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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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1 **RECONSTRUCTION OF CONTROL AND APPLICATION OF THERMAL ENERGY**  
2 **PROCESS AND ITS TECHNICAL, SOCIAL, SYMBOLIC AND**  
3 **PALAEOENVIRONMENTAL CONSEQUENCES**  
4

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8

9 **Abstract**

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

32 **Keywords**

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

35 **Highlights**

- 36 • Fires structures study methodology
  - 37 • Thermal energy history
  - 38 • Fire human uses
  - 39 • Heated stones fires structures
  - 40 • Thermal histories
  - 41 • Archaeological theory
- 42

43 **1. Introduction : Theoretical aspects**  
44

## 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

95 energy. We can evoke the relation between the social organization of residential spaces and  
96 architecture from hunter gatherer societies to states ones (Hough 1928, Wright, 1964 Leroi  
97 Gourhan and Brezillon, 1965, 1972, Binford, 1967, 1983, Yellen, 1977), its role in  
98 communication and territorial strategies, (Hallam, 2014) in passage rituals as cremations and  
99 ceremonies of inhumations (Rojo Guerra and Kuntz, 2002) or in seasonality rituals linked with  
100 agriculture and the cycle of life (Gonzalez Alcantud and Buxo Rey, 1997, Pyne 1949, 1997)  
101 redistribution of foods and salt production (Godelier, 1982) and finally the presence of fire in  
102 religions, myths and cosmovisions of all cultures in our planet (Frazer, 1930, Levy- Strauss  
103 1958, 1964, Goudsbloom, 1992)

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

107

## 108 ***2. Reading traces of fire use and their history: the case of “Polynesian ovens” in late*** 109 ***European Prehistory. Domestic, artisanal or symbolic significance?***

110

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

125 The concept of Polynesian Ovens was developed by the French school in the light of  
126 French colonial history (Wallis 1767 in Saint Perrier 1926, Daleo 1875 in Perles 1977), since  
127 these structures have been frequently compared in prehistoric studies with Polynesian domestic  
128 and ritual cultural practices. These first classifications were supplemented more recently by  
129 ethnoarchaeological projects developed in Polynesia by the “Prehistoric Ethnology” movement  
130 in the 1970s and 1980s, which included the first experimental and analytical approaches  
131 concerning these kinds of structure (Garanger 1973, Perles 1977, Orliac et Orliac 1980, Gascó  
132 1985, Orliac et Watez, 1989 Orliac, 2003 ).

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

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

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

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

163 During the Neolithic period in France, we observe the emergence of a recurring practice  
164 of using stones in gestures related to the use of fire in hearths of various shapes and sizes.  
165 According to the author's experience and bibliographic data, Neolithic hearths contain a  
166 selection of rocks in relation to their availability in the environment. Thus, we find hearths with  
167 granites, sandstones, flints or schists showing different forms and provenance (ranging from  
168 moraines, fluvial or coastal pebbles to blocks extracted from natural outcrops in different  
169 regions of France) (Laporte et al 2005, March and Lemoine, 2006, Philippe et al 2006, March  
170 et al 2007, Hinguant et al 2010, Prost et al 2010, Fromont et al. 2011, Prost et al 2011, Philippe  
171 et al. 2011, Lucquin and March 2010, 2012, March and Cordero 2013, March et al. 2014,  
172 Bemilli et al, 2015 a and b, Dron et al. 2003 Vaquer et al. 2003, Surmely 2003, Leroy et  
173 Lecoeuvre 2006, Marchand et al. 2009, Treffort and Alix 2010, Beeching 2017, Toron et al.  
174 2017, Chopin et al 2018).

175 For the Neolithic and more recent periods such as the Bronze and Iron Ages, other uses  
176 apart from domestic activities related to indirect cooking have also been evoked in the symbolic  
177 sphere. Such uses of stones include the preparation of collective meals linked to rituals of social  
178 reproduction and distribution of food (Hinguant et al 2010, Fromont et al. 2011, Toron et al.  
179 2017), and their association with funeral gestures (Hénon and Jacquet, 2003, Martin et al. 2005).  
180 Recent studies have associated this kind of structure with other functions such as grain  
181 preparation, burial rituals and domestic activities related to the indirect cooking of food  
182 (Dubesset 2021).

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

## 192 **2.1 Some examples of Polynesian ovens in the prehistory of France**

### 193 **2.2 Bronze Age pit fire structures using heated stones**

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

201

### 202 ***2.2.1 Sites of “Le Closeau” and “Les coteaux de la Jonchère”***

203 Our first project concerned the analysis of fire structures at sites from the Bronze-Iron Age  
204 transition located near the villages of “Le Closeau” and “Les Coteaux de la Jonchère” in a  
205 seasonal flooded zone near the River Seine (Hauts-de-Seine, France) (Durand et al .1997 and  
206 1999, March et al. 2003 a & b ). These sites are characterized by the presence of fire structures  
207 showing differences in form and composition that indicate their isolation from other cultural  
208 debris. This first preventive operation was an exercise to establish a protocol based on an  
209 interdisciplinary approach continuing previous studies applied to prehistoric hearths. Since it  
210 was impossible to analyse all the structures found at these sites, we focused on three different  
211 structures (1214, 1037 and 17) (Fig.1), where two of them (st1214 and st1037) could be  
212 characterized as Polynesian ovens. These structures are associated with culinary and domestic  
213 uses and we were able to attribute their “oven” function due to the presence of a large pit,  
214 generally oval to rectangular, full of cracked heated stones like their Polynesian counterparts.  
215 As we have demonstrated, associating one single form to a function or a mode of functioning  
216 is an incorrect simplification, because the reconstruction of these aspects can only emerge from  
217 a study of the specific history of each structure (March 1995 a et b , March and Wünsch 2003).

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

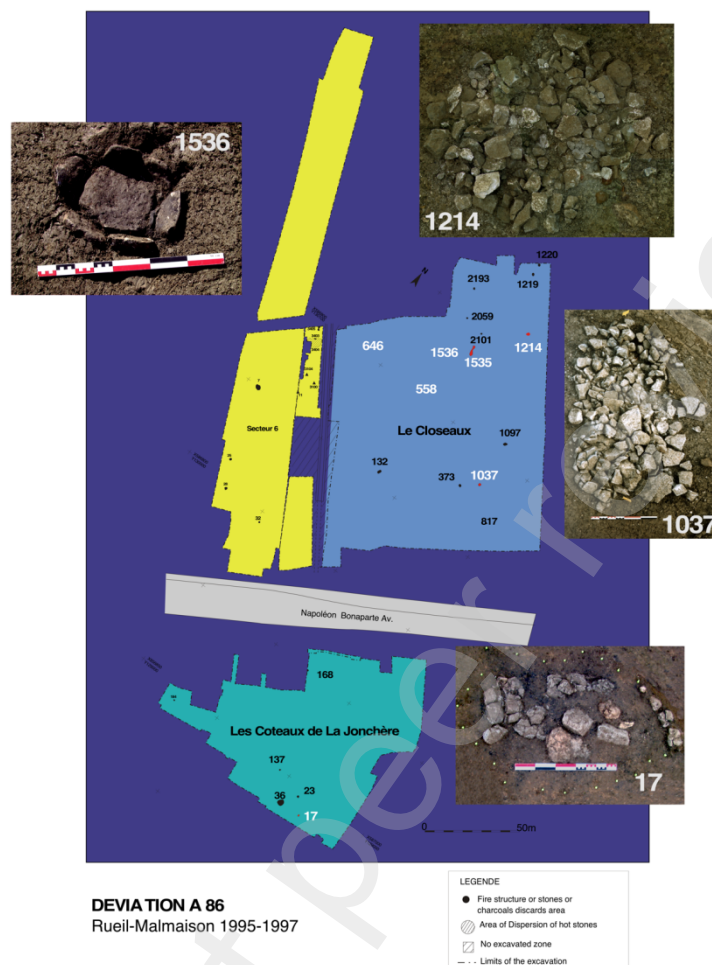


Fig. n°1 Bronze Age pit hearths fire structures using hot stones at Le Closeau and Les Coteaux de la Jonchère site (from March et al. 2003 b with modifications)

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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).

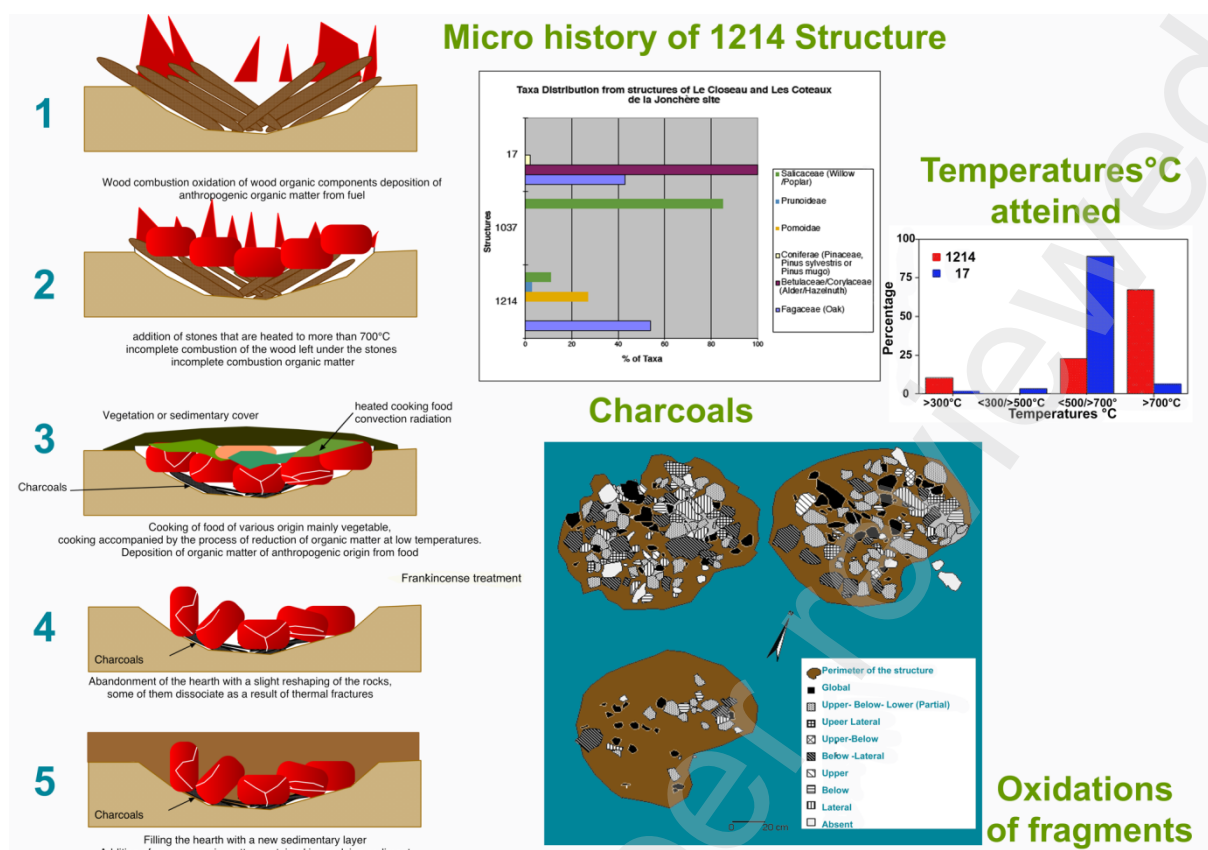


Fig. 2 Micro-history of the structure 1214 at Le Closeau. Examples of mode of reconstruction of mode of functioning based on anthracological data and heat alteration of stones (From March et al 2003a and b with modifications).

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 to suppose that vegetable lettuces were cooked in these structures. At the same time, we detected one unexpected molecule (methyl- $\beta$ -boswelliaonate), 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 archaeological 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

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

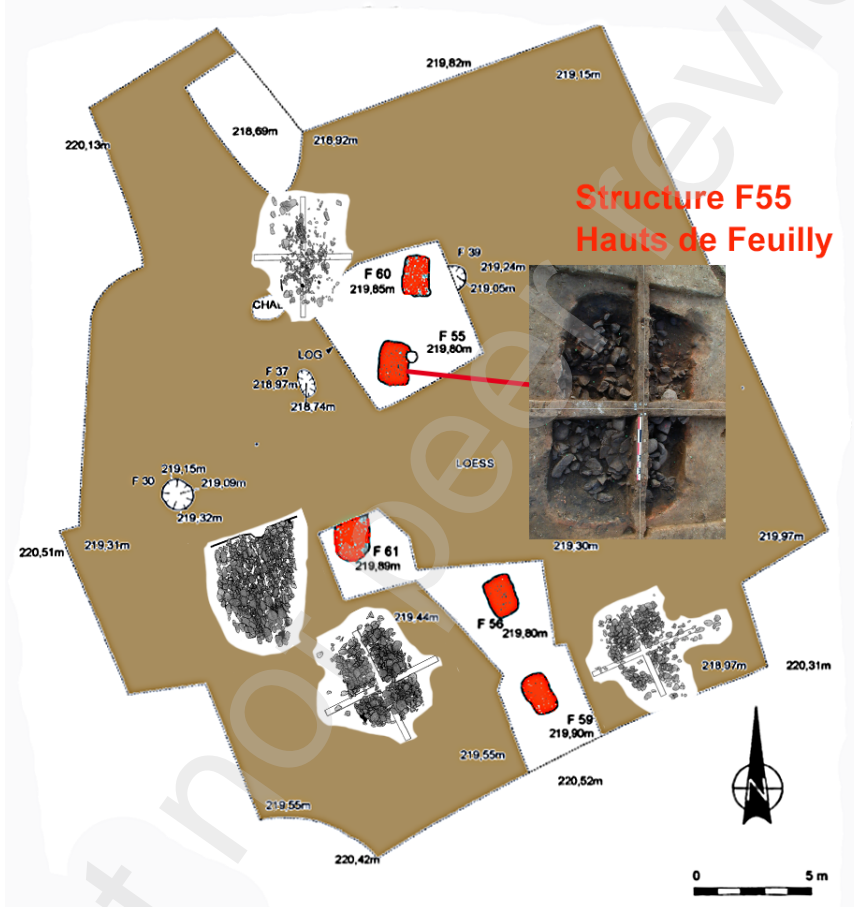


Fig n°3 Plan of fire structures at Hauts de Feuilley after P. Jacquet 2001a with modifications

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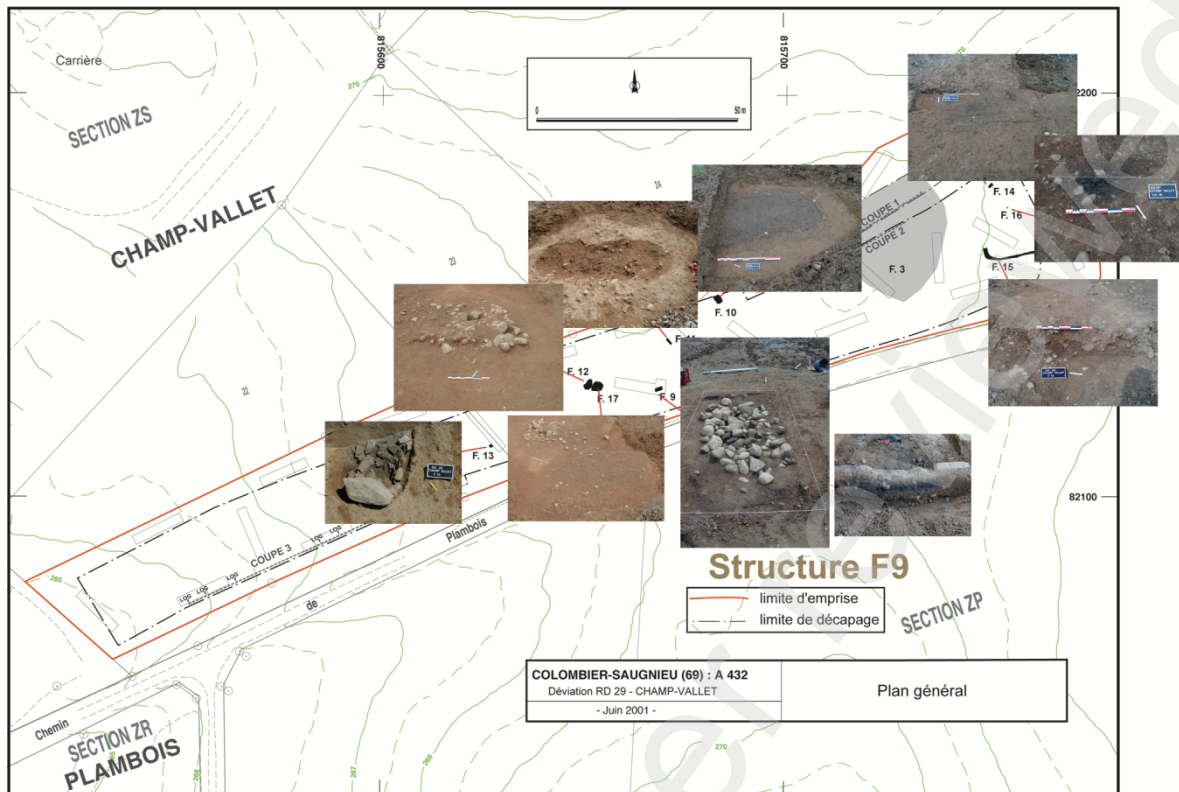
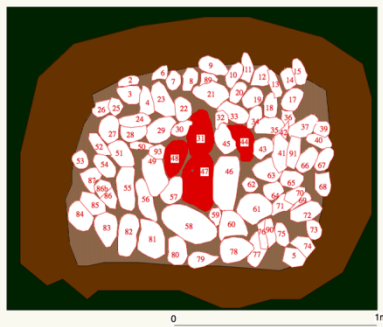


Fig n°4 Plan of fire structures plan at Champ Vallet after P. Jacquet 2001b with modifications

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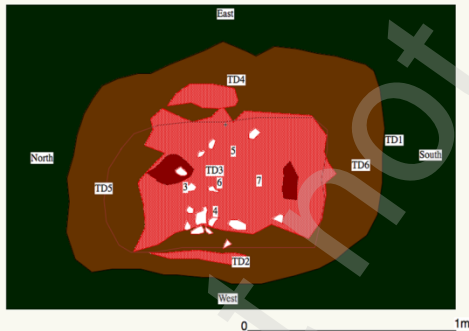
While the mode of functioning and eventual thermal efficiency of fire pits have been discussed - for example the position of fire related to the stones - their “thermal history” (March et al 1989) currently remains uncertain because, in most cases, there has been no attempt to apply experimental or analytical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



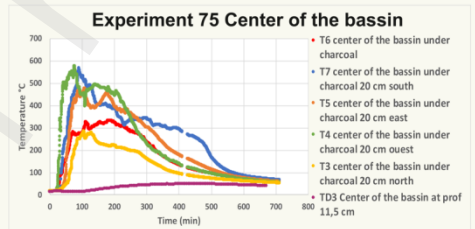
**Position of stones  
Thermal Measured  
With Thermocouples**

- Natural soil
- Perimeter of the bassin
- Perimeter of charcoal zone
- stones
- Stones with thermocouples

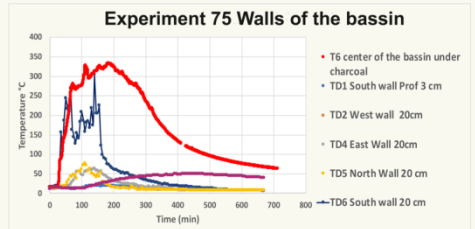


**Bottom of the bassin  
of the experience 106**

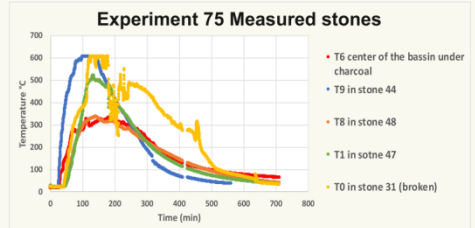
- Natural soil
- 1 thermocouples
- Perimeter of the bassin
- bottom of the bassin
- Oxidazed zone
- Fats concentration zones
- stone



**Experiment 75 Center of the bassin**



**Experiment 75 Walls of the bassin**



**Experiment 75 Measured stones**

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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

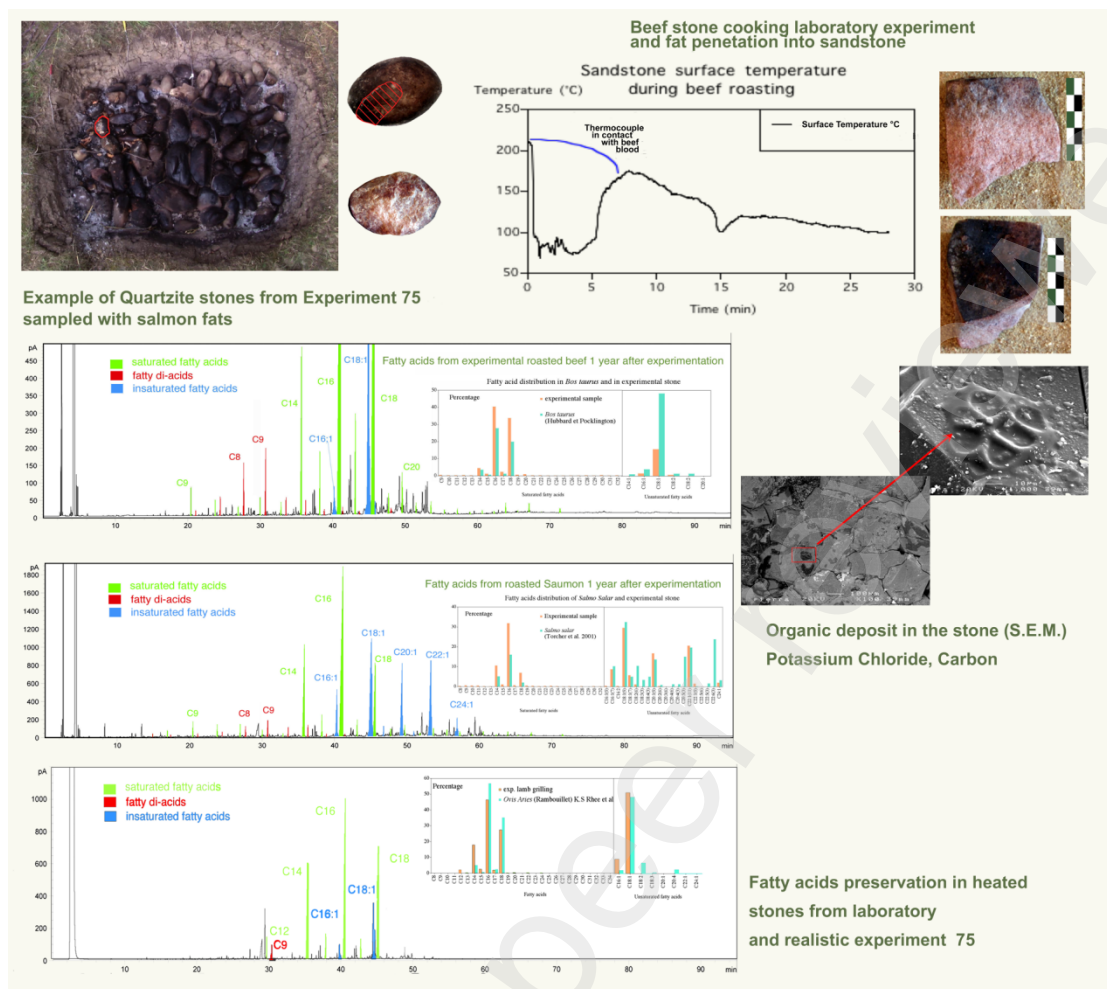


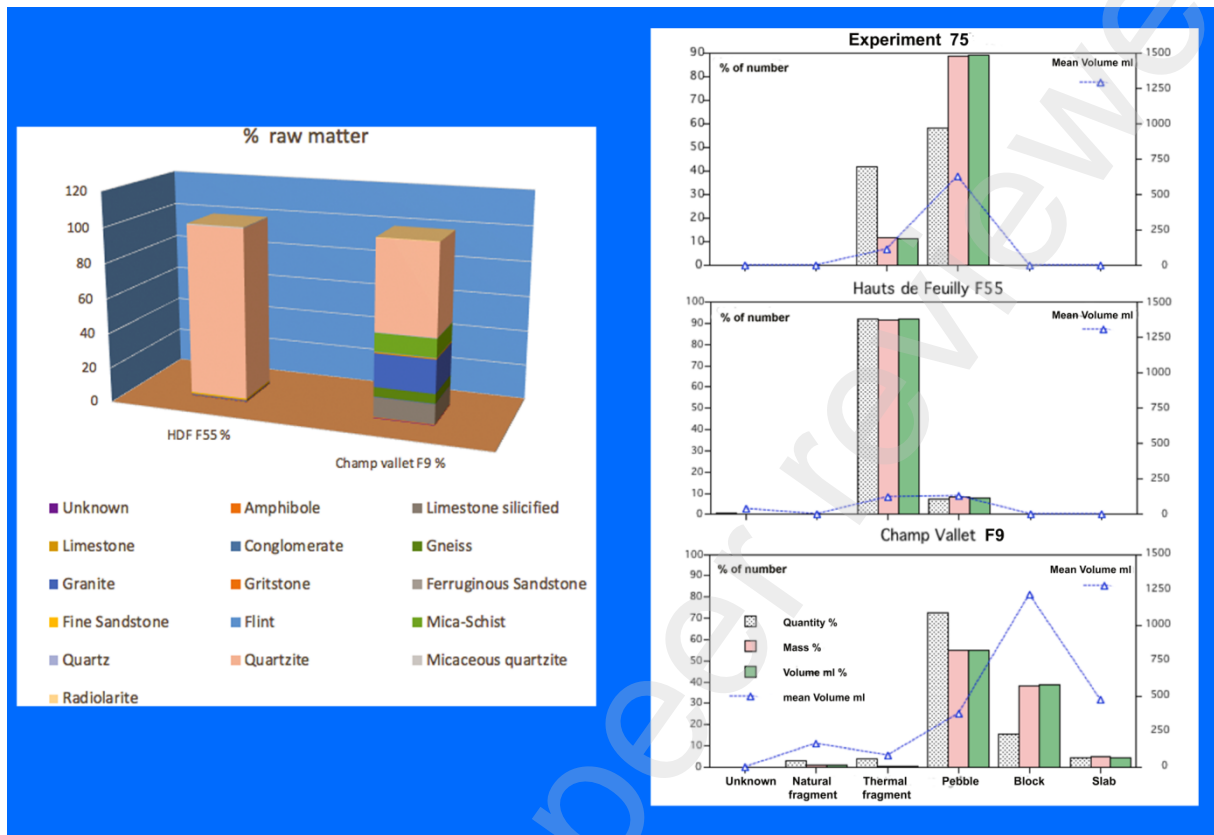
Fig n°6 Results of realistic experiment 75 and Laboratory experiment of fat penetration

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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

346 experiments carried out on similar structures reveal a contrast between the F55 and F9  
 347 examples, since the stones used only once in food cooking experiments have characteristics  
 348 intermediate between the two structures analysed here (Fig.7).  
 349



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 352 Fig 7 Raw material used at Hauts de Feuilley and Champ Vallet showing types and dimensions of fragments (length in cm)  
 353 compare with the Experiment 75 (100% of quartzite)  
 354

355 As regards the functioning of the fire during these different episodes of combustion, we  
 356 observe that the sediments at the two sites reacted almost at the same temperature, and were  
 357 oxidized at 300°C. On the other hand, we also find that higher temperatures were attained in  
 358 the F55 structure compared with the maximum in F9. Thus, the F55 structure would have  
 359 reached a maximum temperature of 800°C while the F9 structure would not have exceeded  
 360 500°C. The thickness of the alteration of the walls also appears to be a slightly different, ranging  
 361 between 4 to 5 cm in F9 at Champ Vallet and reaching 6 cm in F55 at “Hauts de Feuilley”.

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

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

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

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

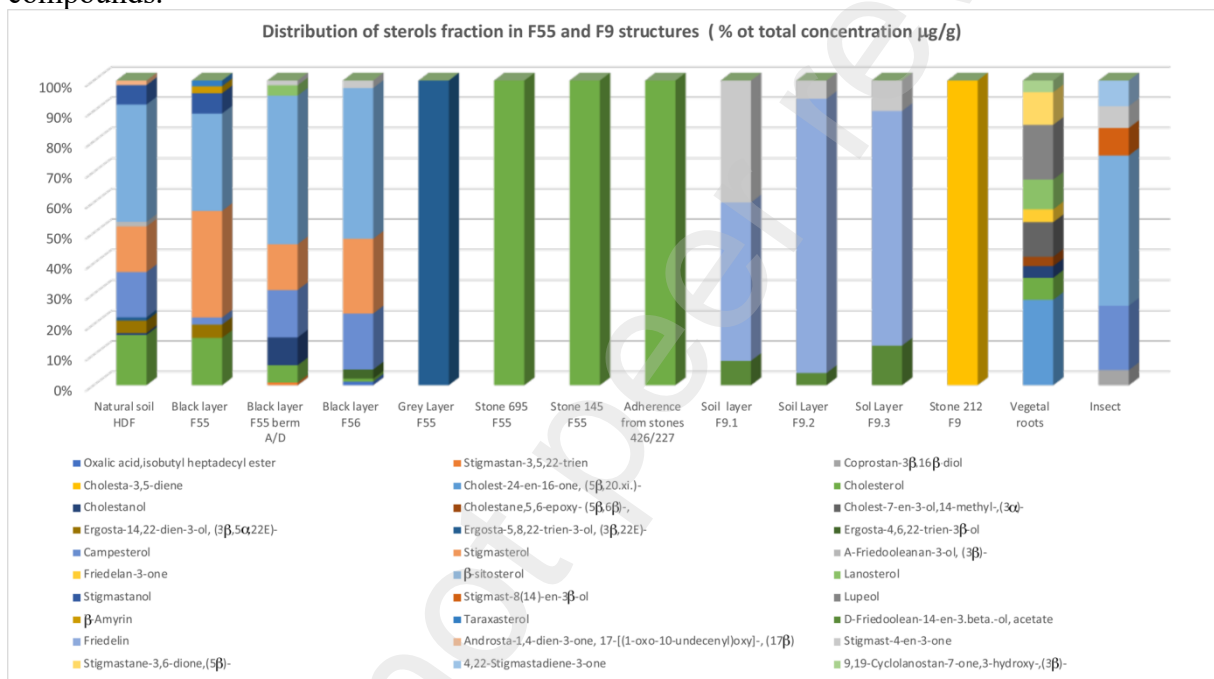


Fig 8 Sterol fraction of samples from Hauts de Feuilley and Champ Vallet

388 This study had shown the complexity of the analysis of this type of structure. Since these  
 389 structures have such a complex history with multiple reuse, it is evident that their utilization  
 390 cannot be considered as ephemeral. In the case of a ritual use, the gestures would have been  
 391 repeated and the social reasons for this reuse remain unresolved. This complex history was  
 392 confirmed by radiocarbon dating carried out after we had finished our preventive archeology  
 393 project, showing that the structures cannot be assigned to the Bronze Age period but rather to  
 394 the early Iron Age for “Hauts de Feuilley” (-2380 ± 30 BP, -517 BCE) and the “Gallo-Roman”  
 395 period for “Champ Valet” (-1865 ± 45 BP, 32 AD). This highlights the crucial problem of  
 396 studying of batteries of structures without dating each structure to confirm their  
 397 contemporaneity. In addition, this also calls into question the dating procedure because, in the  
 398 case of a reuse of the structure, as we can see for “Champ Vallet”, it would have been important  
 399 to obtain dates that fully covered the stratigraphy of the structure.  
 400

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

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

409

### 410 **2.3 From household to village: the Neolithic examples of “Pezou” and “Lillemer”**

411

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

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

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

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

437

#### 438 **2.3.1 Heated stone pit hearths near a household at the Pezou le Clos des Gués site**

439

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

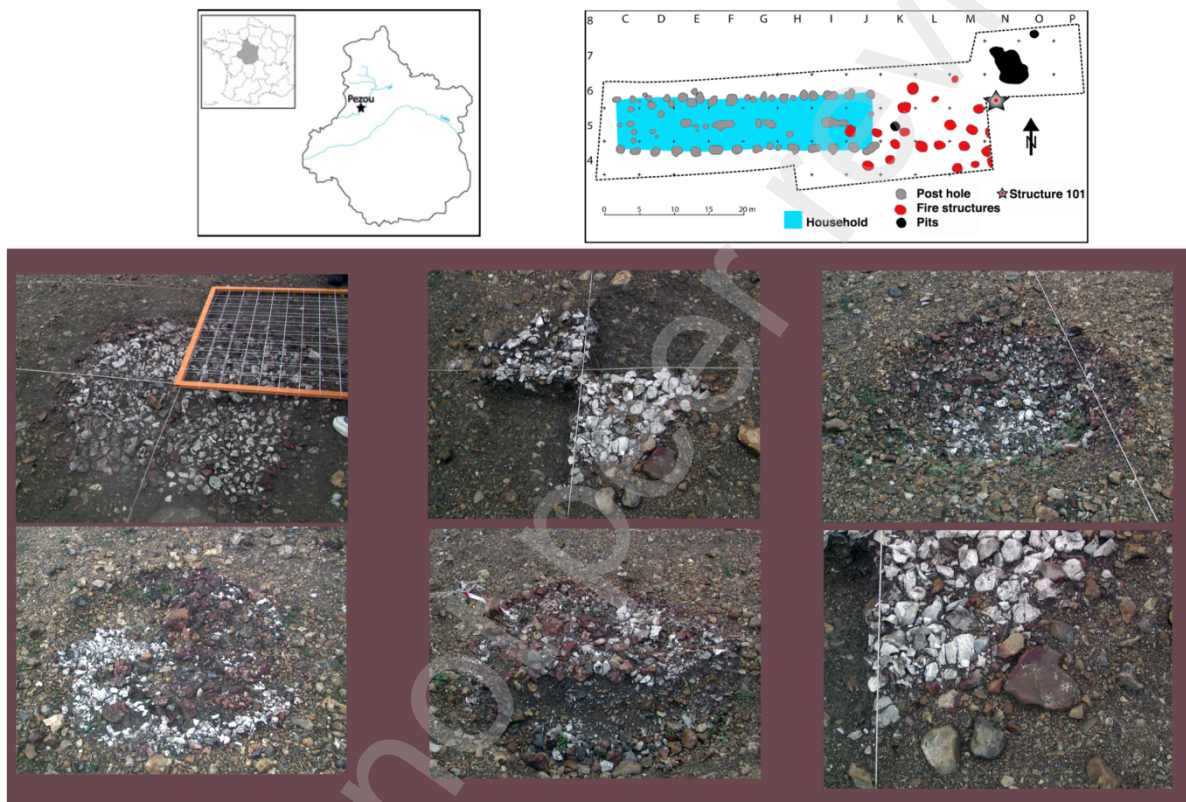
444 This localization leads us to suppose a domestic function due to its particular  
445 characteristics. For example, some structures appear to have not been filled with stones, but  
446 show traces of thermally altered soils and also contain oxidized and thermally fractured stones.

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

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

458 Then, we oriented our experimental archeology project to understand the thermal  
459 behaviour of fire structures using flint as a thermal radiant. Six experiments were carried out at  
460 the Pezou site. Since the natural sediments on the banks of the Loiret River contain fragments  
461 of fluvial flint which could be confused with the anthropic stones used in these fire structures,  
462 one of these six experiments was carried out by lighting the fire directly on the natural ground  
463 to determine the differences between the thermal alteration of natural sediments and the flints  
464 used as a radiant in the hearths.  
465

### Pezou les Clos de Guès site

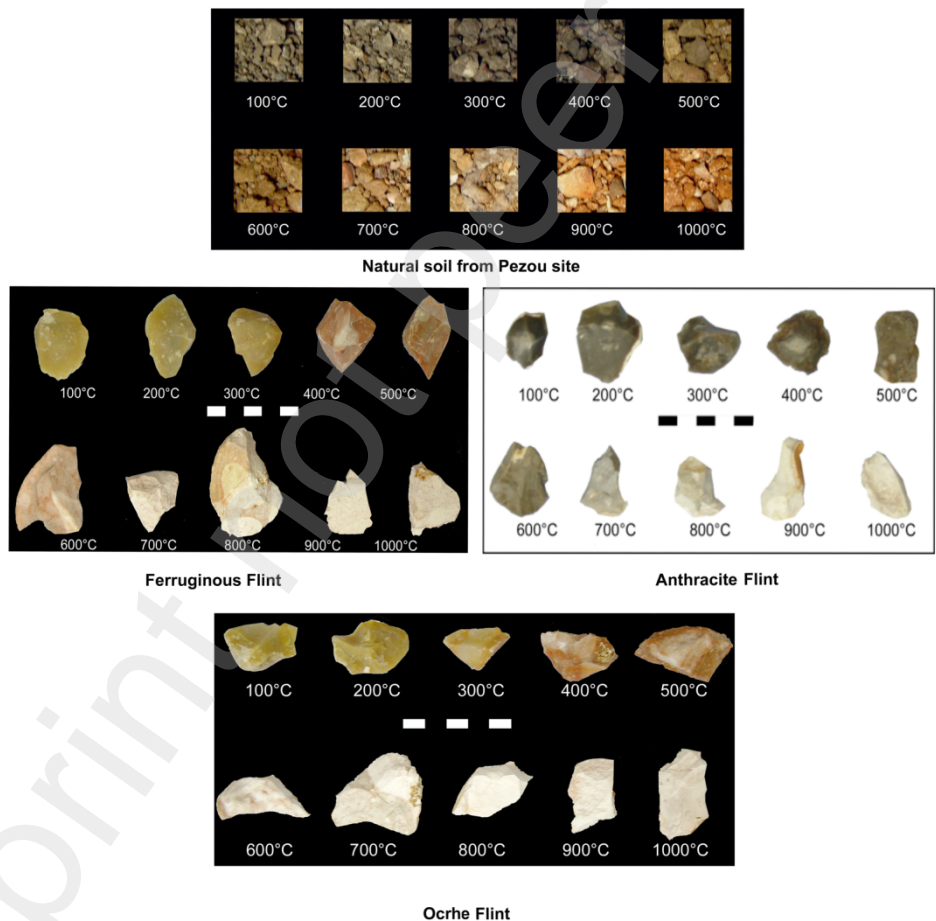


### Examples of archéologiques fire structures

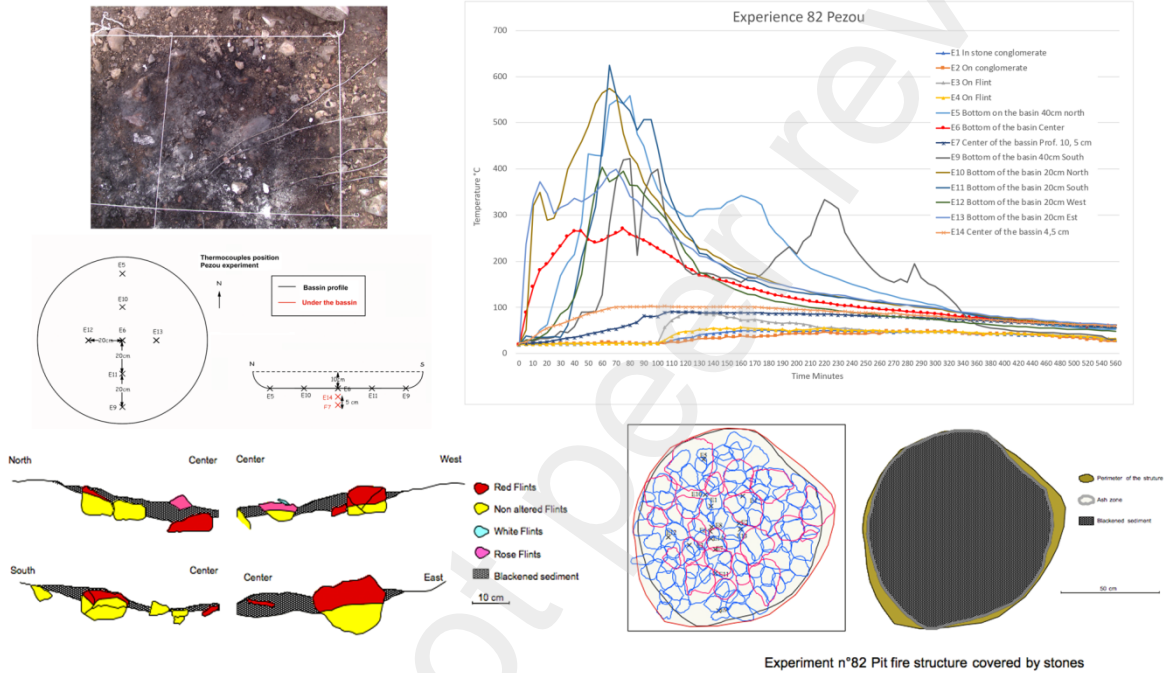
466  
467 Fig 9 Localization of Pezou site and examples of different heated flint pit fires structures during their excavation showing  
468 different kinds of flint alterations  
469

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

482 The mode of functioning of these structures can be reconstructed from our experimental  
 483 results. First of all, we find that just positioning rocks on the embers of a fire previously lit does  
 484 not lead to high temperatures on the stones, since the fire is rapidly extinguished once covered  
 485 by them. On the other hand, this procedure does not cause fracturing in the rocks, so it can be  
 486 excluded as the mode of operation for the archaeological hearths at Pezou. The flints change  
 487 their color according to their mineralogical composition; flints containing traces of iron turn  
 488 red from 300°C or 400°C, then becoming lighter in hue and changing to pinkish at 600°C and  
 489 whitish above 700 °C. The group of “Anthracite” flints change from dark grey to white  
 490 progressively with increasing exposure temperature and attain a white coloration at 800°C.  
 491 Sediments are blackened above 300° C due to their high organic matter content, and then turn  
 492 orange above 500°C (Fig 10). The penetration of this orange coloration is very rapid, reaching  
 493 a thickness of several cm in the sediment with only three hours of ignition. This indicates a high  
 494 diffusivity and conductivity of this type of soil, which is composed of a heterogeneous mixture  
 495 of silts, sandy silts and flint nodules. It is interesting that the archaeological soils affected by  
 496 heat do not preserve this coloration. As a result, we could find layers of soils made up of burnt  
 497 flint and dark-coloured soil, even when these flints were heated to above 700° C reaching a  
 498 whitish coloration.  
 499



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 502 Fig. n° 10 Laboratory experiments of heat transformation of different kinds of flints and soils from the Pezou Site  
 503



Experiment n°82 Pit fire structure covered by stones

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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.

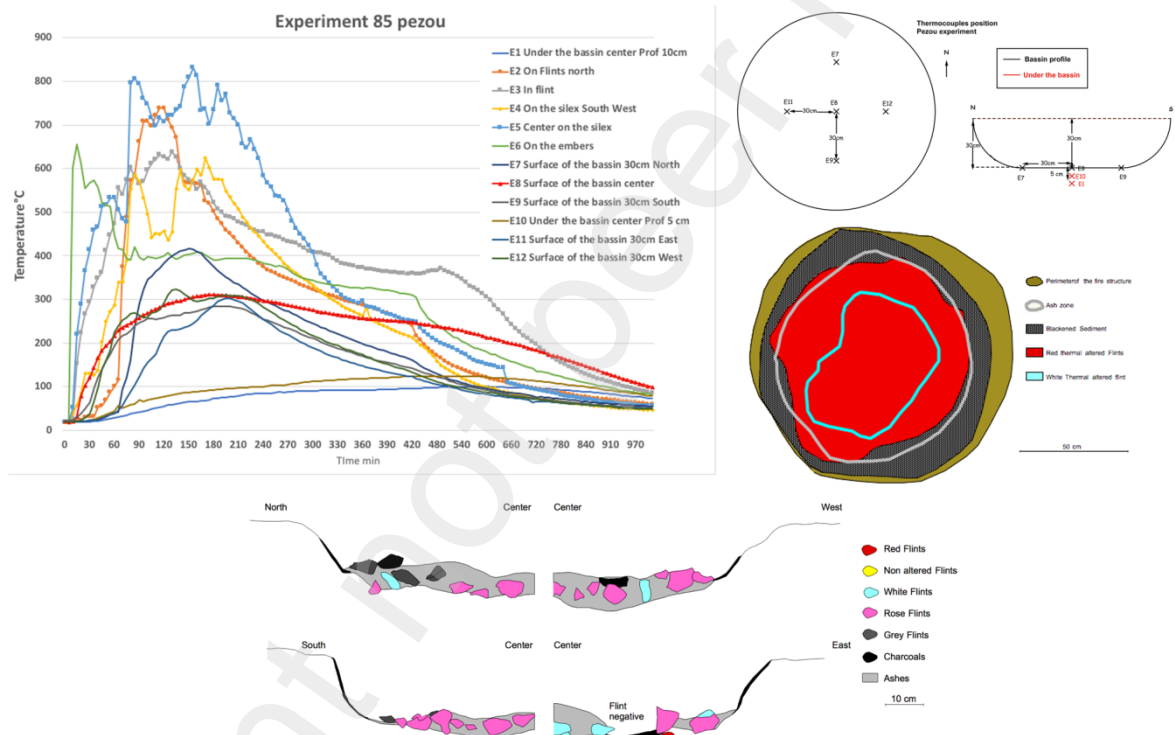
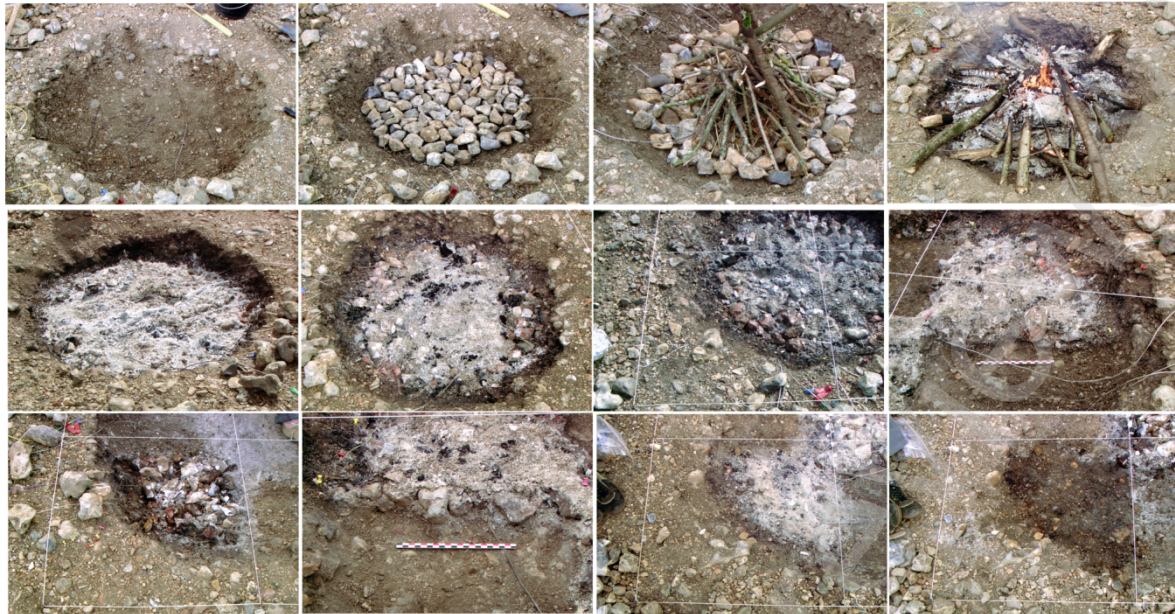


Fig. n° 12 Results of the Realistic Experiment 85 Using heated stones from Pit heart at Pezou Site showing the transformation at high temperatures of included Flints heating both under and above by fire and the oxidation of soils and flints in the natural substrate

At the same time, flints from the walls of the ancient pit hearths were altered over a greater thickness than that observed in our experiments, even if they were of prolonged duration. This clearly shows that the volume of fuel used in the past had been higher than in our experiments, covering the rocks and filling the depression completely. This implies not only that the rocks were heated from below and above, but also that the amount of fuel used for these combustion episodes must have exceeded the amount consumed during our experiments.

In the same way, we observed that the alteration of rocks contained in the sediments was noticeably different from that of the rocks intentionally added to the structure. For example, the flints in the sediment on both the walls and bottom of the depression did not reach a

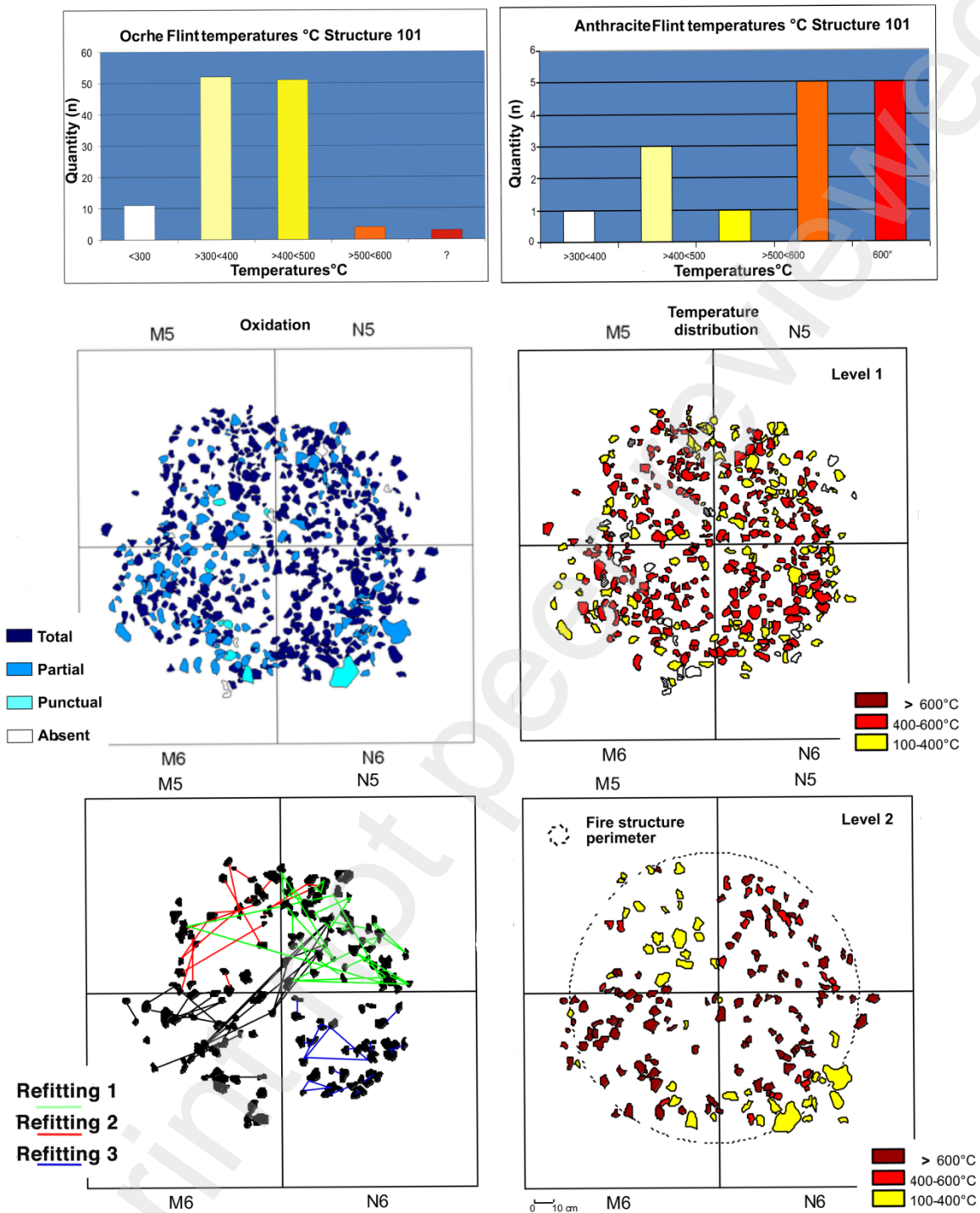
523 completely white oxidation at high temperatures, since this was only achieved in the parts  
524 exposed to the fire while the interior showed lower temperatures. Only a deliberate heating of  
525 these pebbles allowed us to obtain greater quantities of white flint. When flints were added to  
526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

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

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

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

## Structure 101



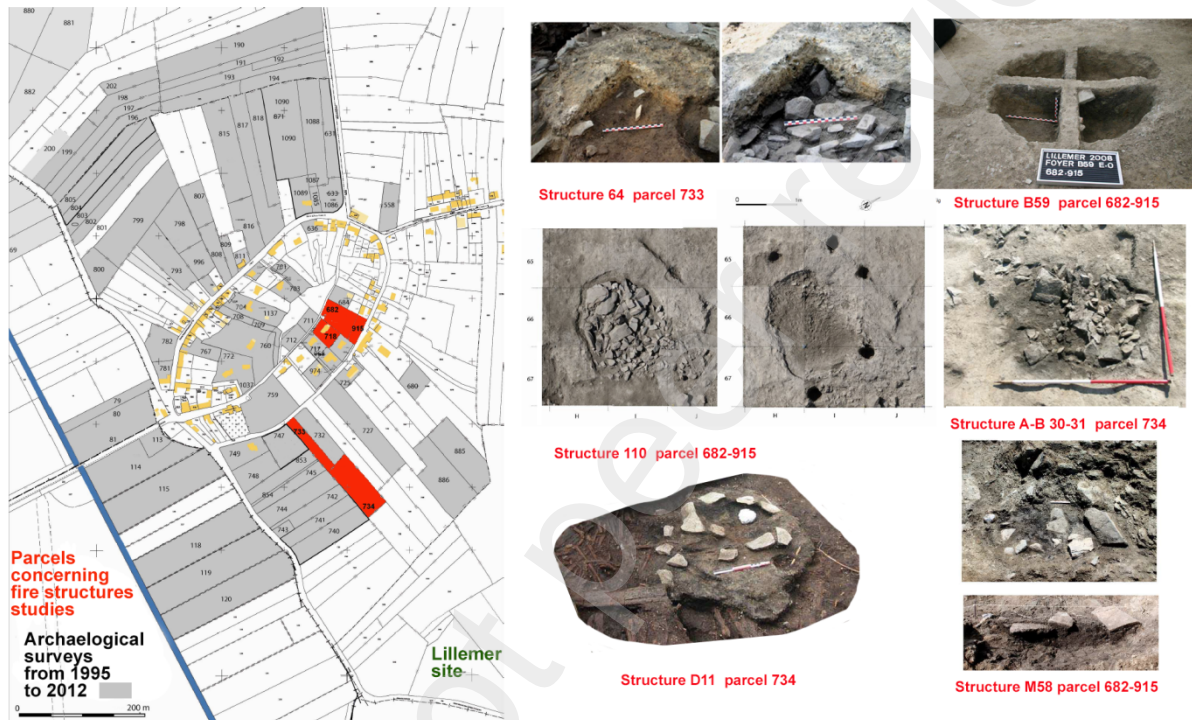
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Fig. N° 13 Thermal alteration inferred for the structure 101 of the Pezou site : Oxidations, Temperature of flints, and refitting of thermal fragments showing their fragmentation and dispersion into the basin.

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

580 Our work with heated stone fire structures belonging to Neolithic societies continued  
581 with the study of the “Lillemer” site (Ille-et-Vilaine, France) (Middle Neolithic, 4500 to  
582 3500/3300 BCE) (Laporte et al 2003, 2005, 2007, Bizien-Jaglin et al 2009, 2010 a et b, 2011,

583 Lucquin et March 2005, 2006a et 2006b, 2009 et 2010, Guyodo et al. 2011 a et b). This work  
584 allowed us to analyse the diversity of combustion structures at these kinds of sites as well as  
585 the use of fire-produced thermal energy for other purposes. In addition to the use of fire for  
586 different purposes, such as the possible domestic production of ceramics, cooking food, and  
587 even some activities that could be related to ritual behaviors, some authors have discovered  
588 traces of fires from arson that affected the palisades surrounding the site as well as room  
589 structures made of mud and rocks (Laporte et al. 2015). The Lillemer site was studied in the  
590 context of academic research programmes and preventive archaeology, with fire structures in  
591 certain sections of the site being excavated both for contractual purposes and for preventive  
592 archaeology (Fig.14).  
593



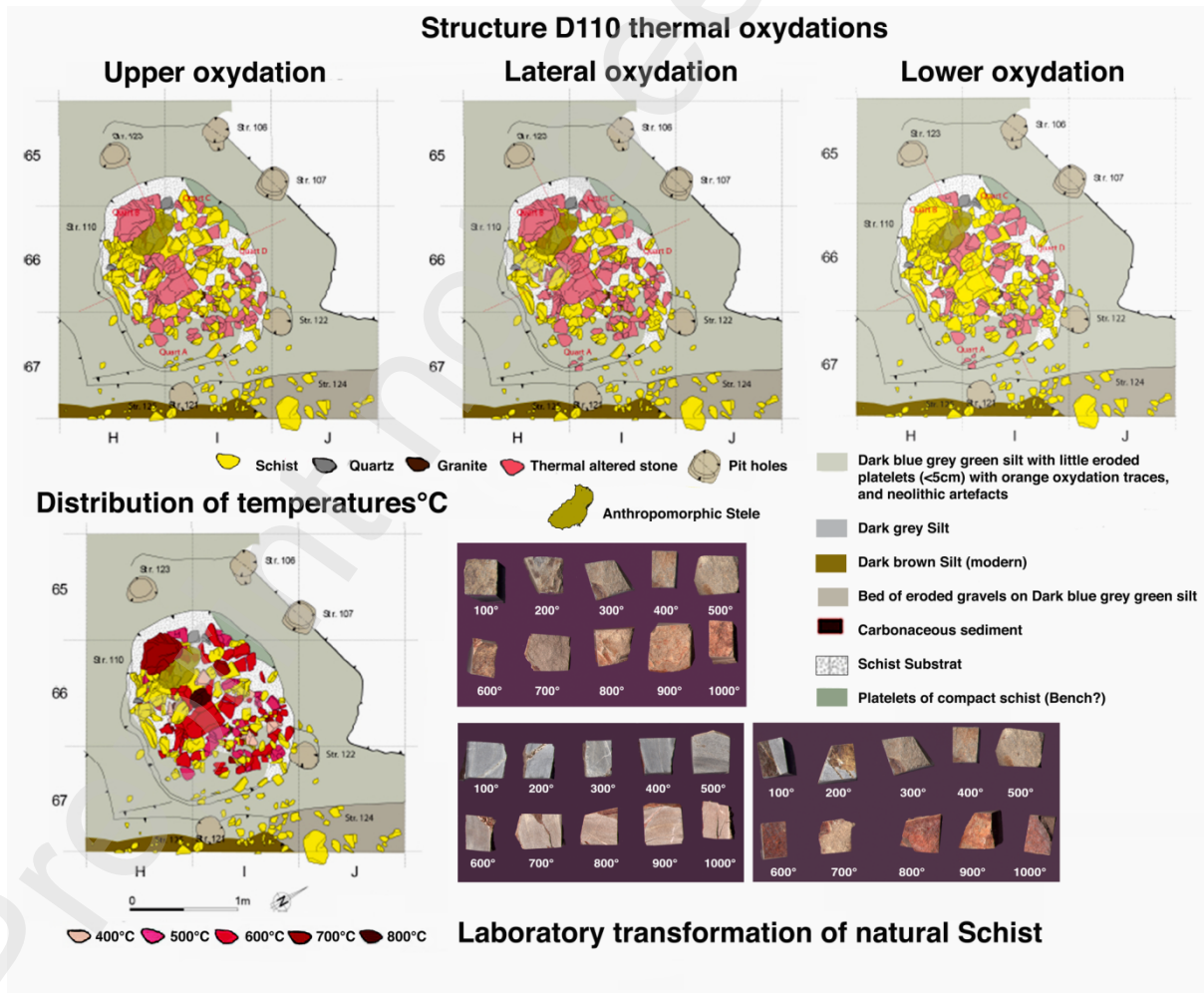
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595 Fig. 14 Fire structures of Lillemer (from Bizien-Janglin et al. 2010 a et b and Guyodo et al.2011 with modifications)  
596

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

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

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

618 The mode of operation of this structure indicates at least two differentiated uses and three  
 619 combustion episodes. Its micro-history could be summarized as follows: First, a shallow  
 620 depression was made on top of a natural outcrop of schist which flanks the occupations of the site.  
 621 A fire was lit on the natural schist bedrock and several slabs, modified mostly on their  
 622 lower side, were placed on top of it. Subsequently, a new fire was lit on these slabs, which  
 623 produced high temperatures of between 600° and 800°C, causing intense fracturing of the  
 624 deposited rocks. A large quantity of burnt bone fragments of unknown origin was found in these  
 625 pits, complicating the archaeological analysis. A new layer of rocks of larger size was deposited  
 626 on these rocks, but this time after the cessation of the second episode of combustion. Finally, a  
 627 third episode of combustion resulted in the alteration of rocks positioned at the top of the  
 628 structure. These latter were also altered at high temperatures but show fewer traces of fractures  
 629 and fragmentation. A stele of schist with anthropomorphic forms, but without any traces of  
 630 thermal alteration, was deposited onto this upper layer. This micro-history has given rise to an  
 631 initial symbolic interpretation concerning the use of this structure. It shows similar  
 632 characteristics to other structures built during this period at other sites with a similar  
 633 organization characterized by rectangular alignments of pit holes surrounding a depression and  
 634 which are interpreted in the same manner (Fig. 15).  
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636  
 637 Fig. 15 Distribution of oxidations and temperatures into stones of the structure D110 from Lillemer and laboratory results of  
 638 stones transformations under heat (from Lucquin et March 2010 in Bizien-Jaglin 2010 with modifications)

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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

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

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

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

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

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

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

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

725

#### 726 ***2.4 Intra site and inter-sites histories : the case of heat stone pit hearths in megalithic sites*** 727 ***near Carnac***

728

729 Returning to the association of Polynesian ovens with ritual practices in the Bronze and  
730 Iron ages, we can evoke the example of the batteries of fire stone pit hearths found at three  
731 different Middle Neolithic sites: ZAC de Montauban at Carnac, Le Mané Roullarde at La  
732 Trinité-sur-Mer and Parc Belann at Carnac. These pit hearths are isolated from other types of  
733 archaeological context and are situated near megalithic alignments, gallery graves “*tombes à*  
734 *couloir*” or burial mounds “*tumuli*” in the Gulf of Morbihan region of France. They have also  
735 been studied in preventive operations (Hinguant et al. 2010, Fromont et al. 2011, Toron et al.  
736 2017). These three sites were characterized by the presence of batteries of fire structures  
737 vestiges. (Fig. 17)

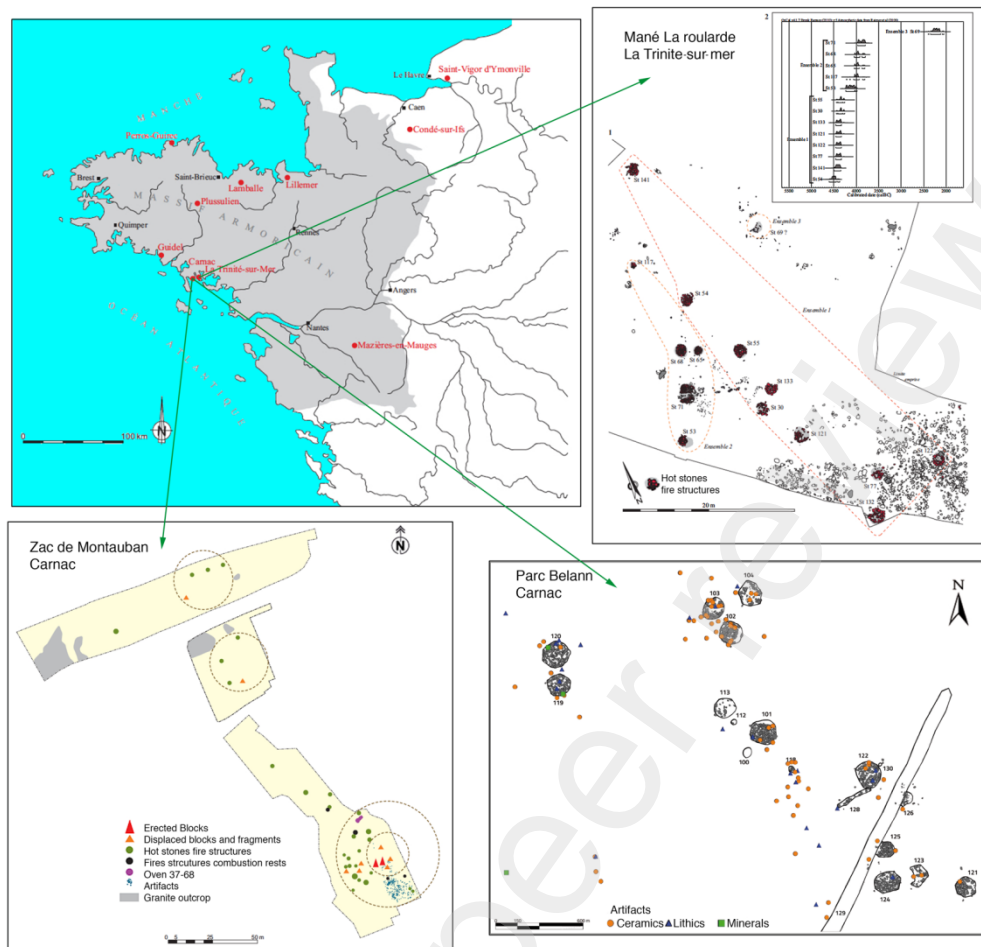


Fig. 17 Fire structures batteries organisation plans from Zac de Montauban, Mané la Roularde and Parc Belann Sites at Brittany (France) (from Hinguant et al. 2010, Fromont et al. 2011, Toron et al. 2017 with modifications)

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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 1/31<sup>st</sup>, Mané la Roularde (2/15<sup>st</sup>) and Parc Belann (3/14<sup>st</sup>), 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 (18/31<sup>st</sup>) Mané la Roularde (8/15<sup>st</sup>), Parc Belann (14/14<sup>st</sup>).

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

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

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

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

780 At Montauban, 26 heated stone pit structures were studied by different methods set up  
781 by mutual agreement, to which are added 1 furnace and 4 combustion waste pits, which brings  
782 to 31 the number of structures linked to the fire at the site (Hinguant et al. 2010). It should be  
783 mentioned that only one structure (n°54) could be studied by micromorphological,  
784 anthracological and biogeochemical analyses. Eighteen structures were dated, demonstrating  
785 that these structures were not all contemporaneous. The dating results cover a period ranging  
786 between 4900 +/- 40 BP and 6930 +/- 40 BP, within which we can recognize at least five phases:  
787 a first around 4900 ±40, a second between 5300 and 5400 ±40 BP, a third between 5540 and  
788 5570 ±40 BP, a fourth between 5690 and 5875 ±40 BP and finally between 6430 and 6930 ±40  
789 BP.

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

793 Fourteen heated stone structures were found at Parc Belann, circular to oval in shape,  
794 and composed of a cluster of granite rocks covering a more or less marked layer of combustion  
795 residues and anthropized sediments. Seven structures dated by C14 range in age from 5596±  
796 28 BP (4486-4358 BCE) to 5278±37 BP (4232-3993 BCE), which means they belong to the  
797 Middle Neolithic period essentially within the Middle Neolithic I This makes them  
798 contemporaneous with structures of Montauban and Mane la Roularde, bracketed between the  
799 most recent phases of Montauban and the oldest structures dated at these two sites. (Fig.18).

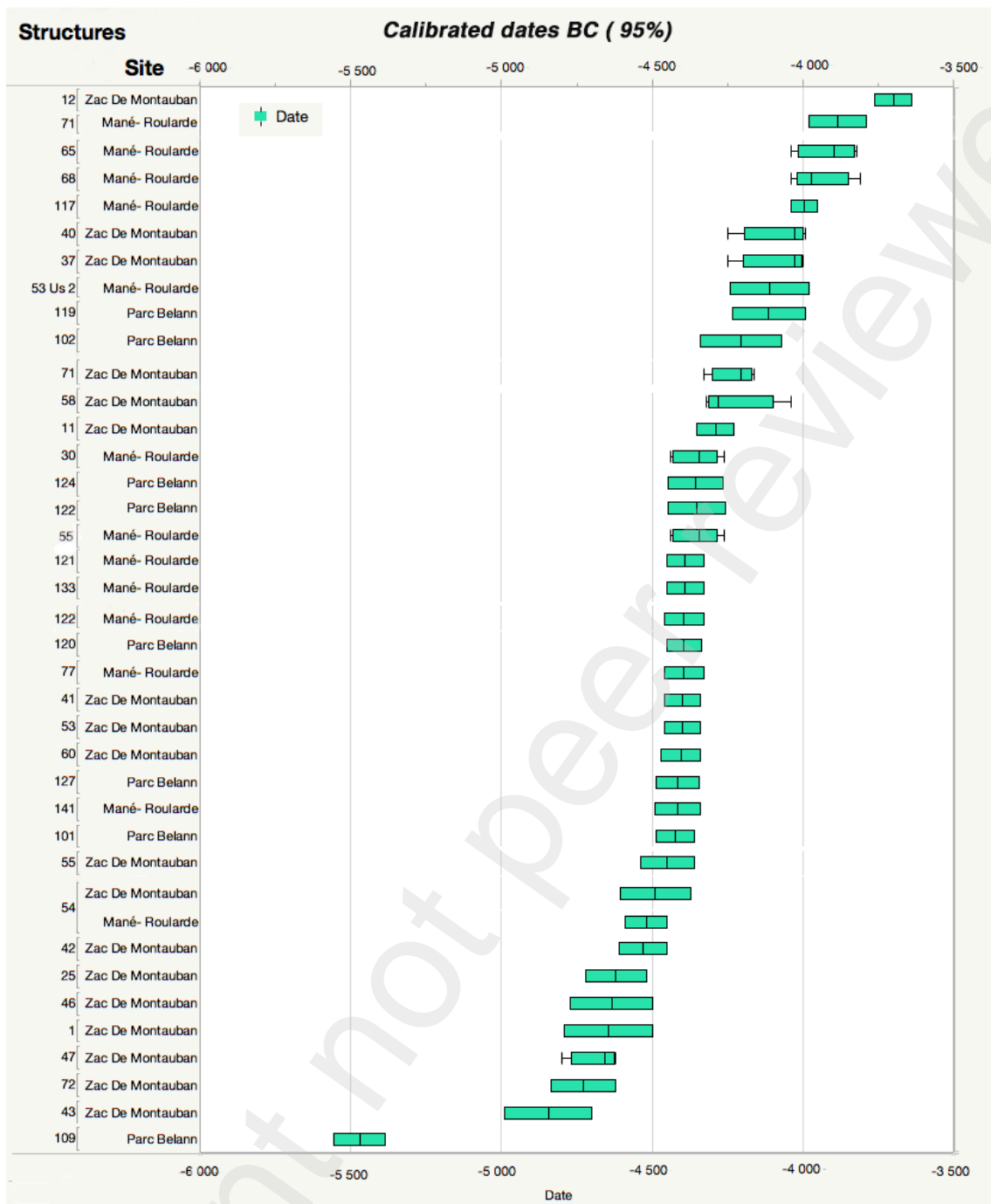


Fig .18 : BC Calibrated dates (95 %) form heated stones fires structures at Zac de Mantauban , Mané La Roularde and Parc Belaann (Hinguant et al. 2010, Fromont et al. 2011, Toron et al. 2017).

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

810 Whether in batteries or sometimes isolated, the mostly circular or sub-circular structures  
811 of the ZAC of Montauban are characterized by fairly standardized dimensions (approximately  
812 1 m in diameter and 10 to 15 cm of preserved depth), with a filling of large contiguous stones  
813 more or less affected by the action of fire. Mane La Roularde shows a differential classification

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

821  
822 The materials used for these structures are very similar at the three studied sites, where  
823 granite stones (extracted blocks) were chosen in majority but sometimes accompanied by quartz  
824 pebbles or schist slabs. The characteristics of these stones vary between the different structures,  
825 showing differences in their dimensions and arrangement. While in all cases stones cover the  
826 charcoal residues and the traces of oxidized sediments, the structures show different  
827 arrangements covering small depressions or lying directly above the soils. These structures  
828 show traces of reutilization or different arrangements sometimes with wide spaces in each  
829 heated stone concentration. At Montauban, these differences lead certain authors (Hinguant et  
830 al. 2010) to establish different categories according to the final position of stones in each  
831 structure: the term "aureole" is used to describe the position of stones encircling an empty space,  
832 while the term "bouchon" [Complete filling] "bouchon partiel" [partial filling] is assigned to  
833 structures in the depression under the stones that were completely or partially covered. These  
834 different positions accompanied by the study of their stratigraphic position and thermal  
835 alteration distributions in stones and soils induce also to different interpretations about the mode  
836 of functioning of these stones arrangement conducting to suppose that fire was generally  
837 lightened over the stones but sometimes the stones were contained in the depression while in  
838 some cases as in Mane La Roularde or Parc Belann heated in an open air system changing their  
839 mode of functioning but also the way in that these structures reconstitute the heat provoked by  
840 combustion.

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

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

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

867 A more comprehensive study involved the analysis of wood employed as fuel for these  
868 different sites. These studies show a dominance of oak or broom/gorse that evolves with time  
869 associated with the different dated phases of the structures at Montauban, while oak is mostly  
870 dominant at Mané la Roularde and Parc Belann. The modification of species found at  
871 Montauban is linked not only to the established choices of fuel within the plant context, but  
872 also to an evolution of the forest of oak following its exploitation which led to its replacement  
873 by moorland in a period of 500 years. These plants are accompanied by other species in minor  
874 proportions that fluctuate in their utilization, such as the hazel tree, the Pomoideae (apple or  
875 hawthorn), the Prunoideae (cherry or plum tree) and the ash. This anthracological spectrum  
876 reflects the exploitation of a local forest and also a form of opportunism in selection that is  
877 adapted over time. The anthracological analysis supports the hypothesis of the use of small-  
878 sized wood in structures where an intense but short-lasting fire is probably wanted. The  
879 proposed mode of operation for these structures raises the question of the mode of functioning  
880 and intensity of exploitation in relation to the duration of each combustion episode and the  
881 consumption of wood at the local level as well as its influence over time on local plant resources  
882 in relation to the energy needs of these social practices. (Hinguant et al. 2010, Fromont et al.  
883 2011, Toron et al. 2017).

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

899 Finally the domestic or cult, culinary stew options of vegetable or animal foods are proposed  
900 for all the sites presented, including the possible reuse of structures at each site, focusing on the  
901 intensity of activities related to at least five phases of activity detected related to this type of  
902 combustion structures with heating stones, cluster in this part of Morbihan (Hinguant et al.  
903 2010, Fromont et al. 2011, Toron et al. 2017).

904

### 905 **3 Discussion and conclusions**

906

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

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

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

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

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

953

### 954 ***3.1 Difficulties created by specialization and the analytical decomposition of the subject*** 955 ***of study***

956

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

963 approaches follow in the excavation methods , description and analytical methods applied as  
964 the function inferred following these divers criteria (Blanchet et Le boulanger 2015, Dubesett  
965 2021.).

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

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

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

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

990 In recent years, the development of scientific hyper-specialization is linked to increasing  
991 competition between the different specialties to guarantee credits for resources and employment  
992 in each discipline. At the same time, the process of hyper-specialization leads to a temporary  
993 departure from the initial objective, a real “tunnel of hyper-specialization” affecting every line  
994 of research, caused by the need to solve problems inherent to these specialized fields. In this  
995 way, we need to go back to our initial questions that could lead to the search for new methods  
996 to explore the relationship between humans and the exploitation of thermal energy. The process  
997 of hyper-specialization has gradually resulted in a lack of dialogue and interaction between the  
998 various specialists who are increasingly subjected to contract management or project-based  
999 organization systems, This economic model has spread to the entire academic system, but  
1000 without the necessary coordination to address the different problems in archaeology as well as  
1001 in other disciplines. This has led to the multiplication of parallel studies carried out by  
1002 specialists who do not communicate among themselves, bypassing generalist archaeologists  
1003 who lack sufficient knowledge or training to synthesize the issues at stake.

1004 Similarly, the economic restrictions linked to the contract-based system and the conduct of  
1005 rescue operations prevent us from having the necessary resources to carry out systematic studies  
1006 on the sites concerned. In turn, these restrictions reduce the possibility of implementing more  
1007 complete studies due to the complexity and the time required to carry out such operations. In  
1008 the same way, there is a tendency to apply analytical techniques to make the work performed  
1009 appear more scientific. But this often leads to a mere provision of services, which reduces even  
1010 more the possibility of dialogue and synthesis between the different hyper-specialists hired to  
1011 answer the different questions. All these problems, and above all the pressure to process the  
1012 actual amount of heritage findings that require a solution, are reinforcing our traditional

1013 inductive approach, which frequently leads us to ignore the broader theoretical perspective for  
1014 addressing these issues.

1015

### 1016 **3.2 Towards a new theoretical perspective**

1017

1018 Even if the number of studied sites with this kind of structure has increased due to the  
1019 progress and multiplication of preventive or regular excavations, we still remain faced with the  
1020 same problems related to the empirical generalization of results obtained for a limited number  
1021 of structures. Consequently, hypotheses about their significance still lead us back to the original  
1022 questions.

1023 The study of different sites such as Lillemer or Pézou show us how fire-related activities  
1024 and the use of heated stones pit hearths in complex contexts can open up the possibility of other  
1025 types of behaviour practiced in open spaces. The studied sites include Neolithic villages and  
1026 domestic rural spaces from different periods and contexts, such as Le Closeau, Hauts de Feully,  
1027 Champ Vallet and three sites from the Gulf of Morbihan. These latter are situated far from the  
1028 domestic or village contexts mentioned here, but show similarities with other contexts in which  
1029 similar practices were carried out on hearths using techniques with heated stones while being  
1030 also used for cooking food or other practices.

1031 However, the micro-histories of each of these structures show particularities in their forms  
1032 and the selection of raw materials as well as in their modalities of use and operation. These  
1033 differences are also reflected in the analysis of the processes occurring at each site where similar  
1034 structures may have significantly different histories. This helps us to reconstruct the entire  
1035 operational chain used for the management of thermal energy and could even open the way to  
1036 understanding of the social space and the persistence of certain techniques over long periods.

1037 Likewise, the archaeological contextualization of combustion structures suggests that, even  
1038 if their use was intended for similar activities, the nature of these activities could be different  
1039 according to the sites and structures studied. But we need to avoid repeating empirical  
1040 generalizations following the criticisms about the systematic extrapolation of the “Polynesian  
1041 oven” category. Proposing a generalized interpretation for such structures could be misleading  
1042 if it is based on a “common sense” extrapolation of the supposed function of a combustion  
1043 structures that remains to be clarified. At the same time, this example shows that our  
1044 interpretation of combustion structures is linked to understanding the control of thermal energy  
1045 and the significance of archaeological remains. Our approach should be focused on the social  
1046 behaviours of the different groups involved and their social modes of production and  
1047 reproduction. Without this rationale, reconstructions of the activity or micro-history of each  
1048 structure can be considered as merely anecdotal, contributing little to our understanding of the  
1049 behavior of human groups in different contexts.

1050 This situation is related to the lack of questions about the use of thermal energy in each type  
1051 of society. And also with the relationship between general archaeologists and specialists, since  
1052 the development of specific problems such as the one we are evoking is extremely difficult, if  
1053 the general archaeologist does not include this fundamental question in the objectives of  
1054 understanding the social behaviour of each human group in the past. These problem increases  
1055 if generalist only consults specialists separately and in a timely manner with the aim of answer  
1056 specific questions without understanding the complexity of the studies needed to interpret the  
1057 significance of data specifically related to the use and traces of fire in each context.

1058

1059 Moreover, our research should also be redirected beyond the study of combustion  
1060 structures as such, to investigate the human evolutionary process and its relation with the  
1061 control and the application of thermal energy. This would allow us to rescale and take another  
1062 step in our approach to these problems.

1063 As a result, we consider it essential to:  
1064 - tackle the problems related to hyper-specialization by adopting a truly  
1065 transdisciplinary approach;  
1066 - systematize the study of sets of structures with the same methods;  
1067 - continue with our experimental effort to solve the interpretation problems but leading  
1068 systematic experimental approach's following the thermal transfer logic and its  
1069 consequences in the structure components and environmental contexts to could finally  
1070 rebuild for understand the formation processes of this different kind of structures  
1071 - define the questions in an appropriate manner and insist on the importance of  
1072 understanding the significance of each set of structures to rebuild the history of thermal  
1073 energy control and its social application;  
1074 - return to the human as the subject of our research and analyse the cultural aspects of  
1075 general thermal energy processes;  
1076 - develop a methodology to explore and reconstruct the social significance of thermal  
1077 processes in the past, with implications for the future of our civilization;  
1078 - incorporate thinking about the different human modes of appropriation, production  
1079 and uses of thermal energy as well as the strategies implemented by different societies  
1080 to reproduce their practices and culture.

1081 Therefore, we need to give priority to questions concerning the significance of fire use at the  
1082 different levels of each society and cultural structure, considering both the infrastructural and  
1083 ideological aspects.

1084

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1086

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1092

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