STATISTICAL ANALYSIS OF SOME NOTTINGHAM CLAY TOBACCO PIPES

by R. C. Alvey, R. R. Laxton and G. F. Paechter

1. Introduction

In two previous papers the first two authors carried out a principal component and a cluster analysis of some clay tobacco pipes made in Nottingham during the period 1670-1730. Here we repeat these analyses but on a slightly bigger collection. Furthermore, we now know a considerable amount about the main pipe-makers of the period and these historical facts are used here to test ideas suggested by the purely formal analyses. In particular, they confirm that the 1st Principal Component gives rise to a chronological sequence for Nottingham pipes, that the volume V of the pipe bowl increases steadily throughout the period whilst at the same time the stem bore diameter does decrease slightly though its variation independent of time is considerably greater. By means of cluster analysis we have tried to describe the different pipe moulds used by the pipe-makers throughout their lives. As a result we have put forward the suggestion that each pipe-maker usually had two moulds at any one time. We are not able to test this further here but we do suggest various lines of enquiry for future investigations.

2. The early Nottingham Pipe Industry

The English clay pipe industry and the method of manufacture of pipes are described in considerable detail in Oswald (1975, Ch. 1 to 3). The Nottingham industry seems to have started in the mid 17th century and continued until the beginning of the 1920s (Alvey 1972). For reasons which will soon be made clear, the concern here is with the early period from about 1670 to approximately 1730. So far as we can tell, both from historical documents and the surviving pipes themselves the period is dominated by four names: R. Brinsley, I. James, W. Sefton and J. Wright. We say 'names' quite deliberately because we are confident we have in our collection pipes by two (or even possibly three) Richard Brinsleys and two James (John and Isaac). Indeed, one of the problems we have set ourselves is to find out which Richard made which pipes and which of the James' pipes were made by John and which by Isaac.

Most pipes from the period found in Nottingham today do not have identifying marks on them. These we ignore and consider only those stamped with the makers' mark. This mark almost always takes the form of the makers' initials incised on the pipe about halfway up the bowl facing the stem. A few pipes have as well a stamp decoration rolled around the stem and a couple have this stem decoration by itself. This latter form of marking, on the stem by itself, appears to have become the accepted mode towards the end of the period being considered; clearly this makes pipe identification extremely difficult and is the reason why our analysis of Nottingham pipes ends where it does—about 1730.

Pratt, E. E. A History of Transport and Communication.

Rogers, A. The Growth of Stamford.

Simpson, J. 1882. Lincolnshire Tradesmens Tokens of the 17th Century. 17

Simpson, J. 1881. Extracts from the Parish Registers of Stamford. In Reliquary and Quarterly Journal. XPR

Wells, P. 1973. Lincolnshire Pipe Makers. City and County Museum.

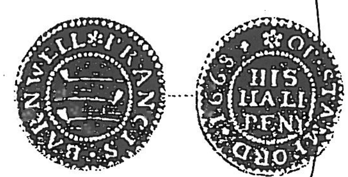


Plate 1. Tobacconist's token, 1668.

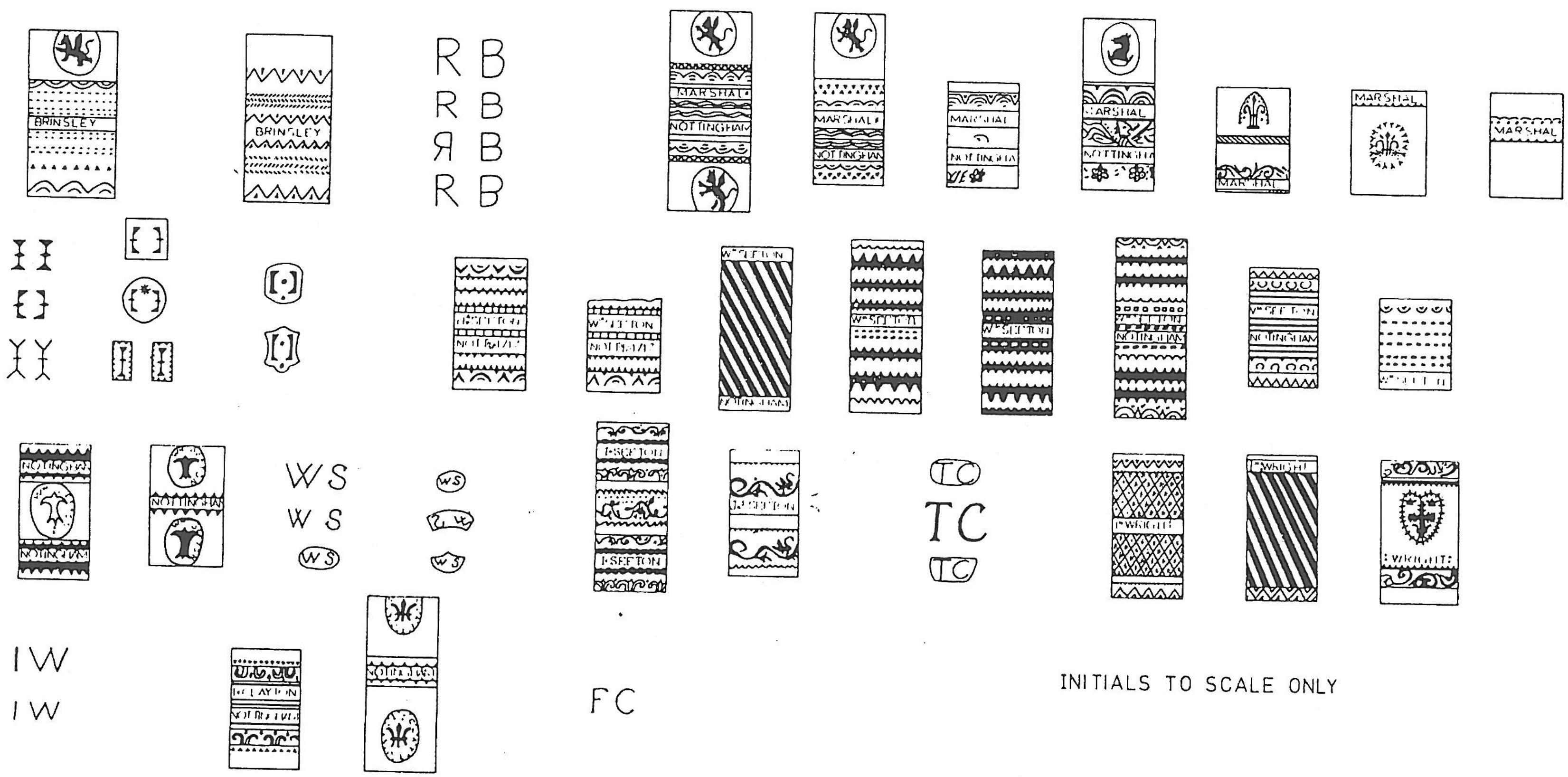


Fig. 1. Stamps of Initials and Stem Decorations.

Drawings of these stamps of initials and stem decorations used by the Nottingham pipe makers and their apprentices are shown in Fig. 1.

We know that pipes were cast in moulds and then fired in kilns. The Nottingham makers' initials were incised on the pipe bowl after moulding. Stamped pipes are almost always of better finish than the unmarked ones found with them in deposits. For example, they are quite often burnished whereas unstamped ones are rarely so. We feel justified in assuming that the (stamped) pipes we are analysing were good quality ones competing for the same market at any one time.

think about marks as signs of a certain quality/standard.

3. Historical records of Nottingham Pipemakers 1670-1730

Richard Brinsleys: The first reference we have to someone of this name in Nottingham is 'Richard Brinsle, for not paying wack, and puting out the constabell out of his house by violenc.' (Rec. Borough Nottm., Vol. V [1625-1702], p. 197, Item 5, 1640). This is dated well before our period begins but it is quite possible that this Richard is the father and grandfather of the two Richards who interest us.

On the 3rd July 1677 a Richard Brinsle, tobacco pipe-maker, is registered as a Burgess (Burgensis Natus, i.e. by birth, Nottinghamshire Records Office—hereafter denoted N.R.O.) and there is a reference to a Richard Brinsley, presumably the same, marrying a Dorcas Pim on 25th July 1682 (Nottm. Parish Reg. (St. Mary's Church), Marriages, Vol. I, 1566-1763, p. 100) and to the burial of two children each named Richard Brinsley on 12th Sept. 1683 and 12th Dec. 1686 (N.R.O., P.R. 2022).

The Richard Brinsley who became a Burgess in 1707/8 (Rec. Borough Nottm., Vol. V, [1702-1760], p. 315) was, presumably, a son of this marriage. The apprentice rolls have a 'Benjamin Marshall, son of William Marshall of Chesterfield, Ironmonger, bound apprentice to Richard Brinsley of the town of Nottingham, pipemaker, for seven years from 2nd Feb. 1724 in consideration of 1d.' (N.R.O., CA 1553). This almost certainly refers to the younger Richard. Marshall himself became a Burgess in 1731/32, (Rec. Borough Nottm., Vol. VI, p. 333) and married in 1746. Richard died a bachelor (N.R.O., PR 2023). The Nottinghamshire Records Office have the inventory of, presumably the younger, Richard's effects dated 30th July 1729 (N.R.O., PRNW). The total value of these is £15 15s 3d which includes pipes to the value of 16s 3d and clay and tools to the value of £6. He left property in Mary Gate and Barker Gate. Richard's mark on his will, dated 11th July 1729, is reminiscent of the R and inverted B stamped on some of his pipes (see Fig. 1).

One of the two persons signing the inventory list was a Joseph Marshall. From the stem decoration shown in Fig. 1 it can be seen that at least one Marshall was a practising pipemaker in Nottingham. Quite possibly this is Richard's former apprentice Benjamin, though there is a reference to a Joseph Marshal (one l) of St. Mary's, Nottm., pipemaker, bachelor, aged 22 marrying a Hester Sheers at St. Mary's on Aug. 14th 1724 (Nottm. Marriage Licences, Vol. II, p. 225, British Record Society). (The Nottm. Parish Reg. [St. Mary's Church], Marriages, Vol. I, p. 157 quotes a John Marshal marrying Hester Sheers on this date.)

John and Isaac James: John James married Elizabeth Chadwick on the 28 Nov. 1684 (Nottm. Parish Reg. [St. Peter's Church], Marriages, 1752-18 p. 61) and became a Burgess in 1700 (N.R.O.). There is an inventory of effects of a John James dated 7th Mar. 1720 (N.R.O., PRNW) which cites Isaac James, pipemaker, lawful son of John James, pipemaker. The tota value of John's effects was £4 10s 0d with clay and working tools valued at

The inventory of the effects of Isaac James is dated 14th June 1723, that he died just 3 years after his father. The value of Isaac's effects was £11 5s 0d and the working tools belonging to his trade were valued at £3. liam Sefton, pipemaker, signed the inventory. At the time of the making c will, 7th May 1723, Isaac, a bachelor, was weak and infirm. He had prop in Barker Gate, the High St. and warehouses, etc., in the Shambles Lane. gave to his aunt Elizabeth Sefton, wife of William, to Nathaniel James the younger, bricklayer, and £2 10s 0d to his nephews William and Richard C wick. William Chadwick was also a pipemaker who first married an Elizal Meachin in 1700 (Nottm. Parish Reg. [St. Nicholas'], Marriages, 1562-18 p. 35) and then as a widower aged 40, an Elizabeth Byard, a widow aged 35 at St. Nicholas' on 17th Oct. 1716 (Nottm. Marriage Licences, Vol. II, p. British Record Society).

Isaac marked his will with a symbol ∤ similar to the mark incised on pipes (see Fig. 1). One final point of a more personal interest, is that Isa entered in his will in brackets 'Elizabeth Sefton, wife of William Sefton (ex of her husband William Sefton, who shall have no power or concern with or the same)'.

William Sefton: Near to the west door of St. Mary's church is a headston in pipeclay to Elizabeth and Mary daughters of William and Elizabeth Seftor Elizabeth was christened on 28th March 1702/3 (N.R.O., P.R. 2025) and d on 29th May 1707 whilst Mary died on 1st June 1714, aged 6 (Alvey, 1972). (Close to this gravestone is one to a Nathaniel James, Bricklayer, who die on 20th Nov. 1710 aged 83; this could be the father of Nathaniel James the younger mentioned in Isaac James' will.) These are our earliest reference William.

The inventory of the effects of William is dated 8th Dec. 1729 (N.R.C PRNW) and from it we see that he was altogether much wealthier than the Brinsleys and James. He had extensive living quarters and the total value his effects was £164 17s 6d. Of this £71 7s 0d was in Malt and Barley so that he must have had associations with the brewing trade. The value of co clay and tools belonging to pipemaking were valued at £14 19s 0d. His will signed by his wife Elizabeth and Joseph and Nathaniel James.

Thomas Crew was bound apprentice to William in 1710 for the sum of £4 (N.R.O., CA 3930/10/126) and became a Burgess in 1716/17 (Rec. Bor Nottm., Vol. VI, p. 332). Thomas Dodds became Sefton's apprentice in 17 for the sum of £3 (N.R.O., CA 3931/12/15). In the latter's apprenticeship document Sefton is spelt Seffon, Seffton and Sephton as well as in the more usual manner.

Elizabeth's will is dated 4th March 1745 and the inventory, dated 10th May 1745, values her effects at £12 15s 0d (N.R.O., PRNW). She had property in Mary Gate and Barker Gate and mentioned Thomas, John and Joseph James as as nephews and gave to James Sefton, tobacco pipemaker, Jonathon Sefton and James Birch, pipemakers. Her will is marked with an inverted S somewhat similar to a mark stamped on certain of the Sefton pipes (see Fig. 1).

James Sefton of Mary Gate is noted in the Nottm. Poll Book for 1774, p. 34, and a pipestem marked Jas Sefton has been found in Nottingham. Others marked I. Sefton could possibly be by James or Jonathan. A George Sefton of Mary Gate is noted in the same Poll Book.

Two pipes by Henry Sefton dated 1717 are recorded in our data bank. The first author has inspected a pipe by W. Sefton which is almost identical to these two and similarly dated. It would appear that Henry married an Ann Rothwell, widow, at Bethnal Green in 1687. He signed the oath of allegiance as a London Journeyman in 1696 (Oswald, 1975, p. 32). It is possible he was related to William and came to Nottingham before 1717. On Feb. 17, 1719 a William Seston and Ann Rothwell were married in St. Mary's (Nottm. Parish Reg. [St. Mary's church], Marriages, Vol. I, p. 149) and later we find a reference to 'Ann wife of William Sefton' who is buried on 26th July 1721 (N.R.O., PR 2023); this seems to confirm it should be Sefton in the previous reference.

John Wright: We have little historical material on the last of our pipemakers, John Wright. He appears to have got a licence to marry on the 3rd April 1716 an Ann Clayton, aged 22, at the age of 27 (Nottinghamshire Marriage Licences, Vol. II, p. 129, British Record Society). He took as an apprentice a John Clayton who was bound to him in 1729 for the consideration of £4 (P. Boyd's Index to Apprenticeships, Vol. 49, Folio 143; Guildhall Library, London). Later this same Clayton became a Burgess in 1737/8 (Rec. Borough Nottm., Vol. VI, p. 337). As a pipemaker he, Clayton, is known by his stem decorations (see Fig. 1).

It is possible that Wright was later to become a pot maker for in the Nottm. Poll Book of 1754 a J. Wright, Mug maker, is listed.

This completes our survey of the historical records concerning the main Nottingham pipemakers and their apprentices. It shows that there was a good deal of inter-relationship between them and that they lived in or had interests in and around Mary Gate or Barker Gate. This is important to us since it means that changes and improvements in the manufacturing process, sources of good clay and changes in fashion would have spread readily among them. Hence their standards of working, type of clay and form of pipes are likely to be similar to each other at any one time. Consequently, we may expect overall fashion changes in shape during the period 1670-1730, rather than personal idiosyncracies, to be the main ingredient in the differences between the pipes in our collection. It is the nature of fashion that objects for a particular market are more alike than they are distinct at any one time; a maker may bring out an innovation which if successful will be copied by others but if not it will be dropped. This is our working model.

4. Nottingham Pipe Data Bank

Our data on Nottingham pipes is stored on the University ~~of Nottingham~~ Computer (Cripps Computing Centre) and contains records of 223 stamped pipes from the period (this compares with 206 at the time the 1974 article was writte Among these are 10 pipes by R. Brinsley and 2 by James which have large flat spurs and these 12 we do not include in our analysis. The remaining 211 we analyse have the typical pointed spur. Among the 211 remaining are 6 pipes made by T. Crew, 5 by E or F. Chadwick and 2 by H. Sefton (both dated 1717). This leaves us with the main part, 198 pipes made up as follows:

48 pipes by the Brinsleys	(numbered 001 to 048 in the bank)
63 pipes by the James	(numbered 101 to 163 in the bank)
46 pipes by W. Sefton	(numbered 201 to 246 in the bank)
41 pipes by J. Wright	(numbered 301 to 341 in the bank).

Fig. 2 shows the 13 measurements which are recorded in the data bank f each pipe. It is these we use in the following analyses and they do, we think, provide an adequate description of the pipes in terms of shape and size. Thus a pipe whose set of values for the 13 coordinates is more or less the same as that for another pipe will look like it and vice versa. Lengths are measured in mm and volume in ml. The 13 coordinates are, in order, V (the volume of the cavity in the pipe bowl), H_1, D_2, D_2-D_1, D_3-D_2, D_3-D_4 (The latter two indicate the shape of the bowl), $(h_1-d_5)/H_1$ (the tangent of the angle of the bowl to the vertical), $(h_2-h_1)/D_1$ (the consine of the angle of the bowl top to the horizontal), d_1, d_2 (stem measurements), d_3, d_4 (spur measurements) and d_5. Thus a typical entry in the Nottingham Pipe Data Bank reads

(205) 04.200 24.000 19.600 04.700 01.600 07.200 00.804 00.888
10.200 02.700 05.000 06.800 04.500 (NR S2.2 G)

The first entry is the pipe record number (5th pipe of W. Sefton), then the 13 measurements in the order given, NR tells us there is no rouletting on the pipe, S2.2 that the stamp is a small one of height 2.2 mm and G indicates that the pipe was in good condition at the time it was measured.

The instruments used for measuring the pipes are described in detail in our 1974 article.

5. Principal Component Analysis

The first quantitative assessment of the data on the 211 pipes is a principal component analysis (P.C.A.). Technical but readable accounts of the method can be found in Hope (1968) and Kendall (1957). It should be emphasized that as we have used this tool here it is not a statistical one in the sense of hypotheses testing. Rather, it is used in a quantitatively descriptive manner so that certain important aspects of the data can readily be seen and interpretations made possible. The formal aspect we want to look at is the variability within the total data on the pipes, i.e., the sum total of the differences betwee all data points in the data bank.

Example: We will describe P.C.A. with the aid of a hypothetical set of data. Imagine for the present that only three measurements have been made on each pipe, say the volume V, the tangent t $(t=(h_1-d_5)/H_1)$ and the spur height d_3. Thus each pipe in our hypothetical collection of 26 pipes is represented in a data bank by three values, for V, t and d_3 respectively.

Table 1. Hypothetical data

V	t	d_3	V	t	d_3
3.10	0.840	5.01	2.80	0.850	5.01
3.00	0.840	5.00	2.90	0.830	5.00
2.80	0.830	5.00	3.00	0.870	5.00
2.80	0.830	5.00	3.10	0.860	5.00
3.20	0.820	5.00	3.20	0.850	5.00
2.90	0.840	5.00	3.50	0.850	4.99
3.10	0.850	5.00	3.40	0.870	5.00
3.20	0.850	5.00	3.60	0.870	5.00
3.30	0.860	5.00	3.30	0.850	5.00
3.40	0.870	5.01	3.10	0.840	5.00
3.50	0.870	5.00	2.60	0.820	4.99
3.60	0.880	5.00	2.80	0.830	5.00
2.70	0.820	5.00	3.60	0.900	4.99

do this once GS

We see immediately that almost all the pipes in the collection have the same value 5.00 mm for the spur height. Hence we fell justified in ignoring this third coordinate altogether and consider instead the data in the simplified form (V,t). That is, a pipe which was previously represented by three numbers is now represented quite adequately by two. This of course, is a great advantage since we can plot this modified data on a graph of V against t and little is lost in doing so. We might even put a figure to this loss in difference between the pipes—say 5% of the total variability is lost in making this approximation.

data collect minimize stupid measurements

The (V,t) data is plotted in Fig. 3.

We see in this graph that there is a marked, though not perfect, positive correlation between the values of the volume V and those of the tangent t—as V gets larger t tends to do so as well. Now let us draw a line P_1 through the centre which passes among the main group of data points, a best fitting straight line. Evidently most of the differences between the pipes in our hypothetical set takes place not so much in their values of volume V alone, or in those of their tangent values t alone, but rather as a combination of the two along this line P_1—which we call the 1st component. The P_1 value of a pipe is the best value to use if we only want to quote one figure for a pipe (and not two or three). Again we might put a figure to the percentage of the total variability between pipes represented by their P_1 values along—say 60%. ?

The remainder of the difference between the pipes must be accounted for by their P_2 values, where P_2, the 2nd component, is the line through the centre drawn at right angles to P_1. Since we have said that d_3 values account for 5% and the P_1 values for 60%, the P_2 values must, therefore, account for 35% of the total variability within the data set.

Both P_1 and P_2 are linear combinations of V and t and there is no difficulty in determining precisely these combinations if they are needed. Notice also that whereas the V and t values are highly correlated the P_1 and P_2 values are not. For this reason, and for others we have mentioned above, it is often advantageous to plot the 2-dimensional data not as a (V, t) graph but as a (P_1, P_2) graph, i.e. use the first two components as the axes of the graph.

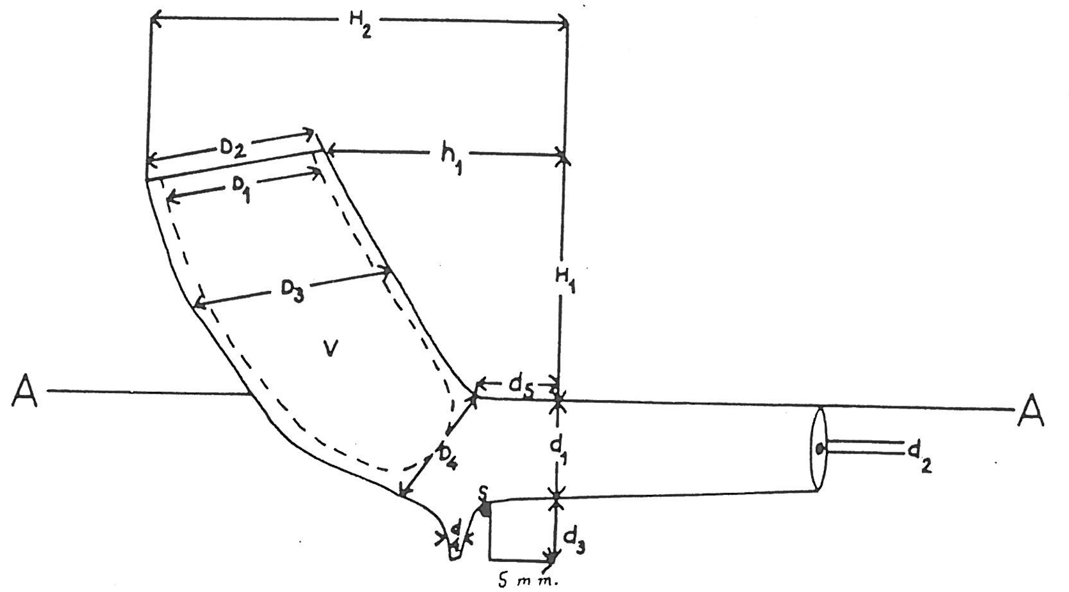


Fig. 2. Pipe Measurements.

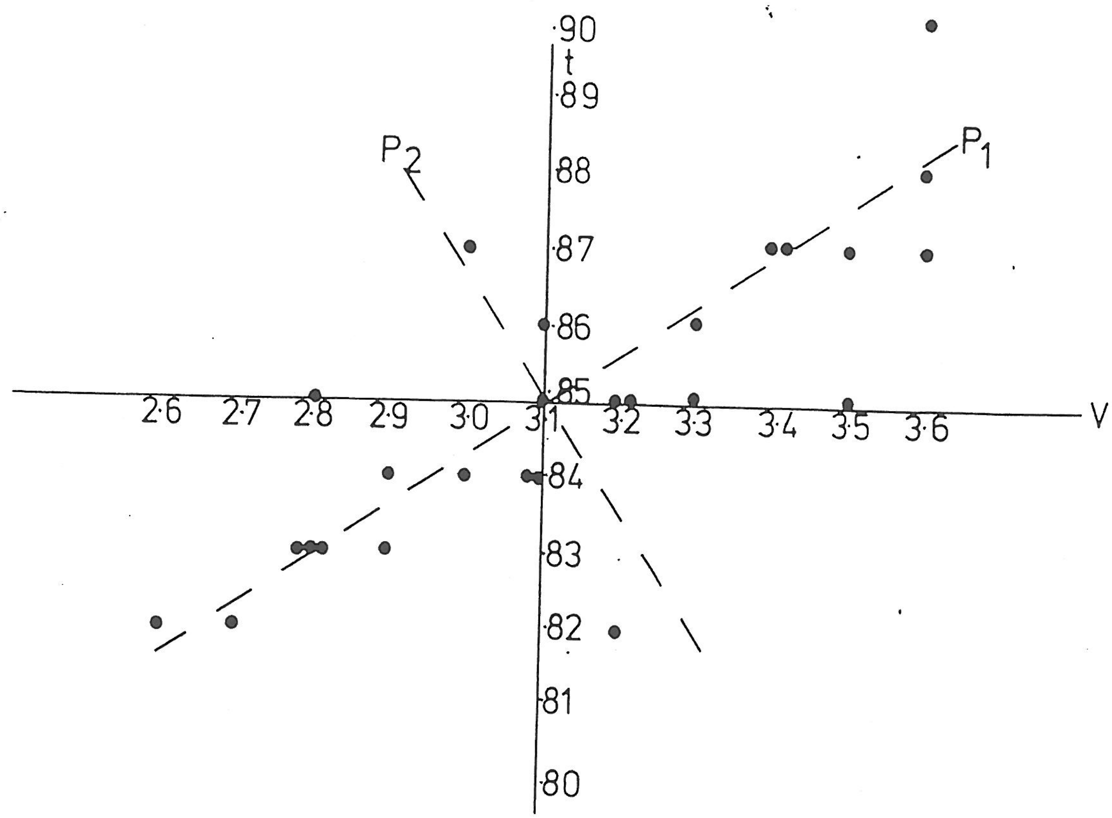


Fig. 3. Plot of Hypothetical Data.

This ends the formal analysis of the hypothetical data and, whilst glossing over certain technical details, it is what constitutes Principal Component Analysis. Of course, the reduction of 13 dimensional data, as in the Nottingham Bank, to 1 or 2 dimensions is much more arduous and a computer is needed to effect it. Nevertheless, in principle it is no more difficult. The real difficulty, and the point of P.C.A. for us, lies elsewhere. Having carried out a formal reduction of the data from many to a good best-fitting 2 dimensions (along the 1st and 2nd components) we have to give an interpretation, in this case an historical one, to the picture we see in the graph. We will attempt this for the Nottingham pipes—especially the meaning of the variation along the 1st component. We have already hinted at what it should be.

The Nottingham Pipe Data

The P.C.A. on the Nottingham pipe data is carried out with the aid of a standard computer program (B.D.M. 01M Biomedical Computer Program, Ed. W. Dixon, Univ. California Press, 1970). Starting with the more complex situation of 211 data points each with 13 coordinates representing the pipes, the program outputted, among other things, the 1st and 2nd p.c.s. Here are the results of this analysis.

The value of a data point $(V, H_1, D_2, D_2-D_1, D_3-D_2, D_3-D_4, (h_1-h_5)/H_1, (H_2-h_1)/D_2, d_1, d_2, d_3, d_4, d_5)$ on the 1st p.c. is given by the formula (linear combinations)

$$(1)\quad P_1 = 0.34V+0.33H_1+0.39D_2+0.25(D_2-D_1)-0.34(D_3-D_2)+0.34(D_3-D_4)$$
$$-0.13(h_1-d_5)/H_1+0.23(H_2-h_1)D_2$$
$$-0.19d_1-0.23d_2-0.07d_3+0.27d_4+0.30d_5$$

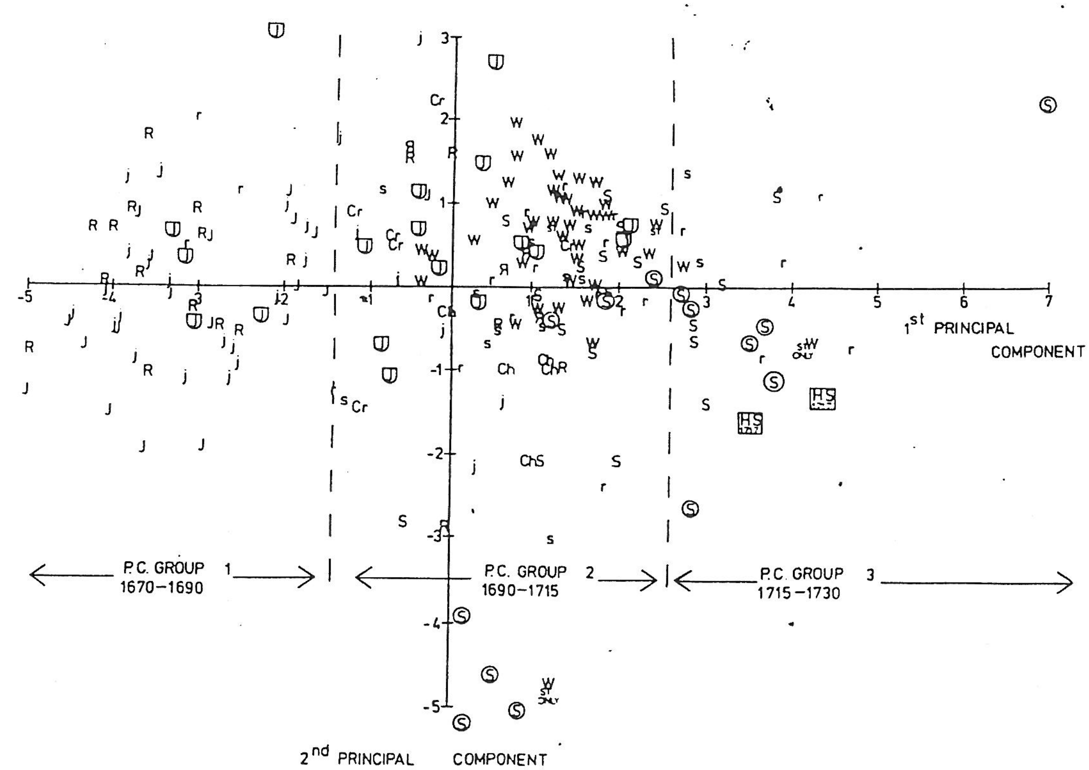
and on the 2nd p.c. by

$$(2)\quad P_2 = 0.11V+0.31H_1+0.19D_2+0.23(D_2-D_1)-0.15(D_3-D_2)-0.30(D_3-D_4)$$
$$-0.30(h_1-d_5)/H_1-0.15(H_2-h_1)/D_2$$
$$+0.58d_1+0.50d_2+0.12d_3+0.07d_4+0.03d_5$$

(Actually the 13 coordinates are normalized so that each has mean 0 and standard deviation unity.)

The 1st p.c. P_1 accounts for 41% and the 2nd p.c. for 13% of the total variation in the data, making 54% in all for the first two components. There are eleven further p.c.s and these account for smaller and smaller percentages of the total variation (all given in the computer output). An important point to remember is that the greatest variation of 41% along the 1st p.c. P_1 is (statistically) independent of the variation along all other 12 principal components. The graph of the values of P_1 and P_2 for the 211 data points is given in Fig. 4. The pipes by the various makers and the various styles of stamps of initials used, small, large, shield, etc., are marked differently in Fig. 4. On the whole this graph agrees well with the one given in the 1974 paper when a smaller collection was used.

The formula (1) shows that it is largely V, H_1, D_2, D_3-D_2 and D_3-D_4, i.e. bowl size and shape, which determines the P_1 value of a pipe and hence a large



KEY

SEFTON	BRINSLEY	JAMES	WRIGHT	
HS H. SEFTON	R LARGE STAMP	J LARGE STAMP	W	Cr CREW
S LARGE STAMP	r SMALL STAMP	j SMALL STAMP	ST STEM DECORATION	Ch CHADWICK
Ⓢ SHIELD	Я REVERSED R	SHIELD		
s SMALL STAMP				

Fig. 4. Graph of the first two principal components of the Nottingham pipes.

part of the variation in the data. The coefficient of V in (1) is relatively large and positive (+0.34) and this means that as we pass along the 1st p.c. P_1 from negative values to positive ones (i.e., left to right in Fig. 4) the volume V increases quite markedly. In contrast the coefficient of d_2 in (1) is negative and not so large in magnitude (-0.23) and so the stem bore diameter d_2 will slowly decrease as we pass along the 1st p.c. P_1 from negative values to positive ones. Finally, because the coefficient of d_3 is relatively small its change of value along P_1 is even less pronounced. To illustrate this we have plotted (to the same scale) V, d_2 and d_3 against P_1 for each pipe.

From (2) it is clear that the most important factors influencing the P_2 value of a pipe are the values for d_1 and d_2, i.e. the stem characteristics.

It remains for us to interpret this formal analysis. We have already indicated at the end of section 3 that time with its attendant changes in fashion, technology and economy is likely to be the main ultimate cause of the differences between the pipes in our collection—time, that is, rather than market distinctions or maker's own idiosyncracies. This, then, leads us to propose that the formal variation along the 1st p.c. P_1 (accounting for 41% of the total) is brought about by changes in the size and shape of pipes as time passes during the period 1670 to 1730. Thus we propose to think of the P_1-axis as a time-axis. We will support this contention now with an indirect historical argument and in section 7.2 put it to more severe tests.

We know that the price of tobacco dropped during the period 1650 to 1750 from 7s-10s per pound in 1652, to 1s-1s 8d per pound in 1684 and thence to 3d-8d per pound in the early 18th century (Thorold Rogers 1920). Such a dramatic decrease in price will almost certainly be correlated with an increase in the size V of the pipe bowl. This is exactly what occurs along the P_1-axis—from about 2.5 ml at low negative values to about 5.0 ml at high positive values of P_1 (see Fig. 5).

We propose, then, that the 1st principal component P_1 in Fig. 4 records the changing shape and size of the pipes as time passed during the period. With this in mind we have split the pipes into three 1st principal component (P.C.) groups according to their P_1-values. (The dates we give to these P.C. groups are merely here to give the reader an idea of our lines of interpretation; they will be substantiated in section 7.)

P.C. Group 1 consists of 55 pipes made by the Brinsleys and James' with P_1 values between -5.0 and -1.4. To this set we give the approximate period 1670-1690 (bottleseals dated 1660 and 1665 were found with 5 of these pipes).

P.C. Group 2 consists of 122 pipes made by all four of our main makers (as well as by the minor ones) with P_1-values between -1.4 and +2.6. To this set we give the approximate period of 1690-1715 (a bottleseal dated 1698 was found with 4 of these pipes).

P.C. Group 3 consists of 21 pipes made by W. Sefton, Brinsley and Wright and two made by H. Sefton (both dated 1717) with P_1-values between +2.6 and +7.0. To this set we give the approximate period 1715-1730.

We carried out a further test, of a quite different sort, to see if our P.C. Groups 1, 2 and 3 were intrinsically distinct from each other. We made a collection of initialled pipes which, although slightly damaged, we were confident

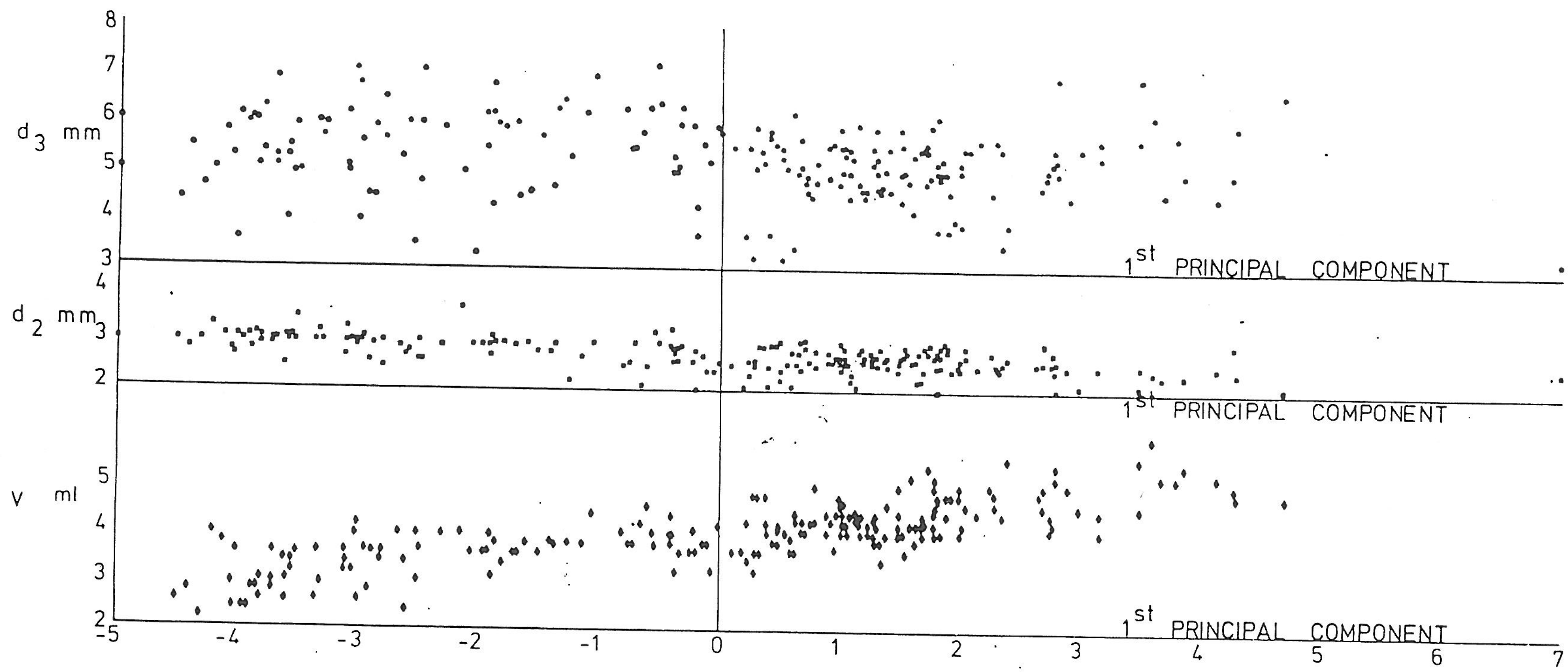


Fig. 5. Graphs of V, d_2 and d_3 against P_1.

were similar to pipes from the different P.C. groups (we carried out a visual inspection and measured where possible). This consisted of 5 by Brinsley and 6 by James similar to those in Group 1, 6 by Brinsley, 6 by James, 6 by W. Sefton and 6 by Wright similar to those in Group 2 and 2 by W. Sefton similar to those in Group 3. The clays of these pipes were chemically analysed by X-ray Fluorescent Spectrometry and it showed quite clearly that the differences in the chemical compositions were between pipes from the different P.C. Groups rather than between pipes by the different makers. This result provides us with independent evidence for the integrity of our P. C. groups. Of course, this does not tell us that our groups are chronological, though an interpretation of the experiment is that the clays used by the Nottingham pipemakers changed from time to time during the period. (The full details of the chemical methods used and the results obtained can be found in Alvey and Laxton 1978.)

6. Cluster Analysis

If we are correct in our interpretation, then, the 1st p.c. P_1 gives us a picture of how Nottingham pipes gradually changed during the period 1670 to 1730. Now we need to look at the differences between the pipes in another way in order to tackle another problem. Since pipes were moulded we expect pipes made in the same mould to look alike. Of course, they will not be identical in shape and size; normal working conditions for moulding, drying and firing will produce differences between them. However, we expect them to be more alike than pipes from different moulds. The task we set ourselves is to separate the collection of pipes made by a maker (and possibly his son) into sets of pipes each made in the same mould. If we can achieve this, then we will know how many moulds the makes used in his working life and, perhaps, how many he was using at any one time.

There are many difficulties in such an analysis. In the first place we have only the evidence of the pipes in our data bank and these may not include samples from all the moulds used by a pipemaker. 1

In the second place there is the technical difficulty of distinguishing between pipes from different but similar moulds, for example, a matching pair. Cluster Analysis is the method we use to help us in this endeavour; it is a formal procedure to split a set of data points into clusters of 'near' points so that the corresponding pipes are similar to each other whilst pipes with data points in different clusters are dissimilar in some important respects. The hoped for interpretation is that each cluster will correspond to a distinct mould. Again as with Principal Component Analysis, it is the interpretation that is the difficulty and needs to be tested with as many independent tests as possible. The book by Everett (1974) contains an introduction to clustering methods. 2

We have used one of the standard methods of cluster analysis and the basic computer program used, CARM, was taken from the statistics package PMMD compiled by M. Youngman of the Department of Education, University of Nottingham. We are grateful to Mr. Youngman for allowing us to use it. We will illustrate the technique with an example we used earlier in an article in Science and Archaeology and thank its Editor Dr. J. D. Wilcock for allowing us to do so.

Example

In very broad outline the process goes as follows. We begin with some large number N of clusters (e.g. N 20, which is many more than we expect to find). Reallocation of points takes place if they can be better grouped. Tw clusters are then amalgamated (according to a fixed criterion) and points re-allocated from the old clusters if they can now be better placed in others in this new clustering. Two clusters among the new (N-1) clusters are then amalgamated and the whole process repeated again and again to get a set of k clusters for each k = N, N-1, . . . , 3, 2, 1 (an agglomerative procedure with re-allocation). The whole program is repeated several times with different groupings to start with. The clusters at each k-level for all runs are compared to see if the same (or essentially the same) k clusters are appearing ea time, at least for the smaller values of k (k 12, say).

sample

The Bristol City Museum very kindly made available to us a large collection of clay pipes found together on a site in the city. (See Jackson and Price [J & P], 1974 Appendix I, where some of the material is described and sample pipes drawn.) We measured some of the groups of pipes in this collection with the same apparatus we had used for the Nottingham pipes (see our 1974 paper for a description of this apparatus). In particular we measured

(i) 16 very similar pipes with the letters PY moulded on the sides of the bowls (J & P, p. 118);

(ii) 21 very similar pipes with the letters IC enclosed in a heart moulded on the sides of the bowls (J & P, p. 116, top right hand).

Table 2. The mean values for each of the groups of Bristol pipes (V in ml, lengths in mm)

Dimension	Y-P pipes (8)	P-Y pipes (8)	IC pipes (21)
V	3.9	4.2	5.0
H_1	22.6	22.4	24.8
D_2	20.7	21.3	22.5
D_2-D_1	5.6	5.4	6.6
D_3-D_2	0.2	0.5	0.4
D_3-D_4	8.3	9.8	8.9
$(h_1-d_5)/H_1$	0.4	0.3	0.4
$(h_2-h_1)/D_2$	1.0	1.0	1.0
d_1	8.9	9.1	8.5
d_2	2.1	2.1	2.1
d_3	4.1	3.4	4.8
d_4	6.5	7.3	7.1
d_5	8.9	9.3	5.9

These pipes have been dated to the early 1780s (J & P, p. 115). Now it is probably correct to assume that these 21 IC pipes were all made in the same mould. Of the 16 PY pipes, half had Y moulded on the left and P on the right (Y-P pipes) whilst the other half had P moulded on the left and Y on the right side (P-Y pipes) of the bowl. Therefore it is very reasonable to assume that these two sets of pipes were made in two very similar moulds.

We applied the CARM cluster analysis program to this set of 37 pipes. The program was run several times with this data starting from several different randomly chosen clusters. (This is necessary because any one set of initial clusters may influence to some extent the final clusters obtained.) The following one starting from 17 clusters was quite typical.

The Y-P pipes are numbered 1 to 8, the P-Y pipes 9 to 16 and the IC pipes 17 to 37. We record here the actual clusters obtained at the 5-, 4- and 3- and 2-cluster stages.

5-cluster stage

Cluster 1 (1,3,9)
Cluster 2 (2,4,6,7,8)
Cluster 3 (5,10,11,12,13,14,15,16)
Cluster 4 (17,18,19,20,24,27,28,29,30,32,33,35,36,37)
Cluster 5 (21,22,23,25,26,31,34)

Clusters 4 and 5 merged, no reallocation, to give the

4-cluster stage

Cluster 1 (1,3,9)
Cluster 2 (2,4,6,7,8)
Cluster 3 (5,10,11,12,13,14,15,16)
Cluster 4 (17,18,...,37)

Clusters 1 and 2 merged, pipe 9 reallocated, to give the

3-cluster stage

Cluster 1 (1,2,3,4,5,6,7,8)
Cluster 2 (5,9,10,11,12,13,14,15,16)
Cluster 3 (17,18,...,37)

Clusters 1 and 2 merged, no reallocation, to give the

2-cluster stage

Cluster 1 (1,2,...,16) The PY pipes
Cluster 2 (17,...,37) The IC pipes

It is perhaps not too surprising that the PY and IC pipes have been clustered separately at the 2-cluster stage since the means are quite different in a few dimensions (see Table 1). But at the 3-cluster stage it has done a much finer analysis and separated the pipes from the two similar moulds into two clusters with only one error.

This example, and some others like it, give us every reason to hope that this clustering program can yield meaningful clusters (i.e. corresponding to moulds) for the Nottingham pipes. Obviously nothing is guaranteed.

Nottingham pipe data

In our 1977 article (see p. 22) we used the idea of 'co-clustering' wherein we compared the clustering of the Nottingham pipes to that of the two sets of Bristol pipes used in the above example. In contrast we will now use the

CARM program by itself because since that article was written the program has had additional statistical tests added to it. One great difficulty with the technique is to decide what is the best number of clusters at which to finish. In the above example we knew beforehand that 3 was very probably the correct number. But how could we have decided this without prior knowledge?—which is clearly the case with the Nottingham pipes. There is no rule or theory for this but the program output does provide statistical aids to help us make a wise decision. Each time two clusters of data points are merged a fusion coefficient is calculated. Roughly speaking, if two such clusters are 'near' to each other, then the fusion coefficient has a low value whilst if they are 'far apart' it has a high value (in the method of Ward used here the value of this coefficient also depends on the size of the two clusters merged). When the merging process starts, with many clusters, this coefficient tends to be small and increases but gradually. If at some point in the merging process the value of this fusion coefficient increases sharply, we pay particular attention to the clusters just prior to this sharp increase. There are as well in the CARM program certain statistical tests which test the hypothesis that any two clusters are genuinely different, and not just two samples from one big cluster These formal aids merely help us to make rational decisions in the face of a vast amount of data.

For each maker (and possibly son) we give a table of cluster size, mean values of the 13 coordinates for each cluster and the p.c. Group 1, 2 or 3 to which they belong (in one or two cases a few outliers belong to a p.c. Group different from that of the main set in the cluster). In all cases it can be assumed that the clusters satisfy the statistical hypotheses that they are distinct (at 95% confidence level in a one-way analysis of variance using the F-test). Each analysis of a makers' pipes is made on the basis of 3 runs starting from different initial clusters with at least 28 clusters each time.

The numbers given to the clusters are those used in the 1977 paper. Thus if we give the number 3/4 to a cluster it refers to the fact that it is in essence the amalgamation of clusters numbered 3 and 4 in the previous analysis.

Richard Brinsleys (48 pipes)

All 3 runs suggested 5 clusters as optimum, 2 gave exactly the same pipes in each cluster whilst the third differed from them in only a few cases. This compares to the 6 clusters previously selected in our 1977 analysis based on 42 pipes. However, apart from the amalgamation of two of the clusters, the final results of the present and the previous effort are not too different (see Table 3).

The distribution of the different stamps of initials used on the pipes in the various clusters is shown in Table 4.

We suggest that the 5 clusters correspond to 5 different moulds used by the Brinsleys and from the evidence of their association with the various P.C. Groups, that the large stamp gradually gave way to the small one. (Note that the four pipes with the B stamped in reverse are entirely within one cluster 3/4.) Furthermore, we might conjecture that although the two Brinsleys worked together over a long period of time using the same moulds, they used different stamps, the elder using the large and the younger the small stamp of initials.

Table 4. R. Brinsleys: Distribution of stamps of initials among clusters

Cluster No.	P.C. Group	Numbers of L.	S.	R.B
1	1	9	1	0
2	1	6	3	0
3/4	2	4	8	4
5	2	0	9	0
6	3	0	4	0

Key: L = large; S =small; R.B = Reversed B

James' (63 pipes)

All 3 runs suggested the same 6 clusters as optimum and these were the same as those obtained in the 1977 analysis based on 58 pipes (see Table 5).

The distribution of the different stamps of initials used on the pipes in the various clusters is as follows.

Table 6. James': Distribution of stamps of initials among clusters

Cluster No.	P.C. Group	Numbers of L.	S.	Sh.
1	1	1	10	2
2	1	7	1	1
3	1	3	5	2
4	1	3	6	1
5	2	0	1	9
6	2	4	4	3

Key: L = large; S. = small; Sh. = shield

We suggest that these 6 clusters correspond to 6 different moulds used by the James, John and Isaac. What is striking from Table 6 is that the two clusters 1 and 2 of rather similar pipes are strongly associated with the stamps of small and large initials, respectively. This, we argue, lends support to their integrity as corresponding to genuinely different sets of pipes. (We remark that clusters 3 and 6 are very close to the P.C. Groups 1/2 border with 3 just in Group 1 and 6 just in Group 2).

W. Sefton (46 pipes): The 1977 analysis was on 39 pipes only and 6 clusters were found. Among the extra 7 pipes are 4 found in Derby. All 3 runs of the present analysis suggested the same 7 clusters, but these are somewhat different from 1977 ones. The original cluster 1 consisting of 2 pipes only (see Alvey and Laxton 1977, Table 2) has now disappeared. Clusters 2, 3, 4, 5 and 6 are essentially the same in both the 1977 and the present analysis. The Derby set of 4 pipes forms a new cluster, numbered 7, and one of the other pipes recently added to the data bank forms the new cluster by itself (see Table 7).

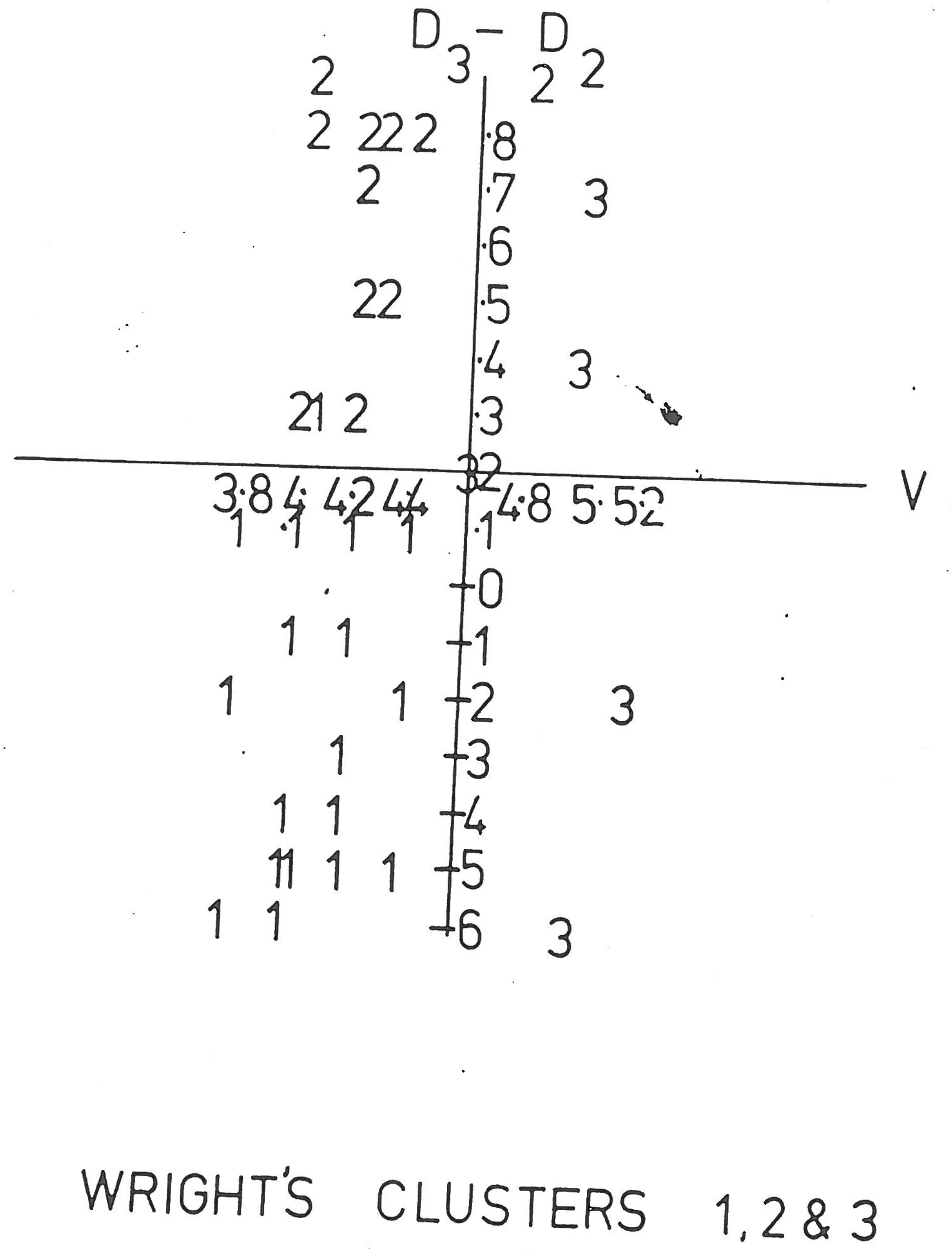


Fig. 6. Distinction of main clusters of Wright's pipes.

The distribution of the different stamps of initials used on the pipes in the various clusters is as follows.

Table 8. W. Sefton: Distribution of stamps of initials among clusters

Cluster No.	P.C. Group	Numbers of L.	S.	S/S
2	2	4	5	0
3	2	3	5	1
4	2	5	3	3
5	2	2	0	2
7	2	0	0	4
6	3	3	0	5
8	3	0	0	1

Key: L. = large; S. = small; S/S = shields/stem

Again we interpret these 7 clusters as groups of pipes from 7 different moulds used by Sefton. The 4 pipes in the 'Derby' cluster are quite different from any of the other Sefton pipes we have found in Nottingham and we wonder whether he had a separate style of pipe to supply towns outside the city. There is little that can be said about how Sefton varied his use of the different styles of initials incised on his pipes except that he took to using a shield and stem decoration towards the end of the period.

J. Wright (41 pipes): We have found no more pipes made by Wright since the 1974 article was written. All 3 runs suggested the same 5 clusters of pipes; the 2 clusters 4 and 5 with just one pipe each are as earlier, cluster 2 is essentially the same as the earlier cluster 2 but the new cluster 1 is a union of the old cluster 1 and half of the old cluster 3 of the 1977 analysis (see Table 9).

Here the interpretation is unclear since two of the clusters are singletons; perhaps we will be content to say that Wright used at least 4 moulds during his working life (the bowl of the pipe in cluster 4 was badly distorted so that it may well be from the same mould as the pipe in cluster 5). Furthermore, there is no help from the incised initials since Wright used the same smallish stamp on all his pipes in the collection except for four which had stem decorations. The two pipes in clusters 4 and 5 had stem decorations only whilst one in cluster 1 and one in cluster 3 had both the initials on the bowl and a stem decoration.

As a final example of what cluster analysis can do we will show how the three Wright clusters 1, 2 and 3 were distinguished by CARM. The output of a computer run indicates in which of the 13 coordinates the various clusters differed most significantly. Here it showed that these three clusters differed a great deal in either their values of V or of $(D_3 - D_2)$ or of both, as can be seen in the opposite graph.

7. Summary and Conclusions

The important historical dates and their relationships to the P.C. Groups are shown in Fig. 7.

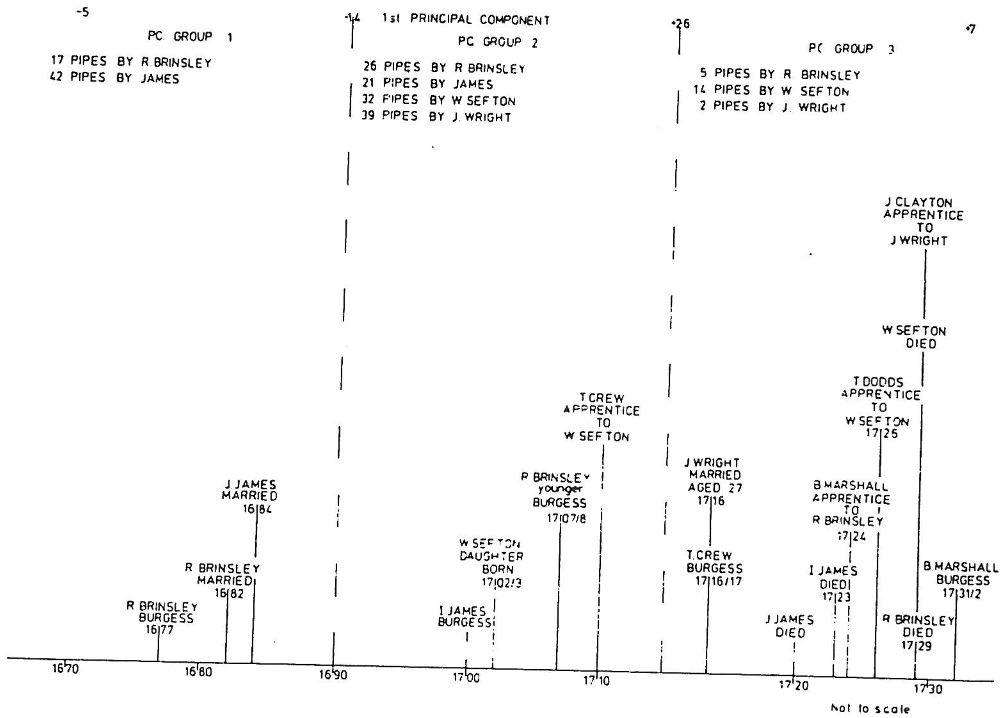


Fig. 7. Historical dates.

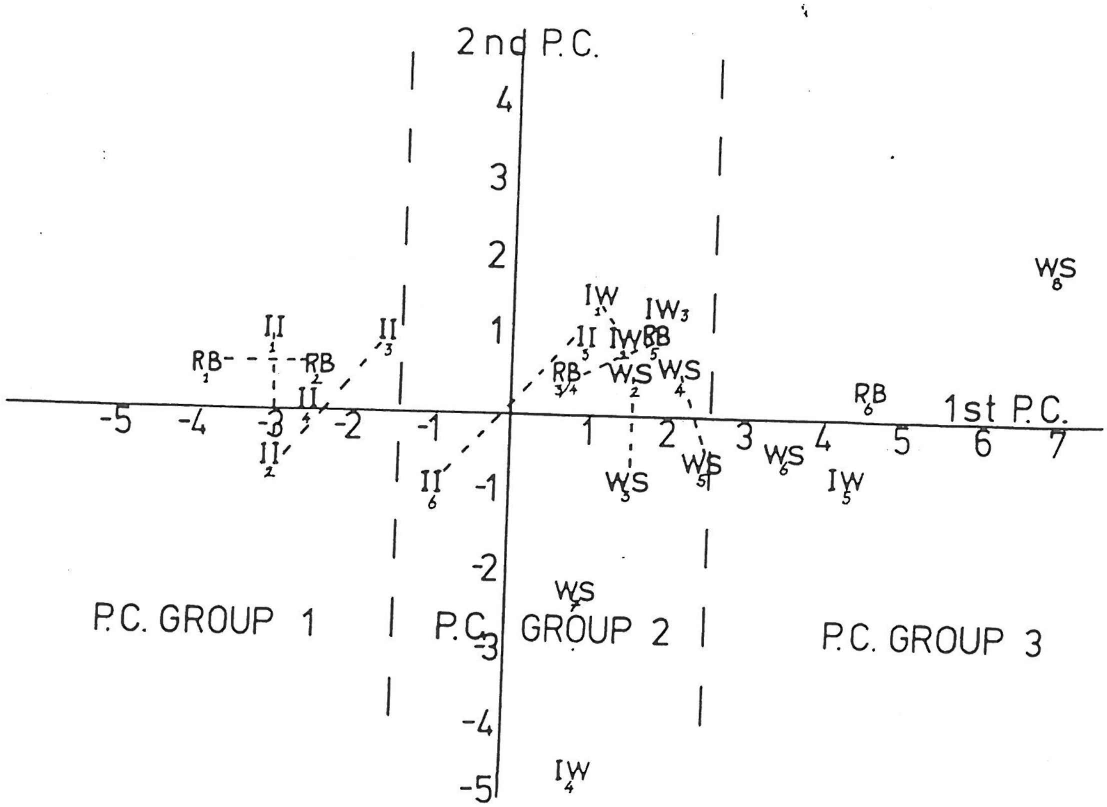


Fig. 8. Suggested pairs of moulds.

This shows quite clearly that our interpretation of the 1st Principal Component of the P.C.A. (see Fig. 4) as a time-axis is largely correct. During the period 1670-90 it would seem that only the elder Richard Brinsley and John James were practicing pipemakers; P.C. Group 1 consists of 17 pipes by Brinsley and 42 by James. During the period 1690-1715 all four pipemakers and/or their sons were producing pipes (John Wright was married in 1716 at the age of 27 so that in the normal course of events he would have been a pipe-maker from about 1710 onwards); P.C. Group 2 consists of 26 pipes by the Brinsleys, 21 by the James, 32 by W. Sefton and 39 by Wright. Both the James died rather early in the period 1715-1730 leaving only the younger Brinsley, W. Sefton and Wright; P.C. Group 3 consists of 5 pipes by Brinsley, 14 by W. Sefton and 2 by Wright.

Only J. Wright was alive in 1730.

The matching of these historical dates with the P.C. Groups reinforces the contention, first put forward in Alvey and Laxton, 1977, that the greatest change in the form of pipes during the period 1670 to 1730 is the overall increase in size of the pipe bowls, in particular, the increase in the volume V. Further-more, we can now with confidence say something about the stem bore controversy (see Walker, 1967 and Whitehouse, 1966). Figure 5 can now be definitely inter-preted as showing that the stem bore diameter d_2 does indeed decrease marginal-ly from 1670 to 1730 but that its variation independent of time (i.e. along the 2nd Principal Component, see equation (2)) is much more pronounced. This latter fact may account for the difficulties encountered at times in using the stem bore size to date certain archaeological provenances.

Substantial independent evidence for the view that the clusters correspond to sets of pipes from distinct moulds is lacking at present. As indicated in the previous section, the different types of stamps of the maker's initials afford a little evidence that a few of the clusters have a reality other than their formal existence. The typology in Fig. 9 for Nottingham initialled pipes 1670-1730, is suggested by this analysis.

On the basis of the Principal Component and Cluster analysis there is some evidence that each pipemaker usually used two somewhat similar moulds at any one time. This, of course, would be a reasonable policy to adopt as an insurance against breakage or loss. The idea is hinted at in Fig. 8 in which mean values of clusters are plotted on the P.C.A. graph (1st and 2nd principal components of axes) and suggested pairs of moulds joined.

Future investigations will depend on certain circumstances. Recent exca-vations have yielded some more pipes from the period, including one by James of a Group 3 type. There seem to be two possible lines to develop. The first is to collect and measure partly damaged pipes, of which there is a plentiful supply, and to cluster these together with complete ones by means of a program which allows for incomplete data. By this means we should be able to define more clearly the clusters of pipes. Furthermore, we may be able to chemically analyse some of these damaged ones to test partially our idea of 'matching-pairs' of moulds—for if indeed such pairs are being used at the same time to produce pipes then the pipe clays must be identical.

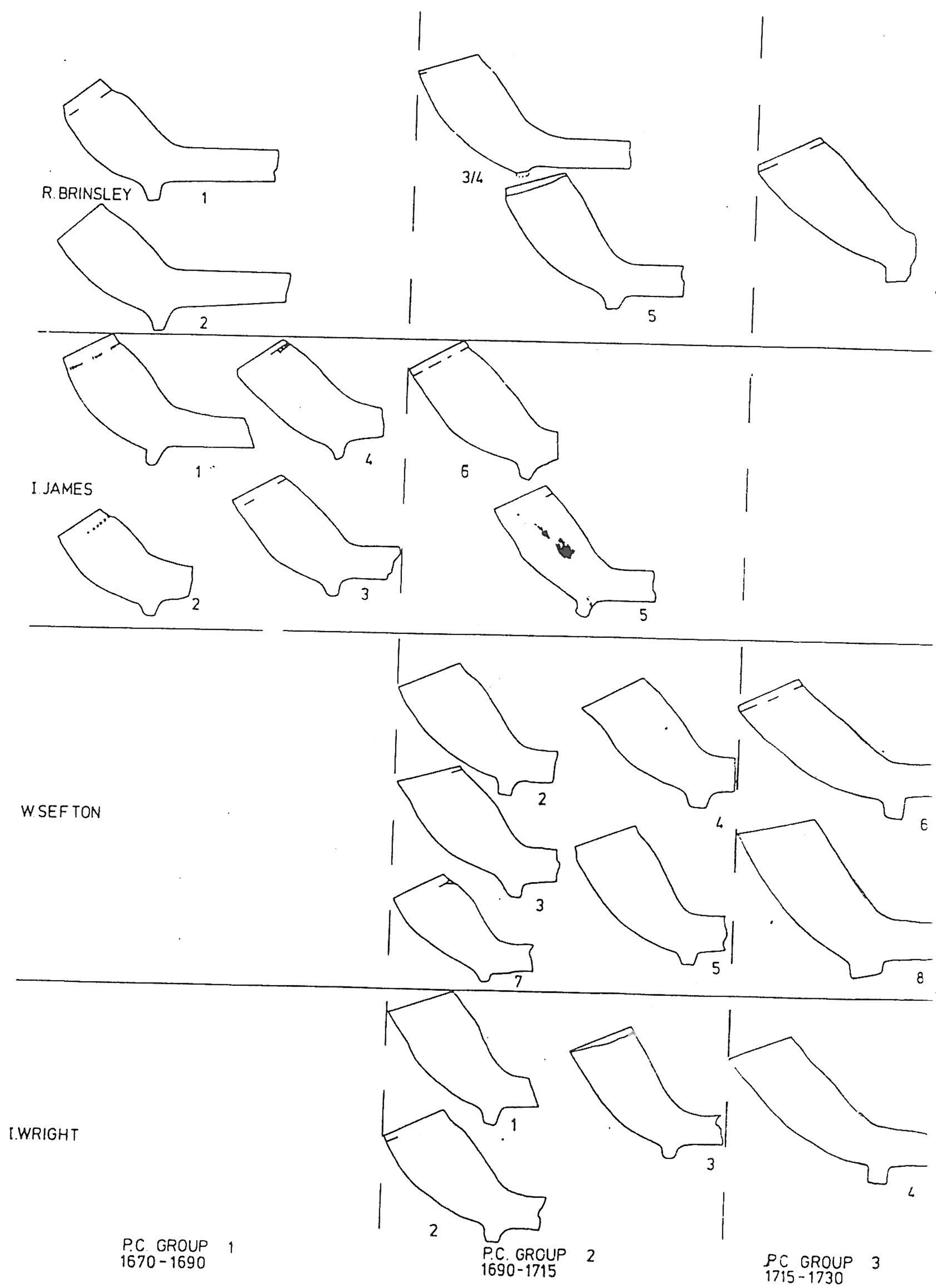


Fig. 9. Cluster Typology.

A detailed stylistic examination of the rolled stem-stamps by our makers and their apprentices is needed. If successful such an enquiry may carry us beyond 1730 into the second half of the 18th century, about which we know little at present.

We would like to thank the Nottingham Records Office and its staff for the help they have given us in our search for historical records.

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Cluster No.	Cluster Size	V	H_1	D_2	D_2-D_1	D_3-D_2	D_5-D_4	$(h_1-d_5)/H_1$	$(h_2-h_1)/D_2$	d_1	d_2	d_3	d_4	d_5	P.C. Group
Table 3. R. Brinsleys: Clusters of pipes and their average dimensions															
1	10	3.5	21.5	16.7	3.3	3.4	3.8	0.91	0.81	11.0	3.1	5.7	5.2	3.1	1
2	9	3.6	22.0	18.3	4.4	1.6	4.2	0.92	0.77	10.6	3.0	6.4	5.1	3.6	1
3/4	16	3.9	23.7	19.7	5.7	0.8	6.4	0.86	0.84	10.2	2.6	5.5	5.8	4.4	2
5	9	4.4	26.4	20.0	5.5	0.9	7.6	0.81	0.88	10.5	2.8	4.7	6.1	5.7	2
6	4	5.4	28.1	21.0	5.5	0.15	8.8	0.97	0.85	9.9	2.6	6.0	7.4	7.9	3
Table 5. James': Clusters of pipes and their average dimensions															
1	13	2.9	22.8	16.2	4.2	4.1	4.8	0.80	0.84	11.0	2.9	5.6	4.6	3.0	1
2	9	2.6	20.0	16.4	4.6	3.6	5.3	1.00	0.76	10.8	2.8	4.4	5.2	2.9	1
3	10	3.8	25.0	18.5	4.4	2.1	4.6	0.73	0.85	10.9	3.0	5.3	5.1	3.2	1
4	10	3.6	21.9	17.6	3.8	2.8	4.6	0.89	0.78	10.6	3.0	5.3	4.8	3.3	1
5	10	4.3	26.5	20.0	5.4	1.3	6.2	0.72	0.86	10.5	2.7	5.4	5.4	3.3	2
6	11	3.9	23.0	18.6	4.8	1.6	5.6	0.85	0.82	10.3	2.7	6.0	5.5	4.1	2
Table 7. W. Sefton: Clusters of pipes and their average dimensions															
2	9	4.1	24.2	20.3	5.9	0.7	6.6	0.80	0.87	10.3	2.7	5.4	5.9	4.8	2
3	9	4.2	23.4	19.6	4.7	1.8	7.2	0.90	0.85	10.1	2.4	4.9	5.8	4.7	2
4	11	4.8	24.9	20.9	4.9	0.1	6.3	0.77	0.86	10.2	2.7	4.7	6.6	5.3	2
5	4	4.9	26.8	20.6	4.5	1.83	7.9	0.61	0.94	9.8	2.6	6.1	5.0	4.8	2
6	8	4.8	27.7	20.5	5.5	-0.1	7.9	1.02	10.1	10.1	2.5	5.3	6.6	7.8	3
7	4	3.8	21.1	18.9	2.6	1.2	7.8	0.87	0.89	8.0	2.2	3.4	5.8	3.0	2
8	1	7.1	32.5	23.0	5.5	0.6	6.0	0.52	0.85	10.0	2.5	3.3	9.0	8.4	3
Table 9. J. Wright: Clusters of pipes and their average dimensions															
1	21	4.1	25.2	20.3	5.3	-0.2	6.0	0.71	0.88	10.4	2.7	5.2	5.4	4.1	2
2	13	4.2	25.1	20.1	5.4	0.7	7.0	0.75	0.90	10.9	2.8	4.9	5.9	4.7	2
3	5	5.0	26.5	20.8	4.9	0.1	6.8	0.65	0.89	10.3	2.6	5.1	5.4	4.3	2
4	1	4.4	24.0	18.5	3.5	2.0	9.1	0.87	1.07	8.3	2.0	6.0	3.7	3.6	2
5	1	5.2	25.0	23.2	7.3	0.7	10.1	0.71	0.93	9.5	2.5	4.5	5.5	3.5	3