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Milking the megafauna: Using organic residue analysis to understand early farming practice

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In Europe, the shift to agriculture starts around cal 7000 BC, spreading across the continent over several thousand years. The island of Ireland lies geographically and chronologically at the end of this trajectory, in the centuries around cal 4000 BC. Molecular and stable carbon isotope analyses undertaken of ca. 450 pottery vessels from a range of Irish Neolithic sites firmly establishes that dairying is one of the very earliest farming practices in evidence in Ireland, successfully introduced into an island environment that had not supported large mammals for at least the preceding 9000 years – a significant logistical feat.

Keywords: Neolithic Ireland, Pottery, Fatty acids, Compound-specific carbon isotope analysis, Dairying

Introduction

The island of Ireland lies geographically and chronologically at the end of the several thousand years long shift to agriculture in Europe. At this western edge, current models see the process beginning in south-east England in the 41st century cal BC and spreading gradually westwards towards southern Britain before a rapid acceleration occurred over western Britain, Ireland, the Isle of Man and Scotland in the late 39th century cal BC (Whittle *et al.* 2011, 860–862). Many aspects of these first centuries of farming life are, relatively speaking, very visible archaeologically and have been well documented. In Ireland, timber houses appear across the island, occurring singly or in small clusters along the main river systems (Smyth 2013, 2014); megalithic monuments, both single-chambered portal tombs and long mound-type court tombs, are also constructed at this time (Schulting *et al.* 2012; cf. Bergh and Hensey 2013), the latter being associated in the northwest of the island with an extensive network of co-axial drystone field walls (Caulfield *et al.* 1998). In at least two other locations, causewayed enclosures have been identified, the characteristic interrupted ditches and palisades delimiting large areas of hilltop, contrasting in scale with the many instances of pit-digging and deposition also recorded during this period. Recently, a comprehensive overview of cereal crops and associated weeds from Neolithic contexts has revealed widespread cultivation of – predominantly – emmer wheat from the 38th century cal BC, with agricultural practice based on a system of permanent plots (Whitehouse *et al.* 2014). Related research has also hinted at the rate at which some of this activity took place, with house-building ceasing as abruptly as it began, within just a few generations during the 38th/37th centuries cal BC (McSparron 2008; Cooney *et al.* 2011; Whitehouse *et al.* 2014).

From a wider European Neolithic perspective, examination of early farming practice on the island of Ireland is valuable for a number of reasons. Firstly, it is geographically and temporally distant from the first manifestations of agriculture in Europe and provides an interesting point of comparison with the farming trajectories of other regions. Secondly, there are several large, recently collated (and in some cases newly commissioned) corpora of radiocarbon dates and related programmes of Bayesian modelling (see references above), which have provided a relatively high chronological resolution for the period. Finally, the establishment of farming in Ireland necessitated the introduction *de novo* of cattle, sheep, goat (and most likely red deer) as well as cereals, such as wheat and barley, to the island. All of these elements render the dynamics of Neolithisation more visible and easier to understand.

Organic Residue Analysis (ORA) and the Irish Neolithic

Despite the above advances, there are still sizeable gaps in our knowledge of the earliest farming groups in Ireland. Bone preservation is particularly poor, due to the predominance of acidic soils over the island. The small amounts of prehistoric animal bone that survive on sites point to the presence of domesticates, such as cattle and sheep, but we can

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only guess at how important these animals were in the diet, how they were exploited and on what scale, and whether different species were favoured at different times and/or places (McCormick 2007; Schulting 2013). Another area that has seen little interpretative work, although not due to a dearth of material, is the ceramic record. In Ireland, as in Britain and many other parts of Europe, pottery is a key component of the Neolithic 'package' and one at the centre of domestic life. While there have been occasional attempts to provide some social context to the manufacture and use of pottery in the Irish Neolithic (e.g. Sheridan 1991; Cooney 2000), analysis has generally been quantitative and confined to catalogues and report appendices. As with faunal remains, basic information is lacking on how this material fitted into everyday activity. What did pots contain? Which foods were processed in them? Were vessels found across domestic, funerary and ceremonial contexts used in similar ways?

As well documented elsewhere (e.g. Evershed 2008), ORA of prehistoric pottery vessels can be a powerful tool in reconstructing past animal management practices, foodways and other patterns of commodity use. A diverse range of molecular and compound-specific isotopic analyses targeting lipids preserved in vessel walls can establish whether animal fats or plant oils are present, or whether contents were strongly heated, i.e. cooked. Analyses can also distinguish between cow/sheep fats and pig fats, between meat fats and dairy fats, and between aquatic products of marine or freshwater origin. Such techniques have proven to be very effective in tracking change in subsistence strategies through time and detecting important stages in the development of animal/human relations (e.g. Evershed *et al.* 2008; Dunne *et al.* 2012). More recently, ORA has been particularly useful in highlighting the differences in the character of farming across northwestern Europe in the early 5th and 4th millennia BC (e.g. Craig *et al.* 2011; Cramp *et al.* 2014). However, the potential exists to use ORA to address even more penetrating questions about the prehistoric past. Specificity is key: integrating the sorts of culturally and regionally specific archaeological datasets listed above with techniques such as compound-specific carbon isotope analysis to create a more ecologically situated approach (see Barrett 2011).

With this in mind, an ORA research project was designed that was grounded in detailed knowledge of the archaeology of the Irish Neolithic and its current research agenda, and which systematically examined assemblages from a range of different site types, in different geographical locations and dating to different stages in the Neolithic. Pottery sherds representing over 450 vessels from a total of 15 sites (Fig. 1) were analysed using molecular and compound-specific carbon isotopic techniques. As well as reflecting the range of activity through the period, sample selection also took into account factors affecting the lipid yield of individual sherds and the statistical robustness of datasets, with upper body/rim sherds rather than lower body sherds preferred and a target of 30 vessels per site assemblage/dataset analysed (see Smyth and Evershed 2014). Seven of the project sites date to the Early Neolithic, and to centuries immediately following the introduction of farming into Ireland, and will be examined in more detail below. The rest of the project results are discussed elsewhere (Smyth and Evershed in press).

The Early Neolithic Sites

By the late 5th/early 4th millennium BC, Ireland had already been an island for nearly 10,000 years, and perhaps more. Between 15,000 and 20,000 years ago, the land mass was covered by ice and likely flanked by large sea-ice corridors, with the waters between Ireland and Britain perhaps never sufficiently shallow for a Late Glacial land bridge to form; by the start of the Holocene around 12,000 years ago, Ireland was clearly separated from Britain and the rest of Europe by water depths in excess of 50 m (Brooks *et al.* 2011). The role of climate and palaeogeography in the formation of the island's post-Late Glacial Maximum ecology is as yet imperfectly understood, but it is clear that the ecosystem that developed did not feature wild cattle, found grazing just across the water in the Severn Estuary (Bell 2007). Red deer, such a prominent feature of Mesolithic faunal assemblages in Britain, does not seem to have been present on the island either at this time (Carden *et al.* 2012). While the 45th century cal BC domestic cattle bone uncovered at Ferriter's Cove on the south-west coast of Ireland (Woodman *et al.* 1999) reminds us that Irish Mesolithic groups could still encounter non-native species (although with what frequency it is impossible to ascertain), it is important to point out that at the point of the transition to farming in Ireland there appears to have been no terrestrial game larger than wild pig.

Into this environment, around the 39th or 38th century cal BC, appears a range of novel 'materials', including cattle, sheep/goat, pottery, certain types of chipped stone tools and new forms of architecture. As mentioned above, this latter includes rectilinear post-and-plank houses and causewayed enclosures. Nearly 90 Early Neolithic houses from over 50 sites have so far been identified in Ireland, constructed over a very short period of perhaps a century or less. They occur in small clusters or singly, and are associated with a variety of materials and traces of activity

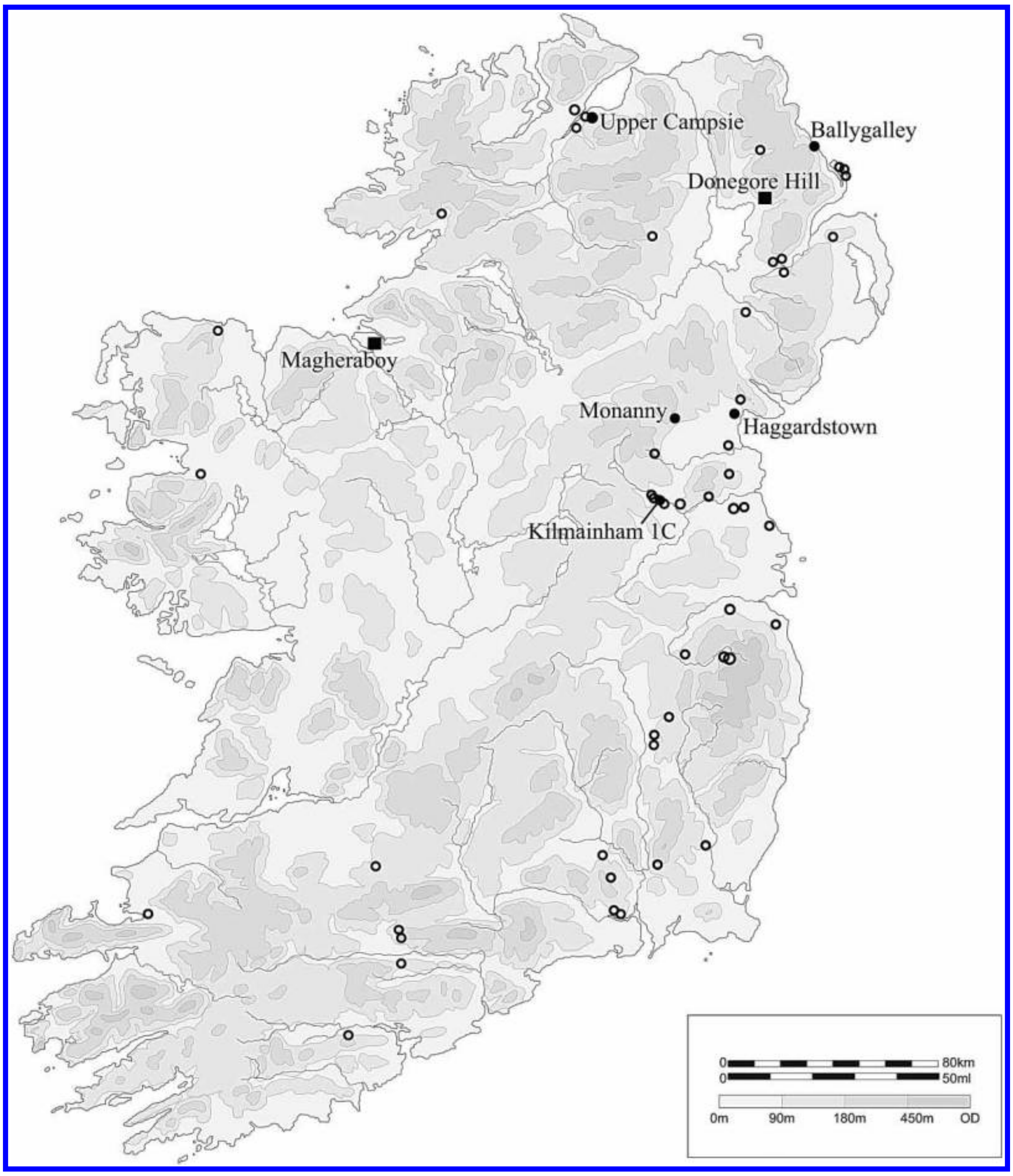

Figure 1 **The current distribution of Irish Early Neolithic houses (open circles), and the location of Early Neolithic sites sampled for this investigation (causewayed enclosures – squares; house sites – circles).**

we might term as domestic, e.g. internal and external hearths, working surfaces, pottery, charred plant and animal bone remains, and stone tool manufacturing debris (Smyth 2014). The five house sites selected for this project – Ballygalley, Upper Campsie, Haggardstown, Monanny and Kilmainham 1C – are located in the north and east of the island (Fig. 1), a choice reflecting both the current distribution of these sites (in turn partly reflecting the location of recent major infrastructural projects and associated archaeological mitigation), and the need to sample pottery assemblages containing at least 30 vessels (Smyth and Evershed 2014). Only two causewayed enclosures have been positively identified to date – Magheraboy and Donegore Hill – and both were sampled. Bayesian modelling indicates that both enclosures had histories of several centuries duration, built before the start of the 'house horizon' and continuing in use afterwards (Cooney *et al.* 2011). Neither have been fully excavated (only 3% of Donegore Hill and approximately 50% at Magheraboy), although the interior of Magheraboy was found to be mostly empty of features, containing just a few small and scattered clusters of pits (Danaher 2007). In total, these seven Early Neolithic sites represented a sample set of 239 potsherds.

Materials and Methods

Sampling

All of the pottery sampled can be classified as Carinated Bowl pottery, the earliest pottery type identified in Ireland (Sheridan 1995). Wherever possible, samples were selected from sealed archaeological contexts – from ditches and internal pits in causewayed enclosures, and from pits, post-holes and slot trenches on house sites. The exception to this was the Donegore

Hill assemblage, over 90% of which was recovered from the ploughsoil (Mallory *et al.* 2011, 19). In this case, an effort was made to take as representative a sample as possible, selecting sherds from excavated grid squares across the site. As mentioned above, upper body and rim sherds were targeted in the sampling process. At Donegore Hill, most of the diagnostic material (rim sherds and shoulder sherds) had been removed for analysis by the pottery specialist, leaving mostly lower body sherds in the archive, although a number of neck sherds were identified and sampled (Appendix 1).

Lipid Extraction

All potsherds were prepared for analysis in the same way. First, small areas of the surfaces of sherds were cleaned using a modelling drill before a 2–3 g piece was removed using a chisel. Cleaned sherd fragments were then crushed in a solvent-washed mortar, and an internal standard (20 μg *n*-tetratriacontane) was added to enable quantification of the lipid extracts. The powdered potsherds were solvent extracted using 2 × 10 ml $CHCl_3$/MeOH 2:1 *v*/*v* via sonication (20 min). After centrifugation, the solvent was decanted and blown down to dryness under a gentle stream of N_2, leaving a total lipid extract (TLE).

Instrumental Analyses

Aliquots of TLEs were filtered through a silica column and treated with 40 μl *N,O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA, 70°, 1 h). The excess BSTFA was evaporated under nitrogen, and the derivatives were dissolved in hexane and analysed via high temperature gas chromatography using a gas chromatograph (GC) fitted with a high temperature non-polar column (DB1-HT; 100% dimethylpolysiloxane, 15 m × 0·32 mm i.d., 0.1 μm film thickness). The carrier gas was helium and the temperature programme comprised a 50°C isothermal followed by an increase to 350° at a rate of 10° min^{-1} followed by a 10 min isothermal.

Further compound identification was accomplished using gas chromatography/mass spectrometry (GC/MS). Where necessary, aliquots of the TLE were hydrolysed (0·5 M NaOH/MeOH; 70°, 1 h), followed by acidification to pH 3 using 1 M aqueous HCl and the extraction of the lipids into DCM (3 × 3 ml). Following derivatisation, as above, samples were introduced by autosampler onto a GC/MS fitted with a non-polar column (100% dimethyl polysiloxane stationary phase (60 m × 0·25 mm i.d., 0·1 μm film thickness). The instrument was a ThermoFinnigan single quadrupole TraceMS run in EI mode (electron energy 70 eV, scan time of 0·6 s). Samples were run in full scan mode (*m*/*z* 50–650) and the temperature programme comprised an isothermal hold at 50° for 2 min, ramping to 300° at 10° min^{-1}, followed by an isothermal hold at 300° (15 min).

Finally, the $\delta^{13}C$ values of individual fatty acids were determined using GC-combustion-isotope ratio MS. Aliquots of TLEs were hydrolysed as above and the neutral fraction was removed (3 × 3 ml hexane), followed by acidification to pH 3 using 1 M aqueous HCl and the extraction of free fatty acids (3 × 3 ml $CHCl_3$). Fatty acids were methylated using 100 μl BF_3/MeOH (14% *w*/*v*, 75°, 1 h) and extracted (3 × 2 ml $CHCl_3$). Analyses were performed using a TRACE GC Ultra GC coupled to a Thermo Finnigan DELTA^{plus} XP mass spectrometer via a Thermo Finnigan GC Combustion III interface. Samples were introduced via autosampler or injected via a PTV injector in splitless mode, onto a fused silica capillary column (HP-1, non-polar, 50 m × 0·32 mm i.d., 0.1 μm film thickness). The flow rate of the carrier gas (He) was set at 2 ml min^{-1} and the Cu/Ni/Pt oxidation reactor was maintained at 940°C. The temperature programme consisted of a 2 min isothermal at 50° and then ramped at 10° min^{-1} to 300°C followed by a 10 min isothermal. The results were calibrated against reference CO_2, which was injected directly into the source three times at the beginning and end of the run. All samples were run in duplicate with external standards every 4 runs; any runs of dubious integrity were discarded and repeated. The $\delta^{13}C$ values were derived according to the following expression and are relative to the international standard vPDB: $\delta^{13}C$ ‰ = ((*R* sample − *R* standard)/*R* standard) × 1000, where $R = {}^{13}C/{}^{12}C$. The $\delta^{13}C$ values were corrected for the carbon atoms added during methylation using a mass balance equation (Rieley 1994).

Results and Discussion

HTGC screening revealed very good preservation of absorbed lipids in Irish Neolithic pottery sherds (Appendix 1). Of the Early Neolithic sample sub-set, ca. 90% of pottery sherds ($n = 216$) yielded appreciable concentrations of lipid residues, i.e. >5 μg of lipid per gram of potsherd. Nearly 60% (n=135) of TLEs screened produced distributions of fatty acids and other acyl lipids consistent with degraded animal fats (Fig. 2). Triacylglycerols (TAGs) and their degradation products – diacylglycerols (DAGs) and monoacylglycerols (MAGs) – were observed in over 90% (n = 127) of these animal fats, indicating the high level of preservation of residues. This is thought to be due to the acidic soils covering much of the island of Ireland, the acidic environment inhabiting lipids leaching into the surrounding groundwater. The same high level of lipid preservation (89% on average) is observed in Scotland, which has similar soils, while in southern England the preservation rate is significantly lower at 58% on average (Copley *et al.* 2005; Mukherjee

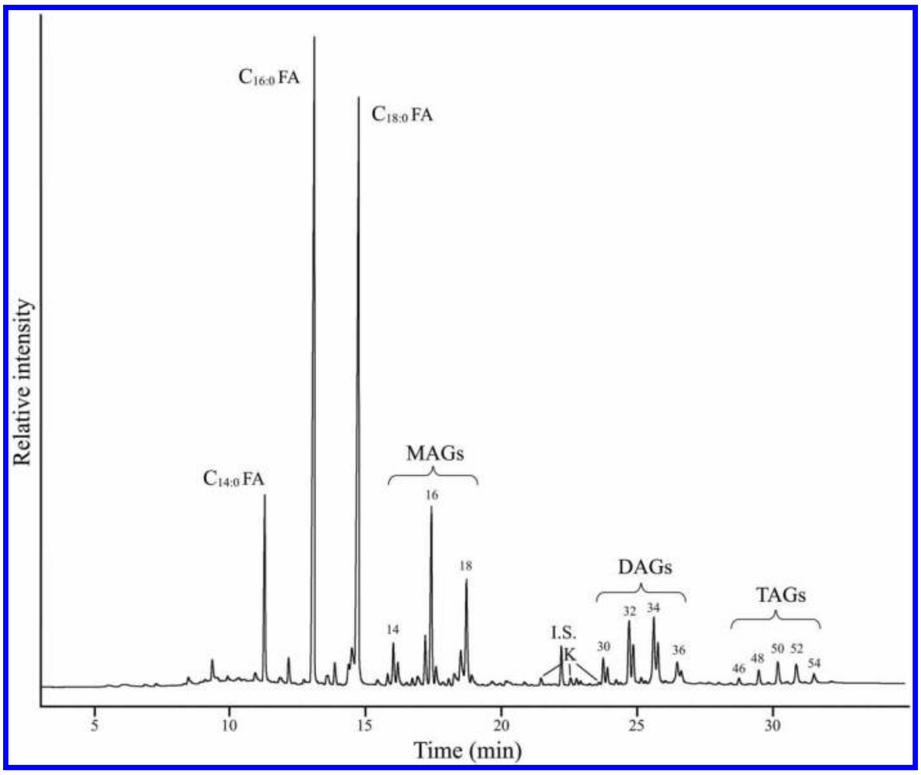

Figure 2 High-temperature gas chromatogram showing a trimethylsilylated TLE containing lipid components characteristic of a degraded animal fat, from sherd MBY-15 (03E0538:230:1) from Magheraboy causewayed enclosure. Key: Cx:y are free fatty acids of carbon length x, and degree of unsaturation y. MAGs are monoacylglycerols, DAGs are diacylglycerols and TAGs are triacylglycerols. K are ketones. I.S. is the internal standard (C_{34} *n*-alkane).

2004; Cramp *et al.* 2014). Further scrutiny of surviving TAGs showed the presence of C_{42}, C_{44} and C_{46} TAGs (Fig. 3), which are only detectable in milk fat (Dudd and Evershed 1998). GC/MS analysis confirmed the presence of ketones, indicative of heating, in 59 samples. Of the samples carried forward for compound-specific carbon stable isotope analysis ($n = 111$), 89% were found to contain $C_{16:0}$ and $C_{18:0}$ fatty acids with $\delta^{13}C$ values consistent with those from reference milk fats (Fig. 4). Together, these results provide the first unequivocal evidence that dairying in Ireland began in the Neolithic and was being practised by some of the earliest farming communities on the island. Strictly speaking, the date for the commencement of dairying in the very south of the island, in the region of the 45th century cal BC Ferriter's Cove cattle bone, has not been conclusively established, as assemblages from early 4th millennium BC house sites in this area were not sampled. When the results from various analyses are resolved by site type, organic residues in vessels from both causewayed enclosures and houses remain dominated by milk fats, the former at 96% ($n = 50$) and the latter at ~84% ($n = 61$). The remainder of residues exhibits values predominantly plotting within ranges expected for ruminant meat fats, or a mixture of milk and meat. Interestingly, meat consumption appears to be more prominent on house sites. To investigate this further, a non-parametric Mann–Whitney U test was run to determine the differences, if any, in the $\Delta^{13}C$ values ($= \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$) of animal fats from causewayed enclosures and from house sites. Use of the $\Delta^{13}C$ proxy removes exogenous factors linked to the environment, highlighting the metabolic and biosynthetic characteristics of the animal fat source and allowing the distinction between non-ruminant and ruminant fats, and adipose and dairy fats, to be drawn. For the purposes of the statistical test, the '$\Delta^{13}C$ value' was considered as the dependent variable and 'site type' the independent variable (composed of two independent groups, 'enclosure' and 'house'). Distributions of the $\Delta^{13}C$ values for enclosures and houses were similar, as assessed by visual inspection. The median $\Delta^{13}C$ value of residues was statistically significantly higher at house sites (−4.9‰) than at enclosures (−5·6‰), $U = 2177$, $P < 0\cdot001$, suggesting different patterns of consumption across these site types.

The generally good preservation of lipid residues across all of the sites examined, which were spread across a wide geographic area, suggests that low lipid yields may reflect real differences in the intensity of vessel use in the past rather than lipid degradation post-burial. Further investigation of taphonomic factors is needed, but there are some indications that variability in lipid yield is again evident at the level

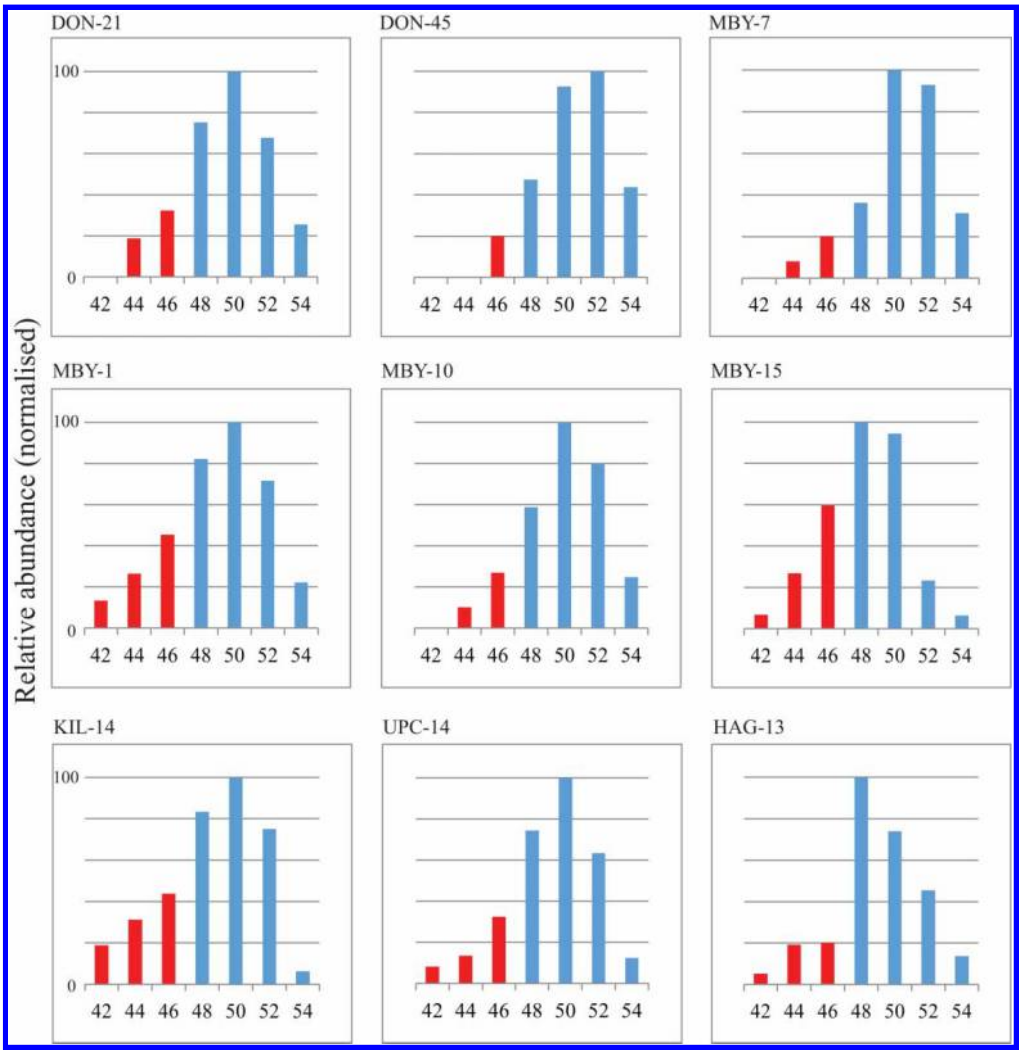

Figure 3 Histograms of triacylglycerol distributions in TLEs of sherds from causewayed enclosures (DON and MBY) and houses (KIL, UPC and HAG). The blue bars denote TAGs present in both adipose and milk fats, whereas those in red are only detectable in milk fat. The δ^{13}C values of these nine samples plot at the top, middle and bottom of the value range for reference ruminant dairy fats, shown in Fig. 4.

of site type. The mean lipid concentration of the sampled Magheraboy and Donegore Hill enclosure assemblages was 510 and 220 μg g, respectively, while at the house sites of Monanny and Haggardstown, the mean lipid concentration was around 90 μg g. Moreover, just 25–30% of samples from Monanny and Haggardstown ($n = 8$ and 9, respectively) contained sufficient concentrations of $C_{16:0}$ and $C_{18:0}$ acids for stable carbon isotope analysis. Across the Magheraboy assemblage, this figure was over 70%, and 56% across the Donegore Hill assemblage. Such variability could mean that a significant proportion of pottery vessels from house sites were not regularly used for cooking or processing but for storage instead. While beyond the scope of this paper, this could be further tested by examining a wider range of domestic sites across regions with similarly high levels of lipid preservation (e.g. Scotland), alongside a consideration of factors such as soil pH, burial conditions and post-excavation processing and storage.

Implications of Dairying in an Irish Context

The results obtained herein go much further than simply providing the earliest evidence for dairying in Ireland. In the first instance, they provide an important reminder of the fact that domesticated animals had to be taken on open sea crossings, shipped most likely in small numbers and in small vessels, then to be landed, herded and tended in a new terrain. The logistics behind this, as Humphrey Case outlined more than 40 years ago, meant it was not a task to be undertaken lightly: expertise in navigation and the handling of sea-going craft would need to be combined with an in-depth knowledge of tides, currents and the right landing places, the stakes raised significantly by the presence of large, restrained and possibly distressed animals who could not have been very easily fed and watered (Case 1969). The danger involved in such an activity is vividly illustrated in a 19th century account of an incident occurring during the routine transportation of livestock from an offshore island to the Donegal mainland. Hill (1877, 31–32)

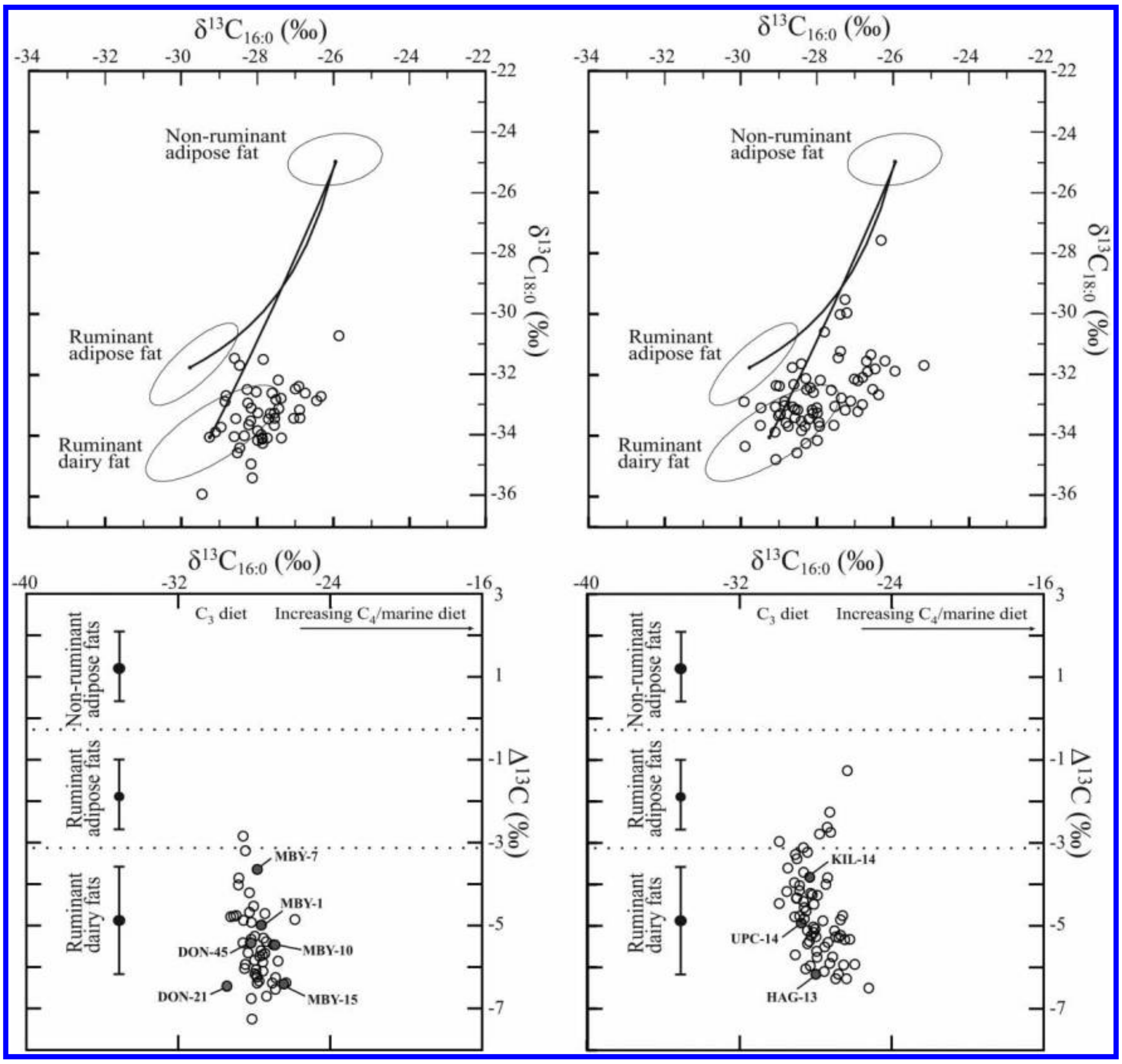

Figure 4 *Top* – Scatter plots showing the $\delta^{13}C$ values determined from $C_{16:0}$ and $C_{18:0}$ fatty acids preserved in pottery from Irish Early Neolithic causewayed enclosures (left) and house sites (right). Ellipses show 1 standard deviation confidence ellipses from modern reference terrestrial species from the UK (Copley *et al*. 2003). Archaeological and modern data are corrected for the addition of a methyl carbon during derivatisation using a mass balance equation (Rieley 1994) and the reference fats are corrected for the contribution of post-industrial carbon (Friedli *et al*. 1986). *Bottom* – The same data with $\Delta^{13}C$ values ($= \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$) plotted against $\delta^{13}C_{16:0}$ values. Ranges of the $\Delta^{13}C$ values are based on a global database comprising modern reference animal fats from the UK, Africa, Kazakhstan, Switzerland and the Near East.

recounts how a bull, tied up and rolled into a small wicker-framed boat, was being paddled back from Dooey island by a local cattle breeder and his two adult sons who had hired the animal for the season. The group was about one mile off the coast when the bull suddenly broke its ties and threatened to capsize the vessel. The sons suffocated the animal, making a split-second decision against cutting its throat and avoiding the further danger of the animal's death throes. The dead beast is brought back to the mainland and the family is sued for its loss (but is shown leniency by the judge in light of the narrowly avoided drowning).

While early prehistoric seafaring doubtless took a number of forms, the transportation of livestock is surely an example of a voyage where directness of route, and the desire to complete it as quickly as possible, is paramount (*contra* Garrow and Sturt 2011, 62). Moreover, these voyages are unlikely to have been undertaken without a significant degree of determination and broader social support (e.g. Case 1969, 180). As to whom was driving this transmission, both indigenous foragers and incoming farmers could have possessed the necessary seafaring capabilities. The later 5th millennium BC domesticated cattle bone from Ferriter's Cove, which predates any specimens so far uncovered in Britain, has been viewed as part of a precocious and ultimately unsuccessful episode of 'Neolithisation' initiated by farmers from western France (Sheridan 2003, 2010; Tresset 2003; Woodman and McCarthy 2003). Such a scenario remains possible but is based on limited evidence (Sheridan 2010, 92); we cannot be certain if such early material derived from (and was transported as) livestock, a dismembered carcass, or as defleshed, clean bone (Cooney *et al.* 2011, 623), and the desire to acquire domesticated resources could have emerged within the evolving value systems of both forager and farmer groups (Barrett 2011, 78). Nevertheless, if we consider the general absence of large, terrestrial (and milkable) mammals in early Holocene Ireland alongside the very few examples of domesticated bone in Mesolithic contexts, it begins to appear unlikely that indigenous groups had developed the expert knowledge required to successfully establish and manage dairy herds. If we add to this picture the simultaneous and very rapid appearance of skilfully manufactured pottery and plank-built houses on the island, the transmission of domesticates and cultigens to Ireland seems even less likely to be indigenously driven. This is not to underplay the importance to the process of pre-existing communication networks between foragers and farmers, something thought to be responsible for the apparent acceleration in the pace of change in the later 39th century cal BC in Britain and Ireland (Whittle *et al.* 2011, 864).

These results also serve to re-focus attention on the role of animals in the development of early farming systems. In an Irish context, they raise important questions about the environmental impact of the introduction of new species, and the proportions of new species that were bred and managed. It stands to reason that different ruminant and non-ruminant animal populations would each become differently enmeshed in the lives of humans and other organisms in the ecosystem (e.g. Hodder 2012); the footprint (and hoofprint) of activity centred on cattle husbandry, for example, may have been very different to that tailored towards sheep, and further investigation into how different domesticates affect the land management strategies and settlement patterns of agriculturalists is needed. Given the plentiful evidence for cereal remains from Early Neolithic Ireland (McClatchie *et al.* 2014) and the generally small size of settlements, what was the optimal size of an early 4th millennium BC herd, and did this depend on whether meat or milk was the primary product? The answers to some of these questions may come from a better understanding of small-scale, pre-industrial farming practices, especially those undertaken in island or in coastal environments (Fig. 5). A further obstacle to fully appreciating the mechanisms surrounding the adoption and development of farming practices is undoubtedly the lack of resolution at species level using current ORA methods; for Ireland and other regions with poor survival of faunal remains and limited opportunities for morphological analysis, the emerging technique of protein profiling of bone fragments holds special potential (e.g. Buckley *et al.* 2010).

Despite the above limitations, compound-specific carbon stable isotope analysis has revealed potential evidence for variation in consumption practices at different types of Early Neolithic sites. It appears, for example, that meat was not cooked and consumed in pottery vessels found at causewayed enclosures. As the boiling of meat has been shown experimentally to leave recognisable and resilient lipid traces in pots (Evershed 2008), this indicates that meat (ruminant or non-ruminant) was either not consumed at all or was consumed in different ways, after being spit roasted, for example. This latter, as a means to provide large quantities of food for people and in a more spectacular way than cooking in pots, certainly fits with the general interpretation of causewayed enclosures as sites of periodic communal gathering and performance (Whittle *et al.* 2011, 5–12), with some southern British sites yielding evidence for the slaughter and consumption of large quantities of meat (e.g. Legge 2008). However, given the very fragmentary faunal remains from Irish enclosures, the scenario that this dairy signal is an accurate reflection of regionally specific consumption practices cannot (as yet) be ruled out. Indeed, when the lipid isotope values from Irish enclosures are compared with those from southern British enclosures, there is a strikingly different pattern of commodity use, with milk and meat fats (from both ruminants and non-ruminants) present in pots from Windmill Hill, Hambledon Hill and Abingdon (Copley *et al.* 2005).

At Irish house sites, pottery vessels are also used for the processing of meat products. Though not a dominant lipid signal, it may indicate that meat was more frequently (or indeed exclusively) consumed at the level of the household and shared among small,

Figure 5 Photograph taken from the steamer *Dún Aengus*, 31 May 1939, capturing the final stages of a bullock's journey from the island of Inisheer (*Inis Oírr*) out to the steamer for transport to Galway. With no pier on Inisheer until 1997, this is how islanders transported livestock from the island between 1921 and 1958 (photograph: National Library of Ireland, ref: INDH3343).

intimately related groups. Alternatively, it may simply reflect the consumption of smaller, less choice cuts of meat more suitable for boiling or stewing. Morphological analysis of the surviving faunal remains from the house site at Upper Campsie identified a relatively large proportion of calcined mammal foot bones, which were interpreted as the remains of meat joints roasted over an open fire (Beglane 2011). In terms of comparable datasets from Britain, there are few published examples; lipid analysis undertaken on pottery from the Early Neolithic timber hall at Crathes, in Aberdeenshire (Murray *et al.* 2009, 94–97) has provided a similar signal to the Irish houses: mainly dairy fats with some meat fat, although unlike the Irish sites it is pig meat fat that is represented. The apparent absence of non-ruminant products from Irish Early Neolithic pots (Fig. 4) could be seen as further evidence of a lack of influence from indigenous Mesolithic groups, who presumably would have regularly hunted and consumed wild pig. However, the large isotopic difference between ruminant and non-ruminant lipids means that the mixing of even small amounts of one lipid source with the other will result in the $\delta^{13}C$ values of the predominant lipid source plotting outside of its reference range. Caution must thus be exercised in interpreting values plotting in the area of ruminant meat fats – they may in fact reflect the occasional cooking of pig products in a vessel used mostly for processing milk products. Of the Early Neolithic sites examined, pig has only been conclusively identified at Ballygalley (represented by 14 teeth; Eileen Murphy, pers. comm.) and culinary practice would still seem to diverge from that on British Neolithic sites, where there is a higher incidence of vessels being used solely or predominantly to process pig products (Copley *et al.* 2005; Mukherjee *et al.* 2008).

As discussed elsewhere (Smyth and Eversherd 2014), pottery vessels are unlikely to be the sole means by which early farming groups processed their food. Nevertheless, with a very strong dairy signal now emerging from Neolithic pottery across the north-western Atlantic archipelago (Cramp *et al.* 2014), the relative importance of milk and dairy foods in the diet of early farming groups in this region of Europe needs to be further examined. In working these ideas through, we might again take our cue from Case, who envisaged '… probably long, hazardous and absorbing struggles needed at first to maintain the farming cycle, with efforts possibly prolonged in the early stages by diet-deficiencies' (1969, 181). Milk may have been a critical energy source for incoming groups; if we have argued that indigenous foragers lacked the expertise to independently develop dairying, we might also allow the converse: that early farmers were just as ill-equipped in immediately tapping the nutritional potential of their new environment. Milk and milk products would have been a dependable, renewable and highly calorific food source, which in time may have assumed a wider cultural importance – even a symbolic role – within society. While acknowledging the growing evidence for diversity of subsistence practices in Irish early prehistory (e.g. McClatchie *et al.* 2014), it is instructive to review the large number of written sources from and about Ireland, dating from the early medieval period up to the 17th century, that document how milk and milk products could constitute a major part of a person's diet (Lucas 1960, 19–21). However, it is important to balance continued research into identifying the full palaeodietary spectrum with recognition of the cultural value of different foods, and their waxing and waning importance within prehistoric lives.

Conclusion

Organic residue analysis can be a powerful tool for investigating human palaeoecology, and especially compound-specific carbon stable isotope analysis of preserved fats. Across regions with poor bone preservation, ORA frequently provides the only means by which animals and human/animal relationships become visible in the archaeological record, and Neolithic Ireland is no exception. However, the real 'novelty' of approach in this study is the integration of molecular/isotopic data with very detailed archaeological research questions, which has allowed us to delve more deeply into the mechanics or logistics of a specific process and which will in turn allow us to establish firmer, culturally and regionally specific palaeoecological interpretations. The sorts of questions posed in this contribution are those that need to be picked apart and answered across all regions of Europe (and beyond) before we can attempt to claim a comprehensive understanding of the introduction of early farming.

Acknowledgements

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Appendix 1: Description of Early Neolithic pottery sherds submitted for analysis and details of the absorbed lipid residues detected

Site	Sherd lab code	Sherd number	Sherd type	Lipid conc. (μg g)	Lipids detected[a]	$\delta^{13}C_{16:0}$ (‰)[b]	$\delta^{13}C_{18:0}$ (‰)[b]	Assignment
Donegore Hill	DON-1		Body sherd	40	FA, MAG, DAG(tr), TAG(tr), ALK, OH	−29.3	−32.0	Mixed dairy and adipose fats; possible plant lipids
Donegore Hill	DON-2		Body sherd	10	TAG(tr)			
Donegore Hill	DON-3		Body sherd	10	FA(tr), OH(tr)			
Donegore Hill	DON-4		Body sherd	nd	(–)			
Donegore Hill	DON-5	SQ50 ZED 1 2	Body sherd	20	FA(tr), TAG(tr)			
Donegore Hill	DON-6		Upr body sherd	1300	FA, MAG, DAG, TAG, K, ALK, OH	−28.3	−34.0	Dairy fats and possible plant lipids
Donegore Hill	DON-7	SQ50 ZEA 6 3	Body sherd	10	FA(tr)			
Donegore Hill	DON-8	SQ50 YEZ 6 2	Body sherd	nd	(–)			
Donegore Hill	DON-9	SQ50 ZEB 1 2	Body sherd	40	FA, MAG, DAG, TAG, ALK, OH	−28.8	−32.7	Dairy fats and possible plant lipids
Donegore Hill	DON-10	SQ50 ZEB 3 2	Body sherd	20	FA, MAG, DAG, TAG, ALK, OH	−29.1	−32.3	Mixed dairy and adipose fats; possible plant lipids
Donegore Hill	DON-11	SQ50 YEZ 5 3	Body sherd	920	FA, MAG, DAG, TAG(tr)	−28.3	−33.9	Dairy fats
Donegore Hill	DON-12	SQ50 ZED 3 2	Body sherd	20	FA(tr), TAG(tr)			
Donegore Hill	DON-13	SQ50 ZEC 4 2	Body sherd	10	FA(tr)			
Donegore Hill	DON-14	SQ50 ZEC 4 3(?)	Body sherd	30	FA(tr), TAG(tr)			
Donegore Hill	DON-15	SQ51 AX 45 1	Body sherd	110	FA, MAG, DAG(tr), TAG(tr), K	−28.8	−33.7	Dairy fats
Donegore Hill	DON-16	SQ51 AX 45 1	Body sherd	200	FA, MAG	−28.0	−34.7	Dairy fats
Donegore Hill	DON-17	SQ52 AR 42 1	Body sherd	10	FA, MAG(tr), TAG(tr)			
Donegore Hill	DON-18	SQ52 AQ 42 1	Body sherd	10	FA			
Donegore Hill	DON-19	SQ53 AW 42 2	Body sherd	40	FA			
Donegore Hill	DON-20	SQ53 AW 41 1	Body sherd	60	FA, MAG, TAG(tr)	−28.9	−34.2	Dairy fats
Donegore Hill	DON-21	SQ53 AX 41 2	Body sherd	460	FA, MAG, DAG, TAG,	−30.1	−36.5	Dairy fats
Donegore Hill	DON-22	SQ53 AW 42 1	Body sherd	620	FA, MAG, DAG, TAG	−28.1	−32.7	Dairy fats
Donegore Hill	DON-23		Body sherd	260	FA, MAG, DAG, TAG, K	−27.5	−33.7	Dairy fats
Donegore Hill	DON-24		Body sherd	180	FA, MAG, DAG, TAG, K	−28.8	−36.0	Dairy fats
Donegore Hill	DON-25		Body sherd	260	FA, MAG, DAG, TAG, K	−28.6	−34.4	Dairy fats
Donegore Hill	DON-26		Body sherd	310	FA, MAG, DAG, TAG	−28.8	−34.1	Dairy fats
Donegore Hill	DON-27		Body sherd	100	FA, MAG, DAG, TAG			
Donegore Hill	DON-28		Body sherd	30	FA, MAG, DAG(tr), TAG(tr)			Degraded animal fat
Donegore Hill	DON-29		Neck sherd	20	FA, MAG, DAG(tr), TAG			
Donegore Hill	DON-30		Body sherd	20	FA, MAG, DAG, TAG			
Donegore Hill	DON-31		Body sherd	80	FA	−28.8	−32.9	Dairy fats
Donegore Hill	DON-32		Body sherd	20	FA(tr)			
Donegore Hill	DON-33		?Neck sherd	1250	FA, MAG,DAG(tr), TAG(tr)	−28.5	−34.7	Dairy fats
Donegore Hill	DON-34		Body sherd	10	FA			
Donegore Hill	DON-35		Body sherd	50	FA			
Donegore Hill	DON-36		Body sherd	50	FA, TAG	−27.6	−33.7	Dairy fats
Donegore Hill	DON-37		Body sherd	220	FA, MAG, TAG	−29.9	−34.6	Dairy fats
Donegore Hill	DON-38		Body sherd	20	FA			
Donegore Hill	DON-39		Neck sherd	10	FA(tr)			
Donegore Hill	DON-40		Rim sherd	160	FA, MAG	−28.0	−33.4	Dairy fats
Donegore Hill	DON-41		Body sherd	150	FA, MAG	−28.8	−35.5	Dairy fats
Donegore Hill	DON-42		Body sherd	90	FA, MAG, K	−28.3	−32.5	Dairy fats
Donegore Hill	DON-43		Body sherd	70	FA, MAG, DAG(tr), TAG(tr)	−29.1	−33.9	Dairy fats

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Site	Sherd lab code	Sherd number	Sherd type	Lipid conc. (μg g)	Lipids detected[a]	$\delta^{13}C_{16:0}$ (‰)[b]	$\delta^{13}C_{18:0}$ (‰)[b]	Assignment
Donegore Hill	DON-44		Body sherd	170	FA, MAG(tr), DAG(tr), TAG(tr), K	−27.9	−34.2	Dairy fats
Donegore Hill	DON-45		Body sherd	1290	FA, MAG, DAG, TAG	−28.6	−34.0	Dairy fats
Donegore Hill	DON-46		Body sherd	640	FA, MAG, DAG(tr), TAG(tr), K	−29.0	−33.7	Dairy fats
Donegore Hill	DON-47		Body sherd	510	FA, MAG, DAG(tr), TAG(tr)	−28.0	−33.3	Dairy fats
Donegore Hill	DON-48		Body sherd	280	FA, MAG, DAG(tr)	−28.5	−34.6	Dairy fats
Donegore Hill	DON-49		Body sherd	10	FA			
Donegore Hill	DON-50		Body sherd	440	FA, MAG, DAG, TAG	−28.0	−34.2	Dairy fats
Magheraboy	MBY-1	03E0538:29:43	Rim sherd	1230	FA, MAG, DAG, TAG	−27.6	−32.6	Dairy fats
Magheraboy	MBY-2	03E0538:35:7	Body sherd	290	FA			
Magheraboy	MBY-3	03E0538:41:5	Shoulder sherd	50	FA			
Magheraboy	MBY-4	03E0538:55:9	Rim sherd	350	FA, MAG, DAG, TAG, K	−27.9	−34.0	Dairy fats
Magheraboy	MBY-5	03E0538:55:34	Body sherd	740	FA, MAG, DAG, TAG, K	−28.2	−32.9	Dairy fats
Magheraboy	MBY-6	03E0538:55:58	Rim sherd	1210	FA, MAG, DAG, TAG, K	−28.0	−32.6	Dairy fats
Magheraboy	MBY-7	03E0538:81:2	Body sherd	180	FA, MAG, DAG, TAG	−27.8	−31.5	Dairy fats
Magheraboy	MBY-8	03E0538:126:36	Body sherd	190	FA			
Magheraboy	MBY-9	03E0538:148:13	Body sherd	870	FA, MAG, DAG, TAG, K(tr)	−27.4	−33.1	Dairy fats
Magheraboy	MBY-10	03E0538:169:10	Rim sherd	580	FA, MAG, DAG, TAG	−26.9	−32.4	Dairy fats
Magheraboy	MBY-11	03E0538:181:16	Body sherd	470	FA, MAG, DAG, TAG, K	−27.6	−33.3	Dairy fats
Magheraboy	MBY-12	03E0538:181:23	Shoulder sherd	220	FA, MAG, DAG, TAG, K	−27.5	−33.4	Dairy fats
Magheraboy	MBY-13	03E0538:220:4	Rim sherd	60	FA(tr)			
Magheraboy	MBY-14	03E0538:226:8	Rim sherd	30	FA(tr)			
Magheraboy	MBY-15	03E0538:230:1	Shoulder sherd	640	FA, MAG, DAG, TAG, K	−26.4	−32.8	Dairy fats
Magheraboy	MBY-16	03E0538:233:6	Rim sherd	40	FA, K	−25.9	−30.7	Dairy fats
Magheraboy	MBY-17	03E0538:233:7	Body sherd	650	FA, MAG, DAG, TAG, K	−26.3	−32.7	Dairy fats
Magheraboy	MBY-18	03E0538:321:12	Rim sherd	80	FA, DAG(tr), TAG(tr), K	−26.9	−33.4	Dairy fats
Magheraboy	MBY-19	03E0538:321:14	Shoulder sherd	210	FA, MAG, DAG(tr), K	−28.6	−33.4	Dairy fats
Magheraboy	MBY-20	03E0538:321:140	Body sherd	470	FA, MAG, DAG, TAG	−26.7	−32.6	Dairy fats
Magheraboy	MBY-21	03E0538:325:9	Rim sherd	1410	FA, MAG, DAG, TAG, K	−27.0	−33.4	Dairy fats
Magheraboy	MBY-22	03E0538:388:1	Body sherd	10	FA(tr)			
Magheraboy	MBY-23	03E0538:418:16	Neck sherd	nd	(–)			
Magheraboy	MBY-24	03E0538:418:18	Rim sherd	nd	(–)			
Magheraboy	MBY-25	03E0538:418:42	Shoulder sherd	20	FA	−28.5	−34.4	Dairy fats
Magheraboy	MBY-26	03E0538:425:1	?Shoulder sherd	2970	FA, MAG, DAG, TAG, K	−27.0	−32.5	Dairy fats
Magheraboy	MBY-27	03E0538:425:10	Rim sherd	180	FA, MAG, DAG, TAG	−27.9	−34.1	Dairy fats
Magheraboy	MBY-28	03E0538:425:31	Body sherd	240	FA, MAG, K	−27.7	−33.5	Dairy fats
Magheraboy	MBY-29	03E0538:469:3	Shoulder sherd	400	FA, MAG, DAG, TAG, K	−-27.5	−32.8	Dairy fats
Magheraboy	MBY-30	03E0538:469:14	Rim sherd	530	FA, MAG, DAG, TAG	−27.7	−34.1	Dairy fats
Ballygalley	BGY-1	BG15691	Rim sherd	880	FA, MAG, DAG(tr), TAG(tr), K	−28.1	−33.3	Dairy fats
Ballygalley	BGY-2	BG2579	Rim sherd	110	FA, MAG, DAG(tr), TAG(tr), K(tr)	−27.3	−29.5	Ruminant adipose fats
Ballygalley	BGY-3	BG2550	Rim sherd	250	FA, MAG	−27.3	−33.2	Dairy fats
Ballygalley	BGY-4	BG6969	Rim sherd	230	FA, MAG(tr)	−25.9	−31.9	Dairy fats
Ballygalley	BGY-5	BG3864	Shoulder sherd	390	FA, MAG	−27.5	−33.0	Dairy fats
Ballygalley	BGY-6	BG15814	Rim sherd	10	FA(tr)			
Ballygalley	BGY-7	BG6992	Rim sherd	70	FA, MAG, DAG(tr)	−27.9	−33.7	Dairy fats
Ballygalley	BGY-8	BG6535	Neck sherd	730	FA, MAG, DAG, TAG(tr), K	−28.1	−33.2	Dairy fats
Ballygalley	BGY-9	BG6627	Body sherd	1480	FA, MAG, DAG, TAG	−29.9	−32.9	Ruminant adipose fats
Ballygalley	BGY-10	BG6888	Body sherd	460	FA, MAG, DAG(tr), TAG(tr)	−27.2	−30.0	Ruminant adipose fats
Ballygalley	BGY-11	BG15303.1	Body sherd	nd	(–)			
Ballygalley	BGY-12	BG7029	Rim sherd	40	FA	−27.8	−30.6	Ruminant adipose fats
Ballygalley	BGY-13	BG6611	Shoulder sherd	110	FA, MAG(tr), TAG(tr)			Degraded animal fat
Ballygalley	BGY-14	BG5246	Rim sherd	20	FA			
Ballygalley	BGY-15	BG7001	Rim sherd	nd	(–)			

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Site	Sherd lab code	Sherd number	Sherd type	Lipid conc. (μg g)	Lipids detected[a]	$\delta^{13}C_{16:0}$ (‰)[b]	$\delta^{13}C_{18:0}$ (‰)[b]	Assignment
Ballygalley	BGY-16	BG5586	Body sherd	90	FA, MAG, K			Degraded animal fat
Ballygalley	BGY-17	BG8239	Shoulder sherd	20	FA			
Ballygalley	BGY-18	BG8862	Rim sherd	110	FA, MAG(tr), DAG(tr), TAG(tr)			Degraded animal fat
Ballygalley	BGY-19	BG8985	Body sherd	120	FA, MAG			Degraded animal fat
Ballygalley	BGY-20	BG7887	Shoulder sherd	10	FA(tr), K			
Ballygalley	BGY-21	BG7860	Rim sherd	430	FA, MAG, DAG, TAG, K	−27.1	−32.9	Dairy fats
Ballygalley	BGY-22	BG8899	Body sherd	nd	(–)			
Ballygalley	BGY-23	BG9275	Body sherd	10	FA, K			
Ballygalley	BGY-24	BG8518	Rim sherd	240	FA, MAG, DAG, TAG	−27.6	−32.5	Dairy fats
Ballygalley	BGY-25	BG8523	Shoulder sherd	3050	FA, MAG, DAG, TAG, K(tr)	−26.4	−32.7	Dairy fats
Ballygalley	BGY-26	BG8008	Body sherd	60	FA, MAG, DAG(tr), TAG(tr)			Degraded animal fat
Ballygalley	BGY-27	BG2214	Rim sherd	230	FA, MAG, K(tr)	−26.5	−31.8	Dairy fats
Ballygalley	BGY-28	BG15417.1	Rim sherd	2140	FA, MAG, DAG, TAG	−27.4	−30.0	Mixed dairy and adipose fats
Ballygalley	BGY-29	BG16213	Body sherd	90	FA, MAG(tr), K			
Ballygalley	BGY-30	BG16216	Shoulder sherd	350	FA, MAG, DAG, TAG	−26.5	−32.5	Dairy fats
Ballygalley	BGY-31	BG15297.1	Body sherd	10	FA(tr)			
Ballygalley	BGY-32	BG12787	Rim sherd	60	FA, MAG, DAG(tr), TAG(tr)	−26.8	−33.0	Dairy fats
Ballygalley	BGY-33	BG16290	Body sherd	80	FA, MAG	−28.6	−31.8	Mixed dairy and adipose fats
Ballygalley	BGY-34	BG15334.1	Neck sherd	110	FA, MAG	−26.7	−31.5	Dairy fats
Ballygalley	BGY-35	BG15335.2	Rim sherd	nd	(–)			
Haggardstown	HAG-1	06E0485:300:1	Body sherd	20	FA, MAG, DAG(tr), TAG(tr)	−29.1	−34.8	Dairy fats
Haggardstown	HAG-2	06E0485:304:9	Body sherd	10	FA, DAG(tr), TAG(tr)			Degraded animal fat
Haggardstown	HAG-3	06E0485:304:10	Body sherd	nd	(–)			
Haggardstown	HAG-4	06E0485:306:9	Shoulder sherd	10	FA(tr)			
Haggardstown	HAG-5	06E0485:306:14	Body sherd	20	FA(tr), TAG(tr)			
Haggardstown	HAG-6	06E0485:306:15	Body sherd	nd	(–)			
Haggardstown	HAG-7	06E0485:308:1	Neck sherd	10				
Haggardstown	HAG-8	06E0485:315:3	Neck sherd	480	FA, K	−26.2	−31.5	Dairy fats
Haggardstown	HAG-9	06E0485:325:16	Body sherd	10	FA(tr)			
Haggardstown	HAG-10	06E0485:325:27	Neck sherd	10	FA(tr)			
Haggardstown	HAG-11	06E0485:325:38	Body sherd	20	FA			
Haggardstown	HAG-12	06E0485:327:1	Body sherd	280	FA, MAG, DAG, TAG	−27.4	−32.8	Dairy fats
Haggardstown	HAG-13	06E0485:333:2	Neck sherd	290	FA, MAG, DAG, TAG	−28.3	−34.2	Dairy fats
Haggardstown	HAG-14	06E0485:370:2	Neck sherd	20	FA(tr)			
Haggardstown	HAG-15	06E0485:370:4	Neck sherd	20	FA(tr)			
Haggardstown	HAG-16	06E0485:377:1	Rim sherd	30	FA(tr)			
Haggardstown	HAG-17	06E0485:398:2	Body sherd	40	FA(tr)			
Haggardstown	HAG-18	06E0485:398:6	Shoulder sherd	10	FA(tr)			
Haggardstown	HAG-19	06E0485:400:1	Neck/shoulder sherd	100	FA			
Haggardstown	HAG-20	06E0485:410:4	Body sherd	50	FA, MAG(tr), DAG(tr), TAG(tr)	−27.0	−32.1	Dairy fats
Haggardstown	HAG-21	06E0485:410:7	Neck sherd	720	FA, K	−26.8	−32.1	Dairy fats
Haggardstown	HAG-22	06E0485:416:12	Body sherd	20	FA, MAG(tr), DAG(tr), TAG(tr)	−28.8	−33.0	Dairy fats
Haggardstown	HAG-23	06E0485:416:6	Body sherd	60	FA, MAG(tr), DAG(tr), TAG(tr), K(tr)	−27.4	−31.2	Dairy fats
Haggardstown	HAG-24	06E0485:425:1	Body sherd	10	FA			
Haggardstown	HAG-25	06E0485:446:2	Rim sherd	10	FA, TAG			
Haggardstown	HAG-26	06E0485:448:35	Neck sherd	20	FA			
Haggardstown	HAG-27	06E0485:448:44	Body sherd	10	FA(tr)			
Haggardstown	HAG-28	06E0485:325:37	Neck sherd	20	FA, MAG(tr)			
Haggardstown	HAG-29	06E0485:448:67	Neck sherd	40	FA			

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Site	Sherd lab code	Sherd number	Sherd type	Lipid conc. (μg g)	Lipids detected[a]	$\delta^{13}C_{16:0}$ (‰)[b]	$\delta^{13}C_{18:0}$ (‰)[b]	Assignment
Haggardstown	HAG-30	06E0485:451:3	Body sherd	40	FA			
Kilmainham 1C	KIL-1	E3140:2:82	Shoulder sherd	360	FA, MAG	−28.4	−33.8	Dairy fats
Kilmainham 1C	KIL-4	E3140:1343:2	Neck sherd	20	FA(tr), MAG(tr), DAG(tr)			
Kilmainham 1C	KIL-5	E3140:1343:6	Neck sherd	630	FA, MAG, DAG, TAG, K	−29.5	−33.7	Dairy fats
Kilmainham 1C	KIL-6	E3140:1343:30	Neck sherd	1690	FA, MAG, DAG, TAG, K	−28.3	−33.7	Dairy fats
Kilmainham 1C	KIL-7	E3140:1343:58	Body sherd	170	FA, MAG, DAG, K	−28.6	−33.1	Dairy fats
Kilmainham 1C	KIL-8	E3140:1343:78	Body sherd	210	FA, MAG, DAG, TAG	−29.9	−34.4	Dairy fats
Kilmainham 1C	KIL-9	E3140:1375:1	Body sherd	800	FA, MAG, DAG, TAG, K	−28.6	−32.3	Dairy fats
Kilmainham 1C	KIL-11	E3140:2585:1	Neck sherd	nd	(–)			
Kilmainham 1C	KIL-12	E3140:2731:1	Body sherd	110	FA, K	−28.2	−33.5	Dairy fats
Kilmainham 1C	KIL-13	E3140:2786:2	Body sherd	240	FA, MAG, DAG	−29.1	−33.0	Dairy fats
Kilmainham 1C	KIL-14	E3140:2788:27	Shoulder sherd	1860	FA, MAG, DAG, TAG, K	−28.3	−32.1	Dairy fats
Kilmainham 1C	KIL-15	E3140:2788:42	Body sherd	240	FA, MAG, DAG, TAG	−29.0	−33.3	Dairy fats
Kilmainham 1C	KIL-16	E3140:2788:57	Body sherd	30	FA			
Kilmainham 1C	KIL-17	E3140:2788:71	Neck sherd	50	FA, MAG(tr), DAG(tr), TAG(tr), K			Degraded animal fats
Kilmainham 1C	KIL-18	E3140:2788:219	Body sherd	70	FA, MAG(tr)			Degraded animal fats
Kilmainham 1C	KIL-19	E3140:2788:291	Body sherd	350	FA	−28.8	−33.6	Dairy fats
Kilmainham 1C	KIL-20	E3140:2788:341	Neck sherd	470	FA, MAG, DAG, TAG			Degraded animal fats
Kilmainham 1C	KIL-21	E3140:2788:370	Shoulder sherd	3100	FA, MAG, DAG, TAG	−28.4	−33.5	Dairy fats
Kilmainham 1C	KIL-22	E3140:2841:12	Body sherd	800	FA, MAG, DAG, TAG, K	−26.9	−32.2	Dairy fats
Kilmainham 1C	KIL-23	E3140:2945:4	Body sherd	80	FA			
Kilmainham 1C	KIL-24	E3140:3092:3	Neck sherd	1340	FA, MAG, DAG, TAG			Degraded animal fats
Kilmainham 1C	KIL-25	E3140:3190:1	Body sherd	1000	FA, MAG, DAG, TAG, K			Degraded animal fats
Kilmainham 1C	KIL-26	E3140:3202:1	Body sherd	90	FA, MAG, DAG, TAG			Degraded animal fats
Kilmainham 1C	KIL-27	E3140:3226:2	Body sherd	80	FA, DAG(tr), TAG(tr)			Degraded animal fats
Kilmainham 1C	KIL-28	E3140:3226:4	Body sherd	180	FA, MAG, DAG, TAG, K			Degraded animal fats
Kilmainham 1C	KIL-29	E3140:3225:10	Body sherd	60	FA, MAG, DAG(tr), TAG(tr), K(tr)			Degraded animal fats
Kilmainham 1C	KIL-30	E3140:3269:11	Body sherd	120	FA, MAG, DAG, TAG			Degraded animal fats
Monanny	MON-1	03E0888:51:6	Body sherd	nd	(–)			
Monanny	MON-2	03E0888:79:1	Body sherd	10	FA(tr)			
Monanny	MON-3	03E0888:105:22	Body sherd	10	FA(tr)			
Monanny	MON-4	03E0888:110:2	Body sherd	nd	(–)			
Monanny	MON-5	03E0888:176:8	Neck sherd	10	FA, MAG, TAG(tr)			
Monanny	MON-6	03E0888:206:1	Body sherd	20	FA, MAG(tr)			
Monanny	MON-7	03E0888:208:8	Body sherd	10	FA, MAG(tr), TAG(tr)			
Monanny	MON-8	03E0888:322:2	Shoulder sherd	20	FA, MAG(tr)			
Monanny	MON-9	03E0888:350:2	Body sherd	80	FA, MAG, DAG, TAG, K	−25.2	−31.7	Dairy fats
Monanny	MON-10	03E0888:499:3	Body sherd	80	FA, MAG, DAG, TAG	−26.3	−27.6	Ruminant adipose fats
Monanny	MON-11	03E0888:502:13	Neck sherd	20	FA(tr)			

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Site	Sherd lab code	Sherd number	Sherd type	Lipid conc. (μg g)	Lipids detected[a]	$\delta^{13}C_{16:0}$ (‰)[b]	$\delta^{13}C_{18:0}$ (‰)[b]	Assignment
Monanny	MON-12	03E0888:515:2	Neck/ shoulder sherd	30	FA(tr)			
Monanny	MON-13	03E0888:521:5	Body sherd	70	FA			
Monanny	MON-14	03E0888:522:7	Body sherd	10	FA(tr)			
Monanny	MON-15	03E0888:555:5	Shoulder/ body sherd	60	FA, MAG(tr), TAG, K(tr)			
Monanny	MON-16	03E0888:580:25	Body sherd	990	FA, MAG, DAG, TAG, K	−28.6	−33.4	Dairy fats
Monanny	MON-17	03E0888:580:34	Shoulder sherd	320	FA, DAG(tr)			
Monanny	MON-18	03E0888:592:51	Body sherd	130	FA, TAG(tr)			
Monanny	MON-19	03E0888:606:1	Body sherd	20	FA			
Monanny	MON-20	03E0888:683:1	Body sherd	100	FA			
Monanny	MON-21	03E0888:733:1	Body sherd	50	FA			
Monanny	MON-22	03E0888:750:1	Body sherd	30	FA, MAG(tr)			
Monanny	MON-23	03E0888:839:1	Neck sherd	200	FA, MAG, DAG, TAG	−27.4	−31.4	Dairy fats
Monanny	MON-24	03E0888:902:2	Body sherd	20	FA			
Monanny	MON-25	03E0888:927:2	Neck sherd	10	FA(tr)			
Monanny	MON-26	03E0888:948:12	Body sherd	10	FA(tr)			
Monanny	MON-27	03E0888:958:1	Neck sherd	240	FA, MAG, DAG, TAG	−26.7	-31.9	Dairy fats
Monanny	MON-28	03E0888:960:1	Neck sherd	nd	(–)			
Monanny	MON-29	03E0888:1045:1	Rim sherd	10	FA(tr)			
Monanny	MON-30	03E0888:1051:22	Body sherd	30	FA, MAG, DAG, TAG(tr)			Degraded animal fat
Monanny	MON-31	03E0888:1100:1	Neck/ shoulder sherd	40	FA, MAG, DAG(tr)			Degraded animal fat
Monanny	MON-32	03E0888:1102:1	Body sherd	10	FA			
Monanny	MON-33	03E0888:1103:1	Neck sherd	60	FA, MAG, DAG(tr), TAG(tr)			Degraded animal fat
Upper Campsie	UPC-1	AE/09/ 102:14:22a	Rim sherd	50	FA, MAG, DAG, TAG	−26.6	−31.3	Dairy fats
Upper Campsie	UPC-2	AE/09/ 102:14:22b	Rim sherd	nd	(–)			
Upper Campsie	UPC-3	AE/09/ 102:14:22c	Body sherd	nd	(–)			
Upper Campsie	UPC-4	AE/09/ 102:78:146a	Shoulder sherd	nd	(–)			
Upper Campsie	UPC-5	AE/09/ 102:78:146b	Neck sherd	nd	(–)			
Upper Campsie	UPC-6	AE/09/102:87:32	Rim sherd	nd	(–)			
Upper Campsie	UPC-7	AE/09/ 102:102:67	Rim sherd	nd	(–)			
Upper Campsie	UPC-8	AE/09/ 102:112:46a	Rim sherd	170	FA, MAG, DAG, TAG	−29.0	−33.3	Dairy fats
Upper Campsie	UPC-9	AE/09/ 102:112:46b	Body sherd	100	FA, MAG, DAG, TAG, K	−29.1	−32.3	Mixed ruminant dairy and adipose fats
Upper Campsie	UPC-10	AE/09/ 102:120:98a	Shoulder sherd	3630	FA, MAG, DAG, TAG, K	−28.6	−33.1	Dairy fats
Upper Campsie	UPC-11	AE/09/ 102:120:98b	Rim sherd	5390	FA, MAG, DAG, TAG, K	−27.9	−32.2	Dairy fats
Upper Campsie	UPC-12	AE/09/ 102:120:109	Shoulder sherd	170	FA, MAG, DAG, TAG	−29.0	−32.4	Mixed ruminant dairy and adipose fats
Upper Campsie	UPC-13	AE/09/ 102:125:53	Shoulder sherd	630	FA, MAG(tr), DAG, TAG, K	−28.1	−32.6	Dairy fats
Upper Campsie	UPC-14	AE/09/ 102:150:144a	Body sherd	90	FA, MAG, DAG, TAG	−28.8	−33.7	Dairy fats
Upper Campsie	UPC-15	AE/09/ 102:150:144b	Body sherd	30	FA			
Upper Campsie	UPC-16	AE/09/ 102:150:150a	Body sherd	690	FA, MAG, DAG, TAG	−28.2	−32.4	Dairy fats
Upper Campsie	UPC-17	AE/09/ 102:150:150b	Rim sherd	630	FA, MAG, DAG, TAG, K	−28.5	−33.2	Dairy fats

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Continued

Site	Sherd lab code	Sherd number	Sherd type	Lipid conc. (µg g)	Lipids detected[a]	$\delta^{13}C_{16:0}$ (‰)[b]	$\delta^{13}C_{18:0}$ (‰)[b]	Assignment
Upper Campsie	UPC-18	AE/09/ 102:163:68	Neck sherd	nd	(–)			
Upper Campsie	UPC-19	AE/09/ 102:193:121a	Shoulder sherd	1580	FA, MAG, DAG, TAG, K	−27.9	−33.6	Dairy fats
Upper Campsie	UPC-20	AE/09/ 102:193:121b	Neck sherd	nd	(–)			
Upper Campsie	UPC-21	AE/09/ 102:193:121c	Rim sherd	620	FA, MAG, DAG, TAG, K			Degraded animal fat
Upper Campsie	UPC-22	AE/09/ 102:193:121d	Body sherd	1330	FA, MAG, DAG, TAG, K	−27.9	−33.6	Dairy fats
Upper Campsie	UPC-23	AE/09/ 102:193:121e	Rim sherd	220	FA, MAG, DAG, TAG			Degraded animal fat
Upper Campsie	UPC-24	AE/09/ 102:193:121f	Body sherd	770	FA, MAG, DAG, TAG			Degraded animal fat
Upper Campsie	UPC-25	AE/09/ 102:210:102	Body sherd	30	FA(tr)			
Upper Campsie	UPC-26	AE/09/ 102:210:108	Shoulder sherd	20	FA(tr)			
Upper Campsie	UPC-27	AE/09/ 102:216:100a	Body sherd	nd	(–)			
Upper Campsie	UPC-28	AE/09/ 102:216:100b	Body sherd	20	FA, MAG, DAG, TAG			Degraded animal fat
Upper Campsie	UPC-29	AE/09/ 102:216:100c	Shoulder/ neck sherd	10				
Upper Campsie	UPC-30	AE/09/ 102:216:100d	Rim sherd	2380	FA, MAG, DAG, TAG, K			Degraded animal fat
Upper Campsie	UPC-31	AE/09/ 102:232:118a	Shoulder sherd	10	FA			
Upper Campsie	UPC-32	AE/09/ 102:232:118b	Rim sherd	50	FA, DAG, TAG, K			Degraded animal fat
Upper Campsie	UPC-33	AE/09/ 102:232:118c	Rim sherd	2100	FA, MAG, DAG, TAG, K			Degraded animal fat
Upper Campsie	UPC-34	AE/09/ 102:235:115	Body sherd	340	FA, MAG, DAG, TAG			Degraded animal fat

[a] FA, fatty acids; MAG, monoacylglycerols; DAG, diacylglycerols; TAG, triacylglycerol; ALK, *n*-alkanes; OH, *n*-alcohols; K, mid-chain ketones; nd, not detected.

[b] Analytical error is ±0.3‰; $\delta^{13}C$ values have been corrected for the carbon atoms added during methylation.

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