Characterisation studies of the Anglo-Saxon pottery from Bloodmoor Hill, Carlton Colville, Suffolk

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Excavations at Bloodmoor Hill, Carlton Colville, in Suffolk, revealed an early Anglo-Saxon settlement which, unusually, included horizontal stratigraphy as well as cut features. The pottery from this site was studied by Dr J Tipper for Cambridge Archaeology Unit. This study included a binocular microscope study of the entire collection, as a result of which 58 samples were selected for further analysis. In addition, five samples of fired clay from the site were examined.

The aims of this further analysis were to provide a check on the visual fabric classification and to determine whether or not the fabrics could be assigned to a source area on the basis of their petrological and chemical composition.

Methodology

A thin section of each sample was prepared at the Department of Earth Sciences, University of Manchester, by Steve Caldwell. Each section was stained using Dickson's method to distinguish ferroan (blue stain) and non-ferroan (red stain) calcite from dolomite (unstained). The thin sections were then examined using a petrological microscope and a checklist of inclusion types and fabric traits. Each recorded trait was recorded semi-quantitatively, on a four-point scale (absent, scarce, moderately common, abundant). Additional details of some of the inclusion types were noted where appropriate.

The thin sections have been added to the AVAC thin section collection under the catalogue numbers V2021 to V2083.

Sub-samples of each sample were prepared for chemical analysis by Peter Hill and analysed at the Department of Geology, Royal Holloway College, London, under the supervision of Dr J N Walsh. Each sample consisted of c.1-2gm of pot from which the outer surfaces and broken edges had been mechanically removed, to minimise contamination from encrustation and soil. The remainder of the sample was crushed to a fine powder in a porcelain mortar and the powder analysed using Inductively Coupled Plasma Spectroscopy. The standard range of elements were analysed, with the addition of lead. The major elements were measured as percent oxides and the remainder as parts per million. To minimise the dilution effect caused by variation in the quartz and organic contents of the samples, the dataset was transformed by normalising the data to Al2O3 before any further analysis.

Petrological Analysis

Description

After an initial scan of the thin sections, a list of inclusion types was made and used as the basis for detailed recording of each section. The inclusion types and traits recorded were as follows:

gsq less than 1.0mm. Almost every section included one or two rounded quartz grains with high roundness and low sphericity. Their shape is typical of grains from Lower Cretaceous deposits, although they are common in Tertiary and Quaternary deposits due to reworking. Some of these grains have a haematite coating or haematite cement, indicating that they originated in an iron-cemented sandstone. However, the majority of the grains had no such coatings. Under x20 magnification the surfaces of these grains appear polished, often leading to the use of the term "glassy". In most sections these grains only occur sparsely.

rq less than 1.0mm. A second group of quartz grains had a higher sphericity, including some almost spherical grains. Grains with this shape are common in the Permo-Triassic strata and were deposited under desert conditions. Under x20 magnification the surfaces of these grains tend to be dull or matt and this, together with the polycrystalline nature of many of the grains, can lead to the use of the term "milky". Again, these grains are present in the majority of sections, although they vary in frequency.

r chert. A distinctive subset of the previous inclusion type is composed of chert, typically with a coarser texture than flint but including brown stained examples and examples with hints of a fossiliferous content. Examples less than 0.3mm across tend to be subangular and difficult to distinguish from fragments of silica cement from silicious sandstones. Only larger, rounded grains were classed here as chert. No examples of the distinctive radiolarian chert of Carboniferous age were noted here, but it is likely that ultimately many of these grains are also of Carboniferous origin.

sa q less than 0.5mm. Subangular quartz grains, less than 0.5mm across, were present in variable quantities in the sections. In many cases it is clear than they derive from medium-grained quartz sandstones with overgrown quartz grains (orthoquartzites) but the type will also include material from other sources. A distinctive group, for example, consists of a coarse silt/fine sand and should really be considered as part of the groundmass of the sample, despite being larger than 0.1mm, the notional cut-off point between "inclusions" and "matrix".

Organics. The identification of organic inclusions in the samples was made more difficult by variations in firing. In low-fired samples in which carbon was still present in the clay actual charred inclusions were present, sometimes surrounded by a dark carbon-rich halo. In oxidized samples it was sometimes possible to identify organic inclusions by the shape of the remaining voids. A distinction was drawn between amorphous organic matter, often present between laminae, and inclusions which appear to be deliberate additions of chaff or similar material (such as dung).

r opaques less than 0.5mm. Rounded opaque grains, often appearing black in reflected light, were present in many samples but never in large quantities. They are common detrital grains and are not diagnostic of any particular strata.

sa flint less than 1.5mm. Flint was identified mainly by its fine texture and the presence of spherical microfossils. Within the samples there was a division into grains which appear to be fresh (unstained, quite often with extremely angular outlines) and those which had undergone erosion and weathering (rounded, or fragments of rounded grains, or brown stained). In addition, in one section the groundmass was found to contain a high proportion of angular, unstained flint less than 0.2mm across.

Calc. Unfortunately, actual calcareous inclusions were rare, as a result of post-burial leaching. In many cases the resulting rounded voids were distinctive and could be identified. However, irregularly-shaped leached calcareous inclusions were probably missed. Only four samples contained unleached calcareous inclusions. In the case of two of the fired clay samples these consisted of a mixture of non-ferroan micrite grains and smaller subangular sparry ferroan calcite fragments. Similar inclusions were present in one pot sample (V2047, CALCT+CHAFF). The only other samples to contain calcareous inclusions both had different characteristics: a non-ferroan calcite micrite with sparse rounded quartz grains (V2082, CALCT) and grains of dolomitic micrite, present alongside leached grains in V2064, CALCT). Some of the samples with leached inclusions could be identified as once containing a shell and oolitic limestone sand, as a result of the shape of the voids and the partial replacement of the structure by unfired clay.

biotite granite. Fragments of acid igneous rocks containing biotite, quartz and feldspar were present in 14 samples. In two cases these fragments were abundant and included sheaves of muscovite (i.e. an original component of the rock rather than replacement of feldspar). In the remaining samples no muscovite was present in the rock, which was similar in appearance to that from the Mountsorrel Granodiorite of north-east Leicestershire but also to rocks found in boulder clay along the east coast of England. In one case no biotite was present and it is more likely that the rock is actually an arkose (feldspathic sandstone).

Basic. In two thin sections moderately abundant fragments of a basic igneous rock were present (V2025, SST1 and V2026, CALCT). This rock is not identical to that found in east coast boulder clays and would repay closer identification. The same rock was present as sparse grains in a third sample. In two further samples sparse examples of a rock composed of interlocking grains of feldspar, less than 0.2mm long, were present.

volc glass? Three sections contained fragments of possible volcanic glass. Two of these samples also contained basic igneous rock fragments. It is extremely difficult to positively identify isolated detrital grains of volcanic glass, since they are similar in appearance to chert and slag.

high grade metamorphic. A single sample, V2061 – SST 2a, contained moderately common fragments of a high grade metamorphic rock.

Musc over 0.1mm. Muscovite laths less than 0.1mm long were not noted separately since they appear to be positively correlated with quartz silt.

Sst. Sandstone fragments of various types were present in over half of the samples. The most common is composed of overgrown quartz grains less than 0.3mm across. This rock is clearly only loosely cemented since samples which contain moderate to abundant fragments of this sandstone also contain abundant angular quartz grains of similar size and shape as those in the rock. Other sandstone fragments were noted which had silica cement. This cement is usually microcrystalline and has a different structure from that typically found in lower Cretaceous sandstones and cherts which often have a chalcedonic structure. Finally, some sandstone with a coarse grain size, overgrown quartz grains and a kaolinitic cement were noted. These are possibly of Carboniferous age and of Millstone Grit type. Sands containing a high proportion of this sandstone and its constituent quartz grains occur widely in English fluvio-glacial sands.

concentric clay pellets. Rounded clay pellets with more or less concentric bands of near opaque clay occur in 15 of the samples but are not common. It is likely that these are iron- and/or manganese-rich nodules formed in the parent clay rather than detrital grains.

sa dark clay sparse silt. Rounded clay pellets with a darker colour than the clay matrix but a similar texture and no sign of any internal structure were noted in 11 samples and were moderately common in two samples (V2025 and V2081, both SST 1).

altered glauc. Small rounded grains of glauconite, mainly altered from green to red, perhaps through firing or oxidation of the parent clay, occur in 10 samples. They were mainly sparse and not indicative of the use of a glauconitic clay, since glauconite although soft does survive in detrital sands. In four samples these grains were moderate or abundant in frequency and these samples may have been made from glauconitic clays. (V2074 – CHAFF+MICA, V2046 – BIOTITE and V2068 and V2075 both of which are CALCT). Glauconitic clays are particularly common in the Lower Cretaceous but are also found in the Tertiary.

Matrix. Where the isotropy of the clay minerals in the groundmass could be observed they were anisotropic, consistent with low firing temperatures. In many cases, the groundmass was obscured by the presence of carbon. In three samples, all fired clays, the groundmass was variegated and included lenses and streaks of lighter-firing clay.

Silt. The quantity of quartz and muscovite silt present in the groundmass was noted. In most cases there was sparse silt but in six samples there was no silt at all whilst in four samples there was moderate silt and in 9 samples there was abundant silt.

r red sandy clay pellets. Three samples contained fragments of oxidized clay, of a different texture to that of the groundmass. In two cases these fragments were moderately common and rounded (V2055 – CALCT+GROG, V2034 – GROG). In the third the fragments were angular and included fragments of differing textures, notably extremely silty fragments. It is likely that the first two samples contained rolled grains of burnt clay but whether this burning was anthropogenic or natural is unknown. In the third case it is likely that the fragments are grog, deliberately crushed pottery.

r brown-coloured clay. Five samples contain rounded fragments of clay of similar colour and texture to the groundmass. These show no internal structure and are therefore unlikely to be mudstone or shale inclusions. They are interpreted here as relict clay which remained as discrete lumps when the clay was prepared for potting. In two cases the pellets were associated with rounded red sandy clay pellets.

variegated clay pellets. Clay pellets with a variegated texture were noted in two samples. One of these samples also have a variegated groundmass but the other, V2057- SST 2a, did not.

silicious microfossils. Spherical silicious microfossils were noted in seven samples but were only moderately common in three, two of which were fired clay samples and the third V2047 – CALCT+CHAFF. Such microfossils occur in chalk and since in all but one of the samples rounded chalk or similar sized voids were noted this is the most likely origin for these microfossils.

Interpretation

These thin sections reveal a remarkably wide range of inclusion types and groundmass traits. Some of these are clearly related to preparation and firing rather than the clay sources utilised. The fired clay samples indicate that two very different clay sources were available locally, the first, termed here FCLAY1, contained rounded chalk inclusions and the second, FCLAY2, contained a rounded quartzose sand in a variegated groundmass. Interestingly, neither fabric is common in the pottery samples. One sample was similar to FCLAY1, V2047 – CALCT+CHAFF. Even this sample was not identical, however, since it had a siltier groundmass, more organic inclusions and more rounded quartz grains. None of the pottery samples had the variegated groundmass found in FCLAY2 nor were precisely the same range of inclusion types found in any of the pottery samples. Thus there is little evidence for the use of the same raw materials for fired clay and pottery on the site. However, the two fired clay samples between them include a large number of the inclusion types found in the pottery and this suggests that most of the pottery fabrics could have been made from locally-available raw materials.

The inclusion types which were not found in the fired clays are as follows:

Biotite granite

Basic

Volcanic glass

Muscovite over 0.1mm long

Sst (except for that with ferroan calcite cement)

Sa dark clay pellets

Altered glauconite

Red clay pellets

Brown-coloured clay pellets

High grade metamorphic rock

In some cases it is likely that the absence of the type is simply due to the small sample size but most of these types are linked, in that they are likely to have been found as erratics in boulder clay or in detrital sands derived from these clays. In total, 20 samples contain definite erratic grains but these should be subdivided into those fabrics in which erratic grains form a moderate or abundant element and those in which only sparse grains are present. Fourteen of these samples contain moderate to abundant erratic grains and of the six other samples three were classed visually as BIOTITE, one as SST 1 and two as CALCT. Of the latter two, one contained a mixed limestone sand including oolitic limestone and this sample too should probably be classed as containing a high erratic element.

The boulder clays of East Anglia can be divided into two types on the basis of their igneous and metamorphic rock content. Those derived from the midlands, the Jurassic drift, may contain biotite granite but not basic or metamorphic rocks. Those derived from Scotland, the North Sea or Scandinavia, the Northern drift, may contain all three types. Boulder clays containing solely chalk and lower Cretaceous rocks and minerals are classed as chalky boulder clay. The fired clay samples, and the majority of the pottery samples, might have been made from boulder clays of these types.

Using these rules of thumb we can assign many of the samples to four groups: a) containing rocks and minerals of Cretaceous origin only, b) containing rocks and minerals of potential Jurassic drift origin, c) containing rocks and minerals of Northern drift origin and d) others or unclassifiable. Table 1 shows the correlation of these groups with the visually-defined fabric groups.

Table 1

Cname	chalky	Jurassic	northern	Other	Grand Total
BIOTITE	2	6			8
CALCT	7	1	3		11
CALCT+CHAFF	3				3
CALCT+GROG				1	1
CHAFF	1			6	7
CHAFF+MICA				1	1
FCLAY1	2				2

FCLAY2				3	3
GROG				2	2
MICA	1	2			3
SST 1	3	1	2	4	10
SST 2	3	1		2	6
SST 2a			1	1	2
SST 4	1	1	1		3
SST 5?				1	1
Grand Total	23	12	7	21	63

It is quite likely that much of the variation found in these samples is due to subsequent reworking of these boulder clays and it is doubtful if the classification is actually very useful other than indicating that the majority of the samples either contain no erratic rock inclusions or could be made from outcrops derived from the chalky boulder clay. Until there is a similar collection from East Anglia analysed in this way it is not even possible to say how much of the variation in fabric is due to the utilisation of variable geological resources and how much to the trade or exchange of pottery between communities in east Anglia.

On a practical level, the thin section analysis does allow some refinement of some of the visual fabric groups and this is best undertaken using the sampled sherds as a guide to reclassification. Nevertheless, the broad groups recognised by eye – biotite, mica, grog, sandstones and calcareous inclusions, are confirmed by this analysis.

Chemical analysis

Factor analysis of the ICPS dataset indicates that the main division in the data, represented by Factor 1, is due to variations in the quantity of rare earth elements (REEs). Examination of the data showed no correlation between REEs and either the visual fabric groups or the source groups suggested by thin section analysis, nor was there any correlation between REEs and the presence of carbon in the sample, as estimated by recording the details of the matrix.

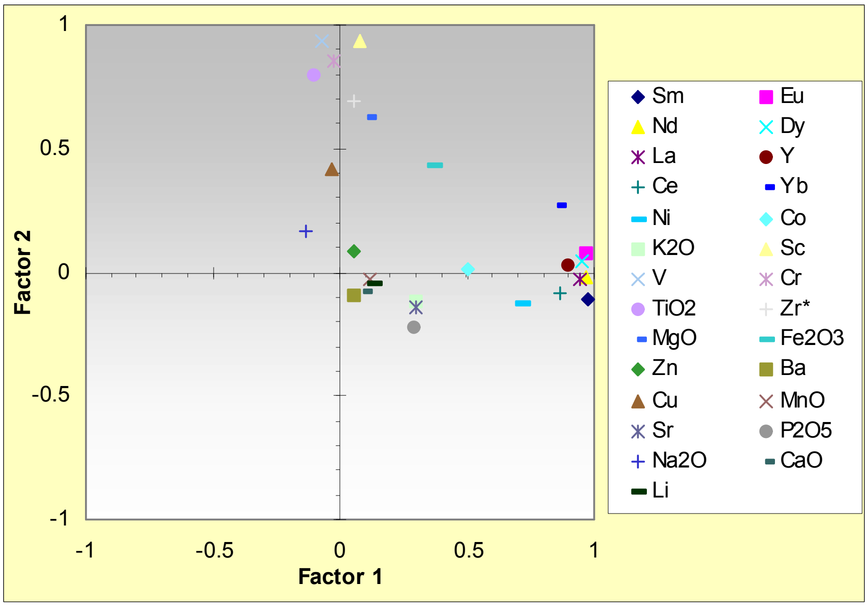

Figure 1

Factor 2 scores, on the other hand, depend on high values for six elements: V, Sc, Cr, TiO2, Zr and MgO. This separates five of the samples from the remainder, all of which are classed as containing calcite (in one case with grog) and were grouped as being derived from chalky boulder clay. It should be noted that neither CaO or its correlate, Sr, were important in this grouping, which would have been affected by post-burial leaching. Cr, Zr and TiO2 are all likely to be present in resistate minerals, such as rutile and zircon. Examination of the petrological data indicates that all of these samples contain abundant quartz silt, in four cases associated with abundant angular quartz up to 0.2mm across. The four other samples which also contained abundant quartz silt did not have high F2 scores and did not contain any calcareous inclusions, all being classed as CHAFF. The chemical analysis therefore indicates a difference within the samples with silty groundmasses which cannot be seen petrologically but which makes some sense.

Three other factors were calculated for this dataset but apart from a slight difference between those samples containing biotite granite and those containing a wider variety of erratic rocks which may confirm that they do in fact derive from difference boulder clays, there is little apparent information in the data. Two samples were isolated as strays by Factor 5: V2024 and V2074. The latter is the only sample to contain abundant glauconite and this probably does indicate that this sample is distinct. The former, however, shows no sign of being unusual in thin section. The remaining samples form a large loose cluster no matter which factors are examined. This may indicate a general similarity in the chemical content of East Anglian pottery fabrics whatever their source. This question cannot be addressed without comparative data from other sites in the region.

Conclusions

The combination of thin section and chemical analysis indicates that the pottery used at Bloodmoor Hill was made from a wide variety of clay sources. Without further research, it is not possible to say whether or not these sources are close to the site or cover the whole of East Anglia. The fact that the chemical analysis indicates a general similarity between all the samples, with six exceptions, suggests perhaps that the raw materials were mainly collected locally. However, it was interesting to see that the fired clays from the site were made from two distinctly different clays, neither of which was precisely matched in the sampled pottery.

This analysis does show that the Anglo-Saxon pottery of East Anglia has enough variation in petrology and chemical content to make further studies worthwhile and it is likely that when such studies are carried out it will be possible to re-interpret the Bloodmoor Hill data to extract more information about the sources of clay used and the relationship of this settlement to its neighbours.

As an indication of the potential, Fig 2 shows a plot of the Carlton Colville data alongside date from other samples from Norfolk, Suffolk collected by the author. These samples are of imported early Anglo-Saxon wheelthrown vessels from two separate sites (ESAXIMP EVI) and two distinct Iron Age and Roman fabrics from Saham Toney (Fabrics 27 and 99). The plot of F1 against F2 shows that the imported vessels plot midway between the silty and remaining Carlton Colville samples, with the two Saham Toney fabrics forming separate clusters within the broad, non-silty Carlton Colville cluster. The fact that these three groups do form discrete clusters suggests that there is no inherent reason why fabrics from East Anglia should not be separated by chemical analysis and does leave open the possibility that there are numerous fabric groups present at Carlton Colville, rather than a few extremely variable ones.

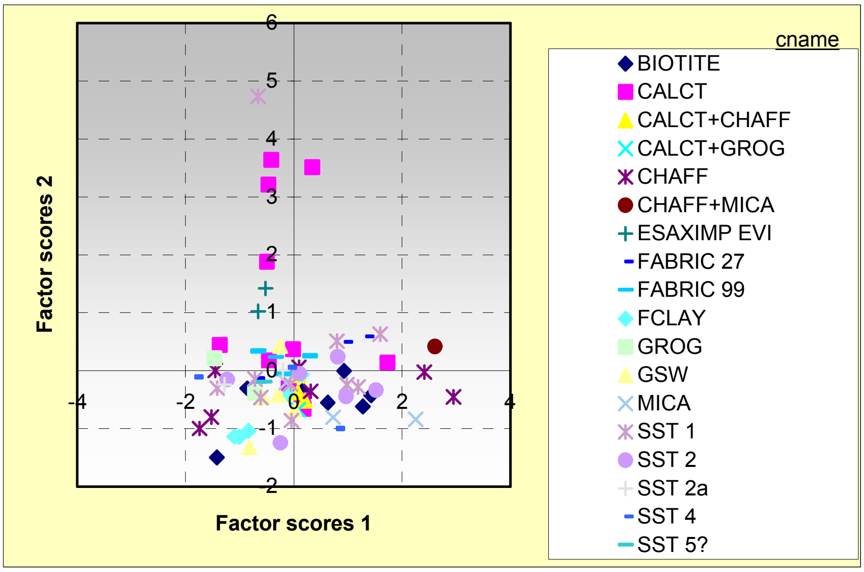

Figure 2

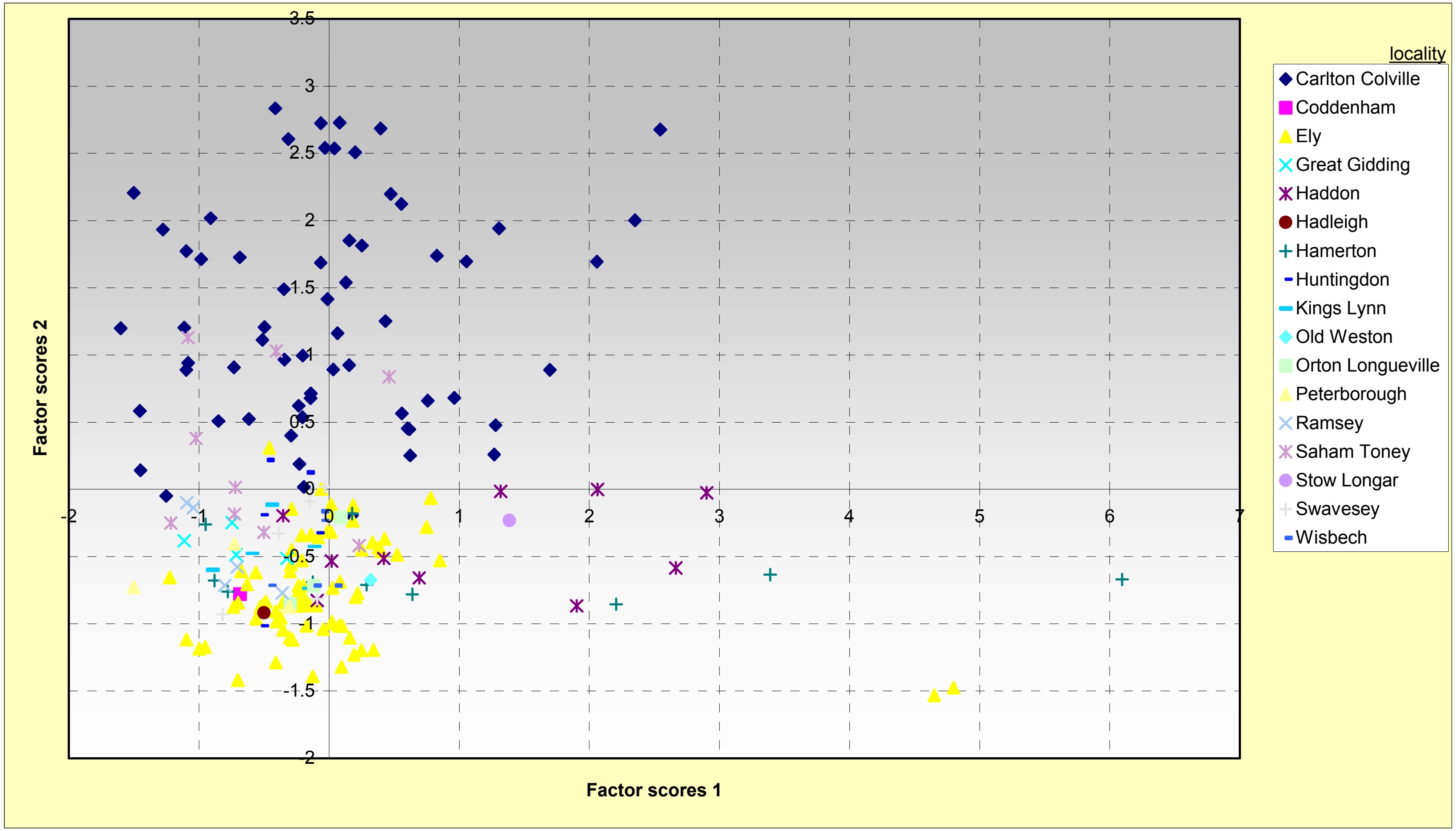
Factor scores 2
Factor scores 1
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1
0
1
2
3
4
5
6
7
locality
Carlton Colville
Coddenham
Ely
Great Gidding
Haddon
Hadleigh
Hamerton
Huntingdon
Kings Lynn
Old Weston
Orton Longueville
Peterborough
Ramsey
Saham Toney
Stow Longar
Swavesey
Wisbech

Figure 3

Appendices

Appendix 1a. ICPS data. Major elements measured as percent oxides

TSNO	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	MnO
V2021	11.84	5.36	0.63	2.44	0.26	1.63	0.47	3.52	0.126
V2022	14.23	4.92	0.89	1.4	0.3	2.18	0.54	1.82	0.038
V2023	10.74	4.17	0.45	1.28	0.49	1.69	0.42	2.82	0.083
V2024	12.56	6.4	0.86	2.14	0.21	1.85	0.51	2.56	0.055
V2025	13.67	6.46	1.08	1.81	0.35	2.05	0.65	1.93	0.028
V2026	13.48	5.62	0.95	2.58	0.3	2.19	0.49	3.3	0.102
V2027	14.89	6.88	0.98	1.83	0.56	2.65	0.61	2.69	0.048
V2028	13.29	5.34	0.96	1.64	0.45	1.97	0.52	2.52	0.016
V2029	14.74	6.32	0.85	2.39	0.3	2.23	0.61	3.48	0.126
V2030	13.77	4.94	1.05	1.06	0.23	1.95	0.62	1.25	0.021
V2031	11.25	4.27	0.73	1.23	0.47	2.13	0.5	1.54	0.03
V2032	10.89	5.98	0.64	1.06	0.26	1.43	0.45	1.65	0.101
V2033	13.93	6.49	0.66	1.35	0.28	2.08	0.55	1.85	0.019
V2034	14.51	5.15	1.05	1.83	0.24	2.04	0.56	2.16	0.036
V2035	7.55	4.35	0.37	1.19	0.42	1.1	0.35	1.18	0.036
V2036	12.03	4.67	0.79	1.23	0.23	1.76	0.56	1.54	0.026
V2037	12.07	7.53	1.16	1.7	0.32	1.97	0.82	1.9	0.275

TSNO	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	MnO
V2038	12.54	6.35	0.86	1.58	0.28	2	0.48	1.88	0.108
V2039	10.67	4.27	0.76	1.86	0.54	1.81	0.48	2.39	0.045
V2040	11.86	5.4	0.8	1.13	0.28	1.66	0.47	1.49	0.051
V2041	11.84	5.75	0.73	2.45	0.21	1.78	0.47	2.96	0.131
V2042	12.51	4.76	0.97	1.33	0.18	1.7	0.54	0.67	0.27
V2043	12.45	5.99	0.57	2.47	0.27	1.84	0.48	4.15	0.111
V2044	12.3	4.78	0.64	1.99	0.19	1.48	0.42	3.08	0.099
V2045	13.37	5.41	1.11	2.16	0.34	1.92	0.54	1.9	0.046
V2046	13.69	5.05	1.03	1.86	0.43	2.25	0.58	2.09	0.232
V2047	12.35	5.64	0.78	5.54	0.32	2.1	0.48	3.57	0.087
V2048	9.53	3.81	0.63	13.08	0.21	1.45	0.38	1.74	0.092
V2049	12.78	5.39	0.89	3.02	0.36	1.9	0.53	3.49	0.508
V2050	14.47	5.88	1	1.38	0.24	2.02	0.51	1.61	0.079
V2051	13.81	5.58	1.01	8.27	0.24	2.11	0.53	2.23	0.081
V2052	12.43	5.43	0.98	12.23	0.3	2.16	0.56	0.87	0.045
V2053	14.67	6.91	0.85	1.82	0.22	1.97	0.42	2.37	0.083
V2054	12.67	4.78	0.73	1.58	0.22	1.72	0.37	1.82	0.018

TSNO	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	MnO
V2055	13.97	5.7	0.96	2.32	0.25	2.18	0.42	2.95	0.211
V2056	12.77	6.54	1.51	1.5	0.41	1.88	1.05	0.91	0.033
V2057	12.53	5.31	0.88	1.15	0.24	1.92	0.51	0.9	0.043
V2058	13.09	6.18	0.72	1.63	0.39	2.38	0.52	2.23	0.068
V2059	12.97	4.85	0.84	1.7	0.46	2.25	0.55	1.86	0.066
V2060	13.65	5.46	0.77	1.51	0.26	2.04	0.47	2.17	0.073
V2061	13.3	5.41	1.06	1.73	0.42	1.92	0.5	1.72	0.169
V2062	14.48	5.93	1.15	1.61	0.26	2.06	0.61	1.46	0.126
V2063	14.05	5.06	1.06	1.36	0.43	2.31	0.57	0.68	0.046
V2064	13.63	5.95	0.95	1.5	0.25	1.96	0.53	1.02	0.178
V2065	11.16	5.5	0.7	1.79	0.26	1.83	0.46	2.03	0.097
V2066	11.48	4.6	0.81	1.28	0.23	1.85	0.46	1.02	0.078
V2067	11.32	5.21	0.49	1.42	0.23	1.59	0.45	2.63	0.093
V2068	13.13	6.82	1.41	1.99	0.45	1.92	0.45	1.66	0.043
V2069	10.02	4.19	0.66	1.94	0.19	1.56	0.35	2.1	0.108

TSNO	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	MnO
V2070	13.66	3.47	0.69	1.34	0.38	2.3	0.58	0.99	0.018
V2071	12.88	6.7	1.55	1.86	0.4	1.65	0.85	1.33	0.024
V2072	14.43	6.21	1.01	1	0.28	2.08	0.62	1.18	0.027
V2073	13.34	5.95	1.08	1.01	0.33	2.05	0.6	0.79	0.019
V2074	9.07	6.64	1.32	2	0.18	2.03	0.29	1.96	0.069
V2075	12.84	6.69	1.13	1.93	0.44	1.75	0.78	2.45	0.028
V2076	13.97	4.6	0.6	1.32	0.21	2.19	0.63	1.7	0.006
V2077	13.41	5.35	0.86	1.37	0.25	1.87	0.54	1.77	0.156
V2078	12.79	5.04	0.82	1.69	0.25	1.88	0.45	2.39	0.051
V2079	12.41	4.97	0.82	1.9	0.25	1.82	0.42	2.86	0.083
V2080	14.03	5.48	1.11	1.71	0.26	1.98	0.59	1.74	0.018
V2081	13.64	5.11	0.92	1.21	0.28	2.06	0.62	1.09	0.018
V2082	14.11	5.36	0.94	1.83	0.32	2.12	0.61	1.57	0.016
V2083	11.43	6.73	0.7	2.17	0.44	1.79	0.48	2.77	0.075

Key: Al203 – Aluminium, Fe2O3 – Iron, MgO – Magnesium, CaO – Calcium, Na2O – Sodium, K2O – Potassium, TiO2 – Titanium, P2O5 – Phosphorus, MnO – Manganese.

Appendix 1b ICPS data. Minor and trace elements measured as parts per million

TSNO	Ba	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zr*	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb	Zn	Co

TSNO	Ba	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zr*	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb	Zn	Co
V2021	700	82	31	38	65	12	399	88	39	70	53	78	55.46	9.392	1.732	6	3	44.96	244	14
V2022	613	102	23	37	54	15	235	108	34	73	50	80	51.888	8.424	1.654	5.2	2.7	37.67	248	14
V2023	649	64	47	37	37	9	318	71	10	46	23	42	23.688	3.349	0.6915	2.2	1.3	38.16	165	15
V2024	422	84	30	79	106	15	302	120	24	113	44	120	45.966	7.98	1.58	4.9	2.6	53.94	164	31
V2025	328	97	27	37	47	15	260	119	30	77	46	68	47.564	6.162	1.377	4.6	2.4	31.03	203	13
V2026	561	89	32	39	56	12	474	106	22	73	37	67	38.54	6.814	1.319	4	2.4	41.02	316	14
V2027	935	93	45	30	54	16	324	120	38	78	48	64	50.478	7.436	1.656	5.7	3	35.51	379	17
V2028	464	87	24	31	34	13	311	102	15	76	32	55	32.712	3.798	0.933	2.8	1.9	36.31	144	10
V2029	1142	99	42	62	57	14	257	101	26	88	43	73	44.838	7.504	1.484	4.7	2.6	36.86	467	13
V2030	645	100	39	55	58	15	114	112	31	75	44	70	45.778	7.318	1.453	4.7	2.5	27.53	449	12
V2031	732	71	23	35	29	11	187	77	12	64	24	39	24.44	2.919	0.6865	2	1.4	37.05	201	9
V2032	1063	75	43	44	36	10	146	88	13	65	25	36	25.85	3.206	0.801	2.5	1.7	38.61	265	9

TSNO	Ba	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zr*	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb	Zn	Co
V2033	546	95	29	42	49	15	241	130	21	61	50	89	50.948	7.253	1.5755	4.2	2.3	44.87	175	12
V2034	1133	101	35	41	53	15	224	113	22	73	36	56	36.848	5.055	1.0425	3.2	2	29.49	653	11
V2035	683	50	28	36	26	6	122	54	10	53	19	28	19.458	1.895	0.4825	1.7	1.1	26.65	233	6
V2036	844	85	30	36	44	12	137	98	10	66	26	34	25.944	2.099	0.5665	1.6	1.3	32.27	405	11
V2037	1376	106	60	40	55	17	201	153	24	93	32	56	34.78	6.241	1.5235	5	2.7	31.93	609	20
V2038	1143	82	40	59	62	12	180	98	30	71	44	65	46.06	7.695	1.5825	5	2.6	39.06	401	15
V2039	965	66	35	34	32	10	335	76	16	65	29	52	29.798	4.019	0.7865	2.7	1.6	31.33	512	21
V2040	820	81	74	56	60	12	144	98	21	67	32	71	33.464	5.68	1.23	3.6	2.2	31.34	389	16
V2041	1262	85	53	60	60	11	289	97	21	68	35	56	36.472	5.175	1.2125	3.8	2.1	27.96	589	12
V2042	375	88	69	38	40	14	107	112	14	76	27	37	28.294	3.072	0.662	3.1	1.6	23.59	277	10
V2043	808	90	30	31	54	12	429	98	24	61	39	69	40.514	6.603	1.4005	4.1	2.3	38.15	250	13
V2044	1237	82	29	48	51	11	299	89	19	61	35	61	36.284	4.966	1.061	3.6	2	46.1	569	19

TSNO	Ba	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zr*	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb	Zn	Co
V2045	728	95	26	44	45	15	261	112	26	80	40	61	40.984	5.477	1.0295	3.6	2.2	26.33	513	12
V2046	759	95	36	39	50	14	262	111	28	72	42	59	43.522	5.385	1.1475	4.3	2.2	37.21	398	13
V2047	870	85	47	43	52	12	449	89	22	67	35	59	36.378	5.808	1.218	3.7	2.3	27.25	503	11
V2048	724	63	29	38	40	9	308	72	20	57	28	44	29.234	4.157	0.9095	3.1	1.8	18.67	367	7
V2049	580	81	37	47	60	12	438	99	24	75	38	60	40.608	5.883	1.3305	5.2	2.2	45.82	434	17
V2050	960	102	37	57	67	14	158	119	26	81	40	78	41.83	7.136	1.506	4.5	2.7	28.73	387	14
V2051	523	91	32	51	53	13	308	109	23	74	36	61	37.506	6.326	1.221	3.9	2.3	27.49	265	12
V2052	322	81	28	58	49	12	286	96	21	60	36	58	37.13	5.971	1.2285	3.5	2.1	23.77	117	12
V2053	579	100	30	37	44	14	221	117	15	63	31	58	31.866	4.727	1.0545	2.9	2	34.73	268	14
V2054	588	85	21	38	35	12	224	99	12	57	29	47	29.234	3.966	0.861	2.1	1.6	32.83	317	8
V2055	1170	97	44	48	62	13	395	115	26	73	40	66	41.83	6.39	1.315	4.5	2.5	32.63	631	13
V2056	527	112	59	48	39	19	133	172	20	111	32	45	33.088	4.038	1.073	3.2	2.4	28.43	443	13

TSNO	Ba	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zr*	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb	Zn	Co
V2057	414	85	30	49	47	12	131	107	21	77	33	60	34.216	4.907	1.0345	3.4	2.1	35.37	275	12
V2058	511	84	31	41	76	12	248	105	38	59	49	94	51.606	9.646	1.791	5.9	2.9	35.41	226	27
V2059	331	86	22	32	43	13	298	102	26	63	40	56	41.078	5.045	1.0575	3.7	2	31.53	248	12
V2060	341	90	23	52	43	12	256	107	17	64	30	49	31.208	4.762	1.027	3.2	2	39.05	200	12
V2061	1042	87	24	42	38	13	207	104	16	75	28	47	29.234	4.077	0.8295	3.1	1.9	34.9	409	11
V2062	633	103	23	46	55	16	213	123	24	80	40	61	41.078	4.421	1.0035	3.7	2.1	24.72	571	13
V2063	613	92	28	45	45	14	135	111	27	70	36	57	37.412	6.282	1.247	3.8	2.2	26.75	361	12
V2064	849	90	33	52	50	13	157	110	23	77	36	63	37.788	6.215	1.3025	4.2	2.3	33.27	391	13
V2065	1010	74	29	48	59	11	211	86	30	59	39	70	41.078	6.95	1.425	4.7	2.5	47.84	397	14
V2066	655	74	29	51	53	10	107	89	18	63	28	47	29.14	4.52	0.97	3	1.8	35.32	562	12
V2067	1146	76	29	40	30	10	206	85	10	56	24	36	24.346	2.537	0.6395	1.9	1.3	32.08	341	7
V2068	829	120	44	37	33	18	274	157	18	65	35	47	35.908	4.054	1.059	3.2	2.3	30.97	327	10

TSNO	Ba	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zr*	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb	Zn	Co
V2069	1001	67	24	33	56	9	260	74	22	51	32	58	33.276	5.543	1.0905	3.4	1.9	37.98	274	15
V2070	487	91	16	37	22	12	169	97	11	74	30	45	29.986	3.559	0.6265	1.9	1.4	31.34	155	6
V2071	526	110	50	41	37	18	204	168	21	93	33	50	34.216	4.09	1.165	3.4	2.5	30.22	417	12
V2072	584	98	61	45	55	16	97	124	26	72	42	66	43.24	5.237	1.1895	4	2.1	35.17	469	16
V2073	551	92	35	50	37	13	85	109	14	79	27	45	27.542	3.115	0.8025	2.3	1.7	36.36	123	11
V2074	923	68	31	26	42	9	206	58	21	51	39	80	40.514	7.608	1.568	4.1	1.7	18.13	452	11
V2075	607	119	43	33	30	19	290	158	20	97	33	49	33.84	3.993	1.0655	3	2.3	30.96	160	10
V2076	523	106	30	31	30	15	135	122	19	80	36	69	37.318	6.52	1.27	3.7	2.4	36.43	71	7
V2077	631	87	28	58	72	13	150	107	32	77	46	92	48.222	7.495	1.5325	5.3	2.7	40.79	247	36
V2078	767	89	28	41	51	12	240	102	26	69	38	63	39.668	6.988	1.348	4.2	2.5	33.81	298	13
V2079	1883	83	29	39	48	11	254	98	22	65	33	58	34.686	5.909	1.1515	3.9	2.2	30.49	229	13
V2080	704	97	23	42	51	15	179	114	22	72	39	61	39.292	3.956	0.926	2.8	1.8	28.27	212	14

TSNO	Ba	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zr*	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb	Zn	Co
V2081	594	93	25	42	46	14	128	111	31	64	47	74	48.41	7.267	1.3445	4.5	2.3	30.76	233	12
V2082	584	99	22	36	44	16	207	115	43	74	52	64	54.144	8.592	1.632	5.6	2.9	30.29	178	11
V2083	594	75	31	39	64	12	374	88	34	68	42	91	44.838	8.581	1.6635	5.7	2.9	35.07	220	16

Key: Ba – Barium, Cr – Chromium, Cu – Copper, Li – Lithium, Ni – Nickel, Sc – Scandium, Sr – Strontium, V – Vanadium, Y – Yttrium, Zr* - Zirconium (possibly under-represented because of resistance of Zircon to solution), La – Lanthanum, Ce – Cerium, Nd – Neodymium, Sm – Samarium, Eu _ Europium, Dy – Dysprosium, Yb – Ytterbium, Pb – Lead, Zn – Zinc, Co – Cobalt

Appendix 2a. Petrological analysis

TSNO	gsq upto 10mm	rq upto 10mm	r chert	sa q upto 05mm	organics	r opaques upto 05mm	sa flint upto 15mm
V2021	s	a	none	a	m	none	s
V2022	s	s	none	a	none	none	none
V2023	s	a	S	a	s	s	none
V2024	s	a	S	a	m	m	none
V2025	s	m	S	a	m	none	none
V2026	s	m	S	a	m	none	s
V2027	s	m	none	s	s	s	none
V2028	none	a	none	a	s small	none	none
V2029	s	s	S	s	a	m	s
V2030	none	s	m	a	none	s	none

TSNO	gsq upto 10mm	rq upto 10mm	r chert	sa q upto 05mm	organics	r opaques upto 05mm	sa flint upto 15mm
V2031	s	a	m	a	s	none	none
V2032	none	m	s	a	s	none	none
V2033	s	m	s	a	s	s	none
V2034	s	m	s	a	m	none	s brown stained
V2035	s	a	s	a	m	s	s brown stained
V2036	s	a	s	a	s	none	s brown stained
V2037	s	s	none	a	none	none	s brown stained
V2038	s	m	s	m	s	m sa upto 1.0mm	s brown stained
V2039	none	a	S	s	s small	s	s broken pebble
V2040	s	m	s	a	m	m sa upto 1.0mm	s brown stained
V2041	s	a	s	a	m	s	s brown stained
V2042	s	s	s	a	m	none	s brown stained
V2043	s	s	s	s	none	s	s brown stained
V2044	s	m	s	a	s	s r <1.0mm	s
V2045	s	s	s	m	none	s	none
V2046	s	s	none	m	s small	s	none
V2047	s	s	none	s	a	s	none
V2048	s	s	s	m	a	none	s
V2049	s	s	none	m	s	s	none
V2050	s	m	s	s	a	s	s brown stained
V2051	s	none	none	s	s	none	none
V2052	s	none	none	s	s	none	none

TSNO	gsq upto 10mm	rq upto 10mm	r chert	sa q upto 05mm	organics	r opaques upto 05mm	sa flint upto 15mm
V2053	s	a	s	m	none	s	s r brown stained
V2054	s	a	s	m	none	s	s r brown stained
V2055	s	m	s	s	a	none	none
V2056	s	none	none	a <0.2mm	none	s	s <0.2mm
V2057	s	a	m	a	s small	s	s r brown stained
V2058	s	m	s	m	none	s	none
V2059	s	m	none	m	none	s	s
V2060	s	a	s	m	s	s	s r brown stained
V2061	s	m	s	m	s	s	none
V2062	s	m	s	s	none	none	none
V2063	s	none	none	a	s small	s	none
V2064	S	S	s	M	s	s	s fresh
V2065	s	m	s	m	s	s	s fresh
V2066	s	none	none	m	s small	s	s r brown stained
V2067	s	s	s	m	m	none	s fresh
V2068	s	none	none	a <0.2mm	none	none	none
V2069	s	a	m	s	none	s	s r brown stained
V2070	s	none	none	a <0.2mm	m	s	none
V2071	s	m	s	a <0.2mm	none	s	none
V2072	s	s	none	m	none	none	none
V2073	s	s	s	m	s	s	none
V2074	none	none	none	a <0.2mm	a	none	none

TSNO	gsq upto 10mm	rq upto 10mm	r chert	sa q upto 05mm	organics	r opaques upto 05mm	sa flint upto 15mm
V2075	s	s	none	a <0.2mm	m	s	a <0.2mm
V2076	none	s	s	a <0.2mm	a	none	none
V2077	s	s	s	a	s	none	s brown stained
V2078	s	s	s	m	s small	s	m r brown stained
V2079	s	m	s	a	s	none	s r brown stained
V2080	s	none	none	s	s small	s	none
V2081	s	s	none	m	none	s	none
V2082	s	none	none	m	s small	s	none
V2083	s	s	s	a	a	s	none

Appendix 2b. Petrological analysis

TSNO	sa flint upto 15mm	calc	biotite granite	basic	volc glass?	Musc over 01mm
V2021	s	none	none	none	none	none
V2022	none	none	s	none	none	none
V2023	none	none	s	none	none	none
V2024	none	none	none	none	none	none
V2025	none	none	none	m ultrabasic	none	none
V2026	s	m leached	none	m ultrabasic	s	none
V2027	none	none	s	none	none	none
V2028	none	none	s	none	none	none
V2029	s	s leached	none	none	none	none
V2030	none	none	s	none	none	none

TSNO	sa flint upto 15mm	calc	biotite granite	basic	volc glass?	Musc over 01mm
V2031	none	none	none	none	none	none
V2032	none	s leached	none	none	none	none
V2033	none	none	none	none	none	none
V2034	s brown stained	none	none	none	none	none
V2035	s brown stained	none	none	none	none	none
V2036	s brown stained	none	none	none	s	none
V2037	s brown stained	m leached	none	none	none	none
V2038	s brown stained	m leached	none	none	none	none
V2039	s broken pebble	none	none	s rounded ultrabasic?	none	none
V2040	s brown stained	s leached	none	none	none	none
V2041	s brown stained	none	none	none	none	none
V2042	s brown stained	s leached	none	none	none	none
V2043	s brown stained	s leached	none	none	none	m sheaves
V2044	s	s leached	none	none	none	none
V2045	none	m inc oolitic lst leached	s	s	none	none
V2046	none	s leached	m	none	none	none
V2047	none	m r chalk <1.0mm;sa feroan <0.5mm	none	none	none	none
V2048	s	m r oolitic;r chalk	none	none	none	s sheaves
V2049	none	m leached	none	s	m	none
V2050	s brown stained	none	none	none	none	none
V2051	none	m r chalk <1.0mm;sa feroan <0.5mm	none	none	none	none
V2052	none	m r chalk <1.0mm;sa feroan <0.5mm	none	none	none	none

TSNO	sa flint upto 15mm	calc	biotite granite	basic	volc glass?	Musc over 01mm
V2053	s r brown stained	none	none	none	none	none
V2054	s r brown stained	none	none	none	none	none
V2055	none	none	none	none	none	none
V2056	s <0.2mm	s leached	none	none	none	m <0.2mm
V2057	s r brown stained	none	none	none	none	none
V2058	none	none	a inc musc	none	none	m
V2059	s	m leached	m	none	none	none
V2060	s r brown stained	none	none	none	none	none
V2061	none	none	m	none	none	none
V2062	none	s leached	s	none	none	none
V2063	none	none	a inc musc	none	none	s sheaves
V2064	s fresh	s leached;s dolomitic micrite	none	none	none	none
V2065	s fresh	none	none	none	none	none
V2066	s r brown stained	s leached	none	none	none	none
V2067	s fresh	none	none	none	none	none
V2068	none	m leached	none	none	none	none
V2069	s r brown stained	s leached	none	none	none	none
V2070	none	none	none	none	none	none
V2071	none	m leached;shell?	none	none	none	s
V2072	none	none	s feldspar but no biotite	none	none	none
V2073	none	none	none	none	none	none
V2074	none	none	none	none	none	m

TSNO	sa flint upto 15mm	calc	biotite granite	basic	volc glass?	Musc over 01mm
V2075	a <0.2mm	a leached;shell;irregular voids	none	none	none	none
V2076	none	none	none	none	none	s
V2077	s brown stained	m leached	none	none	none	none
V2078	m r brown stained	s leached	none	none	none	none
V2079	s r brown stained	s leached	s	none	none	none
V2080	none	none	none	none	none	none
V2081	none	none	none	none	none	none
V2082	none	s non-ferroan micrite with s rq >0.5mm	none	none	none	none
V2083	none	s leached	none	none	none	none

Appendix 2c. Petrological analysis

TSNO	sst	concentric clay pellets	sa dark clay sparse silt	alted glauc	matrix	silt	r red sandy clay pellets	r brown-coloured clay	radiolaria?	variegated clay pellets	high grade metamorphic
V2021	none	s	none	s	anis	s	none	none	none	none	none
V2022	s sa grains with brown cement possibly silicious	s	none	s	anis	s	none	none	none	none	none
V2023	none	none	none	none	anis	s	none	none	none	none	none
V2024	none	none	none	s	anis	s	none	none	none	none	none
V2025	s	none	m	none	black	s	none	none	none	none	none
V2026	s	s	none	none	anis	s	none	none	none	none	none

TSNO	sst	concentric clay pellets	sa dark clay sparse silt	alted glauc	matrix	silt	r red sandy clay pellets	r brown-coloured clay	radiolaria?	variegated clay pellets	high grade metamorphic
V2027	s	s	none	none	anis	s	none	none	none	none	none
V2028	m	s	none	s	anis	none	none	none	none	none	none
V2029	none	none	none	s	anis	m	none	none	none	none	none
V2030	a	s	s	none	anis	s	none	none	none	none	none
V2031	m	none	none	none	anis	s	none	none	none	none	none
V2032	m	none	none	none	anis	s	none	none	none	none	none
V2033	m	none	none	none	anis	s	none	none	none	none	none
V2034	s sa grains with brown cement possibly silicious	none	none	none	anis	s	m	m	none	none	none
V2035	none	none	none	none	anis dk brown	a	none	none	none	none	none
V2036	m	s	none	none	anis	s	none	s	none	none	none
V2037	none	none	none	none	anis	a	none	none	none	none	none
V2038	none	none	none	none	anis	m	none	none	none	none	none
V2039	s	none	none	none	anis	s	none	none	none	none	none
V2040	m	s	s	none	anis dk brown	s	none	none	none	none	none
V2041	s	none	none	none	anis	s	none	none	none	none	none
V2042	a sugary	none	none	none	anis dk brown	s	none	none	none	none	none
V2043	m fe cement	s	none	none	anis	s	none	none	none	none	none
V2044	m	none	none	none	anis with	none	none	none	none	none	none

TSNO	sst	concentric clay pellets	sa dark clay sparse silt	alted glauc	matrix	silt	r red sandy clay pellets	r brown-coloured clay	radiolaria?	variegated clay pellets	high grade metamorphic
					black core						
V2045	s	none	s	none	anis	s	none	none	none	none	none
V2046	none	none	none	m	anis dk brown	none	none	none	none	none	none
V2047	none	none	none	none	anis with black core	m	none	none	m	none	none
V2048	none	none	none	none	anis with black core	s	none	none	none	none	none
V2049	m	none	none	none	anis	s	none	none	none	none	none
V2050	none	none	none	none	anis with black core	none	none	none	none	none	none
V2051	s fine sst with ferroan cement	none	none	none	anis dk brown	s	none	none	m	none	none
V2052	none	none	none	none	anis dk brown	s	none	none	m	none	none
V2053	none	s	none	none	anis varigated	s	none	none	none	none	none
V2054	none	s	none	none	anis varigated	s	none	none	none	none	none
V2055	none	none	none	none	anis dk brown	s	m	m	s	none	none
V2056	none	none	s	none	black	a	none	none	none	none	none
V2057	m	s	none	none	anis with black outer surface	s	none	none	none	s	none
V2058	none	s	none	none	black	s	none	none	none	none	none
V2059	m	none	none	s	anis with black core	s	none	none	none	none	none

TSNO	sst	concentric clay pellets	sa dark clay sparse silt	alted glauc	matrix	silt	r red sandy clay pellets	r brown-coloured clay	radiolaria?	variegated clay pellets	high grade metamorphic
V2060	none	none	none	none	anis varigated	s	none	none	none	s	none
V2061	m	s	none	none	anis with black core	none	none	none	none	none	m
V2062	s	none	none	none	anis	s	none	s	none	none	none
V2063	s	none	s	none	anis with black outer surface	s	none	none	none	none	none
V2064	none	none	none	none	anis	s	none	none	none	none	none
V2065	m	none	none	none	anis with black core	s	none	none	none	none	none
V2066	a	none	s	none	black	s	none	none	s	none	none
V2067	s rounded fine-grained (cf Trent sands)	none	none	none	black	s	none	none	none	none	none
V2068	none	none	s	m	anis dk brown	a	none	none	s	none	none
V2069	none	none	none	none	anis	none	none	none	none	none	none
V2070	none	none	none	none	black	a	none	none	none	none	none
V2071	none	none	none	none	anis dk brown	a	none	none	none	none	none
V2072	a sstmg	none	s	none	anis with black core	s	none	none	none	none	none
V2073	none	none	none	none	anis dk brown	s	m ang grog;some with abundant silt	none	none	none	none

TSNO	sst	concentric clay pellets	sa dark clay sparse silt	alted glauc	matrix	silt	r red sandy clay pellets	r brown-coloured clay	radiolaria?	variegated clay pellets	high grade metamorphic
V2074	none	none	none	a	black	a	none	none	none	none	none
V2075	none	none	none	m	anis dk brown	a	none	none	none	none	none
V2076	none	none	none	none	anis with black core	a	none	none	none	none	none
V2077	a sstmg	s	none	none	anis with black core	s	none	none	none	none	none
V2078	none	none	none	none	anis with black outer surface	s	none	none	none	none	none
V2079	m	none	none	none	black	s	none	none	none	none	none
V2080	m some with fe cement	none	s	none	anis with black core	s	none	none	none	none	none
V2081	m	none	m	none	black	s	none	none	none	none	none
V2082	m some with silica cement	none	none	none	anis	s	none	m	s	none	none
V2083	none	none	none	none	anis with black core	m	none	none	none	none	none