

1 Analysis and reproduction of the techniques of perforation 2 of quartz and amethyst beads from the Ceramic period in 3 the Antilles

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10 Abstract

Personal ornaments are a very specific kind of material production in human societies and are particularly valuable artifacts for the archaeologist seeking to understand past societies. In the Caribbean, Early Ceramic Age sites have yielded a highly diverse production both in terms of raw materials and typology. In recent years they have been the subject of renewed interest, mainly based on the diversity and provenance of raw materials, and on typological similarity, used as proxies for exchange networks, social interactions and the evolution of these phenomena through the Ceramic Age. Meanwhile, the *chaîne opératoire* for lithic beads and pendants has not been investigated in detail, including the process of creating narrow perforations in quartz beads several centimeters long. This hard material (7 on the Mohs scale), represented as rock crystal and amethyst in the collections, is indeed very difficult to perforate without the use of metal drills or harder minerals used as drill-bits or abrasives such as diamond or emery. In this work we demonstrate that it is possible to produce these perforations with cactus thorns and crushed quartz as abrasive powder. We also show that the wear created by our experimental work is fully comparable to the stigmata visible on the archaeological artifacts. This process, using only materials available to Ceramic Age people, also accounts for the absence of both adequate drills and production wastes of quartz beads in the archaeological record. The investment of Ceramic Age inhabitants of the Lesser Antilles in the production of the many beads made of very hard material recovered in archaeological excavations is once again highlighted. The perforation process, not investigated in detail so far in this archaeological context, has to be taken into account in the value of these highly symbolic artifacts, in addition to the exotic provenance of the raw material.

11 INTRODUCTION

12 Personal ornaments are found in many human cultures around the world and is considered as
13 one of the oldest forms of symbolic expression, appearing in the Middle Paleolithic (Bar-Yosef Mayer et
14 al., 2020; Peresani et al., 2013; Radovčić et al., 2015; Vanhaeren et al., 2006) and diversifying in the
15 Upper Paleolithic in the form of durable, archaeologically identifiable remains (Kuhn, 2014). Such
16 ornaments are non-utilitarian artifacts, often attached to a symbolic function, taking its value mainly in
17 what it embodies: social distinction according to gender or a particular status, embellishment of the
18 individual, social links, etc. (e.g. Heizer and Fogelson, 1978; Munan, 1995; Nguru and Maina, 2020;
19 Nobayashi, 2020; Wiessner, 1982). It is also the marker of common concepts and symbolic thought
20 among an ancient society (Bérard, 2013; Carter and Helmer, 2015; d’Errico et al., 2003; Kenoyer, 1997,
21 1991; Vanhaeren and d’Errico, 2006). It can also be valued because of the often associated complex
22 craftsmanship necessary to its production, which is acquired only after many years of practice (Roux et
23 al., 1995).

24 First Ceramic communities are known in the Lesser Antilles for about 2500 years thanks to
25 numerous radiocarbon dates (Fitzpatrick, 2006; Napolitano et al., 2019) and they grew into complex
26 societies until the colonization at the end of the 15th century. During this period, a population of
27 pioneering horticulturists and ceramists, known as being part of Saladoid tradition, occupied the entire
28 Lesser Antilles from -400 cal. B.C. to about 500/750 cal A.D. depending on the regions of the
29 archipelago (Bérard, 2019). Their economy was based on shellfish harvesting, fishing, hunting, and
30 slash-and-burn cultivation of various plants imported from the mainland (Bérard and Giraud, 2006;
31 Giovas, 2019; Pagan-Jimenez, 2011; Serrand and Bonnissent, 2018). In addition to a complex and
32 diversified ceramic production (zoomorphic effigy vessels, incense burners, dishes, pots, bowls and
33 bell-shaped vessels), displaying very elaborate decorations (painted, incised), most of the tools are
34 produced on shell, and from diverse rocks, local or imported from other islands (Bérard, 2004;
35 Knippenberg, 2007). At the very heart of their material culture, personal ornaments have a special
36 place: made of shells (Falci, 2020; Havisser, 1990; Serrand, 2007, 2002) or gemstones, they are very
37 diverse. Raw materials acquisition from far away and variety of shapes demonstrate the important
38 investment in this craft, and the expertise of the craftsmen (Bérard, 2013; Cody, 1993; Falci et al., 2020;
39 Havisser, 1991; Hofman et al., 2008; Knippenberg, 2007; Murphy et al., 2000; Narganes Storde, 1999,
40 1995; Queffelec et al., 2020, 2018). Indeed, if many of these ornaments are designed in soft minerals
41 or rocks, the numerous and long quartz beads¹, much harder, raise an undeniable interest around the

1 ¹ As amethyst is a gem composed of quartz whose color comes from its Fe⁴⁺ ion content (Fritsch and Rossman, 1988), we will use the
2 term quartz in the remainder of this work, since it is the properties of the mineral that are of interest to us here and not its color, while
3 the term amethyst will be retained when describing archaeological objects which do indeed have a clearly visible purple or mauve
4 coloration

42 question of perforations since the first observations of these material productions (Harrington, 1924).
43 It is a mineral with a hardness of 7 on the Mohs scale, and can therefore theoretically only be
44 perforated by materials at least as hard as it. Metal drills, particularly hard rocks or the use of diamond
45 are described in numerous works dealing with lithic adornment as indispensable tools for the narrow
46 perforation of hard objects (Gwinnett and Gorelick, 1998, 1987; Kenoyer, 1997, 1986; Kenoyer and
47 Vidale, 1992; Ludvik et al., 2015). If such studies exist for some archaeological contexts, the perforation
48 techniques used for quartz in the Antilles during the Ceramic period are particularly difficult to
49 imagine. Indeed, no production of metal for utilitarian purposes is known for this period, metal being
50 introduced in the archipelago only with the arrival of the inhabitants from the Greater Antilles around
51 750 cal A.D., in the form of an alloy of copper, silver and gold called guanin, which is used exclusively
52 for ornamentation (Siegel and Severin, 1993). Descriptions of perforations and associated tools remain
53 very limited and poorly documented in the Caribbean context (de Mille et al., 2008; Falci et al., 2020).
54 A fragment of a drill of less than a centimeter associated with a broken amethyst bead was found in
55 Pearls (Grenada) and is very briefly described (Cody, 1991). The works on two Puerto Rican sites
56 mention, without description, drills in hyaline quartz and flint (Narganes Storde, 1999, 1995), while the
57 flint drills found at Gare Maritime (Guadeloupe) are too wide compared to the narrow perforations
58 observed on the hard rock beads found in Antillean sites (Fouéré, 2006). The only drills of the Ceramic
59 period that can correspond to the restricted dimensions of the perforations are found in Mexico,
60 outside the Saladoid context (Hirth et al., 2009), and do not appear to have been able to produce
61 perforations several centimeters long. Finally, several historical sources indicate the use of plants (leaf
62 stem or palm wood) and fine sand to perforate hyaline quartz beads, with a simple hand drill, in
63 Central American communities in the early 20th century (Koch-Grünberg, 1910 cited by Cody 1990;
64 Wallace, 1889). A. R. Wallace, returning from a trip to South America, resumed by V. Roth (1924), then
65 W. Roth (1944) and J. Crock and R. Bartone (1998) describes that it takes two to three human
66 generations to perforate a cylindrical quartz bead. This somewhat incredible investment is based on
67 the narrative saying that the perforation is made with large plant stems, fine sand (of unspecified
68 nature) and a little water. In the ethnographic cases, the lubrication of the perforation is attested but
69 the drills are made of harder materials than the one to be perforated or, in the cases where this
70 difference in hardness is weak, coupled with a harder abrasive (Gurova, Bonsall, et al., 2017; Gwinnett
71 and Gorelick, 1998; Kenoyer, 1991, 1986; Kenoyer and Vidale, 1992; Ludvik et al., 2015). Observations
72 on archaeological Saladoid objects are limited to the mention of unfinished quartz beads with cones at
73 the bottom of the perforation, without photography, which would indicate the use of a hollow
74 (tubular) drill bit without specifying its nature (Cody, 1991; Crock and Bartone, 1998). Observations of
75 stigmata on the inner surface of the perforations would also confirm the use of an abrasive (Falci et al.,

76 2020).

77 In order to understand the techniques used and to measure the investment in time and
78 resources devoted to this particular production by the Amerindian groups of this period, this work will
79 focus on the *chaîne opératoire* and, more particularly, on the question of quartz perforation. For this, a
80 study of beads from several Caribbean archaeological sites will be conducted, and these results will be
81 compared with those from an experiment specifically focused on perforation techniques.

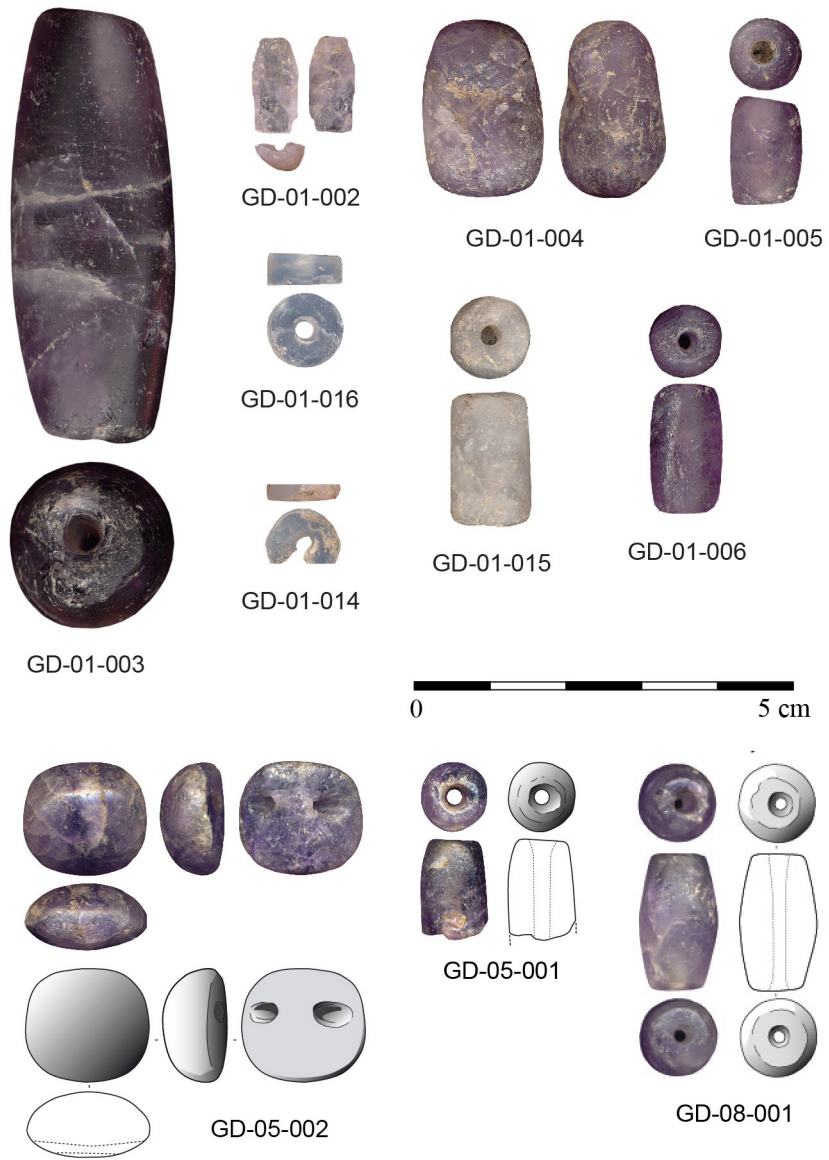
82 **MATERIAL & METHODS**

83 ***Material***

84 The regional inventory of lapidary ornaments from the Ceramic period recently completed
85 (Queffelec et al., 2021), and the systematic study of these objects found in the archaeological sites of
86 Guadeloupe, Martinique and Saint-Martin (Queffelec et al., 2020, 2018) has allowed the identification
87 of numerous beads made of quartz or amethyst. It is this last corpus that could be studied in this work.
88 A total of 32 amethyst beads and 27 quartz beads, found on the three islands, are available for study,
89 but none were found with an unfinished perforation (Table 1, Figures 1, 2, 3 et 4). Also of note is the
90 scarcity of elements from the *chaîne opératoire*, represented by only 6 small amethyst flakes and 5
91 rock crystal flakes and crystals.

Gem material	Type	State	Guadeloupe				St. Martin	Martinique
			Gare Maritime	Allée Dumanoir	Morel	Anse Ste Marguerite	Hope Estate	Vivé
Amethyst	Barrel-shaped	Blank						
		Finished	2		6			1
		Broken		1	2		1	
	Cylindrical	Blank						
		Finished	1		1		2	
		Broken	1				1	
	Discoid	Blank						
		Finished					1	
		Broken						
	Bitronconical	Blank						
Finished				3	1		4	
Broken								
Spherical	Blank							
	Finished			1			1	
	Broken							
Button	Blank							
	Finished		1					
	Broken							
Undetermined	Blank	1						
	Finished							
	Broken					1		
Total			5	2	13	1	6	6
Rock crystal	Barrel-shaped	Blank						
		Finished						
		Broken						
	Cylindrical	Blank						
		Finished	1		11		3	1
		Broken			2		2	
	Discoid	Blank						
		Finished	1				2	
		Broken	1				1	
	Bitronconical	Blank						
Finished								
Broken						1		
Spherical	Blank							
	Finished							
	Broken							
Total			3	0	13	0	9	1

Table 1: Distribution of the types of amethyst and rock crystal beads in the different sites studied.



93 Figure 1: Photographs and drawings of beads from Gare Maritime (GD-01), Allée Dumanoir (GD-05), and Anse Ste Marguerite (GD-08).

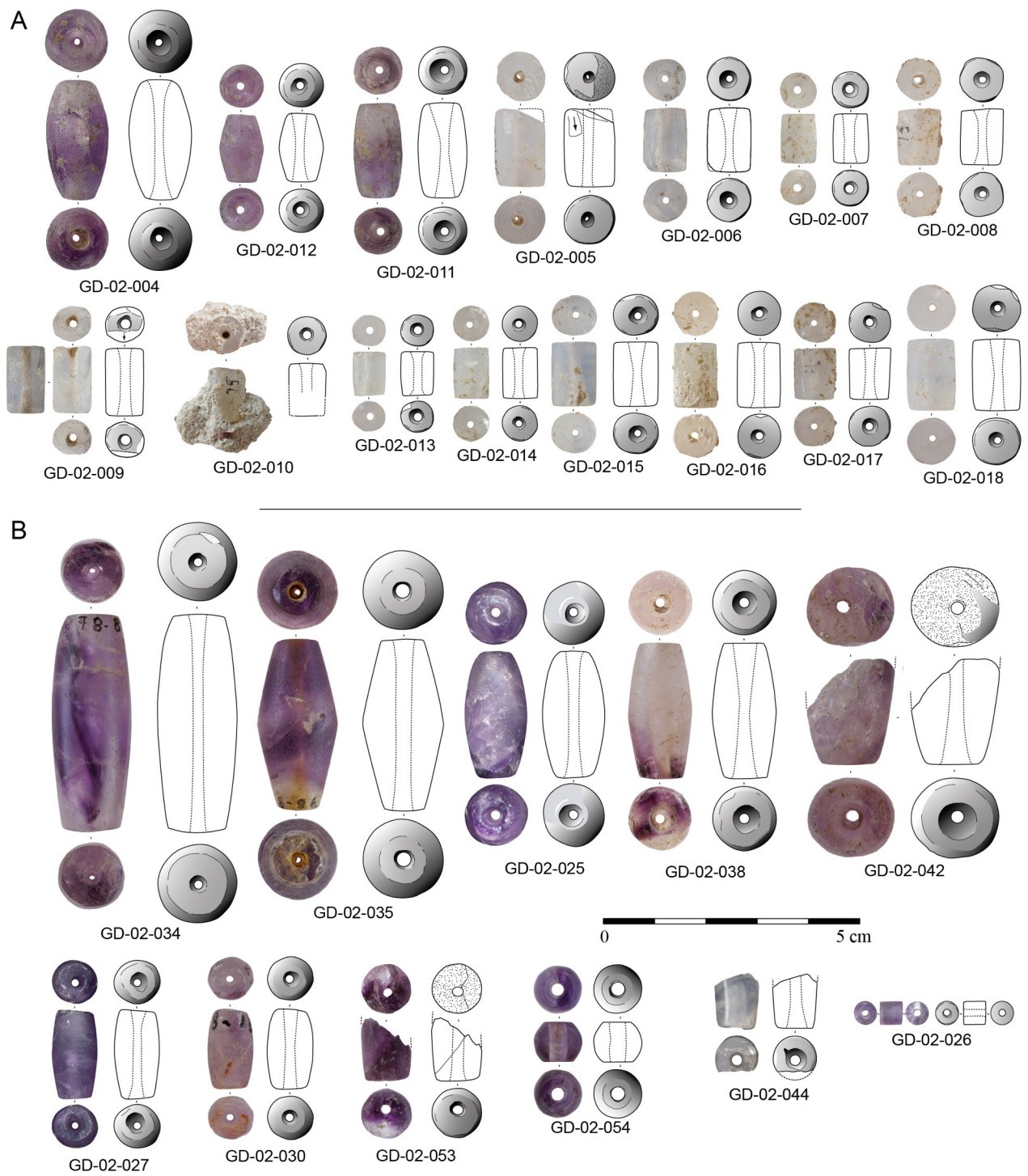
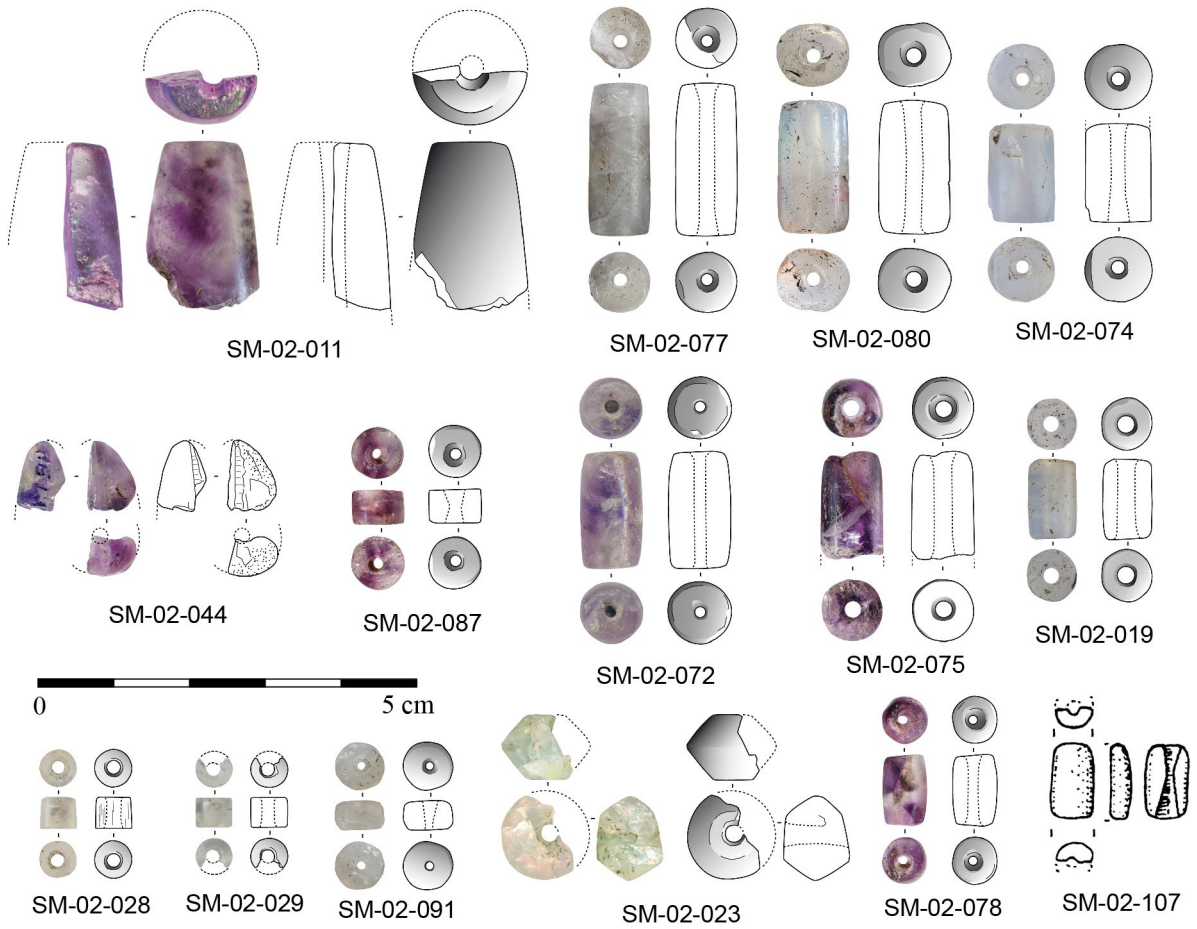
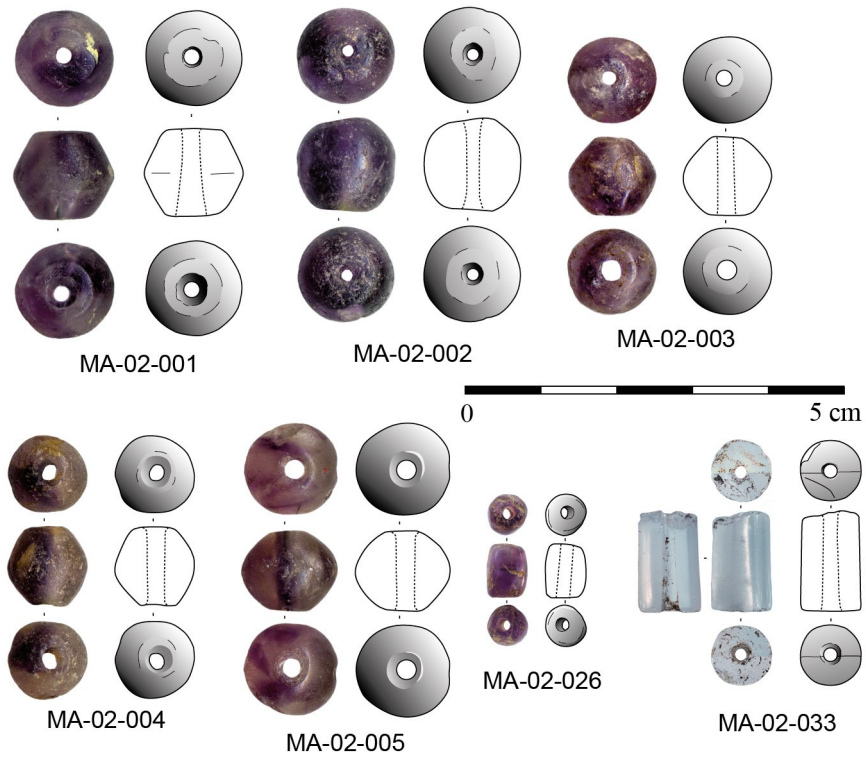


Figure 2: Photographs and drawings of beads from the collar (A) and the other parts of Morel (GD-02) site (B).



95

Figure 3: Photographs and drawings of the beads and products of the Hope Estate chaîne opératoire (SM-02).



96

Figure 4: Photographs and drawings of the pearls of Vivé (MA-02).

97 **Method**

98 Perforations were first observed with the hand lens, and for most of them, an elastomer
99 imprint was made for more advanced observations. For this purpose, the beads are first cleaned with a
100 fine bamboo rod and wet cotton, and three successive imprints are made to clean the perforation. The
101 last imprint is observed and photographed at low magnification (Leica Z16APO Macroscope and Canon
102 EOS 350D digital camera), then under a scanning electron microscope (SEM) after being coated with
103 carbon to ensure electron conductivity. These observations were made with a JEOL IT 500 HR equipped
104 with a Field Electron Gun. SEM observations allow to observe the fine structures on the surface of the
105 elastomer which are the negatives of the surface of the perforation. It is also the only method that
106 allows a comparison with the literature (Kenoyer, 2017; Ludvik et al., 2015; Raad and Makarewicz,
107 2019).

108 X-ray microtomography is a technique aiming at 3D-scanning an object in a totally non-invasive
109 way, and providing access to both internal and external features. It also allows to overcome the
110 constraints of 2D images while avoiding the taking of elastomer impressions (sometimes impossible if
111 the bead is too narrow or broken). In this study four amethyst beads (GD-02-038, GD-02-026, GD-02-
112 025 and GD-08-001) were 3D-scanned using a GE V|tome|x s microtomograph, at a cubic resolution of
113 7 μm per voxel.

114 Numerous perforation techniques exist in the ethnographic record. They fall into two
115 categories: manual perforation systems and mechanical systems (Leroi-Gourhan, 1971). For the
116 hardest materials, mechanical systems are necessary to optimize the applied force and rotational
117 movements. The most effective system for our experiments is the archer drill (Figure 5). This system
118 allows a greater vertical force to be exerted, which is essential when the hardness of the rocks to be
119 drilled exceeds 5 or 6 on the Mohs scale (Kenoyer, comm. pers.). However, the force applied to the
120 handle must not be too high or the drill will break. The archer is made of a piece of green wood (for
121 flexibility) about 85 cm long and slightly curved for a better grip. The diameter is about 1.5 cm along
122 the whole length. A leather cord attached to both ends of the archer induces the rotation of the shaft
123 or rod. This rod is held in a vertical position by one of the hands via any object that allows its rotation.

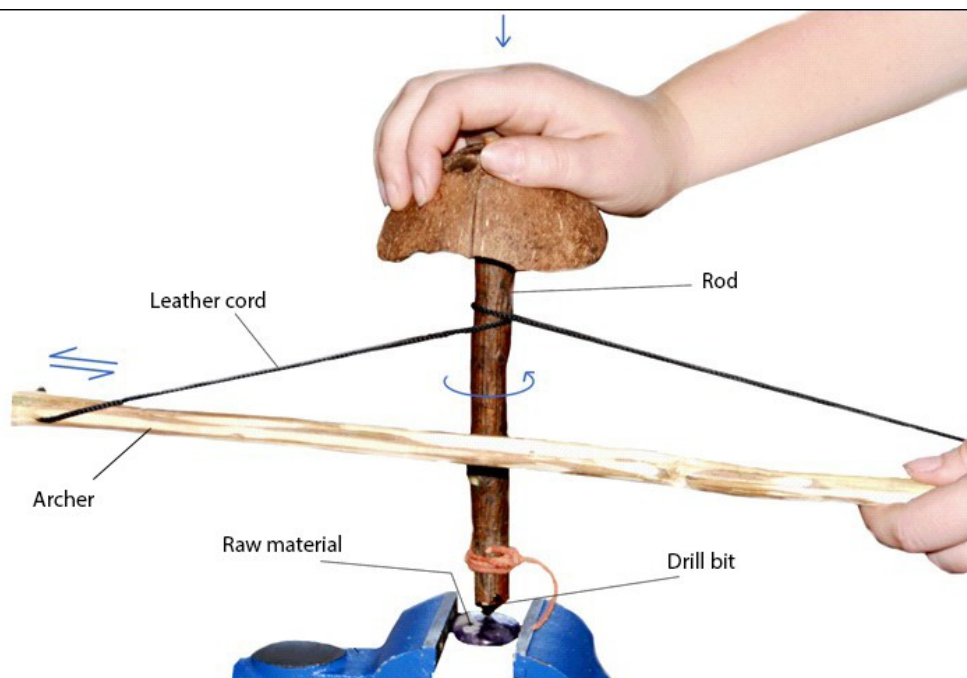


Figure 5. Experimental bow drill device used in this work.

124

125 The drills are inserted and attached to the end of the handle with shellac (insect resin) and held
 126 firmly in place with a leather lace tie. The drills must be both narrow and strong enough not to wear
 127 out too much under the action of the abrasive.

128 Most ethnographic examples indicate that perforations of hard materials is achieved by using
 129 an abrasive, which can be combined with water or oil as a lubricant, considerably increasing the
 130 perforation performance (Gorelick and Gwinnett, 1979, p. 197). From a mechanical point of view, the
 131 volume loss of the future bead, per unit length, during a perforation, depends on three main physical
 132 factors: toughness (ability of a material to resist fracturing), hardness (resistance of a sample surface to
 133 penetration) and abrasion resistance (Sela and Roux, 2000). The drill bits and abrasives were selected
 134 according to two criteria: their hardness, which must be at least equal to that of amethyst, and their
 135 compatibility with the archaeological record. One obsidian and one flint drill were pressure shaped to
 136 maintain straightness along a ridge. These proved too large to make long perforations, so 4 additional
 137 pressure-worked flint flake drills were made. These flake drills have a triangular cross-section, to allow
 138 for more efficient drilling (Kenoyer, pers. comm.). For the organic drills, we used bone, wood and
 139 vegetable thorns. The bone is a fragment of horse rib already shaped into a point and measuring less
 140 than 2 mm in diameter. Two types of wood were tested: Lignum vitae, or guayacan (found in the
 141 Antilles), which is known for its extreme hardness and resistance (Friedrich et al., 2021), and oak wood,
 142 which is less hard but has well-known physical properties. The thorns of selected plants are the tips of
 143 agave leaves and thorns of *Melocactus intortus*, also called « cactus tête à l'anglais », a species of
 144 cactus endemic to the Caribbean. Its thorns have a density, and thus a hardness, much higher than that
 145 of wood (2280 kg/m^3 for thorns of *Melocactus intortus* (S.I. 2) versus 1142 kg/m^3 for fresh oak for
 146 example (Shmulsky and Jones, 2019).

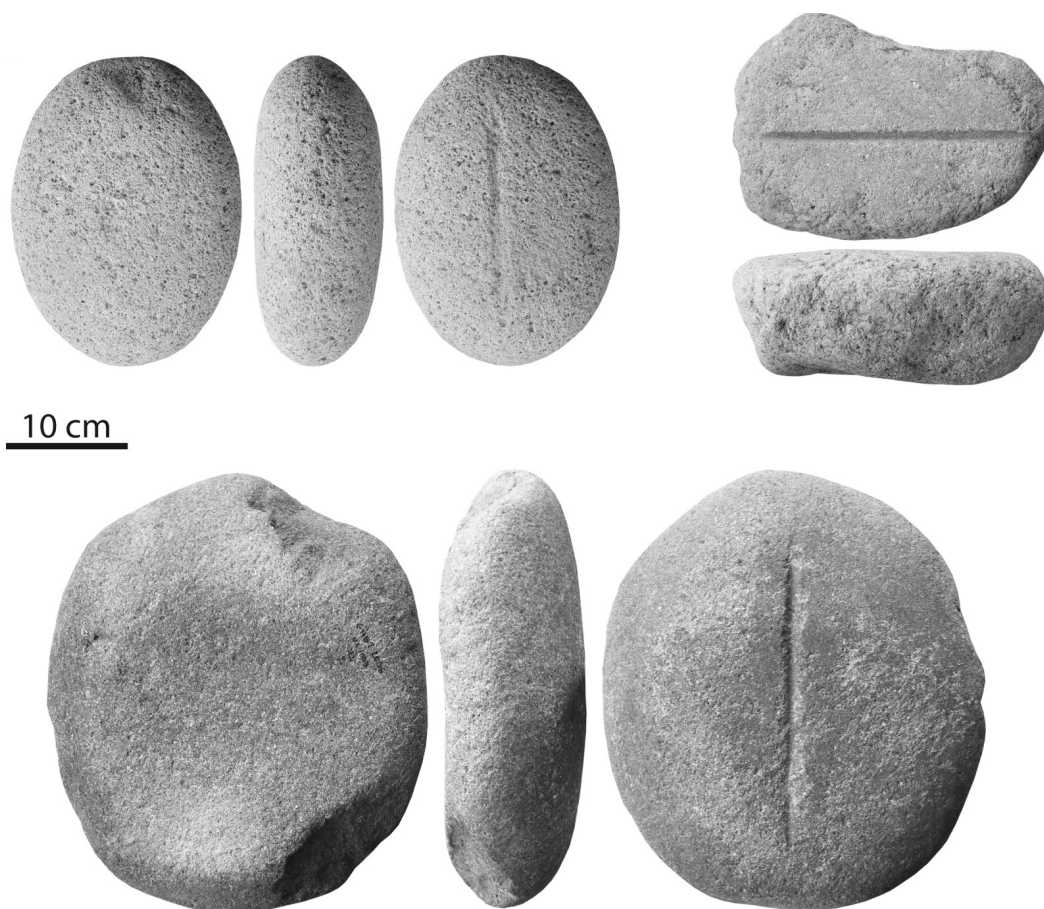
147 Preliminary tests have been made with different abrasives: fine amethyst powder ground using
148 a ball mill (Fritsch brand Pulverisette 23, with a bowl and ball made of zirconium oxide), fine almandine
149 garnet powder (up to 7.5 on the Mohs scale) made by the same process, and industrial silicon carbide
150 (hardness of 9-9.5) used only for tests with wood drill. The final and complete perforation was done
151 using hammered and sieved amethyst to get as close as possible to the archaeological context. To
152 ensure lubrication, drops of water and small amounts of abrasive are deposited at regular intervals
153 (every minute) on the depression. It was necessary to often push back the sand towards the active
154 part. Movements called push and up (applied by making vertical gestures with the handle of the drill),
155 necessary for the perforation, allow the abrasive to stay at the bottom of the depression, avoiding the
156 digging on the edges and thus the enlargement of the cavity in the active area (pushing marks). The
157 surface of the polished amethyst pebbles bought for experiments was previously frosted by abrading it
158 on a diamond wheel, in order to obtain a surface closer to those observed on the preforms of the
159 archaeological record and to guarantee a better grip of the drill on the surface at the beginning of the
160 process.

161 RESULTS

162 *Chaînes opératoires*

163 Rock crystal and amethyst are two gems ubiquitously employed by Saladoid people (Cody,
164 1993; Falci et al., 2020; Queffelec et al., 2020, 2018; Watters, 1997). Unfortunately, this material,
165 although widely distributed in the region, does not allow us to trace its origin, despite some
166 unfortunately unfounded hypotheses (Queffelec et al., 2018).

167 The blanks seem to be processed by flake shaping and then pecking and polishing (Falci et al.,
168 2020), as observed in other parts of the world (Falci, 2015; Kenoyer, 1997; Sela and Roux, 2000). They
169 are then perforated with different profiles: some beads have tapered perforations while others have
170 particularly straight and narrow perforations. Except for some discoid beads, the perforations are
171 made from both ends. Once the perforation is complete, the surface of the bead is finely polished,
172 probably on "grooved polishers", such as those found at the Gare Maritime site in Guadeloupe (Figure
173 6). Their use for the manufacture of shell beads, which are very common at many sites (Serrand, 2002),
174 is also likely. The reuse of broken objects, when the location of the break allows it, is quite recurrent.
175 Some broken beads are roughly repolished at the break.



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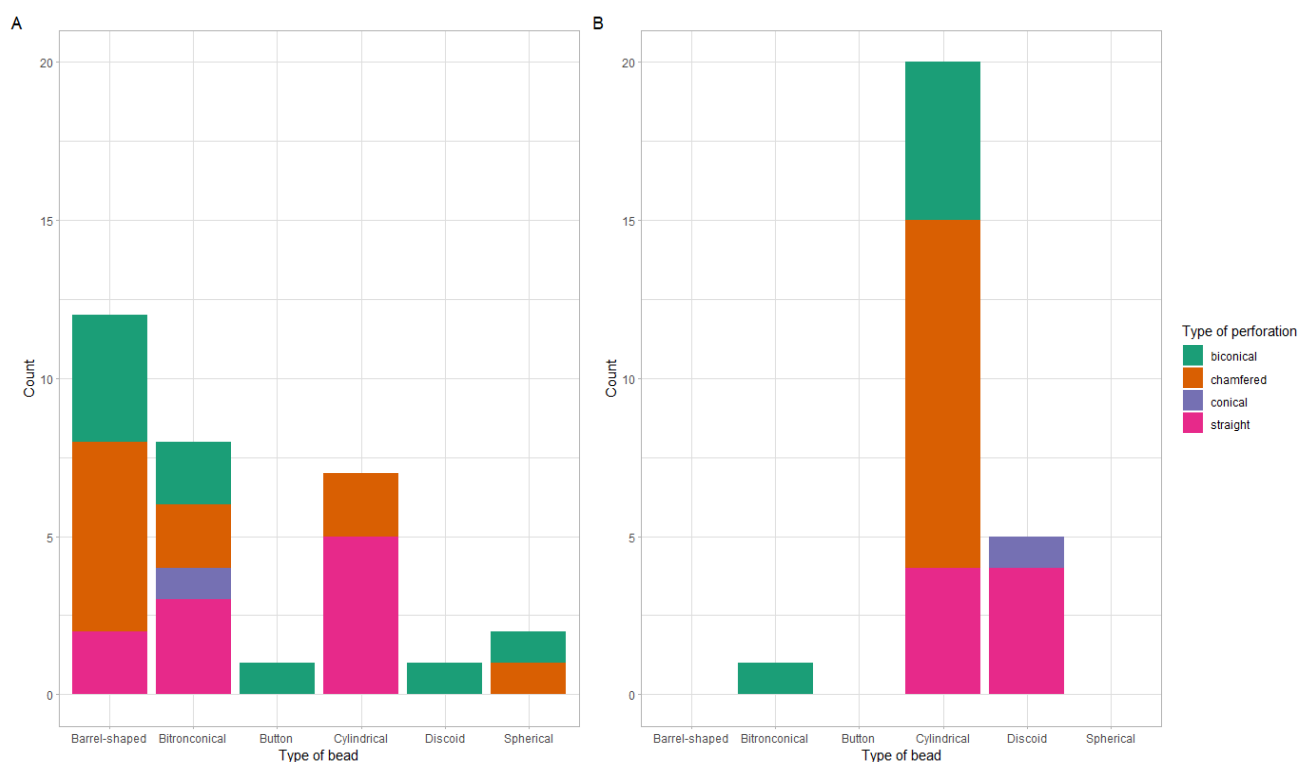
Figure 6: Grooved polishers recovered during excavations at the Gare Maritime site (modified after Fouéré, 2006).

177 Observations and experimental results

178 *Types of perforations in the archaeological record*

179 No bead in the process of being perforated has been identified in our studies. Four types of
180 perforations are observed in the assemblages: rectilinear, chamfered, biconical and conical
181 perforations. With the exception of the last type, they are made by perforating from both ends. The
182 blanks in other materials than quartz do not allow us to define a clear order of perforation: some
183 present a start of perforation on one end only, while others are perforated from both sides ~~at the same~~
184 ~~time~~. The surfaces to be perforated are prepared either by percussion, as shown by centripetal
185 microremovals on carnelian blanks, or by pecking as observed on diorite blanks.

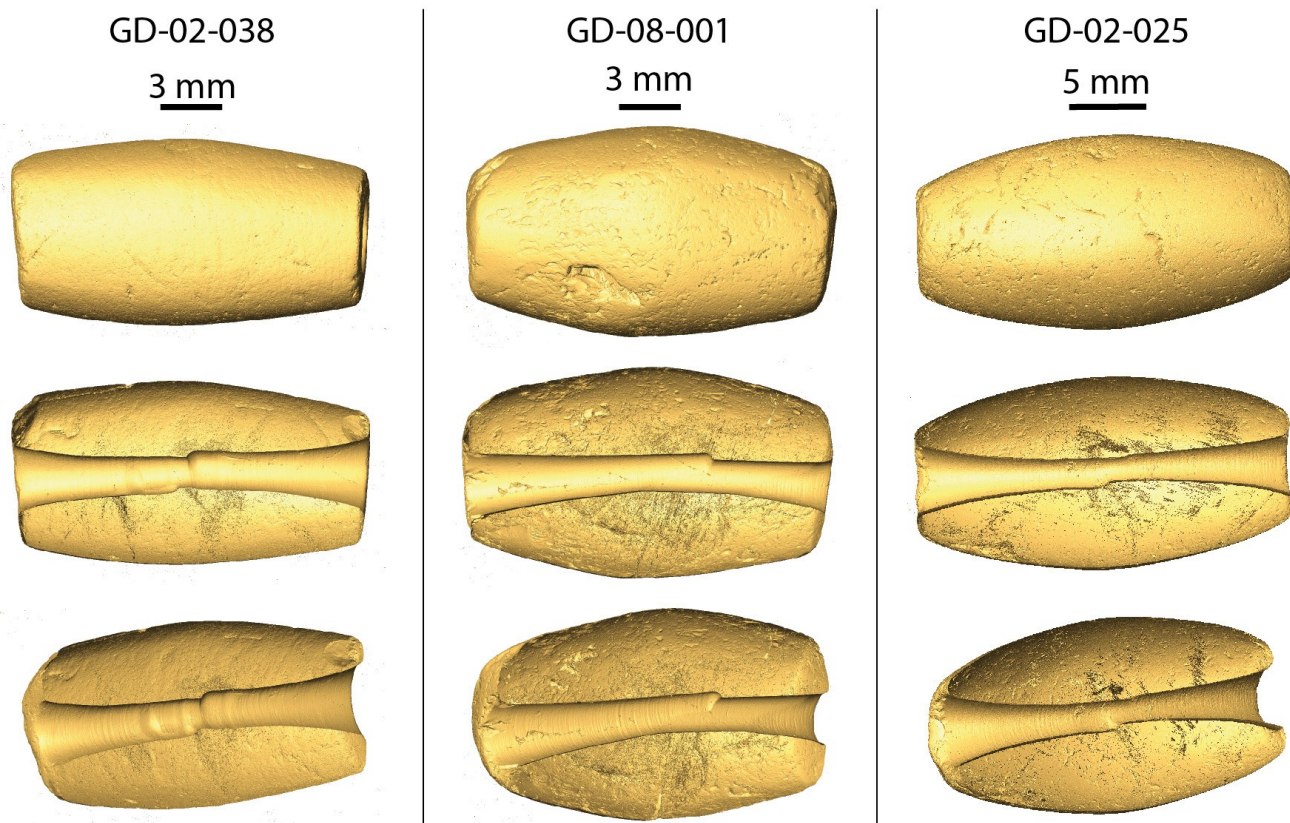
186 Perforations are often asymmetrical, sometimes with different perforation axes. The type of
187 perforation does not appear to be related to the shape of the bead (Figure 7 and Appendix 1). The rock
188 crystal beads from the Morel site greatly influence the results because they make up a significant
189 portion of the sample. Although homogeneous in their typology and found within the same burial
190 (Durand and Petitjean Roget, 1991), their perforations differ: one is rectilinear, 8 are chamfered and 3
191 are biconical.



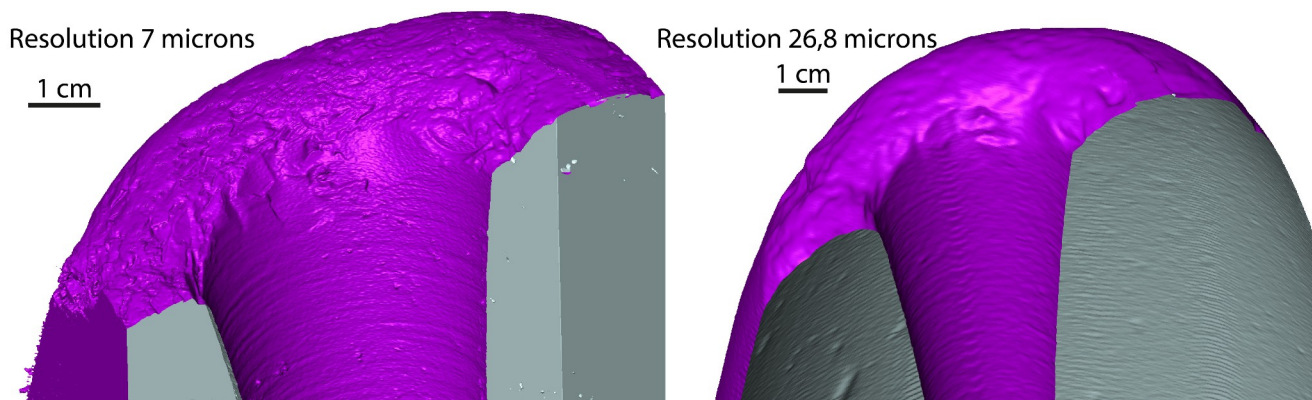
192 Figure 7 : Types of perforation according to the type of amethyst (A) and rock crystal (B) beads.

193 X-ray microtomography images of the selected amethyst beads from Morel and Anse à la
194 Gourde archaeological sites (GD-02-026, GD-02-038, GD-02-025 and GD-08-001) demonstrate how
195 efficient and useful is this method to highlight the morphology of the perforations. They are all

197 biconical and two of them join in the center of the bead with a slight offset (Figure 8). The perforations
 198 are narrow and not very tapered. Striations are clearly visible even with these full bead acquisitions
 199 when one zoom into the figure, these beads not being the biggest ones. Long acquisitions centered on
 200 the perforation are required to obtain 3D models with sufficient resolution to observe them on big
 201 beads like GD-01-003 (Figure 9), since the resolution automatically drops when one wants to have scan
 202 a bigger volume. It is also possible to see on the surface of the beads GD-08-001 and GD-02-025 the
 203 pecking marks under the coarse polish.

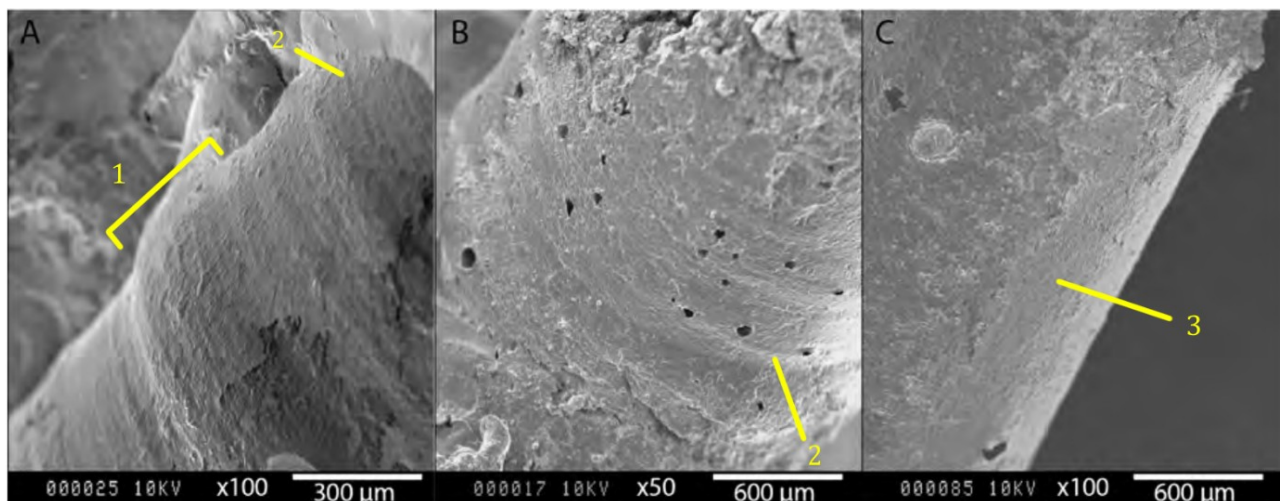


204 Figure 8: X-ray microtomography images of amethyst beads GD-02-038, GD-02-001, GD-02-025 and GD-08-026. The tip of one perforation
 205 has a rounded shape (1) indicating the use of a plain drill bit. Traces of surface staking are visible (2). Abrasive striations can only be
 206 distinguished on three perforations (3) with the resolution reached for the scan of a complete bead.

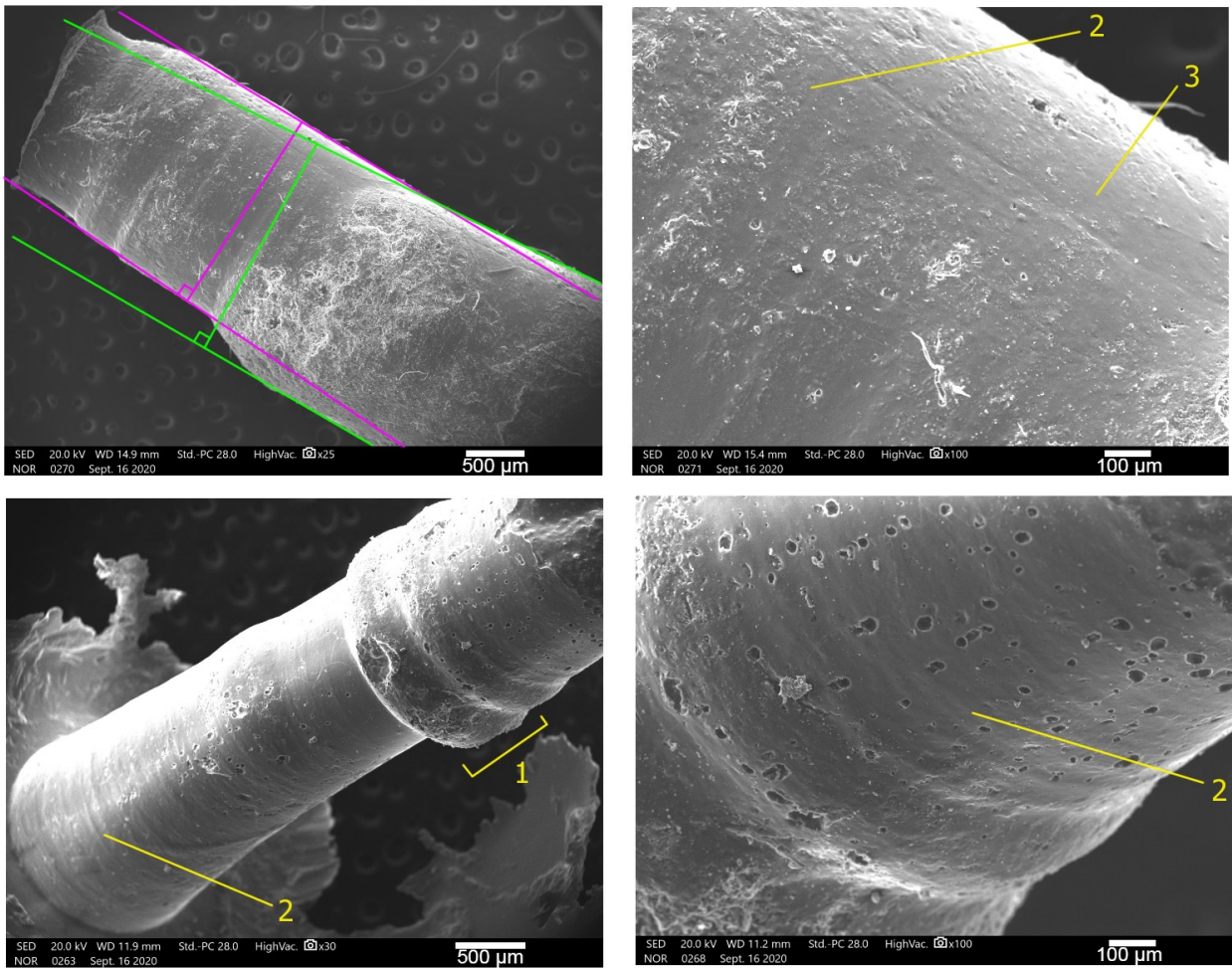


207 Figure 9: Comparison of visibility of perforation details with two microtomography resolutions on GD-01-003. The resolution with 7
 208 microns per voxels on the left allows to observe the striae, while the resolution of 26.8 microns per voxel on the right allows only to
 209 imagine them.

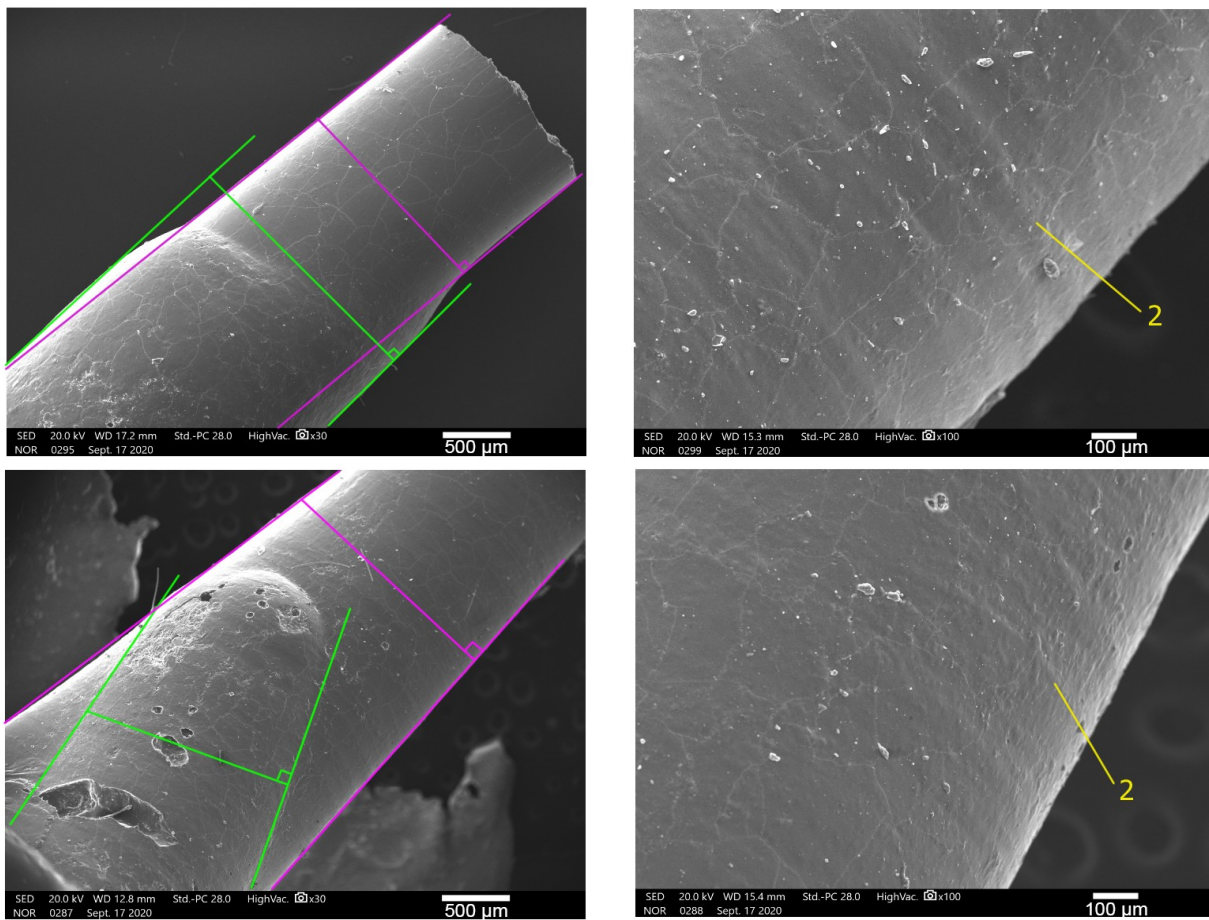
210 Observations of the elastomer impressions of the beads' perforations with a Scanning Electron
211 Microscope (SEM) reveal deep, discontinuous striations on the Gare Maritime amethyst beads (GD-01-
212 002 and GD-01-005; Figure 10, A et B). The striations on the Vivé bead impressions (MA-02-033 and
213 MA-02-006; Figure 11) are more faded. The very smooth surfaces of the St. Martin beads still show
214 very slight striations (Figure 12). This erasure of striations is caused by string rubbing that can cause
215 abrasion of the perforation on the long-term. The resulting smooth surfaces are also visible on the
216 impressions of GD-01-003 (Figure 10, C) and MA-02-033 (Figure 11). The pushing marks are also well
217 preserved. They are visible as slightly larger diameter rings in GD-01-002, GD-01-005, and MA-02-006.



218 Figure 10: SEM images of the elastomer impressions of the GD-01-002 (A), GD-01-005 (B) and GD-01-003 (C) perforations. The pushing
219 marks (1), striations (2) and polished surfaces (3) are shown.

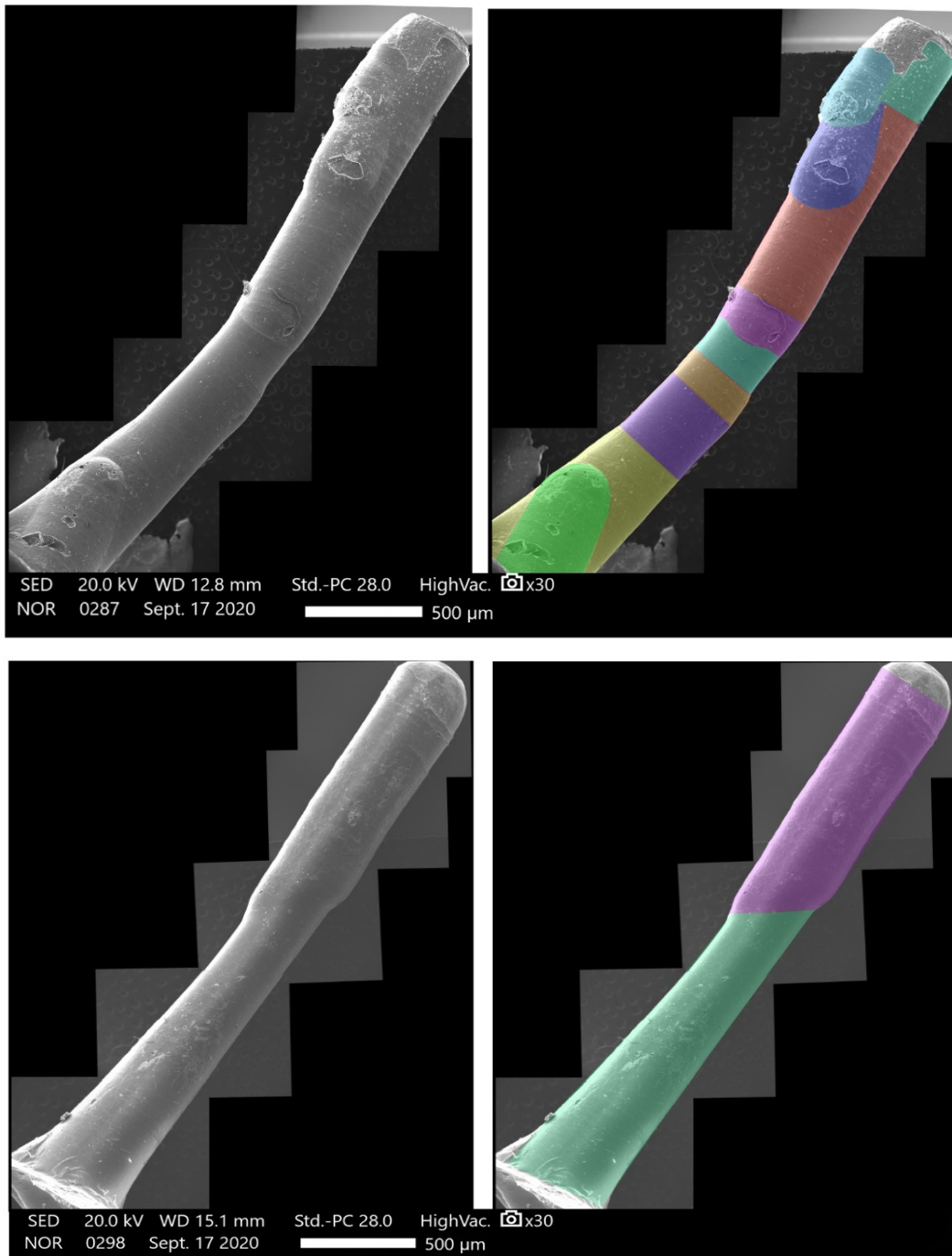


220 Figure 11: SEM images of perforation impressions of beads from the Vivé site (Martinique): MA-02-033 made of amethyst (top) and MA-
 221 02-006 made of rock crystal (bottom). The bead MA-02-33 shows two axes of perforation and we can guess striations (2), probably
 222 partly erased by the wear due to the use of the object (3). The impression of the perforation of bead MA-02-006 shows striations related
 223 to the perforation process (2), as well as very marked pushing marks (1).



224 Figure 12: SEM images of the perforation impressions of Hope Estate rock crystal beads SM-02-77 (top) and SM-02-80 (bottom). The
 225 perforation of SM-02-077 is highly polished where its diameter is smallest. The perforation of SM-02-080 clearly shows an error in the
 226 angle at the beginning of the perforation, which was later corrected by the craftsman. Although the surface of the perforations is very
 227 smooth, the striations are still visible (2).

228 The orientation of the perforation has sometimes changed during the work, as it is obvious
 229 from the observation of the imprint of bead SM-02-080, from the Hope Estate archaeological site,
 230 which shows no less than ten different perforation angles (Figure 13). The second rock crystal bead
 231 from the same site has only two perforation angles but of different diameters, creating a pretty regular
 232 perforation pattern.

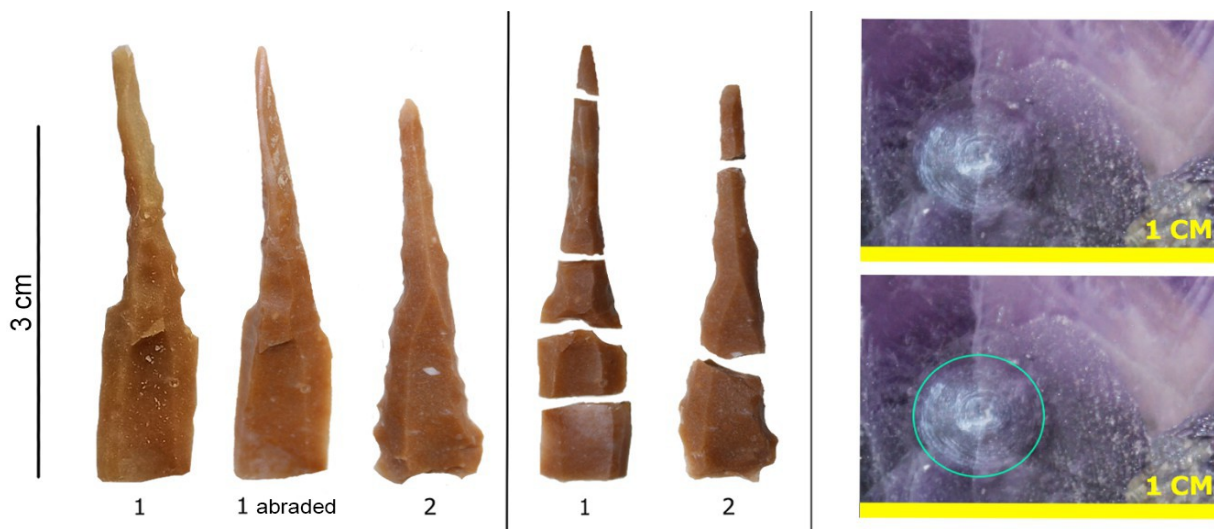


233 Figure 13: Montage of SEM images of the perforation impressions of rock crystal beads SM-02-77 (top) and SM-02-80 (bottom). The
 234 perforation of SM-02-77 shows ten different perforation angles, some of which show a strong offset from the perforation axis (green and
 235 light blue). The bead SM-02-80 shows only two perforation angles.

236 **Experimental perforations**

237 The preliminary tests have implemented the different combinations of drill bits and abrasive, in
 238 order to verify the effectiveness of the bow drill, as well as the parameters allowing to perforate
 239 quartz. It was obviously possible to drill a hole with a copper drill and abrasives harder than quartz
 240 (silicon carbide, rutile), and also by substituting these very hard abrasives with ground quartz: quartz
 241 powder can be used to produce a perforation in quartz.

242 On the contrary, using long and narrow diameter drill bits made of lithic materials, which could
 243 be compatible with the observed perforations, has not been successful since they are too brittle
 244 (Figure 14). These drill bits are not found in the archaeological record. Other shapes of drill bits, found
 245 in the archaeological record, have been tested (Figure 15), but they produce large and short
 246 perforations.



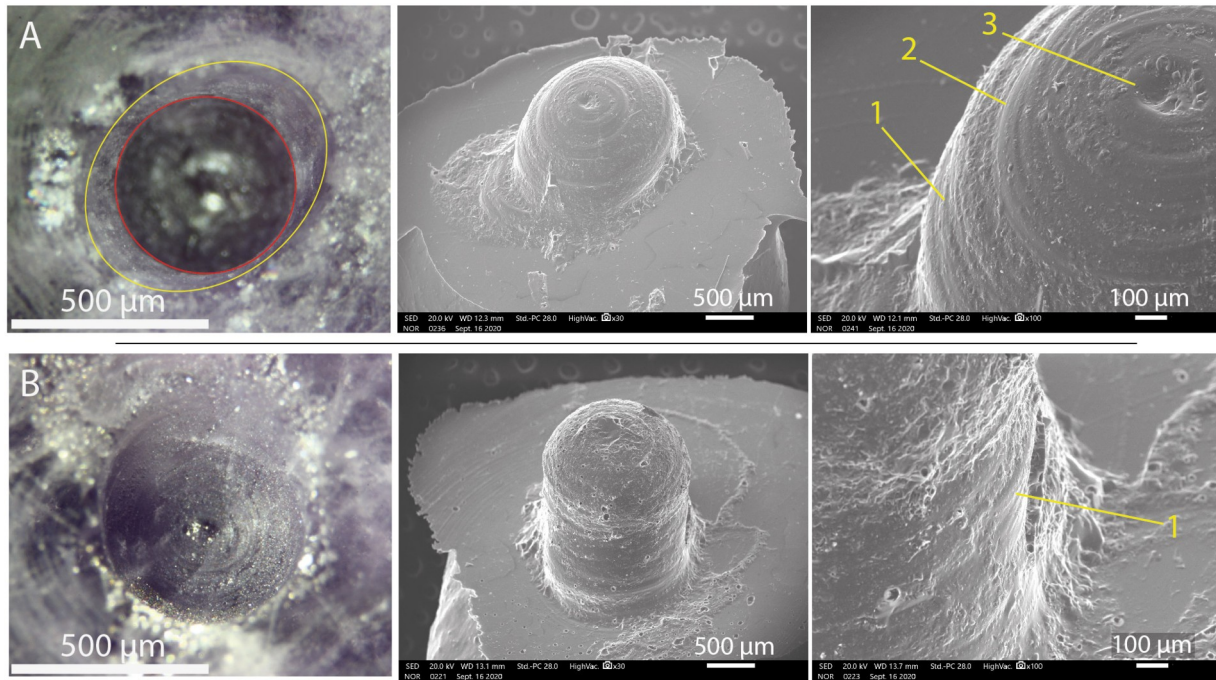
247 Figure 14: Photographs of the two flint drill bits (one of which has been abraded to reduce its diameter), before and after use, as well as
 248 of the perforation created. The diameter of the perforation is almost compatible with the archaeological record but these drills are very
 249 fragile.



250 Figure 15: Flint (left) and obsidian (right) drill bits, before and after use. They allowed to produce the beginnings of perforation, but too
 251 large compared to the archaeological record.

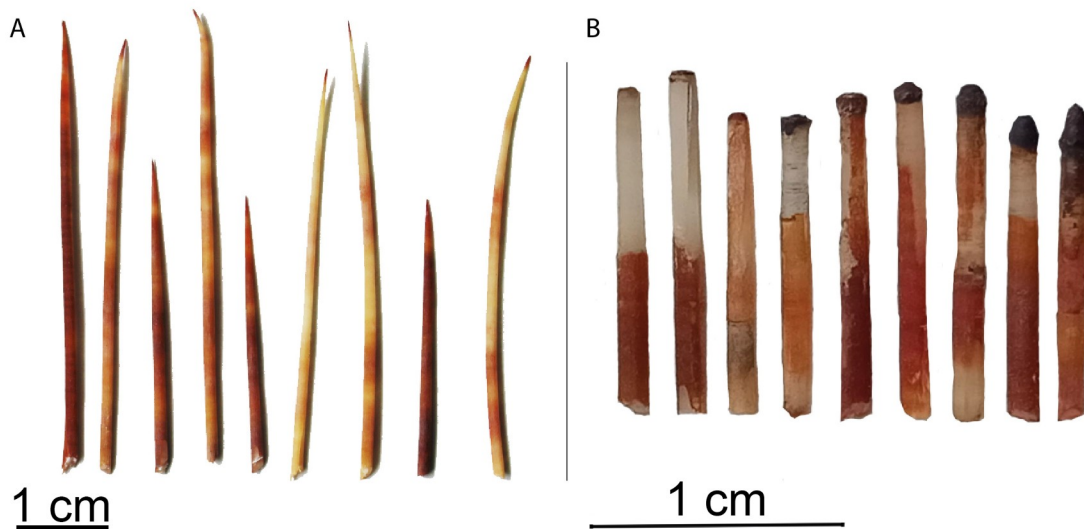
252 The use of bone or wood drills, whether made of oak or *Lignum vitae*, did not allow us to make
 253 a perforation in quartz, even using silicon carbide as an abrasive. Indeed, under these conditions, it is
 254 the drill that wears out or breaks, while the support does not undergo a significant removal of
 255 material. The palm leaf stalk and the agave thorn did not allow the realization of perforation on the
 256 surface of quartz either, because ~~their flexibility is too important~~ to impose a sufficient vertical force.
 257 The only organic material that allowed the realization of a beginning of perforation are the thorns of
 258 cactus. The impressions of the experimental perforations made with cactus thorns and garnet abrasive
 259 show striations due to the abrasive (Figure 16). Inverted cone shapes are observed at the end of both
 260 impressions (i.e., at the bottom of the hole) for the perforations made with the *Melocactus intortus*

261 thorn drill and the amethyst abrasive. In addition, this perforation shows two different perforation
 262 diameters, clearly visible in the macroscopic images. The shape of the beginning of the perforation is
 263 oval, due to the back and forth movements that impacted the verticality of the drill during perforation.



264 Figure 16: Microphotographies of experimental drillings and SEM image of the elastomer impression (20kV HV SS28 SED x30 et x100). A :
 265 amethyst with quartz abrasive and drill made of *Melocactus intortus* thorns, B : amethyst with garnet abrasive and drill made of
 266 *Melocactus intortus* thorns. Fine striae created by the abrasive are visible (1), and also thicker striae of unknown origin (2), as well as
 267 inverted cone at the end of each perforation (3). Perforation in B shows two different diameters of perforation.

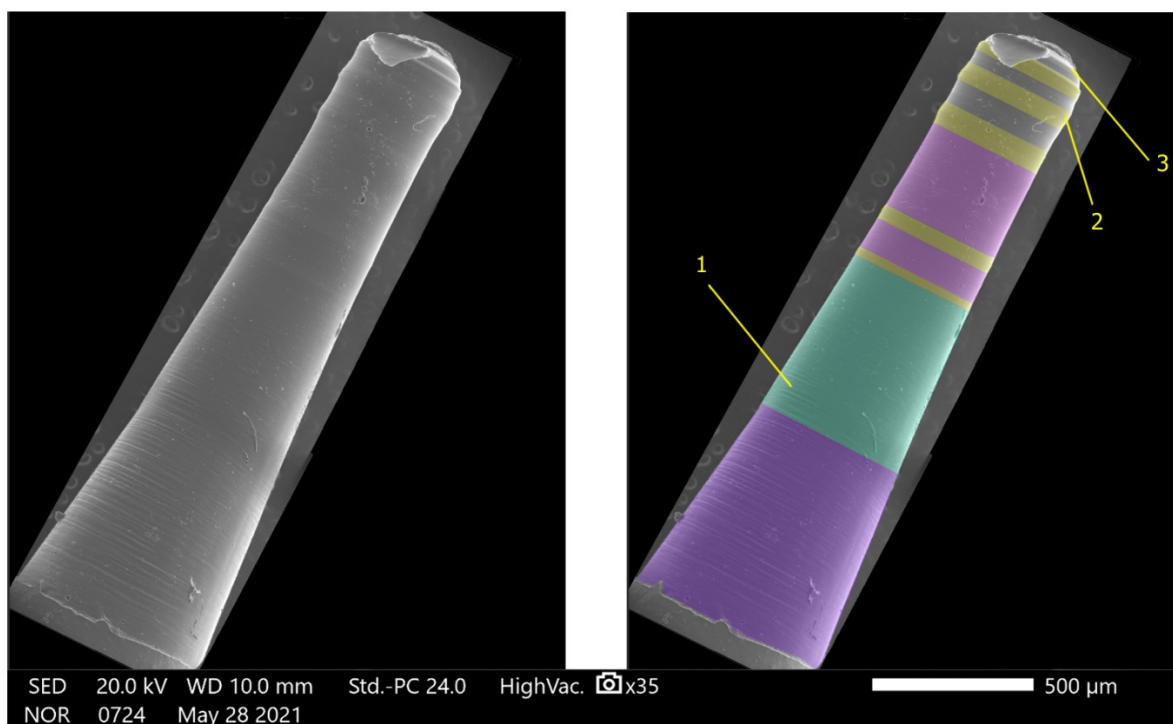
268 A through-hole in an amethyst pebble was made with a total of 28 long *Melocactus intortus*
 269 thorns (Figure 17) and crushed amethyst as the abrasive. It is 10.2 mm long and has a widest diameter
 270 of 2.5 mm at one of the beginning. This represents 43 days of work, 5 hours per day, for a total of 215
 271 hours.



272 Figure 17: Sample of *Melocactus intortus* thorn drills before and after use. We can observe the change of the shape of the active part
 273 according to the wear of the drill, which very often burned because of the friction.

274 The darker, older thorns were found to be more resistant than the lighter thorns which are
275 younger and softer. The active part, ~~blunt~~, sometimes burnt due to insufficient water inflow. The
276 deeper the perforation, the more difficult it was to bring water to the active part (creation of a bubble,
277 less contact with the surface of the thorn, thinner at this point). The thorns wore out in a rather
278 heterogeneous way, between 30 minutes and one hour, depending on the vertical force exerted and
279 the moment when the burning was noticed. Once the active part was burnt, the drill became unusable
280 and sometimes left carbonaceous residues at the bottom of the perforation.

281 Concerning the whole perforation, on the first half of the impression (the elastomer always
282 broke while being pulled out of the perforation), which represents almost the entirety of the biconical
283 perforation created, the striations are well present and the pushing marks quite weak. Four perforation
284 axes are observed, their offset angles are very small (Figure 18). The end of the perforation is "nipple"
285 shaped. On the second part of this perforation, we also noticed the striations due to the abrasive, and
286 high angles between axes of perforation due to the will to join the end of the first perforation.



287 Figure 18: Montage of photographs of one half of the biconical impression of the experimental perforation in the SEM (20kV SED x35).
288 Four different perforation angles are observed with a small variation amplitude (purple, green, pink and original color). We also observe
289 the striations caused by the abrasive which are very marked (1), and the pushing marks, in yellow, are very small and short (2). The tip of
290 the perforation is "nipple" shaped (3).

291 DISCUSSION

292 This work based on both archaeological and experimental material describe in detail one of the
293 crucial steps of beads production in the past: the perforation of hard material without the help of
294 metal.

295 The observation of a significant number of finished archaeological beads from 6 archaeological
296 sites of the Ceramic Age located on 3 islands of the Lesser Antilles, with complete perforations, has
297 provided a great deal of information. From a typological point of view, the length of the bead seems to
298 influence the shape of the perforation. Indeed, rectilinear and chamfered perforations are the most
299 common, especially for cylindrical and barrel-shaped beads. On the other hand, conical perforations
300 are relatively rare for these beads and are observed only on short beads. It should be noted that the
301 chamfer may disappear with heavy polishing of the perforation surfaces or wear of the bead. Thus, a
302 bead with a chamfered perforation that is broken and then repolished may look similar to a conical or
303 straight perforation. It is therefore difficult to establish links between typology and technology on the
304 basis of so few artifacts with so much variability.

305 Imaging techniques, by SEM on elastomer impressions and by microtomography, allowed the
306 observation at high magnification of a surface invisible to the naked eye ~~because located inside the~~
307 ~~pearl~~. The images of the impressions of the perforations of the Antillean beads reveal the abrasive
308 striations and the pushing marks already described in the literature for other contexts (Gorelick and
309 Gwinnett, 1979; Gurova, Bonsall, et al., 2017; Kenoyer, 2017; Kenoyer and Vidale, 1992; Ludvik et al.,
310 2015). Similarly, changes in perforation angles could be identified on the SEM image montages as well
311 as through microtomography. The stigmata observed in this study confirm the use of abrasive for all
312 the archaeological perforations studied here, and to a great diversity in the technical gesture of
313 perforation, highlighted by a great diversity in terms of frequency of pushing marks and multiple
314 perforation angles.

315 On the experimental perforation, the striae are very prominent, most likely due to the fact that
316 it did not undergo post perforation wear. The perforation is also quite short compared to the
317 perforations of long beads, which induces less wear of the abrasive particles on the walls near the end
318 of the bead, when perforating the more internal part of the bead. Our experiment also replicated
319 pushing marks, reinforcing the interpretation of their presence due to abrasive use (Gorelick and
320 Gwinnett, 1979; Gurova, Bonsall, et al., 2017; Gwinnett and Gorelick, 1998; Ludvik et al., 2015). Here
321 they appear to be related to where the drills burned. Indeed, they are located primarily in the
322 innermost part of the experimental perforation (10.2 mm long), where the drills were wearing and
323 burning the fastest. The pushing marks visible on the archaeological beads are located in the central
324 part of the perforation, which confirms the use of abrasive with a resistant drill whose active part

325 wears away. The pushing marks in the context of a perforation with a vegetal drill bit could therefore
326 be reinforced by this specific wear phenomenon combining drill bit wear and accumulation of coals in
327 the active part and then the accumulation of abrasive on the edges of the active part.

328 The reasons for the irregularities in the alignment of the perforation axes are not yet
329 determined. They can be caused by a changing dexterity of the person(s) performing the perforation or
330 by the position of the blank, especially concerning the shapes whose holding is the most delicate
331 (spherical beads for example). In view of our own experimental work, the regularity of the profile
332 seems to have little to do with technical mastery, contrary to what is claimed in the literature,
333 especially concerning materials exceeding a hardness of 5.5 on the Mohs scale (Gurova, Bonsall, et al.,
334 2017). Indeed, although we are novices in this craftsmanship, the entire experimental perforation is
335 rather regular, with 4 identified perforation axes, whose differences in orientation are very small. This
336 may be due to our maintenance system (industrial vice), not compatible with the archaeological
337 context. Only the error in estimating the ideal location of the second part of the perforation could
338 represent the lack of experience. Thus, perforation habit is not clearly identifiable in our experimental
339 study. Intra- and inter-experimental reproducibility tests would be relevant to identify the parameters
340 governing the regularity of perforation, but given the time required to perform this experimental work,
341 it seems difficult to implement.

342 The use of metal to perforate materials as hard as quartz or carnelian, especially with small
343 diameters of perforation, has always been the preferred hypothesis ~~by the authors~~ (Gwinnett and
344 Gorelick, 1998, 1987; Kenoyer, 1997, 1986; Kenoyer and Vidale, 1992; Ludvik et al., 2015), and for the
345 Caribbean islands, Harrington (1924) already indicated that « *Most of the stones used are very hard,
346 and it must have taken a long time to peck and grind them into shape; the nature of the tools available
347 to the workman of that day and place, and capable of drilling such small holes through such obdurate
348 materials as amethyst and quartz crystal, remains a mystery* ». We demonstrate in this work that it is
349 possible to do so with a vegetal drill, in this case made of cactus thorn, a material available in large
350 quantities to the Amerindians, and whose perishable nature helps to explain their absence in the
351 archaeological record.

352 The use of abrasives harder than the material to be drilled has also been widely put forward in
353 the literature (Gorelick and Gwinnett, 1979; Gurova, Bonsall, et al., 2017; Kenoyer, 2017, 1986; Ludvik
354 et al., 2015; Sela and Roux, 2000) while we can confirm that it is possible to use an abrasive of the
355 same hardness as the object to be perforated. It is also interesting to note that the use of bead shaping
356 ~~residues~~ could be crushed to be used as an abrasive, thus explaining their rarity in the archaeological
357 record.

358 Finally, several aspects of the experiment remain to be explored. First, the system for holding

359 the drill bit in the handle has not been addressed. The use of tar for the shank is attested in the Lesser
360 Antilles for the recent ceramic periods (Serrand et al., 2018), its use for fixing the drill bit is a significant
361 possibility. Also, the impact of the shape and size of the abrasive grains are parameters to be
362 characterized, from a qualitative point of view and also to see if there can be an influence on the
363 striations created. Then, the bead holding system remains to be determined, especially concerning its
364 position in relation to the person who drills. Indeed, although exhausting, the use of an archery drill in
365 a standing position is also impractical because it constantly solicits both arms. The joints of the upper
366 limbs, especially the shoulders, are heavily strained. A more elevated position in relation to the vice or
367 a seated practice, already observed in the works of description of the productions of carnelian beads in
368 the Indus Valley, in India (Sela and Roux, 2000) are aspects to be explored if we want to take into
369 account the comfort of the craftsman. Finally, the efficiency and ease of the experimental perforation
370 depend on the appreciation of the experimenter, and therefore remain quite subjective. More precise
371 criteria than simply obtaining a perforation after a given time to determine efficiency could be
372 established.

373 It should be noted that, despite the fact that the analyses of the perforation angles are very
374 instructive concerning the characterization of the regularity of the perforation, they are however
375 carried out on images in 2D despite the 3D nature of the artifacts. The angles are then only apparent
376 angles and further analysis based on a three-dimensional work would allow to evaluate with precision
377 these shifts between the axes of perforation.

378 CONCLUSION

379 The *chaîne opératoire* of the production of quartz beads (and other hard materials) is still very
380 poorly understood in the various archaeological records. If this work has been carried out by a few
381 authors in particular contexts, such as the cultures of the Indus Valley, it is clear that many other
382 chronological periods or other regions of the world have not benefited from such studies. This work, by
383 combining observation of archaeological objects and experimentation, makes it possible to remedy this
384 for the Ceramic period in the Antilles.

385 Very few blanks or shaping wastes are known in the Antillean archaeological record for quartz
386 materials, and observation of finished objects can only point to a shaping technique by pecking before
387 beginning the perforation. A significant variability is observed in the type of perforation of quartz
388 beads from the Ceramic period in the Antilles, preventing any strong link between bead typology and
389 perforation shape to be highlighted. On the contrary, the observation of the stigmata persisting inside
390 the perforations indicates that the technique used is always the same.

391 The study of the impressions of experimentally created perforations, highlighting numerous

392 concordances with the stigmata preserved by the archaeological objects, allows us to explain some of
393 them, confirming the knowledge previously produced in other archaeological contexts and providing
394 explanations in accordance with the archaeological record devoid of drills compatible with the
395 perforations observed. First of all, we can affirm that the use of metal was not necessary for their
396 perforation: it is possible to perforate quartz beads using cactus thorns as a drill bit, widely available in
397 the Caribbean islands. Secondly, it is possible to make very fine and long perforations by combining
398 with this vegetable drill a free abrasive of the same hardness as the material to be perforated. Thus we
399 have been able to demonstrate that it is possible to use crushed quartz to perforate quartz, which
400 could explain the near absence of waste from the shaping of these beads in archaeological sites, if the
401 beads were shaped on site.

402 Such a manufacturing process implies a significant investment in time, but does not require
403 extremely advanced know-how, nor the search for particularly rare materials. It could be implemented
404 directly in the archaeological sites found throughout the Caribbean arc. This investment in lapidary
405 production, already noted by the diversity and distant origin of some of the materials used, confirms
406 the importance of this material culture in these pioneering populations of the Caribbean islands.

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420 **CONFLICT OF INTEREST**

421 The authors declare there is no financial conflict of interest. Alain Queffelec is manager of PCI
422 Archaeology.

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423 Appendix 1 :

Site	Gem material	Type	Inventory number	State	Perforation
Gare Maritime	Amethyst	Barrel-shaped	GD-01-003	finished	biconical
			GD-01-005	finished	straight
		Cylindrical	GD-01-002	broken	straight
			GD-01-006	finished	straight
			GD-01-004	blank	-
	Rock crystal	Discoid	GD-01-014	broken	straight
			GD-01-016	finished	straight
		Cylindrical	GD-01-015	finished	straight
Allée Dumanoir	Amethyst	Barrel-shaped	GD-05-001	finished	chamfered
		Button	GD-05-002	finished	biconical
Morel	Amethyst	Barrel-shaped	GD-02-004*	finished	chamfered
			GD-02-011*	finished	biconical
			GD-02-025	finished	chamfered
			GD-02-027	finished	chamfered
			GD-02-034	finished	chamfered
			GD-02-053	broken	chamfered ?
			GD-02-042	broken	biconical ?
			GD-02-030	finished	biconical
		Bitronconical	GD-02-012*	finished	biconical
			GD-02-035	finished	chamfered
	GD-02-038		finished	biconical	
	Spherical	GD-02-054	finished	biconical	
	Cylindrical	GD-02-026	finished	straight	
	Rock crystal	Cylindrical	GD-02-015*	finished	biconical
			GD-02-017*	finished	biconical
			GD-02-018*	finished	biconical
			GD-02-006*	finished	chamfered
			GD-02-007*	finished	chamfered
			GD-02-008*	finished	chamfered
			GD-02-009*	finished	chamfered
			GD-02-013*	finished	chamfered
			GD-02-014*	finished	chamfered
			GD-02-016*	finished	chamfered
GD-02-005*			finished	straight	
GD-02-010*			finished ?	chamfered ?	
GD-02-044			broken	chamfered ?	
Anse Ste Marguerite	Amethyst	Bitronconical	GD-08-001	finished	chamfered
Hope Estate	Amethyst	Cylindrical	SM-02-072	finished	straight
			SM-02-075	broken	chamfered
			SM-02-078	finished	chamfered
		Discoid	SM-02-087	finished	biconical
		Barrel-shaped	SM-02-011	broken	straight ?
	Undetermined	SM-02-044	broken	-	
	Rock crystal	Cylindrical	SM-02-019	finished	straight
			SM-02-074	finished	biconical
			SM-02-080	finished	chamfered
			SM-02-077	broken	chamfered
			SM-02-107	broken	biconical
		Bitronconical	SM-02-023	broken	biconical ?
		Discoid	SM-02-091	finished	conical
			SM-02-028	finished	straight
	SM-02-029		broken	straight	
Vivé	Amethyst	Bitronconical	MA-02-001	finished	conical
			MA-02-003	finished	straight
			MA-02-004	finished	straight
			MA-02-005	finished	straight
	Spherical	MA-02-002	finished	chamfered	
	Cylindrical	MA-02-026	finished	straight	
Rock crystal	Cylindrical	MA-02-033	finished	straight	

424 Appendix 2 : Specific mass calculation for cactus thorns used in this work

425 Dimensions of the thorn :

426 $h = 39,61 \text{ mm}$

427 $R = 0,50 \text{ mm}$

428 Mass: $m = 0,071 \text{ g}$

429 Volume: $V = \pi \times R^2 \times h = \pi \times 0,5^2 \times 39,6 = 31,10 \text{ mm}^3$

430 Specific mass: $\rho = m / V = 71/31,10 = 2.28 \text{ mg/mm}^3$ (2280 kg/m³)

431 Density: $d_{\text{thorn}} = \rho_{\text{thorn}} / \rho_{\text{water}} = 2280 / 1000 = 2.28$