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Source Provenance of Obsidian Artifacts from Late Classic Contexts in Western and Southern New Mexico

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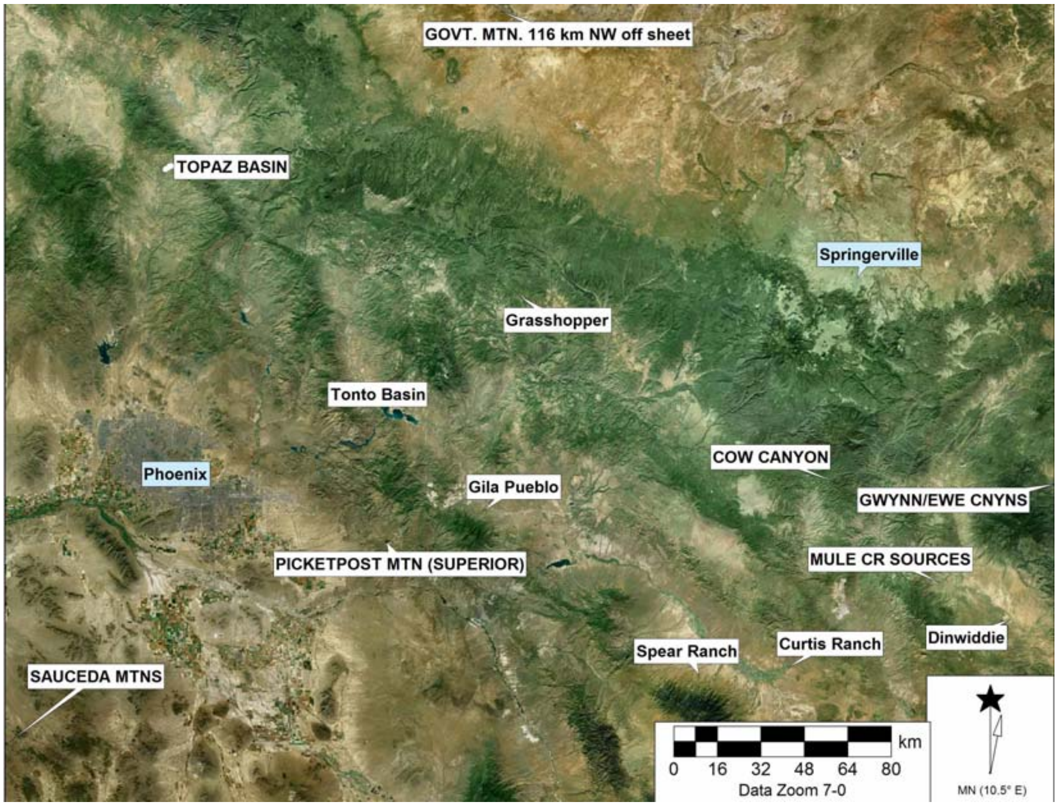
SOURCE PROVENANCE OF OBSIDIAN ARTIFACTS FROM LATE CLASSIC CONTEXTS IN WESTERN AND SOUTHERN NEW MEXICO



SPOT image of study area. Sources in upper case, sites and geographic features in lower case

by

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Report Prepared for

Rob Jones
The Center For Desert Archaeology
Tucson, Arizona

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INTRODUCTION

The analysis here of 132 obsidian artifacts from five sites in eastern Arizona and western New Mexico exhibits are very diverse assemblage. At Gila Pueblo four sources in opposing directions are in nearly equal proportions: Antelope Creek (Mule Creek, NM), Cow Canyon, AZ, Picketpost Mountain (Superior, AZ), and Government Mountain, AZ. At Curtis Ranch and Dinwiddie in western New Mexico the sources are all from western New Mexico and eastern Arizona sources, what I would consider local. Grashopper area sites and Spear Ranch are a mix, but the sample sizes are small.

LABORATORY SAMPLING, ANALYSIS AND INSTRUMENTATION

All archaeological samples are analyzed whole. The results presented here are quantitative in that they are derived from "filtered" intensity values ratioed to the appropriate x-ray continuum regions through a least squares fitting formula rather than plotting the proportions of the net intensities in a ternary system (McCarthy and Schamber 1981; Schamber 1977). Or more essentially, these data through the analysis of international rock standards, allow for inter-instrument comparison with a predictable degree of certainty (Hampel 1984; Shackley 2011).

All analyses for this study were conducted on a ThermoScientific *Quant'X* EDXRF spectrometer, located in the Archaeological XRF Laboratory, El Cerrito, California. It is equipped with a thermoelectrically Peltier cooled solid-state Si(Li) X-ray detector, with a 50 kV, 50 W, ultra-high-flux end window bremsstrahlung, Rh target X-ray tube and a 76 µm (3 mil) beryllium (Be) window (air cooled), that runs on a power supply operating 4-50 kV/0.02-1.0 mA at 0.02 increments. The spectrometer is equipped with a 200 l min^{-1} Edwards vacuum pump, allowing for the analysis of lower-atomic-weight elements between sodium (Na) and titanium (Ti). Data acquisition is accomplished with a pulse processor and an analogue-to-digital converter. Elemental composition is identified with digital filter background removal, least squares empirical peak deconvolution, gross peak intensities and net peak intensities above background.

The analysis for mid Zb condition elements Ti-Nb, Pb, Th, the x-ray tube is operated at 30 kV, using a 0.05 mm (medium) Pd primary beam filter in an air path at 200 seconds livetime to generate x-ray intensity Ka-line data for elements titanium (Ti), manganese (Mn), iron (as $Fe_2O_3^T$), cobalt (Co), nickel (Ni), copper, (Cu), zinc, (Zn), gallium (Ga), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb), lead (Pb), and thorium (Th). Not all these elements are reported since their values in many volcanic rocks are very low. Trace element intensities were converted to concentration estimates by employing a least-squares calibration line ratioed to the Compton scatter established for each element from the analysis of international rock standards certified by the National Institute of Standards and Technology (NIST), the US. Geological Survey (USGS), Canadian Centre for Mineral and Energy Technology, and the Centre de Recherches Pétrographiques et Géochimiques in France (Govindaraju 1994). Line fitting is linear (XML) for all elements but Fe where a derivative fitting is used to improve the fit for iron and thus for all the other elements. When barium (Ba) is analyzed in the High Zb condition, the Rh tube is operated at 50 kV and up to 1.0 mA, ratioed to the bremsstrahlung region (see Davis 2011; Shackley 2011). Further details concerning the petrological choice of these elements in Southwest obsidians is available in Shackley (1988, 1995, 2005; also Mahood and Stimac 1991; and Hughes and Smith 1993). Nineteen specific pressed powder standards are used for the best fit regression calibration for elements Ti-Nb, Pb, Th, and Ba, include G-2 (basalt), AGV-2 (andesite), GSP-2 (granodiorite), SY-2 (syenite), BHVO-2 (hawaiite), STM-1 (syenite), QLO-1 (quartz latite), RGM-1 (obsidian), W-2 (diabase), BIR-1 (basalt), SDC-1 (mica schist), TLM-1 (tonalite), SCO-1 (shale), NOD-A-1 and NOD-P-1 (manganese) all US Geological Survey standards, NIST-278 (obsidian), U.S. National Institute of Standards and Technology, BE-N (basalt) from the Centre de Recherches Pétrographiques et Géochimiques in France, and JR-1 and JR-2 (obsidian) from the Geological Survey of Japan (Govindaraju 1994).

The data from the WinTrace software were translated directly into Excel for Windows software for manipulation and on into SPSS for Windows for statistical analyses. In order to evaluate these quantitative determinations, machine data were compared to measurements of known standards during each run. RGM-1 a USGS obsidian standard is analyzed during each sample run for obsidian artifacts to check machine calibration (Table 1). Source assignments were made by reference to Shackley (1995, 1998a, 2005; see Tables 2 and 3 and Figures 1 through 4 here), as well as source standard data at this lab.

ANALYTICAL TRAJECTORY

In order to effectively discriminate the large number of sources, a combination of a multivariate statistical analysis (Ward's method, Euclidean distance hierarchical cluster) and three-dimensional and bivariate plots of the elements was used in tandem. For the cluster analysis, only those elements with relatively large variability were entered into the analysis, in this case Rb, Sr, Y, Nb. In general, the cluster groupings were mirrored in the plots (Figures 1 through 4 and Appendix).

Due to varying artifact sizes, particularly small size debitage, separating Government Mountain and Cow Canyon required the acquisition of Ba which is a highly charged incompatible element and consequently an excellent discriminating element (Shackley 2005; Figure 4 here). Barium and Zr were plotted to separate four artifacts where the assignment to one of these two sources was difficult (Figure 4). Still, specimen #248 from Gila Pueblo exhibits Sr and Ba slightly outside the source standard data for Cow Canyon and is designated by a question mark in Table 1 (see Figure 4).

RESULTS

Obsidian Sources in the Mogollon-Datil Volcanic Province

Since all of these sites and most sites in the region are dominated by sources in the Mule Creek region, a brief outline of the two major source groups at Mule Creek is helpful.

Mule Creek. One of the most startling discoveries in the 1990s was the chemical variability in Mule Creek obsidian (Shackley 1995, 1998b). In earlier studies, I noted two "outliers" collected at Mule Creek with significantly higher rubidium concentration values (Shackley 1988:767). These outliers have now been identified as a distinct chemical group, often mixed in the regional Gila Conglomerate with three other chemical groups. The geology in the area is complex and has been studied by Ratté, and others for some time (Brooks and Ratté 1985; Ratté 1982; Ratté and Brooks 1983, 1989; Ratté and Hedlund 1981; Rhodes and Smith 1972). Primary in situ perlite localities for three of the chemical groups have been located, but the secondary distribution of these source groups within the Mule Creek Basin is less well understood.

At least four distinct chemical groups are evident, distinguished by Rb, Y, Nb, and Ba, and a lesser extent Sr, and Zr elemental concentrations, and are named after the localities where marekanites have been found in perlitic lava: Antelope Creek; Mule Mountains; and Mule Creek/North Sawmill Creek all in New Mexico (see Shackley 1995, 1998b). It is quite evident that the obsidian at the Antelope Creek locality and adjacent secondary deposits constitute the volumetrically largest source of all the Mule Creek sources. The Tertiary Age dome complex at Antelope Creek covers hundreds of hectares and virtually all of it exhibits artifact quality marekanites. Parenthetically, surveys to the west in the Big Lue Mountains on the Arizona/New Mexico state line indicate a mix of North Sawmill Creek and Antelope Creek marekanites in secondary alluvium at a ratio of about six North Sawmill Creek to one Antelope Creek similar to the ratio reported in Shackley (1988). The Antelope Creek eruptive event about 17 mya was quite extensive.

Additionally, during the 1994 field season, a fourth sub-group was discovered in the San Francisco River alluvium near Clifton, Arizona and in older alluvium between Highway 191 and Eagle Creek in western Arizona north of Clifton called provisionally San Francisco River nodules. While in situ nodules have not yet been found they are certainly located somewhere west of Blue River and north and west of the San Francisco River since none of this 'low zirconium' sub-group was discovered in alluvium upstream from the juncture of the Blue and San Francisco Rivers. The genetic relationship between the Mule Creek localities is apparent in the bivariate plots of trace elements (Figures 1 and 2), and signifies the very complex nature of the Mule Creek silicic geology, with subsequent depositional mixing in the Gila Conglomerate. Glass at other Tertiary sources in the Southwest, such as Sauceda Mountains, Cow Canyon and Antelope Wells, also appear to exhibit more than one chemical mode, although not as distinct as Mule Creek or Mount Taylor, discussed below (Shackley 1988, 1990, 1998b). The Mule Creek case is analytically frustrating because the chemical groups are not always spatially discrete and occur together in the extensive Gila Conglomerate which is mainly composed of Mule Creek rhyolite and tuffs in the area where the marekanites do occur (see Ratté and Brooks 1989).

The Mogollon-Datil Province and the Mule Creek area. The Mule Creek Source Region is one of the most geologically explored archaeological sources of obsidian in the American Southwest (Brooks and Ratté 1985; Ratté 1982; Ratté and Brooks 1983, 1989; Ratté and Hedlund 1981; Rhodes and Smith 1972; Figure 3.5). Ratté has organized most of the research in the area focusing on mapping and establishing the origin of the volcanics during the Tertiary as originally described by Rhodes and Smith (1972). This region, which is on the boundary between the Basin and Range complex to the west and southwest, and the southeastern edge of the Colorado Plateau, exhibits a silicic geology that is somewhat distinctive; from the decidedly peraluminous glass of Cow Canyon with relatively high strontium values and the distinct chemical variability of the Mule Creek glasses (Elston et al. 1976; Ratté et al. 1984; Rhodes and Smith 1972; Shackley 2005). The province has been named Mogollon-Datil for its location and major floristic association (Elston et al. 1976). The region is, in part, characterized by pre-caldera andesites and later high-silica alkali rhyolites in association with caldera formation, subsequent collapse and post-caldera volcanism. Most recently, fieldwork and chemical analyses by Ratté and Brooks (1989) lead them to conclude that the Mule Creek Caldera is actually just a graben, although the typical succession from intermediate to silicic volcanism apparently holds.

The obsidian has been directly dated at the Antelope Creek locality (locality 1 in Figure 3.5 here) to 17.7±0.6 mya by K-Ar, and at the Mule Mountain locality at the same age (17.7±1 mya by K-Ar; Ratté and Brooks 1983, 1989). A single obsidian marekanite taken from the perlitic lava at the Antelope Creek locality was used in the analysis. Unusual in geological descriptions, the obsidian proper was discussed as an integral part of the regional geology.

> Rhyolite of Mule Creek (Miocene). Aphyric, high-silica, alkali-rhyolite domal flows from the Harden Cienega eruptive center along southwestern border of quadrangle [Wilson Mountain 1:24,000 Quad, New Mexico; Figure 4 here]. Unit **ob**, commonly at the base of the flows, consists of brown, pumiceous glass that grades upward into gray to black perlitic obsidian and obsidian breccia. Extensive ledges of partly hydrated, perlitic obsidian contain nonhydrated obsidian nodules (marekenites) which, when released by weathering, become the Apache tears that are widespread on the surface and within the Gila Conglomerate in this region. Age shown in Correlation is from locality about 1 km south of tank

> in Antelope Creek in Big Lue Mountains quadrangle adjacent to west edge of Wilson Mountain quadrangle. Thickness of flows is as much as 60 m and unit **ob** as much as 25 m (Ratté and Brooks 1989:map text, bold as in original).

This description adequately characterizes what is found at the other two primary localities (Mule Mountains, and Mule Creek/North Sawmill Creek). Aphyric, artifact quality marekanites are remnant within perlitic glass and tuff lava units. Nodules at all localities are up to 15 cm in diameter although most are under 10 cm. The devitrified perlitic lava, quite friable, erodes easily into the local alluvium. As discussed elsewhere, this is relatively unique in Tertiary sources in the Southwest where most of the obsidian breccia and perlitic lava is often completely eroded away leaving only the rhyolite interior of the dome and a consequent inability to assign the surrounding marekanites to a specific dome structure (Shackley 2005; see also Hughes and Smith 1993).

The aphyric glass ranges from opaque black to translucent smoky gray with some gray banding. In over 1000 specimens collected from the Mule Creek/North Sawmill Creek group, three are mahogany-brown and black banded similar to Slate Mountain (Wallace Tank) material. Some of the cortex exhibits a silver sheen, but most is a thin black-brown. The material is a fair medium for tool production, but is very brittle much like Los Vidrios. The pressure reduction potential is, however, very good as seen in the sites in this study. The Mule Mountain glass, however, is as good as any in the Southwest, but surprisingly relatively rare in sites in the region.

GILA PUEBLO (AZ V:9:52 ASM)

One hundred-four of the 132 samples analyzed were from Gila Pueblo east of the Phoenix Basin, Arizona (see cover page digital image). The obsidian provenance of these 104 samples is very diverse with nearly equal proportions of Antelope Creek/Mule Creek (26%; 171 km linear) and Cow Canyon (18.3%; 131 km linear) to the east in eastern Arizona and western

New Mexico, Picketpost Mountain/Superior (25%; 38 km linear) nearby to the west, and Government Mountain (22.1%; 245 km linear) well to the north in the San Francisco Volcanic Field on the Coconino Plateau (see Table 2). Distance is not a predictor of assemblage proportion: $r^2 = 0.032$. Sig. = 0.822. If the distance correlate was operating, Superior obsidian would dominate the assemblage. Indeed, Antelope Creek at Mule Creek at 171 km linear has the highest proportion, and Government Mountain at 245 km has the third highest proportion at 22.1%.

DISCUSSION

Based on the long-term NSF funded social network study, Clark has suggested, "late types of Salado pottery...found at several sites in the Upper Gila...[indicating] that displaced Salado groups from southeastern Arizona came to this region in the late fourteenth century" (2010:2). The Gila Pueblo obsidian assemblage could support that inference. While similar to southern Tonto Basin sites, where Government Mountain was present in the assemblage indicating contact to the north, the remaining obsidian assemblage here indicates a strong relationship with the Upper Gila region: Cow Canyon and the Antelope Creek (Mule Creek) sources comprise nearly 70% of the assemblage. In the Tonto Basin, Schoolhouse Point (AZ U:8:24) exhibited nearly the same mix of sources in slightly different proportions, a reflection of distance to source (Shackley 2005, 2006). Similar to the relationship Clark noted above, an affiliation appears to have existed between groups in the southern Tonto Basin, the Globe, Arizona area and the Upper Gila.

Additionally, the Sauceda Mountains source west in western Maricopa County, Arizona comprised nearly 9% of the Gila Pueblo assemblage. Sauceda Mountains was a prominent source for obsidian toolstone in the Classic in the Phoenix and Tucson Basins, and taken with

Picketpost Mountain (Superior) obsidian nearby to the west of Gila Pueblo, some kind of social relationship with the Hohokam is apparent (Shackley 2005).

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Table 1. Recommended values for USGS RGM-1 obsidian standard and the mean and central tendency analyses from this study. ± = 1st standard deviation.

SAMPLE	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th
RGM-1 (Govindaraju 1994)	1600	279	12998	149	108	25	219	8.9	807	24	15.1
RGM-1 (USGS recommended)[1]	1619±120	279±50	13010±210	150±8	110±10	25[2]	220±20	8.9±0.6	810±46	24±3	15±1.3
RGM-1, pressed powder standard (this study, n=11)	1579±32	289±6.2	13167±28	149±2	108±3	24±1	217±3	9.2±1.6	832±79[3]	22±3	19±4

[1] Ti, Mn, Fe calculated to ppm from wt. percent from USGS data.

[2] information valu

[3] instrument error calculated from this single acquisition

Table 2. Elemental concentrations and source assignments for the archaeological specimens. All measurements in parts per million (ppm).

Sample	Site	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	Source
186	Gila Pueblo	1189.08	484.13	9014.25	115.77	22.71	23.09	88.30	30.55		20.30	15.28	Superior
188	Gila Pueblo	1066.69	516.83	8505.18	122.63	26.29	26.02	95.71	30.46		24.38	15.80	Superior
190	Gila Pueblo	924.98	406.52	10144.96	261.92	22.98	42.54	114.45	28.17		32.00	35.91	Antelope Cr (Mule Cr)
191	Gila Pueblo	1135.00	461.40	8654.00	154.20	93.50	18.80	85.60	17.00	1080.00	25.20	13.60	Cow Canyon
192	Gila Pueblo	851.25	353.58	9585.92	244.71	21.67	38.98	110.19	28.80		28.29	32.35	Antelope Cr (Mule Cr)
193	Gila Pueblo	1722.86	656.58	10870.87	130.10	36.14	22.93	105.10	33.64		22.12	16.45	Superior
194	Gila Pueblo	992.37	508.22	8084.19	127.83	21.13	25.60	92.16	36.31		19.65	17.15	Superior
195	Gila Pueblo	929.09	399.42	10022.21	257.08	22.19	41.51	114.00	32.49		31.10	33.84	Antelope Cr (Mule Cr)
196	Gila Pueblo	999.75	514.83	8045.71	126.08	23.96	26.79	93.60	30.99		22.60	18.82	Superior
197	Gila Pueblo	918.63	545.08	10021.80	114.86	80.47	14.18	78.15	51.24		34.06	6.74	Government Mtn
198	Gila Pueblo	1501.25	381.52	10582.74	158.13	75.20	34.58	204.98	26.95		19.60	22.25	Sauceda Mtns
199	Gila Pueblo	823.43	557.59	10035.41	114.26	84.36	20.65	85.00	53.74		33.41	12.67	Government Mtn
200	Gila Pueblo	1307.52	473.96	9440.05	133.54	110.71	20.55	125.51	17.17		19.99	14.27	Cow Canyon
201	Gila Pueblo	1177.38	499.35	9334.11	139.40	114.31	24.02	130.02	19.71		19.15	17.44	Cow Canyon
202	Gila Pueblo	984.29	456.01	7746.33	115.54	18.91	22.97	94.48	31.19		21.34	16.66	Superior
203	Gila Pueblo	984.55	499.61	8132.12	129.76	23.12	25.40	99.73	37.20		25.32	16.12	Superior
204	Gila Pueblo	967.87	424.66	10685.31	250.66	21.20	41.24	110.11	30.08		30.96	40.49	Antelope Cr (Mule Cr)
205	Gila Pueblo	904.81	401.96	10180.68	242.64	18.54	37.75	108.30	28.84		29.84	32.71	Antelope Cr (Mule Cr)
206	Gila Pueblo	998.92	534.61	8290.71	128.37	21.18	23.43	92.11	33.12		21.75	12.66	Superior
207	Gila Pueblo	1595.35	503.24	9563.89	141.60	109.20	21.73	126.12	17.27		21.69	10.71	Cow Canyon
208	Gila Pueblo	783.40	513.85	9922.90	106.97	79.32	19.73	73.29	51.84		32.29	9.70	Government Mtn
209	Gila Pueblo	1174.58	485.33	9492.18	136.20	110.94	22.50	131.21	17.98		17.96	15.91	Cow Canyon
210	Gila Pueblo	1247.91	542.57	9749.47	144.79	112.51	23.26	135.94	21.48		18.97	15.80	Cow Canyon
211	Gila Pueblo	1398.06	532.90	10661.26	142.38	115.39	24.73	135.91	17.15		19.81	12.25	Cow Canyon
212	Gila Pueblo	1230.14	461.86	9190.22	138.13	110.19	23.94	128.33	19.68		19.15	13.68	Cow Canyon
213	Gila Pueblo	816.08	510.45	9420.95	108.70	79.41	18.74	79.60	53.41		28.49	12.57	Government Mtn
214	Gila Pueblo	726.45	516.00	9695.24	110.76	85.11	19.60	77.79	52.18		35.32	7.04	Government Mtn
215	Gila Pueblo	939.76	372.88	10106.72	261.28	18.87	42.87	114.49	24.35		34.61	37.16	Antelope Cr (Mule Cr)
216	Gila Pueblo	939.39	460.11	7808.91	117.16	19.90	26.19	91.92	29.42		22.95	14.13	Superior
217	Gila Pueblo	932.62	385.04	9888.75	242.13	17.65	40.79	112.62	25.91		23.74	33.86	Antelope Cr (Mule Cr)
218	Gila Pueblo	936.91	475.75	7996.00	120.61	21.96	24.25	97.29	30.18		22.42	21.63	Superior
219	Gila Pueblo	1554.67	389.74	10816.69	156.58	72.88	35.40	196.78	26.40		22.82	22.37	Sauceda Mtns
220	Gila Pueblo	777.76	520.34	9467.86	104.65	78.46	21.04	79.25	54.87		29.46	13.60	Government Mtn
221	Gila Pueblo	1298.84	436.36	9309.61	140.05	132.10	14.89	123.96	12.75		20.48	17.62	Cow Canyon
222	Gila Pueblo	797.76	557.91	10094.92	116.21	81.93	18.98	78.64	50.20		34.17	5.38	Government Mtn
223	Gila Pueblo	996.69	522.30	8077.26	125.13	21.24	26.14	101.83	30.97		19.47	9.10	Superior
224	Gila Pueblo	1543.77	370.91	10829.66	163.79	71.99	34.87	195.96	23.79		20.03	25.10	Sauceda Mtns

Sample	Site	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	Source
225	Gila Pueblo	787.19	498.33	9394.01	110.19	81.27	17.32	78.24	51.20		31.92	9.70	Government Mtn
226	Gila Pueblo	935.80	389.87	10299.55	251.72	18.74	44.90	110.59	26.10		29.71	38.50	Antelope Cr (Mule Cr)
227	Gila Pueblo	992.92	473.08	7932.26	120.47	26.17	28.34	94.70	32.92		22.65	17.26	Superior
228	Gila Pueblo	929.09	354.72	9568.48	228.71	21.01	42.72	107.15	24.11		27.90	36.98	Antelope Cr (Mule Cr)
229	Gila Pueblo	1591.98	354.03	10233.18	149.48	72.78	31.58	188.19	18.41		21.17	23.00	Sauceda Mtns
230	Gila Pueblo	1482.16	357.90	10723.73	160.09	76.92	28.89	189.98	22.44		20.29	19.94	Sauceda Mtns
231	Gila Pueblo	757.37	565.92	10226.97	115.78	87.85	19.74	81.85	53.61		35.06	6.39	Government Mtn
232	Gila Pueblo	989.17	487.18	8090.12	121.70	22.19	24.16	90.27	29.48		24.23	17.76	Superior
233	Gila Pueblo	924.38	360.76	9549.09	237.18	19.54	42.36	111.56	28.72		24.99	33.33	Antelope Cr (Mule Cr)
234	Gila Pueblo	761.82	521.06	9572.56	111.44	81.28	19.52	79.61	54.43		33.17	11.67	Government Mtn
235	Gila Pueblo	901.80	359.48	9850.01	256.24	19.44	44.29	112.44	27.40		29.09	40.59	Antelope Cr (Mule Cr)
236	Gila Pueblo	888.32	395.94	10198.39	244.84	23.42	45.95	113.74	27.81		28.09	26.84	Antelope Cr (Mule Cr)
237	Gila Pueblo	1200.71	392.62	9137.19	133.94	126.57	19.66	123.04	14.17		21.23	18.55	Cow Canyon
238	Gila Pueblo	1051.64	495.75	8054.46	123.22	19.93	22.80	93.03	31.13		20.92	8.66	Superior
239	Gila Pueblo	812.66	504.20	9597.99	106.58	78.94	17.06	76.49	50.85		34.62	13.26	Government Mtn
240	Gila Pueblo	907.24	374.56	9917.34	248.60	22.23	42.58	117.76	26.24		25.73	33.87	Antelope Cr (Mule Cr)
241	Gila Pueblo	1285.42	490.07	9571.00	139.85	110.52	23.94	131.92	18.28		21.28	10.95	Cow Canyon
242	Gila Pueblo	1240.92	408.24	9025.14	131.12	128.62	18.64	118.23	13.43		20.32	16.41	Cow Canyon
243	Gila Pueblo	828.52	572.78	10177.57	120.46	88.75	20.77	83.61	56.52		36.08	17.86	Government Mtn
244	Gila Pueblo	924.18	368.22	10100.11	248.65	21.19	44.75	111.15	28.27		29.85	40.66	Antelope Cr (Mule Cr)
245	Gila Pueblo	1195.37	409.77	11179.68	247.60	20.73	46.47	136.06	27.17		30.36	39.42	Antelope Cr (Mule Cr)
246	Gila Pueblo	1483.45	380.60	10749.99	167.98	75.86	34.66	192.62	22.18		21.41	23.96	Sauceda Mtns
247	Gila Pueblo	934.62	449.30	10543.04	262.23	19.18	46.75	116.30	31.55		32.59	39.50	Antelope Cr (Mule Cr)
248	Gila Pueblo	1401.33	431.83	9655.21	144.19	141.08	19.57	122.53	14.87	1407.44	21.61	18.04	Cow Canyon?
249	Gila Pueblo	1005.24	358.62	10329.22	240.92	24.79	36.74	112.92	25.54		28.97	35.84	Antelope Cr (Mule Cr)
250	Gila Pueblo	1369.98	360.74	9955.62	150.58	71.49	32.40	190.65	20.86	1013.29	16.73	18.30	Sauceda Mtns
251	Gila Pueblo	1234.80	411.31	9146.46	136.83	131.16	17.22	119.96	15.04		19.11	12.74	Cow Canyon
252	Gila Pueblo	918.75	376.48	9900.59	244.76	19.81	45.26	110.46	28.51		27.99	36.38	Antelope Cr (Mule Cr)
253	Gila Pueblo	777.27	501.58	9491.85	104.62	81.39	20.89	74.77	48.73		29.58	14.31	Government Mtn
254	Gila Pueblo	1515.37	376.99	10690.84	161.92	75.15	33.26	193.19	24.46	1120.82	20.54	20.49	Sauceda Mtns
255	Gila Pueblo	1117.29	549.18	8449.22	123.28	21.77	26.42	91.54	29.99		21.32	14.16	Superior
256	Gila Pueblo	782.00	566.00	10219.00	126.10	91.60	20.50	82.30	57.80	360.00	35.50	17.68	Government Mtn
257	Gila Pueblo	737.33	540.13	9642.73	109.27	83.96	22.19	80.80	55.13		32.52	14.95	Government Mtn
258	Gila Pueblo	804.63	576.50	10119.80	118.34	83.39	21.45	83.21	52.81		35.75	17.56	Government Mtn
259	Gila Pueblo	1020.40	518.27	8161.99	129.09	22.97	25.41	92.40	32.24		22.51	18.78	Superior
260	Gila Pueblo	758.71	491.18	9312.72	102.51	76.15	18.18	79.05	53.87		27.50	11.51	Government Mtn
261	Gila Pueblo	1045.15	505.00	8085.39	122.20	24.45	25.43	98.74	28.62		24.17	18.98	Superior
262	Gila Pueblo	974.96	342.88	9377.82	234.05	19.68	43.23	108.63	26.23		26.39	32.73	Antelope Cr (Mule Cr)
263	Gila Pueblo	931.64	373.01	9836.46	245.31	20.49	35.87	110.32	29.36		30.15	36.09	Antelope Cr (Mule Cr)

Sample	Site	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	Source
264	Gila Pueblo	755.72	507.46	9735.69	107.41	79.80	20.10	75.11	55.60		31.65	15.94	Government Mtn
265	Gila Pueblo	965.51	398.82	10469.81	253.54	24.13	44.60	112.24	31.87		29.25	33.45	Antelope Cr (Mule Cr)
266	Gila Pueblo	920.69	376.95	9834.72	244.29	19.36	41.14	111.79	25.72		29.78	37.66	Antelope Cr (Mule Cr)
267	Gila Pueblo	741.28	552.96	9917.74	114.81	85.72	17.95	77.22	54.42		32.81	12.23	Government Mtn
268	Gila Pueblo	803.24	560.28	10206.22	116.66	85.95	23.32	80.14	49.90		35.60	15.24	Government Mtn
269	Gila Pueblo	777.81	527.94	9618.56	108.85	80.53	19.39	78.07	48.24		27.65	9.35	Government Mtn
270	Gila Pueblo	1162.46	396.00	10454.86	249.51	21.14	41.64	116.56	29.47		31.77	39.95	Antelope Cr (Mule Cr)
271	Gila Pueblo	933.84	465.62	7799.32	116.72	22.79	22.20	87.84	29.27		18.50	13.20	Superior
272	Gila Pueblo	1218.05	488.58	9277.60	134.86	111.00	23.78	131.44	18.25		15.89	16.44	Cow Canyon
273	Gila Pueblo	1002.12	471.88	7837.17	121.77	21.16	24.83	90.23	28.90		22.38	15.48	Superior
274	Gila Pueblo	1304.24	522.84	9870.40	147.64	115.97	21.32	134.89	18.48		21.35	15.02	Cow Canyon
275	Gila Pueblo	744.97	521.44	9704.36	111.16	83.47	17.12	80.10	51.13		31.92	14.03	Government Mtn
276	Gila Pueblo	888.32	401.64	10005.59	240.89	23.51	44.11	110.64	25.69		27.41	31.76	Antelope Cr (Mule Cr)
277	Gila Pueblo	913.57	359.74	9698.60	240.30	17.69	39.80	108.19	26.01		25.79	28.08	Antelope Cr (Mule Cr)
278	Gila Pueblo	1027.58	476.13	7966.75	119.27	21.94	24.17	90.67	26.19		21.74	9.92	Superior
279	Gila Pueblo	1009.34	518.85	8103.69	125.63	23.52	26.51	93.80	31.60		21.58	13.35	Superior
280	Gila Pueblo	849.28	522.87	9703.95	109.02	81.59	22.06	78.06	49.39		38.49	14.73	Government Mtn
281	Gila Pueblo	915.74	373.82	9798.18	245.21	22.84	45.37	113.81	32.07		27.82	41.00	Antelope Cr (Mule Cr)
282	Gila Pueblo	1380.83	455.42	10272.44	139.36	137.24	21.08	126.67	10.72		19.90	7.08	Cow Canyon
283	Gila Pueblo	1055.88	508.62	8464.35	123.25	21.93	27.72	93.74	32.45		20.85	15.66	Superior
284	Gila Pueblo	1240.52	496.67	9035.67	118.18	29.12	23.89	93.34	31.17		20.43	13.56	Superior
285	Gila Pueblo	927.48	506.95	8059.97	125.85	23.13	26.88	94.83	34.47		20.40	17.97	Superior
286	Gila Pueblo	1183.20	534.38	8944.72	126.32	25.41	23.10	96.17	30.80		21.24	10.63	Superior
287	Gila Pueblo	1251.37	527.20	9692.53	145.32	115.56	25.15	129.39	17.51		19.48	13.00	Cow Canyon
288	Gila Pueblo	912.00	397.08	9948.20	241.47	25.77	43.78	111.71	28.55		29.21	38.33	Antelope Cr (Mule Cr)
289	Gila Pueblo	1336.68	431.43	9510.82	142.46	135.04	22.24	119.56	17.96		22.26	15.07	Cow Canyon
290	Gila Pueblo	1040.35	551.36	8454.31	125.54	20.50	22.10	91.09	36.31		25.99	23.16	Superior
292	Grasshopper	875.82	352.56	9586.80	237.67	23.70	43.14	111.57	25.33		27.74	41.60	Antelope Cr (Mule Cr)
293	Grasshopper	1312.00	398.00	8776.00	121.50	121.90	16.70	117.50	14.40	1310.00	16.02	10.65	Cow Canyon
291	Grasshopper	996.27	483.55	8038.85	123.23	21.64	24.19	92.18	29.41		23.65	11.90	Superior
299	Dinwiddie	1077.40	497.79	8612.12	180.77	14.75	26.56	119.54	33.08		19.41	22.56	Mule Mtns (Mule Cr)
300	Dinwiddie	1067.84	489.15	8848.70	193.49	15.46	22.18	113.43	30.44		23.37	30.86	Mule Mtns (Mule Cr)
294	Dinwiddie	1019.51	454.79	8505.03	184.52	15.47	27.77	116.83	31.74		19.03	29.51	Mule Mtns (Mule Cr)
297	Dinwiddie	1015.89	474.39	8687.01	184.47	16.66	22.21	113.51	34.56		23.43	31.01	Mule Mtns (Mule Cr)
295	Dinwiddie	881.92	378.28	9465.41	233.97	20.24	41.96	106.19	25.95		26.60	31.13	Antelope Cr (Mule Cr)
298	Dinwiddie	992.96	491.98	8655.49	186.61	13.70	26.69	113.34	31.88		22.48	27.71	Mule Mtns (Mule Cr)
296	Dinwiddie	1028.97	467.02	8735.34	182.80	11.93	23.76	110.83	28.47		24.77	29.69	Mule Mtns (Mule Cr)
301	Dinwiddie	886.65	344.52	9581.39	226.85	21.14	41.23	107.08	22.80		24.21	30.82	Antelope Cr (Mule Cr)
317	Spear Ranch	1177.11	493.40	9414.46	136.58	110.91	20.00	129.01	21.01		17.64	10.90	Cow Canyon

Sample	Site	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	Source
318	Spear Ranch	886.50	391.43	9896.16	250.76	22.21	42.66	107.93	27.86		26.64	37.46	Antelope Cr (Mule Cr)
302	Curtis Ranch	1337.12	516.60	9910.72	145.60	119.02	27.01	132.42	17.07		22.15	17.42	Cow Canyon
303	Curtis Ranch	1264.70	534.41	9791.78	142.24	119.85	23.40	131.23	14.34		21.47	11.45	Cow Canyon
304	Curtis Ranch	872.96	367.90	9631.00	237.02	18.52	40.46	107.67	28.81		26.31	32.96	Antelope Cr (Mule Cr)
305	Curtis Ranch	922.53	386.12	9724.31	243.65	21.98	47.72	112.29	24.98		30.88	35.44	Antelope Cr (Mule Cr)
306	Curtis Ranch	901.20	351.96	9207.33	228.97	19.24	41.71	105.60	29.12		26.18	28.65	Antelope Cr (Mule Cr)
307	Curtis Ranch	931.31	383.38	9750.99	245.06	22.57	44.21	112.02	25.39	63.13	28.37	39.31	Antelope Cr (Mule Cr)
308	Curtis Ranch	921.37	409.65	10458.11	258.74	21.92	46.10	115.21	28.45		31.22	36.09	Antelope Cr (Mule Cr)
309	Curtis Ranch	879.13	602.69	9096.35	435.08	10.22	76.17	108.92	126.32		34.01	40.04	N Sawmill Cr (Mule Cr)
310	Curtis Ranch	892.24	372.05	9563.67	234.48	19.50	39.60	110.87	25.18		25.66	34.83	Antelope Cr (Mule Cr)
311	Curtis Ranch	874.17	358.70	9489.83	237.05	20.94	44.49	105.47	25.27	131.96	25.42	35.09	Antelope Cr (Mule Cr)
312	Curtis Ranch	876.21	394.65	9652.70	240.59	19.68	44.77	115.20	26.35		28.01	33.54	Antelope Cr (Mule Cr)
313	Curtis Ranch	922.54	361.49	9510.76	233.15	22.02	39.24	111.52	22.54		28.05	30.90	Antelope Cr (Mule Cr)
314	Curtis Ranch	918.17	364.19	9685.53	241.48	24.91	39.51	110.90	24.67		29.57	37.43	Antelope Cr (Mule Cr)
315	Curtis Ranch	898.92	350.80	9489.87	240.07	20.35	39.36	108.92	24.55		29.16	33.80	Antelope Cr (Mule Cr)
316	Curtis Ranch	932.44	364.71	9831.43	233.65	22.56	43.49	112.38	23.94		27.94	35.56	Antelope Cr (Mule Cr)

Table 2. Crosstabulation of site by source.

			Site					
			Gila Pueblo	Curtis Ranch	Dinwiddie	Grasshopper	Spear Ranch	Total
Source	Antelope Cr (Mule Cr)	Count	27	12	2	1	1	43
		% within Source	62.8%	27.9%	4.7%	2.3%	2.3%	100.0%
		% within Site	26.0%	80.0%	25.0%	33.3%	50.0%	32.6%
		% of Total	20.5%	9.1%	1.5%	.8%	.8%	32.6%
	Mule Mtns (Mule Cr)	Count	0	0	6	0	0	6
		% within Source	.0%	.0%	100.0%	.0%	.0%	100.0%
		% within Site	.0%	.0%	75.0%	.0%	.0%	4.5%
		% of Total	.0%	.0%	4.5%	.0%	.0%	4.5%
	N Sawmill Cr (Mule Cr)	Count	0	1	0	0	0	1
		% within Source	.0%	100.0%	.0%	.0%	.0%	100.0%
		% within Site	.0%	6.7%	.0%	.0%	.0%	.8%
		% of Total	.0%	.8%	.0%	.0%	.0%	.8%
	Cow Canyon	Count	18	2	0	1	1	22
		% within Source	81.8%	9.1%	.0%	4.5%	4.5%	100.0%
		% within Site	17.3%	13.3%	.0%	33.3%	50.0%	16.7%
		% of Total	13.6%	1.5%	.0%	.8%	.8%	16.7%
	Superior	Count	26	0	0	1	0	27
		% within Source	96.3%	.0%	.0%	3.7%	.0%	100.0%
		% within Site	25.0%	.0%	.0%	33.3%	.0%	20.5%
		% of Total	19.7%	.0%	.0%	.8%	.0%	20.5%
	Government Mtn	Count	24	0	0	0	0	24
		% within Source	100.0%	.0%	.0%	.0%	.0%	100.0%
		% within Site	23.1%	.0%	.0%	.0%	.0%	18.2%
		% of Total	18.2%	.0%	.0%	.0%	.0%	18.2%
	Sauceda Mtns	Count	9	0	0	0	0	9
		% within Source	100.0%	.0%	.0%	.0%	.0%	100.0%
		% within Site	8.7%	.0%	.0%	.0%	.0%	6.8%
		% of Total	6.8%	.0%	.0%	.0%	.0%	6.8%
Total		Count	104	15	8	3	2	132
		% within Source	78.8%	11.4%	6.1%	2.3%	1.5%	100.0%
		% within Site	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	78.8%	11.4%	6.1%	2.3%	1.5%	100.0%

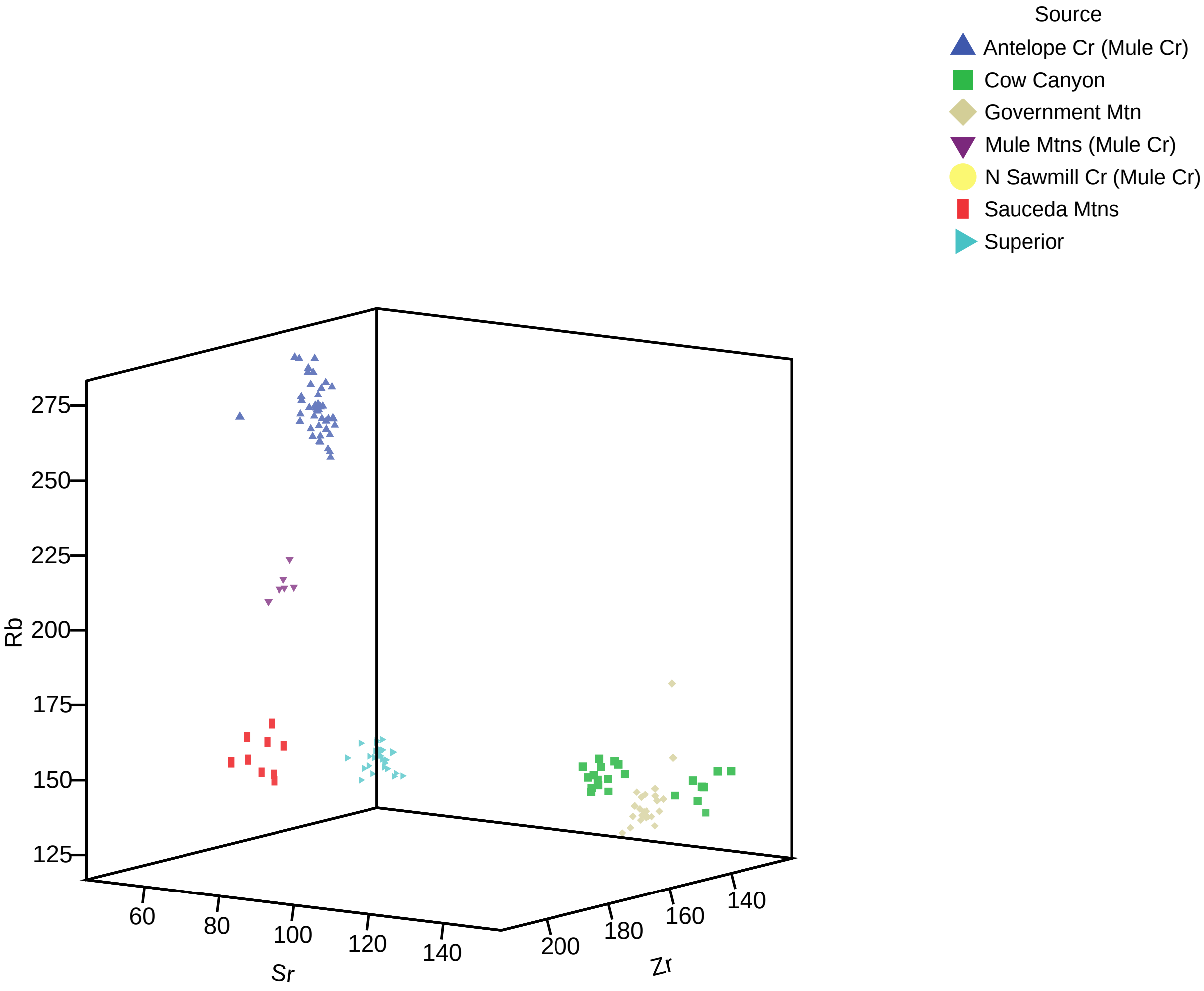

Figure 1. Sr, Rb, Zr three-dimensional plot of all the archaeological specimens. The high Rb North Sawmill Creek not plotted.

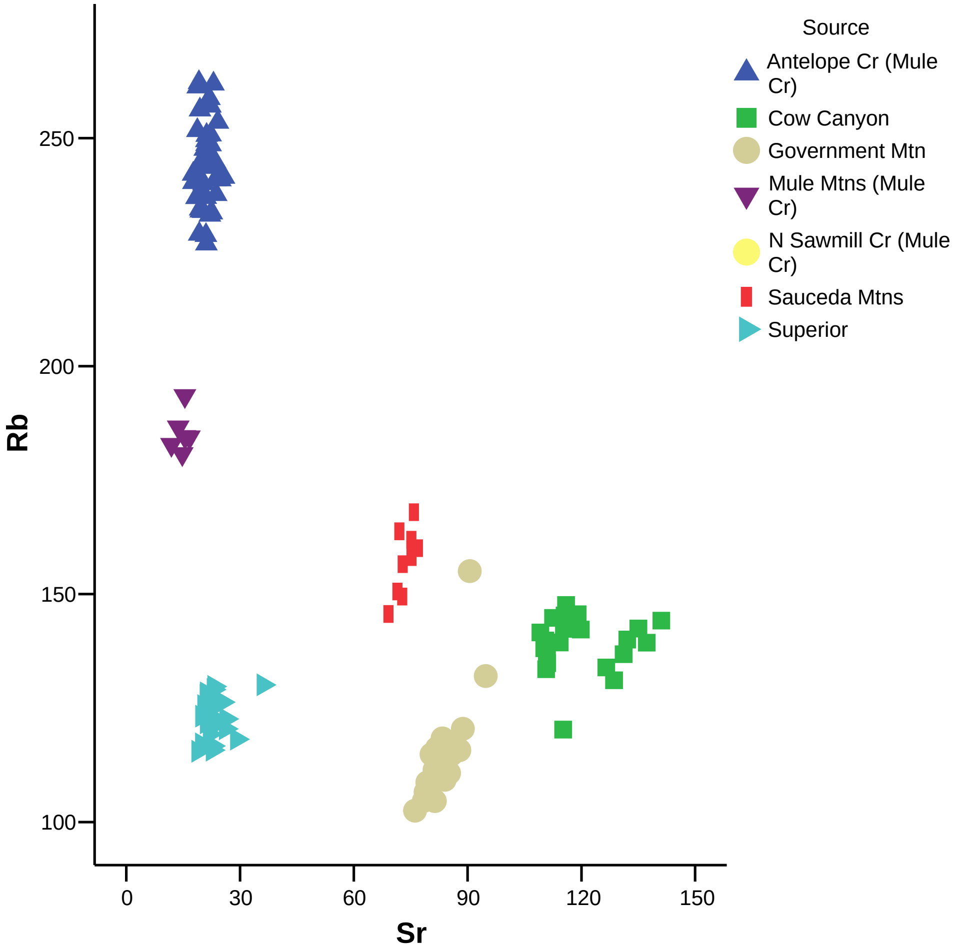

Figure 2. Sr versus Rb bivariate plot of all the archaeological specimens. The high Rb North Sawmill Creek not plotted.

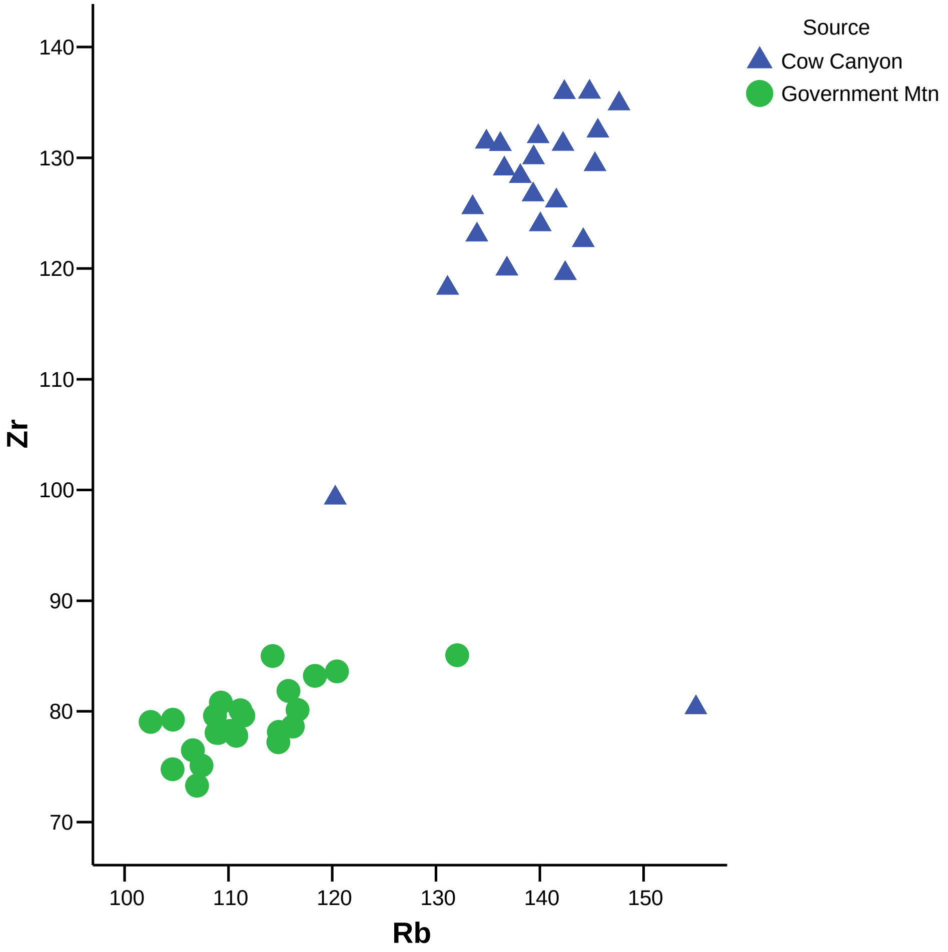

Figure 3. Rb versus Zr bivariate plot discriminating Cow Canyon and Government Mountain (see text).

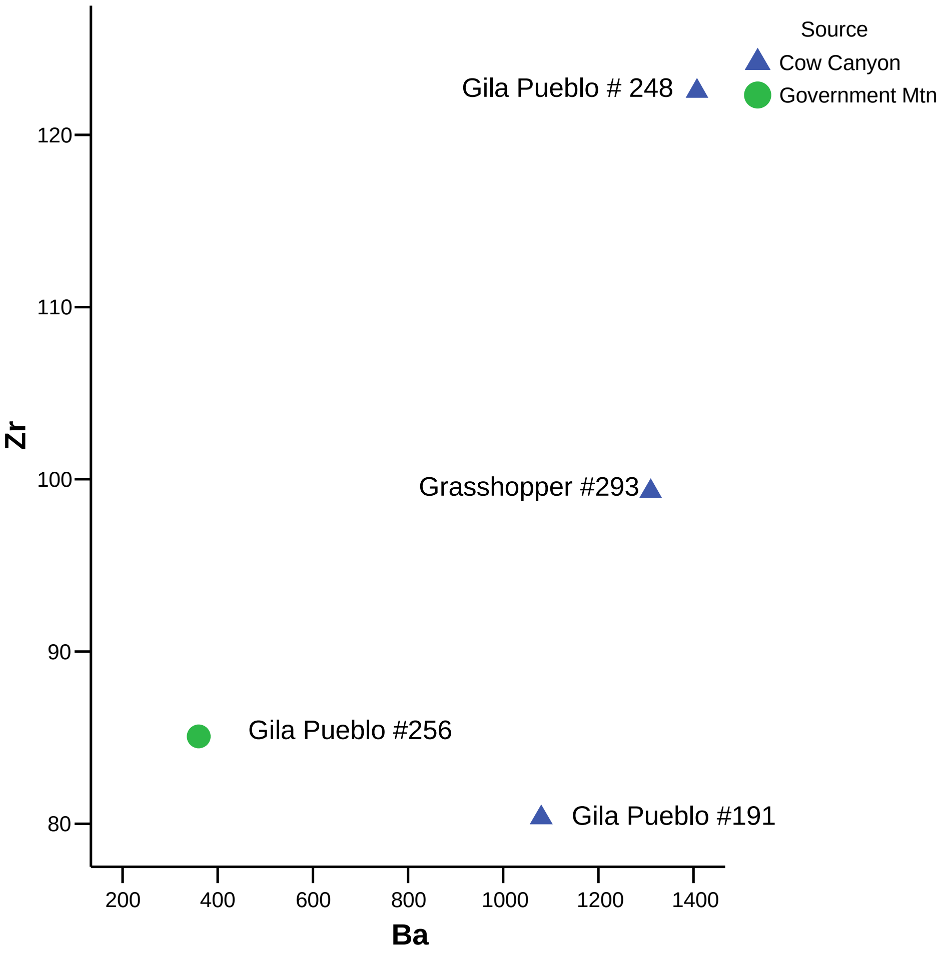

Figure 4. Ba versus Zr bivariate plot effectively discriminating four Cow Canyon and Government Mountain artifacts (see text).

APPENDIX

Ward’s method, squared Euclidean distance cluster dendrogram of source assignments (Rb, Sr, Y, Nb variables)

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                                Rescaled Distance Cluster Combine

        C A S E            0         5        10        15        20        25
Source                Num  +---------+---------+---------+---------+---------+

Superior               24   ⇩⬂
Superior              101   ⇩▫
Superior               43   ⇩▫
Superior               83   ⇩▫
Superior               52   ⇩▫
Superior               17   ⇩▫
Superior               74   ⇩▫
Superior               51   ⇩▫
Superior               65   ⇩▫
Superior               15   ⇩▫
Superior               22   ⇩▫
Superior               76   ⇩▫
Superior               63   ⇩▫
Superior               53   ⇩▫
Superior               82   ⇩▫
Superior               86   ⇩▫
Superior               21   ⇩▫
Superior                7   ⇩⇳⇩⇩⇩⬂
Superior               48   ⇩▫   ⇔
Superior               25   ⇩▫   ⇔
Superior              107   ⇩▫   ⇔
Superior               88   ⇩▫   ⇔
Superior               80   ⇩▫   ⇔
Superior                1   ⇩▫   ⇔
Superior               33   ⇩▫   ⇔
Superior               45   ⇩▫   ⇔
Superior               68   ⇩⬃   ▫⇩⇩⇩⇩⇩⇩⇩⇩⇩⬂
Government Mtn         28   ⇩⬂   ⇔         ⇔
Government Mtn         54   ⇩▫   ⇔         ⇔
Government Mtn         36   ⇩▫   ⇔         ⇔
Government Mtn         66   ⇩▫   ⇔         ⇔
Government Mtn         81   ⇩▫   ⇔         ⇔
Government Mtn         26   ⇩▫   ⇔         ⇔
Government Mtn         89   ⇩▫   ⇔         ⇔
Government Mtn         27   ⇩▫   ⇔         ⇔
Government Mtn         39   ⇩▫   ⇔         ⇔
Government Mtn         71   ⇩⇳⇩⇩⇩⬃         ⇔
Government Mtn        102   ⇩▫             ⇔
Government Mtn         13   ⇩▫             ⇔
Government Mtn         30   ⇩▫             ⇔
Government Mtn         14   ⇩▫             ⇔
Government Mtn         18   ⇩▫             ⇔
Government Mtn         19   ⇩▫             ⇔
Government Mtn         34   ⇩▫             ⇔
Government Mtn         60   ⇩▫             ⇔
Government Mtn         85   ⇩▫
Government Mtn         94   ⇩▫             ⇔
Government Mtn         47   ⇩▫             ⇔
Government Mtn         93   ⇩▫             ⇔
Government Mtn        100   ⇩⬃             ⇔
Sauceda Mtns           16   ⇩⬂             ⇔
Sauceda Mtns           67   ⇩▫             ⇔
Sauceda Mtns           55   ⇩▫             ⇔
Sauceda Mtns           77   ⇩⇳⇩⇩⇩⬂         ⇔
Sauceda Mtns           96   ⇩▫   ⇔         ⇔
Sauceda Mtns           58   ⇩▫   ⇔         ⇔
Sauceda Mtns           99   ⇩▫   ⇔         ⇔
Sauceda Mtns           79   ⇩▫   ⇔         ⇔
Sauceda Mtns           11   ⇩⬃   ⇔         ⇔
Cow Canyon             44   ⇩⬂   ⇔         ⇔
Cow Canyon             46   ⇩▫   ⇔         ⇔
Cow Canyon             78   ⇩▫   ⇔         ⇔
Cow Canyon             42   ⇩▫   ⇔         ⇔
Cow Canyon             75   ⇩▫   ⇔         ⇔
Cow Canyon            117   ⇩▫   ▫⇩⇩⇩⇩⇩⇩⇩⇩⇩⬃
Cow Canyon             57   ⇩▫   ⇔
Cow Canyon             98   ⇩▫   ⇔
Cow Canyon             23   ⇩▫   ⇔
Cow Canyon             73   ⇩▫   ⇔
Cow Canyon             70   ⇩▫   ⇔
Cow Canyon              3   ⇩▫   ⇔
Cow Canyon            119   ⇩▫   ⇔
Cow Canyon            121   ⇩▫   ⇔
Cow Canyon?             6   ⇩▫   ⇔
Cow Canyon             97   ⇩▫   ⇔
Cow Canyon             95   ⇩▫   ⇔
Cow Canyon             40   ⇩⇳⇩⇩⇩⬃
Cow Canyon             49   ⇩▫
Cow Canyon             87   ⇩▫
Cow Canyon            104   ⇩▫
Cow Canyon            106   ⇩▫
Cow Canyon             10   ⇩⬃
Mule Mtns (Mule Cr)   110   ⇩⬂
Mule Mtns (Mule Cr)   113   ⇩▫
Mule Mtns (Mule Cr)   111   ⇩▫
Mule Mtns (Mule Cr)   108   ⇩▫
Mule Mtns (Mule Cr)   114   ⇩⇳⇩⬂
Mule Mtns (Mule Cr)   109   ⇩⬃ ⇔
Antelope Cr (Mule Cr    9   ⇩⬂ ⇔
Antelope Cr (Mule Cr  118   ⇩▫ ⇔
Antelope Cr (Mule Cr   38   ⇩▫ ⇔
Antelope Cr (Mule Cr   92   ⇩▫ ⇔
Antelope Cr (Mule Cr   64   ⇩▫ ⇔
Antelope Cr (Mule Cr    5   ⇩▫ ⇔
Antelope Cr (Mule Cr   50   ⇩▫ ⇔
Antelope Cr (Mule Cr   20   ⇩▫ ▫⇩⬂
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Antelope Cr (Mule Cr  103   ⇩▫ ⬄ ⬄
Antelope Cr (Mule Cr   91   ⇩▫ ⬄ ⬄
Antelope Cr (Mule Cr  116   ⇩▫ ⬄ ⬄
Antelope Cr (Mule Cr   56   ⇩▫ ⬄ ⬄
Antelope Cr (Mule Cr   69   ⇩▫ ⬄ ⬄
Antelope Cr (Mule Cr    4   ⇩▫ ⬄ ⬄
Antelope Cr (Mule Cr   31   ⇩▫ ⬄ ⬄
Antelope Cr (Mule Cr  127   ⇩▫ ⬄ ⬄
Antelope Cr (Mule Cr    8   ⇩▫ ⬄ ⬄
Antelope Cr (Mule Cr  120   ⇩⇳⇩⬃ ⬄
Antelope Cr (Mule Cr  129   ⇩▫   ⬄
Antelope Cr (Mule Cr   32   ⇩▫   ⬄
Antelope Cr (Mule Cr   72   ⇩▫   ⬄
Antelope Cr (Mule Cr   41   ⇩▫   ⬄
Antelope Cr (Mule Cr   29   ⇩▫   ⬄
Antelope Cr (Mule Cr   61   ⇩▫   ⬄
Antelope Cr (Mule Cr    2   ⇩▫   ⬄
Antelope Cr (Mule Cr   90   ⇩▫
Antelope Cr (Mule Cr  126   ⇩▫   ⬄
Antelope Cr (Mule Cr   37   ⇩▫   ⬄
Antelope Cr (Mule Cr  105   ⇩▫   ⬄
Antelope Cr (Mule Cr   12   ⇩▫   ⬄
Antelope Cr (Mule Cr   84   ⇩▫   ⬄
Antelope Cr (Mule Cr  115   ⇩▫   ⬄
Antelope Cr (Mule Cr  128   ⇩▫   ⬄
Antelope Cr (Mule Cr  122   ⇩▫   ⬄
Antelope Cr (Mule Cr  130   ⇩▫   ⬄
Antelope Cr (Mule Cr  123   ⇩▫   ⬄
Antelope Cr (Mule Cr   62   ⇩▫   ⬄
Antelope Cr (Mule Cr  112   ⇩▫   ⬄
Antelope Cr (Mule Cr  125   ⇩▫   ⬄
Antelope Cr (Mule Cr   59   ⇩▫   ⬄
Antelope Cr (Mule Cr  131   ⇩▫   ⬄
Antelope Cr (Mule Cr   35   ⇩▫   ⬄
Antelope Cr (Mule Cr  124   ⇩⬃    ⬄
N Sawmill Cr (Mule Cr)132   ⇩⇩⇩⇩⇩⬃
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