GEOARCHAEOLOGICAL XRF LAB

GEOARCHAEOLOGICAL X-RAY FLUORESCENCE SPECTROMETRY LABORATORY
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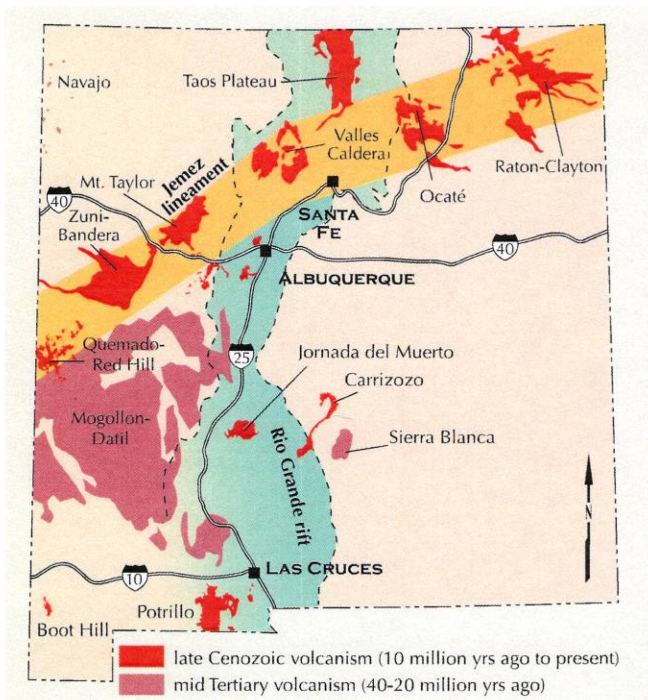
SOURCE PROVENANCE OF OBSIDIAN ARTIFACTS FROM THE GRAND MESA, UNCOMPAHGRE, AND GUNNISON NATIONAL FORESTS, COLORADO



The Jemez Lineament of New Mexico and Colorado (from NM Earth Matters, Winter 2006).

by

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INTRODUCTION

The analysis here of an assemblage of 72 artifacts and one Cochetopa Dome source specimen from numerous sites is dominated by mainly pre-caldera and caldera event sources in the Jemez Mountains of northern New Mexico (84.8% of the total). The remainder of the assemblage was produced from obsidian procured from Colorado, Idaho, Utah, and Wyoming sources, likely representing the sheer number of sites and large time depth.

After a discussion of the instrumental analysis, a discussion of these Jemez Mountains sources will be offered, followed by a general discussion of the results and a short discussion of source provenance.

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 at the Geoarchaeological 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 linear 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 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, and 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 of 20 for obsidian artifacts to check machine calibration (Table 1).

Source assignments were made by reference to the laboratory data base (see Shackley 1995, 2005), Nelson and Tingey (1997), and the Cochetopa Dome source standard supplied. Further information on the laboratory instrumentation and source data can be found at: http://www.swxrflab.net/ (see Tables 1 and 2, Figures 1 and 2). Trace element data exhibited in Table 1 are reported in parts per million (ppm), a quantitative measure by weight.

THE JEMEZ LINEAMENT AND JEMEZ MOUNTAINS SOURCES

Much of the obsidian used to produce artifacts from the sites in the assemblage was procured from one volcanic field along the Jemez Lineament; the Jemez Mountains and Valles Caldera Volcanic Field (see cover image). The Jemez lineament, first identified and named by Mayo (1958), is marked by a prominent alignment of Cenozoic volcanic centers. Several workers have postulated a Precambrian ancestry for the lineament (Aldrich et al. 1983, and references therein). U-Pb geochronologic data suggest that it marks the southward limit of pre-1.7 Ga crust (Wooden and Dewitt 1991). The idea that the Jemez lineament is an important crustal boundary is supported by a long history of reactivation. Strickland et al. (2003) suggest that the Jemez lineament may be a province boundary between the Yavapai (1.8-1.7 Ga) and

Mazatzal (1.67-1.65 Ga) crustal provinces. It's location at the boundaries of the Rio Grande Rift, the Colorado Plateau, and the Basin and Range Complex appears to be reflected in the trace element chemistry with relatively high Y and Nb for North American rhyolites, a result of mantle sampling (Baker and Ridley 1970; Shackley 1998, 2005 and see discussions below). It appears to coincide with a region of low-velocity mantle and possible zone of partial melting, not unexpected in this environment (Karlstrom and Humphreys 1998; Dueker et al. 2001).

The Regional Sources of Archaeological Obsidian

Jemez Mountains and the Valles Caldera

A more complete discussion of the archaeological sources of obsidian in the Jemez Mountains is available in Shackley (2005:64-74). Distributed in archaeological contexts over as great a distance as Government Mountain in the San Francisco Volcanic Field in northern Arizona, some of the Tertiary and Quaternary sources in the Jemez Mountains, most associated with the collapse of the Valles Caldera, are distributed at least as far south as Chihuahua through secondary deposition in the Rio Grande, north through the Rocky Mountains, and east to the Oklahoma and Texas Panhandles through exchange. And like the sources in northern Arizona, the nodule sizes are from to 10 to 30 cm in diameter; El Rechuelos, Cerro Toledo Rhyolite, and Valles Rhyolite (Valles Rhyolite derived from the Cerro del Medio dome complex) glass sources are as good a media for tool production as anywhere. Until the recent land exchange of the Baca Ranch properties, the Valles Rhyolite primary domes (i.e., Cerro del Medio) had been off-limits to most research. The discussion of this source group here is based on collections by Dan Wolfman and others, facilitated by Los Alamos National Laboratory, and the Museum of New Mexico, and recent sampling of all the major sources by this laboratory courtesy of the Valles Caldera National Preserve (VCNP; Shackley 2005; Wolfman 1994).

Due to its proximity and relationship to the Rio Grande Rift System, potential uranium ore, geothermal possibilities, an active magma chamber, and a number of other geological issues, the Jemez Mountains and the Toledo and Valles Calderas particularly have been the subject of intensive structural and petrological study particularly since the late 1960s (Bailey et al. 1969; Gardner et al. 1986, 2007; Heiken et al. 1986; Self et al. 1986; Smith et al. 1970). Half of the 1986 *Journal of Geophysical Research*, volume 91, was devoted to the then current research on the Jemez Mountains. More accessible for archaeologists, the geology of which is mainly derived from the above, is Baugh and Nelson's (1987) article on the relationship between northern New Mexico archaeological obsidian sources and procurement on the southern Plains, and Glascock et al's (1999) more intensive analysis of these sources including the No Agua Peak source in the Mount San Antonio field on the Taos Plateau at the Colorado/New Mexico border, as well as Shackley (2005).

There are at least five eruptive events in the last 8.7 million years that have produced the five chemical groups in the Jemez Mountains.

The earliest pre-caldera event is the Bear Springs Peak source, part of Canovas Canyon Rhyolite that is dated to about 8.7 Ma, firmly in the Tertiary (Kempter et al. 2004; Figure 3 here). This source is a typical Tertiary marekanite source with remnant nodules embedded in a perlitic matrix. It is located in a dome complex including Bear Springs Peak on Santa Fe National Forest and radiating to the northeast through Jemez Nation land (Shackley 2009). While the nodule sizes are small, the glass is an excellent media for tool production and has been found archaeologically at Zuni and in secondary deposits as far south as Las Cruces, as well as the sites here (Church 2000; Shackley 2012).

The second relevant pre-caldera eruptive event that produced artifact quality obsidian is El Rechuelos Rhyolite. This source, well represented in this assemblage, is what I consider one of the best media for tool production of the group. It dates to about 2.4 million years ago, and nodules at least 10 cm in diameter are present in a number of domes north of dacite Polvadera Peak, the incorrect vernacular name for this source. While El Rechuelos has eroded into the Rio Chama and Rio Grande all the way to Chihuahua, the knappers who used El Rechuelos in these sites likely procured it at the primary domes or perhaps nearby secondary deposits.

About 1.4 Ma, the first caldera collapse occurred in the Jemez Mountains, called Cerro Toledo Rhyolite. This very large event produced the Bandelier Tuffs and spread ash flows many kilometers into the area and horizontally southeast from what is now Rabbit Mountain and the Cerro Toledo domes to the east. These large ash flow sheets are responsible for the great quantity of Cerro Toledo obsidian that is present in the Quaternary Rio Grande alluvium all the way to Chihuahua (Church 2000; Shackley 2012).

The second caldera collapse, that produced the Valles Rhyolite member of the Tewa Formation, called Valles Rhyolite here, occurred around one million years ago and created most of the geography of the current Valles Caldera (Gardner et al. 2007). A number or rhyolite ring domes were produced on the east side of the caldera, but only Cerro del Medio produced artifact quality obsidian. Indeed, the Cerro del Medio dome complex produced millions of tons of artifact quality glass, and is the volumetrically largest obsidian source in the North American Southwest challenged only by Government Mountain in the San Francisco Volcanic Field. This source was apparently preferred by Folsom knappers, as well as those in all periods since. While Cerro Toledo Rhyolite often appears in archaeological contexts in New Mexico sites with greater frequency, it is likely because it is distributed in secondary contexts. This was not the case in the sites at Pojoaque. Valles Rhyolite (Cerro del Medio) stone has not eroded outside the caldera to the extent as Cerro Toledo Rhyolite, and had to be originally procured in the caldera proper (Shackley 2005, 2012).

RESULTS OF THE EDXRF ANALYSIS OF THE ARTIFACTS

The diversity of sources in the assemblage is certainly a representation of the number of sites and geographic diversity (Table 2 and Figure 3). The Jemez Mountains sources are generally common in southern Colorado sites. The relative absence of the regional Cochetopa Dome source in these sites, even those nearby, is likely due to the small nodule size of the raw material (see Tables 2 and 3). Other social factors could be operating. A crosstabulation of site by source, particularly if the time frame is known could be illuminating.

Malad, Idaho is not uncommon in early sites (i.e. Paleoindian and Archaic) in Colorado, as with Obsidian Cliff. The major Mineral Mountains sources in Utah are also found in Colorado sites, and certainly indicates contacts to the west, as well as north and south. Again, site by source analysis could be illuminating.

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Table 1. Elemental concentration for the archaeological samples, and USGS RGM-1 rhyolite standard. All measurements in parts per million (ppm).

Sample	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Source
1	717	422	10352	155	14	24	69	47	El Rechuelos, NM
2	651	440	10314	162	14	25	69	51	El Rechuelos, NM
3	526	386	10125	152	13	19	70	47	El Rechuelos, NM
4	588	402	10131	152	13	26	71	50	El Rechuelos, NM
5	698	500	11878	204	8	64	169	98	Cerro Toledo Rhy, NM
6	617	320	9771	127	12	21	64	43	El Rechuelos, NM
7	1303	427	10212	153	13	21	71	50	El Rechuelos, NM
8	708	412	10298	164	14	22	69	45	El Rechuelos, NM
9	10303	415	10317	155	13	24	69	48	El Rechuelos, NM
10	631	375	11780	157	12	41	158	50	Valles Rhy-Cerro del Medio, NM
11	681	358	11718	157	12	41	160	52	Valles Rhy-Cerro del Medio, NM
12	593	408	10235	163	10	22	73	47	El Rechuelos, NM
13	683	404	12029	159	13	47	164	54	Valles Rhy-Cerro del Medio, NM
14	631	395	11991	165	12	40	166	54	Valles Rhy-Cerro del Medio, NM
15	609	368	10200	140	12	22	66	47	El Rechuelos, NM
16	3342	417	10165	162	14	21	68	44	El Rechuelos, NM
17	1226	642	10741	220	8	28	121	28	Cochetopa Dome, CO
18	659	421	10333	155	13	23	70	44	El Rechuelos, NM
19	627	404	10025	151	13	20	71	46	El Rechuelos, NM
20	992	429	10139	156	12	21	69	44	El Rechuelos, NM
21	681	386	11919	160	14	44	160	49	Valles Rhy-Cerro del Medio, NM
22	825	437	10491	160	14	23	70	49	El Rechuelos, NM
23	943	363	11035	200	45	18	107	29	Mineral Mtns, UT
24	561	383	9947	146	11	22	68	47	El Rechuelos, NM
25	1181	361	11444	216	49	21	117	24	Mineral Mtns, UT
26	791	382	9991	148	12	21	65	43	El Rechuelos, NM
27	556	394	10174	155	14	25	72	47	El Rechuelos, NM
28	504	364	9931	148	15	24	69	45	El Rechuelos, NM
29	572	385	10082	150	14	24	67	45	El Rechuelos, NM
30	790	242	10997	114	74	32	82	11	Malad, ID
32	1142	399	10145	155	12	22	74	49	El Rechuelos, NM
33	686	399	12206	169	13	45	165	56	Valles Rhy-Cerro del Medio, NM
34	900	250	11179	124	74	33	90	14	Malad, ID
37	602	237	12615	262	9	80	174	50	Obsidian Cliff, WY
38	606	401	10131	152	14	19	73	49	El Rechuelos, NM
39	637	391	10082	156	13	21	66	50	El Rechuelos, NM
40	1318	379	9857	147	8	21	64	49	El Rechuelos, NM
41	683	406	12117	166	13	42	161	44	Valles Rhy-Cerro del Medio, NM
42	644	404	10474	158	14	26	71	48	El Rechuelos, NM
44	711	390	10139	150	13	24	71	44	El Rechuelos, NM
45	686	411	10390	154	12	22	67	45	El Rechuelos, NM

46	838	456	10910	170	16	26	75	49	El Rechuelos, NM
47	769	372	11864	159	13	41	158	50	Valles Rhy-Cerro del Medio, NM
48	553	343	9881	142	12	21	70	45	El Rechuelos, NM
50	14403	570	11102	201	11	26	115	40	Cochetopa Dome, CO
51	598	393	10173	150	12	22	71	45	El Rechuelos, NM
Sample	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Source
52	836	443	12590	176	13	44	175	54	Valles Rhy-Cerro del Medio, NM
53	970	594	12489	208	11	24	116	27	Cochetopa Dome, CO
54	636	398	10512	152	12	24	70	46	El Rechuelos, NM
55	654	390	11841	160	10	45	161	51	Valles Rhy-Cerro del Medio, NM
56	565	392	10134	158	11	20	69	46	El Rechuelos, NM
57	664	386	11955	160	13	46	164	56	Valles Rhy-Cerro del Medio, NM
58	687	420	10286	154	16	23	69	48	El Rechuelos, NM
60	756	401	12128	168	9	46	174	55	Valles Rhy-Cerro del Medio, NM
61	704	428	12205	174	12	48	175	57	Valles Rhy-Cerro del Medio, NM
62	903	627	11047	218	10	25	131	29	Cochetopa Dome, CO
63	605	440	10449	154	12	24	69	46	El Rechuelos, NM
64	703	388	12047	161	12	41	160	51	Valles Rhy-Cerro del Medio, NM
65	541	359	11573	159	12	43	158	52	Valles Rhy-Cerro del Medio, NM
66	709	431	12086	166	14	46	165	58	Valles Rhy-Cerro del Medio, NM
67	569	399	10215	154	14	25	72	48	El Rechuelos, NM
68	812	487	12191	197	9	60	169	94	Cerro Toledo Rhy, NM
69	581	378	10121	152	13	24	69	49	El Rechuelos, NM
70	647	425	10274	153	12	23	70	48	El Rechuelos, NM
71	605	406	10252	158	13	23	71	48	El Rechuelos, NM
72	635	407	11835	166	12	45	163	56	Valles Rhy-Cerro del Medio, NM
74	669	356	11537	150	11	42	164	57	Valles Rhy-Cerro del Medio, NM
75	3642	355	9843	145	13	19	67	46	El Rechuelos, NM
76	503	504	11620	111	85	21	76	49	Malad, ID
79	629	360	11637	158	12	41	169	54	Valles Rhy-Cerro del Medio, NM
80	525	368	11584	158	11	43	155	55	Valles Rhy-Cerro del Medio, NM
81	965	266	11482	126	78	34	91	16	Malad, ID
RGM1-S5	1534	275	13659	147	108	23	211	11	standard
RGM1-S5	1467	296	13639	141	104	26	210	7	standard
RGM1-S4	1537	279	13704	143	109	23	212	8	standard

Table 2. Frequency distribution of sources in all sites. The Cochetopa source standard not tabulated.

		Frequency	Percent
Source	El Rechuelos, NM	39	54.2
	Valles Rhy-Cerro del Medio, NM	20	27.8
	Cerro Toledo Rhy, NM	2	2.8
	Cochetopa Dome, CO	4	5.6
	Malad, ID	4	5.6
	Mineral Mtns, UT	2	2.8
	Obsidian Cliff, WY	1	1.4
	Total	72	100.0

Table 3. Elemental concentrations for the Cochetopa Dome source standard. All measurements in parts per million (ppm).

Sample	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba
78-Cochetopa Dome	1066	640	8913	74	207	10	25	127	28	<1

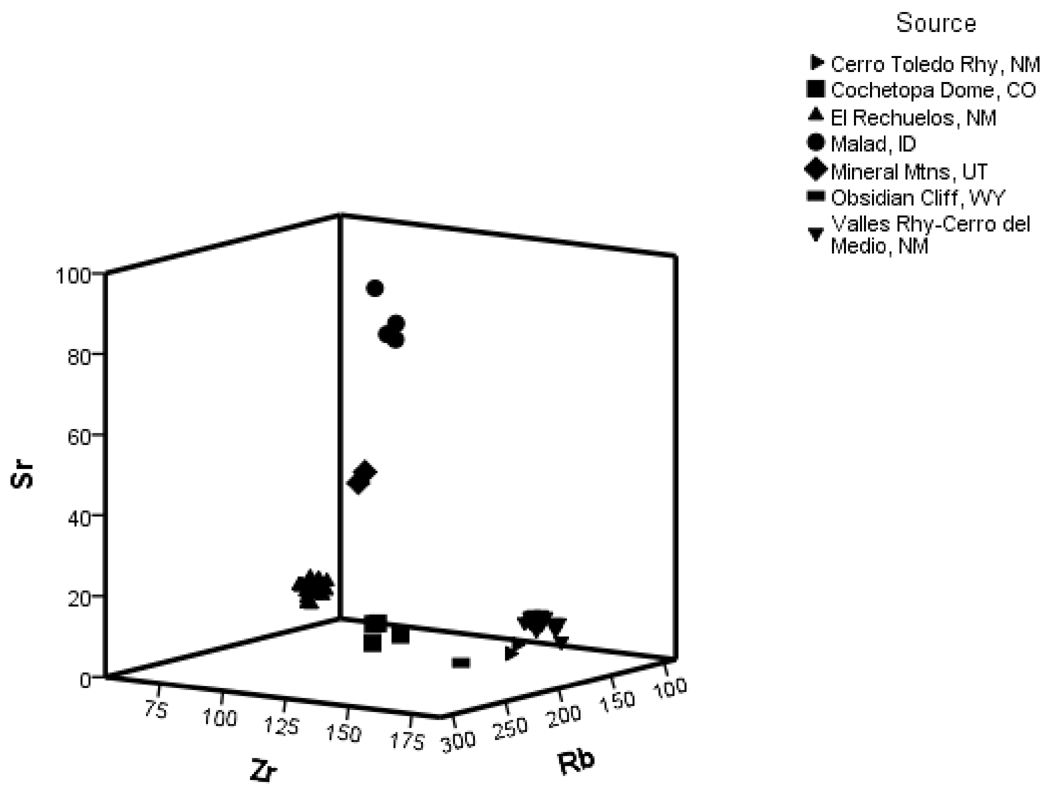

Figure 1. Zr, Sr, Rb three dimensional plot of the archaeological samples. See Figure 2 below for Jemez Mountains source discrimination.

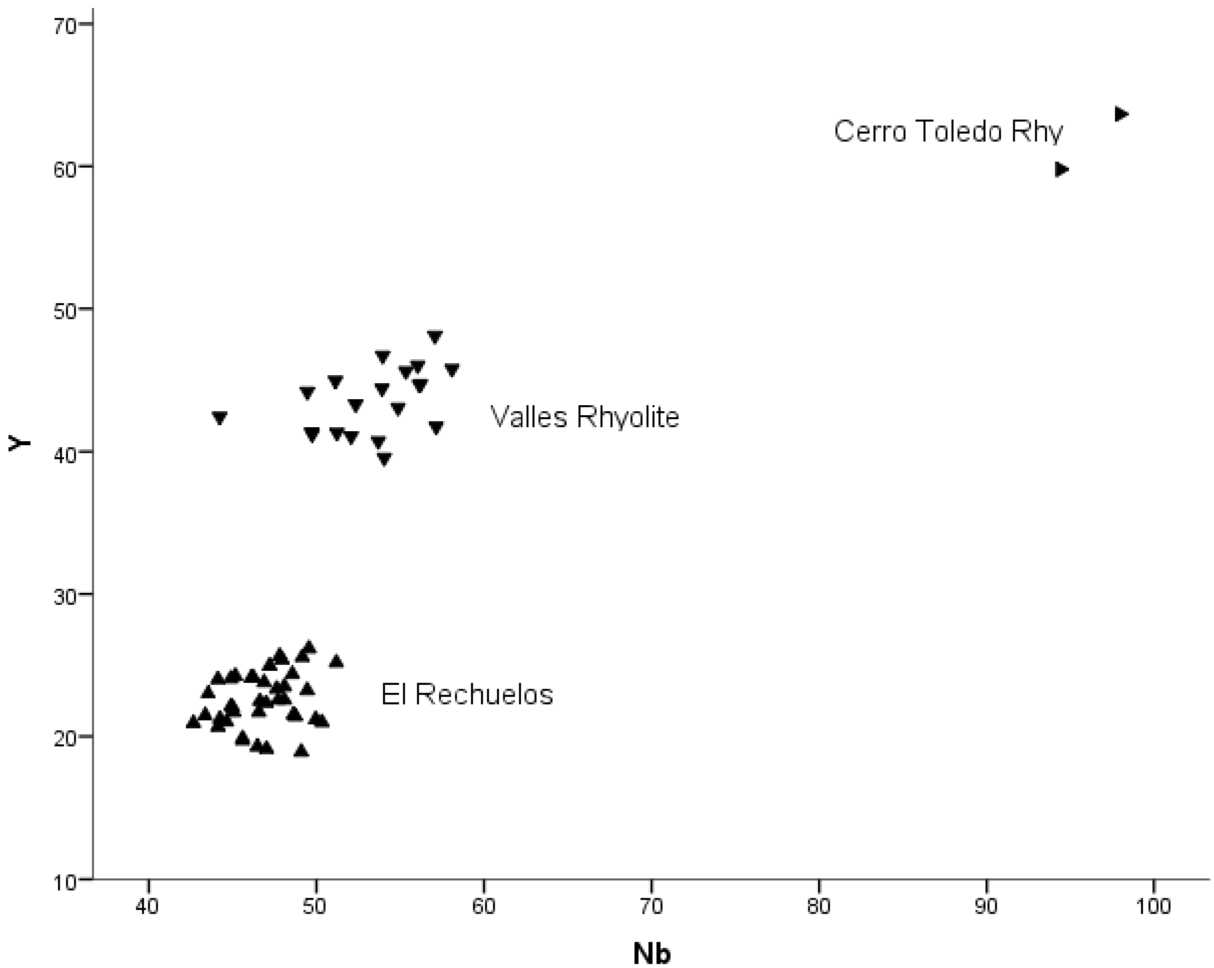

Figure 2. Nb versus Y bivariate plot of the artifacts assigned to Jemez Mountains source providing discrimination.

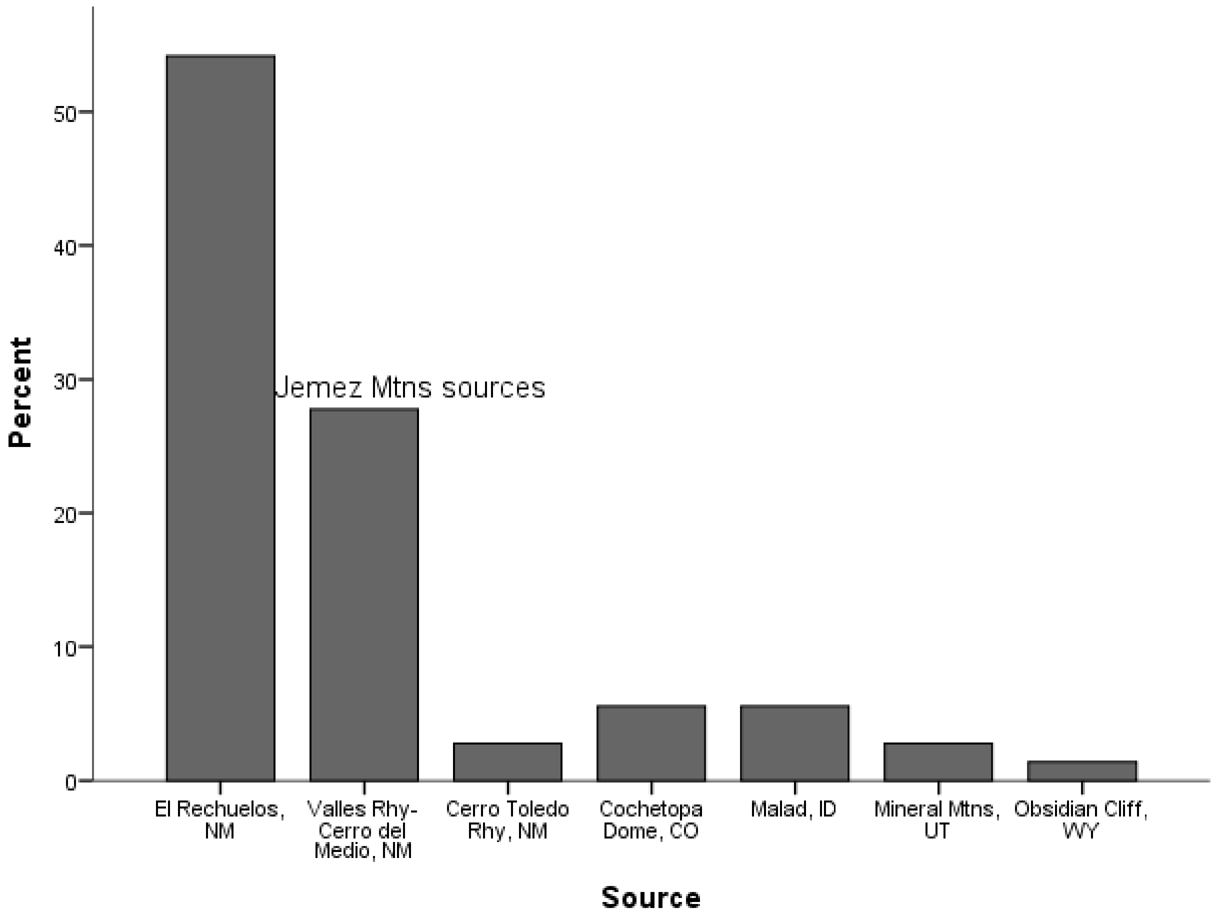

Figure 3. Frequency distribution of sources in the assemblage.