Detailed Discussion of Petrographic Sample Selection, Methods, and Results

Samples

In choosing the samples for petrographic analysis a number of factors were considered, though selecting sherds from each NAA group was paramount (see Table 2 in main text). Along with the geological and site proximity concerns (see main text), was the necessity to select sherds from each site and covering the four categories of pottery (plain and red-slipped utility ware, Belford Plain perforated plates, MMS, and RRW). Since perforated plates are relatively rare in the study area compared with the other three categories, we sampled these preferentially. For example, a single Belford Plain perforated plate from 3-Up was selected from NAA Group 1, which was dominated by utility and decorated ware from this site. The group was believed to represent local production at 3-Up so a likely locally made sample was chosen. The seven sherds in Group 2 were all utility ware samples from TJ Ruin, and a single one was selected for analysis. While most of the Group 3 sherds were from Ormand Village, a few others were not, thus one MMS sherd was chosen from Ormand, along with one RRW from Kuykendall and another MMS from Dinwiddie. A single utility ware sample from Dutch Ruin was selected from the eight such sherds from this site in Group 4. Similarly, Group 5 consisted of three utility ware sherds from LA39035 and a single sample was analyzed petrographically. Decorated and utility ware sherds from Dinwiddie dominated Group 6, thus a single MMS and one utility ware sample were chosen.

While Group 10 had decorated and utility ware samples from a number of sites, the majority were decorated sherds from BVC, so a RRW was thin sectioned. Group 11 seemed to clearly represent production of utility and decorated vessels at Spear Ranch/Krider Kiva. Therefore, a perforated plate from each site and a RRW from Spear Ranch were petrographically examined. Utility ware sherds from Janss and Stailey were mostly in Group 13; however, the binocular temper analysis revealed some had different sand inclusions. In this instance, we exploited the opportunity to examine two utility ware sherds from the same site, Janss, but with different temper. These samples were compared to a single utility ware sherd from Disert, located to the south of Janss and Stailey and derived from Group 15, which was composed mostly of utility ware sherds from Disert. No sherd was selected from Group 19 as it was poorly defined and the 15 decorated sherds came from sites throughout the study area. Group 20, on the other hand, had only three utility ware sherds from Kuykendall and a single one was analyzed. Groups 21, 22, and 23, contained mostly decorated sherds from many sites and samples selected for analysis was based more on site coverage and ware representation. Thus, one MMS and one RRW from 3-Up and one RRW from Dutch Ruin were chosen from Group 21. For Group 22, two RRW from Stailey and one RRW from TJ Ruin were analyzed petrographically. From the 14 samples in Group 23, only a single RRW from Dutch Ruin was selected.

Groups 25, 26, and 27 contained only decorated sherds from Gila Pueblo. As Group 27 had the most samples, a single RRW was examined. Finally, several unassigned sherds were chosen to ensure all sites and wares were represented. A perforated plate from Gila Pueblo provided a likely example of local raw materials. A MMS from Black Mountain was the only sherd from the site to be analyzed petrographically. A utility ware sherd and a RRW from Ormand Village ensured the site had a sample from the three common ware categories. Two RRW from Disert supplemented the single utility ware sample selected from Group 15. Likewise, a utility ware sherd from BVC was chosen to provide an example of probable local raw materials.

This procedure ensured that for most sites, a decorated and utility ware sample was examined, and that sherds were selected in a way to be representative of the NAA group composition, i.e., if a group had more samples from a single ware and one site, a sample was chosen from that ware and site.

Methods

The petrographic analysis followed a qualitative procedure that aimed to acquire frequency data on the various mineral inclusions using visual methods (charts in Matthew et al. 1997 were used). We chose not to perform point-counting as we felt qualitative visual assessments should encapsulate the temper differences, a decision based on initial petrographic examination of the 32 samples.

Petrographic analysis utilized categories of mineral and rock fragments based on the standard Desert Archaeology, Inc. system used by Miksa (2011:Table 15.3) for point-counting sherds with sand temper in the Tucson Basin. Some categories were excluded as they related to schist, rare in our samples, or were combinations of inclusion categories for statistical analysis of point-count data. This resulted in 38 recorded categories of inclusions (Table 1). For each sample, a numerical value was given for each category based on: zero (absent), 1 (1-5 grains), 2 (c. 10% of inclusions), 3 (10-25%), and 4 (25-50%). This qualitative approach provided numerical values for statistical analysis that appeared to highlight the temper differences between the samples when examined through correspondence analysis and provided appropriate data for combining with NAA data.

Results

Table 2 provides the results of the petrographic analysis in terms of the general sand type and its likely geological origin. This information was utilized to suggest whether the samples were local or non-local to the site where they were excavated. Statistical analysis of the frequency data began with correlation and correspondence analysis. The results of the correlation analysis indicated several recorded petrographic categories could be removed as for many samples they had zero values (see Table 1). This resulted in 29 categories that were utilized for the remaining statistical analyses.

The correspondence analysis assisted in identifying outliers in the petrographic dataset. The results suggested most of the samples that were outside the main groups of samples were utility ware sherds from a number of sites (Figure 1). For example, the TJ Ruin utility ware sample contained sand with common rhyolitic rock fragments, which occur near this site. None of the other petrographic samples had this sand temper. We conclude that outliers in our dataset are the result of differences in geology across our study area and the use of unique materials by local potters to produce utility ware. See below for a further discussion of the identification of outliers in both the NAA and petrographic datasets.

Table 1: Petrographic categories used in the analysis

quartz
potassium feldspar
microcline
plagioclase
altered plagioclase
completely altered plagioclase
muscovite
biotite
chlorite (not used in analyses)
pyroxene
amphibole

olivine
opaques
iron oxides
garnet
epidote
sphene
calcite
rutile
felsic volcanic
felsic volcanic with biotite
intermediate volcanic
mafic volcanic
vitric volcanic
hypabyssal volcanic (not used in analyses)
metamorphic felsic volcanic
metamorphic aggregate
metamorphic tectonite (i.e., schist and gneiss)
metamorphic tectonite fine-grained (i.e., phyllite) (not used in analyses)
microgranular quartz aggregate (not used in analyses)
metamorphosed volcanic rock (not used in analyses)
metamorphosed sedimentary rock (not used in analyses)
amphibolite (not used in analyses)
sedimentary siltstone
sedimentary claystone (argillaceous) (not used in analyses)
sedimentary chert
sedimentary carbonate limestone (not used in analyses)
sedimentary carbonate caliche, from clay or temper

Table 2: Results from petrographic analysis

NAA Group	Petrography Results	Geology	Interpretation
1	1 Belford Plain with volcanic sand (basaltic andesite rich)	Oligocene Gila Group surrounding 3-Up	Local production of utility and decorated ware at 3-Up (Upper Gila)
2	1 utility ware with volcanic sand (rhyolite rich)	Upper Oligocene rhyolitic rocks northwest of TJ Ruin	Local production of utility ware at TJ Ruin (Upper Gila)
3	2 MMS and 1 RRW with volcanic sand (basaltic andesite rich)	Oligocene Gila Group surrounding Ormand Village	Likely decorated ware production in the Upper Gila, possibly at Ormand Village
4	1 utility ware with granitic sand	Middle Proterozoic plutonic rocks east of Dutch Ruin	Local production of utility ware at Dutch Ruin (Upper Gila)
5	1 utility ware with granitic sand	Middle Proterozoic plutonic rocks east of LA39035	Local production of utility ware at LA39035 (Upper Gila)
6	1 utility ware and 1 RRW with volcanic sand with minor granite	Oligocene Gila Group surrounding Dinwiddie, Middle Proterozoic plutonic rocks to the northeast	Probable production of utility and decorated ware at Dinwiddie (Upper Gila)
10	1 RRW with volcanic sand (basaltic andesite rich)	Oligocene Gila Group to the east of BVC	Likely decorated ware production in the Upper Gila, possibly at BVC
11	2 Belford Plain and 1 RRW with granitic sand, minor metamorphic	Early Proterozoic metamorphic rocks and Middle Proterozoic granitic rocks south of Krider Kiva/Spear Ranch	Local production of utility and decorated ware at Krider Kiva/Spear Ranch (Safford Basin)
13	2 utility ware with volcanic sand (rhyolite and andesite rich)	Lower Oligocene to Lower Miocene volcanic rocks east of Janss and Stailey	Local production of utility ware in the Mimbres (Janss and Stailey sites)

15	1 utility ware with volcanic sand (rhyolite and andesite rich)	Lower Oligocene to Lower Miocene volcanic rocks east of Disert	Local production of utility ware in the Mimbres (Disert)
19	not sampled		
20	1 utility ware with granitic and volcanic sand	Oligocene to Middle Miocene granitic rocks and felsic volcanic rocks east of Kuykendall	Local production of utility ware at Kuykendall (Safford Basin)
21	1 MMS and 2 RRW with volcanic sand (basaltic andesite rich)	Oligocene Gila Group along the Upper Gila	Decorated ware production probably in the Upper Gila
22	3 RRW with volcanic sand (basaltic andesite rich)	Oligocene Gila Group along the Upper Gila	Decorated ware production probably in the Upper Gila
23	1 RRW with volcanic sand (basaltic andesite rich)	Oligocene Gila Group along the Upper Gila	Decorated ware production probably in the Upper Gila
26	1 RRW with volcanic, granitic and metamorphic sand	Oligocene to Miocene volcanic rocks and Middle Proterozoic granitic, metamorphic and diabase rocks north of Gila Pueblo	Decorated ware production in the Globe Highlands area
Unass-igned	1 MMS and 3 RRW with volcanic sand, 1 fired and 1 unfired utility with volcanic sand, and 1 Belford Plain with volcanic, granite, and metamorphic sand	various	Decorated ware are probably Upper Gila productions, brown ware (including Belford Plain) are likely local productions. Slight chemical differences or a unique composition made them unassigned.

Figure 1: Correspondence analysis of petrographic data. Axis 1=35%; Axis 2=11%.

Procedures for identifying outliers in NAA and petrographic data

Both the NAA and petrographic datasets indicate that some utility ware samples are unique. For the NAA data, we identified a group of samples apart from the main cluster that included utility ware samples from TJ Ruin, Kuykendall, LA39035, and Dutch Ruin. A utility ware sherd from Disert also was separated by NAA alone. For the petrographic data, CA showed that the TJ Ruin and LA39035 utility ware samples were dissimilar to the majority of samples and surprisingly grouped with a RRW from TJ Ruin. Another distinct set of samples included three RRW sherds from Kuykendall, Spear Ranch, and Ormand Village. Finally, a utility ware sample from Dinwiddie and a RRW from Disert were also separate from the main group. Because five samples plotted consistently as outliers based on both individual and combined datasets (see Figure 7 in the main text), we excluded them from subsequent analysis.

Procrustes Analysis

Figure 4 in the main texts presents a Procrustes analysis comparing multi-dimensional scaling (MDS) plots of combined chemical/mineral data for varying values of μ against MDS plots based on only chemical and only mineral data. Procrustes statistics measure how similar two multi-dimensional data configurations are after they have been rescaled and rotated to be as close as possible (this procedure iteratively attempts to minimize the sum of the squared residuals [difference] between configurations). In this analysis, we use the best-fit sum of squared differences between the original MDS coordinates (MDS based on chemical or mineral data only) and each set of rotated and rescaled MDS coordinates (based on the combined mineral/chemical data for values of μ between 0 and 1 at intervals of 0.05) as a measure of association between configurations. This procedure is similar to that presented by Baxter and colleagues (2008) but uses a slightly different association statistic (see Peres-Neto and Jackson 2001). A resulting sum of squared difference statistic of 0 for a comparison between two solutions indicates perfect association (no difference) and values greater than 0 indicate increasing differences between the two MDS configurations being compared. Note that in Figure 4, low values of μ produce strong associations (low sum of squared difference values) between the MDS coordinates based only on mineral data and little association (high sum of squared difference values) with MDS coordinates based only on chemical data. The inverse is true for high values of μ. This is as we would expect as low values of μ represent mixed datasets with greater weight on mineral data and high values of μ represent mixed datasets with greater weight given to chemical data. Interestingly, only scores in a small range between about μ=0.4 and μ=0.6 (crossing over at μ=0.5) produce MDS configurations that differ roughly equally from both the mineral and chemical data alone.

R Code

This section provides the R code (version 3.0.1) used to conduct the analyses presented here.

```
### Data sets
### minl <- two-way table containing mineralogical data
### chem <- two-way table containing log10 transformed chemical ppm data

### initialize required packages
library(cluster)
library(vegan)

### create matrix of Gower dissimilarities among samples for mineral data
min.gow <- as.matrix(daisy(minl,metric='gower'))
### standardize by dividing matrix by maximum observed value
min.gow <- min.gow/max(min.gow)

### create matrix of Euclidean distances among samples for chemical data
chem.ec <- as.matrix(dist(chem,method='euclidean'))
### standardize by dividing matrix by maximum observed value
chem.ec <- chem.ec/max(chem.ec)

### set value for Mu
mu <- 0.5

### create combined dissimilarity/distance matrix based on value of Mu
com.diss <- (chem.ec*mu)+(min.gow*(1-mu))

### subject combined matrix to mullti-dimensional scaling (MDS)
mds.results <- cmdscale(com.diss,k=2) ### k <- number of dimensions returned

### plot MDS results and label points
plot(mds.results,xlab='Dim 1',ylab='Dim 2',pch=16)
text(mds.results,labels=row.names(com.diss),pos=1,cex=0.5)

### Calculating Sibson's coefficient for values of Mu and plotting results
```

```
### create sequence of Mu values from 0 to 1 by 0.05
mu.list <- seq(from=0,to=1,by=0.05)

### Calculate combined dissimilarity/distance matrices for all values of Mu
com.list <- list()
for (i in 1:length(mu.list)) {
com.diss <- (chem.ec*mu.list[i])+(min.gow*(1-mu.list[i]))
com.list [[i]] <- cmdscale(com.diss)}

### Calculate Sibson's coefficient comparing combined dissimilarities to    ###
mineral and chemical data for all values of Mu
sib.min <- list()
for(i in 1:length(mu.list)) {
sib.min[[i]] <- procrustes(cmdscale(min.gow),com.list[[i]],symmetric=T)$ss}

sib.chem <- list()
for(i in 1:length(mu.list)) {
sib.chem[[i]] <- procrustes(cmdscale(chem.ec),com.list[[i]],symmetric=T)$ss}

### Plot Sibson's coefficients for mineral and chemical data by values of Mu
plot(mu.list,as.vector(sib.chem),type='l',col='red',ylim=c(0,1))
points(mu.list,as.vector(sib.min),type='l',lty=2,col='blue')
```

References

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