Title

Source Provenance of Obsidian Artifacts from Archaeological Sites in the University of Oklahoma's Southern Mimbres Archaeological Project, Southern New Mexico

Author

Shackley, M. Steven

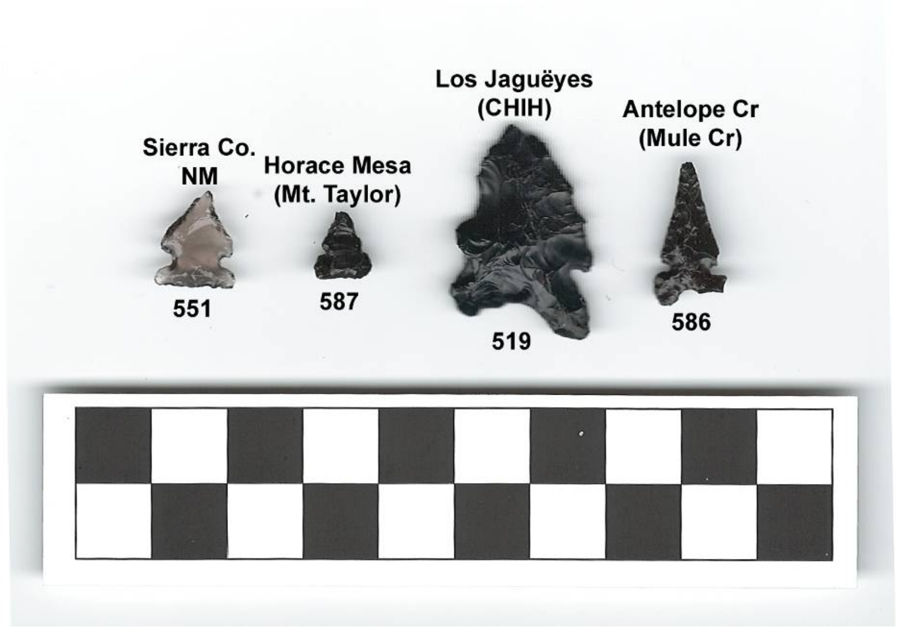
Publication Date

2013-07-01

GEOARCHAEOLOGICAL XRF LAB

GEOARCHAEOLOGICAL X-RAY FLUORESCENCE SPECTROMETRY LABORATORY
8100 WYOMING BLVD., SUITE M4-158 ALBUQUERQUE, NM 87113 USA

SOURCE PROVENANCE OF OBSIDIAN ARTIFACTS FROM ARCHAEOLOGICAL SITES IN THE UNIVERSITY OF OKLAHOMA'S SOUTHERN MIMBRES ARCHAEOLOGICAL PROJECT, SOUTHERN NEW MEXICO



Sample number by source provenance for a sample of the projectile points

by

M. Steven Shackley Ph.D., Director
Geoarchaeological XRF Laboratory

Report Prepared for

Sean Dolan
Department of Anthropology
University of Oklahoma, Norman

1 July 2013

INTRODUCTION

The analysis here of 56 obsidian artifacts from a number of sites and isolates in various contexts in southern New Mexico indicates a diverse obsidian provenance assemblage dominated by the recently discovered southern Mogollon-Datil Volcanic Province source of archaeological obsidian in Sierra County, New Mexico near the Nutt Mountain rhyolite dome. Other sources include both source groups from Mount Taylor, three source groups from Mule Creek, the three major sources in the Jemez Mountains (the former all in New Mexico), Cow Canyon, eastern Arizona, Antelope Wells (New Mexico and Chihuahua) and Los Jaguëyes, Chihuahua. Following is a discussion of the results and a brief discussion of the Sierra County source.

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, Albuquerque, New Mexico. 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. When barium (Ba) is acquired 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 with reference to Shackley (1995, 2005) and source standard data at this lab (Table 1, and Figures 1 through 5).

DISCUSSION

The source provenance of obsidian artifacts is quite diverse in this assemblage. Most of the known sources in New Mexico are present, as well as Arizona and Chihuahua (Tables 1 and 2; Figures 1-4). The dominance of the newly discovered source in Sierra County is likely due to proximity to these sites. Artifacts produced from Cerro Toledo Rhyolite, El Rechuelos, Grants Ridge/Horace Mesa can all be found in Rio Grande Quaternary alluvium (Church 2000; Shackley 2012). All the Mule Creek sources, and Cow Canyon have eroded into the San Francisco/Gila River system at least as far west as Geronimo, Arizona (Shackley 2005). Valles Rhyolite has not eroded out of Valles Caldera in any real size, and not south of Albuquerque, and Los Jaguëyes may erode north into the Rio Casas Grandes (Shackley 2005, 2012). The one "unknown" I have not seen in other assemblages in the Southwest.

The Mogollon-Datil Volcanic Province Obsidian

Recent research at Mule Creek and the newly discovered Sierra County source, as well as earlier work at Gwynn/Ewe Canyons in the Mogollon Mountains indicates close similarity at the elemental level for these sources (Shackley 2005, 2010). Given the popularity of the Mule Creek sources throughout prehistory, careful discrimination is required, at least in XRF analyses.

The Mule Creek Source 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. Recent geological work by me and the Keck Foundation field school suggests that Mule Creek could actually be a remnant caldera around 20 ma in age.

The obsidian has been directly dated at the Antelope Creek locality 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 (marekanites) 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). This season (2013) an ashflow tuff locality with very abundant aphyric Antelope Creek marekanites was located at the head of Antelope Creek as it erodes into the San Francisco River. This locality has abundant reduced cores and flakes and represents the probable major source for archaeological obsidian.

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, except at the new location discussed above. 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 tested in the basin.

Gwynn and Ewe Canyons

The Gwynn and Ewe Canyon source is located in Gila National Forest, south central Catron County, New Mexico, at over 2500 m in elevation (Shackley 2005). In an early study (Shackley 1988), this source was not personally mapped or surveyed. My survey in 1993 indicated that marekanites were directly associated with glassy, perlitic rhyolite in Ewe Canyon to the south, although this stream system erodes into Gwynn Canyon. These coalesced domes shown as Feathery Hill on the quadrangle map, exhibit nodule densities in the regolith up to 200 per m2. This source is located in Telephone Canyon 7.5' Quad 1963, Catron County, New Mexico. Unmodified marekanites on the domes have maximum diameters near 50 mm, although the vast majority (≥95%) are 30 mm and smaller. Bipolar cores and flakes were found on and near Feathery Hill, but in low densities (<1 per 100 m^2). As noted above, marekanites are eroding into the Gwynn Canyon system and possibly the upper San Francisco River, although no nodules were noted in the San Francisco River alluvium as far north as Alma, New Mexico.

The Sierra County Source

In 2008, on the advice of Tim Church, a "new" source was discovered east of Nutt Mountain in Sierra County, New Mexico in and around UTM 13S 0277679/3615415 ±2m on the 1984 BLM 30/60' Hatch Quad. The source appears to be marekanite remnants in an ashflow tuff, the eruptive center of which has not yet been found. It could be related to the Nutt Mountain rhyolite center, but further investigations this year will hopefully solve the issue. Nodules up to 5/100m^2 are present from pea size up to about 5 cm in diameter, and bipolar core reduction evident in all areas. The marekanites may be available as far south as these sites, but it isn't yet known.

The Gwynn Canyon, Sierra County and two of the Mule Creek groups (Antelope Creek and Mule Mountains) are very similar in trace element composition, likely due to a common origin in the Mogollon-Datil rhyolites (see Elston et al. 1976; McIntosh et. al. 1992; Shackley 1995, 1998b). Zirconium plotted against Rb, and/or Ba is the best method to discriminate these sources using XRF (Figures 3 and 4). In order to better understand these geochemical relationships, a Pb, Nd, and Sm isotope analysis was prepared at the University of Hawaii, Hilo ICP-MS laboratory (see Figure 5). Isotopically, these sources separate well and do not necessarily correlate with the elemental variability (Figures 1-4). Care must be exercised when attempting to discriminate these source elementally.

The potential inability to discriminate these sources can be an important issue in western New Mexico late prehistory because these sources are located in very different environments that may have had cultural significance in prehistory. It is possible that during the Mogollon Classic period Gwynn Canyon obsidian could have been controlled by the Cibola branch of the Mogollon while the Mule Creek and Sierra County sources could have been controlled by the Mimbres branch. This may or may not influence the spatial distribution of these obsidian sources in the region and confident source assignment can become crucial. Gwynn/Ewe Canyon obsidian at elevations above 2500 m in elevation are generally well above the elevation favoring maize cultivation and there are virtually no large pueblos at this elevation. Hunting large ungulates, however, is likely in the area. Both deer and elk were seen in the area in the 1990s.

REFERENCES CITED

Brooks, W. E., and Ratté, J. C.
1985 Geologic map of Bear Mountain Quadrangle, Grant County, New Mexico. U.S. Geological Survey Miscellaneous Field Studies Map MF-1782.

Church, T.
2000 Distribution and Sources of Obsidian in the Rio Grande Gravels of New Mexico. *Geoarchaeology* 15:649-678.

Davis, K.D., T.L. Jackson, M.S. Shackley, T. Teague, and J.H. Hampel
2011 Factors Affecting the Energy-Dispersive X-Ray Fluorescence (EDXRF) Analysis of Archaeological Obsidian. In *X-Ray Fluorescence Spectrometry (XRF) in Geoarchaeology*, edited by M.S. Shackley, pp. 45-64. Springer, New York.

Elston, W., R. Rhodes, P. Coney, and E. Deal
1976 Progress Report on the Mogollon Plateau Volcanic Field Southwestern New Mexico. *New Mexico Geological Society Special Publication* 5:3-18.

Govindaraju, K.
1994 1994 Compilation of Working Values and Sample Description for 383 Geostandards. *Geostandards Newsletter* 18 (special issue).

Hamilton, M.J., B.B. Huckell, and M.S. Shackley

2009 Clovis obsidian sources in the central Rio Grande Rift Region of New Mexico. *Current Research in the Pleistocene* 26:62-65.

Hamilton, M.J., B. Buchanan, B.B. Huckell, V.T. Holliday, M.S. Shackley, and M. E. Hill

2013 Clovis Paleoecology and Lithic Technology in the Central Rio Grande Rift Region, New Mexico. *American Antiquity* 78(2):248-265.

Hampel, Joachim H.
1984 Technical Considerations in X-ray Fluorescence Analysis of Obsidian. In *Obsidian Studies in the Great Basin*, edited by R.E. Hughes, pp. 21-25. Contributions of the University of California Archaeological Research Facility 45. Berkeley.

Hildreth, W.
1981 Gradients in Silicic Magma Chambers: Implications for Lithospheric Magmatism. *Journal of Geophysical Research* 86:10153-10192.

Hughes, Richard E., and Robert L. Smith
1993 Archaeology, Geology, and Geochemistry in Obsidian Provenance Studies. *In Scale on Archaeological and Geoscientific Perspectives*, edited by J.K. Stein and A.R. Linse, pp. 79-91. Geological Society of America Special Paper 283.

Johnson, E., V.T. Holliday, and M.S. Shackley

2010 Updated sourcing of Paleoindian obsidian on the Southern High Plains. *Current Research in the Pleistocene* 27:103-104.

Mahood, Gail A., and James A. Stimac
1990 Trace-Element Partitioning in Pantellerites and Trachytes. *Geochemica et Cosmochimica Acta* 54:2257- 2276.

McCarthy, J.J., and F.H. Schamber
1981 Least-Squares Fit with Digital Filter: A Status Report. In *Energy Dispersive X-ray Spectrometry*, edited by K.F.J. Heinrich, D.E. Newbury, R.L. Myklebust, and C.E. Fiori, pp. 273-296. National Bureau of Standards Special Publication 604, Washington, D.C.

McIntosh, W.C., C.E. Chapin, J.C. Ratté, and J.F. Sutter
1992 Time-Stratigraphic Framework for the Eocene-Oligocene Mogollon-Datil Volcanic Field, Southwest New Mexico. *Geological Society of America Bulletin* 104:851-871.

Ratté, J. C.
1982 Geologic map of the Lower San Francisco Wilderness Study Area and contiguous roadless area, Greenlee County, Arizona, and Catron and Grant Counties, New Mexico. U.S. Geological Survey Miscellaneous Field Studies Map MF-1463-B.

Ratté, J. C., and Brooks, W. E.
1983 Geologic map of the Mule Creek Quadrangle, Grant County, New Mexico. U.S. Geological Survey Miscellaneous Studies Map MF-1666.

1989 Geologic map of the Wilson Mountain Quadrangle, Catron and Grant Counties, New Mexico. U.S. Geological Survey Geologic Quadrangle Map GQ-1611.

Ratté, J. C., and Hedlund, D.C.
1981 Geologic map of the Hells Hole Further Planning Area (RARE II), Greenlee County, Arizona and Grant County, New Mexico. U.S. Geological Survey Miscellaneous Field Studies Map MF-1344-A.

Ratté, J. C., Marvin, R.F., and Naeser, C.W.
1984 Calderas and ash flow tuffs of the Mogollon Mountains, southwestern New Mexico. *Journal of Geophysical Research* 89:8713-8732.

Rhodes, R. and E. Smith
1972 Geology and Tectonic Setting of the Mule Creek Caldera, New Mexico, USA. *Bulletin Volcanologíe* 36:401-411.

Schamber, F.H.
1977 A Modification of the Linear Least-Squares Fitting Method which Provides Continuum Suppression. In *X-ray Fluorescence Analysis of Environmental Samples*, edited by T.G. Dzubay, pp. 241-257. Ann Arbor Science Publishers.

Shackley, M. Steven

1988 Sources of Archaeological Obsidian in the Southwest: An Archaeological, Petrological, and Geochemical Study. *American Antiquity* 53(4):752-772.

1990 *Early Hunter-Gatherer Procurement Ranges in the Southwest: Evidence from Obsidian Geochemistry and Lithic Technology*. Ph.D. dissertation, Arizona State University, University Microfilms, Ann Arbor.

1995 Sources of Archaeological Obsidian in the Greater American Southwest: An Update and Quantitative Analysis. *American Antiquity* 60(3):531-551.

2005 *Obsidian: Geology and Archaeology in the North American Southwest*. University of Arizona Press, Tucson.

2011 An Introduction to X-Ray Fluorescence (XRF) Analysis in Archaeology. In *X-Ray Fluorescence Spectrometry (XRF) in Geoarchaeology*, edited by M.S. Shackley, pp. 7-44. Springer, New York.

2012 The Secondary Distribution of Archaeological Obsidian in Rio Grande Quaternary Sediments, Jemez Mountains to San Antonito, New Mexico: Inferences for Prehistoric Procurement and the Age of Sediments. Poster presentation at the Society for American Archaeology, Annual Meeting, Memphis, Tennessee.

Table 1. Elemental concentrations and source assignments for the archaeological specimens by site and sample, and analysis of USGS RGM-1 obsidian standard. All measurements in parts per million (ppm).

Site	Sample	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	Source
SMP 097	476	698	467	10934	66	197	22	31	111	19		22	17	Sierra Co., NM[1]
SMP 097	477	1127	525	9754	121	219	25	28	119	19	46	27	19	Sierra Co., NM
SMP 097	478	684	454	10828	104	197	22	27	106	20		23	17	Sierra Co., NM
SMP 097	479	1090	450	8951	72	189	27	27	109	20	98	22	23	Sierra Co., NM
SMP 097	480	593	419	10501	56	185	24	27	105	20		20	18	Sierra Co., NM
SMP 097	481	997	433	8661	54	194	22	26	111	22	76	18	25	Sierra Co., NM
SMP 097	486	835	463	11066	92	201	27	33	112	23		22	23	Sierra Co., NM
SMP 097	489	687	450	10799	98	189	23	27	111	19		19	17	Sierra Co., NM
SMP 097	490	686	438	10712	72	192	24	28	113	19		22	24	Sierra Co., NM
SMP 097	499	741	497	11115	102	209	24	25	119	18		26	28	Sierra Co., NM
SMP 097	500	770	455	10888	87	197	26	29	109	18		20	23	Sierra Co., NM
SMP 097	501	736	726	8774	163	543	11	75	110	190	0	56	20	Grants Ridge (Mt. Taylor), NM
SMP 097	502	811	460	10927	97	196	26	29	107	20		20	20	Sierra Co., NM
SMP 097	503	1041	491	9151	89	200	22	28	109	26	126	24	21	Sierra Co., NM
SMP 097	507	673	470	10830	74	197	26	30	113	23		19	21	Sierra Co., NM
SMP 097	508	785	451	10777	87	194	22	29	113	19		19	21	Sierra Co., NM
SMP 097	509	801	452	11042	77	198	25	26	111	21		20	28	Sierra Co., NM
SMP 097	510	1053	469	8915	111	199	24	29	114	16	144	22	25	Sierra Co., NM
SMP 097	514	773	671	1083	61	180	22	29	104	23		23	25	Sierra Co., NM

				5										
SMP 103	518	876	396	9298	91	181	8	57	159	93	0	27	21	Cerro Toledo Rhy., NM
SMP 105	519	1749	1164	25466	326	291	9	173	1728	138		64	32	Los Jaguëyes, CHIH
SMP 105	522	1107	496	9912	75	203	27	32	116	19	118	24	24	Sierra Co., NM
SMP 105	524	657	448	10890	67	191	24	35	107	21		21	26	Sierra Co., NM
SMP 105	525	805	481	11155	113	204	26	28	108	21		24	21	Sierra Co., NM
SMP 105	528	885	504	10868	176	212	12	60	167	91	0	35	21	Cerro Toledo Rhy., NM
SMP 105	529	1470	560	10148	105	115	98	26	124	36	1547	22	17	Cow Canyon, AZ
SMP 105	530	632	469	11886	150	195	10	60	166	91		36	22	Cerro Toledo Rhy., NM
SMP 105	533	729	441	10779	71	196	23	32	114	19		23	18	Sierra Co., NM
LA173885	534	325	553	11333	178	502	11	88	132	231		58	29	Horace Mesa, Mt. Taylor, NM
LA173885	536	545	459	11769	115	203	11	63	170	95		33	29	Cerro Toledo Rhy., NM
Site	Sample	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	Source
LA173885	537	937	466	10507	163	203	8	62	163	92	33	33	26	Cerro Toledo Rhy., NM
LA173885	539	317	855	11311	192	599	10	79	118	204		66	29	Grants Ridge (Mt. Taylor), NM
LA173885	541	644	543	12379	193	215	10	69	171	94		38	25	Cerro Toledo Rhy., NM
LA173885	542	737	457	10874	75	198	23	29	112	19		21	25	Sierra Co., NM
LA173885	543	689	565	12506	111	208	8	66	172	98		37	26	Cerro Toledo Rhy., NM
LA173885	544	959	562	11412	176	216	9	66	171	94	0	40	25	Cerro Toledo Rhy., NM
LA173885	546	589	377	10071	97	142	12	21	67	43		26	18	El Rechuelos, NM
LA173885	547	346	581	11427	205	519	12	92	131	227		57	33	Horace Mesa, Mt. Taylor, NM
LA173885	548	477	325	10346	86	153	9	50	146	82		25	21	Cerro Toledo Rhy., NM

LA173885	549	567	375	11764	97	160	10	46	159	54		27	21	Valles Rhy., NM
LA173885	551	1015	459	9063	125	200	24	30	109	22	148	21	28	Sierra Co., NM
LA173885	552	308	825	11277	251	611	11	83	118	194		68	23	Grants Ridge (Mt. Taylor), NM
LA173885	553	669	461	11711	95	194	10	62	173	93		32	21	Cerro Toledo Rhy., NM
LA173885	554	824	417	9617	90	183	9	60	166	96	0	28	26	Cerro Toledo Rhy., NM
LA173885	556	475	457	11657	96	198	9	60	177	96		35	28	Cerro Toledo Rhy., NM
LA173885	557	627	450	10849	67	201	25	31	109	18		20	20	Sierra Co., NM
LA173885	561	469	473	11650	115	193	9	62	166	100		33	26	Cerro Toledo Rhy., NM
IO 509	572	486	283	10769	37	205	19	41	100	21		21	24	Antelope Creek (Mule Cr), NM
LA131174	573	506	557	10849	102	424	11	74	116	123		35	43	N. Sawmill Cr (Mule Cr), NM
LA131174	575	1416	800	20686	214	331	13	124	1171	94	1	45	39	Antelope Wells, NM & CHIH
SMP 109	578	988	632	9489	243	432	9	70	93	111	0	36	34	N. Sawmill Cr (Mule Cr), NM
SMP 109	584	493	347	13110	139	283	10	89	240	63		30	27	unknown
LA173885	586	949	386	10258	91	254	20	41	110	25	61	32	31	Antelope Creek (Mule Cr), NM
LA173885	587	404	553	11435	286	500	11	85	129	218		57	36	Horace Mesa, Mt. Taylor, NM
LA173885	588	1131	492	9728	77	202	27	28	115	21	82	25	24	Sierra Co., NM
IO 526	589	974	190	11528	94	28	27	5	67	5		88	7	not obsidian
	RGM1-S4	1516	288	13711	34	148	106	25	219	5		20	15	standard
	RGM1-S4	1579	279	13720	38	147	108	25	218	7		22	9	standard
	RGM1-S4	1577	293	13287	36	147	111	24	215	15	847	19	13	standard

---

[1] "Sierra County" source name is temporary until the primary source is located.

Table 2. Crosstabulation of site by source.

			Site							
			LA131174	LA173885	SMP 097	SMP 103	SMP 105	SMP 109	IO 509	Total
Source	Antelope Creek (Mule Cr), NM	Count	0	1	0	0	0	0	1	2
		% within Source	.0%	50.0%	.0%	.0%	.0%	.0%	50.0%	100.0%
		% within Site	.0%	4.5%	.0%	.0%	.0%	.0%	100.0%	3.6%
		% of Total	.0%	1.8%	.0%	.0%	.0%	.0%	1.8%	3.6%
	Antelope Wells, NM & CHIH	Count	1	0	0	0	0	0	0	1
		% within Source	100.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%
		% within Site	50.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.8%
		% of Total	1.8%	.0%	.0%	.0%	.0%	.0%	.0%	1.8%
	Cerro Toledo Rhy., NM	Count	0	10	0	1	2	0	0	13
		% within Source	.0%	76.9%	.0%	7.7%	15.4%	.0%	.0%	100.0%
		% within Site	.0%	45.5%	.0%	100.0%	25.0%	.0%	.0%	23.6%
		% of Total	.0%	18.2%	.0%	1.8%	3.6%	.0%	.0%	23.6%
	Cow Canyon, AZ	Count	0	0	0	0	1	0	0	1
		% within Source	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	100.0%
		% within Site	.0%	.0%	.0%	.0%	12.5%	.0%	.0%	1.8%
		% of Total	.0%	.0%	.0%	.0%	1.8%	.0%	.0%	1.8%
	El Rechuelos, NM	Count	0	1	0	0	0	0	0	1
		% within Source	.0%	100.0%	.0%	.0%	.0%	.0%	.0%	100.0%
		% within Site	.0%	4.5%	.0%	.0%	.0%	.0%	.0%	1.8%
		% of Total	.0%	1.8%	.0%	.0%	.0%	.0%	.0%	1.8%
	Grants Ridge (Mt. Taylor), NM	Count	0	2	1	0	0	0	0	3
		% within Source	.0%	66.7%	33.3%	.0%	.0%	.0%	.0%	100.0%
		% within Site	.0%	9.1%	5.3%	.0%	.0%	.0%	.0%	5.5%
		% of Total	.0%	3.6%	1.8%	.0%	.0%	.0%	.0%	5.5%
	Horace Mesa, Mt. Taylor, NM	Count	0	3	0	0	0	0	0	3
		% within Source	.0%	100.0%	.0%	.0%	.0%	.0%	.0%	100.0%
		% within Site	.0%	13.6%	.0%	.0%	.0%	.0%	.0%	5.5%
		% of Total	.0%	5.5%	.0%	.0%	.0%	.0%	.0%	5.5%
	Los Jaguëyes, CHIH	Count	0	0	0	0	1	0	0	1
		% within Source	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	100.0%
		% within Site	.0%	.0%	.0%	.0%	12.5%	.0%	.0%	1.8%
		% of Total	.0%	.0%	.0%	.0%	1.8%	.0%	.0%	1.8%
	N. Sawmill Cr (Mule Cr), NM	Count	1	0	0	0	0	1	0	2
		% within Source	50.0%	.0%	.0%	.0%	.0%	50.0%	.0%	100.0%
		% within Site	50.0%	.0%	.0%	.0%	.0%	50.0%	.0%	3.6%
		% of Total	1.8%	.0%	.0%	.0%	.0%	1.8%	.0%	3.6%
	Sierra Co., NM	Count	0	4	18	0	4	0	0	26
		% within Source	.0%	15.4%	69.2%	.0%	15.4%	.0%	.0%	100.0%
		% within Site	.0%	18.2%	94.7%	.0%	50.0%	.0%	.0%	47.3%
		% of Total	.0%	7.3%	32.7%	.0%	7.3%	.0%	.0%	47.3%
	Valles Rhy., NM	Count	0	1	0	0	0	0	0	1
		% within Source	.0%	100.0%	.0%	.0%	.0%	.0%	.0%	100.0%
		% within Site	.0%	4.5%	.0%	.0%	.0%	.0%	.0%	1.8%
		% of Total	.0%	1.8%	.0%	.0%	.0%	.0%	.0%	1.8%
	unknown	Count	0	0	0	0	0	1	0	1
		% within Source	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	100.0%
		% within Site	.0%	.0%	.0%	.0%	.0%	50.0%	.0%	1.8%
		% of Total	.0%	.0%	.0%	.0%	.0%	1.8%	.0%	1.8%
Total		Count	2	22	19	1	8	2	1	55
		% within Source	3.6%	40.0%	34.5%	1.8%	14.5%	3.6%	1.8%	100.0%
		% within Site	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	3.6%	40.0%	34.5%	1.8%	14.5%	3.6%	1.8%	100.0%

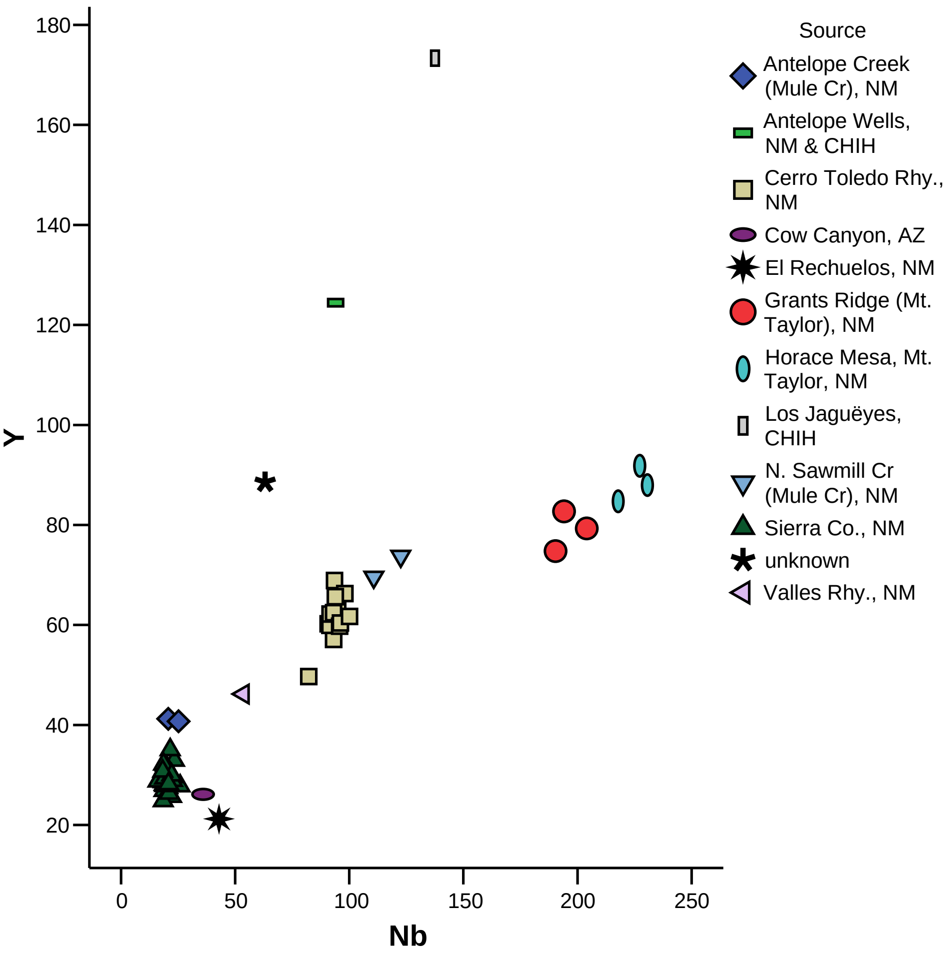


Figure 1. Nb versus Y bivariate plot of all artifacts. Following plots aid in discrimination.

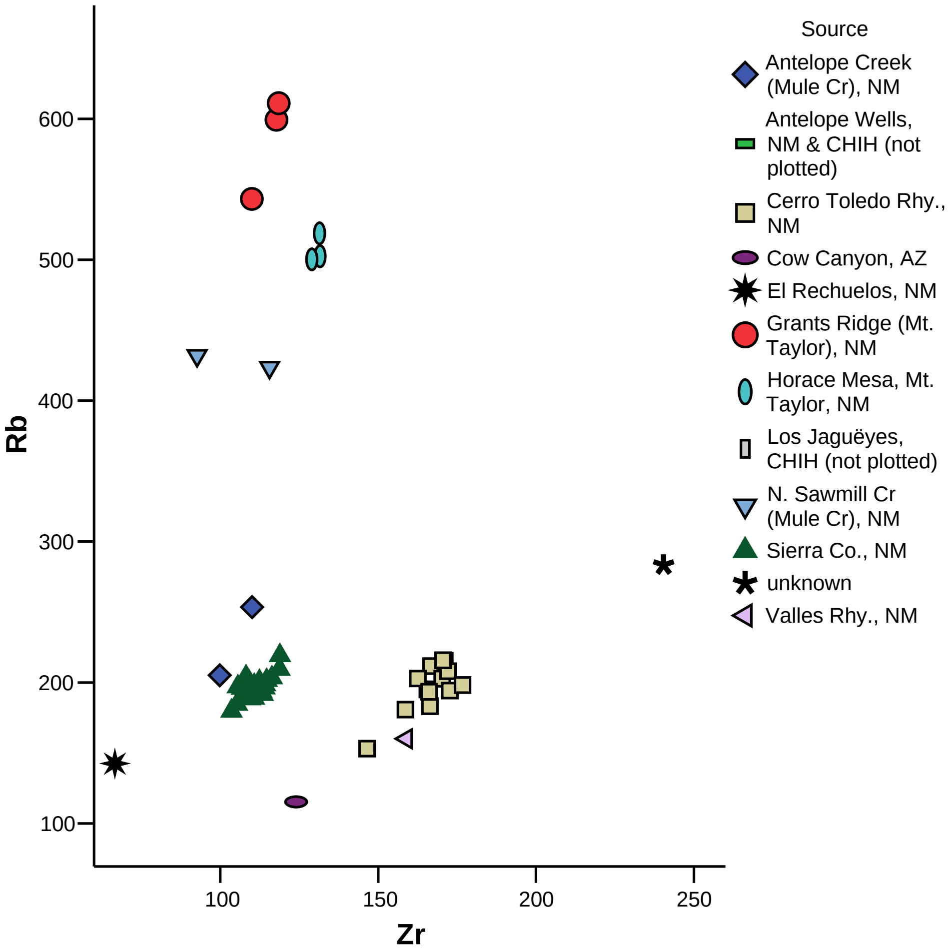


Figure 2. Zr versus Rb bivariate plot of artifacts eliminating the high Zr Antelope Wells and Los Jaguëyes assigned artifacts providing better discrimination. The Sierra County and Antelope Creek samples better discriminated in plots below.

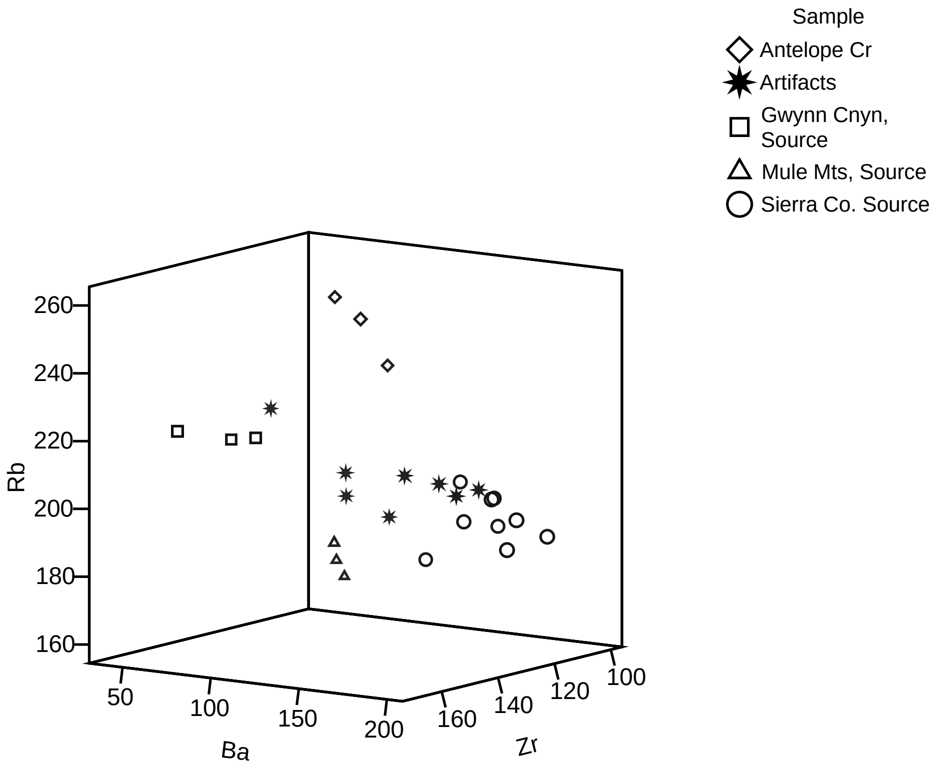


Figure 3. Zr, Ba, Rb three-dimensional plot of Mogollon-Datil source standards and a sample of the artifacts assigned to Sierra County. Bivariate plots of these elements further discriminate the Sierra County data from the other sources (below).

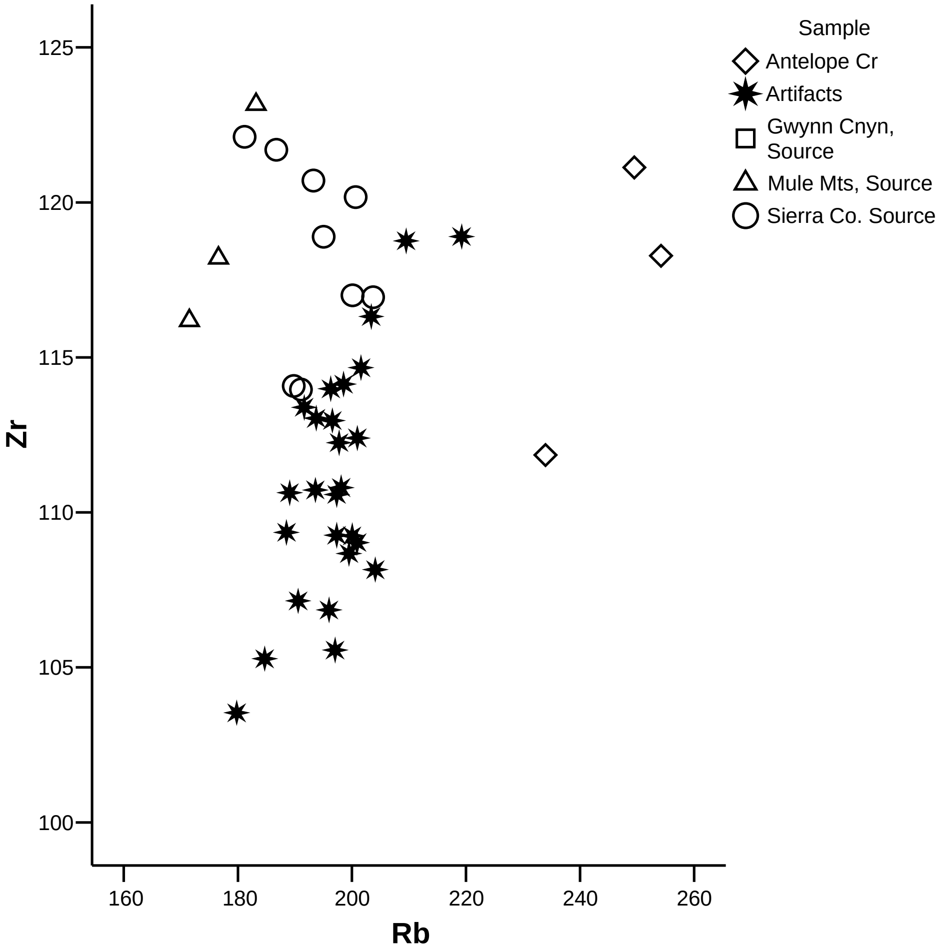


Figure 4. Rb versus Zr bivariate plot of the samples in Figure 3 discriminating Sierra County data. Lower Zr concentrations for the artifacts a likely function of smaller samples sizes and greater variability captured by the artifacts than available source standards (see text).

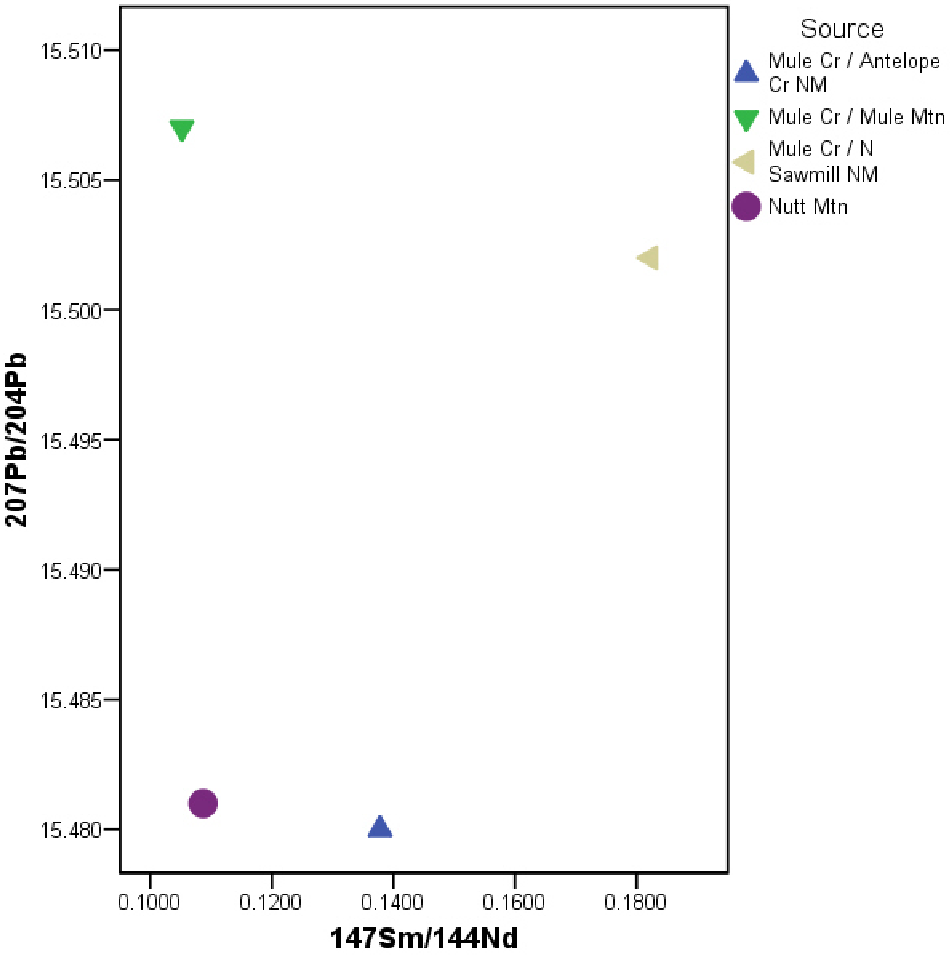


Figure 5. Sm/Nd and Pb isotope plot of the Mule Creek chemical groups and Nutt Mountain, a newly discovered source in Sierra County, New Mexico. Note that the isotopic relationship does not mirror the elemental relationships (see text).