SWEETNESS AND LIGHT: CHEMICAL EVIDENCE OF BEESWAX AND TALLOW CANDLES AT FOUNTAINS ABBEY, NORTH YORKSHIRE

From the primitive pine-torch to the paraffin candle, how wide an interval! Between them how vast a contrast![86]

We report here on the composition of residues from a collection of metal candleholders from the 12th-century Cistercian Abbey of Fountains, one of Britain's best-preserved monastic sites. Fountains Abbey and Studley Royal Estate, located in the valley of the River Skell near Ripon, is a World Heritage Site. The extensive collection of artefacts has been amassed, including all the objects discussed here, mainly from antiquarian excavations.[87] Recent work has examined the collection of lead artefacts from Fountains Abbey.[88] These investigations noted five artefacts, some thought to be candleholders, which contained small amounts of a white, flaky deposit presumed to be organic in origin.

The discovery of these residues prompted investigation into other putative candleholders in the Fountains Abbey collection. Subsequently, three iron 'cupped-stick' candleholders were identified, typical of the late 14th century,[89] containing similar deposits. The lead candleholders lack distinctive features, making typological dating problematic (Figs. 9–10; Tab. 1). However, the austere design probably dates from the 14th century or later.[90] These artefact-dates do not necessarily date the residues. The latter could derive from post-Dissolution re-use of monastic objects, but this is unlikely to account for all the examples noted here.

A total of nine samples from one iron and four lead candleholders were taken and prepared for analysis. The aim of the analytical programme was to identify the deposits in order to learn more about candle production and use at Fountains Abbey.

ANALYSIS

Small (5–10 mg) samples were removed from the artefacts with a clean scalpel blade and transferred into glass screw-capped vials. Sub-samples were dissolved in 2 ml dichloromethane/methanol (2/1 v/v) and agitated using ultrasonication (2 × 15 minutes). The solvent was passed through a Pasteur pipette plugged with glass wool to remove insoluble impurities and then blown to dryness under a stream of nitrogen. The dried residue was stored in small glass vials at -20°C.

Each sample was trimethylsilylated with 50 µl *N,O*-bis(trimethylsilyl)trifluoroacetamide + 1% trimethylchlorosilane (Pierce Chemical Co.), which was added to dry sample aliquots (10 minutes at 60°C). Gas chromatography (GC) was carried out using a Hewlett Packard 5890 Series II instrument equipped with an on-column injector and flame ionisation detector. Data-processing was carried out using dedicated Hewlett Packard 3365 Chemstation software. Combined GC/MS was carried out using a Hewlett Packard 5972A mass selective detector in conjunction with an HP 5890 Series II GC equipped with a split-splitless injector and used in splitless mode. Data were stored and processed using HP G1034C MS Chemstation software.

In both cases the analytical column used was a polyimide clad 12 m × 0.22 mm i.d. fused silica capillary, coated with BP-1 (SGE, UK) stationary phase (immobilised

[86] William Crookes, Preface to *The Chemical History of a Candle: Course of Lectures Delivered before a Juvenile Audience at the Royal Institution by Michael Faraday* (1861).
[87] J. R. Walbran (ed.), *Memorials of the Abbey of St Mary of Fountains*, 2 vols. (Surtees Soc., 42 and 67, 1862 and 1876).
[88] J. A. Frith, Lead Artefacts from Fountains Abbey (unpubl. rep., English Heritage, 1999); eadem, Monastic Lead Working: Medieval Lead Working Activities of the Cistercian Abbey of Fountains (unpubl. undergraduate diss., Dept. Archaeol. Sciences, University of Bradford, 2001).
[89] G. Egan, *The Medieval Household: Daily Living c.1150–1450* (London, 1998).
[90] G. Egan, pers. comm.

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dimethylpolysiloxane, OV-1 equivalent, 0.1 μm film thickness). The GC temperature program was as follows: 10 minute isothermal hold at 50°C following injection, then 50°C to 350°C at a rate of 10°C min^{-1}, with a column-head pressure of 60 psi. For GC/MS, samples were introduced via a splitless injector at 340°C with a 3-minute purge time. The GC was temperature programmed from 50°C-340°C at 10°C min^{-1}. The final temperature was held for 10 minutes. Helium was used as a carrier gas at a column head pressure of 25 psi. The transfer line temperature was set at 340°C. Mass spectra were acquired by electron impact (EI) ionisation (70eV). Full scan mass spectra were recorded over the range *m/z* 50–700.

RESULTS AND DISCUSSION

Analysis by GC and GC/MS revealed two types of residue composition. These are typified by the examples shown in Figure 8. In the first example (Fig. 8a), the residue is dominated by saturated even carbon number fatty acids in the range C_{14}–C_{18} with corresponding aclyglycerols, a pattern typical of degraded animal fats.[91] Octadecenoic acid ($C_{18:1}$) is also present but, as typically seen in degraded fats and oils, is depleted relative to hexadecanoic ($C_{16:0}$) and octadecanoic ($C_{18:0}$) acids. The lipid residue is partially hydrolysed; whilst triacylglycerols are clearly present, free fatty acids and abundant free glycerol are also observed. The presence of C_{15} and C_{17} odd-carbon number fatty acids suggests a ruminant animal source.[92] Other molecules identified include dicarboxylic acids and hydroxyfatty acids. These data are consistent with a degraded tallow. Tallow is essentially animal fat collected during rendering. In this process, animal carcasses were placed into vats of boiling water and the fat collecting at the top was skimmed off. Tallow can be obtained from a wide range of mammals, although beef and mutton tallow were the most commonly used, with the latter especially valued for its 'gloss and hardness'.[93] Fountains Abbey certainly possessed abundant resources to make tallow candles, since the wealth of the Abbey was due partly to wool production. In 1291, some 18,000 sheep were kept on the Abbey's estates.[94]

Three of the candleholders yielded residues composed solely of tallow (Tab. 1). The remaining deposits also exhibited residues with a tallow component. However, in addition, these residues include wax esters in the range C_{40}–C_{50}, *n*-alkanes (C_{21}–C_{33}) with C_{27} as the most abundant, and long-chain free saturated fatty acids $C_{20:0}$–$C_{30:0}$ (Fig. 8b). These compounds are characteristic of beeswax.[95] Hydroxymonoesters, also indicative of beeswax, are present in low abundance as is a suite of long-chain alcohols in the range C_{24}–C_{32} (not seen in Fig. 8a). The latter suggest partial hydrolysis of the wax ester fraction. Hexadecanoic acid ($C_{16:0}$) is released in this process and this may have added to that contributed by the tallow component. Unsaturated wax esters present in fresh beeswax, albeit in low abundance relative to their saturated counterparts, are absent, presumably due to oxidation. Three odd-carbon number ketones, with tritriacontanone (C_{33}) the most abundant, were also identified in this sample and will be discussed later.

Beeswax is a durable natural product and has been confirmed by molecular investigation in a number of archaeological contexts — testimony to humankind's long relationship with bees and the resources they provide. Recent finds include beeswax in association with mid-6th- to mid-4th-millennium B.C. neolithic pottery from northern

[91] R. P. Evershed, C. Heron, S. Charters and L. J. Goad, 'The survival of food residues: new methods of analysis, interpretation, and application', 187–208 in A. M. Pollard (ed.), *New Developments in Archaeological Science: A Joint Symposium of the Royal Society and the British Academy* (Oxford, 1992).
[92] R. P. Evershed et al., 'New criteria for the identification of animal fats preserved in archaeological pottery', *Naturwissenschaften*, 84 (1997), 402–6.
[93] D. J. Eveleigh, *Candle Lighting* (Aylesbury, 1985).
[94] D. H. Williams, *The Cistercians in the Early Middle Ages* (Leominster, 1998).
[95] J. S. Mills and R. White, *The Organic Chemistry of Museum Objects* (Oxford, 1994).

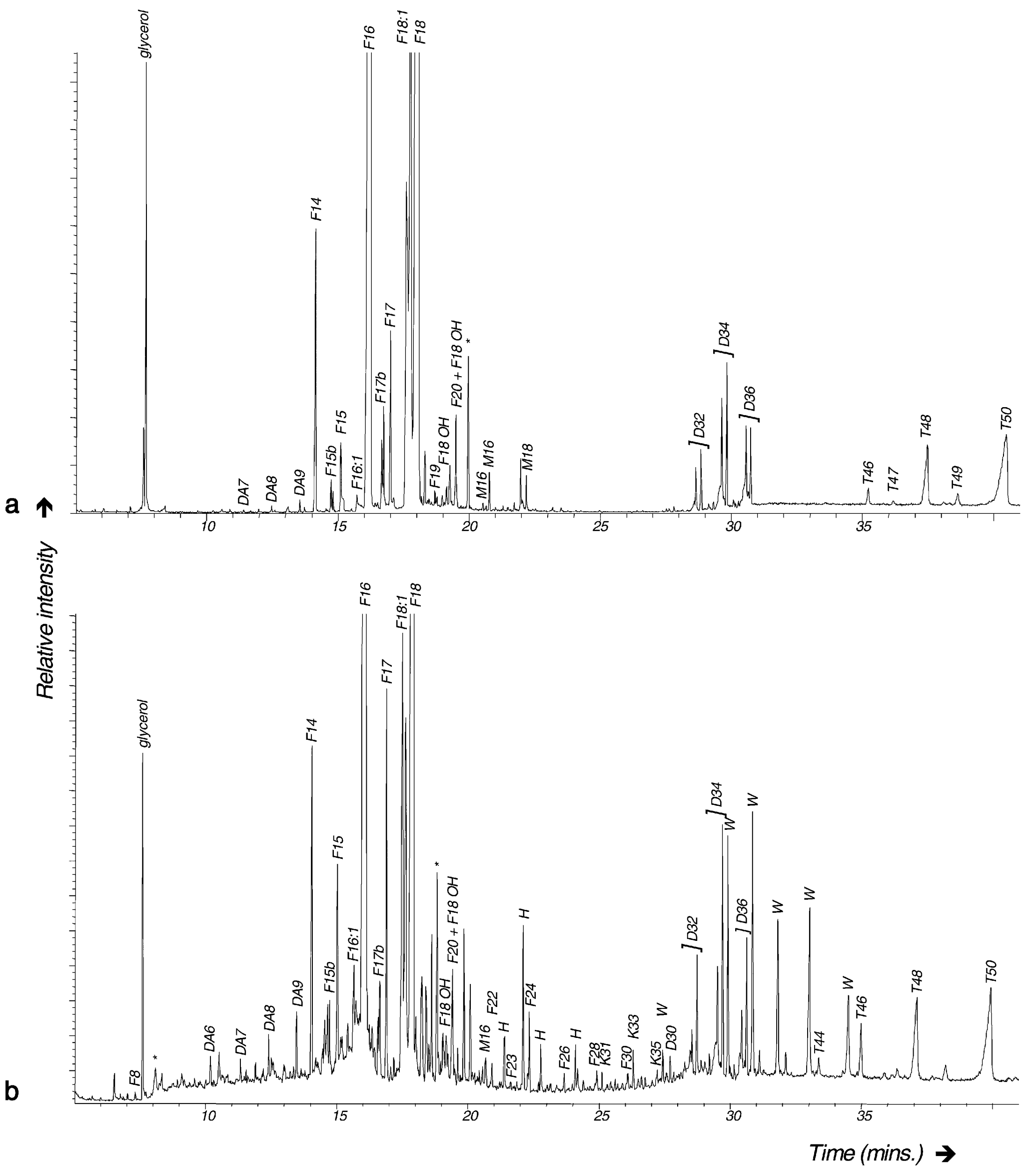

FIG. 8

Gas chromatograms showing the results from samples 671494 (a) and 671502 (b). All acids and alcohols were identified as trimethylsilyl esters and ethers. Peak identities were established by GC/MS. (a): DA*n* — Dicarboxylic acid with *n* carbon atoms; F*n* — Saturated fatty acid with *n* carbon atoms; F*n*b — Branched-chain fatty acid with n carbon atoms; F*n*:1 — Monounsaturated fatty acid with *n* carbon atoms; F*n*OH — Hydroxyfatty acid with *n* carbon atoms; M*n* — Monoacylglycerol with *n* fatty acyl carbon atoms; D*n* — Diacylglycerol with *n* fatty acyl carbon; T*n* — Triacylglycerol with *n* fatty acyl carbon atoms. Note that the triacylglyerol fractions extends to T54 (not shown). (b): DA*n* — Dicarboxylic acid with *n* carbon atoms; F*n* — Saturated fatty acid with *n* carbon atoms; F*n*b — Branched-chain fatty acid with n carbon atoms; F*n*:1 — Monounsaturated fatty acid with *n* carbon atoms; F*n*OH — Hydroxyfatty acid with *n* carbon atoms; M*n* — Monoacylglycerol with *n* fatty acyl carbon atoms; H — *n*-alkane; K*n* — mid-chain ketones with *n* carbon atoms; D*n* — Diacylglycerol with *n* fatty acyl carbon atoms; W — wax ester; T*n* — Triacylglycerol with *n* fatty acyl carbon atoms. Note that the triacylglyerol fractions extends to T54 (not shown).

Table 1

SUMMARY OF THE RESULTS OF RESIDUE SAMPLING OF CANDLEHOLDERS FROM FOUNTAINS ABBEY

Catalogue no.	**Description**	**Sampling details**	**Residue composition**
671408	Iron candleholder, L-shaped bar with enclosed socket. Probably a wall-fixture. Socket plugged with residue.	Single sample taken from residue in plug.	Degraded tallow. Some diacids.
671494	Lead socketed candleholder with bowl base. Base of socket plugged with residue. Thin residue layer covering interior surface of socket.	Two samples taken. 1: From plug of residue in base of cylinder. 2: From interior surface of cylinder near the rim.	1: Degraded tallow; some diacids. 2: Degraded tallow; some diacids.
671499	Lead socketed candleholder with small square base with pierced corner. Scant residue layer interior surface base.	Single sample from interior surface/ base.	Degraded tallow.
671502	Lead socketed candleholder with bowl and short trefoil handle. Socket base plugged with residue. Thin residue layer covering interior surface of socket. Some residue deposits preserved in bowl.	Three samples taken. 1: From interior surface of socket.	1: Beeswax plus degraded tallow; ketones and diacids; trace of long-chain alcohols (identifiable only by ion scanning); hydrocarbons present but depleted.
		2: From plug of residue in socket base.	2: Beeswax plus degraded tallow; hydrocarbons less depleted than in sample (1); ketons and diacids present; no long-chain alcohols.
		3: From surface residue on bowl.	3: Beeswax plus degraded tallow; hydrocarbons even less depleted than sample (2); no ketones or diacids.
671533	Lead cylinder. Base plugged with residue. Thin layer of residue covering interior surface.	Two samples taken. 1: From interior surface of cylinder near rim.	1: Beeswax plus degraded tallow; diacids; possible ketone; hydrocarbons present but depleted.
		2: From plug of residue in base of cylinder.	2: As above but no ketones, and hydrocarbons less depleted.

Greece and southern Germany and Bronze-age lamps from Minoan Crete dating to the early 3rd millennium B.C.[96] Later finds of mixed beeswax and tallow have been reported from a jar and bowl of Late Saxon/early post-Conquest date from Northamptonshire, U.K.[97]

DOCUMENTARY EVIDENCE

The chemical evidence of beeswax as a commodity on the Fountains estate is corroborated by documentary evidence. The chartulary of Fountains Abbey contains a grant dated the 1 October 1284:

Grant by Edmund, son of Richard, King of Germany . . . to the Abbot and Convent of Fountains . . . grants that they may have the honey and bees found in their woods.[98]

Other documentary evidence dates to the 15th century onwards. Records in the Bursar's Book of 1456–9,[99] mention payments to several individuals for *cerae* [wax, especially candles], and list purchases of *lagenis mellis* [a gallon of honey], suggesting goods, previously acquired wholly through self-sufficiency, were supplemented from other sources. The Bursar's Book interestingly also records that one John Schau was paid for skeps, demonstrating that beekeeping continued whilst wax and honey was purchased. The everyday use of wax is illustrated in the retirement terms of 'Sir Thomas Wels, prest' dated 27 July 1535. Amongst his rations of 'meate and drynke' he was allowed 'to have breade, wyne ande wax to say masse and everye yere sex pundes of candels to his chambre'.[100]

In Yorkshire, there are many known bee bole sites. These are wall recesses made to shelter beehive skeps (Fig. 11). Although bee boles have not been identified at Fountains, a set of six, possibly dating to 1453, survive at Nutwithcote, once a monastic grange of Fountains.[101]

CANDLE PRODUCTION AND USE

The presence of tallow in all of the residues indicates that these candleholders may have been used in part for domestic purposes since pure beeswax candles would normally have only been permitted for use in the church. This was due to the superior quality of beeswax candles that emit a much brighter light than tallow and do not splutter or smoke. They also burn with a pleasant honey fragrance as opposed to the putrid stench and offensive smoke of tallow, a point noted by Samuel Pepys in the 17th century.[102] Moreover, beeswax was a cult commodity for the early Christian church. Bees were revered for their ordered mode of life — a model for the church — and what was perceived as their chastity, since they 'produce prosperity, rejoice in offspring, yet retain their virginity'.[103]

While it is possible that the mixed residues comprise components of separate beeswax and tallow candles retained in the holder, it is equally possible that combined tallow and wax candles were used. The wicks of tallow candles were sometimes dipped in beeswax.[104] It is unlikely that monks were adulterating candles for use in the church since the abbey had its own source of wax, whether its own or secularly purchased. It is possible, however, that recycling of spent church candles for domestic use was taking place. The superior light and fragrance with which beeswax burns suggest that candle remnants would not have

96 C. Heron et al., 'The chemistry of neolithic beeswax', *Naturwissenschaften*, 81 (1994), 266–9; M. Regert et al., 'Chemical alteration and use of beeswax through time: accelerated ageing tests and analysis of archaeological samples from various environmental contexts', *Archaeometry*, 43 (2001), 549–69; R. P. Evershed et al., 'Fuel for thought? Beeswax in lamps and conical cups from Late Minoan Crete', *Antiquity*, 71 (1997), 979–85.

97 S. Charters et al., 'Evidence for the mixing of fats and waxes in archaeological ceramics', *Archaeometry*, 37 (1995), 113–27.

98 W. T. Lancaster (ed.), *Some Documents Contained in the Chartulary of the Abbey of Fountains in the West Riding of York* (Leeds, 1915).

99 J. T. Fowler (ed.), *Memorials of the Abbey of St Mary of Fountains: Vol III, Consisting of the Bursars Book 1456–1459 and Memorandum Book of Thomas Swynton 1446–1458* (Surtees Society, 130, 1918).

100 D. J. H. Michelmore (ed.), *The Fountains Abbey Lease Book* (Leeds, 1981).

101 P. Walker, 'Past beekeeping in Yorkshire: evidence from bee boles and other local sources', *Yorkshire Archaeol. J.*, 59 (1987), 119–37 at p.123.

102 B. Bowers, *Lengthening the Day* (Oxford, 1998).

103 E. Crane, *A Book of Honey* (Oxford, 1980).

104 A. C. Knight, 'The Tallow Chandlers' Company: its origin and a sketch of its history', *J. British Archaeol. Assoc.*, NS 24 (1918), 173–216.

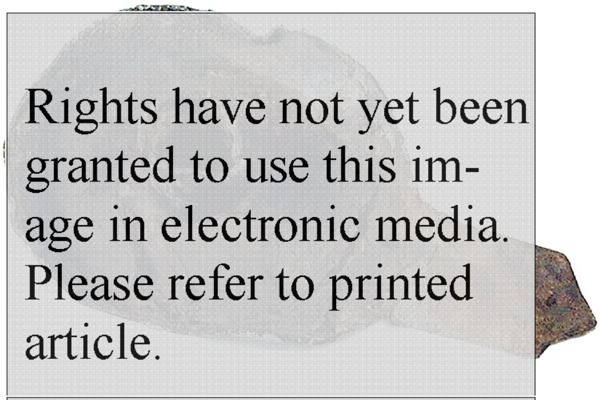

FIG. 9

Lead socketed candleholder with bowl and short handle. Note the deposits (light in colour in comparison with the metal) adhering to the interior surface of the socket and the interior surface of the bowl (Sample 671502). © *English Heritage 2003*.

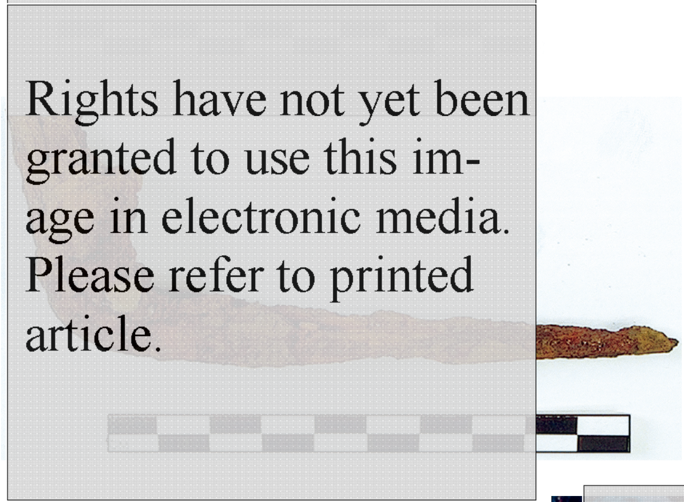

FIG. 10

Iron 'cupped-stick' candleholder, used as a wall fixture. The socket was plugged with a flaky, white deposit similar to that observed in Figure 8. © *English Heritage 2003*.

FIG. 11

A local beekeeper continues small-scale traditional beekeeping at Fountains Abbey today. The rush-woven skeps are placed in suitable locations to encourage bees to settle and make hives. The honeycomb is cut out of the skep, wrapped in linen, and pressed to squeeze out the honey. The remaining wax is washed with water to collect the remaining honey: this mixture of water and honey is fermented to make mead. The wax is melted in a pot standing in hot water, and must be re-melted and strained several times to remove impurities. The pure beeswax candles are made by the dipping process: a wick is dipped in wax and rolled to make a smooth surface; this is repeated until the candle is the required thickness. In the Middle Ages, wicks were usually made of flax. According to the beekeeper, Janet Dowling, a candle with a one-inch thick base will need to be dipped at least twenty times. © *Janet Dowling 2003*.

been wasted. In addition to any economic motivation, there are many practical reasons for mixing wax and tallow. Coating a tallow candle with beeswax enables it to be held in the hand without melting,[105] it improves the smell and increases the robustness of the candle.

MOLECULAR CONSIDERATIONS

The tallow residues display abundant oxidation products (dicarboxylic acids and the hydroxyfatty acids) associated with the breakdown of fats.[106] These are seen in Figure 8a–b. Hydroxyfatty acids can also be formed by microbial reworking of unsaturated fatty acids.[107] The 9– and 10–hydroxyoctadecanoic acids identified here can be linked to the stereospecific hydration of Δ^9-oleic acid, which would have been an abundant component of the fresh tallow.

The chain lengths of dicarboxylic acids can give an indication of the position of unsaturation in the parent molecules. The presence of a range of diacids thus implies a number of different isomers present in the original composition again consistent with ruminant fats. The presence of these degradation products in the candle residues from Fountains Abbey is of particular interest. To date they have principally been identified in the 'bound' (i.e. only released by saponification) fractions of lipid residues from archaeological ceramics, only surviving in the free fractions in samples from very arid environments. The absence of diacids in the residue from the bowl of candleholder 671502 may indicate that the burning of the fat is implicated in their formation. The residues that exhibit thermal degradation products (i.e. ketones) show the widest range of diacids, which may be due to changes in double bond position in response to heating or burning. Connections have been made between the formation of these compounds and heating of residues. They have, however, also been identified in non-thermally degraded residues.

Further indications of chemical alteration of the animal fat are indicated by long mid-chain ketones. These are thermal degradation products of fatty acids and previously associated only with lipid residues from archaeological cooking pots.[108] These compounds occur in sample 671502 and at trace levels in 671553. Experimental studies of their formation have shown that they form at 200–350°C in the presence of a clay mineral catalyst, due to prolonged intermittent heating consistent with prevailing conditions within a pot wall.[109] It is not known whether the ketones are formed during the process of tallow rendering/candle manufacture or when the candle itself is burned. It is interesting to note that the ketones only occur in the beeswax containing residues. Simple experiments have indicated that higher temperatures are attained in the flame of a beeswax candle than in that of tallow; this could be significant in their formation and would support the suggestion of mixed composition candles.

Depletion of the *n*-alkane fraction during combustion of beeswax has been previously demonstrated.[110] The *n*-alkanes in the samples analysed here show different degrees of depletion depending on the location of the residue. Least depleted in bowl of 671502, less depleted in base of socket than on interior surface for 671502 and 671553. The residue in the bowl is melted but not burnt, thus the alkanes are more likely to survive.

[105] S. H. Plat, *Delightes for Ladies, to Adorn their Persons, Tables Closets, and Distillatories, with Beauties, Banquets, Perfumes and Waters* (London, 1609).
[106] M. Regert et al., 'Free and bound fatty acid oxidation products in archaeological ceramic vessels', *Proc. Royal Soc. London*, B 265 (1998), 2027–32.
[107] R. P. Evershed, 'Lipids from samples of skin from seven Dutch bog bodies: preliminary report', *Archaeometry*, 32 (1990), 139–53; F. O. Gülaçar, A. Buchs and A. Susini, 'Preservation and post-mortem transformations of lipids in samples from a 400-year-old Nubian mummy', *J. Chromatography*, 479 (1989), 61–72.
[108] R. P. Evershed et al., 'Formation of long-chain ketones in ancient pottery vessels by pyrolysis of acyl lipids', *Tetrahedron Letters*, 36 (1995), 8875–8.
[109] A. M. Raven et al., 'Formation of long-chain ketones in ancient pottery vessels by pyrolysis of acyl lipids', *J. Analytical Applied Pyrolysis*, 40–41 (1997), 267–85.
[110] Evershed et al., op. cit. in note 96.

CONCLUSIONS

This research has enabled previously unassigned lead artefacts in the Fountains Abbey collection to be confirmed as candleholders based on the parallel of surviving organic residues associated also with known candleholders from the site. The tallow and beeswax residues are the first to be identified in the English Heritage Monastic Collections; future research will examine other Cistercian collections for potential residue survival. Molecular analysis demonstrates the ways in which these substances are altered during both use and subsequent burial.

A self-sufficient lifestyle is the basis of the Cistercian Rule, a model distorted perhaps as a result of wealth accrued by the 13th century. The use of skeps and bee boles simultaneous with the purchase of wax and honey perhaps indicate this distortion, where manual labour is reduced by the ease of commodity purchase. However, the combination of homemade and purchased goods may be indicative of the struggling community simply supplementing meagre resources, in an attempt to retain ideals, particularly as the lay brotherhood declined. The roughly made lead and iron candleholders, the rendering of tallow and the collection of beeswax illustrate the original Cistercian way of life.

THERE was once a big wax-candle which knew its own importance quite well.
'I am born of wax and moulded in a shape,' it said 'I give better light and burn longer than other candles my place is in a chandelier or on a silver candlestick!'
'That must be a lovely existence!' said the tallow-candle. 'I am only made of tallow, but I comfort myself with the thought that it is always a little better than being a farthing dip: that is only dipped twice, and I am dipped eight times to get my proper thickness. I am content! It is certainly finer and more fortunate to be born of wax instead of tallow, but one does not settle one's own place in this world. You are placed in the big room in the glass chandelier, I remain in the kitchen, but that is also a good place; from there the whole house gets its food.'

Passage from *The Candles* by Hans Christian Andersen (1870)

A tallow candle, to be good, must be half Sheep's Tallow and half Cow's; that of hogs makes 'em gutter, give an ill smell, and a thick black smoak.

Anon. (18th century)

Instead of dirt and poison we have rather chosen to fill our lives with honey and wax; thus furnishing mankind with two of the noblest things, which are sweetness and light.

Jonathan Swift, *The Battle of the Books* (1704)[111]

ACKNOWLEDGEMENTS

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[111] Quoted from M. Dillon, *Artificial Sunshine: A Social History of Domestic Lighting* (National Trust, 2002).