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Grimes Graves revisited: a new light on chalk ‘lamps’

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Summary Grimes Graves in Norfolk is one of 10 surviving Neolithic flint mines in England. The first excavations at the site were undertaken in the late nineteenth century, followed by further campaigns throughout the twentieth century, most recently by the British Museum in the 1970s. Within the shafts and galleries of the mine workings deer antler picks were found and also a range of objects made from chalk. A major part of the assemblage is now held at the British Museum, among which are 45 small cup-shaped chalk objects in a range of sizes. These have been previously interpreted as lamps used by the Neolithic miners, although they have also been found in Middle Bronze Age contexts at the site.

Results from chemical analysis of residues in the cups undertaken in the 1980s seemed to provide support for the lamp theory but the interpretation has always been controversial. In particular, the question of the necessity for lamps in the galleries has been discussed, as reflected light from the chalk shaft might have provided adequate illumination. Moreover, no traces of burning or soot stains on either the cups or the interior walls or roofs of the galleries have been reported. This study has sought to re-examine the function of the chalk cups based on new analytical and experimental data. Although experimental reconstructions showed that substances such as tallow could be absorbed into the porous chalk, even if they are not necessarily well retained, analysis by gas chromatography-mass spectrometry showed no evidence of residues of fat or oil lamp fuels in samples from the ancient chalk cups. The potential for depletion and loss of such residues during use and burial is considered and the implications of the findings for interpretation of the function of these objects are discussed.

INTRODUCTION

The Grimes Graves flint mines lie on a low chalk rise in the Norfolk Breckland, with the visible deep mine shafts clustered at the top, see Figure 1 for the location. To the north and west, dry valleys contain a mixture of shattered chalk, chalk mud combined with sand, and sizeable flint nodules and fragments moved downslope by periglacial processes. The flint deposits in these valleys were quite easily exploited by means of shallow workings, but on the hill much deeper shafts had to be sunk to reach the flint, particularly the most desirable flint seam – the so-called ‘floorstone’ – in the deepest of three flint layers. The floorstone is a tabular flint, but it occurs in a discontinuous seam of large, roughly hemispherical nodules that are sometimes joined at the top by a thin layer of flint [1; p. 79]. In order to maximize the return on the labour involved, the miners drove galleries radially from the base of each shaft to follow the seam. The

first shaft to be emptied by archaeologists was excavated by Canon William Greenwell between 1868 and 1870 [2, 3]; the base of the eponymous Greenwell Pit is around 12 m (40 feet) below ground level and the basal 5.5 m (18 feet) comprises solid chalk. Over 400 pits, shafts and quarries have been counted at the site, but there are probably many more.

Flint was mined from a very early stage during the Neolithic period, probably as early as the first causewayed enclosures and long barrows in around 3800 BC. The early mines are chiefly situated on the South Downs, but these had gone out of production by the time that Grimes Graves came on stream during the later Neolithic, around 2600 BC. It was probably unnecessary to go to great lengths to procure flint when there were accessible sources widely available, deriving for example from boulder clay, so it is very likely that the floorstone had a special value, which was enhanced – much like the tuffs exploited at quarry sites in Great Langdale,



FIGURE 1. The location of the Grimes Graves site

Cumbria – by the very difficulty of obtaining it. Stones other than flints quarried at such sites were destined for axes, as was much of the mined flint from the South Downs. Because of particular problems, it has proved more difficult to track the mined product from the Grimes Graves site, but it is known that axes were made in considerable numbers and that these left the mining area as roughouts. The same can be said for discoidal knives, a tool type characteristic of the Late Neolithic. Finally, small tools for immediate use were also made.

Each of the major excavations at Grimes Graves has produced chalk cups or ‘lamps’, found in both Late Neolithic and Bronze Age contexts (the weathering cones in the excavated shaft tops were found to contain deposits of Middle

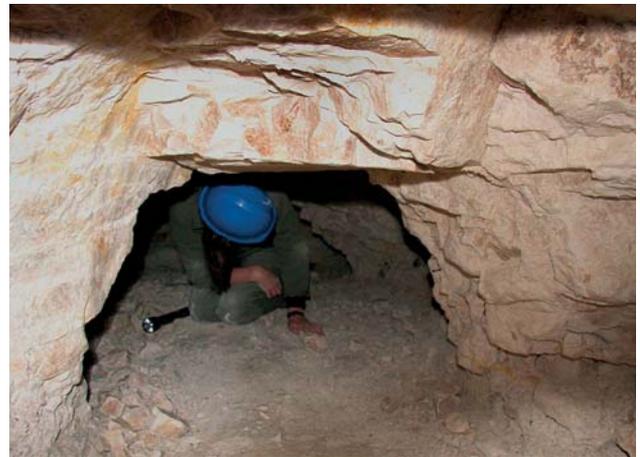


FIGURE 2. One of the shafts at Grimes Graves. The surface of the ceiling and walls rubs off easily on contact. Although the entrance to the shafts was covered when the image was made, light reflects very well from the bright white chalk and illuminates many galleries for some distance beyond the base of the shaft

Bronze Age midden material dumped here from settlement sites that have yet to be located) [2–9]. The degree of finish on these chalk cups varies and they were made on the spot using flint tools. Chalk cups have also been found in association with earlier flint mining activity in Sussex and their function as lamps has been discussed, supported by evidence from scientific analysis undertaken in the 1980s [4; p. 103, 10]. However, it has also been noted that light reflects very well from the bright, white chalk and illuminates many of the galleries for some distance beyond the base of the shafts, so that artificial light may not have been necessary, Figure 2. This has led to the alternative interpretation that these small chalk ‘lamps’ were used for ritual purposes, perhaps as libation vessels [11]. Some Neolithic placed (i.e. deliberately positioned) deposits have been found at flint mining sites in Britain, such as the curled-up dog from Grimes Graves discovered in one of the galleries driven from Greenwell Shaft A [1].

To date, only limited studies on pre-Neolithic and Neolithic lamps from Europe have been published, but lamps

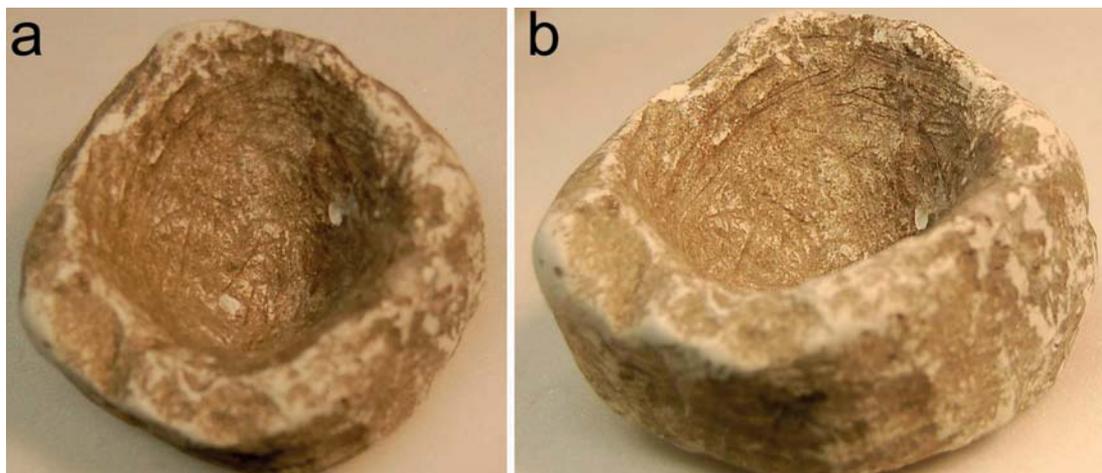


FIGURE 3. Bronze Age chalk ‘lamp’ C28 (1959,0712B.1) from Grimes Graves viewed: (a) from above; and (b) from the side

TABLE 1. Description of the ancient chalk cups and the samples taken from them

Pit name	Period	Object No.; registration No.	Description ^a	Samples taken ^b
Shaft X	Bronze Age	C2; 1987,0202.2	Small, shallow, carefully made cup with one lug handle. Hollow made chiefly by gouging. h. 16; dia. 39; dd 5; and m. 25.7	Interior (0.036)①; and dirt/exterior (0.045)①
		C4; 1987,0202.4	Small, broken cup with hooked protuberance serving as a handle. Roughly oval depression has been made by gouging and reaming; sides of depression bear parallel horizontal grooves. h. 35; l. 47; dd 20; and m. 33	Interior (0.05)①; and dirt/exterior (0.032)①
		C6; 1987,0202.6	Well-made but broken cup. Would have formed a long oval shape with deep oval depression. Base flattened. h. 33; l. 74; dd 19; and m. 78	Interior (0.048)①; dirt/exterior (0.03)①; interior (4.463)②; and dirt/exterior (0.434)②
		C18; 1987,0202.18 ^c	Roughly rounded cup with flattened base and deep conical depression. h. 43; dia. 70; dd 15; and m. 120	Interior (0.06)①; dirt/exterior (0.067)①; interior (10.629)②; and dirt/exterior (0.041)②
		C23; 1987,0202.23	Broken, large, roughly trapezoidal cup. The deep depression has almost vertical sides and a roughly flattened bottom; the sides bear deep vertical grooves and there are marks of pecking on the base and sides. Externally, although there is grooving on the base, no attempt has been made to flatten it. h. 96; l. 164; dd 46; and m. 930	Interior (0.066)①; and dirt/exterior (0.038)①
Greenwell's	Neolithic	C26; 1883,0705.47	Cylindrical cup, with finished depression. h. 40; dia. 60; dd 23; and m. 96. Greenwell Collection [1; pp. 419–439, 2]	Interior (0.051)①; and dirt/exterior (0.001)①
		C27; 1883,0705.48	Fragment of a cup. h. 44.5; w. 57; and m. 45.4. Greenwell Collection [1; pp. 419–439, 2]	Interior (0.063)①; dirt/exterior (0.055)②; and interior (3.953)②
Black Hole	Bronze Age	C28; 1959,0712B.1	Well-made cup the flattened base and sides of which bear traces of working, inside and out, probably with a flint blade. h. 52; dia. 84; dd 35; and m. 284. Armstrong Collection [4; pp. 192–193, 5; pp. 107–109]	Interior (0.059)①; and dirt/exterior (0.047)①
	Probably Bronze Age	C32; 1959,0712B.5	Broken cup with broad, shallow depression and rounded base. Externally, just below the mouth, are two adjacent scars where a vertically pierced lug has broken off. l. 87; and m. 118. Armstrong Collection [4; pp. 192–193, 5; pp. 107–109]	Interior (0.054)①; and dirt/exterior (0.025)①
Pit 4	Neolithic	C38; 1959,0712B.11	Roughly piriform block with well-executed broad and deep depression. The base is roughly flat and the tapering end of the piece forms a crude lug. h. 57; l. 147; dd 32; and m. 644. Armstrong Collection [6; pp. 119–122]	Interior (0.082)①; and dirt/exterior (0.086)①
Floor 4	Neolithic	C45; 1917,1105.27	Small, roughly cylindrical lump with flattened base and deep, oval hollow in upper surface made by scraping. Probably a cup. l. 52; dd 17; and m. 68.4. Oppenheimer Collection [7; p. 104, 8; p. 209]	Interior (0.075)①; and dirt/exterior (0.040)①

Notes

^a Dimensions are in millimetres: h. = height; l. = length; dia. = diameter; w. = width; and dd = depth of depression. 'm.' indicates mass in grammes.

^b Sample masses are given in grammes. Those samples labelled '①' were extracted with CHCl₃/MeOH and those labelled '②' with DCM.

^c Analysed by GC-MS in the past [3; p. 181], but analysed again by the authors.



FIGURE 4. Experimental replica chalk lamps. The cup to the left is filled with 'hard' tallow (T1) and the right cup is filled with 'soft' tallow (T2)

made of stone are believed to be very rare [12–14]. Furthermore, there is little direct evidence for the illumination technique used by early miners, making reliable interpretation of these little cup-shaped chalk objects of considerable importance, Figure 3. The research reported here explores and evaluates the evidence for the 'lamp' theory through fresh scientific and experimental investigation.

METHODS

Sampling and standards

In total, 11 of the cup-shaped chalk objects were analysed (see Table 1 for details), along with a chalk control sample collected from the Grimes Graves site, referred to hereafter as 'chalk standard'.

Samples were taken from the interior surface of each object and from the chalk standard using a hand-held drill to remove the chalk as a powder. In general an area with a diameter of approximately 4 mm was removed to a depth of 4 mm. From some of the objects a larger sample, with a diameter of 8 mm and a depth of 10 mm, was also removed. In addition, residual soil on the exterior surface of each object was sampled by gently scraping with a surgical scalpel so that any residue derived from the burial

environment could be eliminated when interpreting results from the interior surface samples, Table 1.

Sample preparation

Most of the samples were extracted using 1 mL of a mixture of chloroform (CHCl_3) and methanol (2:1 v/v) to which two internal standards – cholestane (2 mg per 5 mL CHCl_3) and tetratriacontane (2 mg per 5 mL CHCl_3) – had been added. Some samples, detailed in Table 1, were extracted with 1–10 mL of dichloromethane (DCM) containing the same internal standards. The insoluble material was allowed to settle and the solution was decanted to a fresh vial. For analysis by gas chromatography-mass spectrometry (GC-MS), 50 μL aliquots were removed and dried under nitrogen. Prior to analysis these dry residues were derivatized with bis(trimethylsilyl)trifluoroacetamide (BSTFA) containing 1% trimethylchlorosilane (TMCS) to form trimethylsilyl (TMS) derivatives. Procedural blanks were prepared alongside the samples to monitor background contamination. The remaining insoluble residue from each sample above was saponified by adding 500 μL of a 5% (w/v) solution of potassium hydroxide and heating at 70°C for four hours. The samples were acidified to pH 2 by adding hydrochloric acid and extracted with a 500 μL aliquot of hexane by vigorously shaking for four minutes. After decanting the hexane layer the procedure was repeated twice with fresh

TABLE 2. Samples taken from the experimental replica chalk cups

Replica cup	Sample name	Mass (g)	Description
T1 (hard tallow)	CTRL1	0.1488	Area on base of T1 that had not absorbed tallow (control sample)
	C4 wick T1	0.1101	Area near wick that had absorbed tallow
	C4 wick clear	0.0560	Area near wick that had not absorbed tallow
	C4 T1	0.0861	Area distant from wick that had absorbed tallow
	C4 clear	0.0786	Area distant from wick that had not absorbed tallow
T2 (soft tallow)	CTRL2	0.1467	Area on base of T2 that had not absorbed tallow (control sample)
	C5 T2	0.0599	Area that had absorbed tallow
	C5 clear	0.0477	Area that had not absorbed tallow

500 μL aliquots of hexane and the three extracts were then combined and concentrated under nitrogen to 500 μL . 50 μL aliquots were removed and dried under nitrogen and derivatized prior to analysis using the procedure described above.

Analysis by GC-MS

All the samples were analysed using an Agilent 6890N gas chromatograph (GC) coupled to an Agilent 5975C mass spectrometer (MS). Samples of 1 μL were injected in splitless mode at 52.47 kPa (7.61 psi), with a purge time of five minutes. An SGE HP-5 (Model number: SGE 1096508) MS column (12 m \times 0.22 mm, with a 0.10 μm film thickness) fitted with a 1 m \times 0.53 mm retention gap was used. The carrier gas was helium in constant flow mode at 1.5 mL per minute. After a two-minute isothermal hold at 50°C the oven temperature was programmed to 370°C at a rate of 10°C per minute with the final temperature held for 15 minutes. The MS interface temperature was 350°C. Acquisition was in scan mode (45–700 $\text{amu}\cdot\text{s}^{-1}$) after a solvent delay of 4.5 minutes. Both the equipment and the data collection/manipulation were controlled using G1701DA Chemstation software. Mass spectral data were interpreted manually with the aid of the NIST/EPA/NIH Mass Spectral Library version 2.0 and by comparison with published and unpublished data [15–20].

Experiments on replicas

Experimental replica cups were carved from chalk standard material collected at the Grimes Graves site. The replica cups were prepared as lamps by filling them with tallow around a section of wick with a length of approximately 3 cm. Two types of tallow were used (both sourced as tallow candles): the first (T1) was a well-refined ‘hard’ tallow and the second (T2) a soft tallow that was slightly pliable at room temperature. The ‘hard’ tallow was melted and poured into the cup while the soft tallow was pressed in around the

wick as a soft, solid mass. In each case, 4.8 g of tallow was used, which filled the cups almost to the rim, Figure 4. The lamps were then burned under observation until the fuel was entirely consumed and the burn time was noted.

After cooling, the lamps were visually examined for soot deposits and then longitudinally sectioned so that the extent of fuel absorption could be assessed and imaged under both visible and ultraviolet illumination, the latter using Philips PL-S 9W fluorescent lamps that emit principally at 365 nm and which were fitted with Schott DUG 11 filters that transmit in the range *c.*280–400 nm.

Samples for GC-MS analysis were taken by drilling from areas that had clearly absorbed the tallow and from areas that had not (*c.*0.06 g, see Table 2 for details) and were extracted with 500 μL of DCM to which of 40 μL of an internal standard of tetratriacontane (1 $\text{mg}\cdot\text{mL}^{-1}$ DCM) had been added. These extracts were further processed as described above for the samples from cups recovered from the mine shafts.

Mercury porosimetry

The porosity of the chalk standard was measured by mercury porosimetry. A sample of the chalk (*c.*1 g) was freeze dried for 24 hours and analysed using an automated mercury porosimeter (Micrometrics, Autopore II 9220). The volumes occupied by pores with radii between 2.8 nm and 0.036 mm were measured.

RESULTS AND DISCUSSION

To date, the main evidence to support the hypothesis that the chalk cups served as lamps has been the results of the previous study using thin layer chromatography and GC analysis [4; Appendix A, p. 181]. In that study of one sample from a single object (C18: 1987,0202.18) degenerate fat/oil compounds (triglycerides) were detected and were then attributed as “probably of a vegetable origin”. The same



FIGURE 5. Neolithic chalk 'lamp' C26 (1883,0705.47) from Grimes Graves. Compared to other finds, such as that shown in Figure 3, this cup appears rather yellow

object (C18) was included in this study (see Table 1), but the earlier results have not been reproduced. The composition of the extracts from almost all the archaeological samples was dominated by phthalate ester compounds derived from the plastic bags in which the samples have been stored since excavation. No significant amounts of fat- or oil-derived components were detected (i.e. nothing above the background levels detected in the chalk standard or in laboratory blanks), nor were any other constituents that might be attributable to a lamp fuel residue observed. The more vigorous extraction conditions of saponification, which can hydrolyse oxidized lipids bound as polymerized degradation products or by mineral interaction [21], also yielded negative results with no residue-derived material detected.

These results contradict those of the previous published study. In the absence of published data it is impossible to meaningfully revisit the earlier interpretation in order to understand this discrepancy, but the current data provide strong grounds to reject it and to conclude that no detectable (by GC-MS) residues of lamp fuel survive in these objects.

Some of the chalk objects from Grimes Graves are more yellow in colour than the remainder of the collection and the chalk exhibits a denser and less powdery texture. One such cup (C26) was included in this study, Figure 5. Analysis by GC-MS showed the presence of abundant stable triterpenoids, such as moronic acid, oleanonic acid and 3 α -acetoxy-*iso*-masticadienolate, which are typically seen in unaged *Pistacia* (mastic) resin. Although this resin has an ancient history of use in the eastern Mediterranean [17, 18], it would have been unknown and unavailable in Neolithic Britain. Moreover, the composition is characteristic of resin that has been subject to limited ageing [16, 18], leading to the conclusion that these yellow-coloured chalk objects have been consolidated or coated with mastic resin at some time since their excavation.

The absence of lipid residues in the chalk cups from Grimes Graves cannot be considered as categorical evidence that these objects were not used as lamps and careful consideration should be given to the possibility that residues are absent because they have not survived. Accumulation of residue is largely dictated by fabric characteristics, most importantly permeability. In archaeological environments, absorbed residues are known to survive better than surface deposits as the former are protected by the encapsulating fabric [22]. The porosity characteristics of the vessel are thus an important governing factor in the survival of residues following deposition [23, 24].

Examination of the porosity characteristics of the chalk standard from Grimes Graves showed that its overall pore capacity was 35.7% (Figure 6), very similar to that of a coarse ceramic fabric [25], and residues should thus be expected readily to penetrate the chalk. It should be noted

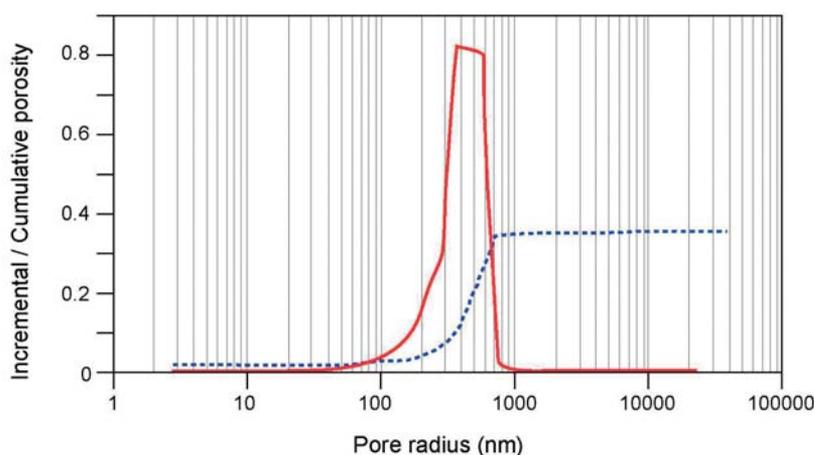


FIGURE 6. Microporosimetric analysis of the Grimes Graves chalk standard. The solid red line indicates pore size distribution and the broken blue line indicates cumulative porosity

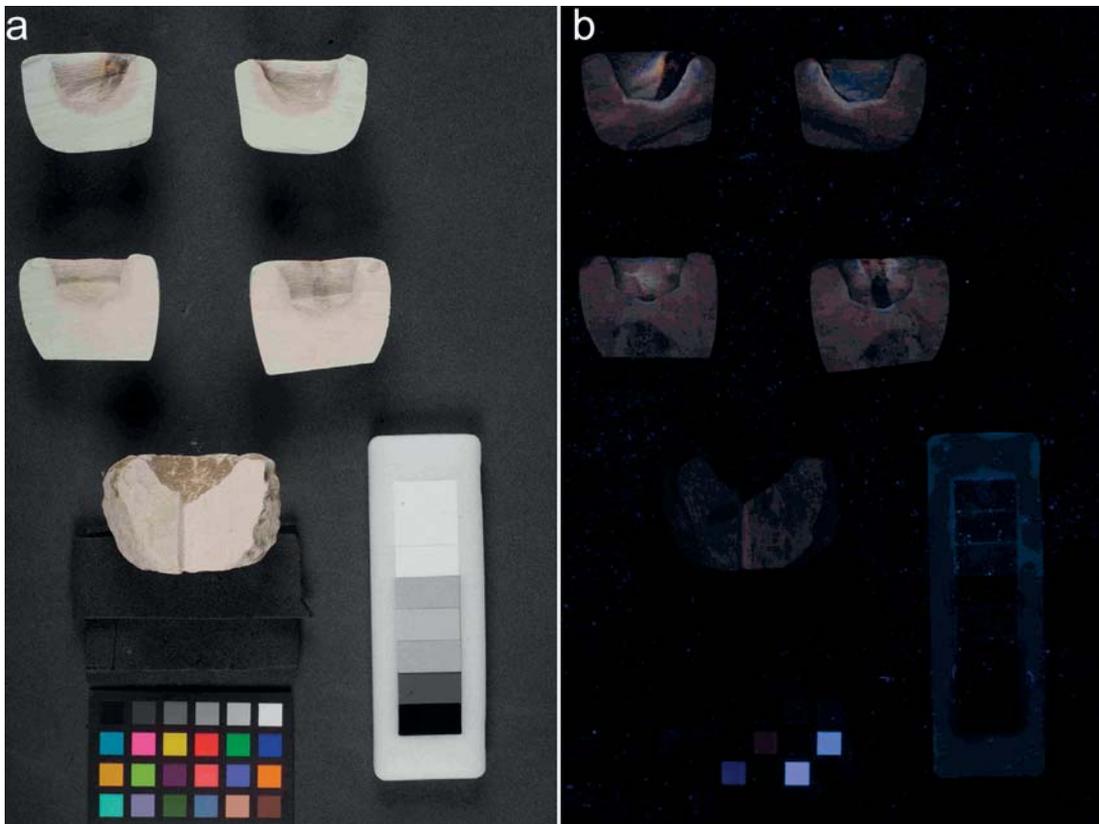


FIGURE 7. Cross-sections of experimental replica chalk lamps after burning and Bronze Age chalk 'lamp' C18 (1987,0202.18) seen: (a) in visible light; and (b) using ultraviolet-induced visible luminescence. From top to bottom: experimental replica cup used with 'hard' tallow (T1); replica cup used with 'soft' tallow (T2); and cup C18

that the porosity of chalk varies with depth within a geological deposit. In East Anglia the porosity–depth gradient has been reported to be in the order of -0.07 to -0.10 percent porosity per metre [26; p. S140]. Although chalk fabric taken from deeper in the ground will have lower porosity, the deepest mine at Grimes Graves is only *c.*12 m below ground level. The difference in porosity between chalk near the surface and that deeper in the ground can, therefore, be estimated at around -1.2% , which yields a value that is still comparable with that of coarse ceramics. In contrast, the pore distribution is rather different, 300–700 nm for chalk samples compared to 3–200 nm for a typical ceramic. This has important implications for residue preservation, since larger pores are less effective at preventing the microbial ingress that leads to degradation of the residues [27–29].

Survival of absorbed lipid residue is further influenced by the prevailing conditions in the burial environment. The relative importance of factors such as temperature, moisture and acidity (and their fluctuation) in residue degradation is not well understood and preservation of residues at different archaeological sites can be unpredictable. Hydrolysis and oxidation are known to be the main chemical reactions involved in the alteration of lipid residues [19]. Acylglycerols may be completely hydrolysed to form free fatty acids that may then be progressively leached away. Survival of lipid residues in association with other material at the site would provide the most reliable evidence for the potential

for residue survival at Grimes Graves (taking into account differences in fabric characteristics already noted) but unfortunately there is no suitable material from Neolithic contexts with which to compare.

The experiments undertaken in this study were designed to evaluate further the extent of absorption of lamp fuel by the chalk fabric and to investigate the practicality of chalk as a fabric for lamps – primarily in terms of how permeability affects its capacity to hold the fuel without leaking – as well as the duration of illumination provided by a single fill of fuel. A perplexing aspect of the previous study was the conclusion that a chalk cup showed evidence of the presence of “vegetable oil”, as there are no obvious sources for such a product in the Neolithic period. Accordingly, animal fat (tallow) was selected in this study as the most likely fuel available in the area during the period, since animal fats have been identified in Ice Age lamps from various archaeological sites, mainly located in south west France [13, 14]. The experiments showed no difference in the performance for the different types of tallow; both ‘lamps’ burned successfully for over an hour (63 minutes for T1 and 61 minutes for T2) and self-extinguished when the fuel was consumed. In each case black soot was deposited on the interior surface, mostly in the area of the wick.

In section, the extent of absorption of the tallow is discernable as staining of the chalk, which is most clearly visible when viewed under ultraviolet light, Figure 7. The

extent of absorption of the tallow is greater where the wick is in contact with the chalk and the surface is heavily sooted. Measurements indicate that tallow has penetrated into the chalk fabric to a maximum depth of 7 mm along the side wall of T1, while the penetration depth at the base of T1 is only 2 mm, Figure 7. When Grimes Graves cup C18 was sectioned in a similar manner (Figure 7), no such phenomenon was observed, casting further doubt on the results of residue analysis for this object in the previous study, but consistent with the lack of residues identified in the analytical work reported here.

The GC-MS analyses reported in Table 2 have shown that the amount of tallow absorbed by replica cups T1 and T2 were 4.98 mg.g^{-1} (1.39 mg.g^{-1} near the wick) and 0.290 mg.g^{-1} respectively. These amounts are considerably less than those reported from experimental studies of lipid absorption in ceramics, which range from 13.5 to 60 mg.g^{-1} [25, 29, 30]. Given the high measured porosity for the chalk, these low levels are puzzling, but a key factor may be that the vessel itself was not heated, since heating of the fabric has been shown to govern absorption in cooking vessels [29]. In addition, the active consumption of the fuel residue during the use of the lamp seems to have a significant effect, for example on the distribution of lipid residues within the lamp body. Even though lipids had penetrated the fabric more deeply in the area of the cup where the wick had been in direct contact with the chalk (Figure 7), the yield of tallow from this region was lower (1.39 mg.g^{-1}) compared to elsewhere (4.98 mg.g^{-1}), presumably due to absorbed fuel being 'wicked' back out of the fabric as the lamp burns down. This phenomenon may have significant wider implications for sampling strategies when working with lamp fuel residues. Low absorption coupled with high potential for residue degradation suggests that even if they were used as lamps, the scope for detecting residues in these cups is poor.

At around one hour, the relatively short burning time of the experimental lamps suggests that even the larger Grimes Graves cups would not have provided a very convenient light source for working miners. In the context of the mining activity and the confined space, the use of many cups or a series of cups seems impractical and such multiple use might be expected to have left unmistakable traces in the archaeological record. A study using replicas of slightly larger Mesolithic Danish 'blubber lamps' (approximate length 20 cm, greatest width 8 cm and height 4 cm) with tallow and seal oil showed that such lamps burn for at least 4.5 hours and that sooting was clearly visible [31]. At Grimes Graves no sooting that might suggest extensive use of artificial light has been observed on the gallery roofs or walls and there are no traces of soot on the cups themselves. Had the cups been used as lamps it seems more likely that they would have been associated with other activities that required only short-term illumination, but the balance of evidence gathered in this study suggests that an alternative function for these objects is more probable.

CONCLUSIONS

The studies reported here have shed new light on the possible use of chalk cups from Grimes Graves. Using more sensitive and diagnostic analysis it has not been possible to reproduce the results of earlier chemical analysis of residues in the cups. The previous analysis provided important evidence to support the identification of these objects as lamps, an interpretation that must now be viewed as questionable.

Nevertheless, it is difficult to interpret the negative GC-MS results obtained here conclusively, as there remains significant scope for loss of residues due to the structural properties of the chalk and the unknown qualities of the burial environment. Despite the low yield, experiments have shown that an animal fat lamp fuel would certainly have been absorbed into the chalk fabric and have offered an insight into the pattern of absorption and yield that may be instructive when sampling other lamps. The experimental reconstructions further demonstrated that, although the cups could function effectively as lamps, the relatively short burn time seems unlikely to have made them a convenient aid to mining activity. Moreover, the absence of soot marks on the gallery walls or roofs should cast further doubt on their use as lamps.

The information gathered by this study does not rule out the possibility that these objects were used as lamps but offers little evidence to support this inference. Alternative interpretations should be considered and the function of these little chalk cups remains an open question.

MATERIALS AND SUPPLIERS

- Tallow candle ('hard'): Gospel Stained Glass Ltd, www.gospelstainedglass.co.uk
- Tallow candle ('soft'): Candles For All Ages, www.candles-for-all-ages.com

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