



The Magdalenian horse (*Equus ferus arcelini*) from Roc-aux-Sorciers (Angles-sur-l'Anglin, France): Seasonality and paleoecology

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ABSTRACT

Roc-aux-Sorciers is one of the most emblematic sites of Magdalenian culture, particularly known for its bas-relief and high-relief sculpted frieze depicting animals and humans, dated to the Middle Magdalenian. The stratigraphic sequence contains archaeological deposits corresponding to the occupations from the Middle Magdalenian, overlain by deposits from the Upper Magdalenian. The study of the horse *Equus ferus arcelini*, the preferentially hunted species, was conducted through various approaches (paleontological, zooarchaeological, palaeoenvironmental, dental wear analyses) to highlight a possible adaptation of these animal populations to the climatic and environmental changes recorded within the Magdalenian sequence, and to better understand the subsistence strategies of Magdalenian groups towards this fauna. In the Middle Magdalenian, in a steppe environment under cold and dry climate conditions, the site was repeatedly occupied for long durations by Magdalenian sculptors. Seasonality data indicate horse hunting in all seasons, suggesting sedentary to semi-sedentary equine populations in the territory. The results are consistent with dental wear analyses. In the Upper Magdalenian, the climate was cold and wet, and the environment more diversified and semi-open. Dental wear analyses show that horses were adapted to a more diversified and less abrasive diet compared to those of the Middle Magdalenian. Occupations were characterised as brief and seasonal.

1. Introduction

The Magdalenian (20,500 – 13,000 cal BP) represents a significant cultural phase of the Upper Palaeolithic, particularly in Europe. It is distinguished by its characteristic long blade technology, advanced osseous industry, and cave art (Pétillon et al., 2016; Fuentes et al., 2019). This period coincides with major climatic fluctuations during the last glaciation. Middle Magdalenian societies flourished during the cold steppe environment of the Older Dryas. This cold phase was followed by the rapid warming of the Bølling period, dated to 14,670 cal BP according to the Greenland isotope curve (Bintz and Evin, 2002). The Upper Magdalenian developed during the Late Glacial Interstadial (Bølling-Allerød) and appears to have disappeared by the end of this phase (Sacchi, 2003).

Despite the rapid climatic transition from the Older Dryas to the

Bølling, there was no significant turnover in the mammalian fauna of Western Europe. Moreover, the animals hunted by Magdalenian societies remained largely consistent. Upper Magdalenian groups continued to follow Middle Magdalenian traditions regarding the acquisition and processing of carcasses (Bintz and Evin, 2002; Kuntz et al., 2016).

Technological shifts within Magdalenian culture also appear minimal, occurring over extended periods and driven more by social and cultural factors than by immediate environmental changes (Pétillon et al., 2016). The variability observed in Magdalenian industries is thought to be related more to the site function than chronological positions (Bintz and Evin, 2002).

The transition between the Middle Magdalenian and the Upper Magdalenian, marked by significant palaeoclimatic and palaeoenvironmental changes, is recorded in the stratigraphic sequence of the Roc-aux-Sorciers site, notable for its Middle Magdalenian sculpted frieze

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(Saint-Mathurin, 1984; Iakovleva and Pinçon, 1997). This site provides an opportunity to address several key issues: assessing the environmental and climatic changes between the Middle and Upper Magdalenian, examining faunal adaptations to these changes, and analysing human behaviours regarding hunted fauna across different occupation levels (e.g. seasonality, site occupation duration).

While the focus of this research is primarily on horses, the faunal assemblage is first analysed from a taphonomic perspective to evaluate the condition of the material. This step is crucial as taphonomic processes can significantly bias archaeozoological and palaeoenvironmental interpretations (Lyman, 1994). Palaeoenvironmental data are derived from the analysis of faunal assemblages and horse dental meso- and microwear. The anatomical and dietary adaptations of horses are studied through palaeontology, population characteristics, and dental wear analyses. Finally, by examining horse population structures (age, sex, mortality profiles) and butchery periods, the research aims to investigate human behaviours and their adaptation to managing hunted fauna, seasonality, and site occupation duration during the Middle and Upper Magdalenian.

2. Presentation of the site

The Roc-aux-Sorciers site, located in the commune of Angles-sur-l'Anglin (Vienne, France), is particularly famous for its monumental rock art sculptures dating from the Middle Magdalenian period (Saint-Mathurin, 1984; Iakovleva and Pinçon, 1997, 1999; Dujardin and Tymula, 2005; Pinçon, 2009). The site, discovered along the Anglin River in 1929 by Lucien Rousseau (Rousseau, 1933), was subsequently excavated between 1948 and 1964 by Suzanne de Saint Mathurin and Dorothy Garrod, who uncovered rock sculptures buried under several meters of sediment (Saint-Mathurin and Garrod, 1950, 1951; Saint-Mathurin, 1969, 1984). The site extends 30 m along the base of the cliff and comprises two localities: "Cave Taillebourg" and "Abri Bourdois", located further downstream. These are two rock shelters of similar morphology, part of the same site but separated by an unexcavated area. The reference chronostratigraphic sequence for the Roc-aux-Sorciers site was established by S. de Saint-Mathurin and D. Garrod in Abri Bourdois (Saint-Mathurin and Garrod, 1951; Saint-Mathurin, 1969, 1984). At the base of the sequence, the RSF layer (i.e., Roc-aux-Sorciers, layer F) corresponds to the weathering of the limestone bedrock. Above it lies the RSE layer, a 5 cm ochre deposit containing very little archaeological material. The RSD layer, referred to as the "large hearths," was described by Suzanne de Saint-Mathurin as featuring hearths aligned parallel to the decorated wall. This layer contains numerous burnt faunal remains and archaeological material characteristic of the Middle Magdalenian period. The RSC layer, which includes the same industry, is separated from the RSD layer by a pavement of limestone and pebbles.

Excavations conducted at Cave Taillebourg by S. de Saint-Mathurin revealed two archaeological layers (TCD and the overlying TCC), both containing a rich assemblage of archaeological material similar to the RSC and RSD layers, including faunal remains, lithic industry, bone industry, portable art, and ornaments). These layers have been attributed to the Middle Magdalenian period, particularly due to the presence of "Lussac-Angles points". The RSC and TCC layers are covered by large collapse blocks from the wall. Following these collapses, numerous sculpted blocks from the wall fell onto the floor of Cave Taillebourg, and the shelter was no longer occupied. In contrast, at Abri Bourdois, the archaeological levels (RSB5 to RSB1) indicate more sporadic human occupations during the Upper Magdalenian period, with no evidence of rock art (Saint-Mathurin, 1984; Guillien and Saint-Mathurin, 1976; Bertrand et al., 2003; Pinçon, 2009; Renault-Miskovsky, 2009; Valensi, 2009; Bozet and Miskovsky, 2010, 2011; Chauvière et al., 2017; Boudier-Blet, 2018; Valensi and Boulbes, 2018).

The correlation between the decorated wall at Roc-aux-Sorciers and the archaeological layers (RSC, RSD of Abri Bourdois and TCC, TCD of Cave Taillebourg) has been established based on several factors:

stratigraphic relationships, fragments of the decorated wall, and sculptor's tools discovered in stratigraphy (Saint-Mathurin, 1984; Guillien and Saint-Mathurin, 1976; Pinçon, 2009; Beyries and Cattin, 2015; Bourdier et al., 2016; Pinçon and Fuentes, 2020, 2021).

Recently, a Bayesian statistical modelling of the nine previously established radiocarbon ages (see Pinçon, 2009) was conducted alongside a 3D landscape evolution reconstruction of the site (Genuite et al., 2023). In this new study, the authors concluded that the first occupation phase, attributed to sculptors from the Middle Magdalenian cultural period, is dated between 17.3 and 16.7 ka cal. BP. The phase of rockfalls leading to the abandonment of Cave Taillebourg and the covering of sculptures at Abri Bourdois is dated between 17.1 and 16.5 ka cal. BP, possibly corresponding to the Heinrich Stadial 1 (H1). Finally, the second major occupation phase (layers B2 and B4), corresponding to populations of the Upper Magdalenian, is dated between 17.1 and 13.2 ka cal. BP (Fig. 1).

The Roc-aux-Sorciers site has yielded numerous faunal remains attributed to various mammals including Rodentia, Lagomorpha (with few remains of *Oryctolagus cuniculus*), Proboscidea, Perissodactyla and Cetartiodactyla). The rodent remains, studied by Marquet (2009), are relatively scarce and mainly originate from earlier excavations by Saint-Mathurin, with some additional samples from stratigraphic sections collected by Marquet himself. In Cave Taillebourg, five rodent species have been identified: *Dicrostonyx torquatus*, *Microtus gregalis*, *Citellus* sp., *Microtus arvalis* and *Arvicola terrestris*, with the first two taxa being the most abundant. In Abri Bourdois, nine rodent species have been identified: *Microtus oeconomus*, *Microtus arvalis*, *Arvicola terrestris*, *Clethrionomys glareolus*, *Microtus agrestis*, *Apodemus sylvaticus* and three notably abundant species: *Dicrostonyx torquatus*, *Microtus gregalis*, *Citellus citellus*. Analysis of the faunal remains from the base to the top of the deposit reveals a trend toward decreasing cold conditions, which were particularly intense during the initial occupation of the site in the Middle Magdalenian period. Additionally, an increase in aridity is observed from the base of layer RSB4/5, which is indicative of the Upper Magdalenian period (Marquet, 2009).

The large mammal fauna of Roc-aux-Sorciers includes a minimum of 19 species, distributed across the Middle and Upper Magdalenian layers (Valensi, 2009; Valensi and Boulbes, 2018). This study focuses on the horse *Equus ferus arcelini*, which is the most abundant taxon in the assemblage in terms of individuals (minimum number of individuals, MNI) and the second most abundant after the reindeer *Rangifer tarandus*, in terms of number of remains (number of identified specimens, NISP). Horses were selectively hunted by Magdalenian populations for their nutritious meat and fat. Archaeozoological evidence, such as the transport of complete carcasses, cut marks on various anatomical parts, and fractures, suggests that these animals were processed and likely consumed on-site (Valensi, 2009; Valensi and Boulbes, 2018). During the Middle Magdalenian, the horse also held significant symbolic value, as evidenced by its numerous representations on the sculpted frieze (Iakovleva and Pinçon, 1997, 1999; Pinçon, 2009) and a series of engraved upper incisors (Mazière, 2009) (Fig. 1C et 1D).

3. Materials et methods

3.1. Material

The faunal remains come from excavations carried out from 1947 to 1964 by S. de Saint-Mathurin. Formerly deposited at the Regional Archaeology Service of Poitou-Charentes under the direction of François Lévêque. These remains are now part of the collections of the National Archaeological Museum (MAN, France). The material was analysed by locality and layer: Cave Taillebourg (Middle Magdalenian: layers TCC and TCD) and Abri Bourdois (Middle Magdalenian: layers RSF to RSC and Upper Magdalenian: layers RSB4 to RSB1) (Valensi, 2009; Valensi and Boulbes, 2018).

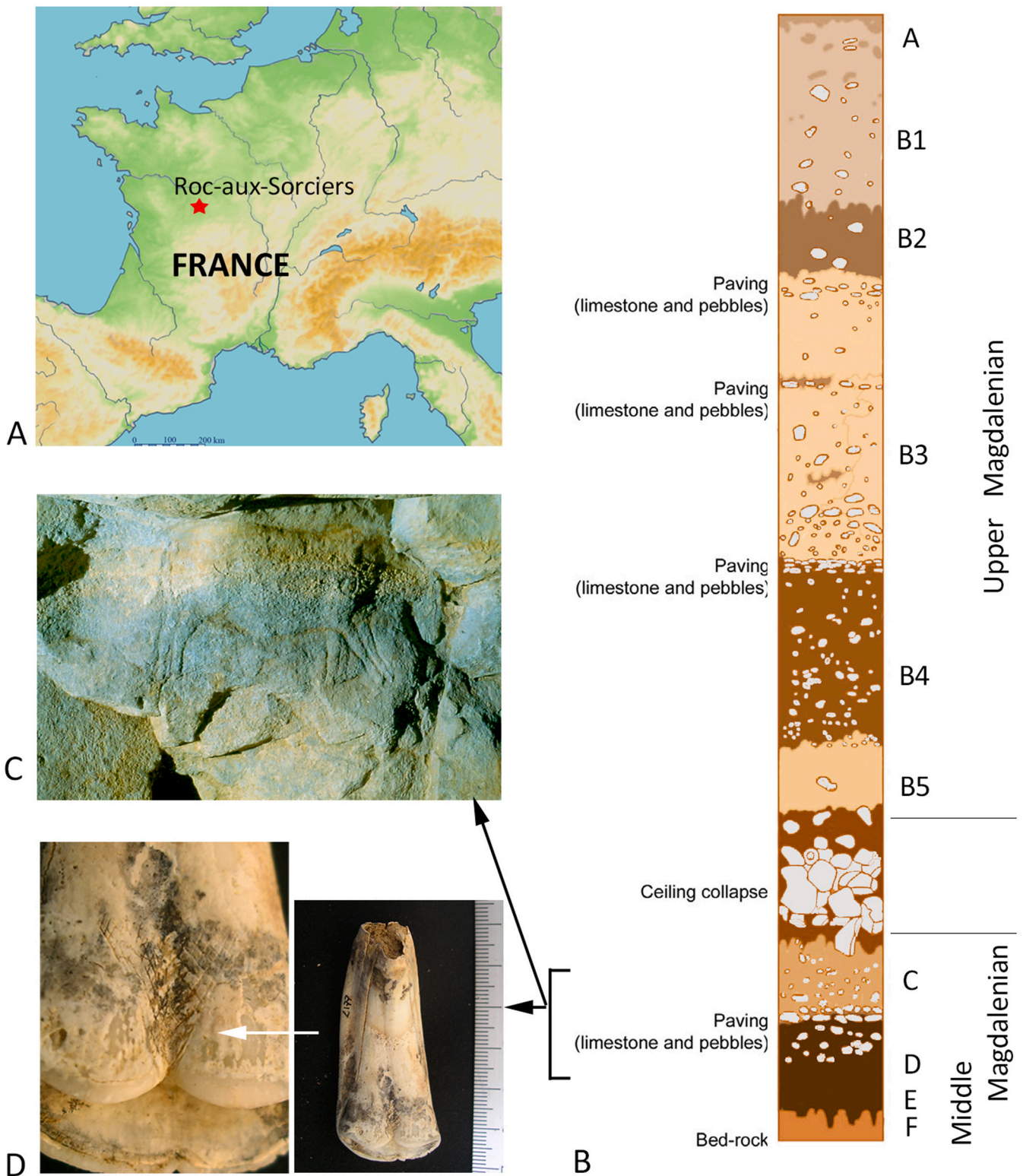


Fig. 1. General presentation of the Roc-aux-Sorciers site (Abri Bourdois and Cave Taillebourg). A. Location of the site, B. Stratigraphic section of Abri Bourdois at Roc-aux-Sorciers (after Saint-Mathurin, 1984; Pinçon and Fuentes, 2020), C. Horse from the sculpted frieze, D. Upper incisor (I2) of horse, engraved (TCC-2177) (Photographs P. Valensi).

3.2. Taphonomy

Given that zooarchaeological and paleoenvironmental results can be influenced by the state of material preservation, we conducted a comprehensive taphonomic analysis of the entire collection. Previous

studies have shown that temperature, humidity, vegetation cover, and soil chemical composition contribute to various stages of cortical bone surface alteration (Behrensmeier, 1978; Lyman, 1994; Fernández-Jalvo and Andrews, 2016). To address this, we considered the primary types of bone surfaces damage caused by climatic and edaphic processes,

including exfoliation and cracking associated with weathering, as well as dissolution pits and patches from water action. In this study, damage was categorized into three stages based on its intensity and extent: low alteration (Behrensmeier's weathering stages 1 and 2; dissolution pits the size of a pinhead), moderate alteration (Behrensmeier's weathering stage 3 or large cortical dissolution patches), and high alteration (Behrensmeier's weathering stages 4 and 5 or extensive dissolution leading to the near-complete loss of cortical bone). We also examined oxidation related to water activity and root etching caused by plants.

For a more detailed analysis of the results, these taphonomic data were compared with climatic and taphonomic results from other disciplines such as palynology and sedimentology (Renault-Miskovsky, 2009; Bozet and Miskovsky, 2010, 2011).

3.3. Paleoecology

The methods used in this work were applied to the faunal assemblage (presence/absence and proportions of taxa) to provide a general overview of the paleoenvironmental conditions for each archaeological layer.

Climatograms were constructed, by site and by layer, using the relative proportions (% MNI) of ungulates, classified by ecological groups (Valensi and Abbassi, 1998): Arctic group (*Mammuthus*, *Ovibos*, *Rangifer*), mountain group (*Rupicapra*, *Capra*), continental steppes (*Equus*, *Bison*, *Saiga*), forest group (*Sus*, *Cervus*, *Capreolus*, *Bos*).

The cenogram method offers an alternative approach to reconstructing past environments by analysing the body weight distribution of species within a mammalian community (Legendre, 1986, 1989). A cenogram plots the logarithm (Ln) of the mean body weight of each species on the Y-axis, with species ranked by decreasing size on the X-axis. This method helps reveal the openness of the landscape and the degree of humidity. A key factor in this reconstruction is the number of species within the 0.5–8 kg body size range, which tends to be lower in open landscapes. Additionally, the slope on the left-hand side of the cenogram curve provides insight into aridity: the steeper the slope, the more arid the environment. In the original method, bats and carnivores are excluded from the analysis but are represented on the graphs without being included in the regression line calculations for large mammals (Legendre, 1986). For the Roc-aux-Sorciers site, the micro-mammal data is unfortunately not exhaustive, as most of the samples originate from earlier excavations (Marquet, 2009). Therefore, the cenograms were constructed using ungulates and rodents studied by Marquet (2009), with carnivores represented above the regression lines. The interpretation of these cenograms is based on the four main categories defined by Legendre (1986), (1989), which correspond to specific environmental conditions (open or closed) and climatic conditions (humid or arid).

3.4. Skeletal proportion and body size of the horse

Among equids, specially Pleistocene caballine horses, certain cranial and limb bone proportions, as well as body size, can reflect ecological adaptation or acclimation. These ecomorphological patterns were recently discussed by Boulbes and van Asperen (2019), Uzunidis (2021) and Eisenmann (2022). Measurements of the muzzle, teeth, metacarpals and overall body size of the horses from Roc-aux-Sorciers were conducted to contribute to paleoenvironmental assessments and potentially track changes between the Magdalenian levels.

The metric system for *Equus* bones was sourced from Eisenmann's web site (vera-eisenmann.com). Additionally, the technique for overall size comparison (Meadow, 1999) was used to characterise the body size of the Magdalenian horses from the Roc-aux-Sorciers. This now widespread method has already been used on Pleistocene horses (Eisenmann and David, 2002; Cramer, 2002; Magniez and Boulbes, 2014; Boulbes and van Asperen, 2019). It is based on the calculation of the Variability Size Index (VSI) from various skeletal elements. The method is effective

when the material to be compared is scarce and diversified, as is the case for the Magdalenian assemblages from Roc-aux-Sorciers. The rich sample of the horse assemblage from Jaurens, dated approximately to 30,000 BP and correlated to the end of MIS 3 (Guérin et al., 2002), is generally used as the reference or standard population because it meets the statistical conditions for calculating the VSI. The variables selected for each bone and the statistical parameters of the reference, according to the measures of Vera Eisenmann (personal data, vera-eisenmann.com) and Mourer-Chauviré (1980), for the calculation of the VSI are detailed in Boulbes and van Asperen (2019). These measurements are essentially the diameters of the bone extremities which, more than the body size, reflect the body mass of the animal (Meadow, 1999). To maximize sample size, VSIs were calculated for all levels of the Upper Magdalenian (RSB1 to RSB5) and the Middle Magdalenian (TCC-D and RSC-D).

3.5. Zooarchaeology (seasonality and mortality patterns)

Identifying the season during which the site was occupied is crucial for understanding the lifestyles and subsistence strategies of Magdalenian societies. To determine the season of occupation, several criteria were considered: the ageing of the main hunted ungulates, the seasonal behaviors of these species (e.g., migration, group size) and their annual biological cycles (e.g., cervid antlers, parturition/birth). These reconstruction methods are primarily based on the principle of actualism, which assumes that the ecological requirements of fossil species are approximately the same as those of their modern counterpart or the closest extant taxa. For *Equus*, *Rangifer*, and *Saiga*, we primarily relied on studies by Bignon (2008), Weinstock (2000), (2002), and Costamagno (2001), respectively.

To establish the hunting seasonality of horses, age was estimated based on the deciduous teeth using tooth eruption and wear stages, the replacement of deciduous teeth and crown heights (Barone, 1976; Eisenmann, 1978; Guadelli and Prat, 1995; Guadelli, 1998; Bignon, 2006, 2008). The mortality curves of horses were established by archaeological level and grouped by cultural assemblage to work with larger sample sizes.

3.6. Tooth mesowear and microwear analyses

3.6.1. Tooth mesowear analysis

Mesowear was scored macroscopically from the buccal side of upper molars. Unworn (and marginally worn) teeth, extremely worn teeth and those with broken or damaged cusp apices were omitted from mesowear analysis. Cusp sharpness is sensitive to ontogenetic age among young and senile individuals. However, for intermediate age groups, mesowear is found to be less sensitive to age and more strongly related to diet (Rivals et al., 2007) and, therefore, suitable for dietary reconstruction. The method is based on seven cusp categories (numbered from 0 to 6), ranging in shape from high and sharp (Stage 0) to completely blunt with no relief (Stage 6) (Mihlbachler et al., 2011). The mode value of the mesowear data from a single sample of fossil dentitions corresponds to the 'mesowear score' or MWS (Mihlbachler et al., 2011). To reduce inter-observer error, dental mesowear analysis was conducted by a single experienced researcher (FR).

3.6.2. Tooth microwear analysis

Microwear features of dental enamel were examined using a stereomicroscope on high-resolution epoxy casts of teeth following the cleaning, moulding, casting and examination protocol developed by Solounias and Semprebon (2002) and Semprebon et al. (2004). The upper and lower p4 to m3 were sampled (Rivals et al., 2015a; Xafis et al., 2017). The occlusal surface of the teeth was cleaned using acetone and then 96 % ethanol. The surface was moulded using high-resolution silicone (vinylpolysiloxane), and casts were created using clear epoxy resin. All casts were carefully screened under the stereomicroscope.

Those with poorly preserved enamel or taphonomic defects (features with unusual morphology and size, or fresh features made during the collecting process or during storage) were removed from the analysis, following King et al. (1999), Uzunidis et al. (2021) and Micó et al. (2024a,b). Casts were observed under transmitted light with a Zeiss Stemi 2000 C stereomicroscope at 35 × magnification. Microwear features were quantified on the paracone of the upper teeth or the protoconid of the lower teeth in a square area of 0.16 mm² using an ocular reticule. Reproducibility is ensured by marking the two analysed areas directly on the cast, allowing anyone to locate them and verify the data. We used the classification of features defined by Solounias and Semprebon (2002) and Semprebon et al. (2004), which distinguished pits and scratches. Pits are microwear scars that are circular or sub-circular, while scratches are elongated features that have straight and parallel sides. The results were compared with a database constructed from extant ungulate taxa (Solounias and Semprebon, 2002; Rivals et al., 2010). All the data were collected by a single experienced observer (FR).

Finally, following Rivals et al. (2015b), two measurements of the variability of scratch density, the standard deviation (SD) and the coefficient of variation (CV), were used to estimate the seasonality of human occupation and accumulation of faunal assemblages at the sites. As seasonal changes in diet are recorded by microwear, the variability of the microwear signal allows for the detection of seasonality. The combination of the two measurements of variability permits the classification of assemblages into one of the following categories: (A) seasonal events or shorter time windows, (B) events longer than a season (i.e., two or more contiguous seasons) and (C) separate events that occurred in different non-contiguous seasons.

4. Results

4.1. Taphonomy: State of preservation of the faunal remains

The fauna is generally very well preserved. The recovery of many costal cartilages (more than a hundred, representing 16 % of the costal arch and 2 % of the identified remains), a few sternebrae, and several elements from foetuses and new-borns (accounting for 5 % of the remains) confirms these initial observations. Considering all the material identified anatomically and/or taxonomically, totalling 6193 remains, 4 % of the bones show signs of alteration. These alteration phenomena are rarely of high intensity, but their frequency varies depending on the occupation levels (Table 1, Fig. 2, Fig. 3).

At the Abri Bourdois, the faunal remains from the Middle Magdalenian levels (levels C to F) are well-preserved. In contrast, the Upper Magdalenian levels (levels B1 to B5) contain approximately 8 % of the

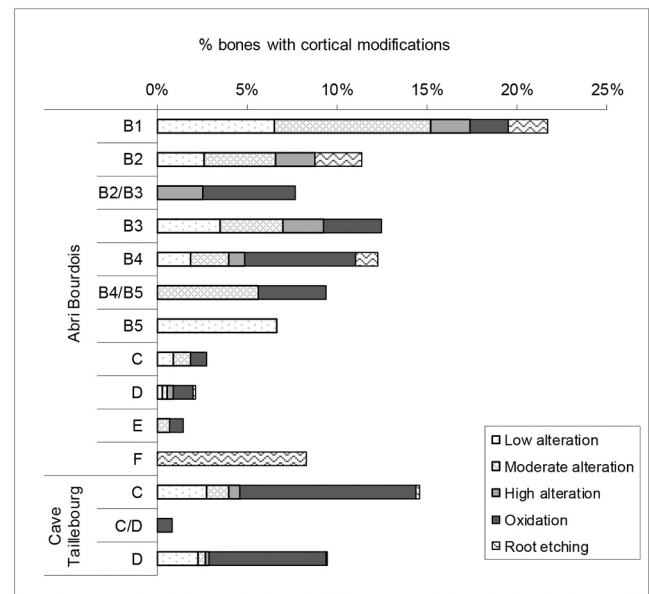


Fig. 2. Quantity of bones with climato-edaphic alterations, oxidation, and root etching. Percentages are based on the total number of anatomically and/or taxonomically identified remains (NRD) by level. Analysis includes 6193 remains (see Table 1).

bones with climato-edaphic alterations. These alterations are primarily due to weathering and dissolution from water action. The manganese oxides, relatively more abundant in levels B2 to B5, seem to support these observations. At the Cave Taillebourg, 4 % of the remains exhibit physico-chemical alterations of climatic and edaphic origin. Oxidation is significant, reaching 10 % in level TCC and 6 % in level TCD. Few remains show bioturbation by plant roots: only 2–3 % of the remains in the levels close to the surface at the Abri Bourdois, and 8 % in level F deposited on the substratum of the shelter.

Overall, the faunal remains are only minimally affected by climatic and edaphic factors and by plant activity; the vast majority of the bones are in a good state of preservation.

4.2. Paleoecological approaches based on the faunal assemblages

A minimum of seven carnivore species and 13 ungulate taxa are represented among the large mammals found at Roc-aux-Sorciers. Horses and reindeer are the dominant species in this faunal

Table 1

Frequencies of altered bones (by weathering or water), bones with root marks, and oxidized bones in Abri Bourdois and Cave Taillebourg. Data are presented as the number of specimens (N) and as percentages of the total number of anatomically and/or taxonomically identified remains (NRD) by level.

Site	Levels	NRD	Bone alteration stage			Total	%	Oxidation		Root etching	
			Low	Moderate	High			N	%	N	%
Abri Bourdois	B1	46	3	4	1	8	17,4 %	1	2,2 %	1	2,2 %
	B2	228	6	9	5	20	8,8 %	0	0,0 %	6	2,6 %
	B2/B3	39	0	0	1	1	2,6 %	2	5,1 %	0	0,0 %
	B3	313	11	11	7	29	9,3 %	10	3,2 %	0	0,0 %
	B4	326	6	7	3	16	4,9 %	20	6,1 %	4	1,2 %
	B4/B5	53	0	3	0	3	5,7 %	2	3,8 %	0	0,0 %
	B5	15	1	0	0	1	6,7 %	0	0,0 %	0	0,0 %
	C	215	2	2	0	4	1,9 %	2	0,9 %	0	0,0 %
	D	744	2	2	3	7	0,9 %	8	1,1 %	1	0,1 %
	E	137	0	1	0	1	0,7 %	1	0,7 %	0	0,0 %
Cave Taillebourg	F	12	0	0	0	0	0,0 %	0	0,0 %	1	8,3 %
	C	2086	58	25	13	96	4,6 %	204	9,8 %	5	0,2 %
	C/D	117	0	0	0	0	0,0 %	1	0,9 %	0	0,0 %
	D	1862	43	7	4	54	2,9 %	121	6,5 %	1	0,1 %
Total		6193	132	71	37	240	3,9 %	372	6,0 %	19	0,3 %

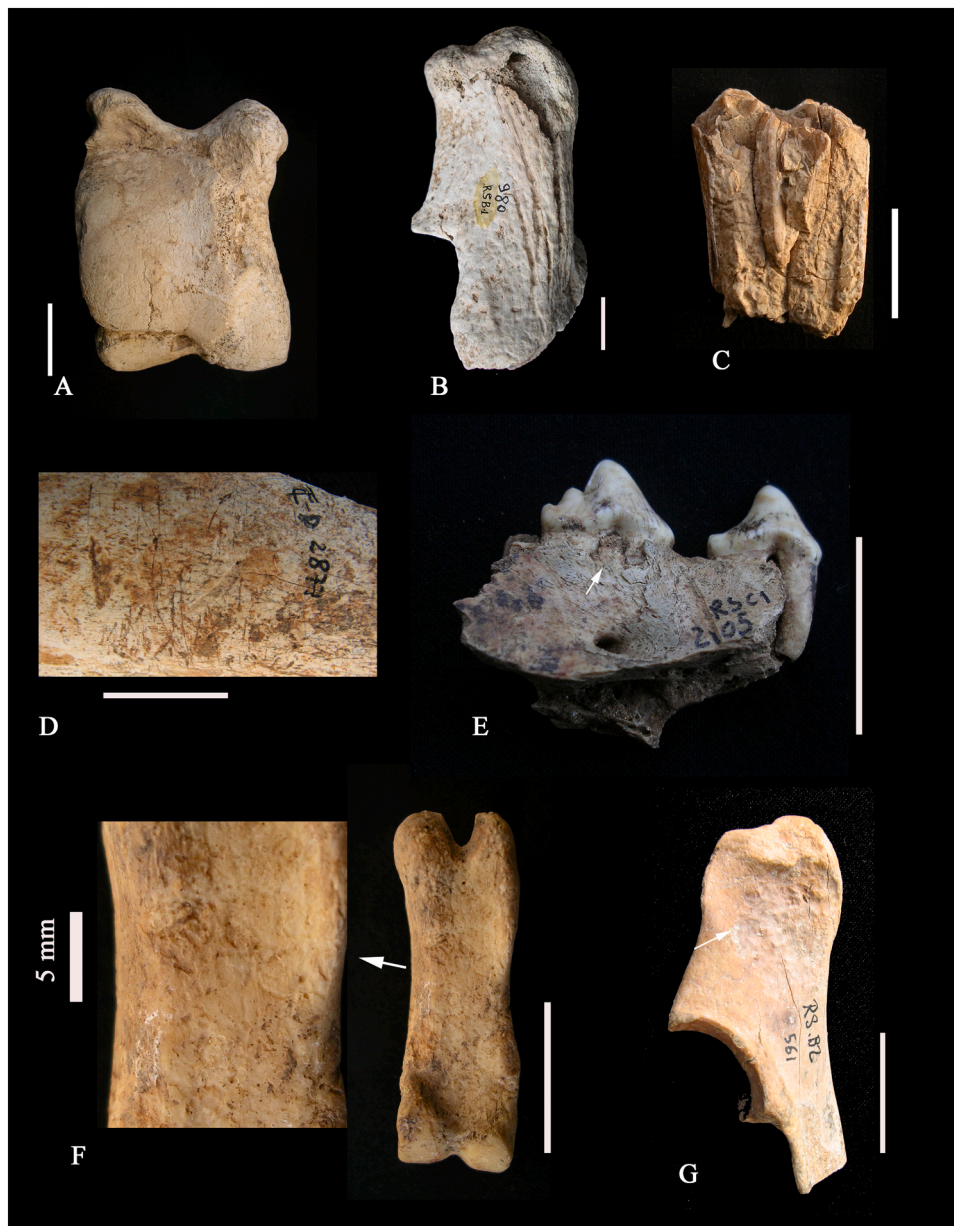


Fig. 3. Examples of faunal remains with taphonomic damage (scale 2 cm). A. Talus of *Bison priscus* showing minor alteration due to weathering (few fissures) and slight desquamation from water and/or sediment (RSB5-960). B. Calcaneus of *Equus f. arcelini* heavily damaged by abrasion due to environmental conditions (water and sediment) (RSB1-980). C. Upper molar of *Bos/Bison*, severely altered by climato-edaphic processes, resulting in the fragmentation of the tooth (RSB3-2075). D. Radius of *Bison priscus* showing minor alteration due to weathering. The few fissures are associated with trampling marks (TCD-2877). E. Mandible of *Canis lupus*, with premolars P2 and P3, showing minor oxidation and moderate weathering (deeper exfoliation indicated by an arrow) (RSC-2105). F. Proximal phalanx of *Capra* showing vermicular marks related to plant activity, with details of the marks (RSB4-1588). G. Ulna of *Capreolus capreolus* abraded by water and/or sediment (moderate alteration) (RSB2-561).

assemblage (Table 2, Fig. 4).

In the Middle Magdalenian, the “horse-reindeer” association was supplemented by other cold taxa from an open, arctic, and steppe environment: *Vulpes lagopus*, *Mustela eversmanni*, *Mammuthus primigenius*, *Coelodonta antiquitatis*, *Saiga tatarica*, *Ovibos pallantis* and *Bison priscus*. Notably, the saiga antelope, the third most abundant taxon, is well adapted to dry conditions. This animal, which also avoids rugged terrain, must have found favorable conditions for its expansion in the environment of Roc-aux-Sorciers (Huguet and Giret, 2013). Additionally, paleoclimatic information can be inferred from species that adhere to Bergmann’s ecological rule, which posits that larger body sizes are advantageous in colder climates (see Ashton et al., 2000 for mammals). Therefore, the large body sizes of *Canis lupus* and *Vulpes vulpes* from the

Roc-aux-Sorciers site may suggest harsh climatic conditions during the period of site occupation (see Davis, 1977; Flower, 2016).

In the Upper Magdalenian (upper layers RSB1 to RSB4), the association composed by horse, reindeer, and to a lesser extent, saiga antelope persists. Temperate-type forest fauna, although very rare, are mixed with the cold fauna: *Sus scrofa*, *Cervus elaphus*, *Capreolus capreolus* and *Bos primigenius*. In this association, most of the cold taxa reported in the Middle Magdalenian are no longer represented. The climate remains harsh, but the overall assemblage indicates a slight warming and the beginning of the establishment of a more forested cover.

The climatograms (Fig. 5) highlight the extent of open environments under cold climates. The Middle Magdalenian layers of Abri Bourdois show homogeneity and are composed solely of the arctic environment

Table 2

– Roc-aux-Sorciers – Quantification of large mammals from Upper and Middle Magdalenian, in NISP (number of identified specimens) and MNI (minimum number of individuals), per locality and per level.

	Cave Taillebourg					Abri Bourdois							Abri Bourdois											
	Middle Magdalenian					Middle Magdalenian							Upper Magdalenian											
	TCD		TCC		TCind	RSF		RSE		RSD		RSC		RSB5		RSB4		RSB3		RSB2		RSB1		
	NISP	MNI	NISP	MNI	NISP	NISP	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI
<i>Canis lupus</i>	39	5	19	4	-	2	4	1	5	3	3	1	-	-	1	1	6	1	-	-	1	1	-	-
<i>Vulpes vulpes</i>	5	2	4	1	-	-	-	-	3	1	-	-	-	-	3	1	1	1	-	-	-	1	1	-
<i>Vulpes lagopus</i>	-	-	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ursus arctos</i>	2	1	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-
<i>Ursus spelaeus</i>	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ursus sp.</i>	-	-	4	(2)	-	-	-	-	1	1	1	1	-	-	-	-	1	1	-	-	-	-	-	-
<i>Mustela (P.) eversmanni</i>	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Panthera (Leo) spelaea</i>	2	1	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-
<i>Mammuthus primigenius</i>	-	-	4	1	-	-	1	1	4	1	3	1	-	-	-	-	-	-	-	-	-	-	-	-
<i>Coelodonta antiquitatis</i>	1	1	1	1	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Equus f. arcelini</i>	561	17	696	18	-	2	68	9	250	13	94	9	6	2	127	9	160	9	95	5	15	2	-	-
<i>Sus scrofa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
<i>Cervus elaphus</i>	-	-	1	1	-	-	-	-	-	-	-	-	-	-	3	1	1	1	-	-	-	2	1	-
<i>Rangifer tarandus</i>	733	10	848	14	-	8	54	3	366	5	91	4	7	3	190	5	152	8	115	6	16	2	-	-
<i>Capreolus capreolus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-
<i>Ovibos pallantis</i>	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Bison priscus</i>	66	10	80	5	-	-	-	-	16	2	4	1	2	1	19	1	9	1	-	-	-	-	-	-
<i>Bos primigenius</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	2	3	1	-	-	-	4	1	-
<i>Bos / Bison</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	(4)	7	(1)	6	(2)	3	(1)	-	-
<i>Saiga tatarica</i>	108	6	148	5	-	-	6	2	33	3	10	1	-	-	9	2	4	2	3	1	1	1	1	-
<i>Capra sp.</i>	3	1	1	1	-	-	-	-	-	-	-	-	-	-	2	1	-	-	1	1	-	-	-	-
<i>Rupicapra rupicapra</i>	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	1522	56	1810	54	1	12	133	16	680	30	206	18	15	6	371	26	345	26	222	15	43	9	-	-



Fig. 4. Photo of dental remains of *Equus ferus arcelini* from Roc-aux-Sorciers. A. Right maxillar from abri Bourdois (RSD-1352–1353), B. Left mandible from Cave Taillebourg (TCC-2012). Scale bar = 2 cm.

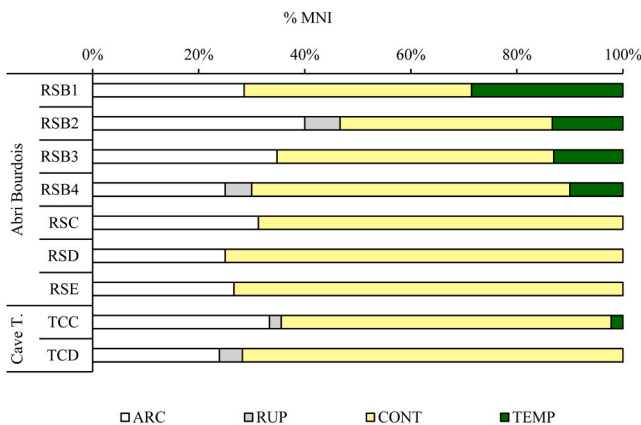


Fig. 5. Climatogram: evolution of ungulate proportions (% MNI) of Roc-aux-Sorciers, grouped by ecological classes. ARC: arctic, cold steppes; RUP: rocky areas; CONT: arid steppe area, open environment; TEMP: deciduous forests.

group and the continental steppe group. The low abundance of mountain species, *Rupicapra* and *Capra*, corresponds with the presence of a few cliffs in a region that is otherwise not very rugged. In the Upper Magdalenian, the climate is still cold and dry, but the forest group increases towards the top of the sequence, reaching 30 % in the RSB1 layer.

The cenograms from Abri Bourdois and Cave Taillebourg (Fig. 6) characterize very open environments for all the archaeological layers. The steep slopes observed in the large mammals in the Middle Magdalenian layers indicate the aridity of the climate at the time the assemblage was formed. Conversely, the lower slopes reported for the Upper Magdalenian suggest a slight increase in humidity.

4.3. Ecomorphological patterns of the horse

4.3.1. Muzzle proportions

The proportions of the muzzle are available only for the Middle Magdalenian levels. The symphyses of the horse from Roc-aux-Sorciers are shorter and wider than those of the extant “*Equus przewalskii*” (Fig. 7). They are similar to those of other Late Glacial horses *Equus arcelini* s.l. The symphyses of specimens from Saint-Germain-la-Rivière are longer, and those of Jaurens a little narrower. Symphyses of *Equus germanicus* are larger. A short and broad muzzle could represent an adaption to a cold climate (following Allen’s rule) and high grazing specialization (Crégut-Bonnoure et al., 2018; Eisenmann, 2022).

4.3.2. Tooth dimensions

Unfortunately, the tooth samples are unbalanced. Despite this, no statistical difference in size was found between the two Magdalenian

samples. The Upper Magdalenian horses have larger protocones on molars (M1/2) than on premolars (P3/4). Following Eisenmann (1991), this morphotype could indicate a more temperate climate. However, studies have shown that the length of protocone should be used with caution to infer environmental conditions (Uzunidis et al., 2017).

4.3.3. Slenderness Index of metacarpal

Among the postcranial elements, the proportion of the autopod can reflect rapid adaptive plasticity of the equids. The proportion can quickly change according to the climatic context and the type of substrate. In particular, the shaft of the metacarpal seems to vary according to the degree of humidity. There is only one complete metacarpal from the layer C of Cave Taillebourg (TCC-2804). The slenderness index of the diaphysis (SI=163) corresponds to a low value in comparison to most upper Pleistocene samples (cf. Fig. 8 in Boulbes and van Asperen, 2019), which would imply not very humid to dry climatic conditions.

4.3.4. Variability Size Index (VSI)

The distribution of the VSI shows that there is no difference in body size between the sample from the Middle Magdalenian layers (TCC+TCD; VSI mean = -22.7; N = 49) and Upper Magdalenian layers (RSB; VSI mean = -23.2; N = 39) (Fig. 8). The medians of the VSI are slightly different (-17,6 and -24,8 respectively) but the Mann-Whitney test result comparing the two samples is not significant (U=882; z=0.6132; p=0.5398). Nevertheless, the temporal resolution may not be sufficient to influence individual size at the local scale.

4.4. Seasonality and structure of the horse populations

4.4.1. Seasonality of horse hunting

For the Middle Magdalenian, the ages determined from deciduous horse teeth yield significant results as multiple wear stages of the same type of tooth are represented within the same layer (Fig. 9). This indicates that horse hunting took place at different times of the year rather than during a single season.

Three new-borns (or full-term foetuses) identified from the postcranial remains indicate spring hunting (TCC, TCD and RSD layers). Additionally, some preterm foetal remains were also identified in the Middle Magdalenian layers (RSC, RSD, RSE, TCC and TCD). These foetuses are not included in the calculation of the MNI but provide valuable information on seasonality, reflecting the slaughter of females during the gestation period, likely corresponding to the colder months within the annual cycle (autumn-winter).

Based on reproductive biology (Turner, 2002; Bignon, 2008), several observations emerge from our results:

- At Cave Taillebourg, seasonality evidence for the TCC layer suggests hunting in the spring, coinciding with calving when horses form family groups. During this season, newborns, as well as second and even third-year young individuals, were hunted. Additional hunting events occurred in autumn-early winter when horses reached their maximum weight and constituted prime prey. First and second-year individuals were also hunted alongside adult individuals within the harems. Furthermore, the presence of four adult males and numerous old individuals suggests hunting within so-called bachelor groups. Seasonality indices for the TCD layer highlight various hunting episodes within family groups throughout the annual cycle, as well as killings within bachelor groups.
- At Abri Bourdois, layer D indicates hunting events throughout the year, similar to those at Cave Taillebourg, targeting different groups of horses. In contrast, Layer C does not yield precise information on seasonality. The composition of the culled population suggests hunting activities within both family and bachelor groups. Additionally, at the base of the sequence, layer E of Abri Bourdois reveals horse hunting within family groups, at least during the summer and autumn, when the horses are in optimal physical condition.

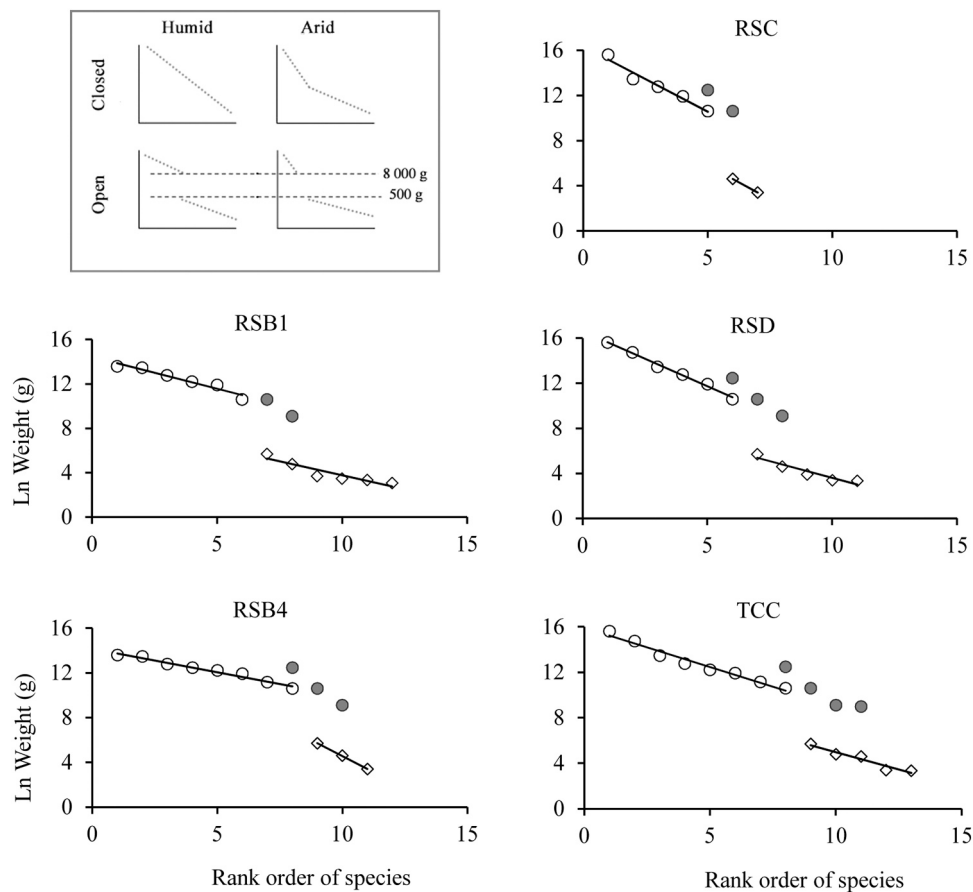


Fig. 6. Cenograms of Roc-aux-Sorciers by archaeological level. Carnivores (grey dots) are not taken into account in the calculation of the straight lines. Top left, schematic representation of large categories of cenograms (after Legendre, 1986, 1989). In closed habitats, the distribution of species is continuous (above), whereas in open environments the medium-weight species (between 500 g and 8 kg) are rare or absent (below). In humid conditions, the large species (weight > 8 kg) are numerous (left), whereas they are rare in arid conditions (right).

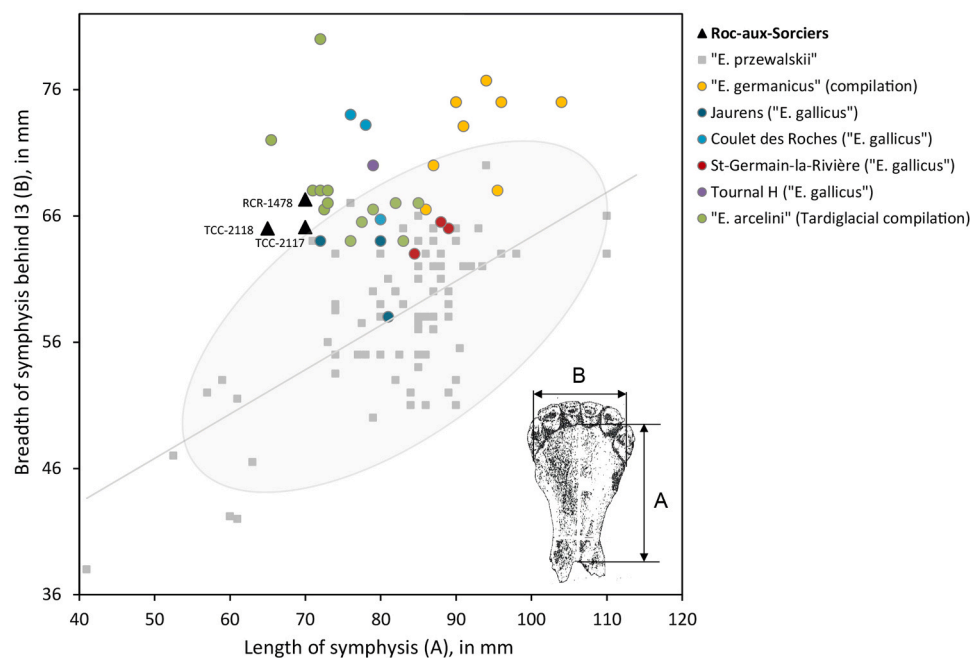


Fig. 7. Symphysis length (A) in relation to symphysis breadth at the posterior borders of I3 (B). Comparative data: Przewalski's horse and Jaurens (vera-eisenmann.com); Coulet-des-Roches (Crégut-Bonnoure et al., 2018); Saint-Germain-la-Rivière and « E. germanicus » (Prat, 1968); « E. arcelini » (Bignon, 2003); Tournal (Boulbes, pers. data).

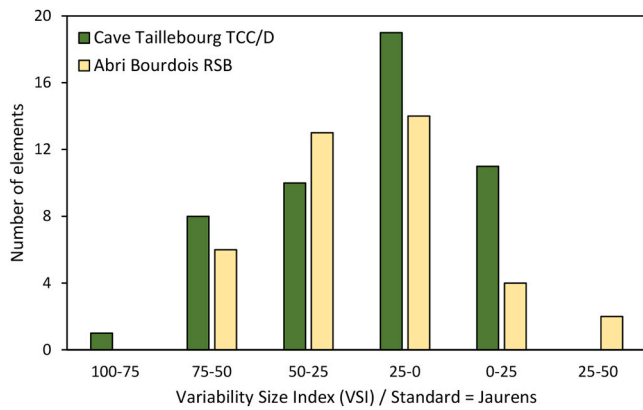


Fig. 8. Variation of size indices (V.S.I.) of Roc-aux-Sorciers horses and other Magdalenian horses. $V.S.I. = 50 * (X_{ref} - m) / 2S_{ref}$. Where X_{ref} and S_{ref} = mean and standard deviation of the metric variable of the reference population; m = measurement of the same variable of the population to be compared. Reference: Jaurens (see Appendix).

In summary, during the Middle Magdalenian period, horses were hunted across various seasons, indicating their continuous presence in the region throughout the year (Fig. 10). The Roc-aux-Sorciers site provides interesting insights into the behaviour of *E. arcelini* populations in the region: they may have been sedentary populations or populations that engaged in small-scale migrations, depending on environmental conditions such as access to food and snow cover.

Regarding the Upper Magdalenian (layers RSB4 to RSB1 of Abri Bourdois), the seasonality results present notable disparities. When compared with reindeer data, the findings suggest that the Upper Magdalenian layers may correspond to one or more short-term human occupations (Table 3). Specifically, layers RSB3 and RSB4 appear to represent two brief occupation episodes (one in spring and another during the cold season), rather than prolonged occupations spanning several months. This inference is supported by the scarcity and nature of the excavated remains within the shelter. These findings align with the observation that the shelter’s functionality differed between the Upper Magdalenian and Middle Magdalenian periods.

4.4.2. Demographic structure of the horse populations

The analysis of horse populations indicates that the Magdalenian people hunted animals of all ages, with a marked preference for adults in their prime (aged 5–10 years) and, to a lesser extent, younger

Sample	Element	Age	Winter	Spring	Summer	Autumn
RSB2-1540	upper i1	10-15 m	---	-----	-----	-----
RSB3-1459	lower D3	7,3 m				-----
RSB3-1459a	lower D4	(replacement)				-----
RSB4-1462	lower D4	newborn		-----		
RSB4-1548	upper i1	5-10 m	-----			-----
RSC-1480	upper ili2	10-15 m	-----	-----	-----	
RSC-1482	upper i1	10-15 m	-----	-----	-----	
RS-C-1940	upper i1	5-10 m	-----			
RSD-1523	upper ili2	0-1 m		-----		
RSD-1573	upper i3	0-4 m		-----		
RSD-1475	upper i2	3-4 m			-----	
RSD-1461	lower D2	9,4 m	-----			
RSD-1479	lower i3	15 m			---	
RSD-1522	lower i3	18 m				---
RSD-1574	upper i3	18-20 m	---			-----
RSE-1476	upper i1	3-4 m			-----	
RSE-1474	upper ili2i3	18 m				---
RSE-1477	lower i1	10-15 m		-----	-----	
TCC	bones	newborn		-----		
TCC-2011	upper D3	7,4 m				-----
TCC-2201	upper i1	10-15 m	-----	-----	-----	
TCC-2161	lower i2	18-20 m	---			-----
TCC-2196	lower i2	18-20 m	---			-----
TCC-2154	upper i3	24 m		---		
TCD	bones	newborn		-----		
TCD-2174	upper i1	5-10 m	-----			-----
TCD-2010	upper D2D3D4	8,3 / 4,8 m	-----			-----
TCD-2109	lower D2D3D4	13,5 / 14,2 m			-----	
TCD-2181	low i2	18-20 m	---			-----
TCD-2196	lower i2	18-20 m	---			-----
TCD-2129	lower ili2i3	24 m		---		
TCD-2006	upper D2D3	25,5 / 24,7 m		-----	-----	
TCD-1478	lower i1	24-30 m		-----	-----	-----
TCD-2192	lower i1	24-30 m		-----	-----	-----

Fig. 9. Seasonality data established from horse remains. In solid line: individuals of 1st year, in broken line: individuals of 2 years and more. Abbreviations: i: lacteal incisor, D: decidual molar, m: months.

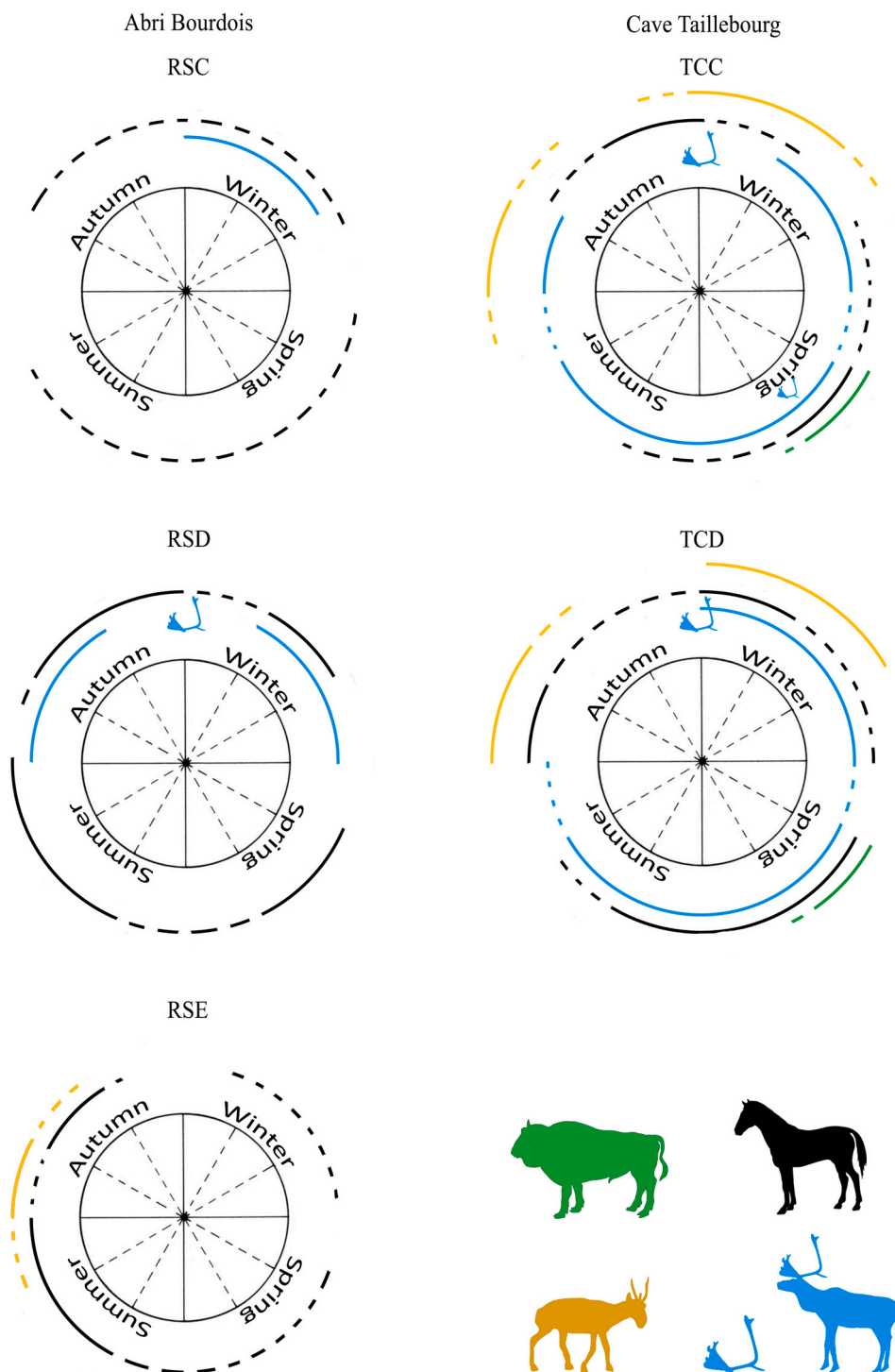


Fig. 10. Occupation data for the Roc-aux-Sorciers site during the Middle Magdalenian, organized by locality and stratigraphic layers. The results are based on the four main ungulate species at the site: reindeer, horse, bison, and saiga. Solid line: precise period; dotted line: season represented, but with imprecise period. The collection of reindeer antlers is indicated.

individuals (Fig. 11). This mortality profile is consistent with patterns of anthropogenic predation observed in small to large sized ungulates (Stiner, 1990; Lyman, 1994). During the Middle Magdalenian period, horse incisors, as along with those of saiga antelopes and bison, have been documented as artefacts used for decorative purposes (Vercoûtère, 2009). This suggests that the selective hunting of subadult and prime-aged individuals could have been influenced by the value placed on specific dental elements as there were sought for their utility in the creation of ornamental items.

4.5. Mesowear and microwear analyses

The results of the mesowear and microwear analyses on the horses from Roc-aux-Sorciers are summarized in Table 4. The raw data are available at Zenodo <https://doi.org/10.5281/zenodo.12316317> (Rivals, 2024)

The mesowear scores recorded on the upper teeth from the three assemblages from Roc-aux-Sorciers show high values comprised between $MWS = 4-6$. The mesowear values appear to be lower for the

Table 3
Seasonality data established on reindeer and horse from the Upper Magdalenian of Abri Bourdois.

Abri Bourdois	Rangifer		Equus	Hunting episode
	Hunting season	Collecting antlers		
RSB1	-	-	Autumn-winter	Brief episode
RSB2	Spring-summer	Late autumn-winter (males) of the previous period	Spring-summer	Brief episode
RSB3	Spring-summer	Spring (females)	Autumn	2 short episodes
RSB4	-	Late autumn-winter (males)	Spring Autumn-winter	2 short episodes
RSB5	Spring-summer	-	-	Brief episode

Upper Magdalenian in comparison to the Middle Magdalenian (Fig. 12), but there is no significant difference among the three samples analysed (One-way ANOVA; $F = 3.305$; $p = 0.0581$). In comparison to modern ungulates the samples fall within the range of values reported for the extant grazers (Fig. 12). The horses from Roc-aux-Sorciers show higher mesowear values than the extant zebras (*Equus quagga* and *Equus grevyi*) but lower or similar to that of the bison (*Bison bison*). Mesowear scores indicate that horses were feeding on a highly abrasive diet mainly composed of grasses.

At the microscopic level, the horses from Roc-aux-Sorciers show a microwear pattern characterized by high number of scratches and relatively low number of pits (Table 4). There are significant differences between the two samples from the Middle Magdalenian (TC and RS) and the sample from the Upper Magdalenian (RS), both in terms of pits and scratches (Table 5). The diet can be better characterized using bivariate graph (Fig. 13) and the percentage of browsers in the sample (%0–17 in Table 4). The horses from the Middle Magdalenian had a pure grazing diet which was significantly more abrasive than those from the Upper Magdalenian that are classified as grass-dominated mixed feeders.

The variability in the numbers of scratches quantified through the

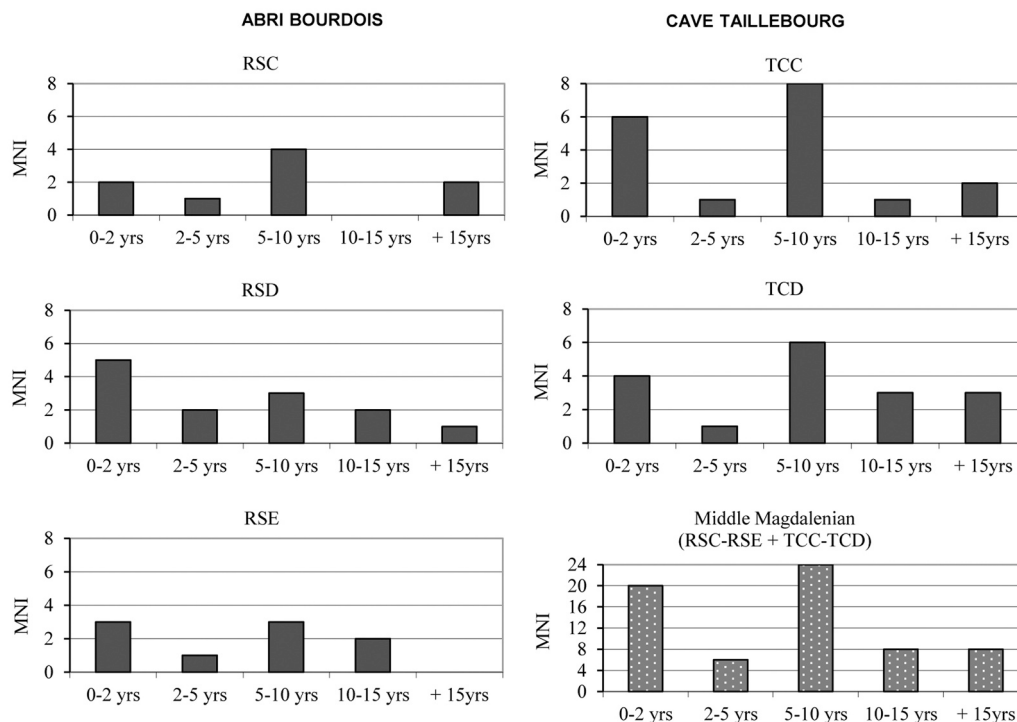


Fig. 11. Mortality profiles of Middle Magdalenian horses at Roc-aux-Sorciers.

Table 4

Summary results of the mesowear and microwear analyses on the horses from Roc-aux-Sorciers. Abbreviations: N = Number of specimens; M = Mean; SD = Standard Deviation; CV = Coefficient of variation; MWS = Mesowear Score (mode); NP = Mean number of pits; NS = Mean number of scratches; %LP = Percentage of individuals with large pits; %G = Percentage of individuals with gouges; SWS = Scratch width score; %XS = Percentage of individuals with cross scratches; %0–17 = Percentage of individuals with 17 scratches or less.

		Mesowear		Microwear		NS	%LP	%G	SWS	%XS	%0–17
		N	MWS	N	NP						
Cave Taillebourg (TC)	M	18	5	17	16.79	22.29	64.71	5.88	1.47	0	0
Middle Magdalenian	SD				2.80	3.71					
	CV					0.17					
Abri Bourdois (RS)	M	14	6	12	17.38	21.92	66.67	0	1	0	0
Middle Magdalenian	SD				1.48	3.79					
	CV					0.17					
Abri Bourdois (RS)	M	7	5	7	12.00	18.14	0	0	1	0	28.6
Upper Magdalenian	SD				1.04	1.07					
	CV					0.06					

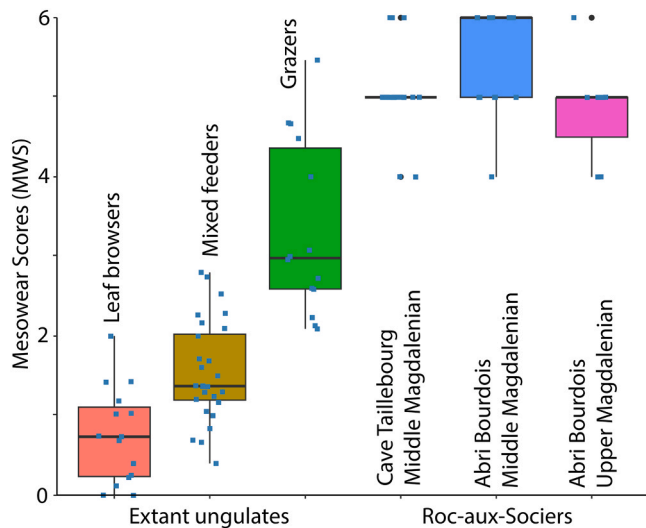


Fig. 12. Mesowear scores for the samples from Roc-aux-Sorciers compared to extant ungulates (Leaf browsers, mixed feeders and grazers). Data from Fortelius and Solounias (2000).

Table 5

ANOVA and Tukey’s HSD test results on the microwear features (pits and scratches) of the horses from Roc-aux-Sorciers. Abbreviations: df = degrees of freedom; SS = sum of squares; MS = mean square; MM = Middle Magdalenian; UM = Upper Magdalenian.

Number of pits					
ANOVA results:					
Source	df	SS	MS	F-ratio	p
Model	2	145.297	726.485	15.41	< 0.005
Residual	35	300.889	0.00004		
Pair-wise comparisons – q values (Tukey’s method) below the diagonal; p-values above the diagonal:					
	TC-MM	RS-MM	RS-UM		
TC-MM	-	0.7596	0.0487		
RS-MM	1.003	-	0.0295		
RS-UM	6.953	7.361	-		
Number of scratches					
ANOVA results:					
Source	df	SS	MS	F-ratio	p
Model	2	910.023	455.012	3.897	0.0302
Residual	35	476.306	0.03115		
Pair-wise comparisons – q values (Tukey’s method) below the diagonal; p-values above the diagonal:					
	TC-MM	RS-MM	RS-UM		
TC-MM	-	0.9539	0.0282		
RS-MM	0.4143	-	0.0466		
RS-UM	3.826	3.284	-		

standard deviation (SD) and coefficient of variation (CV), show differences between the two chronological periods (Table 5; Fig. 14). The two samples from the Middle Magdalenian show relatively high values and falls within area B of the SD-CV bivariate graph (Fig. 14) indicating the accumulation of the horse remains during occupations that lasted longer than one season. During the Upper Magdalenian, the SD and CV values are significantly lower and fall within area A (Fig. 14). This suggest short-term occupation that lasted one season or less.

5. Discussion

5.1. Taphonomy and palaeoenvironments

At Roc-aux-Sorciers, the faunal remains are generally well preserved. The Middle Magdalenian layers at both Abri Bourdois and Cave Taillebourg contain faunal assemblages with minimal alteration. However,

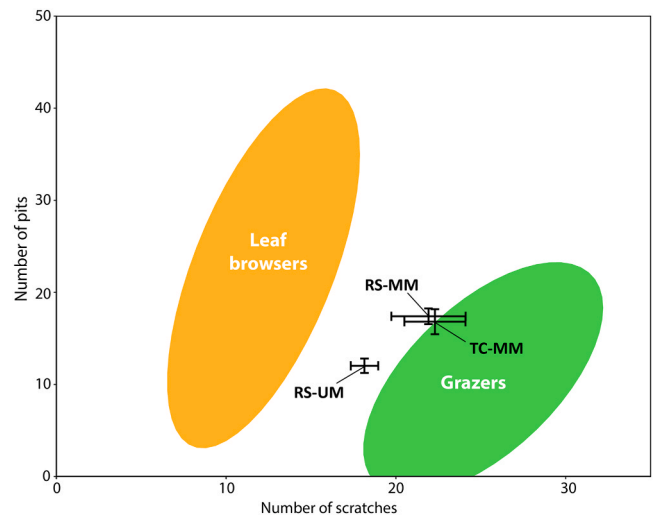


Fig. 13. Bivariate plot of the number of pits and scratches for the horse from Roc-aux-Sorciers. Error bars correspond to standard error of the mean (± 1 SEM) for each sample. Plain ellipses correspond to the Gaussian confidence ellipses ($p = 0.95$) on the centroid for the extant leaf browsers (LB) and grazers (G) based on the reference database from Solounias and Semprebon (2002).

Cave Taillebourg shows a significant number of oxidised bones, likely due to substantial water infiltration. In contrast, the upper deposits at Abri Bourdois exhibit a higher frequency of bones affected by weathering. These findings are supported by the palynological results from the site, which indicate notable alteration and differential preservation of pollen in these layers (Renault-Miskovsky, 2009). This overall good preservation of faunal material enable reliable paleoenvironmental and archaeozoological analyses (Lyman, 1994).

Palaeoenvironmental and palaeoclimatic interpretations based on the study of large mammals and horse autecology are generally consistent with results obtained from other disciplines. Sedimentology, pollen analyses, and rodent studies also suggest climate warming from the Middle to the Upper Magdalenian (Renault-Miskovsky, 2009; Bozet and Miskovsky, 2010, 2011; Marquet, 2009). However, this warming does not appear to have led to a significant turnover in the composition of the mammalian fauna in the region.

During the Middle Magdalenian, corresponding to Dryas I (Bertrand et al., 2003; Dujardin and Tymula, 2005; Pinçon, 2009), the presence of large mammals suggests an open environment under cold and dry climatic conditions. However, sedimentary analyses indicate a relative cold and very humid climate (Bozet and Miskovsky, 2010, 2011). Additionally, rodent associations provide nuanced information, with open habitats observed in very cold and dry climates on the plateaus, and more humid areas in valleys (Marquet, 2009).

At the onset of the Upper Magdalenian, corresponding to layer RSB4, there is a reduction in cold conditions, evidenced by a decline in Arctic large mammals, replaced by a more temperate assemblage. The environment remains predominantly open. Above the RSB4 layer, the RSB3 to RSB1 layers of the Upper Magdalenian record a climatic improvement, with increasing humidity towards the top of the sequence. These deposits mark the beginning of the Pre-Bölling warming period (Dujardin and Tymula, 2005; Bozet and Miskovsky, 2010, 2011). The valleys, becoming more wooded, likely provided shelter for red deer, wild boar, and roe deer. Nevertheless, the environment remains largely open, and the Magdalenians continue to primarily hunt horses and reindeer, with the saiga antelope being of secondary importance.

Ecomorphological patterns of the horse (proportion of the muzzle and distal limb bones) support the harshness of the climatic conditions. Body size index shows no difference between the samples from the Middle Magdalenian layers and Upper Magdalenian layers. The time-scale resolution is probably not long enough to impact the size of

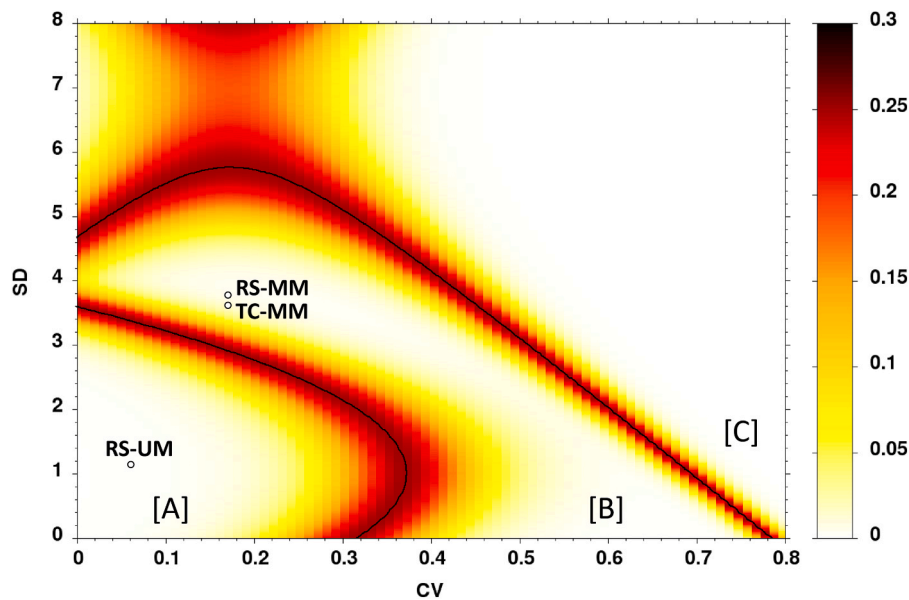


Fig. 14. Boundary lines with the error probability (heat map) based on standard deviations (SD) and coefficient of variation (CV) values of microwear data used for the classification of Roc-aux-Sorciers samples into short events (Region A), long-term events (Region B) or two separate short events (Region C).

individuals at the local scale. Usually, during this period, differences in size are identified on a large scale in Western Europe, reflecting the regional mosaic of the Late Glacial horse populations (Bignon and Eisenmann, 2006; Magniez et al., 2017; Boulbes and van Asperen, 2019).

The results of dental meso- and microwear analyses show no difference between the diet of Middle Magdalenian horses at Roc-aux-Sorciers. They are grazers both at the Cave Taillebourg and at the Abri Bourdois. However, those from the Upper Magdalenian (at Abri Bourdois) had a diet based on grasses but included a higher proportion of ligneous and herbaceous plants (grass-dominated mixed feeders). This indicates a more open habitat in the Middle Magdalenian but a mixed diet still dominated by grasses in the Upper Magdalenian, with greater consumption of ligneous and herbaceous plants. This type of mixed feeding diet is unusual in horses, which are generally grazers. Nevertheless, this type of diet has been observed at other Pleistocene sites such as Schöningen 13 II-4 (MIS 9; Rivals et al., 2015a), Igue des Rameaux amont (MIS 9; Uzunidis et al., 2017) and Taubach (MIS 5e; Rivals et al., 2009). These cases are very rare in the Pleistocene and all occur during interglacial phases.

5.2. Seasonality and site occupation

To determine the seasonality and duration of site occupation, the individual age estimation of young ungulates is based on several classic methods that rely on the principle of uniformitarianism. The results are influenced by factors such as the date of birth, which can vary within the same species due to climate, altitude, vegetation, or individual differences (e.g., birth timing influenced by the age of the female). Although, the ages obtained for young animals are estimates, these estimates, when considered relatively, provide fairly precise insights into the seasons or even the duration of site occupation.

These analyses allow for an investigation into the seasonal behaviour of species in the region (e.g., regular migration) and the subsistence strategies of the Magdalenians in relation to the fauna. They also raise a crucial question about the nature of Magdalenian occupations: do the stratigraphic layers represent single-season occupations, repeated occupations at different times of the year, or long-term occupations extending over an entire year or more?

It is essential to consider the context of cave and rock shelter environments, such as Roc-aux-Sorciers. Given the relatively thick

stratigraphic layers, they likely correspond to palimpsests resulting from multiple successive hunting episodes (Pinçon, 2012). In other words, if all the seasons are represented within a stratigraphic layer, does this indicate a long-term occupation or several visits at different times of the year?

From the perspective of the inhabited space, it is highly probable that the Magdalenians used the entire site (Abri Bourdois and Cave Taillebourg) during their visits, which were well-suited to their various domestic and artistic activities. Unfortunately, the occupation levels are treated separately by locality due to the lack of precise contemporaneity established between the occupations at Abri Bourdois (notably layers RSC and RSD) and those at Cave Taillebourg (TCC and TCD) through multidisciplinary analyses.

The analysis of dental wear and tooth eruption reveals the presence of numerous young individuals of varying ages during the Middle Magdalenian, suggesting hunting activities throughout the year, during all four seasons. The diversity of habitats (plateau, cliffs, riverbanks, steep valleys) and the year-round availability of food may explain the continuous presence of horses in the region. These animal populations were likely sedentary or engaged in small-scale migratory movements, which would have also benefited Magdalenian hunters. It is worth noting that similar findings have been observed for reindeer at Roc-aux-Sorciers (Valensi, 2009; Valensi and Boulbes, 2018). Similarly, this phenomenon of sedentarism in typically migratory ungulates has been documented in other specific regions, such as Dordogne (Fontana, 2017). The type of mortality profile observed in horses could reflect multiple hunting episodes without a selective hunting strategy: slaughter of individuals within family groups (including young and females) and/or mass slaughter of these groups, as well as slaughter within bachelor groups (which would explain the presence of old or sometimes even very old animals and the strong representation of males in certain levels). Overall, the hunting strategies for horses and reindeer suggest that the Middle Magdalenian hunters at Roc-aux-Sorciers were not focused on managing animal groups (Valensi and Boulbes, 2018), as has been noted at other Magdalenian sites (Sacchi, 2003; Bignon, 2008). The results suggest long and intensive occupations of the site during the Middle Magdalenian, consistent with the richness and diversity of faunal, lithic, and other artifacts recovered (Saint-Mathurin, 1969; Beaune, 2013; Beyries and Cattin, 2015; Pinçon and Fuentes, 2020).

In contrast, the seasonality data for the Upper Magdalenian show notable differences from the Middle Magdalenian period. Horses were

predominantly hunted during the spring-summer and/or autumn-winter seasons, depending on the stratigraphic levels, indicating shorter-term human occupations. These findings are consistent with the hypothesis that the shelter did not serve the same purpose during the Upper Magdalenian as it did during the Middle Magdalenian.

The variability of the microwear signal also reveals differences in seasonality between the Middle Magdalenian and the Upper Magdalenian. In the Middle Magdalenian, the high variability indicates occupations longer than a single season, i.e. more than 3 months, both at the Cave Taillebourg and at the Abri Bourdois. Conversely, in the Upper Magdalenian, low variability of the microwear signal indicates one (or more) short occupation(s), of less than 3 months. These results are in agreement with the seasonality established from the dentition of *Equus*.

6. Conclusions

The study of horses from the Magdalenian site of Roc-aux-Sorciers, conducted through various approaches, has highlighted the morphological characteristics of the species and its dietary adaptation to the climatic and environmental changes recorded between the Middle and Upper Magdalenian periods. Due to this adaptation and the diversity of habitats, the horse populations uncovered at Roc-aux-Sorciers were sedentary or semi-sedentary, allowing them to be hunted throughout the seasons by the various human groups that succeeded each other in the territory.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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