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Social context of Mesolithic rock engravings in the Fontainebleau sandstone region (Paris basin, France) : contribution of the experimental study

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Abstract

Anthropogenic engravings were made within more than 2,000 small natural cavities found in the sandstone boulder fields of the central Paris Basin, in an area of 1,800 km² to west of the town of Fontainebleau. These engravings consist mainly of clustered rectilinear grooves arranged in vertical parallel series or organized in grids. These dominant classes of motifs form a unique type of rock art attributed to Early Mesolithic hunter-gatherers (~ 9500–6300 BCE in northern France) on a growing body of evidences. Here, we approach the social context in which these abundant symbolic manifestations were produced by developing an experimental study guided by two main questions: what efforts (i.e difficulty of work and working time) and know-how were required for these engravings? On what occasions were they made?

After quantifying the highly variable hardness of the Fontainebleau sandstone with a Schmidt Hammer, we selected natural blocks and blank cavities in recent quarries to conduct our experiments. These show that the engravable part of the sandstone corresponds to a friable cortex often less than 1 cm thick, which covers a core of hard sandstone that cannot be engraved. In the sandstone boulder fields, this friable cortex is only preserved on surfaces protected from weathering. Our experiments also reveal that curved grooves can be made without difficulty and that the omnipresence of rectilinear grooves is a cultural choice. Finally, our experiments show that these rectilinear grooves are very easy to engrave and make it possible to propose equations for estimating the time required to make archaeological motifs. The average engraving time of a groove has been estimated at less than one minute and less than 15 minutes for the most common grids.

These results, placed in their archaeological context, allow us to formulate the following proposals: (1) the engravings attributed to the Early Mesolithic period were technically easy and could be made in rather short periods of time; (2) the cramped configuration of the engraved places and the absence of apparent distribution pattern of motifs on the walls points to the hypothesis of an accumulation of individual engraving episodes, possibly by several engravers; (3) the engraved cavities

are abundant, easily accessible and connected to daily-life territories. We can deduce that the Fontainebleau rock engraving phenomenon is the result of numerous small, ordinary and stereotyped engraving rites, likely carried out by a large number of engravers.

Keywords:

Rock art, Mesolithic, Experimental Archaeology, Engraving, Sandstone.

Highlights:

- Replicating rock art to question its social context.
- Quantifying sandstone "engravability".
- Assessing engraving constraints and know-how.
- Modelling engraving time for different motifs.
- Identifying highly repeated engraving rites during the Early Mesolithic.

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1 Introduction

A singular rock engraving phenomenon, unique in Europe, was identified in the middle of the nineteenth century in the sandstone formations of the central Paris Basin (Martin, 1868; Bénard, 2014). Known as 'Fontainebleau rock art', this phenomenon covers an area of 1,800 km², corresponding to the sandstone outcrop west of the town of Fontainebleau located 55 km southeast of Paris (Thiry et al., 2015) (Fig. 1A).

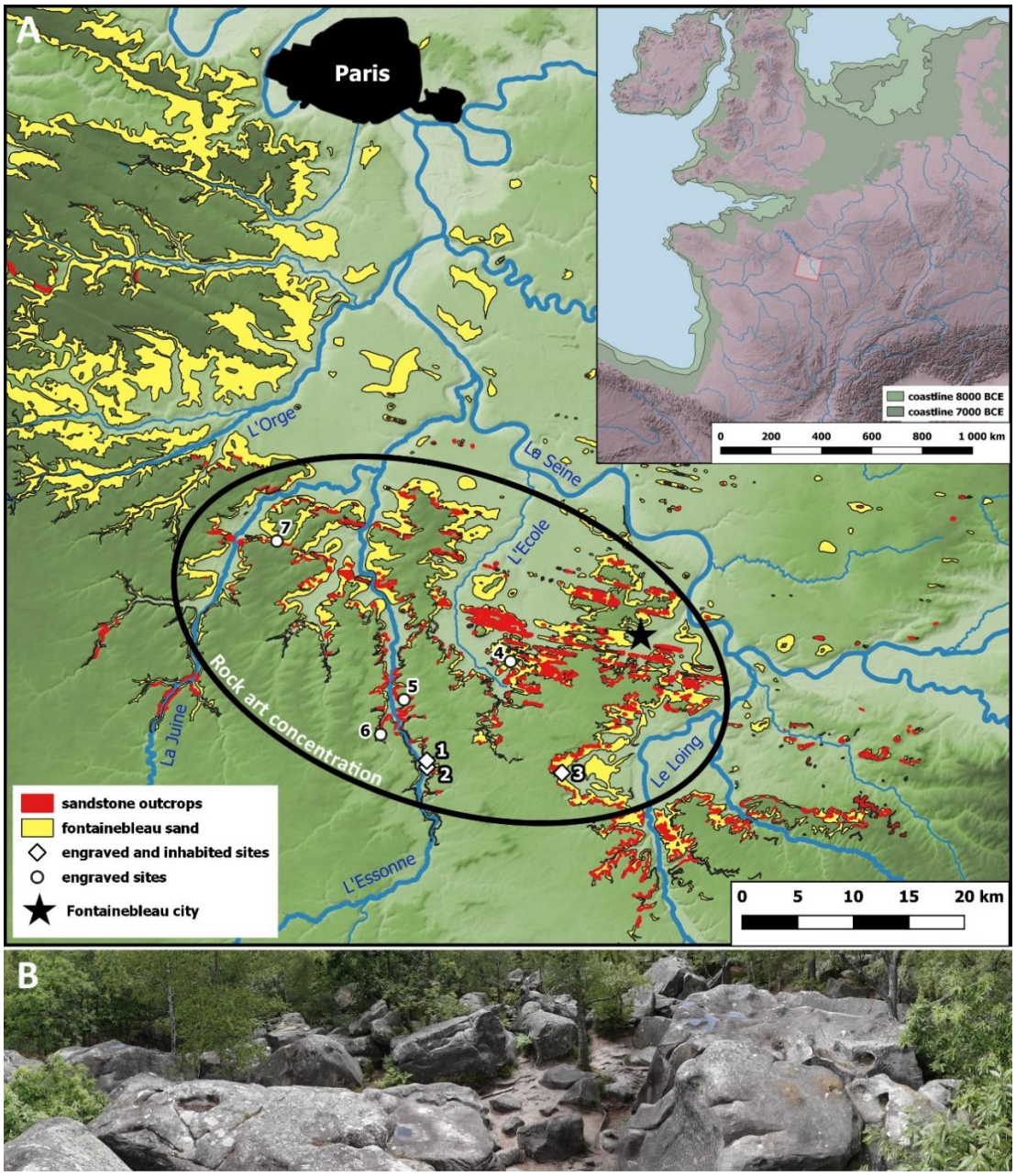

Figure 1: Geographic and geological context of the Fontainebleau sandstone region. A: location of this region in north-western Mesolithic Europe (coastline after McNulty and Cookson 2012, National Geographic Magazine[1]). The sandy deposits in which the sandstones formed are indicated on the map. The extent of the Fontainebleau rock engraving phenomenon corresponds roughly to the 1,800 km² delimited by the black ellipse. All the sites mentioned in the text are located on the map. 1: Bel Air 1 (Buthiers); 2: Bel Air 12 (Buthiers); 3: Dégoutant à Ratard 1 (Larchant); 4: Rocher des Potets 1 (Noisy-sur-Ecole); 5: La Sablonière 3 (Buno-Bonnevaux); 6: Butte du Puits 1 (Villeneuve-sur-Auvers). B: example of typical boulder field resulting from the dislocation of sandstone bars on valley sides and isolated mounds. [colour; 1.5 columns]

[1] https://www.nationalgeographic.org/maps/doggerland/

These sandstone formations, which occupy the slopes of sandy valley sides or isolated mounds, form boulder fields (Fig. 1B) sheltering countless small natural cavities (Thiry, 2017a). To date, engravings have been identified in 2160[2] of these cavities (Fig. 2) owing to the prospecting work of an association of volunteer archaeologists (GERSAR[3]) who study them and work to preserve them.

Figure 2: Example of engraved sites. A: boulder containing a cavity formed after the hollowing out of uncemented sands (photo E.Lesvignes). This is the most frequent site configuration. B: cavity created by the accumulation of boulders. C: large shelter also inhabited during the Mesolithic under a sandstone bar in primary position (Dégoutants à Ratard 1 known as 'Grotte à la Peinture' at Larchant). [colour; 1 column]

These engravings are mainly non-figurative subtractive marks composed of rectilinear grooves arranged in vertical parallel series or organized in grids (Fig. 3A-F). Both types of motifs are quantitatively dominant in the engraved cavities (Tassé 1982: 68). They are often densely clustered with no apparent distribution pattern on the walls (Bénard, 2014). We find them all over Fontainebleau sandstone region in great number (Tassé, 1982; Bénard 2014).

[2] Count in October 2020
[3] Groupe d'Etude, de Recherche et de Sauvegarde de l'Art Rupestre

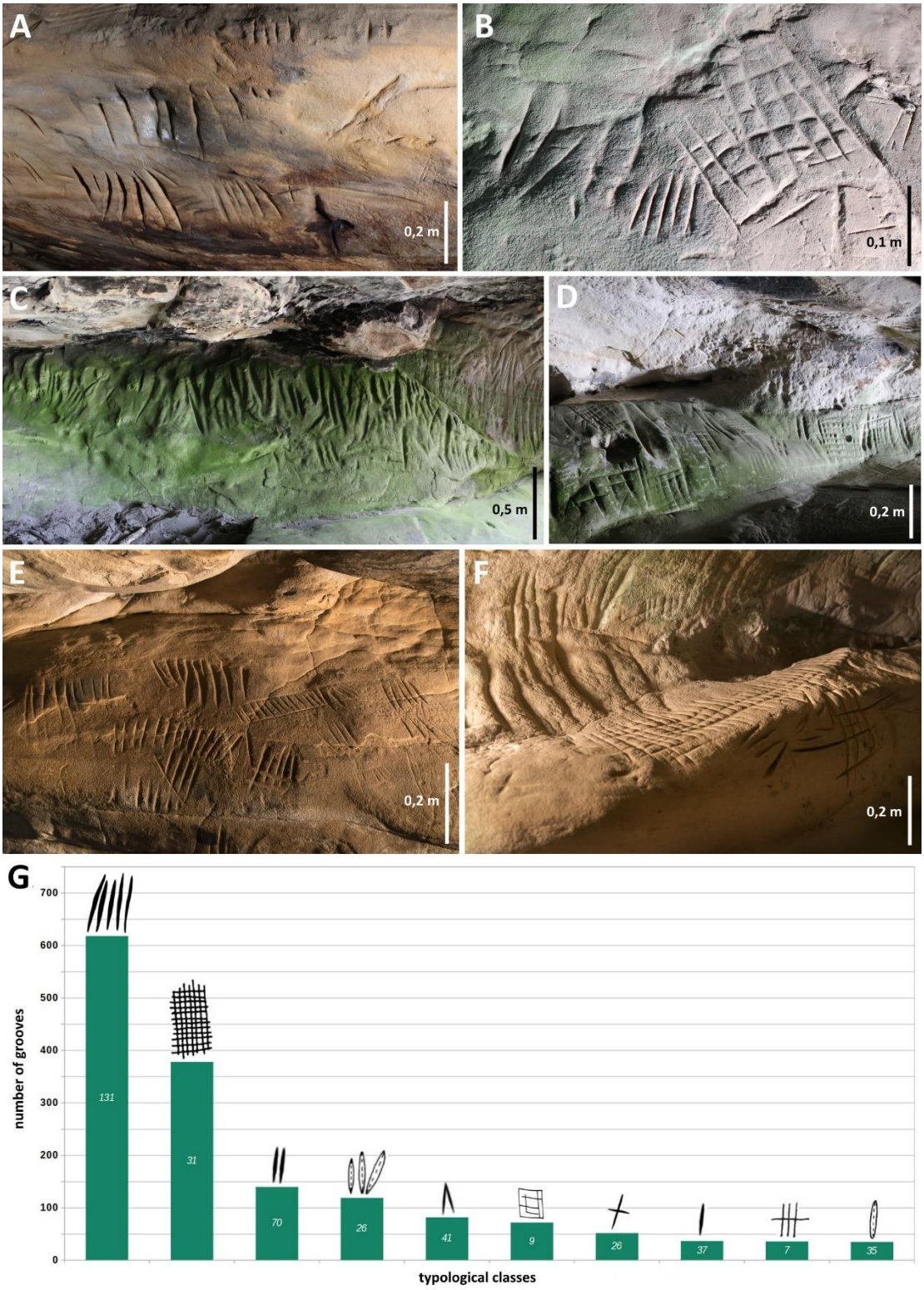

Figure 3: Fontainebleau rock engravings. A: wall engraved with parallel series of grooves and two cruciform (Bel Air 1 at Buthiers). B: parallel series of grooves and grids (Bel Air 1 at Buthiers) C: parallel series of very large and deep grooves called “sillons naviformes" (Bel Air 12 known as “Grotte de Chateaubriand“ at Buthiers). D: cluster of seven grids (Bel Air 12 at Buthiers). E : parallel series of grooves and one altered grid (Dégoutants à Ratard 1 known as “Grotte à la Peinture“ at Larchant ; photo E. Lesvignes). F: grids and parallel series of grooves (Dégoutants à Ratard 1; photo E.Lesvignes). G: number of grooves (total: 1569) per typological classes of motifs common to Bel Air 1, Bel Air 12 and Dégoutants à Ratard 1 sites. The white number on each bar indicates the occurrence of the motif. Note that modern graffiti, which are also a typological class common to the three studied sites, were not included in this histogram given their obvious recent character. From left to right: parallel grooves, grids, paired grooves, parallel series of large and deep grooves called “sillons naviformes”, convergent grooves, parallelogram, cruciform, isolated groove, crossed parallel grooves, isolated large and deep groove. [colour; 2 columns]

In at least 29 cavities, 541 rounded-edge lithic artefacts were discovered in the excavated archaeological sequences situated at the bottom of the engraved walls, some of them showing clear analogies with Mesolithic tool types (Courty, 1904; Baudet, 1952; Hinout, 1998; Bénard, 2014). Thus, the specific use-wear found on these rounded-edge lithic artefacts suggested they were used as engraving tools. For these reasons, the engravings have long been presumed to be prehistoric, possibly from the Mesolithic period (~ 9500–6300 BCE in northern France).

Both a recent use-wear study and the critical review of three engraved and inhabited sites confirms and refines this hypothesis (Guéret and Bénard, 2017). Our contribution here is not to discuss again the different clues used to identify engraving practices during the Mesolithic period, largely developed in a previous research article published in JAS Reports (Guéret and Bénard, 2017). We only summarize here the main milestones and encourage the reader to refer to this paper for more details. Bel Air 1 at Buthiers, Bel Air 12 known as "Grotte de Chateaubriand" also at Buthiers and Dégoutants à Ratard 1 known as "Grotte à la Peinture" at Larchant (see Fig 1A and Fig. 2C) are well documented excavated sites (Hinout, 1993a, 1992, 1993b). They delivered 300 of these rounded-edge lithic artefacts in Mesolithic contexts determined to be sufficiently rigorous (for detailed discussion see Guéret and Bénard, 2017: 111-112) : (1) at Bel Air 1, these artifacts appeared in an Early Mesolithic layer (sensu Marchand and Perrin, 2017 ; ~ 9500–6300 BCE in northern France) 1.30m below the surface overlain by a Late Mesolithic layer (~ 6300–5300 BCE in northern France) and a clearly distinct Final Bronze Age layer; (2) at Bel Air 12, the rounded-edge lithic artefacts proved to be associated with a lithic assemblage typical of the Mesolithic (Early and Late periods mixed) without any pollution of modern material (ceramic sherds, glass fragments or metallic remains) in a layer with a palynological signature of the Boreal age (~ eighth millennium BCE) (3) at Dégoutants à Ratard 1, another coherent Mesolithic layer characterized by a black coloration and situated at the bottom of a 2.70m well-preserved stratigraphic sequence with multiple occupation phases yielded the same rounded-edge lithic artefacts. Microscopic observations and experimental tests indicated that all these rounded-edge lithic artifacts were indeed blunted by grooving[4] and sometimes scraping sandstone (Guéret and Bénard, 2017: 105-107), confirming their use as engraving tools. Thus, typological and technological analysis of the engraving tools' blanks (Guéret and Bénard, 2017: 113–115) indicated a more precise Early Mesolithic dating : the use of some recycled bladelet types, microliths types, denticulates and prismatic tools likely points at least to the most recent phases of this period (eighth millennium-early seventh millennium BCE) (Ducrocq, 2009; Griselin, 2015) (Fig. 4). These results revealed the existence of significant engraving practices amongst local Early Mesolithic hunter-gatherer groups (Guéret and Bénard, 2017: 116-119).

[4] Defined as a bidirectional back and forth movement of a tool on matter in order to carve out a groove.

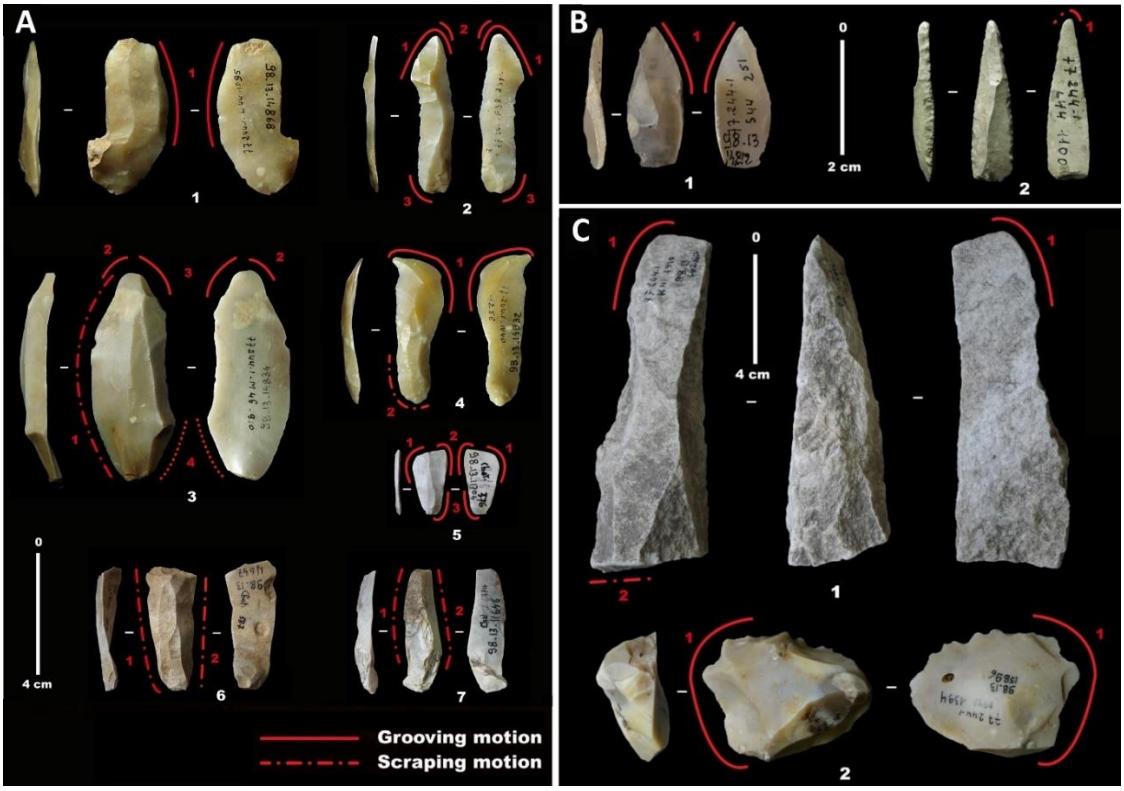

Figure 4: Mesolithic rounded-edge artefacts identified as engraving tools (excerpts from Guéret and Bénard, 2017): red lines indicate used zones related to sandstone grooving and scraping activities. A: bladelet knapped with a soft hammerstone (1-4 Dégoutants à Ratard 1 known as "Grotte à la Peinture " at Larchant, 5-7 Bel air 12 known as "Grotte de Chateaubriand" at Buthiers). B: Microliths from Dégoutants à Ratard 1. 1 point with natural base, 2 point with retouched base. C: Prismatic sandstone tool and denticulated flint flake from Dégoutants à Ratard 1. [colour; 1.5 columns]

In these three shelters that delivered rich assemblages of Early Mesolithic engraving tools, the parallel series of grooves and grids are by far the most represented typological classes of engravings[5] (Fig. 3G). On the other hand, the characteristics of used zones on the engraving tools fit the variable morphologies of the parallel series of grooves and grids (Guéret and Bénard, 2017: 106-107). Thus, we hypothesise that these two types of motifs, which are found all over Fontainebleau sandstone region in great number, could be attributed to the Mesolithic[6]. In this regard, a large part of Fontainebleau rock engravings could be considered as a unique local expression of Mesolithic symbols.

In this paper we question the social context that enabled this large-scale symbolic production amongst hunter gatherer groups by means of experimentation (Bourguignon et al. (ed.), 2001; Beyries (ed.), 2020): with what effort (i.e difficulty of work and working time) and know-how were these engravings made and on what occasions? Experimental archaeology involving grooved incisions have a long tradition in mobiliary art studies (D'Errico, 1994; Fritz, 2000; Rivero, 2015). In the field of rock art, replicative experiments of pecked engravings are the most common ones, often with parietal

[5] Research conducted as part of Alexandre Cantin's PhD thesis in progress at the University Paris 1 under the direction of Boris Valentin.
[6] More evidence for their dating is currently being researched within the framework of a collective research program of the French Ministry of Culture (dir. B. Valentin; PCR "ARBap").

traceology or engraving tool traceology research questions (A. de Beaune and Pinçon, 2001; Alvarez et al., 2001; Plisson, 2009; Aubry et al., 2011; Vourc'h, 2011, 2018; Zotkina and Kovalev, 2019). Data on working time are, however, scarce and scattered (Bednarik, 1998: 30 ; A. de Beaune and Pinçon, *op. cit*.; Vourc'h, *op. cit*) and very few studies attempt to model this parameter to discuss the social production contexts of rock art (Vegara and Troncoso, 2016).

Our experimental work focuses on three questions on the *chaîne opératoire* (sensu Lemonnier, 1986; Schlanger, 2005) of grooves and grids engraving production. The first question is about surface selection: which types of sandstone are engravable and do they impose particular constraints in terms of graphic choices (i.e., is the systematic straightness of grooves determined by difficulties related to the production of curved lines?) ? The second question is about the expertise: what kind of effort and know-how are involved in creating these engravings? The third question is about duration: what is the minimum time required for producing each motif? The ultimate objective of the last two questions is to be able to discuss the importance of this symbolic practice among hunter-gatherer activities.

As a preliminary to these investigations into the production of engravings, it is important to recall that there are sandstones of variable hardness. The abrasive capacity of weakly cemented and therefore friable sandstone was sought after during the Mesolithic period to shape bone, antler or wood (Hamon et al., 2020: 83-84). When sandstone is strongly cemented by silica (it is then called 'quartzite sandstone' or 'lustrous sandstone'), it forms a rock that can be knapped by conchoidal fracture, as was widespread during the regional Mesolithic (Hamon and Griselin, 2014, Fig. 4C). Finally, the sandstone forming the boulders of the Fontainebleau region have been directly cut into masonry stones or paving stones since at least the Middle Ages (Lejeune et al., 2016). The quarrymen categorized this sandstone into three degrees of hardness according to the sound emitted when they struck it with a hammer (Lejeune et al., *op.cit*). Since these same hard boulders form the cavities we are studying (Fig. 2), several generations of archaeologists have considered engraving them to be a difficult task. This has been the case since the first descriptions of engravings, which were considered, for example, to be "carved [...] with long patience"[7] (Martin, 1868), by "stubborn work"[8] (Courty, 1924; 347), or that they consisted of "obtaining in the long run, by wear, a groove [...]"[9] (Bénard, 2014; 156)... However, these subjective judgments were never verified by experimentation.

We will first examine below the means we used to quantify the hardness of the sandstone. After describing our experimental protocols, we will present the results, in particular those concerning the average engraving time of motifs attributed to the Mesolithic. Finally, we will discuss the contribution of these results to the anthropological approach of Early Mesolithic engraving practices in the Fontainebleau sandstone region.

[7] « creusées […] avec une longue patience »
[8] « travail opiniâtre »
[9] « obtenir à la longue, par usure, un sillon […] »

2 Methodology

2.1 Quantifying the hardness of the Fontainebleau sandstone

Since the Fontainebleau sandstone comprises sandstones of very varied hardness, as mentioned above, we required a means to measure hardness objectively, precisely, and simply as a prerequisite to our experiments; the quarrymen's method being destructive, subjective and inaccurate. This type of scientific investigation has, to our knowledge, never been applied to this rock before and is still generally absent from rock art studies, except for those related to conservation (Campbell, 1991; Sjöberg, 1994; Pope, 2000; Mol and Viles, 2010). To measure the hardness of a rock, the first traditional procedure used by material scientists is to test its scratch resistance (Vargiolu, 2008), in order to place it on a relative scale such as the Mohs scale[10]. This is the general principle employed in a very empirical way by G. Tassé, the first author of academic work on Fontainebleau rock engravings, who opted for assessment with a fingernail or an iron point on the engraved walls (Tassé, 1982; 35). The approximate results are unquantifiable and unusable for assessing the influence of the hardness of sandstone on the engravings and leave marks on the engraved walls. G. Tassé was aware of this and called for the development of an objective method as well as the use of a precise instrument dedicated to this measurement (Tassé, 1982; 78). For our part, we used a Schmidt Hammer, classically used in the study of the hardness of concrete and rocks.

2.1.1 Use of the Schmidt Hammer

The Schmidt Hammer is an instrument that measures the surface hardness of a material via the rebound (R) of a hammer propelled by a spring on its surface. It was invented by the Swiss engineer E. Schmidt, and its use developed from the 1950s onwards to measure the strength of concrete before being extended to the geomorphological study of various rocks (Goudie, 2006). Later, it was also applied to rock art in an attempt to quantify the degree of erosion of engraved walls (Campbell, 1991; Sjöberg, 1994; Pope, 2000).

The Schmidt Hammer exists in different forms and powers but the model N proves to be the most suitable instrument for our needs (Viles et al., 2011). It is a portable analogue tool that assesses hardness on a relative scale graduated from 1 to 100 (hammer rebound measurement). Today, it is the most widely used Schmidt Hammer model because of its ease and speed of use: once it is held perpendicularly to the surface, it suffices to push the percussion rod against the rock to be examined for the impact to occur (Fig. 5A). In order to obtain a representative value of the surface hardness of the tested material, it is necessary to average at least five measurements (PROCEQ, 1977).

[10] Hardness scale invented by the German mineralogist Friedrich Mohs in 1812. It organises minerals into ten classes of hardness according to their ability to be scratched by various tools (from the human fingernail to copper, iron, glass etc... until diamond itself).

Figure 5: Measuring the hardness of sandstone. A: Schmidt Hammer during use on a boulder in a recent quarry. B: example of a cup mark impact left by a measurement on friable sandstone. [colour; 1 column]

The major disadvantage of this instrument for our studies lies in its locally destructive character, as it can leave a large cup mark impact in the friable sandstones studied here (Fig. 5B). Its use is therefore strictly limited to the non-engraved sandstone used for our engraving experiments. Another non-destructive approach based on sound transmission velocity in sandstone is being tested for application to archaeological walls (Cantin and Thiry 2017), but its results are unsatisfactory so far (Cantin, 2018).

2.1.2 An 'Engravability' Scale for the Fontainebleau Sandstone

A total of 185 Schmidt Hammer calibration measurements were taken on 18 surfaces of mobile sandstone blocks and on 20 surfaces of boulders and cavities in recent sand quarries (Cantin, 2018). These measurements led to the construction of a hardness scale for Fontainebleau sandstone surfaces consisting of five classes. The experimental engraving of these surfaces with a lithic tool then allowed us to describe each of them with empirical appreciations concerning their suitability for engraving (table 1).

Class	Rebound value	Hardness of sandstone	Suitability for engraving
1	[1-28]	friable	high
2	[28-33]	coherent	good
3	[33-38]	indurated	poor
4	[38-45]	hard	extremely difficult
5	[45-60]	quartzitic	extremely difficult

Table 1: Characterization of the suitability of the Fontainebleau sandstone for engraving using five classes of surface hardness (R) estimated with the *Schmidt Hammer*.

Note that our hardness classes are convergent with those elaborated by Selby (1993) and then modified by Goudie (2006) from numerous Schmidt Hammer measurements on a multitude of rocks throughout the world (associated with qualitative assessments of their surface suitability for engraving with a pocketknife). The remarkable feature of the Fontainebleau sandstone is that its surface hardness is not limited to a particular class but covers a wide spectrum corresponding to five of the six classes proposed by Goudie (2006).

2.2 Engraved sandstones and engraving tools

In order to approach archaeological conditions as closely as possible, we selected sandstones with surfaces that appeared to have a comparable texture to the engraved walls (Thiry, 2017a) and we made engraving tools similar to Mesolithic examples (Guéret and Bénard, 2017).

Initially, we collected movable blocks from the dismantling of sandstone bars by recent sand quarries (Fig. 6A) in order to conduct a first series of workshop experiments (Fig. 8C; Cantin, 2018). Thirty blocks were sampled (Fig. 6B) with average dimensions of 20x20x10 cm and hardness classes corresponding to Nos. 1, 2 and 3 (table 1). In a second step, we directly experimented engraving in three non-engraved cavities, housed in sandstone boulders or bars still in place on the flanks of the quarry (Fig. 6C-D), in order to confirm the results obtained on mobile blocks and increase the production of experimental data (Cantin, 2019a). These non-engraved cavities are in all respects similar to the archaeological cavities, in terms of their morphology and in terms of the texture of the sandstone surfaces.

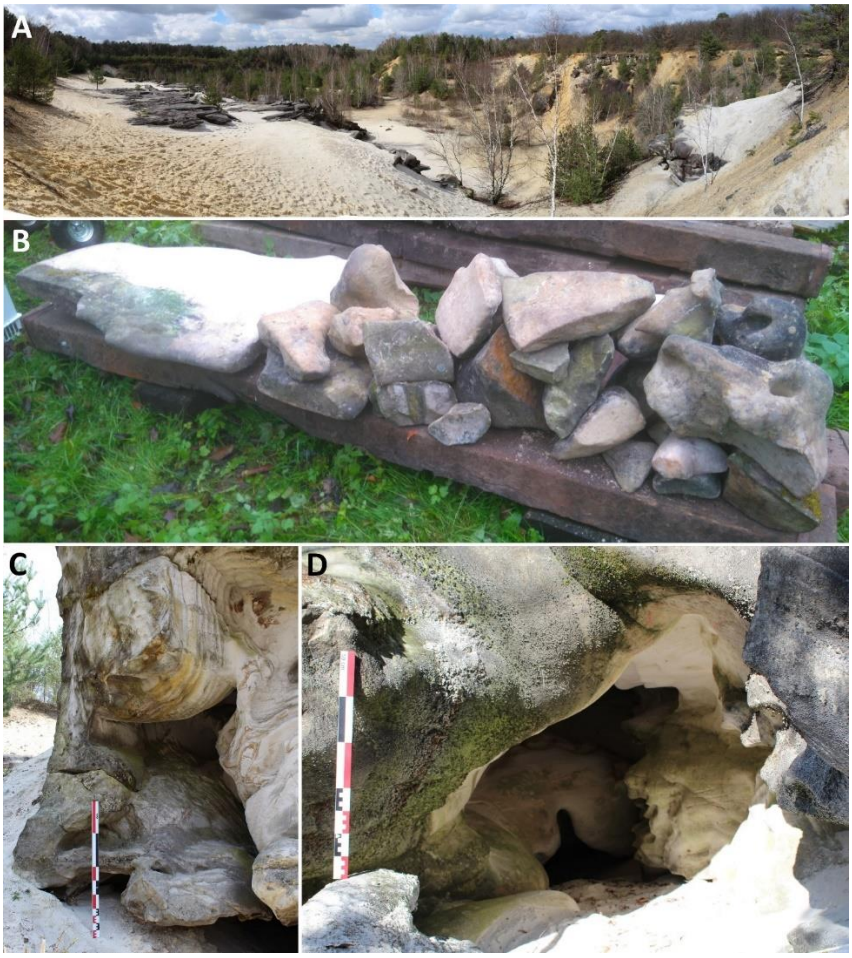

Figure 6: Supply of sandstones for the experiment in a sand quarry of Fontainebleau. A: panoramic view of the abandoned quarry. B: sample of blocks selected for the experimentation. C and D: examples of blank cavities selected for experimental engraving (scales: 1 m for photo C and 50 cm for D). [colour; 2 columns]

There is nothing typologically homogeneous about the Mesolithic engraving tools upon which our experimental replicas are based. Indeed, the entire classical spectrum of lithic industries found on

Early Mesolithic regional settlements is represented (Guéret and Bénard, 2017: 113): macro-tools, microliths, common lithic tools, and especially unretouched flint blanks (Fig. 4A). By recycling them into engraving tools, no particular type of blank was sought after but preferably linear and convex active parts. As a result, and for the sake of simplicity and efficiency, we reproduced the most abundant blanks for our experiments: unretouched flakes and bladelets (Fig. 7), knapped with a soft hammerstone like during the Early Mesolithic and according to the principles of the "Coincy style" debitage (Rozoy, 1978; Kozłowski, 2009). A total of 32 engraving tools (17 on flakes and 15 on bladelets) were produced in the local raw materials used in the archaeological corpus (Loing Valley flint blocks and lustrous sandstone: Guéret and Bénard, 2017).

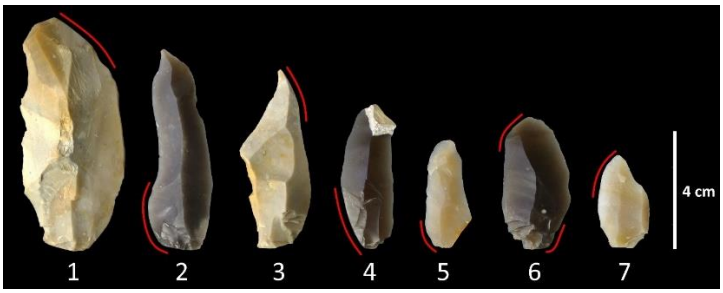

Figure 7: Examples of engraving tools reproduced based on the archaeological corpus: the red lines indicate the active parts for grooving sandstone. 1, 6 and 7: flakes. 2 to 5: Coincy type bladelets. [colour; 1 column]

2.3 Experimental protocols

Four experimental protocols were elaborated to estimate the time required to engrave motifs and to highlight possible factors limiting sandstone engraving. These protocols, detailed in Cantin (2019a), were developed based on classic experimental archaeology methodology (Bourguignon et al. (ed.), 2001; Beyries (ed.), 2020). They were used for the production of:

(1) 35 grooves 15 cm long[11] and 4 mm wide on average[12], for which engraving time was recorded (Fig. 8A).

(2) 14 grooves - all made with the same tool - 15 cm long, for which engraving speed was observed: for 2 minutes, the depth was measured every 10 seconds with an electronic calliper at three points along the groove (A, B and C located respectively at 4 cm, 8 cm and 12 cm from the upper end). Then, for an additional 2 minutes, the three measurements were taken every 30 seconds.

(3) 51 grooves for which only length varied and for which engraving time was recorded.

(4) 23 grids of various sizes (Fig. 8B & 8D) for which engraving time was recorded.

All the experimental data were recorded and processed in a relational database designed using Microsoft Access® software (Cantin, 2019a).

[11] Dimension corresponding to an estimation of the average length of the archaeological grooves.
[12] Variable dimension directly dependent on the width of the active part of the engraving tool.

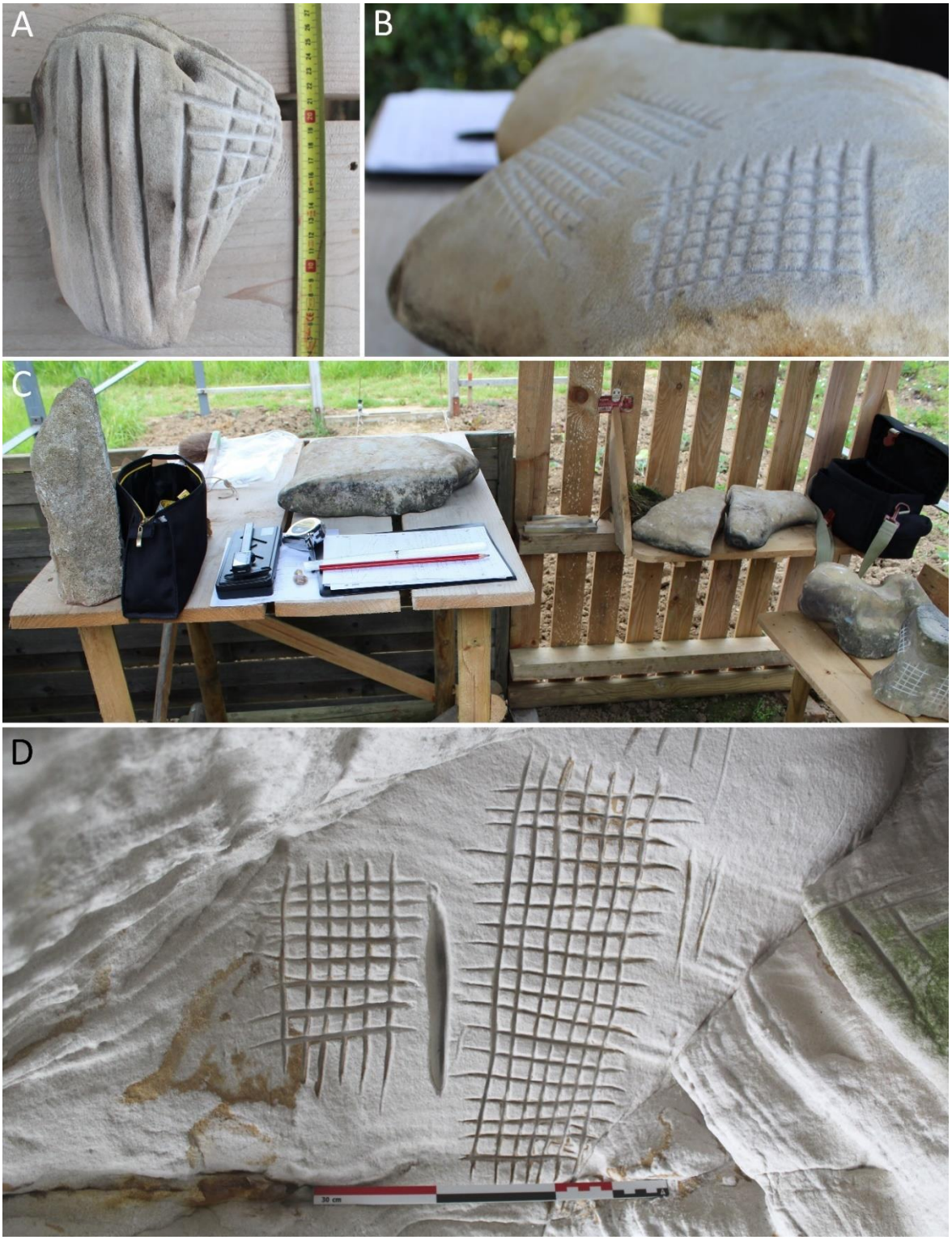

Figure 8: Experimental engraving on sandstone. A: mobile block engraved with grooves. Each groove was recorded independently in our database. B: block engraved with grids. C: engraving workshop of mobile blocks. D: Experimental groove and grids in a natural cavity (scale: 30 cm). [colour; 2 columns]

3 Results

The experiments show that the act of engraving sandstone by grooving is easy and quick and does not have any particular graphic constraints, contrary to what has sometimes been written in the past

(see introduction above). Before reaching these results, we first had to comprehend through experimentation the required sandstone characteristics to render engraving possible.

3.1 Friable cortex: a key element in engraving sandstone

During our experiments, we quickly realized that only the surface layer of the sandstone known as the 'friable cortex' (Thiry, 2017b), which is soft and varies greatly in thickness (Cantin, 2019a), could be engraved by grooving. The immediately underlying hard sandstone, on the other hand, was impossible to engrave. This distinct layering can be seen on the freshly fractured surfaces of some experimental blocks (Fig. 9A), as well as in some archaeological cavities (Fig. 9B), where there is an obvious difference in colour and texture.

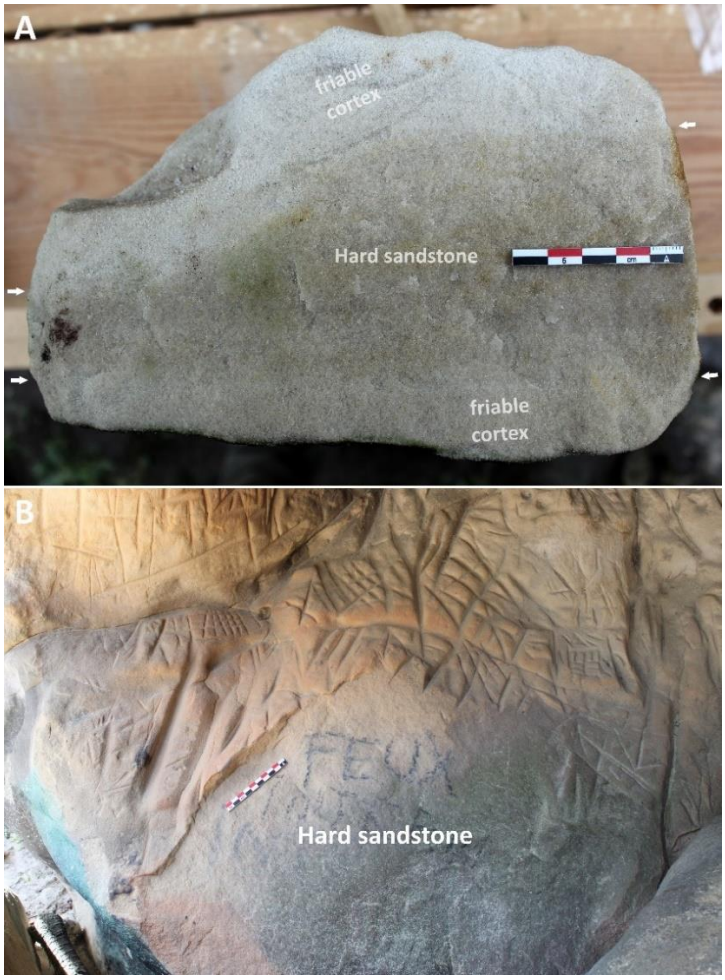

Figure 9: Observation of the friable cortex and the immediately underlying hard sandstone. A: Fractured face of an experimental block with a friable cortex on the front and back (scale: 5 cm). We can see the separation (white arrows) with the hard core of the rock. B: Archaeological cavity (Rocher des Potets 1 at Noisy-sur-Ecole). A recent accidental anthropic fire detached the friable cortex in which the grooves were engraved. The underlying surface revealed by this destruction is not affected by the grooves because of its hardness. [colour; 1 column]

3.1.1 Friable cortex: differential formation and conservation

To understand this abrupt contrast in hardness, we must refer to the geology of the Fontainebleau sandstone (Thiry et al., 2017; Thiry, 2017b). This rock results from the cementation of sands by circulations of silicifying groundwater (Thiry et al., 2015). This siliceous cementation occurs

centrifugally by small successive envelopes with thicknesses - 5 mm on average - varying depending on the water supply (Fig. 10A). The friable cortex corresponds to the last envelope of sandstone formation, which has not been completely cemented (Fig. 10B). The previous hard envelopes that form the core of the rock lie under this friable zone (Fig. 10C).

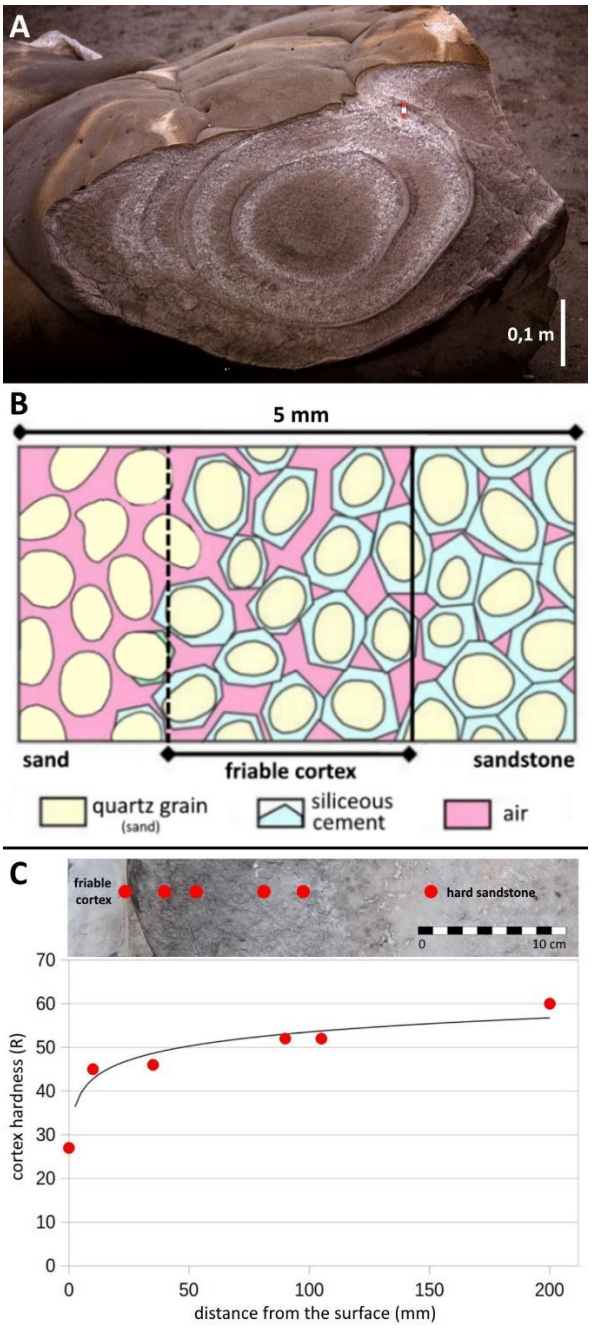

Figure 10: Cementation gradient of the Fontainebleau sandstone. A: cross-section of a rock showing the superimposition of successive silicified envelopes. B: schematic diagram of the cementation gradient between sand and sandstone at the origin of the friability of the cortex. C: Schmidt Hammer measurements (red dots) on a quarry boulder section with a friable cortex on its surface: the hardness increases abruptly over the first few millimetres from its friable cortex (rebound value equal to 27) to the internal hard sandstone (rebound value equal to 60). [colour; 1 column]

Furthermore, this friability, which makes the cortex engravable, also makes it very prone to erosion (Thiry, 2017b). In recent quarries, all the sandstones have cortexes, but they are always absent

from the external surfaces exposed to the open air in natural sandstone boulder fields. This weathering phenomenon implies that grooved engravings only exist in sheltered cavities.

3.1.2 Friable cortex : incidences on engraving

The contrast between friable cortex and hard sandstone can be seen clearly in all our groove engraving curves illustrating engraving time and depth (Fig. 11). Indeed, these curves systematically share the same profile: after a deepening phase, the curves experience a strong deceleration leading to a plateau. This phenomenon corresponds to the encounter with a much harder sandstone that is difficult to engrave.

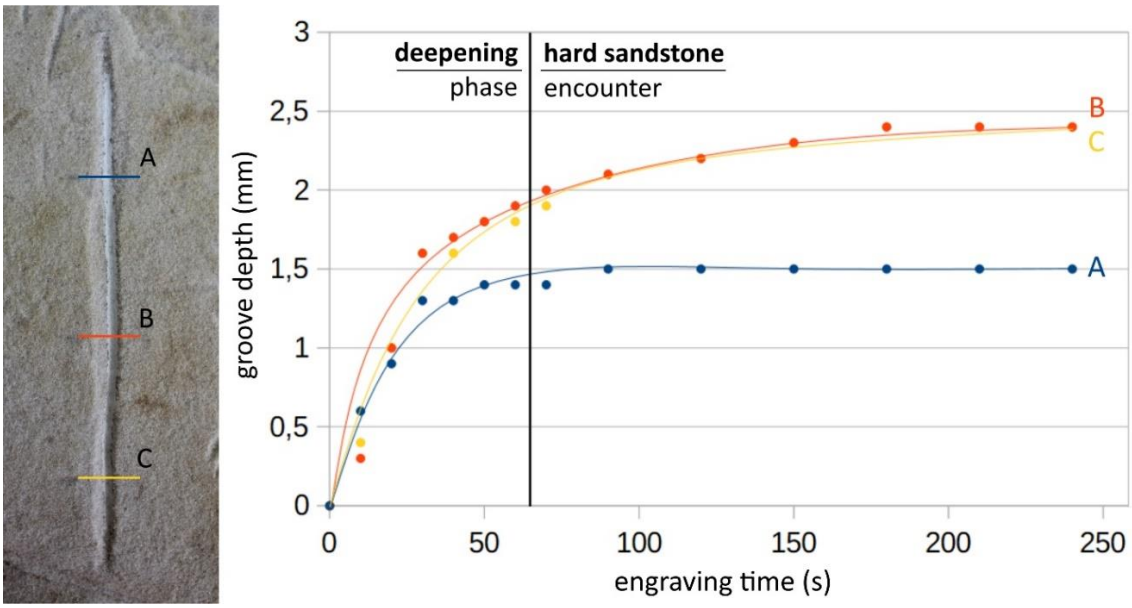

Figure 11: Engraving curves of a same groove 15 cm in length in three points of its layout. [colour; 1 column]

As a result, the practice of engraving by grooving can only be carried out in the presence of a friable cortex: its thickness (an average of 3 mm in our experimental corpus: Cantin 2019a) varies according to the cavities and in each wall, defining the maximum depth of the grooves that an engraver can make. We also noted that the encounter with hard sandstone is clearly felt by the engraver and avoids unnecessary effort. The sound produced by grooving, the vibrations transmitted to the wrist, as well as the resistance of the sandstone under the lithic tool change immediately: these empirical signals thus act as genuine guides for engraving. This observation leads us to believe that, for the most part, the Fontainebleau rock engravings reached the maximum depths possible each time, undoubtedly going through the entire thickness of the friable cortex to the underlying hard sandstone. This proposal is currently difficult to verify directly without damaging the archaeological walls, but two indirect arguments support it:

(1) The only existing count of archaeological engraving depths to date was made by G. Tassé for the 1,652 motifs recorded in the 50 engraved cavities studied in his work (Tassé, 1982; 111). These are average values and the author ordered them into five different classes that we have

reused to compare these data with the average depths[13] of our 116 experimental engravings systematically deepened to the hard sandstone underlying the friable cortex (Fig. 12). The distributional analogy on the histogram suggests that the majority of archaeological engravings were grooved down to the hard sandstone, as is the case for our experimental engravings.

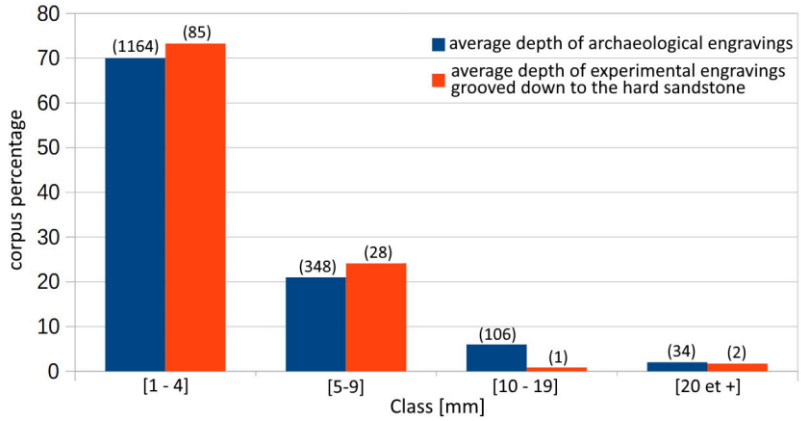

Figure 12: Comparison between the average depths of 1,652 archaeological engravings and those of the 116 experimental engravings grooved down to the hard sandstone. [colour; 1 column]

(2) The use-wear study of archaeological engraving tools allowed us to estimate the maximum depth of the grooves made by Mesolithic people by measuring the invasiveness of wear on the faces of 370 used zones (Guéret and Bénard, 2017: 106; Cantin, 2019b: 40-46). In order to compare these maximum depths with our experimental data, we used the deepest point of each of our 116 engraved grooves down to the hard sandstone. The result is a second histogram (Fig. 13) that also shows analogous distribution. This finding reinforces the idea that the majority of archaeological engravings were grooved down to the hard sandstone.

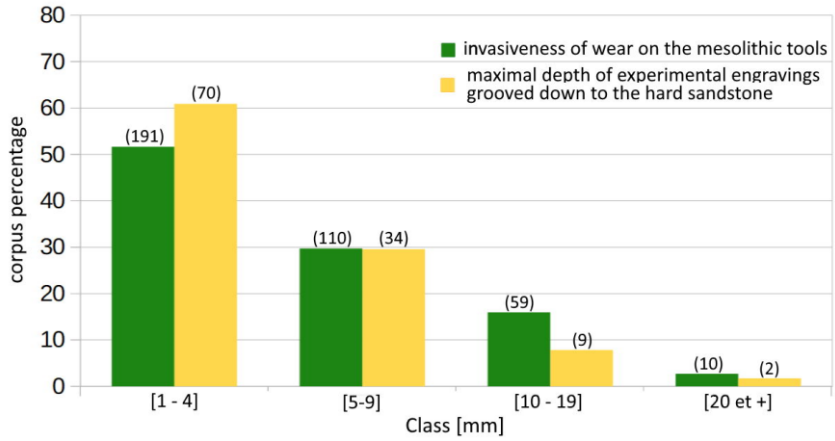

Figure 13: Comparison between the invasiveness of wear on 370 Mesolithic engraving tools and the maximum depths of the 116 experimental engravings grooved down to the hard sandstone. [colour; 1 column]

[13] Values obtained by averaging the depth at three points A, B and C for the grooves. For the grids, it is an approximation of the measurements taken on the whole surface.

Ultimately, all these results show that the thickness of the friable cortexes is an important parameter in the practice of sandstone engraving and undoubtedly determines the choice of the cavities to be engraved.

3.2 Straight rather than curved grooves: a cultural choice

We have seen that it was possible to make rectilinear grooves on friable cortex without any particular difficulties and in several dozen seconds (Fig. 11). Does this same effortlessness characterize curved grooves? Contrary to what several researchers have suggested (e.g., Bénard, 2014: 156), our experiments confirm that it is possible to engrave curved grooves in Fontainebleau sandstone with stone tools. This was already suggested by the only two Palaeolithic-style engraved examples known today (Bénard, 2010; Bénard and Valois, 2014; Thiry et al., 2020). The recent discovery in the south-eastern Fontainebleau sandstone region of geometric and figurative engravings attributed to the Bronze age with predominantly curved grooves made with lithic tools has recently reinforced this view (Lebon et al., 2017, 2018; Guéret, 2020). Through experiments, we definitively demonstrate the absence of constraints in this domain (Fig. 14): the planned curved groove must simply be outlined by a light line that will then guide the engraving predominantly made with unidirectional gesture. Engraving curved lines on Fontainebleau sandstone presents no particular difficulty and only requires a little more care than straight lines. On the other hand, and this is the interest of this simple demonstration, the essentially rectilinear character of the Fontainebleau rock engravings attributed to the Mesolithic period is a choice with cultural value.

Figure 14: Experimental curved grooves made with a lithic tool without any difficulty. [colour; 1 column]

3.3 Modelling the minimum time required for the Mesolithic engravings

To estimate the time required to engrave the main motifs attributed to the Mesolithic, we first evaluated the influence of the hardness and thickness of the friable cortex on engraving time. We then examined how the length of the grooves also influences engraving time in order to propose a general tool of estimation applicable to the archaeological grooves[14] that we can then adapt to the grids.

3.3.1 Thickness and hardness of friable cortex: what influence on engraving time?

The large sample of sandstone that we selected for our experiments allowed us to engrave cortexes of different hardness (Schmidt Hammer rebound values between 11 and 33 covering our classes 1, 2 and 3) and thickness (from 0.5 to 30 mm). However, a relationship between these two parameters quickly emerged during the first experiments: the most friable cortexes are always the thickest (Fig. 15).

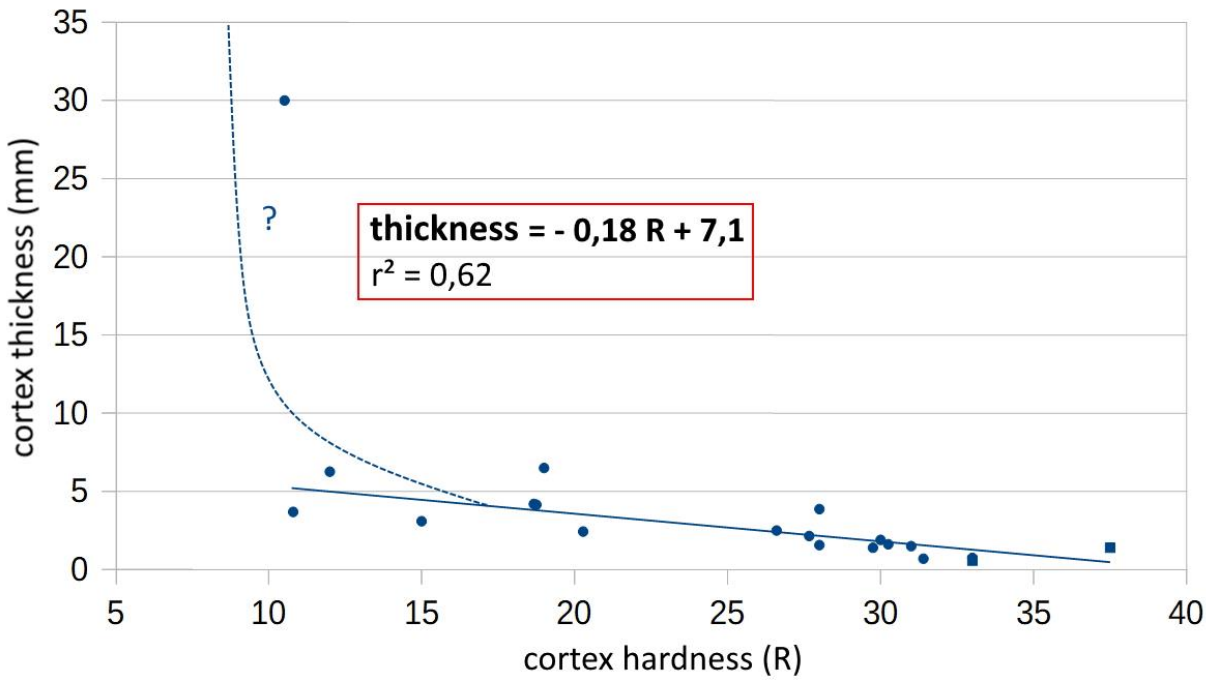

Figure 15: Correlation between the hardness and the thickness of the cortexes of the Fontainebleau sandstone. [colour; 1 column]

To understand the influence of the hardness and thickness of the cortexes on engraving time, we superimposed all of our 15 cm groove engraving curves on the same graph (Fig. 16). Their comparison shows, as mentioned above, sudden decelerations followed by a plateau: hard sandstone is generally reached in less than a minute and classical depths of 4 mm (cf. Fig. 12) in less than 40 seconds, with engraving time differences restricted to an interval of 30 seconds (symbolized by the red beam on figure 16). As a result, the equation of the median of this 30-second interval can be used to estimate the engraving time of any 15 cm long groove based on its depth (engraving time = depth X 10 ± 15 seconds).

[14] The reader can find a slightly more complex tool in Cantin's Master dissertation (2019a) available online (https://dumas.ccsd.cnrs.fr/dumas-03577363) and taking into account several cases of exceptionally thick cortex and very large and deep grooves called " sillons naviformes ". The consideration of such cases here would unnecessarily complicate the discussion.

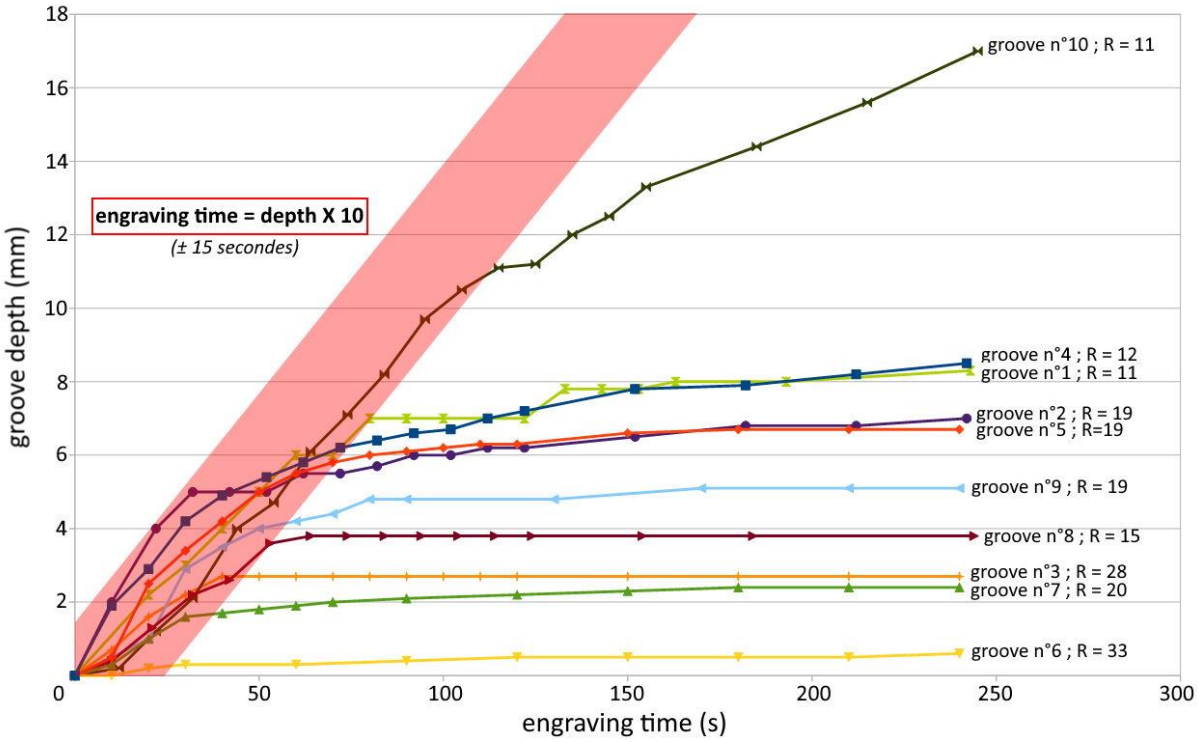

Figure 16: Engraving time for 15 cm grooves. Each curve represents the engraving of a groove in a friable cortex of different hardness (value of the rebound indicated at each end; NB: we also note that the thickest cortexes are the most friable). The curves are all in a 30 second interval (symbolised by the red beam) before reaching a deceleration leading to a plateau corresponding to the encounter with the hard non-engravable sandstone. [colour; 1.5 column]

3.3.2 Influence of the length of grooves on engraving time

In order to extrapolate our estimate of the time required to make 15 cm grooves to other grooves of different lengths, we also studied the influence of this parameter on two different experimental blocks (Fig 17A). By representing the relationship between the length of the grooves and engraving time (until the hard sandstone is reached), figure 17B clearly shows a linear correlation which follows a simple rule: doubling the length of an engraved groove until the hard sandstone is reached is globally equivalent to doubling the time required to make it. Symmetrically, dividing this length by two has the same consequence with respect to engraving time.

Based on this property, a correction index for our 15 cm groove estimation model (Fig. 16) can be calculated if the length of the groove to be evaluated differs. For example, if we consider an archaeological groove 7.5 cm long engraved to a depth of 6 mm, the engraving time can be estimated at 30 ± 15 seconds according to our model, half of what is required for 15 cm.

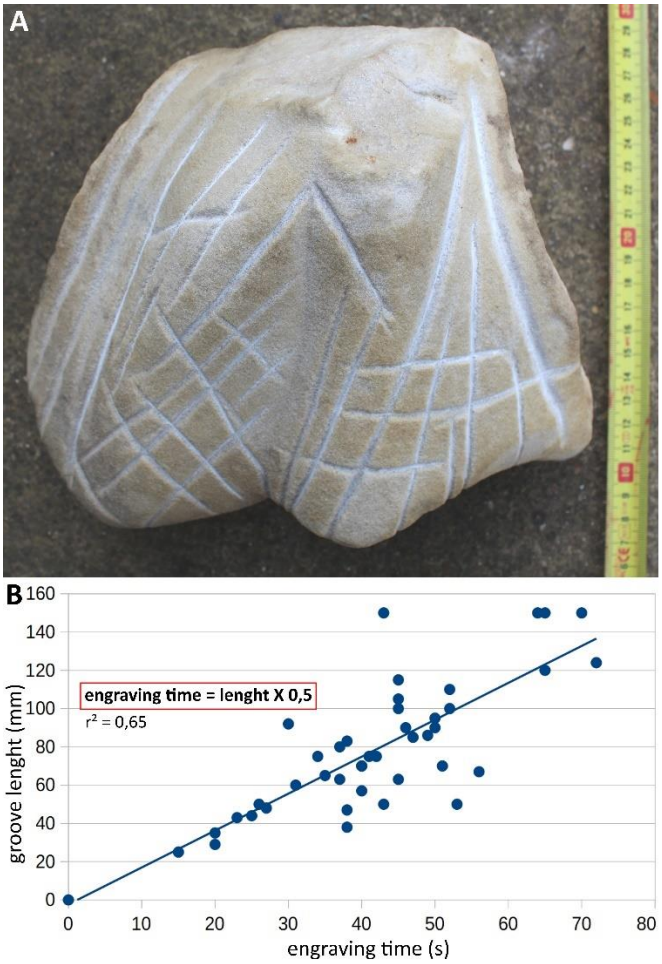

Figure 17: Correlation between the length of a groove and the time required to make it. A: example of experimental block on which grooves of different lengths were engraved. B: graph with all of the 51 experimental grooves of variable length. [colour; 1 column]

3.3.3 Number of grooves and time required to produce the grids

Based on these findings, we addressed the question of the time required for engraving the grids attributed to the Mesolithic. Fifteen experimental reproductions inspired by precise archaeological examples were reproduced on blocks and cavities in representative friable cortexes. The choice was made to groove them by systematically trying to reach the hard sandstone, which corresponds to the prevailing archaeological cases (cf. supra, part 3.1.2), vertical grooves first and horizontal grooves second. The result of these experiments is that the currently known archaeological grid with the most grooves (spread over 35 cm long by 10 cm wide) was reproduced experimentally in 40 minutes. This value can thus be considered as a maximum for this type of motif.

To systematize these estimates, it would have been possible to use our model built from the grooves engraving time outlined above in order to obtain the grids engraving time by addition, but its application to a large number of cases would have required significant calculation time[15]. Moreover, this

[15] For example, forty-eight measurements of depth and length to result in an estimation for the biggest grid known mentioned above.

model was designed to cover the whole spectrum of friable cortex hardness, even those that are difficult to engrave (cf. 'indurated' class 3 in table 1). Its application to the grids would therefore have generated high intervals of uncertainty and not very accurate results[16]. Finally, the simple addition of engraving times of each groove to obtain a grid would not have been very realistic. Indeed, this would not have taken into consideration the multiple downtimes involved in the completion of a whole motif (tool repositioning, changes of position of the engraver, pause between two grooves to blow the sandstone powder produced by grooving which hides the lines, possible decrease of the engraving rhythm after several dozen grooves etc...). Yet these downtimes can, in the end, have a significant impact on engraving time.

We therefore looked to see if there was a simpler relationship between the time taken to complete the grids and another dimensional parameter: the number of internal squares. The size of these squares is very similar from one grid to another (2 to 3 cm² on average), contributing to the emblematic character of this motif (Bénard, 2014). Their number is thus a good indicator of the dimensions of the grid and the number of grooves composing it[17], making this parameter an ideal criterion for estimating engraving time. This is confirmed by the linear relationship established by our experiments including the downtimes (Fig. 18).

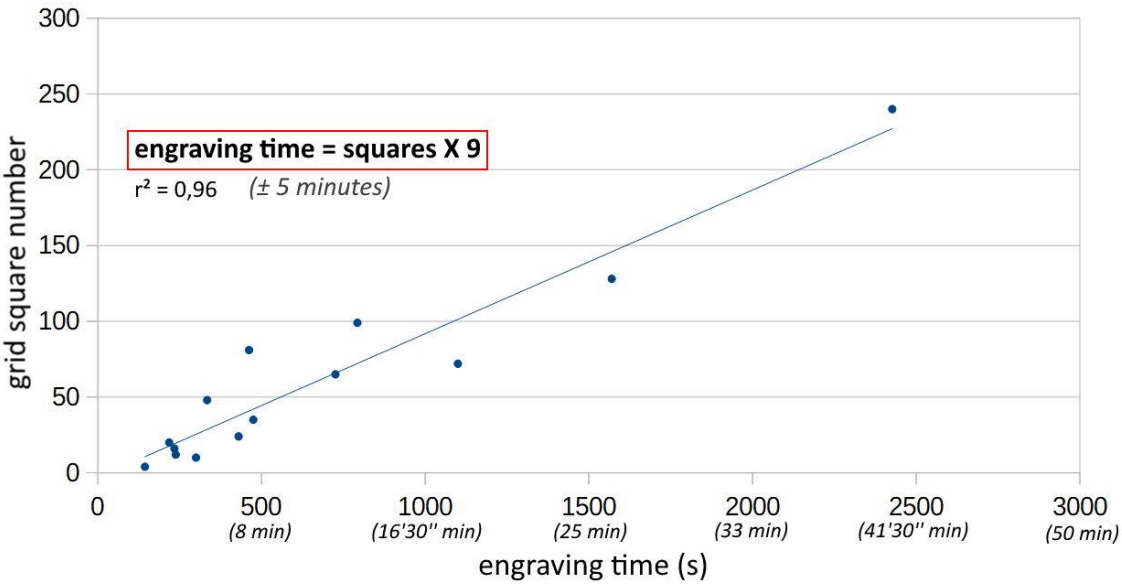

Figure 18: Engraving times of grids. Each point corresponds to an experimental grid inspired by an archaeological example. [colour; 1.5 column]

The precision of this linear relationship - ± 5 minutes based on the dispersion of the points around the line - thus seems sufficient to calculate engraving time of this recurrent motif of Fontainebleau rock art. Let us recall that a statistical analysis of grid square number by A. Bénard,

[16] For example, for a grid composed of 24 grooves, we obtain an estimate of 414 seconds with a standard deviation of 360 seconds taking into account all variants of cortex hardness. Yet, we reproduced it in 793 seconds on an easy to engrave cortex. The estimation is thus correct but not very precise when compared to the actual situation.
[17] The number of internal squares of a grid is obtained with the formula: (number of vertical grooves – 1) X (number of horizontal grooves – 1)

conducted on a representative sample of 80 archaeological grids (Bénard, 2014: 93), shows that 82% of them comprise between 6 and 42 squares, with the 12-square format being the most represented with 12 cases. According to our model, the average time spent making the grids in this sample is therefore around 5 minutes per grid.

4 Discussion: new elements for an anthropological approach to Mesolithic engraving practices

The results of our experimental approach allow us to propose, by reconsidering the more general archaeological context, new elements for an anthropological approach to those symbolic practices attributed to the Early Mesolithic in the Fontainebleau sandstone region.

4.1 A technique accessible to all

The sandstone of the cavities presents a poorly cemented cortex of variable thickness, and the friability of this cortex guarantees effortless engraving, as seen above. The grooving technique used is based on simple rectilinear back-and-forth movements that fit well with the natural biomechanics of the arm (Dounskaia et al., 2002). In addition, the wrist and the hand holding the tool intervene little in the engraving of straight grooves, which does not require fine motor skills acquired through prior training. The engraving tools are made of local raw materials and correspond to the recycling of heterogenous lithic types of tools (cf. above part 2.2) used for daily activities (Guéret and Bénard, 2017: 113). There is no particular graphic complexity in the series of grooves or grids, except for the respect of a certain dimensional pattern. Finally, engraving does not require a lot of time: a groove is generally engraved in less than a minute and the most common grids in less than 15 minutes.

All of these findings, most of which result from our experimental study, do not suggest that the individuals involved were in any way technically specialized in engraving. No apprenticeship is required, the necessary tools are present in the familiar daily environment and the minimum times required for engravings are short.

4.2 An individual act repeated many times

The configuration of the engraved places provides additional information. Indeed, the cavities are mostly small (Tassé, 1982; Bénard, 2014): one to two people can stand in them at the same time (Fig. 19A), rarely three, especially for the purposes of engraving. This observation led A.Bénard (2014: 199) to propose that the act of engraving could not really be considered as a collective activity in most small cavities. Furthermore, we can add that the cavities are generally closed volumes with constrained entrances : no audience on the outside can see what is going on inside (Fig. 19B and Fig. 20).

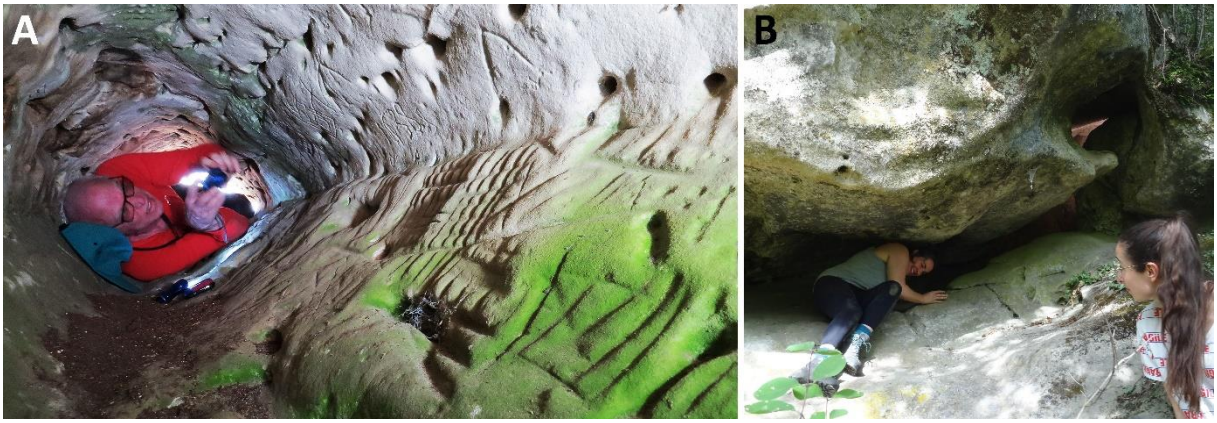

Figure 19: Two examples of small engraved cavities with constrained entrances. A: La Sablonière 3 at Buno-Bonnevaux, photo GERSAR ; B: Masures Brulées 2 at Boigneville. [colour; 2 columns]

This probably individual engraving activity is accompanied by the apparent absence of distribution pattern of the motifs on the walls, floors or ceilings (Bénard, *op. cit.*). Indeed, these rock engravings seem to result from an accumulation with no explicit order, especially on certain abundantly engraved sites (Fig. 20). This suggests short, staggered episodes of engraving, taking advantage of the still available space (*ibid*.). In addition, it is important to recall that the engraved motifs are in general rather small and one never occupy a complete wall.

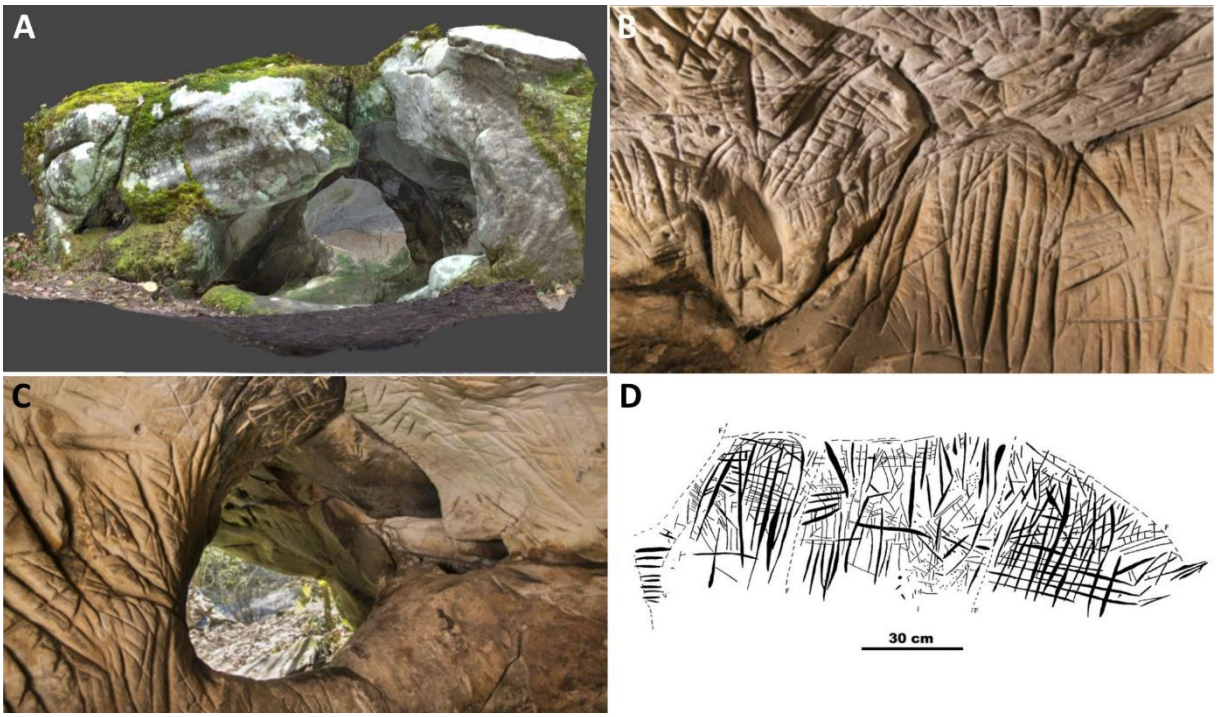

Figure 20 : Totally engraved cavity (Butte du Puits 1 at Villeneuve-sur-Auvers). A: view of the constrained entrance from the exterior (height ≈ 1m, 3D Modelling: Summum 3D-ARBap). B: engravings on the main wall (Photo: E.Lesvignes). C: view of the constrained entrance from the interior of the cavity (Photo: E.Lesvignes). D: schema of an engraved panel of the cavity (GERSAR). [colour; 2 columns]

4.3 Many easily accessible engraving places linked to daily-life territories

Even if precise spatial analysis remains to be done[18]; it is clear that engraved cavities with parallel grooves and grids form a dense network where each site is geographically close to another ; especially in some well researched and/or preserved area of the Fontainebleau sandstone region (Tassé, 1982 ; Bénard 2014: 198). In addition, their location on valley slopes or mounds with differences in height of less than 50 m ensures easy access.

Although most of the engraved cavities are small in size, some of them are nevertheless large enough to be inhabited (25% of a sample of 50 sites: Tassé, 1982: 42). Excavations have already shown that at least three caves (Bel Air 1, Bel Air 12 and Dégoutants à Ratard 1 ; see introduction above) had a dual symbolic and domestic vocation during the Early Mesolithic (Hinout, 1992, 1993b, 1993a; Guéret and Bénard, 2017). In addition to the engraving tools, remains of hunted fauna, debitage waste and other lithic tools etc. were discovered. Among them, Dégoutants à Ratard 1 at Larchant (cf. Fig. 2C), yielded a black organic level 30-40 cm thick, containing more than 500 faunal remains (Bridault and P.Bautista, 1993) and especially 30,000 lithic remains (Hinout, 1993a; Guéret and Bénard, 2017) accumulated throughout the whole Mesolithic period[19]. Moreover, despite the absence of systematic prospecting, several open-air sites in the immediate vicinity of engraved cavities have been reported and have yielded possible engraving tools (Cabrol and Pauron, 1935; Piquet and Vacher, 1970; Rozoy, 1978). In addition, recent spot surveys suggest that the probability of discovering new sites is very high (Guéret and Bénard, 2017; Guéret and Cantin, 2019b). These preliminary data therefore suggest at least occasional overlap between engraving sites, living places and hunting territories.

5 Conclusion: ordinary rites in the eighth millennium BCE in the Fontainebleau sandstone region?

Let us summarize our main observations: (1) the engravings attributed to the Early Mesolithic were technically simple to make with easy-to-access tools, and therefore could have been carried out by a large number of people, during rather short periods of time; (2) the often constrained configuration of the engraved places and the lack of general distribution pattern of the motifs on the walls and floors fits well with the hypothesis of an accumulation of successive engraving episodes done by one or few individuals each time (Bénard, 2014); (3) the engraved cavities are very numerous, easily accessible, and potentially connected to everyday territories (Bénard, *op. cit.*).

In other words, the symbolic practices attributed to the Mesolithic around Fontainebleau would result from the repetition of numerous stereotyped engraving gestures in a multitude of places familiar to the human groups inhabiting the region during the Early Mesolithic (*ibid.*). The repetitive and

[18] Research conducted as part of Alexandre Cantin's PhD thesis in progress at the University Paris 1 under the direction of Boris Valentin.

[19] In order to obtain 14C absolute dating of the Mesolithic engraving tools assemblages, new excavations directed by two of us (Colas Guéret and Alexandre Cantin) are carried out since 2020.

monotonous – almost ascetic? – aspect of grooves and grid engraving correspond well to what is observed in many individual ritual gestures (Cazeneuve, 1957, 1992). While these gestures result in constructed motifs, clearly imprinted in the rock, it is probably the very act of engraving that takes precedence in this context: indeed, "iconography does not necessarily have a representational or expressive function but can compose the context of a ritual performance"[20] (Defrasne and Stépanoff, 2019: 22). Like Ross and Davidson (2006: 311), we believe that "ritual was one social context in which rock art was produced in the distant past". In the case studied here, although further examination is needed to characterise this "ritual performance" in more details[21], it seems to us that Fontainebleau Mesolithic engravings does result from such sociological context.

If the minimum time required for each of these gestures may seem rather short (most often less than 15 minutes), the effort to carry them out is nevertheless not insignificant: the engraving of certain motifs (especially grids) require a certain amount of care while the engraver's body is often contorted given the cramped conditions of most cavities. Moreover, it is possible that a single episode of engraving included series of motifs rather than a single one: some grids share the same orientation on the walls, perhaps showing that they were made during the same unit of time (Costa and Valentin, work in progress). It is also important to remember that traces of sandstone scraping on archaeological tools suggest that it may have been necessary to prepare the walls beforehand in certain cases (Guéret, Bénard, 2017: 107-108). Finally, although it is clearly impossible to demonstrate, other ritual practices (invocations for example?) may have been linked to these engraving gestures and may have extended the minimal engraving time requirements proposed here. Ultimately, these short engraving rites are not at all expeditious.

Nevertheless, it is clear that these Mesolithic symbolic practices are radically different from European Upper Palaeolithic representations in deep caves, which are sometimes very difficult to access (Rouzaud, 1978; Intxaurbe et al., 2021). Among them, some occasionally correspond to genuine meticulously prepared artistic programs (collection of pigments, preparation of lighting, etc.) before being carried out at length. In this regard, among various examples, Lascaux naturally springs to mind (Aujoulat, 2013; Pigeaud, 2017), as well as Pech-Merle for its panel with dotted horses that M. Lorblanchet (1991; 2010) experimentally replicated in 32 hours[22]. In more accessible contexts, certain Magdalenian limestone shelters, such as the Roc-aux-Sorciers at Angles-sur-l'Anglin, attest to the perseverance of their authors: several hours were required to sculpt certain animals and the initial preparation of the 50 m wall necessitated lengthy group work (A. de Beaune and Pinçon, 2001; Bourdier,

[20] " l'iconographie n'a pas nécessairement une fonction de représentation ou d'expression mais peut composer le contexte d'une performance rituelle "

[21] Following the methodology developed in Ross and Davidson (op. cit.). This detailed examination is currently conducted as part of Alexandre Cantin's PhD thesis in progress at the University Paris 1 under the direction of Boris Valentin.

[22] i.e. a minimum of five to six days of arduous work (frequent breaks was necessary) with the assistance of a second party to hold an animal-fat lamp and to prepare the pigments (Lorblanchet; 1991 :31)..

2010). It should be added that, in many cases, Palaeolithic animal representations required a high degree of skill that could perhaps only be achieved by specialists after a fairly long apprenticeship (Guy, 2017; Rivero, 2016; Rivero and Garate, 2020). Clearly, the social organizations underlying these Upper Palaeolithic practices (see current debate in: Guy, *op. cit. ;* Darmangeat, 2018; Stépanoff, 2018) differed – no doubt to varying degrees – from those observed in the Fontainebleau sandstone region in the early Holocene.

By directly confronting the work processes involved in the *chaîne operatoire* (Lemonnier, 1986; Schlanger, 2005; Fiore, 2007), experimental archaeology allows us to assess crucial parameters that would otherwise be inaccessible, such as minimum working time and know-how required to carry it out. The reconsideration of archaeological contexts in the light of these parameters in turn enriches our understanding of social organizations behind the making of rock art (Lorblanchet 1991; A. de Beaune and Pinçon, 2001; Fiore, 2007; Vegara and Troncoso, 2016; Vourc'h, 2018), renewing knowledge beyond traditional analysis. As far as we are concerned, our experimental knowledge of sandstone grooving now allows us to begin research on the spatial organization of the Mesolithic engravings in the Fontainebleau sandstone region[23]. In particular, we will study the precise selection of ritual sites in a context where densely engraved cavities are found side by side with untouched ones. Does this distribution correspond solely to engraving constraints linked to the hardness of the sandstone and/or erosion of friable cortexes? Or can we discern choices in the selection of engraved cavities and motifs, relating for example to topography?

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Our methodology measuring the hardness of sandstone would not have been possible without the indispensable collaboration of Stéphanie Touron and Millena Frouin from the *Laboratoire de*

[23] Research conducted as part of Alexandre Cantin's PhD thesis in progress at the University Paris 1 under the direction of Boris Valentin.

Recherche des Monuments Historiques (LRMH). We thank them warmly for their commitment to this research.

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