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ORIGINAL PAPER

A myth debunked. The *Porosphaera globularis* beads and their relation to the onset of symbolic thinking in prehistory

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Abstract
Because of their inherent symbolic significance, personal ornaments gained a key role in the scientific debate regarding the emergence and evolution of symbolic behaviour; the presumed Acheulean beads discovered in the nineteenth century in northern Europe's sites are considered crucial evidence of this. The fossils of the sponge *Porosphaera globularis*, because of their morphological characteristics, have been interpreted by some archaeologists as the starting point of this evolutionary path. In this work, the largest collection of *Porosphaera globularis* specimens is analysed, after remaining unpublished to this day. This was originally found in the French site of Saint-Acheul and preserved at the Civic Museums of Modena. An integrated analysis was carried out to understand whether these fossils were indeed used as beads; results revealed that they were actually not used as ornaments. This suggests the importance of finding strong arguments and evidence to support theories about the development of cognitive abilities in the genus *Homo*.

Keywords Evolution of symbolic behaviour · Lower Palaeolithic · Ornaments · Symbolism · Fossil sponges · Acheulean

Introduction

An important milestone in the evolutionary history of our genus was certainly the onset of symbolic thinking, but when can we date it? The answer lies in the appearance of symbolic evidence amongst the material culture and, because of this, it suffers from the limits of archaeological research. Moreover, we do have to consider how modern perception affects interpretations about past behaviour, the understanding of the functionality or use of the objects found, thus compromising the chronological interpretation as well.

The realization of symbolic objects proves the ability of sharing, memorizing and passing on coded information within and between groups, which strengthens the idea of the socially shared symbolic meaning of the items considered. Therefore, we can recognize as a moment of change in human behaviour the moment in which these objects became part of the material culture produced by the groups: an innovation that fostered creation, preservation and transmission of rules, social conventions and thus identities (Kissel and Fuentes 2018).

The debate amongst researchers was carried on for decades by referring to various evidence to get closer to an answer (D'Errico and Villa 1997; Ambrose 1998; Mcbrearty and Brooks 2000; Wadley 2001; Vanhaeren et al. 2006; Bouzouggar et al. 2007; D'Errico et al. 2009; Zilhão 2011).

For many years, the onset of artistic activities was attributed to the arrival of anatomically modern humans (AMH) in Europe (Bar-yosef 2002; Henshilwood and D'Errico 2011; Zilhão 2011; García-Díez and Ochoa 2019); today, we know that this is very much backdated. In fact, in recent years, the African origin of the symbolic material culture

Highlights
- Personal ornaments play a central part in the debate around the birth of symbolic behaviour.
- The fossils of *Porosphaera globularis* are amongst the oldest personal ornaments.
- Analyses disprove the use of these fossils as ornamental beads.

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of our species is widely accepted (d'Errico et al. 2005; Zilhão 2007; Bouzouggar et al. 2007; Kuhn et al. 2009; Shell et al. 2009; Henshilwood et al. 2011; Vanhaeren et al. 2013). Moreover, several researchers concluded that other hominid species possibly also used symbolic language and potentially realized material culture of that kind. Therefore, this skill can no longer be conceived as a peculiarity of our species (D'Errico and Nowell 2000; Peresani et al. 2011; Joordens et al. 2015; Hoffmann et al. 2018a, b; Leder et al. 2021). Because of their strong symbolic and social meaning, thus communicative role, personal ornaments play a key role in the debate about the emergence of symbolic behaviour, since they may reflect not only customization, but also ethnic identity and symbolic systems (Henshilwood et al. 2004; Bednarik 2005a; d'Errico et al. 2005; Rigaud et al. 2009; Vanhaeren et al. 2013). The bodily adornments include beads, pendants, bracelets and diadems all in possible contact with the body (e.g. worn next to the skin) (Lbova 2020); amongst them, beads are considered the main distinguishing marks of symbolic thought.

The oldest known ornamental beads, obtained from marine and freshwater shells, were discovered in Africa and in the Levant, and date back to 142–70 ka BP (Henshilwood et al. 2004; Bar-Yosef 2005; d'Errico et al. 2005, 2009; Vanhaeren et al. 2006; Bar-Yosef Mayer et al. 2009; Churchill and Rhodes 2009; Mayer et al. 2020a; Sehasseh et al. 2021). The ones found at Skhul Cave, in the Levant, date back to between 135 and 100 ka BP (Bar-Yosef 2005; Vanhaeren et al. 2006). The shells found at Qafzeh Cave, though naturally perforated, to a deeper analysis show traces of suspension (Bar-Yosef Mayer et al. 2009). In North and South Africa, there are a number of slightly latter sites where shell beads were also discovered, all dating to around 142–70 ka BP, such as Blombos, Sibudu and Border Caves in South Africa; Grotte des Pigeons, Bizmoune Cave, Rhafas and Contrabandiers in Morocco; and Oued Djebbana in Algeria (Vanhaeren et al. 2013; Wei et al. 2016; D'Errico and Backwell 2016; Steele et al. 2019; Mayer et al. 2020a; Sehasseh et al. 2021). These data appear to confirm that the personal ornaments are one of the innovations that emerged in Africa amongst early AMH populations (Mcbrearty and Brooks 2000).

However, divergent opinions exist as to what constitutes the earliest evidence of bead usage and the taxonomic status of the beadmakers. Indeed, some scholars argue that the first beads found are the *Porosphaera globularis* fossils and refer them to the European Acheulean (Bednarik 2001, 2005b; Rigaud et al. 2009; Mayer et al. 2020b).

The issue of the first beadmaking "species" is undoubtedly more debated in Europe, where Neanderthal's traces fit very well with what is defined as "modern behaviours" that include extensive presence of emblems in their material culture. In a recent paper about Cueva de los Aviones (Spain), the use of marine shells by Iberian Neanderthals as beads and pigment containers is supposed, as early as 115 ka BP (Hoffmann et al. 2018a). These findings, together with new dates for some parietal art motives in three Spanish caves that link the earliest European evidence of paintings to Neanderthal groups (Hoffmann et al. 2018c), and the supposed symbolic use of feathers and phalanxes of birds of prey and giant deer (Peresani et al. 2011; Rodríguez-Hidalgo et al. 2019; Leder et al. 2021), generated a major debate concerning the origin of symbolic behaviour, cultural modernity and the first appearance of art in Europe.

The Acheulean beads

Within the previous paragraph, a brief description of the findings, interpreted and defined by most scholars as beads, was provided. Nevertheless, other findings attributed to the Lower Palaeolithic generated a heated discussion amongst scholars in regard to their anthropic use and modification (Keeley 1980; Bednarik 2005b, a, 2020a; Rigaud et al. 2009; Vidale 2018). The presumed ornaments, reported in the literature, are attributed to Lower Palaeolithic and can be divided into two groups: the first one includes three fragments of ostrich eggshell beads that were apparently found at the Acheulean site of El Greifa, in Libya (Ziegert 1995; Bednarik 1997); the second group consists of hundreds of perforated fossil sponges of *Porosphaera globularis*, found in numerous Acheulean sites in England and northern France during excavations undertaken in the nineteenth century (Boucher de Perthes 1847; Rigollot 1854; Wyatt 1862; Smith 1884; Bednarik 1997, 2001, 2005b, a, 2020b, a).

The aim of the present paper is to untangle the main interpretation problems of these fossil sponges and their possible use and meaning: were the *Porosphaera globularis* fossils used during the Lower Palaeolithic as beads or not? To answer this question, we analysed a huge, and to this day unknown, collection of supposed beads of *Porosphaera globularis* coming from the French site of Saint-Acheul. This collection was stored for more than one century at the "Musei Civici di Modena" (Civic Museums of Modena) that bought the entire collection in 1891 directly from Charles Le Beuf. The analyses carried out on the findings of this collection were multidisciplinary and interconnected with each other. Moreover, they took in consideration parameters that had never been considered in previous studies, thus providing an integrated methodological approach in the study of these hypothetical Acheulean beads.

The *P. globularis* beads issue

The so-called Acheulean beads were discovered in numerous Acheulean sites in north-western France and southern England during the nineteenth century (Boucher de Perthes

1847; Rigollot 1854; Wyatt 1862; Smith 1884) (Fig. 1). These spheroidal finds were promptly recognized, as fossil sponges belonging to the Late Cretaceous species (Rigollot 1854): a marine spherical calcareous sponge widely widespread in the boreal Late Cretaceous. These fossils today are commonly found in chalk lithofacies, but can also occur in marls and bioclastic limestones (Rigaud et al. 2009; Wilmsen et al. 2012; Jurkowska et al. 2015). Some of the *P. globularis* found in the natural deposits present central holes (around the 9%), scrupulously studied by Neumann et al. (2008): the fossils with boring traces (ichnospecies *Trypanites mobilis*) were referred to the activity of sipunculid worms, which use the bored sponges as mobile shelters (Neumann et al. 2008).

The first to mention the use of these fossils as beads was Boucher de Perthes (Boucher de Perthes 1847, 1864), who provided a description of the findings from Cagny, an Acheulean site in the Somme River valley (Somme, France), as "grains de colliers" (necklace beads) made of stone. Rigollot (1854) reported similar discoveries in Acheulean sites located in the same area. The French researcher identified these beads as the fossil sponge *Coscinopora globularis*. The fact that these fossils were found together reinforces the idea that they were part of a necklace (Rigollot 1854). In 1862, James Wyatt reported the discovery of more than 200 specimens from Biddenham (Bedfordshire, England) (Wyatt 1862) and described the modifications around the holes as evidence of human activity. In 1884, Smith recovered *C. globularis* specimens from an Acheulean site near Bedford (England). He reported the finding of such an accumulation of fossils in the same spot that it could not be justified as a natural deposit (Smith 1884). Furthermore, he interpreted the abrasions found close to the perforations as a result of the rubbing between beads arranged around a string, as they would in a necklace. Some perforations appeared artificially enlarged and "fresh" to him (Smith 1884). Moreover, within his paper, Smith reported the presence of a "black substance" in the holes of the specimens too, that he interpreted to be residues of "ligaments" used to string the *Coscinopora* together (Smith 1884).

Finally, in 2005, these fossils were the object of a review by Bednarik (Bednarik 2005a) who definitely attributed them to the species *Porosphaera globularis*, and interpreted them as Acheulean beads.

After the above-described discoveries, no more *Porosphaera* specimens were reported from recent excavations undertaken at Biddenham and Saint-Acheul (Tuffreau 1987; Harding et al. 1991; Tuffreau et al. 2001; Antoine et al. 2016).

As we mentioned, the spherical morphology of these fossils, their small size, the presence of a perforation in the centre and the context of finding led some archaeologists of the nineteenth century to interpret them as parts of necklaces.

Nevertheless, some scholars do not agree with this interpretation and argue that the presence of these fossils in the archaeological sites can be explained considering other natural processes and reasons. In their opinion, the attribution of these objects as reliable archaeological finds is not justifiable (Oakley 1965; Rigaud et al. 2009), in opposition to other scholars' hypothesis about the use of these findings as beads for necklaces (Keeley 1980; Bednarik 1997, 2001, 2005b, a, 2020b, a; Vidale 2018).

Even though both groups of scholars recognize that the beads are *Porosphaera globularis* fossils, perforated in ancient times by worms (Oakley 1965; Keeley 1980; Bednarik 1997, 2001, 2005b; Rigaud et al. 2009) and that their presence in the archaeological collections is due to selection, their opinion diverges on two key points: (1) who selected

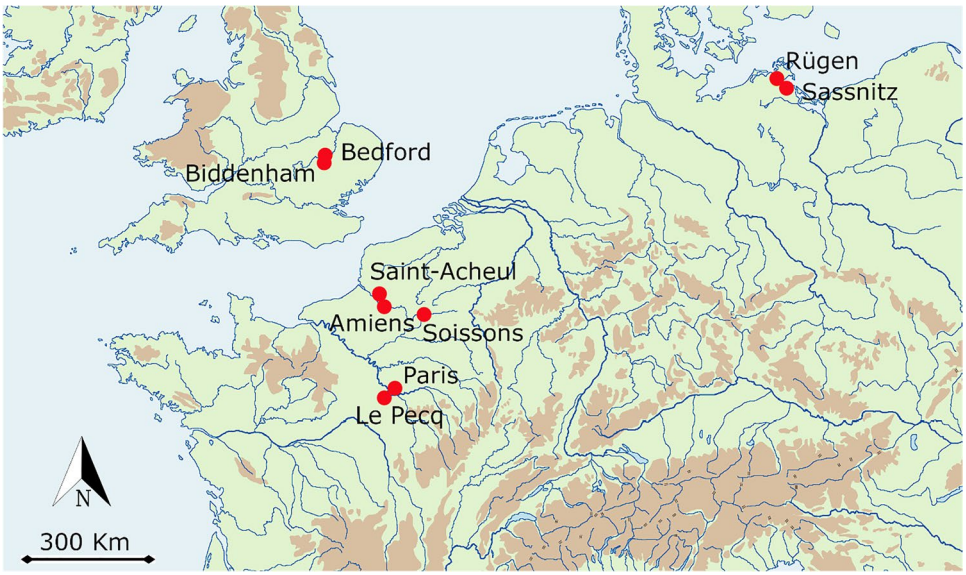

Fig. 1 Archaeological sites where *Porosphaera globularis* have been recovered

the fossils and (2) if these fossils were mounted as elements of necklaces.

The first group proposes that the selection of fossils was probably made in the nineteenth century resulting from a cognitive bias of the archaeologists: only after the discovery the fossils were arranged in such a way as to be necklaces. For the second group instead, these were collected by the ancient humans and used to realize necklaces. Curiously, both groups of researchers were able to identify, near the perforations, marks of suspension and abrasions. However, they came to different conclusions regarding what caused these marks: some support the interpretation of such marks as modern traces (Rigaud et al. 2009); conversely, others consider an ancient human activity (Keeley 1980). To definitively solve this diatribe, we systematically analysed the largest, and unknown, set of "Acheulean beads", preserved at the Civic Museums of Modena. In order to do so, we considered and integrated different approaches and analyses: the historical context into which the pieces were found and sold, accessing the original documentation; the Acheulean beads phenomenon in the wide frame of the most ancient symbolic production; the dimensional and use-wear analysis, that for the first time considered not only the areas adjacent to the perforations but even the external surfaces of the fossils; issues regarding the context of retrieval of the beads in relation to the geological make-up of the area where it is located the recovery site. For each of these approaches, particular methods and materials were used as explained at the beginning of each different paragraph of the "Results" section.

Finally, our research considers all the other studies conducted on the topic of *Porosphaera globularis* collections attributed to the Acheulean. In this way, it was possible to compare the results of the analysis of the 520 fossils in the Modena collection with those of the 331 fossils discussed in previous literature, getting to the full record of the actually available 851 supposed Acheulean beads (Table 1) (Boucher de Perthes 1847; Rigollot 1854; Smith 1884; Bednarik 2005b, a, 2020b; Rigaud et al. 2009).

The Saint-Acheul site and the "Acheulean beads"

Saint-Acheul is known in Prehistoric studies for its Lower Palaeolithic handaxe industry, the so-called "Acheulean" culture. The site is located in the suburbs of Amiens on the left bank of the River Somme, downstream of the confluence with the Avre Valley. Its archaeological layers were subdivided into two main levels: the one corresponding to an Early Acheulean settlement and a second one proper of Late Acheulean, also referred to as "L'atelier Commont" (Commont 1909; Tuffreau et al. 2001; Limondin-Lozouet and Antoine 2006; Antoine et al. 2016). The fluvial succession represented within Saint-Acheul deposit appears typical of the glacial/interglacial Pleistocene sequences of the Somme terrace system (Limondin-Lozouet and Antoine 2006).

The oldest known site of the Saint-Acheul area is Moulin Quignon (Abbeville) which was dated to the beginning of MIS 15, about 670–650 ka BP, and attests to the first spread of the Acheulean above the 50th parallel (Antoine et al. 2019).

Rigaud and co-authors (Rigaud et al. 2009) stated that there is no reliable information recorded during the nineteenth-century excavations about the spatial distribution of the *Porosphaera* within the stratigraphic succession of the Saint-Acheul and Biddenham sites and about their possible relationship with diagnostic Acheulean artefacts. However, valid information comes from Prestwich's paper where the author provides a stratigraphic section indicating where he found fossils of *Coscinopora globularis* sponge (Prestwich 1860a). Within this stratigraphic level, Prestwich recognized "Some large and whole flints, and some fragments angular,

Table 1 Contextual information on *Porosphaera globularis* specimen collections that use as comparison in this study. *PRM*, Pitt-Rivers Museum; NHM, Natural History Museum (data from Rigaud et al. 2009)

Inventory number	N	Site	Country	Place of conservation	References
E.1129	16	Saint-Acheul	France	NHM	Boucher de Perthes (1847); Rigaud et al. (2009)
1884.76.67	30	Amiens	France	PRM	Rigollot (1854), Bednarik (2005a,b); Rigaud et al. (2009)
1894.21.24.1–41	29	Paris	France	PRM	Rigaud et al. (2009); Rigaud et al. (2009)
1910.72.81	11	Soissons	France	PRM	Bednarik (2005a,b); Rigaud et al. (2009)
1910.75.157–186	30	Biddenham1	England	PRM	Smith (1884); Bednarik (2005a,b); Rigaud et al. (2009)
1910.75.188–215	29	Biddenham2	England	PRM	Smith (1884); Rigaud et al. (2009)
1904.49.41.2.1–49	49	Bedford1	England	PRM	Bednarik (2005a,b); Rigaud et al. (2009)
1904.49.1.1–17	17	Bedford2	England	PRM	Bednarik (2005a,b); Rigaud et al. (2009)
1921.91.481	19	UK1a	England	PRM	Bednarik (2005a,b); Rigaud et al. (2009)
1916.34.3.1–2	101	UK2a	England	PRM	Bednarik (2005a,b); Rigaud et al. (2009)
Total	331				

especially many small ones. Much fine chalk debris, pebbles, and small blocks rolled but not rounded. Numerous sub-angular pieces and blocks, small and large, of Tertiary (lower Eocene) sandstone; Tertiary flint-pebbles abundant…" (Prestwich 1860a, b: 290). Finally, he states that these fossils are abundantly found in different parts of Britain's chalk coasts, especially in Newhaven. Amongst the collected record, he had distinguished both perforated and not perforated pieces (Prestwich 1860a, b).

Material: the Civic Museums of Modena's collection

It was Carlo Boni, as founder and first director of the museum, who bought the collection of Acheulean beads for the Civic Museum of Modena (1830–1894) (Fig. 2). In 1891, Boni accepted the proposal of the antiquarian Charles Le Beuf to purchase two lots of a lithic industry collection from the Somme region including four fossil necklaces, for a total amount of approximately 400 francs.

With the headings of the letters in our possession and the contents of the long correspondence with Boni, it is possible to delineate some traits of the French antiquarian. In 1878, Le Beuf was a police commissioner of the town of Meaux, in the Île-de-France region. He was used to combining his profession with archaeological types of research in the area, e.g. he published a report on the discovery of Gallo-Roman burials in Meaux in 1879 (Le Beuf 1879) and had a thriving activity of trading antiquities, documented by a printed catalog of "prehistoric and ethnographic objects" that he had sent to Boni (Zanasi 2019). These objects, recovered during the excavations, were possibly elements of transactions; in fact, the French police commissioner offered two Gallo-Roman skulls from the Meaux necropolis to Carlo Boni in 1880 (Zanasi 2019).

The way Charles Le Beuf used to play several roles, i.e. police commissioner, archaeologist and antiquarian, does not come as a surprise. As a matter of fact, in nineteenth-century Europe, it was common to carry out archaeological activities and scientific disciplines alongside other professions. It was in a way about being multifaceted professionals, lacking a specialization.

In 1881, Le Beuf moved to Amiens, in the department of the Somme, working at the local police station, becoming a member of several archaeological associations as well. That same year, he published the above-mentioned report about the excavation of a Gallo-Roman necropolis in Amiens (Delestre 1987). In 1884, he worked as a police commissioner in Verdun, department of the Meuse, where he undertook archaeological excavations in a Merovingian necropolis (Le Beuf 1884). This was to him an opportunity to sell some archaeological findings to Boni.

Fig. 2 One of the four *Porosphaera globularis* necklaces of the Modena collection assembled on the original twentieth-century support (photographer Paolo Terzi, Archivio fotografico Museo Civico di Modena)

An abrupt break in correspondence between Le Beuf and Boni then occurred until 1891, when the French officer wrote his last letters. At that time, Le Beuf, probably retired, was back again in Amiens, since he no longer qualified himself as a police commissioner but only as an "archaeologist" and as a member of the "Antiquaires de Picardie".

In 1891, Le Beuf sold Boni the first lot of 120 "pearls", then a second lot with two more necklaces was sent to the Modena Museum's director. At last, the fourth necklace was sent as a personal gift (SOM Fig. S1 to SOM Fig. S5).

The necklaces of the Modena collection

The four necklaces were assembled at the end of the nineteenth century, once Boni received all the pieces. Three of the necklaces consist of beads inserted on raffia threads; the fourth has them on a metal wire. The number of beads on

each necklace ranges between 112 and 156. The unrolled necklaces measure more than 1 m in length; they were placed on a rectangular cardboard panel about 50-cm long, on which they were tied by a few turns of red ribbon. Both the surface of the beads and that of the cardboard on which they rest and rub are covered by the dust that has deposited over time. The contact areas between the beads and the cardboard are generally covered by a blackish organic crust, resulting from the degradation of the cardboard itself.

The thread of necklace number 3 results from the connection of three different parts of metal wire. However, there is no residual rust and its general appearance and morphology look well preserved and regular, suggesting that it results from a quite "recent" restoration procedure (SOM Fif. S6).

To complete the research, all four necklaces were disassembled and each *P. globularis* fossil was recorded and analysed.

Results

Metric analysis

As a first step, the analyses considered the dimensional parameter. The total amount of the *Porosphaera globularis* fossils is 520 beads. The strings of the necklaces consist of raffia in three cases and wire in one.

In order to gather dimensional data comparable with the one found in literature, especially in Rigaud et al. 2009, six morphometric variables were recorded on all specimens:

Perforation length

Maximum and minimum diameter of the specimens

Maximum and minimum diameter of both perforation holes (Fig. 3)

Coefficient of sphericity (Wadell 1935), calculated for all specimens (Fig. 3)

Statistical data were elaborated and compared with the data derived from the study of Rigaud et al. (2009). Particular attention has been paid to the specimens from Saint-Acheul and Amiens exposed in Rigaud et al (2009). Moreover, we compared data of the archaeological pieces with those of the natural collection from the paleontological site of Rügen Island (Germany) reported in Rigaud et al. (2009) (Table 2).

What emerges is that the maximum diameter of the archaeological specimens of the Modena Museum collection and of the pieces described in Rigaud et al. (2009) is significantly larger than the reference collection from Rügen as illustrated in Rigaud et al. (2009). Moreover, the maximum perforation diameters of the archaeological specimens from Modena and the other archaeological sites are significantly larger than those from the comparative natural collection from Rügen.

Therefore, our data are very similar to the archaeological one coming from the sites attributed to the Acheulean in the study of Rigaud et al. (2009). The plots of the maximum diameter of the specimens compared to the maximum diameter of the perforations confirm that small pieces with small perforations are absent in our collection and in the possible Acheulean specimens considered in Rigaud et al. (2009). The comparison of the coefficient of sphericity indicates that the specimens from all the

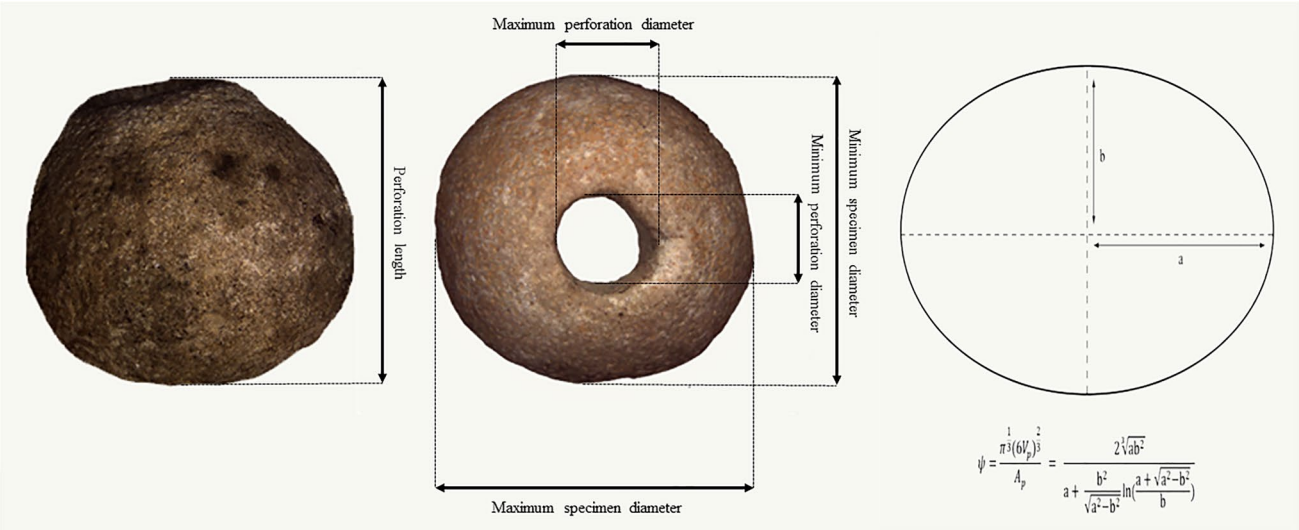

Fig. 3 Morphometric variables recorded on each of the *Porosphaera globularis* specimens and metric variables used to calculate their coefficient of sphericity. Vp, volume; Ap, surface area; a, semi-major axis; b, semi-minor axis

Table 2 Specimen and perforation maximum and mean diameters recorded on *Porosphaera globularis* of the Modena collection in comparison with the data collected in Rigaud et al. (2009) from the sites of Saint-Acheul, Amiens and Rügen

Provenance	N	Maximum diameter (mm)				Perforation maximum diameter (mm)			
		Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Modena collection	520	11.43	1.25	8.5	15.7	3.85	1.19	2.5	6.9
Saint-Acheul	16	11.06	4.31	11.8	20.6	4.38	0.97	2.4	6
Amiens	30	12.07	1.59	8.1	16.5	4.21	0.77	3.1	6.6
Rügen	34	11	4.22	0.72	4.3	24.90	3.38	0.21	0.21

Table 3 Coefficient of sphericity of *Porosphaera globularis* from the collections analysed in this study in comparison with the data collected in of Rigaud et al. (2009) from the sites of Saint-Acheul, Amiens and Rügen

Provenance	N	Coefficient of sphericity			
		Mean	Std. Dev	Min	Max
Modena collection	520	0.98	0.04	0.85	1
Saint-Acheul	16	0.99	0.01	0.95	1
Amiens	30	0.99	0.01	0.95	1
Rügen	34	0.92	0.18	0.24	1

considered archaeological collections are significantly more spherical than those from Rügen (Table 3).

The results of our study indicate that specimens from the Modena Civic Museums collection differ significantly in size and perforation size from those in the Rügen natural reference collection reported in Rigaud et al. (2009). Moreover, many of our specimens show a more regular spherical shape too. In general, our data appear very close to those collected during the study conducted in 2009 by Rigaud and colleagues. Therefore, just as concluded in that study, there are only three reasons that may be taken into account to explain this difference: a sorting bias introduced by a natural process or a deliberate choice made either by Acheulean hominids or by nineteenth-century collectors (Rigaud et al. 2009).

To comment on our data, we can directly address what is written in Rigaud's research (Rigaud et al. 2009), but the archaeological find available to us had already been selected and strung into necklaces. Therefore, apart from the collection of perforated pieces, we remark on the selection of the fossils more spherical and with mayor dimension, whose holes, if not large enough, were further enlarged. It is possible notice preferential attention to the dimensional parameters of the pieces and we share the statement that "larger perforations found in the museum specimens also support a human choice, as one cannot reasonably expect that this feature would be subjected to natural sorting processes" (Rigaud et al. 2009: 31).

Use-wear analysis

To integrate the metric analysis, we undertook the use-wear analysis of the supposed beads collection. Each bead was photographed, measured and observed with different microscopes to identify traces of manufacture and use. The means used to carry out the study included a digital microscope DinoLite 500×, a stereomicroscope Seben Incognita III (20–80×), a stereomicroscope Leica EZ4 HD (8–36×) equipped with an internal digital camera and a metallographic microscope Optica B383Met (objectives 40×–100×–200× and 500×) equipped with a Camera Optica B3.

The stereomicroscope Seben Incognita III was used for the surface analysis as the metallographic microscope Optica B383Met, the microscope Leica EZ4 HD and the digital microscope (DinoLite) were used to take the images.

All the relevant microscopic features were systematically photographed. To create wide-field focused images, several pictures of the same subject were taken using the microscope camera with different focuses: the obtained images were elaborated with the raster graphic editor software Photoshop, according to what described in Berruti et al. (2020).

During the use-wear analysis, it was possible to identify traces comparable to those detected in previous studies and documented in literature (Keeley 1980; Bednarik 2001, 2005b, a; Rigaud et al. 2009). We found a number of specimens with significant traces near the holes.

The analysed specimens present clear traces of suspension and use, similar to the ones of necklaces, just like noted in Robert G Bednarik (2005b): "The wear facets range from flat-angled to quite steep recesses of conical shape, and their extent is always distinctly delineated. Unless discolored by the sediment, the P. glob. specimens are of the same buff color as the weathering rind or cortex on sedimentary silica (which is indeed what they consist of). The wear facets, however, are always of a notably lighter colour, and significantly they never bear any taphonomy markings as found on the rest of the surfaces of these fossil casts. It is evident that all worn specimens were worn only in two areas: next to and surrounding the two-tunnel openings. Only one type of abrasive wear can account for such consistently typical wear patterning: the stones must have been arranged with

their tunnels permanently aligned to be worn in this way. Such consistent wear patterns cannot be explained as natural phenomena, the beads can only have been subjected to this wear through hominid intervention." One of the father of the use-wear analysis, L. Keeley in his book "Experimental determination of stone tools uses" claims to have analyzed a "number" of these beads in the Pitt-Rivers Museum and states: "There is no doubt that some of these fossils show artificial enlargement of their natural orifices" (Keeley, 1980: 164)" (Bednarik 2005b: 211).

In the study of Rigaud and colleagues, numerous traces of artificial enlargements of the holes were found on some of the analysed beads too (Rigaud et al. 2009). However, within the same study, it was also noted that in several archaeological specimens, the yellowish patina that covers their surface is absent on the area adjacent to the perforation.

Our analysis considered a consistent collection made of 520 beads from the Civic Museum of Modena and led to determine the same typologies of traces: 489 pieces have removals near the through-hole and 105 pieces show no sign of patina on the area adjacent to the perforations or on the areas with traces of removals (i.e. traces with a centrifugal orientation that indicates that the agent responsible for them exerted a pressure on the hole edge from inside the perforation to enlarge the hole).

To better define the absence of patina on the above-mentioned areas, we used a method inspired by that used to identify the differentiation of the patina on the Sherborne bone (D'Errico et al. 1998). In order to reduce any errors due to a different orientation of the samples respect to the light source of the microscope (Leica EZ4 HD), we used the internal lights of the microscope always in the same position, with the same intensity and in a dark environment. Furthermore, we have always placed the samples in the same position, at the same distance from both the objective and the lights. Thanks to the image processing program ImageJ on different greyscale pictures obtained by the Leica EZ4 HD microscope, we were able to obtain grey values histograms of the different areas of the beads.

In Fig. 4, clear differences are evident between the values of the light-coloured surfaces, composed of a wide range of light greys, and the surfaces covered by patina, consisting in narrow peaks of dark greys. Therefore, the data resulting from our study are fully consistent with the ones exposed in previous studies (Rigaud et al. 2009) (SOM Fig. S7 to SOM Fig. S19).

With similar results, Bednarik (1997, 2001, 2005b, 2020b, 2020a) concluded that the *Porosphaera globularis* fossils were really used as beads by the Acheuleans. Differently, others ascribe these traces to the activity of scholars and/or collectors of the nineteenth century and to the conservation of the beads assembled in necklaces (Oakley 1965; Rigaud et al. 2009). A practice of forgery aimed at the counterfeit trade that was consistent during the nineteenth century.

However, since it is not possible to date the different traces found in the areas near the holes of the possible Acheulean beads and the hypothesis of the nineteenth century, origin of the traces is as valid as that of the prehistoric origin one. The problem was considered from a different point of view: if the beads were used as part of necklaces by the Acheulean hominids, then they should present other traces to confirm or disprove the use as personal adornments; the ones linked to the friction of the necklace with the body of the bearers (Berruti and Viola 2008; Cristiani and Borić 2012; Falci et al. 2017; Paixão et al. 2019).

If the assembled necklace beads have never been used, then the specimens strung for conservation, study and exhibition in museum purposes would have not any type of friction traces on their external surfaces. Therefore, for the first time, we considered the rubbing activity of the fossils on the bearer's skin.

We took 5, not perforated, fossils of *P. globularis* from two different paleontological formations: four are from the Cretaceous Campanian of Hannover's formation and one is from the formation of the Cretaceous Campanian of Logstor. We then developed an experimental activity consisting in rubbing these fossils on a piece of a pig skin, which is very similar to human skin (Schmook et al. 2001; Summerfield et al. 2015) (SOM Fig. S20 to SOM Fig. S22).

The use of clothes by the Acheuleans was excluded, since different studies undertaken so far have confirmed that clothing has to be considered to a more recent period in the evolution of hominids (Light and Reed 2009; Gilligan 2010).

The experimentation was divided into two parts:

Three fossils were rubbed on a completely clean skin for a total of 10 min each.
Two fossils were rubbed on a piece of skin previously soiled with dirt.

The obtained results allowed us to notice that in all cases the external surfaces of the fossils are completely abraded and rounded after 10 min of contact with skin (Fig. 5).

When dirty skin is used, microscopic striae are present, because of the contact of the fossil surfaces with hard particles (Fig. 5, SOM Fig. S22 to SOM Fig. S25).

If we compare the results of the experimental activity with the features observed on the surfaces of the beads from the Modena collection, we can state that they do not share any similarities at all: no traces of abrasion comparable to that produced during the experiment have been identified on the surfaces of the Modena collection (Fig. 5).

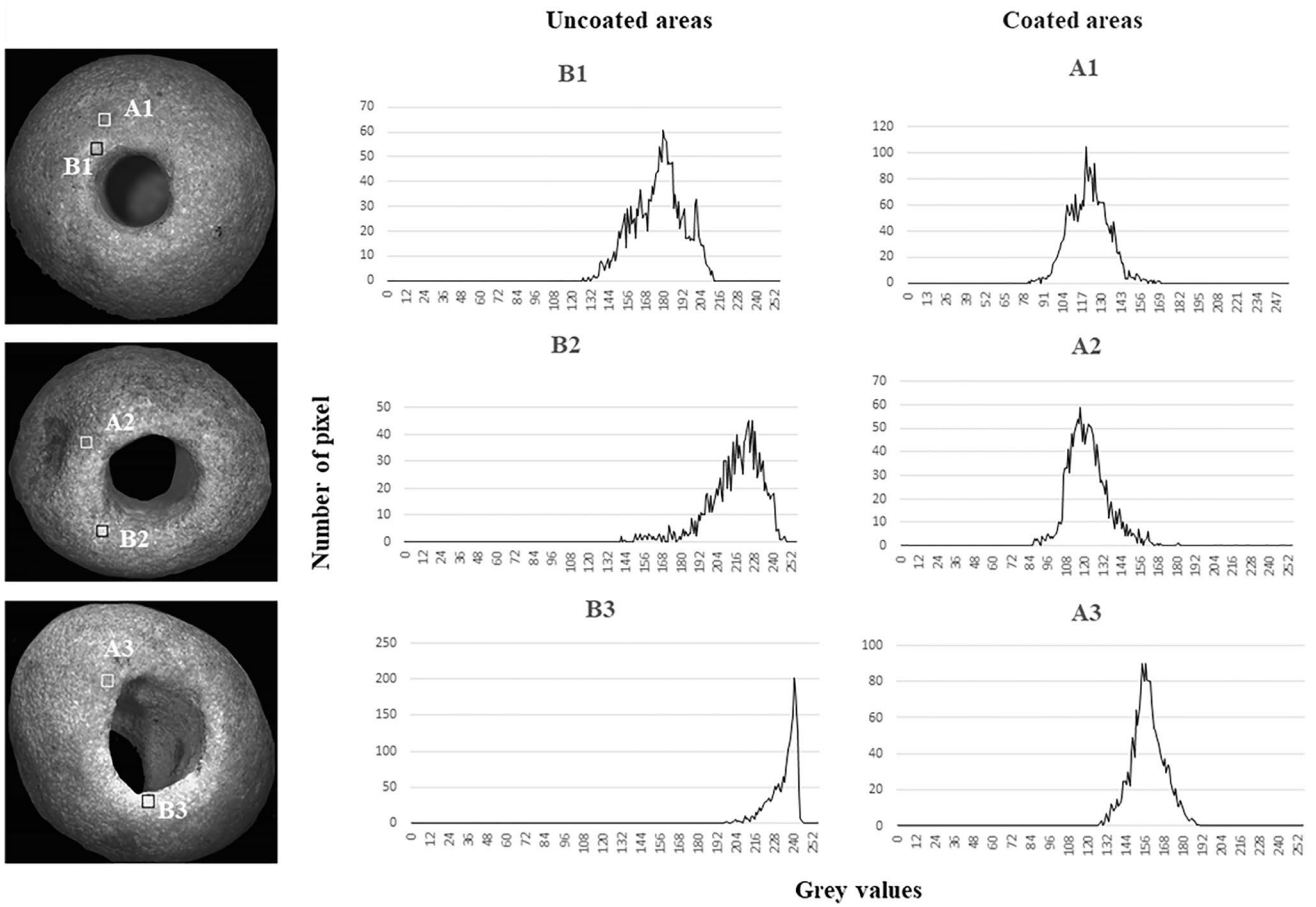

Fig. 4 Comparison between the grey values histograms of the analysed surfaces (i.e. those contained in the squares identified as A and B): the histograms on the left correspond to the areas B, near the holes affected by rubbing action with other specimens or by traces linked to an artificial enlargement of the holes; the histograms on the right are those referred to the areas A covered by patinas

Geological

To carry out this analysis, the four necklaces were observed and described at a macroscopic and at a microscopic scale, using a stereomicroscope Optika SZ series (8 ×–45 ×), equipped whit a camera Moticam 3.0 MP.

A first step of analysis was conducted through the observation and description of the necklaces as they were stored at the Museum. Then, each bead was individually analysed, thus allowing a detailed study of their morphology, state of preservation and alteration of both their external surfaces and their through-holes. In this way, it was possible to identify the alterations of natural and anthropic origin and to establish their chronological sequence.

Based on the morphology of the surfaces, the beads were grouped into three categories:

1. Fossils with surfaces showing marked rounding, smoothing and erosion surfaces, caused by their rolling in aquatic environments (Fig. 6, n. 3–4). The most affected surfaces by this phenomenon are the most exposed ones, i.e. the equatorial belt and the apical and basal portions. Smoothing and erosions are well visible at the stereomicroscope in the shape of micro-striae and traction traces that are on the surfaces and even affect the individual cells of the sponge, whose outlines are poorly defined.
2. Fossils with traces of dissolution, recrystallization and permineralization phenomena, due to circulation of rainwaters rich in iron minerals (limonite and goethite) in a phreatic environment (soils or karst wells). The original microstructure of the sponges is completely altered, at least for what can be seen in their most external stratum. Appearance, mineralogy and distribution of calcite mineralization have strongly been influenced by the action of water circulation. Two subcategories of fossils can be further distinguished:
   a. Fossils with almost uniform superficial concretions, mainly yellowish (goethite, limonite) or reddish (hematite), due to the stay of the fossils into soils or

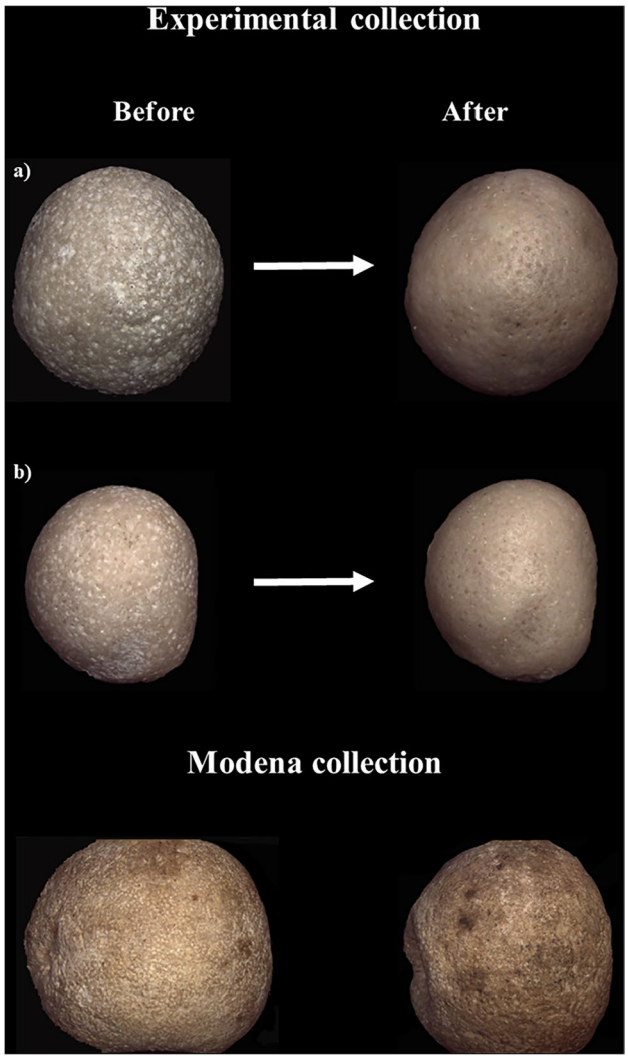

Fig. 5 (a) photomicrographs of the specimen K126 from Hannover before and after the experimentation (rubbing for 10 min on dirty pig skin); (b) photomicrographs of the specimen L844 from Logstor before and after the experimentation (rubbing for 10 min on pig skin); in the lower part of the image, two photomicrographs of the surfaces of two different specimens of the Modena collections. The surfaces of the samples K126 and L844 before the experimentation are similar to the surfaces of the samples from the Museum collection; after the experimentation, the surfaces are strongly smoothed

karst wells with a clayish matrix rich in iron minerals. Therefore, they suffer alterations due to the deposition soils (Fig. 6, n. 5–6).

b. Fossils with marked dissolution and recrystallization phenomena having an irregular distribution and due to rainwater circulation (vadose meteoric environment). In fact, there are clear phenomena of calcite mineralization, macrocrystalline as well, located only on lower fossil surface, the pending one (Fig. 6, n. 7–8). Such processes occur in quite stable clastic sediments that are crossed by rainwater directed towards the water table. A large amount of evidence suggests the presence of processes proper in an underground karst environment (smooth surfaces with scattered dissolutions associated with pending crystallizations).

The beads belonging to this category do not show marked rounding or weathering traces; the alterations identified on their surfaces are consistent with provenance from secondary deposits located close to the primary outcrops, i.e. vadose concretions.

3. Fossils with no alterations, coming from outcrops or from detrital deposits close to the outcrops. These fossils look clean with a whitish appearance and their surfaces show no traces of mechanical or chemical alterations.

At the stereomicroscope, the fossil's microstructure is very well preserved, and the pattern of the cells forming the sponge skeleton is clearly detectable (Fig. 6, n. 1–2). These beads were directly collected from the outcrops or in the immediate surroundings. In this group are even included some beads showing a less fresh appearance, but with clear fractures due to detachment from outcropping rock surfaces.

A considerable number of beads preserves marl residuals (often even of minimal dimension) in the through-hole (Fig. 7, n. 1–3). In most cases, the marl surface is altered (yellowish), thus suggesting a natural process in progress, i.e. a not yet completed process of marl dissolution. The alteration of the marl is the result of the contact with clayish sediments, or it could be due to the action of water rich in minerals.

A reduced number of beads show fresh marl surfaces, whitish in colour, together with marked longitudinal grooves, that could attest to an anthropic recent action of perforation of the marl or of intentional enlargement of the hole. Unfortunately, the presence and the mechanical action of the thread partially overlap these traces and make the interpretation quite difficult. These beads are generally not affected by strong rounding or weathering processes and can be referred to secondary deposits located at a short distance from the primary outcrops (see Table 4).

Two beads have two opposite conical holes that converge in the shape of an hourglass towards the centre of the hole (Fig. 7, n. 5–10). In both cases, it is not possible to understand if they are enlargements of the original hole or if they correspond to a new piercing. Looking in detail at the through-hole surface, concentric striae can be identified. They affect the internal calcite wall of the sponge and they seemingly confirm the use of a drill (Fig. 7, n. 9–10). Then, they could correspond to an action that can be ascribed to late prehistory or to historical ages. Concentric striae are not present on other beads, where longitudinal traces and

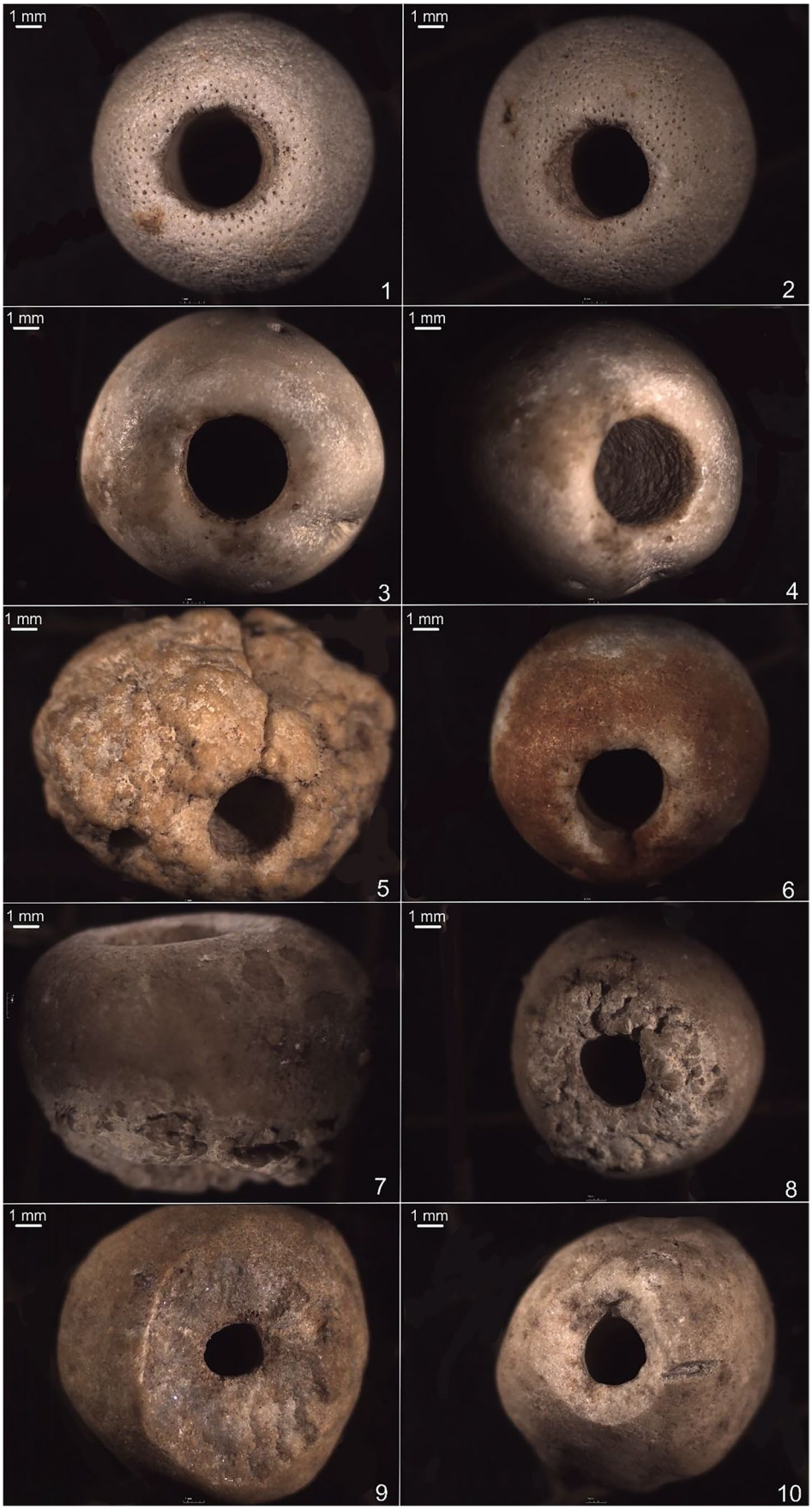

Fig. 6 Specimens of the Modena collection. Specimens with microstructure very well preserved, the pattern of the cells forming the sponge skeleton is clearly readable (1–2); specimens with surfaces showing marked rounding, smoothing and erosion surfaces, caused by their rolling in water environments (3–4); specimens with almost uniform surface concretions, mainly yellowish (goethite, limonite) or reddish (hematite), due to the stay of the fossils into soils or karst wells with a clayish matrix rich in iron minerals (5–6); specimens with marked dissolution and recrystallization phenomena having an irregular distribution and due to rainwater circulation (vadose meteoric environment) (7–8). Indeed, there are clear phenomena of calcite mineralization, macrocrystalline as well, located only on lower fossil surface, the pending one

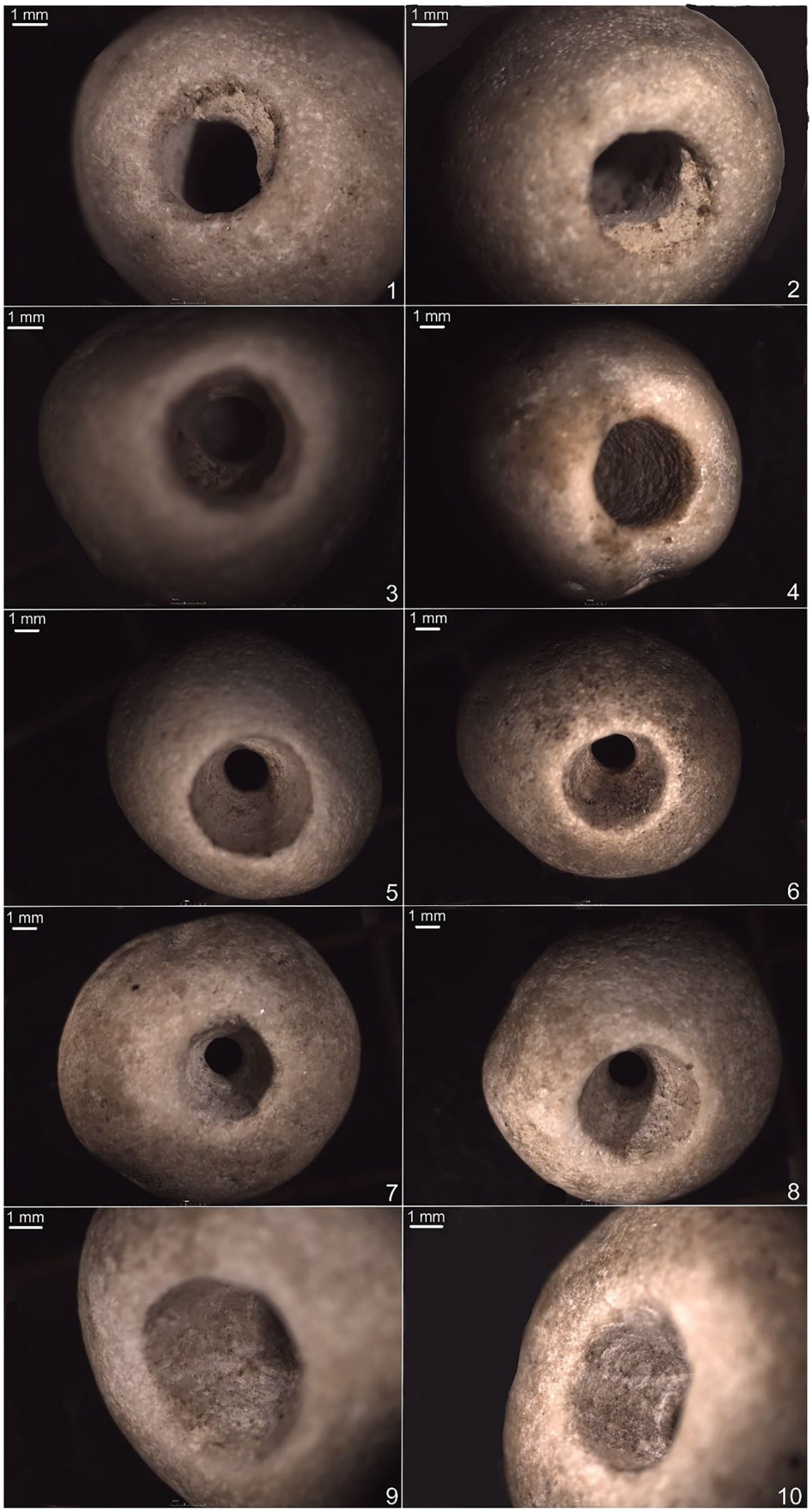

Fig. 7 Specimens of the Modena collection. Specimens with preserved marl residuals in the through-hole (1–4); specimens with two opposite conical holes that converge in the shape of an hourglass towards the centre of the hole (5–10). Looking in detail at the through-hole surface, concentric striae can be identified (9–10); they affect the internal calcite wall of the sponge and they seemingly confirm the use of a bow drill

Table 4 Geological provenience of the specimen of the necklace 3 of the Modena collection

Alluvial deposits	49.35%
Soils/karts wells	44.23%
Outcrops	6.41%
Total	**100%**

striae are dominant. The fresh appearance of the surfaces hypothesizes the work of a good craftsman/forger.

Cultural

Significant advances have been made so far in the understanding of the onset of symbolic behaviour, and the available framework into which to fix our study is undoubtedly richer than the last decade. Of course, there are still scholars who oppose the hypothesis of symbolic practices prior to anatomically modern humans (AMHs), implying that the material culture in Europe would not be older than *c.* 40 ka BP, stating that the different kinds of evidence are "exceedingly rare and often ambiguous" White et al. (2020:3). On the other hand, there are other researchers who support the idea of a gradual acquisition of modern cognitive abilities already before the AMH appearance.

Within this debate, beads and personal ornaments play a fundamental role in investigating the emergence and development of symbolic behaviour (Abadía and Nowell 2015; Lbova 2021). The Acheulean beads from Saint-Acheul were used as a further element to foster this idea of gradual development (Bednarik 1997, 2001, 2005b, a).

However, if we look into both the immediate near regions around the site and the wider territory, no more beads with similar chronology were ever unearthed so far. Nowadays, the only possible Lower Palaeolithic beads recovered are the ostrich eggshell fragments from El Greifa in Lybia (Bednarik 2005a), though their chronology is still ambiguous and their recovery context is not well known, nor any photography has been provided so far. More secure dated examples of personal ornaments are the more recent ones from Skhul Cave and Qafzeh Cave in the Levant (Vanhaeren et al. 2006); Blombos, Sibudu and Border Caves in South Africa (d'Errico et al. 2005; D'Errico and Backwell 2016); Grotte des Pigeons, Rhafas and Contrabandiers in Morocco; Oued Djebbana in Algeria (Bouzouggar et al. 2007; Vanhaeren et al. 2006); and Cueva de los Aviones in Spain (Hoffmann et al. 2018a). Therefore, they do not provide strong supporting references for such ancient findings like the St.-Acheul sponges, and do not help in solving the issue of beads production in the Lower Palaeolithic.

Literature provides more examples of supposed symbolic material culture of this period, but they are still too scant. The Berekhat Ram figurine is the only known one with a precise and securely dated context, together with the 75 fragments of pigment from Terra Amata (D'Errico and Nowell 2000; Bahn 2016). Doubts are still present on the engraved bones from Bilzingsleben, or the red mineral piece found in Bečov in Czech Republic (Bahn 2016). Within this poor and weak framework, the interpretation of the *P. globularis* fossils as collected to be used as beads for necklaces in the Lower Palaeolithic is a mere speculation. Moreover, the traceological analysis, reported above, further excludes the possibility of contact with the skin and the abrasion caused by any lace use ab antiquo.

In any case, the absence of more comparable elements, from Europe at least, may be further justified by the interpretation of the *P. globularis* fossils as witnesses of water environments (Wilmsen et al. 2012; Jurkowska et al. 2015). Any speculation about their anthropic use has been excluded for their abundance and variety in terms of being perforated or not, showing the natural accumulation and alteration of these sponges. This interpretation was already clearly stated in Prestwich (1860a), where the author reported the results of his visit to the St.-Acheul site, providing a stratigraphic scheme of the pit and noting the presence of the *Coscinopera globularis*, now *P. globularis*, in the excavated layers. The scholar already pointed out that the fossilized sponges were abundant on the chalk shores of Britain, especially of Newhaven, excluding the artificial origin for the French ones too (Prestwich 1860b).

We reconsider, in this perspective, the sale of the necklaces at the Civic Museum of Modena since it is known that Le Beuf used to sell archaeological finds and "curious objects", amongst which false pieces could be found as reported in Zanasi (2019).

Discussion

The here presented study deals with the largest collection of the supposed Acheulean beads from the eponymous site of Saint-Acheul and even considers the data from the previous studies about the same fossils whose use has been debated, to definitively "resolve the Porosphaera 'mystery'" (Rigaud et al. 2009: 33). The question linked to the use of these fossils as personal ornaments required the integration of different approaches to investigate the human agency behind their accumulation, transport, selection, anthropic modification and, of course, use. Furthermore, we considered the review of some bibliography not used in the previous literature.

The fossils from the Modena collection are all from the Saint-Acheul site, significantly increasing the record exposed in Rigaud et al. (2009), where authors could count on a very limited number of pieces, 16. Therefore, to trace the context of recovery of the studied fossils, we looked into the bibliography including what seems to us a fundamental work, i.e. Prestwich (1860a, b), excluded from the bibliography

of both Rigaud et al. (2009) and Bednarik (2005b). Within the latter, only the abstract (Prestwich 1860b) was considered, so missing a key part which is the stratigraphic section of the excavation. Indeed, the English scholar who had the opportunity to visit the site was even introduced to the *Coscinopora globularis* fossils, but he recognized their random accumulation within the stratigraphic succession with no specific accumulation, but recalling the outcrops of other sites, for instance Newhaven (Prestwich 1860a). Therefore, we have clear indication of no transportation, nor the human agency in transporting such fossils to the Saint-Acheul site, but a presence of them in association with gravels and more aquatic fossils further confirms their link with the downstream alluvial terraces.

The recent reappraisal of excavation activities in Saint-Acheul (e.g. Tuffreau et al. 2001) that reveal no association of these fossils with Acheulean artefacts provides only a further confirmation of the impossibility of linking the two typologies of evidence. Finally, it has to be remarked that, from the Rigaud et al. (2009) publication, more excavations have been carried out in Saint-Acheul, but still no necklace beads, like the ones of the Museum of Modena, have been found in association with artefacts so far (Antoine et al. 2016, 2019). The information provided by Prestwich (1860a) seems to further exclude any unique selection of the pieces preserved at the Civic Museum of Modena, but a precise selection of some specimens.

The morphometric data about the size and sphericity of the fossilized sponges of the Modena collection reinforces and confirms the preferential selection made by choosing the naturally perforated and more spherical pieces. Dimensionally, the beads fully fall within the variability of the data collected in the study proposed by Rigaud and colleagues that refers to beads from other "Acheulean contexts" and differ, in the same way, from the finds from the paleontological context of Rügen (see Table 5) (Rigaud et al. 2009). Our results are completely comparable to those obtained in the Rigaud and colleagues' study, whose "results indicate that specimens from museum collections differ significantly, with respect to dimension and perforation size, from those of our natural reference collection" (Rigaud et al. 2009: 31).

To explain this, the three main reasons given in Rigaud et al. (2009) can be considered: (1) a selection bias imparted by a natural process, or (2) a deliberate choice made either by Acheulean hominids or (3) by nineteenth-century collectors.

In our case, a collection of exclusively perforated fossils is recognized; these were already sold strung in 4 different necklaces. Nevertheless, the information provided by Prestwich (1860a) confirms the existence of fossils naturally enclosed within the sediment, making the presence of four necklaces within a natural deposition of the same specimens. Differently, it reinforces the hypothesis of a recent intentional selection.

To finally resolve the issue of *P. globularis* fossil's use, wear analysis became strategic. To accomplish this, we considered investigating the through-holes of the pieces and also considered the outer surface of the specimens. In addition, we performed experiments on fossils from natural outcrops to determine the presence of signs of use on the presumed beads.

By examining the perforations, we noted evidence of intentional enlargement of natural holes such as that also found in all collections known in previous studies: "Three archaeological specimens from Bedford2 and two from Biddenham2 exhibit continuous microchipping around the perforation that has removed large areas of the original pitted outer natural surface. The centrifugal orientation of

Table 5 The dimensional data of *Porosphaera globularis* from the collections analysed in this study in comparison with the data collected in of Rigaud et al. (2009). The data of the Modena collection are very similar with the data obtained by all the specimens that came from "archaeological sites" and are very different from the data that came from the paleontological site of Rügen

Provenance	Coefficient of sphericity					Maximum diameter (mm)		Perforation maximum diameter (mm)	
	n	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Mean	Std. Dev
Saint-Acheul	16	0.99	0.01	0.95	1.00	11.06	4.31	4.38	0.97
Amiens	30	0.99	0.01	0.95	1.00	12.07	1.59	4.21	0.77
Paris	29	0.97	0.03	0.86	0.99	13.71	3.03	5.46	1.43
Soissons	11	0.99	0.00	0.98	0.99	13.76	1.79	4.83	0.83
Biddenham1	30	0.99	0.01	0.96	1.00	10.51	3.50	6.09	1.31
Biddenham2	29	0.99	0.01	0.97	0.99	13.80	1.68	5.57	0.95
Bedford1	49	0.98	0.01	0.90	1.00	13.46	2.41	5.66	1.15
Bedford1	17	0.99	0.00	0.98	1.00	19.85	3.30	6.42	1.04
UK1	19	0.99	0.01	0.95	1.00	13.88	2.85	5.67	2.05
Uk2	101	0.99	0.01	0.95	1.00	12.19	2.85	4.11	1.08
Modena collection	**520**	**0.98**	**0.04**	**0.85**	**1.00**	**11.43**	**1.25**	**3.85**	**1.19**
Rügen	***34***	***0.92***	***0.18***	***0.24***	***1.00***	***11.00***	***4.22***	***24.90***	***3.38***

the removals indicates that the agent responsible for them exerted a pressure on the hole's edge from inside the perforation……With a single exception, microchipping is found on the specimens with the smaller perforations, which supports the idea that it was executed in order to enlarge the hole" (Rigaud et al. 2009: 30). Even in Bednarik (2005b: 210), it was reported that: "The other factors demonstrating their use as beads are the evidence of flaking and percussion or pressure damage that occurs at the partially or fully closed end of the fossil's tunnel". Of course, the presence of anthropic intervention on the specimens would not justify a natural selection a priori. However, we were able to notice that the enlargement of the through-holes is on just a limited number of specimens. This limited quantity may reinforce the hypothesis of the need of using the most spherical fossils for the necklaces. Therefore, we examined the perforation profiles, whose conical shape testifies to the use of a drill, which left easily recognizable concentric marks on both the marl residues and the calcite inner wall. Further information is provided by the different colours of the marl residues, which show different states of alteration caused by different exposures to contact with clay sediments or to the action of mineral-rich waters.

The edges of the holes and their adjacent areas show no traces of patina, similarly to what recognized in the record studied by other scholars (Keeley 1980; Bednarik 2001, 2005b, a, 2020a; Rigaud et al. 2009), thus excluding any perforation done in the past (D'Errico et al. 1998; Sigari and Bona 2021).

Along with the puncture marks, we recorded clear traces of suspension. However, these were only caused by their arrangement in necklaces for display, offering a good indication for any revision of *P. globularis* fossils described in previous literature. Analogously, traces of suspension were also identified during the study of the other collections: "The localized abrasions exposing the internal matrix of the archaeological Porosphaera, recorded on a number of specimens, appear fresh and are probably due to friction from rubbing against other fossils strung in ''necklaces'' by collectors and museums curators." (Rigaud et al. 2009) and "Only one type of abrasive wear can account for such consistently typical wear patterning: the stones must have been arranged with their tunnels permanently aligned to be worn in this way." (Bednarik 2005b). If we carefully analyse the images of the beads present in Bednarik's publications of 2005, it can be seen that one of the findings (specimen C) shows evident traces of calcite mineralization while the others seem to have undergone alterations caused by the deposition of soil (Bednarik 2005a) (SOM Fig. S26). These data are consistent with the geological analysis conducted on the beads of the Modena collection.

All the data, collected by different researchers, reasonably suggest that the fossils of the Modena collection are similar to those observed in other collections. This allows us to reconsider not only the finds in the analysed collection but also all *P. globularis* interpreted as Acheulean beads.

In order to add more elements towards a definitive interpretation, we considered more aspects. The experimental part of the present work allowed us to collect information regarding the use of beads as an accessory, thus considering the contact between skin and object, providing further elements for the interpretation of the use of fossils. A brief rubbing on both dirty and clean skin showed significant traces of abrasion on the pieces used for experimentation. On the contrary, no trace of abrasion was recognized on the external surfaces of the beads of the necklaces of the Museum of Modena, so that it must definitively be excluded that they were worn by individuals as body ornaments.

A final question concerns the doubts that must be cast on the seller of the fossils, Charles Le Beuf, whose past is somewhat ambiguous, as evidenced by a number of forgeries that he had sold (Zanasi 2019). The presence of fake archaeological findings does not come as a surprise: trades of this kind were flourishing during the nineteenth century and until the beginning of the twentieth century (Whittaker and Stafford 1999; Elisa Bernard 2020; Sigari and Bona 2021). A proof of this is the complaint of Boucher de Perthes that during its archaeological investigations (1840s–1860s) at Amiens kept receiving proposals for the purchase of forgiaries from the people working at the archaeological site (Rieth 1970; Whittaker and Stafford 1999). This trading activity was common both in Europe and the USA: Thomas Wilson, in 1888, complained about the large number of archaeological fakes (mainly lithic tools) offered for purchase at the Smithsonian Museum (Wilson 1888).

The fossil beads of *P. globularis* preserved at the Museo Civico of Modena were also part of a somewhat blurred picture, on whose uncertainty light was finally shed. Indeed, the present work, reviewing a record of 520 pieces, helps in the resolution of "The Porosphaera mystery" (Rigaud et al. 2009).

Conclusion

Our study gets to finally exclude any anthropic use of the *Porosphaera globularis* fossils as personal adornments during the Acheulean, so further limiting the available documentation of material culture production from this period to a sparse number of pieces. The most ancient evidence of symbolic behaviour in Europe documented so far still remains dated to the Middle Palaeolithic. Differently, the most ancient evidence of personal ornaments has to be found on the European continent, but still remains younger than the supposed Acheulean beads. Of course, further investigations have to be considered to confirm the ostrich eggshell

of El Greifa, but for the moment that record is still too scant and ambiguous to be taken into consideration (Ziegert 1995; Bednarik 1997).

In addition, the study emphasizes the need to consider a comprehensive bibliography, which often contains useful information, and to insist on an integrated approach that includes multiple possible combinations of approaches, as the experimental section of the present work demonstrated, by providing more data for analysis in the review process.

To conclude, it must be emphasized that the exclusion of the "Acheulean beads" of Saint-Acheul from the list of the evidences used to justify the pre-AMH origin of the symbolic behaviour does not prevent the possibility of the existence of a material culture produced in the Lower Palaeolithic.

In our opinion, this study only reinforces the need to continue with an open-minded approach that helps finding solid evidence and arguments to further support the hypothesis of whether or not cognitive skills were acquired gradually.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12520-022-01629-9.

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