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Neolithic shepherds and sheepfold caves in Southern France and adjacent areas: An overview from 40 years of bioarchaeological analyses

Claire Delhon [a,*], Lucie Martin [b,c], Stéphanie Thiébault [d]

[a] Université Nice Côte d'Azur, CNRS, CEPAM, Nice, France
[b] University of Geneva, Laboratory of Prehistoric archaeology and Anthropology, Geneva, Switzerland
[c] University of Savoie Mont-Blanc, CNRS, EDTYEM, Le Bourget du Lac, France
[d] Université Paris 1 Panthéon-Sorbonne, CNRS, Trajectoires de la sédentarisation à l'État, UMR 8215 du CNRS, Paris, France

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ABSTRACT

In southern France, the analysis of fossil dung layers from caves and shelters occupied by the first Neolithic farmers has provided a wealth of information about the lives of shepherds and their flocks, and thus on pastoral systems. Since the early 1980s, the development of sedimentological, archaeozoological and archaeobotanical studies has made possible to collect a large amount of data. More recently, the implementation of a whole range of innovative approaches allows a more detailed approach to pastoralism. This paper proposes a synthetic approach of 40 years of bioarchaeological analysis on Neolithic sheepfold caves (*grottes-bergeries*). Their interpretation focuses on understanding the early agropastoral system: pastoral use of wild and cultivated plant resources (fodder, litter, care and health of livestock), mobility systems, seasonality, practices and appropriation of territory.

1. Introduction

Pastoralism is defined as a form of extensive livestock production in a natural environment, based on spontaneous forage resources. Today, it is a form of subsistence relying on the use of the environment, practiced by populations who live on rangelands and keep herds of domestic ruminants, which aims at converting the cellulose of natural vegetation into meat and milk (Bourbouze and Chassany, 2008, p. 41). Pastoralism is characterized by its seasonality, the mobility of herders and flocks and its collective dimension: pastoral areas are often collectively appropriated and/or managed (Eychenne, 2018). Although mobility is not always clearly mentioned when it comes to pastoralism, it is often implicit. Indeed, dependence on spontaneous vegetation forces people to move according to the availability or depletion of that resource. In this respect, the altitudinal succession of vegetation and the phenological gradient makes mountain landscapes particularly suitable for pastoralism.

In the south of France, there are numerous sites dating from the Neolithic to the Bronze Age, with more or less thick accumulations of fossil dung and various other evidence of stabling. Some of these sites, located in caves or shelters, were called *grottes-bergeries* in French, or "sheepfold caves" (Brochier et al., 1999). The dung levels (*fumiers*, Brochier, 2002) that characterize them contain a wealth of information about the lives of herders and their flocks, and thus about pastoral systems: site status, mobility systems, seasonality, pastoral practices, etc. Since the early 1980s, archaeologists placed great hopes on these contexts to improve the understanding of ancient pastoral systems, drawing the attention of bioarchaeologists, mainly archaeozoologists and archaeobotanists, to the "sheepfold caves". A few decades later, analyzes of plant or animal remains have accumulated a large amount of data. Nevertheless, it is still challenging to produce holistic syntheses and several aspects of pastoral systems are difficult to capture with standard bioarchaeological tools. Therefore, a whole range of innovative approaches to pastoral sites is currently being developed. In addition to the "classic" bioarchaeological approaches (archaeobotany: charcoal, macroremains, pollen and archaeozoology), phytolith analyzes, cementochronology, determination of the isotopic composition of animal bones and plant remains ($\delta^{13}C$, $\delta^{15}N$) and of animal tooth enamel ($\delta^{13}C$, $\delta^{18}O$, $^{87}Sr/^{86}Sr$), and DNA analyzes or the identification of biomolecules (in sediments, e.g. coprostanols, or on artifacts, e.g. dairy products) are increasingly in demand. After 40 years of work, and at the beginning of a renewal of our knowledge thanks to more sophisticated methods, we propose to take stock of the contribution of bioarchaeology to the understanding of Neolithic pastoral systems in southeastern

* Corresponding author.
E-mail address: claire.delhon@cepam.cnrs.fr (C. Delhon).

France, and of the questions that remain open. The synthesis of results from Early, Middle, and Late Neolithic sites in southern France expands our knowledge of the agropastoral activities that took place over almost four millennia and shaped modern cultural and environmental landscapes.

2. Sheepfolds caves and pastoral sites

2.1. A brief history of the identification of sheepfold caves

In their 1986 paper, C. Chang and H. Koster raised the question of the archaeological distinction between exclusively pastoral sites and sites with mixed agricultural and pastoral activities. Indeed, it seems that pastoralists worldwide rely on what P. Salzman (1972) called "multi--resource pastoralism". If pastoralism is taken to mean "the dependence upon domestic herd animals held as property" (Chang and Koster, 1986), then such a definition includes "activities as disparate as a villager keeping several sheep on the commons and the operation of modern ranches or mechanized dairy farms" (ibid).

Indeed, an important point concerning pastoralism seems to be that food production is only one aspect of animal husbandry (together with fleece, strength or manure production), which in turn is only one component of a multiple production system (along with foraging, fishing, cultivation: Chang and Koster, 1986). Interestingly, at the 1983 conference in Montpellier which was attended by almost all researchers dealing with "the first farming communities in the Western Mediterranean" the question of pastoralism was practically never directly addressed (Guilaine et al., 1987). In the mid-1980s, however D. Helmer (1984) and J.-E. Brochier (1985) pointed out the presence of more or less extensive pen areas in several caves in southeastern France (Fig. 1 and supplementary material). The assumption that certain spaces of Fonbrégoua and Baume de Ronze caves were used as enclosures for sheep and goats was first based on the abundance of shed milk teeth in the Neolithic layers. Faecal deposits, characterized by the presence of calcium spherulites originating from the digestive process of caprines (Brochier, 1983) and a low density of artifacts were subsequently recognized as clear evidences of stabling. The term *grottes-bergeries* was then proposed to refer to the sheltered places where the herds stayed and where they were fed and/or penned. Herding area was estimated at 40–60 m^2 in Antonnaire and 80–100 m^2 in La Tune de la Varaime and Courtinasse, suggesting that herds could reach 100 to 200 animals (Brochier et al., 1999), while no contemporary habitat was identified nearby. Later, culling profiles and seasonal studies from several Early and Middle Neolithic caves showed that they were the exclusive or main site of lambing (Helmer et al., 2005).

In French, *bergerie* literally refers to a structure used specifically for housing sheep. Nevertheless, the term *grotte-bergerie* (and thus "sheep-fold-cave") does not allow any conclusions to be drawn about the composition of the flock (Brochier et al., 1999), which may even be unknown. Sheep and goats generally dominate in terms of numbers of heads but are often mixed with cattle and pigs (Helmer et al., 2005).

2.2. Sheepfold caves and pastoral sites in southern France and adjacent areas

In an region stretching from the Pyrenees to the Gulf of Genoa and to the southern edge of the Jura Mountains, there are almost twenty Neolithic caves and shelters identified so far as "sheepfolds" during all or part of their Neolithic occupation (Fig. 1 and supple. material). They have a typical sedimentary fill consisting of mineralized and burnt dung (*fumier*) accumulations (Fig. 2), characterized at the microscopic level by the abundance of faecal spherulites, ash and phytoliths (Brochier, 1983; Canti, 1999; Brochier et al., 1999). In the field, they consist of a succession of thin burnt and unburnt layers forming sequences of contrasting colors (black, white, grey, red) that are easily recognizable (Brochier et al., 1992; Angelucci et al., 2009; Nicod et al., 2010;

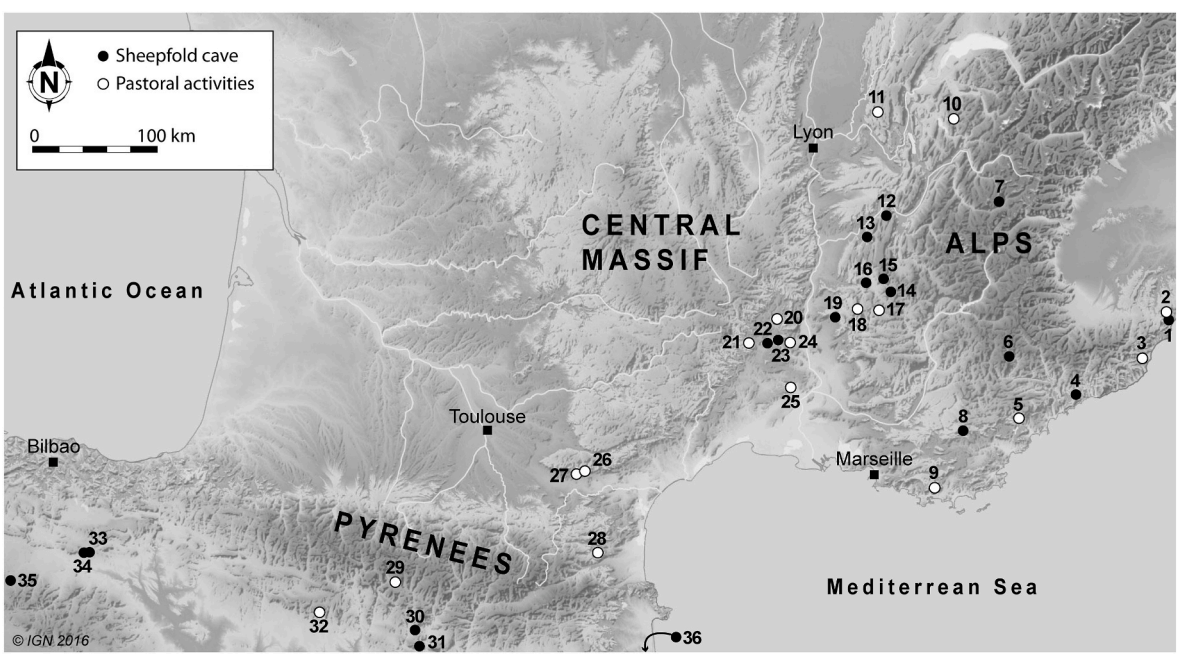

Fig. 1. Sites of southern France, northern Spain and Italian Ligurian coast, cited in the text and/or in the supplementary material table: black dots are sheepfold caves (SC, "Grottes-bergeries"); white dots are sites with pastoral activities (PA). 1. Arene Candide, 90 m; 2. Arma di Nasino, 350 m; 3. Grotta della Pollera, 300 m; 4. Pendimoun, 690 m; 5. Grotte Lombard, 700 m; 6. Pertus II, 1000 m; 7. Les Balmes, 1350 m; 8. Fontbrégoua, 400 m; 9. Vieux Mounoï, 420 m; 10. Vieille Eglise, 620 m; 11. Le Gardon, 373 m; 12. La Grande Rivoire, 580 m; 13. Coufin 2, 580 m; 14. Tune de la Varaime, 1400 m; 15. Courtinasse, 1385 m; 16. Antonnaire, 1172 m; 17. Trou Arnaud, 700 m; 18. Reychas, 800 m; 19. Baume Sourde, 300 m; 20. Combe Obscure, 280 m; 21. Chazelles, 190 m; 22. Baume de Ronze, 298 m; 23. Baume d'Oulen, 220 m; 24. Saint-Marcel, 100 m; 25. Le Taï, 54 m; 26. Gazel, 250 m; 27. Font-Juvénal, 185 m; 28. Caune de Bélesta, 390 m; 29. Els Trocs, 1564 m; 30. Cova Colomera, 670 m; 31. Cova Gran de Santa Linya, 385 m; 32. Chaves, 663 m; 33. Los Husos II, 900 m; 34. San Cristóbal, 920 m; 35. El Mirador, 1033 m; 36. Cova de la Guineu, 733 m.

Fig. 2. Characteristic stratigraphies of dung levels, showing the alternation of ash with mineralized and burnt dung deposits. From left to right: La Grande Rivoire (Isère); La Baume d'Oulen (Gard/Ardèche); Pertus II (Alpes-de-Haute-Provence). Photos: P.-Y. Nicod, L. Martin. Scale: 10 cm.

Martín-Rodríguez and Vergès, 2016). The rhythmicity of the deposits has often been considered as evidence of repeated – perhaps seasonal – occupations and/or of simultaneous or sub-simultaneous activities such as flock penning, fire making or ash disposal (Nicod et al., 2010). In addition to the presence of fossil dung, sheepfold caves often have walls polished by the friction of the fleeces (Brochier et al., 1992; Vergès and Morales, 2016), sometimes several meters above the modern surface, giving an impression of the compaction of the dung pile over time.

Penning into caves is documented almost from sea level up to 1500 m a.s.l (Fig. 1). In the Pre-Alps, the Middle Neolithic floor of the main gallery of La Tune de la Varaime (1400 m a.s.l.) shows an accumulation of dung; in Courtinasse (1385 m a.s.l.), the whole sequence (Neolithic to Final Bronze Age) is primarily due to the keeping of animals in the cave, as well as in Antonnaire (1172 m a.s.l.) and La Grande Rivoire (580 a.s.l.). Burnt dung was also identified in the Neolithic layers of Les Balmes (1350 m a.s.l.) in the inner Alps. Pertus II (1000 m a.s.l.), in the southern Alps, has very characteristic dung layers accumulated during the Middle Neolithic. In the submontane belt, stabling is considered an essential function of Baume Sourde (300 m a.s.l.) which sedimentary fill is composed of spherulites, phytoliths, ash, organic material and detrital grains. Although they are always situated on the slopes of more or less high massifs, some sheepfold caves are clearly located within Mediterranean vegetation belts. Pendimoun (690 m a.s.l.), which is one of the southernmost sites, is probably the oldest, as faecal spherulites already occur as early as in strata of Impressa Early Neolithic (5800-5500 BCE). Burnt and unburnt dung is discontinuously present throughout the Neolithic sequence, while shed milk teeth, initially rare, are abundant at the end of the Middle Neolithic (Binder et al., 2020). Fontbrégoua (400 m a.s.l.), Baume de Ronze (298 m a.s.l.), Baume d'Oulen (220 m a.s.l.) in lower Provence and Ardèche, Font-Juvénal (185 m a.s.l.) in the south-western foothills of the Massif Central and the cave of Bélesta (390 m a.s.l.) in the Pyrenees forelands, all showing typical dung accumulation, are located in the mesomediterrean zone, currently characterized by the dominance of evergreen vegetation. A slight extension of the focus beyond the French borders allows us to also mention important sites from the Iberian side of the Pyrenees and Liguria, Italy (Fig. 1). Besides the typical sheepfolds, which were used more for penning than for other activities during at least part of the Neolithic occupation, there are several other caves or shelters that indicate shorter, less intensive or less exclusive stabling. In these sites, dung is not present or is very diffuse in the sediment ("Pastoral sites", Fig. 1 and supple. material). This could be the case, for example, in Reychas, where sparse spherulites and phytoliths indicate the presence of livestock somewhere in the cave, but are not yet sufficient to prove intense or repeated stabling (Laudet and Daumas, 1991). Moreover, some caves may have been used exclusively as sheepfolds during part of their occupation and for other or mixed activities the rest of the time. Pendimoun, for example, offers mixed sedimentary facies consisting of "an intimate mixture of evidences of habitat, technical activities and animal husbandry" (Binder et al., 1993). At this site, but also at Pertus II (Lepère, personal communication), livestock penning may have alternated with craft activities such as pottery production. The seasonality of pastoral activities may also vary through time: Combe Obscure, which was used as a sheepfold on a long-term or even year-round basis during the Early and Middle Neolithic, is used exclusively in summer during the Final Neolithic (Helmer et al., 2005).

Depending on when the samples were taken and examined, not all of these sites have benefited from the same bioarchaeological analyses. For the most recently excavated sites, novel and particularly effective approaches that are currently being developed should largely renew our understanding of agropastoral Neolithic systems in the near future.

3. Bioarchaeological methods

Dung accumulations are valuable records interfacing fauna (herds), flora (local vegetation, shepherd's and animal's food, bedding) and human practices (herds management). In addition to their relevance for documenting the pastoral system, they also contain bioarchaeological remains linked to other activities such as agriculture, craft activities and various aspects of daily life.

3.1. Traditional micro- and macro-bioarchaeological methods mostly based on compared anatomy

3.1.1. Spherulites

In addition to the presence of lacteal teeth, sedimentological features provided the first evidence of herding in the caves of southern France, of which the abundance of faecal spherulites is the most characteristic. Despite the macroscopic features of fossil dung accumulations are now well known and easily identified in the field, spherulites remain up to the present day as incontrovertible evidence of the permanent presence of living animals, not only in caves and shelters, but sometimes also in open-air penning structures (Brochier et al., 1992; Shahack-Gross and Finkelstein, 2008). Faecal spherulites are microscopic calcitic particles (<20 μm) that form in the digestive tract and are excreted in faeces. They are produced in large quantities by domestic small ruminants, but also occur in a variety of other ruminants and non-ruminants, generally in smaller quantities (Brochier, 1996; Canti, 1997, 1998; Portillo et al., 2014). Leaching and dissolution can affect spherulites but these particles are generally well-preserved in sheltered sites and alkaline sediment (Canti, 1999). They are destroyed by high temperatures - above 500–700 °C, which probably depends on several factors (Brochier, 2002; Shahack-Gross, 2011) - but burning dung at lower heat could concentrate them (Burguet-Coca et al., 2020) and improve their preservation due to the pH increase caused by ash.

3.1.2. Archaeozoology

Together with the abundance of faecal spherulites in the sediment, the archaeozoological record have been crucial in demonstrating that several caves were used specifically for sheep and goat husbandry. The faunal remains are indeed very different from those of open-air sites of the same period (Helmer et al., 2005; Bréhard et al., 2010; Blaise et al., 2010). Numerous sheep, mixed with fewer goats, formed the bulk of the livestock, especially during the Early and Middle Neolithic, although sheepfold-caves also housed cattle and pigs. Lacteal teeth and sometimes preserved coprolites attest to the frequentation of the caves by live animals; bones and tooth remains of lambs or kids indicate that these caves were the scene of lambing; culling profiles point to pastoral strategies oriented towards milk production, often mixed with fleece and meat exploitation (Helmer et al., 2005). Studies based on the height of the fourth lacteal lower premolar (Gourichon, 2004) and more recently on cementochronological approaches (see *infra*) make it possible to determine the culling season for young caprine and to discuss the seasonality of the pastoral occupation, which seems to be restricted to spring and summer on fewer sites than expected (Helmer et al., 2005).

3.1.3. Anthracology

Due to the regular burning of the accumulated dung and bedding by the shepherds, and sometimes to the presence of domestic hearths, charcoal is abundant and very well preserved in the sheep/goat pens contexts. It therefore attracted the attention of anthracologists as early as the early 1980s, when the concept of sheepfold caves emerged (Vernet, 1974; Vernet and Krauss-Marguet, 1985; Vernet and Thiébault, 1987). As a first step, charcoal analyses provided detailed and more or less continuous records of woody vegetation around the sites and accurately documented the impacts of grazing pressure on the landscape, especially in the Mediterranean region (Thiébault, 1994, 2001; Heinz and Thiébault, 1998; Brochier et al., 1998). It soon became apparent that the reconstructed plant communities did not always correspond to currently documented ones, leading to the assumption that human practices influenced the ecological dynamics (Fig. 3) (Thiébault, 2001, 2005). Charcoal analysis revealed the use of woody plants to feed or maintain the herd in the form of leaf fodder, bedding or food supplements/medication at many sites (Laederich and Thiébault, 2004; Delhon et al., 2008; Martin et al., 2011; Battentier et al., 2016).

3.1.4. Pollen and non-pollen palynomorphs

Some palynologists are sometimes reluctant to analyze samples from anthropogenic deposits because they do not provide an accurate record of the surrounding vegetation, which is unfortunate because they are on the other hand very good records of human practices (Mercuri, 2008). Furthermore, pollen grains may be fragmented, corroded, unidentifiable or even nearly absent from fossil dung sequences due to trampling, thermal alteration and digestion (Delhon et al., 2008; Expósito and Burjachs, 2016; Florenzano, 2019; Fuks and Dunseth, 2021). Nonetheless, pollen and non-pollen palynomorphs (NPP) can provide valuable information about various aspects of husbandry practices, such as feeding, animal care, bedding, as well as about the vegetation near grazing areas and the seasonality of pastoral activities (Argant et al., 1991; Leroyer and Heinz, 1992; Expósito and Burjachs, 2016; Ejarque et al., 2011). At a protected site such as a cave, pollen input is mainly due to the frequentation of the site by animals, whose fur and digestive tract carry the grains of the vegetation visited/browsed, and to the input of flowering plants by humans. If only herds are involved in pollen accumulation, pollen spectra are theoretically characteristic of the grazing area and season (Argant, 1990). However, it has been shown that breeding activities often bring substantial amounts of plants into the sheepfold for various purposes, including flowering plants. Indeed, certain flowers may be used to feed the flock; for other species, flowers may not be specifically sought but are present when branches are collected for their wood or leaves. The presence of clustered pollen grains from hazel, lime and fir suggests that whole stamens (i.e. flowers) contributed to the pollen record at La Grande Rivoire (Delhon et al., 2008). The palynofacies may also include NPPs (saprophytes, coprophilous and carbonicolous fungi: Expósito and Burjachs, 2016) and plant debris, including stomata, which are valuable indicators of leaf decomposition in the cave (Delhon et al., 2008).

3.1.5. Carpology

The first archaeobotanical analyses of Neolithic settlements tended to focus on charcoal and pollen (e.g. Argant et al., 1991; Thiébault, 2005). In contrast to most archaeological contexts where plant macroremains are usually dominated by seeds and fruits, coprogenous levels often contain many tree remains, such as leaf buds, flower buds, leaf or needle fragments, and oak galls (Fig. 4). Galls are not properly speaking

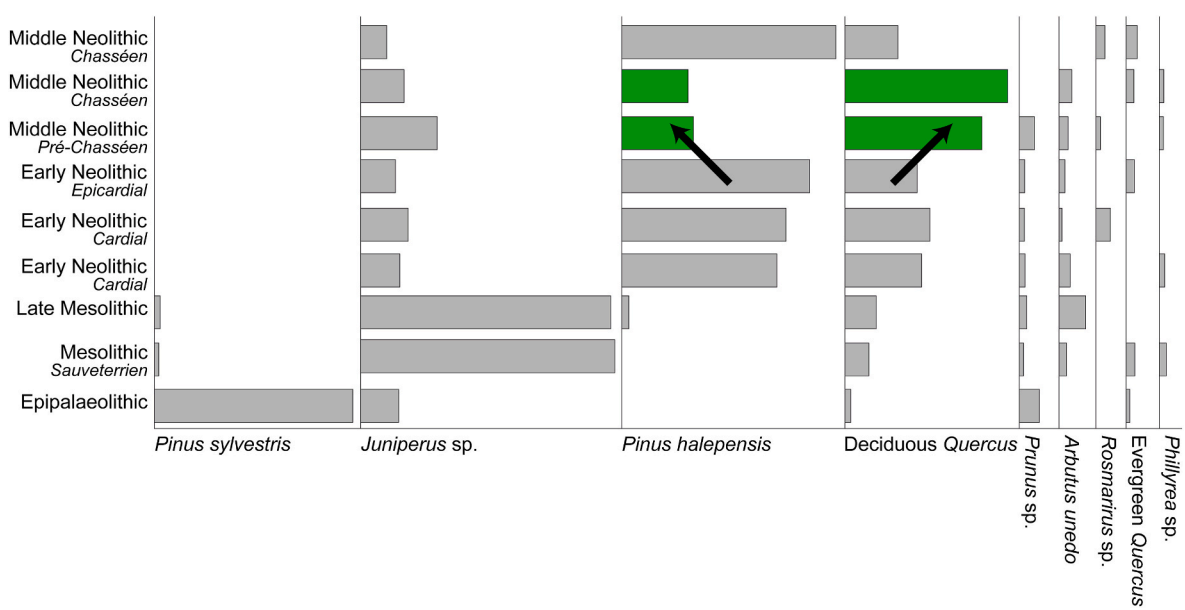

Fig. 3. Anthracological diagram of Fontbrégoua (main taxa) (Thiébault, 1997, 2005).
The increase of deciduous oak to the detriment of Aleppo pine (green bars) is interpreted as the evidence of the use of oak branches as fodder by the shepherds during part of the middle Neolithic.

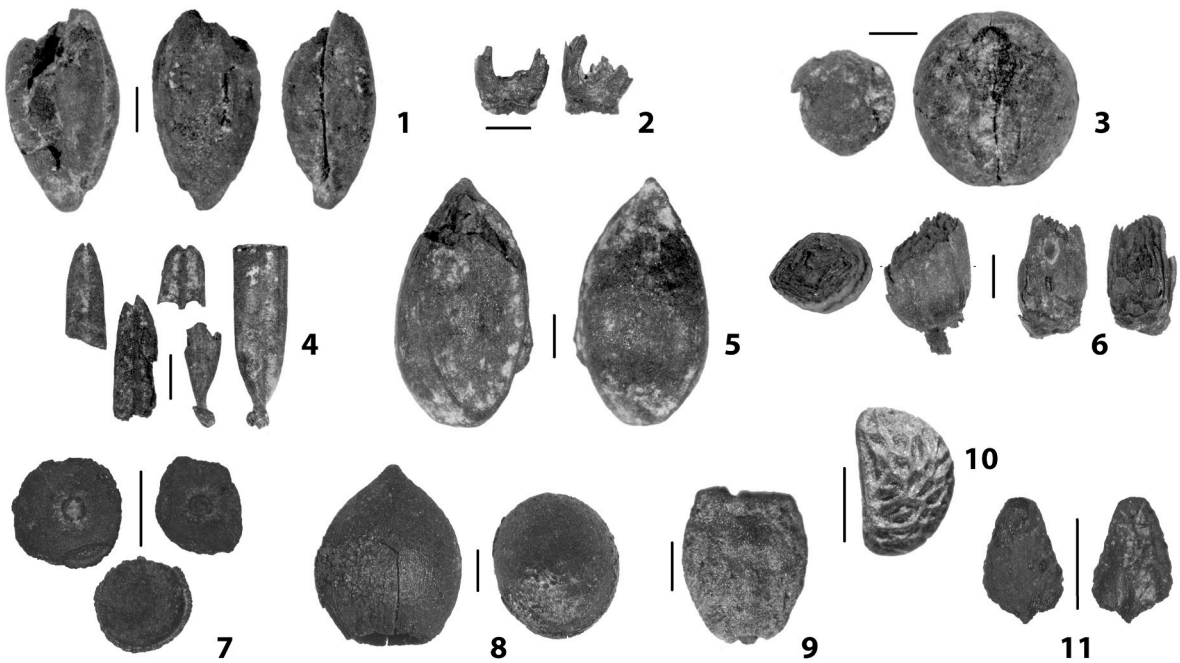

Fig. 4. Plant macroremains found in dung levels. Pertus II: 1. Caryopsis of einkorn (*Triticum monococcum*); 2. Spikelet base of einkorn; 3. Seeds of lentil (*Lens culinaris*) and pea (*Pisum sativum*); 4. Needle fragments of fir (*Abies alba*); 5. Apple seed (*Malus sylvestris*); 6. Oak buds (*Quercus* sp.). La Grande Rivoire: 7. Oak galls (*Neuroterus quercusbaccarum*); 8. Seed of yew (*Taxus baccata*); 9. Seed of fly honeysuckle (*Lonicera xylosteum*); 10. Seed of raspberry (*Rubus idaeus*); 11. Fragment of fern sling (*Pteridium* sp.). Photos: L. Martin, P.-Y. Nicod. Scale: 1 mm.

botanical remains. These structures are generated by a parasite causing an outgrowth of the host plant's tissue. The galls found so far in sheepfold caves are deciduous oak leaf galls due to the laying of wasps of the genus *Neuroterus* (Hayward and Stone, 2005). Plant macroremains, scattered throughout the dung layers, reflect both the feeding of livestock in the form of tree fodder and litter. Fir needles, for example, are very common at several sites such as La Grande Rivoire, Les Balmes or Pertus II (Martin, 2014). The presence of cultivated plant remains in some sheepfolds raises the question of their use and origin. These remains, undoubtedly brought by humans, are found mainly in the form of cereal caryopses, threshing residues and legume seeds. Wheat, barley, lentils or peas might have composed the meals of the shepherds, but they are also traditionally used as food supplements for lambs and/or lactating ewes (Delhon et al., 2008; Martin, 2011). While cultivated plant remains are scarce in La Grande Rivoire or Els Trocs (Antolín et al., 2018), for example, they may be diverse and abundant in several other sheepfolds (Les Balmes, Pertus II, El Mirador), representing several stages of processing (grains, chaff), suggesting that even very typical pen sites may also have been involved in agricultural activities (Martin, 2014). Ruderal plants are generally numerous, which is related to the presence of herbivores.

3.1.6. Phytoliths

Phytoliths are abundant in faeces of herbivores and thus in dung layers, where they are very well preserved. The significant presence of multi-celled phytoliths (or silica skeletons) can be used as a marker of dung or litter accumulation (Cabanes et al., 2009; Portillo et al., 2014); together with high amounts of spherulites, a general abundance of grass phytoliths and the macroscopic characteristics of sedimentary sequences, they are good indicators of stabling (Delhon et al., 2020).

In caves that were used as sheepfolds, phytolith spectra from fossil dung are directly related to the alimentation of livestock, either the fodder brought by shepherds or the stomach contents of animals returning from pasturelands, mixed with the remains of bedding and, possibly but to a much lesser extent, plants collected for other purposes. They usually mostly consist of grass phytoliths, as the production of opal particles is much lower in all other temperate plant groups, and especially in dicotyledons (Tsartsidou et al., 2007). Moreover, wood ash does not contribute significantly to phytoliths assemblages, as dicot phytoliths seem to be concentrated mainly in leaves and other green parts in temperate taxa (Delhon, 2010). Therefore, even a moderate amount of dicotyledons phytoliths may indicate the use of leafy branches as fodder (Fig. 5) (Delhon et al., 2008; Dunseth et al., 2019). In contrast, the use of grasses collected by shepherds, stored and distributed to livestock as needed, is more difficult to detect, as their phytolith footprint would be essentially similar to that which is expected from free grazing. Dental calculus and tooth surface also seem promising traps for diet markers, such as phytoliths but also starch grain or wear marks (Weber and Price, 2016; Mainand, 1998; Jiménez-Manchón et al., 2020). Plant microremains are unfortunately often rare on the teeth and of low taxonomic value, and their representativeness of the whole diet is discussed (Power et al., 2021), but experimental data and methodological improvements could make them very useful in the future.

Phytoliths provide little taxonomic information (ICPT, 2019) and are not accurate indicators of the use of specific plants for livestock care or food supplementation. Nevertheless, grass phytoliths allow the identification of Poaceae subfamilies (Twiss et al., 1969; Twiss, 1992), which may be critical for tracing the introduction of new plants into shepherds or livestock diets, or may provide ecological information that has implications for seasonality of activity, for example (Delhon et al., 2020). Under certain conditions, cereals can be recognized and sometimes identified at the genus level (Shillito, 2013 and references therein). In addition, analysis of grass phytoliths allows the identification of plant parts and thus the assessment of straw versus inflorescences ratios (Regev et al., 2015), which may be indicative of local agriculture or cereal processing (Delhon et al., 2020), or feeding of livestock with grain by-products (Dunseth et al., 2019), and/or may be a seasonal marker (Berna and Goldberg, 2007; Cabanes et al., 2010; Portillo et al., 2010; Portillo and Albert, 2011; Lancelotti et al., 2014; Shahack-Gross et al., 2014; Alonso-Eguíluz et al., 2017; Esteban et al., 2017), although this last aspect deserves further investigation (Burguet-Coca et al., 2020). Silicification of grass cells depends on the phenological state of the

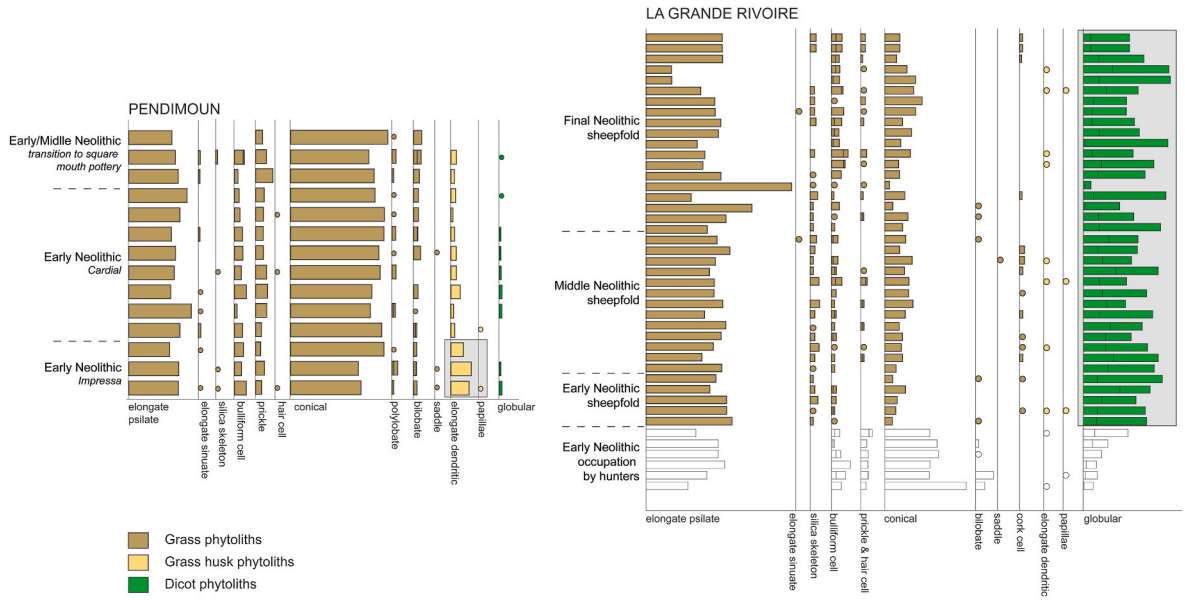

Fig. 5. Phytoliths diagrams of Pendimoun (Delhon et al., 2020) and La Grande Rivoire (Delhon et al., 2008 and in prep.). Grey boxes: The relatively high amounts of husk phytoliths (yellow) in the Impressa levels of Pendimoun indicate *in situ* processing of cereals; the abundancy of dicot phytoliths (green) *vs.* grass phytoliths (brown and yellow) is a good indicator of the use of tree fodder at la Grande Rivoire.

plant: while short cells ("GSSCP", ICPT, 2019) are impregnated with silica as soon as they form (Sangster, 1970), silicification of long cells occurs gradually and increases with age until tissue senescence (Rencheng et al., 2017). Thus, the ratio of short cells to long cells may provide seasonal information.

Recent excavations at pastoral sites often include specific sampling for phytolith analyses, but such data are generally lacking for previously studied sites on which landscape exploitation patterns are based.

3.1.7. *Paleoparasitology*

Identification of parasites in ancient contexts is possible through observation of macroremains, dissemination and reproduction forms (recovered by microstraining or filtration of the sediment: Le Bailly et al., 2017) and biomolecules (Le Bailly et al., 2021). The presence, abundance, and diversity of parasites can provide information on the health condition of the herd, but also on the intensity of pastoral activities. Pastureland ecosystems can be documented by parasites whose cycle includes intermediate hosts (Tejedor-Rodríguez et al., 2021). So far, palaeoparasitological analyses of Neolithic pastoral sites in Europe have mainly concerned lake dwellings (Kühn et al., 2013; Maicher et al., 2017); Mediterranean sheepfold caves remain poorly studied. To our knowledge, the only published study is Els Trocs (Tejedor-Rodríguez et al., 2021); at La Grande Rivoire and La Baume d'Oulen, parasite remains proved not to be preserved (Le Bailly and Bouchet, 2009; Hoffmann, 2019). Biomolecular detection of parasites could be a way to overcome preservation issues (Jaeger and Iñiguez, 2014), but it has not been tested in Mediterranean sheepfold caves.

3.2. *Innovative approaches using amorphous or invisible remains: histology, microbiology, analytical chemistry, isotope analysis*

3.2.1. *Histology: wood and teeth*

In addition to the classical - mainly taxonomic - studies of macroremains, approaches based on histological markers related to the growth of plant and animal tissues are developing. As for charcoal, wood anatomy can be used to infer habits and growth patterns of trees to document pollarding and, more broadly, forest management, using tools such as anthraco-typology (Dufraisse and Coubray, 2018). Tree pollarding is documented in wood anatomy in the form of small or abnormal rings (Fig. 6). The former corresponds to an early growth arrest due to leaf removal and the latter to a weak growth recovery when the tree is able to regenerate leaves before the end of the growing season (Thiébault, 2006). Unfortunately, such wood anatomical analysis is rarely possible, partly because charcoal fragments are often too small. Moreover, at the current state of the art, only a few species among the ring-porous species can be studied using anthraco-typology, which explains why it is not widely used in Mediterranean and mountainous contexts. Nevertheless, the abundance of very small twigs (few millimeters in diameter/few annual rings) in charcoal assemblages is another reliable and quite common indicator of foliage harvesting (Rasmussen, 1990; Delhon et al., 2008).

As for animal remains, recent improvements in cementochronology allow determining not only the age but also the season of death of animals (Naji et al., 2015; Naji and Rendu, 2022). It consists in the interpretation of the seasonal growth pattern of the dental cementum. So far,

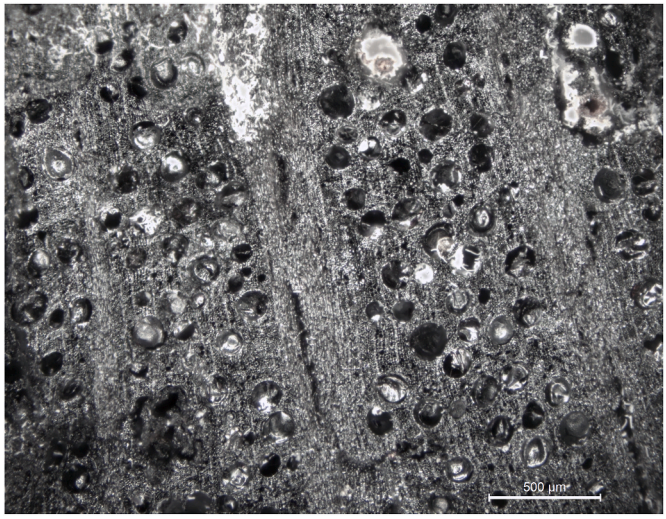

Fig. 6. Oak (deciduous *Quercus*) charcoal from Neolithic dung layers of La Grande Rivoire showing very narrow and abnormal rings due to repeated pollarding (the radial width of the fragment is about 2.3 mm).

cementochronological analyses have been applied mainly to wild animals from Palaeolithic sites to reconstruct hunting strategies and seasonality of prehistoric occupations (Roussel et al., 2021; Livraghi et al., 2022; Rendu et al., 2022). Studies on livestock management and seasonality during the Neolithic in southern France using this technique are in progress (Gourichon, perso. comm. and *cf*. Naji et al., 2022).

3.2.2. Analytical chemistry

Analytical chemistry methods can be efficient to detect various biomolecules from very different contexts. In sheepfold caves, they aim to document the use of animal products, and in particular the processing of dairy, through the analysis of ceramic content (Debono Spiteri et al., 2016; Drieu et al., 2021). In a more geochemical approach, molecular markers of faecal origin can be tracked in the sediment and especially in dung layers to prove its coprogenic nature if needed and to identify the animals that were kept in the cave (Gea et al., 2017; Vallejo et al., 2022; Shillito, 2013). Recently, at El Mirador, it has been demonstrated that the identification and quantification of steroid hormones in dung sediments make it possible to track the gathering of pregnant or recently lambed ewes in a cave or part of a cave (Vallejo et al., 2022).

3.2.3. Biomolecular analysis

In addition to documenting human migrations and interactions between prehistoric populations (Renfrew and Boyle, 2000; Rivollat et al., 2020), mitochondrial and nuclear DNA analyses provide an increasing wealth of information about pastoral systems. The complex processes of selection, importation, and interbreeding leading to local livestock breeds is becoming better documented and understood (Bruford et al., 2003; Frantz et al., 2019). In caves and shelters from the study area, plant remains are most of the time charred, which is detrimental to DNA preservation (Brown et al., 2015; Nistelberger et al., 2016), but other biomolecules such as lipids are promising. Lipid analysis and palaeolipidomics are improving rapidly (Drieu et al., 2022), but they currently focus on molecules trapped in ceramics and thus on human's food and cooking (Drieu et al., 2021) or on lake sediment (Jacob et al., 2008). Beside direct extraction of DNA from biological remains (bones, plant remains if available), metabarcoding of sediment DNA appears promising for characterizing herds kept in caves. However, the method, which has been used efficiently in lake sediments (Giguet-Covex et al., 2014), still needs to overcome some methodological and taphonomic difficulties specific to the context of sheepfold caves. In addition to the increasing recourse to genetics and genomics, an improvement in the taxonomic determination of altered or fragmented bones can be expected through a better accessibility of proteomic analyses. Dental calculus could also be the support of future genomics and proteomics works on animal microbiome and allow tracing ancient pathogens (Ozga and Ottoni, 2021), but concerning domestic herbivores all the work remains to be done.

3.2.4. Isotope analyses

The scope and interpretation of the most common stable isotope analyses based on bioarchaeological remains (plants, animals) from pastoral sites has expanded in recent years. They allow paleoecological reconstructions of the landscape around the site ($\delta^{13}C$: water availability, close/open environments) and can document differences between areas where wild herbivores and livestock fed (Navarrete et al., 2017; Villalba-Mouco et al., 2018). Agricultural practices, such as irrigation ($\delta^{13}C$) and manuring ($\delta^{15}N$) of fields (Bogaard et al., 2007; Gavériaux et al., 2022), or pastoral practices, such as feeding ($\delta^{13}C$, Bogaard et al., 2013), can be examined. Sequential analysis of herbivore tooth enamel allows us to achieve a seasonal resolution and investigate the seasonality of lamb birth. It thus gives access to an important aspect of herd management by shepherds that depends on intended pastoral productions and is related to herd mobility (Tornero et al., 2018, 2020; Martín et al., 2021; Tejedor-Rodríguez et al., 2021). The movements of flocks or shepherds could also be investigated using isotopic strontium analysis ($^{87}Sr/^{86}Sr$ ratio) of bones and teeth (Meiggs, 2007; Makarewicz, 2018); the origin of the individuals (animals or human), through the exposure of their food to marine influences, is recorded by sulphur isotope ratio ($^{34}S/^{32}S$) (Zazzo et al., 2011). So far, for the Neolithic in southern France, strontium and sulphur data is available only for human burials, which allow the sampling of teeth and bones from the same individuals (Goude et al., 2012). The development of such analyses on caprine remains would be valuable and is expected in the near future. Moreover, it is interesting to note that isotope studies based on human remains often include - when available - few samples of animal bones from the same site as reference or comparison materiel. These results, currently scattered, constitute a dataset that could be mobilized for preliminary regional syntheses.

4. Forty years of evidence and questions about Neolithic herders and pastoral systems

After forty years of research, data have accumulated, hypotheses have been formulated, some have been abandoned, and others have emerged thanks to the introduction of new methods or fruitful discussions between disciplines. As archaeobotanists who were early contributors to this field, the authors propose here a progress report on how the bioarchaeology of sheepfold caves, dung accumulations and pastoral occupations has so far answered the anthropological and ecological questions raised by the development of pastoral systems in southern France and adjacent regions during the Neolithic, and what one can expect from ongoing and future research.

4.1. Archaeobotany and pastoral practices

4.1.1. Pastoral use of wild plant resources: fodder, bedding, care, and hygiene

4.1.1.1. Tree fodder and food supplementation. Decidual teeth mainly fall out during chewing, thus their presence is an indication that the animals are being fed inside the sheepfold, despite rumination may have the same result. Therefore, the use of green fodder (collected when needed for an immediate use) or dry fodder (from a previously established flock) by neolithic shepherds could be a widespread practice. It is mandatory if the herd is kept indoors for a period of time, but if the animals are taken to graze frequently the feed may not be essential. In any case, it can be used to compensate for seasonal feed shortages, to supplement individuals with special needs (pregnant or lactating ewes), to maintain adequate weight for reproduction or prior to important travel or simply to keep animals occupied and calm (Battentier et al., 2016). Feeding livestock with leafy branches was first proposed by anthracologists, who were among the first bioarchaeologists to examine a series of sheepfolds. As early as the 1980s, the overrepresentation of few deciduous taxa in pastoral occupation of several caves put some of us on the leaf-feeding trail (Thiébault, 1988, 1997, 2001, 2005; Argant et al., 1991; Nisbet, 1997; Laederich and Thiébault, 2004). Unusually high proportions of ash, deciduous oak, hazel or maple were often associated with the decline of species that are known to be abundant in the surrounding vegetation but less attractive or palatable to livestock (pine, evergreen oak, yew). Sometimes the abundance of twigs or very small branches in charcoal assemblages confirms that wood was not collected primarily for fuel or for infrastructure construction in the cave, and narrow and/or abnormal wood rings provide evidence of frequent pollarding of specific taxa (Delhon et al., 2008; Euba et al., 2016). Other elements have subsequently supported this hypothesis. First, the presence of stomata in the palynofacies (Delhon et al., 2008; Expósito and Burjachs, 2016) confirms the presence of leaves on the branches, and clustered pollen may also indicate the intentional gathering of flowers. At La Grande Rivoire, hazel catkins, which appear very early in the spring, seem to have been a valuable resource during the season when

deciduous vegetation is not yet in leaf. Lime tree was also blooming when it was harvested, but since both leaves and flowers are present at the same time we have no way of knowing which were more desirable (Delhon et al., 2008). Charred hardwood leaves are rarely preserved at archaeological sites. However, buds from various deciduous trees and oak leaf galls have been identified, particularly at La Grande Rivoire (Martin, 2014) and Pertus II (Martin et al., 2021). The abundance of phytoliths of dicotyledonous plants in dung layers suggests that these plants were ingested by the animals. In addition, the existence of leaf feeding in the Neolithic has recently been confirmed by a "canopy effect" demonstrated by sequential isotopic analyses of sheep teeth. At Le Taï and Gazel, some $\delta^{13}C$ values corresponding to the winter period (determined by $\delta^{18}O$) fall within the range of what would be expected if forest resources contributed substantially to the diet (Tornero et al., 2020).

Today, the ability of Neolithic pastoralists to use tree forage is no longer a matter of debate. It has been proved in many sites, on the basis of various proxies. In addition to the southern France sheepfolds, it has also been documented in Spain (Euba et al., 2016; Rodríguez et al., 2016), in the Paris Basin (Balasse et al., 2012) and in lake dwellings around the Alps (e.g. Akeret et al., 1999; Favre and Jacomet, 1998; Haas et al., 1998; Rasmussen, 1993). However, the reasons for the use of tree food are not really understood so far. Indeed, it is not a generalized practice, and at some sites, as Pendimoun, there is no trace of it (Battentier et al., 2015; Delhon et al., 2020). At high elevation sites, tree forage may have been used to feed the herd during seasons when pastures were still covered with snow or before grass or leaves were growing. In this regard, hazel catkins available since the end of winter could compensate for the lack of green plant parts. In sites located in the Mediterranean belt and surrounded by mostly evergreen vegetation, tree fodder more likely served as food supplement. However, so far, whenever the season of tree feeding could be determined by sequential isotopic analyses, it turned out to be winter (Tornero et al., 2020; Martín et al., 2021). The extent of leafy branch use and the geographic distribution of sites with or without leaf fodder should be better assessed to understand the mechanisms at the origin of this practice. The current distribution of evidence may be affected by overestimation of tree fodder use in some contexts/by some researchers and underestimation in other contexts/by other researchers. Multiproxy evidence appears to be the most reliable to date. In addition, the absence of leaf fodder may be due to either the complete absence of foddering or the use of other types of fodder (grasses, crop by-products or other herbaceous plants) that is more difficult to prove. Finally, if it is obvious that the flock was fed with branches, the direct use of freshly collected plants is not easily distinguished from the use of a previously constituted stock of dry fodder. Determination of the food calendar (especially through sequential isotope data) would be of great help in demonstrating the use of particular type of food during a season when it does not match available resources, suggesting the use of dry fodder, as in Gazel and Le Taï (Tornero et al., 2020). Until these points are clarified in a sufficient number of sites, it remains difficult to discuss the reasons - technical, economic, environmental or cultural - for using tree fodder. What seems certain, however, is the amount of labor and organization dedicated to tree pollarding (Halstead, 1998; Tornero et al., 2020) and its impact on landscapes (Rasmussen, 1990; Laederich and Thiébault, 2004; Thiébault, 2006; Delhon et al., 2009; Euba et al., 2016).

Some species were probably not given to animals as regular food, but rather as food supplement or for medicinal purposes. In La Grande Rivoire, the recurrent presence of mistletoe bark (*Viscum album*) is remarkable and led us to think that it was a dietary supplement to promote milk production (Martin et al., 2011), as ethnographic data report the traditional use of mistletoe for its galactogenic properties (Lieutaghi, 2004). It could also have been a winter fodder, since it provides green leaves when those of deciduous trees are no longer available (Hejcman et al., 2014). In the same way, hazel catkins, which are highly nutritious, may be used as food supplements or to feed the flock when green plant parts are scarce (late winter/early spring).

4.1.1.2. Bedding and sanitary uses. Although leaves are not the most commonly preserved plant parts in archaeological contexts, a few species at various sites provided a large quantity of charred leaves or needles. Several thousand of fir needles (*Abies alba*) have been identified in the dung layers of La Grande Rivoire and Pertus II (Martin, 2010, Fig. 4). In Cova Colomera, the same is true for box (*Buxus sempervirens*) leaves (Bergadà and Oms, 2021). Fir may have been used as fodder, but it is unlikely for boxwood, which considered toxic or at least unpalatable and not normally consumed by livestock (Rousset and Lepart, 2002). The abundance of burned, uneaten leaves rather suggests that they were used as bedding for herds, especially considering that they are species whose leaves take a long time to wilt (Durand-Tullou, 1972). Fir stands were present near La Grande Rivoire and Pertus II, but the sites were not located in the heart of fir forests. The harvesting of large quantities of fir twigs seems to have been motivated by a particular use, which we refer to as the making of bedding. Interestingly, some sheepfolds from the Alps and the Pyrenees also provided important quantities of yew (*Taxus baccata*) remains. This conifer reached its maximal Holocene abundance during the Neolithic and the Bronze Age in these two mountain ranges (Martin and Thiébault, 2010; Uzquiano et al., 2015). Yew charcoal is often abundant specifically in caprine dung layers and becomes scarcer in strata associated with the rise of cattle breeding or non-pastoral activities (Antonnaire: Heinz, 1991; La Grande Rivoire: Delhon et al., 2008; Cova de la Guineu: Allué et al., 2009; Coufin 2: Martin and Thiébault, 2010). At least in La Grande Rivoire, many small yew twigs (a few millimeters in diameter) were found along with seeds and flower buds. The possible use of yew as fodder for small ruminants, despite its toxicity, has been discussed elsewhere and several archaeological and ethnographical examples have been described (Delhon et al., 2008; Farris and Filigheddu, 2008; Martin and Thiébault, 2010; Martin, 2014; Uzquiano et al., 2015). When considered harmless to an immunized flock, yew leafy branches and twigs can also be used for bedding because their insecticidal, fungicidal and antimicrobial properties (Daniewski et al., 1998; Erdemoglu and Sener, 2001) are beneficial for keeping the sheepfolds clean and sanitized. To a similar end, micromorphological and phytolithic data from Els Trocs suggest that wild grasses were scattered over a layer of hard material (pottery, bones, stones) to provide a dry and comfortable surface (Lancelotti et al., 2014). Charred macroremains of mosses and ferns found at La Grande Rivoire and Pertus II (Martin, 2014 and unpublished data; Fig. 4) could be linked to this use of plants as bedding. It could also explain the presence of Pteridophyte spores in palynofacies from pastoral sites (Argant, 2001).

The use of wood as fuel obviously explains the large amount of charcoal at the sites. The hearths are usually located near or interspersed in dung layers and were fueled with wood from nearby forests. Nevertheless, not all of the charred wood seems to have been originally harvested for this purpose. The calibers indicate that they were often remnants of tree fodder that were either used secondarily for fire making or burned with the dung and bedding accumulation (Brochier et al., 1992; Brochier, 2002). Heaps of branches could also have served to set fire to the dung when leaving the site to clean the place for the next visit. The selection of particular species for this purpose based on their burning behavior or chemical properties (yew?) deserves further questioning.

4.1.2. Pastoral use of cultivated plants

Historical and ethnographical sources document the use of crops (cereals, pulses) as supplementary feed for the flock. For example, in Greece, suckling ewes eat a mixture of straw and barley during the winter (Chang, 1993); in the Alps, during the Middle Ages, oat was given to the lambs as a nutritional supplement (Dubuis, 1990, p. 192). The use of cultivated plants to feed or care for livestock is more difficult to detect on Neolithic pastoral sites, although cereals and legumes are present. On

the lake sites of the Swiss plateau, where winter stabling is attested, cereal remains were found in waterlogged caprine coprolites. This is a direct proof of cereals consumption, but wheat chaff is present in less than 10% of them (Kühn and Hadorn, 2004). In sheepfold caves, they are few indications that grains could have been brought in caves used exclusively as sheepfolds for any purpose other than feeding the shepherds. In La Grande Rivoire, cereals are present throughout the dung sequence, but in small quantities, and mainly under the form of caryopsis fragments (Delhon et al., 2008; Martin, 2014). At sites where agriculture appears to have been practiced in parallel with livestock farming, it is likely that at least the threshing residues were used as a food supplement or fodder, which is still very common nowadays (Cappers et al., 2016). At Pendimoun, cereals include emmer and einkorn chaff and are accompanied by glume phytoliths, showing that cereals were processed at the site and that their by-products were available to be given to the sheep or goats (Delhon et al., 2020; Binder et al., 2020). At Pertus II, cereals chaff – found also under the form of macroremains and phytoliths – could have been used to feed the flock, as well as pulses. Isotopic analyses are under progress to shed light of this kind of diet (Martin et al., 2021).

4.2. Pastoral mobility during the Neolithic: A renewed debate

4.2.1. Territorial appropriation

One of the aspects that bioarchaeology can address in a pastoral context concerns the appropriation of territory by the shepherds and their flocks and the place that pastoral sites occupy within that territory. According to J. Battentier (2018), the colonization of the entire altitudinal gradient up to the mountains by Neolithic pioneers, shortly after their arrival on the northern Mediterranean coast, may have been driven by the capacity of their herds to spontaneously invest these areas. Plant remains are good proxies to address the question of vertical or horizontal mobility. Whether people moved to find fodder resources or animals grazed outside their stabling areas, the plant remains found in the dung give us with an answer.

Since the Neolithic, the pastoral use of mountain pastures has continuously increased, with noticeable impacts on the vegetation at high altitudes. In the Southern French Alps and Pyrenees, pollen finds at elevation above 1600 m a.s.l. document periods of large landscape openings, grassland expansion, and pastoral markers rise, sometimes accompanied by soil erosion during the Middle/Late Neolithic, Bronze Age, and Medieval period (Southern Alps: Court-Picon et al., 2007; Py-Saragaglia et al., 2015; Pyrenees: Miras et al., 2007; Galop et al., 2013; Leigh et al., 2016).

Many sites used for pastoral purposes are located in mountainous areas, characterized by different vegetation belts (Theurillat et al., 1998). Thus, foraging in high-altitude areas is done for a specific purpose - for example, to search for and exploit a plant resource - during the season when these resources are accessible (Thiébault, 2005). Archaeobotanical data from several occupations in the northern French Alps indicate how Neolithic people took resources from different plant associations growing from the colline to the subalpine levels, contributing to the understanding of vertical mobility in the alpine region (Martin et al., 2019). In sheepfolds, as La Grande Rivoire or Pertus II, harvested plants include woody plants accessible in the immediate vicinity of the site (hazel, lime, fir, or oak), but also plants from higher elevations (bearberry, juniper, spruce), testifying to the mobility of shepherds and/or livestock (Delhon et al., 2008 and unpublished data).

In addition to vertical mobility, demonstrated by the fact that populations moved across several vegetation belts, the presence of cultivated plants, sometimes in large quantities (linked with the durability of occupation), reflects extensive use of the space around the sites. In the Alps and Pre-Alps, the caves and shelters used in particular as sheepfolds have all yielded cultivated plants, in particular cereals. At several sites, such as Pendimoun, Pertus II and Baume de Ronze, they are evidences that cereals were grown and/or processed in the vicinity of the site. In Les Balmes, in the Haute-Maurienne, the presence of dung layers and of several cereal stocks, including einkorn (*Triticum monococcum*) suggests mixed occupation and cultivation around the sheepfold, at 1350 m a.s.l. (Martin et al., 2019). Thus, we are dealing with populations of pastoralists who were also farmers, or at least closely connected with cereal production sites. Since the Neolithic, sheepfold caves, which are only part of a network of more or less specialized sites, testify to the appropriation of an extensive territory whose resources are known and exploited in a rational way, in connection with agricultural and pastoral calendars.

The archaeobotanical and archaeozoological data suggest that the system was based on a mixed agropastoral economy, and that some sites were probably inhabited in a more perennial basis than assumed. Within this system, the cultivation of crops, particularly cereals production, and pastoral practices in both lowland and upland areas allow us to better define the occupation of the territory. The bioarchaeological data show that Neolithic farmers had already managed to establish a complex agropastoral system, characterized by a range of sites occupied for different functions and for different lengths of time, even at high altitudes. Local agriculture and long-term subsistence strategies (especially storage) existed at several mountain sites (Antolín et al., 2018; Martin et al., 2019), indicating that altitude was not necessarily a barrier to permanent settlement or agricultural activities.

4.2.2. Pastoral mobility and seasonality

In such a network of sites, mobility is a key issue for understanding many aspects of the whole system, and in particular the pastoral routes, but, until recently, it has only been documented indirectly or by questionable markers. As for the seasonality of the occupations, the possibility of plant storage makes it difficult to use phenological criteria such as the occurrence of pollen, fruits, seeds or galls. Nevertheless, some clues seem to be quite reliable, such as the use of hazel catkins for feeding animals or phytoliths and pollen data showing that herds grazed plants that were only available in spring or summer (Argant et al., 1991; Lancelotti et al., 2014; Delhon et al., 2020). However, in addition to the caprine culling profiles, the recent development of sequential isotopic analyses of teeth provides an important tool for tracing the seasonal movements of herds between pastures and lowlands since the Early Neolithic.

Caves and shelters are characterized by an abundance of remains of young and very young caprines (0–2 months), whereas this class is absent from open-air sites (Helmer et al., 2005). Thus, sheepfold caves appear to be the most important, if not the only, place for lambing (and consumption of lambs), as the newborns do not tolerate long movements (ibid.). Culling patterns also indicate milk production, but the molecules characteristic of dairy products are not always identified in the associated ceramics (Drieu et al., 2021). On open-air sites, the archaeozoological assemblage is first dominated by 6-month to 1-year animals, slaughtered for meat. Considering that lambing occurs in spring, these data suggest that caves were frequented in spring and summer, and that flocks returned to the lowlands the rest of the year. Indeed, the seasonal indications given by the botanical markers also points to these periods, but autumn and winter seem more difficult to identify in this way. Moreover, the culling profile suggests that some sites were summering sites (e.g. Grotte Lombard or Combe Obscure during final Neolithic), while others were long-lived or even annual sites (e.g. Baume d'Oulen, Le Vieux Mounoï and Combe Obscure during Early and Middle Neolithic). Nevertheless, $\delta^{18}O$ enamel data have recently demonstrated a seasonal shift in sheep lambing, with a proportion of births occurring in autumn (Tornero et al., 2020), which could change our vision of a calendar based only on age-at-death.

A generalized recourse to sequential isotopic analysis will allow a better understanding of the pastoral schedule. The best documented area so far is on both sides of the Ebro basin, in Iberia, in the Eastern Pyrenees and the Pre-Pyrenees. In the cave of Els Trocs (1464 m a.s.l.) in the Central Pyrenees, the double $\delta^{18}O/\delta^{13}C$ curves obtained from several

teeth, including M2 and M3 of the same individuals, provide direct evidence both for the regular practice of high-altitude movement of sheep flocks and for the extended breeding season of sheep (Tejedor-Rodrıguez et al., 2021). The authors consider that these seasonal movements must have required a considerable effort of community organization, based on the existence of individuals or groups of specialized herders within the first mixed farming communities of the Pre-Pyrenean lowlands, developing social and economic interactions within and between the small communities. In contrast, there is no isotopic evidence of mobility toward the highlands in the El Mirador and Chaves caves (600 and 663 m a.s.l.) although, as in Els Trocs, they document "out of-season" lambing (Sierra et al., 2021; Martín et al., 2021). In both cases, the sheep would have grazed near the cave for most of the year, and would probably have been fed with foliage in winter. The Early Neolithic levels of Gazel (275 m a.s.l.) and Le Taï (54 m a.s.l.) in southern France provided similar indications: evidence of lambing in autumn, lack of seasonal movements, grazing near the site and use of tree fodder (Tornero et al., 2020). Nevertheless, these two low-altitude dwelling sites are not sheepfold-caves. Le Taï presents a permanent farmer's occupation, with signs of agriculture (pits, archaeobotanical assemblage) together with domestic animals that were not kept in the cave (Bouby et al., 2019). The functional status of Gazel cave remains uncertain (Tornero et al., 2020). In northern Italy, data indicate that part of the Early Neolithic sheep flock from Arene Candide may have grazed on higher areas during the summer months, but alternative explanations for the isotopic signal are not excluded (foddering, access to different water sources) (Varkuleviciute et al., 2021). On a larger scope, the coincidence of high $\delta^{18}O$ values with low $\delta^{13}C$ values in tooth enamel, indicating ingestion of ^{13}C depleted plants during the summer season, has been noted at Neolithic and Chalcolithic sites from the South Caucasus (Hirose et al., 2021), the Jordan Valley and Anatolia (Makarewicz, 2017).

Finally, the results of isotope analyses currently provide the most serious arguments to prove the existence of seasonal movements of sheep as early as the Neolithic period. Evidence of lambing in spring and autumn should also lead to considerations of differentiated flock management, depending on economic objectives (meat or milk production and/or to make dairy resources available over a longer period of the year) and/or to control the annual distribution of pastoral activities in order to better combine them with farm work (Balasse et al., 2017).

The extent of seasonal movements still needs to be determined more systematically in order to argue whether or not they can be called "transhumance", an often-debated question (Geddes, 1983; Nandris, 1990; Leveau and Walsh, 2005; Arnold and Greenfield, 2017; Antolín et al., 2018). For A. M. Brisebarre (2008), transhumance is a grazing practice in which herds move from one area to another that is ecologically different and complementary to the previous one, depending on the season. Pastoral movements detected by an opposite variation of $\delta^{13}C$ and $\delta^{18}O$ in tooth enamel fulfill both criteria: change in the browsed vegetation and seasonality. Nevertheless, in the current state of the data, neither the extent of these livestock movements (all or part of the herd, all herds or only some) nor the accompanying human movements are known, although the presence of small groups of specialized herders is commonly suspected. Thus, two other important aspects of what we now call transhumance are unknown to us: the size of the herds that are put on the road and the status of the transhumant herders (Rendu, 2006). As F. Antolín and his collaborators point out, terms such as pastoralism or transhumance could be anachronistic for the Neolithic periods. In the absence of clear definitions, they can be interpreted in different ways: "there is not one kind of pastoralism or one kind of transhumance" (Antolín et al., 2018). The understanding of past agro-pastoral systems would benefit from a detachment from preconceived notions, especially regarding the impossibility of a sedentary lifestyle and mixed agriculture economy in mountainous environments (ibid.). A few high-altitude sites seem to be inhospitable in winter (Els Trocs, Tune de la Varaime); at lower altitude, foddering may have made it possible to survive the bad season (La Grande Rivoire, Pertus II); under Mediterranean climate, sheepfolds can be involved in mixed farming economy (Pendimoun). However, we observe that altitude, foddering and agriculture are not sufficient to characterize permanent or seasonal occupations. Foddering is recorded on sites where winter food shortages are unlikely (Gazel, Le Taï), while more or less permanent activities such as crop husbandry are practiced in mountain sites (Les Balmes, Pertus II), and pastoral mobility is suspected on sites where environmental conditions seem rather welcoming all year round (Arene Candide).

4.2.3. *In the path of the Neolithic: pastoralism trajectories*

During the Neolithic, one of the main features of the pastoral system is the clear complementarity between caves and open-air sites. Caves appear as production sites with evidence of milk exploitation, while open-air sites represent meat consumption strategies leading to the slaughter of animals that have reached their optimal weight (6–12 months) (Helmer et al., 2005). During the Neolithic, several practices emerge that demonstrate the herders' zootechnical expertise and the planning of their activities and needs: herd composition and differential management (batching), foddering, control of breeding and lambing seasons, mobility, likely production and exchange of surpluses (tender meat, milk, pregnant ewes) (ibid.).

The exploitation of mountain pasturelands has continuously increased since the Neolithic, with noticeable impact on vegetation (deforestation) and soils (erosion) at high altitude. During the Bronze and Iron Ages, breeding practices became more diverse and specialization in specific productions, varying from site to site, became more evident. Morphometric analyses of bones show that local sheep and goat morphotypes emerged in Provence (Vuillien and Gourichon, 2019; Vuillien, 2020). The Crau plain, in the east of the Rhone delta, is an important historical land of pastoralism, nowadays emblematic of summer transhumance from the lowlands to alpine pastures. Archaeological evidence suggests that the area got specialized in pastoralism since at least the 1st century BCE, with a maximum of pastoral pressure in the 2nd century CE, when probably more than 100 000 sheep browsed in the plain. The oldest evidence from written sources for transhumant pastoralism dates from to the same period, but concerns only southern Italy. The establishment of a system of transhumance in the Crau close to the modern system is only attested by historical data from the 13th century CE onwards (Badan et al., 1995). Further east, summer transhumance from the villages of Nice hinterland and winter transhumance between the Alps and the lower Dauphiné, Isère and Provence are reported in archives only from the 12th century (Brisebarre, 2008).

Today, transhumance is mostly done by truck, but alpine shepherds often remain specialists, hired by the owners of the herds, whose seasonal activity must be completed in winter by other activities, in breeding, agriculture or tourism.

5. Conclusion

Since the 1980s when the existence of sites devoted entirely or mainly to pastoralism has been demonstrated, many hypotheses have been put forward and models proposed on the functioning of Neolithic pastoral systems in southern France. However, a review of the data shows that they are often supported by a rather limited amount of evidence. The development of innovative methods, particularly in the field of bioarchaeology, allows us to explore in detail zootechnical practices, revealing the skills and know-how of Neolithic herders and the organization of Neolithic farming communities. Unfortunately, only few sites are currently being excavated, and it is not always possible to study material from previously excavated caves and shelters, due to a lack of adequate sampling. Moreover, several promising approaches require specific and sometimes rare material – like certain teeth, for example, for sequential isotope analyses - and/or remains whose preservation is not guaranteed at all sites (DNA, parasites, pollen, dental cementum …). Bioarchaeological investigation of prehistoric pastoral systems is at the verge of major advances based on a renewal of data, or at least we have

the technical capability to do so. The various works currently in progress will have broad implications for the understanding of Neolithic economic and territorial systems, as well as for the history of agriculture and pastoralism. In the coming years, they could provide evidence that farmers have a strong expertise in many aspects of production systems since the earliest phases of the European Neolithic. It may then be possible to make comparisons with pastoral systems documented through similar approaches of pastoral caves and shelters that exist in other areas of the northern Mediterranean region (Karg, 1998; Boschian and Montagnari-Kokelj, 2000; Boschian and Miracle, 2007; Angelucci et al., 2009; Forenbaher, 2011; Migliavacca et al., 2015; García Atiénzar et al., 2021 …)

Author contributions

All three authors collected the data, wrote the manuscript and contributed to the ideas presented here.

Data availability

All the original references of the data discussed in this review are provided in Supplemental material S1.

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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Appendix A. Supplementary data

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