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Appendix E

CERAMIC PASTE COMPOSITIONAL CHEMISTRY: INITIAL OBSERVATIONS OF VARIATION IN THE TUCSON BASIN

Ronald L. Bishop
Senior Research Archaeologist
Conservation Analytical Laboratory
Smithsonian Institution

Within the San Xavier Bridge Site Project, analytical emphasis has been placed upon an extensive program of petrographic analysis; in particular, attention has been focused upon an attempt to "match" contemporarily available sands to the nonplastic inclusions found within pottery recovered during the course of the archaeological investigation (Chapter 20). Petrological variability represents but one area for research, and one must consider how present investigations will relate to future projects of more interregional scope. One avenue of interregional investigation that is gaining prominence in the U.S. Southwest is the compositional investigation of pottery through the chemical analysis of the ceramic paste (for example, Deutchman 1980; Crown 1981b; Tuggle and others 1982). Although such investigations have found increasing application in areas such as the organization of production or as aids for questions pertaining to ceramic typological relationships, the predominant area of application is the investigation of the localization of production and the identification of "nonlocally produced" (trade) pottery. Ultimately, questions of local versus nonlocal must be phrased in a regional, rather than a site specific, perspective (Bishop and others 1982). Nevertheless, a necessary starting point is the identification of a local compositional profile for a given site or region. In effect, this initial step represents a feasibility study designed to assess the chemically expressed compositional variability encountered within a target pottery.

It is within such a perspective that a limited program of major, minor, and trace element analysis was carried out as part of the San Xavier Bridge Project. This appendix reports on the procedures employed and the results thus far obtained. As the investigation was limited, so too are the conclusions to be drawn from it; it does, however, permit an assessment of what will be necessary for a more thorough investigation. At the conclusion of the report avenues for future research will be mentioned.

The data are approached from the perspective of a ceramic data analyst who is attempting to ascertain the primary dimensions of observed elemental variability or tendency toward group patterning within a given data matrix. The incorporation of this information within the larger ceramic compositional system and its placement within the regional archaeological context is the responsibility of the investigators who carried out the compositional research design, sample selection and analysis. Their synthesis is contained in Chapter 8.

Samples Selected

The rationale for sample selection has been given in Chapter 8. Samples included the ceramics containing Lombard's (Chapter 20) most commonly identified sand type, comparison pottery, and test tiles composed of unstated proportions of sands and clays. A listing of the analyzed specimens is given in Table E.1. In addition, known nonlocal clays from the Grasshopper Site were included in the analytical program. Through the limited program of analysis and by the broad sampling, it was hoped that the feasibility of differentiating among the various regional clays and ceramic groups could be assessed—albeit within the precision and sensitivity of the analytical methods employed.

Analytical Methods

The samples were submitted for bulk analysis to X-ray Assay Laboratories, Limited, an analytical laboratory that has been providing chemical analysis for the geological exploration community for more than 35 years. Generally, if they can be found, laboratories that are equipped to carry out certain kinds of analyses, such a neutron activation analysis, are prohibitively expensive for large-scale archaeological application. Other laboratories may perform only a limited kind of analysis such as X-ray fluorescence, which by itself has seldom been found to have sufficient sensitivity for obtaining ceramic data commensurate with the requirements of the archaeological questions. X-ray Assay Laboratories performs several different kinds of analytical determinations as part of their "whole rock" analysis program. Neutron activation analysis (NA), atomic absorption (AA), direct current plasma spectroscopy (DCP) and X-ray fluorescence (WR) are all used on a given sample. Determinations of some 52 elements are made and reported as oxides. The reported detection limits are given in Table E.2.

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TABLE E.1

Description of Analyzed Samples

Sample Number	*Thin-section Sample Number*	*Field Number and Provenience*	*Type or Other Information*
1	Tile 1		Cienega clay; Santa Cruz sand
2	Tile 2		Stratum 80, Sample No. 3 clay; Santa Cruz sand
3	Tile 14		Stratum 80, Sample No. 4 clay; Santa Cruz sand
4	Tile 16		Stratum 70 clay; Santa Cruz sand
5	102 (Tile 12)		Stratum 80, Sample No. 3 clay; Grannen sand
6	Tile 13		Stratum 80, Sample No. 4 clay; Grannen sand
7	Tile 15		Stratum 70 clay; Grannen sand
8	Tile 17		Stratum 90 clay; Grannen sand
9	101 (Tile 6)		Argillic horizon at Grannen (northern Tucson Mountains); Santa Cruz sand
10	Tile 7		Grasshopper clay; Santa Cruz sand
11	Tile 11		Argillic horizon, southern Tucson Mountains; Santa Cruz sand
12	99 (Tile 4)		Argillic horizon, southern Tucson Mountains; crushed granitic rock temper
13	Tile 8		Grasshopper clay; crushed White Mountain Red ware sherd temper
14	Tile 10		Grasshopper clay; Grannen sand
15	Tile 19		Argillic horizon at Grannen, Grannen sand
16	Tile 6		Same as Sample 9
17	20	FN 273, Stratum 70	Rincon Smudged bowl; Lombard Group G
18	188	FN 188, Stratum 70	Plain ware; indeterminate form; Lombard Group E
19	1	FN 1101, Feature 62	Tanque Verde Smudged bowl; Lombard Group E
20	10	FN 1578, Stratum 70-80	Tanque Verde Smudged bowl; Lombard Group G
21	64	FN 628, Stratum 80	Tanque Verde Smudged bowl; Lombard Group F
22	84	FN 1304, Stratum 60	Tanque Verde Slipped/smudged bowl; Lombard Group L
23	30	FN 1667, Feature 76	Plain ware jar; Lombard Group J
24	46	FN 2308, Stratum 70-80	Late Rincon Smudged bowl; Lombard Group J
25	57	FN 1285, Stratum 80	Late Rincon bowl; Lombard Group J
26	56	FN 384, Stratum 10	Late Rincon bowl; Lombard Group J
27	58	FN 2376, Feature 102	Plain ware jar; Lombard Group J
28	32	FN 302, Stratum 70	Plain ware jar; Lombard Group J
29	48	FN 472, Feature 34	Plain ware jar; Lombard Group J
30	7	FN 244, Stratum 70	Tanque Verde jar; Lombard Group J
31	34	FN 1722, Stratum 80	Red ware bowl; polished, no striae; Rincon Red tradition; Lombard Group J
32	8	FN 224 Stratum 70	Tanque Verde jar; Lombard Group J
33	87	FN 1974, Stratum 80	Obliterated, indented corrugated, indeterminate form; Lombard Group I
34	86	FN 74, Stratum 80	Stucco plain jar; Lombard Group C
35	39	FN 425, Feature 35	Tanque Verde Smudged bowl; Lombard Group M
36	11	FN 2269, Stratum 80	Tanque Verde jar; Lombard Group K
37	24	FN 425, Feature 35	Red ware bowl (Wingfield tradition); Lombard Group D
38	678d	FN 678, Feature 35	Smudged plain ware bowl; Lombard Group M
39	62	FN 1765, Stratum 70-80	Sells Red tradition bowl; Lombard Group M
40	62	FN 1765, Stratum 70-80	Same as 39–control sherd
41	89	BB:13:3	Brown obliterated, indented, corrugated jar rim; no thin section results yet
42	90	BB:13:3	Tanque Verde/Sahuaro Polychrome jar; no results
43	91	BB:13:3	Tucson Polychrome, hachured variant jar; no results
44	92	BB:13:3	Tanque Verde Red-on-brown smudged bowl; no results
45	93	BB:13:3	Gila or Pinto-Gila bowl rim; no results
46	94	BB:9:33	San Carlos Red-on-brown bowl rim; no results
47	95	BB:9:33	Tucson Polychrome, hachured variant jar(?); no results
48	96	BB:9:33	Tucson Polychrome, solid variant bowl; no results
49	97	W:10:50	Tucson Polychrome, solid variant jar(?); no results
50	98	W:10:50	Tucson Polychrome, hachured variant jar(?); no results

Data are reported according to the varying precision of the constituent determination. At present, details of each method of analysis are not available, nor is information concerning the standards or flux monitors used in the determinations. These will be forthcoming. At the present time, the absolute accuracy of the measurements can not be assessed; however, as multiple samples of an individual sherd and an individual laboratory produced tile were included in the samples analyzed, an assessment of precision—including analytical and counting statistical errors—can be drawn (Tables E.3a and E.3b).

All analytical determinations have a level of error built into them. It may be irreducible error such as that connected with counting statistics. In addition to error, there may be considerable "noise" in the system. Noise may be introduced by the potter who departs from "usual" modes of ceramic production by throwing in a handful of immediately available sand rather than obtaining more of his regularly employed tempering material. Such idiosyncratic variation forces compositional studies to adopt a statistical perspective instead of an object-to-object comparison perspective. Unfortunately, another type of noise was introduced to this sample data set by the process of sample preparation. Sherd surfaces, slips, or paints were not avoided; the concentration data, therefore, in terms of relative weight, represent the ceramic matrix along with some unknown proportions of contaminants introduced with the surface. Red paint or slip, possibly being an iron or iron and manganese containing material, might significantly influence the compositional profile of a sample. However, most of the pottery is not slipped or painted, and thus the data, while perhaps noisier than one would like, are worth retaining.

Data Analysis

The data were numerically summarized as reported with attention given to determining if pottery found in the course of the archaeological investigation was subject to chemical patterning and, if so, if it could be chemically distinguished from other pottery that was more likely to have been imported to the San Xavier area. Several of the analytical determinations were at or below the stated detection levels and were excluded from further consideration; other elements frequently had missing data and similarly were rejected. In all, 36 of the element determinations were considered for data summary (Table E.4), although only certain elemental subsets of the data are considered in this report.

Little explicit rationale exists for choosing one set of elements over another set. Usually the number is limited due to restriction to a single analytical technique; in such a case, those elements whose analytical precision is highest are used. In this investigation, a comparison was made between the replicate analyses (Tables E.3a and E.3b). Those elements that agreed well on the two analyses of the single sample were selected for the initial investigation of grouping tendency in the sample data. Throughout, element concentrations are utilized after a transformation to log distributions. Such a transformation is common for trace elements, as they seem to follow a log normal distribution. No such generalization is possible for minor and major element concentrations. However, without some form of normalization the larger concentrations of major and minor elements would outweigh the smaller. The rationale for a log transformation is discussed further by Harbottle (1976, 1982b).

From a data matrix of the log concentrations of Sc, Co, Ni, Cu, Zn, Sb, Ca, La, Ce, Nd, Sm, Eu, Yb, Lu, Th and U, a matrix of sample-to-sample similarities was calculated

TABLE E.2

X-Ray Assay Laboratories' Analytical Methods and Detection Limits

Element	*Method*	*Detection Limit*
AU PPB	NA	10.000
LI PPM	AA	10.000
BE PPM	DCP	10.000
B PPM	DCP	10.000
WRMAJ %	WR	0.010
SC PPM	NA	0.100
V PPM	DCP	10.000
CR PPM	NA	2.000
MN PPM	DCP	2.000
CO PPM	NA	1.000
NI PPM	DCP	1.000
CU PPM	DCP	0.500
ZN PPM	DCP	0.500
GE PPM	DCP	10.000
AS PPM	NA	2.000
SE PPM	NA	3.000
BR PPM	NA	1.000
WRMIN PPM	WR	10.000
MO PPM	NA	5.000
AG PPM	DCP	0.500
CD PPM	DCP	0.200
SB PPM	NA	0.200
CS PPM	NA	0.500
LA PPM	NA	0.500
CE PPM	NA	3.000
ND PPM	NA	5.000
SM PPM	NA	0.100
EU PPM	NA	0.200
YB PPM	NA	0.200
LU PPM	NA	0.050
HF PPM	NA	1.000
TA PPM	NA	1.000
W PPM	NA	3.000
PB PPM	DCP	2.000
BI PPM	DCP	0.500
TH PPM	NA	0.500
U PPM	NA	0.500

AA = Atomic absorption
NA = Neutron activation
WR = Whole rock analysis (X-ray fluorescence)
DCP = Direct current plasma spectroscopy

TABLE E.3

Replicate Analyses

a, Tile 6*

	NA PCT	MG PCT	AL PCT	SI PCT	P PCT	K PCT	CA PCT	SC PPM	TI PCT	V PPM	CR PPM	MN PPM	FE PCT	CO PPM	NI PPM	CU PPM	ZR PPM	AS PPM
ASM 09	1.12	1.53	18.2	64.1	0.08	3.85	1.14	13.3	0.59	80.	80.	470.	5.30	8.	23.	37.0	280.	11.
ASM 16	1.21	1.55	18.3	64.0	0.08	3.90	1.17	13.6	0.58	90.	83.	500.	5.26	9.	24.	39.0	290.	12.
Number Averaged	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
MEAN CONC	1.16	1.54	18.2	64.0	0.08	3.87	1.15	13.5	0.58	85.	81.	485.	5.28	8.	23.	38.0	285.	11.
GRP STD DEV (PCT)	5.7	0.8	0.0	0.0	0.0	0.8	1.8	1.6	1.3	8.7	2.6	4.5	0.6	8.7	3.0	3.8	2.5	6.4

	RB PPM	SR PPM	Y PPM	ZN PPM	NB PPM	SB PPM	CS PPM	BA PPM	LA PPM	CE PPM	ND PPM	SM PPM	EU PPM	YB PPM	LU PPM	PB PPM	TH PPM	U PPM
ASM 09	230.	170.	40.	280.	20.	2.4	23.8	719.	54.8	85.	35.	6.9	1.3	3.0	0.53	22.	16.0	4.0
ASM 16	250.	200.	20.	110.	20.	2.5	21.8	740.	57.4	89.	34.	7.2	1.2	3.3	0.55	22.	15.0	3.3
Number Averaged	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
MEAN CONC	240.	184.	28.	175.	20.	2.4	22.8	729.	56.1	87.	34.	7.0	1.2	3.1	0.54	22.	15.5	3.6
GRP STD DEV (PCT)	6.0	12.3	63.2	93.7	0.0	3.0	6.6	2.0	3.3	3.3	2.1	3.0	5.9	7.1	2.6	0.0	4.7	14.5

b, Sells Red Bowl Sherd

	NA PCT	MG PCT	AL PCT	SI PCT	P PCT	K PCT	CA PCT	SC PPM	TI PCT	V PPM	CR PPM	MN PPM	FE PCT	CO PPM	NI PPM	CU PPM	ZR PPM	AS PPM
ASM 39	3.88	0.86	18.5	57.5	0.21	3.69	1.30	18.0	0.97	110.	54.	480.	8.59	47.	22.	140.0	370.	160.
ASM 40	3.97	0.87	18.8	58.5	0.22	3.68	1.27	18.2	0.97	120.	81.	520.	8.83	48.	22.	150.0	420.	170.
Number Averaged	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
MEAN CONC	3.93	0.86	18.6	58.0	0.21	3.69	1.29	18.1	0.97	115.	66.	499.	8.71	47.	22.	144.9	394.	165.
GRP SRD DEV (PCT)	1.6	1.0	1.2	1.3	3.3	0.0	1.7	0.8	0.0	6.4	33.2	5.9	2.0	1.5	0.0	5.0	9.4	4.3

	RB PPM	SR PPM	Y PPM	ZN PPM	NB PPM	SB PPM	CS PPM	BA PPM	LA PPM	CE PPM	ND PPM	SM PPM	EU PPM	YB PPM	LU PPM	PB PPM	TH PPM	U PPM
ASM 39	190.	180.	40.	94.	30.	4.6	42.3	590.	57.9	100.	40.	8.8	1.8	4.1	0.79	78.	23.0	2.9
ASM 40	190.	160.	40.	88.	30.	5.3	42.5	590.	56.8	93.	40.	8.7	1.3	4.3	0.76	80.	24.0	3.0
Number Averaged	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
MEAN CONC	190.	170.	40.	91.	30.	4.9	42.4	590.	57.3	96.	40.	8.7	1.5	4.2	0.78	79.	23.5	2.9
GRP STD DEV (PCT)	0.0	8.7	0.0	4.8	0.0	10.4	0.3	0.0	1.5	5.3	0.0	0.7	25.8	3.3	2.8	1.8	3.0	2.5

*Argillic horizon clay, northern Tucson Mountains, and Santa Cruz sand

according to intersample mean Euclidean distances. The intersample relationships were subsequently summarized in the form of a dendrogram resulting from a complete linkage hierarchical clustering (compare Sneath and Sokal 1971: 122–128, 222–228). Complete linkage is a conservative approach that may result in the proliferation of several small clusters of samples; however, the clusters will be more internally homogeneous than with several other approaches such as average or single linkage. The resulting dendrogram is shown in Figure E.1. Lines have been added to set off numbered regions that will be discussed further below. Prominent among the groupings is Region VIII, a concentration of Tanque Verde and Rincon Red-on-brown ceramics. Interestingly, a few Tanque Verde and Rincon samples appear in other divisions (VI, III).

In other parts of the dendrogram, Section I contains test tiles made from Argillic horizon samples, including Santa Cruz sand, granitic rock, and Grannen sand used as temper in the various tiles. Section II is a small group, the linkage of which suggests little clustering tendency. A larger section of the dendrogram, III, is made up exclusively of test tiles. In these tiles, the clays from Strata 80 and 70 have been mixed with

TABLE E.4

Sample Concentration Data for Higher Precision Determinations

Sample Number	NA PCT	MG PCT	AL PCT	SI PCT	P PCT	K PCT	CA PCT	SC PCT	TI PCT	V PPM	CR PPM	MN PPM	FE PCT	CO PPM	NI PPM	CU PPM	ZR PPM	AS PPM	RB PPM	SR PPM	Y PPM	ZN PPM	NB PPM	SB PPM	CS PPM	BA PPM	LA PPM	CE PPM	ND PPM	SM PPM	EU PPM	YB PPM	LU PPM	PB PPM	TH PPM	U PPM
ASM 01	1.90	2.39	18.4	62.5	0.18	3.19	2.19	14.6	0.63	100.	100.	470.	5.93	16.	27.	140.0	180.	9.	260.	360.	30.	160.	10.	3.8	33.8	760.	58.2	97.	36.	7.7	1.2	3.3	0.57	96.	21.0	5.0
ASM 02	2.37	1.84	15.3	63.2	0.33	3.46	4.83	10.9	0.69	90.	160.	760.	4.91	11.	22.	82.0	250.	12.	190.	560.	30.	130.	20.	3.3	22.6	839.	46.1	73.	28.	6.0	1.2	2.8	0.55	74.	17.0	4.6
ASM 03	2.50	1.72	15.7	65.8	0.18	3.60	4.26	10.0	0.62	80.	130.	760.	4.48	11.	20.	71.9	220.	14.	200.	450.	10.	120.	30.	3.1	20.4	871.	43.6	70.	29.	5.5	1.0	2.4	0.50	40.	16.0	4.4
ASM 04	2.57	1.66	15.8	66.5	0.17	3.59	3.59	9.9	0.64	80.	130.	619.	4.57	12.	21.	74.0	200.	11.	210.	460.	20.	110.	20.	3.2	19.9	920.	43.9	73.	25.	5.6	1.2	2.2	0.47	40.	15.0	4.1
ASM 05	2.29	1.00	13.7	71.8	0.19	3.85	2.67	7.6	0.47	50.	93.	610.	3.26	7.	13.	44.0	220.	9.	190.	370.	20.	85.	30.	2.6	17.5	889.	47.5	80.	29.	5.7	0.6	2.6	0.51	32.	13.0	3.6
ASM 06	2.25	1.68	15.7	66.5	0.18	3.77	4.08	10.3	0.59	70.	120.	750.	4.36	11.	20.	71.9	210.	12.	200.	410.	10.	210.	30.	3.2	22.7	899.	48.0	79.	34.	6.2	1.2	2.6	0.50	38.	16.0	4.1
ASM 07	2.08	1.74	15.7	67.1	0.17	3.65	3.47	11.5	0.63	80.	71.	719.	4.56	11.	20.	83.0	220.	14.	190.	370.	40.	220.	20.	3.5	24.9	871.	55.6	90.	37.	6.9	1.4	2.9	0.54	40.	17.0	5.0
ASM 08	1.71	2.45	17.4	64.0	0.26	3.53	3.06	13.4	0.66	90.	65.		5.45	15.	26.	119.9	200.	18.	230.	390.	20.	200.	20.	3.5	25.8	849.	56.6	93.	36.	7.3	1.1	3.1	0.54	60.	19.0	5.2
ASM 09	1.12	1.53	18.2	64.1	0.08	3.85	1.14	13.3	0.59	80.	80.	470.	5.30	8.	23.	37.0	280.	11.	230.	170.	40.	280.	20.	2.4	23.8	719.	54.8	85.	35.	6.9	1.3	3.0	0.53	22.	16.0	4.0
ASM 10	1.08	2.39	14.4	67.0	0.13	2.65	5.35	12.6	0.71	100.	170.	610.	5.24	10.	42.	45.0	230.	9.	160.	200.	20.	92.	20.	1.4	12.1	460.	41.7	67.	29.	5.7	1.2	2.8	0.53	18.	13.0	4.4
ASM 11	1.39	1.39	20.0	64.4	0.09	4.37	1.47	13.1	0.55	100.	100.	520.	4.97	8.	20.	49.0	280.	28.	270.	280.	40.	100.	20.	2.6	40.3	809.	49.3	75.	27.	6.4	0.9	2.8	0.51	24.	15.0	3.9
ASM 12	0.68	1.54	20.6	61.0	0.07	4.22	1.05	15.3	0.54	100.	96.	570.	5.48	7.	24.	38.0	280.	32.	260.	220.	40.	110.	10.	2.6	40.0	670.	51.3	80.	35.	6.6	0.8	2.8	0.50	22.	14.0	3.5
ASM 13	0.40	2.73	15.1	66.1	0.13	2.31	5.85	14.7	0.79	100.	180.	619.	5.73	10.	50.	49.0	220.	10.	120.	90.	50.	92.	30.	1.0	15.6	350.	41.6	68.	26.	6.2	0.9	3.4	0.57	10.	12.0	5.0
ASM 14	0.85	2.33	13.6	69.0	0.12	2.66	5.11	12.0	0.65	90.	190.	610.	4.94	9.	43.	29.0	220.	8.	130.	130.	30.	78.	20.	1.0	11.7	450.	37.5	61.	27.	5.2	1.5	2.9	0.56	12.	9.7	3.9
ASM 15	1.61	1.19	16.5	70.0	0.07	3.86	1.12	10.9	0.49	70.	100.	600.	4.46	8.	19.	35.0	240.	9.	210.	200.	30.	90.	20.	2.0	18.5	791.	47.3	76.	31.	6.1	1.2	3.5	0.69	24.	13.0	3.2
ASM 16	1.21	1.55	18.3	64.0	0.08	3.90	1.17	13.6	0.58	90.	83.	500.	5.26	9.	24.	39.0	290.	12.	250.	200.	20.	110.	20.	2.5	21.8	740.	57.4	89.	34.	7.2	1.2	3.3	0.55	22.	15.0	3.3
ASM 17	2.41	1.28	18.0	62.4	0.18	3.68	3.06	10.4	0.93	110.	70.	520.	5.45	11.	22.	55.0	270.	11.	220.	530.	40.	110.	20.	2.6	20.2	1069.	50.4	84.	32.	6.8	1.3	2.3	0.49	16.	15.0	3.9
ASM 18	2.14	1.70	16.0	63.5	0.16	4.02	4.69	9.8	0.51	70.	100.	600.	4.35	8.	20.	70.0	260.	8.	170.	470.	40.	120.	10.	1.9	13.7	1130.	48.4	73.	28.	6.1	0.5	2.6	0.51	22.	13.0	3.1
ASM 19	2.32	1.79	15.3	65.2	0.22	3.52	4.89	9.4	0.51	70.	120.	791.	4.38	10.	19.	29.0	240.	8.	170.	410.	20.	92.	30.	1.6	14.5	959.	47.2	80.	30.	6.4	0.9	2.8	0.50	16.	13.0	4.1
ASM 20	2.15	2.20	15.4	60.3	0.15	2.97	7.60	11.4	0.60	100.	80.	899.	5.26	13.	21.	44.0	210.	10.	140.	520.	20.	110.	20.	1.8	11.5	920.	42.7	72.	34.	6.0	0.9	2.5	0.48	20.	11.0	3.3
ASM 21	1.89	1.63	13.7	65.2	0.13	3.59	5.04	9.0	0.48	70.	100.	681.	3.77	9.	21.	37.0	260.	7.	160.	430.	30.	110.	10.	1.6	9.9	719.	44.6	73.	29.	5.9	0.9	2.6	0.51	22.	14.0	3.2
ASM 22	2.50	2.17	17.0	59.8	0.21	3.06	6.03	12.5	0.76	110.	110.	910.	5.93	13.	30.	75.0	240.	8.	180.	520.	10.	130.	20.	1.6	14.6	871.	48.8	83.	26.	6.9	1.6	2.5	0.50	22.	14.0	3.7
ASM 23	3.01	1.46	17.7	59.3	0.24	3.45	3.52	12.0	1.23	150.	68.	750.	6.49	16.	29.	97.1	350.	8.	180.	480.	50.	120.	20.	1.3	12.7	820.	57.1	93.	37.	7.7	1.4	3.3	0.59	22.	18.0	5.2
ASM 24	2.52	2.21	16.3	61.0	0.22	2.84	5.96	11.8	0.71	110.	110.	740.	5.90	14.	22.	71.0	210.	8.	140.	560.	20.	120.	20.	3.4	10.7	920.	43.2	72.	31.	6.1	1.3	2.0	0.42	20.	11.0	2.7
ASM 25	3.06	1.41	18.2	61.0	0.22	3.20	4.35	11.8	1.29	130.	97.	590.	6.61	14.	29.	97.9	370.	4.	190.	460.	40.	120.	30.	1.1	13.9	760.	56.8	89.	36.	7.8	1.8	3.0	0.62	18.	17.0	4.9
ASM 26	3.03	1.25	18.2	61.4	0.26	3.36	4.24	11.2	1.16	120.	100.	550.	6.10	12.	27.	63.0	350.	8.	190.	490.	40.	110.	30.	1.6	15.5	910.	55.0	88.	39.	7.0	1.5	3.0	0.58	22.	17.0	4.7
ASM 27	2.26	1.17	17.3	62.4	0.10	3.23	2.29	11.6	0.59	100.	80.		5.65	10.	21.	46.0	310.	12.	140.	370.	40.	87.	30.	1.2	7.4	991.	59.0	101.	40.	7.4	1.3	3.5	0.67	20.	22.0	4.0
ASM 28	2.59	1.47	16.8	61.8	0.18	3.53	2.56	10.7	0.66	80.	60.	791.	4.92	12.	26.	71.0	250.	10.	170.	490.	10.	110.	20.	1.3	12.1	889.	47.3	78.	31.	6.2	1.1	2.5	0.52	24.	16.0	4.8
ASM 29	2.98	1.42	18.3	60.5	0.24	3.36	4.17	12.3	1.09	120.	78.	590.	6.30	14.	32.	71.9	350.	6.	190.	490.	40.	110.	20.	1.0	12.6	859.	58.9	97.	38.	7.9	1.7	3.2	0.58	24.	17.0	4.1
ASM 30	2.61	1.99	15.9	58.2	0.22	3.04	7.40	10.9	0.85	110.	87.	740.	5.31	12.	27.	74.0	280.	9.	150.	550.	30.	100.	30.	1.1	12.6	800.	48.8	81.	35.	6.3	1.2	2.4	0.50	18.	14.0	4.3
ASM 31	2.83	1.38	16.9	57.3	0.26	3.31	5.32	10.3	1.08	120.	76.		5.79	14.	28.	76.9	330.	10.	170.	550.	20.	110.	20.	1.2	11.4	871.	53.7	92.	33.	7.3	1.5	3.1	0.52	22.	17.0	4.9
ASM 32	2.63	1.96	15.7	57.8	0.22	3.01	8.04	9.8	0.84	110.	83.	750.	5.24	11.	26.	65.0	250.	9.	170.	550.	20.	100.	20.	1.0	10.8	750.	43.8	68.	29.	5.8	1.3	2.4	0.41	18.	13.0	3.8
ASM 33	2.28	0.87	19.3	64.7	0.07	3.30	1.68	8.2	0.29	50.	78.		3.25	5.	14.	48.0	100.	7.	160.	400.	20.	72.	30.	0.7	4.8	979.	32.4	57.	22.	5.1	0.9	4.5	0.79	20.	11.0	1.9
ASM 34	1.73	1.25	16.2	67.0	0.11	4.10	1.41	10.5	0.46	70.	95.	579.	4.10	7.	17.	46.0	250.	9.	220.	250.	20.	100.	20.	3.1	23.5	1130.	49.3	76.	32.	6.0	1.1	2.8	0.50	24.	13.0	4.1
ASM 35	2.82	2.34	17.5	59.6	0.21	2.70	5.26	12.2	0.82	130.	78.	530.	6.40	15.	23.	59.0	230.	7.	130.	610.	20.	110.	20.	1.3	8.4	991.	42.2	63.	30.	5.9	1.0	1.8	0.34	18.	10.0	3.1
ASM 36	2.79	1.48	17.4	59.6	0.24	3.20	5.04	11.1	1.04	110.	97.	619.	5.98	14.	30.	74.0	340.	8.	170.	500.	40.	100.	30.	1.0	11.8	700.	54.6	87.	36.	7.2	1.9	2.8	0.55	18.	16.0	3.8
ASM 37	1.21	2.41	15.4	61.8	0.09	3.91	3.49	11.3	0.56	80.	88.		5.00	12.	21.	43.0	240.	20.	180.	270.	30.	190.	30.	4.1	8.4	1009.	41.6	73.	27.	5.6	1.2	2.9	0.53	44.	15.0	3.3
ASM 38	1.34	1.42	16.2	63.4	0.09	3.56	1.43	14.6	0.82	100.	160.	619.	6.75	13.	35.	37.0	340.	12.	180.	280.	50.	94.	10.	1.0	9.5	1109.	66.7	105.	41.	8.3	1.8	3.8	0.66	20.	18.0	2.4
ASM 39	3.88	0.86	18.5	57.5	0.21	3.69	1.30	18.0	0.97	110.	54.	480.	8.59	47.	22.	140.0	370.	160.	190.	180.	40.	94.	30.	4.6	42.3	590.	57.9	100.	40.	8.8	1.8	4.1	0.79	78.	23.0	2.9
ASM 40	3.97	0.87	18.8	58.5	0.22	3.68	1.27	18.2	0.97	120.	81.	520.	8.83	48.	22.	150.0	420.	170.	190.	160.	40.	88.	30.	5.3	42.5	590.	56.8	93.	40.	8.7	1.3	4.3	0.76	80.	24.0	3.0
ASM 41	1.56	3.88	16.2	56.0	0.33	1.82	4.60	20.3	1.36	170.	190.	899.	9.53	30.	74.	48.0	260.	5.	70.	490.	20.	97.	50.	0.6	3.8	719.	43.1	70.	28.	6.1	1.7	2.3	0.42	14.	8.0	1.9
ASM 42	2.65	1.37	16.0	57.3	0.35	3.95	5.79	9.9	0.94	110.	86.	450.	5.56	11.	30.	64.0	300.	8.	140.	719.	40.	96.	30.	1.0	8.7	809.	46.5	73.	34.	6.4	1.1	2.5	0.48	18.	13.0	3.4
ASM 43	2.69	1.01	17.7	64.6	0.10	3.82	2.50	9.2	0.39	50.	95.		3.43	5.	15.	53.0	130.	4.	170.	330.	30.	89.	30.	0.5	6.6	929.	38.4	65.	24.	6.0	1.0	4.6	0.84	28.	12.0	2.6
ASM 44	1.13	1.39	20.2	57.9	0.13	3.83	5.98	9.4	0.50	110.	99.	470.	4.88	8.	19.	35.0	210.	38.	190.	940.	20.	100.	20.	5.5	32.9	1159.	40.8	65.	24.	5.0	0.8	1.8<	0.36	24.	13.0	4.2
ASM 45	1.96	1.13	17.6	64.1	0.09	3.87	2.39	8.9	0.38	60.	110.	951.	3.93	6.	19.	38.0	150.	10.	160.	670.	30.	81.	20.	1.0	6.3	899.	40.6	67.	26.	5.9	0.8	4.0	0.69	22.	13.0	2.3
ASM 46	1.96	1.88	15.7	53.3	0.29	3.44	7.67	12.7	0.92	110.	90.	440.	6.46	12.	32.	83.9	290.	11.	150.	550.	20.	120.	30.	1.0	9.1	889.	47.3	75.	30.	6.4	1.4	2.6	0.46	14.	14.0	3.2
ASM 47	2.18	1.28	17.5	63.2	0.10	4.32	1.40	9.8	0.47	60.	90.		4.27	6.	17.	52.0	200.	3.	190.	230.	50.	89.	30.	0.8	7.5	700.	43.6	65.	30.	6.1	1.4	4.5	0.83	20.	12.0	2.2
ASM 48	2.20	1.09	16.8	65.5	0.12	4.17	1.46	8.5	0.38	50.	120.	670.	3.91	5.	16.	34.0	190.	8.	170.	240.	30.	76.	20.	0.7	7.7	809.	37.1	58.	25.	5.4	1.0	3.9	0.68	22.	11.0	2.6
ASM 49	1.88	1.05	17.4	61.9	0.41	3.43	1.48	10.9	0.73	70.	79.	650.	4.73	11.	28.	39.0	320.	4.	180.	290.	40.	98.	50.	1.0	9.9	1380.	57.4	102.	38.	8.1	1.1	3.8	0.65	20.	16.0	3.3
ASM 50	1.49	1.76	17.8	59.2	1.14	3.73	2.07	14.7	0.72	80.	87.	460.	5.71	16.	40.	57.0	310.	5.	150.	380.	40.	100.	20.	0.9	8.3	1079.	84.9	128.	60.	11.6	1.7	4.6	0.71	20.	16.0	3.4

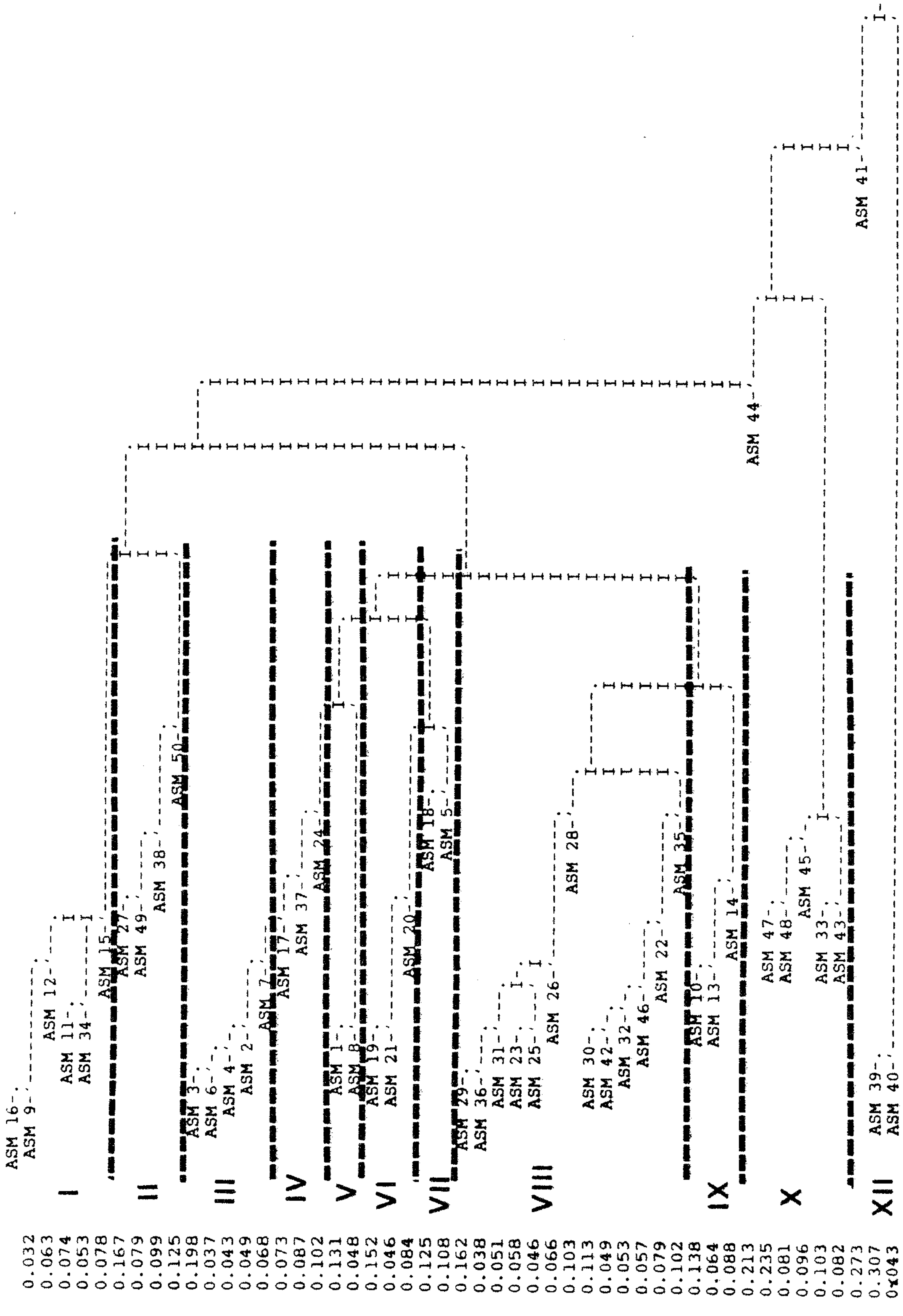

Figure E.1. Dendrogram from heirarchical cluster analysis of chemically analyzed pottery. Complete linkage cluster result based on matrix of mean Euclidean distances. Concentrations used in analysis: Sc, Co, Ni, Cu, Zn, Sb, Ca, La, Ce, Nd, Sm, Eu, Yb, Lu, Th, U. Numbered areas are discussed in text.

Santa Cruz or Grannen sands. The small group of Section IV is composed of two Rincon samples and one Wingfield Red Ware sherd. The high linkage of Section VII suggests that this plain ware sample and the Stratum 80 clay containing Grannen sand are linked together due more to the mechanics of the clustering process than to inherent similarity between the samples. Clays recovered from the Grasshopper Site make up Section IX. Well separated from the groups so far noted is Section X, Gila or Pinto-Gila pottery along with two Tucson Polychrome sherds. Finally, at the bottom of the dendrogram, Section XI contains the two replicate analyses of the Sells Red sherd.

A dendrogram like that just shown is a first approximation in the search for grouping tendencies within a data set, but it is not usually valid for archaeological interpretation. In particular, it can be quite distorted as a result of interelement correlation. The Euclidean distance coefficient treats every measurement as though it were independent of every other measurement and, by its nature, creates spherical clusters. This is not appropriate with clays, sands, or ceramic materials because interelement correlations render the data distributions hyperellipsoidal rather than hyperspherical (compare Harbottle 1976). Rather than being sources of confusion or redundancy, the information concerning the interelement pattern found within a group's variance-covariance matrix can be a powerful aid to group formation and evaluation.

Using the large group containing the Tanque Verde and Rincon pottery (Section VIII on the dendrogram), and working under the assumption that the sample was drawn from a multivariate normal distribution, one can calculate the probability that each group member was, in fact, a member of the group—given the sample's Mahalanobis distance from the group's multivariate centroid. The probability value is expressed by Hotelling's T^2, which is the multivariate extension of the better known Students' t statistic. In similar manner, samples which are not initially members of the reference group may be evaluated as to the likelihood of their membership in the reference group. If they are found to have strong probabilities of belonging to the group, they may be added and the group's variance-covariance properties and sample membership statistics recalculated.

Ideally, one would like to have two or three times the number of samples as one has variates when making a probability assessment. With only a limited number of samples, a subset of the elements can be used, different combinations being tried out in turn. If a sample is found to significantly diverge from a group centroid in univariate space, it also will be divergent in the multivariate space. However, the reverse is not true. Samples found to lie within a given confidence interval univariately may not belong when measurements are used in linear combination. Several iterations through the data set found that all of the members of dendrogram Section VI had strong probabilities of belonging to the Section VIII, the Tanque Verde–Rincon reference group. When these were added to the main group and the likelihood of outside members belonging to the reference group were recalculated, the Rincon samples from Section IV were observed to lie within the chosen 90 percent confidence ellipse. The iteration process was stopped when no additional samples from groups outside the reference unit were found to lie within the 90 percent confidence interval. The expanded group from dendrogram Section VIII contains all but one sample (ASM 44) of the Tanque Verde and Rincon ceramics. Element concentration data for the group, along with element means and standard deviations (expressed as percent), are listed in Table E.5.

The smaller groups contained too few samples to evaluate rigorously in a manner like that of the Tanque Verde–Rincon group. However, the relationships among the groups and their relation to the main group can be illustrated with reference to the standardized characteristic vectors derived from the variance-covariance matrix of the Tanque Verde–Rincon pottery (Table E.6). The characteristic axes are linear combinations of the original measurements which have the property of being independent of each other. Following the projection of the original sample measurements onto these orthogonal axes, previously hyperellipsoidal groups will be hyperspherical in the newly defined space. No information is lost; rather, more information than just the absolute magnitude of the measurements has been incorporated into the data analysis. The axes derived for the reference group can form the basis vectors upon which all of the samples are projected. Most of the time it is possible to illustrate aspects of group-to-group relationships by reference to bivariate plots of a given group's characteristic vectors. Unlike an approach such as discriminant analysis, which mathematically attempts to maximally force separation of the groups, plotting of specimens along a reference group's characteristic vectors is only an illustration of the natural tendencies in the data. However, it should be remembered that when viewing bivariate plots of the projected data, the relationships among the samples have been multivariately determined.

In Figure E.2, the Tanque Verde–Rincon group is shown enclosed by a 90 percent confidence ellipsoid. Most of the other samples are excluded, with the exception of the test tiles made up of clays and sands from the San Xavier area (plot symbol 4, dendrogram Section III). Samples symbolized by number 4 in the plot are seen to lie outside the confidence interval when viewed relative to Axes 3 and 5 (Fig. E.3). Other relationships may be seen more clearly in other combinations. For example, Figure E.4 is a plot of the data relative to Vectors 1 and 5. Here, plot symbol 5, the Gila or Pinto-Gila and Tucson Polychrome group from dendrogram Section X, occupies the left-hand section of the plot. The replicate Sells Red analyses, symbol 8, lies at the top-center while the argillic horizon clay and sand test tiles, plot symbol 2, tends toward the lower right-hand corner. The single plot symbol 7 is the only example of Wingfield Red Ware and, while it is found to lie at the ellipse boundary of Figure E.4, it is fully outside the 90 percent confidence ellipse when Vector 3 is considered.

Discussion

The Tanque Verde and Rincon pottery analyzed from the San Xavier Bridge Site appear chemically to form a single

TABLE E.5

Tanque Verde and Rincon Compositional Reference Group

Sample Number	*NA PCT*	*MG PCT*	*AL PCT*	*SI PCT*	*P PCT*	*K PCT*	*CA PCT*	*SC PPM*	*TI PCT*	*V PPM*	*CR PPM*	*MN PPM*	*FE PCT*	*CO PPM*	*NI PPM*	*CU PPM*	*ZR PPM*	*AS PPM*
ASM 15	1.61*	1.19	16.5	70.0*	0.07*	3.86	1.12*	10.9	0.49	70.	100.	600.	4.46	8.*	19.	35.0	240.	1.
ASM 17	2.41	1.28	18.0	62.4	0.18	3.68	3.06	10.4	0.93	110.	70.	520.	5.45	11.	22.	55.0	270.	11.
ASM 19	2.32	1.79	15.3	65.2	0.22	3.52	4.89	9.4	0.51	70.	120.	791.	4.38	10.	19.	29.0*	240.	8.
ASM 20	2.15	2.20	15.4	60.3	0.15	2.97	7.60	11.4	0.60	100.	80.	899.	5.26	13.	21.	44.0	210.	10.
ASM 21	1.89	1.63	13.7*	65.2	0.13	3.59	5.04	9.0*	0.48	70.	100.	681.	3.77*	9.	21.	37.0	260.	7.
ASM 22	2.50	2.17	17.0	59.8	0.21	3.06	6.03	12.5	0.76	110.	110.	910.	5.93	13.	30.	75.0	240.	8.
ASM 23	3.01	1.46	17.7	59.3	0.24	3.45	3.52	12.0	1.23	150.	68.	750.	6.49	16.	29.	97.1	350.	8.
ASM 24	2.52	2.21	16.3	61.0	0.22	2.84	5.96	11.8	0.71	110.	110.	740.	5.90	14.	22.	71.0	210.	8.
ASM 25	3.06	1.41	18.2	61.0	0.22	3.20	4.35	11.8	1.29	130.	97.	590.	6.61	14.	29.	97.9	370.	4.*
ASM 26	3.03	1.25	18.2	61.4	0.26	3.36	4.24	11.2	1.16	120.	100.	550.	6.10	12.	27.	63.0	350.	8.
ASM 27	2.26	1.17	17.3	62.4	0.10	3.23	2.29	11.6	0.59	100.	80.		5.65	10.	21.	46.0	310.	12.
ASM 28	2.59	1.47	16.8	61.8	0.18	3.53	2.56	10.7	0.66	80.	60.*	791.	4.92	12.	26.	71.0	250.	10.
ASM 29	2.98	1.42	18.3	60.5	0.24	3.36	4.17	12.3	1.09	120.	78.	590.	6.30	14.	32.	71.9	350.	6.
ASM 30	2.61	1.99	15.9	58.2	0.22	3.04	7.40	10.9	0.85	110.	87.	740.	5.31	12.	27.	74.0	280.	9.
ASM 31	2.83	1.38	16.9	57.3	0.26	3.31	5.32	10.3	1.08	120.	76.		5.79	14.	28.	76.9	330.	10.
ASM 32	2.63	1.96	15.7	57.8	0.22	3.01	8.04	9.8	0.84	110.	83.	750.	5.24	11.	26.	65.0	250.	9.
ASM 35	2.82	2.34	17.5	59.6	0.21	2.70	5.26	12.2	0.82	130.	78.	530.	6.40	15.	23.	59.0	230.	7.
ASM 36	2.79	1.48	17.4	59.6	0.24	3.20	5.04	11.1	1.04	110.	97.	619.	5.98	14.	30.	74.0	340.	8.
ASM 42	2.65	1.37	16.0	57.3	0.35	3.95	5.79	9.9	0.94	110.	86.	450.	5.56	11.	30.	64.0	300.	8.
ASM 46	1.96	1.88	15.7	53.3*	0.29	3.44	7.67	12.7	0.92	110.	90.	440.	6.46	12.	32.	83.9	290.	11.
Number Averaged	20	20	20	20	20	20	20	20	20	20	20	18	20	20	20	20	20	20
MEAN CONC	2.50	1.61	16.6	60.6	0.20	3.30	4.54	11.0	0.81	105.	87.	649.	5.54	12.	25.	61.4	279.	8.
GRP STD DEV (PCT)	18.8	25.2	7.6	5.8	44.9	10.4	61.6	10.2	36.1	23.7	19.4	24.4	15.9	19.4	18.9	39.5	19.7	27.5
MEAN + GSD	2.97	2.02	17.9	64.1	0.29	3.64	7.33	12.2	1.11	130.	104.	807.	6.42	14.	30.	85.7	334.	11.
MEAN − GSD	2.10	1.29	15.5	57.2	0.14	2.99	2.81	10.0	0.60	85.	73.	522.	4.78	10.	21.	44.0	233.	7.
Upper 95% Limit	3.58	2.58	19.4	68.2	0.43	4.06	12.39	13.5	1.55	164.	126.	1028.	7.55	18.	36.	123.3	407.	14.
Lower 95% Limit	1.74	1.01	14.3	53.8	0.09	2.68	1.66	9.0	0.43	67.	60.	410.	4.07	8.	18.	30.6	191.	5.

	RB PPM	*SR PPM*	*Y PPM*	*ZN PPM*	*NB PPM*	*SB PPM*	*CS PPM*	*BA PPM*	*LA PPM*	*CE PPM*	*ND PPM*	*SM PPM*	*EU PPM*	*YB PPM*	*LU PPM*	*PB PPM*	*TH PPM*	*U PPM*
ASM 15	210.	200.*	30.	90.	20.	2.0	18.5	791.	47.3	76.	31.	6.1	1.2	3.5	0.69	24.	13.0	3.2
ASM 17	220.	530.	40.	110.	20.	2.6	20.2	1069.	50.4	84.	32.	6.8	1.3	2.3	0.49	16.	15.0	3.9
ASM 19	170.	410.	20.	92.	30.	1.6	14.5	959.	47.2	80.	30.	6.4	0.9	2.8	0.50	16.	13.0	4.1
ASM 20	140.	520.	20.	110.	20.	1.8	11.5	920.	42.7	72.	34.	6.0	0.9	2.5	0.48	20.	11.0	3.3
ASM 21	160.	430.	30.	110.	10.*	1.6	9.9	719.	44.6	73.	29.	5.9	0.9	2.6	0.51	22.	14.0	3.2
ASM 22	180.	520.	10.*	130.	20.	1.6	14.6	871.	48.8	83.	26.	6.9	1.6	2.5	0.50	22.	14.0	3.7
ASM 23	180.	480.	50.	120.	20.	1.3	12.7	820.	57.1	93.	37.	7.7	1.4	3.3	0.59	22.	18.0	5.2
ASM 24	140.	560.	20.	120.	20.	3.4*	10.7	920.	43.2	72.	31.	6.1	1.3	2.0	0.42	20.	11.0	2.7
ASM 25	190.	460.	40.	120.	30.	1.1	13.9	760.	56.8	89.	36.	7.8	1.8	3.0	0.62	18.	17.0	4.9
ASM 26	190.	490.	40.	110.	30.	1.6	15.5	910.	55.0	88.	39.	7.0	1.5	3.0	0.58	22.	17.0	4.7
ASM 27	140.	370.	40.	87.	30.	1.2	7.4	991.	59.0	101.	40.	7.4	1.3	3.5	0.67	20.	22.0*	4.0
ASM 28	170.	490.	10.*	110.	20.	1.3	12.1	889.	47.3	78.	31.	6.2	1.1	2.5	0.52	24.	16.0	4.8
ASM 29	190.	490.	40.	110.	20.	1.0	12.6	859.	58.9	97.	38.	7.9	1.7	3.2	0.58	24.	17.0	4.1
ASM 30	150.	550.	30.	100.	30.	1.1	12.6	800.	48.8	81.	35.	6.3	1.2	2.4	0.50	18.	14.0	4.3
ASM 31	170.	550.	20.	110.	20.	1.2	11.4	871.	53.7	92.	33.	7.3	1.5	3.1	0.52	22.	17.0	4.9
ASM 32	170.	550.	20.	100.	20.	1.0	10.8	750.	43.8	68.	29.	5.8	1.3	2.4	0.41	18.	13.0	3.8
ASM 35	130.	610.	20.	110.	20.	1.3	8.4	991.	42.2	63.	30.	5.9	1.0	1.8*	0.34*	18.	10.0	3.1
ASM 36	170.	500.	40.	100.	30.	1.0	11.8	700.	54.6	87.	36.	7.2	1.9	2.8	0.55	18.	16.0	3.8
ASM 42	140.	719.	40.	96.	30.	1.0	8.7	809.	46.5	73.	34.	6.4	1.1	2.5	0.48	18.	13.0	3.4
ASM 46	150.	550.	20.	120.	30.	1.0	9.1	889.	47.3	75.	30.	6.4	1.4	2.6	0.46	14.*	14.0	3.2
Number Averaged	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
MEAN CONC	166.	486.	26.	107.	23.	1.4	12.0	859.	49.4	81.	33.	6.6	1.3	2.7	0.51	20.	14.5	3.9
GRP STD DEV (PCT)	15.7	28.7	59.0	11.3	32.1	40.2	29.0	11.9	11.7	13.2	12.1	10.6	25.2	19.1	18.3	16.2	20.9	20.0
MEAN + GSD	192.	626.	42.	119.	30.	2.0	15.4	962.	55.2	91.	37.	7.3	1.6	3.2	0.61	23.	17.5	4.6
MEAN − GSD	144.	378.	17.	96.	17.	1.0	9.3	768.	44.3	71.	29.	6.0	1.0	2.2	0.43	17.	12.0	3.2
Upper 95% Limit	225.	825.	70.	134.	41.	2.8	20.4	1088.	62.4	105.	42.	8.2	2.1	3.9	0.73	27.	21.6	5.6
Lower 95% Limit	123.	286.	10.	86.	13.	0.7	7.0	679.	39.2	62.	26.	5.4	0.8	1.9	0.36	14.	9.7	2.6

*Concentrations exceeding 95% confidence limits

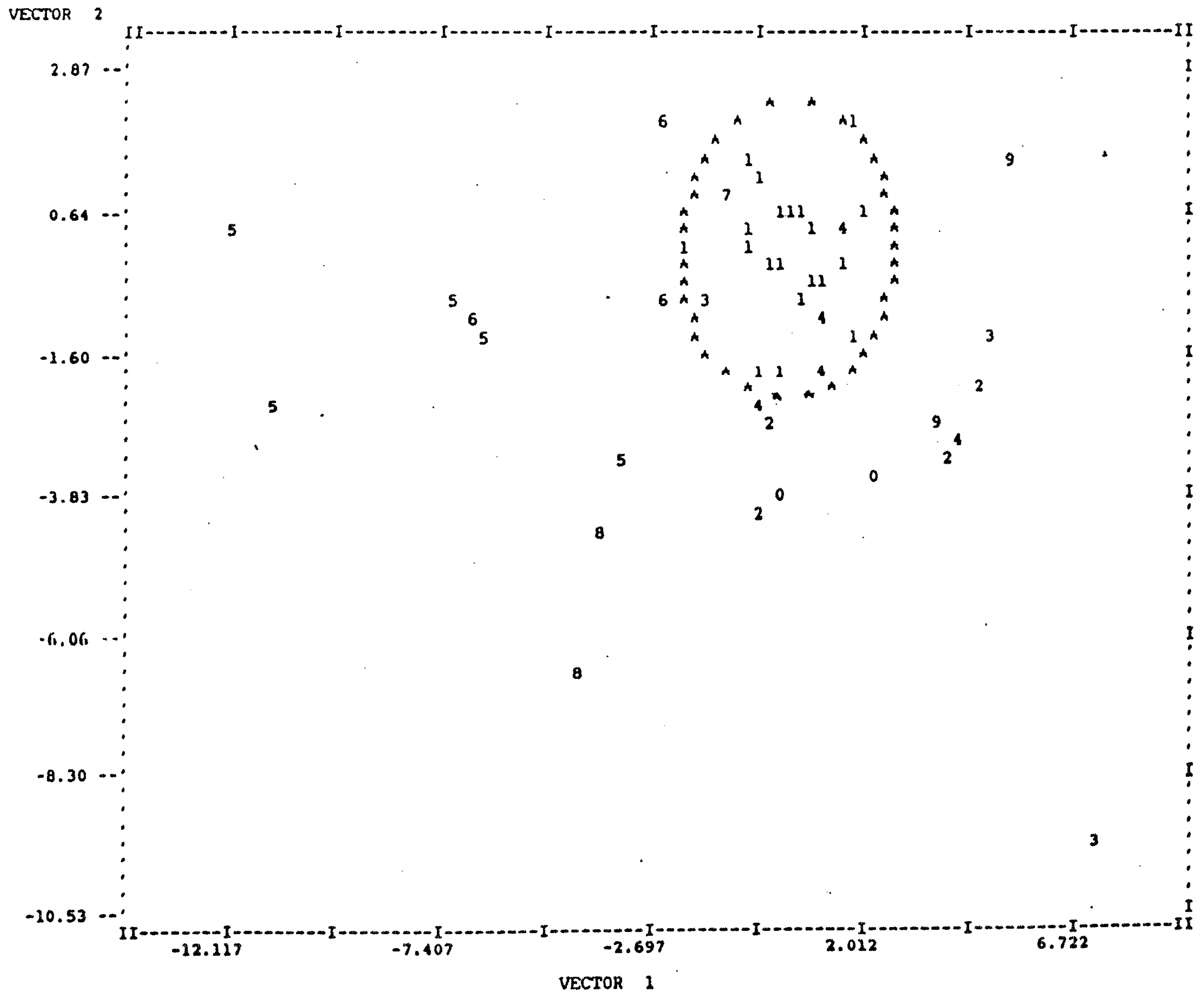

Figure E.2. Bivariate standardized characteristic vector plot, Vectors 1 and 2. Data points in this plot, as well as Figures E.3, E.4, and E.5, are shown relative to the standardized characteristic vectors listed in Table E.6. Plot symbols: 1 = Tanque Verde-Rincon compositional group; 2 = Argillic horizon soils/clays with Santa Cruz and Grannen sands; 3 = Tucson Polychrome and smudged plain sherd; 4 = Test tiles, dendrogram Group VIII, test tiles from clay -4 and clay -3, mixed with Santa Cruz or Grannen sands; 5 = Pinto/Gila and Tucson Polychrome; 6 = Grasshopper clays; 7 = Wingfield Red Ware; 8 = Replicate Sells Red sherd; 9 = Plain sherd and -3 clay with sand (no group); 0 = Cienega clay/Santa Cruz sand and -90 clay/Grannen sand.

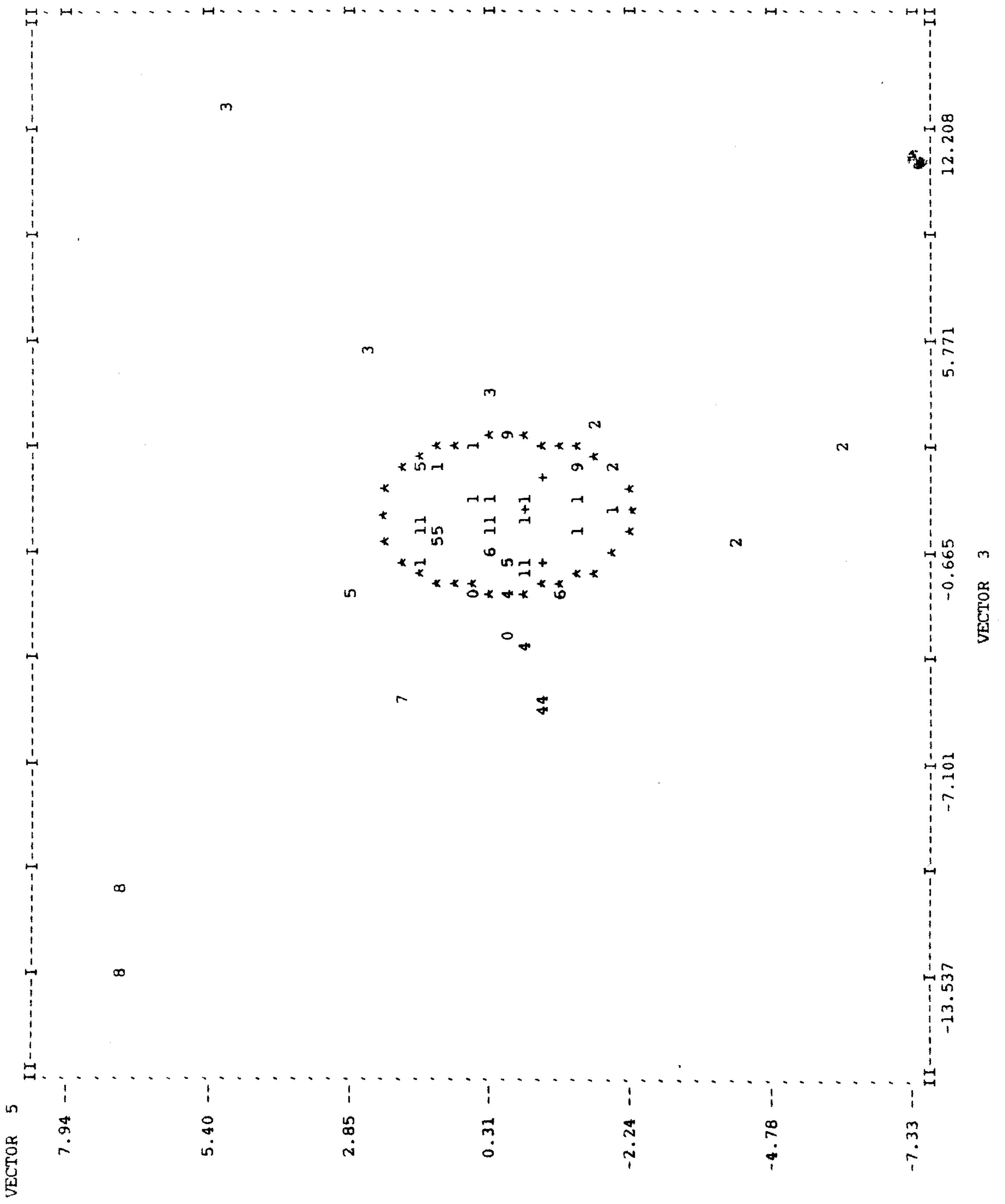

Figure E.3. Bivariate standardized characteristic vector plot, Vectors 3 and 5. Symbols same as in Figure E.2.

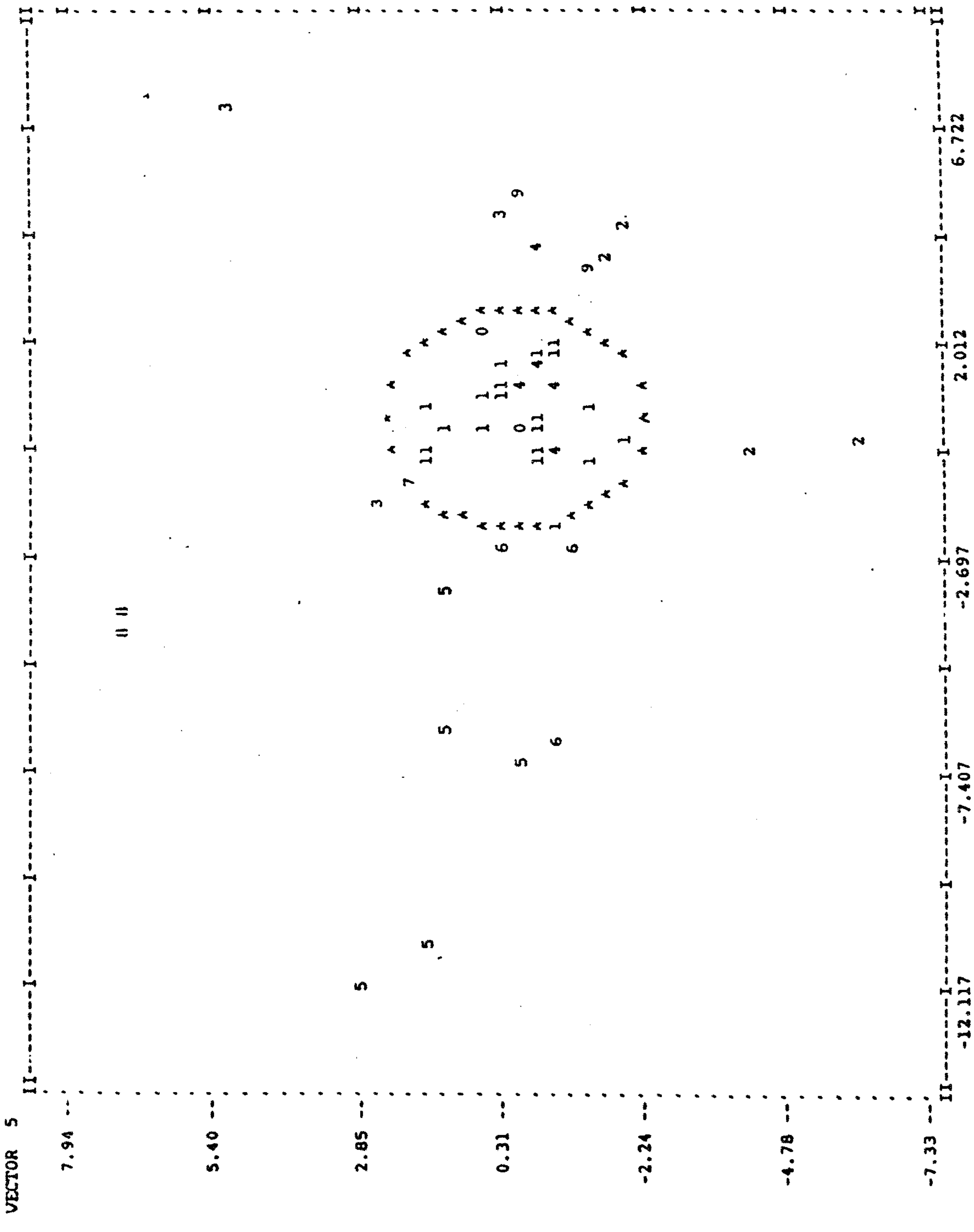

Figure E.4. Bivariate standardized characteristic vector plot, Vectors 1 and 5. Symbols same as in Figure E.2.

TABLE E.6

Standardized Characteristic Vectors for Tanque Verde–Rincon Pottery

	1	2	*3*	*4*	5	6	7
SB	0.036(0)	−0.009(0)	0.057(0)	−0.168(3)	−0.386(15)	0.228(5)	0.875(77)
CS	−0.016(0)	0.021(0)	−0.013(0)	0.331(11)	0.419(18)	−0.723(52)	0.438(19)
LA	0.830(69)	0.055(0)	0.016(0)	−0.367(13)	−0.192(4)	−0.355(13)	−0.097(1)
CE	−0.490(24)	0.495(25)	−0.152(2)	−0.544(30)	−0.213(5)	−0.382(15)	−0.063(0)
FE	−0.043(0)	0.237(6)	0.494(24)	0.515(27)	−0.608(37)	−0.205(4)	−0.144(2)
SC	0.032(0)	−0.111(1)	−0.838(70)	0.333(11)	−0.404(16)	−0.094(1)	−0.038(0)
SM	−0.256(7)	−0.826(68)	0.163(3)	−0.237(6)	−0.246(6)	−0.320(10)	−0.079(1)

Vectors are derived from the variance-covariance matrix. Projection of the samples onto these vectors provide the sample coordinates used in Figures E.2, E.3, and E.4.

TABLE E.7

Compositional Grouping Tiles Made from San Xavier Region Sands and Clays

Sample Number	*NA PCT*	*MG PCT*	*AL PCT*	*SI PCT*	*P PCT*	*K PCT*	*CA PCT*	*SC PPM*	*TI PCT*	*V PPM*	*CR PPM*	*MN PPM*	*FE PCT*	*CO PPM*	*NI PPM*	*CU PPM*	*ZR PPM*	*AS PPM*
ASM 03	2.50	1.72	15.7	65.8	0.18	3.60	4.26	10.0	0.62	80.	130.	760.	4.48	11.	20.	71.9	220.	14.
ASM 06	2.25	1.68	15.7	66.5	0.18	3.77	4.08	10.3	0.59	70.	120.	750.	4.36	11.	20.	71.9	210.	12.
ASM 04	2.57	1.66	15.8	66.5	0.17	3.59	3.59	9.9	0.64	80.	130.	619.	4.57	12.	21.	74.0	200.	11.
ASM 02	2.37	1.84	15.3	63.2	0.33	3.46	4.83	10.9	0.69	90.	160.	760.	4.91	11.	22.	82.0	250.	12.
ASM 07	2.08	1.74	15.7	67.1	0.17	3.65	3.47	11.5	0.63	80.	71.	719.	4.56	11.	20.	83.0	220.	14.
Number Averaged	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MEAN CONC	2.35	1.73	15.6	65.8	0.20	3.61	4.02	10.5	0.63	80.	118.	720.	4.57	11.	21.	76.4	219.	13.
GRP STD DEV (PCT)	8.8	4.1	1.3	2.4	33.1	3.1	14.3	6.5	5.9	9.3	35.6	9.1	4.5	4.0	4.3	7.4	8.7	11.3
MEAN + GSD	2.56	1.80	15.8	67.4	0.26	3.72	4.59	11.2	0.67	87.	160.	785.	4.78	12.	21.	82.0	238.	14.
MEAN − GSD	2.16	1.66	15.4	64.3	0.15	3.50	3.51	9.9	0.60	73.	87.	660.	4.37	11.	20.	71.2	202.	11.
Upper 95% Limit	2.97	1.93	16.2	70.3	0.44	3.93	5.83	12.5	0.74	102.	275.	916.	5.17	12.	23.	93.1	276.	17.
Lower 95% Limit	1.86	1.54	15.1	61.6	0.09	3.32	2.77	8.8	0.54	62.	51.	565.	4.04	10.	18.	62.7	174.	9.

	RB PPM	*SR PPM*	*Y PPM*	*ZN PPM*	*NB PPM*	*SB PPM*	*CS PPM*	*BA PPM*	*LA PPM*	*CE PPM*	*ND PPM*	*SM PPM*	*EU PPM*	*YB PPM*	*LU PPM*	*PB PPM*	*TH PPM*	*U PPM*
ASM 03	200.	450.	10.	220.	30.	3.1	20.4	871.	43.6	70.	29.	5.5	1.0	2.4	0.50	40.	16.0	4.4
ASM 06	200.	410.	10.	210.	30.	3.2	22.7	899.	48.0	79.	34.	6.2	1.2	2.6	0.50	38.	16.0	4.1
ASM 04	210.	460.	20.	200.	20.	3.2	19.9	920.	43.9	73.	25.	5.6	1.2	2.2	0.47	40.	15.0	4.1
ASM 02	190.	560.	30.	250.	20.	3.3	22.6	839.	46.1	73.	28.	6.0	1.2	2.8	0.55	74.	17.0	4.6
ASM 07	190.	370.	40.	220.	20.	3.5	24.9	871.	55.6	90.	37.	6.9	1.4	2.9	0.54	40.	17.0	5.0
Number Averaged	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MEAN CONC	198.	446.	19.	219.	24.	3.3	22.0	880.	47.2	77.	30.	6.0	1.2	2.6	0.51	45.	16.2	4.4
GRP SRD DEV (PCT)	4.2	16.6	87.8	8.7	24.9	4.7	9.4	3.6	10.4	10.5	16.9	9.5	12.6	12.0	6.6	32.5	5.3	8.7
MEAN + GSD	206.	520.	35.	238.	29.	3.4	24.1	911.	52.2	85.	35.	6.6	1.3	2.9	0.54	59.	17.0	4.8
MEAN − GSD	190.	382.	10.	202.	19.	3.1	20.1	850.	42.8	69.	26.	5.5	1.1	2.3	0.48	34.	15.4	4.1
Upper 95% Limit	222.	683.	109.	276.	44.	3.7	28.3	970.	62.2	101.	47.	7.7	1.7	3.5	0.61	98.	18.7	5.6
Lower 95% Limit	176.	291.	3.	174.	13.	2.9	17.2	798.	35.8	58.	20.	4.7	0.9	1.9	0.43	20.	14.0	3.5

compositional group, well separated from the other analyzed pottery. Closely similar, yet statistically separated from the Tanque Verde and Rincon reference group, are the test tiles made up of clay from the San Xavier area and the Santa Cruz and Grannen sands. Interestingly, if one inspects the table of concentrations for the clays and sands (dendrogram Group III), close chemical similarity exists among the group members (Table E.7). It appears that the different clays utilized as part of the test tile experiments were compositionally quite similar, as are the Santa Cruz and Grannen sands. The differences that have been found among the reference group of Tanque Verde–Rincon pottery and the test tiles are extremely small; they exist at a small level, which could be the result of the different production processes. Similarities outweigh the differences and at present the data are not inconsistent with the hypothesis of local manufacture for the Tanque Verde–Rincon pottery. (As a note, if the test tile data are compared to the core group of Tanque Verde–Rincon pottery, it will be observed that the groups differ in the concentration levels for lead [Pb]; lead is found in the clays and sands at almost double the concentration level in the pottery. Similar differences can be found in arsenic concentrations. While not certain, it might be that the recently acquired clays and sands in the San Xavier area have been polluted by modern industrialization).

The Tucson Polychrome pottery fails to form a single compositional unit, but this may reflect the small the number of specimens analyzed. The analytical data available for the Gila or Pinto-Gila (Table E.8) and Sells Red pottery show them to be distinct in composition from the pottery assumed to be "locally produced." The Grasshopper clays separate readily from the other analyzed samples, yet this is to be expected if for no other reason than that the other samples are of tempered materials or at least have a texture as though they were tempered (Bishop 1980).

Recommendations

Regional Sampling

Even limited programs of the analysis of ceramic composition are by their nature regional in scope. To establish chemical profiles that may represent local production, one must first know what is nonlocal. Sampling must be more extensive, for even within a given region different raw material resources may have been exploited, each giving different chemical signatures. An additional aspect of compositional variation arises from possible changes in the processing stages of ceramic production. For example, a shift may be made, within a limited temporal period, to using a naturally silty sandy clay in preference to adding sand to a purer clay component. Other things being equal, ceramically based chemical profiles may differ only as a function of grain size, and such variation must be recognized. This must be done at the regional level of interpretation.

As a rule of thumb, at least 10 samples from each ceramic type under consideration from each site should be analyzed initially. Although more sampling is preferable, this number of samples will usually allow patterns to be seen if not statistically verified.

Analytical Sampling

The archaeologist should take the required sample, seeking to avoid any possible contamination. Ceramics already are multicomponent systems and represent a complex weighted combination of their constitutents. If the analysis is to seek pattern in the elemental concentrations of the paste, then surface (slip or paint) represents contamination. When possible, a broken edge of a sherd should be cleaned and the sample extracted from the paste by a drill. Crushing a small portion of a sherd often fails to yield a homogeneous sample. The amount of sample taken will be determined by the amount needed for analysis and by the relative coarseness of the pottery: the coarser the texture, the larger the sample that must be taken. Regardless of how precise the analytical technique may be, an inadequate sample tends to invalidate the value of the data.

Analysis of replicate samples of the same ceramic or test tile provides valuable information on how well the sampling has been carried out. This should be done for each temper-texture class.

When test tiles are produced in a laboratory, separate analytical determinations should be carried out on each component (clay or temper). This will allow an assesment of the individual sources of variation observed in a ceramic's compositional profile.

Analytical Determinations

A description of the analytical procedures and a statement of standards employed should be obtained from a prospective laboratory before sending samples to be analyzed. The analytical data are reported relative to some standard. This information must be used if sets of data from different laboratories are to be compared or even if different sample sets from the same laboratory will be compared in the future.

A series of "check standards" such as National Bureau of Standards Reference Materials, U.S. Geological Survey Standard Rocks, or "in-house" standards such as Brookhaven National Laboratories analyzed Ohio Red Clay or Berkeley's Perlman and Asaro "Standard Pottery" should be included with each run of samples (Harbottle 1982b). These will serve as controls on a laboratory's analytical precision and accuracy.

TABLE E.8

Compositional Grouping of Gila and Tucson Polychrome

Sample Number	*NA PCT*	*MG PCT*	*AL PCT*	*SI PCT*	*P PCT*	*K PCT*	*CA PCT*	*SC PPM*	*TI PCT*	*V PPM*	*CR PPM*	*MN PPM*	*FE PCT*	*CO PPM*	*NI PPM*	*CU PPM*	*ZR PPM*	*AS PPM*
ASM 47	2.18	1.28	17.5	63.2	0.10	4.32	1.40	9.8	0.47	60.	90.		4.27	6.	17.	52.0	200.	3.
ASM 48	2.20	1.09	16.8	65.5	0.12	4.17	1.46	8.5	0.38	50.	120.	670.	3.91	5.	16.	34.0	190.	8.
ASM 45	1.96	1.13	17.6	64.1	0.09	3.87	2.39	8.9	0.38	60.	110.	951.	3.93	6.	19.	38.0	150.	10.
ASM 33	2.28	0.87	19.3	64.7	0.07	3.30	1.68	8.2	0.29	50.	78.		3.25	5.	14.	48.0	100.	7.
ASM 43	2.69	1.01	17.7	64.6	0.10	3.82	2.50	9.2	0.39	50.	95.		3.43	5.	15.	53.0	130.	4.
Number Averaged	5	5	5	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5
MEAN CONC	2.25	1.07	17.8	64.4	0.09	3.88	1.83	8.9	0.38	54.	97.	798.	3.74	5.	16.	44.3	149.	6.
GRP STD DEV (PCT)	12.2	15.3	5.3	1.2	21.8	10.9	31.4	7.2	18.8	10.5	18.4	28.1	11.7	10.5	12.5	22.0	32.9	65.2
MEAN + GSD	2.52	1.23	18.7	65.2	0.12	4.30	2.40	9.5	0.45	59.	115.	1022.	4.17	6.	18.	54.0	198.	10.
MEAN − GSD	2.00	0.93	16.9	63.7	0.08	3.50	1.39	8.3	0.32	49.	82.	623.	3.35	5.	14.	36.3	112.	4.
Upper 95% Limit	3.10	1.58	20.5	66.6	0.16	5.17	3.91	10.8	0.61	71.	156.	***	5.08	7.	22.	76.9	329.	23.
Lower 95% Limit	1.63	0.72	15.4	62.3	0.05	2.91	0.86	7.3	0.23	41.	61.	34.	2.75	4.	12.	25.5	68.	1.

	RB PPM	*SR PPM*	*Y PPM*	*ZN PPM*	*NB PPM*	*SB PPM*	*CS PPM*	*BA PPM*	*LA PPM*	*CE PPM*	*ND PPM*	*SM PPM*	*EU PPM*	*YB PPM*	*LU PPM*	*PB PPM*	*TH PPM*	*U PPM*
ASM 47	190.	230.	50.	200.	30.	0.8	7.5	700.	43.6	65.	30.	6.1	1.4	4.5	0.83	20.	12.0	2.2
ASM 48	170.	240.	30.	190.	20.	0.7	7.7	809.	37.1	58.	25.	5.4	1.0	3.9	0.68	22.	11.0	2.6
ASM 45	160.	670.	30.	150.	20.	1.0	6.3	899.	40.6	67.	26.	5.9	0.8	4.0	0.69	22.	13.0	2.3
ASM 33	160.	400.	20.	100.	30.	0.7	4.8	979.	32.4	57.	22.	5.1	0.9	4.5	0.79	20.	11.0	1.9
ASM 43	170.	330.	30.	130.	30.	0.5	6.6	929.	38.4	65.	24.	6.0	1.0	4.6	0.84	28.	12.0	2.6
Number Averaged	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MEAN CONC	170.	345.	31.	149.	26.	0.7	6.5	857.	38.2	62.	25.	5.7	1.0	4.3	0.76	22.	11.8	2.3
GRP STD DEV (PCT)	7.3	54.6	38.4	32.9	24.9	28.7	20.8	14.3	11.7	7.7	12.1	8.0	23.2	8.0	10.6	14.7	7.3	14.0
MEAN + GSD	182.	533.	42.	198.	32.	0.9	7.8	980.	42.7	67.	28.	6.1	1.2	4.6	0.84	25.	12.6	2.6
MEAN − GSD	158.	223.	22.	112.	20.	0.6	5.4	750.	34.2	58.	23.	5.3	0.8	4.0	0.69	19.	11.0	2.0
Upper 95% Limit	206.	1157.	76.	329.	47.	1.5	11.0	1241.	51.9	76.	35.	7.0	1.8	5.3	1.01	33.	14.3	3.3
Lower 95% Limit	139.	103.	12.	68.	14.	0.4	3.8	592.	28.1	51.	18.	4.6	0.6	3.5	0.58	15.	9.7	1.6