AN ANALYSIS OF POTTERY
FROM ELGIN AND NORTH-EAST SCOTLAND

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Introduction

In 1976 and 1977 a series of archaeological excavations in advance of an inner
relief road in Elgin, north-east Scotland, started to produce medieval pottery
in quantity. Some of the sherds were recognisable fine ware imports but the
source of the coarse pottery was unknown. However, on the basis of fabric
type it was thought that most of the coarser wares fell into two groups,
perhaps imports and local products. There was also some evidence for early
post-medieval pottery making on one of the sites. The purpose of the project
reported here was to see if a chemical analysis of some representative sherds,
along with comparative material from the rest of Scotland, could distinguish
local sherds from imports.

Atomic absorption spectroscopy was used to analyse 32 sherds and one kiln tile
excavated in Elgin, 19 sherds excavated elsewhere in north-east Scotland and
also three fired clays and one burnt daub sample. Eight elements were
determined - Iron (Fe), Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium
(Na), Aluminium (Al), Zinc (Zn) and Manganese (Mn) - but the analytical
accuracy of the manganese results proved too poor, and these were discarded.

Theoretical background

The basic assumption in using chemical analysis to determine the source of
pottery is that beds of potting clay are chemically unique or are at least
distinguishable on a statistical basis. Several riders have to be added to
this:

1. that the puddling, adding of fillers, grog etc. and the firing of the
   clay either did not change the composition of the clays significantly
   or changed it in a systematic way, i.e. that the finished pots were
   chemically distinctive;

2. that the chemical composition of the pots did not alter significantly
   as they lay in the ground (or that it changed in a systematic way);

3. that the effects of the selection processes by which the original pots
   reached the analyst's bench can be reasonably accounted for.

It was beyond the scope of this work to investigate either the basic
assumption or the first two riders, but Tubb et al (1980:160) and Freeth
(1967) have done limited work related to these themes. The third rider
cannot be investigated scientifically but any attempt to interpret the
results should include some assessment of sample bias (see Discussion).
(Throughout this paper the term 'sample' has been used to denote the whole
set of sherds, clays etc. investigated and not the individual items
analysed.)

The chemical characteristic measured may also influence the interpretation of
the results. Simple chemical composition analysed by atomic absorption
spectroscopy was chosen because it is efficient, accurate and the results are
amenable to statistical manipulation (see Hughes, Cowell and Craddock 1976).

The choice of elements analysed was governed by the consideration that the results should be comparable with those of other workers. Fe, K, Ca, Mg, Na, Zn, Al and Mn are amongst the most frequently analysed elements and these were used here.

Freeth (1967) has suggested that the elements calcium and magnesium in pottery may partake in ion-exchange reactions with the ground water and either be enhanced or lost according to the conditions. If this is universally true then they should not be used as discriminators between pottery from different sources. However, Freeth was looking at Bronze Age pottery and the sherds examined here were undoubtably better fired. Also, calcium must be determined if the total alkali is required, so both elements were measured.

Since the initial choice of elements was to a considerable extent arbitrary, one method of improving the selection was tried. There were three items from Elgin (a possible potting clay, a kiln tile and a waster) which by their nature must have been local in origin. Their composition was more or less similar depending on which elements were taken into consideration. The method of improving the selection of elements was thus to throw out those which were least similar in the three local markers. In this way the 'Elgin local' group should have become more compact relative to the rest of the sherds analysed. On a simplistic view, retaining only the single 'best' element should produce the best results but in practice this would place too much reliance on the individual peculiarities of the three markers and that element. In the end the best four elements for drawing the local markers together were used, although in fact the results were much the same if anything between 2-7 elements were considered.

Choice of sherds and comparative material for analysis

The coarse wares from Elgin divided visually into two groups - earlier, finer off-white wares with relatively large, abundant quartz grits and little glaze and secondly later, coarser orange wares with fewer, smaller grits and better glazes - perhaps imported and locally produced respectively. X-ray diffraction suggested that the off-white wares were relatively low in felspar.

The sherds from Elgin chosen for analysis represented the range of these two fabric types and included also some unique or atypical items. A further 19 sherds from the rest of north-east Scotland were analysed for comparison (see Fig. 1). In addition, three clays (two from Elgin and one from Aberdeen) were fired and they, along with one piece of burnt daub, were also analysed.

The sample contained a number of sherds and clays of known origin. Ignoring the clay which was found to be unsuitable for potting, there were three Elgin local markers - a waster, 24; a kiln tile, 40; clay, 37 - and a number of items which were certainly produced elsewhere - the Scarborough ware 28, 34; Siegburg ware 26, 27; the Balchrystie sherds 75, 76, 77; and the Aberdeen clay 82.

Table 1 describes the items analysed.

Atomic absorption: analytical method

For the analysis of the pottery and fired clays a convenient corner of the sherd was selected and the surfaces progressively ground away until all traces of glaze and surface dirt were removed. The corner was broken off and then crushed in steel percussion and agate mortars to pass a 60 mesh sieve, dried

No.	Site	Context	Fabric colour	Notes	Source suggested by analysis
11	LL	325	Dark grey, sooty externally	'Pictish'	–
12	HH	464	Grey	Refires orange if oxidised	–
13	HS	479	Off-white, darker externally	Cooking pot	Foreign
15	LL	050	Grey	Jug shoulder	–
16	LL	x250	Grey, buff internally		Elgin
17	LL	x283	Orange		Elgin
18	LL	x284	Buff to grey	Basal corner	Elgin
19	LL	x299	Orange with a grey core		Elgin
22	LL	009A	Orange		Elgin
24	LL	419	Red-orange	A waster	Elgin
25	LL	435/444	Buff		Elgin
26	LL	y208B	Off-white	Siegburg stoneware	Foreign
27	LL	415A	Off-white	Siegburg stoneware	Foreign
28	LL	y208C	Buff	Scarborough ware	–
40	LL	318	Orange	Kiln tile	–
42	HS	100A	Pale orange, grey core	Strap handle	Foreign
44	LL	x284	Grey, orange internally		–
45	LL	x250	Orange		Elgin
46	LL	090	Grey with orange surface	Part of rod handle	Elgin
47	LL	x283	Orange		Elgin
50	LW	648	Grey, orange under the glaze		Elgin
51	LW	648	Grey		–
54	HS	124	Purplish grey	Heat-crazed	–
55	HS	124	Off-white, darker externally	Straight-sided cooking pot	Foreign
56	SC	142	Pale orange		Elgin
57	SC	141	Orange		Elgin
58	SC	141	Orange		Elgin
60	HS	130	Grey with darker surfaces	Vesicular, unique	Foreign
62	LW	663	Grey, pale orange, grey-brown		–
64	HS	512	Orange	Like early LL sherds	–
65	HS	130	Off-white, buff externally		Foreign
66	HS	512	Off-white, buff, grey core		Foreign
83	HS	527B	Pale orange, grey core	Refires pale orange if oxidised	–

Key to all Figures and Tables

EL	Elgin	ABG	Aberdeen, The Green
HS	High St., Elgin	ABVS	Aberdeen, Virginia St.
LL	Lazarus Lane, Elgin	BALC	Balchrystie
LW	Lossie Wynd, Elgin	BGHD	Burghead
SC	South College St., Elgin	ELLH	Ladyhill, Elgin (stray finds)
		PLPR	Pluscarden Priory
		PRTH	Perth
		SPPL	Spynie Palace

TABLE 1b : DESCRIPTION OF COMPARATIVE POTTERY

No.	Site and context	Fabric colour	Notes	Source suggested by analysis
29	Pluscarden Priory	Orange		Elgin
30	Pluscarden Priory	Grey		Elgin
31	Burghead	Orange		Elgin
32	Spynie Palace	Grey, orange internally		–
33	Spynie Palace	Grey, buff internally		Elgin
34	Ladyhill, Elgin	Orange .	Scarborough ware	Foreign
35	Ladyhill, Elgin	Grey, purplish externally		–
71	Aberdeen, The Green I(24)	Grey, orange externally		–
72	Aberdeen, The Green I(24)	Orange, grey core		–
73	Aberdeen, The Green I(28)	Off-white, grey	Straight-sided cooking pot	Foreign
74	Aberdeen, The Green II(2)	Buff		Foreign
75	Balchrystie	Grey, buff surface	Basal corner	Foreign
76	Balchrysite	Off-white	Basal corner	Foreign
77	Balchrystie	Off-white, grey core	Basal corner	Foreign
78	Aberdeen, Virginia St. 6	Buff		–
79	Aberdeen, Virginia St. 1	Grey, blackened externally		–
80	Aberdeen, Virginia St. 1	Grey, orange internally		–
81	Aberdeen, Virginia St. 1	Pale orange, grey core		Elgin
53	Perth	Off-white, orange	Strap handle	Foreign

TABLE 1c : DESCRIPTION OF COMPARATIVE CLAYS ETC.

No.	Site and context	Fabric colour etc.	Notes	Source suggested by analysis
36	LL 118	Crumbly, pale orange	Burnt daub	–
37	LL 415	Hard, orange	Clay fired at 750°C	Elgin
68	LL –	Crumbly, orange	Clay fired at 750°C – not a potting clay	–
82	Aberdeen, Virginia St.	Quite hard, pale buff	Clay fired at 750°C	–

for at least an hour and cooled in a desiccator. The burnt daub (36) could not be cleaned effectively but the process was otherwise the same as for the pottery.

In order to reduce the possibility of an unrepresentative result, 2–5 gm of material was removed from each sherd. This was mixed thoroughly and 0.1 gm drawn from it for analysis. However, sherds 11, 26, 27 and 28 were unique and only 0.5 gm or less could be collected.

The powder was dissolved by the lithium metaborate fusion method (see Hughes et al 1976; Ingamels 1970; Van Loon and Parissis 1969). About 0.1 gm of the prepared powder was weighed accurately into a platinum crucible, 0.6 gm of lithium metaborate added and mixed thoroughly with a microspatula. The crucible was then heated in a muffle furnace at 900°C for 15–20 minutes until the contents vitrified. It was then removed and immediately quenched to crack the glass. 4% AR nitric acid was poured into the crucible and stirred using an electric stirrer. The glass generally dissolved in 15–20 minutes and the solution was then made up to 100 ml.

The solutions with the appropriate additions and standards were analysed using a Perkin-Elmer Atomic Absorption Spectrometer Type 305. Table 2 sets out the operating conditions and the results are given in Table 4.

Atomic absorption: accuracy and reproducibility

Several tests were done on both the accuracy and reproducibility of the analyses. Repeat analyses were made on two sherds (15 and 17) and three external standards (a firebrick British Chemical Standard BCS 315 and two artificial pellyite glasses). The results in parts per million (PPM) are recorded in Table 3.

For the repeat analyses of sherds 15 and 17, separate lots of 0.1 gm were drawn from the 3 gm originally collected and analysed in the normal way. With the exception of the single erratic result for zinc (see below), there was good reproducibility.

Four totally independent analyses of BCS 315 were used to check the accuracy of the Fe, K, Ca, Mg, Na, Mn and Al determinations. There was no quoted value but the standard was also analysed for zinc. The results for iron, magnesium and aluminium grouped closely round the standard value. The mean values for potassium, calcium and sodium were also close to the reported analyses of the standard but the individual readings were more diverse due to the greater counting errors involved in analysing the relatively low alkali content of the standard. The repeat analyses of 15 and 17 for these elements showed that reproducibility was normally better than $\pm$ 5% (1 standard deviation). The variation of the manganese results was unacceptably large due to the relatively low signal to noise ratio and it was thought safer to discard manganese completely.

Despite the agreement between most of the duplicate zinc analyses, there were occasional very high results. As a check on the method of analysis, some pellyite glasses recently prepared in the laboratory were used as secondary standards. The results for zinc (and incidentally sodium) were in close agreement with the expected values. It seemed that extra zinc had somehow got into some of the analyses; it may be that rubber bungs were the source, a problem not realised at the time (I am indebted to Dr. M.J. Hughes for this suggestion). In consequence the erratically high zinc determinations of 26, 60, 66, 72, 74 and 77 were discarded.

These tests confirmed the general reproducibility of the method but forced the rejection of the manganese and some of the zinc results.

Statistical analysis of the results: introduction

Principal Components Analysis (PCA) was employed to provide a graphical print out showing which sherds were most similar. A statistical clustering program with tree diagram output was used to divide the sample into groups, firstly on the basis of all seven elements, then on the basis of the best four for drawing the local markers together. The results of the two clustering programs were compared to give a final grouping. For a non-mathematical explanation of the techniques used see Doran and Hodson, 1975.

In order to produce a near-normal distribution pattern for the concentration of each element in the sherds the data was log transformed. To prevent those elements with large variances from dominating the results, the log transformed data was standardised so that the overall mean concentration for each element became zero and the standard deviation equal to one. This standardised data was used for both the PCA and the Cluster Analysis.

Principal Components Analysis

The principal components were calculated using the Fortran package ASF2 (see e.g. Morrison 1976). Where there were missing values the mean (transformed) concentration for that element was substituted. The first three components accounted for 66, 13 and 10% of the variance respectively.

Fig. 2 shows how the analysed sherds were distributed in terms of the first two principal components. As expected, there was a single definite concentration of sherds with a number of outliers. This concentrated group contained many sherds from Elgin and few from elsewhere. The Elgin waster 24 was within this group; the kiln tile 40 and the local clay 37 were on the edge of the group. The Balchrystie, Siegburg and Scarborough ware sherds were all well separated from the main group. So the concentrated group was taken to encompass the locally produced sherds with the outliers being 'foreign'.

Cluster analysis was used to draw the line between the local and foreign sherds.

Cluster Analysis

The Fortran program ASF4 was used. A number of clustering methods were tried but in the end Group Average clustering with Euclidian distance as the measure of dissimilarity was chosen (see e.g. Sokal and Sneath 1963). The results of this method seemed to best reflect the patterns suggested by the PCA.

In the first instance all the elements were considered and the resulting tree diagram is shown in Fig. 3. The local markers were found to be in the top half of the diagram and the foreign markers below. As was seen in the PCA, the local group was tightly bound and the foreign examples more compositionally varied.

The second method was to consider only the best four elements for drawing the Elgin local markers together: Na, Ca, K, Zn. The resulting tree diagram is shown in Fig. 4.

Since the selection of elements used to produce this diagram relied on only three not necessarily representative items, it may not be any more reliable than the diagram in which all the elements were considered. The two diagrams

were similar in general but varied in detail, as might be expected. Some sherds/clays etc. were assigned to the compact local group in both cases and some were equally foreign but a number were borderline. Only one sherd (62) changed from the 'definitely' local to the 'definitely' foreign group according to which diagram was considered.

Discussion

The main problem with the cluster analysis was where to draw the boundaries of the local group. Even if, as here, a band of 'unassignable' examples is allowed, this will only reduce the possibility of error, not eliminate it. Also the unassigned group will of necessity contain some local sherds and the inclusion of the kiln tile 40, a local marker, serves to emphasise this. (If the local group were expanded to include the kiln tile then its range of composition would become rather great and the chances of misassignment unacceptably large.)

The nature of the sample must also be considered. The sherds analysed were hardly representative of Scottish medieval pottery - they included, for instance, few examples from rural sites. It seems likely that the apparent compositional uniqueness of the Elgin local wares will be eroded as more sherds from elsewhere are analysed. It was particularly noticeable that none of the sherds analysed had between 3190-8340 PPM sodium.

One further qualification is that it is theoretically possible that all the sherds found in Elgin came from a single source with a broad band of composition, at one end similar to the known imports and foreign sherds, at the other end similar to the three local markers. As this would imply an unprecedented range of composition for the Elgin clays this hypothesis seems rather improbable.

With all these reservations, the last column in Table 1 presents a list of those sherds believed to be local to Elgin, those thought to be foreign and those which remained unassigned. Local group sherds contained on average more than the foreign group of all the elements analysed excepting aluminium. The sodium content of the local pottery was exceptionally high.

Of the coarse wares found in Elgin, the orange sherds were generally assigned to the local group and the off-white sherds to the foreign group, confirming the original hypothesis (descriptions relate to the most oxidised colour visible). The analysis also showed that local pottery was marketed at least as far abroad as Pluscarden Priory, Burghead and Spynie Palace. More surprisingly, one sherd found in Aberdeen was included in the local group. This is probably a case of misassignment rather than an export from Elgin.

The foreign group included the Balchrystie products, the Scarborough and Siegburg wares, confirming the general validity of the analysis.

Conclusions

Of the 32 sherds found in Elgin which were analysed, 14 predominantly orange in colour were made locally. Eight mainly off-white sherds were imports and 10 remained unassigned. The mean composition of the locally produced pottery was Fe - 35 700 PPM; K - 32 900; Ca - 8 040; Mg - 8 730; Na - 11 900; Al - 88 000; Zn - 93. This sodium content is exceptionally high and may be of primary importance in distinguishing Elgin products.

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TABLE 2 : STANDARD CONDITIONS FOR ATOMIC ABSORPTION ANALYSIS USING THE PERKIN-ELMER 305: LITHIUM METABORATE FUSION METHOD

Element	Flame	Mode	(nm)	Slit (nm)	Linearity (PPM)	Dilution	Additions[2]
Fe	air/acetylene	absorption	248.2	0.2	0-5	1/10	
K	air/acetylene	emission	766.5	1.4	0-2	1/10	1% La
Ca	air/acetylene	absorption	422.7	1.4	0-5	1/10	
Mg	N_2O/acetylene	absorption	285.2	0.7	0-2	1/10	
Na	air/acetylene	emission	589.3	1.4	0-1	1/10 & 1	none
Al	N_2O/acetylene	absorption	309.3	0.7	0-50	1/10	1500PPM Na^+
Zn	air/acetylene	absorption	213.9	0.7	0-2	1[3]	none
Mn	air/acetylene	absorption	279.5	0.2	0-3	1	none

Notes: (1) The analyses of Fe, K, Ca, Mg were made on a single set of solutions.

(2) Standards also contain the appropriate reagent blanks.

(3) Zn in the synthetic class was determined at 1/100 dilution

TABLE 3 : ACCURACY AND REPRODUCIBILITY

In parts per million

Repeat analyses of the British Chemical Standard BCS 315 compared with the reported analysis

	Fe	K	Ca	Mg	Na	Al	Zn	Mn
BCS 315(A)	21 600	4 480	2 330	3 330	854	214 000	149	47
BCS 315(B)	21 000	3 980	2 230	3 330	860	219 000	144	44
BCS 315(D)	21 000	5 020	3 050	3 140	898	225 000	146	83
BCS 315(E)	21 200	5 100	2 620	3 250	1 060	224 000	1 350[1]	107
mean of A-E	21 200	4 645	2 557	3 255	918	220 500	146	70
reported analysis	21 000	4 320	2 430	3 440	965	224 000	—	155

Analysis of two glasses compared with the reported values

	Fe	K	Ca	Mg	Na	Al	Zn
Glass (1)	—	—	—	—	—	—	149 000
reported analysis	—	—	—	—	—	—	146 000
Glass (2)	—	—	—	—	13 200	—	154 000
reported value	—	—	—	—	13 100	—	149 000

Repeat analyses of two sherds

	Fe	K	Ca	Mg	Na	Al	Zn
15 (A)	33 900	35 700	9 840	7 720	12 300	79 500	184
15 (B)	32 500	34 900	9 400	7 330	11 800	81 300	173
15 (C)	32 100	34 500	9 080	7 290	11 400	80 900	170
15 (D)	32 600	32 200	9 520	7 380	11 400	85 700	195
17 (A)	29 300	31 300	7 840	8 870	9 280	83 400	58
17 (B)	30 300	30 300	7 940	9 070	9 410	78 400	73
17 (C)	32 600	32 900	8 380	8 820	11 000	80 200	2 450[1]

Coefficient of variation, i.e.
Standard deviation of repeat analyses divided by mean value (%)

	Fe	K	Ca	Mg	Na	Al	Zn	Mn
15	2.1	3.8	2.9	2.3	3.2	2.8	5.5	
17	4.5	3.4	3.1	1.2	7.9	2.5	11.5	
BCS 315	1.2	9.7	12.6	2.2	9.1	2.0	1.4	37.3

[1] The erratic readings have been ignored in the calculation of the mean and standard deviation.

TABLE 4 : COMPOSITION OF POTTERY AND COMPARATIVE MATERIAL (PPM)

Sample	Fe	K	Ca	Mg	Na	Al	Zn
11A	47 600	17 200	17 100	12 900	11 100	83 300	132
12	37 400	32 300	8 430	9 380	11 000	91 300	214
13	21 200	14 100	2 700	4 030	1 220	143 000	31
15(av.)	32 800	34 300	9 460	7 430	11 700	81 800	180
16	35 200	31 700	7 820	8 150	11 900	81 400	82
17(av.)	30 700	31 500	8 050	8 920	9 900	80 700	65
18	34 600	31 100	7 640	8 080	11 700	80 000	83
19	35 000	34 000	7 780	8 100	11 700	85 400	76
22	34 400	34 900	8 470	9 040	12 300	87 500	93
24	35 500	32 900	6 080	8 620	11 800	86 900	71
25	37 000	37 300	8 740	9 660	13 700	96 000	125
26	9 610	21 000	1 960	5 520	1 690	120 000	571
27	9 200	19 500	1 740	2 990	1 550	115 000	34
28	22 800	19 200	3 970	5 010	2 170	96 500	129
40	26 600	32 100	6 850	7 660	13 100	79 200	50
42	17 500	13 300	4 600	4 040	824	117 000	16
44	35 100	34 300	8 880	7 500	12 300	91 200	209
45	35 400	34 100	8 120	8 690	12 700	102 000	121
46	30 600	30 300	7 770	7 480	10 500	80 700	74
47	35 700	34 700	8 120	8 590	12 600	92 300	93
50	33 900	31 500	7 070	9 280	12 200	90 000	86
51	43 400	29 200	13 100	7 450	10 100	80 000	157
54	29 400	36 500	17 500	10 900	12 200	71 000	52
55	16 900	11 600	3 160	3 670	12 200	139 000	35
56	46 900	34 800	8 250	9 980	11 100	91 600	113
57	36 200	33 200	6 260	8 590	12 000	84 700	91
58	36 800	34 700	9 460	8 460	12 400	85 800	90
60	36 200	19 000	5 200	6 490	2 100	74 000	642
62	39 000	30 900	8 190	8 800	9 510	93 100	517
64	36 600	33 800	11 900	9 860	11 800	88 300	66
65	14 100	6 510	3 010	1 960	932	113 000	135
66	26 500	14 000	8 720	3 310	1 200	109 000	1 200
83	18 700	22 000	3 360	5 350	2 130	101 000	160
29	38 500	30 300	7 770	9 250	13 000	90 300	104
30	33 300	31 900	8 780	8 500	11 400	89 600	96
31	35 400	29 200	6 820	8 130	12 400	86 100	91
32	45 100	30 700	7 380	10 400	9 050	109 000	213
33	37 800	34 800	11 700	9 570	11 500	93 800	117
34	22 900	16 700	2 410	4 540	2 290	87 200	27
35	34 800	31 700	10 300	7 940	11 700	78 100	73
53	19 700	9 310	3 810	2 450	1 250	115 000	35
71	58 800	35 000	9 110	25 500	11 500	102 000	326
72	61 500	34 700	13 900	26 000	13 400	108 000	798
73	16 300	13 800	3 630	3 460	1 510	121 000	39
74	26 900	20 300	2 860	4 790	2 500	87 400	772
75	24 300	15 200	4 090	4 700	1 120	136 000	74
76	13 500	15 000	1 770	4 990	1 100	128 000	75
77	13 800	12 400	1 970	3 420	1 460	120 000	855
78	24 300	20 200	4 730	5 090	2 340	96 400	190
79	38 600	19 700	5 580	8 740	3 190	74 600	397
80	57 000	34 500	16 000	27 100	11 200	108 000	256
81	37 500	28 600	7 850	11 100	12 100	89 000	99
36	41 900	32 700	16 700	11 100	10 300	85 200	118
37	22 100	27 900	7 430	4 490	12 300	73 300	70
68	20 500	27 700	4 850	3 040	8 340	62 300	88
82	21 400	25 300	3 040	7 440	9 900	74 600	101

Burghead

o   o Spynie Palace
         o
        o Elgin
Pluscarden Priory

o Aberdeen

Perth o

o Balchrystie
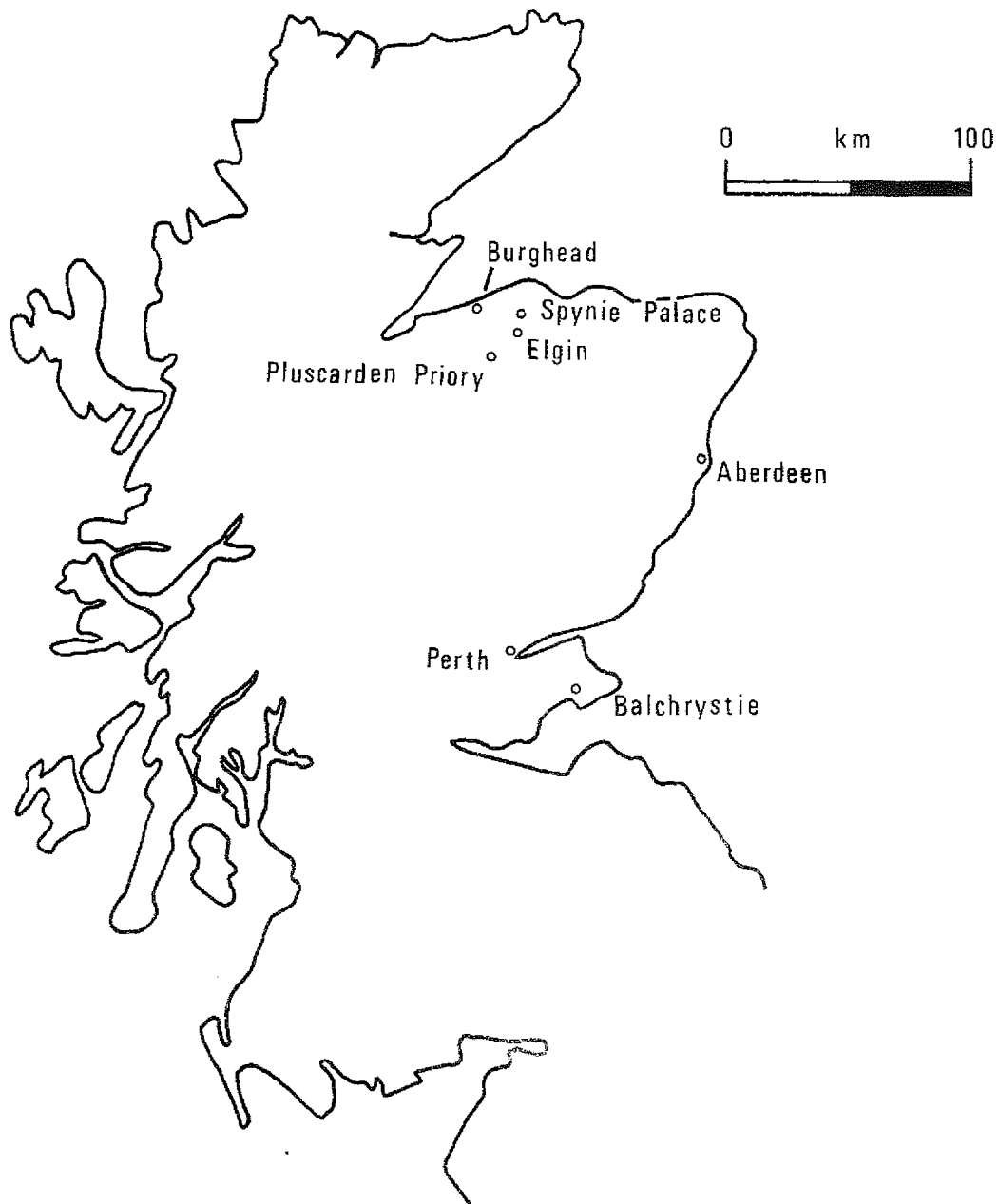
Fig. 1 : Location of sites where analysed items were found
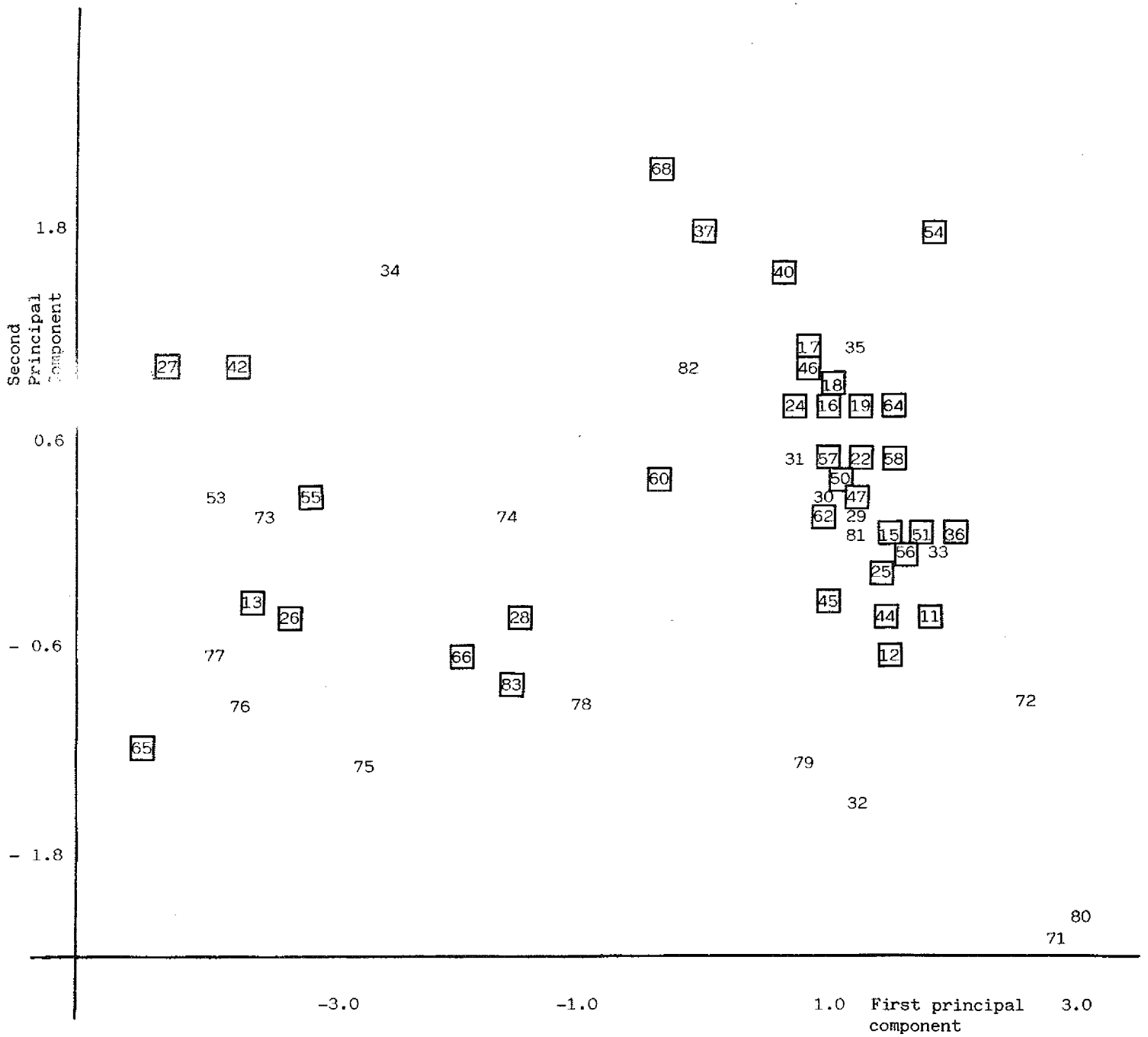
Fig. 2 : Principal components analysis - the positions of the sherds in terms of the first two principal components: sherds etc. with similar composition are close together, dissimilar ones further apart. Numbers in squares were items found in Elgin.

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No./Source  11ELLL  ------------------------------*
            12ELHS  ------*---*                   I
            44ELLL  ------*   I-----*             I
            15ELLL  --------*       I-*           I
            51ELLW  -----------*---* I            I
            36ELLL  -----------*     I            I
            16ELLL  -*---*           I            I
            18ELLL  -*   I           I            I
            19ELLL  -----*-*-*       I            I
            17ELLL  -----I I I       I            I
            46ELLL  -----* I I       I            I
            35ELLH  -------* I       I            I
            22ELLL  ---*-*   I       I            I
            58ELSC  ---* I-* I-*     I-*          I
            47ELLL  -----I I I I-*   I I-*        I
            30PLPR  -----* I I I I   I I I-*-*---*
            29PLPR  -----*-I-* I I---* I I I    I---*
            81ABVS  -----* I  I I     I I I    I   I
Waster      24ELEL  -----* I  I I     I I I    I   I---*
            50ELLW  -----I-* I I      I I I    I   I    I---------------*
            57ELSC  ----I    I I      I I I    I   I    I               I
            31BGHD  -----*   I I      I I I    I   I    I               I
            64ELHS  -----------* I    I I I    I   I    I               I
            25ELLL  -----*-*     I    I I I    I   I    I               I
            45ELLL  -----* I-*---*    I I I    I   I    I----/\----*    I
            33SPPL  -------* I        I I I    I   I    I          I    I
            56ELSC  ----------*       I I I    I   I    I          I    I
Elgin clay  37ELLL  ----------------*---* I I  I   I    I          I    I
Kiln tile   40ELLL  ----------------*     I I  I   I    I          I    I
            32SPPL  ----------------------* I  I   I    I          I    I
            54ELHS  ------------------------*  I   I    I          I    I
            68ELLL  -----------------*--------* I   I    I          I    I
Abdn. clay  82ABVS  ------------------------*   I   I    I          I    I
Scarbro.w.  28ELLL  ----------*              I   I    I          I---*  I
            78ABVS  ----------I-------------*---* I   I    I          I    I
            83ELHS  ---------*              I   I    I          I    I
            79ABVS  --------------------------*  I   I    I          I    I
            71ABGI  -------------*--------------------* I   I    I          I    I
            80ABVS  -------------*                     I   I    I          I    I
            13ELHS  -----------------*                 I   I    I          I    I
            53PRTH  -----------------*-*---*            I   I    I          I    I
            73ABGI  ---------------*     I I---*        I   I    I          I    I
            42ELHS  ------------------*   I I-*-*       I   I    I          I    I
Balchrystie 75BALC  ------------------*-* I I I-----*--------------*    I    I
Balchrystie 76BALC  ------------------*   I I I   I                I    I
Siegburg    27ELLL  ------------------* I I   I                    I    I
Scarboro.   34ELLH  ------------------* I     I                    I    I
            55ELHS  ------------------*       I                    I    I
            65ELHS  ----------------------*                        I    I
Siegburg    26ELLL  ------------*-----------*                      I    I
Balchrystie 77BALC  ------------*                                  I    I
            60ELHS  ------------*--------*   I-----------*    I    I
            74ABG2  ------------*     I-------*          I------/\----I    I
            66ELHS  --------------------*                I    I
            62ELLW  -----------------------*-----------------*
            72ABG1  -----------------------*

                    *                    *              *   (break)   *
Dissimilarity       .125                 2.77           5.41          10.7
coefficient
```

Fig. 3 : Tree diagram taking into account all the elements analysed

Items linked by the shortest route (ignoring vertical distances) are most similar.

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No./Source

```
         11ELLL  --------------------------------------------*
         12ELHS  -------*-*                                  I
         44ELLL  --------*-*----*------*                     I
         15ELLL  --------*  I   I   I----------*             I
         32SPPL  ----------*    I       I                    I
         71ABG1  ----------------------*   I-----------*     I
         51ELLW  --------------------*----*   I         I    I
         36ELLL  --------------------*---*  I------*     I    I
         72ABG1  ---------*------------------*        I    I
         80ABVS  ---------*                           I    I
         16ELLL  -*---*                               I    I
         18ELLL  -*   I-*---*                         I    I
         50ELLW  -----* I   I                         I    I
         19ELLL  -------*  I-*-*                       I    I
         17ELLL  ---*---*  I I I                       I    I
         62ELLW  --*  I---* I I                        I    I
         46ELLL  -------*   I I---*                     I    I
 gin clay 37ELLL  -----------*  I   I                    I    I
         29PLPR  ----*---*   I   I              I--------*--------------------
         81ABVS  ----*  I-----I   I             I    I
         31BGHD  --------*   I   I---*           I    I
 Waster   24ELLL  ---------*---*   I   I------*-----------*   I    I
         57ELSC  ----------*      I   I   I       I---*   I    I
         22ELLL  ---*---*         I   I   I       I   I    I
         47ELLL  ---*  I-----*    I   I   I       I   I    I
         58ELSC  ------I    I     I   I   I       I   I    I
         30PLPR  -------*   I---*-*   I   I       I   I    I
         25ELLL  ----------*  I I     I   I       I   I    I
         45ELLL  --*-*---*---*  I     I   I       I   I    I
         56ELSC  -----*        I     I   I       I   I    I
         33SPPL  -------------*   I     I   I       I   I    I
         35ELLH  ---------*---------*   I     I   I       I   I    I
         64ELHS  ---------*          I     I   I       I   I    I
 Kiln tile 40ELLL  ----------------------*     I   I       I   I    I
 Abdn. clay 68ELLL  -------------------------*---------*     I   I
         82ABVS  -------------------------*               I   I
         54ELHS  -----------------------------------------*
         13ELHS  -----------------*--------*
         73ABG1  ----------------*     I---------*-*
         53PRTH  -------------------------*      I I
 Balchrystie 75BALC  ---------------------------------*  I
 Siegburg  26ELLL  -------*----------------*   I------------*
 Siegburg  27ELLL  --------*         I------------*   I      I-----*
 Scarbro. w. 34ELLH  --------------------*       I----*   I    I
 Balchrystie 76BALC  -------------------*--------------*   I    I
 Balchrystie 77BALC  ------------------*               I    I----------*----*
         42ELHS  -------------------------------*   I            I    I-----------
         66ELHS  -------------------------------*   I            I    I
 Scarbro. w. 28ELLL  -------------*-*               I            I    I
         83ELHS  -----------*---*----*           I            I    I
         74ABG2  ----------*       I---------------*---------------*   I    I
         60ELHS  -----------*----------*       I            I    I
         78ABVS  --------*               I            I    I
         79ABVS  ----------------------------*               I    I
         55ELHS  --------------------------------------------------*   I
         65ELHS  --------------------------------------------------*
```

Dissimilarity   *   *   *   *
coefficient   0.067   .989   1.91   2.83
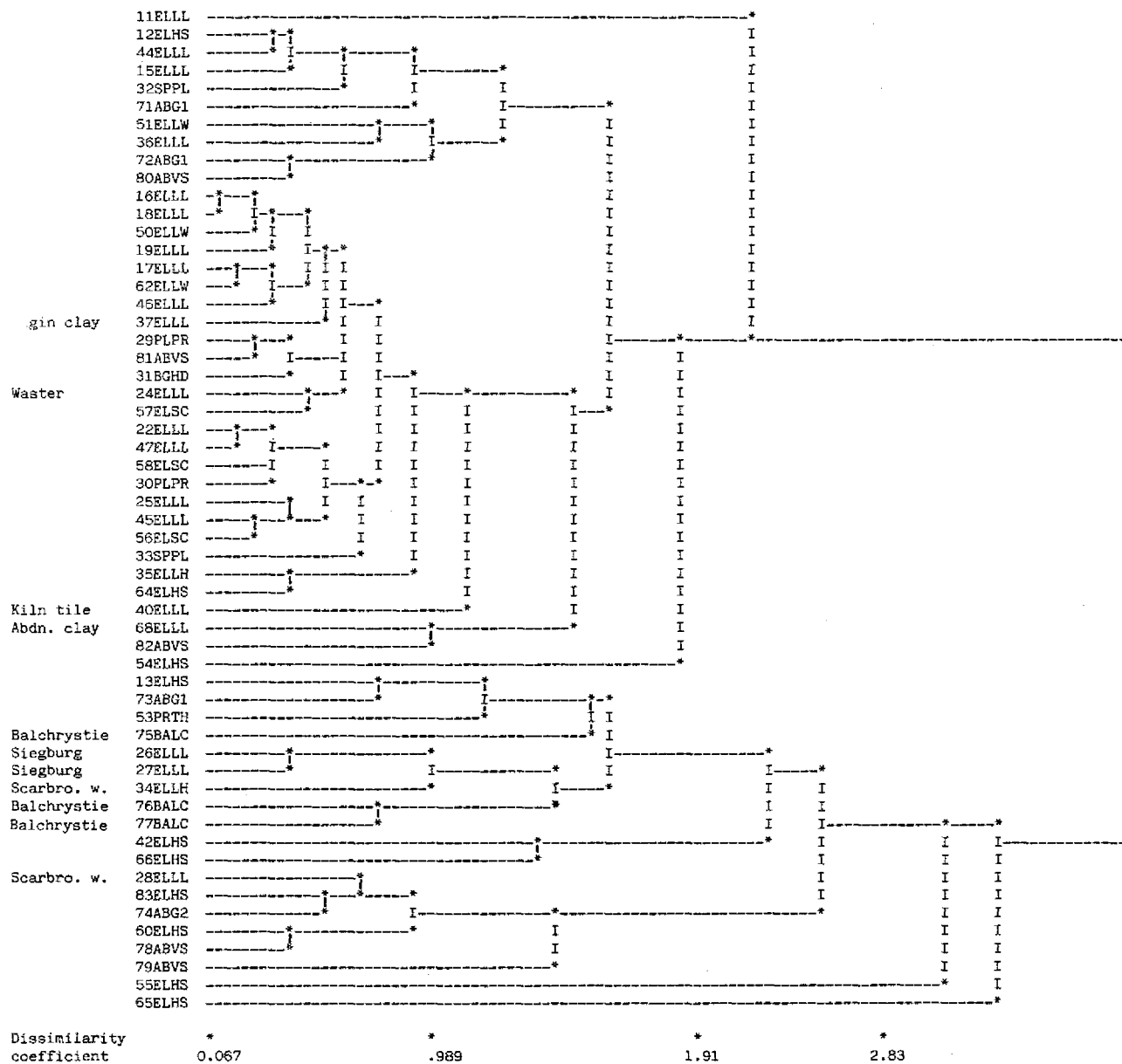
Fig. 4 : Tree diagram using the analyses of Na, Ca, K, Zn

Items linked by the shortest route (ignoring vertical distance) are most similar.

Note: The two branches of the tree join at a dissimilarity coefficient of 3.75.

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