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NOTE DE L'ÉDITEUR

This article was written in 2005 following the round table held in Hasparren in 2003. It aimed at presenting a statement of the research on the Palaeolithic sequence of the cave of Isturitz. We are presenting here the geomorphological, lithostratigraphical and geoarchaeological results up to that date.

We are thanking Christian Normand and Alain Turq, in charge of the excavation fieldwork, who made this study possible by facilitating access to the field and allowing the use of the infrastructure and financial resources of the operation. We are also thanking Matthieu Ruhé and Dominique Todisco for their rigorous proofreading.

Introduction

- 1 The archaeological excavations undertaken since 1996 in the site of Isturitz, initially directed by A. Turq (1996-1997) and then by Ch. Normand (2000-2005), gave us the opportunity to conduct an in-depth geological study of the cave, of its filling and geomorphological environment.
- 2 The main objectives were to understand the overall evolution of the karst system, to establish the lithostratigraphy of the deposits of the filling, to characterize its origin and to evaluate the impact of geological processes on the integrity of the archaeological assemblages contained in the sediments. We are presenting hereafter a summary report of the main results obtained in these different fields.

1 - Study methods

- 3 The study of the geomorphological context of the site was started by field work as well as by the analysis of the 1/25000 topographical map and the 1/50000 geological map of Iholdy.
- 4 The sections, placed in their morphological context, have been described in terms of facies. These were defined mainly on the basis of directly visible criteria in the field: general organization of deposits (massive deposits, with regular or irregular stratification), characteristics of the stratification (thickness, slope, continuity, morphology and type of contact of the different strata), structure of sediments (openwork, clast-supported or matrix-supported structure), graded-beddings, granulometry, morphology and fabric of rock fragments.
- 5 Grain size analyzes were carried out on the matrix of the deposits (i.e. particles less than 2 mm) as well as on archaeological objects. On the matrix sediments, they were achieved by laser diffractometry (device of the Malvern 2600 type) and by mechanical sieving. The archaeological objects recorded during the excavation and collected by sieving were measured with a slide caliper or screened to establish the proportion of objects for three-dimensional classes: objects stopped by the mesh widths 2, 4 and 10 mm. These classes are chosen because they allow a comparison with the experimental model of objects moved by runoff (Lenoble 2005).
- 6 The fabric of rock fragments and archaeological objects was defined from the measurement of the dip and the strike of their main axis (at least 40 measurements per sample). Only those elements with an elongation rate (a/b) greater than 2 were considered. The series of data obtained in this way were processed according to two statistical methods (Bertran and Lenoble 2002). The first one is of two-dimensional type (Curry 1956). It permits to define a Vector Magnitude L , which is used to calculate the probability p to obtain a value higher than L by the combination of n vectors of random orientation (Rayleigh test). The second one, of three-dimensional type (Watson 1956; Mark 1973; Benn 1994), is based on the calculation of eigenvalues E_1 , E_2 and E_3 , which are used to establish an elongation index EL ($= 1 - E_2 / E_1$) and an isotropy index IS ($= E_3 / E_1$) that describe the degree of organization and the shape of the fabrics (girdle vs cluster for the first one and girdle or cluster vs cloud for the second one). We used the "Stereo" software (McEachran 1990) to calculate the values involved in the three-dimensional analysis of the data.
- 7 Finally, these analyzes were supplemented by the study of the microscopic organization of sediments. These were made from large-size thin sections cut in oriented blocks, vacuum impregnated by a polyester resin according to the technique designed by Guilloché (1980). The terminology used for describing these thin sections is adapted from that defined by Bullock *et al.* (1985).
- 8 The facies thus characterized were interpreted by reference to the sedimentary models defined in active environment.

2 – Geomorphological context of the site

- 9 The site of Isturitz is a very large-size cave dug in a block of Urgonian micritic and biopelsparitic limestone (Boissonnas *et al.* 1974). This block bars the Arberoue valley whose path is visibly controlled by a thrusting structure, oriented north-south (fig 1).

Figure 1 - Extract of the 1/50 000 geological map of Iholdy (modified) showing 1) the location of the calcareous block in which the cave of Isturitz is carved as well as 2) the thrust mentioned in the text.

- 10 Isturitz cave is the upper level of a karstic system comprising three stepped levels, the middle and lower levels being called Oxocelhaya and Erberua respectively (fig. 2). These different levels correspond to ancient local base levels and thus mark the valley's downcutting stages. The Arberoue River currently flows in the lower level.

Figure 2 - SW-NE Section of the calcareous hill showing the three stepped levels of the karstic system (following Larribau et Prudhomme, 1983, modified).

- 11 A morphological saddle at the north-east of the block (fig. 3) probably testifies to an ancient passage of the Arberoue River. Given its altitude (15 m above the valley bottom, 45 m lower than the current entrance to Isturitz cave), this passage has been probably active until a rather late Pleistocene period.

Figure 3 - Panoramic view showing the present-day cave entrance as well as the morphological saddle that develops in the eastern part of the calcareous block.

- 12 The upstream and the downstream slopes of the karstic block display a clear asymmetry. The upstream slope, facing south-east, is abrupt and convex as a result of the toe undercutting by the stream. The downstream slope, oriented to the northwest, shows a concave profile due to the presence of a detrital prism at its lower part.
- 13 On the upstream slope (SE), a strip of detrital deposit located in a 10 m wide erosional furrow extends from the upper part of the slope to the present entrance of Isturitz cave. These deposits, laid down by runoff and by rock falls, have yielded a Mousterian industry. They are partially cemented by calcite and are responsible for the sealing of the southeast entrance of the cave.
- 14 On the downstream slope (NW), the above-mentioned detrital prism has sealed the northern entrance of the cavity and extends to the lower part of the slope. These rockfall deposits, also penetrated into the cave up to the level of the current passage between the Isturitz cave *stricto sensu* and that of Oxocelhaya. In this area, R. and S. Saint-Perrier found Aurignacian, Gravettian, Solutrean and Magdalenian industries (Saint-Perrier 1936; Saint-Perrier and Saint-Perrier 1952). These rock-debris talus continued to form during the Holocene. Indeed, Bronze Age levels were found buried 3 m deep (oral communication from A. Turq). This accumulation probably has, at least partially, a structural control: the parent rock is cut by vertical decimetric-spaced joints having a N50° to N60° orientation; the latter delimit panels that gradually open up due to weathering and gravity, then tilt over the slope and fragment.

3 - Evolution of the upper karstic network

15 The filling deposits were observed at numerous locations in the Isturitz cave, both in the St-Martin room and in the Isturitz room (fig. 4). The data collected make it possible to propose the following overall evolution:

- After an in-cutting phase in a phreatic context (Early Quaternary?), a long evolutionary episode takes place in a vadose context: at first, a torrential stream has passed through the cave and has deposited alluvium composed of very large pebbles and cobbles visible in the SW part of the St-Martin room; then carbonate-rich percolations built imposing stalagmitic columns that we can see particularly in the Isturitz room.
- A large collapse occurs in the SW part of the cave. Following this event, or penecontemporaneously with it, it is possible that the cave was momentarily submitted to a phreatic system. The dissolution pockets visible on the walls and on the large stalagmitic pillars of the Isturitz room are indeed classically interpreted as evidence of a phreatic action (Bretz 1942; White 1988). This hypothesis implies a significant increase of the local base level and the flooding of the cave. Such an evolution can be explained by a catastrophic phenomenon, for example a rock avalanche triggered by an earthquake that temporarily has blocked the valley. This hypothesis, which is very plausible given the high seismicity of the region, also permits the aforementioned collapse to be explained. Nevertheless, researchers have found that bat droppings can also produce pockets of dissolution (Lundberg and McFarlane 2009; Martini 2000). This second explanation makes it possible to avoid considering a catastrophic phase but does not account for the observed collapse.
- A return, or the continuation (according to the chosen hypothesis), to an evolution in vadose context with the formation of detrital and phosphatic deposits is then observed. From a general point of view, sedimentation evolved from a period dominated by runoff, or even by high-energy flows linked to the functioning of subterranean streams, towards a period dominated by rockfall processes. The last sedimentary phase is of a chemical nature and corresponds to the formation of a flowstone, quasi-generalized and dated to the Holocene.

Figure 4 - Plan of the upper level of the karstic system. Stars indicate the study loci. The grey rectangle represents the current excavation zone.

- 16 This evolution may have both an intrinsic (evolution of the karst system) and an extrinsic (regional climatic evolution) control. Indeed, the almost exclusive formation of rock fall deposits in the top part of the detrital deposits as well as the very limited sedimentation episode between the last Aurignacian level and the Magdalenian occupation probably reflect a cold to very cold phase. This last one is also expressed by the development of a platy structure in fine-textured deposits as well as by cryoturbation (fig.5) and solifluction phenomena affecting the layers containing the Aurignacian remains. This phase, probably contemporaneous with a cold maximum of the isotopic stage 2, may have led to the development of a permafrost whose presence has been shown elsewhere in Aquitaine (Texier and Bertran 1993; Texier 1996; Lenoble *et al.* 2012). Such a phenomenon could have impeded most of the water infiltrations in the endokarst, thereby inducing a relative paralysis of the geomorphologic system. Indeed, the efficiency of freezing is largely dependent on the degree of saturation of the bedrock (e.g. Lautridou 1976; Berrisford 1991; Matsuoka 1991) and the transfers of matter (dissolved or as particles) are greatly reduced due to the rarity and deficiency of aqueous flows.

Figure 5 - View of cryoturbations. Pictured deposit is one-meter thick. This photo is taken in square V₁31 of the excavation area. Stones are lying in accordance with the distorted limits of units. Involutions tend to damp downwards.

4 - Geological study of Ch. Normand's excavations sector

4.1 – Lithostratigraphy

- 17 Five lithostratigraphic units have been recognized. Their identification is based on the observation of the section located in the current excavation area (fig.6) and, for the two lower units not yet reached by the excavation, by the study of the sections left by Passemard and Laplace. Equivalences between the lithostratigraphy, the archeostratigraphic subdivisions of the current excavation established by A. Turq and C. Normand and the Passemard and Saint-Perrier stratigraphies are given in table 1.

Figure 6 - Section observed at the end of the 2005 campaign in the western part of the excavation zone (explanation in text).

Table 1 - Correspondence between the different stratigraphic systems.

Fouilles actuelles		Fouilles anciennes	
Lithostratigraphie Texier (1997)	Archéostratigraphie (Normand, 2002)	Couches Passemard (Passemard, 1944)	Couches Saint-Perrier (Saint-Perrier R. et S., 1952)
I	c. 1 (a, b et c) c.2	Couche stalagmitique	Plancher
II	<i>Non représenté</i>	E x, y	S I S II
	c. 3a et b	<i>Non représenté</i>	
III	a c. 3b [base], c4a, c4b, c4c1 à c4c5	A	S III
	b c.4c6 à c.4c12		
	c c. 4d1a		
IV	c. 5	M	S IV
V	c. 6	Niveau à Ours	
	- non observé -	Limons à Ours	Plancher « sous-plancher »

18 The following can be seen from top to bottom:

- Unit I: flowstone of variable thickness intercalated with lenses of brown to very dark brown gray (2.5Y 3/2) few centimeters thick laminated clays. The lower limit of the unit is sharp. The clay lenses yielded some pre- and protohistoric remains.
- Unit II: matrix-supported diamicton about ten centimeters thick in the south passing laterally to the north into a clast-supported diamicton of metric thickness. The calcareous blocks and rock fragments are angular and rather flat, heterometric, non-oriented and sometimes covered with a creamy white phosphate coating.

19 The matrix is composed of massive strong brown silty-clay sands (7.5YR 4/6). It display a granular microstructure composed of aggregates surrounded by coatings (fig. 7a).

Figure 7 - Microfacies of lithostratigraphic units II to IV: a, Unit II; the matrix displays an aggregated microstructure. Well-developed cappings are visible around aggregates (LN – line: 1 mm); b, Unit IIIb. Detail of a sedimentary lens containing numerous archaeological remains. Laminae composed of sorted, carbonized and non-carbonized osseous fragments are visible (LN – line: 1 mm); c, Unit IIIa; partial view of a sorted structure not affected by the platy structure (LN – line: 1 mm); d, Unit III; a platy structure superimposed on a granular structure with numerous ovoids (LN – line: 1 mm); e, Unit IIIc; view of an eluviated zone. More or less disaggregated ovoids adjoin washed silty zones (LN – line: 500 microns); f, Unit IV, upper part; pseudo-sands and phosphatic grains (LN – line: 1 mm).

- 20 The facies variations of unit are related to the morphology of the ceiling of the cave. Thus, south of the excavation zone, the deposit is represented only by plurimetric slabs linked to the collapse of the banks of the surrounding rock (White 1988's "slab breakdown" – p. 229). Conversely, the unit thickens towards the north where it is composed of heterometric rock fragments just below karstified faults that form deep grooves in the ceiling and along which the rock is strongly fractured.
- 21 Involutions are observable in particular at the base of the unit. They are expressed by low amplitudes undulations, inframetric to suprametric. The lower limit is more or less clear depending on the color contrast with the underlying deposits. This limit is itself undulating, in accordance with the involutions found within the unit.
- 22 The Magdalenian industry found by Passemard (layer E) and R. and S. de Saint-Perrier (layer S I) is not represented in the excavation zone. The remains collected in this unit are ascribed to an Aurignacian, "generally belonging to a facies close to the early Aurignacian" (Normand 2002 - p. 98).
  - Unit III: It is a rudimentary stratified deposit, on average one meter thick, which contains a Proto-Aurignacian industry. The stratification of the deposit is linked to variations in color and abundance in rock fragments. Three levels, labelled from top to bottom IIIa, IIIb and IIIc, were defined.

Level IIIa

- 23 This level, 30 to 40 cm thick, gently dips northward. To the south, it has a clast-supported diamicton facies, which becomes progressively less stony to the north. The fine fraction is composed of silty-clay pseudo-sands, the color of which varies from dark red brown (5YR 2.5/2) to dark brown (7.5YR 4/4). The lower limit is sharp and slightly undulated. There is a lateral evolution of the sedimentary facies. In the southern part of the section, only a few concave-based subdecimetric structures associated with coarse sands and small grains are present at the top of the unit. In the middle part of the section, a crude sub-horizontal lamination develops. At the northern end of the section, it gives way to a bedded deposit. The bedding is then formed by cut-and-filled lenses, more or less rich in granules and dipping by about ten degrees to the north. Some of these lenses are very rich in archaeological components, mainly bone fragments, burnt or not (fig. 7b).
- 24 Moreover, to the north of the section, the top part of this level is marked by a more clayey bed, ocher red in color, of undulating morphology and decimetric thickness.

Level IIIb

- 25 It is a lenticular level of plurimetric extension, about fifteen centimeters thick. It is formed of massive brown to dark brown (7.5YR 4/4) silty-clay sands and differs from the above and underlying levels by its poorness in rock fragments. Its structure is massive, except for a few isolated beds, darker or sandier. The lower limit is clear, slightly undulated, underlined by small grains and gravels. This contact is sub horizontal, except at the north end of the section where its inclination reaches about twenty degrees.

Level IIIc

- 26 Only the top of this level was observed. It is formed of a gravel associated with a clay-silty dark red brown sand matrix (5YR 3/3). The excavation showed that this gravel corresponds to a residual pavement, composed of juxtaposed rock fragments of various sizes (fig. 8). The associated archaeological pieces are imbricated between the calcareous debris and have a preferential orientation associating two modes; one conforming to the slope, the other transverse to it.
- 27 At a microscopic scale, the pseudo-sands appear to be blunt aggregates frequently coated with a fine-textured capping. Sedimentary features are rare (fig. 7c). The dominant microfacies is that of a platy microstructure superimposed on the original granular structure of the deposit (fig. 7d). Eluviated areas are also observed. They are characterized by a depletion of the fine fraction of the matrix and of the cappings around the aggregates. This phenomenon is particularly visible in the pavement of level IIIc (fig. 7e).
- Unit IV: 30 to 60 cm thick deposit, composed of yellow clayey silts displaying a massive or polyhedral blocky structure and a more or less clear granular substructure. Under the microscope, the sediments appear to be formed by the accumulation of rounded aggregates frequently containing a phosphate nucleus (fig. 7f). A platy structure is locally observed. Some rock fragments, sometimes with an alteration cortex, are scattered throughout this unit. Its lower limit is sharp.

- Unit V (indeterminate thickness): Stony and gravelly deposit with open to semi-open structure containing locally lenses of sorted material. The clasts are more or less blunt.

4.2 - Genesis of deposits

28 The settling of the Saint-Martin Room deposits can be summarized as follows:

- The bedded organization of deposits, their coarse texture and the bluntness of clasts indicate that Unit V result from high energy turbulent flows.
- Unit IV corresponds to an accumulation of pseudo-sands transported by runoff. The sorting and the blunting of the grains testify to this. A contemporary soil freeze has probably favored the production of aggregates (Bertran 1999). Indeed the matrix cappings which develop around the grains characterize the aggregates produced in the superficial horizons of cryosols (Van Vliet-Lanoë 1988). These grains originate from the erosion of pre-existing deposits of the cave, as indicated by their phosphatic nature. The presence of small bone splinters in some of them indicate that the latter derive from the fragmentation of coprolites (Horwitz and Goldberg 1989).
- Runoff, rock fall and solifluction processes contributed in variable proportions to the formation of units II and III. The small structures with concave base filled with a coarse sediment represent the filling of channels (Lenoble 2005). These, added to the lamination of the sediment, attest that concentrated runoff was the dominant process in bringing fine materials. Moreover, the presence of a bedding in relation to erosive structures cut-and-fill structures, granules beds, and stone pavement) in the northern part of the section indicates that the flows were very competent at this place. Rockfall processes are important, even predominant, at the top of Unit III and within Unit II. In addition to the characteristics of the stony fraction (no sorting, isotropic fabric), the close relationship between the size and nature of boulders and gravels on the one hand and the morphology of the ceiling of the cave on the other hand, attests to a simple fall of the debris detached from the walls.
- Numerous ovoids are present among the pseudo-sands of Unit III. They indicate, too, that a freezing of the soil occurred during the formation of the deposit. Moreover, the observation of displaced fragments of boulders, of undulated laminae and of an associated platy microstructure indicates that these deposits were retouched by solifluction processes. However, this dynamic has not profoundly altered the deposits insofar as the original sedimentary structures are still present.
- A cryosol develops at the top of Unit II. Indeed, the regular spacing of the involutions that affect this unit and their association with a well-developed ovoid microstructure testify to the action of cryoturbation. The genesis of this fossil soil implies a local morphological stability. This sedimentation stoppage is also evidenced by the alteration of calcareous debris at the top of the unit and related to the redistribution of phosphates that are at the origin of the films coating the rock-debris (Campy and Chaline 1993). Moreover, the formation of this cryosol implies a colder climate than the current one; it is probably the reflection of a very cold episode of Isotopic Stage 2. This episode has been observed in the whole upper cave level (see above, paragraph "Evolution of the upper level").
- Unit I corresponds essentially to the formation of a flowstone. Detritic sedimentation is limited to decantation deposits in puddles. This radical change of style of sedimentation leads to ascribe this unit to the Holocene.

Figure 8 - View of the runoff pavement located in the upper part of unit IIIc.

5 – Setting up of the layers of Aurignacian remains

- 29 Units II and III provide sequences of industries similar to the early Aurignacian on the one hand, and to the proto-Aurignacian on the other (Normand *et al.* 2007). The thickness of Unit III and the richness of the archaeological material it contains suggests it is possible to identify several evolutionary stages within the proto-Aurignacian (Szmids *et al.* 2010). For these two reasons, the sequence of the site is unique and remarkable.
- 30 However, before any interpretation, it is necessary to question the strictly cultural origin of the stratigraphic distribution of remains. Indeed, as shown by geological study, archaeological levels are associated with various sedimentary dynamics: rock fall processes, runoff and solifluction. The question of a change in the organization of remains due to these natural processes therefore arises. In order to answer this question, the study of the setting up of the layer of remains was undertaken.
- 31 This research is supported by the sedimentological study, which has shown that concentrated runoff is the main sedimentation agent of Unit III. Rock fall and solifluction processes also contributed to the formation of the deposits, but sedimentological study indicates that their contribution is more modest (see above). Therefore, the study of the formation of the site focused mainly on the impact that runoff could have on the constitution of remains layers.

- 32 The approach then consisted in seeking within the archaeological series the characteristics peculiar to this natural agent. Four criteria are used for this purpose (Lenoble 2005). They are:
1. remarkable organizations, that is to say sedimentary structures involving archaeological remains;
  2. vertical distribution of remains;
  3. sorting of archaeological material;
  4. fabric of objects.
- 33 Abrasion lusters were not taken into account because the patina appears on the objects after their burial. Refittings were done (Normand 2002), but they were considered too few to be taken into account.

5.1 - Analytical data

Remarkable organizations

- 34 The residual pavement contained in unit IIIc (see above) is a remarkable organization. As shown in figure 8, large-size archaeological objects, teeth and knapped flints from 3 to 5 cm, are blocked between the rock fragments of the pavement. The orientation of these objects, conforming or perpendicular to the direction of the slope, indicates that they were trapped during transport. In the context of runoff, these pavements form in the zone of erosion or transit and the blocked objects represent the largest objects immobilized during transport (Lenoble 2005). We can thus deduce:
1. that the objects associated with the pavement are in secondary position,
  2. that the smaller objects, that is to say the greater part of the archaeological assemblage, have been transported beyond and consequently that the series contained in this level IIIc represents only a small part of the original set of remains.

Fabrics

- 35 The fabric of the unit III remains was measured at two points in the excavation: one in the south, in the clast-supported diamicton facies (square W₁32) and the other in the north, within the bedded pseudo-sands (squares V₁28 and V₁29). The fabric of the diamicton rock fragments was also measured (table 2).

Table 2 - Statistical characterization of fabrics of archaeological remains and rock fragments contained in unit III

Série	N	Années	Test de Curray		Vecteurs propres normalisés			Indices de Benn	
			L	p	E1	E2	E3	EL	IS
W₁ 31 (diamicton à support clastique)									
vestiges	38	2000-2002	18,0	0,311	0,503	0,325	0,172	0,354	0,342
cailloux	36	2000-2002	13,1	0,540	0,511	0,367	0,122	0,282	0,239
V₁ 28 & 29 (pseudo-sables lités)									
vestiges	45	2000-2002	10,7	0,599	0,510	0,417	0,072	0,182	0,141
vestiges	101	2004-2005	2,9	0,920	0,487	0,448	0,065	0,080	0,133

- 36 These measurements are compared with the experimental model by transfer on the Benn diagram. As shown in figure 9, the measurements made in the unit IIIa diamictic

facies are not compatible with a redistribution of the remains by runoff but are similar to those of rock falls what is consistent with the series of measured rock fragments. On the same diagram, it appears that the fabric of the objects contained in the pseudo-sands facies of unit III is not diagnostic. Both sets of measurements are as similar to objects displaced by runoff as to those of undisturbed sites.

Figure 9 - Benn diagram showing the position of fabrics measured on archaeological pieces and rock fragments of unit III compared with areas of runoff, rock fall and undisturbed archaeological assemblages as defined by Bertran and Lenoble (2002).

- 37 The large number of measurements made during the years 2004 and 2005 ($N = 101$) makes it possible to deepen these results. For this purpose, the parameters L and p of Curray (1956) were established on series of 30 objects, successive in stratigraphic order (figure 10A). This figure shows significant variations, which is expected for runoff deposits (Bertran and Lenoble 2002). The same graph is established with the doubled value of the angles (fig. 10B). This procedure is used in the case of a bimodal distribution of vectors. It has the effect of superimposing initially transverse modes (Baschelet 1981). Therefore, if the series is bimodal, the vector intensity L increases when the angles are doubled. Figure 10B shows that this scenario is frequent within the Isturitz unit III deposits and that in some cases the preferential orientation of the objects reaches values that exclude a sampling effect ($p < 0.05$). In the context of runoff, a bimodal distribution of the objects is observed in the case of material redistributed in channels (Lenoble 2005). Therefore, the shaded areas in figure 10B are interpreted as layers of material redistributed by runoff.
- 38 It is thus possible to deduce from these various statistical treatments:
1. that the layer of remains contained in the facies of bedded pseudo-sands IIIa and IIIb outside gravity facies areas is not homogeneous;

2. that it is constituted by the alternation of layers in which the fabric indicates a redistribution of the remains and of layers where the fabric is not diagnostic;
3. that this redistribution is due to runoff.

Dimensional sorting

- 39 The search for a granulometric sorting of the archaeological series was carried out from the material collected in two 33 x 16 cm sub-squares during the years 2000 to 2002. These sub-squares were selected in such a way that, on top of unit II, the different facies of unit III are represented: clast-supported diamicton in the sub-square V₁31b and bedded pseudo-sands in the sub-square V₁29b. Results are shown in table 3. They are compared with the experimental models of dimensional assemblages produced by hard rock debitage (Bertran *et al.* 2006), and with that of the sorting of archaeological remains affected by runoffs through the texture ternary diagram (Lenoble 2005).
- 40 Two main observations emerge from this (fig. 11):
1. a major distinction appears between the two units. The remains of Unit II are systematically sorted due either to the absence of coarse fraction (V₁29b) or, on the contrary, to the under-representation of fine fraction (V₁31b);
  2. the proportions of the various dimensional classes of Unit III remains follow, for the most part, those of unsorted experimental sets, in agreement with the fact that the majority of the knapped flints collected at the excavation result from a debitage activity at the site (Normand *et al.* 2007). Several exposed surfaces, sometimes successive, differ as the small fraction is under-represented.

Figure 10 - A – Vertical evolution of the vector magnitude L. B – Comparison between the vertical evolution of the vector magnitude calculated from the series of initial orientation measurements and from the series with doubled angle values. Curves represent moving values based on series of thirty measures subset from the 101 measures put in order from the top to bottom.

Table 3: Isturitz, Saint-Martin room. Proportions of lithic remains by dimensional class recovered from the two sample-columns. Dimensional classes are expressed in mesh width. Déc. = exposed surface; N = number of gathered remains (excavation and sieving).

Déc.	Prof	> 2	> 4	> 10	N	Unité	Déc.	Prof	> 2	> 4	> 10	N	Unité
Sous-carré V₁31b													
6	14-20	0	100	0	1	II	17	36-40	56,0	40,0	4,0	75	III
7	22-24	80,0	20,0	0	10		18	40-42	62,2	32,9	4,9	82	
8	24-26	42,9	57,1	0	7		19	42-44	36,1	55,6	8,3	24	
9	26-30	66,7	33,3	0	39		20	44-46	71,7	25,3	3,0	300	
10	28-30	31,3	68,8	0	16		21	46-48	53,2	41,5	5,3	94	
11	30-32	37,5	62,5	0	16		22	49-52	47,7	29,5	22,7	44	
12	32-34	52,8	38,9	8,3	36		23	52-54	62,4	33,3	4,3	93	
13	34-36	50,0	50,0	0	26		24	54-56	51,3	39,5	9,2	76	
14	36-38	28,0	60,0	12,0	25		25	56-58	48,5	37,9	13,6	66	
15	38-40	0	81,3	18,8	16		26	58-60	67,4	29,3	3,3	92	
16	40-42	84,8	15,2	0	46	III	27	60-64	74,2	21,6	4,1	97	
Sous-carré V₁29b													
6	22-24	50,0	50,0	0	4	II	21	58-60	58,6	36,9	4,5	244	III
7	24-28	25,0	66,7	8,3	12		22	60-66	-	-	-	-	
8	29-32	17,4	82,6	0,0	23		23	64-66	23,6	60,7	15,7	89	
9	32-36	35,7	50,0	14,3	42		24	66-68	48,5	42,4	9,1	33	
10	36-40	38,2	52,7	9,1	55		25	68-70	63,4	33,2	3,4	262	
11	40-46	-	-	-	-	III	26	70-72	38,4	52,1	9,6	73	
12	32-36	45,1	53,7	1,2	82		27	72-74	53,0	43,6	3,4	117	
13	40-50	62,3	34,4	3,3	61		28	74-76	68,0	29,1	2,9	103	
14	42-46	61,7	28,3	10,0	60		29	76-78	35,3	64,7	0	17	
15	46-48	53,6	39,1	7,2	69		30	78-80	81,4	16,3	2,3	43	
16	48-50	50,8	39,7	9,5	63		31	78-80	61,3	34,7	4,0	75	
17	50-54	60,2	34,4	5,4	349		32	76-80	61,0	30,5	8,5	82	
18	54-56	64,2	31,8	4,1	296		33	80-84	60,5	37,2	2,3	172	
19	52-56	68,8	27,3	3,9	128		34	84-88	64,8	29,6	5,6	54	
20	56-58	64,2	31,6	4,2	212								

41 The following interpretation may be made:

- In the case of Unit II, the absence of part of the small fraction can be attributed to the cementation of the deposits. On the other hand, the under-representation of the large fraction (V₁29, déc. 6-8 or V₁31 déc. 6-9) indicates that these sorting most likely represent objects deposited in the distal zone of concentrated runoff or as a result of brief episodes of functioning.
- The sorting of Unit III, in particular those observed in V₁29b, agree with redistributions either by a poorly competent runoff outside the rills or by concentrated runoff. In V₁31b, episodes of residual pavement may also be responsible for a large part of the observed sortings. In this square, two exposed surfaces of the top of unit display a sorting that indicates a redistribution. The first corresponds to the facies of brown yellow pseudo-sands (exposed surface 16). The second is located in a transition zone intercalated in the pseudo-sand facies and composed of a matrix-supported diamicton, (exposed surface 19).

42 This information is completed by taking into account the vertical evolution of abundance in lithic material (fig. 12) through which two data appear. Firstly, there is a contrast in artefacts abundance between units II and III, as well as a decrease of archaeological material at the top of unit III, which continues into unit II. Secondly, a strong variability is highlighted in unit III: the layer of remains is made of horizons successively rich and poor in remains. Besides, the thickness of the sorted layers in unit III is pluricentimetric to decimetric, that is to say similar to the thickness of the bedded lenses observed in this unit. Finally, no sorting was identified in the richest layers.

Figure 11 - Triangular texture diagram. Areas drawn on the diagram have been established from an experimental model (lower right). The measurement numbers correspond to those of the exposed surfaces. For clarity purposes, the successive exposed surfaces, which comprise the same dimensional classes, are put together as well as the exposed surfaces whose strength is thought to be too weak.

Figure 12 - Isturitz, Saint-Martin room. Vertical evolution of sorting and archaeological richness of unit IIIa deposits.

5.2 – Interpretation

- 43 In Unit II, the low proportion of anthropogenic sediments, the evidence of sorting and the poorness in lithic material indicate a contribution in remains reworked by runoff. The scarcity of remains and archaeological sediment at the top of Unit III indicates that natural sedimentation continued after the prehistoric abandoning of the room. The few redistributed pieces collected in a mass of natural sediment only seem to represent objects originally contained in Unit III that could crop out laterally or be eroded by runoff incisions.
- 44 Within Unit III, a distinction should be made between areas where rock fall processes was very active (unit IIIa in the southern sector) and areas where runoff is exclusive (unit IIIa, northern sector, and unit IIIb). The fabric of diamicton appears to be characteristic of rock fall deposits. Large remains, like those whose attitude is measured (length > 2 cm), were therefore not affected by runoff. The sorting observed agree with this interpretation insofar as they indicate episodes of formation of residual pavements. Such pavements have also been discovered at the top of level IIIc, which exhibits a comparable lithofacies of clast-supported diamicton. The assemblages of remains contained in these lithofacies are biased by the export of the smallest objects, but the stratigraphic position of the objects found there does not seem to have to be questioned.
- 45 Outside the rock fall zones, the competent runoff episodes identified by the sediment study contributed significantly to the formation of the layers of remains. This is shown by the layers with a pronounced sorting and a diagnostic fabric. These horizons of redistributed materials are intercalated between layers without sorting or preferential

orientation. The wealth of the archaeological material of the latter may indicate that the deposits are not redistributed by natural agents or may reflect the sometimes non-diagnostic nature of the criteria used.

5.3 - Implications on the meaning of the series collected during excavation

- 46 Several implications emerge from this study.
- 47 First, solifluction did not have a significant impact on the formation of the layers of remains. Indeed, all the recognized modifications (remarkable organizations, orientation of the remains or dimensional sorting) are due to runoff action.
- 48 Secondly, a significant portion of the deposits being excavated in the Saint-Martin room yields layers of material in a secondary position. However, this is not the case for the rock fragments lithofacies of Unit IIIa, which are present in the southern part of the main excavation (rows 31 and 32) and beyond to the south (rows 33 to 39). There, the recognized changes are minor. They are not such as to invalidate the relationship of equivalence between the succession of the layers of remains and the prehistoric occupations. On the basis of the similarity of the sedimentary dynamics at the origin of the deposit, this interpretation can also be extended to Level IIIc. The new data provided by the continuation of excavation will be useful to validate this last point.
- 49 Redistributions identified in the other facies where runoff dominates necessarily have consequences on the archaeostratigraphic recording and therefore, *a fortiori*, on the assemblages collected during excavation. These distortions can be apprehended on the basis of the model established by Lenoble (2005). According to this, the redistributions that go with the burial of remains can have two consequences. The first one is that of an enrichment of the archaeological layers by the input of displaced material, contemporary or anterior to the prehistoric occupations. The second one consists in the constitution of archaeological pseudo-levels. In both cases, the material of each occupation is disseminated in the overlying levels. The industries collected within these lithofacies can thus give the illusion of the persistence of a cultural trait, whereas these are only redistributed elements.
- 50 Such an observation necessarily leads one to question the reality of the transition industries collected within the bedded pseudo-sand facies of unit III between a proto-Aurignacian phase and a typical Early Aurignacian phase.
- 51 However, the work carried out is not sufficient to quantify the mixtures between industries. Are they negligible, significant or majority? Further studies are needed to answer this question. This may be, for example, the search for interlayer refittings, the distribution of rare raw materials, etc.

Conclusions

- 52 Isturitz cave is the upper level of a karstic system comprising three levels. Several evolution phases have been identified in this cave: 1) in-cutting of the cave in a phreatic context, 2) deposition by the Arberoue River of torrential alluvium and formation of large stalagmite blocks, 3) collapse of the southwest part of the cave and possibly return to phreatic conditions, 4) settling in a vadose context of the detrital and

phosphate deposits containing the Palaeolithic industries, 5) formation of speleothems which, in the greater part of the cave, are sealing the former deposits. The chronological situation of the first three phases could not be specified; they probably lie between the beginning of the Quaternary and the end of the Middle Pleistocene. The fourth dates to the Upper Pleistocene and the last one to the Holocene.

- 53 The sections currently visible in the Saint-Martin room concern the two last evolutionary episodes. They show that sedimentation first is related to high-energy flows during the Mousterian settlement (Unit IV), is then dominated by runoff during the proto-Aurignacian and Aurignacian (Unit III) settlements and, finally, by rock fall processes associated to runoff (unit II). A superficial frozen ground accompanies the deposition of runoff deposits while a deep frozen ground, possibly a permafrost, develops after the formation of the detrital deposits and before that of the upper flowstone (unit I).
- 54 According to the specific studies carried out, freezing events appear to have had little impact on remains layers, at least in the excavated area. This is not, however, the case of runoff. Indeed, the archaeological objects present in Unit II are probably linked to the functioning of this mechanism; they correspond undoubtedly to a reworking coming from archaeological levels located in Unit III. In Unit III, the impact of runoff is variable both laterally and vertically. Heavily affected areas are bordered on little, or even very little modified zones. In the latter case, there is a simple decrease in small objects; this process is not such as to significantly modify the archaeostratigraphic record.
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RÉSUMÉS

This paper reports on geoarchaeological work conducted at the site of Isturitz during the 1996-1997 and the 2000-2005 excavations. The study of geomorphological context and sedimentary deposits both outside and inside the karstic block permit the main evolutionary phases to be described.

The karstic system comprises three stepped levels, which are linked to downcutting stages of the Arberoue valley. Special attention has been paid to the upper level of the karstic system, i.e. the Saint-Martin-Isturitz level, in which excavations were conducted. Here, sedimentation was initially associated with high-energy flows (torrentially-flowing river followed by an intermittently active underground stream), and later by runoff and rockfall processes. In the upper part of the karstic filling, a sedimentary hiatus, contemporaneous with a very cold phase of OIS 2, has been identified in the rockfall deposits. This climatic episode is characterized by a cryosol that has notably deformed former sedimentary levels. The sequence ends with a flowstone that accumulated during the Holocene.

The Proto-Aurignacian and Aurignacian levels are buried in runoff and rockfall deposits of the upper part of the fill. They were the focus of a detailed taphonomic study, which demonstrated that 1) freezing has had only minor effects on preservation of these levels compared to the role played by runoff, 2) the presence of artefacts in unit II is the result of reworking processes and, 3) archaeological levels identified in unit III represent either sets of reworked pieces or intact artefact assemblages admitting the assumption of a good preservation. Implications of this study

are discussed and it is suggested that refitting analyses should be performed to confirm the site's proposed archaeostratigraphic sequence.

INDEX

Keywords : South-West France, karst, site formation processes, taphonomy, runoff, cryosol, Proto-Aurignacian, Aurignacian

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