
Heated walls of the cave Chauvet-Pont d'Arc (Ardèche, France): characterization and chronology

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Introduction

- 1 In France, quite a number of decorated caves contain accumulations of charcoals for which different functions have been considered. References to combustion areas interpreted as domestic hearths are rare and confined to the Pyrenean caves such as Tuc d'Audoubert (Begouen *et al.* 2009), Fontanet cave (Wahl 1973; Clottes 1977) and Labastide Cave (Omnès 1982; Delibrias *et al.* 1980). In both cases, they are Magdalenian occupations. Hearths dated to the Solutrean and/or the Gravettian, recognized in Arcy-sur-Cure and Cosquer, were interpreted as structures for lighting, path markings, for the lighting of torches or the production of colours (Baffier *et al.* 1998; Clottes *et al.* 2005). The charcoals scattered on the ground are most frequently mentioned and concern in particular caves from the Paris Basin (Arcy-sur-Cure), the Pyrenees (Tuc d'Audoubert) and the South-east of France (Aldene, Tête du Lion, Deux- Ouvertures, Baume Latrone and Cosquer). They relate to periods covering the Aurignacian,

Gravettian, Solutrean and Magdalenian (Baffier *et al.* 1998; Begouen *et al.* 2009; Ambert *et al.* 2005; Combier 1984, 1989; Azéma *et al.* 2012; Gely 2000; Clottes *et al.* 2005; Philippe *et al.* 2009). They are mainly disturbed hearths, hearths cleaning or cinders from fallen torches.

- 2 Traces of heating (reddening) are sometimes indicated on soils – sediment or rock – (Baffier *et al.* 1998; Clottes *et al.* 2005; Begouen *et al.* 2009 for example) but never for the walls or ceilings located near the hearths.
- 3 In the Chauvet cave, the presence of hearths has been recognized since the discovery and confirmed during the expert assessment conducted by J. Clottes (Chauvet *et al.* 1995). The combination of certain combustion areas with traces of reddening and flaking off caused by violent thermal shocking (Megaloceros and Crosshatching Galleries) was mentioned by J.-M. Geneste (2001, 2005). Then, the research undertaken from 2008 on the taphonomy of the decorated walls allowed:
 - To recognize identical traces in the Entrance Chamber, in the Recess of the Bears and in several locations of the Megaloceros Gallery (Debard *et al.* 2012; Ferrier *et al.* 2012);
 - To determine the palaeotemperatures reached, from the thermoluminescence study of samples from these areas (Brodard *et al.* 2014.)
 - To discuss the chronological attribution of the fires.

Macroscopic characteristics

- 4 In the Chauvet-Pont d'Arc cave, sectors with heating traces are characterized by (table 1, fig. 1):
 - Surface colours different from the ones of the limestone. These are mostly pink shades (reddening) associated in some cases with grey patches. The colour change can affect the rock on depths estimated to several millimetres. On the relevant patches, it is not seen on the rudist shells contained in the limestone, showing that the colour change is related to the presence of insoluble particles, particularly iron oxides and hydroxides;
 - A flaking that affects the rock on variable surfaces sometimes greater than a square meter. The resulting clasts are either thin plaquettes, 0.5 cm to 2 cm thick and over several centimetres in length, or blocks whose thickness may exceed 10 cm. The latter break off following pre-existing cracks in the limestone, millimetre wide, often clogged by brown clays. Scars from the flaking correspond to flat surfaces, in general white, delimited by sharp edges. These features contrast with the shape and colour of the rest of the wall: softened micro-forms coming from dissolution processes during the different phases of the karstogenesis, white colour, orange if linked to the presence of clay coatings or again grey, due to the neogenesis of phosphates (Ferrier *et al.* 2012). When the flake is thin, on the order of a few millimetres, the scar can be locally coloured in pink, showing the progression of the reddening inside the rock;
 - Black edging predominantly sub horizontal, a millimetre thick, located on the irregularities of the rock. They could be interpreted as deposits due to smoke.
 - All these characteristics define a surface appearance of the limestone, related to the impact of the fire, called thermal feature. It refers to observations accumulated over time on rocks (limestone or not) and archaeological sediments undergoing heating in a hearth or kiln (Bodu *et al.* 2006; Foucher *et al.* 2000; Guilbert 2001; Mandeville 1973; Weisgerber *et al.* 2001).

Distribution in the cave

- 5 These thermal features were observed at various locations in the cave, in the first chambers, comprising predominantly red paintings made with iron oxides, as well as in the deep chambers where most of the black paintings made with wood charcoals are found (fig. 2).
- 6 The most important areas are located in the Entrance Chamber (around the GE1 survey pit- 11 m² - and the entrance of the Chamber of the Bear Hollows - 25 m²). Elsewhere, they are less developed: 12 m² accumulated in the Megaloceros Gallery and about 3 m² in the Recess of the Bears. In the Crosshatching, Candle and Cactus Galleries, only small areas evoke this feature (tab. 1).
- 7 The traces are usually visible within fairly narrow (Megaloceros Gallery, Recess of the Bears) and/or low zones (around the GE1 survey pit, Crosshatching Gallery, passage of the Cactus Gallery to that of the Apodemus). Only one large location, the entrance to the Chamber of the Bear Hollows, shows reddening to heights of 3-4 m. The traces can extend on the entire height of the walls, affect only their top and the vaults or only the latter (tab. 1).
- 8 It is of course possible that other places, unobservable due to the constraints related to conservation (circulation on footbridges) or covered by recent concretions could have been affected, especially in the Chamber of the Bear Hollows.

Table 1 - Distribution and characteristics of the thermal facies. Relationship with dated charcoals.

Secteur	Localisation	Phénomènes visibles	Surfaces cumulées	Limites par rapport au sol actuel	Présence et forme des thermoclastes	Lien avec des charbons ou un foyer
Secteur d'Entrée	De la base des parois au plafond	. Coloration rose et grise . Thermoclastie	11 m ²	Limite inférieure : 0,30 m Limite supérieure : 1,45 à 2 m	Plaquettes dans les couches C1 à C3 du sondage	Couche 3 base, sondage GE1 32 010 ± 390 BP, 37 584 à 35 283 calBP (SacA14203 et GfA90218) 31 580 ± 370, 36 718 à 35 123 calBP (SacA14232 et GfA90223) 32 283 ± 380, 38 380 à 35 661 calBP (SacA11413 et GfA80111) 31 330 ± 270, 36 480 à 35 130 calBP (SacA11411 et GfA80109) Couche 3 milieu, sondage GE1 31 580 ± 280, 36 628 à 35 224 calBP (SacA11410, GfA80108)
Entrée Salle des Bauges	Plafond	. Coloration rose et grise . Thermoclastie	25 m ²	Limite supérieure : jusqu'à 4 m	S'ils existent, les thermoclastes sont masqués par l'éboulis	Aucun visible
Diverticule des Ours	Milieu de paroi	. Coloration rose et grise . Thermoclastie	3 m ²	Limite : 0,90 à 1,20 m Limite supérieure : 2 m	Rares écailles minces à l'aplomb de la paroi	
Galerie des Cactus	Voûte de l'entrée de la Galerie de l'Apodemus	. Coloration rose	0,5 m ²	Limite supérieure : 0,80 cm		
Galerie du Cierge	Plafond	. Coloration rose . Thermoclastie . Noir de fumée	0,5 m ²	Limite inférieure : 1,20 m Limite supérieure : 1,75 m	Quelques écailles minces	Charbon à proximité d'un petit foyer 26 230 ± 280 BP, 31 237 à 30 437 (GfA 99081) Valladas <i>et al.</i> 2005
Galerie du Mégacéros	Partie haute des parois et plafond	. Coloration rose et grise . Thermoclastie . Noir de fumée	12 m ²	Limite supérieure : 1,5 à 3 m	Écailles minces et blocs Certains thermoclastes ont été déplacés	Charbons au sol à l'entrée de la galerie 31 430 ± 420 BP, 36 671 à 35 030 calBP (GfA99238) 29 740 ± 390 BP, 35 038 à 33 389 calBP (GfA99239) Valladas <i>et al.</i> 2005 Charbon au sol à proximité d'une sagaie 32 850 ± 540, 38 807 à 36 507 calBP (GfA101459) Valladas <i>et al.</i> 2005
Galerie des Croisillons	Plafond	. Coloration rose et grise . Thermoclastie	1 m ²	Limite supérieure : 1,20 à 1,40 m	Thermoclastes déplacés	Charbon en dessous du mouchage de torche GC-00-23 31 560 ± 490, 37 021 à 34 966 (GfA 101456) Valladas <i>et al.</i> 2005 Charbon au sol, sous dépôt calcifié 30 560 ± 370 BP, 36 275 à 34 585 calBP (GfA102566) Genty <i>et al.</i> 2004, Valladas <i>et al.</i> 2005 Charbons au sol sous dépôt calcifié, vers le fond de la galerie 29 180 ± 340 BP, 34 636 à 33 024 (GfA102568) Valladas <i>et al.</i> 2005

The Entrance Chamber and the Chamber of the Bear Hollows

- 9 The Entrance Chamber is in the continuity of the Palaeolithic entrance (fig. 2), closed at about 21,000 BP (Sadier *et al.* 2012). It is divided into two branches, one on either side of

a large rocky pillar: the branch to the east leads to the Brunel Chamber, while the other in the west, opens into the Chamber of the Bear Hollows. It is in this last branch that traces appear here and there, up to the south of the Chamber of the Bear Hollows between 15 to 40 m away from the original entrance.

- 10 In the western gallery, the reddening mainly affects the ceiling, 1.50 m to 2 m high, and the left wall. Grey patches are visible in the area closest to the Chamber of the Bear Hollows, from 40 cm above ground (fig. 3). Traces of flaking off are confined to the vault, near the GE1 survey pit and on the left wall, above it.
- 11 In the Chamber of the Bear Hollows, the affected areas are located exclusively on the ceiling, up to 4 m high, in small domes (diameter less than a meter). Thermal features are represented by colour changes (pink and grey) and flaked off patches.

The Recess of the Bears

- 12 This is a rotunda, 2.50 m in diameter and with a maximum height of 1.80 meters, which is at the end of a low and narrow 6 meters long gallery, accessible from the Brunel Chamber through a chaos of blocks (fig. 2). Three bears were painted on the wall facing the entrance.
- 13 Only the upper part of the decorated wall, 1.10 m to 2 m above the ground, shows traces of heating. The latter are particularly marked on the two bears located in the right part of the panel and correspond, on the one hand, to pinkish and grey colorations that penetrate 2 to 3 mm into the rock (fig. 4), on the other hand, to a flaking off guided by the numerous cracks of the wall. Marks, sometimes reddened, result from the breaking off of small flakes, a few millimetres thick, and of some larger fragments, about 10 cm long. Heat features are also visible punctually at the entrance of the rotunda on the left wall.

Figure 1 - In the Galerie des Mégacéros, the thermal facies is characterized by a pink and gray colour of the rock, flakes due to the heat and thin carbon black coatings. 1: thermal facies on the vault, at the entrance of the gallery (photo C. Ferrier). a: rubefaction, b: desquamation due to the heat. 2: detail of the rubefaction (photo B. Kervazo). 3: detail of the desquamation (photo B. Kervazo). 4: thin carbon black coatings (photo B. Kervazo).

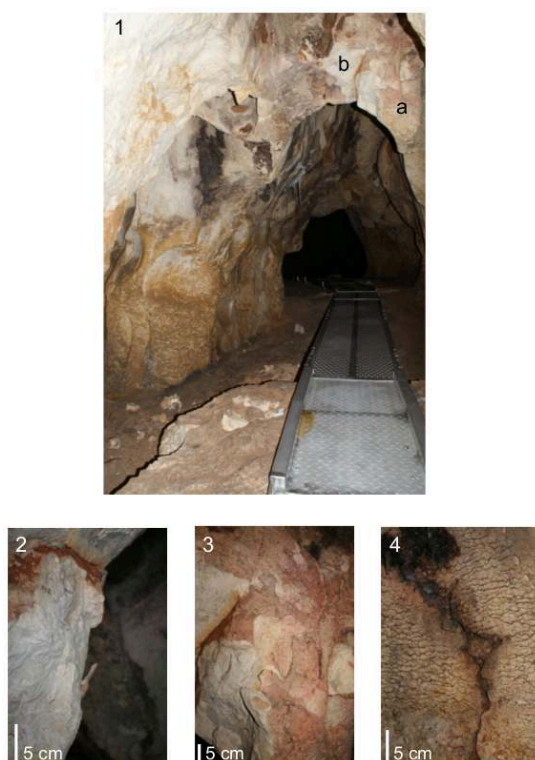
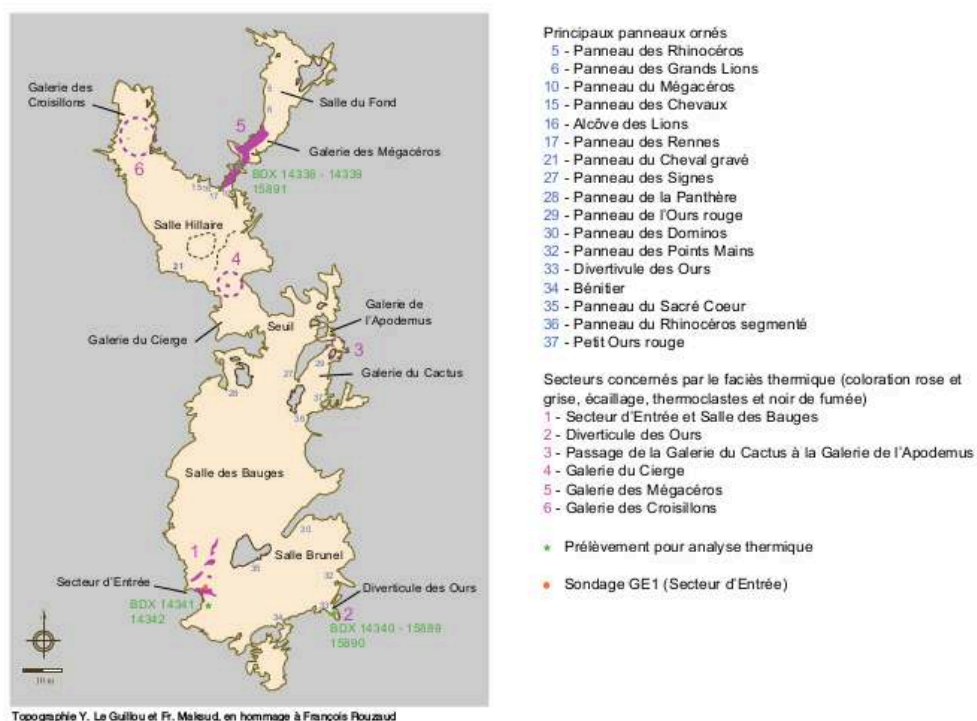


Figure 2 - Location of the areas concerned with the thermal facies, of the pit located in the sector of Entrance, of the samples for the thermal study and the principal decorated panels of the cave.



The passage from the Cactus Gallery to the Apodemus Gallery

- 14 It corresponds to a hole, nearly 2 m wide and about 0.50 m high, located at ground level at the end of the Cactus Gallery (fig. 2). Two pale pink surfaces are visible just above on the right and left edges of the vault. No flaking is visible. Because of the distance imposed by the access path, it was not possible to carry out more detailed observations.

The Candle Gallery

- 15 It is situated in the second part of the cave, beyond the Threshold. The traces of heating are located on the ceiling, about 3 m before the beginning of the Hillaire Chamber, aligned with the axis of progression (fig. 2). They affect two small domes located between rock pendants, at a place where the ceiling lowers to about 1.60 m above the ground.
- 16 They are small pinkish surfaces, accompanied by some very thin flaking scales, sometimes about to fall. Blocks became detached along the cracks. Black coatings and grey stains a few millimetres in diameter may result from the accumulation and re-formation of the combustion residues as vermiculations.

The Megaloceros Gallery

- 17 This is a 25 m long straight gallery connecting the Hillaire Chamber and the Skull Chamber to the End Chamber (fig. 2). In the first part, the width is relatively small (between 2 and 3 m) and the ground relatively level. Then, from a local enlargement due to fractures, the dimension of the corridor reaches 6 m at its base and the floor lowers by successive projections. The right and left walls show very abundant marks of human passage: charcoal drawings, engravings and scrapings, pressing and traces of fingers smeared by different wall coatings (clays, alteration layer...). The bear claw marks and bear polish are also numerous (Feruglio and Baffier 2005; Philippe and Fosse 2003; Fosse and Philippe 2005).
- 18 With the Entrance Area, the Megaloceros Gallery is the place of the cave where the thermal markings are the largest (fig. 2). They are characterized by the frequent association of pink and grey colours and the importance of the flaking. Black coatings that could correspond to deposits due to smoke are also abundant (fig. 1). Five distinct areas, distributed from the entrance of the gallery to its outlet in the End Chamber, are observed:
- The first, on the left wall, extends over 3 m wide. It affects the right side of the Rhinoceros Panel, a shaft that is over 3 m high, and below, a small dome 0.50 m wide located about 1 m above the ground. The pink shades are everywhere, up to 3 m high, and surround the grey areas appearing occasionally near the entrance and in the dome. The colouring penetrates a centimetre into the rock near the grey areas and 0.5 cm elsewhere. Heating up also changed the colour of the clays filling the cracks from brown to red. This change could be related to the transformation of goethite, identified by XRD, into hematite. The flaking covers large areas, especially at the entrance of the gallery, in association with the grey colouring. Two types of thermoclasts – blocks and thin plaquettes – were detached. Edgings of small extent,

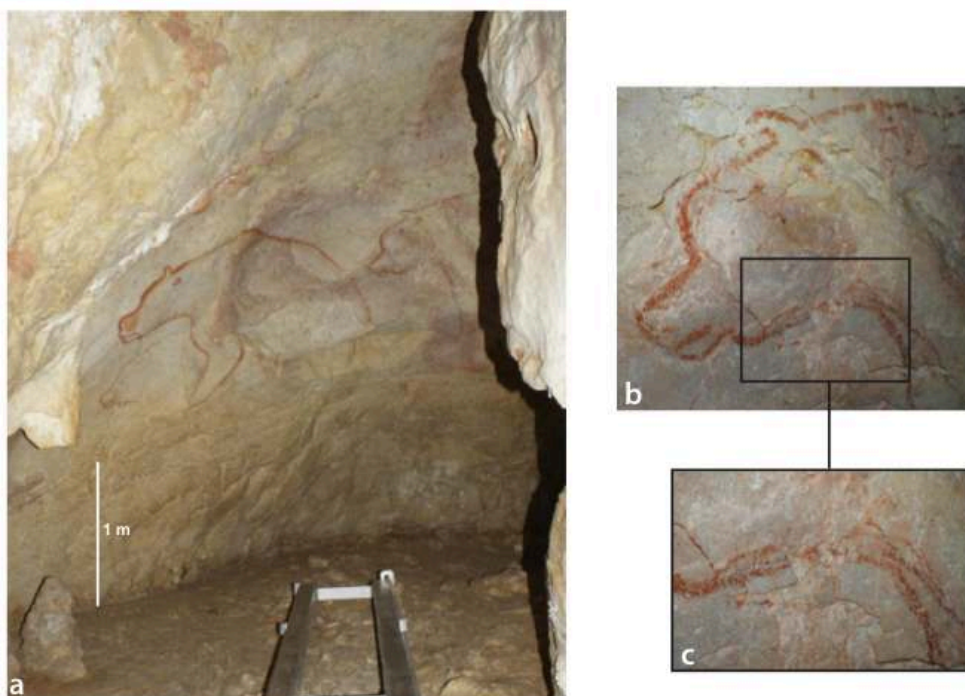
dark brown to blackish, and a stain of identical colour, to the right of the decorated panel, are reminiscent of smoke-related residues.

- The second zone occurs at about 2 m from the previous one, still on the left wall, at the level of a sub-vertical edge, covered with large cupulas. It is constituted by a narrow area (0.80 m) located from 0.90 m to 1.60 m above the ground. The reddening and the flaking affect the limestone, and occasionally the top of the wall, covered by a coating from a phosphate alteration.
 - The third area is located just above a projection determined by a stalagmite floor overhanging the floor of the second part of the gallery. This is the most transformed sector by fire: the traces are found on the ceiling and both walls, often in small domes as well as in stacks, on 3.50 m long and up to more than 3 m high. The small width of the gallery, from 2.50 m to 3 m, could explain the intensity of the thermal impact at this location.
- 19 The reddening forms of variable sized areas visible from 1.20 m to 3.30 m high. The grey colour is observed up to the vault. Flaking on both sides, has mainly produced thin plaques, some of which are not completely separated. A large block (1.20 m wide, 2 m long and 40 cm thick), with reddened edges, broke away from the right wall of the gallery in along a crack and crushed a bear skeleton. Smoke-related deposits evidence correspond to:
- Wavy horizontal edgings that follow the asperities of the rock. They are greyish at the bottom of the walls, blacker upwards. Occasionally, they cover reddened areas or thermal flakes;
 - Black stains, on the right wall, one of which, 15 cm in diameter, is located in a concavity with a grey surface, intersected by the flaking.
- 20 Moving forward towards the End Chamber, in the second larger part of the gallery, two neighbouring areas show thermal traces: the first one is on a projection of the left wall that overlooks the ground by about 1 50 m. Reddening covers the left side of the Panel of the Felines, at the location of two vulvae, and continues on the ceiling. It also affects the clays that form a thin coating on the wall and fill the cracks. The deposits due to smoke, slightly marked, in small areas, are found above the decorated panel and on the opposite wall. The second area shows, two meters further, two small reddened light stains, 25 and 40 cm in diameter, which are located 85 cm above the ground, on either side of the path, at a projection determined by a stalagmite floor. The one on the right wall is associated with grey edging, similar to the areas whose colour evokes smoke residue in the other sectors.
- 21 The last area is located near the entrance to the End Chamber, an overhang of the right wall. The reddening affects both the limestone and an alteration phosphate coating. It appears between 1.15 m and 2.50 m high. Continued at the base, it becomes sporadic at the top, where it is confined mainly to the hollow parts. The flaking off affects the base of the pendant and one of its edges (fig. 5). The thermoclasts form millimetre to centimetre thick flakes. The scars of the former are sometimes coloured in pink. In places, larger cracks have determined the fall of larger fragments (blocks).

Figure 3 - In the Entrance area, heating traces correspond to gray and pink colours on the left wall and the ceiling. The desquamation is confined on the vault (photo C. Ferrier).



Figure 4 - Diverticule des Ours. The bears were drawn on the wall which is opposite the entry. a: pink and gray colours of the wall, due to heating, are perceptible in the upper part of the decorated zone. b: detail of the head of the bear located on the right of panel, showing that the drawing was carried out after the rubefaction. c: the drawing covers a thermal scar (photos C. Ferrier).



The Gallery of the Crosshatching

- 22 In this little decorated gallery, ten meters wide and about 25 m in length, located at the northern end of the cave, fire marks were observed only on the ceiling (fig. 2). The farthest from the entrance appear at about 1.40 m high, in a concavity. The rock is then flaked off, reddened with small grey areas and black stains several decimetres wide. 5 m forward and 1.20 m from the ground, there is a pink and grey area, about 1 m wide, combined with a small shedding flake. Finally, a slightly pink area can be seen near the entrance, in a dome.

Figure 5 - Galerie des Mégacéros. Close to the entrance of the Salle du Fond, the ceiling shows heating marks. On the ground, the charcoals are accumulated in secondary position in the cave bear hibernation nests (photo C. Ferrier).

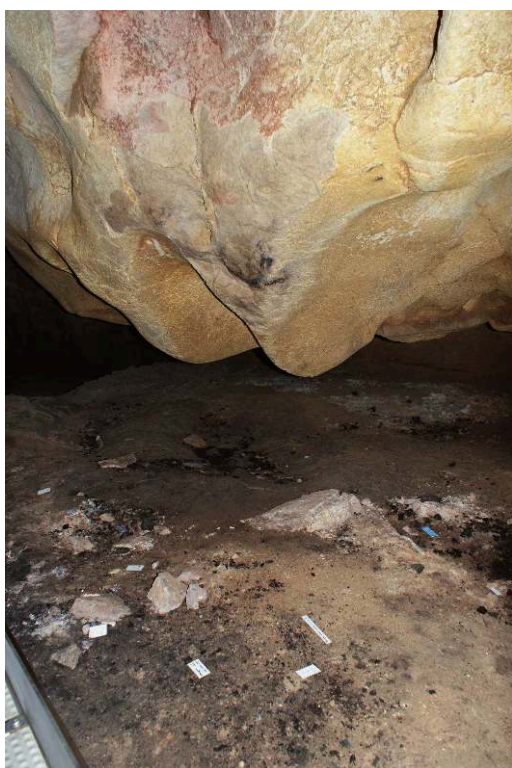


Table 2 - List and location of samples collected or the thermal study by thermoluminescence.

Références de l'échantillon	Localisation	Remarques
<i>Galerie des Mégacéros</i>		
TL#1-2010 / BDX 14338	paroi rubéfiée	Ecaille rubéfiée prélevée à 1,80 m au-dessus de la passerelle métallique
TL#2-2010/ BDX 14339	sol	Ecaille rubéfiée prélevée sur le sol, à l'aplomb de la zone de rubéfaction d'où provient l'échantillon BDX 14338
TL#3-2012/ BDX 15891	sol	Ecaille grise prélevée au sol au pied du gros bloc sous la passerelle
<i>Diverticule des Ours</i>		
TL#3-2010/ BDX 14340	sol	Petite plaquette rubéfiée prélevée à proximité de l'échantillon C14 GC 0803
TL#1-2012/ BDX 15889	sol	Ecaille rubéfiée prélevée au sol entre les deux rails de circulation
TL#2-2012/ BDX 15890	paroi	Fragment du faciès rouge sur la paroi droite en entrant dans le diverticule des Ours
<i>Eboulis d'Entrée</i>		
TL#4-2010/ BDX 14341	plafond	Plaquette rubéfiée extraite du plafond de l'éboulis d'entrée
TL#5-2010/ BDX 14342	sol	Plaque de calcaire non chauffée utilisée comme matériau de référence pour l'étude des rubéfections

Thermoluminescence characterization of fragments of heated walls

Research protocol

- 23 In addition to the intensity of the colour, the absence of calcite coating posterior to the heating up and the discretion of the test samples have been the main sampling criteria (tab. 2). Luminescence properties of the selected samples were compared to that of an unheated reference limestone block coming from the same geological context (tab. 2).
- 24 The protocol is based on the one set up for the thermal characterization of the sedimentary base of hearths from the Bronze Age at the Fraux cave (Saint-Martin-de-Freysengeas, Dordogne - Brodard 2013). While addressing different minerals, calcite in Chauvet, quartz in Fraux cave, the general method remains the same (Brodard *et al.* 2012) and is derived from the conventional method of thermoluminescence dating (Aitken 1985). We are detailing and complementing the data presented at the 2011 MADAPCA Symposium (Brodard *et al.* 2014). The step of thermal characterization of materials, fundamental for the dating of heated rocks, has been particularly developed here (see e.g. Valladas 1980, 1981; Göksu *et al.* 1989; Koul *et al.* 1996; Roque *et al.* 2004a, 2004b; Duttine *et al.* 2005; Lahaye *et al.* 2006; Guibert *et al.* 2009). It should be recalled that calcite, although rarely used, lends itself easily to the dating of the last heating, providing some experimental characteristics we have implemented for dating heated limestone in Combe Saunière and Laugerie-Haute (Roque *et al.* 2001a, 2001b) relating to the siliceous or silicate materials in general use.
- 25 Thermoluminescence TL is based on the cumulative effects of irradiation by particles and of ionizing radiation on crystals, calcite here. Under the effect of surrounding irradiation, electrons torn from atoms by ionizing get trapped by crystal defects (inner traps). Heating up can release some or all of these trapped charges following the temperature reached and its duration. They may then recombine at the level of recombination centres (electron vacancies) causing the emission of light photons: this is thermoluminescence.

- 26 Since the geological times, electrons have accumulated in inner traps inducing a saturation of the filling. An old heating could have partially or completely emptied the traps according to its intensity. Thereafter, and until the measurement of the TL signal by a laboratory heating, electrons were again trapped under the effect of natural irradiation. This process is at the origin of the dating method, in which the age of the heating is obtained by the ratio of the two physical units measured in the laboratory and partially on the ground, the archaeological dose, the amount of energy accumulated by the grains under the influence of natural radioactivity since the heating up, and the annual dose of irradiation, the amount of energy supplied each year to the grains by the presumably constant natural radioactivity (Aitken 1985). In this work, thermoluminescence is used to determine a state of heating.
- 27 An initial qualitative evaluation of the heating was performed by observing the state of saturation of the signals of the natural thermoluminescence of small limestone samples: adding a large dose does not significantly increase the thermoluminescence of a material of ancient geological origin that has never been heated up because irradiation has saturated the inner trap. Conversely, the absence of saturation after irradiation in the laboratory implies that the material has been heated in the past. However, this test is only meaningful if the heating is not too ancient so that saturation is not reached again.
- 28 For the heated material, it is possible to go beyond the simple observation of presence/absence of saturation in order to determine an equivalent temperature reached during heating.
- 29 It was observed that for many mineral species, including quartz, different heating conditions produce variations in the shape of the TL curves (Roque *et al.* 2004a, 2004b; Brodard *et al.* 2012). Therefore we implemented our methodology to the limestone of the Chauvet-Pont-d'Arc cave. Thus, a fragment of unheated Urgonian limestone, collected in the cave, was used as reference (BDX 14342, table 2): several samples were brought to increasing temperatures in the laboratory (200 to 600°C) according to a specific protocol (table 3). Then their TL curves, regenerated by laboratory irradiation (here a dose of 68 Gy⁹, of the order of magnitude of the one received since the heating, assumed to be older than 30 ka) were compared with those of reddened archaeological materials.

Construction of the thermal reference source

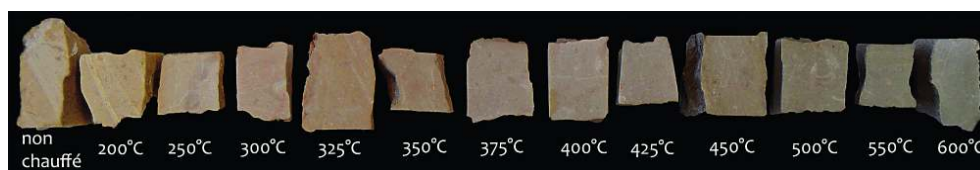
- 30 Heated reference samples offer the colour range shown in figure 6. The reddening begins at 250°C and is particularly visible up to 375°C, from which the limestone gradually becomes grey, like the traces observed in several sectors of the Chauvet-Pont d'Arc Cave.
- 31 The TL curves of the obtained thermal reference sources (fig. 7) show a change with the maximum heating temperature (T_{max}). It is important to note that the test samples have stayed at these maximum temperatures for one hour, as the effects of heating depend on the duration-temperature association of the stage. The more the sample remains at a given temperature, the greater the effect will be because more time is left to thermodynamically possible processes to occur.
- 32 In the study samples, we can note that the geological signal is present for the unheated references or the references heated to a temperature less than or equal to 300°C (fig. 8).

Beyond 300°C, it is no longer significant and the sensitivity to irradiation weakens gradually (fig. 8). We recognize the components of long-term life of the TL of the calcite with peaks at 280°C and 350°C. At 600°C, their intensity ratio is reversed, while it was relatively constant between 300°C and 550°C. It is therefore easy to show that a sample was heated or not. However, between 325°C and 550°C, the shape of the curves offers no neat change (the intensity ratio between the TL emissions at 280°C and 350°C varies little), except for a slight difference of maximum temperature of the second peak from 350°C to 360°C for heating over 450°C.

Table 3 - Experimental details for the TL study of samples.

<p>Cycle thermique de chauffe en laboratoire pour la construction des références thermiques, à l'air et dans un four électrique :</p> <ul style="list-style-type: none"> - Découpe de petits blocs de calcaire dans l'échantillon non chauffé et installation d'un bloc dans le four programmable. - Montée de la température ambiante à la température de consigne avec une vitesse de chauffe de 20°C/min. - Palier d'une heure à la température de consigne. - Refroidissement jusqu'à la température ambiante avec une vitesse de 5°C/min. <p>Préparation des prélèvements pour l'étude TL (échantillons archéologiques et échantillons chauffés en laboratoire en vue de la construction du référentiel thermique) :</p> <ul style="list-style-type: none"> - Broyage et tamisage : récupération de la fraction 80-200 µm. - Attaque H₂O₂ : destruction des matières organiques. - Rinçages à l'eau déminéralisée et séchage. - Répartition de la poudre traitée dans des coupelles en quantités aliquotes identiques d'environ 10 mg par coupelle. <p>Conditions d'étude TL :</p> <ul style="list-style-type: none"> - Utilisation d'un équipement de thermoluminescence développé et construit au laboratoire de l'IRAMAT-CRP2A. - Filtrage optique MTO A520a [480 – 560 nm], filtre Infra Rouge Rejector MTO Ta2, tube photo-multiplicateur EMI 9813 QKA. - Atmosphère de lecture sous CO₂ pour éviter le phénomène de décarbonatation en surface des grains de calcite (Roque <i>et al.</i>, 2001a). - Mesure du signal TL par une chauffe à 4°C/s de la température ambiante jusqu'à 425°C sans palier.

Figure 6 - Urgonian limestone from the Chauvet Pont-d'Arc cave, cubes cut in the reference sample BDX 14342 and heated at the indicated temperatures for 1 hour in air (photo A. Brodard IRAMAT-CRP2A). Note the evolution of the colour.



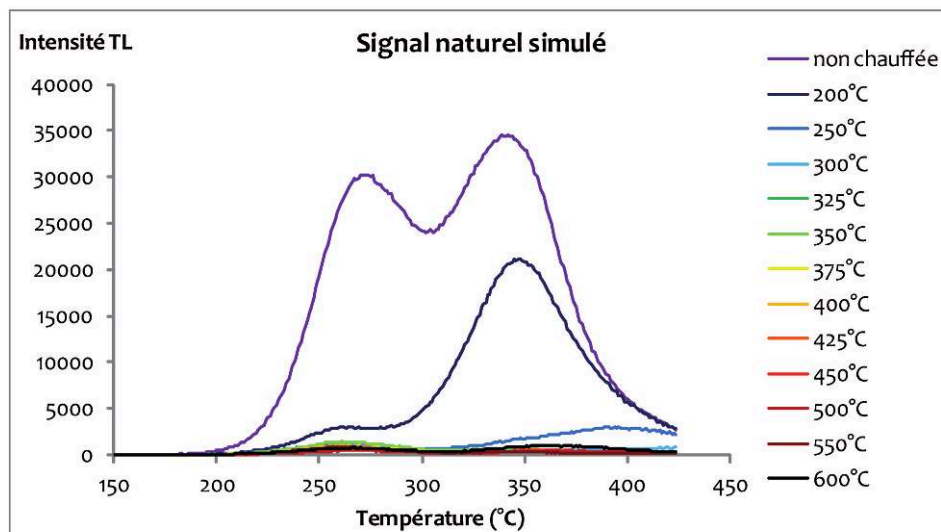
Study of reddened archaeological samples

- 33 The state of saturation of the natural thermoluminescence signals shows that the increase in the luminescence intensity by adding a 68 Gy dose is sharp and very significant for the samples from the ceiling of the Entrance Chamber and the Megaloceros Gallery, while it is rather weak for the one of the Recess of the Bears, despite a profile of the natural TL curve close to that of a sample heated to 300°C. It seems today, after a radiochemical study (Brodard and Guibert 2012), that this sample, in contact with a rather radioactive sediment and in the presence of a large amount of radon (Mangin *et al.* 2005) has been substantially more naturally irradiated than

expected, which would explain both the "heated" aspect of the natural TL and the low intensity increase by adding a 68 Gy dose.

- 34 By comparing the curves of the reddened samples (the luminescence intensity and shape of the curve) to that of thermal references, it is possible to specify the intensity of the heating by providing information on the equivalent palaeotemperature (fig. 9). All the studied samples have a natural TL profile similar to that of samples heated to over 300°C, and less than 375°C if one refers to the colours. Note that the laboratory heating atmosphere is oxidizing, probably similar to the conditions of the Chauvet cave where the rock had to be in contact with the flames of Palaeolithic fires.
- 35 This thermoluminescence study demonstrates that the walls and ceiling of the studied areas have undergone a rather intense ancient heating, when one considers the mass of limestone concerned, and that it is the latter which is responsible for the reddening of the limestone.

Figure 7 - Set of thermoluminescence curves of aliquots of the reference sample BDX 14342 aliquots of which were submitted to a laboratory annealing process for one hour in air at the temperature given in the legend. The curves were obtained by irradiating these annealed aliquots by a beta dose (68Gy). Before the thermoluminescence measurements, every aliquot was preheated at 220°C following a linear ramp using a 4°C/s heating rate, then cooled again rapidly until room temperature. This preheat process is necessary to reduce thermally unstable components in order to simulate a natural TL signal that is compared to the natural TL signal of archaeologically heated samples to determine the attained paleotemperature. (non chauffé = unheated).



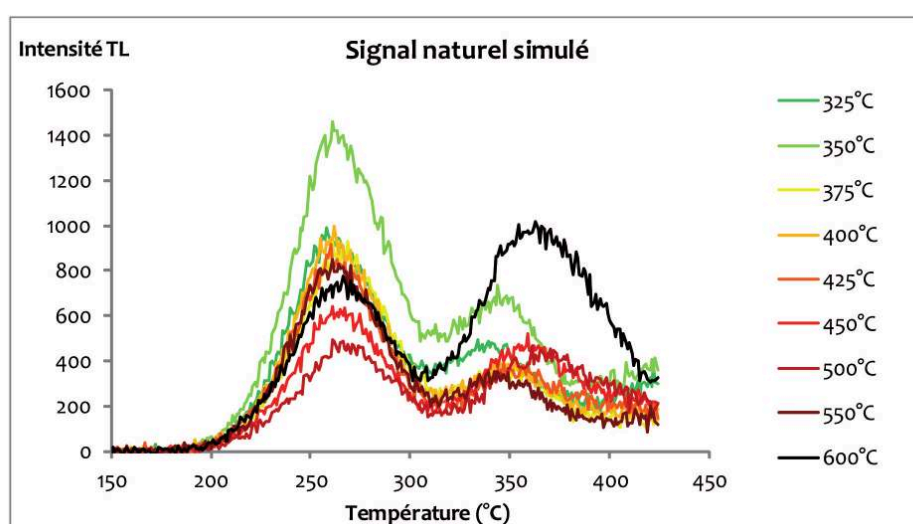
Relationships with the hearths

- 36 The walls bearing the heating traces are usually not associated with visible hearths on the surface of the ground, except in the Crosshatching and Megaloceros Galleries. This lack of consistency can have at least two causes: erosion and the covering of the charcoals by deposits, their shifting by men and/or bears.

Burying

- 37 This explanation can be put forward for three main areas: the Entrance Area and the Chamber of the Bear Hollows, the Recess of the Bears and the Cactus Gallery.
- 38 In the Entrance Area, a survey pit dug in the part above the scree, close to the wall bearing heating traces (fig. 2) revealed, 30 cm below the surface, a level rich in wood charcoal, 8 to 15 cm thick (layer 3 of the GE1 survey; Gely *et al.* 2009, fig. 10). The coals, included in a silty-sandy matrix gravel level, are associated with clasts showing blackish and/or reddening traces. The sedimentological study showed that this level was disturbed by solifluction and runoffs (Kervazo *et al.* 2010). It was later covered by sediments brought by the same processes. It is therefore possible that potential hearths, located directly perpendicularly below the ceilings affected by thermal marks, were re-organized and buried during the progression of the scree towards the entrance of the Chamber of the Bear Hollows.
- 39 In the Recess of the Bears, the Palaeolithic circulation surface is probably masked by washed off sediments, which can originate for example from a small side corridor located on the left wall, at the entrance of the Recess. Currently, this small gallery is crossed by temporary flow, the origin of a stalagmite floor that covers the ground.
- 40 Flowing traces are also visible at the end of the Cactus Gallery. Above, they correspond to inconspicuous incisions along the right wall and, lower near the entrance to the Apodemus Gallery, to a zone of natural filling. This organization can explain the possible burying of hearths.
- 41 In the Megaloceros Gallery, hearths could have been re-organized and the charcoals buried by the digging of the bear hollows. The presence of the latter, between and after the human Aurignacian incursions, is evidenced by the bear scratches and the polish overlapping drawings on the Megaloceros and the Horses Panels (Feruglio and Baffier 2005; Fritz and Tosello 2001). The C14 dates obtained on bones, which indicate a stop in the visiting of the cave by these animals after 33 to 34,000 years (cal BP), suggest that these disturbances may be relatively old.

Figure 8 - Same as fig. 7, zoom on simulated natural TL of high temperature annealed aliquots.



Shifting of the coals

- 42 The shifting by humans of remains such as bear bones or fragments of limestone and speleothem is shown in various places in the cave, for example in the Red Panels and the Skull Chambers (Geneste 2001, 2005; Delannoy *et al.* 2012). In the Megaloceros Gallery, the thermoclasts were accumulated under two projections formed by the stalagmite floor overhang. Their location, inexplicable by natural phenomena, presumably stems from an anthropogenic gesture. This hypothesis can also be formulated for the wood charcoals of the Megaloceros Gallery that, when grouped at the foot of the wall, could be a supply of colouring material (Geneste 2005). This is particularly the case of an accumulation which is under the drawing of the horse with double mane, on the left wall of the gallery. Elsewhere, the positioning of the charcoals indicates that they have slid down the slope, perhaps due to the passage of humans and/or bears, and remained trapped in hollows, especially in the bear hollows (fig. 5).

Figure 9 - Results of the thermal characterization of reddened samples of the Chauvet-Pont d'Arc Cave.

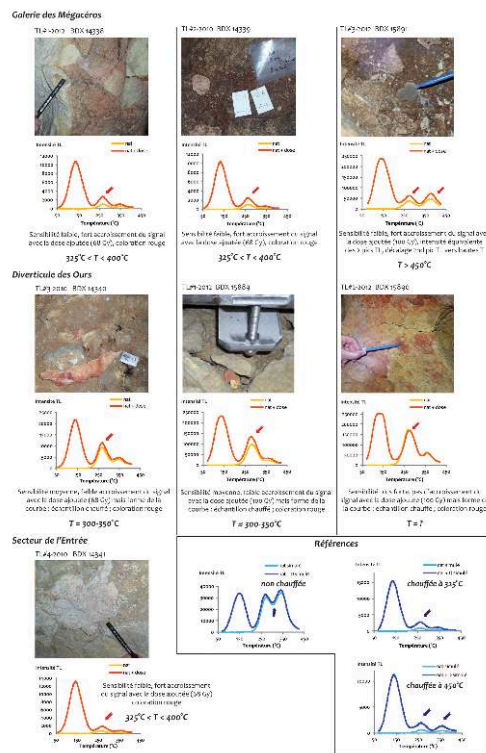


Figure 10 - Pit GE1 carried out in the upper part of the a talus cone which blocks the entry of the cave, near a wall with traces of heating (photo C. Ferrier). a: the charcoal level (layer 3) is dated between 38 380 à 35 661 cal BP (32 293 \pm 380 BP) and 36 480 à 35 130 cal BP (31 330 \pm 270 BP).



Chronology

- 43 Humans came to the cave in the Aurignacian and the Gravettian (Clottes 2001). The dates obtained on charcoal (Valladas *et al.* 2005; Cuzange *et al.* 2007; Valladas 2009) and the observations on the decorated walls provide information on the age of the fires at the origin of the thermal traces in several sectors.

C14 dating of carbonaceous concentrations that may relate to combustion areas

- Entrance Area: dates obtained for layer 3 of the GE1 survey pit (fig. 10) are, after calibration (Reimer *et al.* 2009), 37,584-35,283 cal BP (32,010 \pm 390 BP GifA90218) and 36,480-35,130 cal BP (31,330 \pm 270 BP GifA80109) (private communication H. Valladas). This part of the cave, where the thermal traces affect large areas, is almost devoid of parietal works (the only known element is a yellow line).
- The Gallery of the Crosshatching: a charcoal accumulation in a bear hollow located at the base of one of the reddened ceiling areas, and interpreted as a possible hearth (Geneste 2005), gave a date between 36,469 and 34,877 cal BP (31,060 \pm 400 BP GifA102565, Valladas *et al.* 2005).

C14 dating of charcoals located near the heated walls

- 44 Megaloceros Gallery: many concentrations of charcoal are found near the thermal traces. Many of them were assimilated to hearths (Geneste 2005), even if the ground does not show any reddening (Clottes 1995). The C14 dating (Valladas *et al.* 2005) give ages between 35,038 to 33,389 cal BP (29740 ± 390 BP GifA99239) and 38,807 to 36,507 cal BP (32,850 ± 540 BP GifA101459).

Relative chronology: relationships with parietal representations

- 45 Recess of the Bears: the line of the back of the Great Bear, in the centre of the panel, and of the neck of the bear to the right, were drawn on the thermal flakes scars (fig. 4), showing that the drawings are posterior to the impact of the fire. The falling of flakes continued later, as is evidenced by the removal of the tail of the great central bear and the presence on the ground of thermoclasts with red dots. These bears are related by their style to the other red bears the Entrance Area. Genetic analysis of the cave bear population of Chauvet Cave has shown that this species was endangered, 30,000 years ago in the Ardèche and had disappeared in the Gravettian (Bon *et al.* 2011). Thus, it could be assumed that only the Aurignacian artists could have drawn from the living, excluding as such a Gravettian dating (Elalouf and Feruglio 2012).
- 46 Megaloceros Gallery: in the gallery, many marks, sometimes superimposed on reddened areas and thermal flakes could not be attributed to one or the other of the periods of visiting of the cave: non-figurative lines, finger traces and brown or orange clayey traces.
- 47 However, several representations are attributed to the Aurignacian (Feruglio *et al.* 2005): vulvae on the Panel of the Feline, in the middle of the corridor, and rhinoceroses on the right wall, near the End Chamber. They were done on reddened walls, that is to say, after the latter has undergone heating.
- 48 A torch snuffing, which by analogy with those dated by C14 could be a contemporary of the Gravettian (Valladas *et al.* 2005), affects the scar of a thermal flake. The latter took off part of a bundle-shaped sign engraved before the Aurignacian drawings that have been dated at the entrance of the gallery.
- 49 These different chronological data, both absolute and relative, seem to agree, indicating that the fires identified in the Entrance Area and in the Megaloceros and the Crosshatching Galleries, would fit within the Aurignacian. However, it can not be completely excluded that some hearths, for which we currently have no references, could be the work of the Gravettians.

Conclusion

- 50 Heated walls and ceilings have been identified in various sectors of the cave, from the entrance scree to the deep parts. Except in the Entrance Chamber and the beginning of the Chamber of the Bear Hollows, they are quite narrow or low galleries (Recess of the Bears, passage from the Cactus Gallery to the Apodemus Gallery, Candle, Megaloceros and Crosshatching Galleries). The larger spaces, with high ceilings, such as the Brunel Chamber, in part the Chamber of the Bear Hollows, the Hillaire and Skull Chambers, do

not bear any traces. However, the absence of evidence does not exclude that the fires, away from the walls, may have been on.

- 51 The areas affected by the changes in colour and the flaking, particularly in the Entrance Chamber and Megaloceros Gallery, imply the existence of a group of hearths, possibly lit at different times. The height at which the traces are found (up to over 3 m) suggests that they were fires with particularly high flames. For the Entrance Area, the Recess of the Bears and Megaloceros Gallery, measurements by TL show values equivalent to those of a rock reaching temperatures between 300° and 375°C.
- 52 Only in two sectors, the Recess of the Bears and the Megaloceros Gallery, the walls changed by heat are directly associated with the parietal representations. Several indicators show that the phenomenon pre-dates some drawings. Flaking nevertheless continued locally, destroying some of the artworks (the hind quarters of the central bear in the Recess of the Bears, the bundle-shaped sign at the entrance to the Megaloceros Gallery).
- 53 In the Entrance Chamber and the Megaloceros Gallery, wood charcoals visible on the surface or discovered buried in the sediment can be connected with the traces found on the walls. Elsewhere, the absence of this type of remain could for example be explained by water flows or disruptions due to the presence of the bears. The supply of fuel in the cave is evidenced by the presence of numerous imprints of branches and twigs, sometimes extended by a carbonized part, found under the calcined floor in the Hillaire Chamber, on the surface of the sediments in the Megaloceros Gallery and the End Chamber (Garcia 2001; Geneste 2001). Their abundance, which can not apparently be explained by running water or by an animal transportation, shows that a significant volume of wood could have been brought to supply the fires in that part of the cave (Geneste 2005).
- 54 What could be the functions of the fires associated with these traces? Apart from domestic hearths, which seem to be excluded – no combustion area of this type has been formally identified in the cave – all other proposals already offered during the study of other French decorated caves, can be taken into account: lighting, marking the path, getting torches going again, pigment production. This is the case of one-off marks, located in the Cactus, the Candle and Crosshatching Galleries, which could relate to any of these assumptions. Two small reddened areas, located on the walls, above of an overhang in the middle part of the Megaloceros Gallery, may also correspond to lighting dedicated to marking out this difficulty of the path. In the Megaloceros Gallery, production of pigment was hypothesized (Geneste 2001, 2005), due to the large amount of charcoal scattered on the ground and, in one case, accumulated at the foot of the wall under one of the representations. Nevertheless the question of the usefulness of such important fire in such a small area is raised, since smaller hearths, located in larger volumes such as the Hillaire Chamber, would have been enough to produce the necessary charcoal to make the black panels.
- 55 Other hypotheses can be put forward:
 - protection against animals and soil purification (the cave was occupied by cave bears hibernating during the period of human presence). This could be the case for the fires in the Entrance Chamber and the Chamber of the Bear Hollows;
 - production of smoke, heat or light without direct practical necessity other than that related to the symbolic when making the frescoes or during the "life" of the figures afterwards;

- Looking for a voluntary change in the surface condition of the wall, including its colour and maybe its consistency. This hypothesis could explain the case of the Recess of the Bears: the traces are too large for a lighting hearth while marking up is meaningless at the end of this narrow corridor. In addition, the colour used for drawing the bears is red ochre instead of charcoal.
- 56 The Chauvet-Pont d'Arc Cave was the place of intense fires that have stained and flaked off its walls and vaults on sometimes large areas. It is the first French example where such traces were identified¹⁰. It might be interesting to review the South-east caves, in the Pyrenees, the Quercy and the Dordogne especially for particular traces that may have escaped observation, usually focused on the representations and the soils.

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NOTES

9. The choice of the dose administered in the laboratory approximates the natural dose acquired since the heating. The given value has been calculated according to the assumed age and the radioactivity of the limestone fragments sampled, measured by gamma spectrometry, here primarily due to the presence of uranium (U content close to 4 ppm).

10. To provide additional information to help understand the meaning of these traces of heating, a program of experimental fires in an underground environment was conducted in a quarry in the Gironde (IThEM: Traces of fires in the Chauvet Cave: From the Thermal Impacts on the walls to the characterization of the fires. Experimentation and Modelling). It has allowed us to understand the functioning of a hearth in a cave, to understand its impact on the wall, to measure the associated temperatures (air and rock) and to study the behaviour of the smoke. This program was jointly carried by the UMR 5060- IRAMAT -CRP2A and 5199-PACEA. It has received via the LaScArBx, a state aid managed by the National Research Agency under the program Future Investments bearing the reference ANR-10-LabX-52.

ABSTRACTS

Researches on the taphonomy of the rock art walls of the Chauvet-Pont d'Arc cave led to the identification and the detailed study of marks resulting from a heating process : pink and grey color of the rock, flakes due to the heat, and soot deposits. This thermal facies was observed in the first rooms, where the main red paintings are located, as well as in the deep rooms where

most of the charcoal paintings were found. A paleothermometric study was undertaken by a thermoluminescence analysis of reddened limestone chips sampled on the archaeological floor or extracted from the walls. As a result, this study showed that the surface of the rock was heated in the past at temperatures ranging from 300 to 375°C according to the sample. The chronological data (C14 datings of the charcoals and relative chronology with the rock art) link the fires mostly to the Aurignacian. The function of the fires remains unknown : lighting, getting the torch going again, colourant production, smoke, heat production, without other reason than symbolic, modification of the wall state, protection from the bears who were present in the cave at the same period...

Les recherches sur la taphonomie des parois ornées de la grotte Chauvet-Pont d'Arc ont conduit à l'identification et à l'étude détaillée de traces résultant d'un processus de chauffe : teintes rose et grise de la roche, écaillage et dépôts dus à la fumée. Ce faciès thermique a été observé aussi bien dans les premières salles, comportant majoritairement des peintures rouges, que dans les salles profondes où se trouvent la plupart des représentations réalisées au charbon de bois. Une étude paléothermométrique par thermoluminescence a été mise en œuvre sur des fragments de calcaire rubéfié collectés au sol ou sur les parois. Elle montre que la roche a été chauffée dans le passé à des températures comprises entre 300 et 375°C selon l'échantillon. Les données chronologiques, tant absolues (datation C14 des charbons) que relatives (relation avec les représentations pariétales) indiquent que les feux se rapportent principalement à l'Aurignacien. La fonction de ces feux reste inconnue : éclairage, ravivage de torche, production de colorant, ou encore de fumée ou de chaleur sans nécessité directe autre que symbolique, modification de l'état de surface de la paroi, protection vis-à-vis des ours qui fréquentaient la grotte en même temps que les hommes...

INDEX

Keywords: Chauvet-Pont d'Arc cave, taphonomy, thermal alteration, thermoluminescence, paleothermometry, chronology, radiocarbon dating

Mots-clés: Chauvet-Pont d'Arc, taphonomie, thermo-altération, thermoluminescence, paléothermomètre, chronologie, radiocarbone

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