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RECONSTRUCTION OF CONTROL AND APPLICATION OF THERMAL ENERGY PROCESS AND ITS TECHNICAL, SOCIAL, SYMBOLIC AND PALAEOENVIRONMENTAL CONSEQUENCES

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Abstract

Since the discovery of fire use in the archaeological record, the reconstruction of its control and application to the transformation of matter within different human societies has followed a rather complex path owing to the different theoretical frameworks leading to the emergence of the study of fire structures. This special number focuses on methodological approaches and the use of experimental and analytical methods to study late prehistoric societies having different degrees of complexity that evolved in the Mediterranean region. In previous studies, we point out that, “rebuilding to understand”, is a necessary step in the reconstruction of thermal energy processes. However, this approach is also essential for the reconstruction of the history of fire structures at each studied site and must be adapted in relation to the complexity of thermal energy uses in the different kinds of societies concerned. In this article, we use examples from prehistory to show how the analysis of fire structures continues to be problematic. This is due to the epistemological difficulties of this type of study, the complexity of the phenomena and the inadequate cross-validation between different analytical methods. As a consequence, there has been a hyper-specialization and fragmentation of this field of research as well as a lack of systematic studies using a well-established theoretical framework. Finally, the practical inherent problems of our disciplinary approach have reinforced the inductive tradition that frequently neglects the broader theoretical perspective needed to address the issues at stake. In this sense, our approach needs to consider different human modes of appropriation, production and use of thermal energy as well as the strategies implemented by different societies to ensure the reproduction of social systems by the control and application of fire use. Therefore, we need to question the relevance of these issues vis-à-vis the different aspects of each society and cultural structure, at both infrastructural and ideological levels.

Keywords

Fire structures, Fire history, Homo energeticus, Polynesian ovens, hyper specialization, Fire structures functions, Archaeological theory

Highlights

- Fires structures study methodology
- Thermal energy history
- Fire human uses
- Heated stones fires structures
- Thermal histories
- Archaeological theory

1. Introduction : Theoretical aspects

1.1 *Homo Energeticus* ?

The connection between human evolution and energy management is no longer a subject of debate. In our evolutionary path, the emergence of culture has allowed us to control and harness different sources and types of energy while facilitating the settlement and survival of human groups on this planet, but leading to what appears to be a critical situation for our future. Therefore, analysing the relationship between energy and humanity implies interpreting this interrelation so we can understand its history and its future. How can we deal with the history of fire without asking ourselves this fundamental question?

Research in our specific field aims to understand this relation and its continuity over time, including changes in our social organization in relation to the mode of production of thermal energy. We also need to understand the relation between energy production and the social reproduction of cultural structures which allows the incorporation of emerging changes, thus preserving the traditional modes of production and use of energy. The increasing differences in the emerging economic and social systems led to social differentiation that itself changed the mode of social organization.

Complex theoretical and methodological approaches have been adopted to reconstruct fire use and the consequent control of thermal energy in terms of its application to matter transformation within different human social groups. These branches of research result from different theoretical frameworks such as Evolutionism, Structuralism, Neo-positivism, Marxism and Post-Processualism, as well as academic movements such as Prehistoric Ethnology, New Archaeology, Social Archaeology, Post-Processual archaeology and have also been influenced by Neo-Evolutionism (March 2002, March et al 2014). These different theoretical schools spurred the emergence of the study of fire structures in archaeology following different approaches (e.g. experimental, ethnoarchaeological, archaeometric and paleoenvironmental) including interdisciplinary or transdisciplinary studies. Such developments also reflect the dialectic relation between humans and fire at the present day, and were influenced by the different advances in energy control that allow us to apply new methods to read our past. In this way, the progress in energy uses and applications allows us to explore thermal energy processes with new methodologies and technical innovations.

During the development of methodological and theoretical approaches in our discipline, different questions have arisen from the analysis of different types of societies. Certain questions are inherent to the use of fire and the innumerable technical applications related both to our modes of energy production and the reproduction of social organization.

In the first place, these questions ranged from the origin and domestication of fire, to the role of heat in our biological adaptation and the production and transformation of food (cooking, processing and preservation). Later on, research became increasingly concerned with the different applications of thermal processes in the transformation of matter, such as producing the necessary thermal energy to carry out different activities such as obtaining light and heat from the use of fossil and organic fuels. This latter aspect includes the understanding of the use of fire to obtain and transform raw materials (minerals, rocks, salts, metals and organic resins), along with the extraction of coal, colouring pigments and glues as well as the production of composite materials for the ceramic industry. Other applications of fire use are also involved in manufacture of construction materials and various artifacts such as weapons, everyday items, clothing and ornaments. Finally, we can also mention the production of metals and glass and the development of hunting techniques evoked for the Paleolithic periods, as well as practices such as slash and burn related to the development of agriculture (Pyne 1997 and 2019, Rehren 2021).

At the same time each use of fire was also related to social and symbolic utilization and significations that came to complete these technological and infrastructural uses of thermal

energy. We can evoke the relation between the social organization of residential spaces and architecture from hunter gatherer societies to states ones (Hough 1928, Wright, 1964 Leroi Gourhan and Brezillon, 1965, 1972, Binford, 1967, 1983, Yellen, 1977), its role in communication and territorial strategies, (Hallam, 2014) in passage rituals as cremations and ceremonies of inhumations (Rojo Guerra and Kuntz, 2002) or in seasonality rituals linked with agriculture and the cycle of life (Gonzalez Alcantud and Buxo Rey, 1997, Pyne 1949, 1997) redistribution of foods and salt production (Godelier, 1982) and finally the presence of fire in religions, myths and cosmovisions of all cultures in our planet (Frazer, 1930, Levy- Strauss 1958, 1964, Goudsblom, 1992)

Reconstructing this history implies analysing the social consequences of this sequence of technological discoveries and innovations, to improve our understanding of the whole significance of different fire traces and uses (Schiffer, 1976, 1987 March et al 2014).

2. Reading traces of fire use and their history: the case of “Polynesian ovens” in late European Prehistory. Domestic, artisanal or symbolic significance?

“Polynesian Ovens” represent a particular case of fire structures that provides an interesting example for analysing these problems from our theoretical and methodological points of view. These combustion structures are characterized by the recurrent presence of heated stones in different kinds of anthropic excavated depressions having different forms and dimensions, from cylindrical to rectangular with different heights and volumes. They also contain different natural stones according to the mineralogical resources present in geological formations of different regions and periods. The term “Polynesian Oven” is applied in the European context to combustion structures in different archaeological periods following a typological approach in which the forms and functions of fire structures are classically related. These kinds of structure were utilized from the Paleolithic up to the Bronze and Iron Ages and even in Historic periods. “Polynesian ovens” are not associated with technological innovations, being usually related to the existence of perennial gestures and practices linked to different social activities, mostly domestic. In this perspective, these structures have been studied by a differential methodological approach.

The concept of Polynesian Ovens was developed by the French school in the light of French colonial history (Wallis 1767 in Saint Perrier 1926, Daleo 1875 in Perles 1977), since these structures have been frequently compared in prehistoric studies with Polynesian domestic and ritual cultural practices. These first classifications were supplemented more recently by ethnoarchaeological projects developed in Polynesia by the “Prehistoric Ethnology” movement in the 1970s and 1980s, which included the first experimental and analytical approaches concerning these kinds of structure (Garanger 1973, Perles 1977, Orliac et Orliac 1980, Gascó 1985, Orliac et Wattez, 1989 Orliac, 2003).

By following these approaches, anthropological studies have often related the function of these structures to the systems of social reproduction observed in Melanesian societies (Godelier 1982, Lemonnier 1990). These structures are linked to their domestic or ritual use and the cooking practices of the “big-man” systems of chiefdoms in which these ovens played a role during ceremonies related to the distribution of goods and socio-economic organization (Gasco 1985, Frere Sautot 2003, Vaquer et al. 2003).

In fact, the complex social role played by these fire structures in ceremonies of distribution and reciprocal exchange practiced in Polynesia has not yet been demonstrated for societies on the European continent. However, some collective activities seem to be linked to non-domestic and probably ritual functions given the dimensions of certain structures (south of France, Vaquer et al. 2003, Dubesset 2021) and/or their positioning near ritual sites with high symbolic meaning (Carnac) (Hinguant et al., 2010 Fromont et al. 2011, Toron et al. 2017) or

their association with funerary steles (Beeching 2017). We are yet to explore the events associated with agricultural rites, knowing that fire had a fundamental role in the development of these techniques in different parts of the world (Lewis 1972, Pyne 2019) and that current cultural traditions still reflect this original link between fire and seasonal changes during pre-harvest periods (Gonzalez Alcantud and Buxo Rey 1997, Pyne 1997 and 2019).

It is known that the use of stones in fire structures is related to the control and application of thermal energy from the beginning of human fire use. Stones have been employed since prehistoric times not only to delimit fire and thus obtain a better yield of heat (from radiant materials) or prevent its spread, but also for the indirect cooking of food, the preparation of glues or sealants, or for bathing practices (saunas) and sometimes even as containers for oil lamps (Perles 1977, Pyne 1997, March 2002). The utilization of heated stones was recurrent in the Paleolithic periods and in different geographic contexts of adaptation of hunter gatherer societies, as can be observed on Magdalenian sites in Europe (Julien 1979 and 1985, Olive et Pigeot 1982, Olive 1988, March et Soler 1999, March 2005, March et al 2006 a and b, March et Lucquin 2007). Their utilization continues into the Mesolithic (Beeching and Moulin 1981), with some sites showing structures having very similar characteristics to those found in the Neolithic. These Mesolithic structures were previously related to Polynesian ovens, evoking the emergence of the oven function and stew cooking procedures (Foucher et al. 2000).

During the Neolithic period in France, we observe the emergence of a recurring practice of using stones in gestures related to the use of fire in hearths of various shapes and sizes. According to the author's experience and bibliographic data, Neolithic hearths contain a selection of rocks in relation to their availability in the environment. Thus, we find hearths with granites, sandstones, flints or schists showing different forms and provenance (ranging from moraines, fluvial or coastal pebbles to blocks extracted from natural outcrops in different regions of France) (Laporte et al 2005, March and Lemoine, 2006, Philippe et al 2006, March et al 2007, Hinguant et al 2010, Prost et al 2010, Fromont et al. 2011, Prost et al 2011, Philippe et al. 2011, Lucquin and March 2010, 2012, March and Cordero 2013, March et al. 2014, Bemilli et al, 2015 a and b, Dron et al. 2003 Vaquer et al. 2003, Surmely 2003, Leroy et Lecoeuvre 2006, Marchand et al. 2009, Treffort and Alix 2010, Beeching 2017, Toron et al. 2017, Chopin et al 2018).

For the Neolithic and more recent periods such as the Bronze and Iron Ages, other uses apart from domestic activities related to indirect cooking have also been evoked in the symbolic sphere. Such uses of stones include the preparation of collective meals linked to rituals of social reproduction and distribution of food (Hinguant et al 2010, Fromont et al. 2011, Toron et al. 2017), and their association with funeral gestures (Hénon and Jacquet, 2003, Martin et al. 2005). Recent studies have associated this kind of structure with other functions such as grain preparation, burial rituals and domestic activities related to the indirect cooking of food (Dubesset 2021).

Some of these fire structures using heated stones are characterized by their occurrence in groups or batteries of "contemporaneous" structures located close to or far from habitat areas identified as Neolithic houses, or even completely isolated from such localities. These groupings of structures can be recurrent over time at more or less marked intervals and can also be linked to ritual sites. Currently, these kinds of structures continue to be attributed to the Polynesian model but not on a typological basis. Nevertheless, the social function of these heated stone fire structures is still not resolved and other social functions are beginning to be considered in parallel with their original classification.

2.1 Some examples of Polynesian ovens in the prehistory of France

2.2 Bronze Age pit fire structures using heated stones

While working with the prehistoric ethnology school in France during the initial development of preventive archaeology, our Rennes research group first became involved with the study of these kinds of structure from the Bronze and Iron Ages. This provided the opportunity to implement a methodology for their study in an attempt to address their functional and social significance following previous work on fire hearths from the Paleolithic periods, with the aim of adapting our approach to more recent structures.

2.2.1 Sites of “Le Closeau” and “Les coteaux de la Jonchère”

Our first project concerned the analysis of fire structures at sites from the Bronze-Iron Age transition located near the villages of “Le Closeau” and “Les Coteaux de la Jonchère” in a seasonal flooded zone near the River Seine (Hauts-de-Seine, France) (Durand et al .1997 and 1999, March et al. 2003 a & b). These sites are characterized by the presence of fire structures showing differences in form and composition that indicate their isolation from other cultural debris. This first preventive operation was an exercise to establish a protocol based on an interdisciplinary approach continuing previous studies applied to prehistoric hearths. Since it was impossible to analyse all the structures found at these sites, we focused on three different structures (1214, 1037 and 17) (Fig.1), where two of them (st1214 and st1037) could be characterized as Polynesian ovens. These structures are associated with culinary and domestic uses and we were able to attribute their “oven” function due to the presence of a large pit, generally oval to rectangular, full of cracked heated stones like their Polynesian counterparts. As we have demonstrated, associating one single form to a function or a mode of functioning is an incorrect simplification, because the reconstruction of these aspects can only emerge from a study of the specific history of each structure (March 1995 a et b , March and Wünsch 2003).

Les Closeau (IFP) and les Coteaux de La Jonchère sites General distribution of fire structures

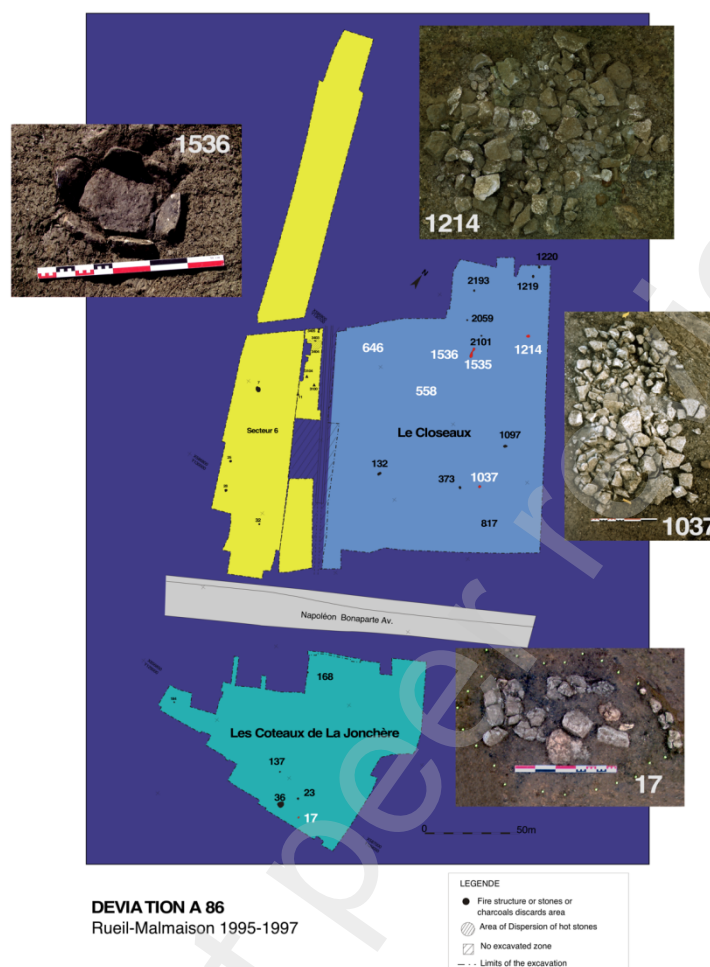


Fig. n°1 Bronze Age pit hearths fire structures using hot stones at Le Closeau and Les Coteaux de la Jonchère site (from March et al. 2003 b with modifications)

For this purpose, we carried out laboratory experiments and different analytical methods to reconstruct the thermal “micro-histories” (March 1995b March, 1996) of these pit hearths, thus obtaining many surprising results. The methods applied included the mineralogical analysis of heated stones, the determination of exposure temperatures of calcareous materials by SEM studies of their heat transformation and the observation of macroscopic changes. This experimental approach was coupled with the study of fragmentation and mode of heating by analysing the distribution of thermal alteration products and the reassembly of stones, linked to anthropological studies. The integration of these approaches reveals differences in the mode of functioning of the hearths, showing short durations of use and reuse as well as a fine control of temperatures which allowed the exploitation of available calcareous materials for indirect heat transfer. Our results suggest different arrangements of hearths showing that these structures were the result of different fire episodes. Their final state and distribution indicate a variability in the choice of wood as fuel related to its form and mode of use (Fig. 2).

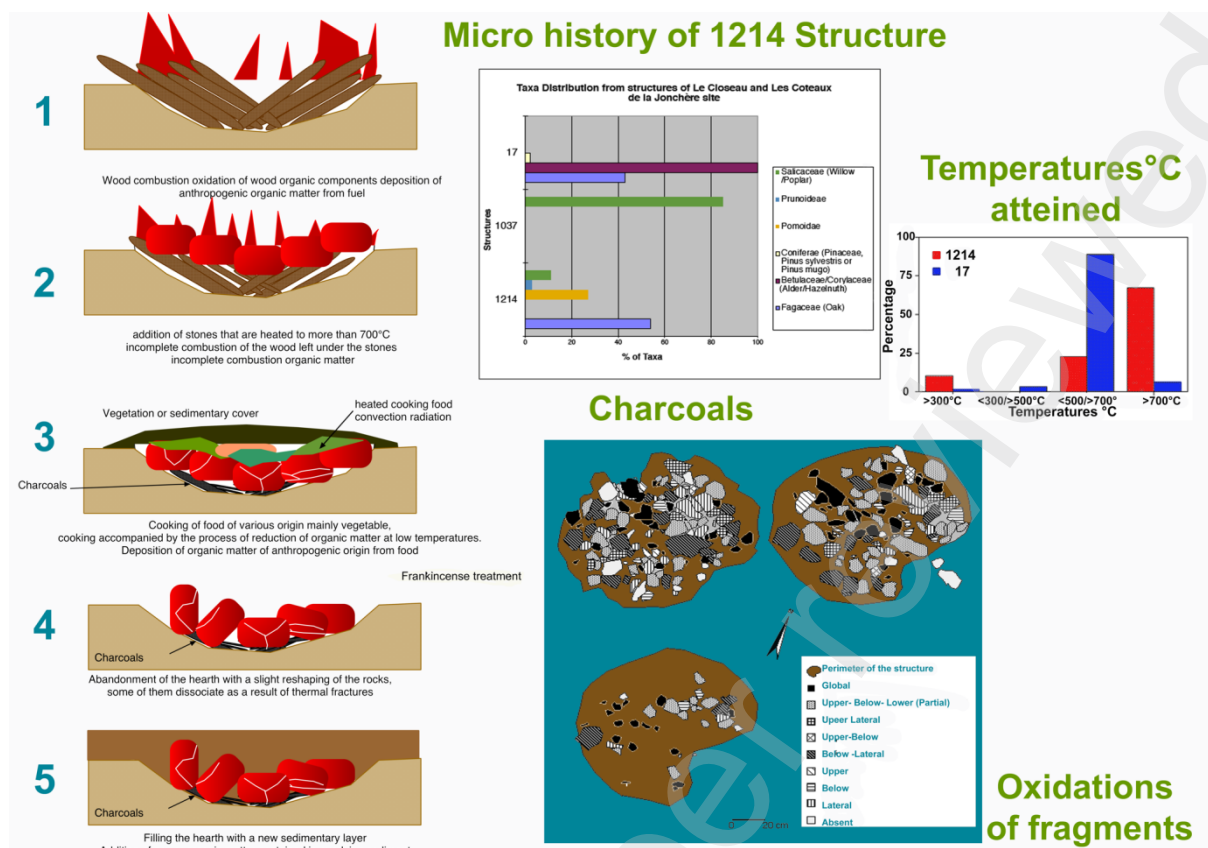


Fig. 2 Micro-history of the structure 1214 at Le Closeau. Examples of mode of reconstruction of mode of functioning based on anthracological data and heat alteration of stones (From March et al 2003a and b with modifications).

In parallel, chemical analyses of organic molecules by GC and GC-MS demonstrate a very good level of conservation with dominance of vegetable fats and only traces of animal fats. Some molecules (taraxerol, germanicol) lead us suppose that vegetable lettuces were cooked in these structures. At the same time, we detected one unexpected molecule (methyl- β -boswellanoate), an incense derivative showing that the fire structures may have been used for purposes other than just cooking.

The differences in the histories of each studied structure and the other forms of fire structure detected at the site reflect the complexity that lies behind the formation processes of these structures. In addition, reconstructing the micro-histories of use and functioning allows us to better understand the methodological constraints inherent in preventive archaeological operations (March et al. 2003 a and b).

2.2.2 2 Batteries of fire structures with heated stones at the “Champ Vallet” and “Hauts de Feuilley” sites

This first experience with fire structures encouraged us to develop an experimental and analytical approach following ethnographic models related to the use of stones for indirect cooking. A further two sites were studied in the Rhône department: “Hauts de Feuilley (Saint Priest) and “Champ Vallet” (Colombier-Saugnieu). At Hauts de Feuilley, the site shows the same kind of structures arranged in batteries assigned to the “Polynesian ovens” category, while the “Champ Vallet” site has only one structure of this kind accompanied by other archeological fire structures of different forms (Figs. 3 and 4). Both sites were found during a preventive archaeology operation (Jacquet et al., 2001a and b, 2003 March et al. 2003c). These structures in eastern France are supposed to date from the Bronze Age, located in a region

showing a recurrence of this kind of fire structure ranging from the Bronze Age to the Iron Age. In this case, previously to our operation, the Melanesian or Polynesian analogy was favoured and the domestic, religious or artisanal functions were ruled out for different reasons, such as: the dimensions of these structures, the absence of any association with human remains or the lack of traces of ceramic manufacture. Moreover, their geographic localization is frequently isolated or separated from dwelling habitats, even if similar structures are sometimes found near houses (Jacquet 2001). Other functions and possibilities have also been considered, such as their domestic use for cooking, grain roasting, or some connection with incineration rituals. These functions are associated with the presence of animal bones burnt on the inside related to agropastoralism according to the Celtic practices in Ireland evoked by O'Kelley (1954) or other functions as recorded at the "Aubiat" site (Mennessier-Jouannet & Vernet 1992).

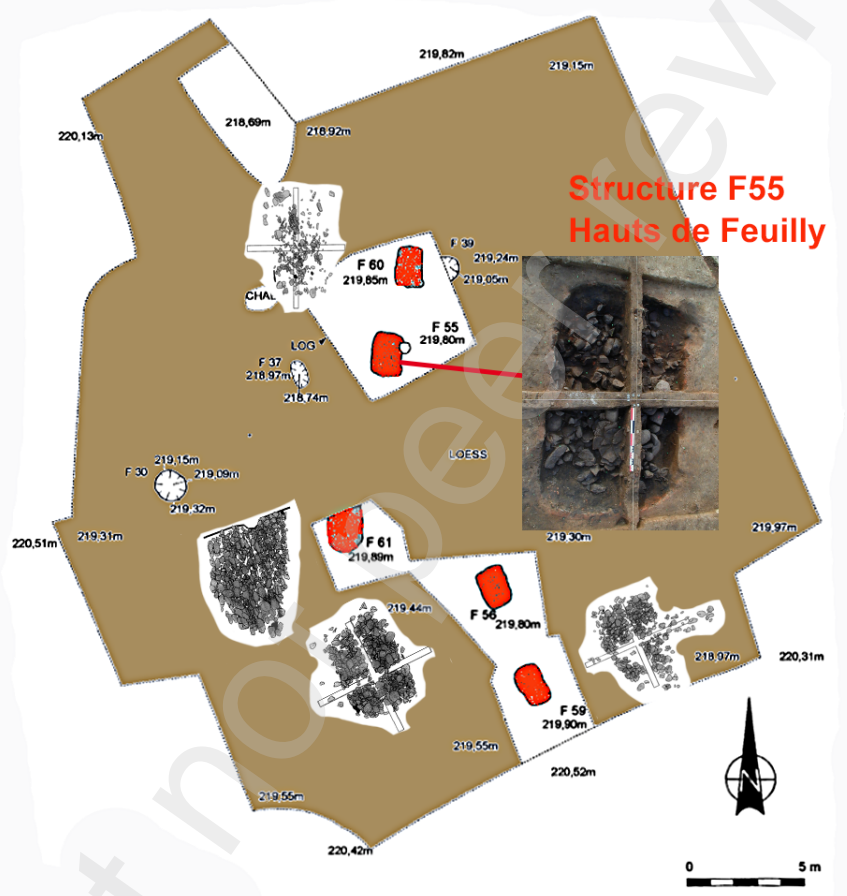


Fig n°3 Plan of fire structures at Hauts de Feuilley after P. Jacquet 2001a with modifications

However, Mennessier-Jouannet & Vernet (1992) have already discussed the full significance of the ethnographic analogy in their paper entitled "*Burnt pits settlements of Early Iron age in Limagne d'Auvergne (Puy-de-Dôme)*". In their words [translated from French]: "Does using the notion of "Polynesian oven" authorize us to establish, without further precautions, a set of socio-economic or socio-political deductions and comparisons between all cultures and societies that have appropriated this technique of domestication of fire?"

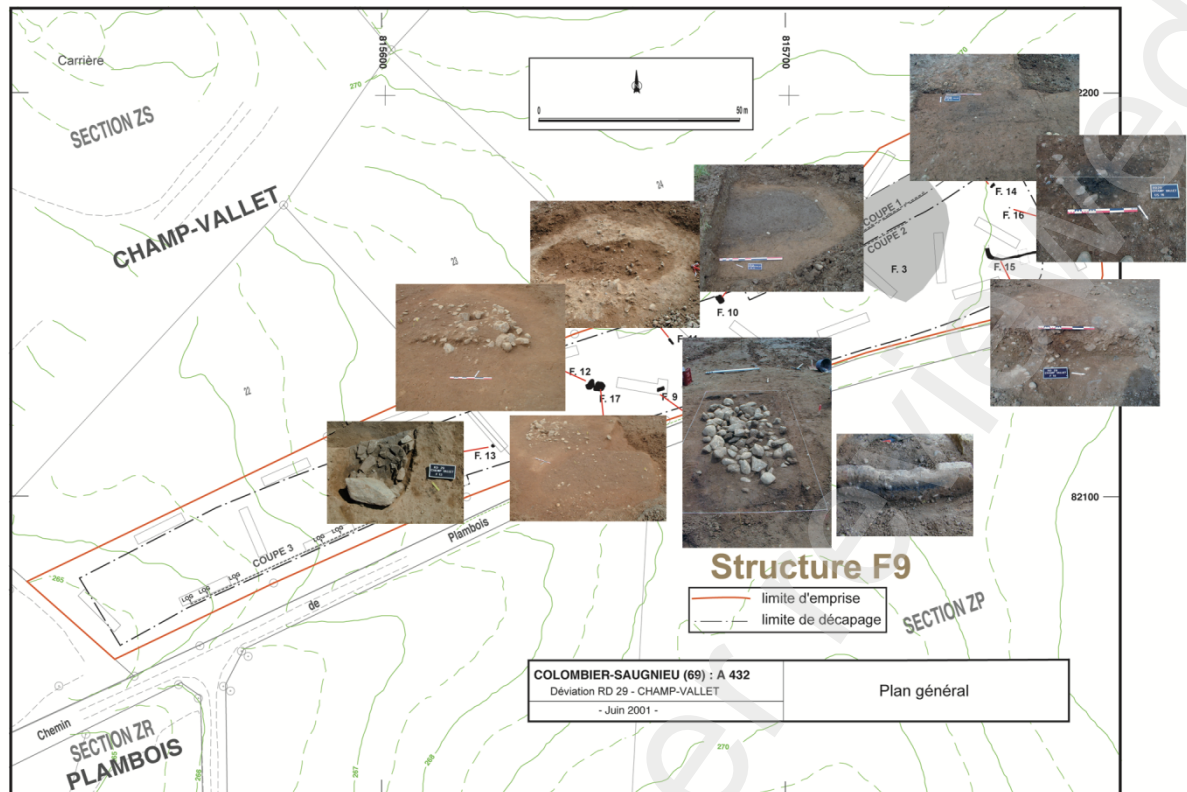


Fig n°4 Plan of fire structures plan at Champ Vallet after P. Jacquet 2001b with modifications

While the mode of functioning and eventual thermal efficiency of fire pits have been discussed - for example the position of fire related to the stones - their “thermal history” (March et al 1989) currently remains uncertain because, in most cases, there has been no attempt to apply experimental or analytical methods to explain the thermal behavior of each structure.

Inspired by the ethnographic model due to Stewart (1977), we oriented our experimental approach to those structures with a rectangular form associated with the predominant use of morainic quartzite pebbles. We chose this example because the forms of the structures and the pebbles used for cooking different kinds of meat (fish) are closely comparable to another ethnographic context where the function of the oven is not strictly evident. We also set out to show that “Polynesian ovens” are not the only model relevant for an interpretation in terms of ethnographic analogies. Our “realistic experiment” (March et al 2014) consisted of cooking two different meats (*Salmo salar*: salmon and *Ovis aries*: lamb) in a comparative analysis to improve the identification of animal fats (Fig.5). This experiment was accompanied by the study of different cooking techniques using stones (such as boiling or roasting), and then analysing the consequences and different traces of cooking that we could find in stones and sediments. Following these experiments, we show that cooking practices can leave traces of organic matter not only deposited in soils and on stone surfaces but which can also penetrate into stones of different nature such as sandstones, limestones, flints or quartzites. Since these traces are preserved, we can determine the nature of the adherence that could be due to the animal or vegetal fats involved in the cooking processes (Lucquin et March 2003, March & Lucquin 2007, Dumarçay et al. 2008 Fig.6).

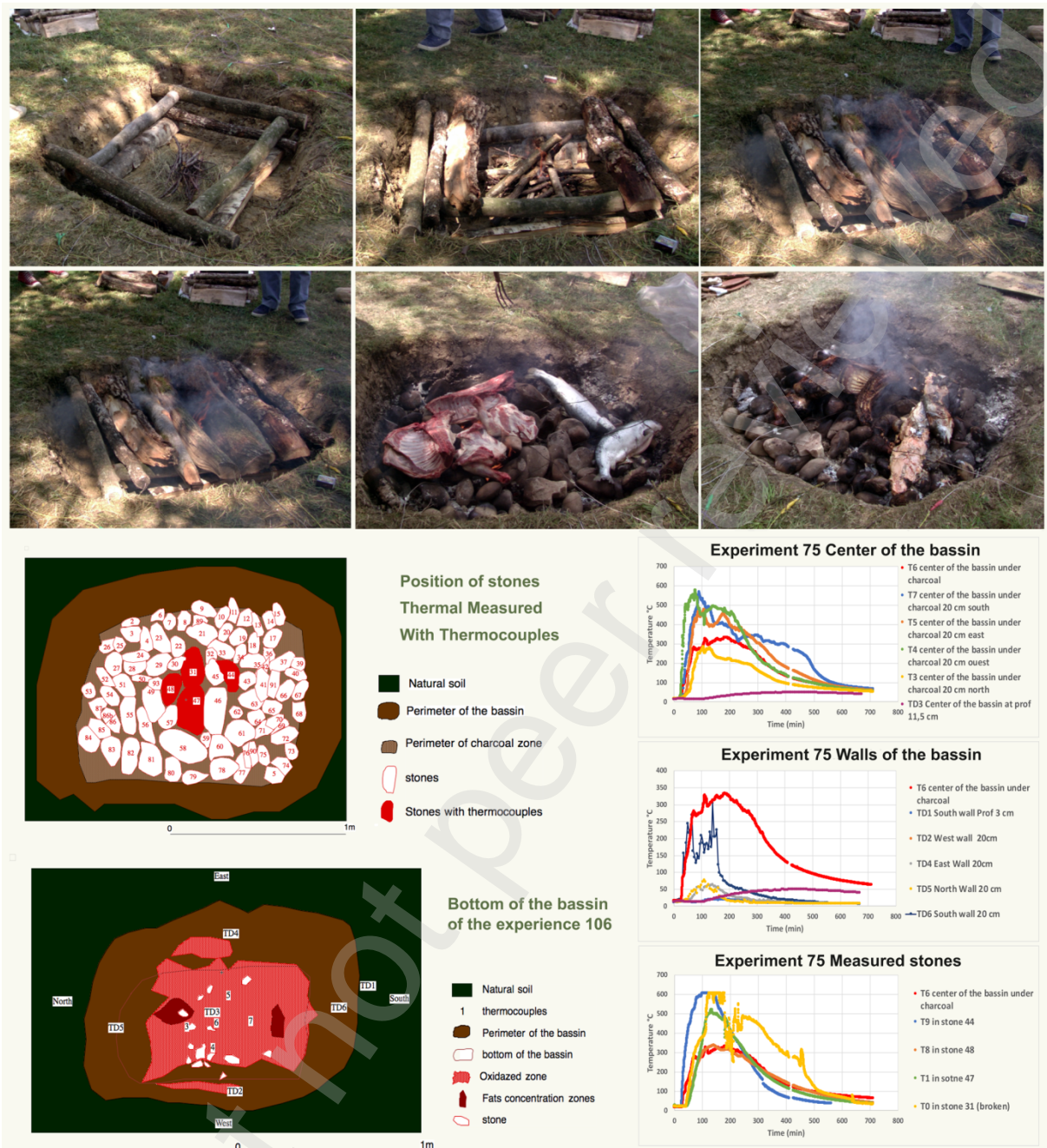


Fig n°5 Experiment n°75 based on an adaptation of the ethnographic model give in the "Indian fishing: Methods on the Northwest coast" of British Columbia from Stewart 1977

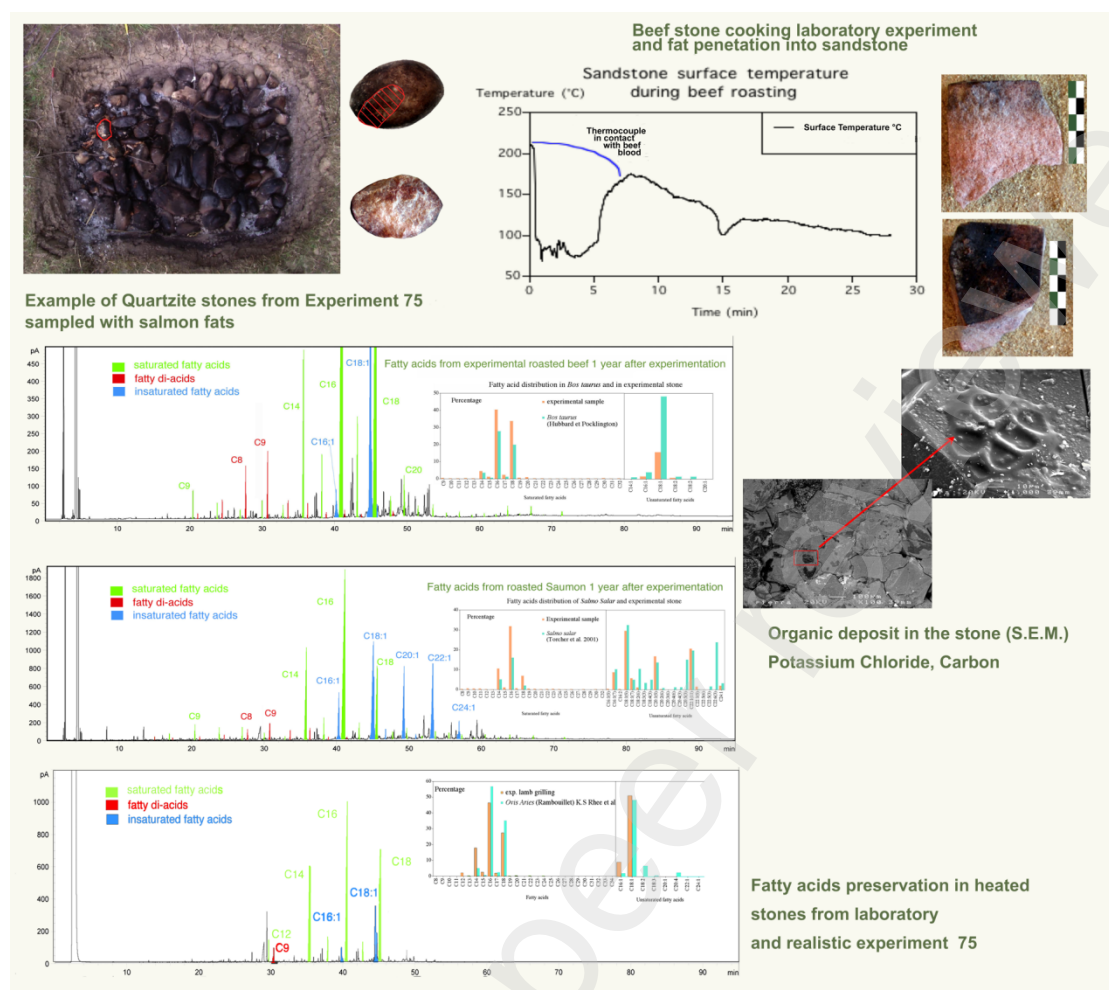


Fig n°6 Results of realistic experiment 75 and Laboratory experiment of fat penetration

Only two structures on these sites could be studied: F55 from “Hauts de Feuilly” and F9 from “Champ Vallet”. Both structures reflect several episodes of combustion and several rearrangements that are quite complex and different. The F9 structure has at least three combustion episodes. The structure shows a fairly marked hiatus between these different episodes, which is also observed in the stratigraphic sequence; this structure is associated with the use of various raw materials taken from morainic material close to the site: quartzite, granite, silicified limestone, micaschist and gneiss. The F55 structure also shows several combustion episodes, but the choice of raw materials remains the same, with quartzites representing more than 90% of the sample (Fig 7). Most of the heated stones were left in place, as shown by the high degree of internal reassembly/refitting of the fragments, which indicates that, without being exhaustive, around 60% of the fragments can be refitted. The fire pit F55 at Hauts de Feuilly was continuously used until the placing of a ceramic tray in the centre of the structure towards the end of its use. However, there appears to be no internal refitting was possible at “Champ Vallet”. This indicates the absence of thermal alteration of the last stones placed in the structure and the extraction of heated stones fractured during the first episodes. The differences between these two fire structures reflect their different histories and utilizations.

In both cases, the stones were heated in their mass at temperatures of between 300° and 500°C. The difference between the two fire structures is that temperatures were controlled at “Champ Valet”, given the low rate of fragmentation in the last episodes observed. At “Hauts de Feuilly”, however, the heat stress must have been significantly higher given the very high rate of fragmentation shown by the stones in the structure. Moreover, real-life food cooking

experiments carried out on similar structures reveal a contrast between the F55 and F9 examples, since the stones used only once in food cooking experiments have characteristics intermediate between the two structures analysed here (Fig. 7).

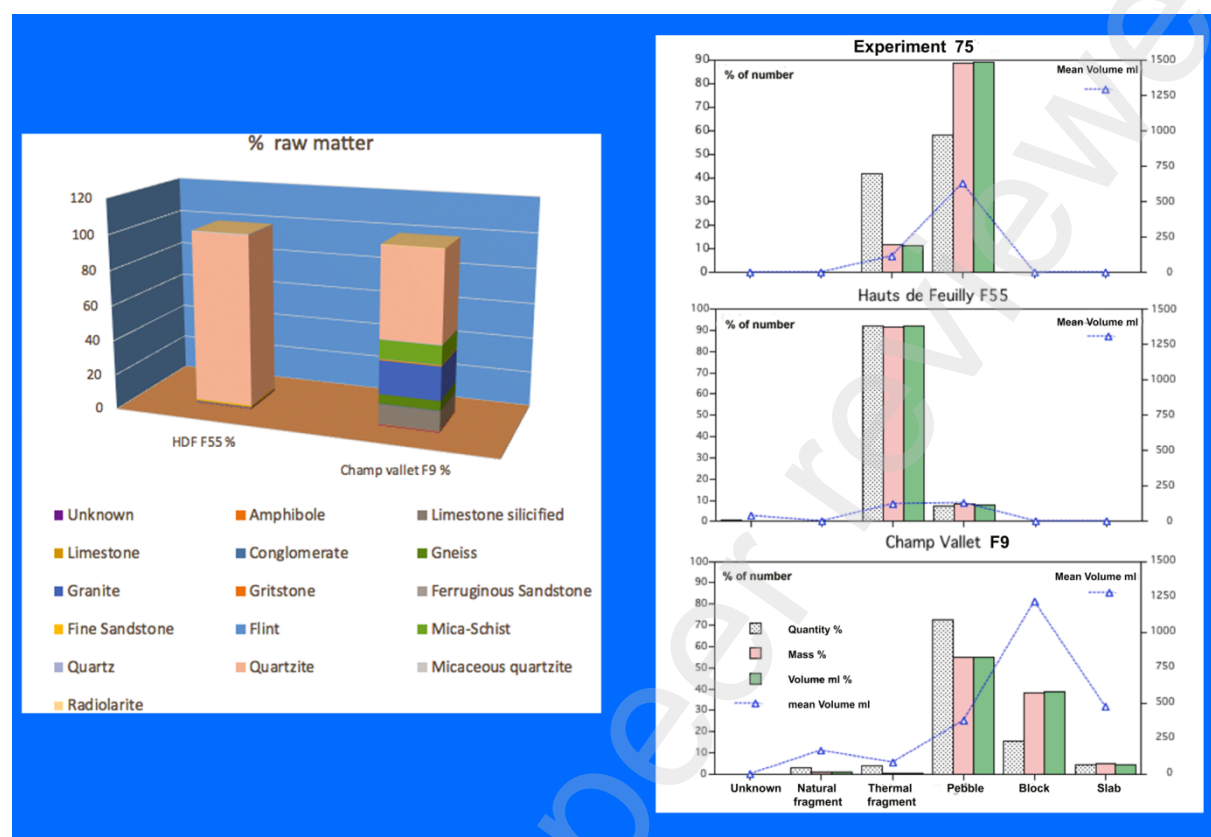


Fig 7 Raw material used at Hauts de Feuilly and Champ Vallet showing types and dimensions of fragments (length in cm) compare with the Experiment 75 (100% of quartzite)

As regards the functioning of the fire during these different episodes of combustion, we observe that the sediments at the two sites reacted almost at the same temperature, and were oxidized at 300°C. On the other hand, we also find that higher temperatures were attained in the F55 structure compared with the maximum in F9. Thus, the F55 structure would have reached a maximum temperature of 800°C while the F9 structure would not have exceeded 500°C. The thickness of the alteration of the walls also appears to be a slightly different, ranging between 4 to 5 cm in F9 at Champ Vallet and reaching 6 cm in F55 at “Hauts de Feuilly”.

The alteration at the base of the structure follows the same trend, being thicker for the F55 structure and less than 1 cm for structure F9. Therefore, the distribution of temperatures reached was different and the combustion mode was clearly different, being more intense for Hauts de Feuilly in the upper part of the structure. More recently (March et al. 2010), we applied a mathematical model developed from our experimental studies, which reproduces the thermal behavior of structures to analyse the thermal history and minimal time of burning for the F55 structure. This digital reconstruction shows us that the fire lit under the stones in the F55 structure had a short minimal time of burning, between 4 hours under humid original soil conditions and less than 1 hour if the soil is dry. A comparison with the structure F9 at “Champ Vallet” shows us that the mode of functioning was different from F55 at “Hauts de Feuilly”. Moreover, the time of burning for the “Champ Vallet” combustion episode was short taking into account the maximum temperatures recorded for both structures.

The analytical and experimental study of the lipid fraction carried out on rocks from the two structures indicates that both were used at some point in their operation for the indirect cooking of food as demonstrated by the distribution of lipids, fatty acids, alkanes, methyl ketones, γ lactones, ketones and sterols (March et Lucquin, 2002 March et al 2003c).

By example, the rocks studied at “Champ Vallet” contain only a cholesterol derivative and fatty acids with an animal profile, while those from “Hauts de Feuilley” contain cholesterol residues associated with fatty acids of mixed animal and vegetal origins.

The sediments of the Hauts de Feuilley structure show this same mixture, but more clearly preserving sterols with a vegetal signature containing traces of β -sistosterol, while the sediments from Champ Vallet differ by showing a strictly vegetal profile (Fig. 8). The degradation profiles of the organic matter as well as the external condition of the studied rocks lead us to consider a “pierrade” type of cooking style for both cases. Finally, the principal fuel used was oak, as shown by the study of the charcoal remains and the chemical analysis of plant compounds.

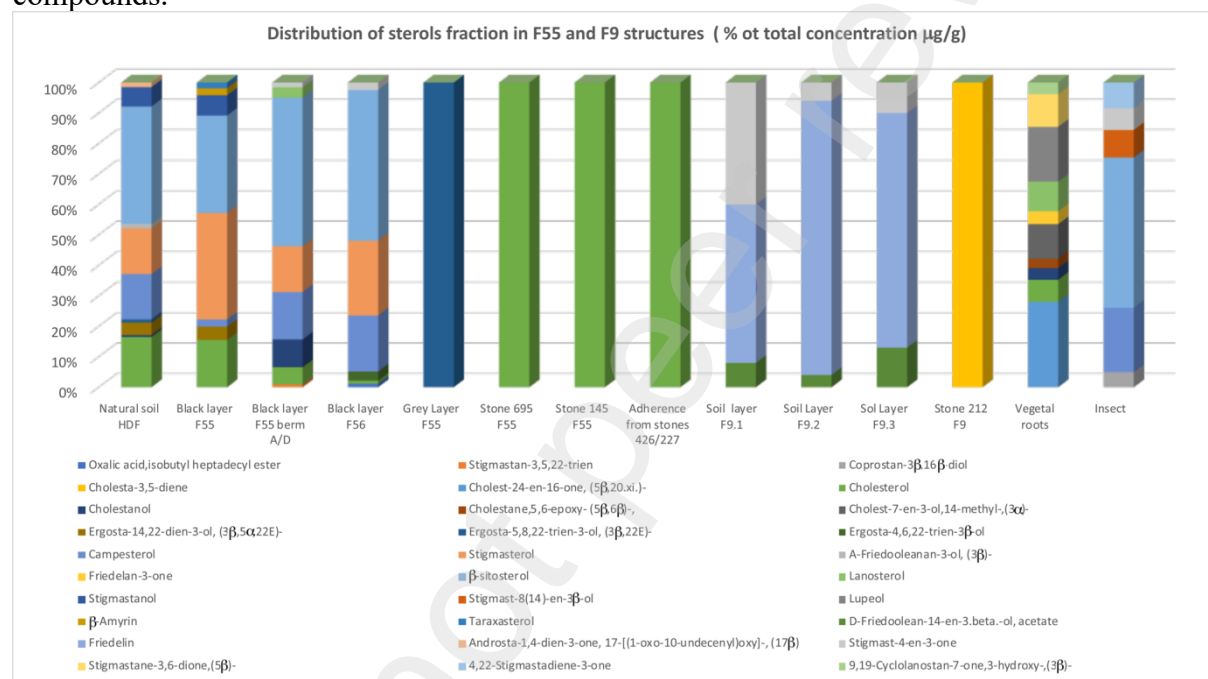


Fig 8 Sterol fraction of samples from Hauts de Feuilley and Champ Vallet

This study had shown the complexity of the analysis of this type of structure. Since these structures have such a complex history with multiple reuse, it is evident that their utilization cannot be considered as ephemeral. In the case of a ritual use, the gestures would have been repeated and the social reasons for this reuse remain unresolved. This complex history was confirmed by radiocarbon dating carried out after we had finished our preventive archeology project, showing that the structures cannot be assigned to the Bronze Age period but rather to the early Iron Age for “Hauts de Feuilley” (-2380 ± 30 BP, -517 BCE) and the “Gallo-Roman” period for “Champ Valet” (-1865 ± 45 BP, 32 AD). This highlights the crucial problem of studying of batteries of structures without dating each structure to confirm their contemporaneity. In addition, this also calls into question the dating procedure because, in the case of a reuse of the structure, as we can see for “Champ Vallet”, it would have been important to obtain dates that fully covered the stratigraphy of the structure.

By following an interdisciplinary experimental and analytical approach to study Bronze and Iron Age structures in a preventive archaeology context, we show that reconstructing the history of each structure can yield some very important information. At the same time, we

demonstrate the necessity of studying all the structures with the same procedure to understand the real significance of the use of these kinds of fire structure in complex societies.

2.3 From household to village: the Neolithic examples of “Pezou” and “Lillemer”

It is important to bear in mind that, in western, central and northern France, Neolithic fire structures of various forms can be found which make use of granite, sandstone, flint, quartz or shale according to availability (fluvial or coastal pebbles, blocks extracted from natural outcrops). In common with Neolithic structures from other regions (e.g. “Acilloux” (Cournond’Auvergne, *Puy-de-Dôme*) or the Chassean structures from “La Roucadour” (Thémines, *Lot*) (Muller-Pelletier 2010), the form of these structures is mostly circular.

As we can see from recent research in Brittany this kind of structure continues to be related to Polynesian ovens such as found during the preventive operation at La Mezière, where a group of 33 fire structures from the Middle II Neolithic period show the same characteristics and are positioned near a rectangular house (Blanchet et Le Boulanger 2015).

In our research work, we have been specifically concerned with heated flint fire pits associated with Neolithic households such as at Pezou (*Loir et Cher*) (Leroy et al. 2003, Leroy and Lecouvre, 2006 March et al 2004, March and Lemoine, 2006) or houses on stilts and flint production areas such as Les Sablins (Etaples, *Pas de Calais*) (Philippe et al 2006, Philippe et al 2011, March et al. 2007, March & Cordero 2013) or isolated from other structures as at Louviers in the Eure department (March et al 2020 and 2021). These structures frequently occur in batteries (e.g. Pezou and La Garenne at Gaillon (Prost et al. 2011)) and show a potential diversity of functions related to the archaeological context.

The “micro-histories” (March, 1995b) of the structures at these sites can be reconstructed using similar procedures as those applied previously to Champ Vallet and Hauts de Feuilly. For “Pezou” and “Les Sablins”, these procedures were accompanied by an experimental approach which multiplies the number of experiments to investigate different hypothetical modes of functioning. This approach aims to differentiate the traces produced by heat transfer in each situation according to the changes observed in stones and natural soil substrates.

2.3.1 Heated stone pit hearths near a household at the Pezou le Clos des Gués site

The Pezou site allows us to analyse the presence of batteries of pit fireplaces filled with stones, located outside a Neolithic house but very close to it. These pit hearths are circular structures ranging in diameter from 1.2 to 1.5 m, dug at shallow depths between 20 and 35 cm and filled with burnt stones (Fig 9).

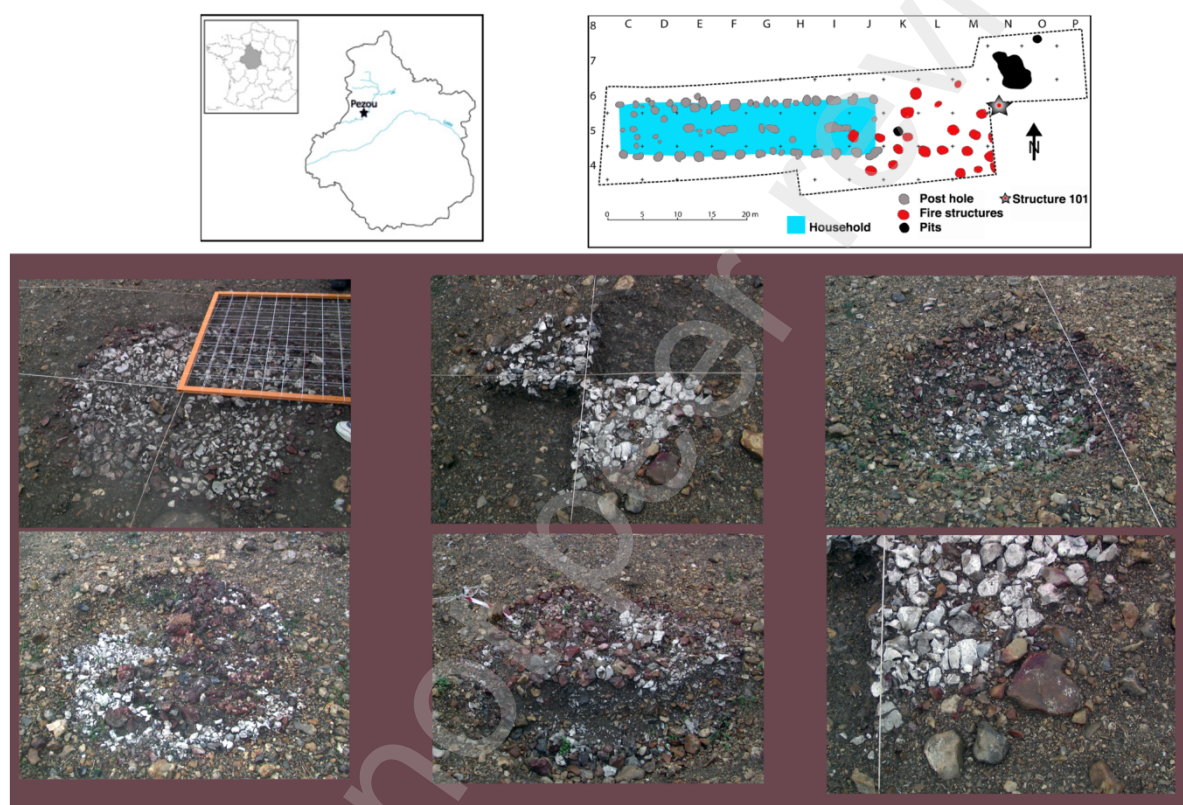
This localization leads us to suppose a domestic function due to its particular characteristics. For example, some structures appear to have not been filled with stones, but show traces of thermally altered soils and also contain oxidized and thermally fractured stones.

One of the most curious facts about these particular structures is related to the reaction of flint to thermal stress. In fact, flint can disintegrate more easily than other rocks if it is in direct contact with fire and thermal stress. At the same time, this results in a higher fragmentation of the rocks used, which modifies their thermal behavior and reduces the surface-areas of the stones that could be used for indirect cooking. However, the frequent formation of micro-fragments may make them extremely dangerous for health in practices involving the use of these rocks in boiling or cooking, since micro-particles of flint may adhere to the food. This implies that the use of heated stones for culinary purposes requires a particular control of the exposure temperatures and that the food should be protected from direct contact with rocks

during the cooking process. The explosion of flint nodules can even be dangerous, thus implying particular constraints in their use.

Then, we oriented our experimental archeology project to understand the thermal behaviour of fire structures using flint as a thermal radiant. Six experiments were carried out at the Pezou site. Since the natural sediments on the banks of the Loiret River contain fragments of fluvial flint which could be confused with the anthropic stones used in these fire structures, one of these six experiments was carried out by lighting the fire directly on the natural ground to determine the differences between the thermal alteration of natural sediments and the flints used as a radiant in the hearths.

Pezou les Clos de Guès site



Examples of archéologique fire structures

Fig 9 Localization of Pezou site and examples of different heated flint pit fires structures during their excavation showing different kinds of flint alterations

The other experiments explored different positions of fire within the hearths in relation to the mode of heating stones, either from below or from above, or from both below and above at the same time. These experiments aimed to reproduce the thermal effects observed on the different components of the fireplace (soils, stones and fuel) so as to be able to infer the mode of functioning of these structures. One of the experiments lasted 12 hours so it could be compared with other experiments of shorter duration (3 hours). Three structures were 30 cm deep and two of them 10 cm deep. The structures were excavated following the same methods inferred for the archaeological structures to allow comparisons between the experimental results and the archaeological data. These “realistic experiments” were accompanied by laboratory experiments where the transformation of flints and sediments were studied in isolation, in order to interpret the observed alteration both experimentally and archaeologically, to reconstruct the thermal history of each structure (Figs.10, 11 and 12).

The mode of functioning of these structures can be reconstructed from our experimental results. First of all, we find that just positioning rocks on the embers of a fire previously lit does not lead to high temperatures on the stones, since the fire is rapidly extinguished once covered by them. On the other hand, this procedure does not cause fracturing in the rocks, so it can be excluded as the mode of operation for the archaeological hearths at Pezou. The flints change their color according to their mineralogical composition; flints containing traces of iron turn red from 300°C or 400°C, then becoming lighter in hue and changing to pinkish at 600°C and whitish above 700 °C. The group of “Anthracite” flints change from dark grey to white progressively with increasing exposure temperature and attain a white coloration at 800°C. Sediments are blackened above 300° C due to their high organic matter content, and then turn orange above 500°C (Fig 10). The penetration of this orange coloration is very rapid, reaching a thickness of several cm in the sediment with only three hours of ignition. This indicates a high diffusivity and conductivity of this type of soil, which is composed of a heterogeneous mixture of silts, sandy silts and flint nodules. It is interesting that the archaeological soils affected by heat do not preserve this coloration. As a result, we could find layers of soils made up of burnt flint and dark-coloured soil, even when these flints were heated to above 700° C reaching a whitish coloration.

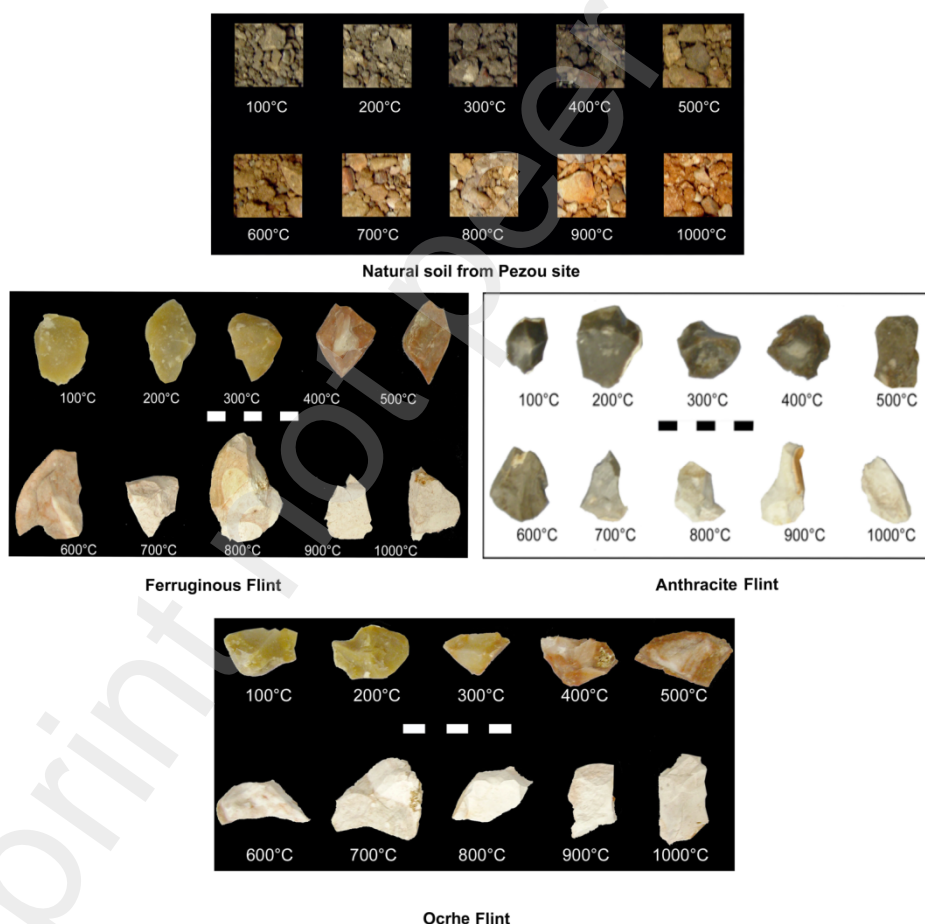


Fig. n° 10 Laboratory experiments of heat transformation of different kinds of flints and soils from the Pezou Site

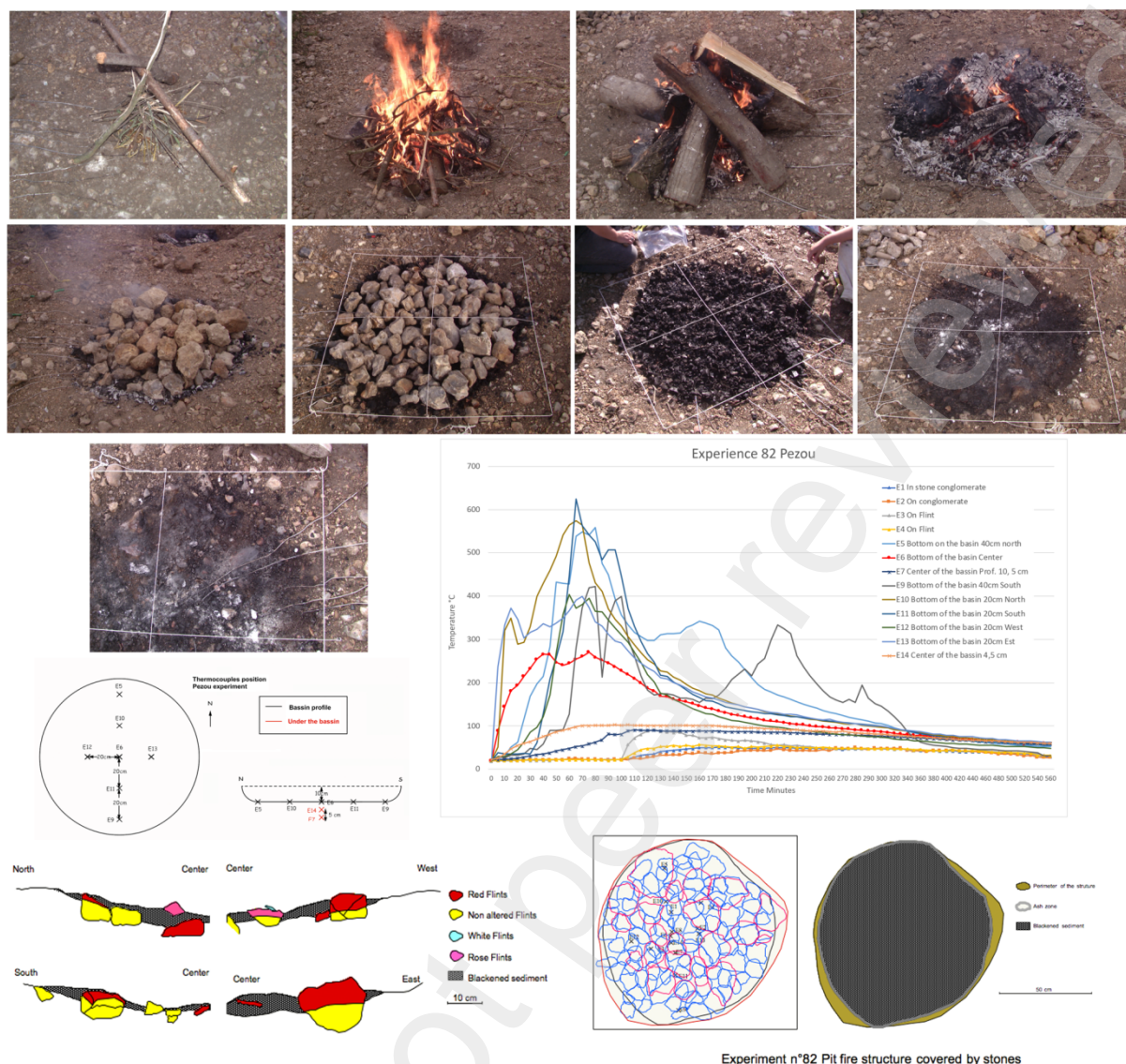


Fig. n° 11 Sequence of the Realistic Experiment 82 Pit heart cover with stones from the Pezou Site showing both the partial alteration of flints intentionally deposited on fire and embers and the natural substrate containing natural flints.

completely white oxidation at high temperatures, since this was only achieved in the parts exposed to the fire while the interior showed lower temperatures. Only a deliberate heating of these pebbles allowed us to obtain greater quantities of white flint. When flints were added to an active fire that was maintained to ensure their heating, we produced large flint fragments and fractured blocks bleached in the hearth. We consider that this second case is closer to the observations made on the archaeological structures, both in terms of the morphology of the blocks and their quantity. All this information suggests the intentional addition of flint to the fire regardless of its presence in the natural context. This leads us to understand that the exposure temperatures were different according to the structures observed.

Organic analyses confirm the presence of organic matter of anthropic origin in both soils and rocks. We could also observe differences in their composition and degradation. The most marked degradation was noted in rocks showing traces of contact with the organic matter in reference to the analysed soils. Some rocks had traces of lipids of vegetal and animal origin while others had only traces of lipids degraded by temperature or derived from combustion remains. The soils contain mixtures of lipids of animal and vegetal origin that vary in their composition and distribution (i.e. presence or absence of certain families such as sterols as well as differences in the dominant molecules in each sample for recurrent families such as alkanes, alcohols or fatty acids). According to the samples analysed, certain differences were found between the natural soils and sediments from the combustion structures, which also indicates the anthropic origin of the lipids in the structures. In the same way, some rocks do not match traces of sterols or contain only a few traces of cholesterol derivatives in some hearth structures, while others contain mixtures of products of vegetal and animal origin, such as cholesterol, cholestanol, campesterol, stigmasterol and γ -sitosterol. These differences indicate that they had been in contact with plant and animal remains, and that their conservation is linked with the exposure of the analysed rocks to high temperatures.

Following our experimental results, as well as the analysis of archaeological structures, we infer that the four fire structures studied here had different functions. Some of these structures situated near the household could be interpreted as culinary hearths. This is because of their thermal history and the presence of organic traces on the surface of the heated stones. Moreover, the lower temperatures attained in these hearths would have preserved the dimensions of the original fragments. Meanwhile, the other fire structures show evidence that their use could not be related to cooking processes, but rather other artisanal activities such as the production of thermally altered fragments of flint. In view of the absence of ashes and charcoal remains within the structure as well as the extreme fragmentation and high exposure temperatures of the stones, the flints could have been destined for reuse in other activities such as ceramic or metallurgical production or related to the use of heated stones, such as in bathing practices similar to the sauna tradition. The refitting of heated fragments of flint shows that some structures were abandoned after their utilization, leaving the stones in the structure, while others show the absence of stones or a low level of refitting indicating that some pieces of flint were retrieved from the structures (Fig. 13) (March et al. 2006 Lemoine & March 2006). Finally, certain structures show no trace of any rocks intentionally placed in the structure, which indicates either the retrieval of rocks for the performance of other activities or the use of these hearths as simple depressions for combustion.

Once again, the diversity of the reconstructed micro-histories for each studied structure and their possible extrapolation towards the other structures on the site reflects the complexity of the modes of operation and the possible functions of these structures even if they were located close to the domestic space. It is important to mention that, at the time of completion of this study of the Pezou site, the resources were not available to carry out systematic dating of the batteries of structures as appeared advisable from the results of our research.

Structure 101

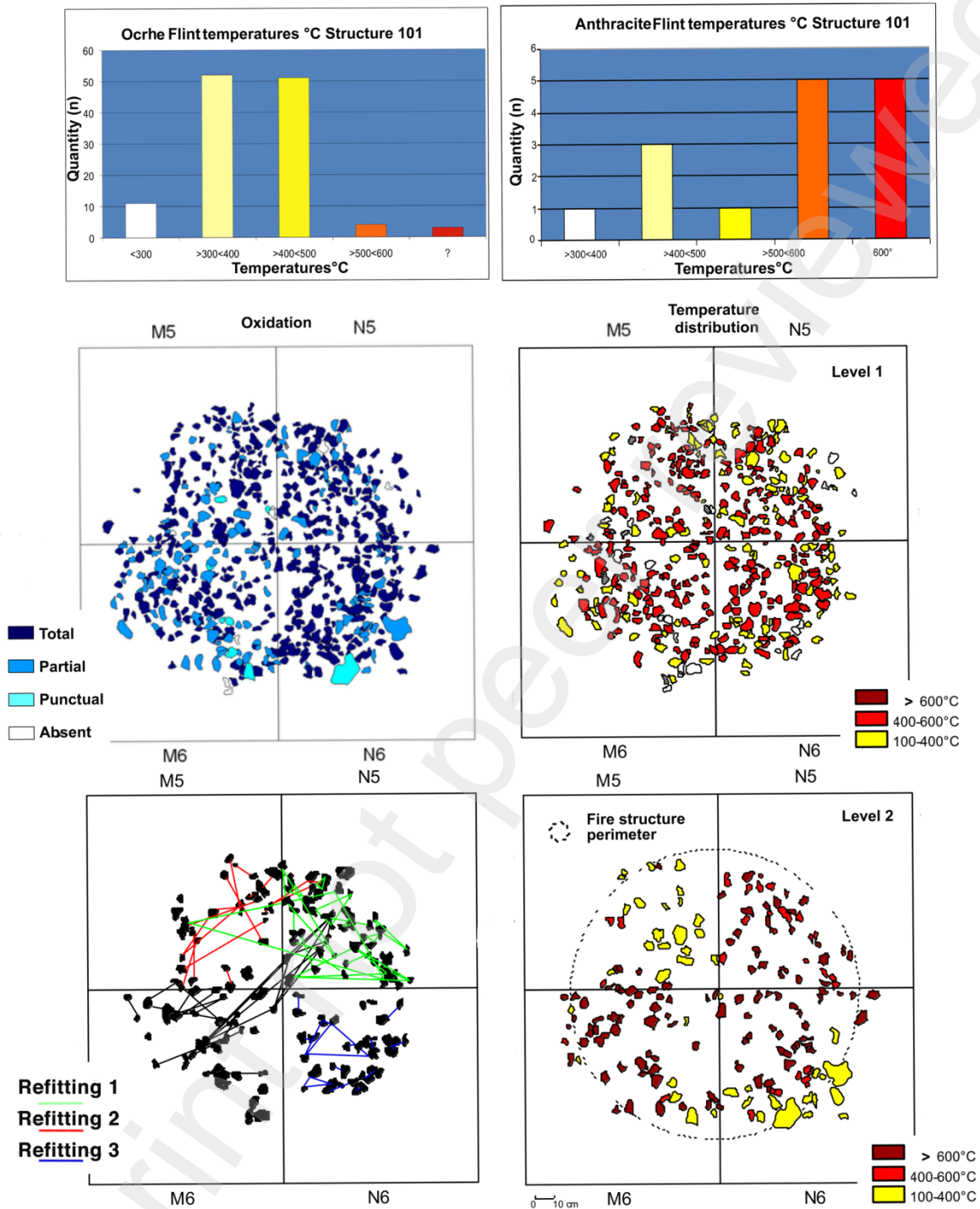


Fig. N° 13 Thermal alteration inferred for the structure 101 of the Pezou site : Oxidations, Temperature of flints, and refitting of thermal fragments showing their fragmentation and dispersion into the basin.

2.3.2 Heated stone fire structures in a village - the Lillemer site

Our work with heated stone fire structures belonging to Neolithic societies continued with the study of the “Lillemer” site (Ille-et-Vilaine, France) (Middle Neolithic, 4500 to 3500/3300 BCE) (Laporte et al 2003, 2005, 2007, Bizien-Jaglin et al 2009, 2010 a et b, 2011,

Lucquin et March 2005, 2006a et 2006b, 2009 et 2010, Guyodo et al. 2011 a et b). This work allowed us to analyse the diversity of combustion structures at these kinds of sites as well as the use of fire-produced thermal energy for other purposes. In addition to the use of fire for different purposes, such as the possible domestic production of ceramics, cooking food, and even some activities that could be related to ritual behaviors, some authors have discovered traces of fires from arson that affected the palisades surrounding the site as well as room structures made of mud and rocks (Laporte et al. 2015). The Lillemer site was studied in the context of academic research programmes and preventive archaeology, with fire structures in certain sections of the site being excavated both for contractual purposes and for preventive archaeology (Fig.14).

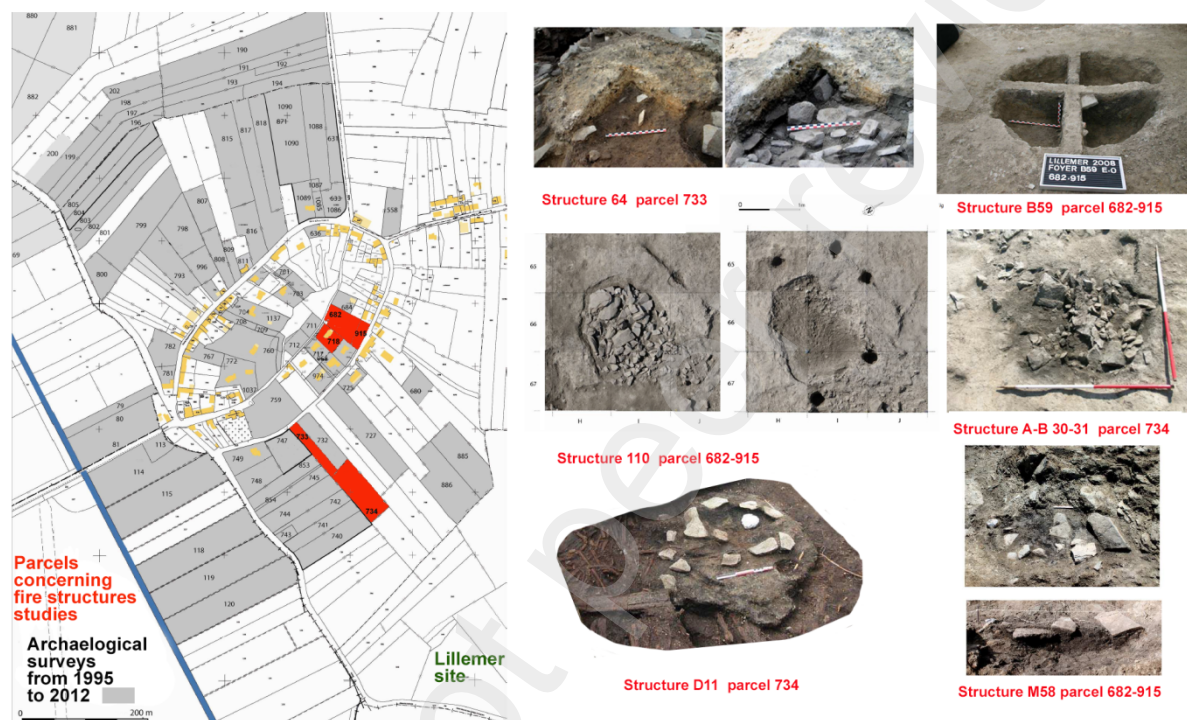


Fig. 14 Fire structures of Lillemer (from Bizien-Janglin et al. 2010 a et b and Guyodo et al. 2011 with modifications)

Although the structures at the Lillemer site were never considered to be Polynesian ovens, the novel hearths found in the Neolithic village at this site led us to reappraise our methodological and theoretical approaches when trying to define the functions and mode of operation of these structures. The combustion structures on the site are found at various locations and dates of human occupation, not only inside the palisade on the various terraces forming the different steps of the enclosure where the domestic and megalithic structures are situated, but also outside the site in the old marshy area where wooden pathways were built to allow the occupation and exploitation of the wetland. The excavated remains at Lillemer can be associated with domestic, as well as symbolic, ceremonial or funerary spheres. (Laporte et al. 2015).

In this case, the rocks chosen for the construction of the hearths were probably taken from naturally occurring schist slabs near the site, thus highlighting the absence of fire structures built mainly with flint or granite, even though some granite was found combined mostly with schist in some of the studied structures. A number of these fire structures are associated with pits, while others could be lit over soils constructed with composite materials, such as the structures found in the marshy section. The dimensions and internal organization of these structures also varies and can sometimes be associated with post holes that encircled the

structure, forming a rectangle (structure no.110: 1.80 m x 1.15m) that reveals the existence of a structure connected to the hearth. This type of structure, which has not been detected at any other site discussed in this article, could indicate the presence of either an elevated cooking surface intended for smoking or drying meat, or an incineration device.

The mode of operation of this structure indicates at least two differentiated uses and three combustion episodes. Its micro-history could be summarized as follows: First, a shallow depression was made on top of a natural outcrop of schist which flanks the occupations of the site. A fire was lit on the natural schist bedrock and several slabs, modified mostly on their lower side, were placed on top of it. Subsequently, a new fire was lit on these slabs, which produced high temperatures of between 600° and 800°C, causing intense fracturing of the deposited rocks. A large quantity of burnt bone fragments of unknown origin was found in these pits, complicating the archaeological analysis. A new layer of rocks of larger size was deposited on these rocks, but this time after the cessation of the second episode of combustion. Finally, a third episode of combustion resulted in the alteration of rocks positioned at the top of the structure. These latter were also altered at high temperatures but show fewer traces of fractures and fragmentation. A stele of schist with anthropomorphic forms, but without any traces of thermal alteration, was deposited onto this upper layer. This micro-history has given rise to an initial symbolic interpretation concerning the use of this structure. It shows similar characteristics to other structures built during this period at other sites with a similar organization characterized by rectangular alignments of pit holes surrounding a depression and which are interpreted in the same manner (Fig. 15).

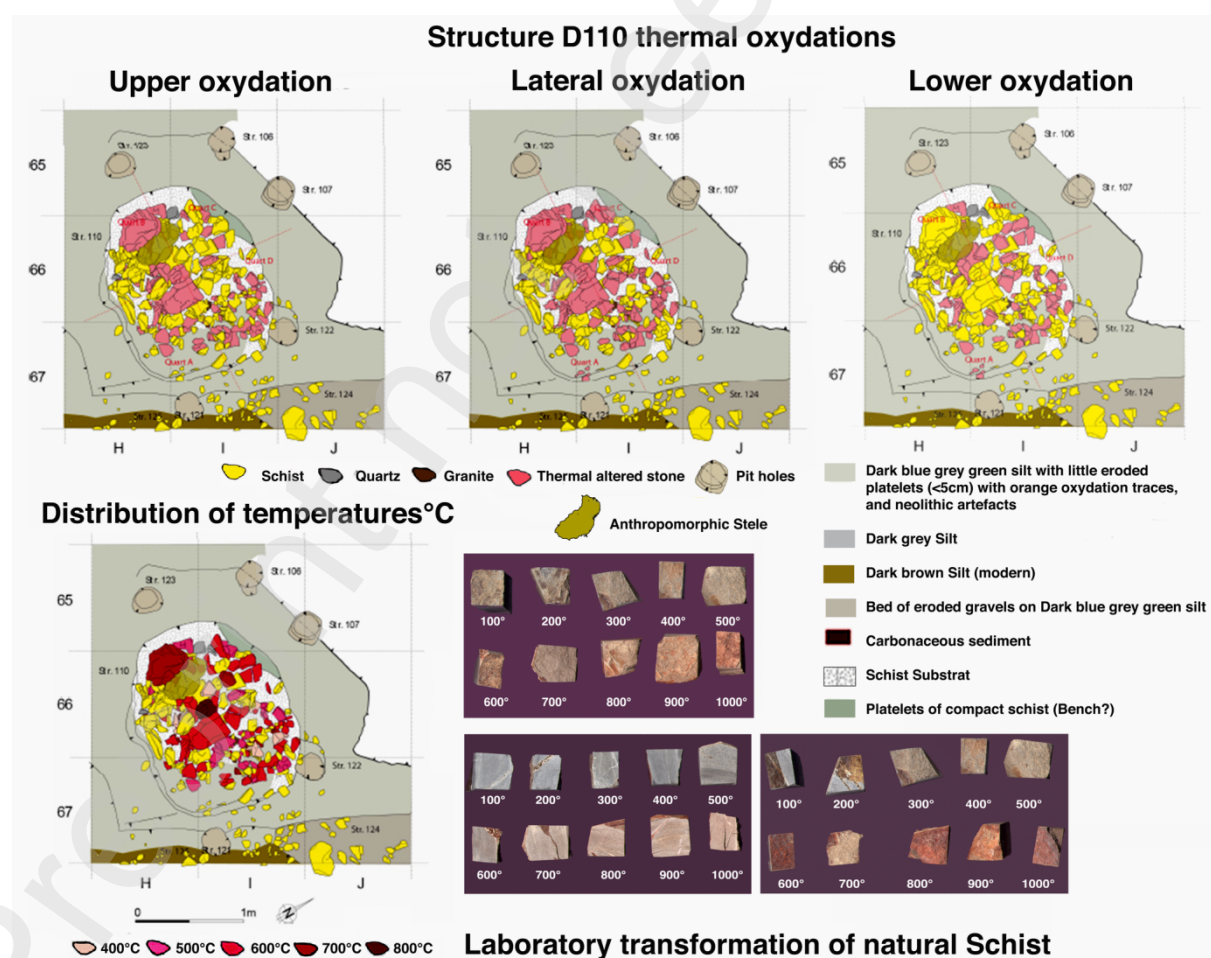


Fig. 15 Distribution of oxidations and temperatures into stones of the structure D110 from Lillemer and laboratory results of stones transformations under heat (from Lucquin et March 2010 in Bizien-Jaglin 2010 with modifications)

The analysis of the organic matter in the sediments of this structure reveals the presence of lipids of animal and vegetal (angiosperms) origin. The lipids of animal origin identified here are associated with the presence of ruminants. Unfortunately, the remains of charcoal in this have not been studied, which prevents us from confirming the hypotheses related to the presence of lipids and the types of fuels used.

Other stony pit hearths of smaller size, such as structure F5 (0.75 x 0.60 cm) which was excavated in the schist substrate (11 cm), show a small extension towards the north characterized by a greater depth reaching 30 cm. Another particular characteristic of this structure is that the burnt schists have spilled out of the depression and extend 1.50 m along its major axis. This change in size and distribution of the stones is evidently related to a change in mode of use of the structure, even though its function may have remained constant. The differences in mode of use have to do with the extension of the surfaces potentially available to transfer heat. This structure contains a sediment with partially altered plant residues and heated stones containing lipids, testifying to the use of these stones as a heating element for grilling. Cooked foods correspond to meat from ruminants and more specifically from cervids.

Thus, the study of each of the hearths reveals a different method of cooking. The fire structure located in the outer zone is found on an access pathway built over the marsh (archaeological survey 2), showing obvious traces of cooking at a high temperature indicating grilling or roasting. The pile found in the vicinity of the fire structure could be part of a suspension system (spit roasted cooking). This hearth contains cooked animal products that could be attributed to cervids and/or cattle. The fire structure from des "Hauts zone" of the site located in the mound can be easily interpreted as having been used for grilling cervid meat on heated stones. Finally, the techniques used for the "Haut Charles" fireplace on the embankment are less clear, but can be linked to methods using more embers rather than heated rocks for the cooking of cervids and/or cattle.

The data from the ceramic contents show certain differences between the foods cooked directly or indirectly in the hearths and those cooked in ceramic containers. These differences lie mainly in the presence of foods of plant origin. The ceramics are systematically associated with plant matter including grains and leaves and, more precisely, some cereals and cabbage, rhizomes, carrot leaves and other vegetables. The lipids of animal origin are characterized essentially by lipids from bovines or cervids, which were cooked directly or indirectly both in the hearths and in ceramic containers (Lucquin, 2007, Lucquin and March, 2005, 2006a et 2006b 2009 et 2010).

Other activities related to the use of fire were also located in the village, such as the preparation of glue for making weapons with beeswax or the preparation of funeral offerings from the remains of birch bark.

Finally, during the excavation, a well delineated layer of burnt clay was found in entrance A of the site in a slope area characterized by a mixture of oxidized clay residues. The oxidized clay plates show substantially different hues in a secondary position, thus ruling out an on-site combustion phenomenon. This characteristic in the construction of the embankment would also imply that a large mass of sediments was burnt elsewhere on the site prior to its use in the construction of the embankment, suggesting the reuse of residues from major combustion episodes due to accidental or intentional fires on the site. (Fig.16).



Arzon area Level at the entrance «B» of Lillemer Site @Luc laporte



Entrance B Arzon area : collapse of sometimes reddened bricks @Luc laporte



Excavation of the southern part of the talus: oxydate clays from Arzon @C. Bizien-Jaglin



Schists scoria slabs over a charcoal wood layer burned roof from an arson @C. Bizien-Jaglin

Fig 16 . Arson traces from Lillemer site Parcel 733 (from Bizien-Jaglin et al. 2009 et 2011 with modifications)

The Lillemer study shows us how the same technique of using heated stones as radiant elements for cooking and other purposes could be employed in domestic activities. In any case, even if these activities were detected inside the “home spaces”, they reflect the diversity of fire uses that can be observed in a village where the different exterior spaces are dedicated to many activities that could be associated with other uses of thermal energy. These examples show how, in the same kind of society, fire-produced thermal energy could be based on the same knowledge but for different tasks. This implies that, during the Neolithic, fire pit structures with heated stones continued to have domestic, technical and ritual uses; they could be employed for different cooking techniques, leading to the appearance of different forms of structure with different histories in relation to different social spaces. A question arises about the stewing techniques evoked in the preceding cases: why are these techniques not identified in the village? This situation implies that these technique were used only in particular cases associated with social behaviours external to the village and are related to collective practices rather than every day or domestic activities. And, even if this were the case, why are there no large fire pits or domestic structures that could be related to cooking ovens. This might be explained by the geological nature of the terrain that could hinder the use of these kinds of fire structure, due to the mineralogical or natural substrate characterizing the internal and external parts of the Lillemer village.

A question arises regarding these social behaviours: if the structures were used for a short time in everyday activities, they should produce a large amount of combustion residues and related heat-transformed materials. This also implies a great consumption of resources, such as stones and wood, as well as food that is not rejected into the domestic space. Once again, this reflects the exploitation of local resources for these activities, which are also connected with each domestic fire structure present in the village. We do not know how these fire

structures were organized and positioned in the more permanent spaces or whether some fires could have been accidental and others deliberate implying the use of fire as a weapon.

As far as the use of thermal energy for the production of ceramics is concerned, no workshop or oven dedicated to its manufacture could be detected in any sector of the site. This suggests that ceramics were prepared on a small scale on open stoves. Unfortunately, we have not been able to study any stove related to these characteristics.

All the above situations imply a social organization that can exploit thermal energy but also a great number of fire-related activities having different rhythms of use related to their functions. How can we interpret the organization and use of these resources according to the social organization of agropastoral societies that continued to practice many hunter gatherer traditions?

The following example shows how these societies use the same thermal know-how for other purposes at another scale.

2.4 Intra site and inter-sites histories : the case of heat stone pit hearths in megalithic sites near Carnac

Returning to the association of Polynesian ovens with ritual practices in the Bronze and Iron ages, we can evoke the example of the batteries of fire stone pit hearths found at three different Middle Neolithic sites: ZAC de Montauban at Carnac, Le Mané Roullarde at La Trinité-sur-Mer and Parc Belann at Carnac. These pit hearths are isolated from other types of archaeological context and are situated near megalithic alignments, gallery graves “*tombes à couloir*” or burial mounds “*tumuli*” in the Gulf of Morbihan region of France. They have also been studied in preventive operations (Hinguant et al. 2010, Fromont et al. 2011, Toron et al. 2017). These three sites were characterized by the presence of batteries of fire structures vestiges. (Fig. 17)

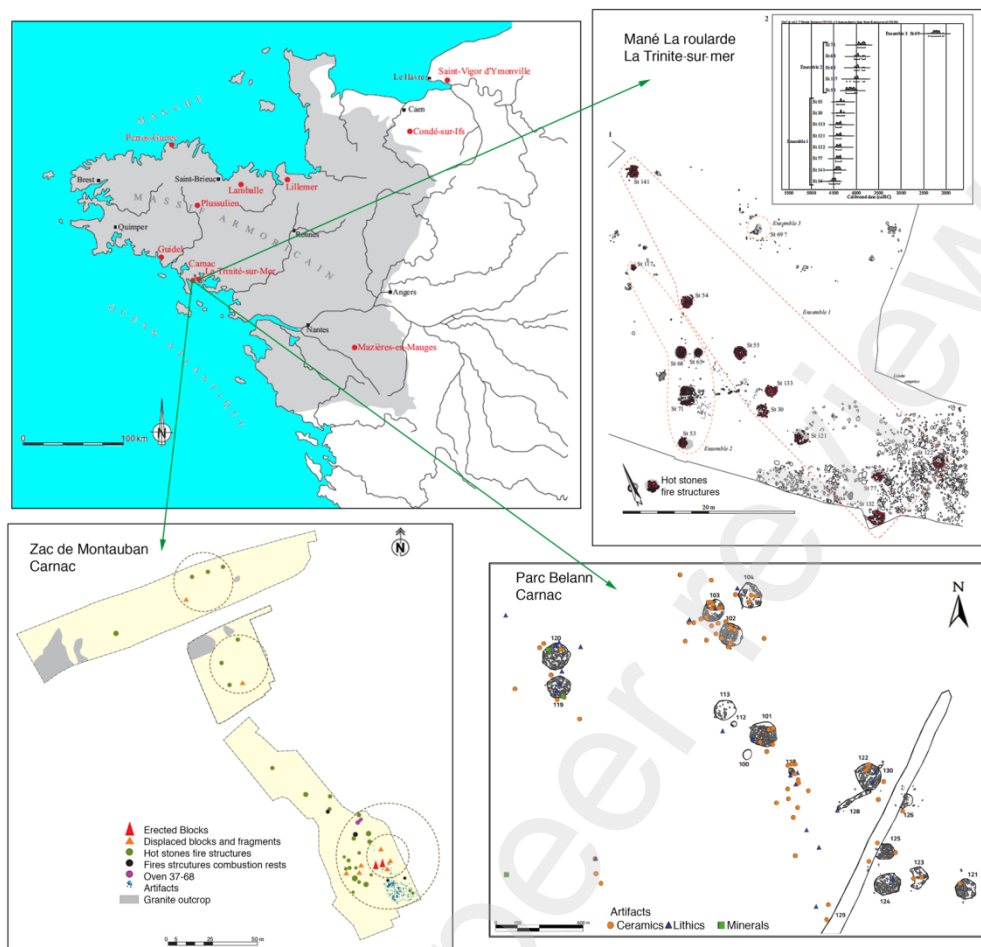


Fig. 17 Fire structures batteries organisation plans from Zac de Montauban, Mané la Roularde and Parc Belann Sites at Brittany (France) (from Hinguant et al. 2010, Fromont et al. 2011, Toron et al. 2017 with modifications)

In Carnac, and more broadly in the region of the Gulf of Morbihan, the Neolithic is above all marked by the omnipresence of megaliths (menhirs, dolmens, gallery graves, etc.). Then, the main question is whether the remains firstly discovered at the Montauban site are related to the rich Megalithism of the region (the Kermario alignments are 1 km to the north and the Saint-Michel tumulus 1 km to the west) or linked to the habitats or activities of the Neolithic builders. A second question is: what kind of activity was practiced on these sites in relation to these symbolic contexts? The problem of the ritual use of Polynesian ovens emerges once more and leads us to consider the nature of their functions. Another objective of our studies was to try to determine whether or not the mode of functioning of these structures could be linked to ritual activities as is the case with Polynesian ovens and their related social practices, even if any attribution to this concept is ruled out according to the typological classification and description of the structures described (Fig. 18).

The operations carried out at these sites out made it possible to apply different methods linked to the reconstruction of human activities related to fire. In addition, an excavation procedure was followed to analyse the formation processes of sediments in these structures, to clarify their stratigraphic sequence and applying micromorphological studies in some cases (Montauban 1/31st, Mané la Roularde (2/15st) and Parc Belann (3/14st), The residues of wood use and the relation between these resources and their selection as well as the behaviours related to exploitation of the paleoenvironment where also studied from different structures Montauban (18/31st) Mané la Roularde (8/15st), Parc Belann (14/14st).

At Montauban (22/31st) and Mané la Roularde (5/15st), these methods were accompanied the analysis of the material used for their construction and followed by two

different analyses of the distribution of thermal alteration observed on rocks and sediments. At Montauban, this study was aimed at understanding the extraction of these stones and their alteration, while at Mane the objective was to understand the thermal histories of each structure.

As in previous cases, these methods were accompanied by the analysis of the lipids found in some of these structures (Montauban 7/31st and Mané La Roularde 5/15st). This approach was aimed at interpreting the possible functional aspects of these structures and supplementing the analysis of the taphonomical and formation processes. Unfortunately, these last two methodological approaches were not applied at Parc Belann.

The stratigraphic position of the fire structures on the Montauban site prompted us to ask for a dating effort in this specific case. Therefore, a systematic programme was implemented to date the majority of the structures on this site, to clearly define the periods of fire preparation and use. Prior to their excavation, the structures were assumed to be contemporaneous, so dating was needed to check this hypothesis but also to analyse the phases and patterns of use of the batteries of structures at the site. This strategy was followed at Mané la Roularde and at Parc Belann, even if it was not applied to all the structures related to the use of fire and heated stones at each site.

At Montauban, 26 heated stone pit structures were studied by different methods set up by mutual agreement, to which are added 1 furnace and 4 combustion waste pits, which brings to 31 the number of structures linked to the fire at the site (Hinguant et al. 2010). It should be mentioned that only one structure (n°54) could be studied by micromorphological, anthracological and biogeochemical analyses. Eighteen structures were dated, demonstrating that these structures were not all contemporaneous. The dating results cover a period ranging between 4900 \pm 40 BP and 6930 \pm 40 BP, within which we can recognize at least five phases: a first around 4900 \pm 40, a second between 5300 and 5400 \pm 40 BP, a third between 5540 and 5570 \pm 40 BP, a fourth between 5690 and 5875 \pm 40 BP and finally between 6430 and 6930 \pm 40 BP.

The fourteen structures dated at "Mane la Roularde" are grouped into two phases: between 5740 \pm 40 and 6190 \pm 40 BP for set 2 and between 6219 \pm 40 and 6540 \pm 40 BP for set 1, which places them between the fourth and fifth phases recorded at Montauban.

Fourteen heated stone structures were found at Parc Belann, circular to oval in shape, and composed of a cluster of granite rocks covering a more or less marked layer of combustion residues and anthropized sediments. Seven structures dated by C14 range in age from 5596 \pm 28 BP (4486-4358 BCE) to 5278 \pm 37 BP (4232-3993 BCE), which means they belong to the Middle Neolithic period essentially within the Middle Neolithic I. This makes them contemporaneous with structures of Montauban and Mane la Roularde, bracketed between the most recent phases of Montauban and the oldest structures dated at these two sites. (Fig.18).

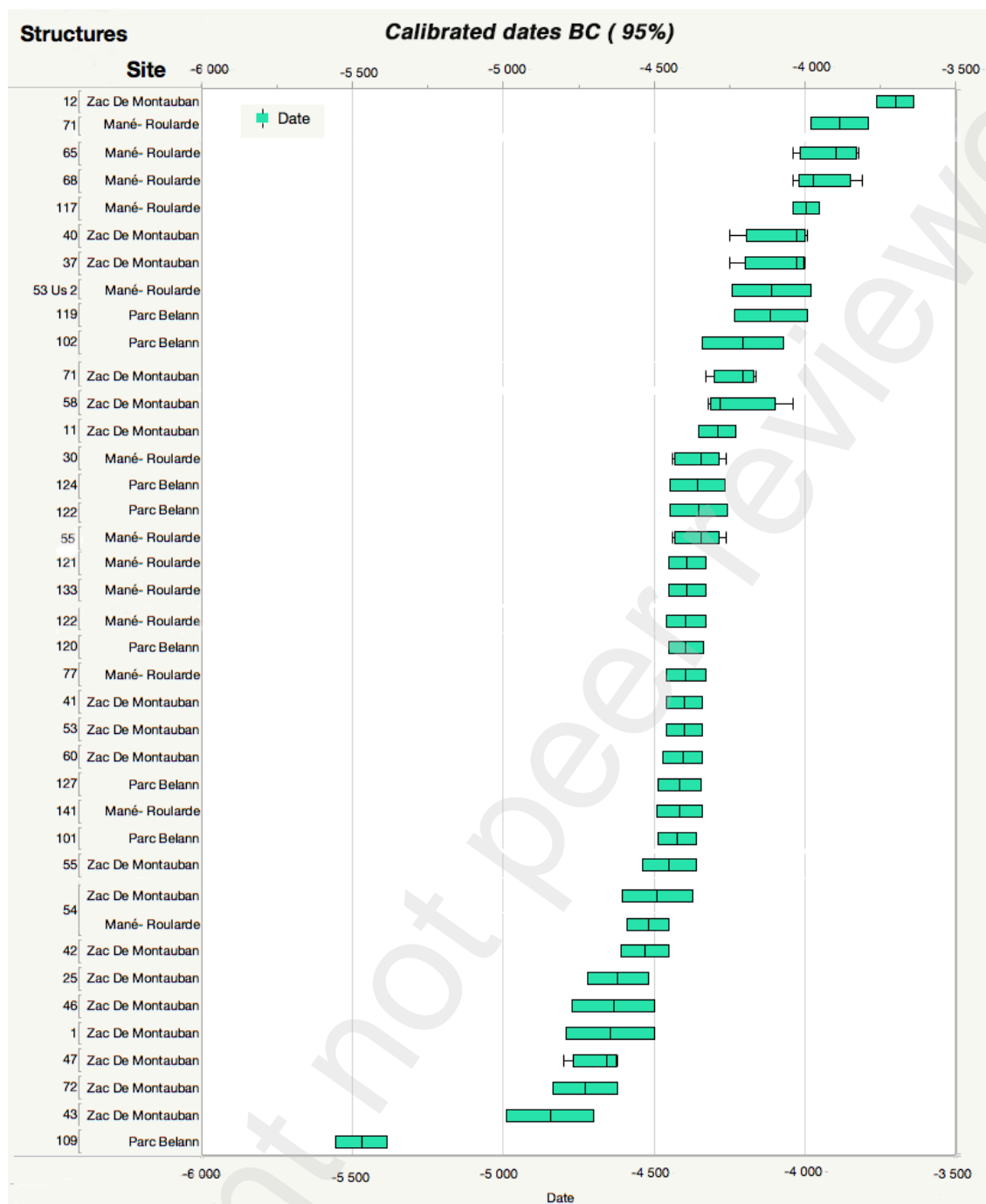


Fig .18 : BC Calibrated dates (95 %) form heated stones fires structures at Zac de Mantauban , Mané La Roularde and Parc Belaann (Hinguant et al. 2010, Fromont et al. 2011, Toron et al. 2017).

These data show that the studied sites were dedicated to a similar activity for a very long period with recurring reuses and showing fluctuating and more or less distinct patterns of use at each site. Sometimes, one site succeeds another, as we can see at Montauban and Mane la Roularde, while other sites have simultaneous occupations.

Whether in batteries or sometimes isolated, the mostly circular or sub-circular structures of the ZAC of Montauban are characterized by fairly standardized dimensions (approximately 1 m in diameter and 10 to 15 cm of preserved depth), with a filling of large contiguous stones more or less affected by the action of fire. Mane La Roularde shows a differential classification

of the structures with the presence of rectangular and square forms compared with the predominant circular forms observed at Montauban. The dimensions of the circular structures are a little greater than the structures found at Montauban. Parc Belann also shows differences in the form of the structures, which are sub-circular to circular having medium dimensions slightly larger than at Montauban or Mané la Roularde. In the same way, fewer structures are found with central empty spaces, which has led us to classify this arrangement of rocks as aureole-shaped in the case of Montauban.

The materials used for these structures are very similar at the three studied sites, where granite stones (extracted blocks) were chosen in majority but sometimes accompanied by quartz pebbles or schist slabs. The characteristics of these stones vary between the different structures, showing differences in their dimensions and arrangement. While in all cases stones cover the charcoal residues and the traces of oxidized sediments, the structures show different arrangements covering small depressions or lying directly above the soils. These structures show traces of reutilization or different arrangements sometimes with wide spaces in each heated stone concentration. At Montauban, these differences lead certain authors (Hinguant et al. 2010) to establish different categories according to the final position of stones in each structure: the term “aureole” is used to describe the position of stones encircling an empty space, while the term “bouchon” [Complete filling] “bouchon partiel” [partial filling] is assigned to structures in the depression under the stones that were completely or partially covered. These different positions accompanied by the study of their stratigraphic position and thermal alteration distributions in stones and soils induce also to different interpretations about the mode of functioning of these stones arrangement conducting to suppose that fire was generally lightened over the stones but sometimes the stones were contained in the depression while in some cases as in Mane La Roularde or Parc Belann heated in an open air system changing their mode of functioning but also the way in that these structures reconstitute the heat provoked by combustion.

The distribution of thermal alteration was studied using the presence or absence of oxidation traces in stones in terms of different rationales for Montauban and Mané La Roularde and their total absence at Parc Belann. This makes it difficult to make a detailed comparison of the mode of functioning between the three sites. Following the results from the first two sites, we could only infer that these stones were generally not or only partially heated above 300°C. Only a limited number of the stones were totally oxidized, showing that their exposure to heat was limited in time and intensity, but also that they were in general heated mostly by fires lit over the stones and covering a limited surface-area related to the surface occupied by each stone arrangement. While in most cases stones are oxidized in the central part of the arrangement of stones, some structures show a lack of stones heated above 300°C in the central part of these accumulations. These differences in their final state could indicate different modes of functioning and/or different micro-histories. It is interesting to note the absence of accumulations of discarded burnt stones, suggesting that the reuse of these structures - if it existed - occurred in the same place or in new similar structures.

The few micromorphological analyses show only traces of disaggregated oxidized soils under the stones, as well as the distribution of charcoals compacted above them. In any case, we can observe a stratigraphic sequence with an oxidized substrate having a thickness and regularity similar to experiments in which the fire was burnt directly on the soil. These phenomena seem to indicate the absence of any previous fire of long duration in the depression, but could also indicate a rapid positioning of stones above the fires leading to their rapid extinction. It is important to mention that this absence could be also be related to taphonomic processes, as can be inferred from the few micromorphological analyses carried out. These analyses also show that the substrate could have been perturbed following natural or anthropic

processes such as the reuse of these structures. Due to the fragmentation of these stones in relation to their extraction methods and the impossibility of refitting, we could not interpret the data in terms of heat stress fragmentation or the mode of functioning of the fire structures.

A more comprehensive study involved the analysis of wood employed as fuel for these different sites. These studies show a dominance of oak or broom/gorse that evolves with time associated with the different dated phases of the structures at Montauban, while oak is mostly dominant at Mané la Roularde and Parc Belann. The modification of species found at Montauban is linked not only to the established choices of fuel within the plant context, but also to an evolution of the forest of oak following its exploitation which led to its replacement by moorland in a period of 500 years. These plants are accompanied by other species in minor proportions that fluctuate in their utilization, such as the hazel tree, the Pomoideae (apple or hawthorn), the Prunoideae (cherry or plum tree) and the ash. This anthracological spectrum reflects the exploitation of a local forest and also a form of opportunism in selection that is adapted over time. The anthracological analysis supports the hypothesis of the use of small-sized wood in structures where an intense but short-lasting fire is probably wanted. The proposed mode of operation for these structures raises the question of the mode of functioning and intensity of exploitation in relation to the duration of each combustion episode and the consumption of wood at the local level as well as its influence over time on local plant resources in relation to the energy needs of these social practices. (Hinguant et al. 2010, Fromont et al. 2011, Toron et al. 2017).

Analysis of the lipid fraction in samples from Montauban and Mané la Roularde shows differences between the structures studied at each site. The seven studied structures at Montauban have a predominance of plant-derived material in their anthropic filling and the lipids fall within a fairly homogeneous composition. The stones also display significant differences in their lipid composition in relation with the soil composition, showing again that food fats can be preserved in stones that were in contact during cooking procedures. The animal fats found in these structures could come from pigs or cattle. In view of the lack of correlation with the kind of fuel found and the lipids distribution in each structure, we can propose a hypothesis that evokes the utilization of stones for cooking meat and also vegetables in some cases. Such a procedure could make use of a vegetal cover to produce an oven effect to produce the vegetable lipid concentration found in the brown and charcoal layers of the studied structures. Animal traces were not found in the natural yellow-grey sandy clay silt layers that surround the structures, thus confirming the anthropic origin of these lipids. The higher abundance of animal remains at Mané la Roularde, differentiates these structures from Montauban.

Finally the domestic or cult, culinary stew options of vegetable or animal foods are proposed for all the sites presented, including the possible reuse of structures at each site, focusing on the intensity of activities related to at least five phases of activity detected related to this type of combustion structures with heating stones, cluster in this part of Morbihan (Hinguant et al. 2010, Fromont et al. 2011, Toron et al. 2017).

3 Discussion and conclusions

As we can see from this last example, the reasons behind the use of combustion structures, above all their ritual or symbolic significance and their relation with megalithic practices, are still not clearly explained. Many hypothesis could emerge taking in account the absence of any trace of individual inhumations or incinerations near these structures, even though they are geographically closely related with megalithic structures (e.g. tumuli, gallery graves).

Some questions arise about energy management, such as why spend so much energy in gathering rocks without any specific purpose? Even if the use of stones for storing thermal energy is known from prehistoric periods, why did this initial domestic function evolve to the use of fire practices in other activities that contributed to preserving the social structure of each group? At the same period, the domestication of plants and animals was changing our mode of social production and reproduction. Maybe these changes in our social behaviour led to the progressive abandonment of these ways of cooking in our everyday procedures, following the acquisition of new techniques related to the presence of recipients. The way of cooking with heated stones became slowly dedicated as a reproduction of ancient traditions, in particular ceremonies that are integral to the structural or super structural system (in terms of social and cultural reproduction) as seen in different ethnological examples which give us the possibility of preserving our knowledge related to this practice.

But what is the symbolic reason associated with the superstructure that justified these supposed rituals? Could they represent seasonal rites, related to agricultural and animal reproduction cycles, or are they related to periodic social events such as the death of a social chief, symbolic pilgrimages or other types of ceremony? Otherwise, these activities could be associated with everyday agricultural practices or the extraction of granite for the construction of megalithic monuments. In all these cases, indirect cooking activities such as stewing, roasting, boiling or grilling became part of some other social activity. However, all these possible activities are related to the use of energy for maintaining social relations and reproduction of the social system, as was the case when we first started to cook our foods.

Even if these questions remain unresolved, the inter-site analysis of heated stone pit hearths in the Gulf of Morbihan region reveals the alternation and periodicity of fire use events. These results show that, in certain cases, one site can reflect a more intense utilization while the others remain unoccupied. Moreover, in view of the dating of certain structures, the fire practices could have been carried out at different sites simultaneously, putting them in relation at a microregional scale (even if not all the structures have been dated, as is the case with Parc Belann. This stresses the need to analyse these kinds of fire practice at a regional and microregional scale, systematically following the same procedures and methods to reconstruct the history of these particular uses of thermal energy. Furthermore, the hypotheses that are evoked concerning their functions and related social behaviours refer us directly to the batteries of heated stone fire structures of the Bronze and Iron Ages in other regions of France discussed in this paper.

If we wish to understand the history of the social control of thermal energy in the past, we should recognize the importance of connecting all the different data collected according to a common rationale. But we also need to use an approach that puts into practice real-life experimental archaeology and laboratory analyses. Such an approach would allow us to interpret the archaeological context in the light of experimental data, thus providing answers to questions such as the mode of functioning of combustion structures, as well as their function and the duration of burning.

3.1 Difficulties created by specialization and the analytical decomposition of the subject of study

The series of case studies presented here, to which we could add many other examples casting doubts about the function of this type of combustion structure (Dubesett 2021), highlight the practical difficulties encountered when reconstructing the social history of the control and application of thermal energy processes, as well as the technical, social, symbolic and paleoenvironmental consequences. In most cases the comparison between the structure studied in different operations are evoked as a difficult action following the different

approaches follow in the excavation methods , description and analytical methods applied as the function inferred following these divers criteria (Blanchet et Le boulanger 2015, Dubesett 2021.).

In our opinion, these difficulties can be summarized as follows:

As we pointed out many years ago (March et Wunsch 2003), the use of analytical methods without a general hypothetical framework to coordinate their use and interpret the meaning of the different results not only fails to answer our questions about the use of fire but can also obscure rather than clarify the problems we seek to resolve. It is also necessary to understand the interactions of these methods in relation to the questions raised.

In most studies about these kinds of structure, the rationale involving transformation by heat has led an analysis of the various elements transformed during the use of fire. However, the logic behind this analysis is not the same as that applied to studying structures related to fire production. In this way, combustion structures have been segmented according to the elements making up the structures. But this approach does not follow the systematic methodology required to understand their mode of operation and the control of heat processes. This would allow us to understand the concepts applied for the production and application of thermal energy and elucidate the different hypotheses evoked to explain the final state of the various components of these structures.

This segmentation is also related to the number of disciplines involved (dating, anthracology, micromorphology, mineralogy, organic and mineral chemistry, physics of porous media, and heat transfer, etc.), whose practical procedures have been oriented towards different problems. Thus, is necessary to develop a combined approach guided by the same hypotheses so different methods can interact in the same sense. Difficulties are created due to the lack of input from experimental approaches, which are needed to understand the interactions of the different processes related to fire use and the formation of combustion structures. Thus, when rebuilding to understand, it is essential to follow experimental procedures to test our hypotheses.

In recent years, the development of scientific hyper-specialization is linked to increasing competition between the different specialties to guarantee credits for resources and employment in each discipline. At the same time, the process of hyper-specialization leads to a temporary departure from the initial objective, a real “tunnel of hyper-specialization” affecting every line of research, caused by the need to solve problems inherent to these specialized fields. In this way, we need to go back to our initial questions that could lead to the search for new methods to explore the relationship between humans and the exploitation of thermal energy. The process of hyper-specialization has gradually resulted in a lack of dialogue and interaction between the various specialists who are increasingly subjected to contract management or project-based organization systems, This economic model has spread to the entire academic system, but without the necessary coordination to address the different problems in archaeology as well as in other disciplines. This has led to the multiplication of parallel studies carried out by specialists who do not communicate among themselves, bypassing generalist archaeologists who lack sufficient knowledge or training to synthesize the issues at stake.

Similarly, the economic restrictions linked to the contract-based system and the conduct of rescue operations prevent us from having the necessary resources to carry out systematic studies on the sites concerned. In turn, these restrictions reduce the possibility of implementing more complete studies due to the complexity and the time required to carry out such operations. In the same way, there is a tendency to apply analytical techniques to make the work performed appear more scientific. But this often leads to a mere provision of services, which reduces even more the possibility of dialogue and synthesis between the different hyper-specialists hired to answer the different questions. All these problems, and above all the pressure to process the actual amount of heritage findings that require a solution, are reinforcing our traditional

inductive approach, which frequently leads us to ignore the broader theoretical perspective for addressing these issues.

3.2 Towards a new theoretical perspective

Even if the number of studied sites with this kind of structure has increased due to the progress and multiplication of preventive or regular excavations, we still remain faced with the same problems related to the empirical generalization of results obtained for a limited number of structures. Consequently, hypotheses about their significance still lead us back to the original questions.

The study of different sites such as Lillemer or Pézou show us how fire-related activities and the use of heated stones pit hearths in complex contexts can open up the possibility of other types of behaviour practiced in open spaces. The studied sites include Neolithic villages and domestic rural spaces from different periods and contexts, such as Le Closeau, Hauts de Feuilley, Champ Vallet and three sites from the Gulf of Morbihan. These latter are situated far from the domestic or village contexts mentioned here, but show similarities with other contexts in which similar practices were carried out on hearths using techniques with heated stones while being also used for cooking food or other practices.

However, the micro-histories of each of these structures show particularities in their forms and the selection of raw materials as well as in their modalities of use and operation. These differences are also reflected in the analysis of the processes occurring at each site where similar structures may have significantly different histories. This helps us to reconstruct the entire operational chain used for the management of thermal energy and could even open the way to understanding of the social space and the persistence of certain techniques over long periods.

Likewise, the archaeological contextualization of combustion structures suggests that, even if their use was intended for similar activities, the nature of these activities could be different according to the sites and structures studied. But we need to avoid repeating empirical generalizations following the criticisms about the systematic extrapolation of the “Polynesian oven” category. Proposing a generalized interpretation for such structures could be misleading if it is based on a “common sense” extrapolation of the supposed function of a combustion structures that remains to be clarified. At the same time, this example shows that our interpretation of combustion structures is linked to understanding the control of thermal energy and the significance of archaeological remains. Our approach should be focused on the social behaviours of the different groups involved and their social modes of production and reproduction. Without this rationale, reconstructions of the activity or micro-history of each structure can be considered as merely anecdotal, contributing little to our understanding of the behavior of human groups in different contexts.

This situation is related to the lack of questions about the use of thermal energy in each type of society. And also with the relationship between general archaeologists and specialists, since the development of specific problems such as the one we are evoking is extremely difficult, if the general archaeologist does not include this fundamental question in the objectives of understanding the social behaviour of each human group in the past. These problem increases if generalist only consults specialists separately and in a timely manner with the aim of answer specific questions without understanding the complexity of the studies needed to interpret the significance of data specifically related to the use and traces of fire in each context.

Moreover, our research should also be redirected beyond the study of combustion structures as such, to investigate the human evolutionary process and its relation with the control and the application of thermal energy. This would allow us to rescale and take another step in our approach to these problems.

As a result, we consider it essential to:

- tackle the problems related to hyper-specialization by adopting a truly transdisciplinary approach;
- systematize the study of sets of structures with the same methods;
- continue with our experimental effort to solve the interpretation problems but leading systematic experimental approach's following the thermal transfer logic and its consequences in the structure components and environmental contexts to could finally rebuild for understand the formation processes of this different kind of structures
- define the questions in an appropriate manner and insist on the importance of understanding the significance of each set of structures to rebuild the history of thermal energy control and its social application;
- return to the human as the subject of our research and analyse the cultural aspects of general thermal energy processes;
- develop a methodology to explore and reconstruct the social significance of thermal processes in the past, with implications for the future of our civilization;
- incorporate thinking about the different human modes of appropriation, production and uses of thermal energy as well as the strategies implemented by different societies to reproduce their practices and culture.

Therefore, we need to give priority to questions concerning the significance of fire use at the different levels of each society and cultural structure, considering both the infrastructural and ideological aspects.

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