33

The analysis of ancient Chinese pottery and porcelain shapes: a study of classical profiles from the Yangshao culture to the Qing dynasty using computerised profile data reduction, cluster analysis and fuzzy boundary discrimination

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33.1 Introduction

Techniques of pottery profile analysis have been employed in Computer Archaeology since the early 1960s. In Britain Clarke (1962) applied matrix analysis to British Beaker pottery. This was based on generalised measurements such as height, height/width ratios, neck width, base width, type of form and decoration. The findings were generally supported, however, by more rigorous profile measurements using the *'sliced'* method by Shennan and Wilcock (Wilcock & Shennan 1975). In the sliced method radii are measured (as percentages of the height) at fixed intervals down the profile of the pot from the rim to the base, e.g. if increments are fixed at 1/10 of the height, radii are measured at the rim, 9/10 height, 8/10 height ... 2/10 height, 1/10 height and at the base. The same method has been applied by Wilcock to Roman Samian ware (Wilcock 1974) and British Medieval pottery (Wilcock 1983).In this method if the pot is wheel-made and cylindrically symmetrical it is only necessary to measure one side of the profile. In principle, however, for non-wheel-made pots both sides can be measured, although in this case there is some problem about which of the non-symmetrical profiles should be measured, i.e. which rotational profile sections to select.

A similar problem arises in the measurement of the shapes of stone axes made of flint or volcanic rocks. Here the shape is decidedly asymmetrical, but the difficulty of knowing the *'handedness'* or which way up the axe should be measured often means that it is best to average the two sides anyway. A *swept radius* method with subsequent harmonic detection by Fourier analysis was employed by Allsworth-Jones and Wilcock (1974). Here a radial arm, centered on the centre of gravity of the axe, is swept around the circumference, and radii from the centre of gravity to the profile

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are measured at equal angles through the full 360 degrees. Fourier analysis is then employed: the *fundamental* is an ellipse, with the *first harmonic* superimposing a sine wave of two complete cycles, the *second harmonic* three cycles, the *third harmonic* four cycles, and so on. Ten harmonics were found to reproduce the most irregular shapes almost perfectly, but required a long time for computation, and the method is not justified for pottery shapes, which are far more regular. However, the *equiangular swept radius* concept, followed by cluster analysis has been employed in the current study (see section 33.3.3).

Wagner (1971) has used profile measurements followed by multidimensional scaling to yield a three-dimensional distribution of pottery shape types. Main (1981) employed a different method of profile reduction, consisting of measurements of distances along the profile and recording the tangential angles of the curve at these points. A similar method, consisting of equal length segments and measurements of angles, is employed in this study (see section 33.3.4).

In the People's Republic of China the first workers to apply computer archaeology were Professors Gao Liming and You Enpu (1985). They developed a fuzzy boundary discrimination function for clusters, and used it to allocate new pots to the most suitable clusters. The technique has been employed in the current study (see section 33.3.6).

33.2 Pottery and porcelain forms to be analysed

The pottery and porcelain forms analysed in this study were selected from classical types of ancient Chinese ceramics. Forty examples were selected, ranging throughout Chinese history (the Yangshao Culture, and the Shang, Western Zhou, Han, Ta'ng, Song, Yuan, Ming and Qing Dynasties). Forty samples were assembled (see Fig. 33.1 for the profile forms selected and the index numbers given to them in this study). The aim of the study was to determine if classes of shapes was a useful concept in Chinese pottery and porcelain, and to see if any trends in pottery designs could be discerned.

33.3 Methodology

33.3.1 Smoothing

The forty pottery and porcelain shapes were digitised, commencing by recording the centre of the base, then the centre of the top, then the whole profile from centre top anticlockwise back to centre top. In the previously mentioned work (Wilcock 1974; Wilcock 1983; Wilcock & Shennan 1975) only one side of the pot was so digitised, since the work was dealing only with wheel-made pots of cylindrical symmetry. In the current study, however, some of the forms are not wheel-made, and moreover there are some very asymmetrical profiles, particularly among the pottery of the Yangshao Culture; there are also asymmetrical examples such as the Ming Dynasty jug (sample no. 28). Digitising the whole profile records both sides of the pot, as well as the base, any lid or irregular top, and any appendages such as spout or handles.

The next decision is whether to smooth the profile or not. The current program allows options to be selected for no smoothing, or smoothing by moving average using the formulae:

$$x_i = \frac{(x_{i-1} + x_{i+1})}{2}$$

$$y_i = \frac{(y_{i-1} + y_{i+1})}{2}$$

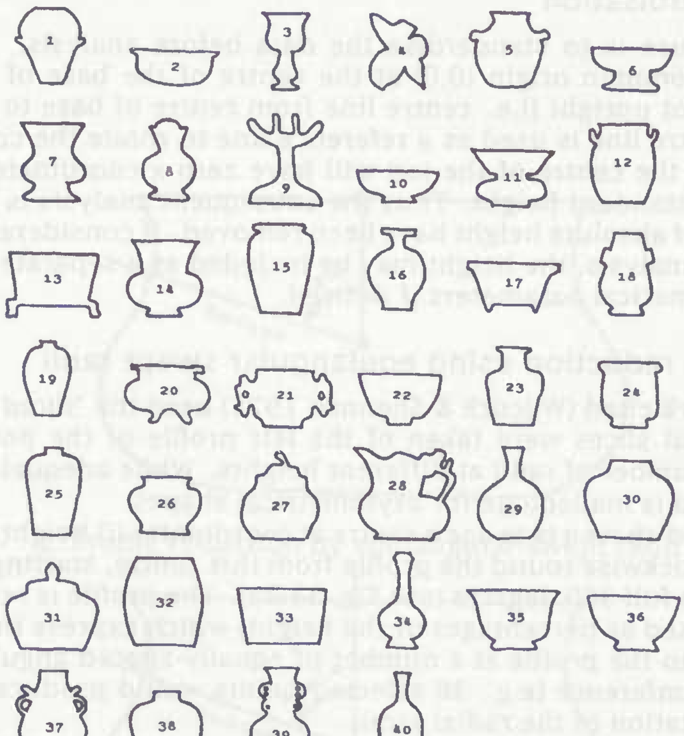


Figure 33.1: The pottery and porcelain forms selected for the study, with their assigned index numbers. Dynasties are indicated in the list which follows:

1 – 4	Yangshao Culture
5 – 6	Shang Dynasty
7	Western Zhou Dynasty
8	Han Dynasty
9 – 12	Ta'ng Dynasty
13 – 24	Song Dynasty
25 – 27	Yuan Dynasty
28 – 34	Ming Dynasty
35 – 40	Qing Dynasty

There is provision for the selection of more complex smoothing algorithms, such as the B-spline functions. If these more complex methods are used the computation time is much increased, and the relatively small improvement in results may not justify this. In the current work moving average smoothing was used, and points were digitised at very close intervals near any sharp changes in direction of the profiles, so that adverse truncation of sharp corners did not occur in the smoothing operation.

33.3.2 Standardisation

The next procedure is to standardise the data before analysis. First the data is *translated* to a common origin (0,0) at the centre of the base of the pot. In case the profile was not upright (i.e. centre line from centre of base to centre of top not vertical), the centre line is used as a reference line to *rotate* the coordinates until it is vertical, when the centre of the top will have zero x coordinate. Finally the pot is *normalised* to standard height. Thus the subsequent analysis is to do with shape, and differences of absolute height have been removed. If consideration is to be given to height in the analysis, the height may be included as a separate property, as may several other numerical parameters if desired.

33.3.3 Profile reduction using equiangular swept radii

The previous work cited (Wilcock & Shennan 1975) used the *'sliced'* method in which several horizontal slices were taken of the left profile of the pot, and the profile expressed as a number of radii at different heights. While adequate for symmetrical pots, this method is inadequate for asymmetrical shapes.

The first method chosen is to use a centre at coordinates (0,height/2) and to sweep a radial arm anticlockwise round the profile from this centre, starting at the centre top and completing a full 360 degrees (see Fig. 33.2a). The profile is recorded as a series of codes (expressed as percentages of the height) which express the radii of the arm from the centre to the profile at a number of equally-spaced angular displacements around the circumference (e.g. 36 selected points would produce a code for every 10 degrees of rotation of the radial arm).

A similar method was used by Allsworth-Jones and Wilcock (1974) to record the profiles of stone axes (see section 33.1) before the use of Fourier analysis, a method not used in the current work.

33.3.4 Profile reduction using equal length segments/angles

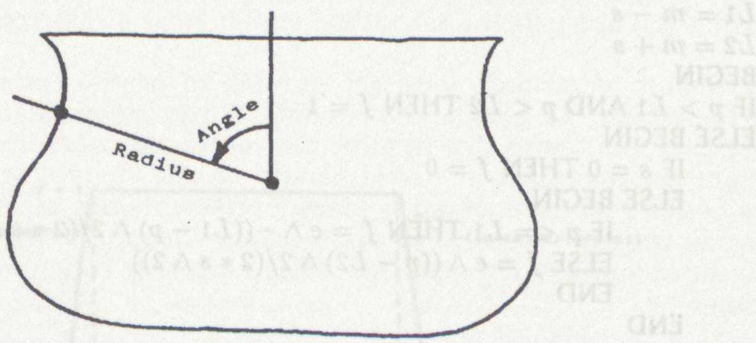
The second profile code method chosen for this work is the principle of measuring distances along the profile and recording tangent angles to the profile at these points, an algorithm developed by Main (1981). In the current work the whole length of the profile is measured, then divided into a number of equal length segments. Angles are recorded at the boundaries of these segments (see Fig.33.2b).

33.3.5 Cluster analysis

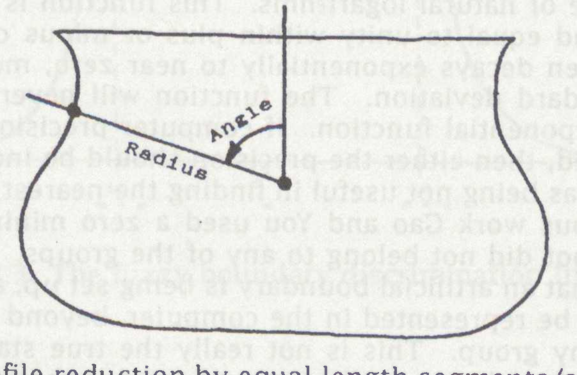
The profile codes, generated by whatever method, are subjected to weighted pair-group average link cluster analysis, producing a minimum spanning tree, a forced linear seriation, and a dendrogram.

33.3.6 Fuzzy boundary discrimination

When a number of groups has been derived by the cluster analysis, and these groups appear to give sensible shape classes, it is desired to examine a body of new unknown



a. Profile reduction by equiangular swept radii



b. Profile reduction by equal length segments/angles

Figure 33.2: Profile reduction methods

pottery shapes, and to allocate each new pot to the most suitable of the derived classes. The algorithm employed in this study is *'fuzzy boundary discrimination'*.

a. First of all the groups derived by the cluster analysis are examined. For each group all the means and standard deviations of the individual profile codes are calculated. A new unknown pot is compared with each of the groups, by comparing each of its profile codes with the corresponding group mean and standard deviation.

b. The fuzzy boundary discrimination algorithm compares each profile code (p) with the corresponding profile code mean (m) and standard deviation (s) of the current group. The function f is unity within plus or minus one standard deviation of the mean, otherwise the fuzzy function declines exponentially but is never zero unless the standard deviation is also zero.

In formal algorithmic terms this is:

```
L1 = m - s
L2 = m + s
BEGIN
IF p > L1 AND p < L2 THEN f = 1
ELSE BEGIN
      IF s = 0 THEN f = 0
      ELSE BEGIN
            IF p <= L1 THEN f = e ∧ -((L1 - p) ∧ 2/(2 * s ∧ 2))
            ELSE f = e ∧ ((p - L2) ∧ 2/(2 * s ∧ 2))
            END
      END
END
```

where e is the base of natural logarithms. This function is illustrated in Fig.33.3. It is flat-topped and equal to unity within plus or minus one standard deviation from the mean, then decays exponentially to near zero, more rapidly for smaller values of the standard deviation. The function will never theoretically be zero, because it is an exponential function. If computer precision does lead to a value of zero being stored, then either the precision should be increased, or zero values should be ignored as being not useful in finding the nearest group for an unknown pot. In the previous work Gao and You used a zero minimum value to indicate that an unknown pot did not belong to any of the groups. If this is done, then it must be realised that an artificial boundary is being set up, at the smallest positive number which can be represented in the computer, beyond which the pot is being said not to join any group. This is not really the true state of affairs, however, for the exponential function is continuous and extends throughout the group space, overlapping all existing groups, even though it may have very small values in some regions. There is also a special case when the standard deviation for a property is zero. The exponential function will then decay so fast that it reaches near zero virtually immediately beyond the plus or minus one standard deviation points. In the current work this occurrence has been recorded as truly zero, and all zero values of the function have been ignored as being not useful.

c. The algorithm finds the minimum non-zero f for all the codes in the current group. Because of the non-acceptance of zero values (see b above), the algorithm is thus finding the property which gives the weakest measurable performance for the unknown pot against each of the existing groups.

d. The algorithm finds the maximum of these minimum f values among all the groups. The unknown pot is allocated to the group with this maximum fuzzy value. Thus the algorithm is choosing the group which performs best on the weakest property.

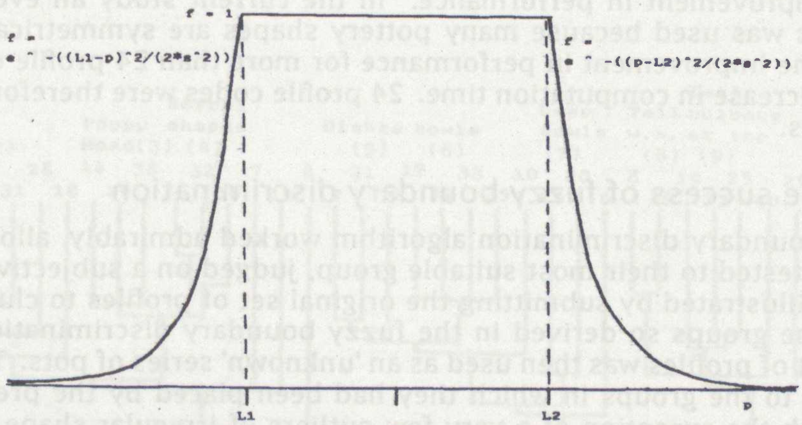


Figure 33.3: The fuzzy boundary discrimination function

33.4 Results

33.4.1 The success of profile reduction methods

Experiments were made with different smoothing and profile reduction methods. It was found that complex smoothing methods were not justified, i.e. the increase in time required for the computation does not lead to significantly better results.

On a subjective assessment of meaningful groups by archaeologists and pottery specialists, the 'best' performance on a test set of data was achieved by the simple running-average smoothed equiangular swept radius profile code method. Next best was the equiangular swept radius method with no smoothing. The equal length segments/angles method with no smoothing gave significantly worse results. The worst performance was given by the simple running average smoothed equal length segments/angles method.

For the main analysis the smoothed equiangular swept radii method was therefore used.

Experiments were made with the number of profile codes recorded. Main (Main 1981) found that 25 profile codes could represent profiles of diverse shapes adequately, and that above this number the increased computation time did not justify the slight improvement in performance. In the current study an even number of profile codes was used because many pottery shapes are symmetrical, and it was found that the improvement in performance for more than 24 profile codes did not justify the increase in computation time. 24 profile codes were therefore used in the main analysis.

33.4.2 The success of fuzzy boundary discrimination

The fuzzy boundary discrimination algorithm worked admirably, allocating all unknown pots tested to their most suitable group, judged on a subjective basis. This was further illustrated by submitting the original set of profiles to cluster analysis, and using the groups so derived in the fuzzy boundary discrimination algorithm. The same set of profiles was then used as an 'unknown' series of pots. The pots were all allocated to the groups in which they had been placed by the previous cluster analysis, with the exception of a very few outliers of irregular shape which joined the main groups in the cluster analysis at a very late stage (these are pot numbers 18 (Song), 29 (Ming), and 34 (Ming)). Most of these cases occur on the borderlines between two groups. The power of the fuzzy boundary discrimination method has thus been demonstrated.

33.4.3 Groups of ancient Chinese pottery and porcelain forms

The groups of ancient Chinese pottery and porcelain forms derived by the cluster analysis are illustrated in Fig. 33.4, and their relationship is shown by the dendrogram (Fig. 33.5) and minimum spanning tree (Fig. 33.6).

The groups are loosely described by the English language terms 'urn shapes' (Group 1, shapes 1, 5, 15 and 16), 'squat jars' (Group 2, shapes 12, 27, 31 and 37), 'poppy head' (Group 3, shapes 14, 26 and 38), 'barrel shapes' (Group 4, shapes 24, 30 and 32), 'ds' (Group 5, shapes 2, 21 and 36), 'bowls' (Group 6, shapes 17, 22, 33 and 35), 'deep bowls' (Group 7, shapes 13 and 20), 'tall, wide-necked' (Group 8, shapes 8 and 39), 'tall, bulbous at top' (Group 9, shapes 19, 23 and 25) and 'pedestals' (Group 10, shapes 3 and 9). These are generalised English language terms, and it is suggested that classical Chinese terms for these shapes of pottery and porcelain should be substituted where appropriate.

Group 1	1	5	15	16	'Urns'
Group 2	12	27	31	37	'Squat jars'
Group 3	14	26	38		'Poppy head'
Group 4	24	30	32		'Barrel shapes'
Group 5	2	21	36		'Dishes'
Group 6	17	22	33	35	'Bowls'
Group 7	13	20			'Deep bowls'
Group 8	8	39			'Tall, wide-necked'
Group 9	19	23	25		'Tall, bulbous at top'
Group 10	3	9			'Pedestals'

Figure 33.4: Groups of ancient Chinese pottery and porcelain forms derived by cluster analysis

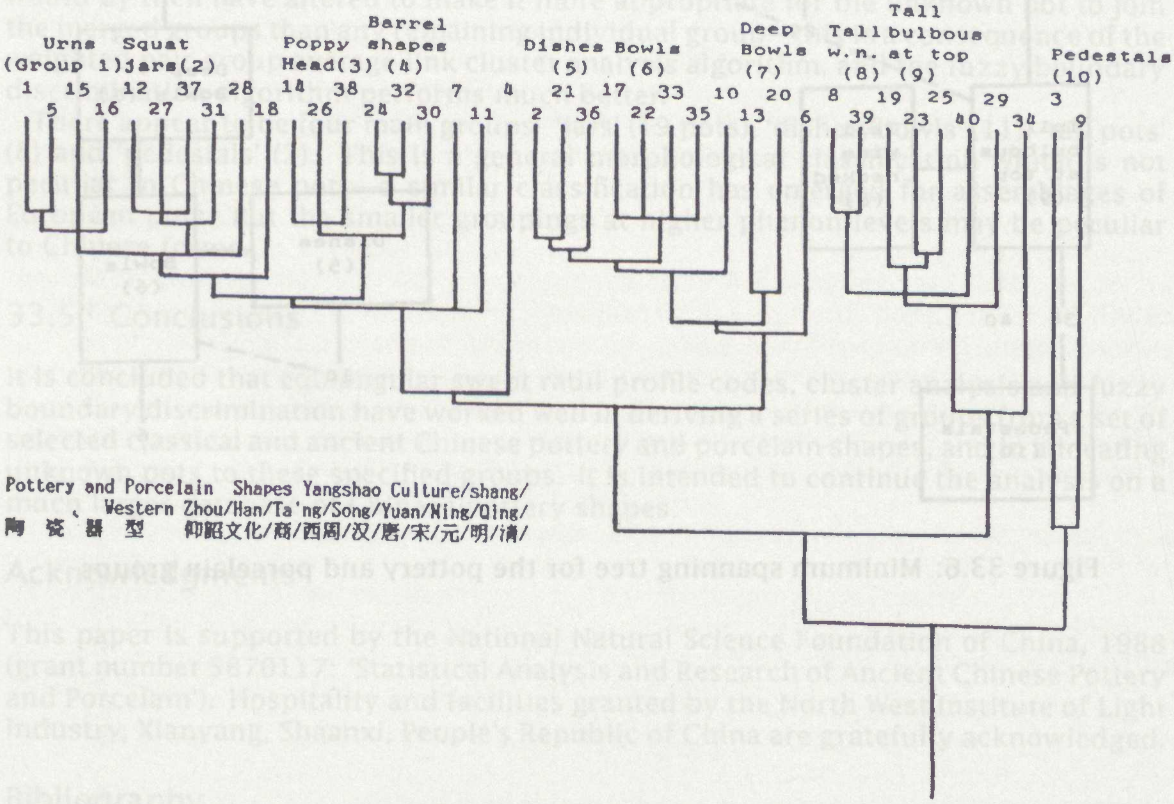


Figure 33.5: Dendrogram for the pottery and porcelain groups

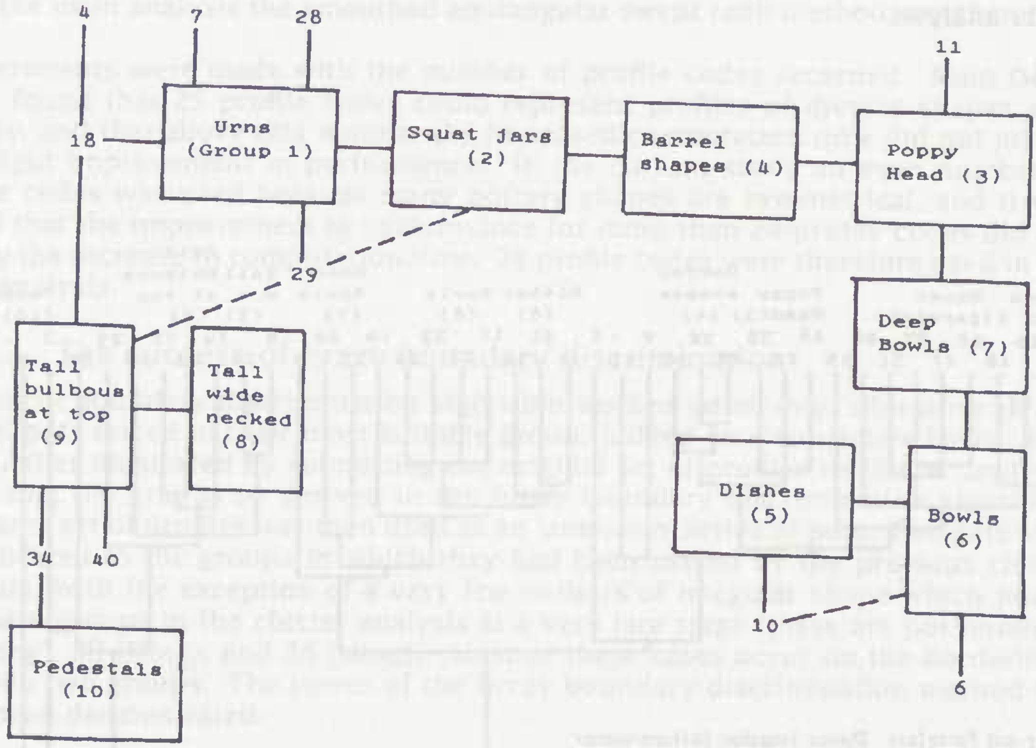


Figure 33.6: Minimum spanning tree for the pottery and porcelain groups

Shape No.	*Group*
4	1
6	6
7	1
10	5
11	3
18	9
28	1
29	1
34	6
40	9

Table 33.1:

The fuzzy boundary discrimination algorithm allocated the outliers to the groups listed in Table 33.1. These results agree with the associations made in the cluster analysis, except that shape 18 was placed by the cluster analysis with groups 1 and 2 at a late stage, 29 was placed with groups 8 and 9, and 34 with groups 8 and 9. In both the latter cases group 9 was the 'second choice' of the fuzzy algorithm by a short head. Since all these cases joined already merged groups, the properties would by then have altered to make it more appropriate for the unknown pot to join the merged groups than any remaining individual group—this is a consequence of the weighted pair-group average link cluster analysis algorithm, and the fuzzy boundary discrimination algorithm performs much better.

There appear to be four main groups: 'jars' (19 pots), 'dishes/bowls' (11), 'tall pots' (8) and 'pedestals' (2). This is a general morphological classification which is not peculiar to Chinese pots—a similar classification has emerged for assemblages of European pots. But the smaller groupings at higher phenon levels may be peculiar to Chinese forms.

33.5 Conclusions

It is concluded that equiangular swept radii profile codes, cluster analysis and fuzzy boundary discrimination have worked well in deriving a series of groups from a set of selected classical and ancient Chinese pottery and porcelain shapes, and in allocating unknown pots to these specified groups. It is intended to continue the analysis on a much larger database of Chinese pottery shapes.

Acknowledgments

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