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# Multiproxy analysis of Upper Palaeolithic lustrous gravels

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## Abstract

Upper Palaeolithic sites in southwestern France attributed to the Upper Gravettian and the Solutrean yielded sub spherical gravels with a highly shiny appearance that have intrigued researchers since the 1930s. In this work, we analyze specimens from five sites, including the recently excavated Solutrean site of Landry, to establish whether their presence in archaeological layers and peculiar aspect are due to natural processes or human agency. We study the spatial distribution of gravels at Landry and submit archaeological gravels from the five sites, natural formations, Landry sediment sieving, and polishing experiments with a rotary tumbling machine to morphometric, colorimetric and textural analyses. Our results suggest that the lustrous gravels found at the five sites result from deliberate selection and their shiny appearance is the probable consequence of prolonged contact with a soft material such as animal skin. Ethnographic accounts indicate that these gravels may have been used for magico-religious ritual purposes (charms, sorcery, divination etc.), in games, as elements of musical instruments, and as items serving other social and personal purposes. We argue that these objects reflect a cultural innovation emerged during the Gravettian and continued into the Solutrean.

## 36 **Introduction**

37 Upper Palaeolithic sites in southwestern France attributed to the Upper Gravettian and the  
38 Solutrean have yielded sub spherical gravels with a highly shiny appearance that have attracted  
39 the attention of Palaeolithic archaeologists since the 1930s (Baumann et al., 2015; Detrain,  
40 2016; Detrain et al., 1992, 1994; Moncel et al., 2009; D. Peyrony, 1922; E. Peyrony, 1934).  
41 Peyrony (1922) thought that they were attached on a leather tag with a resin and arranged next  
42 to each other to be used as ornaments (Fig 1). Other researchers have limited themselves to  
43 reporting their discovery without attempting to determine whether their presence in  
44 archaeological layers and their shine were due to natural processes or human activity.

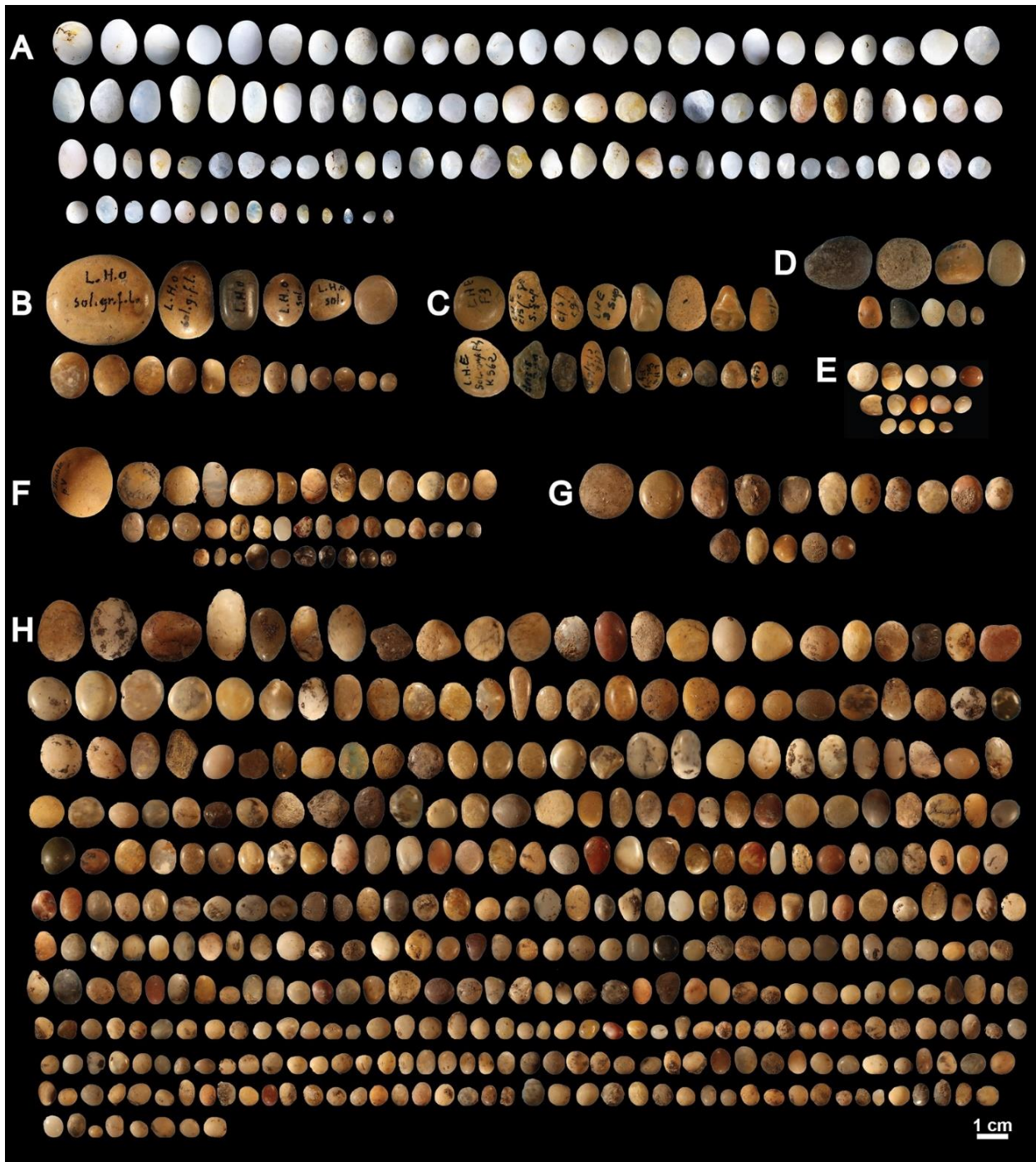
45 Answering these questions has been made difficult by the fact that these gravels were  
46 uncovered during excavations for which we lack relevant contextual data. We do not know, for  
47 example, whether gravels were systematically collected nor do we have precise information on  
48 their spatial distribution and eventual association with other archaeological remains. The  
49 discovery of about a hundred lustrous gravels on the recently excavated Solutrean site of Landry  
50 (Dordogne, France) (rescue excavation by Inrap in 2011, Brenet dir.), and the application of  
51 new analytical methods make it possible to approach the question of the origin and eventual  
52 anthropogenic modification of these objects in new ways.

53 In order to address this topic we combine in our study four approaches: 1) spatial analysis  
54 of lustrous gravels and their relationship with other archaeological remains unearthed at Landry,  
55 2) morphometric and colorimetric analysis of gravels discovered at this site, four other Upper  
56 Palaeolithic sites from Dordogne, and gravels from geological deposits accumulated by known  
57 sedimentary processes, 3) surface texture analysis of lustrous and non-lustrous gravels from  
58 archaeological sites and natural accumulations as well as gravels experimentally polished to  
59 mimic natural and anthropogenic actions, and 4) a survey of ethnographically-attested uses of  
60 gravels and small pebbles. The objective of the spatial analysis was to establish whether the  
61 gravels' distribution was random or not, and connected with that of other archaeological  
62 remains. The morphometry and colorimetry of the lustrous and non-lustrous gravels aimed at  
63 verifying whether the former represents a selection of the gravels naturally available on the site.  
64 The textural analysis of archaeological, natural and experimentally polished gravel was  
65 intended to document and quantitatively compare their wear patterns to establish whether shine  
66 on archaeological objects could be found in nature, and which experimental polishes generated  
67 by a tumbler and a metallographic polisher better mimic archaeological wear.

68 The last decade has seen a substantial development of studies applying confocal microscopy  
69 and roughness parameters to archaeological artifacts with the objective of understanding the  
70 function of tools, the intensity of use, and taphonomic processes affecting the artefact after its  
71 production and use (Calandra, Pedernana, et al., 2019; Calandra, Schunk, et al., 2019; Evans  
72 & Donahue, 2008; Galland et al., 2019; Henshilwood et al., 2018; Li et al., 2019; Marreiros et  
73 al., 2020; Martisius et al., 2020; Procopiou et al., 2011; Rosso et al., 2017). The present study  
74 is the first in which this approach is combined with others to establish whether the presence of  
75 objects in archaeological layers is the consequence of human action and to infer possible  
76 function just from wear. Implementation of this holistic approach leads us to conclude that the  
77 lustrous gravels found at the five sites result from deliberate selection and their shiny  
78 appearance is the probable consequence of prolonged contact with animal skin. The  
79 characteristic shine may have been produced deliberately or be the consequence of transport or  
80 use of the gravels. A survey of historical and ethnographic sources allows us to explore, for  
81 these three cases, what functions these gravels may have had and to suggest a general strategy  
82 for how to approach the study of archaeological objects presenting minimal modifications but  
83 potentially reflecting significant cultural innovations.

#### 84 **Archaeological context**

85 Lustrous gravels are reported from four sites of the South-West of France: Fourneau du  
86 Diable, Casserole, Pech de la Boissière and Laugerie Haute (Fig 1 and Table 1). The recent  
87 excavation at a fifth site, Landry, has for the first time yielded these objects in a stratigraphically  
88 secure and culturally well assigned context.



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 94

**Fig 1. Lustrous gravels discovered in several Palaeolithic sites in southwestern France.** (A) Late Solutrean gravels from Landry; (B): Late Solutrean gravels from Laugerie Haute West; (C) Late Solutrean gravels from Laugerie Haute East; (D) Solutrean gravels from Pech de la Boissière; (E) Solutrean gravels from the Abri Casserole; (F) Gravettian gravels from Fourneau du Diable; (G) Solutrean gravels from Fourneau du Diable and (H) Late Solutrean from Fourneau du Diable.

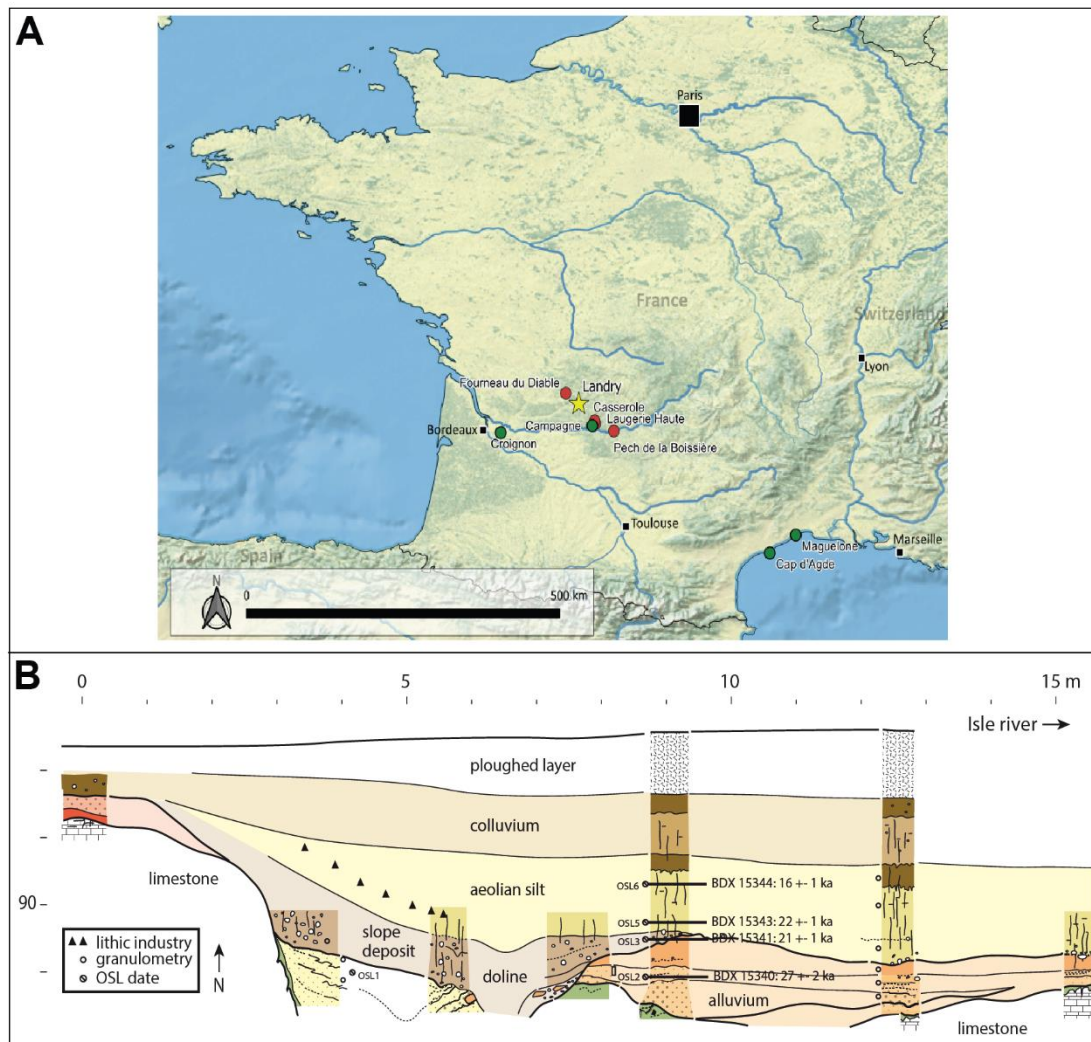
**Table 1. Contextual data on Upper Palaeolithic sites with lustrous gravels.**

Site	Type	Culture	Ages (BP)	Layer	NB	Sedimentary processes	Excavator(s)	Year(s)
<b>Landry</b>	Open air	Late Solutrean	21000	Upper level, sector 3	106	Solifluxion, acid attacks	Brenet	2012
<b>Fourneau du Diable</b>	Rock-shelter	Gravettian	29000-22000	Lower terrace	40	Screes before/after occupations, erosion, colluvium, sedimentary reorganization	Peyrony	1912-1929
		Solutrean	26000-23000	Lower terrace	16			
		Late Solutrean	24000-23000	Upper terrace	409			
<b>Pech de la Boissière Casserole</b>		Solutrean	26000-23000	No information	30	Screes, surface runoff	Peyrony	1929-1934
		Solutrean	23300-20500	No information	14	Block collapse, trampling, percolation, bioturbation, gelifraction	Kelley, Chadoune, Breuil, Dutrain	1939, 1991-1992
<b>Laugerie Haute</b>		Late Solutrean	23500-19600	East sector, layer 25	19	Block collapse, trampling, percolation, bioturbation, gelifraction	Lartet-Christy, Massenat-Girod, Capitan, Peyrony, Bordes, Smith	1863, 1892, 1895, 1921-1935, 1950
				West sector	18			

96

97 **Landry**

98           Excavated by one of us (MB) in 2011, Landry is an open-air site located close to  
99 Boulazac, Dordogne, France (Table 1). The site features several levels of aeolian silts overlying  
100 a low alluvial terrace of the Isle River (Fig 2). The Solutrean occupation layer is interstratified  
101 in the aeolian silts. Although periglacial processes, such as solifluxion, have slightly affected  
102 the uppermost layers of the site, geoarchaeological analyses (Brenet et al., 2018) and refitting  
103 of stone artifacts show the well-preserved spatial distribution of archaeological finds has not  
104 been significantly disturbed (Fig 3). Furthermore, due to the well-drained soils, bacteria in an  
105 oxidizing environment have completely degraded organic matter such as bones. The remarkable  
106 diversity of the lithic raw materials used (local Senonian flint, and allochthonous flints, quartz,  
107 granite, and dolerite) and the discovery of schist slabs engraved with geometric patterns make  
108 this site unique in the region (Feruglio et al., 2014).



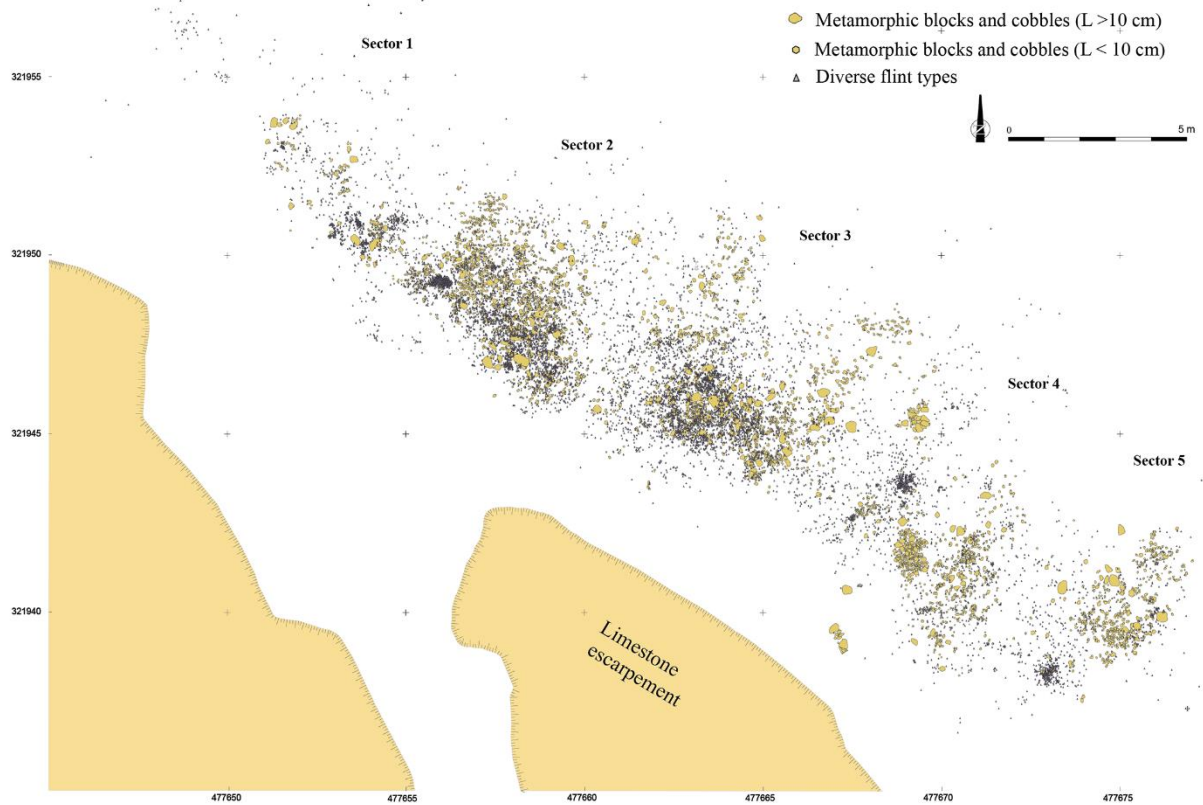
109

110 **Fig 2. (A) Geographical map of France locating the Solutrean site of Landry in Dordogne (yellow star), the**  
 111 **archaeological sites (red dots) and the natural sites (green dots). (B) Synthetic stratigraphic profile and**  
 112 **location of OSL dated samples to the west of the excavated area, according to Bertran [modified after [20]].**  
 113 The topography of the site slopes gently toward the Isle River and masks an alluvial terrace. Aeolian silts cover  
 114 the layer on which the Solutrean hunter-gatherers settled. (A) Map created with QGIS 3.30.2 “s-Hertogenbosch”,  
 115 background maps created with Natural Earth. Free vector and raster map data @ naturalearthdata.com.

116

117 Spatial analysis identified five distinct concentrations of artefacts (Fig 3) spread over  
 118 300 m<sup>2</sup> in different excavated sectors, interpreted as resulting from different activities taking  
 119 place during the same occupation (Brenet et al., 2018). This is particularly well evidenced by  
 120 the analysis of sector 3. Combining data on the different nature, spatial distribution and use  
 121 wear of artifacts, it is proposed that this concentration retains evidence of activities related to  
 122 returning from hunting, flint tool knapping and shaping, butchery, skin preparation, hard  
 123 organic material working, slab engraving and ochre processing (Bachelierie, 2017; Mesa,  
 124 2016). Thermoluminescence dating of burned flints has provided an average age of  $21.5 \pm 1.25$   
 125 ka for the site (Brenet et al., 2014), which is consistent with an attribution taking into account  
 126 the margin of error, based on diagnostic stone tools found in the five concentrations, to the Late

127 Solutrean. As many as 106 lustrous gravels were retrieved in the sieving from sector 3 and, to  
128 a lesser degree, from sector 2 (Figs 1 and 3). Those gravels are kept in the Inrap research  
129 laboratory of Campagne, Dordogne, France. All sediment from the excavated surface was  
130 sieved with a 2, 5 and 10mm mesh. The spatial origin of the gravels is known with a precision  
131 of a quarter of square meter.

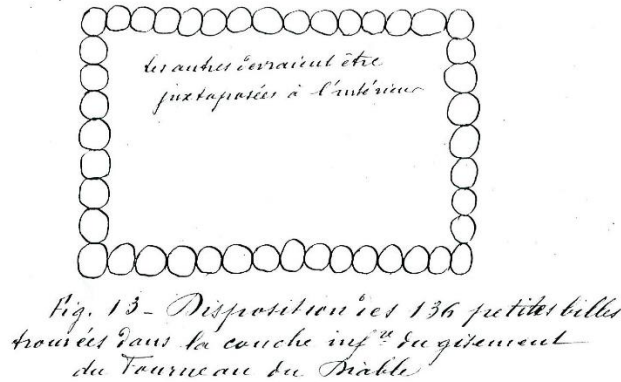


132  
133 **Fig 3. Spatial distribution of flint and metamorphic rock artifacts highlighting the 5 different activity sectors**  
134 **and size clusters (Brenet et al., 2018).**

135  
136 **Fourneau du Diable**

137 This site is located on the right bank of the Dronne River, near Brantôme, Dordogne, France  
138 (Fig 2A). It consists of a small shelter, delimited to the north by a cliff, overhanging two superimposed  
139 terraces. The Quaternary sediments covering these terraces (Table 1) contains archaeological layers  
140 attributed to the Gravettian, the Solutrean and the Magdalenian (Baumann et al., 2015). These layers  
141 were covered by Holocene sediments and the fall of hanging blocks. Peyrony reports the discovery of  
142 lustrous gravels in the Gravettian or the Solutrean layers from the upper terrace (D. Peyrony, 1922).  
143 According to this author, 136 spherical gravels, aligned and positioned closed to each other, were  
144 arranged in nine rows of 15 forming a rectangle (Fig 4). The pattern was interpreted by Peyrony as the  
145 remnant of a chest piece made of perishable material on which they were originally attached. These  
146 gravels are kept in the Musée Fernand des Moulins in Brantôme, Dordogne, France. New excavations,  
147 conducted by Baumann (2015), led to the discovery of 465 new lustrous gravels (Fig 1). They were all

148 recovered when sieving sediment from Gravettian and Solutrean layers. Forty gravels come from  
149 Gravettian layers and 16 from Solutrean layers, both located in the lower terrace. As many as 409 gravels  
150 were discovered in Late Solutrean layers located in the upper terrace. Gravels from this last excavation  
151 are curated in the Musée National de Préhistoire, Les-Eyzies-de-Tayac, Dordogne, France.



152  
153 **Fig 4. Drawing by Denis Peyrony of the gravels discovered at Fourneau du Diable (D. Peyrony, 1922).**  
154 Retranscription: « Les autres devraient être juxtaposées à l'intérieur. Fig. 13 – Disposition des 136 petites billes  
155 trouvées dans la couche inférieure du gisement du Fourneau ». Translation: "The other 153 should be juxtaposed  
156 inside. Fig. 13 - Arrangement of the 136 small balls found in the lower layer 154 of the Fourneau site".

157

## 158 Pech de la Boissière

159 Located near Carsac-Aillac, Dordogne, France (Fig 2A), the Pech de la Boissière rock shelter  
160 has a stratigraphic sequence comprising rich Solutrean and Magdalenian archaeological layers (E.  
161 Peyrony, 1934). The archaeological deposit has suffered rock falls and runoff from the upper plateau.  
162 Of the 30 lustrous gravels discovered in the Solutrean layers by Peyrony, only nine are kept in the Musée  
163 National de Préhistoire, Les-Eyzies-de-Tayac (Fig 1 and Table 1).

## 164 Casserole

165 One of the shelters overlooking the Musée National de Préhistoire, Les Eyzies-de-Tayac (Fig  
166 2A), this comprises a stratigraphic sequence containing 13 archaeological layers attributed to the  
167 Gravettian, the Badegoulian, the Proto-Solutrean, the Solutrean and the Magdalenian (Table 1).  
168 Although geoarchaeological analysis shows that boulder falls, trampling, percolation, gelifraction and  
169 bioturbation have, albeit at small scale, contributed to the site formation process, the excavation  
170 conducted between 1991 and 1993 (Detrain et al., 1992, 1994), showed a low degree of disturbance of  
171 the Solutrean layers and identified a concentration of remains on a small surface interpreted as an area  
172 of intense human activity (Detrain et al., 1994). The Solutrean layers are dated by <sup>14</sup>C AMS on burned  
173 bones to 20.5 – 23.3 cal BP (Detrain, 2016; Ducasse et al., 2020). Fourteen lustrous gravels were  
174 retrieved in this layer (Fig 1 and Table 1). They are kept in the Musée National de Préhistoire at Les-  
175 Eyzies-de-Tayac.

## 176 **Laugerie Haute**

177 Located at Les Eyzies-de-Tayac, on the right bank of the Vézère valley (Fig 2A), and firstly  
 178 excavated in 1863 by Lartet and Christy, this iconic rock shelter has been since then the subject of  
 179 numerous digs (Table 1). It includes two distinct sectors, Laugerie Haute East and Laugerie Haute West.  
 180 The excavations yielded a long stratigraphic sequence encompassing Solutrean (Bachelier & Schmidt,  
 181 2022), in particular Proto Solutrean, Lower Solutrean, and Late Solutrean layers (Bosselin & Djindjian,  
 182 1997; Demars, 1995; Smith, 1966). Radiocarbon dating indicates these layers were accumulated  
 183 between 28 and 19 ka cal BP. Late Solutrean layers of Laugerie Haute West are dated by 14C AMS  
 184 from 19 600 to 23 500 ka cal BP (Texier et al., 2006; Tisnérat-Laborde et al., 2003). Successive  
 185 excavations conducted the last century by Peyrony and Bordes (Bosselin & Djindjian, 1997; Demars,  
 186 1995; Smith, 1966) at Laugerie Haute East have uncovered 19 lustrous gravels in layer 25 (Fig 1),  
 187 attributed to the Late Solutrean. Eighteen gravels from Laugerie Haute West (Fig 1), of unknown  
 188 stratigraphic origin, are also kept at the Musée National de Préhistoire, Les Eyzies-de-Tayac.

## 189 **Methods**

190 Table 2 below describes the various natural and geological factors that can modify the gravel  
 191 surfaces. We thus rely on this inventory to better characterize the surfaces of archaeological gravels.

192 **Table 2. Known natural processes producing luster on gravels.**

	Wind erosion	Water	Ground or ice polishes	Chemical alterations	Animals
<b>Environments</b>	Desert, coast, periglacial region, mountains	River, sea	Periglacial region	Soil	Various (sea lions, galliformes, birds)
<b>Phenomena</b>	Abrasion	Transport (rolling, saltation, sedimentation)	Solifluxion, cryoturbation, gelifluxion	, Patina, corrosion	Geophagy, attack of gastric juices, abrasion-polishing by organic or vegetable elements
<b>Macroscopic stigmata</b>	Shiny facets, sinuous ridges	Smoothed and shiny pebbles	Unworn shiny pebbles with accentuated reliefs	-	Gastroliths (small matted gravel)
<b>Microscopic stigmata</b>	Wide grooves with preferential orientation along the wind direction	V-shaped impact cupules, preferentially oriented microstriations, conchoidal fractures	Micro-polished, conchoidal fractures, parallel striations, circular grinding traces, impact cupules	-	Polished surfaces, microstriations

193 Data from (Abrahams, 1997; Bertran & Texier, 1999; Bishop & Mildenhall, 1994; Bourguignon et al., 2001; Cailleux  
 194 et al., 1959; Cane, 1982; Clark, 2006; Esque & Peters, 1994; Fiedler, 1988; Galland, 2016; Galland et al., 2019; Hladik  
 195 & Gueguen, 1974; Judson & Barks, 1961; Klaus et al., 1998; Knight, 2008; Le Ribault, 1977; Lenoble, 2003; Schlyter,  
 196 1995; Tryon, 2010; Wings, 2004)

197 Table 3 provides information on the studied material and the analytical techniques applied.  
 198 This includes lustrous and non-lustrous gravels recovered at Landry, lustrous gravels from  
 199 Fourneau du Diable, Casserole, Pech de la Boissière, Laugerie Haute, gravels from four natural  
 200 deposits, gravels polished experimentally (see below), and the number of gravels presenting

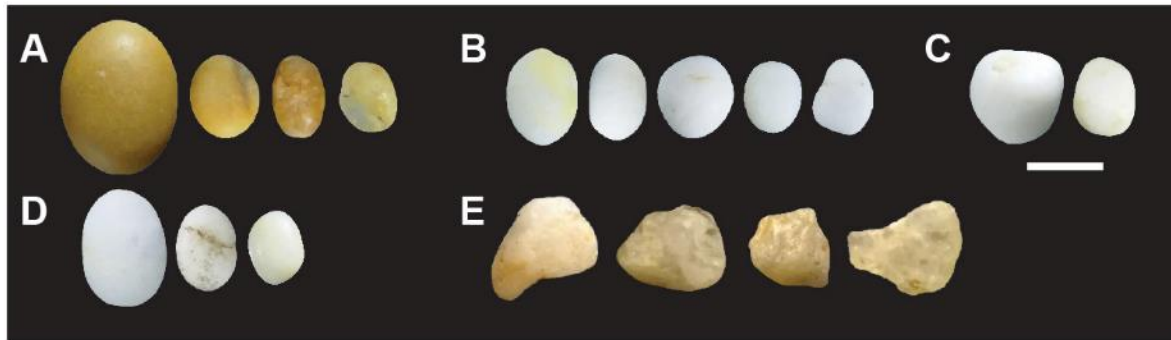
201 micro-concretions. Each archaeological gravel displays a similar degree of luster all over its  
 202 surface. Permission was obtained to temporarily store and analyze the archaeological material  
 203 at the PACEA laboratory, University of Bordeaux, Pessac, France. Lustrous gravels from  
 204 Landry were retrieved in the sieving. Their white and shiny appearance facilitated their  
 205 identification and comprehensive collection. Non-lustrous gravels come from Landry upper  
 206 layers and were collected in the sieving from sectors bordering the area that yielded the lustrous  
 207 gravels (Fig 5). The gravels from natural accumulations were collected by two of us (LG and  
 208 MB) in 2018 (Fig 2A and 5). They come from several Mediterranean beaches located in the  
 209 Hérault, dated from the Pliocene, Cap d'Agde beaches, Maguelone beaches, Oligocene alluvial  
 210 terraces located at Croignon, Gironde and Upper Cretaceous alluvial terraces close to  
 211 Campagne, Dordogne.

212 **Table 3. Number of gravels measured in the different approaches of this study for each archaeological sites**  
 213 **including those collected in the sieve refusals, different natural environments and the experimental**  
 214 **gravels.**

	Concretions	Morphometry	Colorimetry	Surface texture analysis
<b>Archaeological site</b>				
Landry	11	102	102	41
Casseroles	1	14	14	4
Fourneau du Diable	288	465	465	11
Pech de la Boissière	2	9	9	3
Laugerie Haute East	2	19	19	5
Laugerie Haute West	3	18	18	5
<b>Natural gravels</b>				
Landry from sieving		42	42	22
Cap d'Agde		2	2	2
Campagne		3	3	3
Croignon		3	3	3
Maguelone		5	5	5
<b>Experimental gravels</b>				
Process 1: gravels used on animal skin		10	0	10
Process 2: gravels used on ochred and greased animal skin		10	0	10
Process 3: gravels polished with silts from Landry		2	0	2

215 Regarding the spatial analysis of the Landry gravels, we have included all the lustrous gravels in the analysis. Data  
 216 on the spatial distributions of the gravels at the other sites were lacking, so we did not perform any spatial analysis.

217



218

219 **Fig 5. Examples of gravels from natural sites.** (A) Gravels from the tertiary terraces of Campagne (Dordogne,  
 220 France); (B) marine gravels from Maguelone (Hérault, France); (C) marine gravels from Cap d'Agde (Hérault,  
 221 France) (D) gravels from the Quaternary alluvium and vineyards of Croignon (Gironde, France) and (E) gravels  
 222 from the Landry's sieving. These gravels were selected and collected according to previous observations of the  
 223 Landry gravels and before having had knowledge of the lustrous gravels of the other archaeological sites whose  
 224 raw material is visibly different. Scale = 1 cm.

225

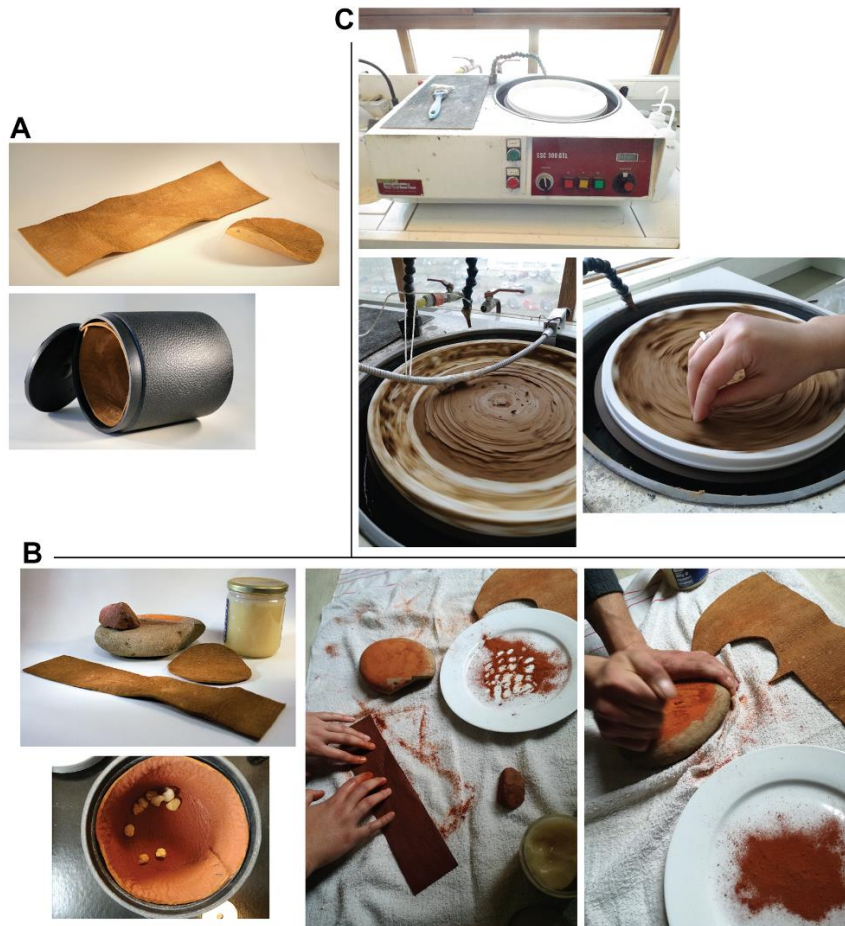
## 226 **Distribution and spatial association of Landry's lustrous gravels**

227 It has been proposed that distributions of items at an archaeological site fall in three  
 228 categories: concentration, uniform distribution, or random distribution (Bertran et al., 2005;  
 229 Djindjian, 2017). The occurrences of the items in a grid or their spatial coordinates can be used  
 230 to establish to which of these three cases the distribution most closely approximates (Djindjian,  
 231 1991). We used gravels' occurrences in the 50x50 cm Landry excavation grid to calculate the  
 232 dispersion index. The *corrplot* package (Wei et al., 2021) was used to plot the spatial  
 233 distribution of the gravels. The Poisson function law was applied to simulate numerous random  
 234 distributions of the same number of lustrous gravels retrieved at the site (n= 106). The  
 235 dispersion index was calculated and compared to simulated uniform distributions. A variance-  
 236 to-mean ratio indicates whether the concentration of items is random or not.

237 We explored the degree of spatial association between the lustrous gravels and major  
 238 knapped stone tool classes, as well as between the former and artefacts made of metamorphic  
 239 rocks, via a permutation test whose script was created by F. Santos (Merrill & Read, 2010).  
 240 This test allows us to statistically verify the non-random association between two categories of  
 241 artifacts by measuring their average Euclidian distance. This distance is then compared to  
 242 values generated by a large number of runs in which the category of each object is randomly  
 243 assigned, while the positions of all artefacts remain unchanged (Berry et al., 1980). Since they  
 244 were not spatially plotted during the excavation, we assigned Landry gravels random  
 245 coordinates within their original 50 x 50 cm square. The results of this test give association  
 246 indices for each pair of remains categories compared (gravel/flint, gravel/metamorphic rock).

## 247 **Experimental polishing**

248 Three experiments were implemented to produce lustrous gravels. In the first two  
249 experiments we used two models (3A and 33B/3-1.5) of rotary tumbler machines produced by  
250 Lortone Inc. (Mukilteo, WA, USA), commonly used to smooth and polish semiprecious stones.  
251 In the first two experiments, aimed at testing the effect of anthropogenic modifications, we used  
252 two animal hides. In the first experiment the inner surface of the barrel was covered with tanned  
253 cow leather (Fig 6A), in the second with a leather treated with a mixture of finely ground ochre  
254 powder and duck fat (Fig 6B). The choice of skin is justified by the fact that the available data  
255 suggest animal skin was widely used in the Gravettian and the Solutrean to produce articles of  
256 leather. As well, the small size of the gravels makes it unlikely that they could have been  
257 transported in nets or similar containers. Ten non-lustrous gravels from Landry were put in the  
258 tumbler barrel. The tumbler was set at 60 revolutions per minute and run for 504 hours. The  
259 gravels were cleaned under running water and acetone at the end of both experiments. The third  
260 experiment aimed at reproducing abrasion attested in periglacial environments, caused by  
261 sediments in contact with gravels mobilized by sedimentary processes (Caspar et al., 2003;  
262 Iverson, 1990; Mathews, 1979). A board covered with silt from the site of Landry, moistened  
263 with water, was attached to a metallographic polisher (ESC300 GTL model, produced by  
264 ESCIL, Chassieu, France) (Fig 6C). The gravels were manually held in contact with the silt-  
265 covered surface for 7 hours. They were then attached to a metal rod and maintained in contact  
266 with the silt for an additional 5 hours. Only one side per gravel was polished following this  
267 protocol. The polisher was operated at 110 rpm. The experimental gravels were then subjected  
268 to the same morphometric and roughness analyses applied to the other gravels analyzed (see  
269 below).



270

271 **Fig 6. Presentation of the three experiments.** (A) Material used for experiment 1, the animal skin used and the  
 272 cylinder of the polishing drum. (B) Material used for experiment 2, the ochred and greased animal skin. Illustration  
 273 of the *chaîne opératoire* reproducing an ochre tanning: obtaining the ochre powder and applying the ochre/grease  
 274 paste on the hide. (C) Equipment used for experiment 3, the soil polish. A mechanical polisher covered with silt  
 275 collected on the Landry site. Presentation of the manual (bottom left) then mechanical (bottom right) method of  
 276 gravel gripping.

277

## 278 **Microscopic, morphometric and colorimetric analysis**

279 Archaeological, experimental and natural gravels were photographed with a Sony  
 280 A6000 equipped with a Sony E30-mm F3.5 macro lens. Selected gravels were molded using  
 281 Coltène® President regular body high resolution dental impression material and cast in resin  
 282 (Epoxy Araldite 2020, Escil, Chassieu, France). Replicas were observed and photographed in  
 283 transmitted light with a Leica Z6 APOA microscope equipped with a multifocus module. The  
 284 *Particle Analysis* plug-in of the image processing software ImageJ (Schneider et al., 2012) was  
 285 applied to digital images of archaeological lustrous and non-lustrous gravels as well as gravels  
 286 collected at natural sites to measure length, width, area, perimeter, and calculate circularity  
 287 ( $4\pi \cdot \text{area} / \text{perimeter}^2$ ) and rounding indexes ( $4 \cdot \text{area} / (\pi \cdot \text{major axis}^2)$ ). Thickness was  
 288 measured manually using a digital caliper. Colorimetric values, expressed in RGB, were

289 extracted by averaging the color of each gravel thanks to the Color Inspector 3D plug-in, and  
290 converted into  $L^*a^*b^*$  with the *grDevices* package (Team, 2009). Inter-group comparison of  
291 the distribution of those quantitative data was performed through the Kruskal-Wallis non-  
292 parametric statistical test with the *pgirmess* package (Giraudoux et al., 2018).

### 293 **Surface texture analysis**

294 Confocal microscopy applied to archaeological artifacts is able to distinguish wear  
295 signatures of natural and anthropogenic agents (Evans & Donahue, 2008; Galland et al., 2019;  
296 Ibáñez et al., 2016; Rosso et al., 2017). Archaeological lustrous and non-lustrous gravels from  
297 Landry and lustrous gravels from Fourneau du Diable, Casserole, Pech de la Boissière, Laugerie  
298 Haute, from natural deposits and gravels experimentally polished (Table 3) were analysed with  
299 a Sensofar S-Neox confocal microscope equipped with a long-working-distance 50x objective  
300 (numerical aperture = 0.45), allowing a spatial sampling of  $0.26\mu\text{m}$ . We measured on opposite  
301 aspects of each gravel two areas of  $351 \times 264\mu\text{m}$  with a vertical repeatability of 3 nm and  $42^\circ$  of  
302 maximum acquisition slope. Measures were taken on areas free of micro-concretions. The data  
303 obtained were processed by the SensoMAP Premium 7.4 software. Post-acquisition data  
304 treatment followed a procedure similar to that described by Martisius and colleagues (Martisius  
305 et al., 2018). Using built-in operators, this included levelling the surface with the least squares  
306 method, removing isolated outliers and noise, filling in non-measured points by interpolating  
307 from neighbours, and removing the surface form using a polynomial of third order.

308 A Gaussian filter of  $80\mu\text{m}$  was applied as a cut-off to remove waviness from roughness,  
309 which appeared to separate roughness values of glossy from non-glossy gravels better than the  
310  $25\mu\text{m}$  filter. Three ISO 25178 parameters were calculated (Table 4): the root mean square  
311 height (Sq), the degree of bias of the shape of the roughness (Ssk), and the developed surface  
312 ratio (Sdr). Previous studies have shown the pertinence of these parameters to characterize  
313 different degrees of polish on archaeological artefacts (d'Errico et al., 2022; Galland, 2016;  
314 Galland et al., 2019). In addition, they present the advantage of being largely independent from  
315 one another. Univariate and multivariate statistical analyses were applied to these data. We  
316 present here the results of two PCA (Principal Component Analysis) with convex hulls for each  
317 group of gravels. We obtained those PCA via the FactoMineR package (Lê et al., 2008).

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#### Amplitude parameters (characterization of the z axis perpendicular to the surface)

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Sq     $\mu\text{m}$     Root mean square height, standard deviation of heights. A low roughness will have a Sq value equal to 0 while a high roughness will have a Sq value superior to 0.

**Ssk** Skewness. Degree of bias of the shape of the roughness (asperity). A low roughness will have a Ssk value under 0 (surface dominated by valleys) while for high roughness le Ssk value will have a value superior to 0 (surface dominated by peaks).

---

**Hybrid parameters (information present on the three axes x, y and z of the surface)**

---

**Sdr** % Developed surface ratio. 0% indicates a flat and smooth surface, 100% indicates a complex surface with large peaks and valleys.

---

318 **Table 4. Three ISO 25178 parameters used to measure the textural surfaces.**

319 We selected 2 amplitudes parameters: the root mean square height (Sq), the degree of bias of the shape of the  
320 roughness (Ssk), and one hybrid parameter: the developed surface ratio (Sdr).

321

## 322 **Ethnographic survey of small pebble use**

323 To explore historical and contemporary uses of small stones similar to the lustrous  
324 gravels examined, we used the electronic Human Relations Area Files (eHRAF), a collection  
325 of full-text, subject-coded global ethnographic materials  
326 (<http://www.ehrafworldcultures.yale.edu/>). A text search on [“pebble\* OR stone\*” NOT  
327 subject:building and construction] was performed (the term “gravel\*” yielded only 15  
328 descriptions of material used for paths). The search was restricted to the 186 Standard Cross  
329 Cultural Sample (SCCS) cultures, a subset of eHRAF with the most detailed and robust  
330 ethnographic descriptions. This yielded 23022 paragraphs across 175 cultures. The eHRAF  
331 Outline of Cultural Materials (OCM) has subject codes tagged to each paragraph. The top five  
332 for this search were Sacred Objects and Places, Prayers and Sacrifices; Mythology; Literary  
333 Texts; Spirits and Gods. Utensils, Tools, Weapons, and Burial Practices were in the top 20.  
334 Because each paragraph is usually tagged with multiple OCM codes, we developed a bespoke  
335 coding scheme for specificity.

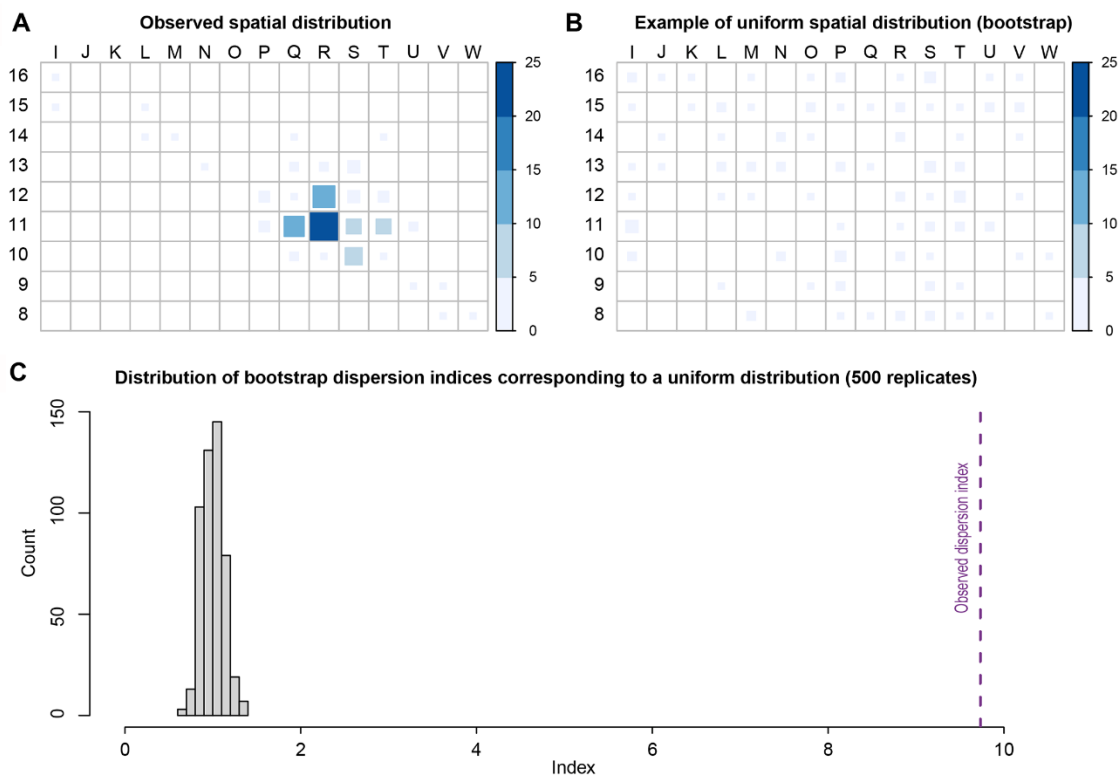
336 All material in a sample of 82 cultures (all 38 hunter-gatherer societies in the SCCS plus  
337 44 others stratified by region, c.20% in each totalling 10488 paragraphs) was read and coded  
338 for how pebbles were used. We noted if pebbles were present in multiples of four or more at  
339 one time (Yes, No, Unclear), and any information about bags or other carrying items. We did  
340 not code keyword mentions that were irrelevant to our study, especially where stones were  
341 described as larger than a fist (e.g. grinding or cooking stones, cairns, commercial use) or when  
342 the keywords were associated with technologies not relevant for our study (e.g. pebbles  
343 associated with metal or glass in ornaments, pebbles with holes for stringing, for use as weights  
344 in commercial trade etc.). Other rare mentions, such as being described in fantastical folklore,  
345 or stones referring to the seeds of fruit, were also not assigned to a code.

346 **Results**

347 **Distribution and spatial association of lustrous gravels at Landry**

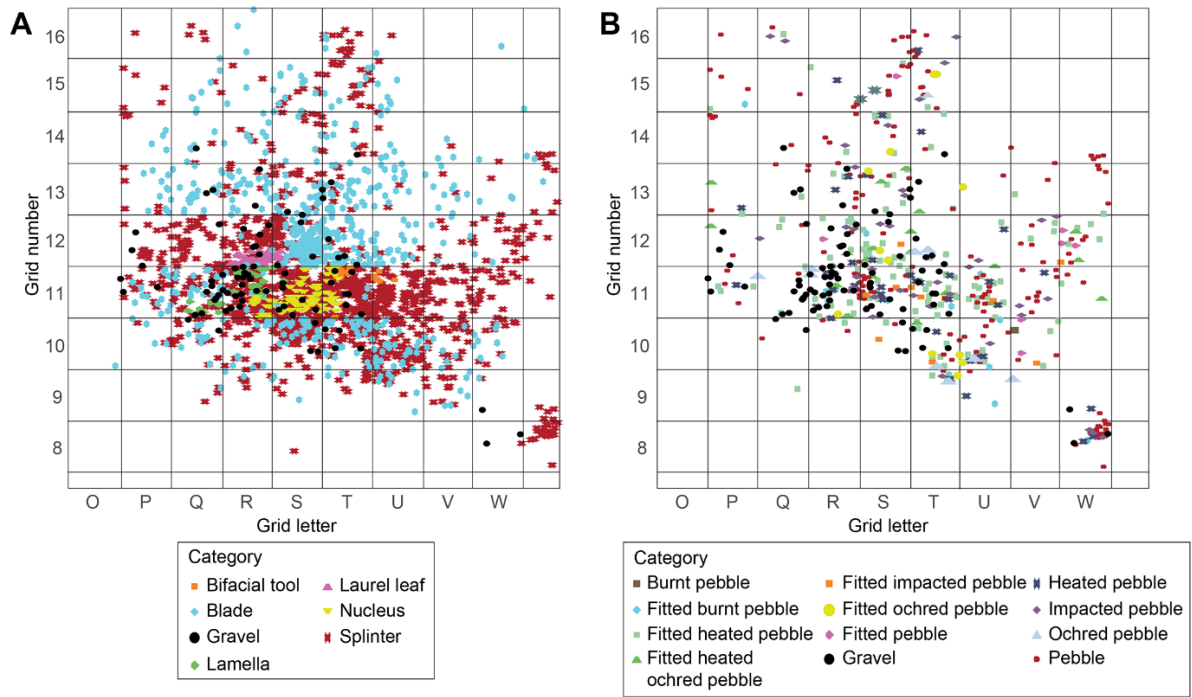
348 Lustrous gravels are concentrated in squares R11, R12, and Q11, sector 3, and to a lesser  
349 extent in adjacent squares (Fig 7). A few gravels are present in sector 2. They are virtually  
350 absent in the rest of the excavated area. This is confirmed by a dispersion index of 9.7, much  
351 higher than that expected for a uniform or random distributions (Fig 7).

352 The spatial distribution of flints and metamorphic rocks appears strongly correlated with  
353 that of the lustrous gravels (Fig 8). As indicated by a significant difference in association indices  
354 (Fig 9), the average distance between the gravels and the objects in the other categories is  
355 greater than if the category had been randomly assigned to objects with the same geographic  
356 coordinates. This result establishes that the concentration of gravels is stronger than that of the  
357 other categories of remains.



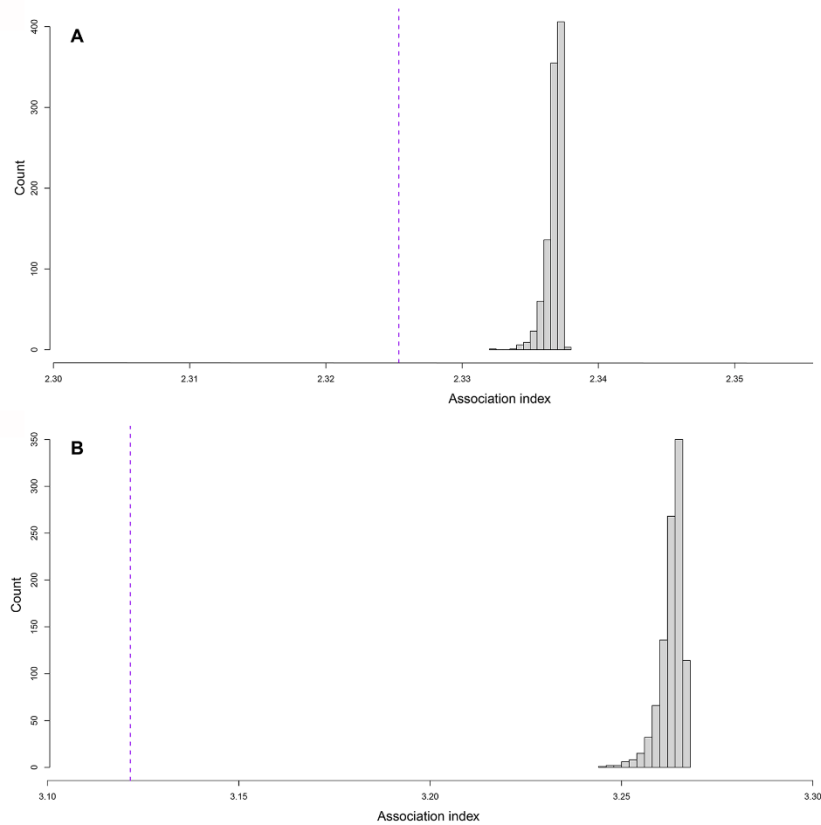
358 **Fig 7. Graphics presenting the results of the spatial analysis.** (A) Count of gravels in the Landry grid. This area  
359 corresponds to sector 1 (squares columns I through J), sector 2 (columns K through P), and sector 3 (columns P  
360 through V). (B) Simulation of a uniform spatial distribution of gravel on sector 1, 2 and 3. (C) Distribution of  
361 dispersion indices corresponding to a uniform distribution (500 random draws) and on the right in purple,  
362 dispersion index associated with real glossy gravel's distribution.  
363

364



365  
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**Fig 8. Spatial distribution observed on sector 3 of different flints tools and lustrous gravels (A) and of the latter and metamorphic stone tools (B).**

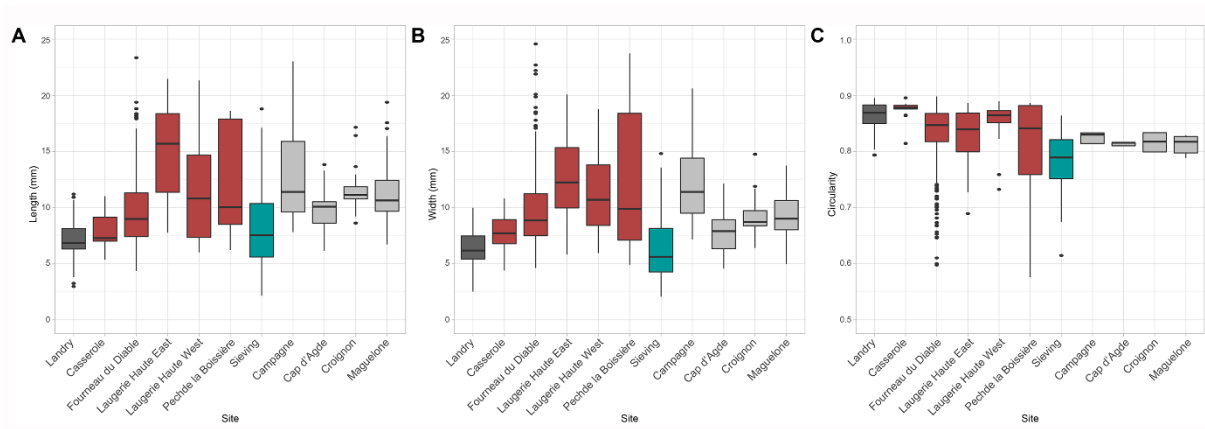


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373

**Fig 9. Permutation tests displaying association indices.** The dashed line shows the association index between gravels and flints (A) and metamorphic rocks (B). Histograms represent the distribution of indices over 500 draws with random position permutations.

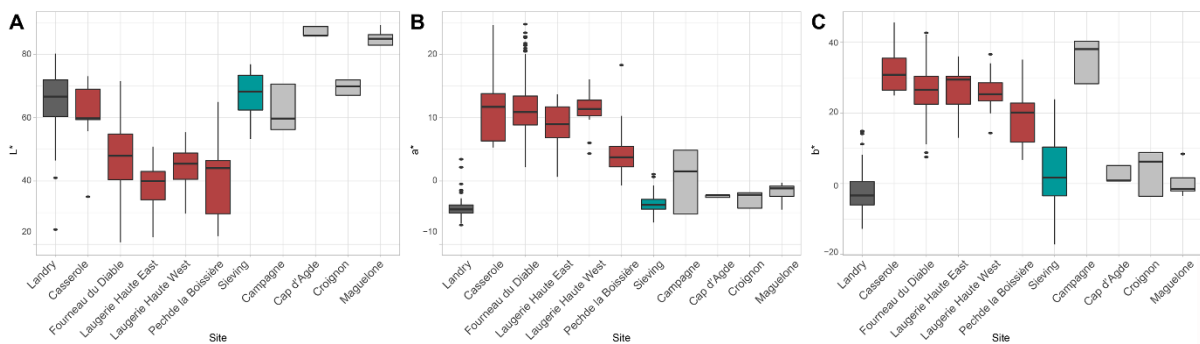
374 **Morphometry and colorimetry**

375 Morphometric analysis identifies significant differences ( $p < 0.05$ ) (see SM Table 1)  
 376 between lustrous gravels found at Landry, Casserole, and a part of those from Fourneau du  
 377 Diable, which are smaller and more spherical (Fig 10). These are also different from those at  
 378 Pech de la Boissière, Laugerie Haute, a part of those from Fourneau du Diable, those of Landry  
 379 retrieved outside the concentrations and those from natural sites, which are more elongated and  
 380 more variable in size. The gravels from the Fourneau du Diable, Pech de la Boissière and  
 381 Laugerie Haute sites are also more homogenous in color; less so for the others (Fig 11 and SM  
 382 Table 1). At Landry no significant differences are observed in the color of lustrous and not-  
 383 lustrous gravels, since they are all made of quartz.



384  
 385 **Fig 10. Comparison of gravel length (A), width (B) and circularity index (C) for each site.** The circularity  
 386 index is close to 1 for a round object and 0 for an object of more complex morphology.

387



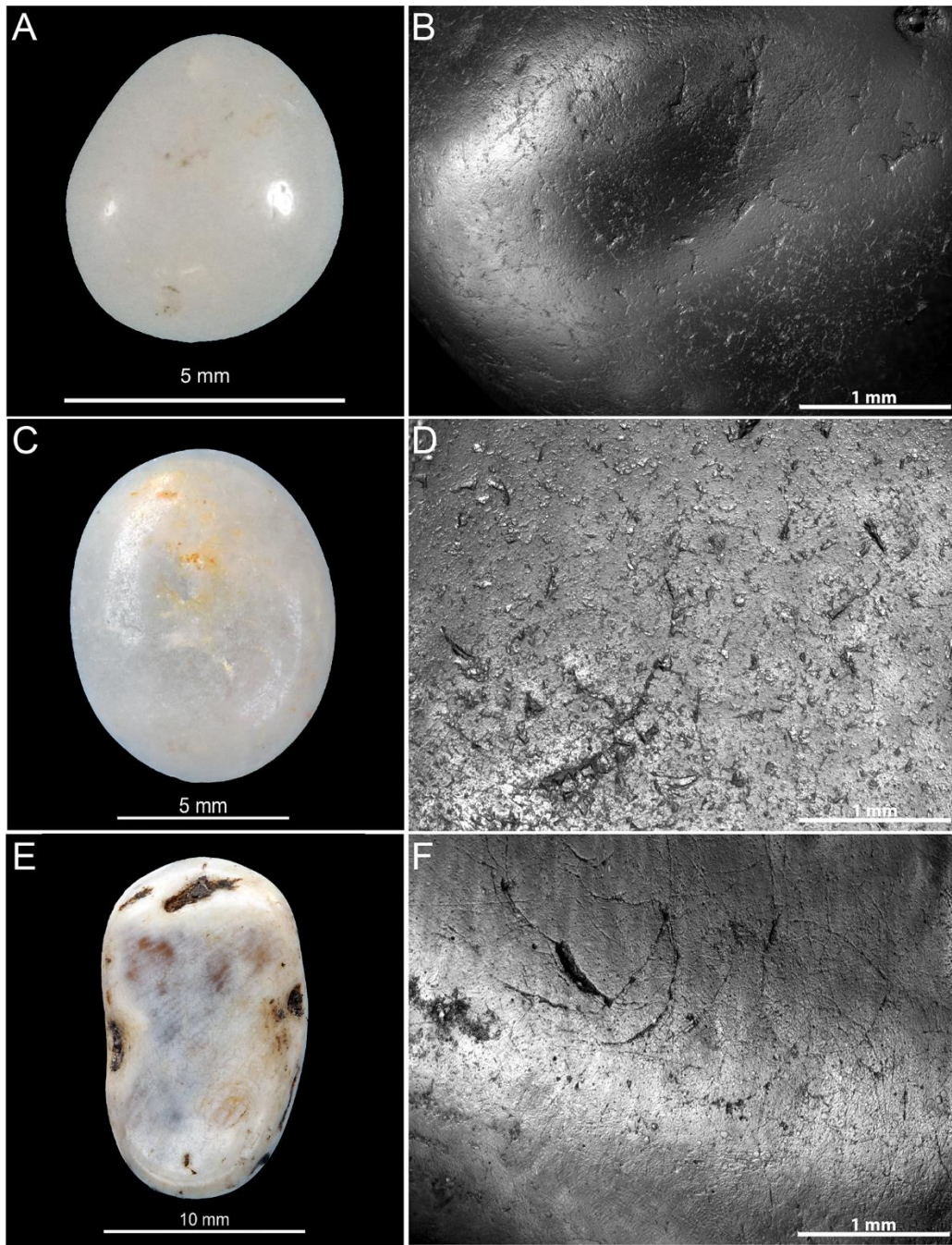
388  
 389 **Fig 11. Representation of gravel color according to the parameters L\* (luminescence, 0 = black, 100 = white),**  
 390 **a\* (green-red axis) and b\* (blue-yellow axis).** The two parameters range from +127 to -128.

391

392 **Microscopic analysis**

393 The archaeological lustrous gravels are characterized by homogeneous surfaces on  
 394 which depressions are either absent, or rare and of dimensions not exceeding 10 $\mu$ m. Curved

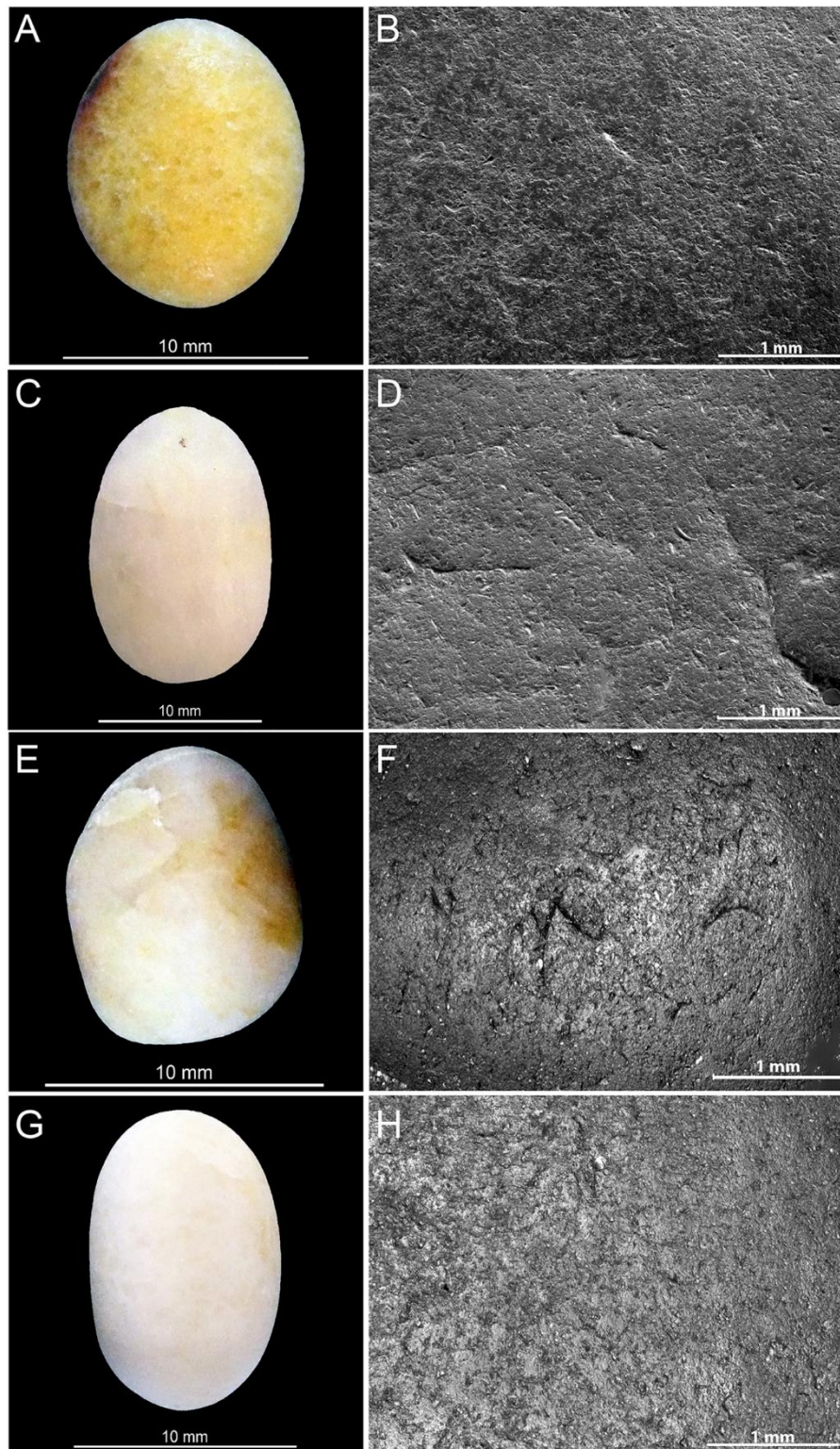
395 micro-cracks corresponding to incipient fracture cones are also discernable (Fig 12). The edges  
396 of these fracture lines occasionally reveal chipping and conchoidal micro removals. The  
397 frequency of depressions and the degree of surface homogeneity is dependent on the degree of  
398 luster observed to the naked eye. The natural gravels (Fig 13) which are visually matte are  
399 characterized at the microscopic scale by more uneven surfaces than those observed on the  
400 archaeological pieces. The natural gravels present small homogenous areas exclusively on  
401 prominent zones. This is particularly evident on pieces from river terrace deposits. Gravels  
402 collected on beaches show more intense pitting associated, in some cases, with incipient  
403 fracture cones not flattened by wear, as is the case for archaeological gravels. The surfaces of  
404 gravels tumbled in barrels are similar to those on archaeological specimens without reaching  
405 the same level of homogeneity (Fig 14). Notably, treatment with tumblers covered with ochred  
406 skin produces the surface modification comparable to those observed on archaeological gravels.  
407 Abrasing natural gravels with a polishing machine covered with wet silt produces lustrous areas  
408 entirely covered with 20-50 $\mu$ m wide parallel striations.



409

410 **Fig 12. Macroscopic (left) and microscopic (right) photos of gravels from archaeological sites illustrating**  
 411 **the lustre on surfaces. (A-B) Gravel from Landry; (C-D) gravel from Casserole and (E-F) gravel from Fourneau**  
 412 **du Diable.**

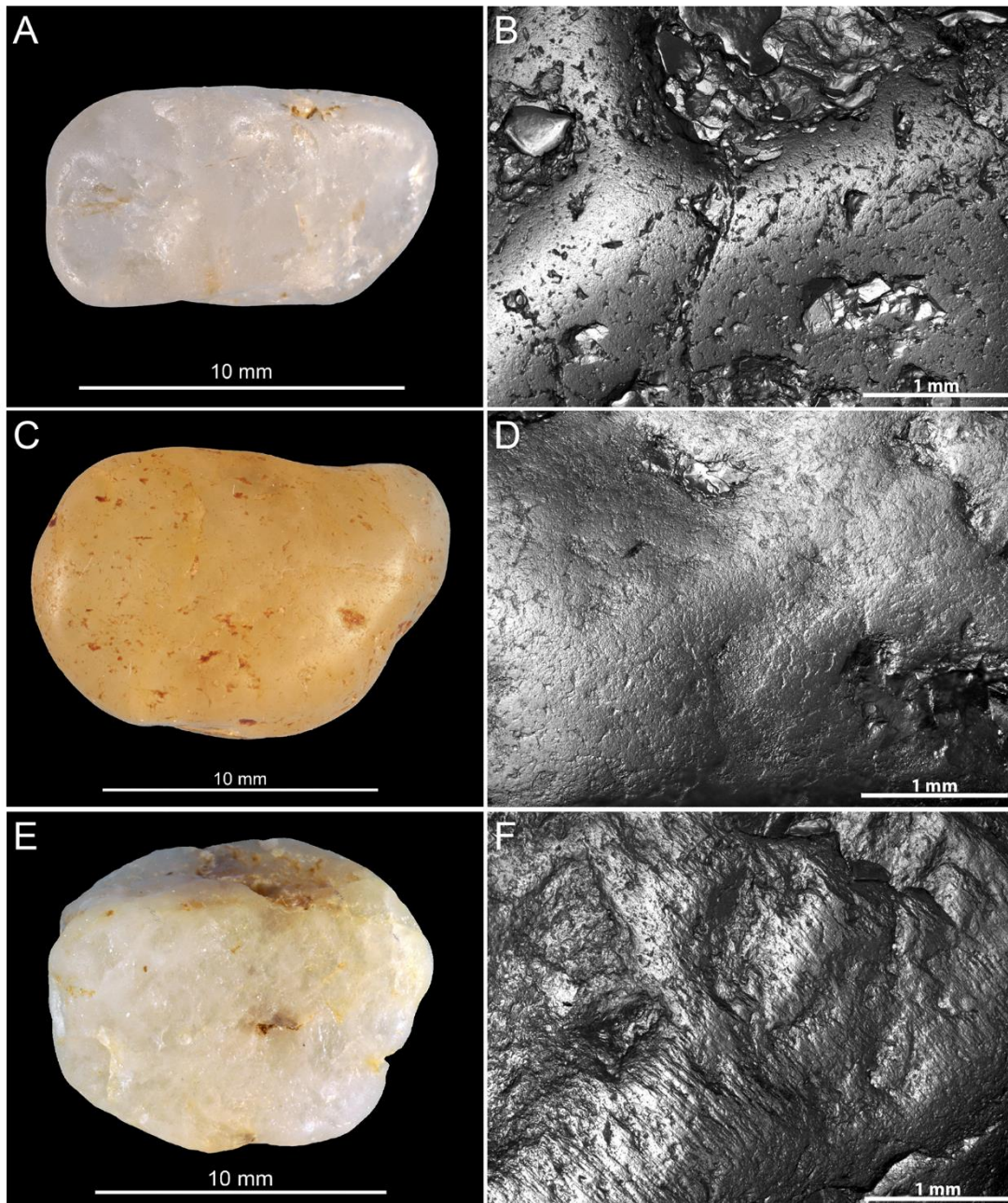
413



414

415 **Fig 13. Macroscopic (left) and microscopic (right) photos of gravels from natural sites illustrating the**  
 416 **variability of surfaces. (A-B) Gravel from Campagne; (C-D) gravel from Croignon; (E-F) gravel from Cap**  
 417 **d'Agde and (G-H) gravel from Maguelone.**

418



419

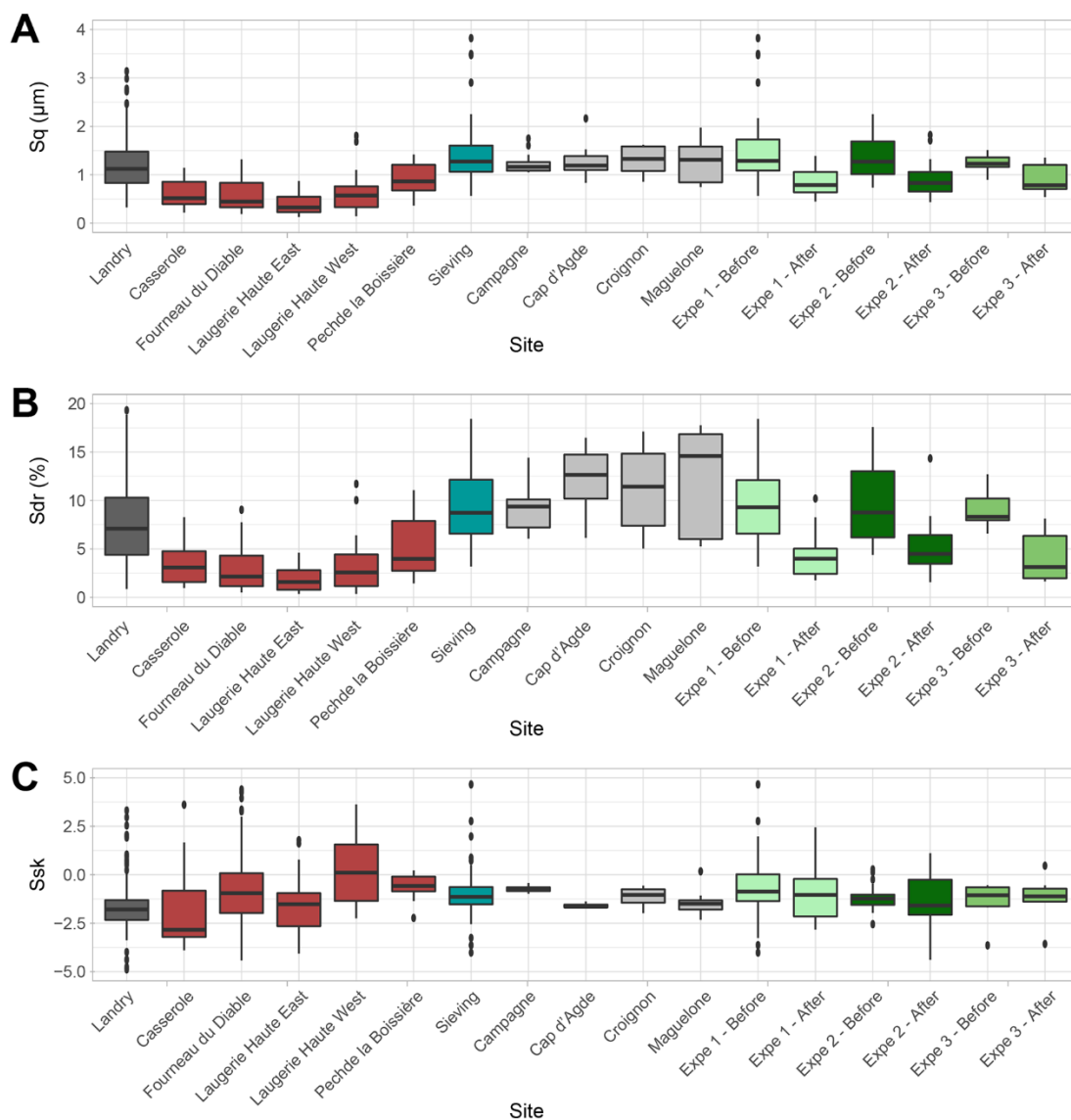
420 **Fig 14. Macroscopic (left) and microscopic (left) photos of experimental gravels.** (A-B) Gravel from the  
 421 experiment 1 processing the animal skin; (C-D) gravel from the experiment 2 processing the ochred skin with  
 422 animal fat; (E-F) gravel from experiment 3 processing wet silt from Landry.

423

## 424 **Surface texture analysis**

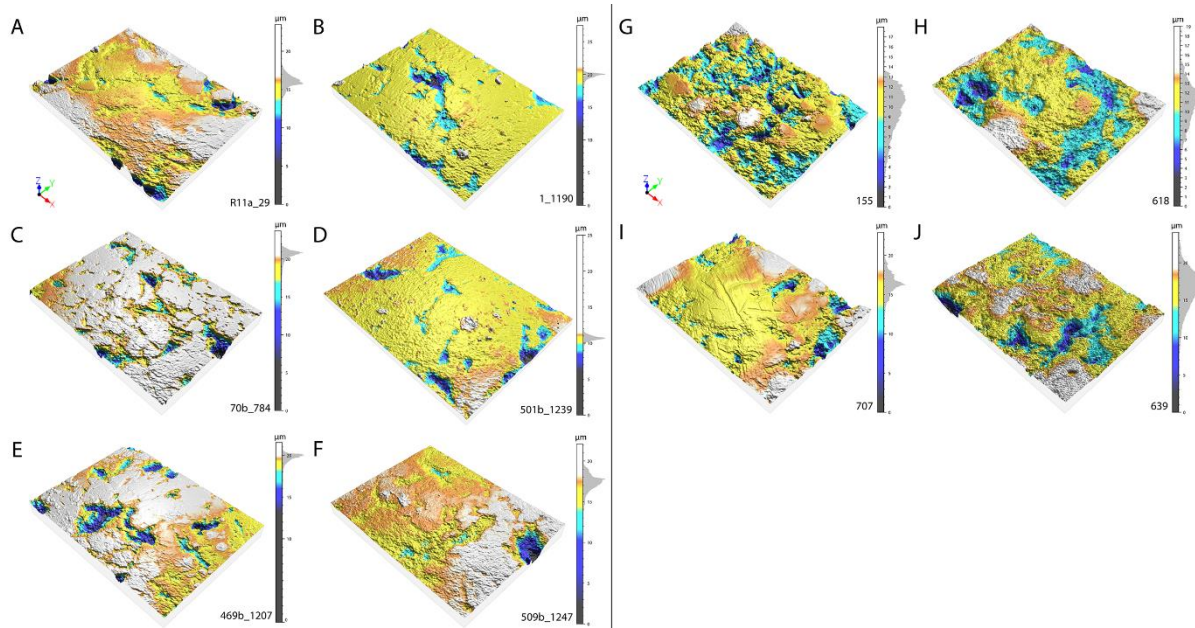
425 Roughness parameters identify significant differences ( $p < 0.05$ ) (see SM Table 1)  
 426 between natural and most archaeological gravels (Fig 15). Gravels from Casserole, Fourneau  
 427 du Diable and Laugerie Haute show low Sq and Sdr values, which reflect smooth and not very  
 428 complex surfaces (Fig 16). The positive reliefs of the micro-topography appear erased, leaving  
 429 a flat surface with hollows and valleys (Fig 16C). This wear pattern gives these gravels a strong  
 430 shine. In contrast, the gravels from the Landry sieving and from natural sites have rougher

431 surfaces, resulting in a dull appearance. The lustrous gravels from Landry are significantly  
 432 rougher than those found in the other archaeological sites ( $p < 0.05$ ) (see SM Table 1). They  
 433 are, on the contrary, not significantly smoother ( $p > 0.05$ ) (see SM Table 1) than those from  
 434 natural sites but significantly smoother than those recovered at Landry outside the  
 435 archaeological concentrations. This intermediate state of surface for the Landry lustrous gravels  
 436 comes from more heterogeneous surface textures: some individuals show values close to those  
 437 recorded on gravels from the other archaeological sites, and some show values close to those  
 438 from the Landry sieving and natural sites. In summary, the gravels from archaeological sites  
 439 and lustrous Landry gravels display a roughness incompatible with that recorded on gravels  
 440 from natural sites.



441  
 442 **Fig 15. (A) The distribution of Sq (µm) parameter, (B) the distribution of the Sdr (%) parameter and (C)**  
 443 **the distribution of Ssk parameter.**

444

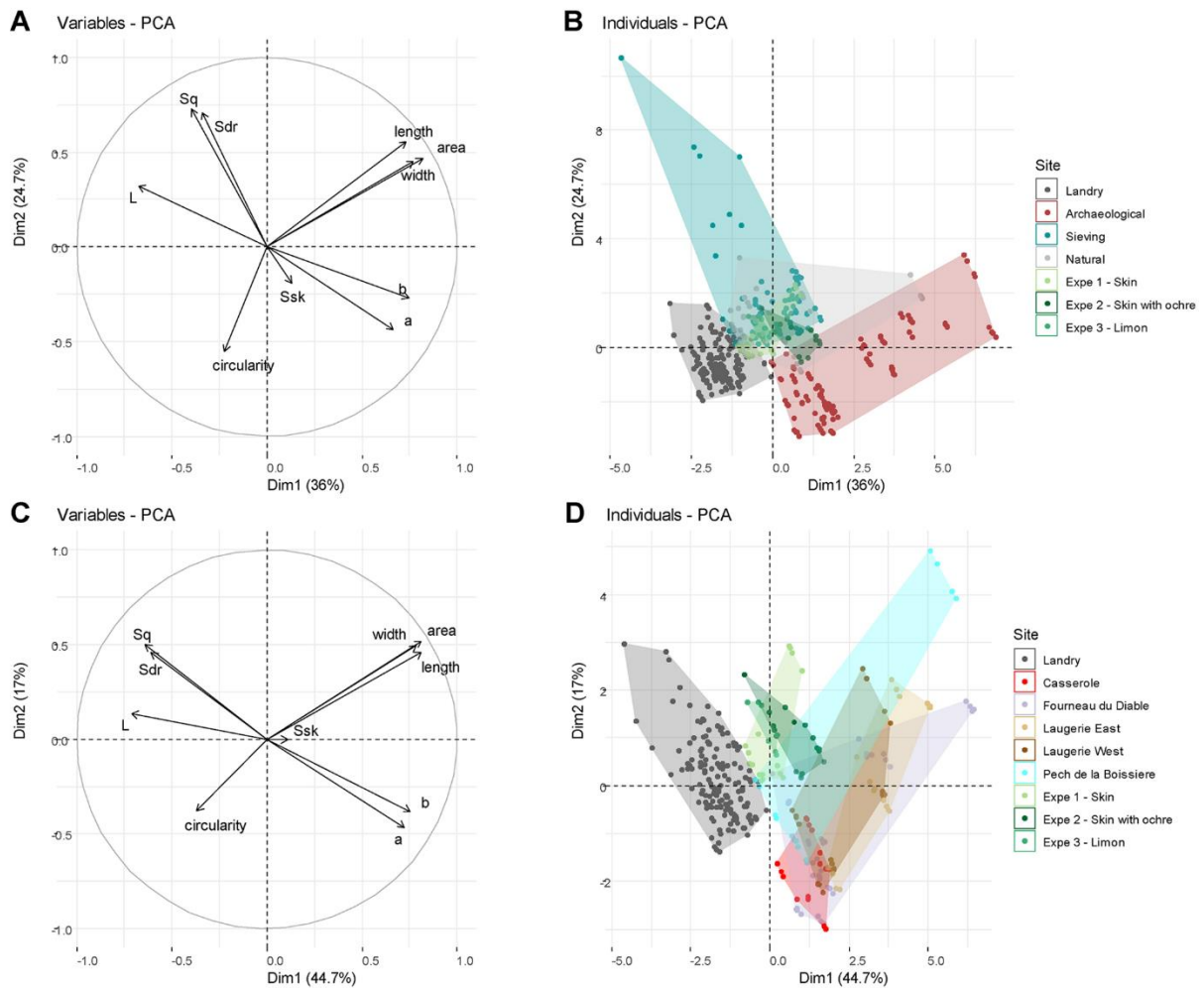


445  
 446 **Fig 16. Three-dimensional representations of the surfaces of four gravels from different sites.** The Landry  
 447 gravel (A) has a Sq of  $0.98\mu\text{m}$  and a Sdr of 4.45%, its surface is of intermediate roughness. The Casserole gravel (B)  
 448 is quiet similar to Landry one. The Fourneau du Diable gravel (C) has a Sq of  $0.84\mu\text{m}$  and a Sdr of 4.98%, it  
 449 is characterized by a regular luster. The Laugerie Haute East gravel (D), Laugerie Haute West gravel (E) and Pech  
 450 de la Boissière gravel (F) also present a regular luster. The gravel from the Landry's sieves (G) has a Sq at  $1.69\mu\text{m}$   
 451 and Sdr at 16.4% and the gravel from Croignon (J) shows a Sq values at  $1.75\mu\text{m}$  and a Sdr at 16%. They are both  
 452 characterized by a rough surface. The Campagne gravel (H) and Maguelone gravel (I) present similar values than  
 453 (G) and (J) and their surfaces are rougher. These visualizations highlight the folds of the glossy surfaces as well  
 454 as the shape of the histograms on the Z-scales expressing the distribution of the points with respect to the average  
 455 plane of the surface.

456

## 457 **Multivariate analysis**

458 The principal component analysis of all recorded parameters (Fig 17) highlights a clear  
 459 difference between gravels found at archaeological sites excavated in the past, natural gravels  
 460 and gravels found at Landry both inside and outside the concentrations of archaeological  
 461 artifacts. While very few gravels from the Landry concentrations display features compatible  
 462 with those recorded on natural populations, a consistent portion of those found outside the  
 463 concentrations are comparable with the natural ones. A clear difference appears also between  
 464 the lustrous gravels of Landry and those from the other archaeological sites. The former are  
 465 more circular, whiter in color, and display comparatively rougher surfaces.



466

467 **Fig 17. Principal component analyses taking into account morphometric, roughness and colorimetric**  
 468 **variables.** The PCA in (A) and (B) compares natural, experimental and archaeological gravels. Gravels from  
 469 Landry and those retrieved during the sieving of the sediments from this site are plotted separately. The PCA in  
 470 (C) and (D) compares experimental gravels with those found at each archaeological sites. Dots correspond to one  
 471 of the four measurements performed on each gravel: 35 natural, 69 archaeological and 22 experimental gravels.

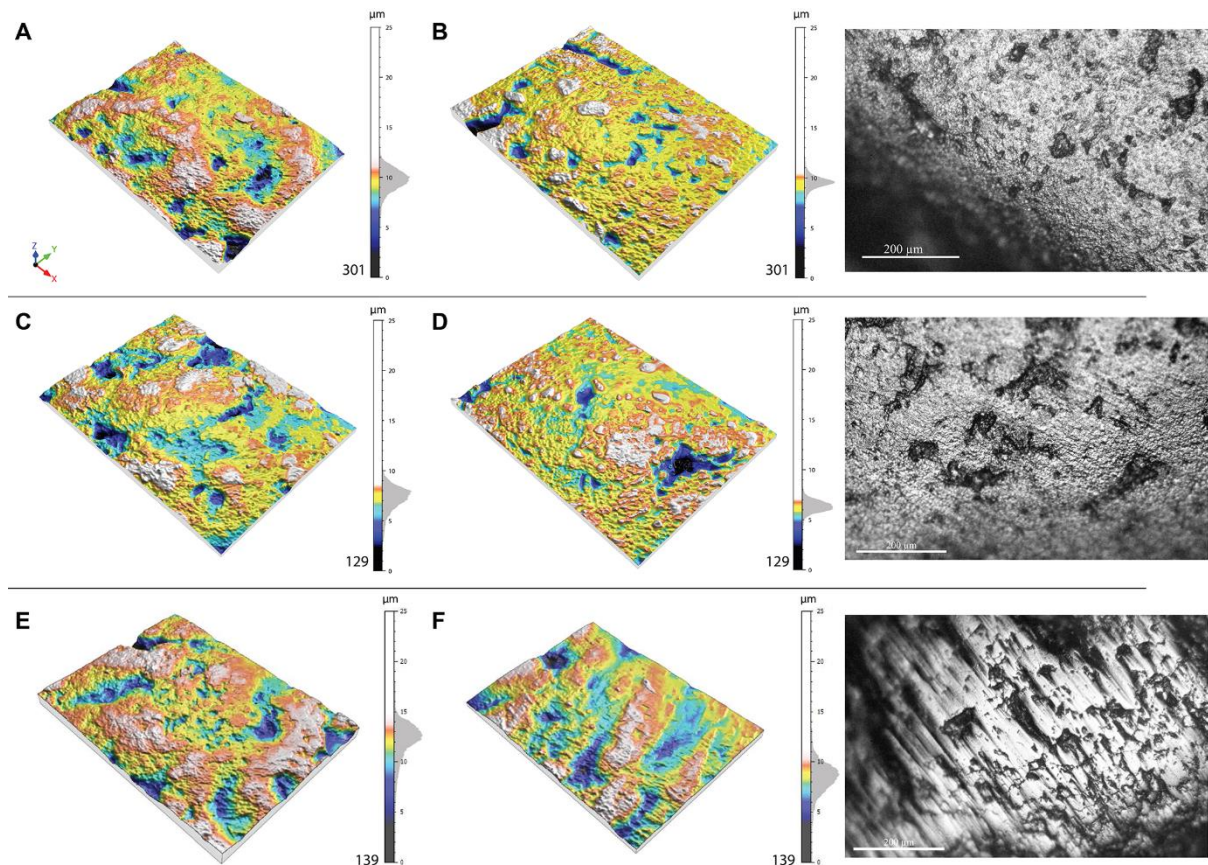
472

## 473 Experimental results

474 As expected, all experimental treatments significantly reduced the roughness of the  
 475 gravels. The tumbling process, entailing impact of the gravels on each other and their contact  
 476 with the skin, causes a gradual flattening of the surface resulting in a shiny appearance (Fig 18).  
 477 Abrasion of gravel against Landry silt also produces a shine.

478 At microscopic scale, however, the area smoothed by abrasion is covered by micro-  
 479 striations not found on lustrous gravels from Landry, the other archaeological sites and natural  
 480 accumulations (Fig 18). Gravels tumbled in a barrel coated with untreated animal skin reached  
 481 Sq values not substantially different from those recorded on gravels tumbled in a barrel covered  
 482 with skin treated with ochre and fat. Similar Sq values are also seen on facets modified by

483 abrasion against Landry silt. Wear produced by tumbling with untreated skin and abrading on  
 484 silt, however, display a more intense gloss, reflected by lower Sdr values. Both tumbling with  
 485 treated and untreated skin and without ochre and fat produce a smoothness comparable to that  
 486 recorded on archaeological gravels from Fourneau du Diable, Casserole, Pech de la Boissière  
 487 and Laugerie Haute and stronger than that measured on Landry lustrous gravels. The roughness  
 488 values recorded on experimentally tumbled and abraded gravels fall outside the variability of  
 489 gravels from natural accumulations.



490  
 491 **Fig 18. Three-dimensional visualization of the surfaces before and after experimentation.** Process 1 (gravels  
 492 used on animal skin) has erased the reliefs in favor of hollows and valleys and the polish is more homogeneous.  
 493 (A) Shows the 3D surface of the experimental gravel before the experiment and (B) shows the surface of the same  
 494 gravel after the experiment. The picture to the right is taken with petrographic microscope and shows the surface  
 495 after the process. Process 2 (gravels used on ochred and greased animal skin) has smoothed the surface leaving  
 496 some hollows and valleys (in blue). (C) Shows the 3D surface of the experimental gravel before the experiment  
 497 and (D) shows the surface of the same gravel after the experiment. The picture to the right is taken with  
 498 petrographic microscope and shows the surface after the process. Process 3 (gravels polished with silts from  
 499 Landry) is the only one to produce striations. (E) Shows the 3D surface of the experimental gravel before the  
 500 experiment and (F) shows the surface of the same gravel after the experiment. The picture to the right is taken with  
 501 a petrographic microscope Leica 2055P. All treatments produced a strong downward shift on the Z scale.

502

### 503 **Ethnographic survey results**

504 Uses were first documented at a low level (e.g. “as luck charm”), and then on completion  
 505 of the sample, our coding system aggregated initial categories into a higher level (e.g. charm,

506 divination etc. as “ritual”), as described in Table 5. Some cultures had many different uses  
 507 categorized from keyword mentions; roughly a quarter (19 cultures, of which 13 were hunter-  
 508 gatherers) had no relevant uses despite the mention of the keyword in a paragraph. A small  
 509 number of uses crossed multiple categories (e.g. medicine and ritual, counting and social  
 510 coordination). The final judgement considered the immediate functions to be primary.

511 **Table 5. Coding scheme for pebble use with representative examples.**

Use	Definition	Example
<b>Ritual</b>	Use is given as charms, amulets, religious symbols, curse stones, embodiments of spirits/gods, funeral tokens; or otherwise used as a magic ritual	There is a very strong magic power in these stones, and their form is regarded as variable. For instance, if such a stone is left uncovered it may grow legs and run away; so they are worn hanging from the neck in little sacks. [Aranda]
<b>Games</b>	Used as game tokens, or in other childhood activities	Thirty-three stones are arranged in a line which may be straight, but is more often curved or crooked. The player must touch each stone and say “Too” for all 33 stones in order, at a high rate of speed. [Kpelle]
<b>Tool</b>	Used in hunting, fishing, craft, headshrinking, or as weights	Dressing a hide is generally woman's work; sometimes men do this work, using woman's tools, which include a small sack of pebbles held behind the haft of the leg bone scraper to give added force to each push of the scraper removing fat and detritus from the hide. [Innu]
<b>Weapon</b>	Stones explicitly thrown at other people in defence or offence	The sling stones were not worked but were selected from waterworn pebbles (ala) of appropriate size. [Samoan]
<b>Medicine</b>	Primary functional use given in a medical remedy	Pour over the head of the sufferer an infusion of bark from the top of the trunk of the Bugare. But before pouring the liquid, it must be frothed. This is done by throwing little stones in and mixing it with a stick. [Azande]
<b>Music</b>	Used to make musical instruments or noisemakers (including ritual functions)	A woman's dance rattle contains many small pebbles and the handle passes entirely through the gourd. [Kuna]
<b>Counting</b>	Explicit mention as a counting tool	Pebbles are occasionally employed as a mnemonic aid to counting warp threads when weaving; each pebble represents 10 threads. [Aymara]
<b>Other</b>	Various uses as ornament, social coordination, genealogical tool etc	He talks about pedigrees. Our expert ... gathers a heap of small stones and says: “This is Ancestor Bangáchon and this is Gáyon, his wife”. Meanwhile he places two small stones, side by side in front of his big toes. “They had four children”, he continues... and four stones are put at a short distance of the two first ones. [A]nd so it goes on; names and more names, stones and more stones... [Ifugao]
<b>None</b>	Paragraphs contained the words stone* or pebble* but no relevant uses	

512  
 513 In the full sample, ritual uses (as charms, divination, or other magico-religious functions)  
 514 were the most commonly described (n=44), followed by games (n=25) and music (n=18). A  
 515 range of other uses accounted for the remainder. Hunter-gatherer societies differed in the most  
 516 common use (none, n=13) but followed the trend for music (n=11), ritual (n=10) and games  
 517 (n=9) as most common (Table 6). Eating/ingestion as one hypothesized source of shine for  
 518 pebbles was not noted in the sample; some medicinal uses mentioned pebbles placed in a  
 519 shaman's mouth but then removed (Chewings, 1936). Table 1 in the supplementary materials  
 520 gives full information including the bibliographic sources, paragraph text, and main  
 521 subsistence, for each case. A bag for carrying is mentioned in four cases; polish is mentioned  
 522 in one. Separate counts are given for the 38 hunter-gatherer cultures of the full sample.

523 ‘Multiples’ indicates if pebbles were found or inferred to be in groups of four or more, with  
 524 percentages of Yes:No:Unclear (rounded to nearest integer), and it makes it clear that uses of  
 525 multiples pebbles together is largely dominant.

526 **Table 6. Uses of pebbles in 82 cultures of the Standard Cross Cultural sample.**

Use	Full sample (n=82)	Hunter- gatherers (n=38)	Multiples (%)		
			Yes	No	Unclear
<b>Ritual</b>	44	10	39	39	22
<b>Games</b>	25	9	84	12	04
<b>Music</b>	18	11	100	00	00
<b>Tool</b>	12	3	67	25	08
<b>Weapon</b>	11	4	64	18	18
<b>Medicine</b>	9	5	78	22	00
<b>Counting</b>	3	1	100	00	00
<b>Other</b>	10	5	40	30	30
<b>None</b>	19	13	NA		

527

## 528 **Discussion**

529 Polished pebbles have been found repeatedly at archaeological, including ancient, sites  
 530 (Boivin et al., 2007; Moncel et al., 2012). Few are the cases, however, in which complementary  
 531 analyses were conducted to eliminate the possibility of a natural origin of the polish or that, the  
 532 case of Landry, provide contextual information to assess their nature. A remarkable exception  
 533 are the polished pebbles found at the Jiahu site, Henan Province, China (Zhang et al., 1999). At  
 534 this site, the skeleton of a male individual with the skull missing, dated to c. 9,000 BP, is  
 535 associated with two seven-hole bone flutes and a turtle shell with polished pebbles inside. The  
 536 latter is interpreted as a musical instrument to produce a rhythmic sound.

537 The geoarchaeological study of the Landry site indicates that the spatial distribution of  
 538 archaeological remains has not been marginally affected by post-depositional disturbances  
 539 (Brenet et al., 2018). Landry is currently the only site for which unequivocal information is  
 540 available on the stratigraphic and the spatial provenance of the lustrous gravels, their spatial  
 541 relationship to the other archaeological remains, and their cultural affiliation. The lustrous  
 542 gravels are clearly associated with the other archaeological remains and dispersed within the  
 543 archaeological layer, which make their attribution to the Solutrean undisputable. They are  
 544 highly concentrated in an area interpreted as reflecting domestic activities connected to the use  
 545 of metamorphic rocks. This area has also yielded few incised dolerite blocks and pebbles  
 546 (Brenet et al., 2018). For the archaeological sites excavated earlier, only the cultural and, in few

547 cases, the stratigraphic provenance are known. Theoretically, the best available information on  
548 the gravel cultural attribution come from Fourneau du Diable (D. Peyrony, 1922) where  
549 Peyrony is formal in attributing them to both the Gravettian and the Solutrean. The 136 gravels  
550 arranged one next to the other to form a rectangle (Fig 4) were apparently found in Gravettian  
551 layers, the others in layers attributed to the Upper Solutrean. Although left a drawing of this  
552 chest piece, it is difficult at present, in absence of additional information, to assess the reality  
553 of this surprising findings. At Laugerie Haute the gravels were also apparently retrieved in  
554 Upper Solutrean layers; at Pech de la Boissière and Casserole, they were recovered in Solutrean  
555 layers. Our spatial analysis has demonstrated that the distribution of lustrous gravels at Landry  
556 is not random nor uniform. They are concentrated in an area corresponding to a portion of the  
557 zone with the highest density of the other archaeological remains. On the contrary, the non-  
558 lustrous gravels are evenly distributed on the excavated area. Unlike the lustrous gravels, all  
559 made of white quartz, they are more variable in size, morphology and color. This finding  
560 contradicts the hypothesis that the distribution of the lustrous gravels is the result of a natural  
561 process and argues in favor of humans being the main or the exclusive accumulation factor.  
562 Apparently Landry visitors selected small, round, white gravels and left or disposed them inside  
563 their main activity area. Although the lack of direct comparative samples makes it difficult to  
564 establish what criteria guided the choice of the gravels at the other archaeological sites, their  
565 comparatively low dimensional variability and roundness suggest these were certainly key  
566 selection criteria. It can be therefore reasonably inferred that humans were the major gravel  
567 accumulation factor at the other sites as well.

568         At all the analyzed sites, what makes the gravels peculiar is also their shiny appearance.  
569 Since the mode of formation of the sedimentary layers is not different at Landry between the  
570 concentrations and the areas outside them, there is no reason for thinking that the site formation  
571 processes could have affected the gravels inside and outside the concentrations in a different  
572 way and create a gloss only on the former. No evidence of chemical alteration or a similar gloss  
573 is observed on the remainder of the archaeological remains found inside the concentrations of  
574 artifacts (Brenet et al., 2014; Mesa, 2016). In addition, experimental polishing of quartz gravels  
575 from the Landry sieving rules out the possibility that the action of silt may produce the gloss  
576 observed on the gravels found in the archaeological concentrations. The hypothesis of  
577 gastroliths originating from animal carcasses can also be discarded since the lustrous gravels  
578 differ in size, morphology and surface condition from such gravels (Tryon, 2010; Wings, 2004).  
579 This supports the hypothesis that differences in the appearance of gravels found inside and

580 outside the concentrations are due to human agency. Roughness analysis has identified three  
581 significantly different types of surfaces: rough, typical of gravels collected in natural  
582 accumulations and in the Landry sieving; glossy, only found on archaeological gravels from  
583 sites excavated in the past; moderately glossy, characteristic of the Landry gravels associated  
584 with concentrations of cultural remains. Experimental tumbling of Landry gravels collected  
585 outside the archaeological concentrations has produced a shine absent in natural accumulations  
586 and similar to that of gravels found at archaeological sites excavated in the past and some  
587 lustrous gravels from Landry.

588 In summary, the roughness analysis of natural, experimental and archaeological gravels,  
589 supports the hypothesis that after being selected by their size and shape, they have been  
590 subjected to a human action that has strongly polished them. The wear could have been  
591 produced deliberately or be the unintended consequence of their use or transport. These three  
592 possibilities are not mutually exclusive. The differences in roughness observed between the  
593 lustrous gravels from Landry and other archaeological sites may be due to: the fact that only  
594 the most lustrous gravels were collected in early excavations; the fact that at Landry non- or  
595 low-gloss gravels were naturally present in archaeological concentrations, which created a  
596 sample that included both lustered and non-lustered gravels; the fact that the activity that  
597 lustered the gravels at Landry was not as extensive as at other sites; or the fact that due to their  
598 mineralogical composition, the Landry gravels could not reach the degree of lustering observed  
599 at other sites, where the gravels are composed of other rocks, while being subjected to the same  
600 modifications. Selective collection of gravels from older excavations is possible, but two of the  
601 collections examined were from recent excavations in which the sediment was systematically  
602 sieved with water. The degree of luster of the gravels from these sites is not substantially  
603 different from that observed in the ancient collections, which contradicts the hypothesis of  
604 selective gathering. The possibility that the rock of which they are composed may determine  
605 the lower luster of the Landry gravels seems partly contradicted by the fact that the  
606 experimentally tumbled gravels, composed of quartz, attained a degree of luster similar to that  
607 observed on the lustered gravels from other archaeological sites. Although it is difficult to rule  
608 out the possibility that some of the discarded factors may be a contributing factor to the  
609 differences in luster between Landry and the other sites, the most likely hypothesis appears to  
610 be that the luster on the Landry gravels is either the result of the same action to which the  
611 gravels from the other sites were subjected, but for a shorter period of time, or the result of a  
612 slightly different action. The fact that experimental tumbling of gravels produced wear that was

613 comparable to that of archaeological gravels suggests that prolonged contact with a soft material  
614 such as hide was the cause of the luster. The experimental results also indicate that variations  
615 in the treatment of soft materials in contact with the gravels may be responsible for the  
616 differences in roughness observed between sites. The long duration of the experiment necessary  
617 to produce the luster seems to contradict the hypothesis that sporadic contact with soft material  
618 or human skin, for example when handling the gravels, can produce such a developed luster.  
619 These results do not allow us to identify with certainty the action to which the gravels were  
620 subjected to acquire the luster and it is possible that this action tells us little about the function  
621 for which the gravels were intended. The luster may, for example, be the result of repeated  
622 transport of the gravel from one site to another in leather containers, but this does not tell us the  
623 function for which the gravel was intended once the Solutreans arrived on site, as this function  
624 may have produced little or no luster. In reverse, the luster could be the direct consequence of  
625 the function of the gravel. In this case it could have been produced deliberately by tumbling the  
626 gravel into a leather bag to then exploit its lustrous appearance, for example in an adornment  
627 device as suggested by Peyrony, or unintentionally, for example by tumbling the gravel into a  
628 leather container to produce a rhythmic sound. These last two cases do not eliminate the  
629 possibility that the transport of gravels from one site to another may also have contributed to  
630 the production of the luster. The likely multi-causal nature of the luster and its variation between  
631 sites, as well as the potential equifinality of different process, which could produce the same  
632 luster, reduces the likelihood that further experimentation will be able to identify precisely the  
633 action that produced the luster, let alone the function of the gravels. One cannot rule out,  
634 however, the possibility that future experiments will identify more precisely the material to  
635 which the archaeological gravels have been in contact during their social life.

636 It is worthwhile for this reason to turn to the ethnographic and archaeological record. The  
637 former may inform us on the uses of gravels in different traditional human cultures. The latter  
638 may identify cases in which contextual information would allow us to understand the function  
639 that gravels had in past populations. Both records open the possibility of analyzing in the future,  
640 with the same methodologies applied in our study, ethnographic and archaeological gravels and  
641 compare the results of these analyses with ours.

642 Our ethnographic survey shows that the most common functions for small pebbles are  
643 magico-religious ritual uses, and as game pieces. Worldwide, pebbles are used as talismans,  
644 amulets, and charms (Bunzel, 1932; Fortune, 1934; Róheim, 1945) (see SM Table 1 for  
645 examples), appear in divination or sorcery kits (Karsten, 1935; Little, 1951), and often embody

646 spirits and ancestors (Lehtisalo & Schütze, 1924; Olson et al., 2001; Preuss & Furst, 1996).  
647 When used in games, pebbles are most often in multiples and handled frequently, including by  
648 children (Anderson, 1983; Junod, 1927; Opler, 1966; Taylor, 1962). The use of gravels in  
649 musical instruments mimics experimental tumbling and can obviously produce the same  
650 effects: in our survey we noted drum/rattle containers made from dried fruit (Larken, 1926),  
651 cocoons (Kaufmann & Neuse, 1910), animal shells (Birket-Smith & De Laguna, 1938), birch  
652 bark (Skinner, 1911), as well as hides and gourds (Gayton, 1948). Further uses include tools or  
653 weapons, elements in medicinal treatments, ornaments, and in counting (see SM Table 6 for  
654 examples). All these functions involve the transport of gravels, which can produce their gradual  
655 polishing. A use for games or shamanism/divination also implies a more or less prolonged  
656 handling, which can contribute to their polishing—possibly, in the case of games, from  
657 hide/leather surfaces on which pieces are scattered. Some of these functions (games, music,  
658 medicine, and counting) are more consistent with the use of many gravels than others (weapons,  
659 tools and ‘other’ uses are often single items), but ritual uses can involve single or multiple  
660 stones with equal likelihood (Table 6).

661 While many of the ethnographically attested functions imply a choice of gravels on the basis  
662 of size, shape, weight and raw material criteria, exact remarks on size were uncommon in the  
663 sources. Anthropologists occasionally noted qualitative features such as color or shape e.g.  
664 “marble-like stones” (Westermann, 1912), “preferably those of a black color” (Teit, 1956).  
665 However, these remarks were too infrequent (only 12/152 cases) to support generalizations  
666 regarding specific functions for the archaeological gravels studied in our work. It is however  
667 possible that the smaller and rounder gravels from the Landry and Casserole sites had another  
668 function than the larger gravels of the Fourneau du Diable, Laugerie Haute and Pech de la  
669 Boissière. However, this is only partially consistent with the result of the textural analysis,  
670 which rather highlights a difference between Landry and the other sites. By ethnographic  
671 analogy, ritual and gaming uses are most likely, with the uniformity of the gravels indicating a  
672 deliberate aesthetic preference. Although our cross-cultural survey indicates the use of gravels  
673 in counting systems is relatively uncommon (in our sample, 3 of 128 uses or 2.5%), their use  
674 for other functions (games, ornaments, divination etc.) certainly implies their approximate and,  
675 especially in the case of games, possibly precise quantification. In both cases, the creation of a  
676 cultural innovation involving the use of small, visually homologous objects may have played  
677 an adjunct role in the complexification of modalities for precise quantification (verbal, finger

678 counting, notational) or may have been a reflection of contemporary or prior advances in these  
679 fields (Bender & Beller, 2018; d’Errico et al., 2017; Núñez, 2021).

## 680 **Conclusion**

681 The results of our study indicate that there are means to distinguish objects modified by  
682 natural processes from artifacts minimally modified by humans. Use-wear analysis has been  
683 widely applied to prehistoric artefacts to identify their function. However, this approach has  
684 been implemented on artefacts recognized as the outcome of human agency. In our case,  
685 instead, we have faced the challenge of identifying such agency exclusively from surface  
686 modification. The chosen means to pursue this endeavor involved evaluation of contextual data,  
687 creation of natural and experimental frames of reference, and characterization of natural,  
688 experimental and archaeological material using adapted analytical tools. These analyses leave  
689 no doubt: the lustrous gravels discovered in several Gravettian and Solutrean sites in  
690 southwestern France were lost or abandoned in these sites after having been selected on the  
691 basis of size and shape criteria and having been involved in one or more specific activities that  
692 produced their lustrous appearance. These gravels were not discovered in older Gravettian  
693 layers during the numerous excavations conducted in the region despite the fact that many of  
694 these excavations were conducted in recent times, with modern excavation techniques and by  
695 archaeologists aware of the possibility of discovering glossy gravels in Upper Palaeolithic  
696 archaeological layers. This leads us to conclude that the activity in which the gravels were  
697 involved, which is impossible to identify precisely but could involve a long-time use or curation  
698 in a leather bag, reflect a cultural innovation that developed during the Gravettian period and  
699 continued into the Solutrean period at the least.

## 700 **Author’s contributions**

701 Lila Geis: conceptualization, methodology, formal analysis, investigation, visualization, writing-  
702 original draft. Francesco d’Errico: conceptualization, methodology, formal analysis, investigation,  
703 writing-original draft, supervision, funding acquisition. Fiona M. Jordan: methodology, formal analysis,  
704 investigation, writing-original draft. Michel Brenet: excavation, funding acquisition. Alain Queffelec:  
705 conceptualization, methodology, formal analysis, investigation, visualization, writing-original draft. All  
706 authors have read the manuscript and the submitted manuscript and contributed comments.

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## 718 **Supplementary materials**

719 R script and data to produce figures 7-11, 15 and 17, and supplementary tables 1 and 2 are available  
720 online at the OSF repository <https://osf.io/9wpm7/>.

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