39 Computer clustering in the analysis of non–morphological attributes of pottery sherds: two examples from Poland

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39.1 INTRODUCTION

Pottery is that category of finds, which most often can be found on archaeological sites from the Neolithic until modern times. Called the "alphabet of archaeologist" by many, it actually has a very special place in archaeological studies. It is potentially a source of variety of information, extending far beyond purely chronological and typological questions. Still, the abundance of pottery sherds from every excavation, often results in the misunderstood "ceramology", in which the pottery, instead of being the object of study, becomes the ultimate aim of study, the object of cognition. In this paper we would like to present two simple examples of computer–aided mathematical analysis of non–morphological attributes of pottery assemblages to obtain behavioural information not necessarily connected with the pottery itself. Our aim is also to show and discuss the similarities and differences between the results of the "classical" archaeological methods and computer methods applied to the same problem and the same body of data.

The methods we have used are not new; our position is simply to make use of available computer software libraries. These methods however, as we will try to demonstrate, efficiently contribute to an increased understanding of past processes. This "practical" aspect of computer applications in archaeology is important, since many applications, despite their innovative and advanced character, supply archaeologists with information that is trivial or meaningless from the point of view of historical reconstruction (cf. Cleziou & Demoule 1980:12). Therefore, our focus is rather on archaeological significance of results than on the specific problems of analytical methods.

The starting point for the analyses presented is pottery sherds recovered from various contexts of Medieval deeply stratified sites. Every sherd can be defined as a matrix of an infinite number of attributes belonging to three main categories: morphology (including decoration and symbolic features), technology and the state of preservation. The first group is that most often studied by archaeologists. However, in the case of a mass of small fragments, analysis of morphological attributes does not usually provide important evidence. Therefore, we believe that an attempt to gain information from the study of two other groups of attributes is worth consideration. Our two examples will be connected with observation and analysis of chosen attributes belonging to just these two groups: the size of sherds in pottery assemblage and the chemical composition.

39.2 SIZES OF SHERDS IN POTTERY ASSEMBLAGES FROM CZERSK CASTLE

The size of sherds in an assemblage is usually regarded as not worth scholarly attention. However, if we accept Schiffer's (1976) distinction between primary and secondary refuse in archaeological remains as an important behavioural aspect, we are entitled to guess that the size of artefacts in a deposit is the archaeological correlate of the type of refuse this deposit contains. It should be remembered that in present–day villages of Australian Aborigines the maximal size of refuse abandoned *in situ* is 9 cm; that the strict relationship between the size of refuse and the distance between the original place of use, and the place of ultimate deposition has been observed by Binford among Nunamiut Eskimo and

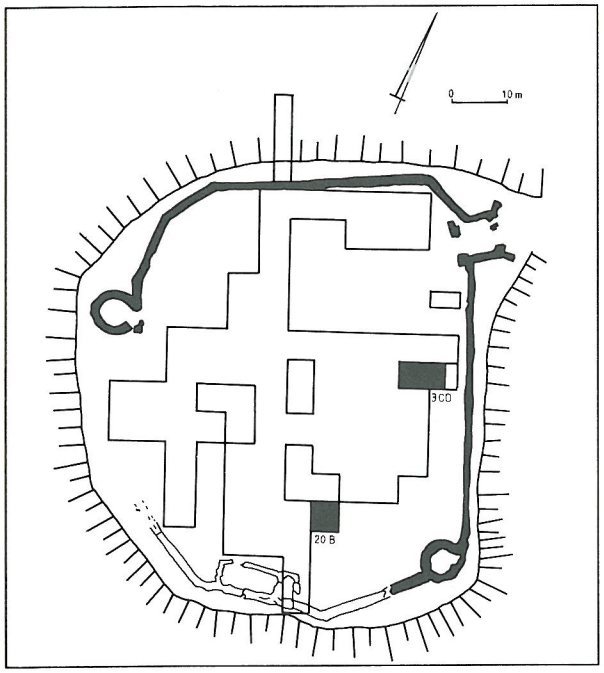

Figure 39.1: Czersk, Poland. Plan of Castle Hill with the marked outline of defensive walls and the area excavated 1959–1983. Trenches 3CD and 20B marked black.

by Yellen among !Kung Bushmen; and that even in the modern American cities only garbage bigger than 7.5 cm is collected from the streets (cf. Binford 1978; DeBoer & Lathrap 1979:133; Schiffer 1978:244; South 1979:218; Yellen 1977).

These facts may suggest that studying sizes of pottery sherds can provide important information on the original function and derivation of a given archaeological context. The British scholars, Bradley and Fulford (1980), were probably the first to call the attention of archaeologists to the importance of studying sherd sizes in deposits. In the light of their analysis of this attribute in the pottery assemblages from Knossos and their experiments with trampling, it can be proposed as a rough guideline that in the case of systematically used settlement sites, bigger sherds should be regarded as secondary refuse, while smaller ones can represent primary refuse or secondary refuse strongly disturbed during post–deposition processes. This would mean that the bigger sherds, producing much information on form and decoration of pots, can cause confusion when used as chronological or functional indicators.

Our study was an attempt to verify and refine these general principles in the case of the deeply stratified Medieval site of Czersk Castle in central Poland. Evidence from this site seems particularly suitable because of a number of circumstances. First, pottery assemblages collected there come from functionally differentiated contexts, varying from the fills of grave pits, areas inside and outside wooden buildings, deposits of earthen walls, rubble layers, to deposits connected with the construction of a brick castle in the 15th century. Moreover, almost the whole bulk of this deep stratification represents a relatively short time span, mainly from the 11th to the 14th century. Physical characteristics of this pottery, such as hardness and thickness, are comparable throughout the period, therefore we are entitled to assume that it responded to fracturing activity of deposition and post–deposition processes in similar ways. Very important is also the fact that we have detailed stratigraphic analysis available for the site (Urbańczyk 1988). This analysis also involves the interpretation of the origins of every single deposit, based exclusively on the stratigraphic criteria and physical characteristics of the layers, without taking the finds into consideration. Eventually it would thus be possible to compare the two independent functional–genetically classifications of stratigraphic units of that site.

For this experiment, the pottery assemblages from two trenches, labelled 3CD and 20B have been chosen (Figure 39.1), a total of 8268 fragments. A measure of sherd size is set to be the longer of its two dimensions: heights or widths, measured with a precision of ±1 mm. The smallest fragments were ca. 0.6 cm, the biggest ca. 18 cm. This range has been divided into 18 discrete size classes, each of a range of 1 cm, with 0.6 cm as a starting point (Figure 39.2). In this way the pottery assemblage from every stratigraphic context could be defined by the frequencies of these 18 variables, and the whole body of data was subsequently cluster analysed.

Obviously it is not necessary to discuss the details of cluster analysis here. Actually it is a set of methods aimed at the discovery of previously unknown groups of objects based on a mathematically defined similarity in one or more variables. Due to the possibility of using various similarity functions and applying different methods of joining objects in clusters, as well as the subjective nature of the decision, as to which step in the agglomeration procedure to accept as the interpretative basis, cluster analysis is a heuristic device rather than a procedure through which fixed groupings can be established. Many statistical packages, as well as strictly archaeological software libraries include a cluster analysis utility. On an early stage of our experiment we tried several of them. Due to the ease of data input, the possibility of applying several methods of ag-

glomeration and measures of similarity, we decided to use the SYSTAT package as our analytical tool.

Three sets of data formed the basis of our analysis: data describing the structure of pottery assemblages from trench 3CD, from trench 20B, and from both of them together. For each body, raw counts were considered, as well as data standardised across variables and across units. Because the number of sherds in individual contexts varies considerably, it appeared that when raw counts or standardised variables were used together with Euclidean distance as a similarity function, there was a tendency for contexts with similar number of sherds to be agglomerated in clusters. This bias was eliminated by using the correlation coefficient as a measure of similarity. Standardisation of variables resulted also in assigning unreasonable importance to single sherds occurring in the extreme size classes. Ultimately, it was decided to consider two sets of computations: raw data with Pearson's correlation coefficient as the similarity function and data standardised within units using Euclidean distance as the similarity function.

A subjective matter is also the choice of clustering method. The advantages of the single linkage method as the one most realistically representing real similarities are often cited. In our case however this method did not produce satisfying results, as it created stair-like dendrograms without readable clusters. More comprehensible and elegant dendrograms were obtained when the method of average linkage was used, and particularly when we used the method of complete linkage and minimum variance. The two latter methods were therefore chosen, in spite of their sometimes quoted biases. Especially the minimum variance method of linkage (known also as Ward's method) is supposed to produce dendrograms with unrealistically dense clustering on lower steps of the agglomeration procedure and extreme stretching on the higher steps at the same time. Nevertheless, in our case, this method appeared useful in distinguishing obvious clusters. Specific biases inherent in every method could be overcome thanks to the comparison of their results. It appeared that all dendrograms obtained for the same body of data, independently of the standardisation and the distance measure, were similar, and the composition of clusters was almost identical. Of more importance to the structure of the dendrogram was the method of linkage.

Observation of changes in dendrograms due to various groupings of variables formed a check on

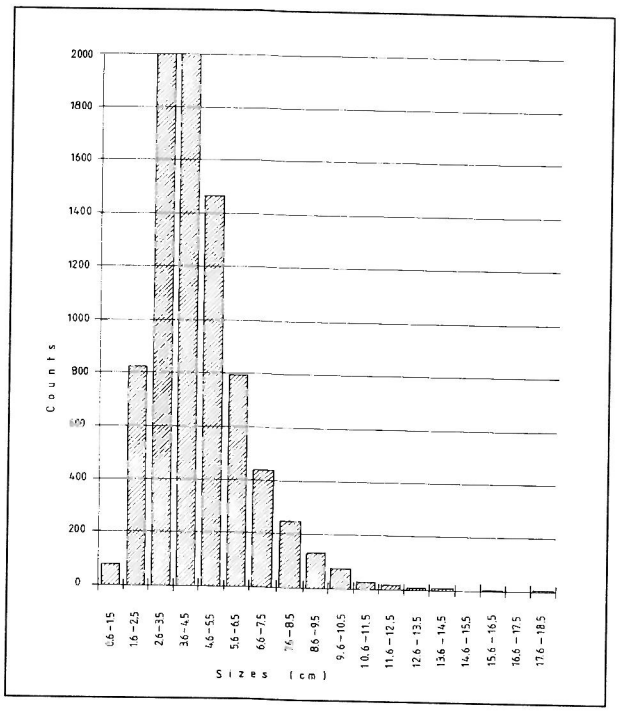

Figure 39.2: Czersk Castle, Poland. Frequencies of pottery sherd size classes in trenches 3CD and 20B.

arbitrary division of the range of variability into discrete classes and at the same time was one of the checks on reliability of results. Several correlation coefficients were computed and neighbouring size classes that showed some positive correlation, were joined in a number of ways to form broader classes. Though some of the previously distinguished clusters were still visible, it seems that in this way the diagnostic value of specific smaller size classes has been obscured.

Let us now summarise briefly the most important results.

In the material from trench 3CD (Figure 39.3), which was the principal data set for our analysis, 37 pottery assemblages (6501 sherds in total) were joined in two broad macroclusters labelled I and II, irrespective of similarity function and method of linkage. This agglomeration however does not give any interesting information, since, disregarding the unexpected position of a few layers (L83, L85 and L104), these macroclusters are apparently related to the position of a given layer in the stratigraphic sequence: layers lying in the upper part of the stratification contain material less fractured, due to the shorter period of post-deposition disturbance and the lesser weight of overlying masses of soil. However, the second macrocluster can be divided into two clusters: IIA and IIB. Further division ultimately produces six clusters, two of which emerge from

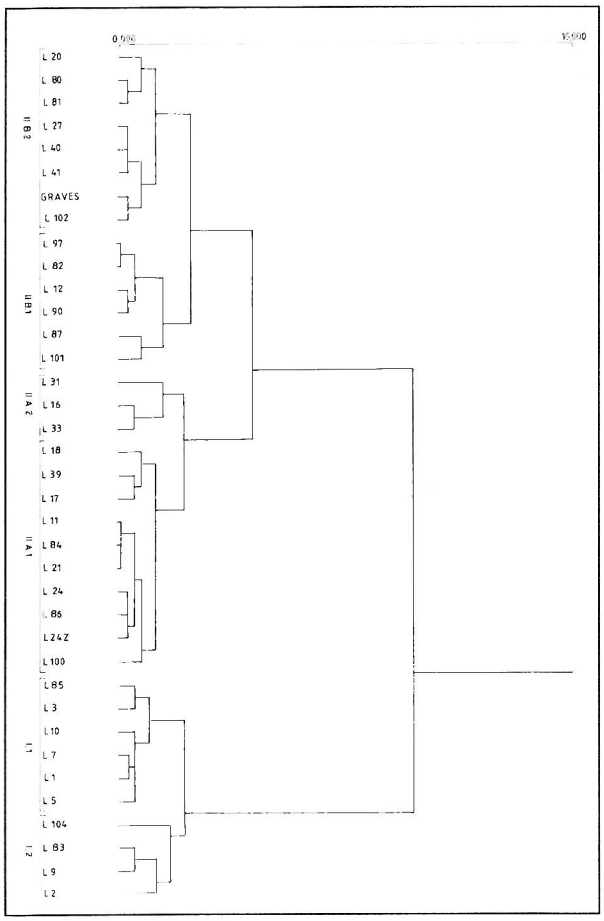

Figure 39.3: Czersk Castle, Poland. Dendrogram of a cluster analysis of pottery assemblages from trench 3CD described in terms of their size structure.

the first macrocluster, and four from splitting of clusters IIA and IIB.

Identical clusters have been produced by complete linkage and minimum variance methods for both raw and standardised data; slight differences could be observed in dendrograms produced by the average linkage method, where clusters IIA.1 and IIB.1 formed one cluster.

Subsequently we returned to the data to see what characteristics were responsible for these groupings.

For cluster I.1 it is first of all the presence of many diverse size classes, including very large fragments, and excluding the smallest as a rule. The modal value for this cluster is higher (4.6–5.5 cm) than for the whole population. Assemblages forming this cluster include also relatively high counts of big sherds (bigger than 6.5 cm).

For cluster I.2 the common feature is the even frequency of sherds in classes 2.6–9.5 cm, and a relatively high frequency of sherds bigger than 7.5 cm, usually without smaller pieces.

For cluster IIA.1 the specific feature is diversity of represented size classes with a particularly high and even frequency of sherds in the classes 2.6–6.5 cm.

Cluster IIA.2 can be characterised by the lack of the smallest and big fragments, with the occurrence of only 3 or 4 size categories and an even frequency of sherds in classes 1.6–4.5 cm.

Cluster IIB.1 can be characterised by a clear modality of size class 2.6–3.5 cm.

For cluster IIB.2 the specific feature is the diversity of size classes up to 9.5 cm, with a relatively high and even frequency in the range 1.6–4.5 cm.

It is necessary now to discuss the behavioural and functional–genetic meaning of the distinguished clusters. The lack of detailed experimental observations prevents any fully reliable interpretation, but in general terms, and solely based on the results obtained, it may be proposed that macrocluster I represents secondary refuse, while macrocluster II represents primary refuse or secondary refuse strongly influenced by post–deposition processes. Going into details, it may be proposed that cluster IIA.2 represents primary refuse, while cluster IIB.2 represents mostly secondary refuse. It is more difficult to interpret the derivation of deposits containing pottery assemblages of clusters IIA.1 and IIB.1. It seems possible that both represent primary refuse deposited *in situ*, but the stronger fragmentation of sherds in cluster IIB.1 may suggest a longer period of layer formation with intensive trampling of discarded sherds. As to macrocluster I, it could be argued that cluster I.2 represents rubbish deposits, while cluster I.1 represents rubbish deposits transposed during post–deposition processes.

A second analysis of a smaller set of data consisting of pottery assemblages from 22 contexts in trench 20B, 1767 fragments in total, was used to check the universal nature of the clusters. Here (Figure 39.4) a cluster analysis allowed distinguishing 5 clusters, with a structure comparable to the clusters obtained for trench 3CD. The only important difference is that cluster IIB is not further divided into smaller aggregates.

Another method of verification has been joint cluster analysis of data from both trenches. It has been assumed that since some of the layers registered in both trenches were actually the same widely stretched layer, the pottery assemblages from these layers should consequently be found in the same clusters, if the method of analysis is adequate. Actually this could be observed (e.g. L40 and L41 from trench 3CD are the same units as XL43 and XL43a from trench 20B — all these

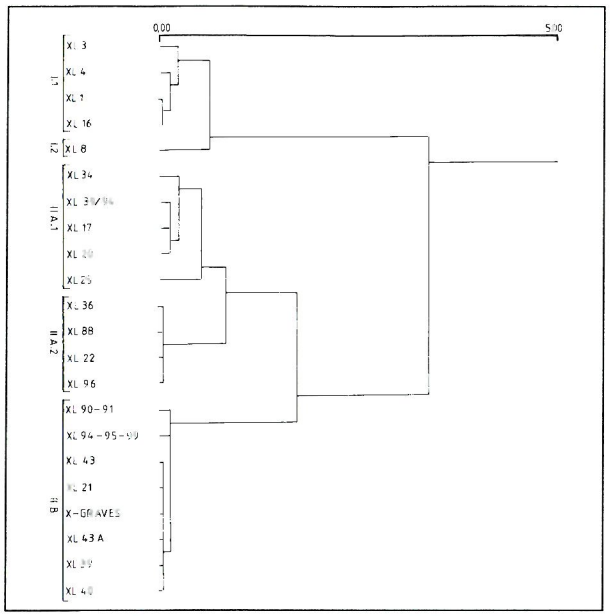

Figure 39.4: Czersk Castle, Poland. Dendrogram of a cluster analysis of pottery assemblages from trench 20B described in terms of their size structure.

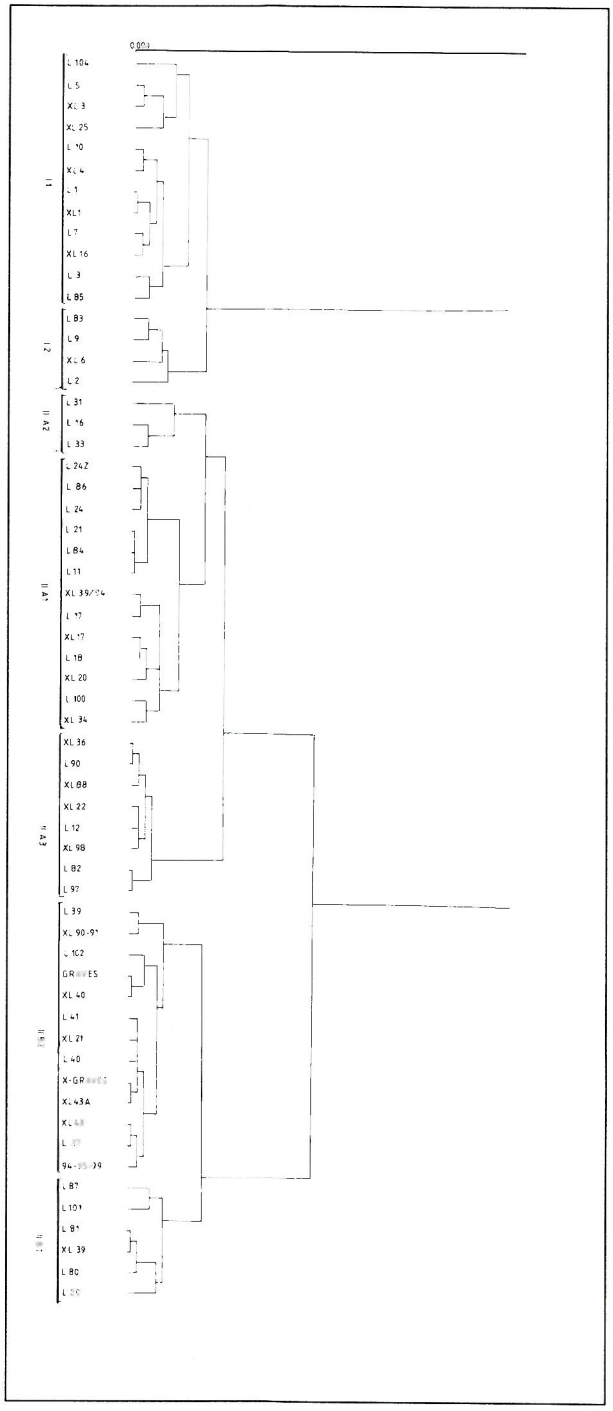

Figure 39.5: Czersk Castle, Poland. Dendrogram of a cluster analysis of pottery assemblages from trenches 3CD (labelled L) and 20B (labelled XL) described in terms of their size structure.

contexts appeared in the same cluster — Figure 39.5). Moreover, dendrograms obtained for the joint data produced seven clusters, partly identical with those obtained for the separate sets of data. The only significant structural difference is that cluster IIA now can be divided into three smaller clusters, and not two as before. Cluster IIA.3 in these analyses joins cluster IIB.1 from trench 3CD with cluster IIA.2 from trench 20B. Also the position of a few assemblages (especially of those from units XL25 and XL94–95–99 from trench 20B) became unclear.

Anyway, the existence of three principal macroclusters, here called I, IIA and IIB has been demonstrated (Figure 39.5). We can propose the following interpretation of these macroclusters:

I assemblages formed due to the deposition of broken pots outside the area of their normal use, and successive short post–deposition processes, not resulting in further fracturing;
IIA assemblages of sherds deposited *in situ* (e.g. in the inner parts of houses and areas between them);
IIB assemblages of secondary refuse, intensively fractured during post–deposition processes.

The chronological value of the assemblages belonging to each macrocluster is different. Assemblages from macrocluster I should contain chronologically diverse sherds and can be treated as providing a *terminus post quem* for the moment of layer formation only. Assemblages from macrocluster IIA should be chronologically consistent and can be treated as providing a *terminus a quo*. Assemblages from macrocluster IIB should again

be chronologically diverse and, since some fragments can represent the actual moment of layer formation, while others are residual, should be treated as providing a *terminus ante quem non* for the formation of a layer.

Until this stage of analysis we did not consult the results of the stratigraphic analysis. When we compared the two it appeared that all the layers containing assemblages of macrocluster I have been described as results of major earthworks intended to flatten the previous surface. Cluster I.1 contains layers of mixed material, while layers in cluster I.2 were deposits of homogeneous clay. Cluster IIA.1 consists of layers evidently related to the use of buildings and surrounding areas (so it constitutes primary refuse *in situ*). Cluster IIA.2 contains layers of decomposed wood or other organic matter, and cluster IIB.1 — layers of ashes and charcoal (the remnants of fireplaces, hearths and house–burning). Both should represent a primary context for the finds. More difficult is the interpretation of the last two clusters. The first, IIA.3 consists of contexts described as deposits in pits, and layers of sand and clay covering hearths and ruins left by a fire. They are therefore probably transposed contexts, but containing primary refuse. The last cluster, IIB.2 consists of seemingly diverse layers described as levelling, fills of grave and settlement pits and deposits covering hearths. On the basis of our results we can say that they probably contain secondary refuse, transposed during post–deposition processes.

There are several important lessons to be learned from this comparison. First, cluster analysis of pottery assemblages described in terms of their size structure, enables behavioural and functional–genetically classification of stratigraphic units surprisingly similar to that based on purely stratigraphic characteristics. Second, our results entitle us to refine and question some previous statements concerning the nature and derivation of particular deposits. Third, these results give clear indications of the potential chronological value of particular pottery assemblages. Fourth, it seems possible that there are some universal rules in refuse disposal and fracturing activity of post–deposition processes which can be discovered and used as sources of qualitatively new behavioural information. Certainly, this experiment is too limited in chronological and spatial terms to be used as a conclusive proof. Also, the applied method of clustering and the way the continuous variable was partitioned into discrete categories can be criticised. It seems however, that there is some future in studying this so often overlooked attribute of pottery from excavations.

39.3 ELEMENTAL ANALYSIS OF POTTERY SHERDS FROM SANDOMIERZ

Besides size, the composition and structure of clay materials is a second major group of attributes characterising potsherds from excavations. According to many scholars the choise of materials used for pottery manufacture have special value in pottery studies. They can be used for several research purposes:

1) to obtain data for determining the provenance of pottery;
2) to learn about methods of clay exploitation in the past;
3) to learn the potters' motivation in choosing particular clay deposits;
4) to identify ceramic pastes prepared on the base of clay mixtures.

In a simplified way, the "clay recipes" correspond often to "clay groups" distinguished by archaeologists through morphological examination of ceramics. Several years ago an analysis of pottery sherds from the medieval site of Sandomierz in southern Poland (Buko 1981) has led to the definition of 6 groups of clay material:

I ferruginous ceramics made of boulder clay;
II white, coarse–grained pottery;
III pottery made of mixtures of various clays;
IV ceramics made of Vistula river mud;
V fine–grained white pottery made of tertiary clay imported from the Holy–Cross Mountains area;
VI grey pottery (fired in the reducing atmosphere).

This analysis was based mostly on petrographic studies, reinforced by macroscopic examination of sherds. Our recent experiment tried to verify the existence of these groups by means of computer cluster analysis of the chemical composition of 85 pottery samples from the same site, dated to the 10th to the 13th century. For every pottery sample the quantity of 7 chemical compounds (SiO_2, Al_2O_3, CaO, MgO, Fe_2O_3, K_2O and Na_2O) using the XRF method was determined. Data were standardised, Euclidean distance was used as the similarity function, and average linkage was used as the method of clustering (data description and details of computations were presented in Buko & Lewandowska 1991).

The main similarity of the two classifications (Figure 39.6) is based on the presence of evident clusters of samples in the new classification, pre-

viously classified as clay groups I, II and V. More interesting however are the differences between the two classifications.

One such difference is the lack of separate clusters for the groups III and VI in the dendrogram. Samples of group III are placed in groups I and II, and samples of group VI in group IV.

The characteristic feature of group III of pottery clays was heterogeneity of composition with a simultaneous clearly defined pattern of petrographical structure. On this basis, a suggestion was previously put forward that, for the manufacture of this group of pottery, a mixture of various clays had been used. Using present results we can reinforce and develop this thesis arguing that this group of pottery was made with the mixture of clays belonging to groups I and II.

Another example is group VI of ceramic materials. This group (grey ware) seemed to be completely different from the other groups. A suggestion that it was produced somewhere outside the Sandomierz area was previously expressed. But if we consider the results of our analysis, it is possible to formulate an alternative hypothesis. Pottery samples of grey ware appear to be closely related to those of group IV (river mud). It may indicate that potters simply chose special kinds of the same raw material to obtain a fine-grain and more ferrous paste.

Interesting observations can be made on the basis of the left part of this dendrogram, where the samples of group II and V appear. According to petrographic data, clay group II is very close to the boulder clay of group I. But, as the dendrogram shows, there are closer chemical similarities between samples of groups II and V; in two cases samples of the group II are even included in one cluster with the samples of group V. We now think that pottery manufactured with clay group II (11th–12th century) was made using tertiary Miocene materials, strongly tempered with medium and coarse-grained granite, while material used to manufacture ceramics of group V (12th–13th century), fired at higher temperatures (850–900°C) was not tempered by the potters. Its petrographic characteristics are therefore more closely related to natural kaolin clay, tempered only with fine-grained quartz.

Cluster analysis of the chemical composition of sherds therefore offers new interpretative possibilities in the analysis of pottery manufacture and trade. In our case it is reasonable to see the beginning of regional exchange already at the end of the 10th century, and not in the 12th century, as was previously believed. Sometimes however, cluster analysis of sherds based on their chemical

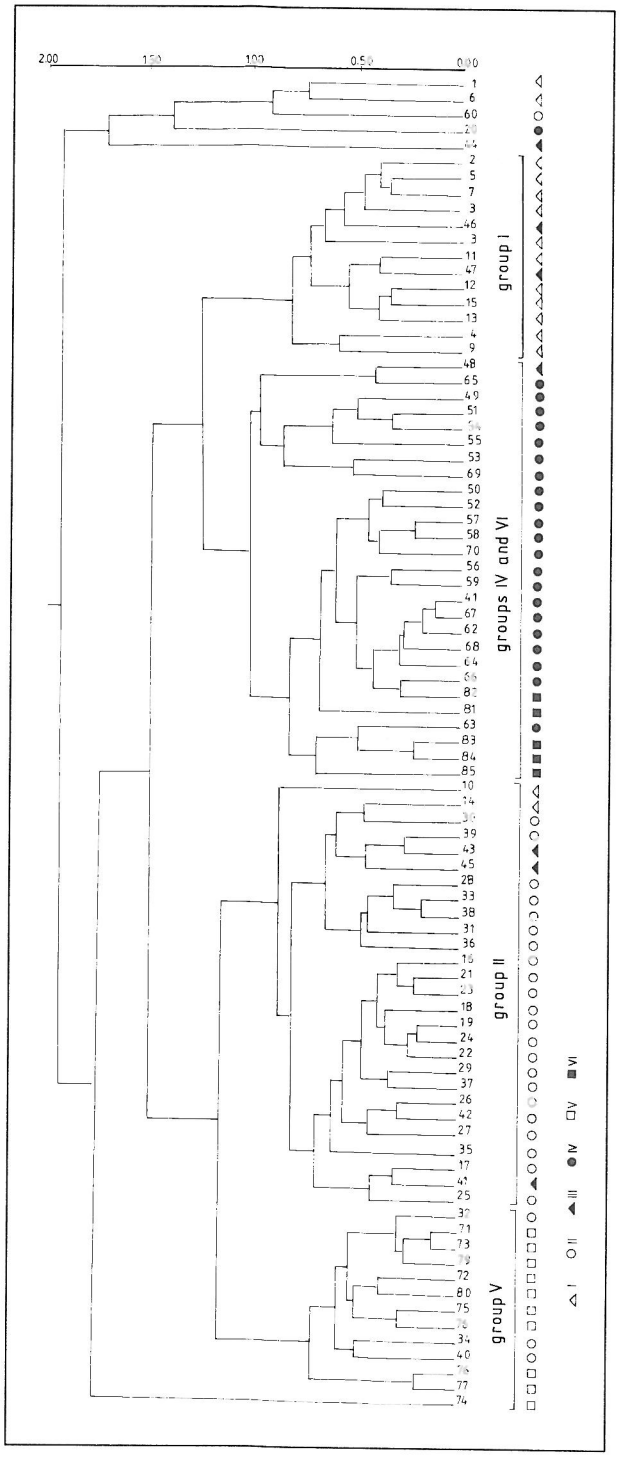

Figure 39.6: Sandomierz, Poland. Dendrogram of a cluster analysis of pottery samples described in terms of their chemical composition. Symbols I–VI denote samples previously classified into separate groups on the basis of petrographical analysis.

composition, can produce results that from the point of view of our knowledge must be considered false. For instance if we look at the right side of the dendrogram, samples 6, 20, 44 and 60, pre-

viously defined as belonging to various groups forms a cluster here. If we look at the original data we will see that high content of CaO is responsible for this cluster. From the geological studies on clay deposits we know that this compound is particularly "capricious", varying in quantity even in the same quarry. Therefore we are entitled to recognise this cluster as meaningless.

39.4 CONCLUSION

While our whole presentation here is aimed to show some new cognitive possibilities connected with replacement or supplementation of traditional methods of archaeological reasoning with more objective computer clustering, and also taking into consideration some traditionally neglected attributes of pottery, there are also several inherent dangers. First, as both our examples showed, the results of computer clustering have to be confronted with the original data, because sometimes unimportant (from the point of view of a particular study) factors can be responsible for the clustering of objects. Clusters obtained may be real, but meaningless. Second, it is obvious that the results obtained depends not only on the particular method of linkage and the measure of similarity, but also on the choice of variables, and on the particular division of their continuous values into discrete classes or categories. Therefore clustering should be repeated with various parameters, measures and methods to obtain results maximally free from biases inherent both in human categorisation of reality and in computer taxonomic procedures.

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