the values from the diagram's point of origin is where isotropic fabrics are located.

Another representation used for projecting the sedimentary fabrics was proposed by Benn (1994), who defined the isotropy ($I = S_3/S_1$) and elongation ($E = 1-(S_2/S_1)$ indices. Both indices are projected in a Sneed and Folk ternary diagram, in which the continuous variation in the shape of the fabric is reflected, delimited by the vertices corresponding to the isotropic fabrics, planar *girdles* and linear *clusters*. Other indices proposed by Benn (1994) relate to the flatness index ($F = S_3/S_2$) or the cluster-girdle index ($CGI = S_1 - S_2/S_1 - S_3$), which varies between 0 (planar fabrics) and one (linear fabrics).

4. Results

The azimuths and dip angles measured in artefacts and clasts were used for analysing the fabrics. Measurements of clasts were recorded in levels 497A and 497C (upper unit of Cova Gran) and level S1B (lower level of Cova Gran) and level N12 of Roca dels Bous. Measurements of artefacts were recorded in level 497C of the upper unit of Cova Gran (early Upper Palaeolithic), and the levels of the lower unit – 497D (early Upper Palaeolithic), S1B and S1C (Middle Palaeolithic) -and also level N12 of Roca dels Bous (Middle Palaeolithic).

4.1. Sedimentological fabrics

In Cova Gran, the clasts measured both in the upper and lower units do not display a preferential orientation (Fig. 6). In the upper unit, the clasts of level 497A are mainly distributed between orientations E and W, directions close to N being frequent (Fig. 6), while in level 497C the values are distributed between NW and E orientations, with occasional concentrations around NE orientations (Fig. 6). However, in level S1B (lower unit), the clasts are spread mainly between 270° and 45° (W-NE). The values obtained from Curray's two-dimensional index (L) for the three levels are situated between 7 and 11%, and high values of p (0.65–0.26), which would discount eminently linear fabrics (Lenoble and Bertran, 2004, Table 2A). The three-dimensional index of the degree of preferential orientation *R%* also corroborates these data, giving values of 20.8% (497A), 30.9% (497C) and 29.1% (S1B). In the stereographic projections the three levels show concentrations with the shape of an arc around the periphery (Fig. 6), typical of low-angle planar distributions.

The dominant orientation of the fabrics of the upper unit (eigenvector V_1) is NE and E (Table 2B), with a very low dip angle in the case of level 497C (0.25°) and moderately high in level 497A (10.93°). On the other hand, eigenvector V_1 of level S1B (lower unit) presents west orientations (259°) and low dip angle (Table 2B). The K index (Woodcock, 1977), displays values very close to zero for the three levels (497A, 497C and S1B, Table 2C), typical of planar fabrics. The strength parameter C presents moderate and high values ($1.54 < C < 2,40$). The elongation and isotropy indices (Benn, 1994) also put the three levels of Cova Gran in the planar fabrics, although with a different tendency towards isotropic fabrics (Fig. 7). Level 497C contains most planar fabric, with very low elongation and flatness indices (Table 2C), while the fabric of level 497A has the highest isotropy index ($I = 0.22$). Level S1B has an intermediate isotropy index (Fig. 7).

The rose driagrams of level N12 (Roca dels Bous) display a very disperse distribution with no preferential orientations (Fig. 6). The values of L and *R%* are 9.6 and 27.3 respectively for level N12, distant from linear fabrics. This dispersion can also be observed in

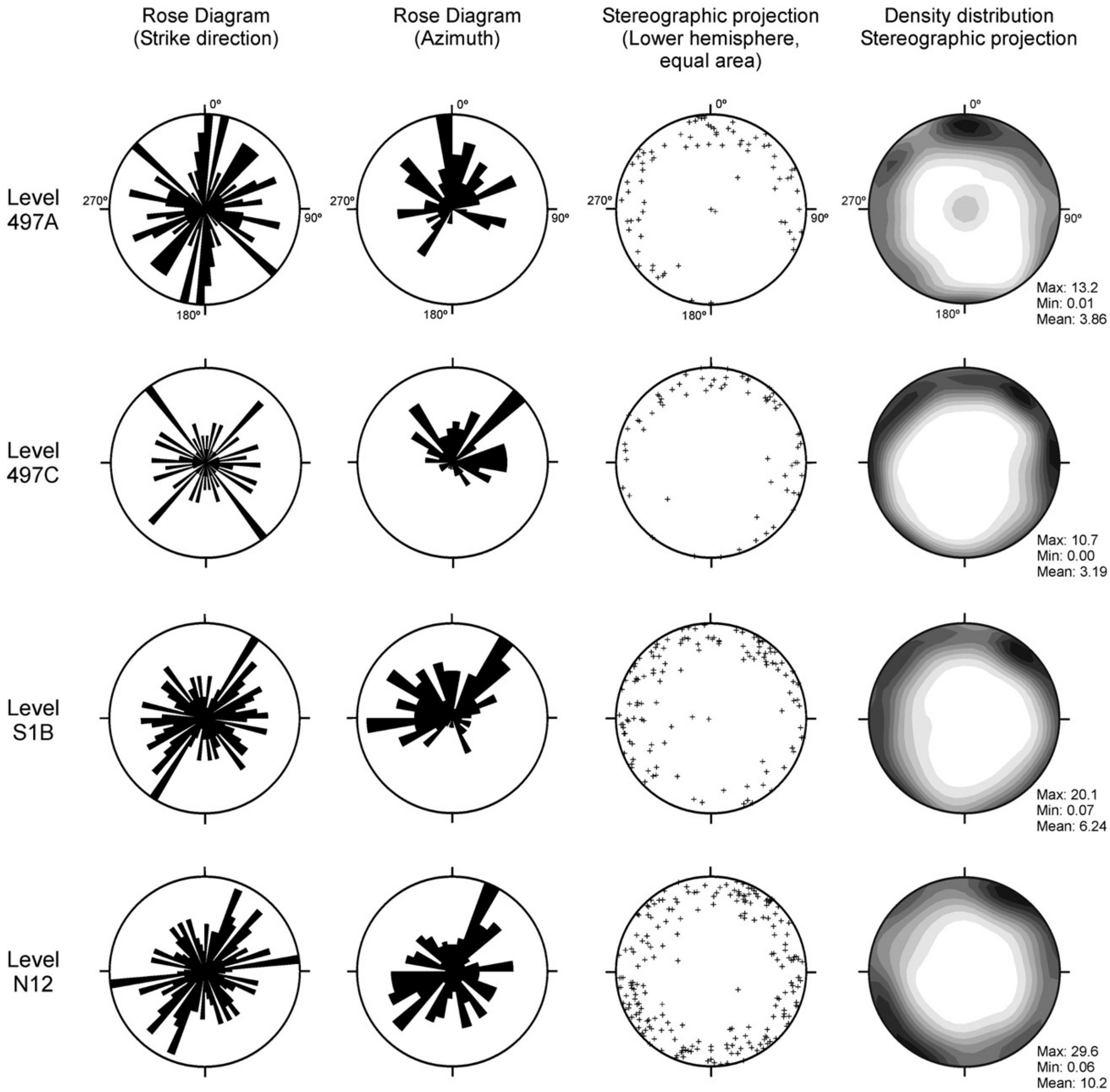

Fig. 6. Rose diagrams (strike and azimuth), stereographic projection and density distribution of the measurements of azimuth and dip angle for the clasts in the sedimentary levels of Cova Gran (497A, 497C, S1B) and Roca dels Bous (N12). See Table 1 for the number of measurements in each level.

the stereographic projections, where the values have a circular distribution, although with slight concentrations NW-SE (Fig. 6). This direction is also reflected in the azimuth of the mean vector (Table 2A) and in the dominant orientation defined by the eigenvector V_1, which presents a SE orientation and very low dip angle (0.93) (Table 2B).

According to the K index, level N12 is also characterised by markedly planar fabrics ($K = 0.15$), with significant C values ($C = 1.70$). Even so, considering the continuum of fabric shape (Fig. 7; Benn, 1994), the planar fabric of level N12 has a moderate tendency towards more isotropic shapes ($I = 0.18$).

4.2. Archaeological fabrics

The orientations of the artefacts measured in levels 497C (upper unit), and 497D (lower unit), and S1B and S1C (lower unit) of Cova Gran show a random distribution, with no preferential orientation (Fig. 8). This arrangement also coincides with the values of the L index, with distant values of linear fabrics (Table 3A). Only level 497C has somewhat higher values, with $L = 16.44\%$ and $p = 0.07$. This value of p is above 0.05, below which Lenoble and Bertran (2004) situate eminently linear fabrics. The index of the mean vector $R\%$ does not indicate strongly lineal orientations either, the four levels being situated between values of 29 and 14% (Table 3A). In levels 497C, 497D and S1B the preferential orientation of most of the clasts is in the northern half (Fig. 8). In the stereographic projections, slight concentrations that coincide with the dominant eigenvector V_1 can be observed; these show NE orientations for levels 497C, S1B and S1C, and west for level 497D (Table 3B). In these projections there are also dip angles with low value averages, although high values are also observed (Fig. 8).

The K index values rule out linear fabrics ($K << 1$, Table 3C), while the C parameter shows moderate or low strength fabrics ($1 < C < 1{,}6$). The calculation of the isotropy and elongation indices

Table 2
Indices calculated for the analysis of the sedimentary fabrics of Cova Gran (497A, 497C, S1B) and Roca dels Bous (N12) levels: *N*, number of clasts measured. A) Curray's two-dimensional index and mean vector: *L*, Curray's two-dimensional index (%); *p*, probability (Rayleigh text); *A*, azimuth; *D*, dip angle; *R%*, degree of preferential orientation. B) Eigenvalues and eigenvectors calculated for the sample: Eigenvector *V*1; Eigenvector *V*2; Eigenvector *V*3; *A*, azimuth; *D*, dip angle; Eigenvalue *S*1, Eigenvector *S*2, Eigenvector, *S*3. C) Fabric indices: *K*, Woodcock index (1977); *C*, fabric strength; *I*, isotropy index; *E*, elongation index; *F*, flatness index; *CGI*, cluster-girdle index.

A

			Curray's index		Mean vector		
	Level	*N*	*L*	*p*	*A*	*D*	*R%*
Cova Gran	497A	81	7.33	0.6468	355.60	18.29	20.8
	497C	67	9.41	0.5527	285.50	1.75	30.9
	S1B	131	10.13	0.2609	269.50	6.31	29.1
La Roca dels Bous	N12	215	9.60	0.1380	234.90	2.48	27.3

B

			V1			*V2*			*V3*		
	Level	*N*	*A*	*D*	*S1*	*A*	*D*	*S2*	*A*	*D*	*S3*
Cova Gran	497A	81	31.56	10.93	0.49	299.10	12.29	0.40	162.00	73.44	0.11
	497C	67	101.00	0.25	0.51	10.98	10.75	0.44	192.30	79.25	0.05
	S1B	131	259.74	4.98	0.50	350.65	10.28	0.43	144.27	78.55	0.08
La Roca dels Bous	N12	215	222.41	0.93	0.50	312.43	1.79	0.41	105.05	87.99	0.09

C

	Level	N	K	C	I	E	F	CGI	Confidence level
Cova Gran	497A	81	0.14	1.51	0.22	0.17	0.27	0.22	>99%
	497C	67	0.07	2.40	0.09	0.14	0.11	0.15	>99%
	S1B	131	0.09	1.86	0.16	0.14	0.18	0.16	>99%
La Roca dels Bous	N12	215	0.15	1.70	0.18	0.19	0.23	0.24	>99%

(Table 3C) situate levels 497D, 497C, S1B and S1C in the planar fabrics sector, although with a considerable degree of isotropy, with *I* values of between 0.2 and 0.4 (Fig. 9, Table 3C).

Level N12 of Roca dels Bous presents an irregular distribution of orientations (Fig. 6), and *L* and *R%* values that discount linear fabrics (Table 3A). In the stereographic projections of the artefacts of this level different concentrations and medium-low and high values in the dip angles can be observed (Fig. 8). The orientation of the dominant vector presents WNW orientations and dip angles of 1.74° (Table 3B).

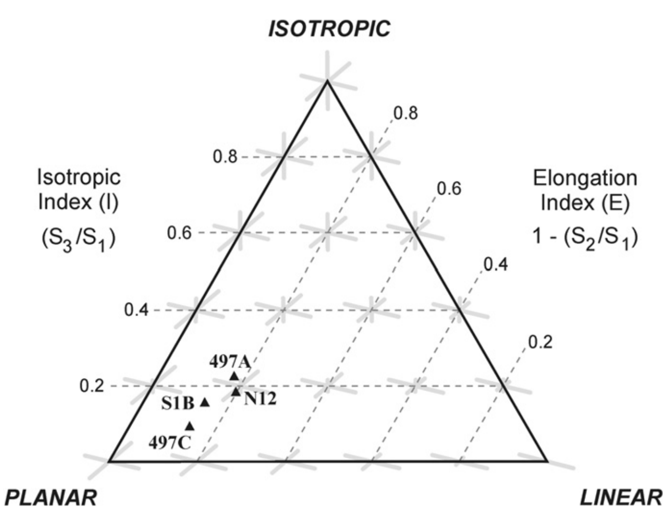

Fig. 7. Fabric of the sedimentary levels of Cova Gran (497A, 497C, S1B) and the Roca dels Bous (N12), according to the Benn's diagram.

The *K* index gives values of planar fabrics ($K = 0.22$), but with the lowest strength fabric ($C = 0.91$). In this sense, the isotropy index has a high value ($I = 0.40$, Table 3C), which puts it in an area close to the isotropic fabrics within the general shape triangle (Fig. 9).

5. Interpretation

The various techniques applied for analysing the sedimentological fabrics of the Cova Gran and level N12 of Roca dels Bous produced similar results. Clasts do not present preferential orientations (Fig. 6), giving different two-dimensional values from linear fabrics ($7 < L < 11$, $0.65 < p < 0.14$). This is also confirmed by three-dimensional methods ($20 < R\% < 30$), which situate the data in eminently planar fabrics ($0.07 < K < 0.15$), located in the lower left part of the Benńs diagram (Fig. 7). These data indicate the absence of post-depositional movements (solifluxion, surficial creep) or flows during sedimentation that would have orientated the clasts lineally, at least in the range of average sizes (>2 mm, gravel size). The absence of high energy flows capable of sorting gravel-size clasts suggests that the Sant Miquel ravine had little impact on the sedimentation processes at Cova Gran, despite its proximity to the sedimentary sequence and the presence of Upper Pleistocene palaeoflood deposits in nearby valleys (Rico, 2004). The planar shape of the fabrics is supported by the sedimentary characteristics of the deposits, formed by subangular and poorly classified autochthonous clasts and blocks, caused by gravitational processes with gentle depositional slopes. However, in level 497A subrounded clasts have been observed, which could come from the bedrock brecchias or washed down from the hill above the rock-shelter. With regard to the latter, the sediment matrix contains significant concentrations of quartz and feldspars that could come from limestone dissolution or be related with very low-energy surface runoff caused by infiltration which emerges from the limestone during periods of greater humidity. In any case, this runoff would have been incapable of rearranging the gravel-sized clasts linearly.

In the Benn's diagram, the Cova Gran and Roca dels Bous fabrics display a low degree of isotropy (Fig. 7, Table 2C). In gravitational materials, a certain component of isotropy is frequently imposed by the slope and the roughness of the depositional plane (Benn, 1994; Mills, 1983; Bertran et al., 1997). In this case, the gentle slopes of the Cova Gran and Roca dels Bous deposits would have defined this low degree of isotropy, somewhat more accentuated in levels N12 (with slightly convex geometry) and in level 497A. The latter level occupies the top of the sequence in Cova Gran and part of the isotropy could be influenced by current processes of trampling. However, this influence must be minimal since the clasts measured were located in the bottom and middle part of the level, and were not exposed to the surface of the ground.

In the proximal and intermediate parts of gravitational deposits with acute slopes, the major axis of clasts tends to be orientated along the line of maximum inclination, although a large number of clasts ordered perpendicularly to the slope due to downhill rolling are also noted (Bertran et al., 1997). Both directions constitute dominant orientations, reflected by the eigenvectors V_1 and V_2 which define a plane parallel to the hillside (Benn, 1994). In Cova Gran the mean vector does not reflect the depositional slope, but can be observed in the distribution of the azimuths (Fig. 6) and, in particular, in the orientation of the dominant vector V_1 (Table 2B). The orientation of this vector in the archaeological levels analysed reflects the geometric discordance that exists between the gravitational cones of the lower unit and the upper unit. The eigenvector V_1 of the lower unit (S1), represented by level S1B, presents orientations towards the W (259°), while that in the levels of the upper unit (497), V_1 has E

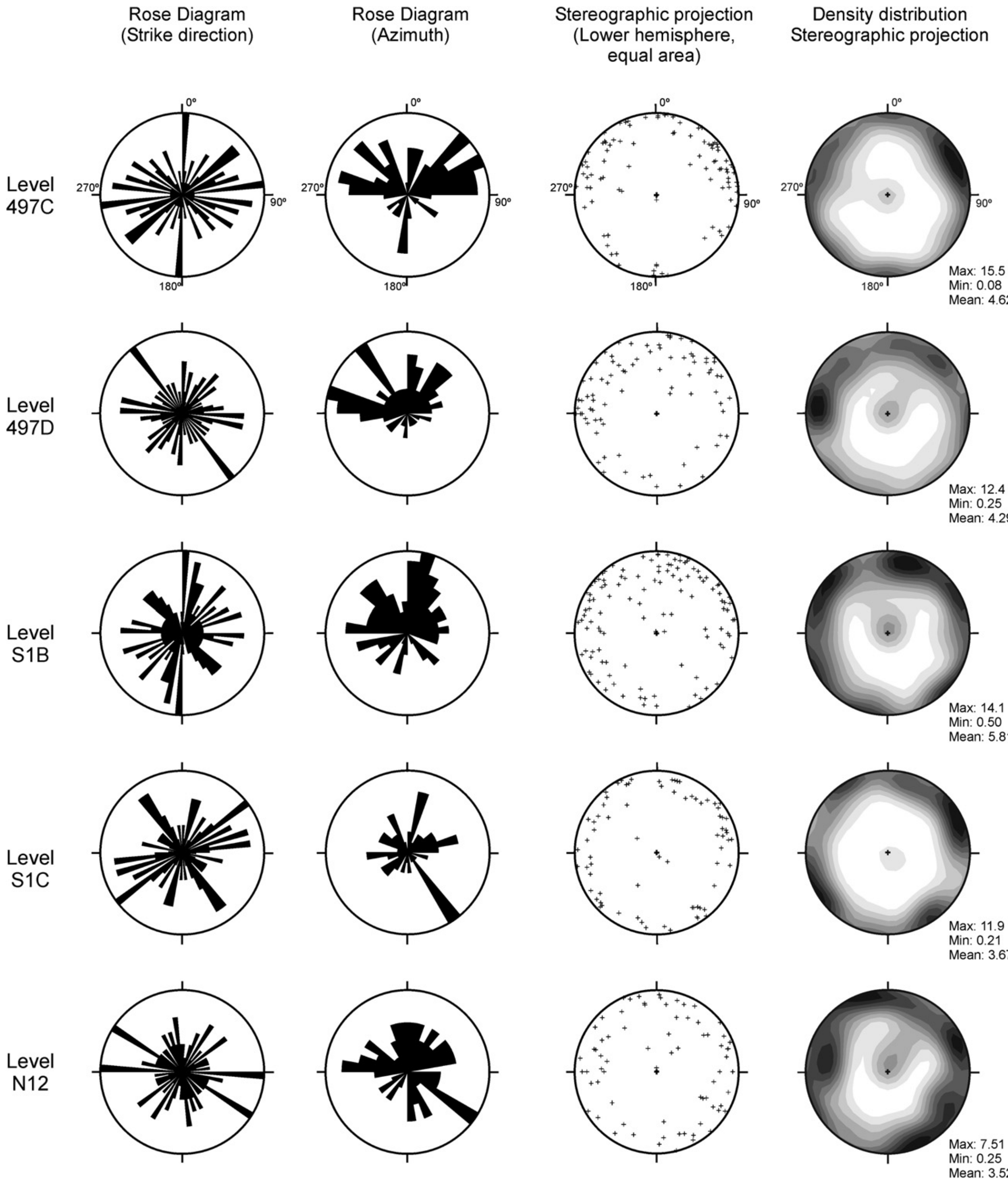

Fig. 8. Rose diagrams (strike and azimuth), stereographic projection and density distribution of the measurements of azimuth and dip angle for the artefacts in the archaeological levels of Cova Gran (497C, 497D, S1B, S1C) and Roca dels Bous (N12). See Table 2 for the number of measurements in each level.

azimuths (101°, level 497C), or NE to roof (31°, level 497A). This shows that the depositional origins for the two cones were different, maybe separated by a markedly erosive period. This could have generated an erosive surface with a palaeotopography inclined towards the E, to which the base of the cone of the upper unit adapted. On the basis of its direction towards the E, the erosive processes that dismantled part of the lower level would correspond to the W-E flooding of the Sant Miquel ravine. With the aggradation of the cone of the upper unit, the influence of the palaeotopography in the distribution of the clasts would become less obvious, the dynamics of the gravitational processes playing a more influential role. This process could have been partly responsible for the slight difference in the orientation of eigenvector V_1 between levels 497C and 497A.

On the other hand, the fabrics of the artefacts display intrinsic characteristics that differentiate them from the sedimentological

Table 3
Indices calculated for the analysis of the archaeological fabrics of the Cova Gran (497C, 497D, S1B, S1C) and Roca dels Bous (N12) levels: *N*, number of artefacts measured. A) Curray's two-dimensional index and mean vector: *L*, Curray's two-dimensional index (%); *p*, probability (Rayleigh test); *A*, azimuth; *D*, dip angle; *R%*, degree of preferential orientation. B) Eigenvalues and eigenvectors calculated for the sample: Eigenvector *V*1; Eigenvector *V*2; Eigenvector *V*3; *A*, azimuth; *D*, dip angle; Eigenvalue *S*1, Eigenvector *S*2, Eigenvector, *S*3. C) Fabric indices: *K*, Woodcock index (1977); *C*, fabric strength; *I*, isotropy index; *E*, elongation index; *F*, flatness index; *CGI*, cluster-girdle index.

A

			Curray's index		Mean vector		
	Level	*N*	*L*	*p*	*A*	*D*	*R%*
Cova Gran	497C	97	16.44	0.0727	68.01	3.22	28.5
	497D	90	8.23	0.5433	45.61	13.58	14.6
	S1B	122	4.39	0.7908	345.30	17.36	24.5
	S1C	77	6.52	0.7206	34.65	5.69	24.9
La Roca dels Bous	N12	74	5.03	0.8212	303.50	10.52	19.4

B

			V1			*V2*			*V3*		
	Level	*N*	*A*	*D*	*S1*	*A*	*D*	*S2*	*A*	*D*	*S3*
Cova Gran	497C	97	75.02	0.75	0.51	344.86	11.88	0.38	168.58	78.10	0.11
	497D	90	275.27	9.50	0.45	8.61	19.22	0.40	160.29	68.39	0.15
	S1B	122	42.19	7.11	0.44	310.50	13.31	0.41	159.63	74.85	0.16
	S1C	77	56.65	2.88	0.49	326.51	2.74	0.41	192.96	86.03	0.10
La Roca dels Bous	N12	74	298.75	1.74	0.44	29.03	9.98	0.38	197.89	80.85	0.18

C

	Level	N	K	C	I	E	F	CGI	Confidence level
Cova Gran	497C	97	0.24	1.51	0.22	0.25	0.29	0.32	>99%
	497D	90	0.12	1.06	0.35	0.11	0.39	0.16	>99%
	S1B	122	0.07	1.02	0.36	0.06	0.38	0.10	>99%
	S1C	77	0.14	1.58	0.21	0.18	0.25	0.22	>99%
La Roca dels Bous	N12	74	0.22	0.91	0.40	0.15	0.47	0.25	>99%

fabrics and would be associated with human activity, indicating that both the levels of the lower (S1B) and upper units of Cova Gran (497C), and level N12 of Roca dels Bous, are *in situ*. In Cova Gran, the orientations of artefacts display a high dispersion, although the majority are located on the northern semi circumference (Fig. 8), as in the case of the orientation of clasts. This indicates that the local topography had a certain influence, and this is also implicit in the direction indicated by the dominant eigenvector V_1 (Table 3A), although it is not a one-to-one relationship. In the same way, in level 497C of Cova Gran and level N12 of Roca dels Bous, the V_1 presents a similar orientation both in the clasts and in the artefacts, of a western tendency for level N12 (298°–222°), and an eastern tendency for level 497C (75°–101°). This direction of V_1 in the archaeological fabric coincides with the depositional slope of the sedimentary unit, but not with level 497C, whose V_1 vector is orientated towards the west, contrary to the dip angle of the strata of the upper unit of Cova Gran.

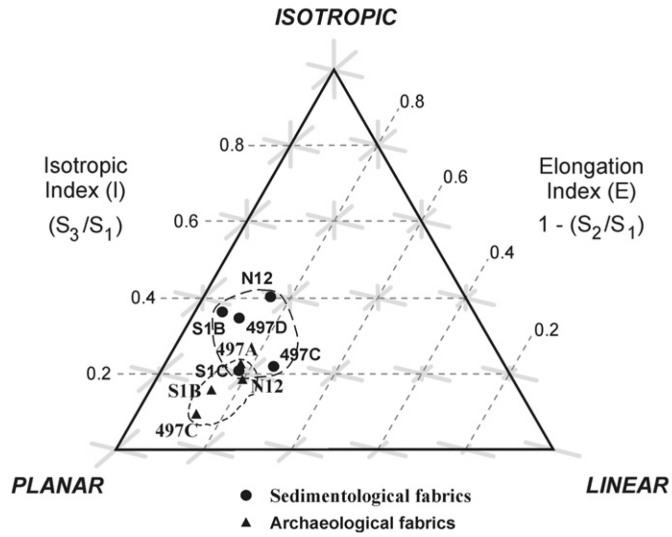

Fig. 10. Clast and artefact fabrics of the levels of Cova Gran and Roca dels Bous, Benn's diagram. Note the more isotropic character of the archaeological fabrics compared with that of clasts within the same sedimentary levels that contains them (levels S1B, 497C and N12).

The archaeological fabrics of levels S1B and N12 show more random directions than the respective sedimentological fabrics, as indicated by lower values of *L* (Tables 2A and 3A). The greater dispersion of the direction and the presence of greater dip angle in the artefacts (stereograms of Fig. 8) increase the three-dimensional dispersion of the archaeological fabrics compared with the sedimentological fabrics (levels 497C and S1B of Cova Gran and level N12 of Roca dels Bous), indicated by lower values of the *R%* index in the samples of artefacts (Tables 2A and 3A).

In the same way, the archaeological fabrics of levels 497C, S1B and N12 are more isotropic than the sedimentary fabrics, as can be deduced from the lower strength fabric and the higher isotropy indices indexes presented by the artefacts compared with the clasts (Tables 2C and 3C). The elongation values are lower in the archaeological fabrics (levels S1B and N12), except for level 497C, where greater elongations agree with the highest value of *L* that characterises this level. The fact that the archaeological fabrics are more isotropic than the sedimentary fabrics that contain them (Fig. 10) is due to a greater dispersion both in the orientation and in the dip angle of the clasts. The different pattern displayed by the archaeological fabrics is attributable to human action. Human accumulations of archaeological materials in particular areas and the presence of hearths generate the rearrangement of contiguous areas and, therefore, their disturbance. We should not overlook the fact that unintentional processes, such as trampling, could have also contributed to taphonomic disturbances.

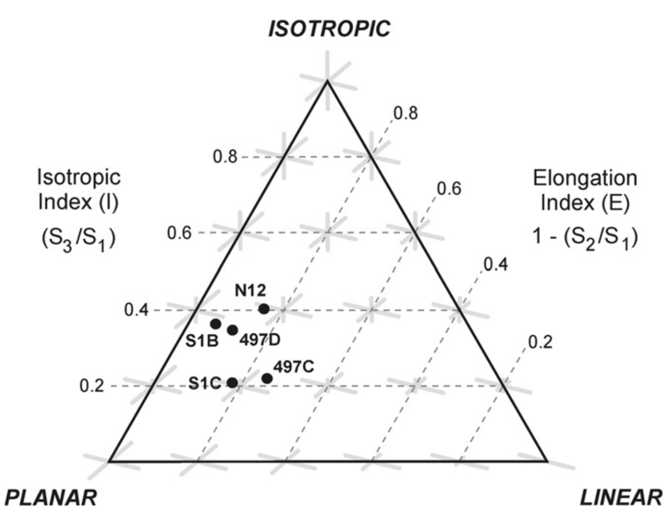

Fig. 9. Fabrics of the archaeological levels of Cova Gran (497C, 497D, S1B, S1C) and Roca dels Bous (N12), according to the Benn's diagram.

6. Conclusions

Fabrics analysis is a useful method for determining the formation dynamics of archaeological sites, especially in combination with other geological and sedimentological data. A new methodology has been developed in this study, based on analysing the sedimentary fabrics (orientations and slopes of natural clasts) and archaeological fabrics (orientations and slopes of artefacts) separately. This new procedure permitted the effective determination of non-significant disturbance of the archaeological assemblages at Cova Gran (Middle and early Upper Palaeolithic) and Roca dels Bous (Middle Palaeolithic) due to sedimentary or post-depositional processes.

The sedimentary fabrics of the Cova Gran levels indicate gravitational processes of rock-falling in depositional planes of gentle slopes, in addition to the influence of minor surface runoff. The sedimentary fabrics are eminently planar shaped, with slight isotropic components attributable to the inclination of the depositional plane. As the orientation of planes V_1–V_2 shows, Cova Gran levels are organised in two stratigraphic sequences with different geometry separated by an erosive surface.

The archaeological fabrics in Cova Gran present intrinsic characteristics differentiated from the sedimentary environment that contains them, indicating that the archaeological assemblages have not been reorganised by natural processes, at least in the range of sizes considered (>20 mm). This observation is relevant when evaluating the possible effect of the Sant Miquel ravine on this deposit, since palaeoflooding events during the Upper Pleistocene have been reported in similar incised valleys belonging to the same geographical area (Rico, 2004).

The archaeological fabrics systematically present a greater degree of isotropy, quantified in a notable increase of I (of approximately +0.2), related with greater dispersions in the orientation and slope that can be attributed to human activity. This difference between the archaeological fabrics and the sedimentary fabrics was observed not only in the levels of Cova Gran, but also in the Roca dels Bous site, formed under similar sedimentary dynamics.

This inference implies that they are homogeneous archaeological assemblages, with little post-depositional alteration, and so the human activities in levels accumulated by Neanderthals (S1B, S1C of Cova Gran and Roca dels Bous N12) and anatomically modern humans (497C, 497D of Cova Gran) can be effectively reconstructed. In this respect, the spatial organisation detected in the horizontal and vertical dispersion of archaeological items significantly reflects the activities of humans at the site. In this sense, the information concerning the site formation processes described in this study is relevant for discussing the *tempo* and *modo* of the Middle to Upper Palaeolithic transition in the Eastern Pyrenees (Martínez-Moreno et al, submitted for publication) and the rest of the Iberian Peninsula.

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Appendix A. Supplementary information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jas.2009.07.012.

References

Benn, D.I., 1994. Fabric shape and the interpretation of sedimentary data. Journal of Sedimentary Research A64, 910–915.

Benn, D.I., Ringrose, T.J., 2001. Random variation of a fabric eigenvalues: implications for the use of A-Axis fabric data to differentiate till facies. Earth Surface Processes and Landforms 26, 295–306.

Bertran, P., Hétu, B., Texier, J.P., Steijn, H., 1997. Fabric characteristics of subaerial slope deposits. Sedimentology 44, 1–16.

Bertran, P., Lenoble, A., 2002. Fabriques des niveaux archéologiques: Méthode et premier bilan des apports à ĺetude taphonomique des sites paléolithiques. Paleo 14, 13–28.

Curray, J.R., 1956. Analysis of two-dimensional orientation data. Journal of Geology 64, 117–134.

Drake, L., 1974. Till fabric control by Clast shape. Geological Society of America Bulletin 85, 247–250.

I.C.C., 2002. Mapa geològic de Catalunya 1:250.000, second ed. Institut Cartogràfic de Catalunya, Generalitat de Catalunya, Barcelona.

Jordá Pardo, J.F., 2005. El registro arqueológico kárstico durante el Pleistoceno superior final en la vertiente meridonal de los Pirineos: geoarqueología, geodinámica y sedimentación. In: Cura, M., Sóler, N., Maroto, J. (Eds.), Prehistoria Pyrenaica. II Congrés Internacional Història dels Pirineus, Centre Associat de la UNED – Girona, pp. 129–159.

Jordá Pardo, J.F., Martínez, J., Mora Torcal, R., Sánchez Casado, F.L., 1994. Modelos deposicionales y ocupación antrópica en el NE de la Península Ibérica durante el Paleolítico Medio. In: Jordá Pardo, J.F. (Ed.), Geoarqueología (Actas de la 20 Reunión Nacional de Geoarqueología. I.T.G.E., Madrid, 14, 15 y 16 de diciembre de 1992). Instituto Tecnológico Geominero de España y Asociación Española para el Estudio del Cuaternario, Madrid, pp. 35–48.

Kjaer, K.H., Krüger, J., 1998. Does clast size influence fabric Strength? Journal of Sedimentary Research 68, 746–749.

Lenoble, A., Bertran, P., 2004. Fabric of Palaeolithic levels: methods and implications for site formation processes. Journal of Archaeological Science 31, 457–469.

Lenoble, A., Bertran, P., Lacrampe, F., 2008. Solifluction-induced modifications of archaeological levels: simulation based on experimental data from a modern periglacial slope and application of French Palaeolithic sites. Journal of Archaeological Science 35, 99–110.

Martínez Moreno, J., Mora, R., de la Torre, I. The middle-to-upper Palaeolithic transition in Cova Gran (Catalonia, Spain) and the extinction of Neanderthals in the Iberian Peninsula. Journal of Human Evolution, submitted for publication.

Martínez Moreno, J., Mora, R., de la Torre, I., 2004. Methodological approach for understanding middle Palaeolithic settlement dynamics at La Roca dels Bous (Noguera, Catalunya, Northeast Spain). In: Conard, N.J. (Ed.), Settlement Dynamics of the Middle Palaeolithic and Middle Stone Age. Kerns Verlag, Tubingen, pp. 393–413.

Martínez-Moreno, J., Mora, R., de la Torre, I., Casanova, J., 2006. La Roca dels Bous en el contexto del Paleolítico Medio final del Noreste de la Península Ibérica. Zona Arqueológica 7, 252–263.

McPherron, S.J.P., 2005. Artifact orientation and site formation processes from total station proveniences. Journal of Archaeological Science 32, 1003–1014.

Mills, H.H., 1983. Clast-Fabric strength in hillslope colluviom as a function of slope angle. Geografiska Annaler 65, 255–262.

Mora, R., de la Torre, I., Martínez Moreno, J., 2004. Middle Palaeolithic mobility and land use in the Southwestern Pyrenees: the example of level 10 in La Roca dels Bous (Noguera, Catalunya, Northeast Spain). In: Conard, N.J. (Ed.), Settlement Dynamics of the Middle Palaeolithic and Middle Stone Age. Kerns Verlag, Tubingen, pp. 415–435.

Peña Monne, J.L., 1983. La Conca de Tremp y sierras prepirenaicas comprendidas entre los ríos Segre y Noguera Ribagorzana. Estudio geomorfológico. Instituto de Estudios Ilerdenses Lleida.

Rico, M. 2004. Las paleocrecidas en la cuenca media del río Segre durante el Pleistoceno superior-Holoceno: registros morfosedimentarios y análisis hidrológico. Ph.D. Dissertation, University of Zaragoza.

de la Torre, I., Martínez-Moreno, J., Mora, R., Pizarro, J., 2005. Los remontajes del nivel 10 de la Roca dels Bous (Cataluña, España); una herramienta analítica para reconstruir los procesos de formación de los yacimientos. In: Ferreira Bicho, N. (Ed.), O Paleolítico (IV Congresso de Arqueología Peninsular). Centro de Estudios de Património, Departamento de História, Arqueologia e Património, Universidade do Algarve, Faro, pp. 397–406.

Woodcock, N.H., Naylor, M.A., 1983. Randomness testing in three-dimensional orientation data. Journal of Structural Geolology 5, 539–548.

Woodcock, N.H., 1977. Specification of fabric shapes using an eigenvalue method. Geological Society of America Bulletin 88, 1231–1236.