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Selected with care? – the technology of crucibles in late prehistoric Scotland. A petrographic and chemical assessment

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ABSTRACT

Prehistoric crucibles and other metalworking ceramics are often described as highly specialised tools made from refractory materials, but little is known about regional trajectories and individual material developments. Hence, further analyses of materials from less studied regions are needed. The current study investigates the technological development of crucibles from late prehistoric Scotland and its relation to technological choices and specialisation. The examination, using ceramic petrography and Energy Dispersive X-Ray Spectroscopy, focuses on the selection of clays and additives for the manufacture of crucibles in contrast to moulds and pottery. It is demonstrated that the production of crucibles in the late prehistoric period predominantly used local resources. Late Bronze Age crucibles have a close relationship with other types of technical and domestic ceramics, while materials in the Iron Age indicate an increased material specialisation for the preparation of particular fabrics. This development is seen across Scotland and echoes trends seen in other areas of Europe, emphasising the role and importance of metallurgical and technological networks.

1. Introduction

Metalworking ceramics, including moulds, crucibles, tuyères, and furnace lining, are a group of tools used for the production and processing of metals and metal alloys. These materials are often classified as specialised technical tools demanding a high degree of technological skill, and said to indicate socio-economic status of a particular site or society (e.g. Howard, 1983; Levy, 1991: 68; Ehrenreich, 1991: 78). Technical studies have shown that these materials and practices are more nuanced. Early materials were simple, predominately made from local clays (e.g. Childs, 1989; Schneider, 1989; Evely et al. 2012); while technically advanced refractory materials were used first in post-Roman periods (e.g. Freestone and Tite, 1986; Bayley et al., 1991; Rehren, 2003). The technology of metalworking ceramics is well documented, but based on chronologically and geographically spread case studies; Bayley and Rehren (2007) and Freestone (1989) provide good summaries of previous literature. Little is known about regional trajectories and few studies have looked at the material in a diachronic perspective, hence more detailed studies from specific areas are needed to give a fuller understanding of this material.

This article discusses data for the manufacture of crucibles in late prehistoric Scotland, the period from the Late Bronze Age to the Early Historic period[1] (Table 1)(cf. Harding, 2004). The focus here will be on crucibles, vessels used for high temperature processes of various substances, for example metals, glass and pigments (Bayley and Rehren, 2007). Scottish late prehistoric crucibles were mainly used for casting of copper alloyed with lead and/or tin in varied amounts, but crucibles used for casting and processing precious metals, particularly silver, are known from the later part of the Iron Age (Hunter et al., 2007: 56). The goal is to investigate the technological development of crucibles in the context of material choices and specialisation. Other types of metalworking ceramics together with domestic pottery will be used to assess the material properties of crucibles. A central aim is to assess the technology of late prehistoric crucibles and test if the craftworkers selected particular clays different from those used for other groups of ceramics.

Recent decades have seen a development of our understanding of technology, from a static residue of human culture to an active

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[1] The period from ca. AD 400 to AD 800 is termed Early Historic for most of Scotland, while some scholars argue that this period is a final phase of an extended Iron Age (IA) in Atlantic Scotland and term it the Late Iron Age (Ralston and Armit, 2003: 218).

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Table 1
The late prehistoric period in Scotland, compared with SE England and continental chronology; Early Historic refers only to Scotland; periods marked in bold are discussed in this paper.

Period	Scotland, absolute chronology	SE England, [a]absolute chronology	Hallstatt/La Tène[a]
Late Bronze Age (LBA)	1000–700 BC	1150–800 BC	Hallstatt B/C
Early Iron Age (EIA)	700–200 BC	800–600 BC 600–400/300 BC	Hallstatt C/D
Middle Iron Age (MIA)	200 BC – AD 300/400	400/300–100/50 BC	La Tène I/II
Late Iron Age/Early Historic (LIA/EH period)	AD 300/400–800	100/50 BC – AD 43	La Tène II/III

[a] After Cunliffe (2005).

process constructing social meanings and processes (cf. Dobres, 2010). Studies of ceramics, particularly pottery, have increasingly looked at individual or social practices for the technological sequence, from material procurement to firing or use (Sillar and Tite, 2000) commonly in the context of *technological choices* – choices made by the potter during the manufacturing process. This research has shown that production is often embedded in daily life and a central part of traditions and social practices (e.g. Gosselain and Livingstone Smith, 2005). This article looks at the first two steps in the production sequence in the manufacture of metal-working ceramics, particularly crucibles in late prehistoric Scotland and views this in relation to material selection:

1. the selection of clays and tempering agents
2. the preparation of the ceramic fabric

Discussions of the use of clay sources have traditionally focused on the question of provenance with the goal to characterise material groups or point towards a geological or geographical origin (Wilson and Pollard, 2001), but an increasing theoretical literature has looked more in detail at why certain sources were selected. Several scholars have highlighted the difficulties in determining the exact provenance of a particular ceramic material following the often high variability of ceramic materials, due to both anthropogenic and natural causes (Blackman, 1992; Tite, 1999: 197; Rapp and Hill, 1998: 140–41). The issue of the provenance of the ceramic material is not a key-question in the current study, but the assessment of the use of local vs. non-local clays will be essential. Local is based in this context on Arnold's assessment of the use of clays in ethnographic contexts (1985; 2000). Arnold argued that a potter would usually collect clay and temper within a 1–3 km radius from the production site, and rarely go beyond 7 km. His conclusion is supported by later research (e.g. Gosselain and Livingstone Smith, 2005: 35; Sillar, 1997); but both Gosselain/Livingstone Smith and Sillar emphasised that social rather than economic mechanisms, as Arnold stressed, were central to the formation of particular selection processes.

Previous studies looking at the provenance of pottery from late prehistoric Scotland (e.g. Topping, 1985; MacSween, 1990, 2007) have highlighted that pottery was produced locally using local resources. This follows the main trend seen in late prehistoric Britain (Morris, 1996; Fig. 5.2), where there is little evidence that communities would travel beyond the local surroundings to collect clays, and likewise there was little evidence for the trade of pottery. Centralised production of pottery is first seen in southern England at the end of the prehistoric era (Morris, 1996: 49). Specialised production and trading of pottery was not seen in Scotland until the medieval period (cf. Jones et al., 2003), while large parts of Scotland have been described as aceramic during the late prehistoric period (see below).

The origin of clay and temper used for metalworking ceramics has not been as well studied as the provenance of pottery, and the understanding of practices during prehistoric periods of particularly north/northwest Europe is still sketchy. The ceramic technology of crucibles and metalworking ceramics from Scotland has never been assessed in detail. Most studies have instead focused on material morphology and its chronological potential (e.g. Heald, 2001; Campbell and Heald, 2007). Hilary Howard's (1983) thesis is the only comprehensive study of prehistoric materials from Britain. She concluded that LBA crucibles (Howard, 1983: 490) and moulds are made from carefully selected local clays. This is in contrast to other studies which have shown that predominantly local alluvial clays were used (Bayley and Rehren, 2007: 47; Evely et al., 2012:, 1833).

Howard made no assessment of the provenance for the clay or tempering materials used in the Iron Age, but stressed the presence of three distinct refractory crucible fabric groups: carbon-rich fabric; carbon/quartz-rich fabric; sand-rich fabric (Howard, 1983: 496). Other studies north of the Alps have shown a continuous use of local clays in the Iron Age, as for example the Celtic oppidum Kelheim in north Germany (Schäfer and Scharff, 2003) and the Viking Age city Birka in Sweden (Vince, 2005: 244). The use of refractory fireclays is first seen in the medieval period (Freestone and Tite, 1986: 48–53; Bayley et al. 1991).

2. Materials

Functional qualities of a prehistoric crucible depend on its shape and fabric (Bayley and Rehren, 2007: 46–49). A general trend in crucible morphology from thick-walled shallow vessels to thin-

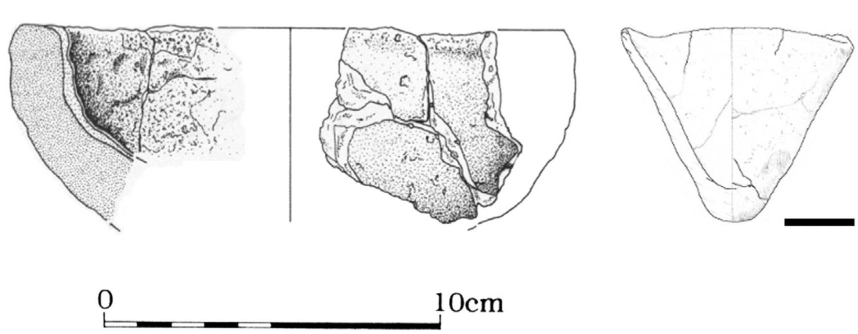

Fig. 1. Example of late prehistoric crucibles from Scotland, LBA crucible from Birnie (left, scale bar 10 cm) and MIA crucible from Traprain Law (right, scale bar 2 cm); from original drawings by Alan Braby.

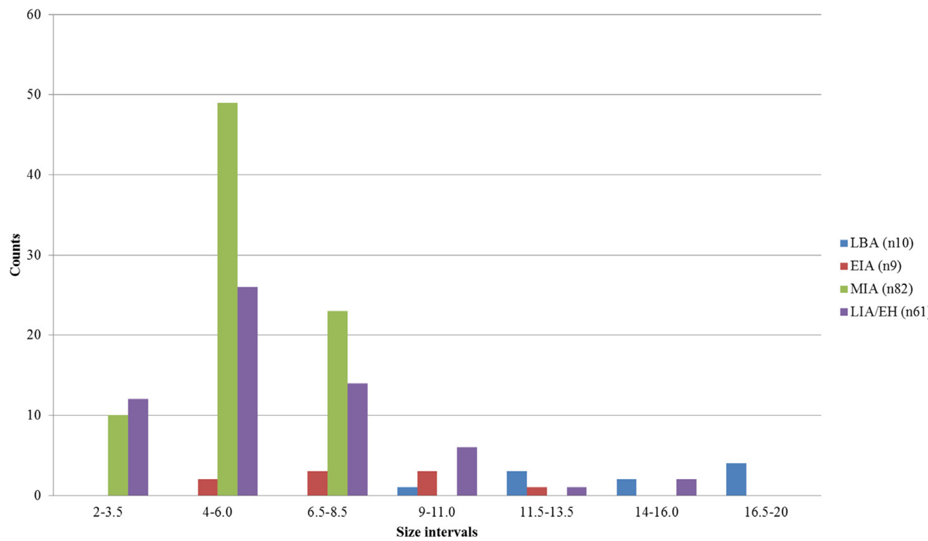

Fig. 2. Wall-thickness of Scottish late prehistoric crucibles; measurements in mm.

walled deeper vessels in pre-Roman periods is well documented (Bayley and Rehren, 2007: 53–54). The former were heated from above with the heat directed into the vessel, while the later were heated from below with the heat directed through the vessel wall. The fabric had to change accordingly, with the latter demanding a fabric which was more heat resistant but at the same time with a good thermal conductivity. Scottish LBA crucibles were thick-walled shallow vessels (mean 14.6 mm; Figs. 1 and 2), similar to their southern British counter-parts (cf. Tylecote, 1986: 97, Fig. 50), however a complete crucible has still not been found in Scotland. The crucible was heated from above, which is shown in an uneven vitrification, and the presence of slag, metal residue and heavy vitrification particularly on the inside and the rim. MIA and LIA/EH crucibles are in contrast thin-walled (MIA mean 5.4 mm; LIA/EH mean 5.9 mm, Figs. 1 and 2) and the size and the capacity varied. Most types are open and were probably filled with charcoal to create a reduced atmosphere, but there are also examples of closed shapes. Thicker crucibles shapes are known from the LIA/EH period, but these were used for particular metallurgical processes, such as mixing and refining of metals. Crucibles from the Iron Age often show a more complete vitrification. The heat was probably often directed from below, but the evidence from vitrification cannot rule out the possibility that crucibles at some sites were heated from above.

Different writers have tried to define a more detailed typology of crucible shapes in Scotland and Britain generally (e.g. Tylecote, 1986: Table 58; Bayley, 1989: 293–296; Lane and Campbell, 2000; Fig. 4; Heald, 2005, Table 2), but a stylistic scheme of Scottish crucibles beyond a rudimentary classification of basic shapes has still not been successful. It seems that crucibles are not chronologically sensitive and morphological differences are more related to function and utilization. The most common shape in the Iron Age is the deep triangular crucible (Fig. 1), but other shapes are also known (Heald, 2005; Table 1).

Late prehistoric Scotland has a rich assemblage of sites – over 100 – with evidence of non-ferrous metalworking, mainly dating to the later part of the Iron Age and the Early Historic period (Heald, 2005; Hunter et al., 2007; Sahlén, 2011: 146–47). This large group of material gives a great potential for the study of material and technological developments over a wide chronological sequence. The current study analyses material from nine sites dating from the LBA, the MIA and the LIA/EH period (Fig. 3, Table 2). The sites were selected to cover a comprehensive geographical and chronological spread of sites throughout the late prehistoric period. Material from the EIA was omitted since materials from this period are largely undiagnostic and trends in this period are only vaguely understood.

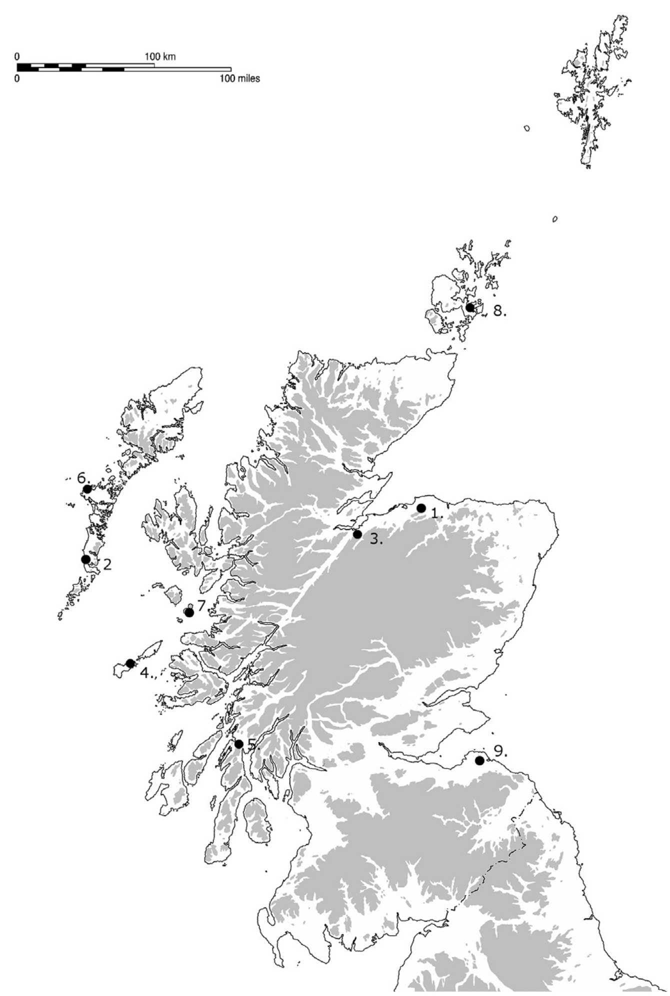

Fig. 3. Map of Scotland with the sites analysed in this study marked; numbers refers site numbers (S.no) in Table 2.

Table 2
List of sites, with details of location, site context, period and number of samples (including all types of ceramics) analysed with TS (thin section, number in brackets refers to number of crucibles) and SEM-EDX (scanning slectron microscopy/energy dispersive X-ray spectroscopy) per site; S.no: site number and refers to the numbers in Fig. 3.

Sites	S.no	Site context	Regional location	Period/s	TS	SEM/EDX
Birnie	1	Unfortified settlement	Moray	LBA/MIA	17 (4)	12 (4)
Cladh Hallan	2	Unfortified settlement	South Uist	LBA	7 (3)	7 (3)
Culduthel	3	Industrial complex	Inverness-shire	MIA	10 (6)	10 (6)
Dun Mor Vaul	4	Fortified settlement	Isle of Tiree	MIA	11 (3)	8 (3)
Dunadd	5	Hillfort	Argyll	LIA/EH	12 (5)	7 (4)
Eilean Olabhat	6	Isolated workshop	North Uist	LIA/EH	9 (3)	6 (3)
Galmisdale	7	Isolated deposit	Isle of Eigg	LBA	6 (2)	4 (2)
Mine Howe	8	Ritual complex	Orkney	MIA	21(5)	10 (5)
Traprain Law	9	Hillfort	East Lothian	LBA/IA	34 (8)	15 (8)
Total					127	79

In addition to the metalworking ceramics pottery (excluding some sites from where pottery is absent; see Sahlén, 2011 for full details) and occasionally other ceramic/clay materials from the selected sites are included. The examinations of the pottery are limited and included purely as a comparison to the metalworking ceramics. Clays were sampled and analysed from three sites (cf. Sahlén, 2012a): Birnie, Mine Howe and Traprain Law, but the sampling of clays from two sites – Birnie and Traprain Law – was more thorough, providing a more detailed picture of the relation between clay and the ceramic materials (Table 3).

3. Methods

An integrated analytical methodology, using a series of different archaeometric techniques, was applied to samples of metalworking ceramics, pottery and sampled clays. The use of multiple techniques offers the possibility of looking at the same dataset from different perspectives, to provide supporting evidence or answering alternative but related questions (cf. Day et al., 1999; Tite, 1999: 201; Spataro, 2011). Sample selection was based on a macroscopic analysis of the material from each site. The number of samples from each site was constrained by the fragile and rare nature of some of the material analysed, although a representative sample of materials from each site was selected. All samples were analysed using petrographic thin section analysis (TS), and selected subsamples were studied using scanning electron microscopy, combined with energy dispersive X-ray spectroscopy (SEM-EDX)(Table 2); a few samples were analysed using X-ray diffraction (XRD).

TS was used for a first general characterisation of the materials with the goal to identify material groups based on the material background and the technology (cf. Whitbread, 2001). Analyses were carried out at National Museums Scotland (NMS), Department of Geology using a Leica DM LSP polarising microscope in plain polarised (ppl) and cross polarised light (xpl). A quantitative assessment predominantly of the crucibles was made performing a point-counting analysis, quantifying the proportion of ceramic matrix, voids, and three classes of grain sizes: silt (<67 μm), sand (67–500 μm), coarse sand (>0.5 mm). Image analyses were conducted using the software ImageJ (cf. Reedy, 2004). This analysis was combined with the measurement of average and largest inclusion sizes. The method was based on the work by Middleton et al. (1985) and Stoltman (1989), but was adapted to suit the facilities and the materials in the current project.

Table 3
List of sampled clays from Birnie (BC), Mine Howe (MHC) and Traprain Law (TLC) respectively, with details of location, type of deposit and approximate distance to the archaeological site.

S. no.	Location	NGR	Deposit type	Distance
BC1	S of Birnie, the Sand Quarry	NJ210 585	Natural	<1 km
BC2	SE of Birnie, Clay Pot	NJ221 567	Clay pit	Ca 3 km
BC3	N of Birnie, Loch of Spynie	NJ235 665	Clay pit	>7 km
BC4	At the site	NJ210 585	From excavation	0
MHC1	Vicinity	Unknown	Natural	Unknown
MHC2	At the site	HY510 060	From excavation	0
TLC1	W of Traprain, Cairndinnis	NT571 747	Natural deposit	<1 km
TLC2	S of Traprain, Luggate	NT581 743	Natural deposit	<1 km
TLC3	SW of Traprain, Renton Hall	NT546 720	Clay pit	Ca 7 km
TLC4	E of Traprain, Sunnyside	NT595 755	Natural deposit	<1 km
TLC5	S of Traprain, West Mains	NT577 725	Natural deposit	Ca 3 km

The analyses with the SEM and SEM-EDX (Sahlén, 2012b) were performed on selected samples to support the petrographic analysis. Back-scattered electron (BSE) images of polished blocks and polished thin sections were analysed to study the microstructure of the material, assessing firing/heating temperatures and vitrification processes. This work was primarily carried out at NMS Analytical Research section on uncoated polished thin sections and blocks in en-vac using a CAMSCAN MX2500; additional samples were analysed as fractured surfaces and carbon coated polished blocks at the University of Glasgow, School of Geographical and Earth Sciences using a field emission environmental Quantas 200F SEM. Microanalysis with SEM-EDX was used to study the compositional relationship between different groups of ceramics and between ceramics from particular sites. Analyses were performed at NMS with a Norum Vantage spectrometry package, at 20 kV 35 mm working distance (which is the standzard at NMS),$\times$500 magnification and 4×4 μm spot size. Analyses were taken at three spots across the section, avoiding metal stained areas, to analyse the ceramic matrix rather than a bulk analysis of the whole sample. This was performed since the composition of the clay matrix was of primary interest and the, often extensive, amount of large lithic inclusions and quartz in moulds and crucibles was thought to dilute the composition of the clay. A central question was to assess if a specific fireclay was selected. Bulk analyses of the ceramic material and stained areas were occasionally carried out as a comparison to the spot analysis. The accuracy of the data was tested at different times with a sample of Edinburgh Standard clay, a standard tested at the Scottish Universities Environmental Research Centre (SUERC) with NAA and often used as a standard in ceramic analyses in Scotland (e.g. Topping and MacKenzie, 1988: 95).

Nine oxides were measured as standard for all samples analysed: Na_2O; MgO; Al_2O_3; SiO_2; K_2O; CaO; TiO_2; FeO; P_2O_5. A principal components analysis (PCA), using SPSS (version 18), was carried out on the composition of ceramics and fired sampled clays, comparing the materials from different sites, groups of materials and the whole assemblage, with the aim to identify compositional groups. The refractory quality of crucibles, moulds and other ceramics was assessed by calculating the ratio between the amount of alumina (Al_2O_3) and the amount of alkali metal and alkali earth metal oxides (Na_2O; MgO; K_2O; CaO):

$$Al_2O_3/(Na_2O + MgO + K_2O + CaO)$$

A high value of aluminia and a low value of alkali metals and earth metals would mean a higher refractory quality. This assessment was adopted from the work of Martinón-Torres and Rehren (2009; see also Martinón-Torres, 2005) based on their investigation of the refractory quality in European post-medieval crucibles.

Analyses using XRD were conducted at Historic Scotland's Technical Conservation Group on ground samples of ceramics and fired clays, using an ARl X'tra XRD. The technique was carried out as a pilot study on a minor selection of samples from Traprain Law, and was used as a supplement to the thin section analysis to characterise the mineralogy and mineral alteration (cf. Stanjek and Häusler, 2004).

4. Results

4.1. Petrographic analysis

The petrographic analysis indicated a clear difference between the LBA material and the material from the MIA and LIA/EH periods (Appendix 1, Fig. 4). The LBA crucibles were made from coarse sandy clay, consistent with the local geology and the likely use of local clays (Appendix 1). This conclusion is also supported by the analyses of sampled clays from two of the sites: Birnie and Traprain Law (Table 3, Sahlén, 2012a). Larger inclusions, often with an angular/subangular shape seem to have been added as temper, but could in some cases be part of the natural clay. The type of inclusion varies between the different sites, a reflection of differences in the local geology, but the size of the inclusion is consistently that of coarse to very coarse sand (Fig. 4). Inclusions in the different fabrics are assorted both in type and size, suggesting the use of secondary clays. The often very porous nature of the material derives from the bloating of the clay following the extreme temperatures used during the melting of the crucibles, but stems also from the use of organic temper, mainly in the form of grass and other thick fibrous organic materials.

The crucible fabrics show close petrographic similarities with other ceramic fabrics from the same site and the use of the same source of clay for the production of different ceramic materials is probable. There are particularly strong similarities between the crucible fabric and the coarser mould fabric from Cladh Hallan and Traprain Law, suggesting that the materials were prepared in the same way or from the same paste (Fig. 5). Samples of LBA pottery was not obtained from all sites, but analyses of pottery from some of the sites and assessments of unpublished reports, demonstrated a petrographic relationship between the pottery and metalworking ceramics. Further analysis is on-going to explore this relationship further, but the current understanding is that pottery and metalworking ceramics were often made from the same or geologically related clay.

In contrast, the material from the MIA shows a higher variability in preparation of specific fabrics and use of different clay sources (Appendix 1, Fig. 4), but a shared technology throughout the later part of the Iron Age and the Early Historic period is evident. Most fabrics are made from secondary clays, which are probably local in origin. There is also evidence in the Iron Age of the use of the same, or a similar clay, for different ceramic materials (Fig. 6), which supports the conclusion that the material is made from local resources. There are a few cases where the use of specific sources for a particular ceramic material is evident and there is often a distinct difference between different ceramic fabrics. The sampling of local clays around Birnie and Traprain Law provided the possibility to match ceramic fabrics with particular clays. The crucibles and most of the pottery at Birnie were made from a similar clay, probably collected within the range of 3 km, but it is also clear that some pottery was made from alternative resources (Sahlén, 2012a: 5–7).

The MIA crucibles from Traprain Law were possibly made from a non-local clay resource located at least 7 km away, based on X-Ray Diffraction analyses of the ceramics and sampled clays (Fig. 7), whilst most of the pottery and the moulds were probably made from local clays, similar to those used in the LBA. XRD analyses of ceramic materials from Traprain Law indicated that the dominant mineral in all crucible fabrics, excluding quartz, is mullite. Natural

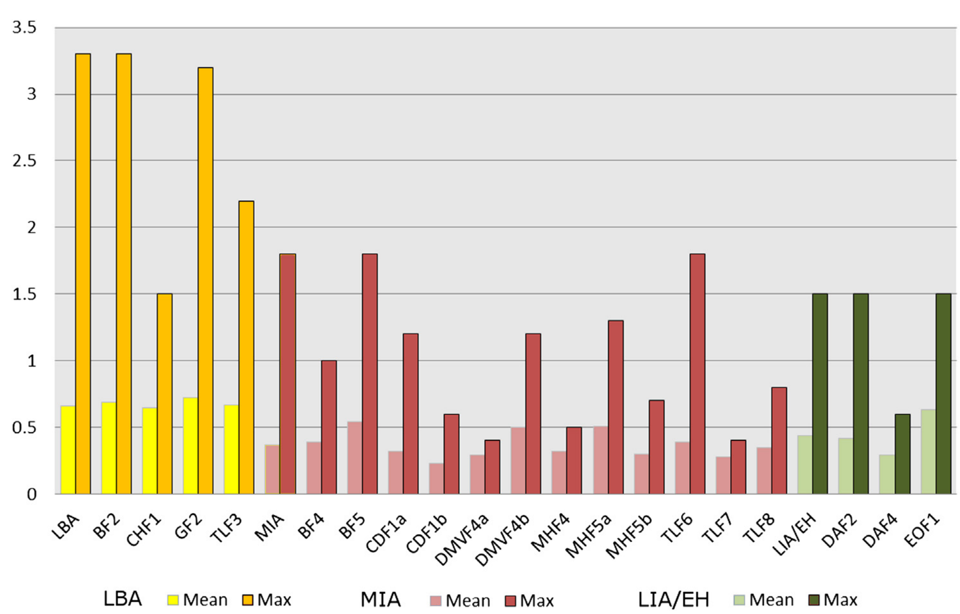

Fig. 4. Clustered bar chart showing the mean and max size of grains in late prehistoric crucibles (number of samples in brackets); measurements are based on the average of the 10 largest grains in three randomly selected areas (measurements in mm).

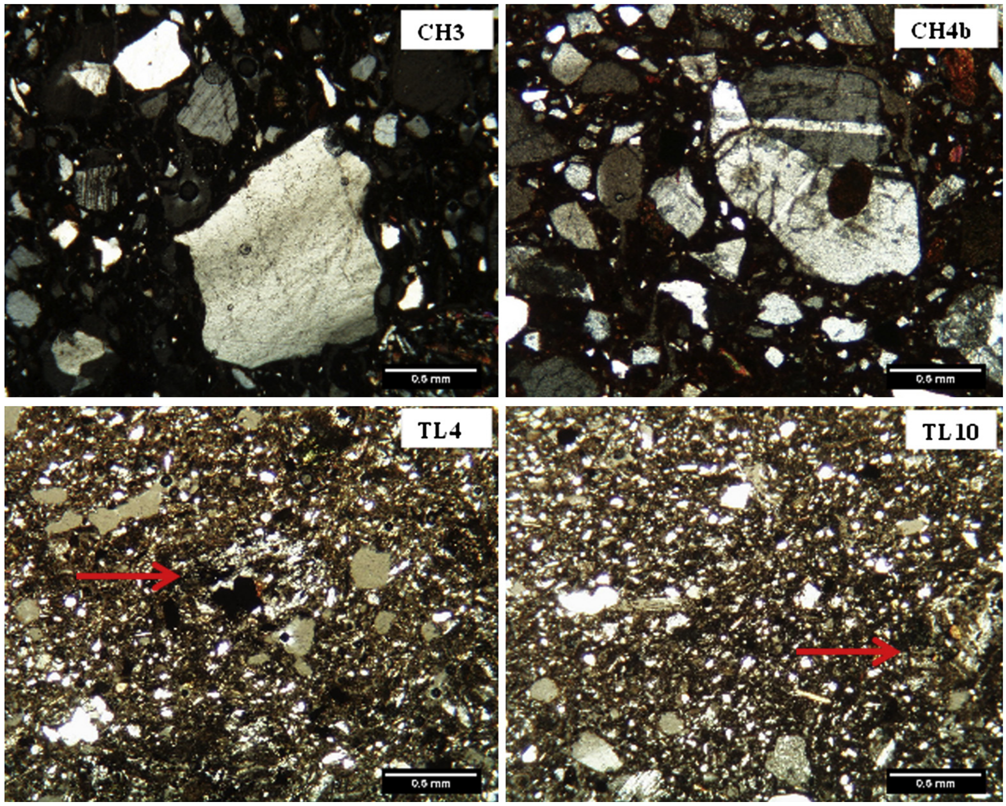

Fig. 5. Example of crucible (left) and outer mould (right) fabrics from Cladh Hallan (upper pair) and Traprain Law (lower pair)(xpl, scale bar 500 μm); the large minerals in the centre of the upper micrographs are coarse grains of feldspars; the red arrows in the lower micrographs indicates coarse grains of phonolite. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

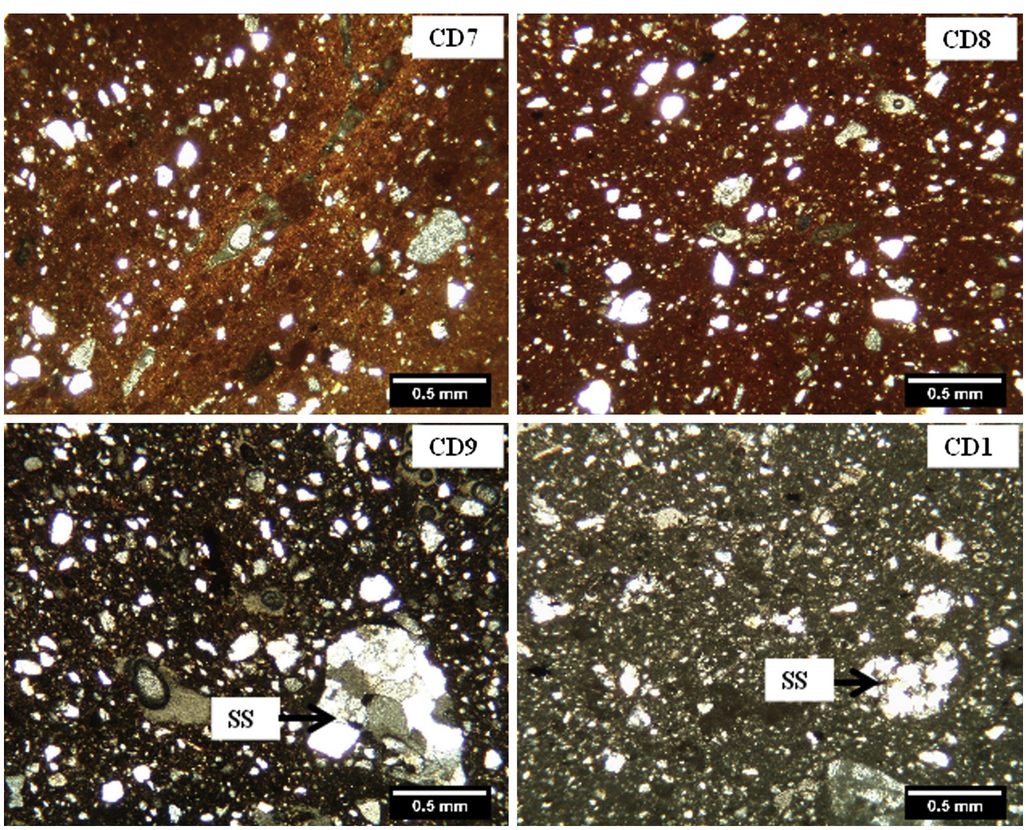

Fig. 6. Comparison of ceramic fabrics from Iron Age material from Culduthel, Invernessshire, from left: fired clay (CD7); furnace lining (CD8), mould (CD9), crucible (CD1) (xpl, scale bar 500 μm); ss marks the sandstone inclusions.

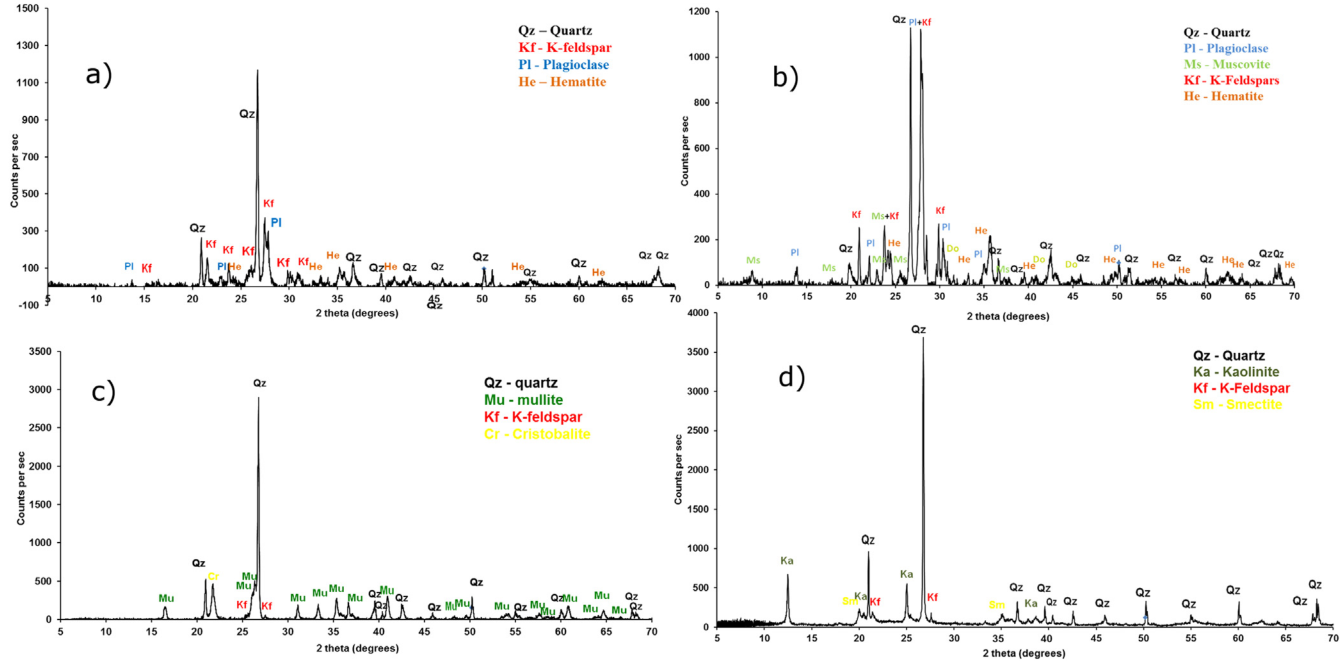

Fig. 7. XRD spectra of a) LBA crucible from Traprain Law (TLF3); b) late prehistoric pottery from Traprain Law (TLF11); c) crucible sample from Traprain Law (TLF6); d) unfired clay sample from Renton Hall, East Lothain (NGR NT546 720).

mullite is rare, but is found in some basic igneous rocks. Synthetic mullite forms from decomposed kaolinite heated to around 1100–1200 °C for an extensive time (Martinón-Torres et al. 2008: 437) or other alumina-silica-rich minerals, such as feldspars, and is a common mineral in modern crucibles. The presence of mullite in the crucibles from Traprain Law suggests that the crucibles were made of a clay rich in kaolinite, a mineral associated with coal measures and the main clay mineral in refractory fireclay. The nearest known location of fireclay is the coal measure circa 7 km to the west of Traprain Law. Clays from these deposits have been extracted for ceramic production since the middle ages (Jones et al. 2003). Neither mullite nor kaolinite were detected in any other materials analysed from the site.

MIA crucibles were sometimes refined and typically mixed with a large amount of quartz sand, or alternatively made from sandy clays. The fabrics regularly contain larger inclusions, predominately quartz or sandstone, but are not as large or as frequent as in the LBA (Fig. 4). Most of the inclusions seen in the Iron Age have angular or subangular shapes and it seems likely that at least part of these inclusions were added as temper. Organic temper was possibly also used, but the crucible fabrics are typically less porous than their LBA counterparts. The organic temper used is predominantly fibrous; probably grass which is also seen in contemporary pottery, but the crucibles from Culduthel may have been tempered with hair, a practice which is known from other ethnographic and archaeological contexts (e.g. Evely et al., 2012:, 1827).

The crucibles from Traprain Law stand out with distinct ceramic fabrics, which can be classified as three recipes: grog-tempered (TLF6), sand-tempered (TLF7), and fine sandy fabric (TLF8; Figs. 8 and 9). Grog-tempered crucibles are so far unknown from a prehistoric context in Britain. Crucibles from other MIA sites are less diverse, but it is possible to distinguish between two different fabrics: one coarse and one fine (Fig. 4). This is at least in the case of Culduthel due to the wall-thickness: a coarse fabric was used for crucibles with a thicker wall and a fine fabric for crucibles with a thin wall (Fig. 10). It is possible that this difference relates to the size or the shape of the vessel, but due to the fragmentary nature of the samples analysed this has not been assessed in full. The relation between MIA crucibles and moulds/pottery is less clear than in the LBA. The use of similar clay sources is in most cases likely on mineralogical grounds, but the materials are often prepared distinctly differently, and it is possible to distinguish between particular mould fabrics (Sahlén, 2013).

The LIA/EH crucibles are technologically comparable to the MIA crucibles, but there are clear differences between the two sites (Appendix 1; Fig. 4). The material from Dunadd shows a clear diversity between different sets of materials, both in the use of resources and the preparation of the material. The material is to a large extent undiagnostic, but could possibly be local. The crucibles are vaguely divided into two fabrics (Fig. 4), one coarse (DAF2) and one fine (DAF4), comparable to the trend observed in the MIA (see above). The ceramics from Eilean Olabhat are generally made from coarse clay, with large inclusions of Lewisian gneiss which indicates a local origin (Table 3, Fig. 4). Two exceptions are one fine mould fabric (EO3)(Sahlén, 2013) and one pottery fabric tempered with igneous rocks. The closest source of igneous rocks is on the islands of South Uist and Harris, and strongly suggesting either the use of external clay resources or that the pottery was brought to the site. The mould is made from a fine clay rich in iron, without any larger inclusions or coarse sand. It could be local, but it is clearly different from the other ceramic fabrics at the site. The crucible fabric is considerably coarser than that seen at Dunadd (Fig. 4).

4.2. Chemical analysis

The characterisation of groups based on compositional data of the material confirmed the conclusions made in the petrographic analysis; the same or similar sources were used for the production of different ceramic materials, but the low number of samples from each site should be stressed (Appendix 2). The compositional data presented in Appendix 1 shows a considerable variation of certain oxides, for example FeO, Al_2O_3 P_2O_5. This variability indicates the mixed nature of the ceramic material, but is also related to post-depositional-processes and firing/heating of the material (see below). It is possible that a more refined picture would be seen if more samples from each site were analysed, but an anomalous

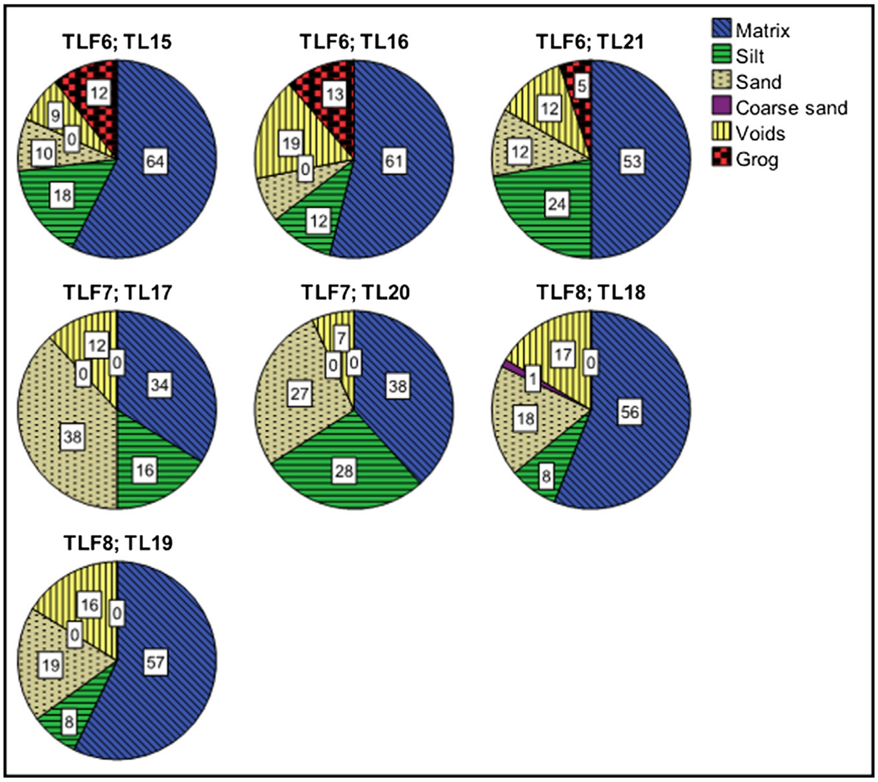

Fig. 8. Pie-charts showing point-counting analysis of the MIA crucibles from Traprain Law (TLF6-TLF8; values in percentage).

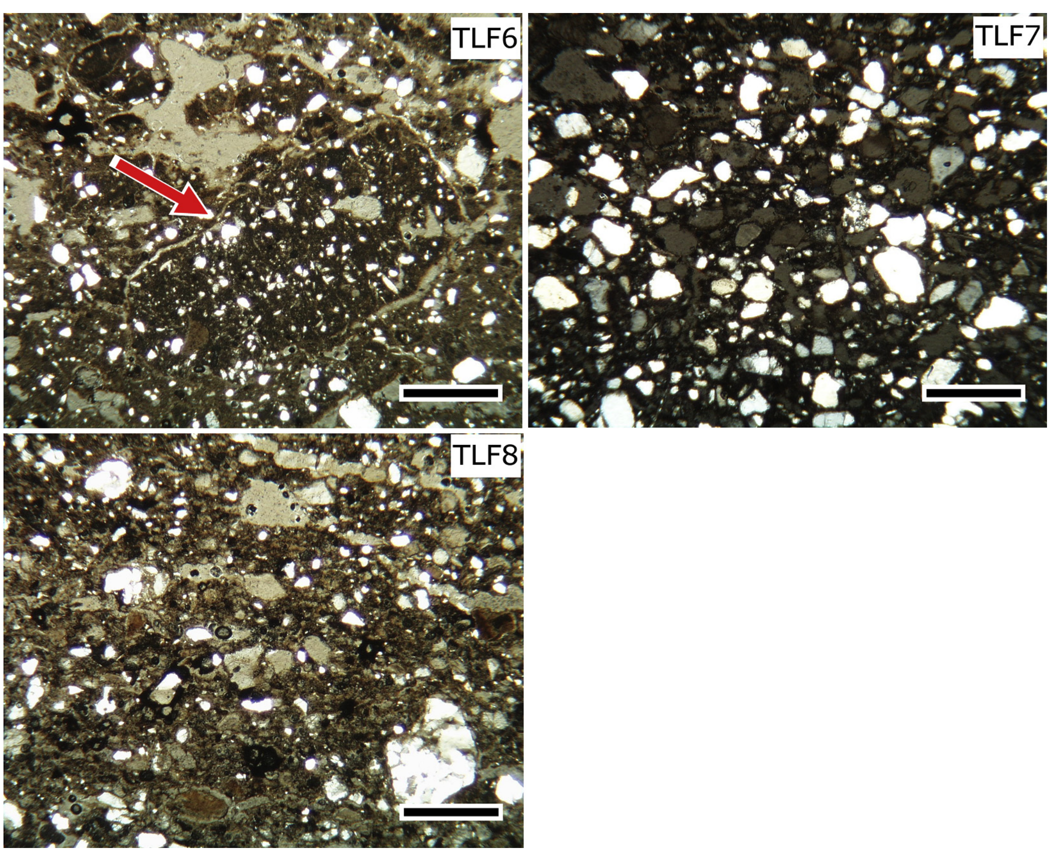

Fig. 9. Comparison of crucible fabrics TLF6, TLF7 and TLF8 at Traprain Law, East Lothian (xpl, scale bar 500 μm); the red arrow marks large grog inclusion in TLF6. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

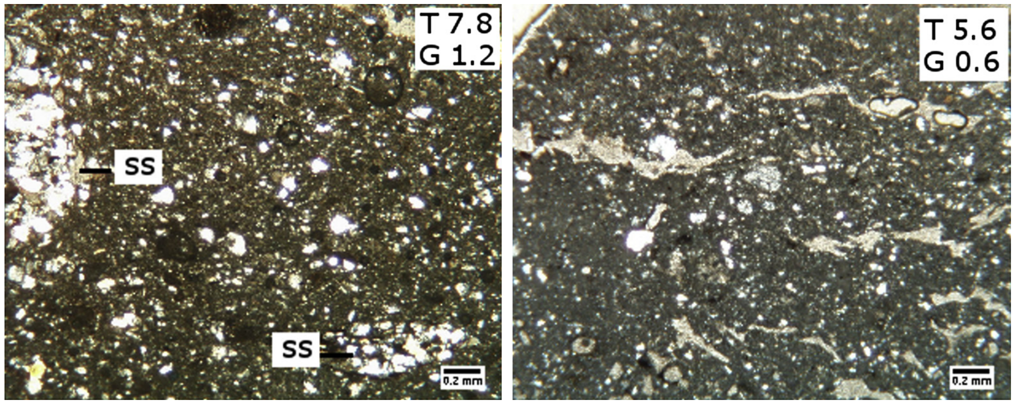

Fig. 10. Comparison between wall-thickness and texture of fabric in Culd1 (left) and Culd5 (right) (xpl, scale bar 500 μm); T: wall-thickness, G: max grain size; SS marks out sandstone inclusions in Culd1.

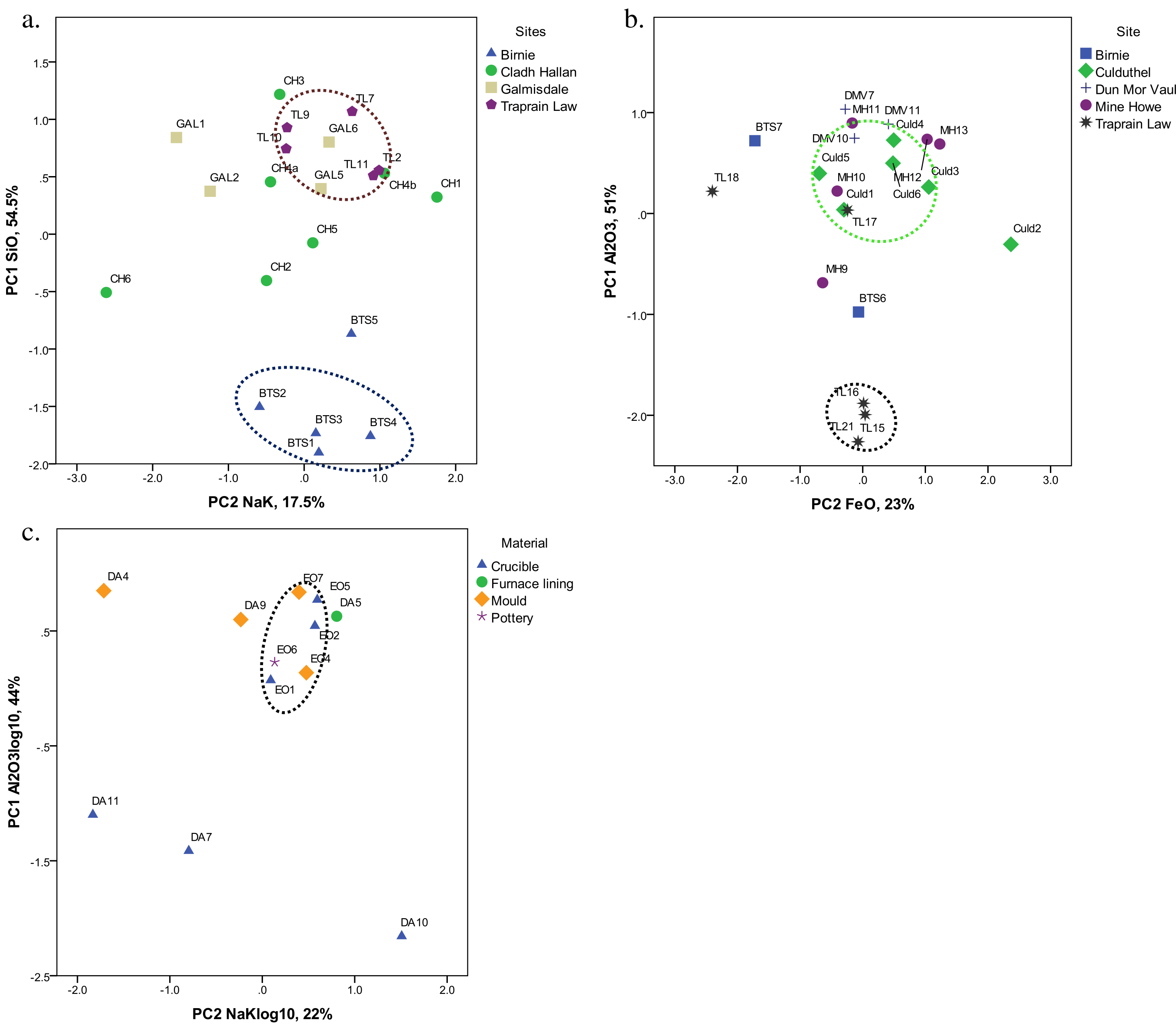

Fig. 11. Scatterplot of the first and second principal components of composition for each period: (a) samples of LBA metalworking ceramics; (b) samples of MIA crucibles; (c) samples of LIA/EH metalworking ceramics. The dashed coloured circles in Fig. 8a and 8b mark a possible material group. The dashed circle in 8c marks the cluster of samples from Eilean Olabhat.

chemical composition of coarse ceramic fabrics has been stressed by others (e.g. MacSween, 2007). It is possible in the current dataset to distinguish between loose groups, but there is no clear relationship within sites or material groups (Fig. 11). Some of the groups and the presence of outliers are related to unusually high values in alumina, which probably relates to vitrification processes rather than properties of the original clay (see below).

The values of P_2O_5 vary considerably in the analysed samples (Appendix 1), which most likely relates to post-depositional factors, rather than properties of the natural clay or the use of the material (cf. Freestone et al. 1985, 1994; Dunnell and Hunt, 1990). Analysis of the materials in the current study indicates that values of P_2O_2 were higher in moulds and pottery than in the crucibles and furnace lining (Fig. 12; Appendix 2). This supports the arguments put forward by Freestone and his colleagues (Freestone et al. 1985: 164), who argued that there was a relationship between the vitrification and the amount of P_2O_5 a ceramic material would absorb after deposition. Vitrified ceramic materials would absorb less. Crucible and fired clay samples with higher values of P_2O_5 in the current study were less vitrified or unused.

The assessment of the relation between Al_2O_3 and alkali metal and alkali earth metal oxides is presented in Fig. 13. Fig. 13a shows the difference in refractoriness in late prehistoric crucibles, including for comparison one Roman crucible from Elginhaugh (Hanson, 2007) and an early modern handmade crucible from Dùn Èistean (Barrowman, 2008). The plot shows the presence of two clusters and one outlier (TLF6). Cluster I consists of a group of MIA and LIA/EH crucibles with an apparent higher refractory quality (following the current model), while cluster II contains the main group of late prehistoric crucibles with a lower refractoriness. The outlier TLF6 with notably high refractoriness is interestingly the grog-tempered crucible fabric from Traprain Law which was stressed above as unique in a prehistoric context. The plot in Fig. 13b shows the relation in refractoriness between crucibles and pottery, and indicates that there is little difference between the two groups, and the division between cluster I and II seen in Fig. 13a is now less clear, and TLF6.

It is remarkable that the presence of more refractory crucibles from some sites is not consistent; at several sites it is possible to define one sample or group of samples which are more refractory than the other samples from the same site (e.g. BF4/BF5, MHF4/MHF5). This relationship is particularly clear looking at the crucibles from Dunadd. These samples are classified on petrographic grounds as one group (DAF2), but there is a clear difference in refractoriness between the samples (Fig. 13c). DA10 with the highest refractoriness is heavily vitrified, while sample DA11 with a much lower refractory quality shows less evidence of vitrification and is probably from an unused crucible (Fig. 14). Similar relationships are seen in materials from other sites. This suggests that there is possibly an alteration in the values of alumina in the clay matrix following vitrification. Alumina-rich minerals, such as feldspars and muscovite, may have acted as a flux. This conclusion, based on analyses of archaeological ceramics, needs to be confirmed from more experimental work, but a similar reaction was discussed by Lowe et al. (1991) in their study of crucibles used in the production of “wootz” single quotes cast-iron ingots in India. They suggested that “the basic composition” of the clay was reinforced by alumina-rich minerals (Lowe et al. 1991: 628).

5. Discussion

The current study suggests that predominantly local clays were used for the production of crucibles and other ceramics throughout the late prehistoric period, but the MIA and LIA/EH provide more evidence of varied uses of clays for the production of certain ceramic materials. The production in the LBA shows a relationship between the crucibles and other ceramic materials, both in the use of resources and the preparation of the ceramic fabric. The use of local clays and the close relationship between crucibles and other ceramic materials seen in the LBA appears to contrast with the corresponding situation in southern Britain outlined by Howard (see above). Instead, the evidence from Scotland shows little evidence of the selection of particular sources.

The use of local clays prevails in the MIA, but we can now see a more varied use of different sources and the preparation of specific

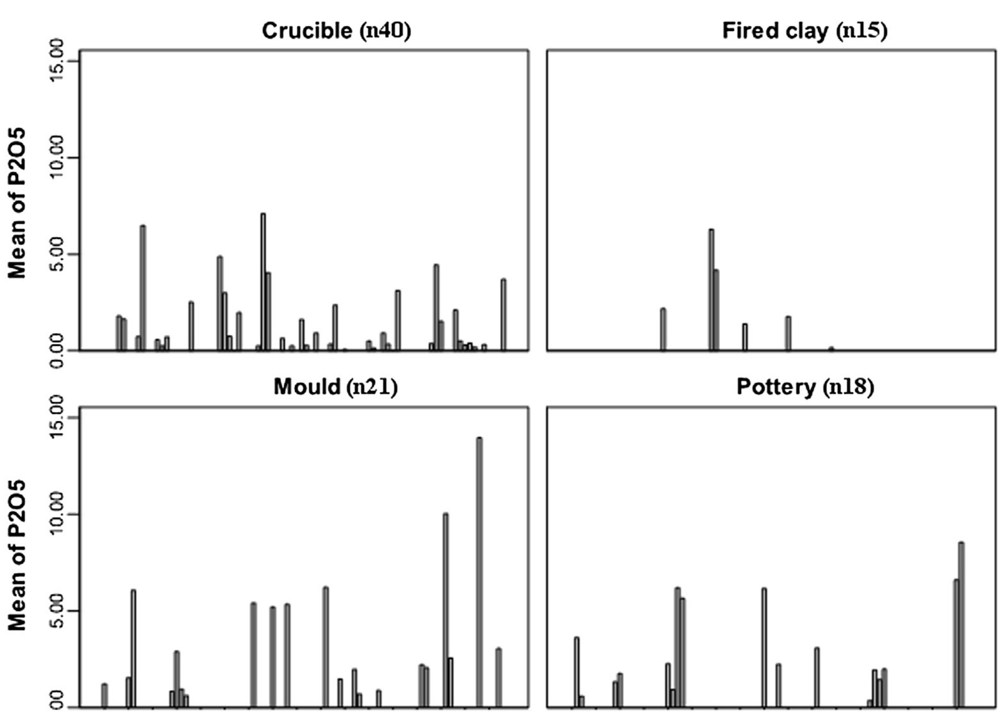

Fig. 12. P_2O_5 content in different ceramic materials; fired clay includes furnace lining, daub and unidentified fired clay samples; numbers of samples are in brackets.

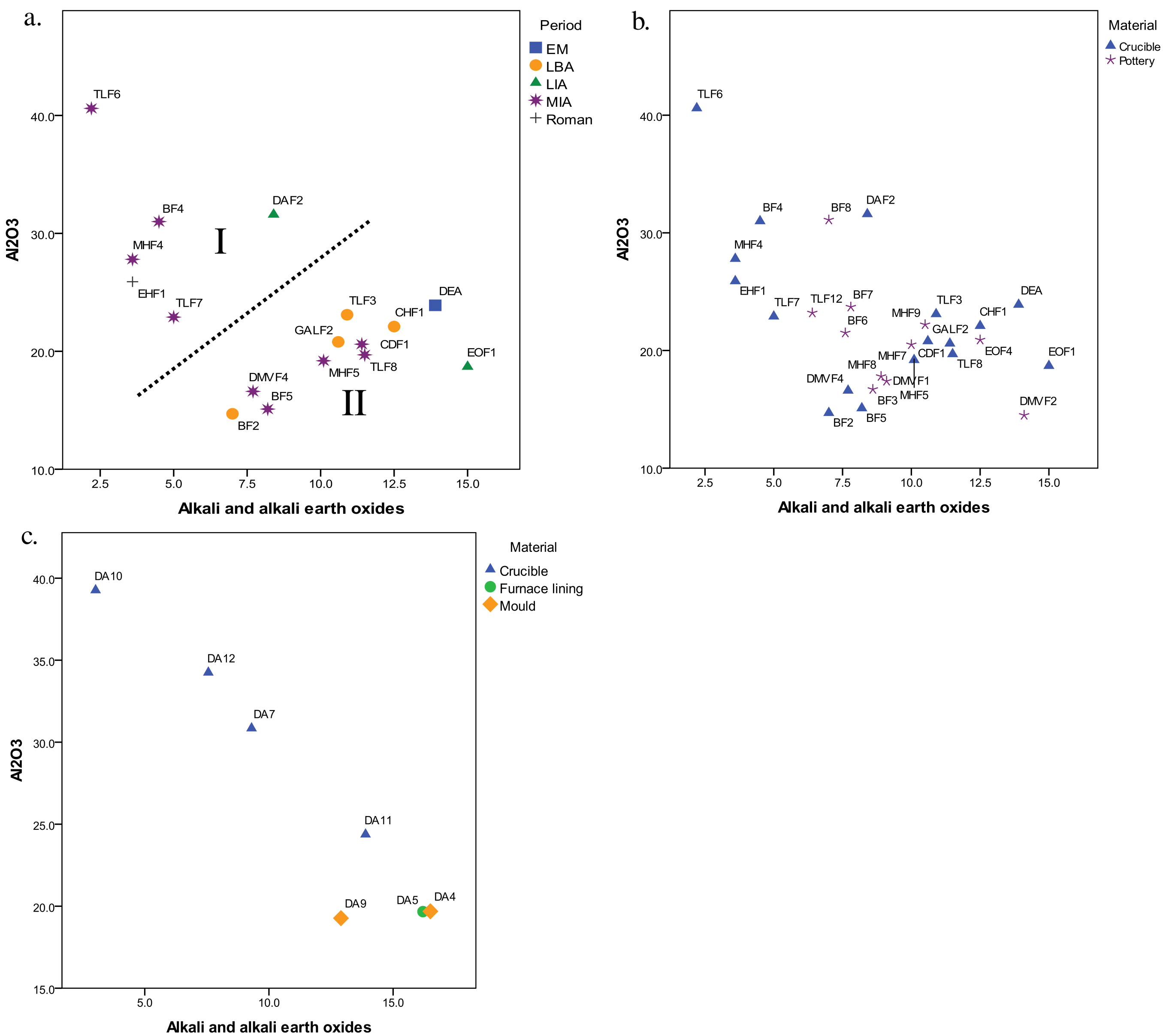

Fig. 13. Plot of the alumina vs. alkali oxide (percentage) contents; (a) all late prehistoric crucible fabrics – including a Roman crucible (EHF1) and an early modern crucible (DEA); (b) crucible fabrics compared with pottery fabrics; (c) samples of metalworking ceramics from Dunadd.

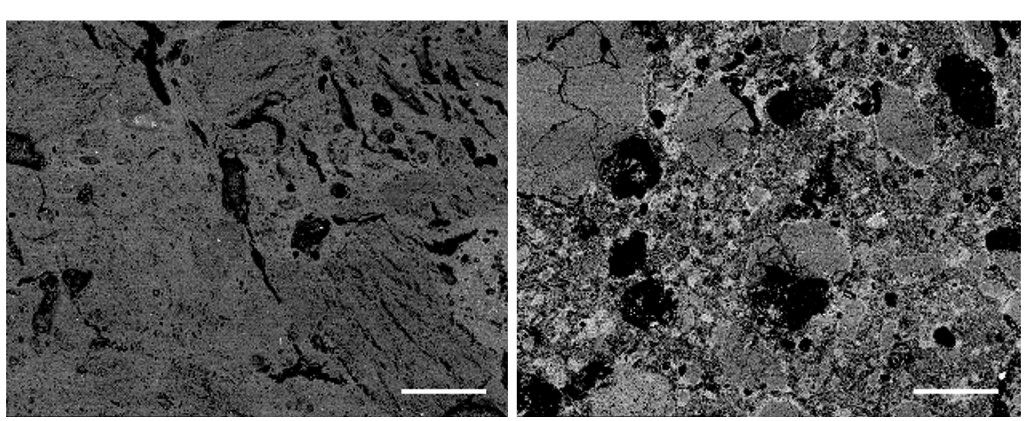

Fig. 14. Comparison of vitrification in DA10, left and DA11, right; back-scatter electron (BSE) images (the scale bar is 200 μm).

fabrics, marking a more specialised production. The selection of particular resources seen in the later periods does not represent a systematic use of a particular clay for a specific set of materials, except in the case of the crucibles from Traprain Law (see below). There is also a more widespread use of quartz and quartz-rich inclusions as the main temper, a trend also seen in south Britain and the Continent (cf. Bayley and Rehren, 2007). Quartz is also present, either naturally or as added temper, in LBA crucibles, but quartz is a more dominant inclusion in the IA fabrics. This indicates that craftworkers were consciously selecting quartz and sandstone as a temper for metallurgical ceramics during these later periods.

The development of crucible technology in late prehistoric Scotland indicates a shift from thick-walled crucibles fired from above in the Late Bronze Age to crucibles with thinner-walls fired from below in the IA, similar to patterns observed in other parts of Europe. During the latter period the preparation of two main fabrics – a sandy and a coarse sandy – is apparent. This pattern is seen at most sites, but is more pronounced at some larger sites, such as Culduthel and Dunadd. This technological development is in line with more varied use of resources seen in the MIA and the LIA/EH period, and is demonstrative of a more specialised production generally in the IA. The difference between sites could be evidence of a more extensive production at some sites, but could likewise be an indication of specialised technology. The material from IA Traprain Law stands out from the rest of the Iron Age material on two grounds: the presence of three distinct crucible fabrics, and because the craftworkers seem to have selected a particular clay with higher refractory qualities than other ceramic materials from the site. More materials from south and southeast Scotland need to be analysed before it possible to say if this pattern is specific to Traprain Law or whether it is a pattern more widely encountered in southeast Scotland.

The development in the crucibles in the late prehistoric Scotland contrasts that of the pottery. In the late prehistoric period, large parts of mainland Scotland have often been classified as aceramic, similar to northern England. This is, to some extent, a misnomer since pottery was produced throughout the period, although the production was often limited and of poor quality. The northwest of Scotland and the Western Isles in particular witnesses a more extensive production and use of pottery, often richly decorated (cf. Campbell, 2002). The production of pottery throughout Scotland showed little change during the late prehistoric period, as for example, there is no evidence for the use of kilns or wheel-made pottery until the medieval period. This indicates that the development of crucibles and other metalworking ceramics followed a different technological tradition than that of pottery. The technological change of crucibles observed in Scotland is instead closely connected to the development of crucibles more widely in Europe, demonstrating the presence of extensive metallurgical networks and traditions.

6. Conclusion

The question posed in the title of this paper, alludes to the frequent view that crucibles are a specialised set of tools made from carefully selected refractory clay, showing the presence of high levels of technical skill and socio-economic status of a particular site. This paper has demonstrated that, in the case of late prehistoric Scotland, crucibles were often made from local clays, also used for the production of other groups of ceramics. A diachronic approach has been applied here to study the manufacture of crucibles in the LBA, the MIA and LIA/EH period (ca. 1000BC – AD800) with the goal of assessing long-term technological developments. Crucibles displayed considerable developments from the LBA, when there was a close relation between crucibles, ceramic moulds and pottery, to the later part of the IA, when crucibles were often made from specialised ceramic fabrics.

A central sub-question was to test if the craftworker selected a particular clay for the manufacture of crucibles, different from that used for the production of pottery or other ceramics. In fact this was rarely the case as at only one site, Traprain Law, was there convincing evidence for the use of particular clay in the production of crucibles during the Iron Age.

Acknowledgements

I want to thank National Museums Scotland and the Hunterian Museum for giving the access to ceramic materials in their collections. I also want to thank the department of Analytical Research and Geology, NMS, and the department of Geographic and Earth Sciences, University of Glasgow for the use of analytical equipment, lab space and advice. I want to thank Michael Charlton, Fraser Hunter, Richard Jones and Thilo Rehren for critically reviewing this work. Any errors or mistakes remain my own. The Society of Antiquaries of Scotland, the Arts Faculty at University of Glasgow and Inverness Field Club provided research grants.

Appendix 1. Petrographic description of fabrics; full details of individual samples are presented in Sahlén (2011) (Appendix 1)

LBA								
Sample	No	Texture	Main inclusions[a]	Porosity[b]	Sorted	Max[c]	Shape	Source[d]
Birnie								
Crucible, BF2	2	Sandy	Quartz, sandstone	High	Unsorted	3.3	Subangular	<1 km
Mould, BF1	3	Fine sandy	Quartz, sandstone	Low	Unsorted	0.77	Rounded	<1 km
Pottery, BF3	1	Fine sandy	Quartz	Low	Unsorted	0.6	Rounded	<1 km
Cladh Hallan								
Crucible, CHF1	3	Coarse, sandy	Granite, basalt	Moderate	Unsorted	1.5	Subangular/angular	Local
Mould, CHF2	3	Fine sandy	Quartz	Moderate	Unsorted	0.7	Rounded	Local
Mould, CHF3	1	Coarse	Quartz, feldspars	Moderate	Unsorted	2	Subangular, angular	Local
Pottery[e]	n/a	Coarse	Igneous, metamorphic	Unknown	Unknown	6	Subangular, angular	Local
		Coarse sandy	Granite, feldspar	Unknown	Unknown	3	Rounded	Local
Galmisdale								
Crucible, GF2	2	Coarse sandy	Quartz, sandstone	Moderate	Sorted	3.2	Subangular/rounded	Local
Mould, GF1	2	Fine sandy	Quartz	High	Unsorted	0.9	Rounded	Local
Furnace lining, GF3	1	Coarse	ARF, igneous	Moderate	Not sorted	3.2	Subangular/rounded	Local
Traprain Law								
Crucible, TLF3	4	Sandy	Quartz, phonolite	Moderate	Unsorted	2	Subangular	<1 km
Mould, TLF1	8	Fine sandy	Quartz	High	Sorted	0.95	Rounded	<1 km
Mould, TLF2	6	Medium fine	Quartz, phonolite	High	Sorted	1.7	Subangular	<1 km

MIA								
Sample	No	Texture	Main inclusions	Porosity	Sorted	Max size	Shape	Source
Birnie								
Crucible BF4	1	Fine	Quartz	Moderate	Sorted	0.8	Subangular	Undefined
Crucible BF5	1	Coarse sandy	Sandstone, quartz	High	Sorted	1.4	Subangular	1–3 km
Pottery BF6	1	Fine sandy	Quartz	Low	Sorted	1.3	Subangular, rounded	Undefined
Pottery BF7	1	Micaceous gritty	Sandstone, grog	High	Unsorted	3.5	Subangular, angular	1–3 km
Pottery BF8	4	Gritty porous	Metamorphic rock fragments	Moderate	Unsorted	2.6	Subangular	1–3 km
Pottery BF9	2	Course gritty	Metamorphic rock fragments, quartz	High	Unsorted	4.1	Subangular	1–3 km
Pottery BF10	1	Coarse sandy	Quartz, feldspars	Low	Sorted	0.21	Rounded	1–3 km
Culduthel								
Crucible CDF1a	3	Fine sandy	Sandstone, ARF/grog	Moderate	Sorted	1.2	Angular	Local
Crucible CDF1b	2	Very fine sandy	Quartz sand/silt	Low	Unsorted	0.6	Angular	Local
Mould, CDF2	1	Fine	Quartz, sandstone, metamorphic	Moderate	Sorted	0.9	Subangular	Local
F. Lining, CDF3a	1	Coarse	Sandstone	Low	Unsorted	1.3	Subangular	Local
Tuyère, CDF3b	1	Fine	Quartz sand	Low	Sorted	0.4	Rounded	Local
Daub, CDFc	1	Coarse	Sandstone	Low	Unsorted	2.0	Subangular	Local
Dun Mor Vaul								
Crucible DMVF4a	2	Sandy	Sedimentary	Minor traces	Unsorted	1.2	Angular	Local
Crucible DMVF4b	2	Fine sandy	Sedimentary	Minor traces	Unsorted	0.4	Subangular	Local
Mould DMVF5	1	Sandy	Quartz, metamorphic rock fragments	Moderate	Unsorted	1.1	Subangular	Local
Fired clay, DMV3a	1	Coarse	Sandstone, metamorphic rock fragments	Moderate	Unsorted	4.0	Angular	Local
Fired clay DMV3b	1	Sandy	Quartz sand, sandstone	Low	Sorted	0.7	Subangular	Local
Pottery DMVF1	3	Coarse sandy	Quartz sand, large lithic inclusions	High	Unsorted	2.4	Angular	Local
Pottery DMVF2	2	Sandy	Quartz sand	High	Sorted	0.9	Angular	Local
Mine Howe								
Crucible MHF4	1	Fine sandy	Quartz sand	Low	Unsorted	0.67	Subangular, rounded	Local
Crucible MHF5a	2	Sandy	Quartz, metamorphic rock fragments	High	Unsorted	1.1	Subangular	Local
Crucible MHF5b	2	Coarse sandy	Sandstone, metamorphic rock fragments	Low	Unsorted	4	Subangular	Local
Mould MHF1	3	Sandy	Quartz sand, sandstone	Low	Sorted	0.7	Subangular, rounded	Local
Mould MHF3	2	Coarse sandy	Quartz sand large lithic inclusions	Moderate	Unsorted	2.4	Subangular	Local
F. Lining MHF2	3	Coarse sandy	Quartz sand, large lithic inclusions	High	Unsorted	1.8	Subangular	Local
Pottery MHF6	2	Sandy	Quartz sand	Low	Sorted	0.9	Subangular, angular	Local
Pottery MHF7	2	Sandy	Sedimentary	Low	Unsorted	1.2	Subangular, rounded	Local
Pottery MHF8	2	Sandy	Quartz, metamorphic rock fragments	High	Unsorted	1.1	Subangular, rounded	Local
Traprain Law								
Crucible TL6	3	Fine	Grog, quartz sand, iron-ore	Moderate	Sorted	2.0	Subangular	>7 km
Crucible TLF7	2	Sandy	Uniform quartz sand	Low	Well sorted	0.4	Subangular	Undefined
Crucible TLF8	2	Fine	Quartz sand, iron ore	Moderate	Unsorted	0.8	Subangular, rounded	>7 m
Mould TL4	2	Fine sandy	Quartz sand	High	Sorted	1.3	Rounded	Local
Mould TL5	2	Fine	Quartz sand	High	Well sorted	0.25	Rounded	Local
Pottery TLF9	6	(very) Coarse	Igneous rock fragments	Moderate	Unsorted	5.0	Angular	1-3
Pottery TLF10	1	Coarse	Igneous, phonolite	High	Unsorted	1.7	Subangular	1-3
Pottery TLF11	2	(very) Coarse	Basalt, phonolite	High	Unsorted	4.0	Subangular	1-3
Pottery TLF12	3	Fine sandy	Quartz sand, sandstone	Low	Sorted	0.7	Rounded	1-3
Pottery TLF13	1	Coarse sandy	Quartz sand, feldspar	Moderate	Unsorted	1.0	Subangular	1-3

LIA/EH								
Sample	No	Texture	Main inclusions	Porosity	Sorted	Max size	Shape	Source
Dunadd								
Crucible DAF2	3	Sandy	Quartz, sandstone, schist	Moderate	Sorted	1.5	Subangular, rounded	Local
Crucible DAF4	3	Sandy	Quartz sand and micas	High	Sorted	0.22	Subangular, rounded	Local
Mould DAF1a	3	Fine, micaceous	Micas, quartz sand, sandstone, schist	High	Unsorted	0.85	Subangular, rounded	Local
Mould DAF1b	1	Very fine, micaceous	Micas, sandstone	Low	Sorted	0.45	Subangular, rounded	Local
Furnace lining DAF3	3	Coarse	Crushed quartz	Moderate	Unsorted	2.5	Angular	Local
Eilean Olabhat								
Crucible EOF1	3	Coarse sandy	Quartz, gneiss	High	Unsorted	1.5	Subangular, angular	Local
Mould EOF2	2	Coarse sandy	Quartz, gneiss	High	Unsorted	3.5	Subangular, angular	Local
Mould EOF3	1	Fine						Not established
Pottery EOF4	3	Coarse sandy	Quartz, gneiss	Moderate	Unsorted	3.2	Subangular, angular	Local
Pottery EOF5	1	Sandy, coarse inclusions	Quartz, basalt	Low	Unsorted	4	Subangular, angular	Not established

[a] Main or significant inclusion, quartz sand refers to sand of mainly quartz but also containing miner amounts of auxiliary minerals, eg. Feldspars and micas; crushed quarts means quartz which based on its form probably is crushed before if was added to the paste; ARF: Argillaceous rock fragment.
[b] The porosity of material present has been evaluated on a three-tiered scale: some, moderate, high.
[c] Measurements in mm.
[d] Local means that the mineral and lithic contents match that of the local geology, but the provenance of the material is not established.
[e] Based on an unpublished report from the Cladh Hallan excavation and has not been analysed as part of this study.

Appendix 2. Compositions of metalworking fabrics from late prehistoric Scotland[a](SEM-EDX Wt%, normalised to 100%; for material category refer to Appendix 1)

LBA	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	FeO
BF1 (3)	3.6	1.3	14.3	71.9	3.3	2.5	1.0	0.3	1.3
STD	0.8	0.3	2.7	6.7	2.8	0.4	0.4	0.1	0.1
BF2 (2)	2.4	1.2	14.7	74.1	1.7	2.5	1.0	0.3	1.9
STD	0.5	0.8	0.4	2.7	1.7	0.5	0.7	0.1	0.6
BF3	2.0	1.2	16.7	70.2	0.6	4.9	0.5	0.7	2.8
STD	0.7	0.8	1.2	3.5	0.0	3.9	0.3	0.4	1.4
CHF1 (3)	5.0	2.6	22.1	58.1	0.5	1.9	2.9	0.6	6.2
STD	2.5	2.3	3.4	6.0	0.4	1.7	1.8	0.4	4.6
CHF2 (3)	4.7	1.8	20.5	20.5	0.8	1.5	2.4	0.6	6.0
STD	1.2	0.8	3.8	4.2	0.3	0.9	1.1	0.7	4.2
CHF3 (1)	3.0	2.2	16.0	58.6	2.9	1.5	5.3	1.3	9.2
STD	1.5	0.7	3.9	2.4	0.6	0.3	1.0	1.0	2.5
Galf1 (1)	0.3	0.7	32.8	57.4	0.7	2.7	0.4	1.5	3.6
STD	0.2	0.4	4.1	3.9	0.2	0.3	0.2	0.2	0.9
Galf2 (1)	3.4	1.8	20.8	59.5	0.3	2.4	3.1	0.8	8.0
STD	2.4	1.3	4.5	6.4	0.5	1.7	3.8	0.9	5.8
Galf3 (1)	1.2	3.1	22.1	62.0	0.2	3.0	0.6	1.0	7.0
STD	0.3	0.6	5.1	5.5	0.3	0.8	0.3	0.3	1.7
TLF1 (2)	1.5	1.2	22.0	53.4	8.5	3.5	1.3	0.9	7.5
STD	1.1	0.6	4.0	2.7	6.1	2.8	0.4	0.4	1.2
TLF2 (3)	2.7	2.6	23.4	55.2	2.6	4.4	1.5	0.8	7.1
STD	1.0	0.9	0.8	0.7	1.5	1.0	1.0	0.4	1.7
MIA	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	FeO
BF4 (1)	0.4	0.3	31.0	58.7	0.7	3.6	0.3	1.0	3.7
STD	0.1	0.1	2.9	4.7	0.1	0.8	0.0	0.3	0.7
BF5 (1)	1.4	0.9	14.5	73.2	4.0	3.8	0.8	0.4	1.0
STD	0.4	0.6	0.9	7.4	3.6	0.7	0.5	0.0	0.6
CDF1a (3)	1.3	1.3	21.3	57.7	3.5	6.9	1.0	0.8	5.1
STD	0.3	0.4	3.0	4.9	1.5	1.6	0.5	0.3	2.6
CDF1b (2)	1.8	1.9	21.8	61.7	2.0	7.3	1.2	0.6	3.2
STD	0.7	0.8	2.5	1.7	1.2	0.8	0.6	0.4	1.3
CDF2 (1)	3.0	1.3	15.5	60.2	5.4	7.8	1.8	0.6	3.6
STD	0.7	0.1	0.2	2.2	1.3	1.8	0.6	0.1	1.1
CD3 (3)	3.3	1.9	16.0	58.1	4.8	7.7	3.4	0.8	4.8
STD	1.1	0.9	2.0	6.5	2.9	1.1	1.3	0.7	1.7
DVMF3b (1)	1.7	1.2	21.1	61.9	1.8	5.0	0.9	0.8	5.0
STD	1.1	0.7	3.3	3.5	0.7	2.3	0.5	0.3	0.7
DVMF4 (3)	2.0	1.2	16.6	66.3	0.9	3.0	1.5	0.6	5.8
STD	0.9	0.4	3.0	5.6	0.6	1.3	1.2	0.3	2.3
DMVF5 (1)	1.4	1.1	18.3	59.6	6.2	4.7	2.0	0.9	4.6
STD	0.2	0.1	4.1	6.6	1.0	1.8	0.5	0.3	0.5
MHF1 (2)	2.5	0.9	19.5	63.7	1.5	4.1	1.4	1.3	4.9
STD	1.4	0.1	1.7	3.6	1.0	1.1	0.5	0.5	2.6
MHF3 (1)	3.8	3.3	19.8	61.4	2.0	2.9	1.3	0.4	5.1
STD	5.2	1.7	0.5	1.3	1.0	0.6	0.7	0.2	1.5
MHF4 (1)	0.7	0.4	27.8	64.3	0.4	1.8	0.7	0.9	2.5
STD	0.4	0.3	1.8	2.8	0.2	0.1	0.3	0.2	0.5
MHF5 (4)	1.5	2.1	17.9	60.1	1.3	6.8	1.0	0.5	6.7
STD	0.6	0.8	2.2	5.6	1.4	2.8	0.9	0.3	2.3
TLF4 (1)	0.5	0.4	24.5	53.2	10.4	3.6	1.1	0.9	5.4
STD	0.1	0.2	4.3	9.3	6.9	1.0	0.4	0.6	3.2
TLF6 (3)	0.8	0.4	40.6	53.3	0.4	0.8	0.3	1.2	2.3
STD	0.7	0.4	3.1	3.3	0.2	0.4	0.1	0.3	0.6
TLF7 (1)	1.3	0.8	23.0	64.9	0.4	2.6	0.3	0.6	5.1
STD	0.1	0.2	0.5	1.4	0.1	1.1	0.2	0.3	0.7
TLF8 (1)	0.8	0.1	19.7	66.2	0.2	10.5	0.1	0.2	2.1
STD	0.2	0.2	0.2	0.1	0.2	3.6	0.1	0.1	2.8
LIA/EH	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	FeO
DAF1a (2)	3.7	3.3	19.5	48.6	5.3	5.2	3.3	1.5	9.7
STD	3.9	1.7	2.2	5.8	2.3	3.1	1.9	1.3	4.4
DAF2 (4)	3.7	0.6	31.6	52.7	3.1	3.1	1.2	2.0	2.7
STD	3.7	0.4	7.4	2.5	3.2	1.4	0.5	1.8	1.3
DAF3 (1)	2.3	4	19.7	54.5	1.4	2.3	7.6	0.9	7.4
STD	0.4	0.3	3.5	3.0	0.6	1.3	2.5	0.4	0.9
EOF1 (3)	4.2	3.3	20.8	53.0	1.3	1.9	2.7	1.1	12.0
STD	2.0	0.5	2.2	2.8	1.1	0.2	0.9	0.8	5.0
EOF2 (1)	3.3	5.6	19.2	51.9	2.0	2.6	2.8	0.8	11.9
STD	1.6	1.0	1.8	2.0	0.6	0.4	0.3	0.2	0.8
EOF3 (1)	0.2	2.1	23.5	47.7	2.8	4.3	0.3	0.9	18.2
STD	0.1	0.5	1.8	2.3	0.6	0.6	0.1	0.5	3.4
EOF4 (1)	3.5	3.6	20.9	55.5	3.1	3.9	1.5	1.0	7.0
STD	0.4	1.0	3.5	5.1	1.2	1.5	0.7	0.2	2.1

[a] Details of the pottery have been excluded since these analysis were limited.

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