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More Observations on the Problem of Tempering in Compositional Studies of Archaeological Ceramics

Hector Neff[a], Ronald L. Bishop[a] and Edward V. Sayre[a]

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Provenance studies of archaeological ceramics by means of chemical characterization may be complicated by the presence of temper in the ceramic paste. The impact of tempering on the compositional distinctiveness of ceramics derived from two distinct clay sources defines an "overlap curve" whose shape is described by the point of maximum temper effect and spread of temper effect. Values of these parameters are determined in part by (1) relative magnitudes of elemental concentrations in clays versus tempers and (2) the initial distinctiveness of the clay sources. Demonstration of these effects with artificially generated data is presented here.

Keywords: POTTERY, ARCHAEOLOGICAL CERAMICS, CHEMICAL CHARACTERIZATION, TEMPER, NEUTRON ACTIVATION ANALYSIS, SIMULATION, PATTERN RECOGNITION.

Adding temper (usually non-plastic material) to clay during paste preparation is a common practice among traditional potters (Shepard, 1956; Rye, 1981; Arnold, 1985; Rice, 1987). This practice complicates the application of neutron activation analysis or other chemical characterization techniques to problems of archaeological provenence determination (Rice, 1978; Arnold *et al.*, 1978; Bishop, 1980; Rice, 1987; Bishop & Neff, 1988). One problem is that tempering may blur the compositional distinctiveness of ceramics derived from separate sources. In a previous paper dealing with the tempering problem (Neff *et al.*, 1988) we mentioned that the effect of temper on attenuating the distinctiveness of two compositional groups depends on (1) the relative magnitudes of elemental concentrations in clays versus tempers and (2) the initial distinctiveness of the clay resources. We did not, however, demonstrate the effect of these characteristics in our previous paper. We provide the demonstration here.

As discussed in our previous paper, we use the term "temper" to refer to non-plastics added to clay by potters. We specifically exclude from our definition naturally occuring non-plastics because, in the absence of other paste preparation practices which may alter composition, a ceramic paste containing natural non-plastics may match its source clay; the mixing (tempering) problem does not exist in this case. Although our focus is on

[a]Conservation Analytical Laboratory, Smithsonian Institution, Washington, D.C. 20560, U.S.A.

mixtures of clay and non-plastic material, our results apply in principle to any mixtures, including mixtures of two clays. Shepard (1956) and Rice (1987) provide more extensive discussions of alternative definitions of "temper".

In our previous paper we introduced the use of simulation techniques to study the effects of tempering. We showed that, for two compositional groups that are initially quite distinct, addition of a given temper may not seriously affect group distinctiveness until quite large amounts of temper are added. Further, for our simulated data sets, although attenuation of group distinctiveness occurs more rapidly for more heterogeneous tempers, even a quadrupling of compositional heterogeneity of the temper does not seriously affect the differentiability of the compositional groups when amounts of temper are within the range of real-world proportions (40 ± 20%).

Here, we elucidate aspects of the tempering problem. As before, we use simulation techniques to examine the effects of added temper. First, we show how the magnitudes of elemental concentrations in the temper help determine the effect of tempering on the separability of ceramics derived from two distinct clay sources. Next, we show how the initial compositional separation between clay sources determines how quickly they coalesce as temper is added. The results we present here reinforce our suggestions (Neff *et al.*, 1988) regarding the importance of characterizing all raw material components (not just clays) to aid the interpretation of ceramic compositional data. We present some guidelines, towards the end of this paper, for conducting chemical characterization studies of tempered ceramics.

Although our simulations are of neutron activation data, the principles we examine apply to other chemical characterization techniques. The main differences with other techniques are (1) the determined elements differ and (2) the precision of the analyses differ, and this may attenuate correlational properties in a data set.

Methods

We employ standard simulation techniques to generate multivariate log normal data sets (e.g. Naylor *et al.*, 1966; Mihram, 1972; Everitt, 1974), which we take to be models of the components, clay or temper, normally mixed by potters during the preparation of ceramic paste. Parameters of these distributions can be varied arbitrarily to model different kinds of components. Elemental concentrations in mixtures of two components are easily found by weighting the elemental concentrations contributed by each component according to that component's proportion in the mixture. These techniques are presented more formally in our previous paper (Neff *et al.*, 1988).

Adding a single class of temper to clays from two compositionally distinct sources attenuates the distinctiveness of ceramics pertaining to the two sources. The progressive attenuation caused by increasing the proportion of temper relative to clay in mixtures derived from two distinct clay sources defines an "overlap curve" (e.g. Neff *et al.*, 1988: Figure 1). Obviously, at 100% temper both groups will take on the compositional characteristics of the temper, and overlap will approach 100%. The first derivative of every overlap curve expresses the magnitude of temper's effect on group attenuation at every possible temper proportion. Thus, if the overlap curve were a straight line ending at 100% overlap, the effect of temper would be constant, i.e. the "effect of temper curve" would be flat at a value equal to the slope of the overlap curve.

In reality, the effect of temper on attenuating the distinctiveness of two clay source-related compositional groups is concentrated around some particular proportion, not spread uniformly over the range of possible tempering values. For example, in the univariate example presented in Table 1, adding temper produces very little increase in overlap below proportions of about 40% temper. More generally, we expect the effect of temper

Table 1. Univariate example of increasing overlap with increasing temper proportion

	Example mixtures					
	Group 1*		Group 2*			
Proportion temper	Mean	S.D.	Mean	S.D.	Av. standard distance†	Av. Probability‡
0·0	10·00	1·00	4·00	1·00	6·00	0·00
0·1	9·70	1·20	4·30	1·20	4·50	0·00
0·2	9·40	1·40	4·60	1·40	3·43	0·00
0·3	9·10	1·60	4·90	1·60	2·63	0·00
0·4	8·80	1·80	5·20	1·80	2·00	0·02
0·5	8·50	2·00	5·50	2·00	1·50	0·07
0·6	8·20	2·20	5·80	2·20	1·09	0·14
0·7	7·90	2·40	6·10	2·40	0·75	0·23
0·8	7·60	2·60	6·40	2·60	0·46	0·32
0·9	7·30	2·80	6·70	2·80	0·21	0·42
1·0	7·00	3·00	7·00	3·00	0·00	0·50

Concentration of element X in Clay 1: 10 (S.D. = 1).
Concentration of element X in Clay 2: 4 (S.D. = 1).
Concentration of element X in temper: 7 (S.D. = 3).
*Mixing formula: $S = Pc(c) + Pt(t)$
where S is sherd concentration, Pc is proportion of clay, c is concentration in clay, Pt is proportion of temper, and t is concentration in temper.
†Average standard distance = (Mean 1 − Mean 2)/S.D.
‡Average probability associated with each average standard distance.

(i.e. the derivative of overlap, not overlap itself) to increase to a peak, then fall off. Assuming further that the distribution of the effect of temper around its maximum value is roughly symmetric, we can, if the initial overlap is not too great, use the probability density function of the normal distribution as a model for the effect of temper. For particular values of maximum temper effect and spread of temper effect, this function is

$$f(x) = (1/\sqrt{2\pi b})\mathrm{e}^{-[(x-a)/b]^2/2}\mathrm{d}x, \tag{1}$$

where e is the base of natural logarithms, x is the proportion of temper, a is the point where temper has its maximum effect, and b is the spread of the effect of temper.

Assuming that the effect of temper is normally distributed over the 0–100% range and that overlap is the cumulative effect of addition of temper, the overlap curve for particular values of maximum temper effect and spread of temper effect is the integral of the probability density function of the normal distribution:

$$F(x) = (1/\sqrt{2\pi b})\int \mathrm{e}^{-[(x-a)/b]^2/2}\mathrm{d}x. \tag{2}$$

The parameters a and b in equations (1) and (2), which express the central tendency and spread of the effect of temper, define the shape the cumulative effect of temper [equation (2), the overlap curve] or its derivative, the instantaneous effect of temper [equation (1)]. Thus, we can describe and compare overlap curves in terms of the parameters a and b.

Figure 1 shows the overlap curve for the data of Table 1 along with an overlap curve fit by nonlinear least squares and the corresponding "effect of temper curve". The empirical and fit overlap curves are farthest apart at 100% temper because, in our example, we assume identical means for the two samples of temper added to each clay. In the real world, the means of two samples from the same temper source would certainly differ, so the observed overlap at 100% temper would not be 100%. In effect, the fit curve probably approximates a real world example better than our contrived example.

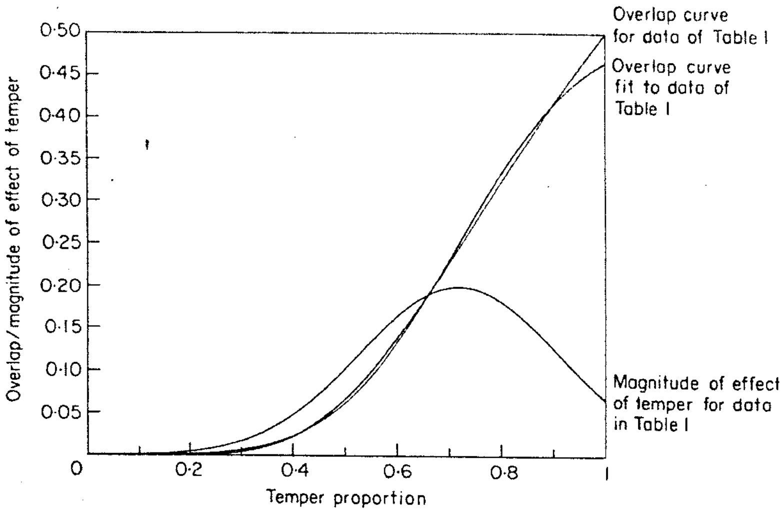

Figure 1. Overlap curves and magnitude of temper effect curve for the univariate data in Table 1. Maximum temper effect = 0·719; spread of temper effect = 0·190.

As a model of temper-induced attenuation of group distinctiveness, the normal distribution model not only is appealing theoretically, but it also fits our data extremely well. We experimented with fitting empirical overlap curves to a logistic model, but found that the sums of squared residuals for the same data are always much greater than for the normal distribution model. Most importantly, the parameters of the logistic model are not as easily related to the effects being modeled.

Our investigative strategy here, as previously, is to use simulation and artificial mixing techniques to generate overlap curves for different kinds of clays or tempers. The distributions of elemental concentrations in our clay and temper "sources" are derived from analytically determined elemental concentrations in clays (two sources) and volcanic ash temper used by contemporary potters in the Valley of Guatemala (see Neff *et al.*, 1988). We vary the parameters of the distributions of elemental concentrations in the components in order to test our ideas about how tempering affects the overlap between compositional groups. Table 2 shows the elemental concentration means for all components (clays and tempers) used in the experiments discussed below.

Each data point on an overlap curve is found by mixing simulated clays representing two distinct "sources" with a simulated temper representing a single "source". Overlap between the two ceramic paste groups thus generated can be measured by (1) the average probability of membership in the wrong group or (2) the total number of specimens showing above some arbitrary probability cut-off value of belonging to the wrong group (Neff *et al.*, 1988). For the illustrations presented here, we use the average probability of membership in the wrong group as a measure of overlap. Theoretically, 50% average probability of membership in the wrong group constitutes total overlap, or total inseparability of the two original groups, and is expected to occur when the mixtures in each paste group approach 100% temper. Of course, the observed average probability of membership in the wrong group always diverges from the expected value of 50% at 100% temper, simply due to chance effects inherent in the sampling of the temper.

A series of data points ranging from nearly pure clay to pure temper defines the overlap curve, for which equation (2) is the model. Nonlinear least squares estimation is used to

Table 2. Elemental concentration means and standard deviations for clays and tempers used in the examples

	Clay no. 1: "Chinauta/Sacojito" clay	Clay no. 2: "Durazno" clay	Clay no. 3: Artificial clay	Temper no. 1: Basic volcanic ash temper	Temper no. 2: Artificial temper
K	13,227·4 ± 2764.2	7818·8 ± 2365·5	10,663·7 ± 1945·8	28,616·7 ± 2142·0	28,458·7 ± 2040·4
Sc	19·8 ± 2·1	18·6 ± 1·5	19·3 ± 1·5	3·9 ± 1·1	22·1 ± 5·6
Cr	63·3 ± 10·2	17·6 ± 5·1	41·0 ± 7·9	3·4 ± 2·4	88·2 ± 60·1
Fe	27,217·4 ± 3172·4	25,323·2 ± 4209·7	26,452·8 ± 2714·1	9212·3 ± 2162·3	29,494·8 ± 6835·4
Zn	141·9 ± 18·6	85·0 ± 13·6	113·4 ± 12·3	35·0 ± 14·5	173·4 ± 76·8
Rb	161·3 ± 13·6	62·8 ± 25·6	112·1 ± 17·5	132·0 ± 7·1	166·4 ± 8·2
Cs	10·0 ± 1·3	0·3 ± 1·0	7·2 ± 1·0	5·5 ± 0·9	10·3 ± 1·8
Ba	391·2 ± 56·7	613·9 ± 103·4	500·2 ± 63·4	1010·3 ± 75·9	995·1 ± 74·9
La	26·1 ± 5·2	27·5 ± 5·0	27·1 ± 4·3	22·9 ± 4·4	29·0 ± 5·5
Ce	48·8 ± 10·0	46·7 ± 10·1	48·7 ± 8·2	35·7 ± 6·1	49·9 ± 9·0
Sm	6·5 ± 1·5	6·0 ± 1·0	6·4 ± 1·0	2·9 ± 0·5	7·4 ± 1·4
Eu	1·2 ± 0·3	1·3 ± 0·2	1·3 ± 0·2	0·5 ± 0·1	1·4 ± 0·3
Yb	3·2 ± 0·8	3·5 ± 0·4	3·4 ± 0·5	1·7 ± 0·3	3·6 ± 0·6
Lu	0·4 ± 0·1	0·5 ± 0·1	0·4 ± 0·1	0·2 ± 0·0	0·5 ± 0·1
Hf	3·7 ± 0·5	4·7 ± 0·8	4·2 ± 0·5	3·2 ± 0·4	4·7 ± 0·7
Ta	0·7 ± 0·1	0·6 ± 0·1	0·7 ± 0·1	0·5 ± 0·1	0·8 ± 0·1
Th	9·3 ± 1·1	7·2 ± 0·7	8·3 ± 0·7	11·1 ± 1·0	11·1 ± 1·1

find the parameters (a, the maximum temper effect, and b, the spread of temper effect) which most closely fit each empirical curve to the model. Because complete overlap implies a 50% average probability of membership in the wrong group, the nonlinear function actually used is equation (2) multiplied by 0·5.

[Technical note: Programs were written in the microcomputer language Gauss (Edlefsen & Jones, 1986), and most are available from the first author. The nonlinear least squares program (Edlefsen, 1985) is provided with the Gauss language package.]

The Relative Magnitude of Elemental Concentrations

Olin & Sayre (1971) first called attention to temper effects in compositional studies when they noted a proportional lowering of elemental concentrations in tempered 16th century North Devon pottery. The proportional lowering was attributed to addition of a relatively pure quartz temper. Such a relationship between elemental concentrations in clays and tempers represents one extreme of a continuum, the extreme in which all determined elemental concentrations in the temper are close enough to zero so that "tempering" can be regarded as equivalent to pure dilution of elemental concentrations. Under these conditions, tempering of clays from compositionally distinct sources does not seriously attenuate separability of the ceramics until the clay–temper mixture approaches pure temper and the elemental concentrations all approach zero.

The effect of adding an inert diluent such as quartz sand can be imagined most easily in one dimension. Assume the concentration of some element, x, in clay source no. 1 is normally distributed with mean 5 and S.D. 2, and that the corresponding element in clay source no. 2 is normally distributed with mean 10 and S.D. 2. The standardized distance between mean 1 and mean 2 is $(10-5)/2=2\cdot5$. Combining clay from both sources with equal amounts of an inert temper (i.e. a temper in which the concentration of element x is effectively 0) halves the elemental concentration means and standard deviations, yielding means of 2·5 and 5, and S.D. of 1. The standardized distance between the means, then, is still $(5-2\cdot5)/1=2\cdot5$.

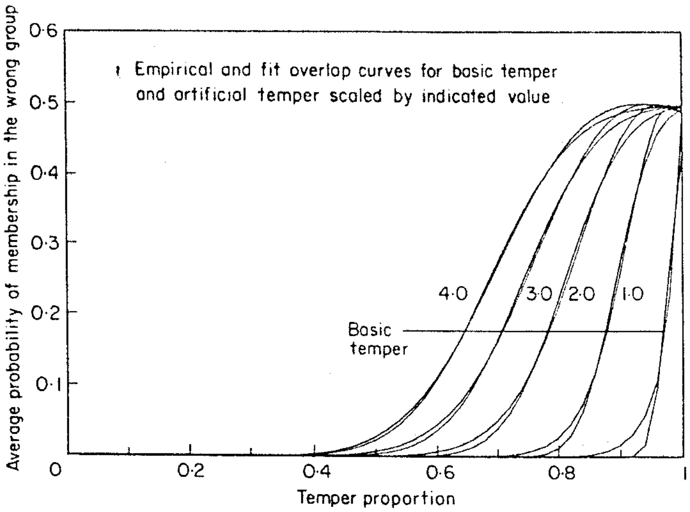

Figure 2. Overlap curves for tempers characterized by distinct elemental concentration means. Both empirical and fit curves are shown. Parameters of the fit curves are given in Table 3.

Table 3. Parameters of the overlap curves plotted in Figure 2

Temper used*	Point of maximum temper effect	Spread of temper effect
Temper 1 (basic temper)	0·978	0·021
Temper 2 × 1·0	0·895	0·048
Temper 2 × 2·0	0·811	0·078
Temper 2 × 3·0	0·743	0·097
Temper 2 × 4·0	0·686	0·111

*Elemental concentration means and S.D.s for tempers nos 1 and 2 are shown in Table 2.

At the opposite extreme from tempering with an inert diluent, a temper whose elemental concentrations are uniformly much higher than in two initially distinct clay sources may seriously affect the separability of ceramics even when the proportion of temper in the ceramic paste is very small.

In order to explore the relationship between the magnitudes of elemental concentration in temper and the shape of overlap curves, we tempered clays derived from two separate "sources" with a series of tempers with differing mean concentrations of all elements (the variance–covariance structure of the temper remains constant). The lowest curve in Figure 2 results from using the basic volcanic ash as the temper. Most elemental concentration means in the basic temper are below the corresponding values in the clays (compare the two basic clays, clays nos 1 and 2, with the basic temper, temper no. 1, in Table 2). As expected, very large proportions of temper must be added before there is any appreciable increment in overlap. When the elemental concentrations in the temper are modified so that each mean value is at least as large as the corresponding mean value in

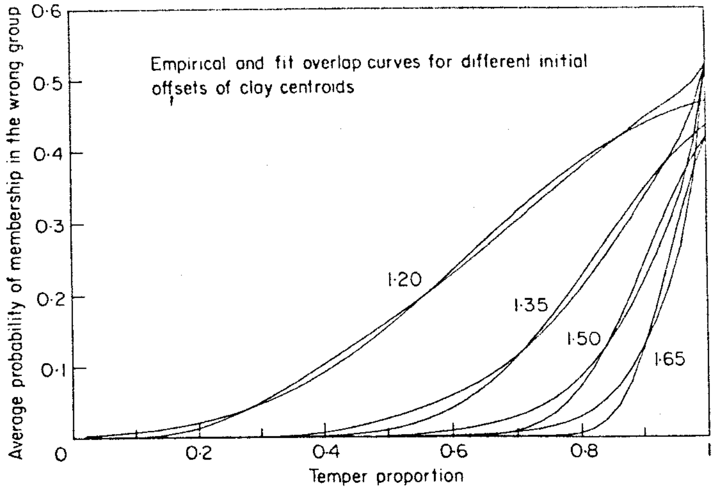

Figure 3. Overlap curves for different initial offsets of clay centroids. Both empirical and fit curves are shown. Parameters of the fit curves are given in Table 4.

Table 4. Parameters of the overlap curves plotted in Figure 3

Initial offset of clay centroids*	Point of maximum temper effect	Spread of temper effect
1·20	0·622	0·243
1·35	0·821	0·158
1·50	0·904	0·097
1·65	0·942	0·060

*"Offset" is the factor by which elemental concentration means in clay no. 1 (see Table 2) are multiplied to produce the comparison clay data set. Standard deviations are identical in the two clay data sets.

each of the clay sources (these are the values given for the temper no. 2 in Table 2), the overlap curve shifts upward. Further shifts occur as the elemental concentrations in the temper are increased further.

Table 3 shows the parameters of the overlap curves plotted in Figure 2. The point of maximum temper effect gradually falls as elemental concentrations in the temper are increased, while the spread of temper effect increases gradually.

The Effect of Initial Separation Between Clay Sources

In the foregoing example and in our previous study, the centroids of the two basic clay "sources" (clays nos 1 and 2 in Table 2) are very far from one another in elemental concentration space. While this separation facilitates illustration of the effects of adding different kinds of tempers, one may reasonably question how often this condition obtains in the real world. Further, one may reasonably ask, if the groups are initially less distinct, will tempering pose a more serious threat to the efficacy of compositional analysis?

Again, it is useful to imagine the univariate case of two groups with different mean values of a single element. If the elemental concentration means are initially 3·0 and 4·0, and the S.D. of both groups is 1·0, their initial separation, defined as the standardized distance between the two means, is 1·0. Combining both clays with equal parts temper with a concentration of 2·0 and S.D. of 1·0 yields two groups whose means, 2·5 and 3, are now separated by 0·5 standardized units. If the initial concentrations in the clay are instead 3·0 and 5·0, adding equal parts temper with a concentration of 2·0 ± 1·0 yields two groups whose means, 2·5 and 3·5, are separated by 1·0 standardized units.

Figure 3 illustrates the effect of moving the centroids of two clay sources closer together. Using the same variance–covariance structure for two hypothetical clay sources (we used the Chinautla clay source, clay no. 1 in Table 2, but the choice was arbitrary), the mean vector of elemental concentrations for one clay is offset by a factor of 1·20, 1·35, 1·50, and 1·65, producing the sequence of overlap curves shown in the figure. As expected, the initial separation between the clays significantly determines the effect of tempering. For the extreme case of one centroid offset by only 1·20 from the other, overlap begins to rise above negligibility at temper proportions below 20%. As shown in Table 4, as the initial separation of the clay centroids increases, the point of maximum temper effect approaches 100% temper, and the effect becomes concentrated over a smaller range of tempering proportions. Thus, as expected, predicting whether or not a given proportion of temper added to clay will obscure clay source-related patterning depends on knowing something about the initial separation between untempered clays in compositional space.

Practical Implications

As we will discuss in more detail below, the implications of our findings for compositional analysis of archaeological ceramics have to be assessed with reference to specific ceramic components from a specific region. Nonetheless, it is instructive to imagine various possible situations and to ask whether any of them might present insurmountable obstacles to the effective separation of clay source-related compositional groups. We must acknowledge that most of the ceramic components we have used for illustrative purposes above are not likely to characterize real ceramic components. For example, it would be very unusual in the real world to find a temper with all elemental concentrations double or quadruple the corresponding concentrations in the clay. On the other hand, one might reasonably expect to find a temper in which elemental concentrations are all right around or somewhat higher than elemental concentrations in local clays.

We have shown elsewhere (Neff *et al.*, 1988) that common pattern recognition techniques easily recover the Chinautla/Sacojito versus Durazno distinction (clay no. 1 versus clay no. 2 in Table 2) in a data set with a mean of 40% volcanic ash (temper no. 1) added, even when the heterogeneity of the ash is increased greatly. But imagine that one of the clay sources exhibited a compositional profile intermediate between the Chinautla/Sacojito and Durazno clay (clay no. 3 in Table 2). Sedimentary environments typically give rise to such mixtures and gradations of chemical composition. Further, imagine that a temper like our artificial temper (temper no. 2) was mixed with both the intermediate and the pure clay. A "grog" or crushed sherd temper might, like our artificial temper, be characterized by elemental concentrations about the same as or slightly higher than local clays. Such a situation might present significant challenges to the utility of compositional analysis for recovering the true structure in an analysed data set.

Figure 4 shows the empirical and fit overlap curves for the two clays and temper just discussed. At 40% temper, the average probability of membership in the wrong group is 3–4%, which might suggest that the two groups are still separable. Taking 40% as a typical real-world tempering proportion, we can further examine the extent of temper-related attenuation of group distinctiveness by plotting the first two principal components of mixed and unmixed data sets. Although the first two principal components do not show the true multivariate separation between the groups (there are a total of 17 dimensions and

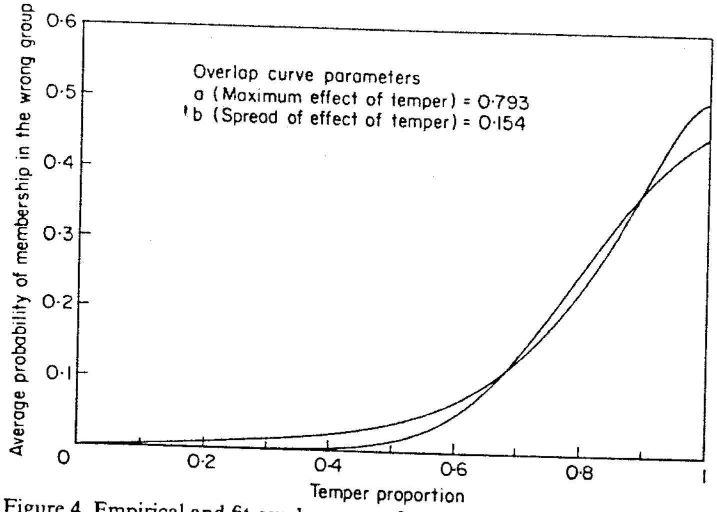

Figure 4. Empirical and fit overlap curves for two hypothetical sedimentary clays (clay nos 1 and clay 3) mixed with a hypothetical grog temper (temper no. 2).

only two are depicted), they subsume most of the variance in the data set, and give a rough approximation of the structure that would be recovered with cluster analysis (cf. Neff *et al.*, 1988). The upper plot in Figure 5 shows the first two principal components of the unmixed data set, while the bottom plot shows the components of the tempered data set. The two ellipses shown on each plot indicate points having $>10\%$ probability of membership in each group, based on Hotelling's T^2 calculted in the two plotted dimensions. While picking out two centroids would be difficult on both scatterplots, the overlap between groups is significantly greater for the tempered data set.

In confirmation of the impression gleaned from inspection of the principal components plots, average linkage hierarchical cluster analysis of Euclidean distances effectively separates the two untempered groups (and identifies a total of five outliers) but fails entirely to separate the tempered groups. In summary, if 40% grog temper resembling our artificial temper (temper no. 1) were added by potters to the Chinautla/Sacojito clay (clay no. 1) and our artificial sedimentary clay (clay no. 3), recovery of the true, two-centroid structure of the data set might be impossible. Here, then, is a plausible case in which tempering would pose a very serious threat to the utility of compositional analysis.

Conclusion

Whether or not tempered ceramics derived from two distinct clay sources subdivide into two groups in compositional space depends on three general characteristics of the raw materials.

(1) The amount of temper added is crucial, since overlap increases with increasing temper no matter what combination of components is mixed.

(2) As shown above and elsewhere (Neff *et al.*, 1988), both the heterogeneity of the added temper and the elemental concentrations in the temper are important.

(3) As shown above, one must consider the compositional distinctiveness of the two clays. These observations imply some general methodological lessons for compositional studies.

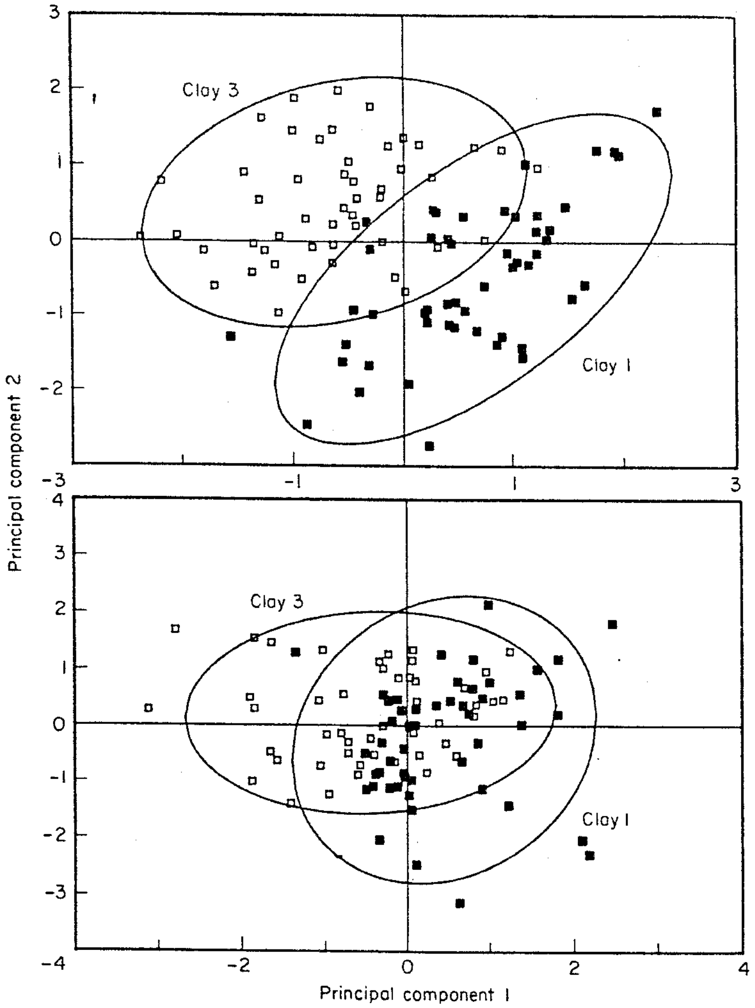

Figure 5. Plot of first two principal components of data sets produced from hypothetical sedimentary clays (clay nos 1 and clay 3). Top: unmixed; plot represents 78% of total variance in the data. Bottom: mixtures of 0·6 clay with 0·4 (0·1 S.D.) temper no. 2; plot represents 70% of the total variance in the data. Points lying within each ellipse have > 10% probability of membership in the group. Probabilities are calculated using Hotelling's T^2, and are based only on the two indicated dimensions.

Other things being equal, one may generalize about the degree to which different classes of temper will obscure the distinctiveness of clay source-related groups in compositional space. At one extreme, adding quartz to two clay source-related groups simply dilutes the elemental concentrations in both groups but does not obscure their distinctiveness unless extremely high concentrations of temper are added. This is because quartz is nearly pure SiO_2 and the concentrations of most elements determined by neutron activation analysis are near 0. Calcite temper similarly is unlikely to destroy compositional patterning since the effect on all clays would be enrichment of calcium along with dilution of most other elements (cf. Bishop, 1980). Even volcanic ash temper, which may have high concentrations of several elements determined by neutron activation analysis, often will not seriously compromise the separability of compositional groups because the concentrations of many other elements, particularly rare earths, are likely to be far below the concentrations in clays (cf. Rice, 1978; Bishop, 1980; Neff *et al.*, 1988).

At the opposite extreme from tempers which pose a very small threat to compositional analysis, crushed sherd temper could seriously attenuate the distinctiveness of two clay source-related compositional groups, even when added in comparatively small proportions. Two conditions would promote this effect. First, sherd temper is likely to have mean elemental concentration values nearly as high or higher than corresponding concentrations in local clays. In addition, if a heterogeneous collection of sherds were crushed to make the temper, the temper itself would manifest substantial compositional heterogeneity. Both these conditions would enhance the attenuation of group distinctiveness with increasing temper. Other things being equal, some skepticism is warranted regarding the use of compositional analysis to differentiate clay source-related groups in a collection of sherd-tempered pottery.

We must emphasize that all the above generalizations about temper carry the "other things equal" qualification. To formulate useful expectations about the compositional patterning likely to be encountered in ceramics from some region, as much information as possible should be collected about both the ceramics under investigation and the ceramic environment. Binocular examination of a large sample of the excavated collections followed by division of the sample into texture subgroups can provide especially important information to use in the formulation of expectations about compositional patterning. Binocular observations (e.g. identification of crushed sherd fragments, distinctions in angularity, or deviations from expected size distributions) may permit identification of temper as distinct from naturally occurring non-plastics. Thin-section examination of a smaller sample will help establish the accuracy of the binocular identifications. Once the likely classes of tempering material have been identified, appropriate expectations can be formulated about compositional patterning in tempered ceramics. Data on the ceramic environment, including the nature of depositional regimes (obtainable from geological maps) and, if possible, analyses of raw clays and tempers, will facilitate formulation of more specific expectations about the level of compositional resolution likely to result from a particular research program. Also, analysed ceramics from the region may be compared with artificial data sets representing various mixtures of the sampled raw materials, and, in some cases, it may be possible to relate tempered ceramics directly to raw material sources.

Even if it is impossible to make definitive distinctions between natural and added non-plastics, binocular examination will identify classes of non-plastics that may have been added, and this information can be crucial in formulating alternative expectations about patterning in compositional data. For instance, if a class of pottery with abundant quartz inclusions is identified among the ceramics from a region, the possibility that elemental concentrations in the quartz-containing ceramics bear a proportional relationship to those in non-quartz containing ceramics would have to be taken into account in the interpretation of compositional data. On the other hand, as suggested by the results presented above, one could be fairly confident that clay source-related distinctions would be preserved in the quartz-containing ceramics even if the elemental concentrations were diluted by the addition of temper.

Raw material characterization is useful even if the exact sources of clays and tempers used by ancient potters are not located and analysed. For example, finding that compositional differences among clay deposits within a region are relatively large (i.e. the centroids pertaining to various deposits are distant from one another in compositional space) would suggest that clay source-related patterning will be easily discovered in tempered ceramics from the region. If analysed tempers are then found to be homogeneous and elemental concentrations are much lower than in clays, one becomes even more certain of the usefulness of compositional analysis for recovering clay source-related patterning.

We must note in conclusion that tempering may create as well as destroy compositional patterning in a group of tempered ceramics, either through bimodal addition of a single temper to clay from a single source or through addition of distinct tempers to clay from a single source (Bishop & Neff, 1988; Neff *et al.*, 1988). Although our purpose here is not to discuss the details of temper-related compositional patterning, we point out that the strategy advocated above, involving binocular examination of a large sample of ceramics combined with a ceramic resources survey, would produce information relevant to whether tempering may have created the structure observed in an analysed sample of ceramics.

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