IpoTESI di Preistoria | VOL. 12 | 2019 | PP. 351-368
ISSN 1974-7985
https://doi.org/10.6092/ISSN.1974-7985/10319

FOCOLARI, FORNI E FORNACI TRA NEOLITICO ED ETÀ DEL FERRO

COMPRENDERE LE ATTIVITÀ DOMESTICHE E ARTIGIANALI ATTRAVERSO LO STUDIO DELLE INSTALLAZIONI PIROTECNOLOGICHE E DEI RESIDUI DI COMBUSTIONE.

IIPP INCONTRI ANNUALI DI PREISTORIA E PROTOSTORIA 6
DIPARTIMENTO DI STORIA CULTURE CIVILTÀ, UNIVERSITÀ DI BOLOGNA, 29 MARZO 2019

THERMAL STUDY OF A PROTOHISTORIC FURNACE: FROM THEORY TO PRACTICE

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PAROLE CHIAVE: tecnologia ceramica, archeometria, età dei metalli, forni da vasaio, fornaci, forno di Sévrier

KEYWORDS: ceramic technology; archeometry; metal ages; ovens; kilns, Sevrier kiln.

SOMMARIO

Sull'isola sommersa del Crêt de Chatillon nel Lago di Annecy, in un sito palafitticolo dell'età del Bronzo, sono stati scoperti dei frammenti di un forno di terracotta. Aimé Bocquet, padre dell'archeologia subacquea francese, lo restaurò nel 1974. Questa struttura dal piano forato, che all'epoca non trovava confronti con alcun ritrovamento già effettuato fu logicamente interpretata come un forno da vasaio. Mezzo secolo dopo, molte scoperte simili non hanno comunque posto fine al dibattito sulla funzione di questi dispositivi. Grazie all'archeometria e in particolare all'analisi termica, cerchiamo evidenze che possano confermare o smentire alcune ipotesi funzionali avanzate in letteratura.

ABSTRACT

On the sunken island of Crêt de Chatillon (Annecy Lake), in a Final Bronze Age pile-dwelling site, were discovered fragments of a terracotta kiln. Aimé Bocquet, father of the French underwater archaeology restored it in 1974. This perforated floor structure, without equivalent at the time was logically interpreted as a potter's kiln. Half a century later, many similar discoveries did not put an end to the debate about the function of these devices. Will it be possible to promote or rule out certain functional hypotheses by means of archeometry and in particular through a thermal study ?

1. INTRODUCTION

In the 1970s, several vestiges of furnaces, interpreted as potters' kilns, were unearthed in France. The most emblematic is the so-called "potter's kiln" of Sévrier discovered on the Crêt de Châtillon, an actually submerged island of the Lac d'Annecy en Haute-Savoie (France) (BOCQUET, COUREN 1975). Considered as one of the oldest pottery kilns in Western Europe, over the years it has become an internationally known reference (Figg. 1-3; Tab.1).

Fifty years later, it remains, among others, a symbol within a large family of firing structures widespread throughout Europe during the Metal Ages (Figg.4-5). Their main characteristics are as follows: a) a modular, hand shaped clay structure with a circular plan, small enough to be portable, unlike the more massive permanent ovens; b) a perforated floor separating two distinct spaces: the firing chamber and the combustion chamber.

These fragile clay devices, of which most of the time only the aerial part remains, do not integrate the typologies of potter's kilns (CUOMO DI CAPRIO 1972; DELCROIX, HUOT 1972; DUFAÝ 1996; DUHAMEL 1973; HANSEN STREILLY 2000; HASAKI 2002; MAJIDZADEH 1975) based on the buried parts.

A renewed interest accompanied the recent discoveries in several western and central European countries: in Spain at Celanova (Galizia) loc. As Peireira (GARCIA ROLLAN 1991; ABOAL FERNANDEZ, COBAS FERNANDEZ 1999) and Castromao (FARIÑA BUSTO 2001); in France at Saint -Jean-de-Caps, Mailhac (Aude) (BOISSON 2002 p. 8), Martigues (Bouches-du-Rhône) (CHAUSSERIE-LAPREE, NIN 1990), Roquepertuse (Velaux, Bouches-du-Rhone) (BOISSINOT, BOUBY, MARINVAL 2011), Mortagne (Charente-Maritime (LANDREAU MARATIER 2008), Les Courtinals in Mourèze (Hérault), (DEDET, ROUQUETTE 2002), dating to Final Bronze Age, Saut de la Pucelle (Tresserve, Lake Bourget, Savoie) (BILLAUD 2004), Savenay (Loire -Atlantic) (COULON 2013); in Italy at San Giorgio Ingannapoltron (province of Verona)(BERTASI 2009; SALZANI, SANTINON 2015), Castello di Annone (province of Ast, Piemonte)(PEINETTI 2014), Montecastello (Piemonte)(GAJ *et alii* 2016), Villa del Foro (Alessandria) (VENTURINO GAMBARI 2017), Gropello Cairoli (province of Pavia, Lombardia) (RUFFA 2019); in

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Switzerland at Sion (Canton du Valais) (MARIETHOZ inedit), Hauterive-Champréveyres (Cantone di Neuchâtel) (ANASTASIU, BACHMANN 1991).

Fig.1. *Islet of Crêt de Châtillon, Lake Annecy, Haute-Savoie, France.*

Fig.2. *Sevrier kiln. Conservatoire des lacs. Tour de la Reine. Musée Chateau d'Annecy. Photo credit Musée Chateau Annecy.*

Sole / Piano forato / Perforated floor	Dimensions en mm
Nombre de perforations : 54	
Diamètre perforations	30 / 35
Epaisseur	35 / 45
Diamètre externe	665 / 713
Base	
Epaisseur	30 / 40
Hauteur	203 / 213
Diamètres externes haut et bas	637/ 659
Cheminée / Caminetto / Chimney	
Diamètre haut (externe)	144
Diamètre bas (externe)	181
Hauteur	71
Epaisseur	20 / 25
Couvercle / Copperchio / Lid	
Epaisseur	30 / 40
Hauteur	230 / 258
Diamètre haut	473
Diamètre bas	659
Hauteur totale externe: base + couvercle	633

Tab.1. *Sevrier kiln. Measurements*

Fig.3. Reconstitution of scenes from prehistory: firing potteries in the Sévrier kiln on the Crêt de Châtillon. Cantonal Museum of Archeology and History. Lausanne, Cantonal Museums, Sion and Museum of Art and History Geneva. Drawing: André Houot, coloring: Jocelyne Charrance.

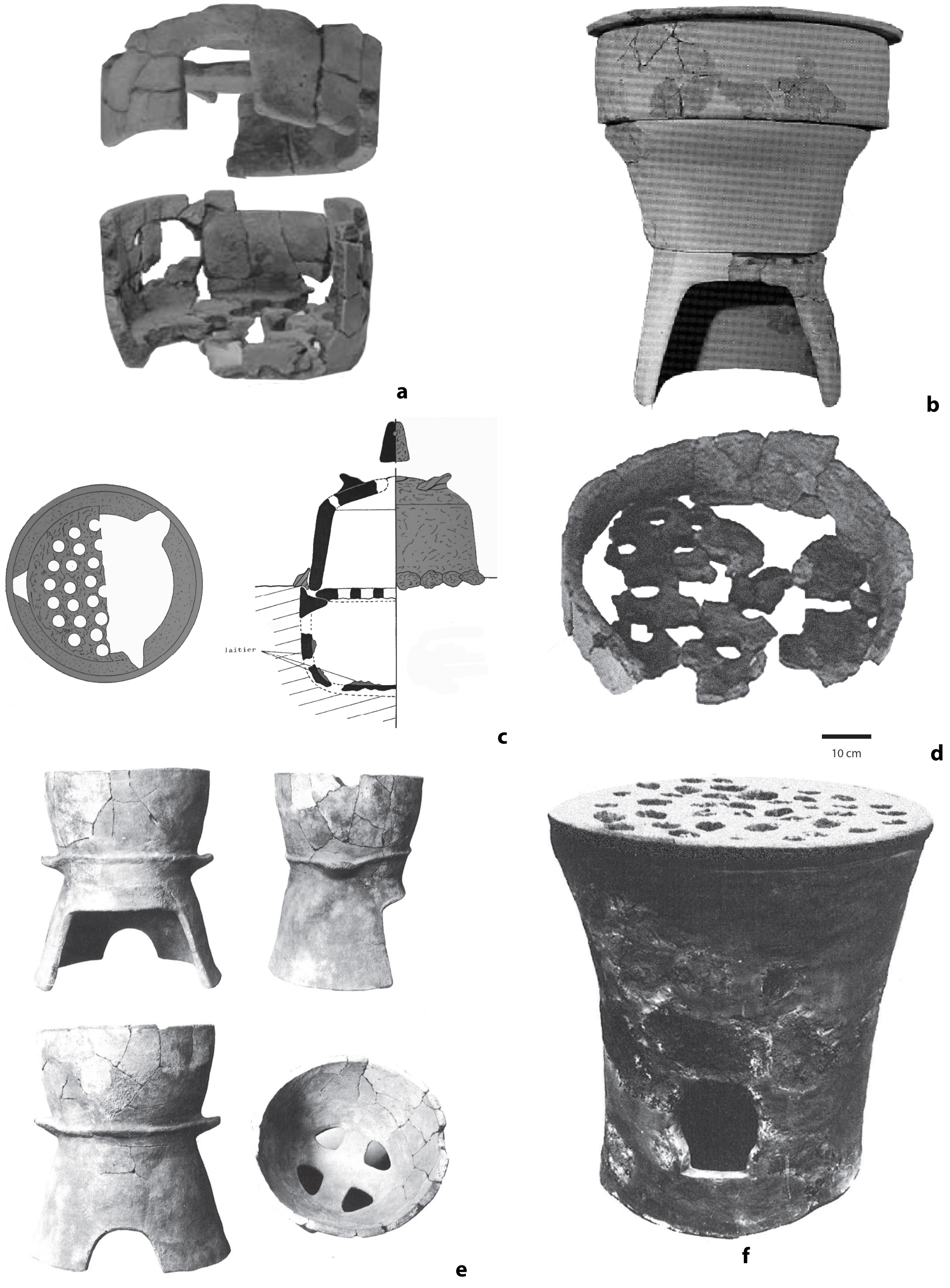


Fig.4. *Some examples of modular clay furnaces: a) Castromao (Spain) (Garcia Rollan 1971) (type 1), b) Martigues (France)(Chausserie Laprée 2005) (type 2), c) Le Cluzel, Toulouse (Haute-Garonne, France) (type 3), d) As Peireira, Celanova (Galicia, Spain) (Aboal Fernandez , Cobas Fernandez 1999) Type 4, e) Belverde di Cetona (Siena, Italia) (Scheffer 1981) Type 5, f) Scoglio del Tonno (Taranto, Italia)(Scheffer 1981) Type 6.*

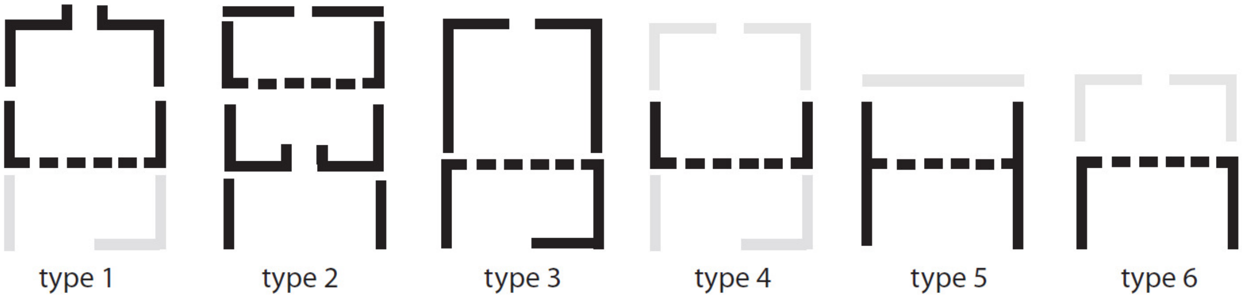


Fig.5. *Schematic typology of modular clay furnaces, that does not take into account specific dimensional variables or morphological details (COULON 2012).*

This has raised the issue of interpretation, since domestic use becoming more and more mentioned (DESBAT, SCHMITT 2003; NIN 2003; CHAUSSERIE, LAPRÉE J. 2005; BOUBY *et alii* 2011; COULON 2012; PEINETTI 2014; VENTURINO GAMBARI *et alii* 2015, 2017; GAJ *et alii* 2016; RUFFA M. 2019; GROPPO 2018; TASCA 2018). The absence of convincing material evidence to associate the Sévrier kiln with pottery firing has led us to a new functional approach. We present here the results of the thermal analysis reached for this particular kiln, in order to deepen our knowledge, and from there, to enhance our understanding of other comparable material.

2. THE PROBLEM

Our objective is to evaluate the maximum temperature experienced by the Sévrier kiln. Thermal studies is a broad term that does not generally refer to a single method, but rather,is related tothespecific objectives concerned, it is a question of implementing and crossing several methods, from the most basic to the most complex.

These are likely to provide answers to questions concerning the characterization of the clay materials of the kiln,and of the mineralogical changes undergone by the clay as a function of the maximum temperatures, directly related to the intensity of the firing, and therefore the use of the oven.

2.1 Study of heat treatment: framework and interpretative limits

Determining the temperature of a clay kiln from a shard allows, *a priori*, to link it to a type of operation, culinary or craft, and thus to hypothesize its initial use. Yet the interpretation is more complex than it seems, since it turns out that the maximum temperature recorded is not always representative of the initial function. In order to understand the links between heat treatment intensity and kiln function (Fig. 6), five cooking scenarios are possible:

- Scenario 1 is the assumption that the raw kiln and its pottery load were involved in a ceramic process at a temperature of the order of 800/950°C.
- The second and third scenarios include a common intermediate phase, during which the kiln is initially fired in a high temperature pit (800/900°C). Successive firings are ceramic type (800/900°) in scenario 2 or culinary (300/400°C) in scenario 3.
- Scenario 4, suggests that the raw oven has been subjected to an initial firing of the culinary type. Subsequent firings were of the same type. Under these conditions, the perforated floor has been exposed to a temperature of approximately 300/400°C,whereas the other parts of the furnace recorded a much lower intensity.
- Scenario 5 is the same as the previous one, but suggests that the shack in wich the oven was stored was subsequently exposed to fire, an accidental event unrelated to the original function of the furnace.

2.2 Evaluation of maximum temperature

By simple observation, it is possible to determine certain thresholds of transformation of the clays such as: the extreme disintegration of the shards; the acoustic response (dull or more or less acute sound);a spot vitrification, and hardness (a material that can be scratched with a nail or steel blade).In fact, temperature is not the only factor that gives cohesion and resistance to the ceramic material. Indeed, the conditions of conservation and the mineralogical composition can also be determining factors.

Since the 1960s, the study of ceramic technology has been revolutionised by a multidisciplinary approach. The five associated technologies are infrared spectrometry, dilatometry, thermo differential and gravimetric analysis (ATD/ATG), X-ray diffractometry (MUNIER 1951; PERINET 1960; TITE 1969; FABRE 1973; KINGERY 1974; MANIATIS, TITE 1975; BILLAUD 1982; MAGGETTI 1982; PICON 1994-1996; COLAS 1998; CUOMO DI CAPRIO; PICON 1999). The first two have been rejected as they do not favor the interpretation of data for temperatures lower than 600°C. We have focused on the mineralogical characterization of materials.This work, carried out by X-ray diffractometry and scanning electron microscopy, was carried out within theInstitut de Chimie des Milieux et Matériaux of the University of Poitiers (UMR CNRS 7285 IC2MP).

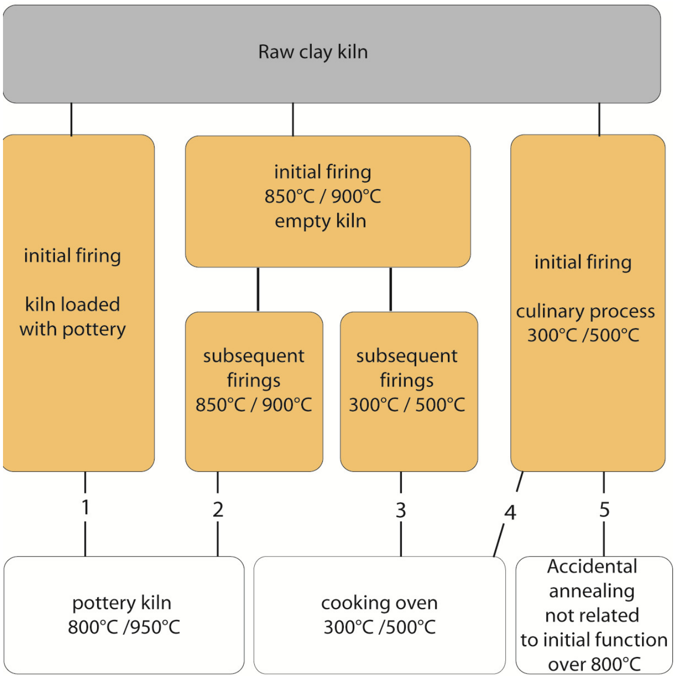


Fig.6 *Functional interpretation of a modular clay kiln, illustrated by 5 firing scenarios.*

3. MATERIALS

These are archaeological clues, represented by shards from the kiln, and clay samples collected in a deposit located near the Crêt-de- Châtillon, presumed known to Bronze-Age potters.

3.1 The archaeological fragment

In order to analyze the maximum temperature reached by the Sévrier kiln, a fragment of the perforated floor (Fig. 7), the part most exposed to the flames, was analysed. The uneven temperature distribution inside kilns is a phenomenon well known to potters, whatever the type, the shape and the volume of the cooking chamber. These differences are observed both in the content (potteries on or under fired) and the container (the different parts of the kiln). Thus, at one time *t*, the combustion chamber recorded a temperature higher than that of an area located near the chimney. Very different levels of heat exposure are also recorded between the inner and outer faces of the structure.

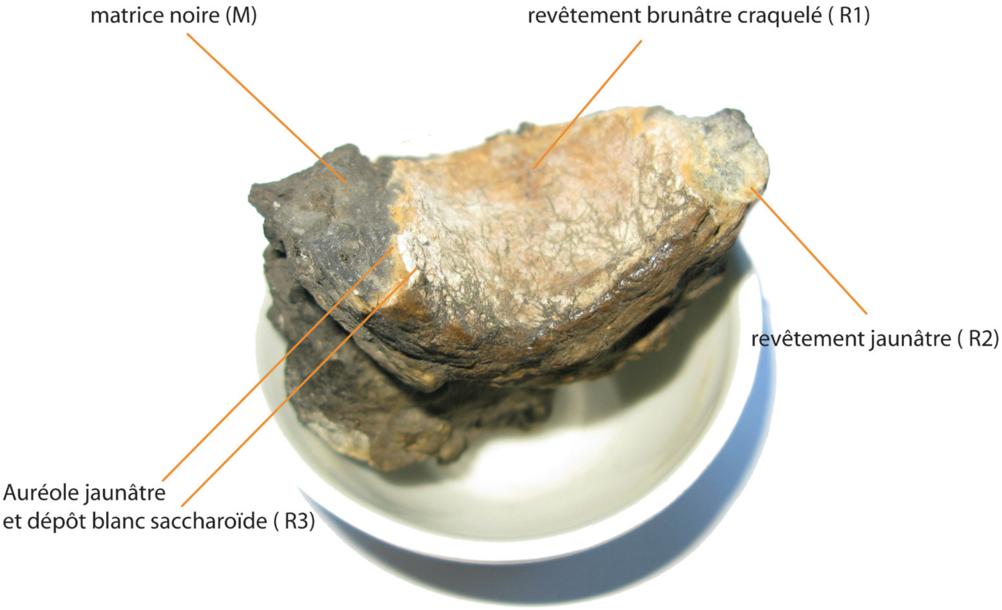


Fig.7. *Archeometric analyzes : fragment of perforated floor of the Sévrier kiln.*

3.2 Raw clay collected near the site

Due to its small surface area and the calcareous nature of its soil, the island of Crêt-de-Châtillon could not be a place of clay extraction. The inhabitants had to go to the shore of the lake (minimum distance 0.8 km) to stock up.

The geological map of the area highlights an abundant area downstream of Saint-Jorioz (1.2 km from the islet). This is the delta of Laudon, whose current hold today corresponds to the ZAC of the Tuileries. As the place name testifies, an abundant deposit allowed the development of a very old artisanal activity that lasted until the 1960s. In the zones not built or remodeled, one finds without difficulty outcrop clay veins.

Downstream from Saint-Jorioz (1.2 km from the islet), the geological map of the area shows an area rich in clay. This domain corresponds to the Laudon delta, whose right-of-way covers the current ZAC des tuileries, located at the place called les Marais.

As this toponym testifies, the abundance of clay material allowed the development of a very old craft activity that lasted until the 1960s. In areas not built or modified, the outcrop of the clay veins is easily observed (Fig. 8).

Fig.8. *Archeometric analyzes : sampling of raw clays from ZAC des Tuileries of Saint-Jorioz.*

Three criteria have conditioned the collection of clay in this location: a) its proximity to the site, b) its strong visual resemblance to the material constituting the archaeological fragment c) its plasticity and quality adapted to all phases of the ceramic process. Samples, taken in different places and at different depths, allowed us to check the abundance of the clay layer, with colours ranging from yellow to green.

Raw clay, without special preparation, has excellent plastic qualities that make it pleasant and reliable for modeling. We made several replicas of the kiln and many pottery items (Fig.9) that behaved well in drying and firing. In parallel were made 12 x 3 x 1.5cm specimens that were fired in an electric oven. The series obtained consists of 10 plates fired in a range of temperatures between 300° and 900° with 50° steps (Fig.10). After firing, the color of these clay plates is very similar to the walls the archaeological kiln.

Fig.9. *Pottery and kiln replica made with clays collected in ZAC des Tuileries. Saint-Jorioz.*

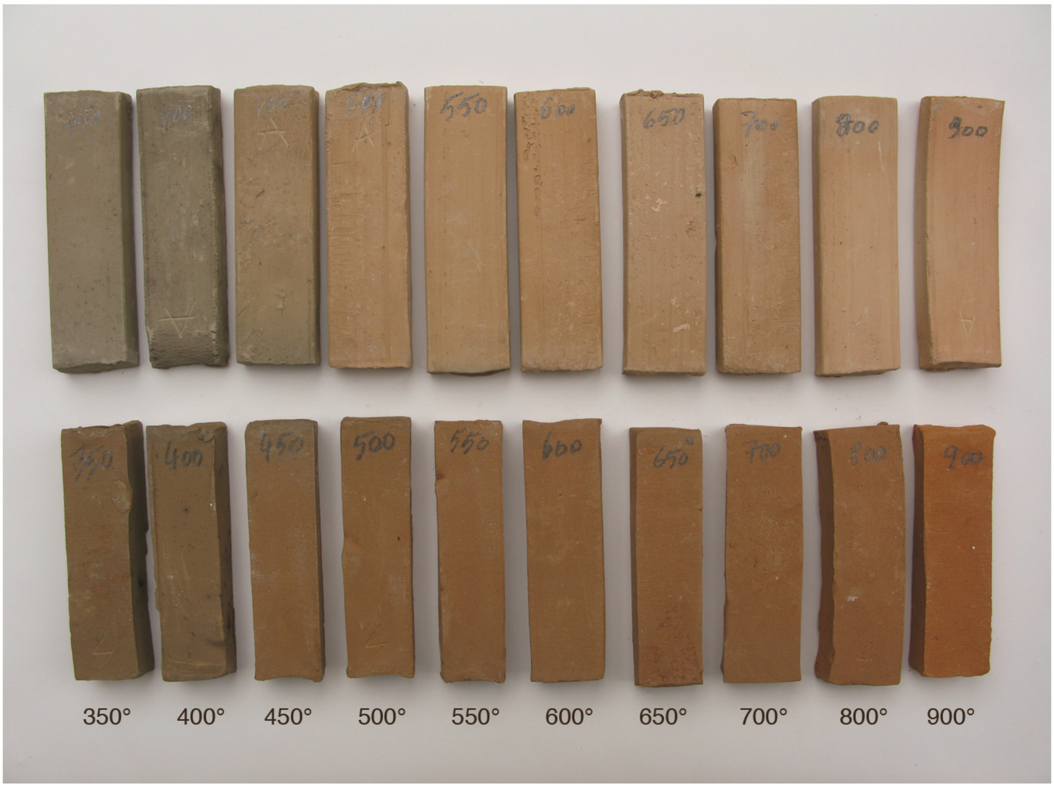


Fig.10 *Clay test plates after firing. Temperature range between 350°C and 900°C.*

4. MINERALOGICAL ANALYSIS

4.1 X-ray diffractometry

a) X-ray diffractometry was used to determine the mineralogical composition of materials (raw clay and kiln fragment) and to follow the changes in the pattern of clay minerals during the calcination tests. The principle is based on the phenomenon of diffraction of a monochromatic X-ray beam by the crystalline network of minerals. This is described by the law of Bragg (2.dhkl.sinθ= n.λ) which, for a given wavelength (λ)assigns to each family of reticular planes (dhkl) of the network an angle (θ)of X-ray beam diffraction (resulting reflection).

b) Methodology and material used for the study:
The diffractometer used is a PANalytical Xpert Pro, equipped with a copper anticathode (lCuKa = 1.541838 Å) and mounted in Bragg-Brentano. The optical system is composed by q / q configuration (anti-divergence slots ¼° 2 and anti-diffusion ½° 2), system Soller slits (0.04 rd), fixed sample holder (flatstage) and Ni filter). The sample holder is in a fixed position. The Xccelerator detector allows cumulative counting over an angular sector of 2° 2 . The analytical conditions in powder mode are: 40 kV, 40 mA, Ni filter, angular range 2.5 to 65,0° 2 , counting time of 30s / 2° 2 .
For the total mineralogical analysis, the diffractograms were made on the previously crushed material, sieved at 50 µm and then placed on a support so as to obtain a powder in which the diffracting crystallites are randomly oriented. The diffractograms obtained make it possible to characterize the principal minerals (mass content greater than 1%) constituting the sample, from all their specific reflections (hkl) and the behaviour of reflections (00*l*) of clay minerals subjected to thermal treatments (Brindley, Brown 1985; Moore, Reynolds 1997).

4.2 Scanning electron microscopy

The morphological and punctual chemistry studies are carried out successively using a JEOL JSM 5600LV SEM, equipped with a SiLi EDS AXS Brucker detector. Imaging is performed in secondary electron mode. The chemical data is acquired using Quantax software to obtain either elemental distribution maps or chemical weight compositions. The analysis conditions are: vacuum 10-5 Pa, probe current 1.0 nA, working distance 17 mm, spot size 0.1 µm, counting time 100 s. The minerals used for calibration are: albite, orthose, forsterite, diopside, pyrite, almandine plus chromium metal.
After air drying, small sample fragments (< 0,5 cm) and surface deposits were mounted on a glass slide covered with a double-sided adhesive. For larger items, the use of silver lacquer was necessary for fixing. The assembly was then placed in a vacuum chamber; when it reached 10^{-2}torr, an electric arc created between two graphite pencils volatilizes the latter which is then deposited in a very thin layer (30 nm) on the sample, thus making it conductive.

5. RESULTS

5.1 Mineralogy of the raw clay deposit

Two clay samples were analysed according to their dominant hue: yellowish and greenish.
The yellowish material is clay-rich(in the mineralogical sense) and dominated by chlorite (reflections at 14.3 Å, 7.06 Å, 4.72 Å and 3.53 Å) and illite or mica (peaks at 10.0 Å and 4.99 Å) mixed with smaller amounts of kaolinite (reflection at 7.20 Å) and probably an interstratified phase (shoulder around 16.0 Å). These phyllosilicates (common reflection at 4.49 Å) are associated with quartz (peaks at 4.26 Å and 3.34 Å) and with plagioclase (reflections at 6.38 Å, 3.67 Å and 3.19 Å), of composition close to the albite. Finally, calcite appears in traces (peak at 3.03 Å).
The greenish material has the same assemblage of clay minerals, in proportions that seem similar. The difference to the yellowish material is based on the other minerals. Indeed, if quartz is still present, the plagioclase content (3.19 Å) is much lower, while that of another potash feldspar of microline type (3.24 Å reflection) and calcite (3.03 Å) increase significantly.
The difference between these clays, distinguishable by their hues, is essentially based on the quantities of feldspar (alkali i.e. potassium) and calcite. On the other hand, the assemblages of clay minerals are identical (chlorite> illite >> kaolinite and interstratified mineral), both from the point of view of the present phases and of their apparent proportions.

5.2 Thermal tests

Like deposit clay, the base material used for thermal tests is sandy clay. The detrital fraction consists mainly of quartz (reflections at 3.34 Å and 4.26 Å) associated with plagioclase, probably albite (3.19 Å and 4.03 Å) and small amounts of potassium feldspar (3.24 Å). The clay phases, meanwhile, are composed of chlorite (14.4 Å and 7.10 Å), illite (10.0 Å and 5.00 Å) and a little kaolinite (7,20 Å). To these clearly identified phyllosilicates must be added one or more poorly organized clay phases which are responsible for a high background between 14 and 10 Å.

During the tests (Fig. 11), as the temperature rises,we note the following mineralogical evolution:

- from 100 to 300°C: the clay phases do not show any modification.
- at500°C: the reflection at 7.20 Å, attributed to kaolinite, begins to fade, because at this temperature this mineral is completely or partially dehydroxylated, which leads to the destabilization of the crystalline lattice and the formation of amorphous metakaolin;
- at600°C: this reflection has completely disappeared and the major reflections (001) of illite (10.0 Å) and chlorite (14.4 Å) become sharper. For the latter, there is also a slight displacement of the reflection (001) from 14.40 Å to 13.90 Å. This is a classic phenomenon of collapse of the interlayer domain of this mineral when the proportion of iron in its chemical composition is significant;
- at 750°C: the 10.0 Å reflection of the illite is maintained while the reflection intensity at 13.9 Å of the chlorite decreases drastically. This is indicative of the destabilization of the chlorite crystalline network, whose melting product can recrystallize as minerals of olivine-group;
- from 800°C to 950°C: the illite reflection at 10.0 Å gradually decreases, while at the same time reflections specific to the hematite (3.67 Å, 2.69 Å and 2.51 Å) are growing.

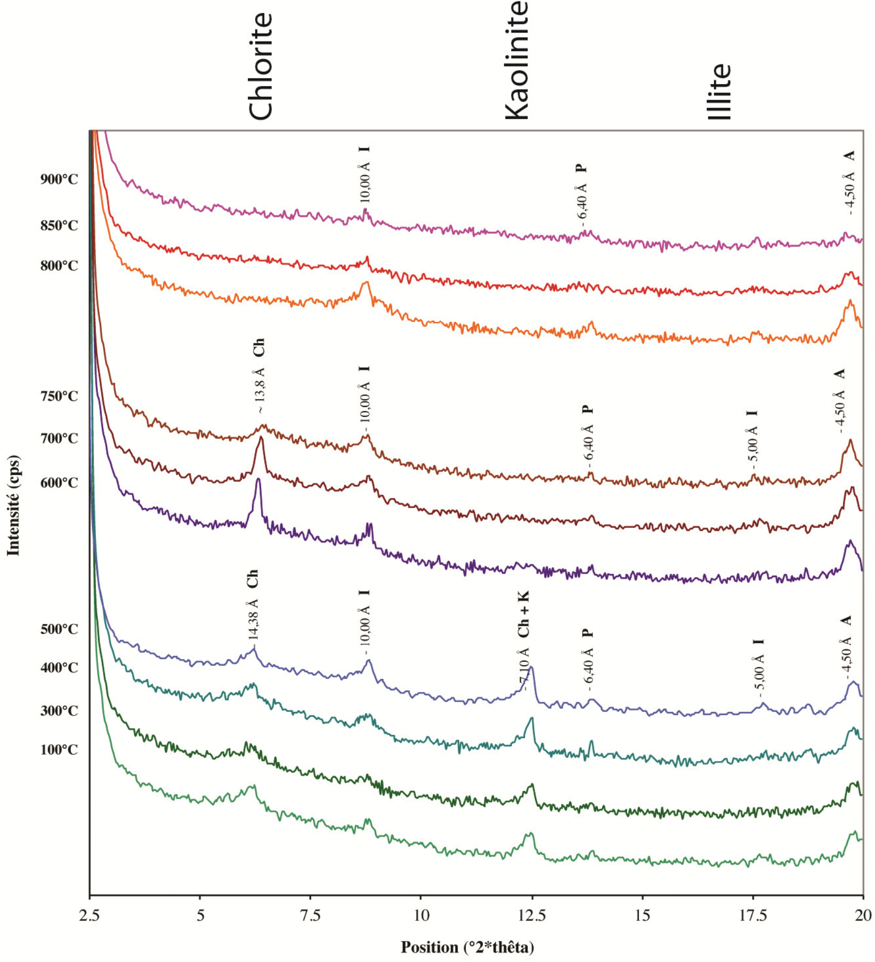


Fig.11. *Diffractograms of powders in the range of 100 ° to 900 ° C, illustrating the mineralogical evolution of clay materials as a function of the intensity of heat treatment:* (A) *dehydration (100 ° C [1], 300 ° C [2], 400 ° C [3] e 500 ° C [4]); (B) deidrossilation (600 ° C [5], 700 ° C [6] e 750 ° C [7]); (C) recristallization (800 ° C [8], 850 ° C [9] e 900 ° C [10]). Minerals: (C) clorite, (Ca) calcite, (F) K-Feldspato, (I) Illite o Mica, (K) Caolinite, (P) Plagioclasio, (Q) Quarzo.*

5.3 The fragment of perforated floor

5.3.1 Macroscopic description

The perforated floor fragment is in the form of a coarse parallelepiped of dimensions 5 cm × 4 cm × 3 cm. One of the ends present a concave edge that corresponds to an angular section (about 1/3) of nozzle. This edge is further marked by a bulge of about half a centimeter. The fragment consists of a black material (M) whose surface appears relatively clean. In some places, especially on the upper part of the bulge, we observe brownish to dark-ocher (R1) plaques with brilliant reflections on the most raised areas (consolidation resin?). Some white efflorescence (Eb) is visible under a binocular microscope in contact with the flat part and the bulge. Finally, at the right of the breakage of the bulge, the surface is partially covered with a yellowish material (R2).

The inner part of the nozzle is entirely covered with a white coating (R3) formed of very small crystals (saccharoid appearance). The contact between this white coating and the black substrate (M) is made by a continuous yellowish rim.

The underside of the perforated floor is relatively flat. The black matrix appears cracked, in large beaches some of which are covered with a film of gray matter (Eg).

5.3.2 Mineralogy of the main constituent

The black matrix (M) (Fig. 12), which constitutes the bulk of the studied hearth fragment, is composed of a mixture of quartz (4.26 Å and 3.34 Å) - the most abundant phase - and of clay minerals which are manifested by a broadband centered on 12.3 Å (unidentified). To these two components are added small amounts of calcite (3.03 A) and illite (10.0 Å and 4.99 Å), as well as traces of gypsum (7.59 Å), plagioclase (3.19 Å) and potassium feldspar (3.24 Å).

The brown beige coating (R1) taken from the upper face of the fragment, in contact with the black matrix, is composed of small quantities of quartz, calcite and illite, packed in an amorphous matrix (organic material) or poorly crystallized (silica) as suggested by the increasing of background intensity between 17 and 35Å.

The yellowish coating (R2), collected on breakage of the black matrix, has the same characteristics as the previous coating (R1).

The coating (R3), covering the interior of the conduit of this perforated floor, is composed of a mixture of quartz and calcite. To these two components are added some barely detectable traces of illite (9.95 Å, 4.49 Å and 2.57 Å). It is possible to envisage that, in the lacustrine context, calcite is the product of carbonation of a coating which was initially lime.

The amounts of material corresponding to white efflorescence (Efb) and gray film (Efg) were insufficient to be analyzed by X-ray diffraction, and could therefore only be studied in scanning electron microscopy.

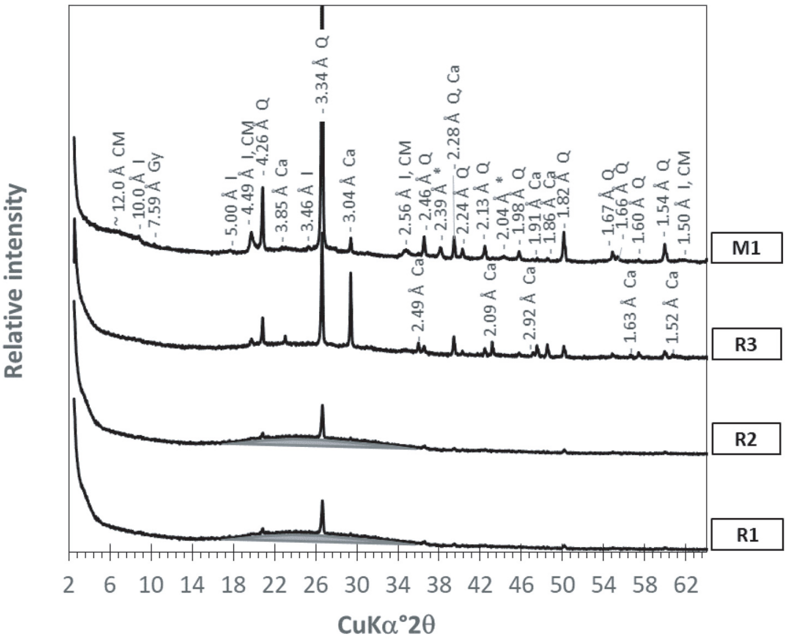


Fig.12. *Series of diffractograms of different coatings observed on the Sévrier kiln floor: a) diffractogram of the black matrix (M1). b) diffractogram of the beige veneer (R1). c) diffractogram of yellowish plating (R2).d) diffractogram of white veneer (R3). Minerals: (CM) Indifferenciated Clay Minerals, (Ca) Calcite, (Gy) Gypsum, (I) Illite or Mica, (Q) Quartz, and amorphous material (grey area).*

5.3.3 Microtexture and chemistry of the different constituents

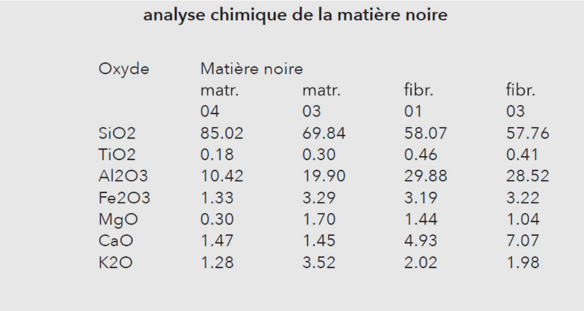
Dark matter, which constitutes the essential material of this perforated floor fragment, is composed of a matrix of massive appearance at low magnification. However, there is a part corresponding to a compact aggregate of small micrometric grains (matrix) packing coarser elements, several tens of micrometers elongation, having a fibrous or woody texture (fibr.). In more detail, these elements have areas of splinter breaking and reveal a lamellar structure whose outer parts are cut into large partitions while the internal parts are partitioned much finer. These elements, in all likelihood of vegetable origin and whose nature remains to be determined, are almost everywhere covered with a thin mineral film.

The matrix part (Tab.1) of this dark matter is essentially siliceous (70 to 85%), alumina being the second constituent (10 to 20%), whereas the iron, calcium and potassium contents are minor. On the other hand, the fibrous elements are less rich in silicium($SiO_2 \approx 58\%$) and richer in aluminium($Al_2O_3 \approx 29\%$) and in calcium ($CaO \approx 6\%$). This distribution seems to indicate that quartz is mainly in the matrix while clay minerals and carbonates constitute the mineral film covering the fibrous elements.

The brownish coating (R1), taken from the upper surface of the hearth, is a very disparate mixture of micrometric elements composed of siliceous grains (quartz), grains and silico tablets. -aluminous more or less potassic (illite or mica) and fibers with very complex chemistry (fragments of fibers on which precipitated clay minerals, carbonates and sometimes even sulphates).

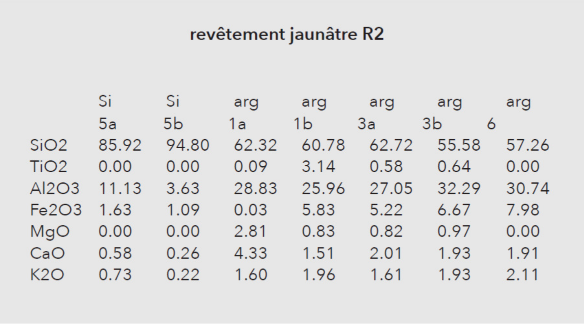
The yellowish coating (R2), collected on breakage of the black matrix, is of composition and general appearance very similar to those encountered for the coating R1 with however a less heterogeneous character. In fact we can distinguish (Tab.2) unreservedly siliceous zones (Si) and clearly silico-aluminous zones, *i.e.*more argillaceous (arg), more or less ferriferous.

The covering (R3) or coating which covers the interior of the conduit of this perforated floor can be divided into two parts: a yellowish halo (aur.) directly in contact with the black material and a saccharoid deposit. The chemical analyzes carried out from the black material to the deposit show that the contents of Si and Al decrease sharply to the right of the halo and collapse for the deposit. Iron seems to follow the opposite trend since its content can locally double from black material to halo, but becomes zero in the deposit. On the other hand, the calcium content increases continuously to become the only constituent of the deposit, confirming its carbonate nature. Finally, note that it is in the vicinity of this coating, in the black matrix and the yellowish coating, that we find the most important traces of sulfur and phosphorus. These gradations of chemical compositions could signal phenomena of mineralogical transformations to the right of this thermal interface.



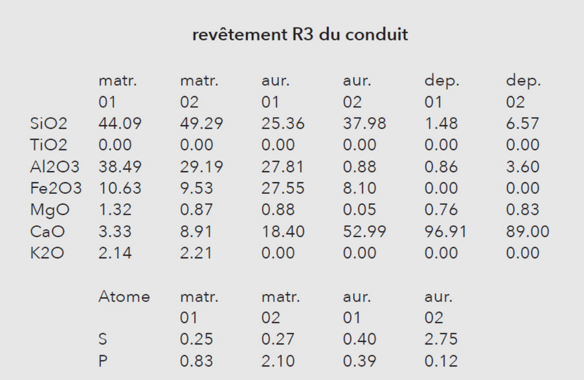
analyse chimique de la matière noire

Oxyde	Matière noire matr. 04	matr. 03	fibr. 01	fibr. 03
SiO2	85.02	69.84	58.07	57.76
TiO2	0.18	0.30	0.46	0.41
Al2O3	10.42	19.90	29.88	28.52
Fe2O3	1.33	3.29	3.19	3.22
MgO	0.30	1.70	1.44	1.04
CaO	1.47	1.45	4.93	7.07
K2O	1.28	3.52	2.02	1.98



revêtement jaunâtre R2

	Si 5a	Si 5b	arg 1a	arg 1b	arg 3a	arg 3b	arg 6
SiO2	85.92	94.80	62.32	60.78	62.72	55.58	57.26
TiO2	0.00	0.00	0.09	3.14	0.58	0.64	0.00
Al2O3	11.13	3.63	28.83	25.96	27.05	32.29	30.74
Fe2O3	1.63	1.09	0.03	5.83	5.22	6.67	7.98
MgO	0.00	0.00	2.81	0.83	0.82	0.97	0.00
CaO	0.58	0.26	4.33	1.51	2.01	1.93	1.91
K2O	0.73	0.22	1.60	1.96	1.61	1.93	2.11



revêtement R3 du conduit

	matr. 01	matr. 02	aur. 01	aur. 02	dep. 01	dep. 02
SiO2	44.09	49.29	25.36	37.98	1.48	6.57
TiO2	0.00	0.00	0.00	0.00	0.00	0.00
Al2O3	38.49	29.19	27.81	0.88	0.86	3.60
Fe2O3	10.63	9.53	27.55	8.10	0.00	0.00
MgO	1.32	0.87	0.88	0.05	0.76	0.83
CaO	3.33	8.91	18.40	52.99	96.91	89.00
K2O	2.14	2.21	0.00	0.00	0.00	0.00

Atome	matr. 01	matr. 02	aur. 01	aur. 02
S	0.25	0.27	0.40	2.75
P	0.83	2.10	0.39	0.12

Tab.2. *Chemical composition of the constituent elements of the perforated floor.*

6 DISCUSSIONS

6.1 Comparison : Reference Clay vs Perforated Floor

The two materials analyzed are different from the point of view of their composition in clay minerals. This point of view can be reinforced by observing feldspars (potassium feldspar and plagioclase) that are relatively abundant in the reference clay, but in the state of minor compounds, even traces, in the perforated floor matrix. Since these minerals are chemically very stable and completely refractory (melting at around 1200° C), none of the temperatures tested can make them disappear and/or modified their crystallinity.

It follows that the reference clay is not the basic product having served for the manufacture (or for a very small fraction) of the perforated floor matrix. So, it is very difficult to compare the mineralogical evolution of the clay phases, demonstrated experimentally, on the specimens and the mineralogical composition of the perforated floor.

It is the same for oxides and especially for hematite, because if the perforated floor production material contained no iron-bearing mineral, it cannot form hematite as a product of the thermal action. Consequently, the absence of hematite in the hearth matrix cannot be used to dispute a heating temperature lower than 800°C.

6.2 Presence of plant debris

Scanning electron microscope observations revealed the presence of plant debris. These are quite numerous and clearly packed in the perforated floor matrix.

Their state of preservation is remarkable: the micrometric views (Fig. 13) show extremely fine details of the cell walls. This can only be explained by a good initial state when they were buried in the lacustrine sediment.

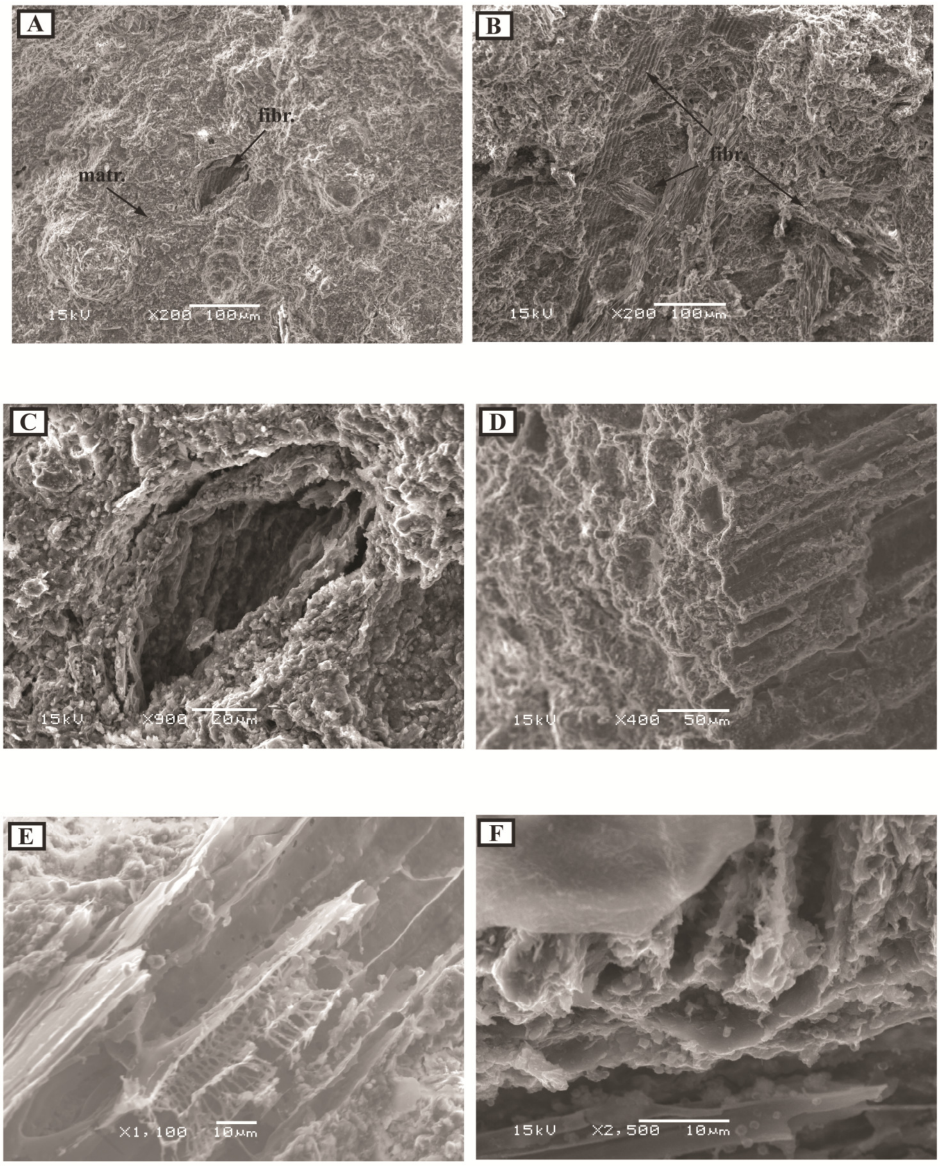


Fig.13. *Scanning electron micrographs of the black hearth material showing (A, B, C) a mineral matrix (matr) packing fibrous elements (fibr) with partitioned texture (D, E) locally coated with fine siliceous or clay deposits (F).*

The recovery of plant debris by a silica film or the silicification of their structures occurred after burial, in contact with lake water rich in diatoms which may be the provider of silica.
Observations under a binocular microscope confirm those made with a scanning microscope. The presence of vegetable matter distributed in the clay paste is very clearly distinguished.

The good state of conservation of plant debris is an indication of the maximum temperature experienced by the furnace. Such a state is incompatible with intense heat treatment.
In fact, it is conventional to determine the organic matter content of a material by calcination at 500°C, a threshold that allows their complete oxidation (CO_2)and their reduction to ash. Therefore, if the organic elements included in the matrix of the hearth have undergone a thermal effect, it must be well below 500°C.It is the presence of such remarkably preserved plant remains that seems to be the essential argument in favor of a weak heat treatment undergone by the matrix of the perforated floor of the Sévrier kiln.

7. CONCLUSION

Often used in the field of archeology, X-ray diffractometry has proven effective in highlighting the phase changes of the clay deposits as the temperature rises. It also allows a fine analysis of the clay minerals that constitutethe fragment of perforated floor, its black matrix and the various veneers covering its surface. However, to deduce, by a comparative method, the temperature at which the perforated floor of the Sévrier kiln was exposed, it is essential to have at disposal ~~a~~raw clay of identical composition. Assuming that the building of thekiln is local, it was logical to search for a potential clay deposit available in proximity to the islet of Crêt de Châtillon. The clay from the Laudon Delta was the best candidate for its proximity, abundance and quality. However, this material shows a certain heterogeneity, both at outcrop and depth, which does not allow us to base our comparisons on mineralogical criteria. On the other hand, given the small size of this furnace, whose constituent elements are removable, it cannot be ruled out that it was made in somewhere other than the place where it was found. Therefore, the clay raw material used to make it would come from a completely different source.

The one collected near the island has a mineral disparity that does not allow us to base our comparisons or reach our goal. Either the clay deposit is inhomogeneous and varies mineralogically depending on the location and depth of the sampling, or the archaeological kiln has been shaped with clay from a different origin.

The first index of a heat treatment below 500°Ccomes from observations under binocular (Fig.14) and scanning electron microscope in which vegetable debris could be observed.
This index was confirmed after studying three fragments of similar kilns deposited at the « Musée Savoisien » in Chambéry. In fact, several perforated floors fragments of a very similar design to the Sévrier kiln were discovered on the pallafittic sites of Lake Bourget (Savoie-France) 30 km from lake Annecy.Organic remains are detected both in the ceramic paste and on the surface of the shards.
The fragment ref. 897100 (Grésine site, Bourget lake) presents dark clusters, identified by a binocular microscope examination. Despite their state of carbonization and their colonization by calcareous deposits, millet seeds are clearly recognizable (Fig.15a). Other remains of seeds less well preserved are observed on another fragment ref. 897 1242 from the same collection. Another calcined and eroded seed of which only the outline of the envelope remains is also located on the fragment ref. 89794 (Fig.15b).

Thus, two convergent indices have to be considered for the understanding of these Savoyard modular kilns, and perhaps beyond, for similar architectural structures spread over central and western Europe during the Metal Ages. On the one hand, the presumption of a moderate heat treatment less than 500°C subject to the remarks made in paragraph 2.1. On the other hand, the relationship between millet and perforated floor, is a strong argument that reinforces the hypothesis of the culinary function of the furnaces discovered on the late Bronze Age sites of lake Bourget.

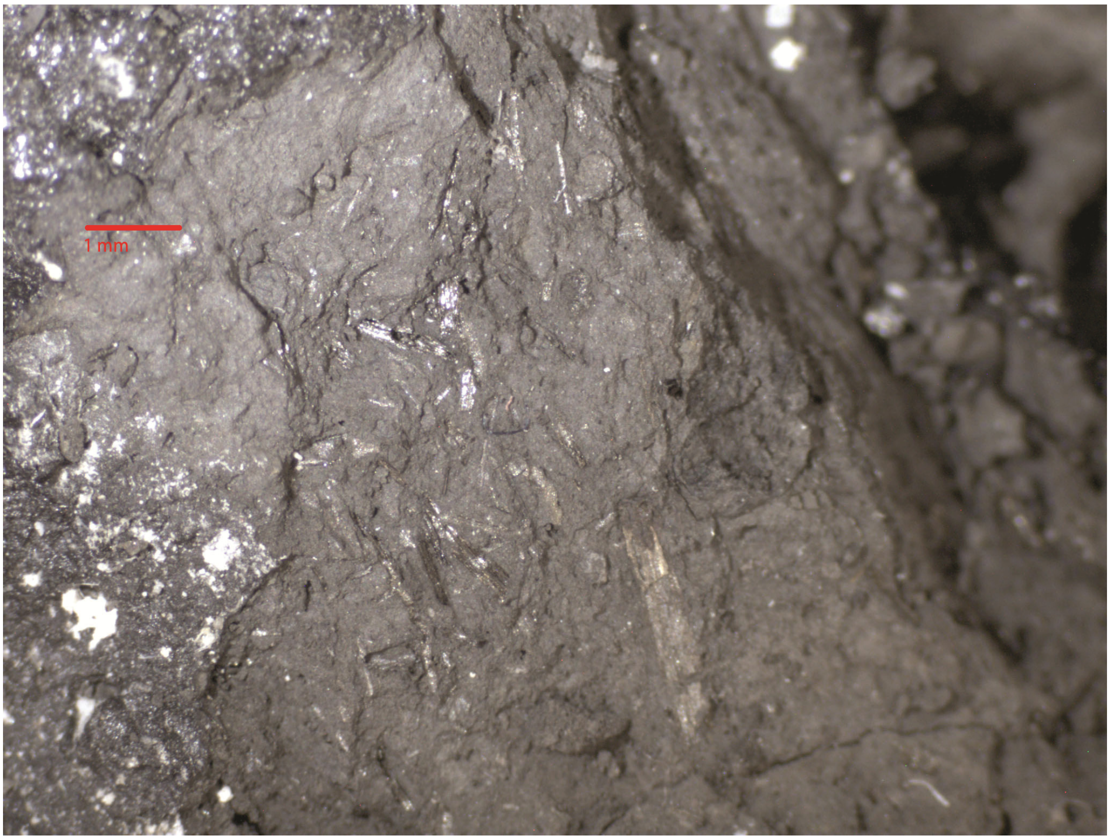


Fig.14. *Plant debris well preserved in a fragment of the Sévrier kiln. Leica Firecam Binocular Photography.*

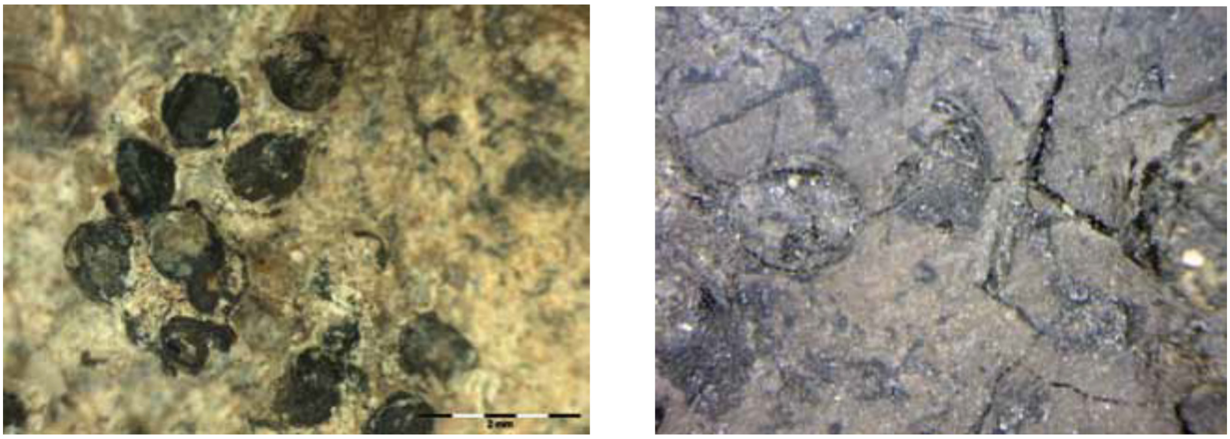


Fig.15. *Millet seeds and perforated floor fragments. Musée Savoisien. Chambéry. a) fragment ref 897100: heap of millet seeds calcined, agglutinated on the surface of the kiln floor. b) fragment ref. 89794: calcined and eroded seed. Gresine site, Late Bronze Age, Lake Bourget (Savoie) © J Coulon.*

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