Geochemical Variability of Obsidian in Western New Mexico with Laboratory-Based pXRF

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TABLE OF CONTENTS

ABSTRACT

Mule Creek and Mt. Taylor, located in southwestern and western New Mexico respectively, are obsidian source regions for archaeological lithic artifacts. Trace element concentrations can be used to distinguish obsidian from different regions and from different sites within regions, permitting archaeologists to identify the original source of obsidian artifacts. Within each region, source obsidian was sampled at six sites to compare its geochemical variability at three geographical scales. The chemical composition of 491 obsidian samples was analyzed using portable x-ray fluorescence. Multivariate statistical methods were used to show that obsidian varies at the broadest geographical scale (between regions) and at the intermediate geographical scale (between sites within regions) but not at the finest geographical scale (within sites). Thus, although obsidian artifacts can be sourced confidently to regions and sites, they cannot be sourced to different areas of a site using geochemical methods.

INTRODUCTION

The American Southwest is dotted with obsidian-capped rhyolite flows produced by Neogene and Quaternary volcanism (Shackley, 2005). Prehistoric cultures in the region discovered that obsidian, due to its siliceous composition and conchoidal fracturing, can be fashioned into hard projectile points with sharp edges. They collected obsidian at these flows and used it to create points; their migration and trade then spread the projectile points across the region. Southwestern projectile point obsidian artifacts have been found at archaeological sites ranging from Mexico to Wyoming and dating from the Clovis people 13,000 years ago to the Postclassic cultures in the A.D. 1300s and 1400s (Glascock et al., 1999; Shackley, 2005). If there is a known variability in some distinguishing characteristic between obsidian flows, archaeologists can identify the original source of artifacts' obsidian by matching the artifacts to their flow sources using this distinguishing characteristic. Such an obsidian sourcing permits archaeologists to reconstruct trade routes and cultural contacts throughout the American Southwest.

The first Southwestern obsidian sourcing study, published in 1956, used the variability in obsidian refractive index between flows as a distinguishing characteristic (Boyer and Robinson, 1956). Other early methods used variability in specific gravity, thermoluminescence, electrical conductivity, and physical appearance of obsidian from flow to flow (Shackley, 2008; Church and Caraveo, 1996). One of the most recent distinguishing characteristics applied to Southwestern obsidian is variability in magnetic properties, such as susceptibility and hysteresis (Church and Caraveo, 1996; Sternberg et al., 2010). However, the most successful method to date has been measuring variability in obsidian chemical composition (Shackley, 2008), specifically trace element composition; due to melt fractionation, different obsidian flows contain different concentrations of trace elements (Shackley, 2005). Several analytical techniques have been used to characterize the geochemistry of obsidian, including neutron activation analysis (NAA), proton induced x-ray emission proton induced gamma ray emission (PIXE-PIGME), inductively coupled plasma mass spectrometry (ICP-MS), and x-ray fluorescence spectrometry (XRF) (Shackley, 2005). XRF is favored because it is non-destructive (no damage to artifacts); it is relatively fast and cheap; it is widely available; and it requires minimal preparation (Glascock, 2011).

Prior XRF work with Southwestern obsidian has concentrated on chemically distinguishing and assigning artifacts to the various sources, frequently by using trace element bivariate or trivariate plots to group and discriminate typical source concentrations (e.g., Duff et al., 2012; Hughes and Smith, 1993; Shackley, 1998; Shackley, 2005). Although multivariate statistical methods such as cluster analysis, discriminant analysis, and principal component analysis have been used to distinguish obsidian artifacts (e.g., Baxter, 1994; Glascock and Neff, 2003; Neff, 2002) and to a lesser extent source obsidian outside of the Southwest (Tykot, 1997), previous statistical methods applied to Southwestern source obsidian have been almost entirely limited to confidence ellipses (e.g., Glascock et al., 1999; Glascock, 2011).

Additionally, the instrument most commonly utilized in measuring chemical composition of Southwestern obsidian has been desktop XRF (e.g., Duff et al., 2012; Glascock et al., 1999; Shackley, 1998; Shackley, 2005). Portable x-ray fluorescence (pXRF) is a form of XRF that uses a more compact instrument, constructed ultimately to permit in-field analyses. pXRF has been used to characterize source obsidian in South America and the Near East (see Appendix A of

Speakman and Shackley, 2013), but not at a large scale in the American Southwest. Dybowski (2012) used pXRF on Arizona source obsidian, but measured just seven samples.

If obsidian variability within a flow as well as between flows can be established, archaeologists can source obsidian artifacts at a finer geographical scale. Hughes (1986, 1993) in the northwestern United States and Tykot (1997) in the Mediterranean surveyed and measured the geochemistry of source obsidian across flows, both as exploratory components of larger studies. Tykot found no statistically-significant subgroups, and Hughes and Smith (1993) concluded based on the work of Hughes (1986, 1993) that obsidian trace element composition is homogenous on the small scale of across a flow.

This study builds upon such work by employing pXRF and multivariate statistical tests to characterize and distinguish the geochemistry of 491 spatially-referenced samples of New Mexico source obsidian, collected at a fine intra-flow scale. The objectives of this work are (i) to examine geochemical variability at three geographical scales, testing whether obsidian can be distinguished within a flow as well as between flows, (ii) to accomplish this by applying rigorous statistical methods to source obsidian rather than artifacts, and (iii) to compare the capabilities of pXRF and desktop XRF in achieving this. Results show that obsidian can be geochemically distinguished at two of the three geographical scales.

GEOLOGIC SETTING

This study uses obsidian from six source sites (flows) in two regions: Mule Creek and Mount Taylor, both in New Mexico (Fig. 1). Mule Creek is located in southwestern New Mexico, about 80 km northwest of Silver City and 10 km east of the Arizona border. It is part

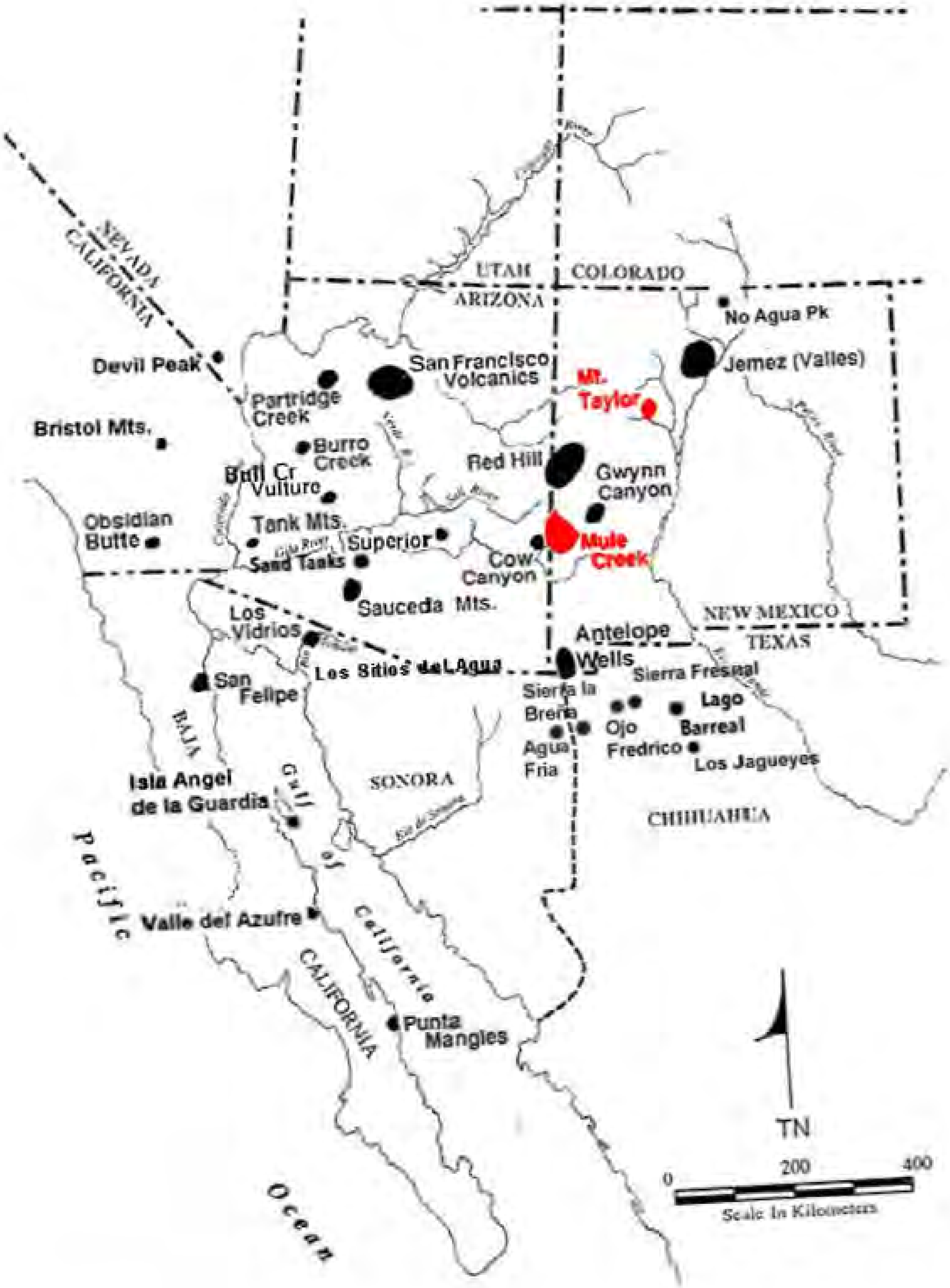

Figure 1. Obsidian flow sources in the American Southwest. The source regions for this study, Mule Creek and Mount Taylor, are marked in red. Modified from Shackley (2013b).

of the Mogollon-Datil volcanic field, an area of rhyolitic and andesitic collapsed calderas which covers southwestern New Mexico and extends into southeastern Arizona. Volcanism at the Mule Creek main vent that produced the obsidian in this study dates to about 17 Ma (Ratte, 2004). Mount Taylor is located about 300 km north of Mule Creek, in western New Mexico, about 110 km west of Albuquerque. Mount Taylor is a stratovolcano, active between about 3.5 and 2 Ma. It is part of the Jemez Lineament, a series of faults and volcanic fields extending from Arizona through northern New Mexico and into Colorado. Some researchers see the Jemez Lineament as a hot spot trace, but others disagree because the volcanic fields do not have the age progression typically associated with hot spots (Crumpler, 1982; Goff, 2009). The obsidian in this study is located in andesite and basalt flows to the west of the volcano peak; these flows date to 3.2 – 3.5 Ma (Crumpler, 1982; Dillinger, 1990).

Within each region, obsidian was sampled at three geographically-distinct sites, each about 3 – 6 km apart and 0.2 – 0.5 km^2 in area. The Mule Creek sites (Fig. 2a) are known as North Sawmill Creek, Antelope Creek, and West Antelope Creek, and the Mount Taylor sites (Fig. 2b) are known as Grants Ridge, Horace Mesa, and La Jara Mesa. Obsidian is exposed as black marekanite nodules ranging from 2 – 4 cm in diameter at Mule Creek sites and 1 – 12 cm in diameter at Mount Taylor sites. Marekanite nodules occur *in situ* in hydrated perlitized outcrop (Fig. 3a) and as float weathering out from the ground surface (Fig. 3b). Obsidian specimens at all sites often bear percussion marks from ancient knappers testing the obsidian quality. At some sites (e.g., Grants Ridge) the marekanites contain sanidine phenocrysts, 2 – 5 mm long; at others (e.g., Horace Mesa) the marekanites are aphyric.

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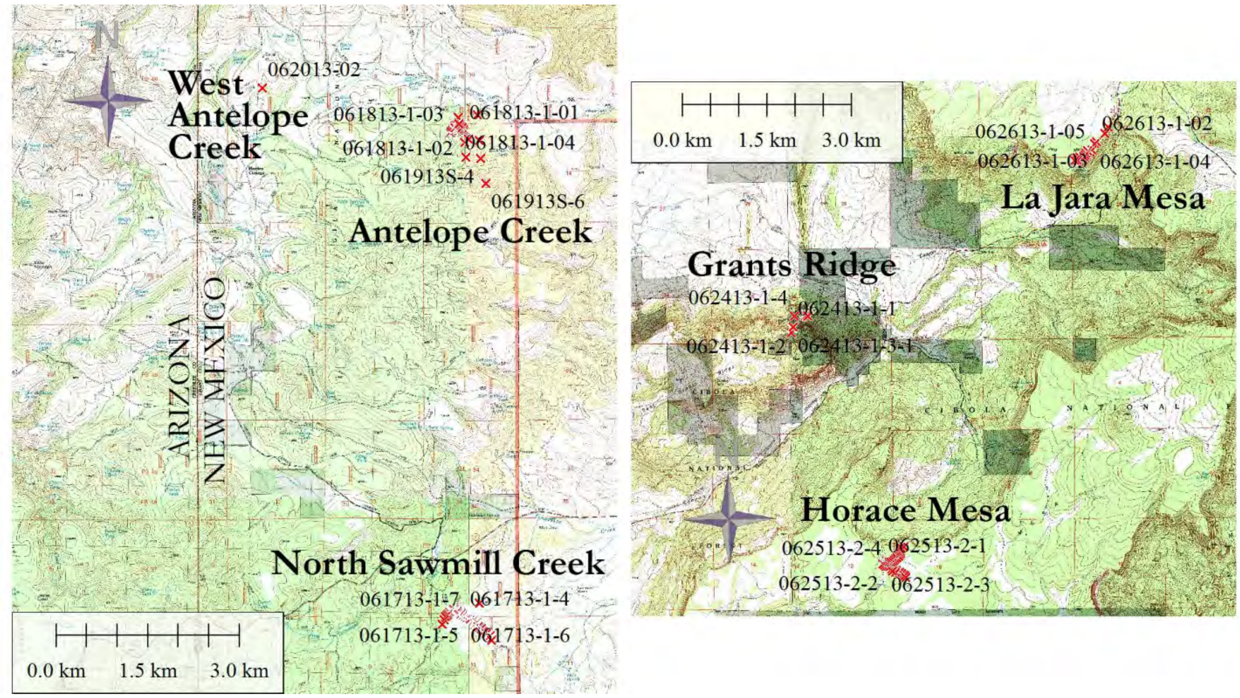

Figure 2. (a) Sites where obsidian was sampled in the Mule Creek region: North Sawmill Creek, Antelope Creek, and West Antelope Creek. (b) Sites where obsidian was sampled in the Mount Taylor region: Grants Ridge, Horace Mesa, and La Jara Mesa. Basemaps for each are USGS 7.5 minute topographic maps.

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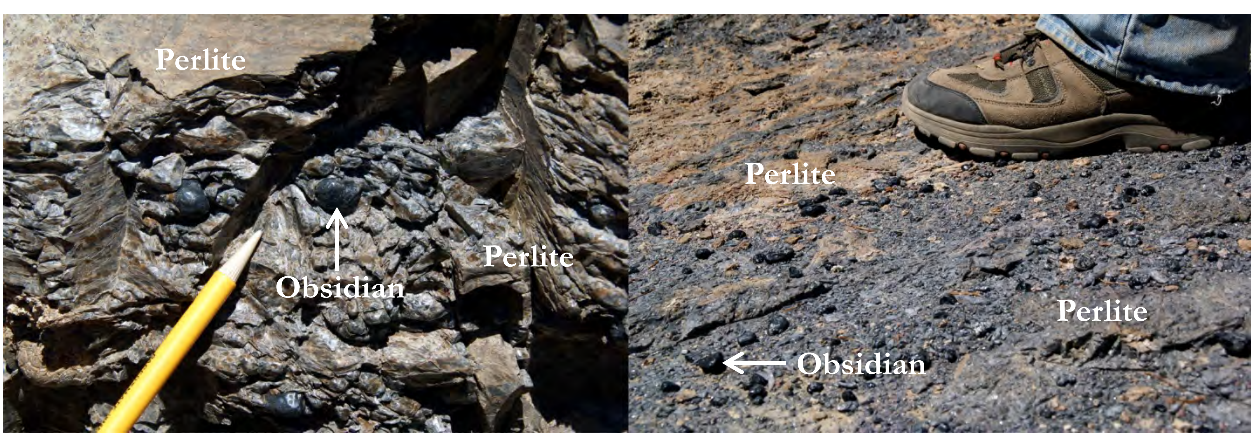

Figure 3. (a) Obsidian marekanites embedded in perlite outcrop at Antelope Creek. For scale, the tan-colored tip of the yellow pencil is 18 mm long. (b) Obsidian marekanite float weathering from the ground surface at Antelope Creek.

METHODS

Field methods

At each site, obsidian marekanites were collected and brought back to the lab for analysis. Samples were either chipped out from the perlite outcrop with a rock hammer or collected from the ground surface. The number of samples collected from each site was limited by the abundance or scarcity of obsidian at each site; thus, significantly more samples were collected at Antelope Creek than at West Antelope Creek or La Jara Mesa.

The sampling strategy was constructed to provide three geographical scales for variability analysis. The broadest scale, termed 'inter-region', is a comparison between obsidian collected in the Mule Creek region and obsidian collected in the Mount Taylor region. The intermediate scale, termed 'inter-site', is a comparison among obsidian collected at each site within a region. The finest scale, termed 'intra-site', is a comparison of obsidian within a site. To enable intra-site analyses, obsidian was collected within each site either along transects (one sample and one GPS measurement taken at each point along the transect) or in populations (several samples collected at a single GPS measurement).

North Sawmill Creek.

Samples were collected in three transects (oriented approximately southeast, northeast, and west) from the center of the site (Fig. 4a). Along each transect, the largest nodule available was sampled from the ground surface every five meters. A total of 100 samples were collected in the southeast direction, 69 in the northeast direction, and 63 in the west direction, of which 69, 62, and 49, respectively, were analyzed (selected in sections of 7, 9, or 8 every 10 samples).

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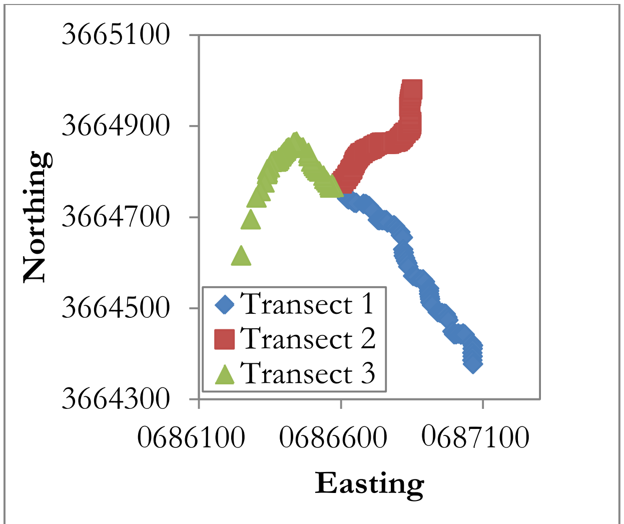

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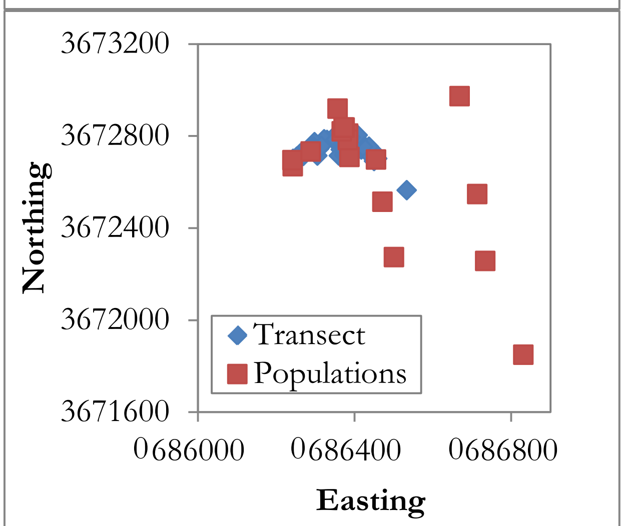

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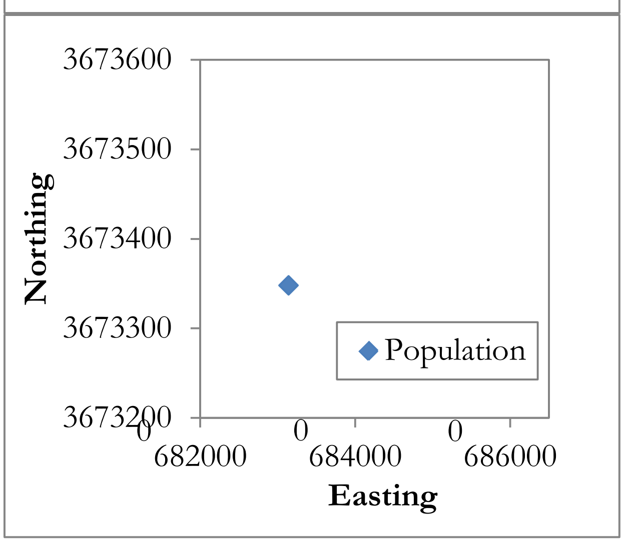

Figure 4. Transect/population locations and site photos at (a) North Sawmill Creek, (b) Antelope Creek, and (c) West Antelope Creek. Axes are in UTM coordinates.

Antelope Creek.

Seventeen populations of 20 to 40 samples each were collected, with the samples of each population taken from one spot less than two meters squared. Eleven of the populations were collected at points spread around the main area of the site, and six of the populations were collected at points on the southeastern ridge of the site (Fig. 4b). One transect of 50 samples, taken around the perimeter of the central wash, was also collected. Ten samples from each population (randomly selected) and all 50 samples from the transect were analyzed.

West Antelope Creek.

Sixty samples were collected from the ground surface within an area of approximately 160 m^2 (Fig. 4c). Ten samples were randomly selected and analyzed.

Grants Ridge.

Thirteen populations of 8 to 109 samples each were collected in three transects along a hillside outcrop and in the wash channel in front of the outcrop, moving upslope (Fig. 5a). One sample each from 12 of the populations was randomly selected and analyzed.

Horace Mesa.

Samples were collected along three transects (oriented approximately southwest, northeast, and southeast) from the center of the site (Fig. 5b). In each direction, samples were collected from the ground surface within segments 30 meters long (parallel to the transect) and 10 meters wide (perpendicular to the transect). A total of 21 segments in the southwest direction, 17 segments in the northeast direction, and 21 segments in the southeast direction were sampled; from this 16, 13, and 17 samples, respectively, were randomly selected and analyzed.

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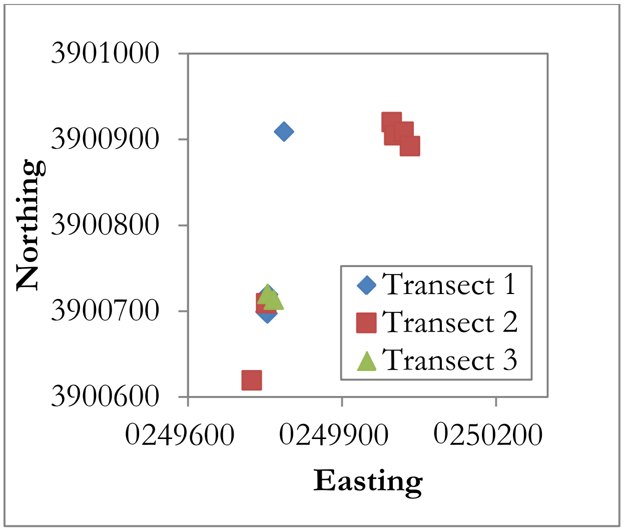

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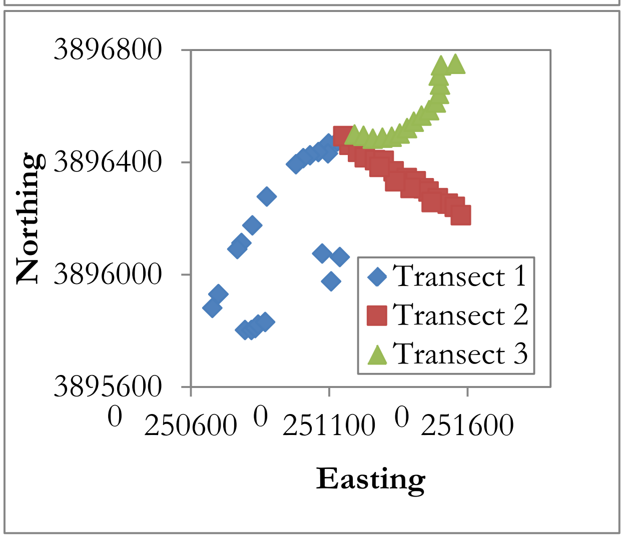

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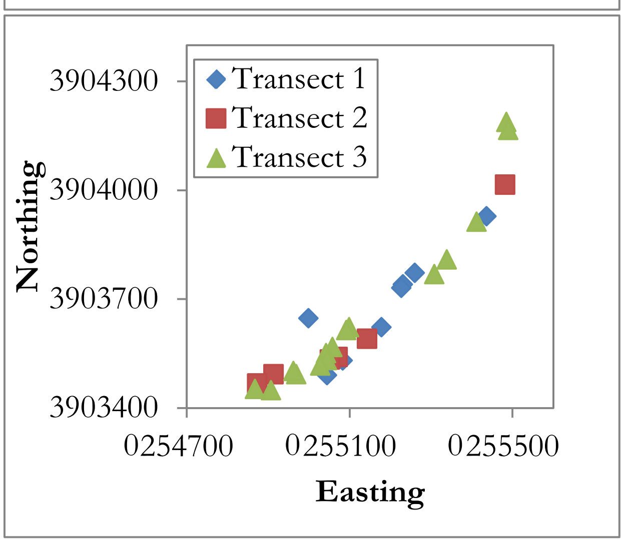

Figure 5. Transect/population locations and site photos at (a) Grants Ridge, (b) Horace Mesa, and (c) La Jara Mesa. Axes are in UTM coordinates.

La Jara Mesa.

Samples were collected along three parallel transects directed southwest from the site entry point (Fig. 5c). Due to the low nodule density, every nodule found was collected from the ground surface. A total of nine samples were collected along the northwestern transect, seven samples along the central transect, and 26 samples along the southeastern transect, of which five, seven, and 11 samples, respectively, were randomly selected and analyzed.

Laboratory methods

A total of 491 samples were analyzed: 180 from North Sawmill Creek, 220 from Antelope Creek, 10 from West Antelope Creek, 12 from Grants Ridge, 46 from Horace Mesa, and 23 from La Jara Mesa. Samples were washed in an ultrasonic machine for 20 – 25 minutes each to remove surface dirt that might affect the chemical analyses. They were split if necessary to create a flat surface, to reduce x-ray attenuation. The chemical composition of each sample was measured using energy dispersive pXRF.

In an ED-pXRF analysis, atoms in the sample are excited by x-rays emitted from the instrument. Energized electrons become dislodged from the atoms' inner shells, leaving vacancies that are filled by outer shell electrons dropping down in energy. This loss of energy is released in the form of fluorescent x-rays that return to the instrument's detector. Since electron shell energies (and thus the energy difference between electron shells) are quantized, the fluorescent radiation consists of energy levels specific to and characteristic of the elements producing it. If the retuning radiation is plotted as a spectrum like that in Figure 6, with energy level on the x-axis and intensity (number of x-rays with that energy level) on the y-axis, then the position of each x-ray peak along the x-axis identifies the elements present in the sample. The intensity of each returning energy level is used to calculate the concentration of the corresponding element in the sample (Kaiser and Wright, 2008).

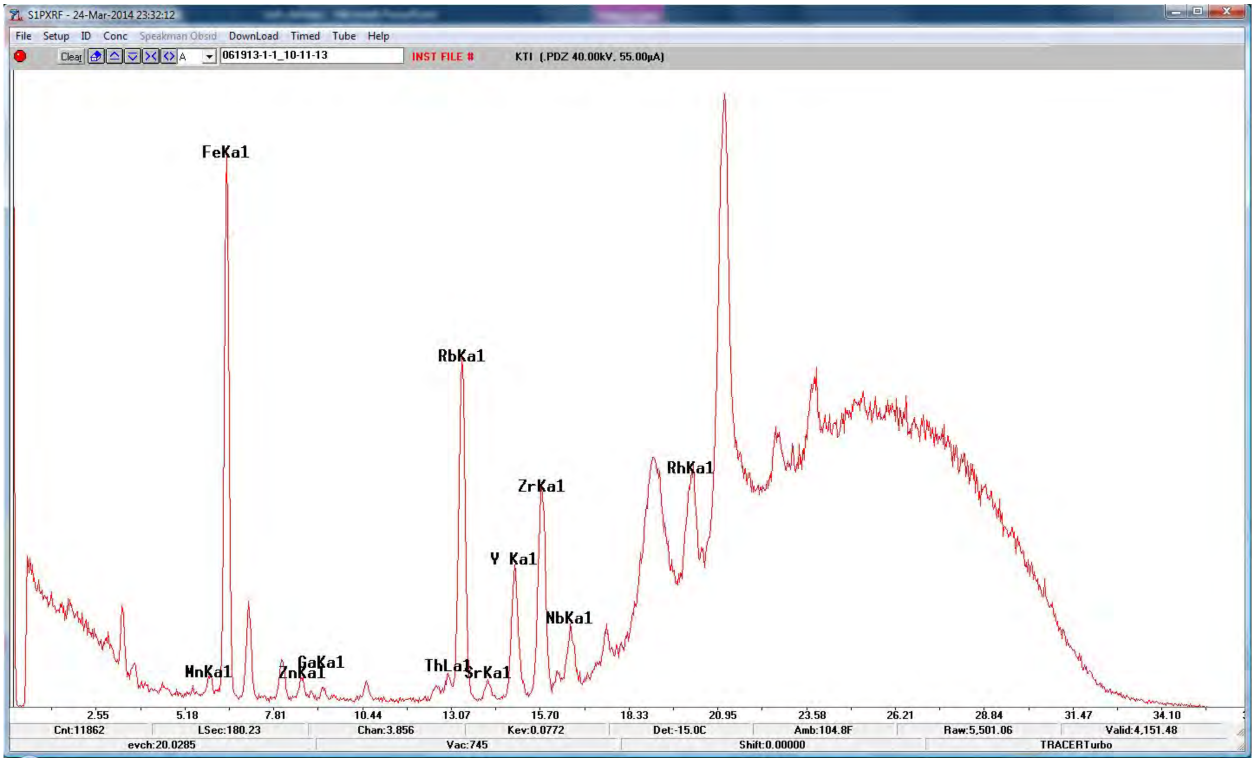

Figure 6. Example pXRF spectrum, for sample 061913-1-01 (Antelope Creek). The x-axis represents the energy of x-rays returning to the instrument from the sample, and the y-axis represents x-ray intensity (number of x-rays per each energy). The peak positions for the elements used in the study are marked. Spectrum was generated with the Bruker S1PXRF software.

A Bruker Tracer III-SD Handheld ED-XRF Spectrometer, housed in the Integrative and Quantitative Center at Washington and Lee University, was used (Fig. 7). Each sample was analyzed for 180 seconds at 40 kV and 55 µA, using a 12 mil Al, 1 mil Ti, 6 mil Cu filter to focus on the trace elements of interest. The resulting peak intensities were ratioed to the Compton peak of rhodium and converted to ppm concentrations using a version of the Bruker obsidian calibration (Speakman and Shackley, 2013) modified by Speakman for older Tracer models, including the Tracer III. The concentrations of 10 elements were calculated: Mn, Fe, Zn, Ga, Rb, Sr, Y, Zr, Nb (all from the Kα peak), and Th (from the Lα peak). Element concentrations for all samples can be found in Appendix A.

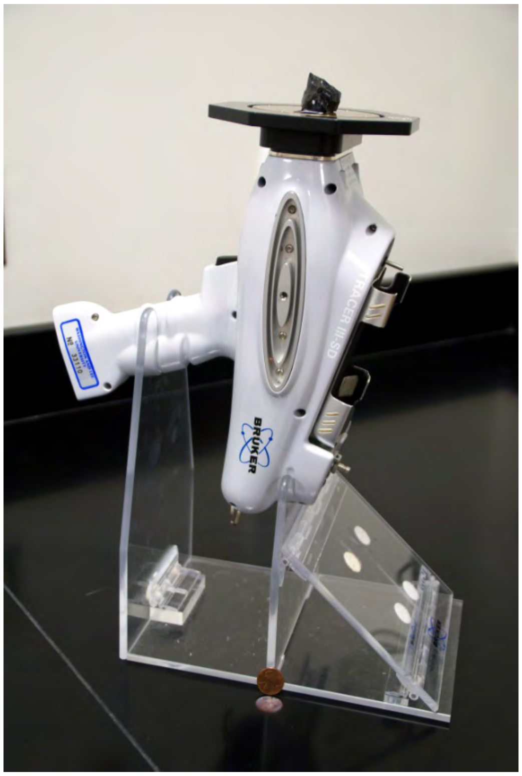

Figure 7. Washington and Lee University's pXRF. The sample is placed on top of the instrument and covered with a cap, to prevent x-rays from escaping. Analyses are run through a computer hooked up to the instrument, although for fieldwork a PDA inserted into the metal frame on the top may also be used. At the base of the instrument stand is a penny, for scale.

Data analysis

One-way multivariate analysis of variance

The inter-region, inter-site, and intra-site variability in composition were compared using one-way multivariate analysis of variance (MANOVA). A MANOVA tests the null hypothesis that vectors of means of observations are the same among groups (Harris, 1975). Rejection of this hypothesis indicates that the dependent variables (in this case, concentration of each element) vary due to change in the independent variable (in this case, sample location) rather than random error. MANOVA is an expansion of the Hotelling's T^2 statistic to more than two groups and an expansion of univariate analysis of variance (ANOVA) to more than one dependent variable (Harris, 1975). It is thus a multi-group, multivariate form of the Student's t-test, which tests the null hypothesis that the means of two groups are the same. The use of a MANOVA instead of multiple t-tests or ANOVAs controls the familywise error rate, reducing the increased probability of Type I errors (incorrectly rejecting the null hypothesis) due to multiple hypotheses in multiple tests.

Calculations were performed in the MATLAB Statistics Toolbox using the *manova1* function. This function uses the Wilks' lambda test statistic as a hypothesis-testing criterion. Wilks' lambda is a measure of the proportion of variance in the dependent variables that cannot be attributed to the independent variable (Harris, 1975). The *p*-value for this test statistic provides the choice of accepting or rejecting the null hypothesis; if the *p*-value is less than the analysis' significance level, α, then the null hypothesis is rejected, meaning in this case that chemical composition varies with sample location.

A total of sixteen MANOVAs were run, all with $\alpha = 0.05$. At each site except West Antelope Creek and Grants Ridge, three MANOVAs were run. The first assessed the intra-site variability among transects or populations at that site; in this type of run, groups consisted of transects, subsets of transects, populations, or multiple populations, selected to maximize geographical distance among groups. The second assessed the inter-site variability among that site and its neighboring sites in the region; in this type of run, groups consisted of samples from individual sites, selected to evenly represent all transects or populations at each site. The third assessed the inter-region variability among that site and the sites in the other region; in this type

$\alpha = 0.05$	Run	Groups (n)	Group locations	Samples /group (n)	*p*-value	$p < \alpha$? (null hypothesis rejected?)
North Sawmill Creek	Intra-site	3	Central parts of transects 1, 2, and 3	35	2.81E-01	No
	Inter-site	3	N. Sawmill site center; Ant. Creek western area; Ant. Creek eastern area	35	2.12E-02	Yes
	Inter-region	3	N. Sawmill site center; Horace M. site center; Grants + La Jara (all samples)	35	7.94E-06	Yes
Antelope Creek	Intra-site	3	Ant. Creek western area; Ant. Creek central area; Ant. Creek western area	35	8.03E-02	No
	Inter-site	3	Ant. Creek western area; Ant. Creek eastern area; N. Sawmill site center	35	1.77E-04	Yes
	Inter-region	3	Ant. Creek populations from each area; Horace M. site center; Grants + La Jara (all samples)	35	2.31E-05	Yes
W. Antelope Creek	Inter-site	3	W. Ant. Creek all samples; N. Sawmill site center; Ant. Creek population 1	10	4.09E-02	Yes
	Inter-region	3	W. Antelope Creek all samples; Horace Mesa site center; Grants transects 1 + 2	10	5.27E-16	Yes
Grants Ridge	Inter-site	3	Grants (all samples); Horace M. site center; La Jara M. center of each transect	12	1.15E-01	No
	Inter-region	3	Grants (all samples); Ant. Creek populations 1 + 2; N. Sawmill site center	12	9.54E-23	Yes
Horace Mesa	Intra-site	3	Central parts of transects 1, 2, and 3	12	9.64E-01	No
	Inter-site	3	Horace M. site center; Grants (all samples); La Jara M. center of each transect	12	1.15E-01	No
	Inter-region	3	Horace M. site center; Ant. Creek populations 1 + 2; N. Sawmill site center	12	3.51E-26	Yes
La Jara Mesa	Intra-site	3	Southern, central, and northern parts of transects	7	7.71E-01	No
	Inter-site	3	La Jara M. center of transect 3; Grants populations from each area; Horace M. site center	7	2.07E-01	No
	Inter-region	3	La Jara M. center of transect 3; Ant. Creek population 1; N. Sawmill site center	7	9.65E-11	Yes

Table 1. Parameters and results for each MANOVA run. "Site center" is defined as the point where three transects meet at either North Sawmill Creek or Horace Mesa. For the North Sawmill Creek and Antelope Creek inter-site runs, the furthest extents of Antelope Creek were used instead of West Antelope Creek to increase group size.

of run, groups consisted of samples from one or two sites, selected to evenly represent all transects or populations at the sites. The number of samples available from West Antelope Creek and from Grants Ridge was too small to permit assessment of intra-site variability, so only the inter-site and inter-region MANOVAs were run for these two sites. Table 1 summarizes the parameters of each MANOVA run and lists the resulting *p*-value.

Since MANOVA is sensitive to differences in group size, the same number of groups and samples per group were used for the three scales of assessment at each site to permit comparison between, for example, variability at North Sawmill Creek and variability between North Sawmill Creek and the other Mule Creek sites. Since MANOVA is also sensitive to small group sizes, the maximum number of groups and samples per group that number and geographic spread of samples permitted were used for each site; groups were selected accordingly.

MANOVA results

The null hypothesis is rejected (meaning composition varies with location) for all the inter-region assessments. Obsidian can be chemically distinguished at the broadest scale, between Mule Creek and Mount Taylor, and thus obsidian artifacts can be confidently sourced to either the Mule Creek region or the Mount Taylor region.

However, the null hypothesis is not rejected (meaning composition is not dependent on location to a statistically-significant level) for all the intra-site assessments. At this finest scale, the obsidian flows are sufficiently homogenous that samples cannot be chemically distinguished between one part and another of a site. Obsidian artifacts cannot be confidently sourced to a specific area of a site, at least by geochemical variability.

The null hypothesis is rejected at the inter-site scale for the three Mule Creek sites, indicating that obsidian is chemically distinguishable between each site in the Mule Creek region (for example, between North Sawmill Creek and Antelope Creek). However, the null hypothesis is not rejected at the inter-site scale for the three Mount Taylor sites, indicating that at least two of the sites are chemically indistinguishable.

Figures 8 and 9 compare the three scales of analysis for Mule Creek on a trace element bivariate plot, demonstrating the results of the MANOVA runs.

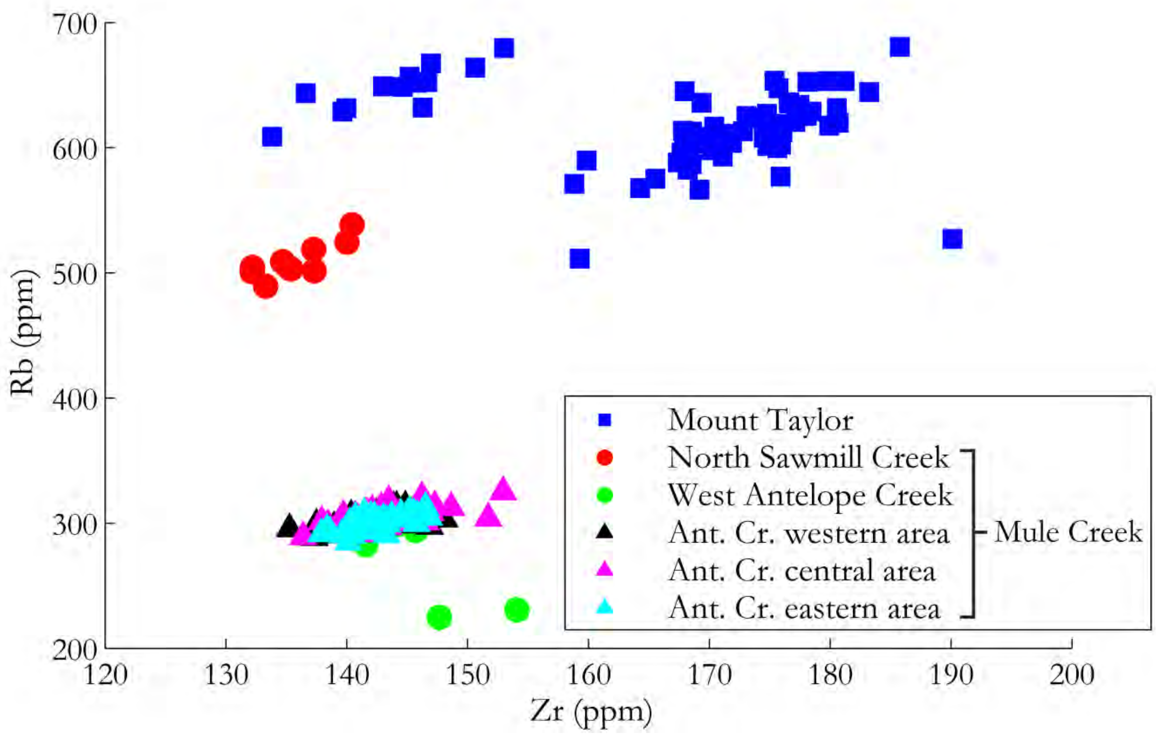

Figure 8. Bivariate plot of Rb and Zr, showing the three scales of MANOVA analysis at Mule Creek. Points are individual samples and axes are element concentrations. At the broadest scale, inter-region, squares represent Mount Taylor and circles or triangles represent Mule Creek. This scale produces distinct clusters between regions. At the intermediate scale, inter-site, red circles represent North Sawmill Creek, green circles represent West Antelope Creek, and triangles represent Antelope Creek. This scale produces distinct clusters among sites. At the finest scale, intra-site, each color of triangle represents a spatially different area of the Antelope Creek site. This scale does not produce distinct clusters among areas.

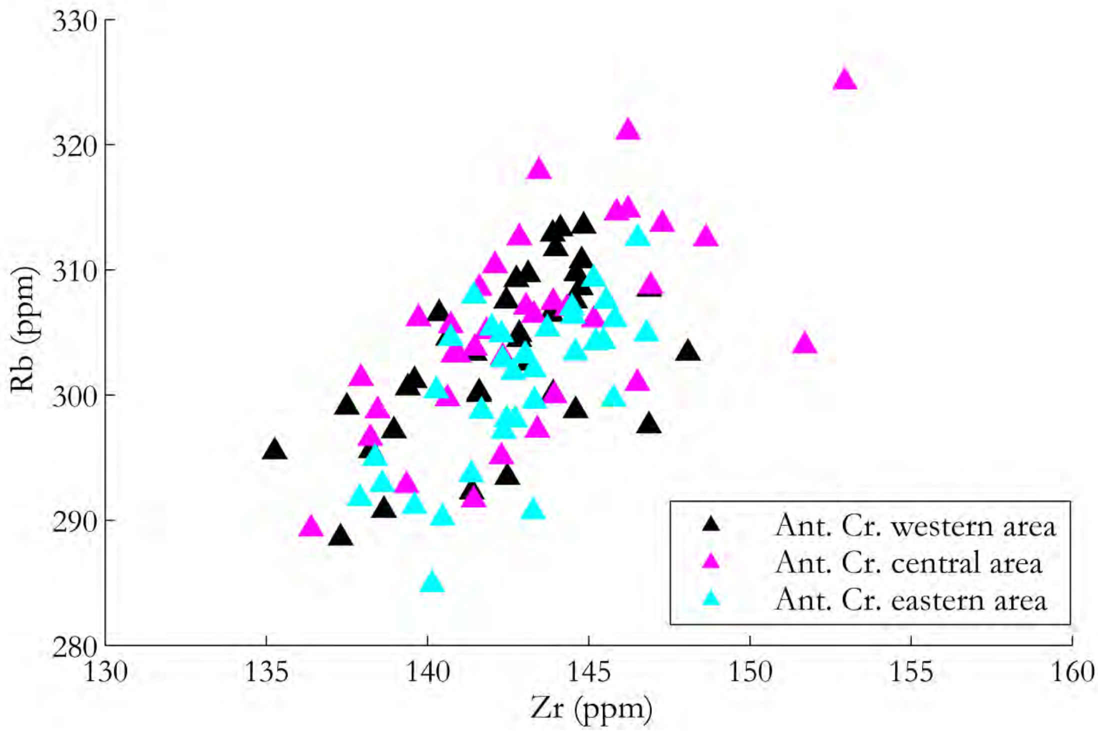

Figure 9. Zoomed view of the Antelope Creek section of Figure 8, demonstrating the lack of distinction among Antelope Creek areas.

Hotelling's T^2 statistic

To identify the chemically indistinguishable sites at Mount Taylor, Hotelling's T^2 tests were performed using the MATLAB function *T2Hot2ih.m* (Trujillo-Ortiz and Hernandez-Walls, 2005). Hotelling's T^2 is the two-group version of MANOVA, testing the null hypothesis that vectors of means of observations are the same between two groups (Harris, 1975). Like MANOVA, the Hotelling's T^2 test is run at a significance level, α, and produces a *p*-value; if $p < \alpha$, the null hypothesis is rejected and chemical composition varies with sample location. Three Hotelling's T^2 tests were run, one for each possible pairing of the three Mount Taylor sites. In each test, a group represented an individual site, with samples in the group selected to evenly represent all transects or populations at the site. The results of each Hotelling's T^2 test are presented in Table 2.

Group 1	**Group 2**	***p*-value**	**$p < \alpha$? (null hypothesis rejected?)**
Grants Ridge	Horace Mesa	0.0000	Yes
Horace Mesa	La Jara Mesa	0.1114	No
Grants Ridge	La Jara Mesa	0.0000	Yes

Table 2. Results of the three Hotelling's T^2 tests on the Mount Taylor sites.

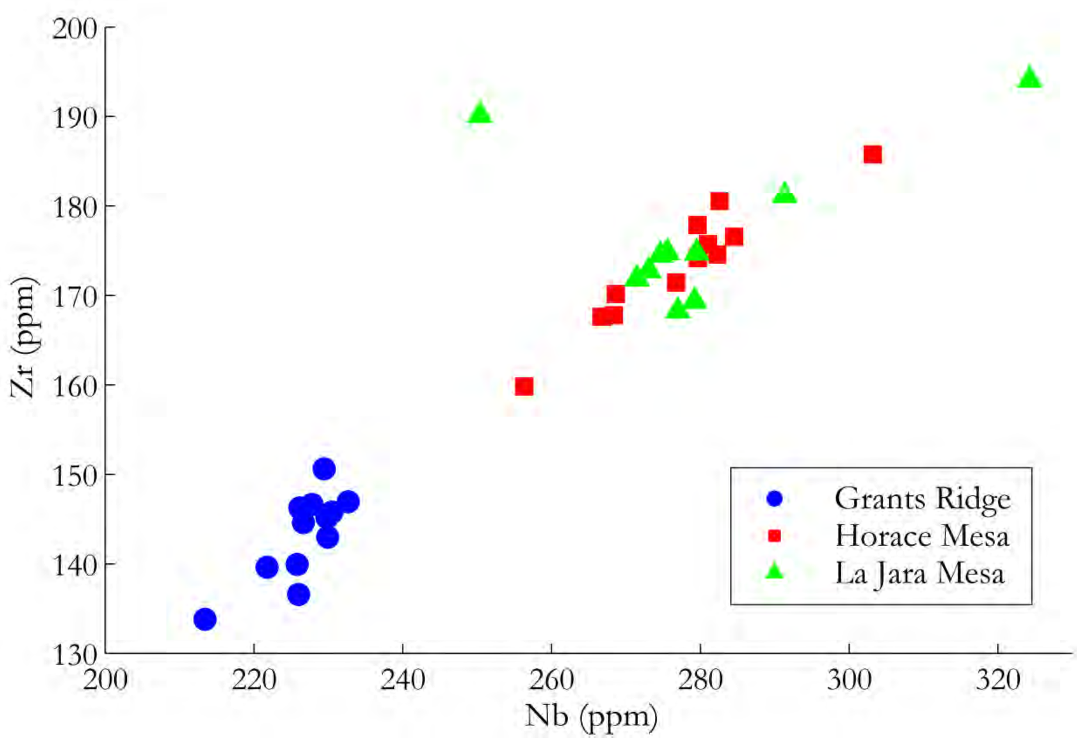

Figure 10. Bivariate plot of Zr and Nb for the Mount Taylor sites. Points are individual samples and axes are element concentrations. Although the Grants Ridge samples are clearly distinct from the Horace Mesa and La Jara Mesa samples, the Horace Mesa and La Jara Mesa samples are not clearly distinct from each other.

Hotelling's T^2 results

The rejection of the null hypothesis for the Grants Ridge vs. Horace Mesa test and the Grants Ridge vs. La Jara Mesa test, but not for the Horace Mesa vs. La Jara Mesa test, indicates that Grants Ridge is chemically distinguishable from both Horace Mesa and La Jara Mesa, while Horace Mesa and La Jara Mesa are not chemically distinguishable from each other. This is demonstrated in Figure 10 with a bivariate plot. Thus, although obsidian could be confidently sourced to Grants Ridge or to Horace Mesa / La Jara Mesa, it could not be sourced between Horace and La Jara Mesas by geochemical variability.

Principal component analysis

It has been shown that obsidian source locations can be chemically distinguished at a statistically-significant level using the multivariate statistical methods of MANOVA and Hotelling's T^2. However, in order to actually assign artifacts to a source, the features that permit obsidian to be chemically distinguished must be identified; these are the trace elements that best separate samples, and thus artifacts, into clusters characteristic of individual sites. A principal component analysis was performed to identify the dependent variables (element concentrations) that contribute most to any inter-site variability present and so would best differentiate sites.

Principal component analysis transforms multiple variables into a new set of variables, the principal components, each of which is a linear combination of the original variables. Each successive principal component contains the successive greatest variance in the original data. Thus, just the first two or three principal components show the directions of most variability in the structure of the original data, simplifying a multidimensional dataset into a two- or threedimensional dataset that highlights the dependent variables contributing most to variability (Harris, 1975).

The analysis was performed in the MATLAB Statistics Toolbox using the *pca* function. Two principal components analyses were run, one each for the Mule Creek and Mount Taylor regions. Groups for each PCA run were drawn from the MANOVA inter-site groups for the corresponding region by choosing the groups that most evenly represented each site while maintaining an equal number of samples per group between groups.

PCA results

The first two principal components are displayed on a biplot for each region (Fig.11, 12). Trace elements with larger coefficient values for component 1 represent more variability and separate the samples into discrete populations. For the three Mule Creek sites, these trace elements are Nb and Rb; for the three Mount Taylor sites, these elements are Zr and Nb. Trace elements with smaller coefficient values for component 1 represent less variability and do not separate the samples into discrete populations as efficiently. For the three Mule Creek sites, these elements are Ga and Zn; for the three Mount Taylor sites, these elements are Th and Ga. The elements with more and less variability are compared on bivariate plots in Figures 13a and 13b (for Mule Creek) and 14a and 14b (for Mount Taylor). In both regions, there is clearer sample clustering in the more-variability plots.

Since the first principal component contains a greater variance than the second, an element may have a large coefficient value for the second principal component but still not separate samples if it has a small coefficient value for the first principal component. For example, for the Mount Taylor sites Rb has a larger second principal component coefficient value than Nb. But since Rb has a smaller first principal component coefficient value than Nb, Rb does not distinguish sites as well as Nb, as demonstrated in the bivariate plots in Figures 15a and 15b.

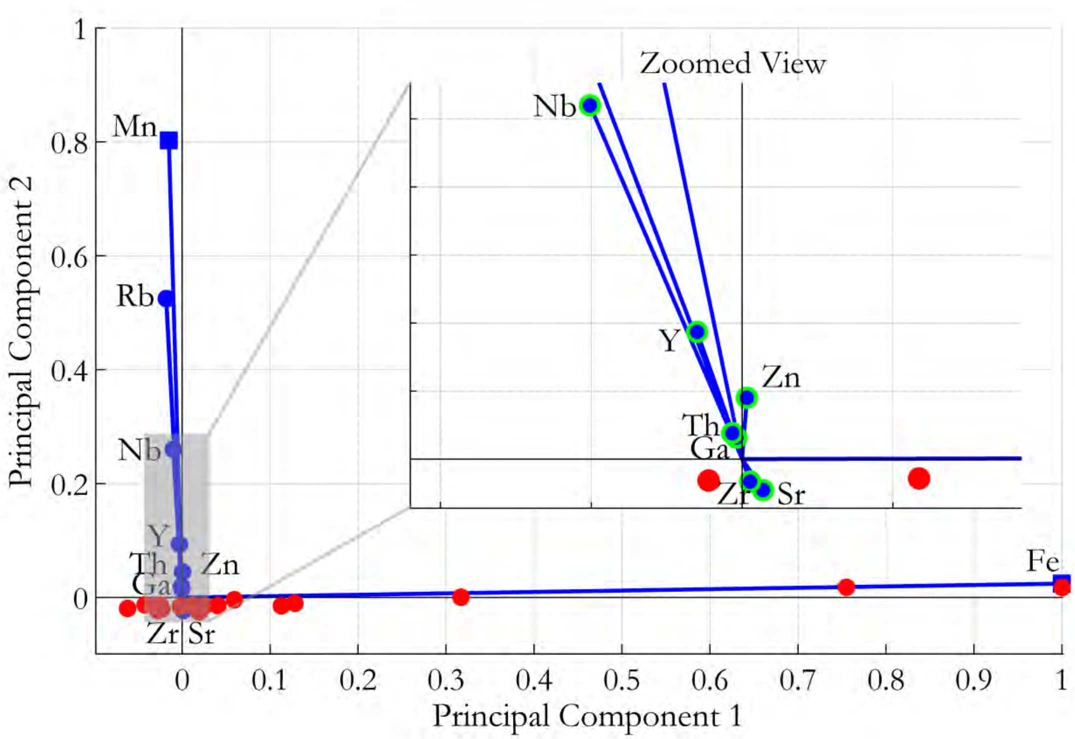

Figure 11. Biplot of the first two principal components from the principal component analysis on the Mule Creek sites. Axes are the coefficients of each component; red points represent samples. Each blue or green point/vector combination represents an element, with minor elements (> 0.1 wt%) shown as squares and trace elements (< 0.1 wt%) shown as circles. The direction and length of each vector indicates that element's contribution to the variability.

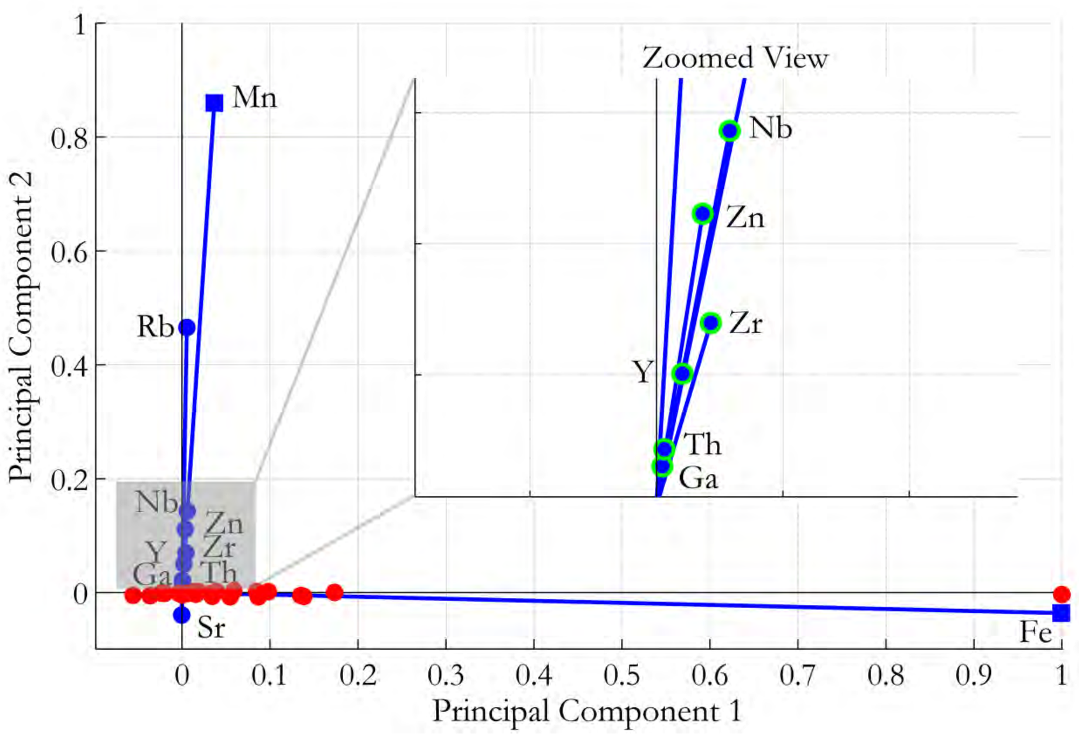

Figure 12. Biplot of the first two principal components from the principal component analysis on the Mount Taylor sites. Axes are the coefficients of each component; red points represent samples. Each blue or green point/vector combination represents an element, with minor elements (> 0.1 wt%) shown as squares and trace elements (< 0.1 wt%) shown as circles. The direction and length of each vector indicates that element's contribution to the variability.

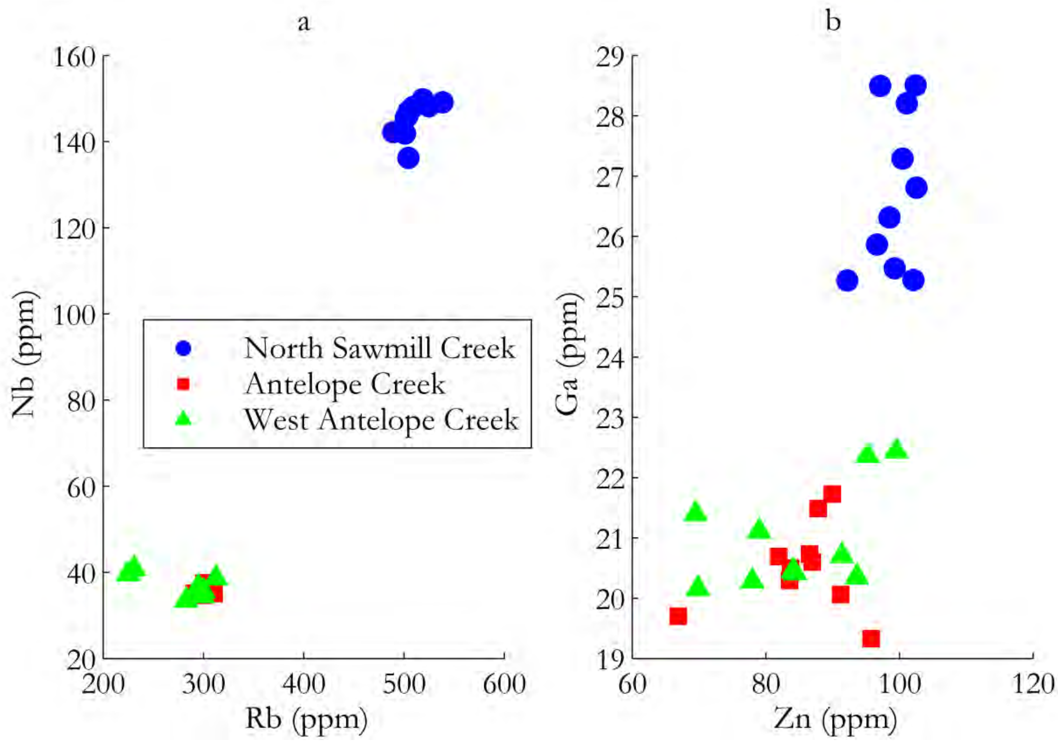

Figure 13. Bivariate plots of the trace elements contributing most (a) and least (b) to variability of the Mule Creek sites, as determined from the principal component analysis. The elements in plot *a* distinguish among sites more clearly.

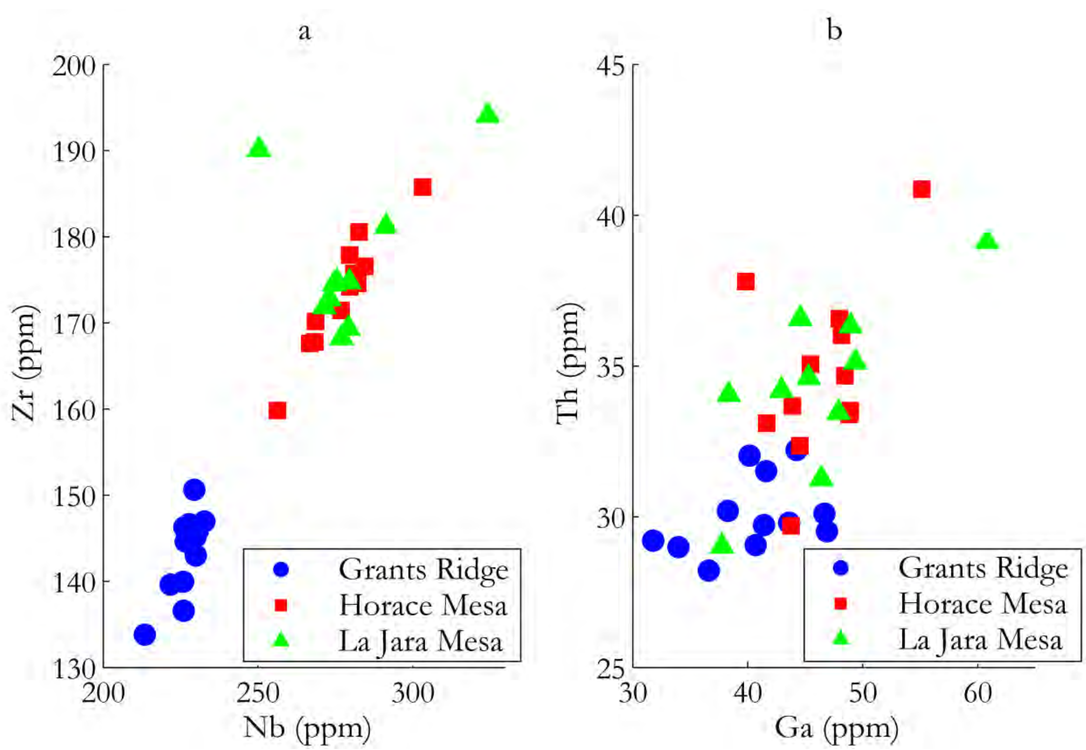

Figure 14. Bivariate plots of the trace elements contributing most (a) and least (b) to variability of the Mount Taylor sites, as determined from the principal component analysis. The elements in plot *a* distinguish among sites more clearly.

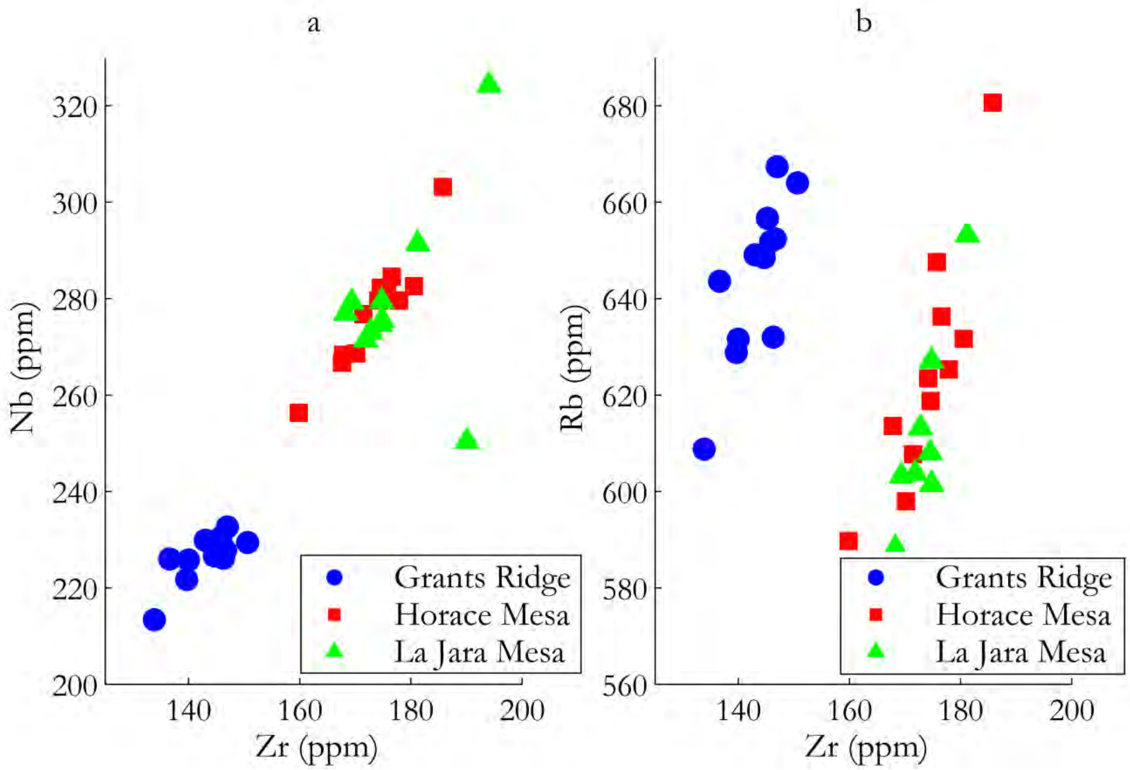

Figure 15. Bivariate plot of the Mount Taylor sites. Points are individual samples and axes are element concentrations. Nb (a), with a larger coefficient value for the first principal component, better distinguishes sites than Rb (b).

pXRF vs. XRF

For every tenth sample in the southeastern and northeastern transects at North Sawmill Creek, and for the first three samples from the first eleven populations at Antelope Creek, concentrations of the elements Zn, Ga, Th, Rb, Sr, Y, Nb, and Zr were compared against concentrations generated with desktop XRF by Caroline Hackett at Smith College (Northampton , Massachusetts). Hackett's samples were located at most 10 meters away along a transect at North Sawmill Creek and were from the same populations at Antelope Creek. Although the two instruments performed equally well at distinguishing the two sites on a bivariate plot (Fig. 16), the pXRF concentrations were systematically skewed higher for all elements and all samples.

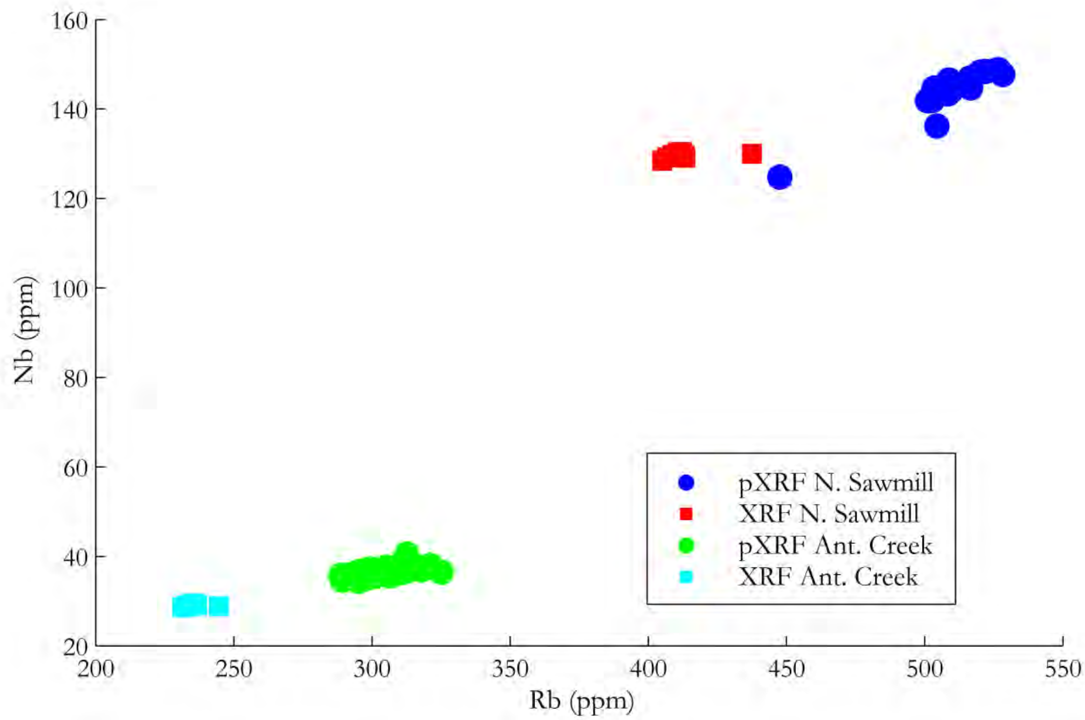

Figure 16. Bivariate plot of pXRF and XRF measurements of North Sawmill Creek and Antelope Creek obsidian. Points are individual samples and axes are element concentrations. Although the pXRF concentrations are higher than the XRF concentrations for both elements and both sites, they still distinguish between the two sites.

Discussion

Inter-site and inter-region

Results from all three statistical tests agree with those of previous workers in chemically distinguishing obsidian at the inter-site and inter-region scales, indicating that the application of multivariate statistical tests to source obsidian is a valid as well as a useful technique.

The MANOVA analyses show a statistically-significant difference among the Mule Creek sites. This concurs with and confirms the conclusion of Shackley (1995, 2005), who identified North Sawmill Creek and Antelope Creek as distinct chemical groups based on bivariate and trivariate trace element plots. Likewise, Shackley (1995) found through trial and error that Rb, Y, Nb, and Ba best distinguished North Sawmill Creek and Antelope Creek obsidian; this corresponds with the identification here, through the more rigorous method of principal component analysis, of Nb and Rb as good elements for distinguishing among Mule Creek sites. However, Shackley (2013b) did not find a difference in geochemistry between Antelope Creek and West Antelope Creek obsidian, basing this conclusion on a Y and Nb bivariate plot; the application of MANOVA in this study indicates that there is a statistically-significant difference.

Among the Mount Taylor sites, the MANOVA analyses showed a statistically-significant difference between Grants Ridge and Horace Mesa obsidian. This concurs with Shackley (1998), who found geochemical variability between Grants Ridge and Horace Mesa obsidian using a different multivariate statistical technique, discriminant analysis, as well as bivariate/trivariate trace element plots. MANOVA adds another layer of statistical confirmation to Shackley's discriminant analysis. Shackley chose Mn, Y, Zr, and Nb for the discriminant analysis, since these elements exhibited the most variability on inspection. This corresponds with the identification in this study of Zr and Nb as good elements for distinguishing among Mount Taylor sites, again using a more rigorous principal component analysis.

The Hotelling's T^2 results from this study are also in agreement with previous work. Shackley (2013a) was able to geochemically distinguish Grants Ridge and Horace Mesa / La Jara Mesa obsidian, using a Nb, Y, and Rb trivariate plot, but he could not geochemically distinguish Horace Mesa and La Jara Mesa obsidian; he speculated that the two mesas are in fact one flow unit separated by a normal fault. The use of the Hotelling's T^2 test confirms these results of Shackley (2013a) and adds to his trivariate plot.

The inter-site and inter-region differences found in this study have been applied to obsidian artifacts by previous workers, demonstrating the usefulness in confirming such geochemical differences. Duff et al. (2012) were able to distinguish between the Mule Creek and Mount Taylor regions in sourcing obsidian artifacts from Chaco Canyon, New Mexico. Duff et al. (2012) also sourced Chaco Canyon artifacts distinctly to North Sawmill Creek and Antelope Creek, but were less successful in sourcing distinctly to Grants Ridge and Horace Mesa, attributing this trouble to the small physical size of the Mount-Taylor-sourced artifacts. Taliaferro et al. (2010) successfully sourced obsidian artifacts from the Mimbres region in southwestern New Mexico distinctly to Mule Creek and Mount Taylor and distinctly to North Sawmill Creek and Antelope Creek. Future application of the statistical methods in this study could potentially improve sourcing studies like these.

Intra-site

Results agree with those of previous workers in that obsidian is not chemically distinguished at the intra-site (intra-flow) scale. Hughes (1986) sampled transects across obsidian flows in central Oregon and northeastern California and found by inspection that the variability among flakes detached from a single sample was similar to the variability between samples in a transect. Hughes (1993) sampled populations on a transect across a flow in Oregon and found by inspection overlapping mean concentrations between populations. These studies led Hughes and Smith (1993) to conclude that the magma source of each obsidian-bearing flow is homogenous, which would be congruous with the lack of statistically-significant variability found within each flow (represented by a site) in the intra-site MANOVAs of this study. In addition, this study confirms Hughes' results on a finer geographical scale. The transects in Hughes (1986) were sampled every 20 to 50 meters, while transects in this study were sampled as closely as every 5 meters. Thus, the conclusions of Hughes and Smith (1993) can be extended to suggest homogeneity even between sub-areas of flows. The use of MANOVAs to test the overlap of population means rather than just inspecting the overlap of population means provides additional grounding.

Tykot (1997) sampled source obsidian across western Sardinia, Italy, but found by cluster analysis, discriminant analysis, and principal component analysis only five statistically-significant source groups, all on the inter-site scale (2 – 6 km apart) rather than the intra-site scale. As with the comparison to Shackley (1998), the use in this study of a different multivariate statistical method (MANOVA) provides additional support.

pXRF

As Liritzis (2011) and Shackley (2010) point out, pXRF systems are known to perform worse than desktop XRF systems when measuring light elements ($Z < 11$ or 14). However, for the heavier elements used in the comparison with Hackett's desktop XRF analysis ($30 \leq Z \leq 90$), the systematically higher values produced by the pXRF analysis in this study are most likely a calibration error, caused by the Bruker calibration file not being zeroed to the specific pXRF instrument used. Thus, it would be advisable when using a factory-produced calibration file to check the results for the specific instrument by analyzing geochemical standards, such as the USGS's RGM-1 (a rhyolitic obsidian).

Although the pXRF data in this study could not be used for sourcing obsidian artifacts until the calibration error was corrected with a geochemical standard, the geochemical variability of Mule Creek and Mount Taylor at different scales is still consistent with previous work, indicating that pXRF remains a valid approach for distinguishing sources.

CONCLUSION

Characterizing the geochemical variability of source obsidian among sites in the American Southwest facilitates the sourcing of obsidian artifacts to these sites, permitting archaeologists to map trade routes among prehistoric cultures. To expand upon previous work in this field that used confidence ellipses and desktop XRF, and to test the ability to source obsidian to a fine scale, obsidian geochemical variability was compared among six sites in the Mule Creek and Mount Taylor regions of New Mexico. pXRF and three multivariate statistical methods (MANOVA, Hotelling's T2, and principal components analysis) were used. Chemical concentration was found to vary statistically at the largest scale analyzed, between the Mule Creek and Mount Taylor regions, and at the intermediate scale, between sites within each region, but not at the smallest scale, within a site. This verifies with robust statistical methods the conclusions of Shackley (2005) and Hughes and Smith (1993) that although trace element composition varies between obsidian flows and can be used as a distinguishing characteristic for sourcing archeological artifacts, trace element composition is homogenous on the small scale of across an obsidian flow. Thus, although georeferencing of samples within a site is most likely not necessary for geochemical studies, archaeologists cannot source artifacts to specific areas of a site using geochemical methods. Instead, they must turn to other promising methods, such as characterizing the magnetic properties of obsidian across flows.

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APPENDIX A

The concentrations (in ppm) of the 10 measured elements are included here for all 491 analyzed samples, to permit comparison with published data.

North Sawmill Creek

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061713-1-4	938.90	7322.17	99.27	25.47	41.75	504.40	1.87	83.50	132.18	136.22
061713-1-5	926.89	7589.08	96.62	25.86	41.43	504.62	2.93	89.03	135.15	147.05
061713-1-6	828.32	7754.81	102.08	25.28	39.65	503.23	1.83	89.86	135.37	145.96
061713-1-7	856.84	7238.85	98.48	26.31	40.21	508.99	1.94	87.80	134.68	148.03
061713-1-8	915.91	9900.69	105.67	27.57	43.67	511.42	2.67	90.45	139.26	142.09
061713-1-9	914.56	7141.52	99.35	24.09	40.29	490.61	1.58	88.77	135.10	137.21
061713-1-10	831.58	6985.03	97.55	23.43	39.15	493.96	2.25	82.36	131.05	143.35
061713-1-14	942.97	7762.37	100.54	27.35	39.14	502.70	2.31	87.20	136.45	141.91
061713-1-15	894.51	6897.84	92.90	23.51	39.39	472.93	0.83	81.80	128.78	135.94
061713-1-16	934.23	7387.12	91.59	28.40	38.78	521.39	2.72	90.18	137.04	144.25
061713-1-17	997.53	7813.23	99.96	26.70	41.94	537.64	1.65	90.61	143.85	148.01
061713-1-18	955.51	7191.33	98.74	25.98	38.98	512.13	2.54	91.92	138.30	149.41
061713-1-19	878.84	7225.67	96.39	24.14	41.17	490.54	1.42	90.00	131.67	137.58
061713-1-20	827.98	7866.74	104.65	26.72	41.06	499.66	1.57	87.48	133.22	146.35
061713-1-24	828.99	6707.24	83.73	23.59	37.78	447.57	0.80	78.54	125.00	124.79
061713-1-25	919.84	8989.56	108.17	25.91	39.00	500.93	2.46	88.55	134.75	144.62
061713-1-26	893.48	7984.14	114.38	27.13	41.60	518.62	1.62	86.45	135.01	149.38
061713-1-27	940.01	8044.27	94.66	25.80	42.10	521.71	1.87	88.17	142.76	146.38
061713-1-28	849.33	7294.23	101.63	26.72	41.12	502.38	2.28	83.94	135.51	144.06
061713-1-29	897.40	7927.44	101.92	30.24	39.78	496.05	1.18	85.43	131.06	138.16
061713-1-30	975.37	6872.98	98.34	22.51	38.82	498.16	0.29	88.51	151.51	147.16
061713-1-34	883.91	7407.70	96.53	30.02	40.14	507.00	1.81	89.29	137.53	148.21
061713-1-35	900.47	7296.83	101.84	24.77	38.37	498.35	1.90	88.39	133.15	145.38
061713-1-36	903.14	7277.14	101.60	26.45	41.58	515.26	2.38	88.05	139.23	145.06
061713-1-37	823.92	6625.56	90.15	23.72	36.77	466.62	1.13	79.62	123.80	131.39
061713-1-38	969.15	7266.65	104.05	29.98	42.29	519.99	1.53	87.37	132.86	148.22
061713-1-39	786.20	6439.68	94.15	24.35	36.34	451.57	1.08	79.19	120.85	127.56
061713-1-40	972.34	7242.17	107.63	26.93	40.12	510.31	2.19	86.58	132.14	140.80
061713-1-44	892.62	7166.64	100.24	24.76	38.39	508.37	0.38	84.92	134.35	143.37
061713-1-45	917.25	7631.28	105.35	29.26	42.11	516.64	1.72	92.68	139.89	149.29
061713-1-46	858.85	7430.09	97.44	28.47	42.03	513.35	2.55	89.10	135.33	145.90
061713-1-47	887.78	7718.75	98.96	31.82	39.40	515.14	2.17	89.84	136.64	143.71
061713-1-48	1049.11	7901.44	103.05	27.15	43.91	544.23	2.22	96.04	142.79	157.58
061713-1-49	938.73	7594.54	98.75	29.37	41.50	531.26	2.04	95.75	138.41	149.95
061713-1-50	915.73	7722.59	102.67	30.35	42.37	533.99	2.77	92.99	141.91	152.52

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061713-1-54	935.03	7164.82	104.43	25.84	39.96	516.34	1.44	88.27	145.64	146.92
061713-1-55	867.89	9128.40	109.19	32.72	37.95	516.47	2.10	89.18	138.77	144.71
061713-1-56	841.53	7208.37	90.98	25.68	40.40	508.95	1.73	85.82	132.55	141.38
061713-1-58	861.61	6823.81	102.00	26.11	39.72	483.33	1.56	82.91	137.86	139.54
061713-1-59	959.58	7519.94	96.46	30.69	42.65	514.28	1.11	92.28	136.63	146.38
061713-1-60	876.79	10307.74	101.00	24.83	39.92	471.60	3.04	82.43	126.42	137.38
061713-1-64	864.27	8657.86	106.91	29.74	38.96	508.75	2.51	89.08	134.42	146.51
061713-1-65	883.61	7738.84	98.83	26.88	40.03	484.28	2.14	84.13	132.52	142.29
061713-1-66	850.34	8884.62	103.54	25.20	40.46	503.64	2.65	86.78	137.73	144.21
061713-1-67	819.85	9416.13	102.05	27.92	37.92	511.76	3.47	88.57	139.19	142.35
061713-1-68	847.26	8067.24	92.42	26.48	38.41	498.28	2.95	85.97	133.48	142.07
061713-1-69	962.34	7922.02	101.58	24.22	41.98	511.93	2.90	86.85	134.69	143.66
061713-1-70	851.94	7533.45	103.25	23.27	40.35	489.16	1.39	83.90	129.45	139.96
061713-1-74	889.56	7309.99	92.56	29.52	38.73	502.73	2.06	90.26	141.49	142.80
061713-1-75	936.82	6981.69	102.48	28.10	38.78	507.99	1.07	85.02	133.94	143.01
061713-1-76	926.00	7319.29	99.54	24.97	40.61	499.99	1.51	89.12	130.71	143.60
061713-1-77	904.57	9567.71	110.18	28.46	40.10	530.43	3.30	89.39	137.22	146.41
061713-1-78	884.56	7256.70	95.03	31.20	43.25	515.64	2.68	96.45	142.11	150.71
061713-1-79	926.57	7851.98	94.64	26.87	41.30	509.10	2.18	92.22	135.90	145.73
061713-1-80	903.15	7012.45	92.56	23.28	38.52	471.51	1.22	81.92	129.49	135.51
061713-1-84	911.14	7340.23	105.48	26.59	39.85	509.55	0.72	92.07	137.35	144.04
061713-1-85	919.18	7291.07	99.26	29.01	41.22	518.25	0.88	92.98	134.61	148.33
061713-1-86	950.68	7045.44	100.59	24.14	39.33	493.90	1.29	88.22	135.98	144.09
061713-1-87	879.60	7123.77	100.16	25.52	39.94	493.18	2.16	86.85	131.34	141.69
061713-1-88	930.46	7505.06	98.20	25.08	39.25	513.21	2.07	87.79	135.05	143.83
061713-1-89	976.11	10570.15	103.59	25.28	44.88	518.89	2.90	91.85	153.11	147.09
061713-1-90	911.18	8239.03	101.55	26.73	38.72	517.49	3.25	89.64	137.23	145.29
061713-1-94	1045.24	7971.87	106.49	27.90	43.17	526.55	1.58	90.48	140.01	148.85
061713-1-95	944.87	7551.11	100.40	26.26	42.35	517.34	2.24	89.35	137.23	146.79
061713-1-96	1032.35	7155.09	110.69	26.91	39.68	498.45	2.33	85.16	130.86	138.21
061713-1-97	998.79	7766.14	107.49	28.22	41.36	531.04	2.61	96.38	140.24	151.71
061713-1-98	870.05	6903.19	95.19	25.73	37.79	495.31	1.31	86.35	129.53	136.47
061713-1-99	941.33	7366.50	99.42	23.26	40.05	510.65	2.02	89.86	136.79	143.52
061713-1-100	851.90	7275.06	99.73	28.02	41.27	511.44	0.98	88.11	143.20	147.90
061713-2-1	813.69	7240.34	102.51	26.81	40.20	501.74	1.94	89.07	137.31	145.55
061713-2-3	922.45	7986.43	101.09	28.21	40.66	524.63	1.74	92.42	140.00	148.20
061713-2-4	886.67	7223.91	100.45	27.29	39.51	500.97	1.42	89.38	132.17	141.87
061713-2-5	1002.29	8788.39	118.27	25.82	42.22	537.19	1.88	93.15	141.64	148.69
061713-2-6	921.27	7236.09	94.31	27.52	39.18	494.70	2.78	84.78	133.31	143.21
061713-2-7	934.90	7405.22	104.30	27.71	41.76	515.63	1.90	90.28	140.30	147.41
061713-2-8	945.81	7457.62	105.71	24.77	40.81	525.75	1.47	90.34	150.39	147.80
061713-2-9	925.27	7064.13	104.50	26.94	36.40	503.10	1.19	87.65	139.50	146.05
061713-2-10	1015.39	7621.23	103.53	31.00	41.75	529.69	2.03	89.33	139.05	149.00

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061713-2-11	934.84	8704.44	107.14	30.82	41.75	517.86	2.49	92.75	139.05	149.97
061713-2-13	938.89	7202.89	103.35	27.93	38.22	501.79	1.35	89.60	135.13	144.12
061713-2-14	977.06	7786.83	94.91	27.06	41.30	514.32	3.18	91.60	136.14	149.10
061713-2-15	960.55	7484.71	96.33	28.04	40.73	512.69	2.58	89.79	138.68	144.73
061713-2-16	944.76	7380.00	91.82	25.99	42.15	523.98	2.44	92.80	140.33	148.89
061713-2-17	917.43	7258.14	101.47	28.83	42.51	524.24	1.75	89.17	137.27	146.44
061713-2-18	833.23	7384.17	112.06	27.21	38.78	493.54	1.76	82.26	131.41	140.27
061713-2-19	905.05	7239.64	110.00	26.54	41.69	512.17	2.13	93.12	133.76	145.51
061713-2-20	895.68	7411.62	104.54	25.90	41.82	518.46	2.62	89.12	137.40	146.59
061713-2-21	933.73	8360.65	105.54	27.05	45.95	528.84	3.88	93.41	142.39	151.30
061713-2-23	883.57	8071.41	101.35	25.27	42.64	490.99	1.67	88.12	134.35	143.16
061713-2-24	921.20	7644.37	104.79	28.72	39.31	528.18	2.53	93.41	136.56	147.74
061713-2-25	893.75	7310.34	97.42	26.98	40.68	514.79	2.17	88.59	137.57	147.95
061713-2-26	901.67	7569.43	102.81	26.44	40.04	503.44	2.34	92.24	138.96	146.42
061713-2-27	979.64	7705.96	99.53	30.17	44.03	526.67	2.89	92.15	137.63	149.19
061713-2-28	911.72	8322.35	105.30	26.17	39.00	530.47	1.70	94.65	139.43	149.10
061713-2-29	993.27	7732.66	95.94	26.56	39.58	498.89	1.27	89.05	132.29	143.56
061713-2-30	938.12	7387.57	98.65	27.47	40.83	514.41	2.19	89.94	135.72	145.69
061713-2-31	837.28	7782.14	102.91	25.28	39.63	496.24	2.33	89.67	140.03	138.15
061713-2-33	952.30	7667.53	103.97	27.10	43.35	520.62	2.60	89.45	140.16	148.10
061713-2-34	903.24	7346.43	100.92	27.20	38.85	503.41	2.51	92.01	136.05	144.69
061713-2-35	940.32	7963.62	101.47	26.32	42.13	521.16	1.60	89.22	138.56	148.10
061713-2-36	902.59	7089.45	97.25	26.28	38.73	502.42	2.68	86.27	131.69	145.81
061713-2-37	850.91	7055.02	95.57	26.97	38.62	512.43	3.13	89.88	135.84	149.33
061713-2-38	1019.98	7947.11	109.93	29.18	41.77	544.56	2.80	96.00	140.70	152.94
061713-2-39	856.60	6884.02	97.99	27.52	37.69	491.09	0.96	84.75	130.71	143.87
061713-2-40	981.71	7338.02	102.97	26.27	42.87	509.07	1.86	88.06	139.82	146.16
061713-2-41	855.59	9053.16	110.18	25.39	39.63	520.32	3.15	91.00	154.80	145.15
061713-2-43	878.07	7606.30	111.14	28.72	42.83	523.31	2.22	92.30	138.05	148.70
061713-2-44	971.07	7767.89	111.79	25.21	43.81	519.99	2.11	94.56	139.66	148.24
061713-2-45	874.04	7223.31	97.38	27.32	40.88	491.73	0.71	88.50	133.30	139.64
061713-2-46	934.27	7078.96	94.55	27.26	37.38	484.84	1.22	87.40	137.42	139.24
061713-2-47	911.98	7572.44	101.44	27.56	40.26	515.92	2.27	91.03	139.98	145.03
061713-2-48	995.53	7403.76	110.04	27.97	42.33	537.96	2.75	93.76	143.48	153.03
061713-2-49	917.24	7349.60	106.61	26.89	39.12	513.43	2.26	89.14	133.54	145.79
061713-2-50	904.44	7471.38	104.51	25.22	41.84	526.56	1.07	87.89	136.72	150.95
061713-2-51	954.35	7669.85	98.50	26.59	39.89	517.52	2.29	89.72	145.28	146.08
061713-2-53	875.82	7323.56	98.48	23.63	37.97	490.23	1.63	90.32	133.51	143.65
061713-2-54	941.09	7107.99	98.81	25.59	43.44	516.56	1.57	88.94	134.00	144.74
061713-2-55	876.36	7066.69	95.14	24.89	43.03	502.09	1.99	88.73	147.43	147.15
061713-2-56	970.70	7519.91	100.36	24.97	40.96	508.36	1.23	90.76	137.22	145.44
061713-2-57	971.26	7509.15	94.09	27.79	44.19	530.06	2.43	91.60	136.32	149.87
061713-2-58	940.28	7426.22	100.32	25.09	41.63	520.17	2.22	90.21	141.55	146.05

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061713-2-59	974.93	7040.31	87.38	30.64	40.16	505.78	0.40	90.45	136.28	141.10
061713-2-60	913.94	7045.73	97.38	25.61	40.76	505.42	1.64	85.83	135.43	143.14
061713-2-61	892.44	7230.18	95.01	24.53	40.00	501.98	1.64	84.79	130.59	138.47
061713-2-63	902.84	7864.27	97.29	25.91	41.73	519.05	2.05	86.93	137.88	146.27
061713-2-64	885.78	7338.91	95.40	25.12	43.41	521.99	1.82	87.85	136.89	148.43
061713-2-65	923.33	7338.70	99.99	26.31	40.84	509.21	1.86	91.50	132.84	140.88
061713-2-66	909.46	8421.86	99.03	25.08	39.92	503.49	2.51	89.28	135.71	141.12
061713-2-67	947.03	7373.16	106.74	26.05	43.69	513.52	2.06	91.46	146.22	148.44
061713-2-68	877.24	7272.64	98.92	26.49	40.06	514.74	2.04	88.35	134.10	147.18
061713-2-69	836.58	9017.91	108.89	28.64	40.46	516.00	2.90	89.07	136.41	143.81
061713-3-3	1006.21	7760.39	97.11	28.49	41.65	538.53	2.44	96.69	140.43	149.13
061713-3-4	917.23	7575.10	92.17	25.27	40.30	489.38	1.52	84.52	133.29	142.21
061713-3-5	963.23	7747.89	102.41	28.51	40.98	518.86	2.15	90.91	137.25	149.81
061713-3-6	856.66	7565.47	102.28	27.94	38.57	494.68	1.98	89.73	139.02	145.67
061713-3-7	932.98	7635.81	99.35	24.23	42.89	507.62	2.11	94.05	144.56	149.10
061713-3-8	885.89	7754.83	100.53	27.77	42.93	497.30	2.29	85.49	132.09	142.43
061713-3-9	879.63	7965.73	99.46	28.03	40.24	520.61	2.55	90.45	137.62	148.70
061713-3-10	922.73	7348.82	103.84	24.53	41.68	519.01	2.41	90.88	135.76	148.35
061713-3-13	834.52	7248.87	97.49	26.54	38.78	504.65	2.38	87.82	130.98	145.72
061713-3-14	911.06	7080.38	104.98	28.00	42.10	510.08	1.96	90.38	137.14	147.44
061713-3-15	875.19	7311.41	99.45	22.99	38.17	501.49	1.16	82.40	131.97	142.97
061713-3-16	893.50	7344.83	101.33	29.98	39.84	514.85	2.00	88.32	153.68	145.51
061713-3-17	893.28	7469.29	109.74	27.63	39.38	521.62	2.04	92.86	139.60	148.08
061713-3-18	904.50	6762.97	93.50	23.79	37.95	486.88	1.38	85.37	133.53	136.43
061713-3-19	952.09	7583.02	99.25	25.32	44.87	514.63	2.79	88.97	133.95	142.56
061713-3-20	942.07	7830.45	108.76	27.02	43.49	532.98	3.13	91.35	138.22	146.29
061713-3-23	937.06	7996.62	103.67	26.94	39.65	510.70	1.65	87.95	136.43	142.34
061713-3-24	842.29	7559.39	96.23	23.70	42.32	525.50	2.06	87.82	136.26	147.16
061713-3-25	904.40	6809.11	97.55	26.58	37.97	489.62	0.92	86.54	131.47	138.32
061713-3-26	978.32	7599.24	96.08	27.03	39.88	527.40	1.60	91.65	140.27	148.11
061713-3-27	765.63	7029.92	95.75	22.79	38.15	466.93	1.21	81.78	123.35	133.06
061713-3-28	944.17	7158.43	104.43	23.97	42.59	509.99	1.38	88.99	136.97	147.74
061713-3-29	891.95	7516.82	103.05	29.14	42.50	517.45	1.32	90.16	136.22	146.43
061713-3-30	921.44	8097.35	104.91	24.86	44.18	537.52	2.09	94.72	143.94	156.16
061713-3-33	887.46	7516.37	102.72	26.95	42.84	510.13	2.17	89.76	130.33	145.08
061713-3-34	954.13	7484.66	113.62	27.52	40.69	523.70	1.98	94.23	139.20	149.51
061713-3-35	781.66	6329.74	94.91	25.91	40.88	488.61	1.50	85.29	153.83	140.36
061713-3-36	899.96	7374.51	97.81	25.99	39.72	492.48	0.98	89.33	133.48	140.38
061713-3-37	979.63	8071.72	111.53	27.29	41.93	520.06	2.17	97.57	138.36	152.06
061713-3-38	854.07	8637.63	106.68	26.68	40.47	506.65	2.95	89.79	138.91	145.87
061713-3-39	864.42	7231.55	104.36	28.82	42.31	515.11	2.11	90.35	139.89	145.93
061713-3-40	935.77	7545.12	104.09	24.84	42.10	516.90	1.83	87.42	138.25	144.78
061713-3-43	911.27	8431.04	98.28	24.80	42.15	513.26	1.67	90.98	139.96	147.29

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061713-3-44	841.03	7160.26	101.46	25.95	43.31	515.56	1.31	88.19	132.72	145.67
061713-3-45	869.18	7427.30	94.45	26.58	41.79	509.65	1.68	91.57	140.64	143.16
061713-3-46	933.09	7665.82	104.53	27.34	43.58	527.28	2.17	94.78	140.24	151.07
061713-3-47	944.98	6916.99	101.79	26.55	40.44	482.35	1.39	81.53	129.81	135.39
061713-3-48	896.01	7453.70	99.96	25.36	42.72	509.27	1.30	87.64	135.28	143.35
061713-3-49	974.63	7108.05	101.52	26.45	42.17	511.33	2.06	88.12	136.30	149.80
061713-3-50	918.24	7583.70	105.24	26.73	38.27	516.14	1.32	90.56	137.25	145.37
061713-3-53	872.01	6895.28	90.50	25.05	39.24	477.15	1.50	80.75	131.29	136.99
061713-3-54	857.79	7385.17	104.98	29.59	41.63	521.81	1.35	91.20	142.90	147.63
061713-3-55	506.87	8985.15	73.45	20.69	29.17	266.86	21.96	45.42	143.76	31.72
061713-3-56	980.37	7798.29	100.44	28.89	40.77	518.86	1.76	91.24	138.25	148.36
061713-3-57	921.01	7235.34	104.40	28.71	40.41	508.15	1.78	89.57	141.50	145.63
061713-3-58	1000.34	7742.29	100.61	25.58	43.69	517.51	2.47	92.29	146.55	148.21
061713-3-59	816.74	6688.64	95.60	24.96	36.02	480.51	1.60	89.63	132.19	140.17
061713-3-60	994.88	7983.06	103.31	25.02	41.34	612.12	3.03	86.42	136.08	145.89
061713-3-63	877.19	6964.72	96.67	26.14	37.36	477.77	1.87	83.67	127.64	135.60

Antelope Creek

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061813-1-01-A	618.49	8853.58	83.72	20.50	33.54	308.48	12.73	56.44	146.87	36.11
061813-1-01-B	617.25	9476.48	95.77	19.33	32.21	293.43	12.21	54.49	142.47	35.08
061813-1-01-C	533.04	8860.97	87.83	21.49	33.05	297.16	13.86	52.09	138.96	35.05
061813-1-01-D	621.31	9216.89	86.93	20.60	34.28	300.59	11.35	51.92	139.39	34.64
061813-1-01-E	494.09	9283.45	83.54	20.29	34.02	300.14	11.70	53.06	143.90	35.97
061813-1-01-F	643.30	8886.40	86.54	20.73	32.77	297.56	12.25	51.74	146.86	35.44
061813-1-01-G	606.17	9090.45	81.94	20.69	33.27	302.56	12.69	52.80	143.11	37.58
061813-1-01-H	615.53	8848.26	91.20	20.06	34.04	310.75	13.48	55.15	144.78	35.12
061813-1-01-I	650.15	8730.15	89.92	21.73	32.51	300.21	12.29	51.13	141.60	37.51
061813-1-01-J	594.71	8548.71	66.90	19.70	29.41	290.81	11.47	49.49	138.65	35.15
061813-1-02-A	446.29	7762.05	73.14	21.59	33.40	304.85	13.55	56.92	142.85	36.27
061813-1-02-B	483.42	8507.65	72.25	20.19	34.03	301.17	12.88	52.61	139.60	35.54
061813-1-02-C	520.93	8092.39	65.43	21.51	32.48	298.77	13.78	52.48	144.59	35.32
061813-1-02-D	503.46	8526.04	70.05	20.32	33.58	309.70	13.37	55.23	144.61	37.88
061813-1-02-E	512.54	8567.98	77.03	21.24	34.49	309.23	12.61	53.86	142.76	37.64
061813-1-02-F	577.97	8740.46	77.00	20.00	31.77	300.06	12.51	52.11	141.59	35.34
061813-1-02-G	402.36	7132.92	71.93	19.83	31.81	292.28	13.74	50.80	141.37	34.61
061813-1-02-H	557.02	8575.75	77.55	21.71	32.59	309.63	13.05	52.87	143.12	38.04
061813-1-02-I	434.71	8744.53	70.50	22.32	35.63	303.35	14.12	64.02	148.08	36.75
061813-1-02-J	545.91	8356.76	77.89	21.10	34.65	308.58	12.97	53.73	144.75	37.26
061813-1-03-A	580.16	8484.25	74.62	20.01	34.90	288.60	11.55	53.28	137.30	35.77

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061813-1-03-B	557.00	9084.78	78.65	21.49	34.10	306.52	13.90	50.91	140.36	35.63
061813-1-03-C	500.97	8608.02	76.42	19.22	32.45	295.49	11.20	53.74	135.26	35.01
061813-1-03-D	526.12	8408.74	72.80	21.31	34.50	307.53	12.54	54.40	144.57	35.01
061813-1-03-E	591.76	8063.88	69.99	20.07	32.31	303.36	13.10	52.56	141.46	37.16
061813-1-03-F	506.59	8639.62	72.27	20.59	34.25	295.58	13.79	54.48	138.25	33.98
061813-1-03-G	614.20	8727.74	76.92	20.67	32.63	312.87	12.73	53.66	143.88	36.78
061813-1-03-H	609.85	9284.61	67.96	21.52	34.46	313.28	13.15	53.12	144.12	37.75
061813-1-03-I	590.87	8642.09	70.58	21.23	34.74	304.45	13.16	53.83	142.84	36.93
061813-1-03-J	531.11	8505.13	73.74	20.86	33.89	299.06	12.73	53.21	137.49	35.77
061813-1-04-A	578.84	9166.91	83.04	21.51	34.99	311.70	12.09	54.05	143.98	36.55
061813-1-04-B	628.83	9314.39	74.40	20.13	35.89	313.50	11.61	53.21	144.84	38.38
061813-1-04-C	626.93	9078.51	82.45	20.48	33.32	307.53	11.83	53.21	142.44	36.74
061813-1-04-D	612.09	8974.60	77.61	20.70	35.43	306.46	13.60	54.45	143.83	36.39
061813-1-04-E	619.31	9073.55	68.94	21.17	31.88	304.56	15.03	56.37	140.64	35.87
061813-1-04-F	595.24	9004.04	75.89	21.29	34.55	299.29	12.07	53.48	140.34	36.64
061813-1-04-G	576.48	9151.25	78.07	21.45	36.54	300.54	12.99	50.31	141.79	36.81
061813-1-04-H	546.55	8750.29	77.35	21.67	33.86	293.02	12.27	51.58	139.50	36.22
061813-1-04-I	553.33	9453.09	81.24	20.40	34.76	302.24	13.01	53.74	142.12	37.15
061813-1-04-J	581.11	9193.80	79.65	22.74	35.19	300.12	12.26	52.50	142.15	38.04
061813-2-01-A	574.74	9271.26	79.51	21.48	37.64	321.02	12.83	55.51	146.22	38.07
061813-2-01-B	638.66	9120.84	83.16	20.49	35.58	317.88	13.45	55.09	143.46	36.93
061813-2-01-C	567.77	8468.29	71.67	19.63	34.09	303.03	12.83	51.61	142.33	36.61
061813-2-01-D	1004.25	9412.43	70.19	21.18	33.36	308.54	13.71	54.55	141.61	36.22
061813-2-01-E	615.46	8823.90	69.35	21.07	32.62	303.77	12.72	55.24	141.47	34.83
061813-2-01-F	491.27	9015.86	74.39	20.64	34.49	307.41	11.75	54.33	143.90	36.13
061813-2-01-G	511.70	8632.41	74.38	22.12	34.59	305.55	13.53	53.54	140.72	36.00
061813-2-01-H	555.23	8539.36	77.38	21.50	31.74	306.03	12.39	56.61	145.16	35.99
061813-2-01-I	553.41	8698.51	73.62	20.29	35.02	306.12	11.94	50.87	139.72	36.60
061813-2-01-J	548.60	8778.72	69.69	20.38	36.10	314.79	13.20	52.38	146.22	35.52
061813-2-02-A	549.37	9755.34	72.60	20.77	31.32	289.32	15.60	51.22	136.39	34.68
061813-2-02-B	559.22	9096.81	80.84	22.13	34.00	312.57	13.55	53.06	142.84	40.57
061813-2-02-C	554.58	9053.21	74.70	20.71	33.73	308.69	13.37	53.69	146.93	37.61
061813-2-02-D	510.78	8387.96	70.09	20.78	32.90	298.76	10.72	50.77	138.45	38.06
061813-2-02-E	496.15	8911.26	74.69	21.85	33.28	303.22	12.70	52.39	140.80	37.31
061813-2-02-F	571.81	8958.32	75.81	19.29	29.31	296.56	11.22	53.58	138.22	36.73
061813-2-02-G	588.56	10349.11	79.53	19.92	34.73	297.21	14.39	51.27	143.41	35.66
061813-2-02-H	506.74	8929.97	75.76	21.02	29.74	295.07	12.53	51.73	142.29	36.07
061813-2-02-I	491.46	8648.39	71.54	22.57	33.72	292.79	12.67	52.75	139.35	34.39
061813-2-02-J	517.20	9022.50	71.98	21.12	34.22	310.35	11.33	53.96	142.09	36.75
061813-2-03-A	479.43	9479.14	74.76	19.82	33.67	307.04	14.30	55.28	143.05	37.08
061813-2-03-B	614.71	9717.40	66.85	21.24	36.83	325.04	13.83	57.52	152.94	36.48
061813-2-03-C	568.60	9215.45	74.67	21.57	29.22	306.38	12.28	51.60	143.30	36.47
061813-2-03-D	487.90	8785.39	76.00	19.70	36.71	313.66	13.19	54.83	147.28	37.38

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061813-2-03-E	530.66	8874.15	78.28	22.02	34.98	303.22	12.92	55.86	140.95	36.58
061813-2-03-F	454.19	8445.47	74.82	19.58	31.17	291.63	22.62	51.45	141.43	35.79
061813-2-03-G	501.03	8899.65	77.10	19.89	37.43	306.93	13.33	54.70	144.32	36.77
061813-2-03-H	513.30	8423.48	72.60	19.43	31.28	300.94	12.75	52.01	146.51	36.82
061813-2-03-I	493.57	8592.76	70.63	20.89	32.16	299.72	14.91	54.17	140.62	36.63
061813-2-03-J	427.09	8140.90	70.79	22.02	33.49	303.94	15.40	55.39	151.70	34.97
061813-2-04-A	538.88	8951.90	70.80	20.79	35.07	301.33	13.18	50.65	137.93	36.36
061813-2-04-B	654.93	9350.31	72.59	20.35	30.60	314.55	13.68	54.19	145.87	38.35
061813-2-04-C	573.43	8992.07	76.85	21.39	37.50	305.08	12.32	50.83	141.84	37.54
061813-2-04-D	448.98	8277.70	71.89	20.05	31.78	299.96	14.99	51.92	143.93	36.79
061813-2-04-E	515.11	8611.37	77.46	21.61	37.14	312.50	13.27	56.10	148.63	38.09
061813-2-04-F	497.34	7891.27	84.87	21.64	31.61	296.72	11.45	51.50	138.33	36.05
061813-2-04-G	500.89	6956.09	72.42	21.70	36.45	301.13	11.96	54.48	141.21	37.95
061813-2-04-H	483.25	8565.88	73.31	19.92	33.04	303.51	12.10	53.06	142.57	38.10
061813-2-04-I	488.77	9568.71	80.14	20.60	33.53	299.31	14.45	54.90	140.75	35.41
061813-2-04-J	564.12	9177.51	77.91	21.55	32.75	305.79	18.81	53.63	142.73	37.09
061813-2-05-A	575.31	9029.90	81.40	19.35	34.89	295.27	12.23	50.34	137.84	34.42
061813-2-05-B	552.48	8978.59	74.52	21.73	33.55	307.15	13.34	52.32	146.89	36.73
061813-2-05-C	478.51	8299.63	68.68	20.21	31.30	292.86	11.45	53.06	139.19	36.03
061813-2-05-D	462.48	7581.14	68.81	20.97	35.96	297.95	13.02	49.45	141.89	35.50
061813-2-05-E	451.59	8321.91	73.34	21.52	36.21	306.39	12.24	52.16	143.49	34.54
061813-2-05-F	682.46	9050.95	77.32	20.29	34.61	307.50	11.98	52.03	142.33	38.56
061813-2-05-G	563.93	8904.95	72.31	21.42	32.20	304.74	11.70	52.27	141.90	35.43
061813-2-05-H	477.21	6917.00	67.88	21.14	35.19	306.29	12.29	52.67	142.91	37.21
061813-2-05-I	561.39	8538.52	79.57	19.84	35.80	307.75	12.15	52.84	146.09	37.89
061813-2-05-J	455.64	8309.65	73.41	22.96	32.96	303.80	12.52	51.75	143.23	34.47
061813-2-06-A	550.24	8826.65	71.70	21.54	35.30	308.35	12.16	54.09	141.56	36.42
061813-2-06-B	544.64	8743.31	74.13	21.07	32.84	295.56	11.21	54.57	144.17	36.65
061813-2-06-C	570.19	8735.79	72.61	20.56	34.50	304.79	12.86	56.54	141.56	36.33
061813-2-06-D	597.63	9413.83	82.28	22.58	33.99	314.74	11.69	55.48	145.41	35.01
061813-2-06-E	591.68	9256.70	80.11	24.38	35.83	317.17	11.68	56.50	144.17	37.43
061813-2-06-F	596.65	8934.65	76.12	21.60	34.16	307.81	12.17	53.13	146.50	37.54
061813-2-06-G	608.61	8710.17	71.54	20.31	36.53	311.67	12.32	55.19	143.78	36.07
061813-2-06-H	515.54	8480.23	74.78	20.26	30.92	292.44	10.88	52.14	136.00	35.24
061813-2-06-I	549.81	8917.78	76.83	20.84	31.49	299.41	12.33	54.66	138.63	35.74
061813-2-06-J	575.32	8579.92	70.77	21.14	31.47	287.78	11.64	49.26	137.51	34.95
061813-2-07-A	579.11	9022.04	79.38	20.10	36.81	299.24	12.61	53.30	141.52	37.23
061813-2-07-B	598.40	8987.76	75.82	20.55	35.23	297.05	13.17	53.31	139.91	35.68
061813-2-07-C	644.26	9253.20	80.71	20.74	35.81	312.78	12.83	54.38	143.73	37.69
061813-2-07-D	492.31	8571.51	72.24	22.71	35.26	304.94	14.65	56.03	145.02	37.15
061813-2-07-E	514.19	8362.21	77.41	21.48	33.83	288.77	12.84	51.17	138.38	36.07
061813-2-07-F	450.99	7604.62	70.82	20.73	32.53	304.45	11.96	52.72	142.59	36.05
061813-2-07-G	490.94	8928.73	69.83	20.41	33.70	295.94	13.10	55.07	140.05	35.72

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061813-2-07-H	531.34	8676.51	70.28	18.62	36.96	308.79	14.84	52.37	141.54	36.58
061813-2-07-I	554.01	8344.79	72.30	20.06	32.90	292.38	11.90	52.93	138.64	36.56
061813-2-07-J	580.28	9379.45	76.44	21.67	33.72	310.88	12.84	54.55	147.72	37.27
061813-3-1	546.65	8752.50	72.94	20.97	35.72	302.21	11.57	51.03	139.59	34.73
061813-3-2	621.21	9352.10	87.50	20.00	34.30	294.93	11.65	52.11	137.58	37.43
061813-3-3	631.26	11071.49	98.90	20.17	33.16	299.73	24.26	53.61	138.96	34.41
061813-3-4	1288.43	10390.95	101.95	20.69	36.26	310.30	13.57	53.63	142.87	35.59
061813-3-5	555.81	8625.74	86.26	20.03	30.60	284.07	12.78	52.84	134.92	34.91
061813-3-6	502.57	8909.99	93.78	19.36	32.44	304.06	11.07	51.68	141.21	35.78
061813-3-7	570.11	8754.27	64.26	21.98	32.73	294.60	10.58	53.22	143.06	34.00
061813-3-8	497.29	8677.60	71.22	20.78	34.80	305.88	14.01	55.02	143.87	36.61
061813-3-9	950.71	9102.67	87.14	19.86	32.08	296.78	11.14	51.26	136.56	36.43
061813-3-10	568.34	8429.57	71.89	20.83	32.19	290.82	11.58	47.34	133.24	36.40
061813-3-11	626.87	9066.23	89.02	21.28	35.06	295.95	11.05	50.49	140.80	35.21
061813-3-12	574.94	9187.24	88.78	20.40	32.35	299.52	12.02	54.52	143.29	35.76
061813-3-13	577.20	9355.94	78.31	21.99	35.53	309.32	12.80	51.67	141.35	36.56
061813-3-14	516.72	8491.24	86.79	19.01	31.88	294.90	12.96	53.59	138.80	36.36
061813-3-15	506.95	8974.04	94.22	20.96	32.42	300.75	12.60	55.79	143.63	36.42
061813-3-16	657.26	9381.89	88.52	19.47	33.37	300.03	12.39	53.73	142.29	36.99
061813-3-17	529.01	9246.00	73.65	20.81	34.46	316.07	13.76	53.87	146.23	35.54
061813-3-18	546.24	8941.80	83.62	19.76	36.96	309.81	13.25	52.97	140.67	38.05
061813-3-19	584.35	9563.28	85.25	21.18	33.80	301.62	11.85	53.12	142.18	35.54
061813-3-20	694.36	9864.57	94.11	20.79	38.95	313.84	14.03	57.69	144.10	37.06
061913-1-01	563.39	8505.36	76.82	21.09	31.85	289.33	11.56	52.60	141.76	35.56
061913-1-02	743.13	9333.65	93.71	20.95	36.47	304.92	12.48	52.74	144.17	37.56
061913-1-03	1504.61	9274.56	95.85	21.04	36.41	308.28	14.61	54.00	142.32	37.40
061913-1-04	1600.61	10340.72	93.49	22.82	31.55	297.25	12.38	52.97	140.54	36.44
061913-1-05	994.94	9272.92	72.21	21.37	33.29	307.29	12.99	56.15	142.08	37.37
061913-1-06	507.93	9269.31	92.67	19.72	33.87	301.78	13.95	52.26	144.99	36.17
061913-1-07	625.34	8552.85	83.34	20.86	33.82	292.10	10.65	51.62	142.31	34.27
061913-1-08	554.74	8687.59	74.36	18.72	33.10	287.11	12.16	50.79	135.59	32.97
061913-1-09	561.22	9253.66	93.60	20.99	34.47	301.41	14.17	54.93	143.19	35.16
061913-1-10	597.04	10052.20	89.66	19.40	32.90	300.73	12.53	55.53	138.17	35.39
061913-1-11	710.75	9033.82	86.76	21.19	36.99	306.39	12.64	55.04	144.77	36.07
061913-1-12	1148.15	10216.22	86.51	20.45	32.74	301.03	14.05	54.62	139.36	35.52
061913-1-13	1016.52	9200.97	84.05	20.61	33.43	301.62	10.96	51.97	139.33	37.50
061913-1-14	548.77	10243.18	86.85	21.65	34.90	296.85	12.44	51.24	138.19	35.14
061913-1-15	1564.60	10618.44	87.54	20.56	34.43	300.94	12.58	54.54	139.50	35.85
061913-1-16	1267.22	9435.16	90.43	22.26	32.00	303.20	12.39	56.53	140.55	34.56
061913-1-17	1833.59	8837.75	87.90	21.86	32.29	300.81	13.57	49.84	141.97	34.66
061913-1-18	764.55	9933.20	92.97	21.22	34.05	296.71	13.11	49.96	136.51	33.74
061913-1-19	537.53	8586.38	74.42	19.23	31.68	287.79	12.82	49.35	134.35	35.80
061913-1-20	661.00	9090.13	89.52	21.95	33.02	310.43	11.49	54.34	144.72	35.96

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061913-1-21	609.84	9120.94	86.93	21.00	31.38	308.70	12.24	49.55	140.33	36.25
061913-1-22	566.06	8779.26	72.22	19.61	29.81	303.09	12.27	51.95	140.71	38.58
061913-1-23	550.64	8464.18	71.56	20.76	30.76	282.69	10.78	49.94	136.45	34.08
061913-1-24	558.59	8362.79	71.83	22.12	29.09	280.55	11.56	51.60	135.82	36.05
061913-1-25	533.58	8799.52	74.50	20.48	29.82	308.46	12.33	50.43	141.64	37.10
061913-1-26	682.94	9146.65	86.60	20.99	35.25	303.17	11.76	54.51	141.34	34.11
061913-1-27	565.39	8944.24	79.51	19.80	33.13	300.11	10.77	58.67	139.65	36.67
061913-1-28	579.35	8613.77	70.27	20.63	34.42	294.39	11.08	54.40	140.64	35.81
061913-1-29	686.50	9729.84	87.82	22.76	37.61	308.65	12.48	54.58	141.30	38.31
061913-1-30	637.76	9714.31	91.41	21.10	33.03	301.11	14.30	51.11	143.92	33.80
061913S-1-A	534.23	8917.72	79.54	20.48	32.19	301.82	14.56	52.98	142.66	36.46
061913S-1-B	578.86	8954.02	76.02	19.93	30.41	304.83	13.62	50.19	142.29	36.37
061913S-1-C	532.61	9094.64	75.00	20.30	33.82	298.73	12.60	49.30	141.68	34.62
061913S-1-D	578.05	9470.15	79.75	20.25	35.39	306.99	12.57	52.77	144.48	35.32
061913S-1-E	563.94	9016.82	69.55	20.47	33.89	307.92	13.15	53.02	141.44	36.17
061913S-1-F	495.59	8781.23	71.77	21.51	33.76	293.65	14.22	51.61	141.36	35.19
061913S-1-G	579.55	9156.46	64.85	19.68	34.15	290.19	12.97	53.05	140.46	37.11
061913S-1-H	551.14	8981.19	68.66	20.52	32.88	298.05	12.73	53.85	142.45	38.23
061913S-1-I	595.05	8848.24	75.98	20.16	34.74	303.17	14.02	49.93	143.05	37.61
061913S-1-J	565.31	8889.72	74.10	19.58	33.79	298.02	14.21	50.90	142.71	36.37
061913S-2-A	625.07	9094.69	77.82	20.32	32.08	299.54	12.49	53.16	143.32	37.46
061913S-2-B	714.95	8748.95	70.50	19.65	32.14	290.70	13.75	54.19	143.27	33.52
061913S-2-C	602.03	9216.75	67.56	21.00	36.20	304.29	14.26	53.41	145.46	34.17
061913S-2-D	583.41	8594.23	69.46	20.41	33.22	284.88	12.62	50.69	140.14	35.25
061913S-2-E	792.23	8583.47	76.99	20.84	34.06	291.75	12.51	51.08	137.90	35.15
061913S-2-F	808.77	8745.44	74.47	20.89	33.17	299.70	15.65	52.62	145.77	35.91
061913S-2-G	639.76	9170.98	84.44	21.48	33.30	291.13	12.48	50.74	139.59	34.84
061913S-2-H	613.13	9137.55	75.94	21.71	37.16	302.03	13.68	51.60	143.29	36.54
061913S-2-I	528.41	8932.05	74.48	20.12	36.79	304.89	12.63	51.60	146.79	36.48
061913S-2-J	596.99	8890.42	69.00	20.73	31.39	303.38	14.80	53.11	144.59	36.95
061913S-3-A	649.91	9147.35	73.69	23.24	35.86	312.52	12.97	53.27	146.52	36.81
061913S-3-B	508.79	8851.77	68.74	22.11	34.44	306.05	11.07	55.02	145.81	35.73
061913S-3-C	523.37	8919.51	68.53	21.17	33.95	303.15	13.71	51.09	143.01	36.43
061913S-3-D	500.48	8308.85	76.49	20.90	33.75	300.35	12.18	52.94	140.27	34.45
061913S-3-E	489.26	8500.51	79.14	21.07	35.08	294.96	11.97	54.74	138.37	34.88
061913S-3-F	512.01	9681.47	77.96	20.64	32.62	306.30	15.49	52.62	144.51	36.82
061913S-3-G	561.52	8811.83	79.27	21.03	35.94	307.49	11.86	53.31	145.53	36.42
061913S-3-H	569.96	9292.13	78.25	20.91	30.75	309.26	13.46	51.71	145.15	36.11
061913S-3-I	600.55	9005.19	76.77	21.28	34.85	305.36	12.58	53.94	141.99	34.72
061913S-3-J	432.23	8421.14	71.47	21.07	31.37	292.88	12.72	49.85	138.59	36.35
061913S-4-A	570.18	9302.06	69.04	19.43	33.02	304.20	14.54	52.12	145.22	34.99
061913S-4-B	541.63	9518.98	71.44	21.19	33.31	297.11	15.13	51.38	142.37	35.27
061913S-4-C	579.22	9109.06	79.20	20.61	35.69	305.30	13.25	52.16	143.71	35.22

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
061913S-4-D	543.12	9369.01	71.32	21.07	32.68	302.84	14.44	52.59	142.33	36.33
061913S-4-E	567.17	9015.77	73.83	20.09	36.58	304.53	13.78	51.59	140.72	36.08
061913S-4-F	567.56	9224.10	78.34	21.03	36.02	300.68	13.30	52.85	143.67	37.82
061913S-4-G	569.88	9184.20	83.58	20.63	30.75	299.02	15.30	52.03	142.49	36.12
061913S-4-H	559.15	9171.97	72.39	20.38	35.30	294.94	12.67	52.97	142.27	35.55
061913S-4-I	592.21	9430.30	75.99	21.86	36.79	303.69	12.77	54.33	145.28	35.43
061913S-4-J	569.26	9089.04	74.06	19.99	35.92	295.79	13.07	50.58	141.55	35.26
061913S-5-A	551.89	8773.83	72.91	20.32	32.82	300.02	12.17	49.44	140.61	35.56
061913S-5-B	595.36	8694.54	70.85	21.23	35.95	306.34	11.84	55.59	146.67	36.35
061913S-5-C	607.35	8761.85	68.89	21.54	35.02	303.12	12.51	51.48	144.52	37.90
061913S-5-D	565.59	8801.02	67.04	19.16	35.06	304.26	11.72	53.00	142.11	36.03
061913S-5-E	562.09	9017.52	77.32	21.59	33.64	305.89	12.71	50.84	144.40	36.26
061913S-5-F	577.65	9274.90	81.48	19.96	35.37	306.04	12.90	51.51	142.43	36.13
061913S-5-G	559.98	8648.38	73.99	19.71	31.36	305.00	13.21	54.73	146.14	36.06
061913S-5-H	555.91	8542.60	71.60	21.16	31.59	294.83	10.83	52.78	141.89	35.48
061913S-5-I	495.23	8561.53	72.10	20.14	36.17	303.83	12.68	54.27	139.35	36.34
061913S-5-J	531.03	8839.51	73.03	21.06	32.74	303.25	11.88	54.07	143.81	36.33
061913S-6-A	503.89	9197.37	72.99	21.52	32.56	303.57	16.29	52.24	149.09	36.59
061913S-6-B	480.65	8529.66	75.20	20.58	33.65	291.67	14.59	53.41	139.27	35.34
061913S-6-C	556.55	9228.63	75.19	21.04	32.26	300.17	15.60	50.59	143.45	32.87
061913S-6-D	700.41	8690.82	75.94	19.93	34.08	300.69	13.54	54.90	142.41	36.33
061913S-6-E	464.23	8257.27	68.89	21.63	33.36	304.97	14.61	56.28	145.14	34.85
061913S-6-F	587.49	9321.22	67.66	20.64	33.95	294.69	13.54	51.23	141.27	36.80
061913S-6-G	514.87	8620.17	73.65	20.89	34.84	304.71	14.96	52.08	145.12	36.45
061913S-6-H	460.74	8259.48	76.70	20.41	35.16	311.41	15.27	52.18	148.46	35.52
061913S-6-I	649.61	8889.69	81.48	21.56	34.94	298.96	16.21	49.27	144.13	37.40
061913S-6-J	621.71	9892.32	81.70	20.57	34.22	293.15	16.41	51.17	145.19	35.05

West Antelope Creek

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
062013-02-A	590.21	10130.52	84.07	20.46	35.75	298.38	14.95	54.80	141.43	34.79
062013-02-B	704.59	11980.04	91.39	20.70	33.08	300.17	14.28	49.94	143.44	35.61
062013-02-C	726.24	9649.33	84.36	20.42	31.69	294.92	12.71	54.67	141.24	36.61
062013-02-D	635.20	10269.92	93.63	20.35	32.84	298.53	14.81	54.07	144.01	34.54
062013-02-E	719.42	18161.59	95.21	22.37	30.91	282.88	14.69	50.00	141.56	33.47
062013-02-F	782.56	15945.45	99.51	22.44	32.17	294.24	15.61	49.70	145.68	34.55
062013-02-G	571.27	8902.35	69.51	21.40	35.36	291.93	12.99	50.38	137.87	34.69
062013-02-H	706.68	6835.56	77.97	20.28	25.12	224.84	6.20	33.29	147.65	39.64
062013-02-I	598.02	9336.49	79.00	21.11	33.36	312.52	12.39	53.36	144.89	38.66
062013-02-J	759.05	6973.38	69.86	20.16	29.35	230.89	7.39	30.09	154.08	40.76

Grants Ridge

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
062413-1-1	1231.15	7013.71	196.77	40.14	32.03	652.38	1.93	99.16	146.65	227.79
062413-1-2	1218.46	7264.82	195.89	41.40	29.73	643.61	0.57	93.75	136.60	225.99
062413-1-3-1	1215.27	7091.52	201.62	40.68	29.06	651.87	0.79	91.64	145.79	230.47
062413-1-4	1257.88	7435.77	219.64	44.24	32.22	664.02	2.73	99.48	150.63	229.43
062413-2-1	1255.01	7101.60	201.70	41.60	31.51	648.53	2.38	92.50	144.63	226.64
062413-2-2	1215.87	7190.77	208.92	46.88	29.52	656.70	1.20	91.52	145.20	229.79
062413-2-3	1242.67	6893.12	193.49	31.77	29.21	632.02	0.89	93.02	146.28	226.16
062413-2-4	1282.44	7342.56	208.47	46.66	30.10	667.40	1.14	91.37	146.96	232.65
062413-2-5	1156.42	6688.78	191.93	36.60	28.22	628.85	0.77	92.81	139.63	221.76
062413-2-6	1256.90	7280.85	214.11	43.60	29.80	649.09	2.90	96.37	142.99	229.90
062413-3-1	1058.29	6544.36	188.01	33.96	28.99	608.81	2.75	87.16	133.83	213.41
062413-3-2	1203.32	7110.06	208.10	38.26	30.20	631.60	1.88	93.89	139.96	225.80

Horace Mesa

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
062513-1-1	1199.99	10763.70	219.69	43.77	29.70	589.72	4.13	101.75	159.84	256.32
062513-1-2	1009.02	9022.66	228.34	41.65	33.10	607.75	3.47	111.90	171.45	276.76
062513-1-3	885.83	8761.59	229.51	48.45	34.68	613.58	3.16	109.44	167.80	268.38
062513-1-4t	938.83	10208.58	215.67	44.53	32.35	794.05	3.21	110.53	167.62	266.73
062513-1-8t	937.00	17611.22	228.78	43.53	35.52	599.75	4.74	108.77	175.63	270.43
062513-1-9	990.01	10046.12	244.55	46.19	36.17	635.92	2.80	108.88	169.35	273.79
062513-1-11t	938.49	11348.22	206.32	38.50	33.13	511.45	4.55	111.84	159.27	233.61
062513-1-14	1089.73	10692.56	252.70	49.99	36.97	608.71	4.68	109.01	169.96	281.58
062513-1-15	908.53	9093.73	224.63	45.86	33.90	603.86	2.15	111.44	167.93	273.64
062513-1-16	903.45	10753.55	220.94	40.95	32.29	604.69	3.47	110.11	168.76	276.40
062513-1-17g	944.62	9543.30	236.65	45.22	34.76	612.95	3.26	107.68	168.58	278.09
062513-1-17t	1004.26	9017.78	229.24	41.15	35.59	604.51	3.00	112.16	169.20	272.02
062513-1-18	852.60	8232.31	217.91	43.84	31.68	592.99	5.12	107.18	171.10	271.56
062513-1-19t	1008.38	10093.63	235.70	47.13	33.60	611.15	3.13	110.60	171.88	272.71
062513-1-20	943.26	10024.26	233.07	42.56	32.72	589.39	3.04	108.95	168.05	267.88
062513-1-21	1094.26	24814.67	214.62	39.70	32.62	566.55	4.84	103.05	169.19	251.33
062513-2-1	922.78	10680.59	237.30	43.87	33.67	597.95	2.68	109.46	170.17	268.63
062513-2-2	1062.35	9834.48	251.03	55.14	40.86	680.65	3.41	122.96	185.77	303.16
062513-2-3	985.75	9855.27	238.14	39.83	37.80	623.46	4.06	113.74	174.16	279.65
062513-2-4	1162.30	11311.49	236.32	48.16	36.02	618.77	2.81	109.83	174.59	282.27
062513-2-5	1045.33	15230.30	207.12	38.38	30.14	567.77	5.49	104.92	164.27	262.41
062513-2-6	1003.23	10861.85	250.23	46.91	35.96	634.27	3.13	111.02	177.44	287.00
062513-2-8	1006.74	9596.91	232.54	45.83	33.61	602.99	3.20	111.30	170.49	272.24
062513-2-9	928.32	8762.03	235.95	43.45	33.14	620.58	2.69	107.97	177.11	276.70

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
062513-2-10	1324.77	10661.14	233.94	44.29	31.29	582.51	3.29	108.54	168.20	265.84
062513-2-11	862.46	9286.50	230.30	43.51	33.92	616.83	3.13	107.89	170.40	277.13
062513-2-12	975.63	10664.29	235.28	47.21	34.10	645.09	2.82	110.11	167.95	282.72
062513-2-13	1034.09	9855.01	257.92	42.81	34.98	652.62	3.23	119.16	178.11	281.69
062513-2-14	2788.52	16316.28	226.79	42.58	35.12	577.02	5.77	106.75	175.89	263.38
062513-2-15	907.74	14546.41	228.13	37.43	32.80	602.73	4.40	112.15	175.94	275.58
062513-2-18	1002.88	11548.63	245.27	53.86	36.40	628.93	3.68	118.05	178.46	284.61
062513-2-19	993.41	10324.26	241.60	47.17	34.55	653.60	2.90	112.67	175.39	284.21
062513-2-21	796.49	8510.64	234.15	44.16	32.07	588.27	2.49	106.08	167.39	265.69
062513-3-4	994.40	12451.90	225.44	48.91	33.52	625.32	4.98	113.56	177.88	279.61
062513-3-5	994.88	9640.47	242.40	45.46	35.06	636.28	2.62	114.48	176.57	284.55
062513-3-6	1082.73	9924.06	238.57	48.81	33.39	647.58	3.91	114.80	175.72	281.01
062513-3-7	1158.43	11591.87	240.96	47.97	36.57	631.66	3.65	114.90	180.56	282.60
062513-3-8	1024.62	11706.57	220.49	43.07	33.84	596.15	4.76	107.32	168.34	271.70
062513-3-9	901.14	11107.40	220.48	37.29	32.77	586.88	3.28	106.23	168.53	268.68
062513-3-10	841.37	9250.30	220.20	37.29	32.03	571.05	2.36	101.39	158.84	257.12
062513-3-11	923.18	9679.58	246.08	46.66	32.97	618.99	3.82	112.53	175.32	281.38
062513-3-12	922.41	8556.63	229.85	39.44	33.47	603.48	1.48	109.24	168.52	267.40
062513-3-13	945.34	9436.27	240.46	45.01	36.38	653.16	4.07	114.21	179.78	282.39
062513-3-14	1141.44	13479.46	227.19	45.92	33.24	625.35	5.34	111.20	173.08	278.32
062513-3-15	1455.91	12880.31	244.05	45.18	33.61	612.34	4.28	118.27	176.05	279.44
062513-3-17	956.93	10064.91	231.19	40.73	34.05	596.17	2.56	114.84	167.70	269.09

La Jara Mesa

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
062613-1-02	143.34	2369.20	28.78	19.05	-1.39	9.86	89.01	7.42	28.99	3.57
062613-1-03	942.09	11359.51	245.81	45.30	34.61	608.02	2.80	111.94	174.51	274.65
062613-1-04	137.61	6920.24	34.28	18.51	-2.49	15.40	27.68	21.83	33.94	5.98
062613-1-05	1042.82	10348.06	284.51	60.83	39.12	735.60	5.27	129.90	194.07	324.27
062613-1-07	953.00	8839.19	240.40	41.65	35.03	618.61	2.62	113.47	175.57	283.49
062613-2-1	1315.24	7771.09	209.40	46.50	30.80	679.61	4.62	95.54	153.02	237.44
062613-2-2	923.63	10253.96	243.23	42.93	34.18	603.21	3.81	112.11	169.36	279.23
062613-2-3	976.35	9112.78	243.67	49.36	35.13	653.18	2.21	117.89	181.19	291.35
062613-2-4	1212.00	13179.77	239.81	48.94	36.33	601.45	4.69	109.06	174.80	275.55
062613-2-5	894.49	8356.66	235.46	46.39	31.26	588.23	3.07	106.98	168.27	276.97
062613-2-6	912.03	9877.09	248.50	49.88	34.86	619.78	3.22	110.26	174.58	278.08
062613-2-8	1240.79	16271.08	235.81	38.84	31.52	575.15	4.97	106.41	165.53	258.79
062613-3-4	928.27	11888.78	240.50	43.60	32.90	617.68	2.62	111.08	179.92	267.63
062613-3-11	957.93	9215.61	256.00	44.80	34.16	635.41	2.82	114.84	176.62	282.67
062613-3-12	984.11	10438.93	262.00	51.04	35.51	644.53	3.32	120.68	183.22	292.19

Sample	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
062613-3-13	1044.70	12374.75	245.75	44.57	36.57	603.77	3.55	111.41	171.87	271.44
062613-3-16	997.93	9452.03	242.58	47.90	33.45	627.09	3.11	113.67	174.77	279.51
062613-3-18	1896.89	30619.90	197.44	37.75	29.02	527.13	22.66	99.61	190.12	250.38
062613-3-19	952.23	9537.40	243.76	38.35	34.05	613.16	3.41	107.56	172.78	273.08
062613-3-20	245748	38728.17	228.82	28.11	6.74	15.06	713.55	66.88	285.65	51.65
062613-3-21	1045.30	12605.38	238.11	39.96	34.71	619.88	4.75	112.25	180.71	284.31
062613-3-22	990.95	9269.50	242.15	45.64	34.19	625.58	3.00	113.61	178.06	284.54
062613-3-26	983.15	12413.61	245.82	50.85	34.35	626.66	4.03	111.97	175.21	284.50