Characterisation of Local Medieval Pottery from Croft Castle, Herefordshire

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Excavations at Croft Castle, Croft, Herefordshire, undertaken by Herefordshire Council for the National Trust, produced a large collection of medieval pottery. Whilst some of this pottery was of types well-known from excavations in Hereford, the majority consisted of sherds from vessels whose fabric contained large amounts of biotite, usually visible at x20 magnification as gold-coloured flakes up to 1.0mm across. This ware, noted on other sites in North Herefordshire but not studied in detail, is here termed North Herefordshire Medieval Biotite-rich ware (Code NHMB).

These sherds include examples which probably came from handmade jars, similar in shape and rim form to those produced in the Malvern Chase in the early to mid 13th century, together with sherds of wheelthrown jars with complex everted rim forms which owe nothing to the Malvern Chase (and have their best parallels in the pottery of Shropshire and the north-west Midlands) and sherds of glazed vessels, including some which appear to have been handmade (possibly tripod pitchers) and others which were probably from wheelthrown jugs. Using typological parallels these North Herefordshire vessels appear to have been produced in the early to mid 13th century through to the 14th century.

In addition, a smaller quantity of sherds from Croft contained the large rounded red mudstone inclusions typical of Hereford Fabric A4. However, it was apparent where the division between this ware and NHMB lay and all these sherds contained some biotite and did not appear to be identical to the fabric of the vessels from Hereford.

To test the identification of HERA4 and to examine its relationship to NHMB samples for thin section and chemical analysis were therefore chosen from Croft. (App 1). For NHMB, samples were chosen to reflect the various form/typology/manufacture groups to test whether there was any correlation between fabric and form/date and therefore evidence that the different groups were produced in separate centres.

The results of these analyses show that the samples can be grouped into five “local” fabrics and one misidentified sample of HERC2 and into three chemical groups. Combining the two sets of results the samples can be assigned to three wares: NHMB, HERA4 and HERA7B and within each ware into subfabric groups based on petrology or chemical composition.

The potential source areas for the two main wares are suggested. NHMB was made in an area of Silurian rocks and tempered with a predominantly siltstone sand and a source on the borders of the glacial Lake Wigmore is likely. HERA4 was made from micaceous marl and tempered with river sand of mixed origin, including Ordovician volcanic rocks and Silurian siltstones and bentonite which probably came from the River Teme, at or just to the south of Ludlow.

Thin Section Analysis

The thin sections were prepared by Steve Caldwell at the University of Manchester and stained using Dickson's method (Dickson 1965). The sections were scanned by the author and a list of inclusion types was prepared. The sections were then examined in more detail, listing the frequency, size range and distinguishing features for each type. This data was then examined to see whether any patterning could be found. One sample was then recognised as a sherd of Hereford Fabric C1 that had been mis-identified in the hand specimen and this was left out of further analysis.

Composition

The following inclusion types were present in the thin sections:

- Biotite. Laths often up to 1.0mm long.
- Sandstone. Small fragments of a quartzose sandstone containing rounded grains of quartz in a colourless silicious cement. The fragments range up to 1.0mm across and individual quartz grains range from 0.2mm to 0.5mm across. Some coarser grains occur with a red-stained cement and in some of these there is very poor sorting, including one fragment with a large rounded quartz pebble, c.0.7mm across, in a groundmass of much finer grains with an average size of c.0.2mm.
- Rounded quartz. Grains of similar size and shape to those in the sandstone fragments, together with some larger grains, up to 1.0mm across.
- Siltstone. Rounded fragments of siltstone, consisting of quartz, biotite, muscovite, amorphous brown and opaque grains up to 0.1mm across. Rocks of different texture are present and the coarser-grained examples have a higher quartz content and therefore a lighter colour than the finer ones.
- Altered Rhyolite and glassy volcanic rock. Rounded fragments of altered volcanic rock with a cryptocrystalline groundmass but containing sparse laths of feldspar, confirming a volcanic origin. They vary in the frequency of large crystals and in the colour of the groundmass (which ranges from colourless to almost opaque).
- Chert or Altered Rhyolite. Similar to the altered rhyolite but without conclusive evidence for a volcanic origin.
- Mudstone. Rounded ovoid pellets, usually composed of dark brown clay minerals with few individually identifiable grains. Bedding is sometimes visible. In some cases, the mudstones are light-coloured, similar to the kaolinitic seatearths found in the Coal Measures.

- Bentonite? Rounded fragments of a light brown, optically isotropic laminated material often containing inclusions consisting of angular shards of quartz, up to 0.2mm across, rounded rock fragments consisting of biotite and finegrained micaceous minerals up to 0.5mm long and 0.3mm wide. This is identified as bentonite based on the similarity with a sample of a bentonite clay collected from the Elton Beds at Pipe Aston. The vitrification point of this material is variable, and in some sections both anisotropic and isotropic fragments occur. The isotropic varieties seem to have more inclusions than the isotropic ones. The material also clearly has a high shrinkage rate and several inclusions have wide shrinkage cracks between the inclusion and the groundmass.
- Clay/iron concretions. Rounded concretions, often with an oolitic structure, containing inclusions of quartz similar in size but lower in frequency to those found in the groundmass.
- Plagioclase feldspar. Euhedral crystals, some with twinning but others untwined and recognisable as feldspars because of their outlines.

Two distinct types of groundmass were present. The first has similarities with the bentonite? inclusions whilst the second contains abundant angular quartz, sparse to moderate muscovite, and sparse biotite.

The two different groundmass types allow the samples to be divided into two groups, which correspond to differences in chemical composition discussed below.

The incidence of these inclusion types in each sample is given in Appendix 2.

Interpretation

The two different groundmass types indicate two quite different sources of clay. The first is presumably derived from weathered bentonite, in which case some or all of the bentonite inclusions could be interpreted as relict clay, fragments of the parent clay which were insufficiently worked to merge into the groundmass. In these samples it is likely that the biotite fragments were also present in the parent clay. All other inclusions are probably detrital.

The second groundmass type is similar to that of the Old Red Sandstone “marl” which forms the parent clay for much of the pottery produced in Herefordshire. However, it is possible, and likely considering the nature of the detrital inclusions, that the source in this case is a marl from the Ludlow Anticline. Only two formations include shales or mudstones which could weather to clay: the Wenlock Shale and the Lower Elton Beds (1971, 58-71, Pl.VII). The clay/iron concretions were presumably also present in this second clay.

The bentonite? is similar in thin section to the fired clay sample from Pipe Aston Quarry. Specifically, in addition to the light colour, the clay has a low vitrification point and has formed an isotropic glassy body. This clay was present in the Elton Beds, which are otherwise siltstones. These inclusions occur in both groundmass types. In the silty groundmass they must be detrital and therefore must have been present in sands or gravels in a river whose catchment includes Silurian strata. In the area in which these wares occur, this could either be a river draining southwards into the Lugg or the Teme, which in this area flows east and north through Ludlow.

Siltstones are extremely common in the Palaeozoic strata of the Welsh borderlands and siltstone facies occur throughout the Silurian and Devonian deposits of North Herefordshire, from the Wenlock Shale through to the Old Red Sandstone deposits. Mudstones are less widely distributed, but include facies within the Wenlock Shale, the Lower Elton Beds and the Ledbury Group of the Lower Old Red Sandstone.

The sandstone and volcanic rock fragments do not seem to be from the Silurian strata of the Ludlow Anticline. The lack of iron in the cement suggests that the sandstone is not from the Old Red Sandstone and the closest sources are probably in the Ordovician rocks of the Powys/Shropshire border. However, given the size of the grains, it is not possible to say that the volcanic grains were derived directly from the original outcrop rather than from a sandstone or conglomerate.

Examination of the data in App 2 suggests that there are five fabric groups present in the Croft local medieval pottery samples: HERA4; NHMB, a sample of HERC2 (only recognised during thin section analysis), and a sample of a fine biotite-rich wheelthrown glazed ware V3938 and a sample with the bentonite-derived groundmass of NHMB but coarse quartz sand temper taking the place of the siltstones (V3954).

Chemical Analysis

Sub-samples of each sherd were removed for chemical analysis. After removing the outer surfaces which have the highest likelihood of contamination, the sub-samples were crushed and ground to a fine powder and submitted to Dr J N Walsh at Royal Holloway College, London, where they were analysed using Inductively-Coupled Plasma Spectroscopy. A range of major elements were measured as percent oxides (App 3) and a range of minor and trace elements were measured as parts per million (App 4).

Silica is not measured but was estimated by subtraction of the total measured oxides from 100%.

The data were then normalised to Aluminium and analysed using factor analysis (using the factor analysis package in Winstat for Excel ().

Various datasets were analysed to explore the similarities and differences between the various medieval samples, clay samples from north Herefordshire, and post-medieval ceramics whose source is known. These comparanda are listed below, together with the group names used in the factor analyses:

- CROFT ESTATE. A series of analyses of brick and roof tile produced at two locations on the Croft Castle estate, less than 1 mile apart.
- CROFT CLAY. A sample of fired clay from the Croft Castle excavations.
- HERA10. A series of analyses of bricks and other ceramic building material from the Croft Castle excavations have similar chemical characteristics.
- HERA7D. A series of analyses of glazed ridge tiles of late 16th to mid 17th-century date from Croft Castle and probably produced in the North Herefordshire potteries situated in various parishes in Deerfold Forest. The Croft Castle ridge tiles probably all come from a single batch produced at one of these potteries.
- Aston Stream, Mortimer Wood and Pipe Aston Quarry, Pipe Aston (PA STREAM; PA MW; PA QUARRY. Three samples of clay collected by Allan Peacey from sites within the parish of Pipe Aston. The clays were collected because of their light colour to test the possibility that they were used as pipeclay. They are probably bentonites, formed from volcanic ash deposited within the Silurian Wenlock Limestone. The stream sample was collected from a clay bed within the Wenlock limestone and has a high calcium content. The Mortimer Wood sample was also apparently a bentonite clay. The quarry sample was collected from a clay bed within the Elton Beds and may be either a marine mudstone of terrestrial origin or another bentonite deposit.

Internal Variability

Factor analysis of the 26 samples revealed four factors. A plot of the first two factors revealed that they could be divided into three groups, but that these groups did not correspond to the visual distinction between HERA4 and NHMB fabric groups (Fig 1). The main differences between the groups are in their F1 scores, which depend on high weightings for chromium, iron, vanadium, nickel, titanium, scandium, cobalt, lithium and manganese and negative weighting for potassium. These three groups show no correlation with the typology/glaze/manufacture groups (Table 1). In total, fourteen elements show some sign of correlation with these three groups (Table 2).

Table 1

cname	Comments	GL	HM	ND	WT	Grand Total
NHMB		3	5	4	5	17
NHMBv	V3954		1			1
HERA4		2	2	1	2	7
HERA4v					1	1
Grand Total		5	8	5	8	26

Table 2

Element	NHMB	NHMBv	HERA4	HERA4v
Estimated Silica	Lower mean	Lower mean	Higher mean	Higher mean
Aluminium	Higher mean	Higher mean	Lower mean	Lowest
Iron	Low	Low	Moderate	High
Potassium	Low	Low	Lower mean	Higher mean
Titanium	Low	Low	Moderate	High
Manganese	Lower mean	Lower mean	Higher mean	Highest
Chromium	Lower mean	Lower mean	Higher mean	Highest
Copper	Lower mean	Lower mean	Higher mean	Higher mean
Lithium	Lower mean	Lower mean	Higher mean	Highest
Nickel	Lower mean	Lower mean	Higher mean	Highest
Scandium	Lower mean	Lower mean	Higher mean	Highest
Vanadium	Lower mean	Lower mean	Higher mean	Highest
Rare Earth Elements	Higher mean	Higher mean	Lower mean	Higher mean
Cobalt	Lower mean	Lower mean	Higher mean	Highest

Lead shows a correlation with the presence of glaze and is therefore probably present as a contaminant. No elements show a strong correlation with lead.

Comparison with other groups

The Croft Castle medieval pottery data was then compared with the Croft Estate, North Herefordshire ridge tiles and Pipe Aston clay samples. Factor analysis of this data set produced five factors. A plot of the first two factors (Fig 1) indicated that the first factor distinguished the three local medieval ware groups from each other and from the Croft Estate and HERA7D ridge tiles. The Mortimer Wood sample plots close to the NHMB and HERA4 groups whilst the Pipe Aston quarry sample has a similar F1 score to the NHMB samples but a lower F2 score. A plot of the 3rd and 4th factors produced one large cluster with outliers consisting of the Pipe Aston Stream sample, one of the Croft CBM samples, the Pipe Aston Quarry sample and the Croft clay sample. The Mortimer Wood sample plots close to the main cluster but is still separated from it. The fifth factor separates two of the Pipe Aston clay samples (Mortimer Wood and the Pipe Aston quarry) from the remainder, which all have similar F5 scores.

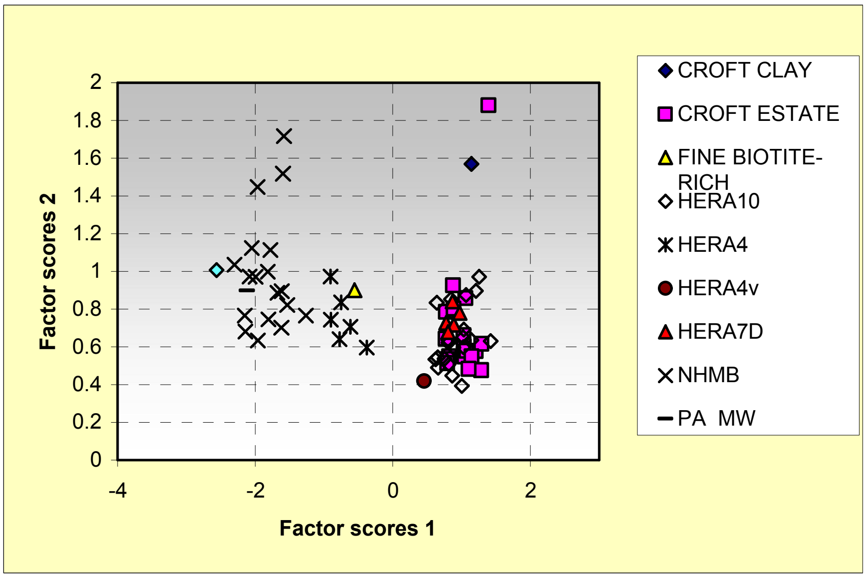

Figure 1

Study of the weightings which give rise to the Factor 1 score indicate a similar range of elements as those which distinguished the three North Herefordshire groups in the first analysis. Fig 2 shows a plot of chromium against vanadium content, indicating the strong correlation of the two elements and showing that for these two elements HERA4v has similar characteristics to the Croft Estate samples.

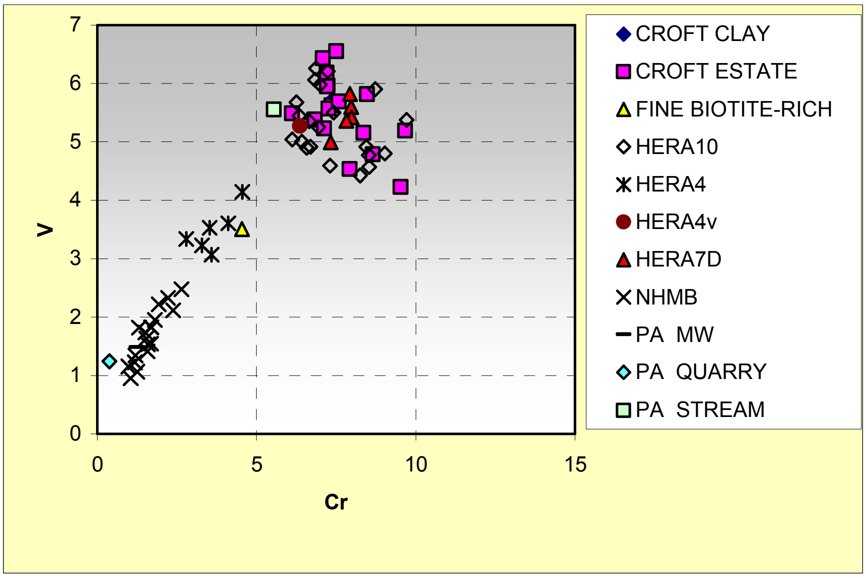

Figure 2

The similarity of the NHMB and HERA4 groups to the Pipe Aston clays, and particularly to that from Mortimer Wood, suggests that these two groups were also made from Silurian clays. Further clay samples of known geological position are required to establish whether the differences between the three Pipe Aston clays is significant but it may be significant that NHMB samples consistently have similar characteristics to the Mortimer Wood clay.

Discussion and Conclusions

The samples from Croft Castle form a representative sample of the coarse locally-made medieval pottery found at the site (there are a number of fine glazed wares which contain more prominent muscovite and/or sparse rounded siltstone fragments which are probably also from a "local" source).

Thin-section analysis indicates that they can be divided on the basis of their groundmass into two groups, one of which was probably made from a weathered bentonite whilst the other was made from a weathered silty mudstone or "marl". Within the Bentonite group, all but one of the samples appear to have similar inclusions and the ICPS analyses indicate that they all form a single chemical group. It is therefore likely that they all come from a single source and that this unknown centre was producing handmade pottery in the early 13th century and wheelthrown pottery in the later 13th and early 14th centuries. The glazed samples mostly come from jug handles and these include at least one vessel with a wheelthrown body. The handles are in the main the narrow strap handles, decorated with a column of stab marks, which are similar to Worcester jugs (HERC2). The wheelthrown jars are all of types with a complex everted rim, not paralleled in south Worcestershire but similar to examples from Shropshire. Until a stratified medieval sequence containing these wares is studied it is not possible to tell whether the three types (handmade jars, wheelthrown jugs and wheelthrown jars) are contemporary, in which case they may indicate that the pottery included potters trained in south Worcestershire and in the northwest midlands, or successive. In either case, the lack of chemical differentiation between the groups suggests that all were made in one place.

Table 3 lists the sites from which vessels of this fabric have been recorded. It indicates that the type, within Herefordshire, is restricted to the extreme north of the county. The combination of thin section and chemical analysis indicate a source within the Ludlow Syncline for this ware, utilising an outcrop of weathered bentonite and using a predominantly siltstone sand as temper. The lack of calcareous inclusions may be significant, since much of the Silurian outcrop consists of limestones and most of the bentonite deposits occur within sequences of limestone deposition. However, it most likely indicates that the sand deposit from which the inclusions were obtained was decalcified.

The lack of angular fragments of siltstone (and rare mudstone and sandstone) in the inclusions probably enables a head deposit formed of slumped or colluvial material to be discounted as a potential source. The geological drift map for this area (Sheet 181, Ludlow) indicates several sand and gravel deposits which should be considered as potential sources for the inclusions. All are terrace sands deposited around the fringes of the glacial/early post-glacial Lake Wigmore. Of these, the most likely lies at the south end of this lake, at Yatton, since this sand is closest to outcrops of Elton Beds and Wenlock Limestone, where bentonite clays occur. Other possibilities are at Walford and Buckton.

Table 3

Locality	Frequency	Comments
Croft Castle	Abundant	
Richard's Castle	Abundant	Curnow and Thompson 1969
Pipe Aston, Roy's Orchard	Abundant	Excavated by Allan Peacey for the Pipe Aston Project
Wigmore Castle	Abundant	
Hereford	Absent	Vince 1985;Vince 2002
Leominster	Absent	Based on collections from Leominster Poultry Packers, and Ettnam Street, both investigated by Archaeological Investigations Ltd

The remaining samples form one group and two isolated samples. Five of the samples have the same fabric characteristics as HERA4: moderate flakes of biotite in a silty, micaceous groundmass with a mixed rounded sand which includes siltstone, mudstone (mostly red but including some white-firing examples), rounded quartz and bentonite pellets. Other inclusion types occur in some but not all of the sections: coarse sandstone fragments; volcanic glass; chert/rhyolite; angular fragments of plagioclase feldspar; rounded fragments of acid igneous rock; clay/iron concretions (only in one sample).

The chemical composition of the five HERA4 samples is very similar and they form a discrete group, separate both from the NHMB samples and the Croft Estate/North Herefordshire post-medieval pottery groups. However, one of the HERA4 samples has a chemical composition which separates it from the remainder (HERA4v) and a sample of a fine micaceous, wheelthrown jug with a high biotite content has a similar composition to the HERA4 samples.

Table 4 shows the distribution of HERA4. Within Herefordshire, the ware has a more southerly distribution than NHMB. A source south of the Silurian outcrop is possible, in which case the source of the coarse sand inclusions would have to be the Lugg valley, since the Arrow catchment does not include Silurian strata. However, a source in the Lugg does not fit the paltry distribution data, since it is most common at Richards Castle, and a more likely source is therefore the Teme valley. Such a source would also fit the presence of volcanic rock fragments, since a tributary of the Teme drains the Ordovician volcanic rocks on the Shropshire/Powys border. Within the Teme valley terrace sands are mapped at Priors Halton, north of Ludlow; Ludford, immediately opposite Ludlow; Ashford Bowdler and Ashford Carbonell. Bentonite clays are present in the cliff at Ludford Corner, within the Upper Whitecliffe Formation and could therefore be present in river gravels from this point southwards. However, it is unlikely that soft Silurian siltstones and bentonite pellets would survive in river sands much further south than the Ashfords.

Table 4

Locality	Frequency	Comments
Croft Castle	Present	
Richard’s Castle	Present in moderate quantities	Curnow and Thompson 1969
Pipe Aston, Roy’s Orchard	Absent	Excavated by Allan Peacey for the Pipe Aston Project
Hereford	Present but rare	Vince 1985;Vince 2002
Leominster	Present	Based on collections from Leominster Poultry Packers, and Ettnam Street, both investigated by Archaeological Investigations Ltd

The chemical distinction between one of the HERA4 samples and the remainder, indicated in the section on the chemical analysis as HERA4v, does not appear to have any correlation in the thin section analysis but does show a similarity with the North Herefordshire post-medieval pottery and Croft Estate fabrics. This may indicate the use of the same parent clay as those samples but with the same coarse sand temper as in the remaining HERA4 samples.

Finally, the single sample from a biotite-rich fine micaceous wheelthrown glazed ware vessel contains a similar suite of inclusions to the HERA4 samples (siltstones, mudstones and rounded quartz, but without the less common types; bentonite, the rounded acid igneous rock, chert/altered rhyolite, volcanic glass, and coarse sandstone fragments. The similarity of the chemical composition of this sample to that of the HERA4 samples suggests that they have a similar source but that the wheelthrown vessel was made from untempered clay. However, until more is known of the variability in clay composition in North Herefordshire and south Shropshire the significance of this similarity remains uncertain.

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Appendix 1

Form	TSNO	drawing no	Action	Sitecode	trench	Context	cname	Description
JUG	V3792	26	DR;TS;ICPS	CC03	29	29041	NHMB	STRAP WITH ROW OF STAB HOLES DOWN BACK
JAR	V3794	28	DR;TS;ICPS	CC04	45	45003	HERA4	WT?;GLAZE SPOT EXT;FLAT-TOPPED EVERTED RIM;WAVYCOMBING ON TOP OF RIM
TP	V3793	27	DR;TS;ICPS	CC04	44	44004	HERA4	RECT-SECTIONED FOOT
BOWL, HANDLED	V3790	24	DR;TS;ICPS	CC02	17	17053	NHMB	
JAR/BOWL	V3789	0	TS;ICPS	CC02	17	17041	HERA4	INT PLAIN GL
JUG	V3791	25	DR;TS;ICPS	CC03	29	29019	NHMB	HM;PLAIN EXT GL;NARROW STRAP WITH SQUARE STABBING
JUG	V3938	0	TS;ICPS	CC03	SPOILHEAP	U/S	HERA7B	DEC COMBING; VERT AND DIAGONAL; CUGL?
JAR	V3951	0	TS;ICPS;DR	CC04	42	U/S TR42	NHMB	WT;CF HERB1 L13THC
JAR	V3947	0	TS;ICPS;DR	CC03	29	29028	NHMB	HM;E13TH MALV FORM
JAR	V3945	0	TS;ICPS;DR	CC04	40	40003	NHMB	HM?;FLAT-TOPPED EVERTED RIM
JAR	V3949	0	TS;ICPS;DR	CC04	40	40003	NHMB	WT?;EVERTED INFOLDED RIM
JAR	V3953	0	TS;ICPS;DR	CC04	40	40005	NHMB	WT;EVERTED WITH INTERNAL LEDGE
JUG	V3940	0	TS;ICPS;DR	CC04	40	40009	NHMB	HM;FLAT-TOPPED RIM;CLOSE-SET GROOVES ON NECK
JAR	V3948	0	TS;ICPS;DR	CC04	43	43002	NHMB	WT;OXID;FLAT-TOPPED

Form	TSNO	drawing no	Action	Sitecode	trench	Context	cname	Description
								EVERTED
JUG	V3935	0	DR;TS;ICPS	CC03	29	U/S TR29	NHMB	ROD/RECT SECTIONED;TWO DEEP VERT GROOVES; THUMBED ON EITHER SIDE;PLAIN GL
JAR	V3942	0	TS;ICPS;DR	CC04	40	40018	NHMB	HM:EVERTED INFOLDED
JUG	V3936	0	TS;ICPS;DR	CC02	17	17033	NHMB	EXT PLAIN GL;STRAP HANDLE;TWO PARALLEL GROOVES WITH COLUMN OF DIAGONAL SLASHES BETWEEN THEM
JAR	V3952	0	TS;ICPS;DR	CC04	42	U/S TR42	NHMB	WT;FLAT-TOPPED EVERTED FLAT-TOPPED EVERTED
JAR	V3944	0	TS;ICPS	CCG01	5	502	NHMB	INTURNED E13TH
JAR	V3955	0	TS;ICPS;DR	CCG01	4	401	NHMB	WT;LID-SEATED RIM
JUG	V3937	0	TS;ICPS;DR	CC04	45	45006	NHMB	WT;FLAT-TOPPED RIM;APPLIED THUMBED STRIP BELOW RIM;WT
JAR	V3943	0	TS;ICPS	CC04	45	45021	NHMB	HM;CYLINDRICAL NECK;ROUNDED RIM
JAR	V3946	0	TS;ICPS;DR	CCG01	11	1109	NHMB	HM?;CF MALV E13TH RIM
JUG	V3939	0	TS;ICPS	CC02	17	17015	NHMB	STRAP HANDLE;SINGLE COLUMN OF SLASHES DOWN BACK CF HG/WORCS
JUG	V3941	0	TS;ICPS;DR	CC04	43	U/S TR43	NHMB	WT;THUMBED STRIP BELOW RIM;UNGLAZED?
JAR	V3954	0	TS;ICPS	CC03	33	U/S TR33	NHMB	INFOLDED RIM

Form	TSNO	drawing no	Action	Sitecode	trench	Context	cname	Description
JAR	V3950	0	TS;ICPS;DR	CC03	29	29028	NHMB	WT?; EVERTED FACETTED RIM

Appendix 2

TSNO	biotite	coarse sst	siltstone	volcanic glass	chert/altered rhyolite	mudstone	rounded quartz	plagioclase	rounded acid igneous	clay/iron concretions	tuff? with biotite etc	micaceous silty groundmass	bentonite-rich groundmass
V3789	m	s	s	s	s	s	s	n	s	s	s	y	n
V3790	s	n	m	n	s	s	s sa	s	s	n	s	n	y
V3791	s	n	m	n	s	n	s sa	n	n	n	s	n	y
V3792	m	n	m	n	n	n	s sa	n	n	n	m pink stained	n	y
V3793	m	s	s	n	s	s	s	n	s	n	s	y	n
V3794	m	s	s	n	s	s	s	n	s	n	s	y	n
V3935	m	n	m	n	n	n	s sa	n	n	n	m	n	y
V3936	m	n	m	n	n	n	s sa	m	n	n	m	n	y
V3937													
V3938	m	n	s	n	n	s	s <0.3mm	s	n	n	n	y	n
V3939	m	n	m	n	n	n	s sa	s	n	n	m	n	y
V3940	m	s	s	n	s	s	s	s	s	n	s	y	n
V3941	m	n	s	s inc fine-grained basic	s	s	s	n	s inc gneiss 2.0mm	n	s	y	n

TSNO	biotite	coarse sst	siltstone	volcanic glass	chert/altered rhyolite	mudstone	rounded quartz	plagioclase	rounded acid igneous	clay/iron concretions	tuff? with biotite etc	micaceous silty groundmass	bentonite-rich groundmass
V3942	m	n	m	n	n	n	s sa	m	n	n	m	n	y
V3943	m	n	m	n	n	s	s sa	m	n	n	s	n	y
V3944	m	n	m	n	n	n	s sa	m	n	n	m (some isotropic some anis)	n	y
V3945	m	n	m	n	n	n	s sa	m	n	n	m	n	y
V3946	m	n	m	n	n	n	s sa	m	n	n	m (some isotropic some anis)	n	y
V3947	m	s (grains <0.2mm)	m	n	n	n	s sa	s	n	n	m (some isotropic some anis)	n	y
V3948	m	n	s	s dark glass	n	s	s	s	s	n	s	y	n
V3950	m	s (grains <0.2mm)	m	n	n	n	s sa	s	n	n	m (some isotropic some anis)	n	y
V3951	m	s (grains <0.2mm)	m	n	n	n	s sa	s	n	n	m (some isotropic some anis)	n	y

TSNO	biotite	coarse sst	siltstone	volcanic glass	chert/altered rhyolite	mudstone	rounded quartz	plagioclase	rounded acid igneous	clay/iron concretions	tuff? with biotite etc	micaceous silty groundmass	bentonite-rich groundmass
V3952	m	s (grains <0.2mm)	m	n	n	n	s sa	s	n	n	m (some isotropic some anis)	n	y
V3953	m	s (grains <0.2mm)	m	n	n	s	s sa	s	n	n	m (some isotropic some anis)	n	y
V3954	m	m (inc one with large pebble in finer groundmass)	m	n	s	s	m	s	s	n	s	n	n
V3955	m	s (grains <0.2mm)	m	n	n	s	s sa	s	n	n	m	n	y

Appendix 3

TSNO	**Al2O3**	**Fe2O3**	**MgO**	**CaO**	**Na2O**	**K2O**	**TiO2**	**P2O5**	**MnO**
V3789	18.42	5.26	2.18	0.89	0.92	2.97	0.65	0.26	0.072
V3790	19.81	3.29	2.2	1.03	0.88	3.28	0.5	0.45	0.045
V3791	20.86	3.52	2.8	1.46	0.74	4.12	0.52	0.6	0.057
V3792	18.92	4.16	2.51	1.39	0.84	3.55	0.53	0.88	0.133
V3793	17.12	5	2.01	0.72	0.67	2.48	0.67	1.33	0.07

V3794	18.02	5.05	2.6	0.75	0.63	3.09	0.65	1.02	0.074
V3935	20.72	3.49	3.16	1	0.99	5.05	0.58	0.26	0.053
V3936	18.26	3.76	2.17	1.06	0.78	2.65	0.7	0.91	0.063
V3937	18.18	3.84	2.82	0.8	0.5	3.46	0.59	0.78	0.057
V3938	17.39	4.82	2.93	1.07	0.57	3.05	0.68	0.51	0.071
V3939	20.74	4.22	3	1.02	0.95	4.48	0.64	0.53	0.04
V3940	16.12	4.06	2.29	0.74	0.57	2.77	0.61	0.65	0.059
V3941	15.74	6.09	1.77	0.42	0.51	2.24	0.74	0.7	0.164
V3942	22.44	3.31	3.17	1.83	1.05	4.74	0.61	0.57	0.037
V3943	21.93	3.59	3.14	1.5	1.2	4.74	0.65	0.51	0.043
V3944	24.12	3.8	3.62	0.93	0.9	5.3	0.61	0.36	0.057
V3945	22.54	3.09	3.34	1.29	1.05	4.86	0.57	0.26	0.046
V3946	21.03	3.54	2.27	0.68	0.9	3.74	0.57	1.15	0.037
V3947	21.94	3.03	3.65	1.33	0.64	5.02	0.49	0.39	0.056
V3948	19.23	5.21	3.15	0.92	0.59	3.48	0.67	0.14	0.066
V3949	14.93	6.92	2.4	0.46	0.41	3.41	0.58	0.68	0.053
V3950	21.62	3.13	3.49	0.75	0.67	5.23	0.5	0.25	0.034
V3951	21.37	3.57	3.03	0.46	0.8	4.49	0.54	0.43	0.04
V3952	22.05	3.25	3.03	0.88	0.87	4.66	0.53	0.17	0.044
V3953	20.85	3.17	2.63	1.37	0.95	4.5	0.57	0.37	0.039
V3954	18.47	3.35	2.14	1.51	0.75	2.82	0.54	0.96	0.05
V3955	22.48	3.95	3.35	0.77	0.95	4.85	0.63	0.36	0.07

Appendix 4

TSNO	Ba	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zr*	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb	Zn	Co
V3789	592	65	20	46	36	13	85	65	36	98	53	94	44	11	2	6	3	212	79	16
V3790	627	26	14	30	19	10	76	36	46	129	65	117	64	13	2	7	4	367	57	11
V3791	1,192	33	21	29	26	10	104	32	40	139	66	146	55	13	2	5	4	971	63	11
V3792	851	45	19	28	33	10	85	40	40	132	62	131	45	12	2	8	4	318	165	11
V3793	757	78	24	35	46	13	75	71	37	108	55	96	44	12	2	6	4	401	79	14
V3794	609	74	23	42	45	13	72	65	35	104	52	102	40	10	2	6	3	6,857	82	15
V3935	456	31	16	37	24	11	68	36	44	137	64	132	68	13	2	7	5	770	61	12
V3936	945	51	132	36	38	12	96	61	38	125	57	119	51	11	2	6	4	1,696	124	14
V3937	548	48	21	38	33	11	71	45	33	112	56	108	49	9	2	5	3	993	68	14
V3938	531	79	27	47	45	13	79	61	29	95	51	100	43	8	2	5	3	1,051	71	16
V3939	536	40	18	40	28	13	92	46	41	130	64	115	52	12	2	6	4	278	60	12
V3940	520	53	17	36	33	11	70	52	29	100	49	93	43	8	1	3	3	215	79	16
V3941	560	100	23	45	52	13	61	83	34	102	52	107	52	12	2	8	3	136	75	18
V3942	517	27	19	36	22	12	99	30	50	136	66	132	65	13	2	7	5	48	145	15
V3943	497	37	20	39	24	12	104	40	43	144	62	122	57	13	2	6	4	58	216	17
V3944	488	38	21	44	23	13	83	34	52	150	76	142	69	15	2	7	5	50	169	15
V3945	414	22	14	42	22	11	94	26	50	129	76	139	69	15	3	7	4	53	119	13
V3946	559	38	21	30	26	12	73	41	45	137	69	136	66	14	2	6	4	34	117	11
V3947	464	23	15	42	23	10	75	21	54	156	76	148	77	15	2	8	5	48	64	10
V3948	399	69	20	48	42	13	63	59	28	101	52	97	40	8	1	5	3	165	74	16
V3949	624	88	19	66	34	12	69	87	11	60	30	57	4	3	1	2	1	29	71	16

TSNO	Ba	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zr*	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb	Zn	Co
V3950	410	27	15	42	17	10	57	23	45	142	67	130	63	12	2	6	4	28	52	11
V3951	429	36	16	41	23	10	56	33	34	135	65	125	57	11	2	5	4	63	109	12
V3952	388	26	14	41	17	10	71	27	43	146	67	133	56	12	2	6	4	43	54	11
V3953	515	32	15	29	22	11	91	34	46	147	66	123	64	12	2	7	5	45	56	10
V3954	1,113	41	19	29	25	11	131	43	40	119	60	113	58	11	2	5	4	36	61	12
V3955	428	38	21	40	25	13	69	41	41	135	69	128	63	14	2	7	4	75	113	14