

Spanish tin-glazed tiles from Woking Palace and other sites in south-east England

IAN M BETTS

THE ANALYSIS BY INDUCTIVELY COUPLED PLASMA-ATOMIC EMISSION ANALYSIS (ICP-AES) AND -MASS SPECTROMETRY ANALYSIS (ICP-MS) OF TILES FROM WOKING PALACE

MICHAEL J HUGHES

Introduction

Tin-glazed decorated floor tiles from Woking Palace have been analysed by inductively-coupled plasma-atomic emission (ICP-AES) and -mass spectrometry (ICP-MS) to determine their sources. These two techniques provide a comprehensive chemical 'fingerprint', namely the concentrations of many chemical elements in the fabric of the pottery; Lambert (1997) outlines the basic philosophy behind such pottery sourcing. Chemical analysis measures the overall chemistry of clay fabric plus inclusions in the ceramic. Spanish sources were suspected for the Woking Palace tiles, including Valencia and Seville. It was therefore necessary to compare the analyses on the Woking tiles with previously obtained analyses on Spanish ceramics.

Chemical analysis

Powdered samples were obtained from each tile using a hand-held 12-volt drill fitted with a 2mm diameter solid tungsten carbide drill bit. The powders were analysed for 27 elements by ICP-AES and 26 elements by ICP-MS at the Department of Geology, Royal Holloway, University of London by Dr J N Walsh using their routine technique (Thompson & Walsh 1989). In addition to the tiles, standard reference clays of known chemical composition were analysed: Brick Clay NBS679 produced by the National Institute of Standards and Technology, Washington DC; and samples of British Museum Standard Pottery previously used by the author in many projects using neutron activation. The list of samples analysed is given in table 1 including the full ICP-AES and ICP-MS results.

Atomic emission ICP gave results on all the major elements of the clays (except silicon) and a range of trace elements. Among the latter are the rare earths and of these, lanthanum and cerium are well measured by atomic emission but the other rare earths less so. Conversely, ICP-MS is especially good for trace elements, including accurate results on all the rare earths, and important elements for chemical provenancing such as the alkalis rubidium and caesium and the heavy elements uranium and thorium. These were the main elements drawn from the mass spectrometry data which were used in the statistical interpretation of the analyses.

Interpretation of the chemical analyses

The analytical results are given in table 1 (atomic emission and mass spectrometry data). The aim of the statistical tests was to draw out the significance of the analyses by looking for patterns of similar chemistry among the tiles, which indicates similar origin

In normal circumstances, provenance studies such as the present investigation require that a dataset has been accumulated of analyses of pottery known to have been made at the likely sources, and of the same period. In this case, although a project was carried out on Spanish tin-glazed and other pottery some years ago, the method of chemical analysis was different, namely neutron activation analysis (Hughes & Vince 1986, etc). This presents two problems for its potential use in the present investigation. First, the elements analysed by the two methods may not be the same. In fact, the atomic emission version of ICP has only eight out of 27 elements which are in common with those by neutron activation. The major drawback to having relatively few elements to compare test pieces with a database is that the fewer the elements, the less degree of certainty about finding genuine matches. An example of this is the previous report on ICP analyses of tiles in the Guildford Museum (Hughes 2002), where one of the tiles was wrongly attributed to Antwerp production because for the eight elements in common, there were similarities between Spanish and Antwerp clays. The resolution

of this attribution is discussed below. The problem of too few elements has now been substantially overcome with the introduction of ICP analyses by mass spectrometry as well as atomic emission; the combined techniques now allow an overlap with neutron activation of 21 elements. Thus analyses acquired by ICP can now be compared with a much greater degree of confidence with analyses previously acquired by neutron activation.

The second problem arises because it is necessary to establish if the same analysis results are obtained by both techniques, or whether some inter-method standardisation is necessary. While a previous study has established the adjustment factors necessary to convert atomic emission ICP results to be equivalent to neutron activation, the very recent introduction of mass spectrometry means that only a few analyses are available which have been carried out on reference standard clays by the mass spectrometry method. In the present investigation, three analyses were available on a standard clay, and were used to calculate the adjustment factors for the mass spectrometry analyses.

All apart from one tile are of lime-rich clays containing 15–22% calcium oxide, which is entirely typical for tin-glazed wares. The exception is tile VIN88 37 which contained only 4.82% calcium oxide, and as such is quite atypical for tiles of the period and supposed origin in question.

PRINCIPAL COMPONENTS ANALYSIS OF BOTH THE ATOMIC EMISSION AND MASS SPECTROMETRY RESULTS ON THE TILES

Since the two analytical methods used in this project yielded a very large number of element results, it was important to exploit the full range of elements and test whether any extra information on the samples was contained within the analyses obtained by mass spectrometry. A selection of the atomic emission elements and many of the mass spectrometry elements were combined to represent different parts of the Periodic Table and these 30 elements were submitted to principal components. The list included: aluminium, magnesium, calcium, sodium, potassium, rubidium, caesium, lithium, iron, manganese, titanium, vanadium, yttrium, niobium, scandium, chromium, nickel, zinc, yttrium, uranium, thorium, and the rare earths: lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, dysprosium, ytterbium, and lutetium. The analytically-superior measurements by mass spectrometry were used in this statistical test. The results were converted to logarithms before input into the computer program SPSS version 10 used for the statistics. Also included in the Principal Components Analysis were four examples of Malaga lustreware from the excavations at Deansgate, Worcester and three sherds of Seville tin-glazed wares from the shipwreck in Studland Bay, Dorset. A plot of the first and third principal components is shown in figure 1; the individual items are identified by a number which is also given in table 1 for cross-reference. This figure is a type of ‘chemical map’ in which individual items that have similar clay chemistry plot close together (and are therefore presumed to be made from the same clay, and therefore from the same production centre). One caveat to this is that the first principal component (see below) reflects mainly the lime/clay ratio (higher clay percentage in the fabric towards the right of the figure) so a horizontal spread of points indicates the same basic clay chemistry but diluted with different amounts of lime – as will happen when potters are mixing red and white clays.

The initial results showed that the tile VIN88 was very different indeed in chemistry from all the rest of the tiles and pottery analysed. The obvious conclusion, given the doubts that have been raised about it, is that it is a Victorian copy of an earlier design, and not an original tin-glazed tile. It is not proposed to try to identify its origins further now that the doubts have been confirmed. The remaining tiles and pottery were included in a further statistical test (fig 1) and the principal components program extracted just four statistically-significant components – that is, most of the ‘useful’ variation in chemistry in the analyses could be reduced to just four principal components (the theory and practice of this and similar computer programs used in archaeology can be found in Baxter (1994), Orton (1980) and Shennan (1997)).

The pattern of associations between items on figure 1 is interesting. A group of five tiles form a group that is thinly spread across the top of the figure. This indicates that the proportions of major elements in the clay vary systematically, and inspection of the results confirms this. (They have a much narrower range on the second component – see the caption to fig 1 which lists them.) The tiles vary in lime content from approximately 15 to 20%, while other elements vary in inverse proportion to the lime – which acts as a simple diluent to the ‘red clay’ component of the ware. These five tiles

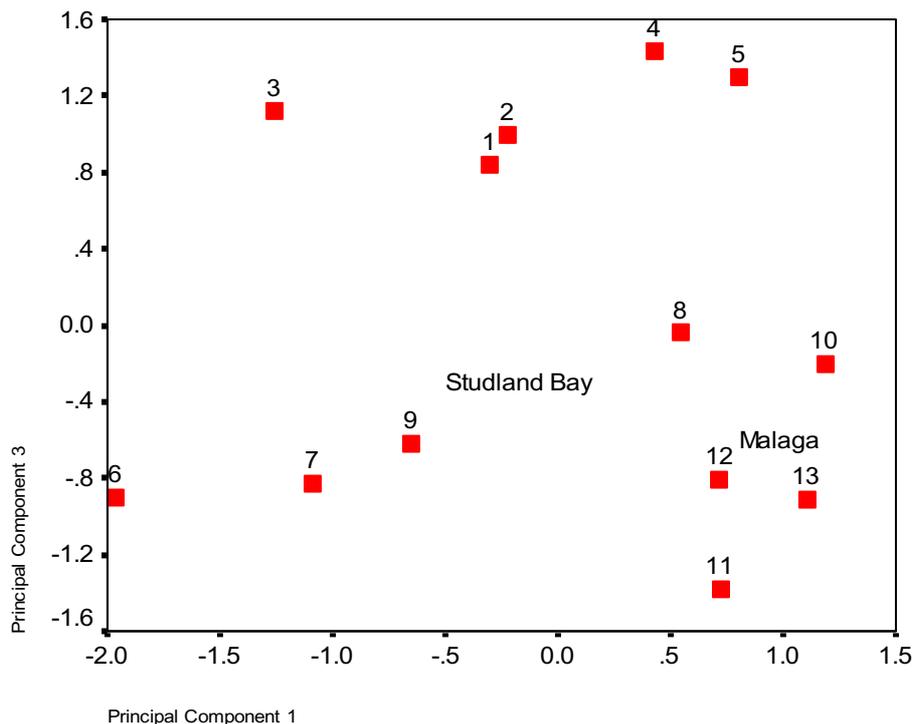


Fig 1 Plot of the first and third principal components arising from a combination of elements obtained by ICP–atomic emission and mass spectrometry analyses of tiles and comparison pottery in this project. The first principal component contains 46.9% of the variation in the data and is positively correlated with many of the concentrations of the elements used in the statistics, but is negatively correlated very strongly with calcium, and to a lesser degree magnesium, manganese and sodium – tiles and pottery with high concentrations of many elements will therefore be plotted on the right of figure 1 (positive values of principal component 1), and low concentrations to the left. The third principal component contains 15.1% of the variation in the data and is positively associated with manganese (0.79), iron (0.65) and europium (0.63), and negatively with sodium (-0.64). Hence high concentrations of iron, manganese and europium and low concentrations of sodium will be expected for tiles or sherds which plot towards the top of the Figure. The second component (not shown) contains 23.4% of the variation in the data and is associated positively with two heavy rare-earth elements lutetium (0.80) and ytterbium (0.85), as well as chromium (0.75), titanium (0.67), sodium (0.65), magnesium (0.65), scandium (0.63), and vanadium (0.60), and negatively with lithium (-0.78), potassium (-0.77) and rubidium (-0.52).

(nos 10, 21, 33A, 33B and 21A) are sufficiently consistent in chemistry that they can be judged to have come from the same general source, though with some variations in clay chemistry. The mean and standard deviation have been calculated and are quoted in table 1 under the analyses of the five. As something of a rule of thumb, analyses of ceramics from a single source (with the exception of coarse pottery) often show a spread of about 10% or less in the standard deviation of the element concentrations relative to the mean, and this seems to be true of these five right across the range of elements analysed (for example, aluminium has a ‘spread’ of about 9% relative = $1.08/12.02$ expressed as a percentage). Quite a few of the rare earths have a spread nearer 5% – this indicates a fairly close chemical grouping, and by implication, source clay.

It had been suggested that these were Valencian tiles. Only one previous ICP analysis on Valencian ceramics is known: a late Valencian bowl fragment found at Southampton and analysed by A Vince for A Gutiérrez (AG80 in table 1). It bears the same features as the five Woking tiles – relatively high magnesium, moderate iron, and similar levels of the trace elements – and suggests the five are Valencian. Another previous ICP analysis of a tile from Guildford Museum (from 15 Tunsgate, inv no 1993, 25) was analysed as part of a group of suspected Antwerp tiles. Its analysis is given as C4 in table 1; in the report on the Guildford analyses (Hughes 2002) it was suggested that it was an Antwerp product. The data has now been re-examined because it and tile 21A from Woking

share the same heraldic design which A Ray has identified as definitely Spanish. In the earlier report (Hughes 2002) tile C4 does show a different composition to the other tiles, which are very probably Antwerp. It plots in a different part of the principal components plot (*ibid*, fig 2) from the other Guildford tiles, and contains significantly more magnesium, aluminium and sodium and less strontium (these elements seem to be significant discriminators between these two sources). The earlier analyses were carried out by atomic emission ICP only, which gave fewer elements on which to base the conclusions as to origin compared to the combined atomic emission–mass spectrometry used in the present project. Tiles 21A and C4 are not identical in chemistry, so were not part of the same batch, but they are sufficiently similar to indicate a common origin in Spain at Valencia.

Apart from these two ICP analyses, a much larger programme of neutron activation analyses was carried out in the 1980s and 90s at the British Museum, when substantial numbers of Spanish ceramics from Valencia, Seville and Malaga were analysed, and smaller numbers from several other Spanish production centres (Hughes 1991; 1995; Hughes & Vince 1986). The overall program is as yet unpublished (Hughes 2000), apart from the earliest analyses in the programme (Hughes & Vince 1986). A study of the earliest Valencian lusterware has been published by Blake *et al* (1992). One other application of the database has been published in detail, of a Valencian jug found at Cannon Street, London (Gaimster *et al* 1991), which was compared by principal components against analyses of Valencian ceramics sorted by cluster analysis into groups of similar origin. Four clusters were found for the Valencian ceramics in an earlier statistical study of the neutron activation analyses (Hughes 2000), differing mainly in the lime/clay ratio, though also showing other element-ratio differences between the clusters. Blake *et al* (1992: fig 2) shows a plot of the cluster diagram, and (fig 3) shows a plot of the principal components with the items in each cluster marked (1–3, 5 in fig 3) which are separated from two clusters of Malaga-produced pottery. Comparison of the averages for these neutron activation clusters with the Woking five tiles was made after adjusting the ICP analyses to be standardised against neutron activation. This was done using previously-derived standardisation factors for the atomic emission elements, and new factors arrived at for the mass spectrometry elements by comparing results on three repeat analyses of a standard clay (British Museum Standard Pottery) which had itself been used to calibrate the original neutron activation analyses. The results of the comparison are as follows.

Tiles 10 and 21 from Woking are very similar to each other in analysis across the whole range of elements. This suggests they were made in the same place and perhaps at the same time. As a pair, they are very similar for many elements to Valencia cluster 2 which contains ten items (Hughes 2000), including two tiles in blue and white, one with a shield in a circular medallion and one with a bird of prey amid rough foliage (V&A C206-1912 and C209-1912 respectively) and a dish showing a ship in the Godman collection in the British Museum (G517). Tile 33A has higher amounts of most elements compared to the other four, though the alkali trace elements rubidium and caesium, and the rare earths, are similar to 10 and 21. Tile 21A has the lowest amounts of lime (15.0% calcium oxide) and higher amounts of other elements generally: it is not unlike cluster 1 (Hughes 2000 = cluster A in Gaimster *et al* 1991, table 3) which contains some 20 items including high-quality lustreware including pieces from the Godman collection, and a tile in blue and white with palmette (V&A C205-1912 from Manises). These comparisons indicate that all five of these tiles from Woking Palace are Valencian, and that they reflect the range of chemical compositions found for production there. The fact that the tiles are not all identical in chemistry suggests that they represent products of a range of kilns or perhaps chronology.

Tile BPL95 361 was suspected to be a Seville product. Analytically it is clearly different to the other five from Woking (cf its position on fig 1), and as that figure shows, it is close to a group of three sherds of Sevillian pottery from the Studland Bay wreck (Gutiérrez *et al* 2003), being very close indeed across most elements to sherd A from Studland, with the tile having a slightly higher proportion of lime to clay than the sherd – this has previously been noted for Seville tiles. The lime content is 22.03% calcium oxide, and is the highest of the tiles analysed in this project. The tile is also similar to the analysis of a sherd of green-glazed Seville pottery found at Scarborough (Hughes 2003; Q54 in table 1).

Four items from the excavations at Deansgate, Worcester were also included in the principal components – they form a group in the bottom right of figure 1, and show very similar chemistry to each other, and are consistent with production at Malaga.

Discussion and conclusions

We can now draw together the implications of the analytical project. For chemical provenancing work to succeed, clear differences in chemistry are needed between the different sources proposed, and the analytical technique must be capable of detecting these differences.

The combined use of two types of plasma spectrometry, ICP-atomic emission and mass spectrometry has produced accurate analyses on a very large number of elements in each pottery sherd, and has proved very successful in differentiating the products of different production centres in Spain. Importantly, it is now possible to make full comparison of ICP data with the established databases of Spanish pottery previously obtained by neutron activation analysis.

The analyses indicated that five tiles are Valencian (nos 10, 21, 33A, 33B and 21A): they show the range of chemical compositions typical of Valencian ceramics; tiles 10 and 21 form a chemically closely-matching pair and seem to be made from the same clay. Tile BPL95, 361 is confirmed by analysis as a Seville product. Tile VIN88 37 is of a low-lime clay and generally very different indeed from the others and is therefore, as suspected, a Victorian copy.

BIBLIOGRAPHY

- Baxter, M, 1994 *Exploratory multivariate statistics in archaeology*, Edinburgh: University Press
- Blake, H, Hughes, M J, Mannoni, T, & Porcella, F, 1992 The earliest Valencian lustreware? The provenance of the pottery from Pula in Sardinia, in D Gaimster & M Redknap (eds), *Everyday and exotic pottery from Europe c 650–1900. Studies in honour of John G. Hurst*, Oxford: Oxbow Books, 202–24
- Gaimster, D R M, Nenk, B, & Hughes, M J, 1991 A late medieval Hispano-Moresque vase from the City of London, *Medieval Archaeol*, **35**, 118-23
- Gutiérrez, A, Williams, D, & Hughes, M J, 2003 A shipwreck cargo of Sevillian pottery from the Studland Bay wreck, Dorset, UK, *Int J Nautical Archaeol*, **32(1)**, 24–41
- Hughes, M J, 1991 Provenance studies of Spanish medieval tin-glazed pottery by neutron activation analysis, in P Budd, B Chapman, C Jackson, R Janaway & B Ottaway (eds), *Archaeological Sciences 1989*, Oxbow Monogr, **9**, 54–68
- , 1995 Application of scientific analytical methods to Spanish medieval ceramics, in C M Gerrard, A Gutiérrez & A G Vince (eds), *Spanish medieval ceramics in Spain and the British Isles*, BAR Int Ser, **610**, 356-66
- , 2000 Provenance studies of medieval Spanish tin-glazed ceramics, unpubl paper
- , 2002 Report on ICP-AES analyses of ten tin-glazed decorated floor tiles of probable Low Countries origin in the collections of the Guildford Museum', unpubl report
- , 2003 Chemical analyses of a suspected Spanish ceramic from Scarborough by inductively-coupled plasma atomic emission spectrometry', unpubl report
- , & Vince, A G, 1986 Neutron activation analysis and petrology of Hispano-Moresque Pottery, in J S Olin & M J Blackman (eds) *Proceedings of the 24th International Archaeometry Symposium*, Washington: Smithsonian Institution Press, 353–67
- Lambert, J, 1997 *Traces of the past – unravelling the secrets of archaeology through chemistry*, Reading, Mass: Addison-Wesley
- Orton, C, 1980 *Mathematics in archaeology*, London: Collins
- Shennan, S, 1997 *Quantifying archaeology*, Edinburgh: University Press, 2 edn
- Thompson, M, & Walsh, J N, 1989 *A handbook of inductively coupled plasma spectrometry*, Glasgow: Blackie, 2 edn

Table 1 List of samples, and full analysis results on tiles analysed in this project by inductively-coupled plasma atomic emission spectrometry (ICP-AES) and inductively-coupled plasma mass spectrometry (ICP-MS) together with comparison analyses on pottery from the deduced sources of the tiles

ANALYSES BY ICP-ATOMIC EMISSION

Sample	Fig 1	Description	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	Ba	Co	Cr	Cu	Li	Ni	Sc	Sr	V	Y	Zn	Zr	La	Ce	Nd	Sm	Eu	Dy	Yb	Pb
Q49	1	Betts 10	11.69	4.52	2.02	19.01	0.16	2.46	0.51	0.13	0.069	654	25	52	54	51	29	9	269	52	23	60	59	34	48	36	4.7	1.0	4.0	2.4	528
Q50	2	Betts 21	11.41	4.52	1.99	19.60	0.19	2.27	0.52	0.17	0.092	457	17	51	206	51	30	9	268	55	23	224	63	34	50	36	4.6	1.0	4.1	2.3	873
Q51	3	Betts 33A	10.72	5.59	2.50	20.22	0.16	1.90	0.50	0.19	0.155	553	21	46	80	46	32	9	273	42	22	70	55	31	45	33	4.3	0.9	4.1	2.2	724
Q52	4	Betts 33B	13.06	5.40	2.38	18.17	0.15	2.35	0.57	0.25	0.098	485	19	60	34	50	34	10	305	46	26	143	66	37	51	39	4.5	1.1	4.4	2.6	414
Q53	5	Betts 21A	13.22	6.59	2.06	15.03	0.21	2.63	0.60	0.33	0.126	623	39	64	233	44	39	10	240	65	23	321	68	38	57	40	4.9	1.1	4.6	2.4	1639
		mean	12.02	5.32	2.19	18.41	0.17	2.32	0.54	0.21	0.11	554	24	55	121	48	33	9	271	52	23	164	62	35	50	37	4.6	1.0	4.2	2.4	836
		standard deviation	1.08	0.86	0.23	2.03	0.02	0.27	0.04	0.08	0.03	85	9	7	92	3	4	1	23	9	2	110	5	3	4	3	0.2	0.1	0.3	0.1	483
<i>compare:</i>																															
C4		1993, 25	14.21	4.81	2.45	15.98	0.79	2.64	0.60	0.25	0.06	368	23	39	85	70	40	11	234	76	25	88	68	39	69	39	7.0	1.4	4.1	1.7	961
AG80		Late Valencian bowl	12.27	5.23	2.84	15.82	0.77	1.91	0.55	0.48	0.12	376	17	86	83	37	44	12	387	85	23	88	59	30	57	27	5.1	1	3	1.7	
Q54	6	Betts BPL95 361	10.61	4.11	2.14	22.03	0.67	2.09	0.56	0.14	0.079	384	10	53	27	34	29	10	382	69	20	63	53	30	49	32	4.1	0.9	3.7	2.3	116
<i>compare:</i>																															
		Scarborough green glazed	13.53	5.37	2.40	15.66	0.65	2.90	0.66	0.35	0.081	389	12	79	87	51	37	12	410	69	23	96	44	31	55	32	6.3	0.8	3.5	1.5	759
Q56	7	Studland Bay A	12.16	4.74	2.80	18.13	0.75	1.83	0.59	0.25	0.072	314	17	80	66	33	32	11	500	77	23	77	67	32	49	34	4.7	1.1	4.3	2.5	2709
Q57	8	Studland Bay B	13.82	5.50	2.81	15.09	1.13	1.22	0.68	0.55	0.084	316	11	95	60	24	40	13	471	92	26	83	83	36	57	38	4.2	1.1	4.9	2.8	8399
Q58	9	Studland Bay C	12.28	5.14	3.10	18.90	1.43	2.09	0.59	0.21	0.070	375	11	77	67	43	33	11	437	86	23	76	68	33	47	35	4.2	1.0	4.1	2.6	3877
Q55		Betts VIN88 37	14.54	2.68	0.60	4.82	0.35	1.81	0.74	0.10	0.018	270	16	55	23	48	25	12	143	91	19	82	71	36	51	37	4.7	1.0	3.1	2.1	270

The results from Al₂O₃ to MnO inclusive are given as the oxide, in weight percent; all the rest are given as the element, in parts per million.

Key: Al₂O₃ aluminium; Fe₂O₃ iron; MgO magnesium; CaO calcium; Na₂O sodium; K₂O potassium; TiO₂ titanium; P₂O₅ phosphorus; MnO manganese

Ba barium; Co cobalt; Cr chromium; Cu copper; Li lithium; Ni nickel; Sc scandium; Sr strontium; V vanadium; Y yttrium; Zn zinc; Zr* zirconium; Pb lead

Rare earth elements: La lanthanum; Ce cerium; Nd neodymium; Sm samarium; Eu europium; Dy dysprosium; Yb ytterbium.

ANALYSES BY ICP-MASS SPECTROMETRY

Sample	Description	U	Th	Rb	Nb	Cs	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Lu	Ag	As	Pb	Cd	Tl	Mo	Sb	Bi	
Q49	1 Betts 10	3.00	11.47	105	10.6	6.81	24	38.3	66.5	8.4	34.2	6.78	1.54	6.26	4.03	0.73	2.31	1.92	0.28	0.5	18.4	519	0.2	0.4	0.7	1.1	7.5	
Q50	2 Betts 21	3.06	11.36	96	11.2	6.94	24	37.9	67.3	8.6	35.2	6.87	1.44	6.62	4.32	0.76	2.22	1.88	0.28	0.7	19.6	871	0.1	0.4	0.7	1.2	12.1	
Q51	3 Betts 33A	2.87	10.78	64	10.9	5.48	23	35.2	61.4	7.7	32.3	6.21	1.37	5.81	3.74	0.71	1.99	1.80	0.24	0.6	20.2	717	0.1	0.3	0.7	1.7	9.9	
Q52	4 Betts 33B	3.17	12.15	93	12.6	5.98	27	40.5	69.9	8.8	37.3	6.96	1.52	6.74	4.37	0.85	2.46	2.10	0.30	0.6	20.1	401	0.3	0.3	0.7	1.2	5.6	
Q53	5 Betts 21A	3.40	13.04	119	12.9	9.41	24	40.5	74.5	9.1	38.6	7.55	1.58	6.78	4.28	0.79	2.22	2.00	0.27	0.8	20.6	1508	0.0	0.6	1.0	1.6	21.0	
	mean	3.10	11.76	96	11.6	6.92	25	38.5	67.9	8.5	35.5	6.87	1.49	6.44	4.15	0.77	2.24	1.94	0.27	0.7	19.8	803	0.1	0.4	0.7	1.3	11.2	
	standard deviation	0.20	0.87	20	1.1	1.51	2	2.2	4.8	0.5	2.5	0.48	0.08	0.41	0.26	0.05	0.17	0.11	0.02	0.1	0.9	433	0.1	0.1	0.1	0.3	6.0	
Q54	6 Betts BPL95 361	2.42	9.13	66	10.2	3.62	21	32.7	59.3	7.4	30.4	5.78	1.25	5.41	3.68	0.67	1.95	1.65	0.26	0.5	12.4	115	0.0	0.1	0.3	1.0	1.8	
<i>compare:</i>																												
Q56	7 Studland Bay A	2.68	9.62	62	11.5	4.61	23	34.8	62.1	7.8	33.2	6.08	1.27	5.66	3.91	0.74	2.12	1.99	0.28	0.6	13.8	2252	0.3	0.8	3.2	2.1	31.3	
Q57	8 Studland Bay B	3.67	11.48	63	13.3	7.02	27	39.2	71.7	8.9	37.4	7.11	1.48	6.71	4.59	0.89	2.55	2.35	0.33	0.8	15.9	5357	0.2	2.3	14.2	3.8	98.5	
Q58	9 Studland Bay C	2.63	10.34	75	12.0	5.52	23	35.9	63.9	8.1	33.7	6.57	1.38	6.02	3.97	0.80	2.28	1.97	0.29	0.8	17.3	3067	0.1	1.1	0.6	2.2	46.9	
Q55	Betts VIN88 37	2.84	9.60	117	17.4	9.68	19	40.5	73.3	8.9	37.5	6.34	1.26	5.72	3.42	0.64	1.91	1.72	0.24	0.7	16.9	271	0.7	0.8	0.4	12.1	3.7	

All element concentrations are in parts per million in the dry powdered clay.

Key to element chemical symbols: U uranium; Th thorium; Rb rubidium; Nb niobium; Cs caesium; Y yttrium; La lanthanum; Ce cerium; Pr praeosodinium; Nd neodymium; Sm samarium; Eu europium;

Gd gadolinium; Dy dysprosium; H holmium; Er erbium; Yb ytterbium; Lu lutetium; Ag silver; As arsenic; Pb lead; Cd cadmium; Tl thallium; Mo molybdenum; Sb antimony; and Bi bismuth.

All analyses were done as part of this project except for:

sample AG80 is an analysis courtesy of A Vince, for A Gutierrez in 1997 using the same laboratory and technique as the rest of the results in this table

sample C4 is a tile from 15 Tunsgate, Guildford, in Guildford Museum

Scarborough green glazed' was a Sevillian sherd analysed in 2003