Comparative petrography of prehistoric pottery sherds and potential source-rocks in the East Midlands

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Abstract: One tried and tested method for assessing likely exchange links and activities within and between prehistoric communities is to observe the materials that they used for making pottery, since sherds of pottery are common finds on many archaeological sites. In this article, the findings of a systematic petrographical survey of pottery sherds from ten sites in the Trent-Soar basin are presented, and attempts are made to match the pottery raw materials, rock and mineral temper and clay with local rock outcrops and Quaternary deposits. It is shown that Ordovician granitoid lithologies of the Mountsorrel Complex and South Leicestershire Diorites were particularly favoured as sources of temper, while the pottery clay itself could have been sourced from silt and mud-rich floodplain deposits. It is suggested that several ceramic exchange networks may be indicated by the spatial distribution of Neolithic to Late Iron Age pottery tempered with granitoid inclusions derived from the Mountsorrel Complex, South Leicestershire Diorites or other as yet unidentified outcrops.

Geology plays an important, but often background, role in archaeological research, only occasionally achieving prominence with headline-grabbing topics such as the source of the bluestone megaliths of Stonehenge (Ixer and Bevins, 2011; Parker Pearson *et al*., 2015). A further linkage between geology and archaeology which will be explored here, however, revolves around the identification and host-rock sourcing of rock and mineral inclusions in pottery found at a great many archaeological sites. Inclusions in pottery are either naturally occurring constituents of the original clay resource, or may have been deliberately added as temper, along with other introduced constituents such as plant fibres, shell, sand and broken pottery ('grog'). Temper reflects an important part of ancient pottery-making technology, as discussed in detail in Knight *et al.* (2003); its main functions were to reduce the plasticity of the clay and to improve strength and toughness during firing and use, but it may also have been added for cultural reasons (Kilikoglou *et al.,* 1998). Temper, and inclusions that occur naturally in the clay, are potentially important indicators of pottery provenance, and can provide insights into the cultural and exchange links between cultures in diverse prehistoric settings (e.g. Ixer, 1994; Dickinson, 1998).

In recent decades, there has been a considerable upsurge in studies to understand the prehistoric settlement of the East Midlands. Impetus for this research has been provided by the rapid growth from the 1990s of developer-funded archaeology and the consequent increase in the density of known prehistoric sites. Other important sources of financial support, particularly from Historic England, have encouraged a plethora of regional archaeological research initiatives. One of these included a publication synthesising the evidence for climatic, geomorphological and anthropogenic changes in the Trent basin spanning the Palaeolithic to medieval periods (Knight and Howard, 2004). This review included discussion of the subject of the present paper, which is concerned with some of the pottery industries that flourished in the region from the Neolithic to the Iron Age periods, from the fourth to first millennia BC.

In East Midlands prehistoric pottery, the frequent occurrence of various types of granitoid temper has long been recognised (Knight *et al.*, 2003), and many previous petrographical studies from archaeological sites in the Trent and Soar valleys have concluded that the source of much of this is local, derived from some of the several small inliers of Ordovician-age granitoids in Leicestershire (Fig. 1). It has therefore become increasingly necessary to constrain by systematic study which of those outcrops were the most intensively exploited for temper.

To this end a major study was initiated, the first stage of which, reported on here, was a petrographical investigation (Carney, 2010a) of rock and mineral temper in 51 thin sections of pottery sherds selected from discoveries previously made on 10 archaeological sites, mostly located on or close to the Trent and Soar floodplains (Table 1, Fig. 2). The pottery for this project was selected following hand-specimen fabric analysis to identify sherds that were thought to contain granitoid temper. These pottery thin sections were then compared with 26 thin sections of potential source rocks mainly collected from the Leicestershire Ordovician granitoid exposures, which provided the temper, but also including lithologies and Quaternary deposits likely to have provided the clay resource. Concomitantly with the petrographic survey, electron microprobe investigations of minerals in the same pottery and rock samples were conducted (by EF) using microstructural imaging and chemical compositional analysis by quantitative wavelength dispersive spectrometry. When the conclusions drawn from the petrographic and microprobe studies of temper in the sherds were compared, it was found that there was an impressive 79% agreement between the two methods. Although the petrographical aspects are the main focus of this paper, selected findings of the microprobe work to be published in the final project document (Knight *et al.*, in prep) will be mentioned briefly where relevant.

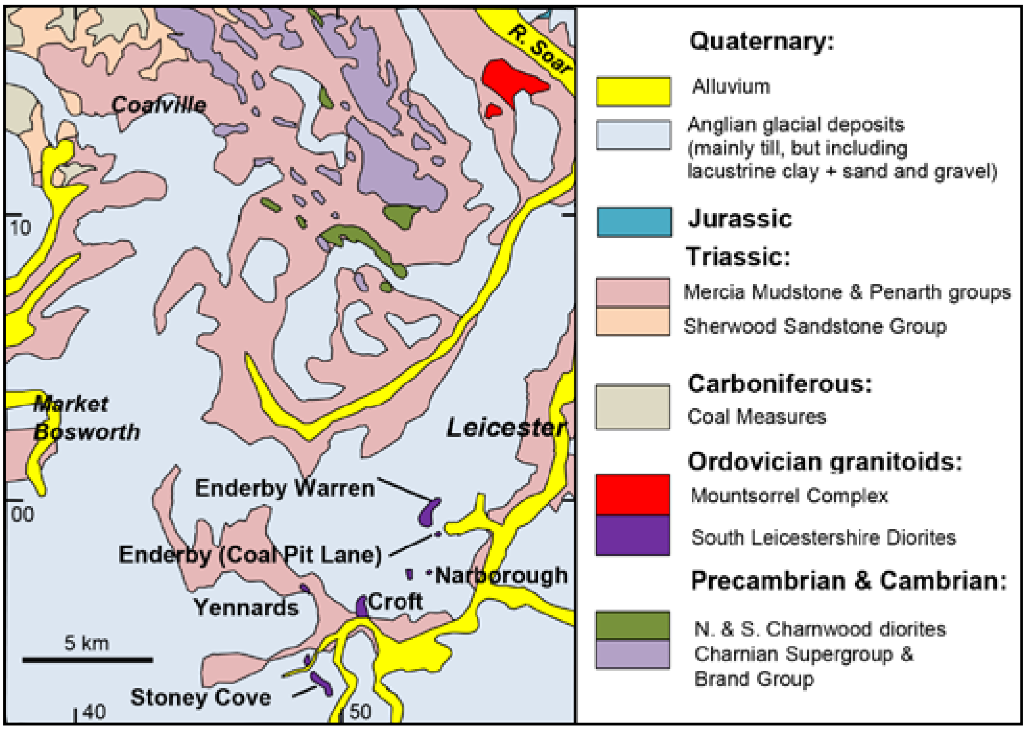

***Figure 1**. Simplified geology of the area, with the main exposures of rocks with potential as sources of pottery temper and clay materials. Smaller outcrops are either omitted or merged. (After BGS DigMap50)*

Fortunately there are subtle, but nevertheless recognisable, differences in the petrography of the various Ordovician igneous rocks. This article demonstrates that these variations are also reflected in the nature of granitoid temper in the pottery, thus establishing, with a reasonable degree of confidence, which source rocks were the most favoured by the pottery makers.

The pottery inclusions

Here, the term ‘inclusion’ covers any component that is not the pottery clay matrix. Typically within a single pottery sample, inclusions can range in size from fine silt (<1mm) to larger multigrain assemblages which can attain 5 mm or larger, but are more usually up to c.3 mm across. Emphasis will be placed on descriptions of the larger, multi-crystalline silicate inclusions, which are mainly aggregations of felsic minerals such as quartz, plagioclase and K-feldspar. In thin sections, it is the composition of these minerals, and their textural relationships, that can be diagnostic of the rock types from which they were originally derived. Where it is not necessary to specify the precise mineralogical composition of such igneous inclusions, the generic term ‘granitoid’ will be used.

A survey of thin sections by Carney (2010a) found that the same types of inclusion kept appearing among the various pottery sherd samples. Therefore to rationalise this distribution, and to assist the descriptions that follow, a number of inclusion assemblages were delimited (A-D in Table 1). It is accepted that these assemblages may not necessarily represent pottery of radically different provenances. For example, a given pottery production site might have used a variety of raw materials, so that different rocks could be used for different pots or even within the same batch of pots. Furthermore, as indicated in Table 1, only a few pottery sherd samples were available from some of the archaeological sites; thus not all of the assemblages identified will be truly representative of the entirety of that particular pottery suite.

In the 51 pottery sherds studied, 38 were found to contain temper material derived from Ordovician granitoid intrusions of the Mountsorrel Complex and South Leicestershire Diorites, the geology of which is described by Le Bas (1968, 1981), Carney *et al.* (2009) and Pharaoh *et al.* (1987, 1993) among others. Furthermore, it appears that most of the pottery samples contained granitoid material from either the Mountsorrel Complex or the South Leicestershire Diorites.

Inclusions from the Mountsorrel Complex

Pottery sherds with angular granitoid inclusions diagnostic of derivation from the Mountsorrel Complex are widely distributed among the samples investigated. The Complex is of Ordovician (Caradoc) age and, while consisting mainly of granodiorite, also contains subordinate bodies of more basic composition, including quartz-diorite, microdiorite and gabbro (Le Bas, 1968, 1981; Carney *et al.*, 2009). The granodiorite pottery inclusions were designated by Carney (2010a) as petrographic assemblages A and A1, the latter with additional inclusions of metamorphosed sedimentary lithologies (metasandstone and metasiltstone). The A-series assemblages were identified in some 48 per cent of the sherds examined: they are present in all the Wanlip and Aston-upon-Trent sherd samples and about half of the Eye Kettleby, Hallam Fields (Birstall) and Manor Farm (Humberstone) suites (Fig. 2, Table 1). They are, however, less dominant in the Gamston, Great Briggs (Holme Pierrepont), Swarkestone Lowes, Willington and Crick samples.

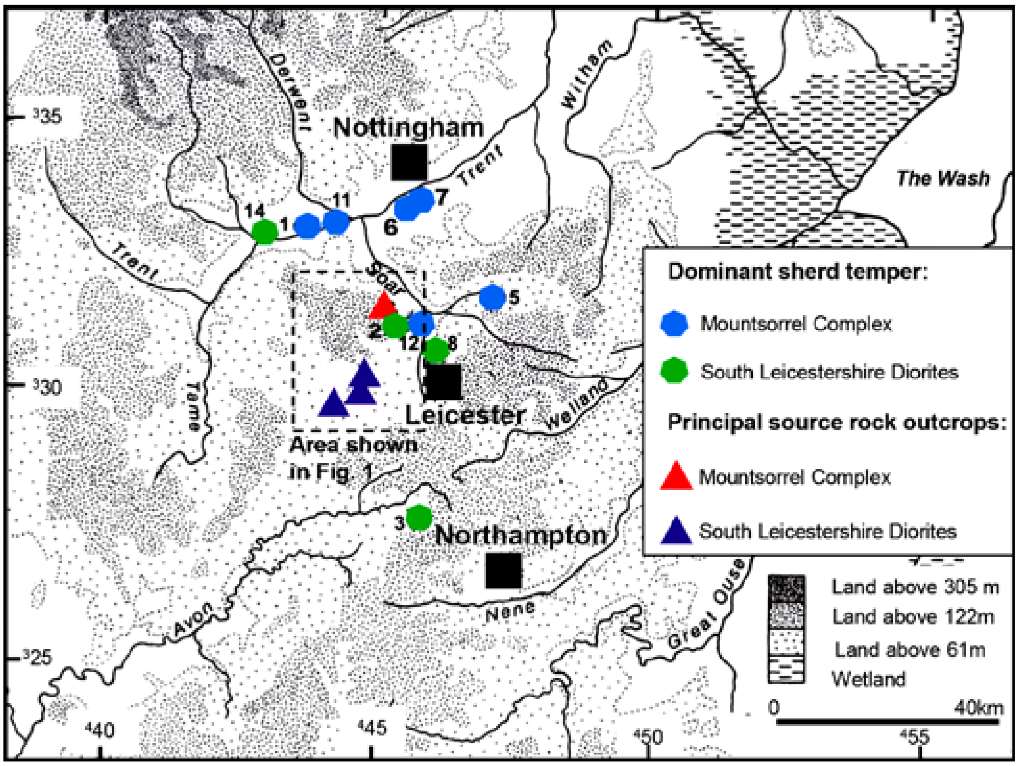

Figure 2. *Locations of numbered archaeological sites yielding pottery sherds studied for the project, indicating main outcrops of the Ordovician granitoids inferred to have provided temper material (see also Figure 1). Missing numbers refer to other sites that have yielded granitoid -tempered sherds but were not included in this study. Localities, dates and sample index for the sites are given in Table 1. (After Knight et al., 2003 & in prep.)*

Mountsorrel Complex granodiorite inclusions

These are identified as such because they have the same mineralogy and inequigranular texture (Fig 3A) as Mountsorrel Complex granodiorite (Fig. 3B) from the main outcrops around Buddon Hill and Mountsorrel (Fig. 4). The diagnostic features consist of large euhedral crystals of plagioclase feldspar, commonly with oscillatory zoning, surrounded by aggregations of much smaller crystals of plagioclase, perthitic K-feldspar and quartz, some of these showing well-formed faces (hypidiomorphic-granular texture). Biotite with strong red-brown pleochroism is a common accessory mafic mineral, as is hornblende with a pale green to brown or almost colourless pleochroic scheme. Smaller angular inclusions in Assemblage A mainly represent fragments of the larger aggregates. There are also angular fragments of individual zoned plagioclase, suggesting that upon crushing, the granodiorite may have separated along the edges of these larger crystals, particularly if the rock was already weakened by weathering (see below). Additionally the pottery clay matrix of many Assemblage A sherds contains very small laths of red-brown biotite, no doubt because being a sheet-silicate, that mineral would readily have formed flakes upon crushing. One variant, found in the Willington sherd collection, contains particularly abundant green-brown hornblende and may derive from a pre-existing exposure of a more basified facies of granodiorite in the Mountsorrel Complex; such lithologies have been recorded in former quarries and at other localities marginal to the main quarried outcrop on Buddon Hill (Fig. 4; Carney *et al*., 2009).

In discussing possible methods of prehistoric exploitation of Mountsorrel granodiorite, Knight *et al.* (2003) suggested that the most readily extractable material would have been from naturally weathered exposures; it is those, rather than fresh (i.e. unweathered) samples from the active or disused quarries, that would be more appropriate for provenancing. Much of Buddon Hill is now the site of a massive quarry (Fig. 4); thus samples for this study were collected from small, craggy, natural exposures (Fig. 5A) and possible shallow excavations at the summit of Rowhele Wood, immediately north of the quarry. It was noted that these

Site	Sample prefix	Location	NGR	Date	Petrographic assemblages
1	ACS (3)	Aston-upon-Trent	SK 427300	Mid to Late Iron Age	A1
2	HLF (8)	Hallam Fields	SK 590100	Mid to Late Iron Age	A, A1, B, C
3	CRI (6)	Crick	SP 571736	Mid to Late Iron Age	B, B1
5	EKE (8)	Eye Kettleby	SK 731180	Early, Middle & Late Bronze Age	A, A1, C, D
6	GAM (2)	Gamston	SK 602369	Mid to Late Iron Age	A, C
7	GBR (3)	Great Briggs	SK 619382	Early Neolithic	A, C
8	MNF (8)	Manor Farm	SK 627065	Mid to Late Iron Age	A1, B, C, D
11	SWL (1)	Swarkestone Lowes	SK 366295	Late Bronze Age to Late Iron Age	A
12	WAN (8)	Wanlip	SK 597111	Middle Iron Age	A, A1
14	WIL (4)	Willington	SK 285278	Late Neolithic	A, B

Table 1. *Brief locality and sample details of sherds and sites described in the text and shown on Figure 2, including archaeological information from Knight et al. (in prep.). The number beside each sample prefix indicates the number of sherds that have been examined from that site.*

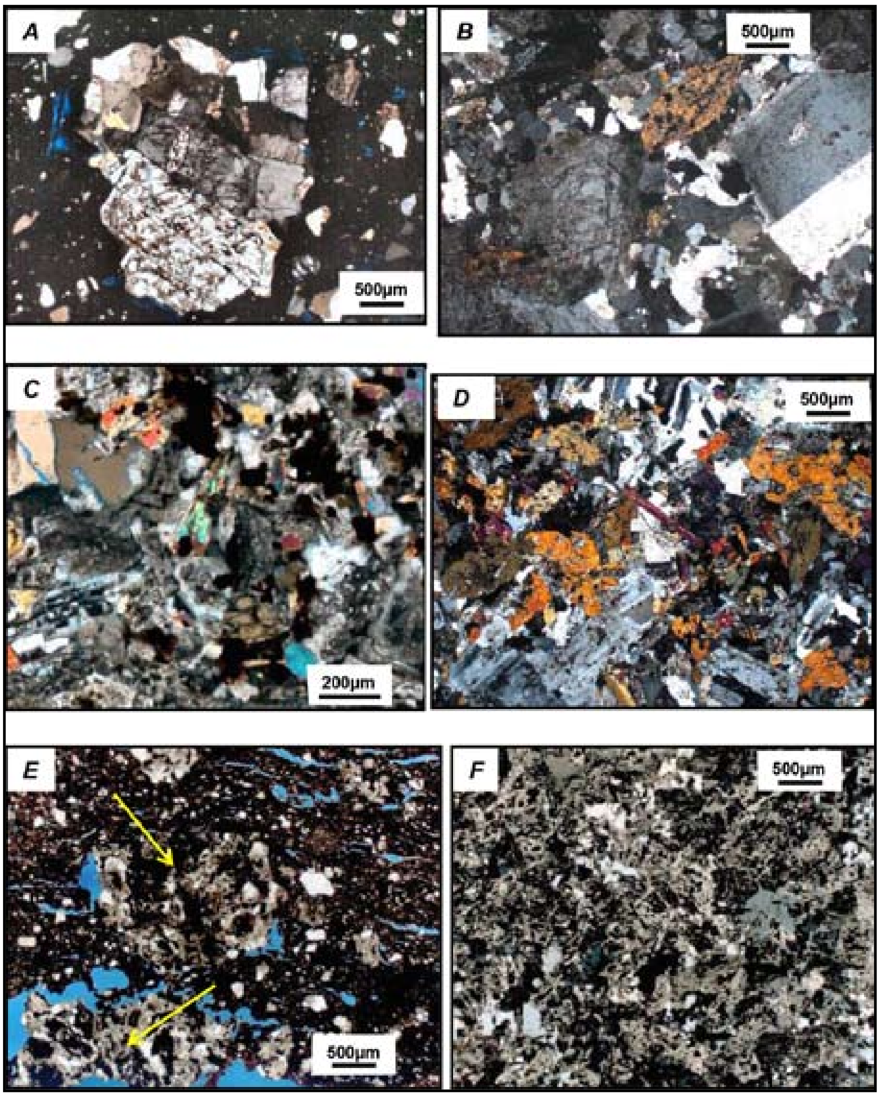

Figure 3. *Photomicrographs of sherd inclusions interpreted as temper, compared (on right) with their inferred source rocks. Sherd sample prefixes indicate which site they were collected from (see Table 1 & Figure 2), with archaeological collection numbers from Knight et al. (in prep.). Rock sample numbers are those of the BGS petrographic collection (Carney, 2010a: Table 1).* ***A****: Granodiorite inclusion typical of Assemblage A, with large plagioclase (lower part of inclusion) enclosed by granular aggregate of quartz, plagioclase and perthitic K-feldspar; sherd sample EKE0909 (x-nicols).* ***B****: Mountsorrel Complex granodiorite, with inequigranular texture and diamond-shaped section of hornblende; slide E73857, from Halstead Road Field (x-nicols).* ***C****: Close-up of assemblage A quartz-microdiorite inclusion in sherd sample HLF 0904, showing fresh hornblende laths (bright blue-green-orange).* ***D****: Mountsorrel Complex quartz-diorite; note abundant hornblende (red-orange-brown laths and diamond-shaped crystals); slide E73866 from Brazil Wood, Swithland reservoir (x-nicols).* ***E****: Assemblage B quartz-microdiorite inclusions (arrowed) showing characteristic alteration textures (centre and lower part of picture); sherd sample MNF 0902 (ppl).* ***F****: Quartz-diorite from the South Leicestershire Diorite outcrop at Stoney Cove Quarry, with equigranular texture, pervasive sericite alteration of feldspars and oxides replacement of ferromagnesian minerals; slide E43871 (ppl).*

rocks gave a rather dull sound when hit with a hammer, and also that the large feldspars appeared unusually white and thus possibly were altered. Furthermore, when hammered the rock crumbled easily along a centimetre-scale anastomosing fracture system that was obviously related to weathering. A thin section showed that the minerals in this apparently weathered granodiorite were unaltered and indistinguishable petrographically from fresh rock sampled from the adjacent quarry. This suggests that natural weathering of the granodiorite mainly involved mechanical rather than chemical agencies, and would have rendered the granodiorite easy to extract and crush by the ancient workers. Other sources could have been granodiorite debris constituting the extensive surficial spreads of Holocene 'head' (slope deposits) mantling the granodiorite outcrop (Fig. 4) or sands and gravels from the small streams that drain the Mountsorrel granodiorite massif.

There is, however, another possible source of Mountsorrel granodiorite. At the Manor Farm (Humberstone) archaeological sites (Table 1, Fig. 2), Iron Age features dug into boulder clay yielded lumps of granodiorite (Marsden, 2011). One explanation for their presence can be found just 700 m to the northwest of Manor Farm, where in a field [SK623071] there is a large glacial erratic of Mountsorrel granodiorite, estimated to weigh about 20 tonnes (Fig. 5B). This 'Humber Stone' received the attention of conservationists as far back as 1878, and again in 1904 when more of it was revealed by excavation, but long before that it was the subject of myths and legends as to its origin. In fact, the newly published British Geological Survey map shows that the Humber Stone lies squarely within an outcrop of Thrussington Till: a boulder clay deposited by an Anglian Stage ice sheet. During this glaciation (see below), ice sheets originating in the Pennines region travelled south-eastwards, across the Mountsorrel Complex, and so could have incorporated the Humber Stone, as well perhaps as a 'nest' of smaller erratics of the type found at Manor Farm, depositing them in their present location about 10 km from the granodiorite outcrop. No doubt these erratics would have been uncovered by cultivation or during ground excavations by the prehistoric inhabitants of the Manor Farm area. The larger erratics would have been difficult to work, but smaller ones may have provided convenient local supplies of temper for prehistoric potters.

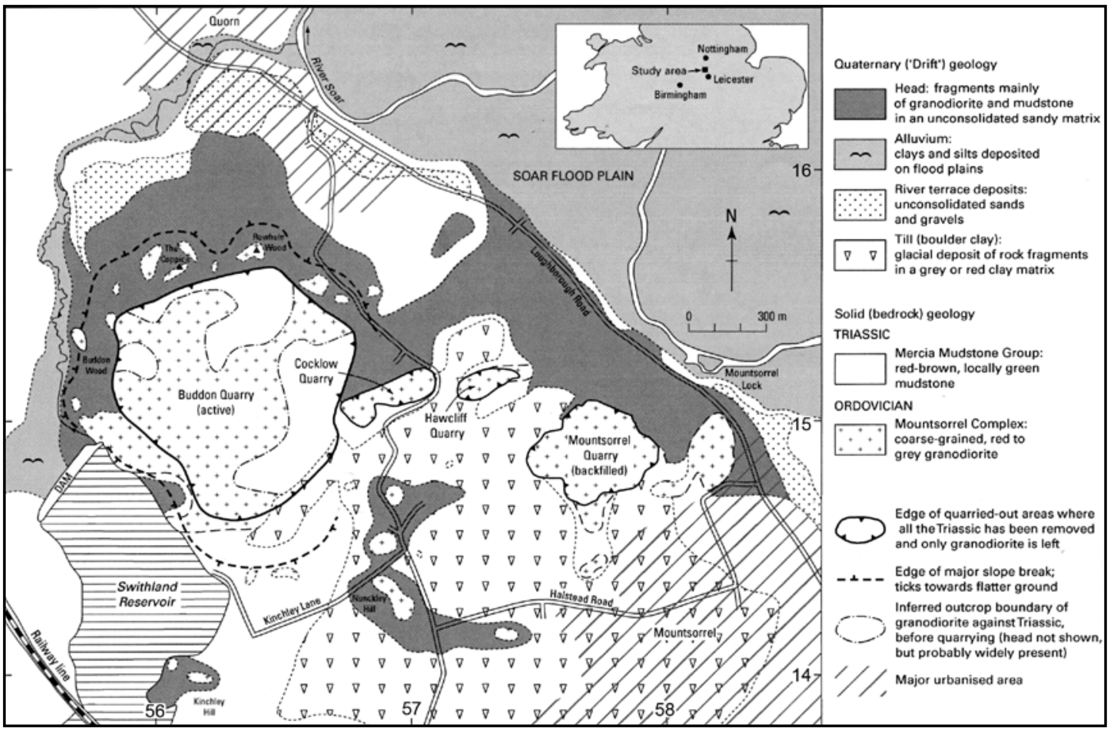

Figure 4. *Past and present-day outcrops of the Mountsorrel Complex. The Brazil Wood site is 100 metres south of the railway line crossing Swithland Reservoir. (After Knight et al., 2003)*

Mountsorrel Complex quartz-diorite inclusions

This variant lithology of the Mountsorrel Complex has been tentatively identified in a pottery sherd from Hallam Fields (Birstall; Fig. 2). It is typically finer grained and more equigranular than the Mountsorrel granodiorite inclusions, and mostly consists of medium- to fine-grained hypidiomorphic-granular aggregates of plagioclase crystals, which are either anhedral or bounded by only a few well-formed faces (Fig. 3C), together with abundant laths of hornblende with pale green to green-brown pleochroism. Other constituents include primary Fe-Ti oxides and interstitial quartz aggregates. These inclusions are petrographically very similar to certain facies of the quartz-diorite (Fig. 3D) exposed at Brazil Wood (Carney *et al.*, 2009): a small hill which is now an island within Swithland Reservoir (Fig. 4). A further textural variant of quartz-diorite, found at the same Birstall site, shows subordinate granophyric intergrowths suggesting that some pottery temper may have been sourced from Precambrian intrusions of the North and South Charnwood Diorites (Fig. 1).

Inclusions from the South Leicestershire Diorites

Inclusions which are petrographically similar to at least some of the several outcrops of South Leicestershire Diorite (Fig. 1) are the second most abundant type, being found in about 25% of the sherd samples investigated (Carney, 2010a). Designated as Assemblages B and B1, they are particularly common in sherds from the Crick, Manor Farm (Humberstone) and Willington sites, but are either absent or extremely rare in the other sherd suites that were investigated.

B-type inclusions are typically finer grained and sometimes more equigranular (even-grained) than the granodiorite inclusions of Assemblage A. Further distinctions are a high content of secondary oxides and a pervasive alteration of feldspars that appear turgid and grainy in thin sections (e.g. Fig. 3E). Of the original mafic minerals, green pleochroic hornblende is partially or completely altered to oxides. All of these features invite comparison with rocks from the South Leicestershire Diorite occurring at the Stoney Cove series of small outcrops (Fig. 3F) and at The Yennards. There are also smaller inclusions of relatively less altered, inequigranular quartz-diorite in some of the Manor Farm (Humberstone) sherds, which are petrographically similar to the South Leicestershire Diorite at Croft Quarry (Carney, 2010b). Quartz-diorite inclusions belonging to Assemblage B1 were found only in sherds from Crick; they are similar in most respects to Assemblage B types, except that they contain hornblende which, with a pleochroic scheme of green to dark red-brown, has not yet been observed in samples from South Leicestershire Diorite exposures.

It should be noted that the South Leicestershire Diorite suite encompasses a wide variety of igneous rock types, particularly the Stoney Cove series of outcrops shown in Fig. 1. Thus in the western part of Stoney Cove Quarry itself, pegmatitic veins consisting mainly of coarse aggregates of microperthitic K-feldspar, together with subordinate sodic plagioclase and quartz, traverse the altered host quartz-diorite (Bridge *et al.*, 1998). It is possible that such 'syenitic' veins may have been the source of inclusions dominated by perthitic K-feldspar aggregates in certain pottery samples from sites at Eye Kettleby, Swarkestone Lowes, Wanlip and Willington (Fig. 2).

Microstructural studies of quartz-diorite sherd inclusions by microprobe analysis largely bear out the petrographical conclusions, but suggest techniques for refining this further (Knight *et al.*, in prep), to the extent that it may be possible to discriminate between

Figure 5. *Examples of settings likely to have yielded Mountsorrel granodiorite temper material. Above: Rubbly exposure and partly vegetated scree (head) composed of weathered Mountsorrel granodiorite blocks, near summit of Rowhele Wood; the survey rod is one metre long; for location see Figure 4 (photo: P. Marsden). Below: The Humber Stone, a large glacial erratic close to the Manor Farm archaeological site (photo: Geograph.org.uk).*

temper material derived from the several different outcrops of South Leicestershire Diorite shown in Fig. 1. A further outcome of the microprobe studies is that one sherd sample, from Manor Farm (Humberstone), contains a mixture of granitoid temper material that includes Mountsorrel Complex granodiorite and South Leicestershire quartz-diorite of the type exposed at Enderby (Coal Pit Lane) quarry. Chemical compositions of K-feldspars for source rocks and pottery inclusions determined by electron microprobe analysis provide further means of discriminating between Mountsorrel Complex granodiorite and South Leicestershire Diorite temper sources (Knight *et al.,* in prep).

Metasandstone and sandstone inclusions

These inclusion types form minor components in many assemblages, but when they are the dominant temper material they define Assemblage C (Carney, 2010a); this constitutes 13 per cent of the 51 sherd samples investigated. Metasandstone inclusions have been recognised in sherds from Eye Kettleby, Manor Farm (Humberstone), Hallam Fields (Birstall), Aston-upon-Trent and Great Briggs (Holme Pierrepont; Table 1, Fig. 2). Most have well-rounded outlines and are either quartzitic or subarkosic, the latter containing minor feldspar which includes microcline. Textures are granoblastic, indicating derivation from a terrane that has experienced moderate to high grades of metamorphic recrystallization, most probably with gneissose rocks present. One metasandstone inclusion shows mortar texture, in which large crystals with strained extinction are surrounded by mosaics of smaller ones (Fig. 6A).

Undeformed to mildly deformed, fine-grained quartzitic or subarkosic sandstone forms a minority of smaller pottery inclusions in Assemblage C, but is dominant in certain sherds from Gamston and Hallam Fields (Birstall). Silt to sand-size inclusions in Assemblage C sherds mainly represent the finely comminuted debris of larger fragments, but also include flint, metasiltstone, schist/phyllite and silicified-rock, together with clinopyroxene, biotite and K-feldspar crystal fragments.

There are no diagnostic features of these inclusions that would precisely reveal their source. Undeformed quartzite and subarkosic sandstone lithologies do occur in the Midlands region: for example, the Cambrian outcrops in the western parts of Charnwood Forest, and the early Palaeozoic successions exposed at Nuneaton, the Lickey Hills of Worcestershire and the Stiperstones in the Welsh Borders. The metamorphosed sandstone inclusions were most probably derived from pebbles or sand-size clasts in Namurian, Millstone Grit sandstones and the Triassic-age Sherwood Sandstone Group (Fig. 1). For example, a study of 66 pebbles from breccia at the base of the Triassic sequence in the Lichfield area (Lott, 2006) identified meta-quartzite, quartzose sandstone, volcaniclastic sandstone, volcanic rocks and various igneous rocks as pebble lithologies. Millstone Grit, on the other hand, contains particularly abundant pebbles of granitic material, such as granophyre and pegmatite (e.g. Gilligan, 1919), which have only rarely been encountered as temper during the present study.

Given the location of these pottery sites on or close to major floodplains (Fig. 2), further sources to be considered are alluvial gravels and associated Quaternary river terrace deposits. Quartz-rich granules, pebbles and cobbles eroded from Carboniferous and Triassic sandstones, and perhaps also recycled from Anglian-age till and glaciofluvial deposits, are preferentially concentrated in these local fluvial systems because of their resistance to abrasion and dissolution. The selection of suitable temper material would therefore be greatly facilitated by searching through such loosely-bound deposits. Flint is also a sporadic constituent of the silt to fine-sand size inclusion component, again suggesting an alluvial influence (see below). A fluvial source may also explain why Mountsorrel granodiorite and South Leicestershire Diorite inclusions appear to be poorly represented in Assemblage C-dominated tempers since, owing to the instability of feldspars relative to quartz-rich material in fluvial systems, the concentration of granitoid debris would rapidly decrease, or at least be significantly diluted, with distance away from the small outcrops shown in Figure 1.

Basalt and microgabbro inclusions

These inclusion types occur rarely, but are highly distinctive and thus were categorized as Assemblage D (Carney, 2010a). They occur in a minority of the

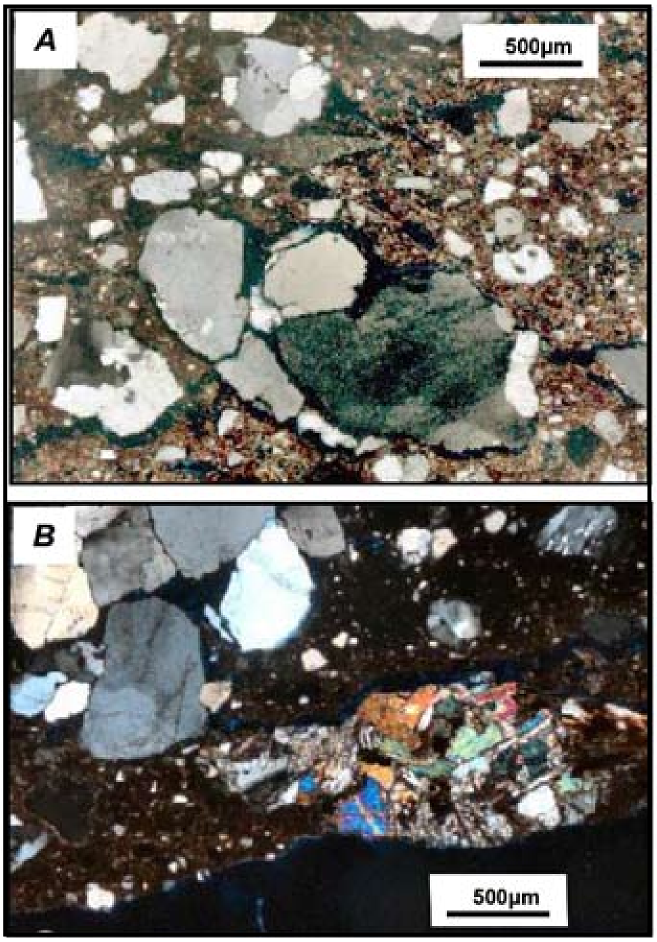

***Figure 6**. Other common inclusion types; for an explanation of sample numbers, see Table 1 and caption to Figure 3. **A**: Metasandstone inclusion (Assemblage C) in sherd sample MNF 0901, showing granoblastic, 'mortar'-type texture (x-nicols). **B**: Microgabbro inclusion (Assemblage D), lower right, with a subarkosic sandstone forming the large quartz-rich inclusion, top left; sherd sample MNF 0906 (x-nicols).*

pottery sherds from the Eye Kettleby and Manor Farm (Humberstone) sample suites. Microgabbro inclusions consist of fine-grained aggregates of lath-shaped plagioclase, which is sub-ophitically enclosed by plates of clinopyroxene (Fig. 6B). Orthopyroxene is sparsely present as early-magmatic euhedral crystals that do not enclose plagioclase, with Fe-Ti oxides and minor interstitial quartz aggregates forming the other constituents. The occurrence of quartz together with orthopyroxene indicates derivation of the rock from oversaturated, tholeiitic magmas. Basalt inclusions have essentially the same mineralogy, but are finer grained with intergranular textures where clinopyroxene and orthopyroxene occur as granules rather than plates. They possibly represent fragments from a chilled, or extrusive, facies of the magma that produced the microgabbro. Other inclusion types in Assemblage D consist of subarkosic sandstone and green, fine-grained chlorite-rich fragments of metavolcanic rock. Coarse-grained granitoid inclusions are also present, but microprobe investigations showed that the feldspars in these inclusions differed microstructurally from those in rocks of the Mountsorrel Complex and South Leicestershire Diorites (Knight *et al.*, in prep).

The basic igneous inclusions are unlike any of the outcropping East or West Midlands Carboniferous basic igneous rocks, which being generally olivine-bearing and thus deficient in modal primary quartz belong to an alkaline basic magmatic suite. It is noted that the Carboniferous-age Whin Sill of northern England is quartz-bearing, with orthopyroxene and a sub-ophitic texture; however, the interstitial quartz is commonly expressed as myrmekite rather than the granular to ophitic pools found in the Assemblage D microgabbros. The Whin Sill is a well-known archaeological resource in central and eastern England, albeit of prehistoric stone tools (Group XVIII) as opposed to pottery material (Williams-Thorpe *et al.*, 2003). The latter authors attributed the distribution of Whin Sill artefacts to the 'opportunistic use of glacial erratics rather than trade from the primary source'. In the case of the pottery discussed here, however, this is less likely as the local East Midlands glacial successions contain few, if any, basic igneous erratics.

One other possible source of gabbroic material in the UK was ruled out (Carney, 2010a). Gabbro from the Lizard peninsula, Cornwall, does not have ophitic textures and the mafic minerals consist of hornblende rather than clinopyroxene. Other Cornish gabbro samples are extremely coarse-grained (pegmatitic), unlike the texture of Assemblage D inclusions.

It is concluded that Assemblage D-type pottery may have been manufactured outside of the East Midlands, or was manufactured locally but with imported basalt and microgabbro raw materials used as temper. Electron microprobe investigations by EF largely bear out these findings (Knight *et al.,* in prep).

The pottery clay matrix

When viewed in thin section, the matrixes of most pottery sherds consist (in lithological terminology) of red-brown to black clay with abundant angular to sub-rounded, silt-size crystal or rock fragments; exceptionally, as with many of the Willington sherd samples, there are clays with very few of these silty inclusions. Although some pottery clays appear structureless, many samples show interlayering between pale red-brown (or pale brownish green) and very dark red-brown to black clay types. Some also exhibit heterogeneity due to the presence of rounded to ellipsoidal, shadowy inclusions of silty clay that is of a slightly different firing colour (in terms of the red-brown spectrum) to the surrounding matrix. These shadowy inclusions could represent incompletely incorporated relicts of the original pottery clay source-rock: for example, Mercia Mudstone. They could also be crushed pottery fragments (grog), deliberately used as temper, or perhaps represent accidentally incorporated dried clay fragments derived from the potter's working area. Although some sherd matrixes are compared (below) with possible geological red clay sources, such as the

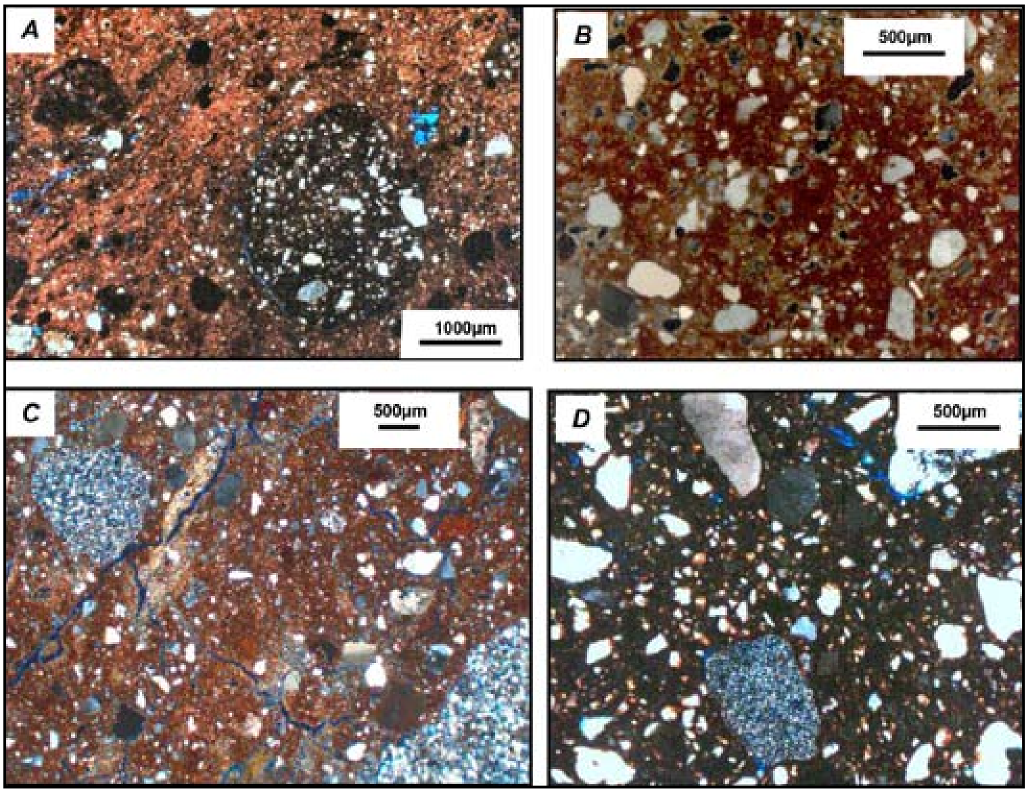

Figure 7. *Pottery clay compared with local argillaceous lithologies and Quaternary deposits that may have provided source materials. For pottery sherd sample numbers see Table 1 and Figure 3.* ***A****: Typical red pottery clay matrix, with rounded inclusions of black silty clay and black non-silty ?carbonaceous material; sherd sample WAN 0901 (ppl).* ***B****: Fresh Mercia Mudstone; sample JNC 927, from 233.6 m depth in the Asfordby Hydro Borehole (x-nicols).* ***C****: Thrussington Till, with fragments of dolomitic siltstone (e.g. lower right); sample JNC 930, from a shallow excavation in Wigston, near Leicester.* ***D****: Clay brickette, made from Trent floodplain mud sampled at Shelford. Amorphous quartz grain in lower part of view is interpreted as flint (x-nicols).*

Mercia Mudstone and Thrussington Till, it is realised that the atmosphere during the firing process is mainly responsible for the colour of the final pottery product.

A significant proportion of pottery samples contain rounded, petrographically opaque aggregates of black silty clay or black, non-silty material. Such aggregates contain silty, silicate inclusions which are either arranged at random or show a concentric distribution (Fig. 7A). These opaque aggregates were not investigated by polished thin section petrography and so their nature is yet to be determined. They might be iron oxide-rich, or they could represent incompletely burned-out organic material. The latter alternative is suggested by the experimental firing of local alluvial clays into brickettes (Knight *et al.,* in prep) which does not completely burn off the included organic material, even when the clay was fired to 750° C. The opaque aggregates also resemble those described by Beck and Neupert (2009), who noted that in some clayey soil profiles iron oxide can precipitate along plant rootlets, before being dispersed as small rounded aggregates when the clay is processed for pottery making. Those opaque aggregates with concentrically arranged silicate inclusions may suggest such an original pedogenic origin.

Silt to fine-sand inclusions in the pottery clay matrix are virtually ubiquitous, forming the ‘background’ constituents to the sherds shown in Figures 3, 6 and 7A. Some consist of angular crystal fragments, such as quartz, plagioclase and K-feldspar, which match the crystal constituents of the larger inclusions described and thus are probably their more finely pulverised equivalents. Others, however, may have been integral components of the silty source material that provided the pottery clay, or be contaminants introduced during the pottery-making process. They are dominated by quartz, which commonly has strained extinction or occurs in granoblastic aggregates, some with a strong foliation suggesting they were derived from a metamorphic parent rock. Other very common silty or sandy inclusions consist of foliated quartzose meta-siltstone. These inclusions indicate an ultimate derivation from metamorphic sources not present *in situ* in the East Midlands, although such lithologies are common as pebbles in local Triassic conglomerates and Quaternary deposits, as discussed above. Laths of muscovite mica occur sporadically, or are absent from clay matrixes, except in pottery sherds from Crick, where they are present in abundance.

Origin of the pottery clay

Clay, comprising most of the raw material for the pottery, is often wet and heavy when extracted from the ground, and it has been demonstrated that it is most likely to be obtained from resources relatively local (<7 km) to where the particular potters worked (Arnold, 1985, 38–50). East Midlands prehistoric potters would have been surrounded by a diversity of potential clay resources (Fig. 1). Suitable bedrock units yielding workable clays, particularly in their uppermost, weathered parts, would have included Carboniferous and Jurassic mudrocks. However the most widespread sequences, and those considered here as they are local to all of the archaeological sites, are the various Triassic-age formations of the Mercia Mudstone Group. Clay-rich Quaternary deposits are similarly widely distributed (Fig. 1), those selected for investigation here being Anglian-age tills and Holocene alluvial clays of the modern floodplains.

Because of the very nature of clays, it is unlikely that conventional petrography, which relies on mineralogy and texture in thin sections, will provide conclusive evidence of origin of the source material. Geochemical techniques, particularly utilising Pb, Sr and Nd isotopes, do hold great promise; for example, in one study mentioned in a recent review by Hunt (2016), isotope geochemistry was able to constrain a pottery clay resource to a specific sedimentary rock formation in Cyprus (Renson *et al.,* 2013). Such techniques were beyond the remit of this project; however, petrographic examination of the diverse clay resources within the study area can at least provide pointers to those most likely to have been favoured by the potters.

Mercia Mudstone. This lithology consists of red to brown, rarely green-grey, silty mudstone weathering to a sticky clay that is usually bright red when dry and dark red-brown or brown when wet. In thin section (Fig. 7B) a typical unweathered example contains abundant, dispersed silt to fine sand size crystal fragments, which represent aeolian grains that mixed with fine dust in Triassic desert conditions (Jefferson *et al.*, 2002). These fragments show a wide variation in distribution throughout the mudstone, producing an appearance very similar to the silty inclusions in the pottery clays shown in Figures 3 and 6. They mainly consist of metamorphic quartz (see also, below), showing strained extinction and sutured grain boundaries, but can also include K-feldspar, plagioclase and, in formations from near the top and base of the Triassic sequences, laths of muscovite mica. The muscovite mica laths that are particularly common in sherds from Crick (Table 1, Fig. 2) suggest the possibility that micaceous facies of the Mercia Mudstone or overlying Triassic strata of the Penarth Group may have been exploited as a local clay resource. Muscovite-rich pottery clay was also reported in a sherd sample from Swarkestone Lowes (Knight *et al.*, 2003) although, in the present study, the single sherd sample from there contained laths of the red-brown (biotite) mica variety.

Thrussington Till. This Quaternary deposit represents one component of an extensive superficial sequence formed during the Anglian Stage glaciation, which occurred between 478,000 and 424,000 years ago (Lisiecki *et al*., 2005). It can be found in most parts of the generalized till outcrop shown in Figure 1, underlying the Oadby Till (see below). The Thrussington Till ice sheet moved south-eastwards and incorporated much Mercia Mudstone bedrock, explaining why it is similar in both gross appearance and petrography to the latter (compare Figures 7B and C). The till matrix is a yellow clay when weathered, but this passes down over c.0.5 m into a red to red-brown clay with abundant silt to sand-size grains that include crystal and lithic fragments of the type found in Mercia Mudstone and in the pottery sherds. Crucially however, there are also common fragments of Triassic dolomitic siltstone (Fig. 7C), which have not been seen in any of the 51 sherd samples investigated. On account of this, it is concluded that Thrussington Till is unlikely to have been used as a clay resource in pottery manufacture.

Oadby Till. Being the youngest Anglian Stage till, this is the most extensively outcropping glacigenic unit. It was deposited from ice sheets travelling from the east and consequently has a dark blue-grey clay matrix, mainly derived from Jurassic mudstones. Its erratic suite includes flint, chalk and various types of Jurassic limestone or fossil. Of the non-clay components, only flint is present in the pottery sherds examined, but has been attributed to an alluvial source (see below). The absence from the pottery sherds of inclusions composed of chalk, shelly fossils or Jurassic limestone is significant and appears to rule out the possibility that Oadby Till was a clay resource.

Alluvial clays. Ground surveys of alluvial tracts, such as the Trent floodplain, indicate that it is the low-lying, backswamp areas that mainly accumulate the clays and silts most likely to have been targeted for pottery making. Such alluvial clay provinces probably occupy less than about 30% of an average floodplain. To test the possibility that alluvial clay may have formed a convenient local resource for pottery material, five samples were collected at shallow depths (c.0.5-1.0 m) by hand-auger from localities on the Trent and Soar floodplains (locality details given in Carney, 2010a). In order to present them for examination by microscope and microprobe, and to compare them realistically with the pottery sherds, they were first of all processed by converting them into pottery brickettes; when dried, these were fired together in the furnace, in an oxidising atmosphere, at temperatures of up to 750° C, before being left to cool back to room temperature (Knight *et al.,* in prep).

Of the five alluvium samples, the brickette made from clay collected from the Trent floodplain at Shelford is regarded as fairly typical. It contains 40-50% of silt to very fine sand silicate inclusions in a black to dark maroon clay matrix (Fig. 7D). In the latter are sporadic, small, rounded opaque silty aggregates, similar to the black inclusions in the pottery sherds discussed above, and most probably representing carbonised organic or pedogenic material. The silicate inclusions mainly comprise granoblastic quartz aggregates of medium to high-grade metamorphic origin, some foliated with strained extinction and sutured grain boundaries, together with very minor proportions of microcline. Significantly, there are also very common, subangular fragments of microcrystalline quartz, some with small chalcedonic segregations comparable to petrographic textures associated with flint.

Given that the silt or fine sand-size silicate inclusions so ubiquitous in pottery (Figs. 3 & 6) are also extremely common in Mercia Mudstone, Thrussington Till and alluvium, it follows that they are not diagnostic of derivation from any of the three potential geological sources. Those found in Thrussington Till and alluvium were most probably recycled through agencies of Quaternary erosion from Mercia Mudstone and also perhaps Carboniferous bedrock cropping out in this region (Fig. 1).

Such sources cannot, however, explain the presence of the silt-size flint inclusions, seen in 20 per cent of the pottery sherds and particularly common in sherds from Manor Farm (Humberstone), Hallam Fields (Birstall), Great Briggs (Holme Pierrepont) and Gamston. Flint is a Cretaceous lithology, which was transported westwards to the East Midlands during the Anglian glaciation and, as noted earlier, forms an important erratic component of the Oadby Till. Subsequent erosion of the Oadby Till has been responsible for notable concentrations of flint pebbles, which typically form up to 50% of Quaternary alluvial and river terrace gravels in the Trent–Soar catchment. Moreover, the alluvial clay brickettes described above show that silt-size flint is also a constituent of the muds and silts of these fluvial systems, in which case its very presence in pottery indicates that at least some clays were most probably dug from such settings. It should be noted that so sporadic are these flint fragments that their absence in thin sections does not necessarily preclude an alluvial source for any of the pottery clays. An alluvial source is also in keeping with conclusions drawn from the petrography of certain of the larger inclusions, particularly those of Assemblage C which, as suggested above, may represent temper hand-picked from larger pebbles in gravelly alluvium.

Conclusions

The archaeological implications of this study are discussed fully in the archive report (Knight *et al.*, in prep), where it is suggested that the distributions of pots containing either Mountsorrel Complex granodiorite or South Leicestershire quartz-diorite may signify different pottery and/or raw material exchange networks of variable spatial and possibly temporal extent.

Pottery tempered with Mountsorrel granodiorite has been shown to occur widely, having been identified at each of the sites considered in this study, and to have been added to Neolithic, Bronze Age and Iron Age pottery (Table 1). This distribution does not reflect the direction of river flow, as it extends upstream to Willington, Swarkestone Lowes and Eye Kettleby, and overland to Crick. Nor does it reflect glacial action, as much of the pottery is found north of the potential rock inclusion sources, whereas Anglian ice flowed towards the south.

South Leicestershire quartz-diorite temper, by contrast, has been recorded only in a Neolithic sherd at Willington in the Trent Valley and on three Middle to Late Iron Age sites in the southern part of the study region. At each of the latter three sites, Iron Age sherds yielding Mountsorrel Complex granodiorite have also been recorded (Fig. 2).

The mechanisms by which the granodiorite or quartz-diorite temper and/or pots containing these inclusions were transported remain uncertain, together with the chronological relationships between these fabric types. It is recommended, therefore, that additional work be conducted to investigate further the systems of production and distribution that are represented by these sherds. A further layer of complexity is provided by the above-mentioned Neolithic sherd from Willington; this includes, in addition to Mountsorrel granodiorite, granitic and syenitic inclusions deriving from an unidentified source, raising the option of additional but as yet unlocated raw material sources.

Prehistoric East Midlands pottery production

A systematic petrographic study of prehistoric silicate tempers has shown that 73% of the pottery sherds analysed in this project contained silt- to sand-sized fragments mainly derived from locally outcropping igneous lithologies of the Mountsorrel Complex and South Leicestershire Diorite (petrographic assemblages A & B respectively, Table 1). This suggests that potters in this region were skilled enough to realise that there were different types of outcropping granitoid rock available for use as temper material, and this knowledge may have formed the basis for a local system of ceramic exchange networks.

Actual exposures or scree-like weathering products of these rocks (Fig. 1) probably furnished most of the granitoid temper material. It is also possible that glacial erratics of the Mountsorrel Complex contained within the Thrussington Till may have been opportunistically exploited: for example, around Humberstone in Leicester, and perhaps elsewhere to the south-east of the Mountsorrel outcrop. An alternative source as pebbles in local alluvium is not considered likely; nor would it explain the dominance of Mountsorrel and South Leicestershire-type granitoid inclusions in sherd tempers from sites 1, 11 and 14, which are upstream of the local fluvial transport pathways (Fig. 2). However, the non-igneous inclusions, which mainly comprise various types of quartz-rich sandstone and metasediment (Assemblage C), would have been abundantly available in loosely-bound alluvial or terrace gravels from which they could have been selected by hand-picking. Sherds containing basic igneous material (Assemblage D) were only rarely encountered during the survey, and could represent pottery or temper introduced from outside the East Midlands region or perhaps from hand-picked small erratics.

Electron microprobe investigations of the same pottery and source-rock temper materials, the results of which will be detailed in the full archive report (Knight *et al.*, in prep), show close agreement with the thin section survey. They also provide a further means of discriminating between temper derived from the Mountsorrel Complex and South Leicestershire Diorite suites, as well as between certain of the granitoid varieties constituting the latter. The microprobe also has the potential to categorize single crystal fragments found in the pottery clays, giving a better resolution than standard petrographic methods which, relying on observations of mineralogy and texture, require the presence in thin sections of larger, multicrystalline inclusions.

The clay raw materials could in some cases have been sourced from the extensively outcropping Mercia Mudstone, but the common presence of silt-sized flint inclusions suggests that a more likely origin would be by exploitation of alluvial muds and silts; these would have been easy to dig and are exposed in reasonably close proximity to many of the archaeological sites shown in Figure 2. However, more complex situations could also be envisaged. For example, pottery clay could have been dug from weathered Mercia Mudstone bedrock that had previously been intermixed with flint-bearing silty or sandy material representing the cryoturbated remnants of overlying Anglian glacigenic deposits. This or other possibilities could be tested by further investigations using isotope geochemistry.

Acknowledgements

We are grateful to Historic England for funding the project upon which this report is based, and in particular to Paddy O'Hara and Dr Helen Keeley for their help and advice during the course of this project. Dr Rob Ixer kindly reviewed a final draft of this paper. Thanks are also due to Rachel Atherton, Dr Patrick Clay, Dr Amanda Forster, Ann Inscker and Dr Richard Pollard for providing access to pottery samples and for permitting the extraction of sherds for petrographic and microprobe analysis. Nick Cooper, Neil Finn, Graeme Guilbert, Dr Rob Ixer, John Thomas, Dr Ian Whitbread and Dr Ann Woodward provided much useful information about the pottery from the sites considered in this study. Thanks are due also to Dr Jane Evans, Prof Julian Henderson, Dr Jonathan Last, Dr Michael Russell, Dr Harriet White and Dr Jim Williams their comments and advice.

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