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The Mas del Pepet experimental programme for the study of prehistoric livestock practices: Preliminary data from dung burning

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ABSTRACT

The research for referential data on current livestock contexts is essential for correctly interpreting archaeological records documented in prehistoric livestock spaces. Experimental programmes such as the one begun in 2014 in the Mas del Pepet pen (Rojals, Tarragona) has permitted an understanding, among other matters, of fold characteristics according to the type of livestock, the seasonality of occupations and herd management. This study also contributes to the identification of taphonomic processes that have taken place and to determine the representativeness of the botanical content in the deposit, in relation to the environment and pasture areas. Finally, the dung burning experiments conducted have provided data that will help to reveal the way manure was treated in prehistoric fold caves.

1. Introduction

Archaeological sites related to livestock activities are a major source of information for the understanding of prehistoric societies. Several fold cave sites dated from between the Neolithic and Bronze Age in Europe are characterised by the periodic burning of manure in order to reduce its volume and to eliminate parasites (Brochier et al., 1992; Charles, 1998; Badal, 1999; Angelucci et al., 2009). This activity has been identified at numerous sites: Arene Candide in Italy (Maggi, 1997), Caune de Belesta; Grotte Antonnaire, in France (Argant et al., 1991; Brochier et al., 1998) and Cova de les Cendres (Badal, 1999), Los Husos (Alday-Ruiz et al., 2003), Cova Gran (Polo-Díaz et al., 2014), La Cova de la Guineu (Bergadà et al., 2005); El Mirón (Peña-Chocarro et al., 2005), and others on the Iberian Peninsula.

This practice led to a distinctive and complex series of stratigraphic deposits that are difficult to study due to the different actors and phenomena involved in their formation and also because of the dynamic nature of taphonomic processes. The characterisation of this sedimentological formation in animal enclosures is based on the identification of four criteria: presence of micro-lamination, dung spherulites, authigenic phosphate and some specific types of phytoliths (Shahack-Gross et al., 2003, 2005; Shahack-Gross, 2011).

Until now, the study of penning practices in prehistoric contexts has been approached by different disciplines with important implications for understanding the socio-economic practices of agro-pastoral groups (Shahack-Gross, 2011).

Generally, these kinds of accumulations are rich in archaeobotanical material because they were formed by the repeated burning of waste from different practices, including agriculture, livestock and domestic activities (Brochier et al., 1992; Canti, 1999; Vergès et al., 2008; Angelucci et al., 2009). Archaeobotany can therefore contribute to addressing topics such as: reconstructing past vegetation; determining the seasonality of the occupations;

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gaining knowledge of the existing plant resources; observing the use of domestic space, analyzing taphonomy and site formation processes; forest management; and the detection of the presence of domestic taxa linked to agriculture or to farming practices (Shahack-Gross et al., 2003, 2005; Albert and Henry, 2004; Albert et al., 2008; Allué et al., 2009; Cabanes et al., 2009; Portillo et al., 2009; Portillo and Albert, 2011; Lancelotti and Madella, 2012; Euba et al., 2016).

Soil micromorphology applied to fold caves has enabled some topics to be addressed, characterising the phases that make up a complete combustion cycle and providing information about the taphonomy and formation processes of these sequences (Bergadà, 1995, 2001; Macphail et al., 1997; Bergadà et al., 2005; Polo-Díaz and Fernández-Eraso, 2010; Polo-Díaz et al., 2014).

Several ethnoarchaeological studies have documented patterns which can be extrapolated to prehistoric contexts to compare and generate new hypotheses about pastoralism and folding spaces (Brochier, 1983; Shahack-Gross et al., 2003; Elliott et al., 2014; Portillo et al., 2014) and the use of dung as a by-product (Reddy, 1999; Silla, 2000; Zapata Peña et al., 2003).

Some experimental archaeological studies have examined specific issues (Macphail et al., 2004; Vergès, 2011; Schepers and Haaster, 2015). However, a systematic and comprehensive experimental programme dedicated to the study of the complexity of the multiple factors involved in pastoralism and animal enclosures has yet to be developed.

The study of livestock areas, in particular those managed differently from ones known in historical times, thus requires experimental reference data that can contribute to set out and contrast hypotheses and establish more precise interpretations for the archaeological context.

2. The Mas del Pepet experimental project

The Mas del Pepet experimental programme was set up in 2014, motivated by the need to obtain data to interpret prehistoric fold cave dynamics. The experimental program aims to characterise and interpret the formation processes and human activities related to livestock management and pen contexts (see below, Section 2.3).

One of the specific goals of the experimental program is related to the *in situ* burning of dung in pens. Up to now, some experiments involving the burning of dung heaps have been conducted and have provided data leading to the identification of some relevant variables related to the dung burning process (Vergès, 2011). However, it is necessary to address *in situ* burning to characterise the impact of combustion on the substrate where the burning event took place. In order to resolve this specific problematic, we present here the preliminary results from *in situ* dung combustion, including in the Mas del Pepet experimental program.

2.1. The Mas del Pepet pen

The area where the prehistoric livestock experimental program was carried out was in the Mas del Pepet pen, located in the village of Rojals, in the municipality of Montblanc (Tarragona, Catalonia) (Fig. 1). The Mas del Pepet pen is located on the left bank of the Mas d'en Llort cliff, at 880 m a.s.l. This was the old farmyard of the Pepet farmhouse, now in ruins, and recently refurbished to accommodate the flock of Pere Domenech. The enclosure is at the foot of the cliff wall. It encompasses areas with different conditions that allow much of the variability observed in the archaeological sites. Between these are two spaces that are enclosed by walls which prevent the lateral movement of manure and ensure that the surfaces remain flat and even. There is one covered area and one open-air area. The former prevents rain and other meteorological conditions from affecting the interior of the pen. In addition, there is a large space around the buildings that includes a sloping area that has been subjected to the phenomena of gravity erosion, and another flat area surrounded by a metal perimeter fence, where accumulation phenomena are commonplace.

2.2. Livestock and pasture areas

The Mas del Pepet herd consisted of 400 heads of livestock, made up of approximately 350 goats and 50 sheep (Fig. 2). The flock grazed in the eastern sector of the Natural Area of National Interest (PNIN) of Poblet (Tarragona, Catalonia), in order to control the undergrowth. This activity is part of a government forest-fire prevention plan. This involves traditional extensive grazing, with the herd accompanied by a shepherd who stays in the pen during the night. This practice of staying in the pen is seasonal and usually starts in April/May and lasts until October/November.

The vegetation of the area is open woodland of *Quercus ilex-coccifera* and *Quercus pubescens* that includes *Genista scorpius*, *Ulex parviflorus*, *Cistus albidus*, *Ruscus aculeatus*, *Smilax aspera*, *Euphorbia dendroides, Rubia peregrina*, *Brachypodium* sp., *Pinus* sp. and other characteristic species of sclerophyllous brush and grasses typical of Mediterranean mixed-oak forests.

2.3. The objectives of the Mas del Pepet experimental program

The experimental program has included a series of experiments intended to provide information on a wide range of variables for managing livestock and enclosures. It is a long-term project, promoted by the Institut Català de Paleoecologia Humana i Evolució Social (IPHES), with the support of the Natural Area of National Interest of Poblet as the managing body. Here we present the main research objectives that are addressed. Although they are described individually to facilitate the organisation of information, many of them actually overlap and experiments and analysis were shared.

The experimental project is currently in progress. Since 2014 we have developed annual experimental fieldwork sessions, during the period when the pen is abandoned. We are carrying out general sampling, including archaeobotany, micromorphology, archaeomagnetism and humidity samples, representative of before and after the *in situ* dung burning. Also, we are performing a number of experiments in relation to the analysis of spatial distribution, site formation processes and dung accumulation rates, inside the pen.

In this section we introduce the principal aims of the experimental project, for which we have, at present, only preliminary results concerning the *in situ* dung combustion.

2.3.1. Estimate of the rate of dung accumulation

Based on the volume of dung accumulated, we do not currently have reliable data to offer an estimate about the relationship between the number of livestock and the length of stay in the enclosure necessary to generate deposits similar to those documented in the archaeological sites. Our aim is therefore to study the rate of dung deposition in the pen according to the occupied area, the time span of the occupation and how many heads of livestock there were.

The documentation of the volume of excrement accumulated during the livestock's stay is carried out by comparing 3D models of the floor of the pen before the arrival of the flock and after its departure. The 3D models are generated from data captured with a FARO Focus 3D laser scanner. This procedure allows to obtain precise numerical data of the volumetric increase of the deposits over time. Based on the variable volume of waste, the number of livestock and the length of stay in the enclosure, an accurate picture of the amount of waste deposited by the animals daily in the pen can

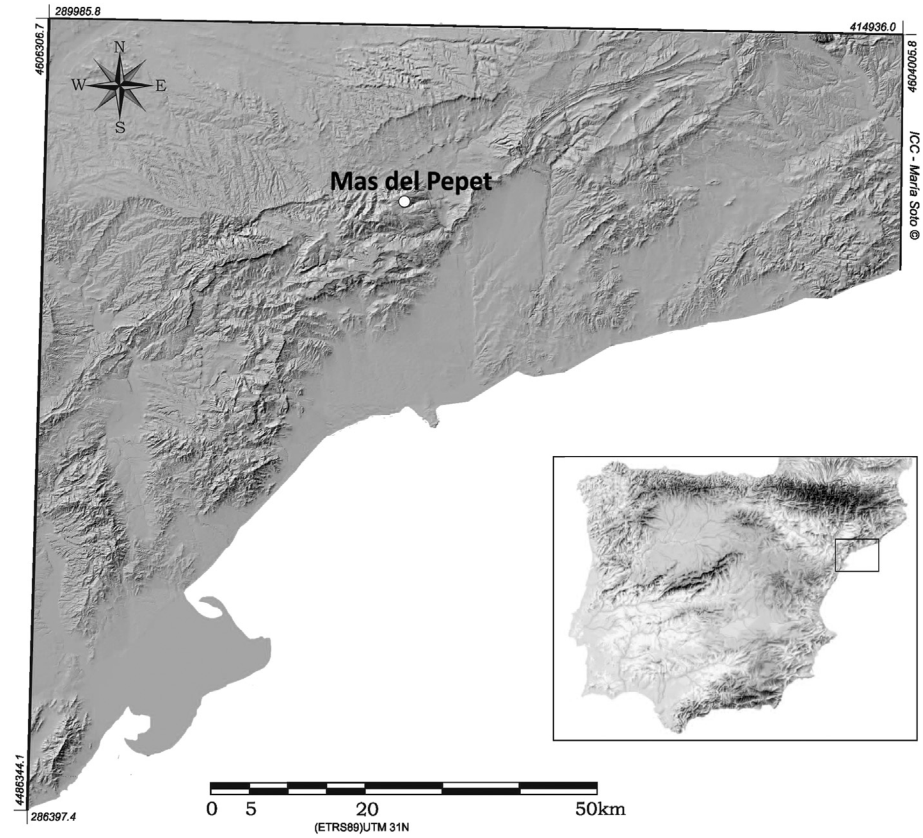

Fig. 1. Location map of the Mas del Pepet pen.

be made. Variables stemming from the type of livestock, plant environment as well as the weather, among others, are of course taken into account. All of these possibilities affected the deposition rate, and it is necessary to collect data from different years and places to capture process variability.

This procedure is also used for calculating the reduction in the volume of dung material by combustion. In addition, the aim is to develop dung distribution models according to the relief characteristics obtained from 3D data distribution. This allows us to estimate of the influence of topographical features in the accumulation rates of dung in the different sectors of the pen and to extrapolate the data to the archaeological sites. The Mas del Pepet pen is therefore perfectly adapted to this kind of work since it has several areas with different reliefs and slopes, thus allowing for the examination of a high degree of variability.

Fig. 2. The Mas del Pepet flock is formed by 350 goats and 50 sheep and the landscape of the Natural Area of National Interest (PNIN) of Poblet is typical of a Mediterranean mixed-oak forest.

2.3.2. The polished rock wall

The animals in contact with the walls of the pens (both the man-made and natural ones), caused the polishing of their surfaces (Brochier et al., 1992). Polished bands were distributed differently depending on the animal's physical features (height, fur type, etc.). Their distribution also varied according to whether or not the accumulated dung had been removed since this factor effectively modified the height of the animals.

This characterisation can help to identify the animal that produced the polishing in archaeological contexts and contribute to the understanding of manure management (Vergès and Morales, 2016) and the intensity of use of the site for livestock. This information is especially relevant in cases where the sedimentary deposit has disappeared, as it constitutes the only remaining evidence of the past use of this space as a fold.

To carry out this polishing study we placed rock fragments in different places in the pen. The surfaces of these fragments were previously documented with a 3D digital microscope (Hirox KH-8700). The evidence of the recurrent loss of the roughness of the surface of the rocks documented with 3D images provided information relating to the height of the polishing marks, the number of animals and the length of their stay in the pen.

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2.3.3. Study of plant remains

Palaeobotanical data obtained from the study of dung recovered from archaeological sites is used to develop paleoenvironmental reconstructions, estimates of the diet of the animals, characterisation of the type of livestock and identification of human activities related to the management of plant resources, among others (Bryant and Holloway, 1983; Greig, 1989; Argant et al., 1991; Diot, 1991; Badal, 1999; Thiébault, 2005; Shahack-Gross, 2011). It is thus essential to know how much of the surrounding vegetation is represented in the dung, in what proportions it is represented, and what were the agents contributing to its incorporation into the deposit. With these objectives in mind, we designed a pilot program that includes the following steps:

- Botanical inventory of the neighbouring areas and the pasture zones.
- Observation of the pollen rain in the area of the pen by installing artificial pollen traps and samples of natural traps (mosses).
- Elaborating reference collections of phytoliths for the most abundant taxa in the study area.
- Analyzing the pollen, NPPs (non-pollen palynomorphs), phytoliths and charcoal present in the dung deposits.

Once all of the relevant data has been obtained, the plant species present in the fold may be compared with those documented in the environment and the pasture areas. It is then possible to establish how many of the species present in the flock's area of influence are represented in the pen, and if the percentages observed are reliable or not. This data is of critical importance to determine the bias existing between the picture of the plant community from the botanical study of the deposits and the real composition of the local and regional vegetation. It also contributes to clarifying the role of the different agents involved in the formation of the dung accumulation (Fig. 3). More detailed paleoenvironmental interpretations can thus be carried out in order to identify, in a more reliable way, the behaviour of pastoralists on livestock management, food supply (from gathering or agriculture), among other issues.

On the other hand, the study of non-pollen palynomorphs (NPPs) allows us to evaluate the micro-environmental conditions during the dung accumulation, mainly from a local point of view. This includes: the existence of water accumulation zones, areas with presence of decaying organic matter, carbonaceous horizons, erosive episodes, etc. As a result, we found that, contrary to what was expected, the presence of these micro-remains was generally low in burnt prehistoric pens. The main hypothesis for this poor representation is that systematic burning evidenced in the archaeological recordings effectively reduced the accumulation of dung and cleaned the pens. The NPPs also provided data concerning the invertebrates, such as associated livestock parasites.

The work plan related to the study of phytoliths and other micro remains is based on the analysis of the dung deposits during all stages of the process: the prior plant consumption by the herd; faeces deposition; compaction/erosion; and the burning of accumulated debris. In addition to this, the presence of calcium-oxalate, formed in the aerial parts of a large number of plants in contexts of confinement, has been linked with a herd's diet when dicotyledonous leaves are provided as fodder or consumed during grazing (Brochier, 1983). In addition, the presence in these contexts of spherulites, calcium carbonates formed in the digestive tract of herbivores, was one of the main inorganic markers used to identify and characterise the pens (Canti, 1997, 1998, 1999).

Another aim of this approach is to monitor the taphonomic agents involved in the process and to address specific topics regarding the formation of the deposits. This study provides us with information about the representativeness of the results in relation to existing vegetation and the impact of different taphonomic agents, allowing us to establish criteria concerning the type

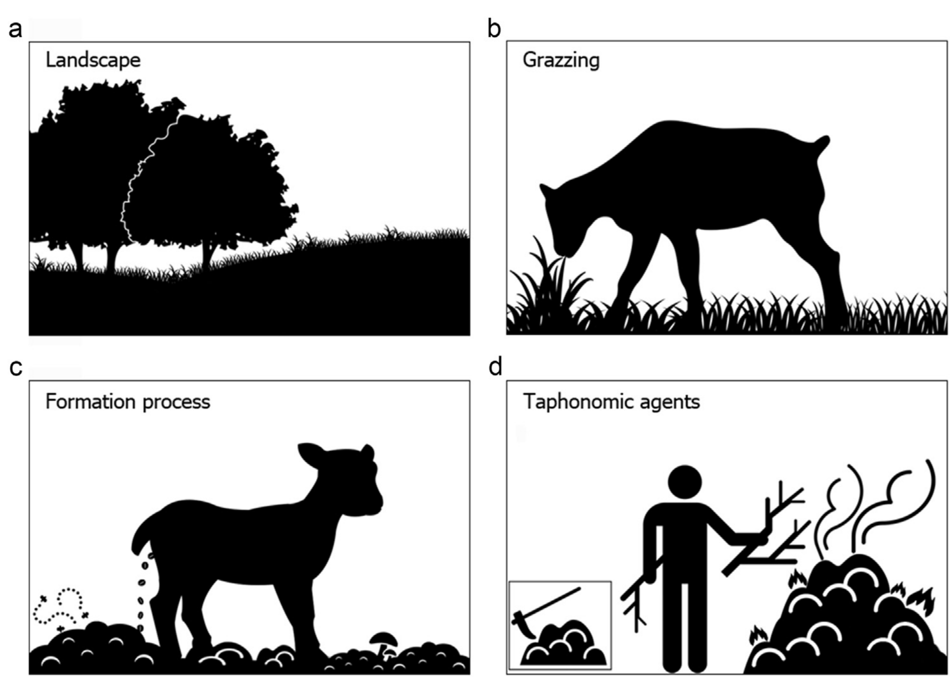

Fig. 3. Botanical diagram objectives. a) Study of the current landscape with pollen traps and botanical analysis. b) Documenting the plants consumed by the herd. Elaborating reference collections. c) Analysis of the dung deposits composition. d) Analysis and characterization of taphonomic agents and their impact on the botanical assemblage. Comparative study between the final botanical assemblage and the current landscape and the plant resources consumed by animals.

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of livestock from data about their diet (goats, sheep, etc.). Furthermore, it allows us to detect anthropogenic inputs of plant resources (provision of fodder, bedding for animals, etc.).

The study of plant macro-remains aims to explain the formation processes of these assemblages in archaeological contexts. In this context, mixed botanical materials from agricultural activities, fuel and fodder, as well as other materials such as building supplies or wood from domestic activities, are usually mixed in the heaps found (Argant et al., 1991; Zapata et al., 2003; Euba et al., Rodríguez et al., 2016). The study of plant macro-remains, including charcoal and seeds, helps us to gain an understanding of differences in the preservation of the materials, while an analysis of the dung content makes it possible to analyse the foddering process.

2.3.4. Micromorphological analysis

After seasonal period of use of the enclosure by the animals, we collect samples to obtain thin petrographic sections for the micromorphological analysis of the deposits. The samples are collected both from burnt areas and from areas unaffected by dung heaping and combustion. These experimental samples form a part of a reference collection elaborated to permit the identification and interpretation of micromorphological features from prehistoric herding facilities.

The thin section experimental material provides high-resolution parameters for the characterisation of three key aspects in the formation processes of archaeological pen deposits: surface crusts derived from subaerial exposure related to periods of abandonment of a pen; compaction, related to the action of livestock during their stay; and combustion residues, both *in situ* and disturbed.

2.3.5. Study of the dispersion of the material

Another problematic relating to archaeological pens is the spatial dispersion of the material, given the very dynamic context where the objects may have been displaced both horizontally and vertically. There are cases documented of archaeological contexts where it is clear that there has been translocation and mixing of objects, together with others where the material seems not to have been displaced.

To document the conditions for determining one or another of these situations, we periodically placed groups of objects in the pen after arrival the animals (mainly stone tools, pottery and skeletal remains). The objects are deposited on the surface, in various areas of the pen that present different topographic features.

The objects are attached to one or more fragments of metal plates (depending on the size and possibility of fracturing) and are numbered for easy identification and location. The elements that are covered and hidden by the animals can thus be located with the aid of a metal detector. Their three-dimensional position is recorded with a Total Station, at the time of abandonment and then monitored periodically: when the herd leaves the pen; before and after heaping and dung burning. The data on the movement of the objects allows us to identify the most likely context associated with the translocation patterns, including the mixing of materials or more stable contexts. In addition, the data collected allows us to evaluate the variability in the degree of displacement of the objects, while taking into account their physical characteristics. The results should help researchers to establish criteria to estimate the displacement suffered by the objects in archaeological sites.

2.3.6. Taphonomy

Thanks to various programmed experiments, we will obtain a wide range of objects well known in taphonomic processes. Once the experiments complete, these objects will become part of a reference collection that will be useful for interpreting the changes observed in archaeological materials (bone and botanical remains, ceramics, and stone remains).

To facilitate the identification and documentation of the modifications undergone by the objects, they are photographically documented and, in cases where changes are microscopic, with the aid of optical and electron microscopes, obtaining high resolution moulds and casts.

2.3.7. Archaeomagnetism

The magnetic properties present in the dung accumulation related to the increase in heat caused by combustion were analysed to understand their behaviour (Carrancho et al., 2016). This data is useful as a reference for studies that are being conducted on dung burning in prehistoric pens and that are aimed at obtaining data about geomagnetic secular variation, taphonomic alterations of ash deposits, and for determining the maximum temperatures reached (Carrancho et al., 2012, 2013).

3. The dung combustion experiment

The practice of burning dung heaps in prehistoric pens located in rock shelters or caves has been widely documented, and is one of the most characteristic features of this type of sedimentary deposit. However, there is no experimental data available to help us to interpret the phenomena observed in archaeological records. Some studies have been done, but they have been conducted by burning dung away from the pens which does not allow to document the role of the substrate in the development of combustion (Vergès, 2011).

One of the main goals of this experiment was to document the thermal curve of dung burning and to relate the temperatures reached to the colour range of the ashes. The aim was to observe how some of the variables, such as humidity and dung shape (already observed experimentally in previous approaches outside a pen), affected the combustion process. Most of these variables determined the development of the combustion. This is the case for dung conservation, the shape of the excrements and the degree of moisture (Vergès, 2011). The aim was thus to define under what conditions the combustion was limited to the piled-up dung, the most common situation in archaeological records, and at what moment the fire spread to the substrate, causing total or partial burning of the remaining deposits.

Another highly relevant aspect was the testing of hypotheses regarding the necessary conditions that ensured the preservation of the ashes once the flock occupied the space again. So, if

Fig. 4. Incinerating process of the heaps during the 2014 experimental field season.

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accumulations of ash were affected by the transit of livestock we documented the changes and modifications suffered and their evolution. The objective was to obtain data to establish the time span between the occupation and the abandonment of the pen and identify related livestock management practices.

4. Materials and methods

To carry out the experiment we used different procedures and technical equipment that will be described in the following paragraphs. Prior to the heaping process, the surface was scanned using

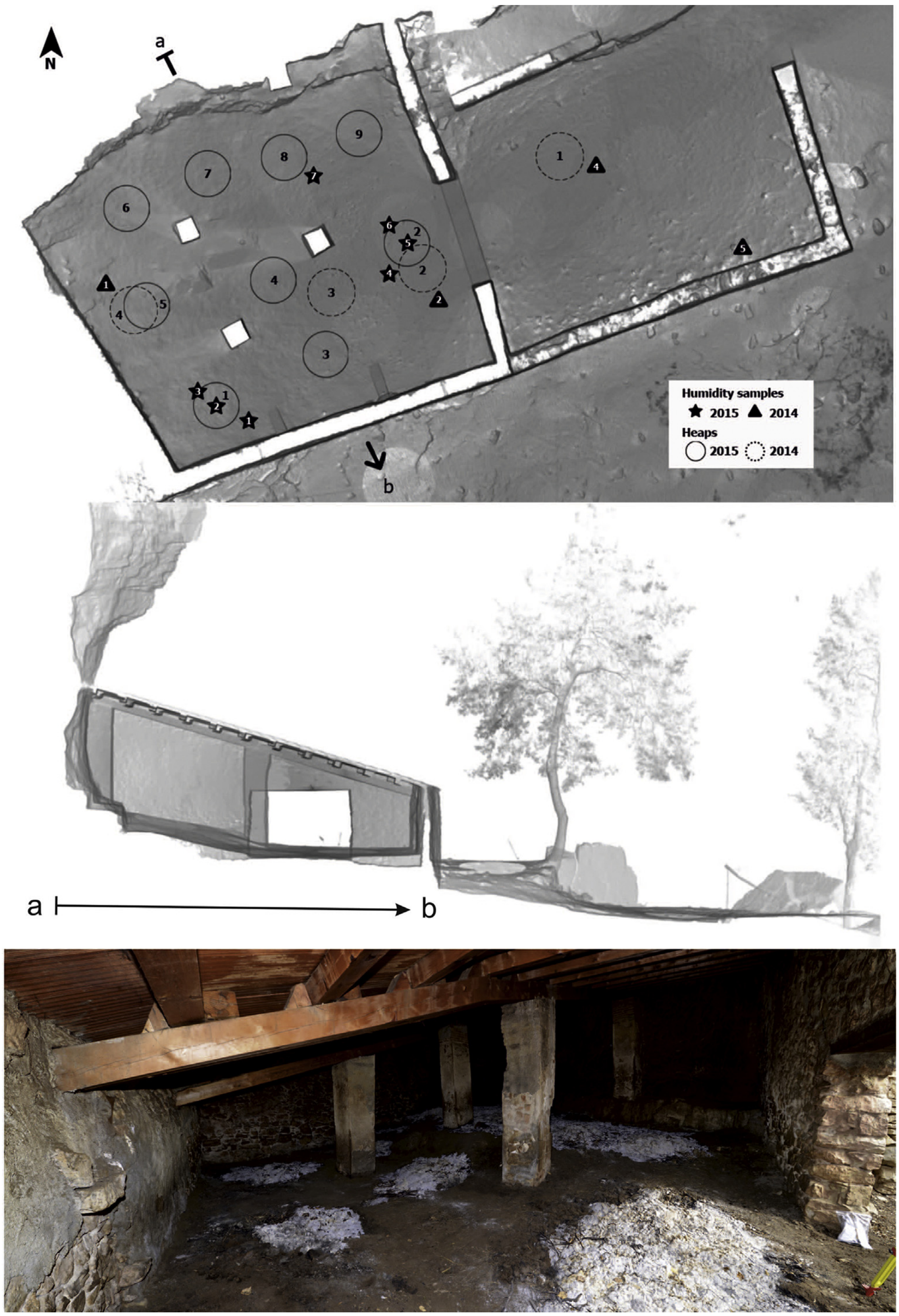

Fig. 5. 3D model of the Mas del Pepet pen with the location of the experimental heaps and humidity samples from the 2014 and 2015 experimental field season (upper). 3D model profile of the Mas del Pepet pen (middle). Internal view of the Mas del Pepet pen after burning during the 2015 field season (bottom).

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a FARO Focus 3D scan laser. This procedure was repeated when the burning was finished. The aim of this procedure was to quantify the reduction in volume of the dung.

Before burning, the dung heaps were sampled to calculate their relative humidity. This measurement was carried out by weighing the sample with precision scales once it had been collected and then repeating the process after leaving the sample in a muffle furnace at 50 °C for 18 days. The lighting of the heaps was carried out using dried *Quercus ilex* branches that were put on and next to the piles (Fig. 4). The branches were lit using dried grasses. As observed in previous experiments, this ignition method is the best overall when the humidity rate of the heaps is high.

Temperatures were recorded with digital thermometers (models TL-309 and PCE-T 390) with type K thermocouples (Chromel-Alumel). In the 2014 experiment, two thermometers were fixed to each heap; one at the base in a central position in contact with the soil (probe 1) and a second one in the middle of the pile (probe 2). For the second experiment another one was also placed in the side (probe 3). In addition, 2 aerial thermometers were placed in the enclosure's ceiling (probes 4a and 4b) to measure gasses and the thermal increase in the interior of the enclosure.

Weather forecast data, including temperature and relative air humidity, during the period the experiment was carried out were taken by the meteorological station at Rojals. This is situated 1650 m from the enclosure, at 975 m a.s.l. and 100 m above the enclosure.

5. Results

Up to now, two experiments of burning dung material accumulated inside the Mas del Pepet enclosure have been conducted; one in 2014 and one in 2015.

5.1. The 2014 combustion experiment

The first experiment was carried out on the dung deposits accumulated during the livestock's stays in 2011, 2012 and 2013. During that period, no cleaning of the dung was carried out. On 10th March 2014, four dung heaps were piled up at the outer/open air part of the enclosure (pile 2014-1) and three heaps under the roof (heaps 2014-2, 3 and 4) (Fig. 5). We decided to make a single pile outside because of the rainfall from the previous days that caused a 70% humidity level (Fig. 6: samples 14-H3 and 14-H4) which might have prevented lighting.

The innermost parts of the dung heaps were clearly drier with humidity values of around 25% (Fig. 6: samples 14-H1 and 14-H2). At the top of the heaps two defined layers could be observed, a superficial one formed by disaggregated and loose dung lying over a second layer of a compact, laminated dung layer covering the entire surface of the enclosure. This superficial layer was deposited during the last stay of the livestock between May and November 2013.

A small pit dug into the dung deposit permitted a prior analysis of the burning process of alternate loose and compacted dung to be

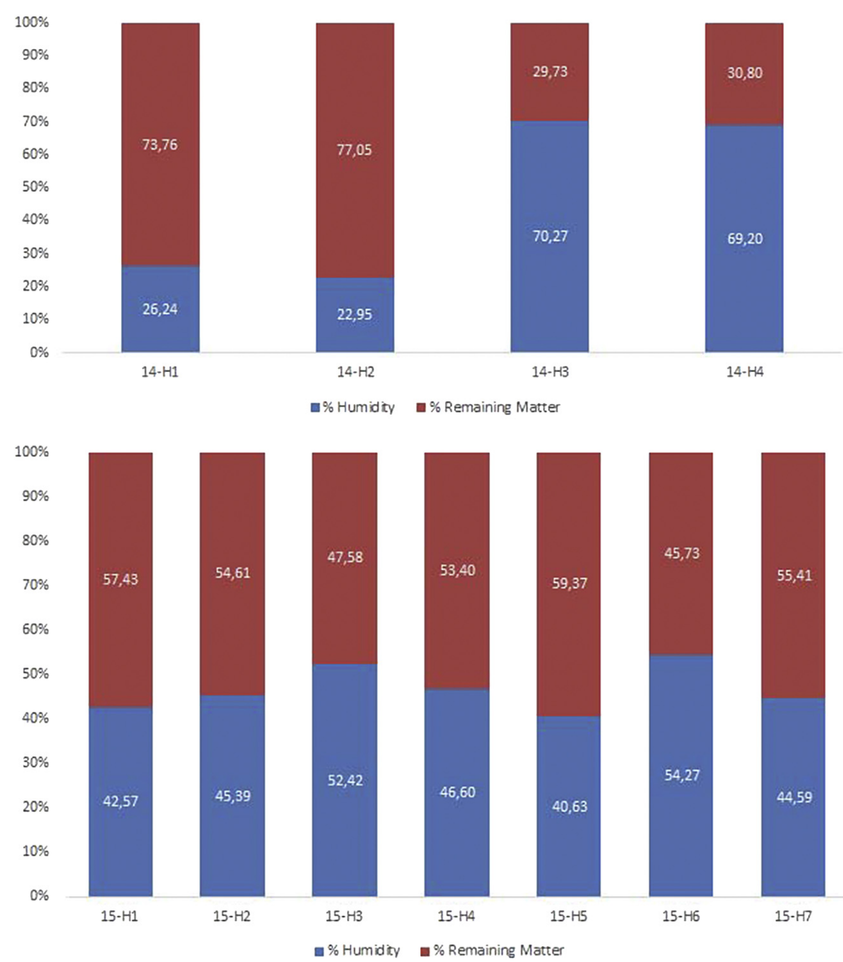

Fig. 6. Humidity control samples corresponding to 2014 and 2015 experimental field season. Percentages of humidity and remaining matter.

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repeated underneath as a consequence of the different seasonal visits of the livestock. Piles were built up with the loose dung to observe if the fire would be limited to the heaps or would propagate to the compact layer underneath. Heaps under the roof area were located next to the entrance (2014-2), in the central area (2014-3) and the third one was in the inner part next to the wall (2014-4).

The combustion process of the piles was begun on the morning of 11th March 2014. As expected, the heap located in the outer part of the enclosure did not burn at all. The high level of humidity did not allow the fire to spread from the branches. The heaps located inside the enclosure started burning immediately, slowly, without a flame and creating abundant smoke, as is usual in dung-burning processes (Fig. 7). After a few hours the combustion spread out to the compacted dung layer. This was visible on the surface as at a deeper layer, showed by the presence of small fumaroles in areas where no combustion was visible. The combustion spread slowly to the entire enclosure, as is standard in dung combustion processes: slow outward spread, low or no flames (small flames of about a few centimetres that come out of the fissures) and a large amount of low-temperature smoke.

After 42 h the fire was put out by firemen after the rural agent in the area received an emergency call. The smoke from the enclosure, seen some kilometres away, created an alert. The pressurised water used to put out the fire almost entirely destroyed the ash deposit and the dung that was still burning.

Thermal data obtained show that the maximum temperature did not exceed 600 °C and also that the temperature increase was slow and gradual. Only probe 2 from the 2014-2 pile went clearly above the thermal point of inflexion. We cannot be sure of the maximum temperatures of the other probes, but they were probably the same as those observed in previous experiments. Maximum temperatures were the same as experimental data that showed that non-degraded dung, with structures that did not allow air circulation (loose and laminated, compacted dung), did not exceed 650 °C and oscillated between 500 and 650 °C (Vergès, 2011).

During this experiment we observed that the position of the heap in the inner area affected the combustion process. The 2014-2 heap, located next to the entrance, recorded the fastest combustion and a slight fluctuation of the thermal curve. The 2014-3 pile, located at the entrance of the enclosure/pen, recorded a slower temperature increase, and the combustion of 2014-4 heap, located in the inner area, was the slowest. These differences occurred as a consequence of the entering of a thermodynamic air flow generated by combustion. The output of smoke through the top of the access opening generated a stream of air intake at the bottom: oxygen for combustion. It mainly affected the 2014-2 heap, which was just in front of the door; it affected the 2014-3 heaps located in the central part to a lesser extent; and affected the 2014-4 heaps located at the bottom very little.

Fig. 7. The 2014-2 dung heaps during the combustion process.

5.2. The 2015 combustion experiment

The second experiment was carried out on the dung deposited during the 2014 May to November season and on top of the remains from the previous experiment.

During the 2014 experiment the upper area of the enclosure was not affected by combustion and so the dung accumulations from 2011 to 2013 were still there. In contrast, the dung in the lower area had burnt irregularly. In the places where there were heaps, the combustion was almost total, whereas only the upper layer of the rest were affected. In the area of maximal combustion there were soil depressions as a consequence of the reduction in volume of the dung after combustion. The water used to put out the fire dragged the combustion residues and unburnt dung to the depressions, generating a layer of mixed materials. These depressions were not totally covered and the surface remained irregular. The irregular surface and the slope (the depressions were located on the lower part) caused the dung deposited during 2014 to be distributed heterogeneously over the enclosure's surface. It was preferentially accumulated in the depressed areas until they were entirely covered, whereas in the upper part of the enclosure that was not affected by combustion there was no increase in the deposits.

Summing up, at the beginning of the experiment, the dung deposits showed two different areas: one located in the upper part of the enclosure formed by dung from 2012 to 2013, deposited on the bedrock, and another, formed almost entirely of dung from the 2014 season and located in the lower part of the enclosure, laying over the layer generated after the extinction of the fire. The latter consisted of a mixture of combustion residues and dung.

For the 2015 experiment we made 9 piles with the loose dung from the surface and the compacted and laminated layer below (Fig. 5). In the half upper area of the enclosure this hard layer was probably made up of depositions from 2013, whereas the lower part was from ones from 2014. Thermal data were controlled from two heaps, heap 2015-1 and heap 2015-2. Heaps 2015-1 and 2015-2 were located in the lower area where most of the dung accumulated in 2014. However heap 2015-1 was not affected by the previous combustion and had dung from 2011 to 2013, whereas for heap 2015-2 all the dung was from 2014.

The mean humidity of heaps 2015-1 (Fig. 6: samples 15-H1 and 15-H2) and 2015-2 (Fig. 6: samples 15-H4 and 15-H5) was 43.79%, with a maximum of 45.39% for heap 2015-1 and 46.59% for heap 2015-2. The values of the substrate were 52.4% and 54.2% (Fig. 6: samples 15-H3 and 15-H6).

The combustion of the upper area of the enclosure spread out towards the dung deposits on which they lay, made up of dung from 2011 to 2013. This dung burnt completely down to the bedrock. In contrast, in the lower part combustion was limited to the heaped dung and a small area of the perimeter.

The thermal data from the two controlled heaps show some differences (Fig. 8) Heap 2015-1 shows very similar values of 451, 515 and 544 for probes 1, 2 and 3, whereas heap 2015-2 showed values of 565, 809 and 1,369 °C for probes 1, 2 and 3.

In heap 2015-1 there were temperature oscillations that were probably related to the volume that the heap lost. The maximal temperature reached at the base of the heap (probe 1) was the same as that of the starting point of the upper probes (probes 2 and 3). During the last phase a new increase in the temperature at the base was recorded in the same way prior to the final decrease.

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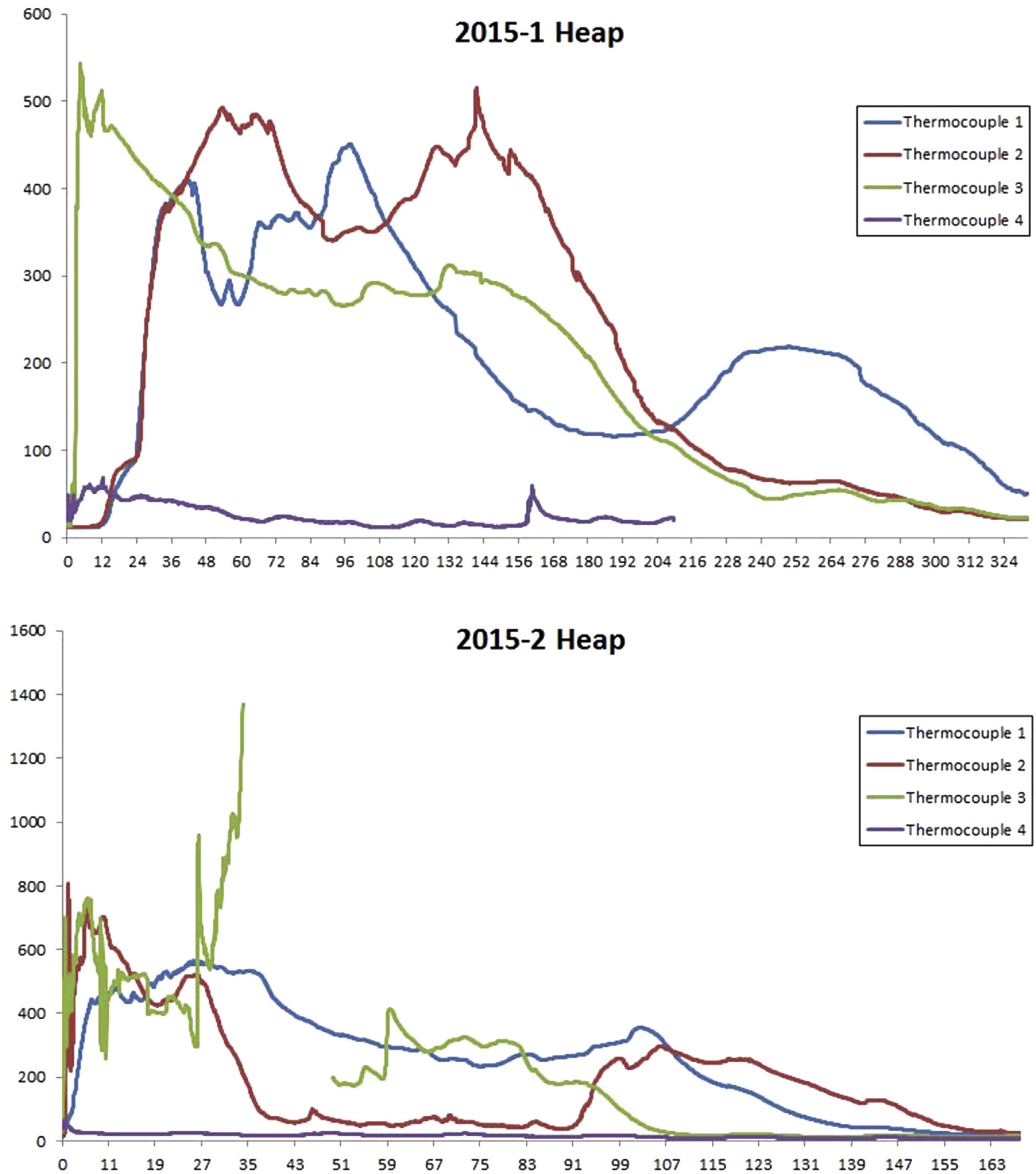

Fig. 8. Thermal data from the heating process 2015-1 and 2015-2. The X axis indicates the hours and the Y axis the temperature in °C.

This phenomenon was basically related to the fact that as a consequence of the gradual loss of volume during the burning process the thermometer moved vertically and relocated to places where there was still combustion. This movement and the consequent thermal oscillation was the same as that which the materials in the dung underwent.

The same process allows for an explanation of the oscillation of probes 1 and 2 from heap 2015-2, but not for the strong fluctuations of probe 3. In this case it was probably due to the effect of the wind. Its location at the perimeter of a heap exposed to the exterior makes this the most likely possibility.

In the other cases, air flow cannot be discarded as a cause of thermal oscillation, such as wind or draughts generated by the combustion thermodynamics inside the enclosure. But in any case, they are less important and are difficult to distinguish from the ones produced by the movement of the probes.

The case of probe 3 is abnormal as it stopped recording data after recording a temperature of 1,369 °C. This value is very different from those documented in previous dung experiments. We therefore do not have an explanation for this data, but it could be an error in the measurement.

The aerial probe reached a maximum temperature of 69.7 °C during the time that the branches were burning. During the dung combustion the aerial probe oscillated between 40 and 20 °C.

The combustion of heap 2015-1 started on March 2nd 2015 at 11:30 and temperatures were controlled until 7:45 on March 16th

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when the probe was at 50 °C. On March 15th at 10:27, the same probe was at 100 °C. The combustion of heap 2015-2 started on March 9th at 12:15 and data was recorded until March 16th at 19:00. Values over 100 °C were maintained until March 14th at 20:00.

It should be pointed out that, due to the problems with the ignition process of some of the heaps, it was necessary to burn branches at various times during the first hours of the experiment. This is shown as temperature oscillation during the initial period of probe 4a. Moreover a technical problem with one of the thermometers obliged the burning of heap 2015-2 to be postponed for seven days. The increase of environmental heat due to the burning of branches used for lighting the heap is reflected in the final measurement of the curve of probe 4a and the start of probe 4b.

6. Discussion

The most relevant data provided by these experiments is that if a heap of dung is burnt on a layer of non-degraded dung, under similar humidity conditions, the combustion spreads out to the entire deposit, burning out entirely. This was the case of the first experiment and the behaviour of the upper layer of the experiment in 2015. In both cases the burning affects the heaps and the remains from the previous years. This process indicates that the main part of the burning of the archaeological folds was carried out when the dung from the base did not have the same fuel properties as the heaps. This process is not in accordance with the field archaeology observations in which the burning only affected the heaps.

The differences between dung from heaps and dung from substrate were related to the level of humidity and the level of degradation of the organic matter, or a combination of both. In the 2014 experiment, the dung from the outer part of the enclosure was not burnt due to the levels of humidity. It there was up to 70% and the dung was affected by meteorological phenomena that accelerated degradation. Therefore, experiments to analyse the level of humidity and carbon preservation where it was possible to burn dung were carried out.

Data from 2015 show that in well-preserved dung with humidity level values up to 46.59%, and with the substrate with values between 52 and 54% burning took place partially without spreading out. It is probable that with values from 60% and up dung does not start burning.

Previous experiments of dung heaps outside this enclosure showed that the morphology, the fraction and the conservation state of the dung were basic variables for the type of combustion and determined the thermal curve and the maximal temperature achieved (Vergès, 2011). The same experiments showed that in advanced phases of organic matter degradation combustion is very difficult. The main reason is the loss of fuel properties as a consequence of carbon degradation. The behaviour of the dung heaps in the lower part of the 2015 experiment has therefore yielded significant data. The substrate on which they were formed was made up of a mix of combustion residues and disaggregated dung. This dung was probably affected by water and was likely damper than it was supposed to be.

In the past the dung burning process was probably carried out on a damper base, probably caused by the percolation of animal urine. The lower layer would have therefore have been damper that the loose upper one. In those cases the burning was probably carried out while the fold was occupied or immediately after abandonment. Another possibility is that the dung base was degraded and did not have fuel properties. In this case a temporal lapse of several years would have been necessary to cause the degradation of the organic carbon matter.

The answer to this question is very important for explaining cultural traditions in the use of folds related to cleaning and the periodicity of the use of the livestock enclosures. This provides insights into the reiteration in the mobility paths of prehistoric herders.

The following steps of the experimental program involved the burning of the dung heaps immediately after abandonment to conserve the animal urine. This allowed us to find out if the dampness generated by the urine and its different vertical spatial distribution was enough to place a limit between an upper part that could be burnt and a lower substrate that could not.

Other important questions for understanding prehistoric sites were thermal data and combustion duration. In our experiments, maximal temperature rose to between 450 and 810 °C. The 2014 data concurred with previous experiments where heaps with well-preserved disaggregate dung reached temperatures between 500 and 600 °C. The disaggregated dung formed a compact structure that permitted a good circulation of the gasses inside the heap. A similar case was the 2015-1 heap formed by dung heaps and disaggregated dung that filled the spaces between them and did not allow the circulation of air.

On the opposite side was heap 2015-2, mainly composed of dung heaps forming a structure that permitted the circulation of gasses. In this case, maximal temperatures reached were higher than 800 °C, as recorded in previous experiments (Vergès, 2011). It is important to understand that the quantity of oxygen available greatly conditions the type of combustion.

In this regard it is interesting to observe the behaviour of the heaps, especially those from 2014, which all burnt at the same time, depending on their position in relation to the gate of the enclosure. The burning speed of the piles and the partially achieved maximum temperatures were conditioned by their distance from the entrance, the entry point of the outside air and obviously the oxygen needed for combustion. When the heaps were far from the entrance there was more accumulated smoke and so less oxygen. Also, some thermal fluctuations observed in the probes of heaps 2014-2 and 2015-2 can be explained by their position in the areas regarding air intake. The variable position of the heaps in relation to the openings to the outside should be considered especially in cases of relatively closed cavities as the presence of wind or the formation of thermodynamic currents generated by the combustion itself may have regulated oxygen combustion.

In addition, it was observed that the maximum temperatures reached were higher in the high parts of the heaps and decreased towards the base; the same phenomenon was documented from the outside inwards. This coincided with data from experiments by Vergès (2011) and was related to: a combination of reducing the amount of oxygen to the interior; the difficulty in penetrating the structure; and the higher level of dampness usually present in the substrate that is in contact with the base.

Another interesting fact is related to the temperature of the gasses produced by the combustion process. Gasses coming into contact with the atmosphere at low temperatures caused only a moderate temperature increase of the atmosphere of the enclosure. The maximum temperature reached was of 69.7 °C, coinciding with the time when the bundles of branches were burnt. While the dung was burning the gas temperature values ranged between 40 and 20 °C.

This means that in cases where the space was well ventilated and there was not an accumulation of smoke, people were able to circulate in the area without risking burns or suffocation. This implies that during the dung burning process people were able to intervene and manage the combustion process. In some cases this could have involved the re-heaping of piles or other interventions aimed at accelerating the combustion or ensuring that the process was completed.

This aspect is important because if there was an intervention during the burning process, the date regarding the lighting method used could be lost. In the case of using bundles of branches, a firewood ash layer was created over the combusted dung. This layer is macroscopically visible in experimental cases and has been identified in archaeological cases via micromorphological analysis (Polo et al., 2014). Heap manipulation during combustion would cause the destruction of these layers and would mix the ash from the wood with the manure.

Another important aspect is related to the duration of the combustion. In the case of heap 2015-1, after 13 days from the start of the combustion the temperature was still at 100 °C in the centre of the heap. In the case of heap 2015-2, after 5 days the values did not fall below 100 °C.

During this period, although people could walk inside the enclosure, it was not possible for the flock to be inside the pen because the combustion waste remained at high temperatures for quite some time. Likewise, the phenomenon of burning taking place underground in some parts of the perimeter of the heaps was not superficially visible. These two factors made it very easy for animals to suffer burns on their legs when stepping on the ashes or falling in places that seemed apparently inactive. It is therefore almost certain that all livestock was removed from the enclosure until the end of the combustion process and the combustion waste had cooled.

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