A Preliminary Report on Pech de l'Azé IV, Layer 8 (Middle Paleolithic, France)

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ABSTRACT

Pech de l'Azé IV (Dordogne, France) is a collapsed cave with an approximately three meter sequence of well-preserved Mousterian assemblages. At the base of the sequence, resting on bedrock, is a ~50cm thick layer (Layer 8) of dark, primarily anthropogenic sediments that show unambiguous evidence of Neandertal use of fire dating to the time of OIS 5c. The faunal assemblage, which suggests a temperate, wooded environment, has evidence for the exploitation of some small game, and provides possible evidence for some non-subsistence related activities. The stone tool assemblage is characterized by the use of Levallois technology and, among the retouched tools, scrapers are predominant. Raw materials were primarily local and the complete reduction sequence is present in the assemblage with no evidence for import or export of prepared elements. Because of the state of preservation of all aspects of this layer, it represents one of the clearest examples of human management of fire in the European Middle Paleolithic.

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INTRODUCTION

Pyrotechnology is essentially universal among recent and modern hunter-gatherer cultures and, in these contexts, the use of fire represents one of the most important components of hunter-gatherer adaptations. The initial emergence of the use of fire and the development of different fire applications must rank among the most important steps in technological development in human prehistory (Barbetti 1986; Bellomo 1993; Clark and Harris 1985; Eiseley 1954; Gowlett 2006; James 1989; Oakley 1961; Perlès 1977, 1987). There have been a number of claims for fire extending well back into the Early Pleistocene but many of these claims remain controversial (James 1989; Rolland 2004). There is perhaps better evidence in Eurasia starting in the late Middle Pleistocene (Gowlett 2006; Rolland 2004), but it is not until the end of the Middle Pleistocene and particularly the Late Pleistocene that well preserved 'hearths' have been identified; in fact, it is only in the Upper Paleolithic that the use of fire appears to become relatively common. Thus, many questions remain about the emergence and development of pyrotechnology. The site of Pech de l'Azé IV, especially in its basal Layer 8, does have well-preserved evidence for domestic use of fire and as such, it represents a particularly important dataset from which investigations of fire-use can begin.

Pech de l'Azé IV is one of a complex of four Lower and Middle Paleolithic sites located in the Perigord region of southwest France (Figure 1). Bordes discovered and first tested the site in the spring of 1952 (Bordes 1954), and then excavated there continuously from 1970 to 1977. A preliminary note describing the stratigraphy, lithic industries, and fauna was published in 1975, based on his analysis of material recovered through the 1973 season (Bordes 1975). Beginning in 2000, and following an analysis of the totality of Bordes' original collections (McPherron and Dibble 2000), a new excavation at the site was undertaken. The major goals included clarifying the archaeological sequence, obtaining fresh samples for dating, and understanding more completely the formation processes of the site.

In addition to the original trench that ran perpendicular to the cliff behind the site, Bordes opened a 7 x 6m area that, with the exception of a four-square meter bench near the western section, was excavated to bedrock (Figure 2). The recent excavation moved the western section back an additional meter, excavating both it and the adjoining bench to bedrock. At its thickest, at the base of the cliff, the deposits are about 3m deep (Figure 3), and contain a variety of traditional Mousterian industrial variants. These include Typical Mousterian occupations at the base (Layer 8, which rests directly on a relatively smooth bedrock floor), followed by a relatively rare industry called the Asinipodian (which is characterized in part by an emphasis on the production of small flakes [Dibble and McPherron 2006, 2007]), followed by more scraper-rich assemblages (including some true Quina occupations), and finally Mousterian of Acheulian Tradition components near the top of the sequence.

The site, a collapsed cave, is situated at the base of a cliff with a steeply sloping hillside continuing down in front of what was once the area in front of cave mouth. Along the northwest edge of the excavation area, the floor

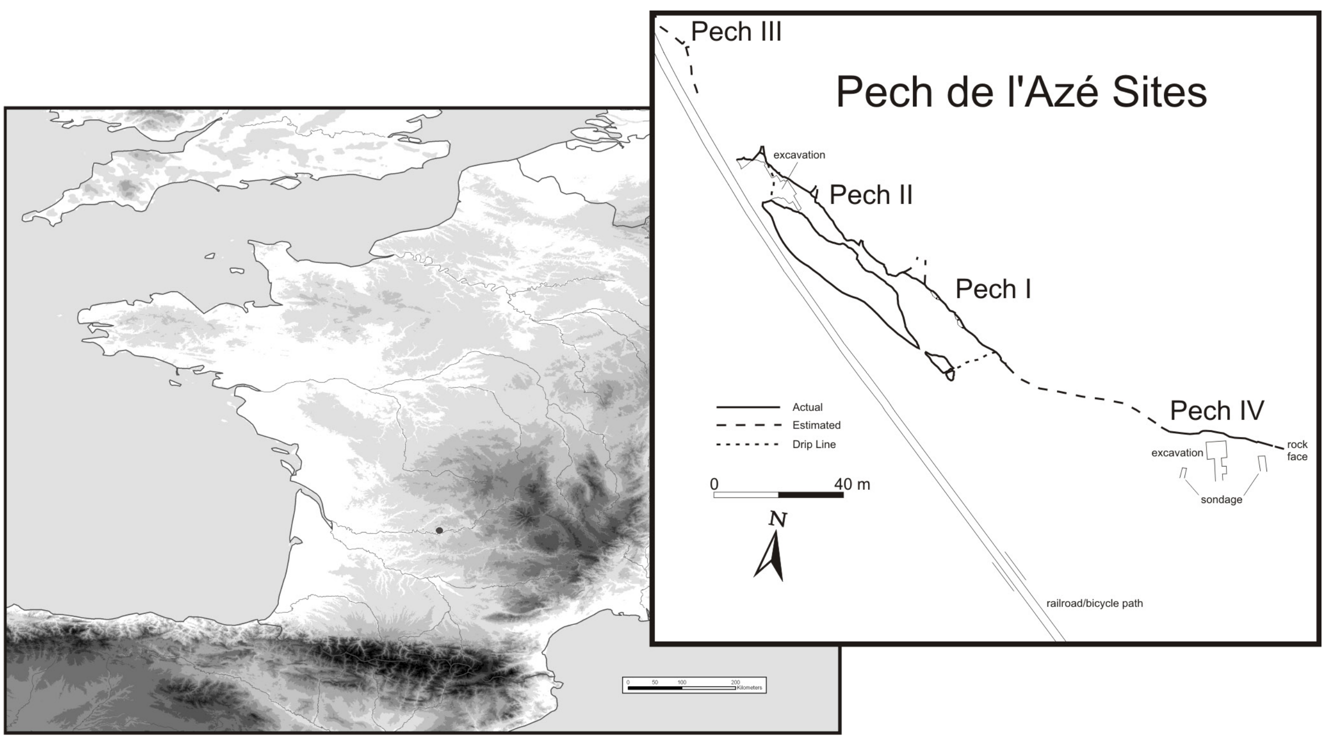

Figure 1. Location of the four Pech de L'Azé sites in France (map prepared by McPherron and Dibble 1998, outline of Pech de l'Azé I and II caves redrawn from Bordes 1972, topography of France from USGS).

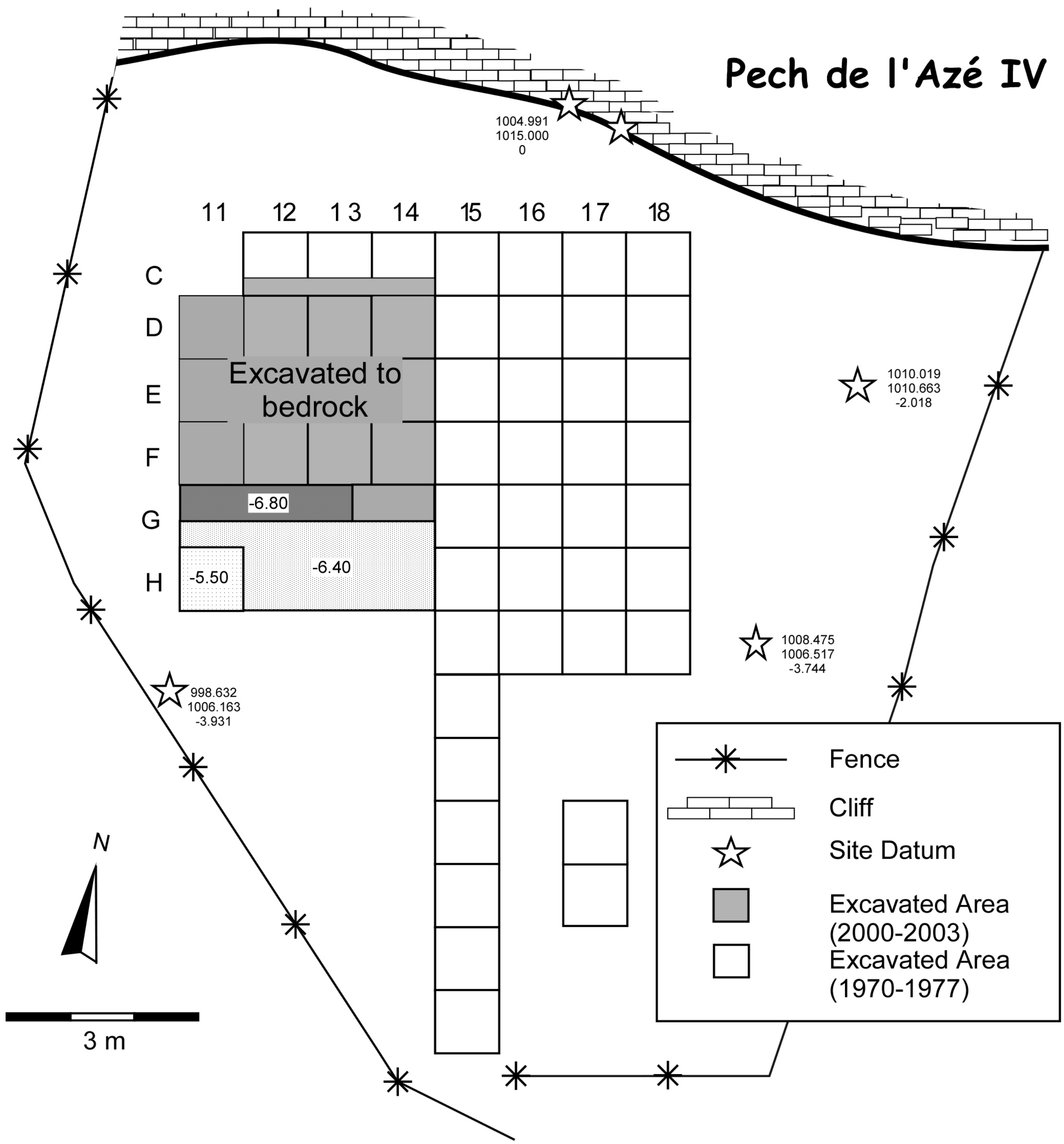

Figure 2. Excavation grid at Pech IV showing areas excavated by Bordes and Dibble/McPherron.

has a shallow, yet distinct, basin morphology with a curved rim that rises to the north and west and slopes gently down toward the south and east until it is truncated by the slope of the hillside. Layer 8 follows this general topography and pinches out in the northern part of the site roughly at the D/E boundary, just at the location where the rim of the bedrock basin rises at the rear of the excavated area (Figure 4).

Although there is a certain degree of independence between the stratigraphic sequence defined by Bordes and that of the recent excavations, the correspondence is clear between our own Layer 8 and Bordes' Layers Y and Z, and the basal portion of X. While Bordes did make these finer subdivisions, in our view there is an overall similarity of these layers, and it is difficult to differentiate among them

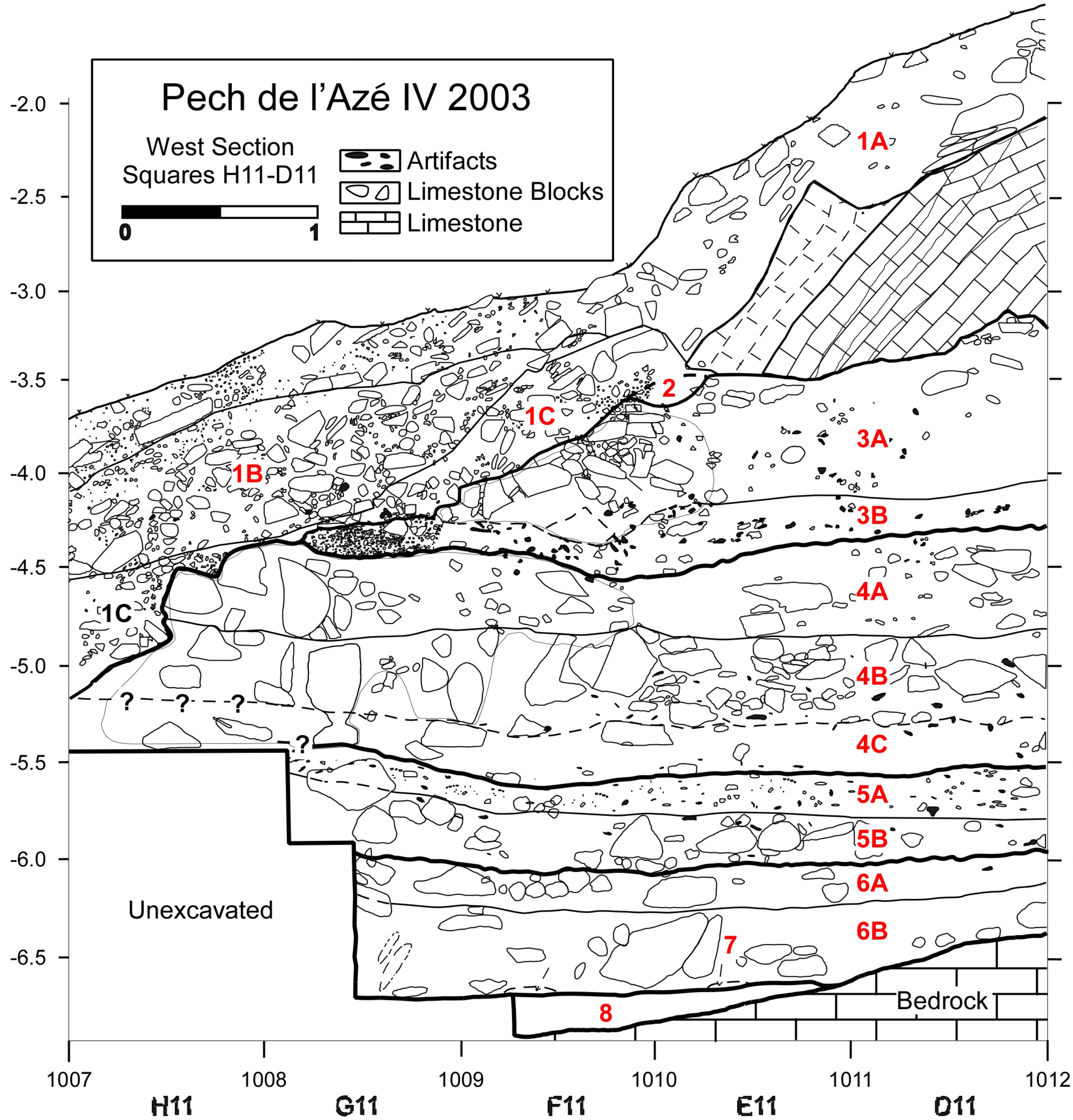

Figure 3. West profile showing the complete stratigraphic section on the grid-west boundary between the 11 and 10 units. Note that the vertical and horizontal extent of Layer 8 was much greater in other excavated portions of the site further toward grid-east.

over any significant area. On the other hand, the upper part of Bordes' Layer X, as both described by him and apparent in the recent excavations, represents a depositional event that is clearly distinct from the underlying sediments and is characterized by significant syn- and post-depositional modification. In our sequence, this later unit is designated Layer 7.

Initial examination of the sections showed that Layer 8 included striking thin lenses composed of ash, charcoal/organic matter, and burned bone. In section view these appear to be numerous, individual, discrete combustion features—"hearths"—that were potentially intact and in place, and not reworked by running water or cryoturbation. In this paper we use the word 'hearth' to indicate the remnants of a domestic fire feature that retains some or most of its original structural or compositional elements (e.g., organic matter and overlying ash). As will be discussed in more depth below, these features clearly represent what were once numerous discrete burning events, which together with their associated artifactual materials, are remarkably intact.

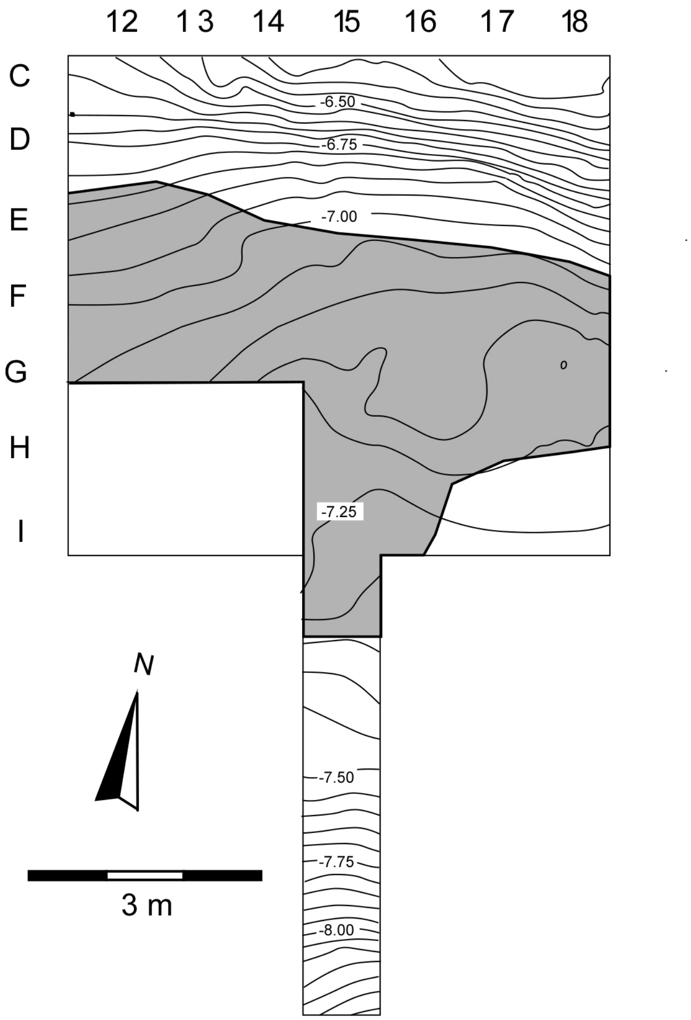

Figure 4. Bedrock topography and areal extent of Layer 8 deposits (shaded).

The remainder of this paper will present the results of analyses focused on several principal lines of evidence, derived from the Layer 8 deposits, about Neandertals' use of the site and the role that the use of fire may have played here. The analytical sections include discussions of the age of the deposits, sedimentary context, and both lithic and faunal remains. These sections are followed by a synthetic discussion.

SEDIMENTARY CONTEXT OF LAYER 8

Taken as a whole, Layer 8 consists of greasy, organic-rich, slightly clayey silty sand with burned and calcined bone, and flint. The darkest levels are exposed along the west profile in Squares G14 and H14 (Figures 5 and 6) where they reach a maximum thickness of ~60cm. In addition to the overall dark color in these squares, horizontally discrete charcoal lenses, approximately 1cm thick, can be readily distinguished; some are clearly capped by thin (1cm) bands of ashes (Figures 6b, 6c, 7a, and 7b). At the very base, a ~3cm-thick black layer is overlain by sediments that are redder and about 5–10cm thick. This basal layer is commonly covered with a light-colored band about 2–3cm thick, which is visible over much of the west section of Squares F14 to H14, as well as along the south faces of F12, F13 and F14.

Both to the north and south, the thickness of Layer 8 decreases dramatically and eventually pinches out toward the north just at the location where the bedrock floor rises toward the back of the excavated area (see Figures 5 and 6); therefore, Layer 8 does not extend to the rear wall of the cave. In the E, D, and F rows of squares near the south entrance to the site, the organic zones characteristic of Layer 8 interfinger with lighter colored (strong brown: Munsell 7.5YR5/6) quartz sand.

Within this overall generalized stratigraphic framework, several localized variations in composition and aspect can be observed. These differences include:

- 3 to 4cm thick bands of reddened sediment (Munsell 2.5YR5/6) occur within certain exposures, as, for example, Square F13, where the bands are roughly parallel to the bedding (see Figure 6), which slopes a few degrees toward the entrance of the cave. In addition, in areas where the bedrock floor was covered by Layer 8 sediments, localized stains of reddened (Munsell 2.5YR5/6) bedrock can also be seen. These rubefied areas were ascribed by Bordes to fire reddening; research in progress indicates, however, that they are rich in kaolinite and hematite (Devault 2007) and resulted from diagenesis; similar reddening demonstrably unrelated to burning has been documented from nearby Grotte XVI in Dordogne, and Theopetra Cave, Greece (Karkanas et al. 1999; 2002).
- The lowermost part of Layer 8 that rests on bedrock is locally indurated with sparry calcite, a feature that is coupled with a high degree of porosity, large (cm-size) voids, and markedly less fine fraction. The trapping of water on the floor of the cave is likely responsible for these phenomena.

The anthropogenic components and their mutual spatial associations at the microscale provide clear evidence that numerous burning events occurred during the accumulation of Layer 8. The burned zones vary from tabular features, to (less commonly) more circular ones with slightly depressed centers. These features are roughly consistent in morphology with some of the combustion features from Middle Paleolithic sites in the Levant, such as at Hayonim and Kebara Caves, Israel (Meignen et al. 2000). At Pech IV, however, the combustion features are fewer and less structured, although diagenesis and chemical alteration are much less pronounced in comparison to the Israeli sites. Within the preserved structures and throughout Layer 8, ashes are composed of calcite, and FTIR results reveal no phosphate diagenesis as is commonly found in several Middle Paleolithic ash deposits (e.g., Karkanas et al. 2002; Shahack-Gross et al. 2004; Weiner et al. 2002). Nevertheless, it is uncommon to find calcareous ash resting upon a charcoal layer; similarly, the presence of a "baked/rubefied" substrate is not present in any sample (cf. Goldberg 2003; Weiner et al. 2000).

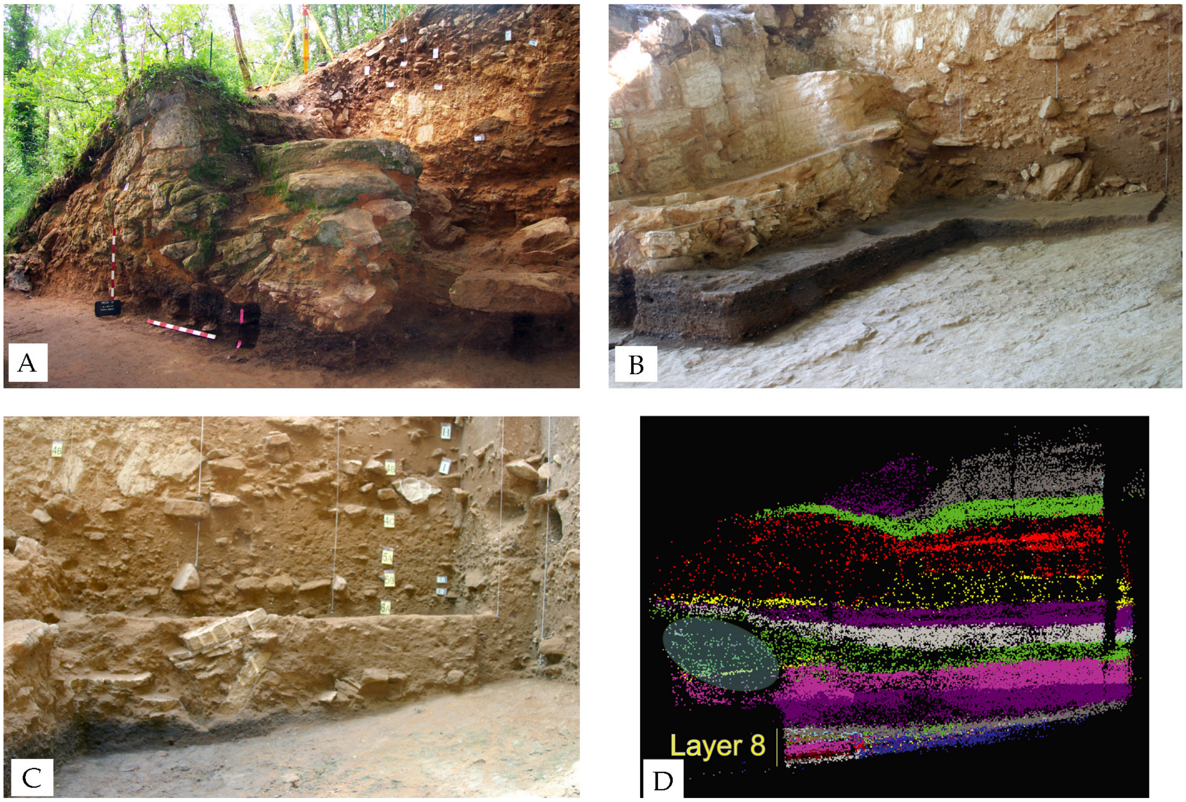

Figure 5. Views of Layer 8 in stratigraphic context. a: photograph of the western side of entrance section of Pech de l'Azé IV showing organic-rich ashy sediments of Layer 8; b: photograph looking to the SW of the entrance, south, and west sections at the end of the 2003 season. The thickest part of Layer 8 is at left, and thins laterally away to the right where it pinches out upon the sloping bedrock, roughly in square D13. In addition, note the large pieces of roof fall that effectively seal the layer. c: west profile at the beginning of the 2003 season showing the pinching out of Layer 8. Distance between vertical strings is 1m. d: plot of lithic artifacts and bones at the cave site of Pech de l'Azé IV. Note the overall inclination of the deposits to the left (south). The ellipse broadly demarcates a large mass of rocks for which there are few data points. As a consequence of these blocks, some of the layer (e.g., pale blue) which overlies them is draped toward the back of the cave, to the right (N). The width of this profile is ca. 6m.

Based on past experience with similar deposits at Zhoukoudian (Goldberg et al. 2001) and at Kebara (Meignen et al. 1989; 2000; in press) and Qesem Caves, Israel (Karkanas et al. 2007), micromorphology was used for studying the evidence for burning and other activities related to the use of fire in Layer 8 (Goldberg and Sherwood 2006). This method is particularly suitable to evaluate the processes that produced the often indistinct boundaries observed between the layered ashy deposits and the darker sediments, as well as the locally cemented areas at the base of the layer. Between 2001 and 2003, about 45 sediment samples were collected from Layer 8 as large (commonly 15–20cm x 10cm x 10cm), intact blocks of sediment using the procedures outlined in Goldberg and Macphail (2003), which yielded approximately 53 thin sections. The sections were studied using a petrographic microscope at magnifications ranging from 20X to 400X, under both plane-polarized light (PPL) and cross-polarized light (XPL). A microfiche viewer and flatbed scanner (Arpin et al. 2002) also were employed to study overall organization of the material, including microstructure and void shape; oblique incident light (OIL) was used to distinguish organic material from charcoal and burned bone from Mn-stained bone; it was also effective in highlighting secondary iron precipitation. Fluorescence microscopy in combination with Fourier transform infrared spectroscopy (FTIR) of complementary loose samples helped in the mineralogical characterization of the sediments. Some slides were analyzed with the electron microprobe to examine elemental distributions. All thin sections were described using the micromorphological terminology of Courty et al. (1989) and Bullock et al. (1985), with more recent revisions by Stoops (2003).

Coarse and fine fractions of the sediment can be viewed from the standpoint of geogenic and anthropogenic contributions. Much of the geogenic material in the coarse fraction is dominated by larger clasts (éboulis) of the Middle and Upper Coniacian bedrock (Capdeville 1986)—a yellow, sandy limestone (quartz calcarenite)—or its weathering products. Specifically, the geogenic coarse fraction ranges from fresh to weathered sand- to gravel-size pieces of rounded limestone fragments, to sub-angular to subrounded silt- and sand-size quartz grains. The quartz grains are polymodal, with modes in the silt, fine to medium sand, and coarse sand sizes. Rare coarse components include fresh and weathered sand-sized grains of glauconite and muscovite, both of which are present within the bedrock.

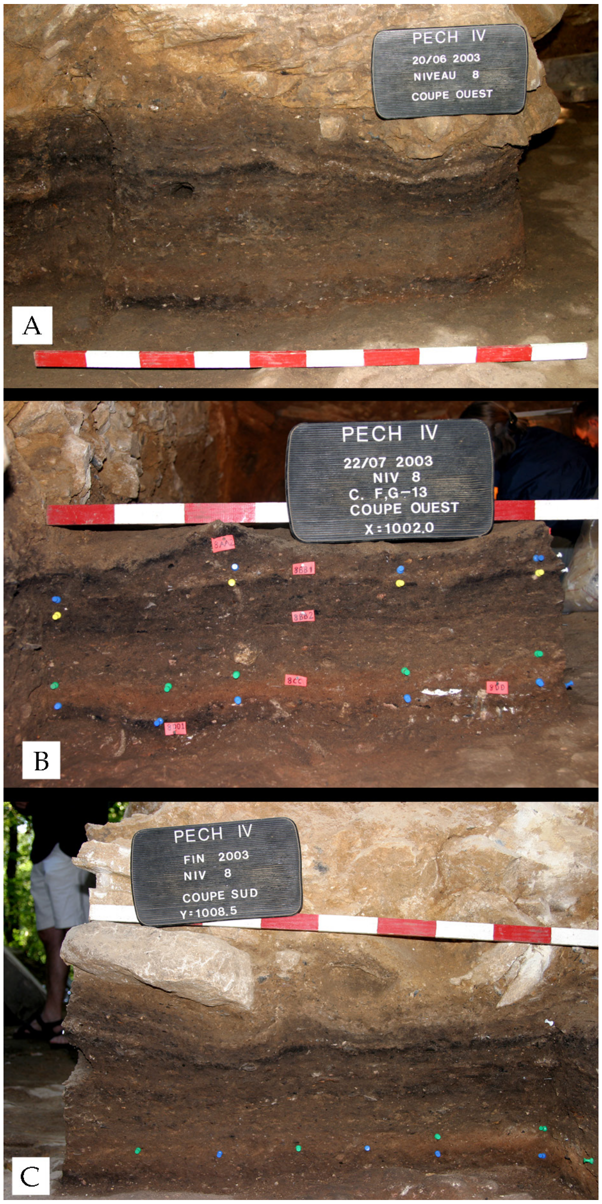

Figure 6. Close-up views of Layer 8. a: detail of the Layer 8 sediments in Square H and I 14 (see Figure 2) as seen from the east. Also shown here is Layer 7, a lighter-colored sediment wedged between the large slab of bedrock and the darker deposits of Layer 8. b: detail of Layer 8 in excavated profile 50 west of that shown in Figure 6C. Note the rubefied zone of sublayer 8cc and bright, thin discontinuous stringer of ash in sublayer 8BB1. A thin lens of Layer 7 is visible between the meter scale and Layer 8 below. The red color is due to enrichment in hematite and appears to be a diagenetic feature, not directly tied to heating. c: south profile showing bedded ashes and organic units. This photograph is at 90 degrees (i.e., viewed from the north) to Figure 6A above.

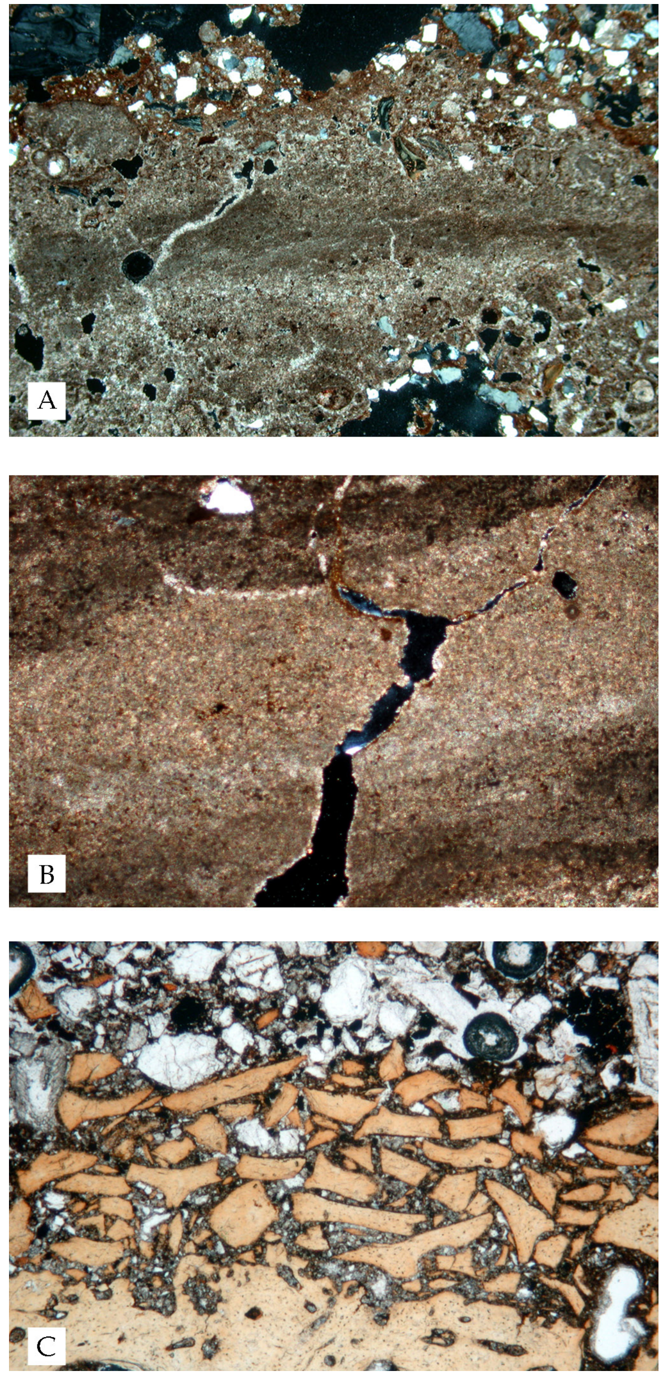

Figure 7. Thin-section photomicrographs. a: block of cemented, laminated ashes from sample 51a. XPL; width of view ca. 4.6mm. b: fragmented piece of cemented ash, likely broken due to trampling. XPL; width of view ca. 4.6mm. c: sample 57d showing a piece of crushed spongy bone with interstitial fine material composed of ash crystals and finely divided charcoal. The visible refits between these bone fragments indicate that the sediments have not been disturbed following trampling. PPL; width of view ca. 4.6mm.

The geogenic fine fraction is composed of low amounts of clay-size material (<10%) and traces of quartz silt.

The coarse anthropogenic materials include fragments of angular chert and pieces of charcoal, as well as burned and unburned bones and teeth that constitute the largest proportion of the anthropogenic coarse fraction. Bone fragments are generally angular, somewhat equant to tabular in shape (Figure 8), and comparatively small, both in the field and in thin section. Average fragment size ranges from 0.25cm to 2 cm. Several of the bone fragments show *in situ* breakage, presumably due to trampling and/or heat-

Figure 8. Macro scan of sample 3a from East side of site (see Table I) illustrating numerous cm-size chunks of bone (b) heated to various degrees as shown by differences in brown color. A fragment of tooth (t) and chert (ch) are also illustrated. The darker color of the matrix is due to finely divided organic matter and residues produced from heating. Width of view is 50mm.

ing (Théry-Parisot and Costamagno 2005; see below) with angular fragment edges that refit within the field of view. Charcoal is present, but relatively rare in the site and much of the dark color appears to be organic residues derived from bones and vegetal matter (B. Ligouis, personal communication, 2008).

The similarity in color and burned bone content between the basal layer and the ones directly overlying them (our Level 6, in which Bordes noted "traces of fire," although none were identified during the recent excavations) suggests that the preservation of the combustion structures in Level 8 is due to massive blocks of limestone that cap the lowest deposits on the west side of the site. This roof fall deposit protected the sediments and acted as a chemical buffer that saturated groundwater in carbonate before it reached the lowest layers. Carbonate-saturated water would not dissolve carbonate-containing materials, such as ash, and could be the cause of some secondary calcite precipitation in the lowest layers that rest on the bedrock floor.

In summary, detailed microscopic and macroscopic geoarchaeological study reveals that the lowest layers are dark, organic deposits that contain evidence of multiple burning, trampling, and hearth-cleaning events. The anthropogenic deposits are well preserved, despite the temperate climate, due to a fortuitous roof collapse that capped the burned features with a layer of coarse blocks and smaller éboulis. Nevertheless, microscopic analysis of all layers of the site above Level 8 reveals a complex series of calcite dissolution and precipitation cycles that may have degraded the integrity of ash deposits in overlying deposits in certain areas of the site.

AGE OF THE LEVEL 8 DEPOSITS

THERMOLUMINESCENCE DATING

Thermoluminescence (TL) dating of heated flint from archaeological sites estimates the time elapsed since the last incidence of firing. In contrast to many other chronometric dating methods, it is thus possible to date a past human activity directly, especially in the context of structures like hearths.

Background to the Method

The principles of luminescence dating methods have been described in great detail elsewhere (Aitken 1985; Aitken 1998; Wagner 1998; Bøtter-Jensen et al. 2003), and with a special emphasis on TL dating of heated flint (Valladas 1992; Richter et al. 2000; Richter 2007). Basically, luminescence dating is based on the accumulation of a radiation dose (paleodose: P) in the crystal lattice of the flint from omnipresent ionizing radiation (dose rate: $\dot{D}$) from the sample itself ($\dot{D}_{internal}$), the sediment ($\dot{D}_{external}$), and cosmic radiation ($\dot{D}_{cosmic}$). The radiation dose (P) returns to zero when a flint is heated above ~400 °C and accumulates again as soon as the flint is cooled and buried in sediment. This leads to the (simplified) age formula:

$$\text{age (a)} = \frac{P_{(Gy)}}{\dot{D}_{(Gy \cdot a^{-1})}} = \frac{P}{\dot{D}_{internal} + \dot{D}_{external}} = \frac{P}{(\dot{D}_{\alpha} + \dot{D}_{\beta} + \dot{D}_{\gamma}) + (\dot{D}_{\gamma\text{-external}} + \dot{D}_{cosmic})}$$

where the paleodose (P) is expressed in Gy and the dose rates ($\dot{D}$) in $\mu Gy\ a^{-1}$. It should be noted that luminescence ages are given in calendar years and do not need to be calibrated.

The TL-dating technique used in this study follows Aitken (1985), Valladas (1992), and Richter (2000, 2007). The outer two mm of each sample were stripped with a water-cooled diamond saw. The obtained 'cores' were carefully crushed in a hydraulic press, sieved and ground to <160μm. A sample of about 200mg for neutron activation analysis (NAA) was taken before further sieving through a 90μm mesh. A subsample of the 90–160μm (coarse grain) material was heated to 360 °C for 90 minutes in order to remove the natural TL signal without causing severe sensitivity changes, before all crushed material was subjected to a 10% HCl treatment to remove carbonates. Measurement of the glow curves (Figure 9) was performed with a Risoe-DA15 system, under a constant flow of N_2. Luminescence detection by an 'EMI 9236QA' photomultiplier was restricted to the UV-blue spectral region by optical filters (BG25 + KG5). The samples were heated to 450 °C at a rate of 5 º C s^{-1} during which a second TL measurement was made. The heating plateau (Figure 10) derived from the ratio of the luminescence signal of the artificially increased luminescence

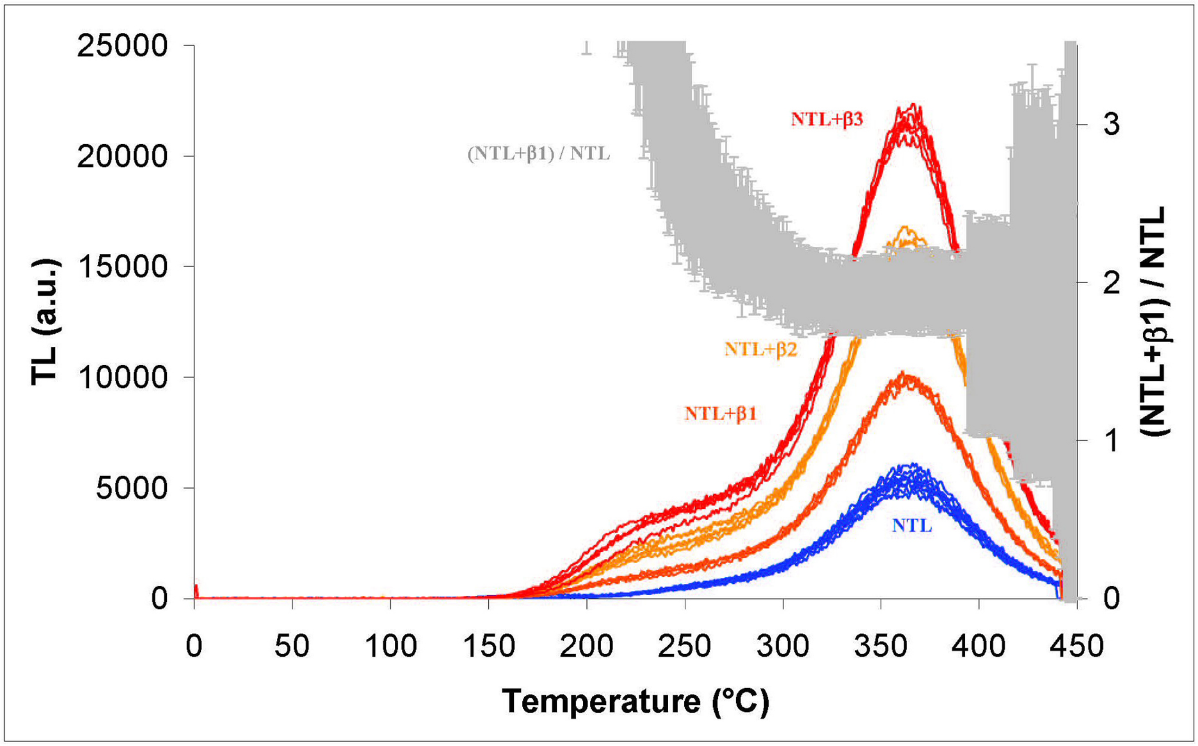

Figure 9. Natural and additive TL glow curves of sample PA-081. The natural (NTL) TL signal is increased by artificial irradiation with known doses (b1 to b3). The heating plateau (grey) from 330° C to 395° C is the ratio of NTL to NTL+ b1 and indicates the sufficiency of the ancient heating for TL-dating.

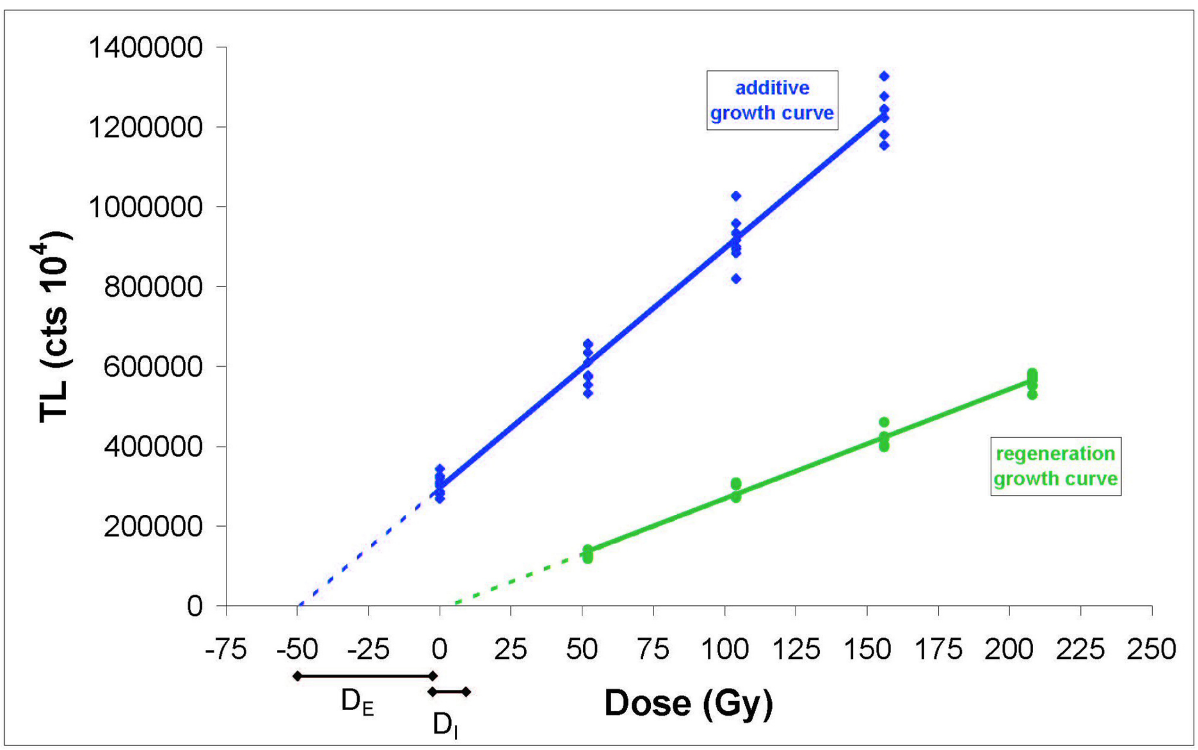

Figure 10. Additive and regeneration growth curves for sample PA-091. The sum of the absolute values of the extrapolation of both data sets to the x-axis essentially gives the palaeodose.

TABLE 1. POSITIONS AND GAMMA DOSE RATE OF THE Al_2O_3:C DOSIMETERS.

Dosimeter #	X (m)	Y (m)	Z (m)	Square	γ–dose rate (μGy a^{-1})
15	999.059	1009.69	-6.893	F	349
16	999.086	1009.303	-6.908	F	361
17	1001.786	1008.561	-6.999	G	300
18	1002.671	1007.92	-7.018	H	303

(additive) to the natural luminescence (natural dose point) indicates the sufficiency of the heating for TL-dating purposes. Paleodoses were determined by irradiating multiple coarse grain aliquots with increasing doses from a calibrated $^{90}Sr/^{90}Y$-source (delivering 0.26 Gy s^{-1} at the time of irradiation). These increasing doses for three to four additive dose points (additive growth curve to obtain the equivalent dose (D_E) with natural sample material) were set according to a first approximation of the natural dose, in order to step increase the TL-signal by an amount roughly equivalent to the natural dose. The dose points for three to five regeneration dose points (regeneration growth curve to obtain the supralinearity correction (D_I) with the laboratory heated material) were set in a similar manner (see Figure 10). Every dose point consists of 6–10 individual measurements. Linear regressions of the integrals defined by the overlapping temperature range of the heating plateau (see Figure 9) with the D_E-plateau (not shown) were employed to obtain the paleodose as the corrected sum of the x-intercepts (see Figure 10) of both growth curves (Richter et al. 2008).

The alpha sensitivity was determined by the additive method, where sets of six fine grain (4–11μm) aliquots were irradiated with calibrated alpha (^{241}Am) and beta ($^{90}Sr/^{90}Y$) sources, with two and three dose points respectively. Linear extrapolation provided dose equivalent values for these two kinds of radiation, and the b-value system (Bowman and Huntley 1984) was used to express the alpha sensitivity of the samples in terms of beta.

Dosimetry

The determination of the various dose rate parameters (see formula) is crucial in luminescence dating because the resulting ages are highly dependent on the correct determination of these values (see e.g., Richter 2007). As part of the external dose rate ($\dot{D}_{external}$), the gamma contribution from the sediment was measured with TLD-500 dosimeters (Al_2O_3:C), which were implanted in the sediment for one year. Excavations had already ceased at the time the dosimeters were set 30 cm deep into the profiles. Their total number (n=4) was therefore limited because of the lack of sufficient sediment overburden to ensure full 4π geometry for the measurement in the remaining Layer 8 sediment.

The gamma dose rate was determined by reading the accumulated luminescence in the dosimeters by optical stimulation (OSL), followed by an irradiation with a known dose from a Cs-source and subsequent measurement of the OSL. A simple comparison of light levels provides the dose received because of the excellent linearity and reproducibility of this artificial material. A travel dose was obtained in the same manner from a dosimeter that had been zeroed at the time when the dosimeters were retrieved from the site and which then travelled with the other dosimeters until measurement. After subtraction of this travel dose, the cosmic dose, which was determined in the same manner as described for the samples below, was subtracted as well, taking into account the actual sediment overburden at the time the dosimeters were buried. The results (Table 1) indicate a rather homogeneous γ-radiation field for the sediment volumes measured, and provide an average of 328 μGy a^{-1}.

The correct estimation of the moisture is one of the most influential parameters of the external gamma dose rate estimate since water attenuates gamma rays considerably (Aitken 1985), thus decreasing the dose rate (see Richter 2007). Because of the lack of precise information we use the 'as is' moisture and do not attempt to model the water history of the sediment.

The cosmic dose rate was calculated after Prescott and Stephan (1982), Prescott and Hutton (1994) and Barbouti and Rastin (1983), taking into consideration the shielding by the sediment overburden and the cliff to the north. The latter is at a maximum distance of seven meters from the samples and rises almost vertically to an elevation about 20m above the TL-samples. This provides shielding of the samples from cosmic radiation to a large extent and we used an estimated shielding from one side (2π) for 20m of rock at a density of 2.75 g cm^{-3} (9 μGy a^{-1}). Shielding of the other side (2π) was provided only by the sediment on top of Layer 8 which increases towards the cliff. Estimates for each sample position were obtained by extrapolation of the present day surface and assuming that this overburden is representative approximately for the entire burial time. Given that the Middle Paleolithic layers are truncated by the Holocene sediments, which lay on a steep slope, it is unlikely that there had been more sediment since the collapse of the roof. An additional shielding by 1.5m of rock was added to take into account that the cave still had a roof for a considerable amount of time after deposition of Layer 8 (Table 2). We consider these estimates as representative for the entire burial time of the samples. However, difference in sediment overburden by one or two meters have little effect on the total dose rate, and thus on the resulting ages.

Results

Heated flint is abundant in Layer 8 and a large number of pieces indicate significant exposure to fire, which suggests a degree of heating sufficient to erase the geological TL-signal completely (Richter 2007). However, only 5 out of 15 tested samples satisfy the criteria of a heating as well as D_E-plateau over the temperature range of a single TL-peak (Richter 2007), and thus only these samples were used. The internal dose rates ($\dot{D}_{internal}$) for the samples were determined by the analysis of U, Th, and K concentrations using NAA on about 200mg of crushed material from each of the extracted cores (see Table 2). Element concentrations were converted after Admiec and Aitken (1998) to internal dose rates ($\dot{D}_{internal}$) which are low, never contributing more than 45% to the total dose rate ($\dot{D}$) (see Table 2). This contribution is a result of low alpha sensitivities (1.09–1.25) which, together with low concentrations of radionuclides (0.7–1.3 ppm U; 0.1–0.7 ppm Th; 520–650 ppm K) result in small internal dose rates, constituting between 31% and 45% of the total dose rate (see Table 2). The dependency of the resulting ages on the external gamma dose rate ($\dot{D}_{external}$) is therefore larger than on the internal dose rate.

The statistics of preliminary TL-ages obtained for the five samples suggest that their heating took place at the same time (majority even at the 1σ level of confidence), despite a spread of 17ka in age. Such spreads are not uncommon in heterogeneous environments. Statistical analysis (Chi-squared) show that the data are normally distributed, which suggest that there are no significant time differences between the individual heating events. The samples are therefore considered to be of the same age (heating event) and a weighted mean (individual ages with their statistical errors) with an error estimate (weighed mean of total individual errors plus the systematic errors, after Walcher 1985) may be calculated. On this basis, an age estimate for the artifact assemblage from Layer 8 at Pech de l'Azé IV of 99.9±5.4ka is obtained. This places the occupation, which resulted in the accumulation of the archaeological material of Layer 8, into Oxygen Isotope Stage (OIS) 5.

A more precise age estimate for the accumulation of Layer 8 can be determined when the available proxy data is taken into consideration with the chronometric age range at 95% probability (2σ). At the 2σ level of probability, a date of 99.9±5.4 ka for Layer 8 excludes the last interglacial *sensu strictu* (Eemian, OIS 5e), as well as the last warm phase within isotopic stage 5 (OIS 5a) as the time of formation. This leaves only OIS 5c as the most likely age for the human occupation at the base of the sequence at Pech de l'Azé IV. No concise dates are available for the boundaries of the substages of OIS 5, but 5c likely spans the 100,000 year mark (e.g., Gibbard and Van Kolfschoten 2005; Hillenbrand et al. 2007; Lehman et al. 2002; Rasmussen et al. 2003; Sprovieri et al. 2006; Winograd et al. 1997).

PALAEOBOTANICAL RESULTS

A sample of charcoal from five excavation squares was analyzed (Table 3, top). Collecting of charcoal was accomplished by wet sieving 100 liters of sediments with mesh sizes of 2mm, 1mm and 500 microns. Proportionally, Squares E13-F13 contained the majority of charcoal. Although relatively numerous overall (n=460), charcoal specimens are mostly <2mm and just 34% of these could be identified to taxon: *Quercus*, *Carpinus*, *Betula*, and *Ulmus* (Table 3, bottom). The remaining 30% of the sample represents either unidentifiable angiosperms or is made up of fragmented, unidentifiable specimens.

The small sample size of identifiable botanical remains does not allow a detailed quantitative interpretation, though the overall consistency of this sample provides a precise palaeoecological context. The anthracological data show a temperate to cold flora representing a forested environment and conditions slightly cooler than present day. It is difficult to estimate the density of vegetation surrounding the site from our data, although the identified taxa indicate woodland environs. In sum, the palaeobotanical data conform to the climatic stage in which this deposit was formed, OIS 5c.

PALEONTOLOGICAL RESULTS

Eight mammalian taxa were identified in this layer, while the remaining specimens were assigned to genus, family or order (Table 4). Red deer (*Cervus elaphus*) represents the predominant prey taxon of Neandertals, while roe deer (*Capreolus capreolus*), boar (*Sus scrofa*), and horse (*Equus ferus*) were only occasional prey. Three or fewer specimens each of reindeer (*Rangifer tarandus*), indeterminate rhinoceros, wolf (*Canis lupus*), beaver (*Castor fiber*), hare (*Lepus* sp.) and a medium-sized raptor were also identified.

The presence of red deer, roe deer, and boar indicates a wooded environment during the time of occupation. Based on fossil records, all three ungulate taxa occurred in both deciduous and coniferous forests. The presence of beaver also points to wooded environs; trees are crucial to this rodent's survival in terms of food and shelter, and the fossil record of *Castor* is thus closely associated with temperate climates (Stuart 1982). These data are consistent with the paleobotanical results and fit comfortably within the absolute date range.

The scant evidence for reindeer could indicate a colder phase, considering that this animal is supremely adapted to cold, open, and dry environs. Alternatively, Pleistocene reindeer may have inhabited a broader range of environments than we currently appreciate. The co-occurrence of temperate ungulates and reindeer in Pleistocene faunal assemblages is documented at other Paleolithic sites across southwest France (e.g., summarized in Grayson and

TABLE 2. RESULTS OF ANALYSIS FOR TL DATING*.

						Internal dose rates		External dose rates					
Sample #	Palaeodose	b-value	U	Th	K	eff. a	b	eff. g	cosmic	Total dose rate	Internal dose rate	External dose rate	Age
	(Gy)	(Gy cm²)	(ppm)	(ppm)	(ppm)	(mGy a^{-1})	(mGy a^{-1})	(mGy a^{-1})	(mGy a^{-1})	(mGy a^{-1})	(% total)	(% total)	(kya)
PA-026	54.4 ± 2.2	1.09 ± 0.08	0.71 ± 0.04	0.26 ± 0.02	523 ± 35	14 ± 1	152 ± 7	312	52	536 ± 32	32	68	101.5 ± 10.6
PA-032	61.9 ± 2.3	1.25 ± 0.04	0.77 ± 0.03	0.69 ± 0.03	604 ± 33	20 ± 1	178 ± 6	308	55	569 ± 32	36	64	108.7 ± 11.9
PA-036	62.5 ± 1.5	1.09 ± 0.04	1.32 ± 0.04	0.32 ± 0.02	657 ± 33	26 ± 1	252 ± 7	305	51	645 ± 31	45	55	97.0 ± 8.7
PA-060	49.5 ± 1.5	1.16 ± 0.02	0.71 ± 0.03	0.15 ± 0.01	523 ± 32	15 ± 1	148 ± 5	315	57	541 ± 32	31	69	91.5 ± 8.7
PA-081	58.8 ± 1.8	1.25 ± 0.02	0.74 ± 0.03	0.39 ± 00.2	652 ± 39	18 ± 1	170 ± 6	303	55	553 ± 31	35	65	106.4 ± 10.5

*a flat uncertainty of 10%is used for the external gamma and 5% (cf. references in text) for the cosmic dose rate.

TABLE 3. SUMMARY OF ANTHRACOLOGICAL REMAINS FROM THE LAYER 8 SAMPLE (top: excavated square and recovered charcoal; bottom: charcoal identified to taxon or type).

Square	volume (liters)	N charcoal	N identifiable	% identifiable
E12	9.5	17	17	100
E13	27	213	78	37
F12	25.5	93	23	25
F13	18	125	33	26
G14	19	12	7	58
Total	99	460	158	34

Taxon/type	N	%
Angiosperm	53	33.3
***Betula* sp.**	33	20.8
***Carpinus* sp.**	68	42.8
***Quercus* f.c.**	4	2.5
***Ulmus* sp.**	1	0.6
Total	159	100

Delpech 2006: Table 1), and should not be considered an anomaly resulting from mixing of find horizons. Instead, it is likely an indication of past ecological conditions that have no modern analog.

THE STATE OF PRESERVATION OF THE LAYER 8 DEPOSITS

MICROMORPHOLOGICAL EVIDENCE

Some effects of post-depositional processes are evident in the micromorphology of Layer 8. For example, most limestone fragments—particularly sand-size grains—are in various stages of dissolution, as evidenced by faint edges, and rounded and saw-tooth grain boundaries. Dissolving limestone fragments are commonly uncoated, grade into the groundmass, and occasionally contain vughs. Locally high concentrations of quartz sand within the groundmass or in voids seem to be remnants of decalcified limestone fragments. On the other hand, as noted above, some of the samples collected just above the bedrock (e.g., Square E13) locally exhibit abundant secondary carbonate which tightly cements rounded rockfall fragments. In these samples, porosity is high, and the fine fraction is somewhat diminished.

In addition to carbonate cementation, post-depositional iron oxidation has stained some of the bone fragments a reddish hue (Figure 11). This iron precipitation clearly post-dates the fragmentation of the bones. In any case, both stained and unstained bone fragments occur within the same sample, a feature that could result from mixing of the sediment or preferential uptake of solution on and into some bone fragments.

ARTIFACT ORIENTATIONS

In addition to geological observations, the nature and extent of post-depositional processes can be studied using various types of archaeological data including observations on the density of small finds in the screens, lithic assemblage composition and edge damage, and fabric analysis based on the faunal and lithic artifact orientations.

It is well understood that an assessment of the orientations of clasts within a deposit can be useful in assessing formation processes (e.g., McPherron 2005 and citations within). In general, this notion is based on the assumption that patterning in orientations tends to indicate that the deposits have been subject to some sort of post-depositional alteration, while randomly distributed orientations are more likely to represent *in situ* or minimally disturbed deposits. At Pech IV, artifact orientations were recorded on elongated objects by measuring two points at their extremities using the total station (see McPherron 2005). These data are then analyzed following methods outlined by Lenoble and Bertran (2004; see also McPherron 2005).

The artifact orientations from Layer 8 are presented in Figure 12 and discussed in the context of the full sequence in McPherron (2005). In short, they show no evidence for

TABLE 4. SUMMARY OF FAUNAL REMAINS FROM LAYER 8, INCLUDING NISP (Number of Identified Specimens), MNI (Minimum Number of Individuals), N, AND ANTHROPOGENIC MODIFICATIONS.

taxon	NISP	MNI	cut	%	burn*	%
Lepus sp. (hare)	1	1	0	0.0	1	100.0
Castor fiber (beaver)	3	1	1	33.3	0	0.0
Canis lupus (wolf)	2	1	0	0.0	0	0.0
Rhinocerotidae sp. (indet rhinoceros)	1	1	0	0.0	0	0.0
Equus ferus (horse)	8	1	0	0.0	0	0.0
Cervus elaphus (red deer)	363	7	67	18.5	72	19.8
Rangifer tarandus (reindeer)	3	1	0	0.0	1	33.3
Capreolus capreolus (roe deer)	79	2	15	19.0	24	30.4
Sus scrofa (boar)	20	2	0	0.0	0	0.0
indet bird	1	-	1	100.0	1	100.0
indet cervid	1042	-	153	14.7	324	31.1
indet sm artiodactyl (deer/ibex sized)	419	-	22	5.3	111	26.5
indet lg artiodactyl (bovid/horse sized)	53	-	10	18.9	13	24.5
total NISP	1995					
unidentifiable (n)	43	-	0	0.0	14	32.6
total	**2038**	**17**	**269**	**13.2**	**561**	**27.5**

*buring totals include only piece-plotted specimens

post depositional movement or alteration of the deposit. In the Benn diagram (Figure 12, left) the layer plots closest to the planar pole indicative of randomly oriented objects on a flat surface. From the McPherron-Schmidt diagram (Figure 12, right) it is clear that this surface slopes to the southeast and likely reflects the combined influences of the orientation of the karstic system which slopes to the southeast and the effects of the hill slope which is inclined to the south.

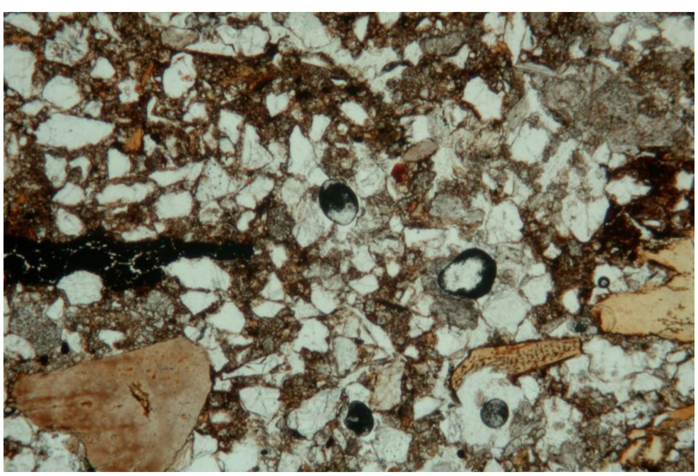

Figure 11. Lower part of sample 51 showing fragment of charcoal and numerous bone fragments, some stained with a thin coating of iron as seen in the lower right. The haphazard nature of the staining indicates that it is post-depositional. PPL; width of view ca. 4.6mm.

LITHIC EDGE DAMAGE

The very low rates of edge damage in Layer 8 also indicate minimal post-depositional alteration. Edge damage is assessed on all stone artifacts and is divided into four basic categories: none, 1-side, 2-side, and rolled. Sides in this case refer to macroscopic removals that originate from either the interior or the exterior faces (1-side) or that originate from both faces (2-side). Rolled artifacts also show worn and smooth flake scar ridges. Using these criteria and applying them to complete and proximal pieces only (to control for differential breakage rates that might also have affected edge damage), Layer 8 has one of the lowest rates in the Pech IV sequence with 72% of the pieces showing no damage at all (Table 5).

With regard to artifact breakage, Layer 8 has the third highest rate of broken flakes (see Table 5). While this could be a sign of post depositional problems, in this instance the high rate of burning (as indicated by a high percentage of burned lithics) is likely affecting the breakage rate (Tables 6 and 7). Levels with a higher percentage of burned pieces, like Levels 6A, 6B, and 8, all have elevated levels of bro-

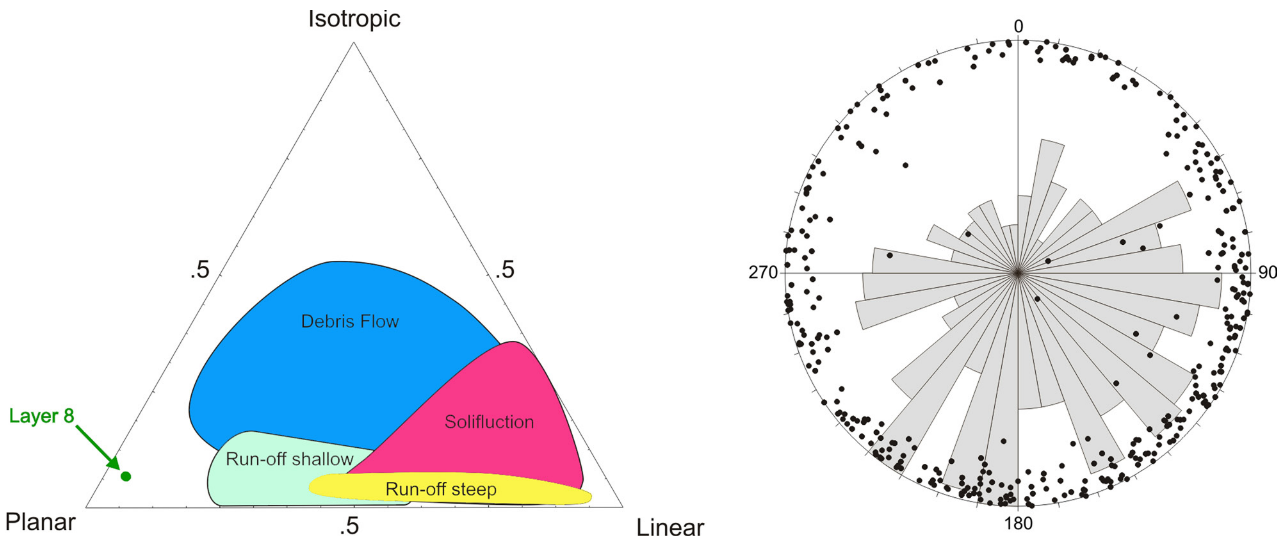

Figure 12. Benn diagram and McPherron-Schmidt diagram (right) for artifacts (stone and bone) from Layer 8. Geological processes noted on Benn diagram are redrawn and modified from Lenoble and Bertran (2004).

ken pieces. Level 7 artifacts are affected by burning plus solifluction, and the high breakage in Level 5B is due to solifluction. Trampling may play a contributing role, along with heating, in the high artifact breakage rates, although trampling is not obvious in the edge damage data. It is also possible that the fine textural composition of the surrounding matrix may have minimized damage to the lithics.

Finally, as shown in Figure 13, there is an abundance of small lithic materials recovered from the wet screens. Small lithics indicate on-site lithic reduction, and since small lithics are more easily removed by water action (Schick 1986), their presence here in such high frequencies suggests that little or no modification to the layer occurred due to this process.

To summarize the lithic evidence pertinent to the taphonomic effects on the Layer 8 deposits, artifact orientations, breakage, edge damage, and small flake data show no evidence of post-depositional alteration of the structure and character of the artifacts.

FAUNAL EVIDENCE

The evidence from the faunal remains concerning the state of preservation in this layer is consistent with the above interpretations. Fragmentation of bone from Layer 8 is extensive but is characterized by two distinct breakage types—helical, fresh breakage of long bones resulting from marrow processing, with mean fragment length of 4.2cm; and dry breakage, which occurred after the organic content of the bone was lost. The majority of dry-broken bone

TABLE 5. LITHIC EDGE DAMAGE BY LEVEL IN THE PECH IV SEQUENCE.

Level	None	1-Side	2-Side	Rolled	N
3A	78.1	16.0	5.7	0.1	1079
3B	71.0	21.4	7.6	0.0	1826
4B	71.0	22.6	6.5	0.0	31
4C	68.9	24.3	6.8	0.0	399
5A	66.9	25.8	7.2	0.1	903
5B	40.0	30.4	22.8	6.8	355
6A	67.3	22.9	9.7	0.2	1302
6B	48.2	30.9	19.5	1.4	1186
6C	25.0	25.0	50.0	0.0	8
7	17.6	22.9	44.6	14.9	1846
8	72.0	20.1	6.7	1.2	1259

TABLE 6. LITHIC BREAKAGE RATES BY LEVEL IN THE PECH IV SEQUENCE.

Level	Complete	Broken	Percent Broken
3A	828	273	24.8
3B	1344	516	27.7
4B	26	n/a	n/a
4C	282	125	30.7
5A	654	268	29.1
5B	228	136	37.4
6A	876	496	36.2
6B	721	528	42.3
6C	n/a	n/a	n/a
7	841	1137	57.5
8	804	578	41.8

in the Layer 8 assemblage was burned and subsequently trampled, leaving fragments of <2cm in length. Numerous burned long bone shaft specimens exhibit both green and dry breakage, which likely represents a sequence of activities—the initial breakage in a fresh state during marrow processing, followed by burning in which the bone broke into multiple, smaller pieces (see Stiner et al. 1995). In other cases, it is not clear whether the skeletal part had been broken by anthropogenic actions or by fire; this is applicable especially to crania.

Despite the level of fragmentation, the condition of piece-plotted bone surfaces is relatively good, allowing for recognition of stone tool cutmarks, scraping striations, and striations resulting from the use of bone as retouchers. Density-mediated destruction of bone seems to have played a significant role in the preservation of the less robust skeletal parts such as vertebrae, ribs, and the cranial vault, although multiple fetal bone specimens did survive intact. It is likely that the loss of fragile bone was caused by multiple factors including burning, trampling, and chemical processes.

From all of these lines of evidence, it is clear that Layer 8 has remained in a very stable condition since the time of occupation. There are no indications of significant post-depositional movement of artifacts or any other natural processes that may have altered the character and composition of the artifact and faunal assemblages. On the other hand, what damage does occur seems to be linked to anthropogenic processes, specifically movement across the site by the hominins themselves. While such processes had relatively small effects on the assemblages, they were responsible for making it almost impossible to excavate the burned zones as individual features. None of our approaches, which in-

TABLE 7. BURNED LITHICS BY LEVEL IN THE PECH IV SEQUENCE.

Level	Percent Burned	N
3A	1.2	1039
3B	0.6	1798
4B	0.0	31
4C	0.7	404
5A	1.2	908
5B	0.9	351
6A	4.6	1322
6B	6.0	1207
6C	0.0	8
7	8.7	1897
8	21.3	1344

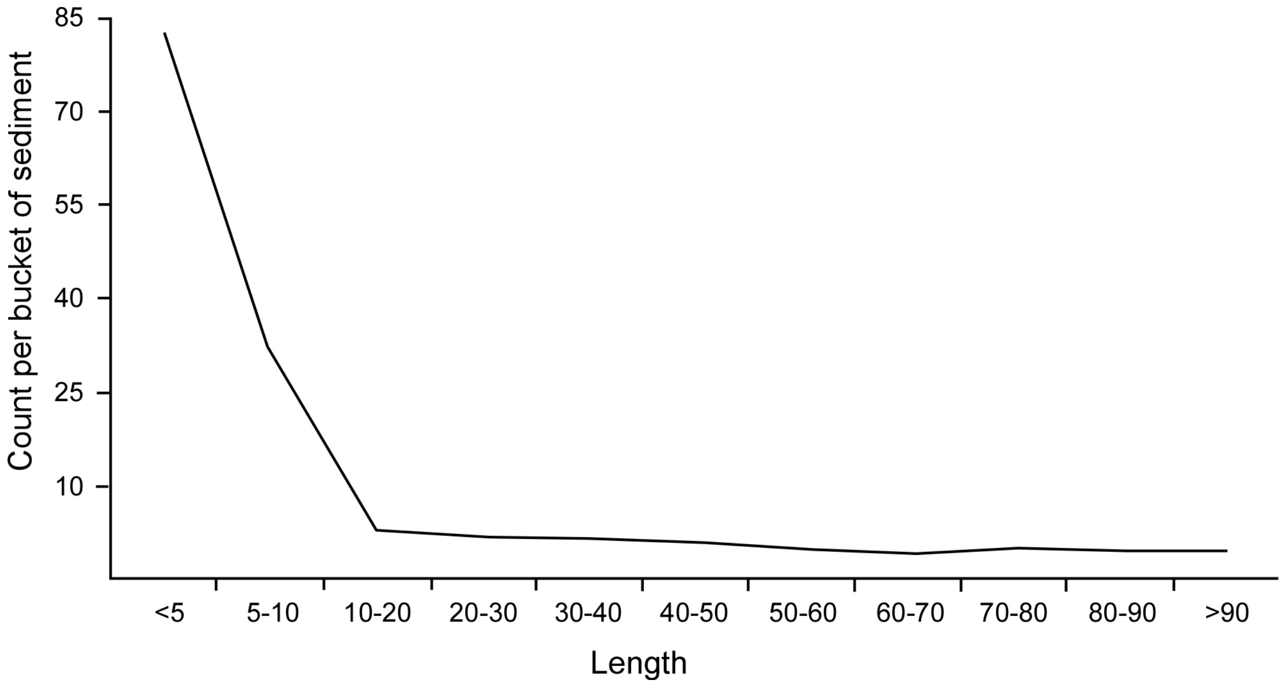

Figure 13. Size classes of lithics in Layer 8 from the point-provenienced and wet-screen samples.

cluded removing thin, horizontal layers of sediment over both large and small areas, and by removing relatively thin vertical slices, was successful in exposing individual combustion features because their boundaries could not be followed laterally with any degree of confidence over distances > 25cm. As such, these individual features cannot be used effectively in reconstructing the spatial organization of the site (e.g., Vaquero and Pasto 2001), although based on the stratigraphy, it seems that throughout Layer 8 time, occupants appeared to live within the cave space just inside of the former dripline.

THE LAYER 8 LITHIC ASSEMBLAGES

LITHIC RAW MATERIALS

The area around Pech IV is a synclinorium composed of Upper Cretaceous deposits (Turonian, Coniacian, Santonian, and the base of the Campanian; Figures 14 and 15), oriented along a southeast/northwest axis. At the heart of this structure are several anticlines that contributed to the development of the karstic features that served as shelters, including Pech de l'Azé itself (Turq 2000), and also exposed outcrops of flint from the base of the Coniacian deposits. This anticlinal ridge, seen only along a small stream called the Farge, measures only two kilometers in length (Demars 1982; Geneste 1985; Morala 1983; Seronie-Vivien 1987; Turq 2000).

In the immediate area of Pech de l'Azé (Table 8), Coniacian flint occurs in the limestone slopes from the center of the anticline and in front of the site itself. The formation is apparent again, and in primary context, toward the north along the Enéa valley (7km towards the village of Saint Natalène), and toward the south-south-east in the Dordogne valley, on the left bank of the river upstream from Domme (5km) and on the right bank at Vitrac (4km). It is also seen in secondary context in the *altérites* some hundreds of meters west of Pech de l'Azé, but especially in the alluvial sediments of the Farges and Enéa, and from them into the Dordogne. On the eastern flank of the synclinorium, Coniacian flint also outcrops both to the north and south of the Dordogne and thus is deposited, for example, by the Carlux and Tournefeuille, respectively. Less abundant are Santonian flints, which exist in a thin bed at the base of the upper part of the formation in a whitish, chalky limestone (Capdeville 1987: 14). As in the case of the Coniacian flint, the Santonian is also found in secondary deposits in the *altérites* covering the flat upland areas and in the Enéa alluvium. The Campanian outcrops only north of the town of Sarlat in high elevations yielding localized silica-rich accumulations.

Chalcedonic chert can have different origins. One is as geodes formed in the Cretaceous beds in the Enéa valley. Another origin is from a silicification of Tertiary limestone, which outcrops some 8km to the south-southwest on the left bank of the Dordogne upstream from Domme, or in the crust of the Bor plain, or further upstream at Le Forêt in the *altérites* and slope deposits. This last formation, which is drained by the Germaine and Céou, is fed by Tertiery siliceous alluvium from the Dordogne, where they are mixed with other similar materials from the Massive Central.

The Quaternary formations are particularly favorable sources for raw material of good quality and quantity, and they were frequently recharged with materials coming downstream or eroded from banks. These resources are different, however, in the Dordogne valley than in that of the Enéa. The latter only transported local rocks (limestone,

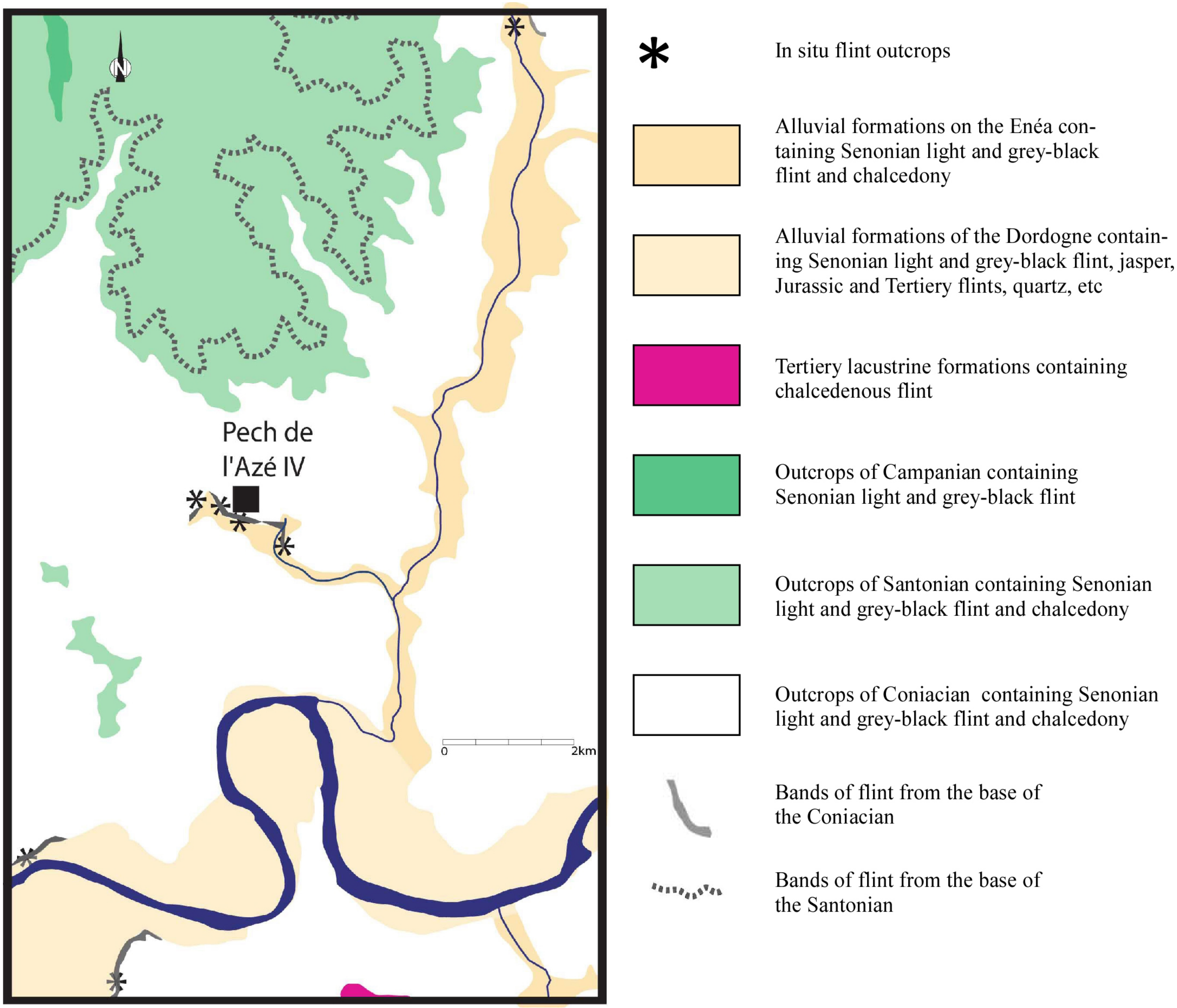

Figure 14. Flint outcrops in the vicinity of Pech de l'Azé IV.

flint, and sandstone) coming from the slopes of its drainage, so that the initial transport included more local rocks from the upstream part of the basin, including metamorphic, plutonic, quartz, quartzites, and other silicified rocks, including Hettangian jaspers, and Jurassic and Tertiary flints.

For the study of raw material from Layer 8, a total of 1,245 objects were examined, and it was possible to identify the type of material for 90% of them, and the context from which they were recovered (based on examination of the cortex) in 42% of the cases (Table 9). As is most often the case for the Mousterian of this region, 99% of the raw material in the assemblage is of local origin. Only 13 objects come from more than 7km or 8km from the site, either on Jurassic flint (n=3), jasper (n=1), or chalcedony (n=9). For 11 others, which lacked cortex, it is impossible to say whether they came from the Dordogne alluvium or from other upstream sources some 40km distant (both Hettangian and Jurassic).

The local Senonian flint, which constitutes the bulk of the assemblage, is divided about equally between light (50.7%) and dark (49.3%) varieties. Most come from alluvial contexts (89%), followed by *altérites* (8%), and then slope deposits (2%). The under-representation of pyritic flint is probably due to an under-exploitation of slope deposits. More precise determinations of the specific geological stages represented was made difficult by the ubiquity of different flints in the area and the rarity of diagnostic organisms contained in them (Turq 1999, 2003); at most, it is possible to note the presence of both Santonian and Campanian flints. Among the non-local pieces brought to the site, three are scrapers (two simple scrapers and one scraper on the interior). One of these scrapers is made on a Levallois flake.

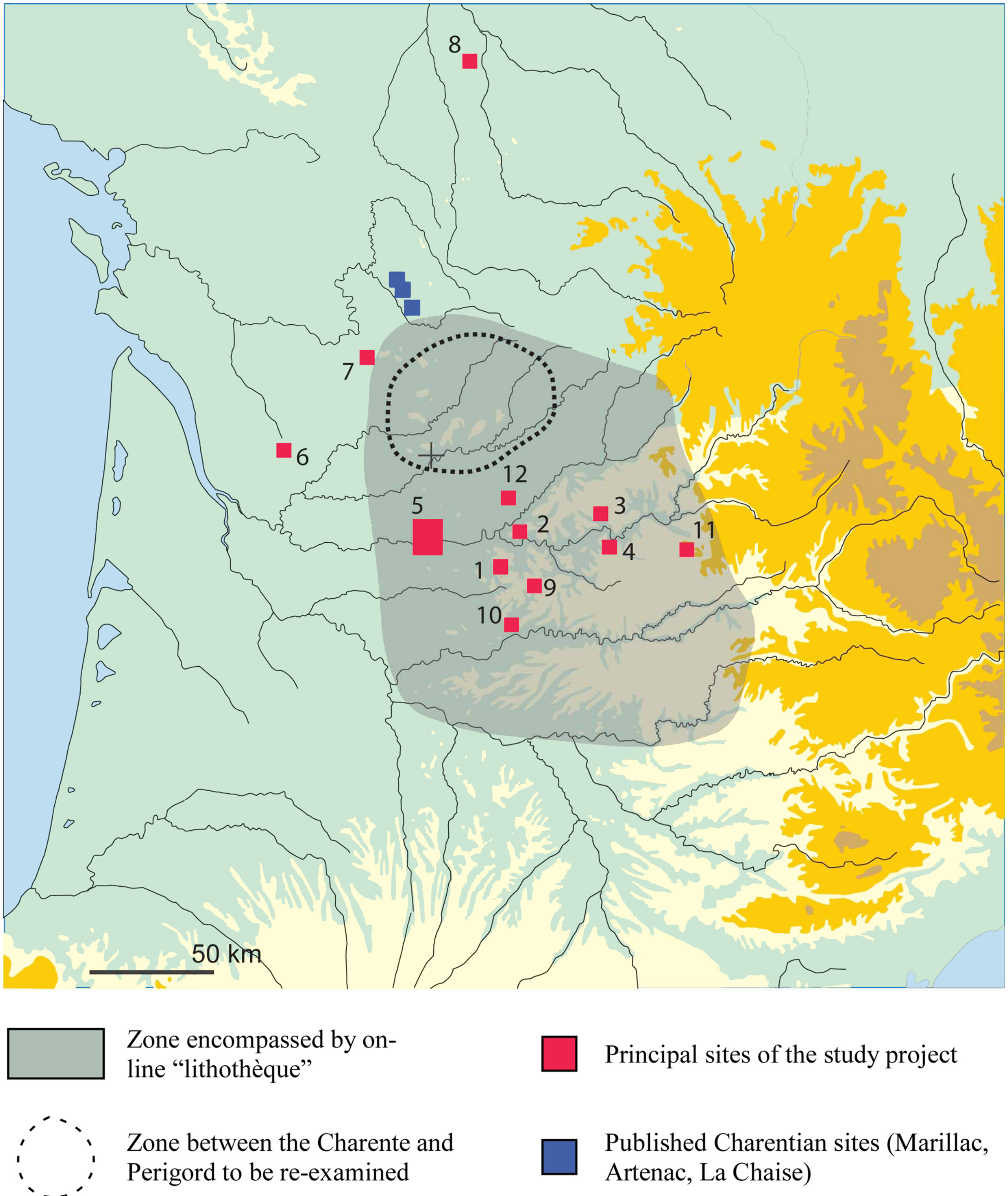

Figure 15. Principal sites included in the detailed study of raw materials of Southwest France. 1: Combe-Capelle; 2: Roc de Marsal; 3: the Pech de l'Azé sites; 4: Combe-Grenal; 5: Bergeracois sites; 6: Jonzac; 7: La Quina; 8: Les Cottés ; 9: La Plane ; 10: Sous les Vignes ; 11: Mas Viel ; 12: La Ferrassie.

TYPOLOGICAL AND TECHNOLOGICAL ANALYSES

Based on examination of material coming from only the first half of his excavation, Bordes considered the assemblages from Layers X, Y, and Z to be examples of Typical Mousterian (Figure 16). Our analysis of the newly excavated material (Table 10), shows that scrapers are more common than Bordes' count indicated, with "essential" Scraper Indices (IR, or percentage of scraper types relative to the total of the retouched tools) higher than 70. This means that the vast majority of the retouched types are various kinds of scrapers (n=341), and of these, most are single forms, followed by double and convergent types; transverse scrapers are rare (Figure 17). Most of the other retouched pieces are notches,

TABLE 8. GEOLOGIC ORIGIN OF FLINTS.

	CONIACIAN	SANTONIAN	CAMPANIAN	TERTIARY	QUATERNARY
Senonian Dark Flint	Yes	Yes	Yes	No	Yes
Senonian Light Flint	Yes	Yes	Yes	No	Yes
Pyritic Flint	Yes	No	No	No	Yes
Chalcedony	Yes (geode)	Yes (geode)	Yes (geode)	Yes	Yes

denticulates, and other notched types (n=110). On the other hand, the number of retouched pieces is still relatively low, with only 5.7% of the total lithic assemblage (artifacts larger than 2.5cm) represented by scrapers and only 8.7% of the total being pieces exhibiting any form of retouch.

In terms of technology, there is some Levallois (with the percentage of flakes and cores that are Levallois equal to 12.9) and a relatively high degree of faceting. There are also some so-called Asinipodian elements (see Dibble and McPherron 2006, 2007), including 43 truncated-faceted pieces, and a small number (n=9) of Kombewa cores or flakes, but these are present in much lower frequencies than in the overlying levels. There is a significant number (n=46) of naturally-backed pieces, but only a few (n=37) core maintenance flakes (*éclats débordants*).

Overall intensity of utilization of the lithic resources does not appear to be extremely high. For the combined assemblage, the blank (all complete and proximal pieces, retouched or not, larger than 2.5cm) to core ratio is 32.1, and the retouched tool to unretouched flake ratio (based on complete and proximal pieces only) is only 0.07. This is also in agreement with the low number of heavily reduced types (convergent and transverse forms) among the scrapers.

As shown in Table 11, size appears again (see Dibble 1995, Dibble and McPherron 2006) to be the main criterion for selecting blanks for retouching. There is also a significant association between retouched pieces and Levallois blanks (Table 12), but it is also the case that Levallois blanks are larger than non-Levallois (t=7.11, P<0.001).

Following the methods described by Dibble et al. (2005), an assessment of the quantity of cortex present on lithics made from the local materials is shown in Table 13. The ratio of observed to expected cortical surface area (Cortex Ratio) is geometrically calculated based on an assumption of average nodule weight. In this case, raw material surveys in the immediate vicinity of the site have shown that the local material comes in relatively small nodules (ranging from roughly 1–2kg), although, of course, it is impossible to know exactly the sizes of the nodules used during the occupation of Layer 8. However, we can compute the Cortex Ratio at two extremes in an effort to bracket the expected results, and in both cases the ratios are close to 100. A value of 100 is expected if all elements from a reduced nodule are present in the assemblage. These results, supported by the presence (n=22) of fully cortical complete blanks and a very low percentage of exotic raw materials (13 of 1,092 pieces), suggests that virtually all of the flintknapping took place at the site with little importation or exportation of prepared pieces.

In sum, the lithic assemblage from Layer 8 appears to have been largely manufactured at the site, with some use of Levallois technology for blank production. While some of these blanks were modified through retouch (pri-

TABLE 9. SOURCES OF FLINTS BY TYPE IN THE LAYER 8 ASSEMBLAGE.

	Slope Deposit	Altérite	Alluvial	Indeterminate	TOTAL
Senonian Dark Flint	3	17	241	261	522
Senonian Light Flint	6	21	172	357	556
Pyritic Flint	4		9	19	32
Chalcedony		1		9	10
Jasper				1	1
Jurassic Flint			1	2	3
Indeterminate		1	20	100	121
TOTAL	**13**	**40**	**443**	**749**	**1245**

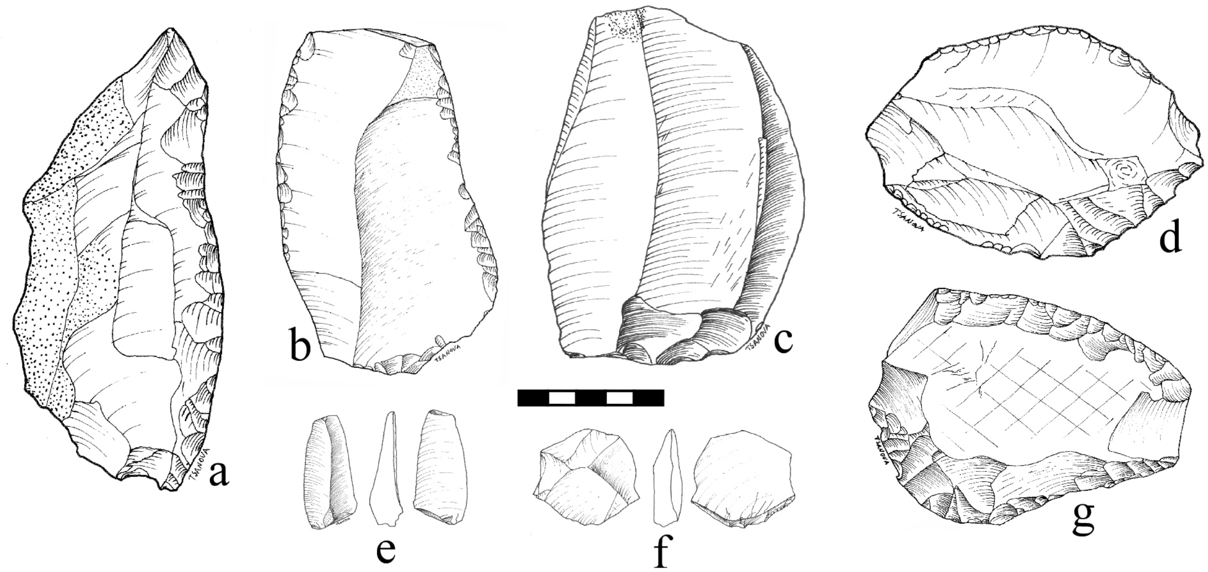

Figure 16. Drawings of lithics from Layer 8. a: D12-4691 (single convex scraper). b: E12-3947 (double convex-concave scraper). c: F13-2140 (Levallois flake). d: F13-2292 (convex convergent on overshot Levallois flake). e: F12-3288 (blade). f: F12-3459 (Levallois flake). g: E13-3036 (double convex scraper).

marily into scrapers), the overall level of tool production was extremely low. At least a couple of hypotheses can be advanced to explain these patterns. First, it could be that occupations were highly ephemeral, with some reduction of whole nodules that were brought into the site, but with little time to select a high percentage of the manufactured flakes and retouch them into tools. While a large number of hearths are present, which may represent a prolonged occupation with several burning events, it could just as well be the case that each hearth represents only a restricted period of occupation followed by abandonment of the site until the next visit. Second, it could also be that the activities carried out at the site were accomplished largely with unretouched flakes. As was shown in the overlying "Asinopodian" layers (Dibble and McPherron 2006, 2007), it is clear that flakes were deliberately manufactured for use in their unretouched state, and such use may be more common than is typically recognized by Paleolithic archaeologists.

ZOOARCHAEOLOGY OF LAYER 8

A total of 1,746 piece-plotted remains (>2.5cm or teeth and identifiable small bones) and 292 specimens recovered from 6mm mesh waterscreen were analyzed in this study. Although the waterscreen material is part of a preliminary sampling of this enormous assemblage, it yielded impor-

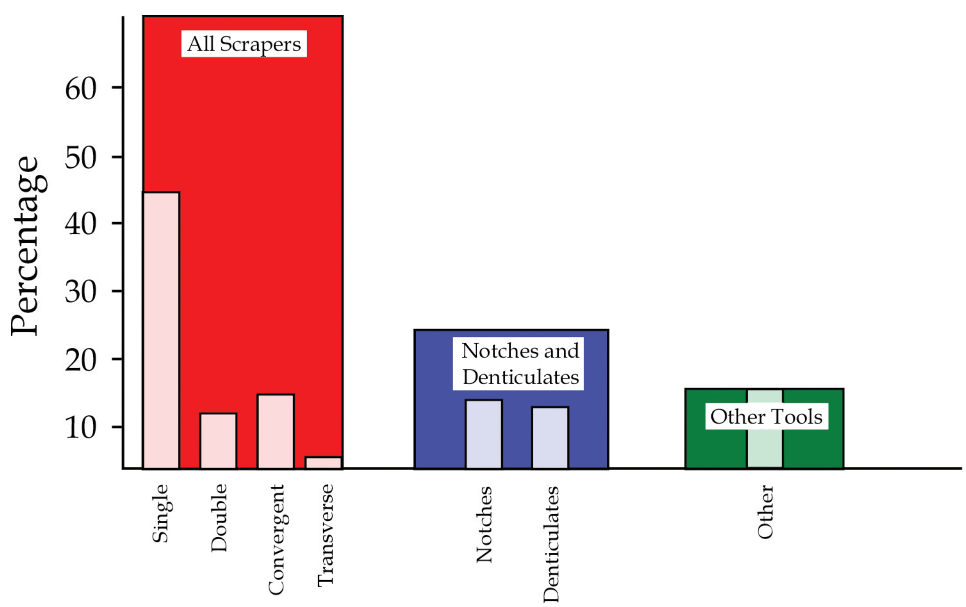

Figure 17. Distribution of typological classes for Layer 8.

TABLE 10. BASIC TECHNOLOGICAL AND TYPOLOGICAL COUNTS AND INDICIES FOR LAYER 8.

Typical Levallois flake	122	Convex transverse scraper	3
Atypical Levallois flake	40	Concave transverse scraper	2
Levallois point	3	Scraper on interior	1
Retouched Levallois point	1	Atypical endscraper	1
Pseudo-Levallois point	13	Typical burin	5
Mousterian point	5	Atypical burin	1
Straight single scraper	20	Typical backed knife	1
Convex single scraper	44	Naturally-backed knife	46
Concave single scraper	5	Truncation	2
Double straight-convex scraper	3	Notch	15
Double straight-concave scraper	1	Denticulate	10
Double Convex scraper	7	Retouch on interior	1
Double Concave-convex scraper	2	Abrupt/alternating retouch	72
Straight convergent scraper	1	End-notched flake	1
Convex convergent scraper	10	Truncated-Faceted piece	14

Real Count	438	**Technological Indices**	
Essential Count	141	IL	12.9
Complete and Proximal Flakes	1288	IF	32.6
Flake Fragments	802	Ifs	19.3
Cores and Core Fragments	6		
Shatter	203		

Typological Indices			
Real Count		**Essential Count**	
ILty	37.9	IR	70.2
IR:	22.6	IAU	0
IAU	0	II	83
I	37.9	III	7.1
II	26.7	IV	7.1
III	2.3		
IV	2.3		

tant results in that five species not recovered in the main assemblage were identified; and the small bones from the joints and feet as well as teeth and fragments of petrous were found, eliminating a bias against these elements in the faunal assemblage overall.

All faunal remains were examined for surface modifications resulting from anthropogenic activities (e.g., cutmarks, hammerstone impact fractures, retoucher traces); burning (see below); carnivore involvement (e.g., tooth furrows, pits); and natural factors (e.g., chemical alteration, abrasion, rounding). This was accomplished with a strong light source, hand lens, and when necessary, 10–40x binocular microscope.

TABLE 11. BASIC METRIC OBSERVATIONS ON FLAKES (UNRETOUCHED) VERSUS TOOLS (RETOUCHED) FOR COMBINED LITHIC ASSEMBLAGES*.

	Flakes			Tools					
	Mean	N	S.D.	Mean	N	S.D.	T	DF	P
Length	36.59	1808	11.47	48.42	287	14.08	-15.69	2093	0.0000
Width	24.70	1704	7.79	29.78	292	7.85	-10.28	1994	0.0000
Thickness	6.33	1705	2.89	8.50	290	3.38	-11.52	1993	0.0000
Weight	7.74	1766	9.07	17.57	251	16.87	-14.92	2057	0.0000

*Bordes' Layers Y and Z, Dibble/McPherron Layer 8

TABLE 12. ASSOCIATION BETWEEN BLANKS SELECTED FOR RETOUCHING AND TECHNOLOGY OF BLANK PRODUCTION FOR COMBINED LITHIC ASSEMBLAGES*.

	Non-diagnostic		Levallois	
	N	%	N	%
Tools	278	73.7%	99	26.3%
Flakes	1372	85.1%	241	14.9%

*Chi-Square=27.57, df=1, P<.0001

TABLE 13. ANALYSIS OF CORTEX PRESENT IN THE LAYER 8 ASSEMBLAGE*.

Assumed Nodule Weight (gm)	Cortex Ratio	Observed Blank to Core Ratio	Expected Blank to Core Ratio
1000	91.83	51.92	85.24
2000	115.62	51.92	172.58

*following the method described in Dibble et al. (2007)

PREY EXPLOITATION

Red deer was the only prey taxon represented by a sample size large enough for evaluating skeletal element frequencies, and in turn, for understanding butchery and processing choices of Neandertals (Figure 18).

As mentioned above, differential bone preservation biased the frequencies of elements such as vertebrae, ribs, and cancellous long bone articular ends. However, long bone shaft fragments are well-preserved and frequencies show that fore- and hindlimb long bones are similarly represented. The number of carpals, tarsals, and sesamoids, some of which rearticulate, indicate that appendicular segments were transported in a complete or nearly complete state.

The small samples of roe deer and boar limit what can be said about Neandertals' exploitation of these species. Roe deer skeletal element frequencies are similar to red deer in that appendicular elements, including joints and feet, are well-represented.

A variety of traces from butchering and processing of ungulate prey are evident, including cutmarks, longitudinal scraping of long bone shafts, helical breakage, and impact fractures. Cutmarks are evident on 13.2% of the fauna (see Table 4).

Cutmarks indicating disarticulation, skinning, and meat removal are all present in this sample, though the latter are more common since the locations usually exhibiting disarticulation—articular ends—are scarce due to density-

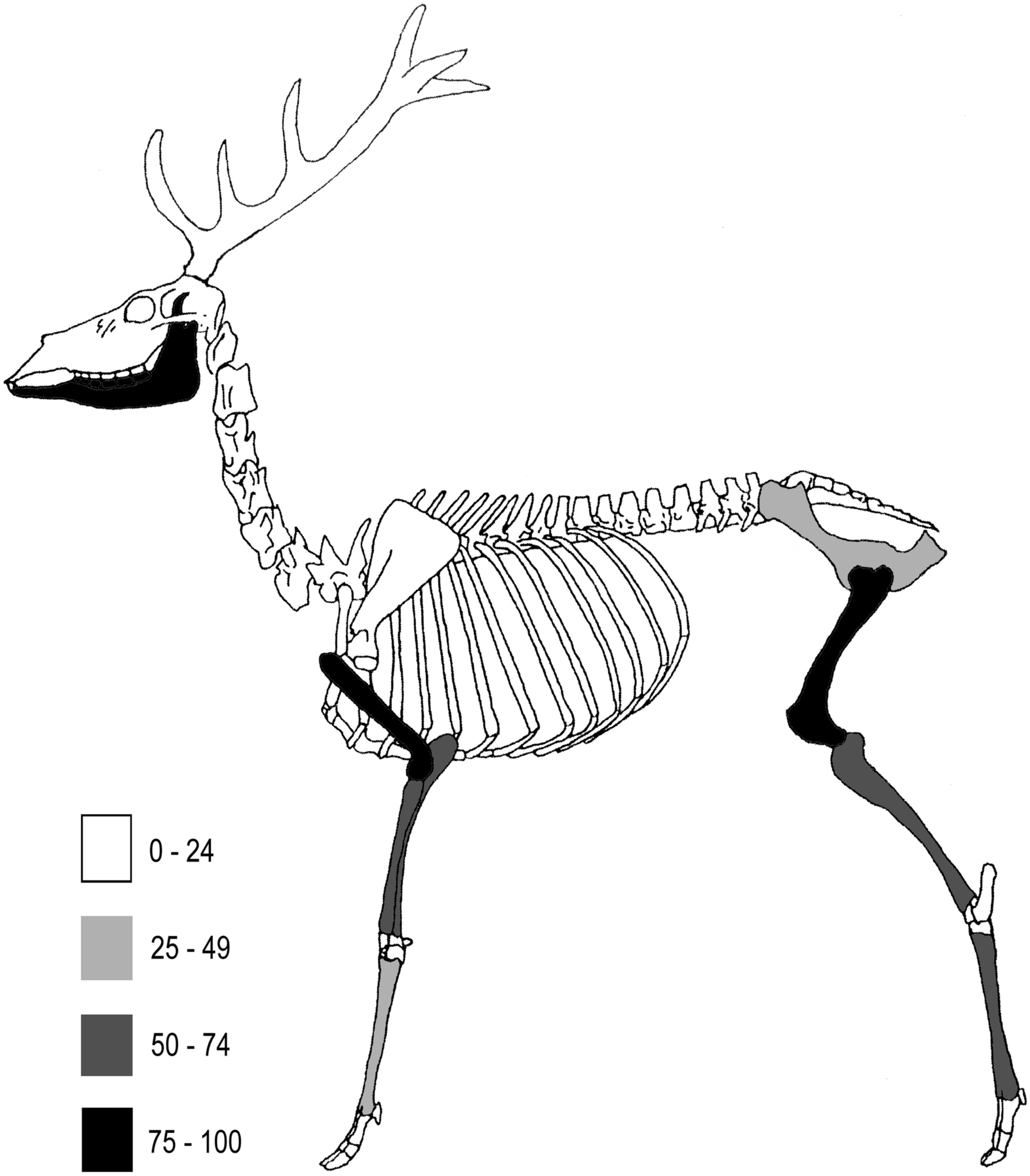

Figure 18. Standardized minimum animal unit (%MAU) values for Cervus elaphus *(red deer) in Layer 8. NISP=363.*

mediated destruction. A number (n=70) of long bone shaft fragments exhibit longitudinal scraping striations, involving well-defined series of parallel lines on the long axis and occasionally overlying cutmarks. The consistent nature of these modifications, both in terms of morphology and skeletal elements affected, leaves no doubt that they were part of the butchering process. Moreover, striations caused by sediment abrasion are characterized by random placement and direction. Binford (1981: 134) attributed longitudinal cutmarks to the removal of periosteum on long bone shafts, facilitating cleaner and more efficient breakage during marrow extraction.

Fresh, helical breakage affects 37.8% (n=730) of the bone, indicating that marrow processing was a frequent activity. This conclusion is supported by the association of hammerstone impact fractures, although these traces are not numerous (n=16). The low frequency of impacts may be partly attributed to the extensive fragmentation due to burning and trampling.

SITE SEASONALITY

The best evidence for estimating the season of occupation comes from a sample of ungulate fetal bone. A total of 16 specimens represent three individual red deer and one boar. An additional eight specimens were too fragmentary for precise taxonomic identification but belong to ungulates.

Fetal red deer was identified and aged using a modern comparative fetal skeleton of this taxon that died at approximately halfterm. Modern red deer mate in September–October and give birth to a single calf in May–June after a gestation period of 240–260 days. The fetal red deer specimens from Layer 8 fall into two distinct groups based on their stage of development, namely winter and late winter-spring.

Identification of the complete fetal boar radius was facilitated by illustrations of fetal domestic pig found in Prummel (1987), while determining its age at death was based on measurements of long bones from fetal domestic pig at various stages of gestation (Habermehl, 1975: Tab. 14; Prummel, 1987: Fig. 6). According to Habermehl (1975, 1985), modern wild boar and domestic pig have gestation periods of 110–120 days and give birth to 5–6 young in early spring. A maximum length of 25mm for the Pech IV fetal boar radius is comparable to an individual close to full-term, i.e., early spring. These results correspond well to those from the red deer.

SMALL FAUNA

The presence of beaver and a medium-sized raptor is remarkable in part because small mammals and birds are rarely recovered from Mousterian contexts. These finds from Layer 8 are particularly interesting because one specimen from each taxon exhibits cutmarks and all are burned.

The second and third phalanges from beaver do not articulate but are likely from one individual. Cutmarks on the lateral side of the second phalanx might relate to skinning of the animal. Weighing up to 30kg—equivalent to a small roe deer (Coles 2006)—beaver was presumably a good source of meat and fat, as well as warm fur.

The bird is represented by a single third phalanx from the talon. Cutmarks are found on the articular surface, similar to those illustrated by Fiore et al. (2004) on an eagle specimen from a Mousterian horizon at Fumane Cave, Italy. These authors surmise that cutmarks were the result of removing the talon's sheath, although the purpose of this activity remains unclear. Since there is no meat or otherwise edible tissue on this part of the foot, the motivation to remove the sheath must relate to a non-subsistence type of activity.

Generally, small mammals and birds are sparsely represented in Mousterian faunas in Europe, and therefore thought to have played little, if any, role in Neandertal subsistence. However, an increasing number of sites are yielding remains from these taxa, suggesting that their exclusion from faunal assemblages might in part relate to other factors such as preservation or excavation techniques not recovering the smallest bones. The ongoing faunal analysis at Pech IV will provide a clearer picture of the use of small mammals and birds throughout the Mousterian sequence, including Layer 8.

AN ANTHROPOGENIC OR CARNIVORE ACCUMULATION?

Because Pleistocene caves and rockshelters served as both living space and the end trajectory for prey transport by hominins and large carnivores (e.g., bears, hyenas, wolves, lions) the potential for overlapping behaviors and mixed bone remains of hominins and carnivores in these localities is great. Therefore, a critical aspect of any zooarchaeological analysis involves determining whether a faunal assemblage was accumulated by human or nonhuman predators.

Two specimens belonging to wolf represent the only carnivore predator in Layer 8 and only one faunal specimen exhibits evidence of bone gnawing by wolf or any other carnivore. Typical signatures of carnivore destruction on bone, such as tooth furrows and pits, long bone shaft cylinders with sharp, ragged break edges or areas where cancellous bone was scooped out, were not detected on this assemblage. Specimens showing the corrosive effects of digestion by carnivores also are lacking.

Wolves and other large bone-collecting carnivores can and do break bone leaving fresh and helical fracture angles similar to those created by anthropogenic activities (Haynes 1983). However, in light of the nearly complete lack of carnivore traces on the Layer 8 bone, but the abundant anthropogenic signatures (see below), there is no question that Neandertals were the main, if not only accumulator of animal bone in this deposit.

EVIDENCE SPECIFICALLY RELATED TO PYROTECHNOLOGY

MICROMORPHOLOGICAL EVIDENCE

Burned bone, expressed as variations of yellow, brown, and black color, is the most abundant indication of burning; whitened calcined bone is present but is relatively rare. Evidence of burned bone is present in nearly every thin section from Layer 8. In some samples, burned bone is directly associated with ash and charcoal, while in others it is homogenously mixed with unburned bone; layering between the two types is not apparent.

Charcoal, another anthropogenic input, is often irregularly shaped and less than 0.25mm in diameter. Large fragments occasionally preserve relics of the plant cellular structure, such as vesicles. However, there is relatively little charcoal in relation to the burned bone and calcareous ash (Wattez and Courty 1987), the latter of which locally contributes a significant part of the anthropogenic fine fraction.

Ashes in Layer 8 occur in different ways, generally as rhomb-shaped grains. In some cases, ash rhombs are mixed with silt, clay, and micro-charcoal, whereas in others, they occur as loose, individual calcite crystals (Karkanas et al. 2002) (see Figure 7). In the latter instance, they locally form links and caps on larger clasts of bone and chert; the undersides of these fragments are generally open voids. Ashes are also often associated with thin channel voids. Lastly, some of the ashes are layered and locally cemented (see Figure 7a), or occur as more massive calcite-cemented bands, some of which have been fragmented (see Figure 7b) and the pieces rotated.

Overall, coarse anthropogenic components are most abundant in the upper portions of Layer 8 and decrease in abundance closer to bedrock. Moreover, samples from the western units contain more anthropogenic fine materials—including organic components—than their eastern counterparts. In the field this is clearly represented by the somewhat lighter color of the Layer 8 sediments in the Eastern Profile.

The geometrical arrangement of the organic-rich and ashy components of Layer 8 are instructive in elucidating their origin and whether they represent *in situ* burning or redistribution of combustion products by natural or human agents. As described above, ash is present in some cases as thin lenses and cemented ash clusters, while in others it is mixed into the sediment groundmass. These differences imply different localized scenarios for accumulation and modification of combustion features and materials. Some of the original ash likely formed in discrete layers as a product of combustion. However, gravitational settling and translocation by water caused some of the unconsolidated ash to filter through the sediment profile, thus accumulating within voids, interstices, or on the top of larger clasts (see Figure 7c). In other instances, ash layers became compacted and cemented by calcite soon after combustion. In some instances this induration disrupted, disfigured, or masked the typical rhomb shapes of ash crystals. Moreover, some of the cemented ash layers were broken and slightly displaced from their original position.

The presence of fractured clumps of cemented ash is also mirrored by *in situ* bone breakage (see Figure 7c) and reduction of charcoal to fine powder (e.g., Angelucci 2003). These physical disturbances, as well as ash layer compaction, are likely due to trampling rather than to other, geogenic processes, such as solifluction, since the components retain their roughly subhorizontal bedding and are semi articulated. Furthermore, the sediment shows no textural indications of cold climate phenomena, such as banding due to ice lensing or aggregation due to cryoturbation.

The dominance of trampling as a post-depositional agent suggests that these samples come from commonly used activity areas of the site (i.e., close to the site entrance), as opposed to peripheral regions, such as the center (Schiegl et al. 2003) or along the back wall of the cave [cf. (Henry et al. 2004)]. However, the preservation of delicate ashes and trampled bone could suggest that the site was not intensely occupied or was used only infrequently. On the other hand, it was not possible to locate with certainty any stabilized surfaces or sterile zones.

In a few samples, broken pieces of laminated cemented ash (~0.75cm diameter) were reworked and rounded, but they were not extensively dissolved. Some bone fragments also exhibit signs of rounding. Because there is no field or textural evidence for significant post-depositional movement of the lowest sediments (i.e., cryoturbation or bioturbation), the cementation and subsequent reworking and rounding of the fragments occurred soon after deposition.

In addition, ashes, bone, and charcoal could have been mobilized in association with activities such as hearth rake-out, which would have laterally redistributed the combustion materials. These activities, in combination with trampling, may have contributed to the breakdown of charcoal within the deposits and their fragment size reduction. While charcoal is not readily abundant on the macro-level, it can be seen in thin section. Charcoal and organic burned residues of plant and animal matter no doubt contributed to the dark color and organic nature of Layer 8; the 'greasy' aspect of the Layer 8 sediments in the field attest to the presence of organic remains as well.

The thickest part of the Layer 8 sequence appears to follow a subparallel line that follows the former position of the dripline and gets markedly thinner toward the bedrock walls at the rear of the excavation. At the base of the layer where water could become perched above the limestone, fine materials seem to have been partially removed by the process of elutriation and the remaining cemented by secondary carbonate. The contact with the bedrock is the only location, save for the dripline, where water activity has played any significant role in the character of the deposits, as they lack the grain size sorting, pronounced void coatings, laminations, and channels that result from water flow. In other areas within Layer 8, localized dripping has resulted in some secondary carbonate precipitation, as has late-stage rooting. In sum, the cementation of the ash layers suggests moist localized conditions on the bedrock floor, whereas the sifting of fine material through the profile points to relatively dry conditions above this.

Finally, the rapid compaction and cementation appears to have protected the visible ashes from significant dissolution, as the dense layers are better preserved than nearby limestone grains. In areas where roof blocks are small and patchy (as in the east wall), ashes are less abundant or absent. Part of this good preservation may thus be due to the buffering effects and physical stability provided by the massive blocks of calcareous rockfall that mark the accumulation of Layer 6 (cf. Goldberg 2000), as well as the buffering capability of the ashes themselves (Sherwood et al. 2004). Nevertheless, the processes of trampling, hearth cleaning, and localized dissolution of the ashes are also reflected in the often indistinct and discontinuous ash concentration morphologies at the macro-scale.

One consequence of the cemented, reworked, and slightly dissolved nature of the ash deposits visible in microscale is that one cannot draw any definitive conclusions regarding the absolute frequency of fire use at Pech IV. The reworked ash zones cannot be interpreted as separate layers within the sedimentary sequence, even though fragments may be separated by centimeters of "natural" sediment. Rather, they should be considered as penecontemporeaneous production and distribution areas of the ashes and organic matter by the cave's inhabitants. The only evidence that could indicate discrete periods of deposition is the presence of *in situ* trampled bone between two cemented ash fragments. Such evidence, however, is not abundant and thus information about timing and reuse is not apparent. Moreover, the consistent evidence of limestone dissolution, and the uniform distribution of burned bone and charcoal throughout the layers suggest that there was likely more ash present in the past than we observe at present; pinpointing its original location(s) is not feasible at this point, but redistribution must be considered as very localized, since the limits of ash and organic-rich layers is concentrated below the former dripline (see above). In other words, combustion products (charcoal, ash, bone) were likely shoved aside or moved on the scale of centimeters to decimeters, but not meters. While it is also possible that some of the ash was removed from the combustion area by the site's inhabitants during cleaning activities, some of the ash was possibly removed by natural processes, such as winnowing by wind.

EVALUATION OF THE BURNED BONE

Indications that bone was burned extensively in Layer 8 come from several lines of evidence, including field observations, context, analysis of geological thin sections with micromorphological and microscope FTIR techniques, and macroscopic evaluation of bone surfaces and structure. Because visual examination can often mistake mineral staining by manganese oxide for burning (e.g., Shahack-Gross et al. 1997; Stiner et al. 1995), additional microscopic methods are necessary to confirm that archaeological bone was indeed heated (e.g., Bellamo 1993; Hanson and Cain 2007; Nicholson 1993; Schiegl et al. 2003; Shipman et al. 1984; Stiner et al. 1995). Results of the micromorphology and FTIR analyses are presented below.

It is clear from visual evaluation of the faunal remains that burning has significantly affected the Layer 8 assemblage and influenced a range of species (Table 14) and skeletal elements. The macroscopic evaluation of burning included all of the piece-plotted bone (>2cm), a sample of waterscreen bone (<2cm) and a sample of hearth fill. The latter two samples came from a total of 15 excavated 1-meter squares.

Documentation of burned bone follows the six stages of burning outlined by Stiner et al. (1995: Table 3) and quantification follows the protocol of Costamagno et al. (2009), a method designed for interpreting the origin of burned bones in archaeological sites. The combined results of these studies provide insight on the role of bone as a source of combustible material in these hearths and the implications for Neandertals' use of fire.

In comparison to charcoal, burned bone of all sizes number ~32,000 specimens and indicate that 54% of the overall bone assemblage is burned (see Table 14). Nearly all (99%) of the burned bone was carbonized (stages 3–6 from Stiner et al. 1995), i.e., lower temperature fires, although some calcinization was also documented. Analysis by microscopic FTIR (Berna et al., in prep) of burned bone within thin sections (see below) show similar results in that the majority of bone was heated to about 300° C degrees and some to 500° C.

The large amount of burned bone in comparison to the relative scarcity of burned plant remains raises questions regarding the fuel source(s) used in the Layer 8 hearths. Also an issue at other sites yielding evidence for fire, bone as a primary source of fuel can only be argued in cases where burned bone is closely associated with combustion features (e.g., Bombail 1987; Costamagno et al. 1999, 2009; Castel 1999; Perlès 1977; Théry-Parisot 2001; Théry-Parisot et al. 2005; Villa et al. 2002). However, a direct correlation between the presence of burned bones and scarcity of charcoal does not unequivocally indicate the intentional use of bones as fuel, since taphonomic factors can influence poor preservation of charcoal.

In order to address this issue in Layer 8, we use here a statistical model designed by Costamagno et al. (2009) that calculates the probability that a burned bone assemblage in question fits one of three types: 1) bone was intentionally used as fuel; 2) bone was not intentionally used as fuel; or, 3) the assemblage is a combination of bone used as fuel and bone having been burned as part of site maintenance. According to the model, Layer 8 plots as a combination of fuel and site maintenance (Figure 19). The main criteria

TABLE 14. SUMMARY OF BURNED BONE FROM PIECE-PLOTTED AND WATERSCREEN SAMPLES.

Category	N	%
N bone <2cm	21,052	91.3
N bone >2cm	2018	8.7
total N bone	23,070	
total N bone, burned (Stages 1–6)	12,510	54.2
total N bone, burned (Stages 1–6), <2cm	11,947	56.7
total N bone, burned (Stages 1–6), >2cm	563	27.9
N carbonized bone (Stages 3–6)	12,403	
N carbonized spongiosa (Stages 3–-6)	2375	
Carbonized index (∑ Stages 3–6 / total N burned) (100)		99.1
< 2cm index (∑ Stages 1–6 / total N burned) (100)		95.5
spongiosa index (∑ spongiosa Stages 3–6 / sum all Stages 3–6) (100)		19.1

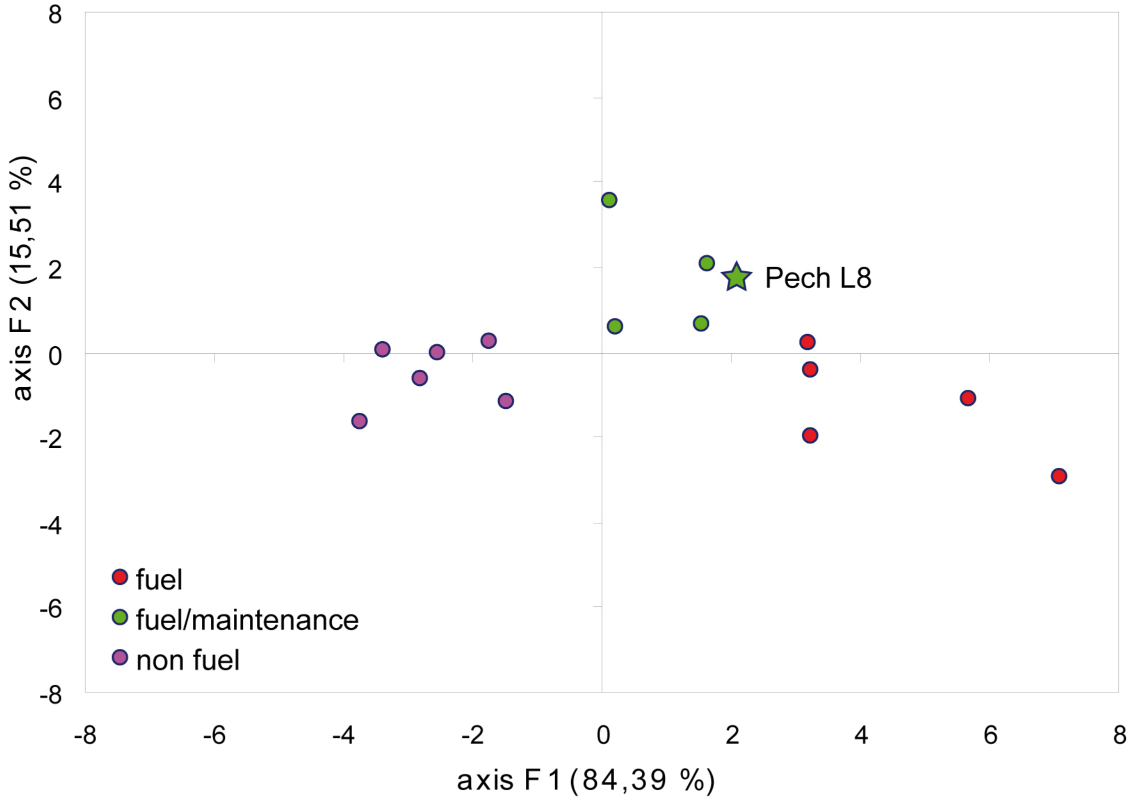

Figure 19. Discriminant factor analysis graph plotting the burned bone samples from Pech de l'Azé Layer 8 versus those from other Middle and Upper Paleolithic burned bone samples.

contributing to this assignment are the high percentages of less intensely burned (i.e., carbonized) bones, the degree of dry bone fragmentation, and the small amount of burned spongy bone. Clearly, there was no preferential use of the spongy bone portions for burning; experimental studies show that these greasy and fat-rich bone portions are the only skeletal parts that burn well (Théry-Parisot et al. 2005). The low frequency of burned spongy bone contributed to the placement of Layer 8 well outside the bone-as-fuel assemblage type.

It is difficult to distinguish between a case in which bone was burned for site maintenance and one in which bone was systematically and intentionally burned as the primary source of fuel. Similarly, many combustion features might be the result of multiple events for different purposes that are impossible to pull apart archaeologically (e.g., Cain 2005). There are a number of possible activities behind the presence of burned bone in archaeological contexts, including but not limited to cooking and site maintenance (Cain 2005; Gifford-Gonzalez 1989; Pearce and Luff 1994; Spennemann and Colley 1989; Speth 2006), or simply accidental proximity to a fire (Bennett 1999; Stiner et al. 1995). We can say confidently that in the case of Layer 8, the burned bone was not the result of natural fire, although we cannot rule out the possibility that some bone was burned through indirect exposure to fire, likely the result of multiple fires overlying one another and the processes of site maintenance (e.g., Rabinovich and Hovers 2004; Sergant et al. 2006; Stiner et al. 1995).

We evaluated whether bone in Layer 8 was burned in the process of food preparation, prior to the later maintenance and fuel combustion events, as this would shed light on the degree that Neandertals utilized fire for cooking prey resources. Speth and Tchernov's (2001) approach for addressing this question at Kebara Cave involved evaluating which skeletal elements were burned. They concluded that among various ungulate prey species at Kebara, long bones were burned in higher proportions than skulls, feet, or the axial skeleton; cancellous epiphyseal ends were burned more than the middle portions of the shaft; and parts of juvenile ungulates were burned less than those of older age classes. In Layer 8 differential representation of anatomical parts could only be evaluated with cervid and indeterminate small ungulate material. Based on these limited data, the percentage of burning is comparable among all anatomical units except for the feet, which show a higher incidence; however, this likely reflects the better preservation of these hard, small bones among the otherwise thoroughly fire-damaged bone. In sum, the results are inconclusive in regard to the cooking of animal parts.

The presence of bone in hearths has led some to argue that wood sources must have been poor or otherwise unavailable (e.g., Schiegl et al. 2003) but, in contrast, bone has been used as fuel by Paleolithic groups at Abri Pataud despite local availability of wood (Théry-Parisot 2002). Based on the anthracological study of the Layer 8 hearth fill, and in particular the tree taxa represented, there should have been ample sources of quality firewood in the vicinity. However,

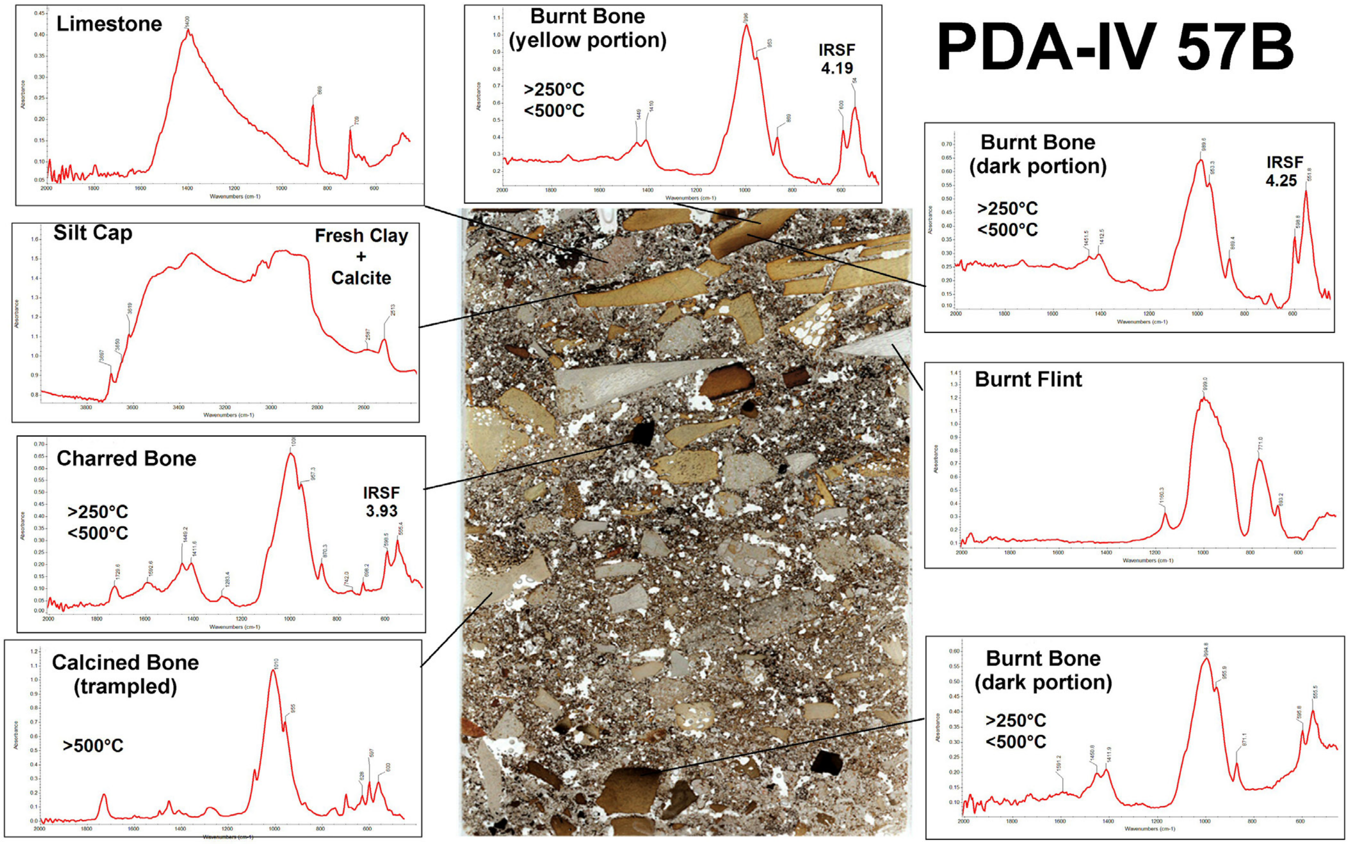

Figure 20. Thin section (PDA-IV 57B) from Layer 8 (Sq G14 X:1002.630; Y:1008.146; Z~6.85) and FT-IR spectra of several particles collected in situ in ATR and Transmission mode.

abundance of firewood may not have been a crucial factor for mobile hunter-gatherers, for whom a small amount of wood would be sufficient for short-term occupations. More relevant would be the availability of dry wood, since green tree limbs do not burn well and the drying process can take anywhere from 6–36 months, depending on the size. Instead, immediate fuel needs would have focused on collecting dead wood, drift wood, or perhaps beaver dams, as well as taking advantage of food refuse already on-site in the form of animal bone (Théry-Parisot 2001; Villa et al. 2002). In fact, using bone to supplement a wood fire had the multiple benefits of minimal labor costs in collecting fuel sources, cleaning up living space (Speth 2006), hearth maintenance (Cain 2005), and providing a longer-burning fire (Théry-Parisot 2002; Théry-Parisot and Costamagno 2005). That said, bone as fuel would have been viable only for short-term use. Calculations based on experimental data show that to fuel three hearths containing equal proportions of bone and wood for six hours, one would need 40kg of bone, equivalent to four animal carcasses of 40–60 kg (Barone 1966; Théry-Parisot 2001).

The rich assemblage of burned animal bone in Layer 8 adds to the list of regional sites where similar evidence is present. Although less common in the Middle Paleolithic, we do see burned bone at Saint-Césaire (Morin 2004; Patou-Mathis 1993) and La Quina (Chase 1999). Early Upper Paleolithic examples are more numerous, for example Abri Pataud (Théry-Parisot 2001, 2002), Abri Castanet (Théry-Parisot 2001; Villa et al. 2002), Caminade-Est (Bordes and Lenoble 2000), Le Flageolet (Bombail 1987) and La Ferrassie (Delporte et al. 1984).

FTIR MICROSPECTROSCOPY

Samples processed in thin section were analyzed by FTIR microspectroscopy using a Thermo-Nicolet Continuum IR microscope attached to the spectrometer. Spectra of particles with diameter of about 100µm were collected either with ATR diamond objective, or with a Reflectocromat 15x objective in Transmission mode. The spectra were collected between 4000 and 450cm^{-1}at 8cm^{-1} resolution.

In thin section sample PDA-IV-57 B several objects were analyzed in place, including burned, charred, and calcined bone, limestone, and a silt capping developed on one of the bone fragments (Figure 20; scale of photomicrograph is 50x75mm). It is interesting to notice that the silt capping is composed of fresh clay mineral (e.g., kaolinite and probably smectite/illite) and of calcite. The presence of fresh clay (unburnt) is an indication that the silt capping was deposited after the fire.

Micromorphological fabrics show that there are in fact two distinct stratigraphic units, both with burned material. Furthermore, these materials are not part of intact fireplaces as shown by the lack of structuring of the components (as opposed to other areas of Layer 8 where it was possible to find combustion ashes in place). Rather, they appear to have been redistributed by hearth cleaning and rake-out, as well as trampling. This interpretation is born out to some extent by the mixed temperatures inferred from calibrated spectra in Figure 20. In the center left, for example, a piece of trampled calcined bone was heated to temperature ≥550° C as shown by the characteristic recrystallization of bone carbonate hydroxyl apatite due the calcination process, whereas in the lowermost part of the slide darkened parts of charred bone yielded temperature estimates of above 250° and below 500° C since charred collagen is still contained in the bones and only a slight amount of bone mineral recrystallization is detected by IR microspectroscopy. In the upper part of the slide, estimated temperatures for bone are more uniform (250° C to 500° C), although the spectrum for limestone suggests it was not heated at all.

From the integration of micromorphology and IR microscopy it is clear that the quasi totality of the bone fragments are burned at temperatures between 300° to 450° C.

The high concentration of burnt bone is used as an indicator of bone being used as fuel (see above). Preliminarily, organic petrology analysis revealed the presence of low counts of fat derived char, an organic byproduct due to the burning of bone with fatty tissue, a common practice when using bone as fuel (Berna et al. in prep). On the other hand, the very low incidence of calcined bone suggests that bone was not used exclusively as fuel, at least locally; our macroscopic study of the burned bone, showing that bone was burned as fuel but as part of site maintenance, corresponds to these findings.

DISCUSSION OF THE USE OF FIRE IN LAYER 8

What really distinguishes Layer 8 from many other Mousterian assemblages is the clear evidence of the management of fire by Neandertals. Use of fire represents one of the most important technological advances that occurred in human evolution, though documenting its earliest occurrences and subsequent development has been highly debated in recent years (Bellomo 1993; Clark and Harris 1985; Eiseley 1954; Gowlett 2006; James 1989; Oakley 1961; Perlès 1981; Rolland 2004). This debate is the result of three main issues with the archaeological evidence. First, what has been considered direct evidence for fire, mainly charcoal and ash, is easily removed by post-depositional processes, thus leaving little or no traces in the remaining sediments (Barbetti 1986; Bellomo 1993; Binford and Ho 1985; Gowlett et al. 1981; James 1989; Goldberg and Macphail 2006; March 1995; Weiner et al. 1998). Second, even when preservation is good, it can be difficult to distinguish human-managed fires from natural events, such as grass and forest fires started by lightning and spontaneous combustion of organic deposits, such as coal, peat, or bat guano (Barbetti 1986; Bellomo 1993, 1994; Binford and Ho 1985; Clark and Harris 1985; Gowlett et al. 1981; James 1989; Rigaud et al. 1995; Weiner et al. 2000). And finally, there are many examples of natural mineral stains (particularly manganese) that have been mistakenly identified as fire (see Binford and Ho 1985; Dibble et al. 2006; James 1989; Shahack-Gross et al. 1997).

Indeed, there are relatively few sites with unequivocal evidence for human use of fire prior to 250kyr (see Barbetti 1986; Barbetti et al. 1980; Bellomo 1990 ,1994; Bellomo and Kean 1997; Clark and Harris 1985; Goren-Inbar et al. 2004; Gowlett et al. 1981, 2005; cf Binford and Ho 1985; James 1989; Rigaud et al. 1995; Weiner et. al. 1998). One example is Hayonim Cave, Israel, which is in the geographical range of Neandertals and where evidence of fire begins before about 230kyr (Mercier et al. 2007) and continues throughout the Levantine Mousterian. Between 250 and 125kyr ago there is increasing evidence of fire in Europe and the Levant, and after 125kyr there are numerous examples (Karkanas et al., 2002)—Pech de l'Azé II (Bordes 1972; De Lumley et al. 2004; Straus 1989); Les Canalettes, France (73.5±5kyr) (Théry et. al. 1996; Théry-Parisot and Meignan 2000); Abric Romani (≈70–40 kyr) (Vaquero and Pastó 2001); and, Roca dels Bous, Spain (≈40kyr) (Martinez-Moreno et. al. 2004). The dates for Pech IV Layer 8 put this occupation in the earlier part of this period when fire becomes more common.

In conjunction with geological results from the Layer 8 analysis, the faunal data show that animal bone was burned intentionally as part of site maintenance and as an additional source of fuel to wood. This supports the notion that Neandertals' knowledge and control of alternative fuel sources were sophisticated. Based on the presence of multiple combustion features, these activities took place over the course of repeated hominin occupations.

These are the basic facts as we know them from Layer 8, but these data also lead to several questions. For example, as important as fire is, it is somewhat surprising that the context(s) under which Neandertals used it is still poorly understood. Quite clearly, while Neandertals had the ability to use fire for most of their existence, they did not always do so. This is not a question of preservation. At Pech IV, for example, there is much less direct evidence for fire in the levels immediately above Layer 8, virtually none in the middle portion of the sequence, and only traces near the top. The decrease of direct evidence through the sequence is matched by similar decline in heated flints. As noted above, heated flints are a reliable indicator of the presence of fire, and, likewise, its absence is a reliable indicator of the absence of fire at that particular location. It is possible that fire related activities simply moved further into the cave through time, and that our excavations did not sample these activities. However, a similar situation occurs (Figure 21) at the Mousterian site of Roc de Marsal (Turq et al. n.d.)—located approximately 30km west of Pech de l'Azé—where a complete sample through the center of the cave and a large portion of the edges still shows a marked upward decrease in burning. The fact is, even after taphonomic factors are taken into account, it is quite likely that most levels from Mousterian sites in southwest France do not show evidence for the use of fire.

Along the same lines, the presence of the hearths (or their absence in other cases) does not appear to be reflected

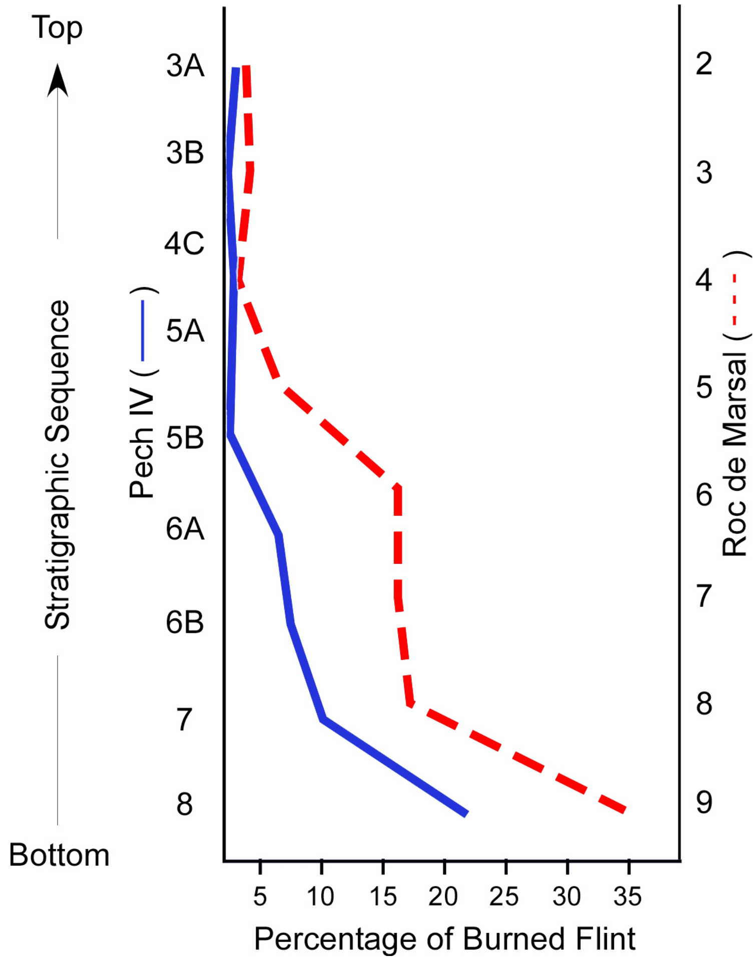

Figure 21. Evidence for the decline in the use of fire at Pech de l'Azé IV and Roc de Marsal.

by any clear evidence for task specialization that may be related to them. The combustion features at Pech IV are more in line with applications associated with what might be termed normal "hearths"—sub-circular ground-surface fires, typically less than a meter in diameter that are most commonly associated, among ethnographic hunter-gatherers, with cooking food, providing warmth, and manufacturing non-lithic implements (e.g., Binford 1996, 1978a, 1978b; Hayden 1981; Gould 1971; Mallol et al. 2007; O'Connell 1987). However, none of these behaviors exactly fits the evidence that is available from Layer 8.

Ethnographically, the use of domestic hearths to cook meat and vegetables is essentially universal, which might lead one to assume that it was a common practice in the Paleolithic. While there are plenty of burned bones in Layer 8, it is not clear that they were burned during food preparation prior to their use as fuel. As noted by Cain (2005), distinguishing between multiple burning events in a bone assemblage is not yet feasible with current methods. This is particularly relevant to the Layer 8 assemblage since the final burning event rendered much of the bone unidentifiable and therefore limited its value for understanding how and to what degree Neandertals utilized fire for cooking prey. The single argument against cooking meat is that, along with the decrease in the use of fire through the sequence at Pech IV, there is a lack of evidence for fires in many other Paleolithic site components that contain abundant faunal remains. If cooking did take place, we would probably expect to see direct or indirect evidence for fire in most assemblages. The only alternative is to argue that those instances where there is no evidence for fire reflect more specialized processing of prey, while food preparation and consumption took place elsewhere. This would seem to defy probability given the number of sites and assemblages we have with no evidence of burning.

In a similar vein, while Neandertals may have used fire for warmth in Layer 8, it does not explain its absence elsewhere in the sequence. If a primary use of fire was for producing warmth, its use would logically correlate with colder climatic periods. In fact the opposite appears to be the case at Pech IV where evidence for fire is abundant in levels associated with warmer climatic periods and almost non-existent in levels associated with colder climatic periods. This is also true for Roc de Marsal (Sandgathe et al. 2007; Turq et al. 2008). Of course, seasonality may be playing a role, and based on the data at hand, Layer 8 appears to be a late winter/early spring occupation. Unfortunately, seasonality data is not yet available for the upper layers at Pech IV or for Roc de Marsal.

A final interpretation for the hearths in Layer 8 is that they may have been used in the manufacture of non-lithic raw materials (hide preparation, manufacturing wooden tools). Admittedly, it is not clear how this can be demonstrated given the typical Mousterian lithic and faunal assemblage present in this layer. Without other evidence of such applications it would be difficult to demonstrate that fire was used for these.

Ultimately however, while some activities can be argued to be the more likely to have produced the fire residues in Layer 8, any interpretations of fire use are going to remain extremely tentative. Ultimately, our understanding of the characteristics and interpretations of fire at Pech de l'Azé IV—and any other Paleolithic site for that matter—will depend on *in situ* analyses of intact samples whereby the original geometric relationships of the components (bone, charcoal, ash) can be analyzed and understood as they fit into a whole (Berna and Goldberg 2007).

A final point to be made regarding the abundant fires in Layer 8 is that, whatever their function, the use of fire left no discernable signature in the rest of the archaeological assemblage. For example, the lithic assemblage is completely within the normal range of variability for Mousterian sites, and the full range of the lithic reduction sequence is present. And while proportions of different tool types in the Mousterian reflect a continuum of variability (Dibble and Rolland 1992), the retouched tools and technologies are the same as found elsewhere and in moderate proportions. In other words, there is absolutely no indication of specialization in the stone tool assemblage. The rarity of fire argues that it was used only under specific conditions, but it is clear that those conditions are reflected in other remains to only a limited extent. This probably indicates that fire-related activities are independent of stone tool related activities.

CONCLUSIONS

There are many reasons to conclude that Pech IV Level 8 is a remarkable source of data on Neandertal adaptations. Based on micromorphological analysis of the samples, Level 8 shows very little evidence of post-depositional, geological disturbances. Additionally, taphonomic analysis of fine fraction lithics, artifact orientations, and edge damage all suggest very little disturbance. Evidence for anthropogenic modification (trampling), primarily in the high percentage of broken pieces, and geological observations, particularly thin-section data, support this conclusion.

In terms of climate and environment, there is no geological evidence for cold conditions or of cold-related processes, such as cryoturbation. Geological observations also suggest wetter conditions in the base of the deposit and drier conditions towards the summit, but these could be local effects related to proximity to the cave floor, and not to climate. Overall, the fauna also suggest a temperate climate. Particularly significant are the presence of beaver and boar, both species that prefer wooded environments. The only cold climate species present is reindeer (n=3), but it is not uncommon to find small amounts of reindeer in faunal assemblages that otherwise indicate temperate conditions.

Thermoluminescence dating of five samples from Level 8 yielded an average age of 99.9±5.4kyr. This places the occupation in Isotopic Stage 5, and given the faunal and geological evidence that suggest a warmer period, it is likely that the deposits date to OIS 5c.

Based on gnaw marks, breakage, and bone surface modifications, there is virtually no evidence for carnivore input or modification of the assemblage, and there are only two specimens identified as wolf. Cutmarks are present on approximately 13% of the bones and their location is suggestive of meat and periosteum removal from longbones, which is consistent with marrow extraction. Significant too is the presence of smaller, more difficult to hunt animals including hare and bird. Fetal remains of red deer and boar point to occupation of the site in the winter through spring.

The lithic data show a preponderance of on-site production using local materials. Aside from 13 items made on non-local materials (of 1,092 total), based on the amount of cortex there is no evidence for either import or export of prepared cores in the local material. Of the 13 non-local items, three are retouched tools. Levallois technology is present, and retouched tools are preferentially made on Levallois and large blanks. Tool production is not high, but among the retouched tools scrapers predominate. There is also some evidence for small flake production.

What makes Level 8 particularly interesting, however, are the numerous, intact hearth features that occur throughout the whole Level 8 depositional sequence and cover most of what was likely the entrance area of the cave. Both the frequencies of burned bone and burned lithics throughout the site sequence make it clear that the existence of fire features in Level 8, but not in the upper levels, is not a product of differential preservation, but actually reflects variability in the use of fire through time at this site.

The fire structures at Pech IV are most likely interpretable as small-scale domestic hearths given their restricted size, lack of obvious internal structuring, and relatively low temperature ranges. The thin and patchy nature of the intact ash layers suggest that these hearths were not used over long periods of time, but represent relatively short-lived events. One likely possibility is that the hearths in Layer 8 were used for a range of domestic tasks, perhaps including cooking and warmth. While there is no evidence in Level 8 to contradict this interpretation, it does beg the question as to why fire was apparently used with much less frequency in the upper layers at Pech IV, which are associated with cold periods, or at other Mousterian sites where evidence for fire is also lacking. Thus, at least in the case of Pech IV, it is currently not possible to formulate an explanation that accounts for the presence of fire in Level 8 and its absence in subsequent layers.

Undoubtedly the explanation will involve more factors than we are able to analyze and control for at Pech IV. Thus, in order to better understand the use of fire in the Mousterian, strategies at different scales must be used. These range from microanalyses of intact deposits to multi-site comparisons in which multiple lines of evidence from each site are necessary. As a necessary first step, further work is needed to build an accurate database of Mousterian assemblages with both indirect and/or direct evidence of burning and, importantly, to establish where burning does not exist through proxies such as heated flints and burned bone. To do this we need to continue to improve our methods of excavation, analysis, and reporting, including the use of multiple lines of evidence for taphonomic processes, the use of micromorphology to study ephemeral and chemically unstable features such as hearths, and the use of standardized measures and scales for assessing burning in artifacts and bones.

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