Title

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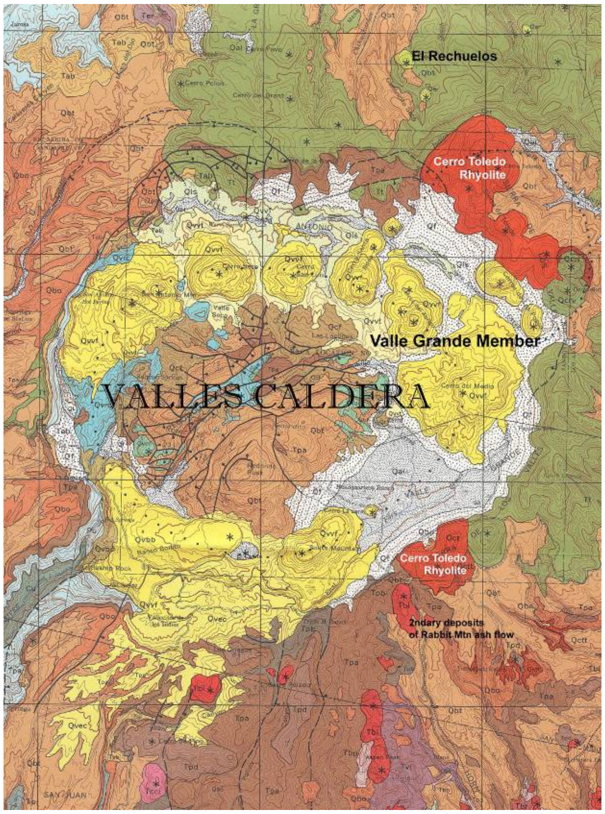
ARCHAEOLOGICAL OBSIDIAN AND SECONDARY DEPOSITIONAL EFFECTS IN THE JEMEZ MOUNTAINS AND THE SIERRA DE LOS VALLES, NORTHERN NEW MEXICO



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Los Alamos National Laboratory
Los Alamos, New Mexico

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INTRODUCTION

Distributed in archaeological contexts over as great a distance as Government Mountain in the San Francisco Volcanic Field in northern Arizona, the 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, and east to the Oklahoma and Texas Panhandles through exchange. And like the sources in northern Arizona, the nodule sizes are up to 10-20 cm in diameter; El Rechuelos, Cerro Toledo Rhyolite, and Valle Grande glass sources are as good a media for tool production as anywhere. While there has been an effort to collect and record primary source obsidian, the focus here has been to understand the secondary distribution of the Jemez Mountains sources. Until the recent land exchange of the Baca Ranch properties, the Valle Grande primary domes (i.e. Cerro del Medio) have 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 (see Broxton et al. 1995; 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 1970s (Bailey et al. 1969; Gardner et al. 1986; Heiken et al. 1986; Ross et al. 1961; Self et al. 1986; Smith et al. 1970; Figures 1 and 2 here). 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 Taos Plateau Volcanic Field at the Colorado/New Mexico border.

This study is focused on the analysis of obsidian and rock samples submitted by Los Alamos National Laboratory (LLNL), and the report of the long-term secondary depositional study by this laboratory, in part funded by LLNL. The secondary depositional study is geared toward an understanding of the probable patterns of prehistoric procurement of artifact quality obsidian from sources in the Jemez Mountains.

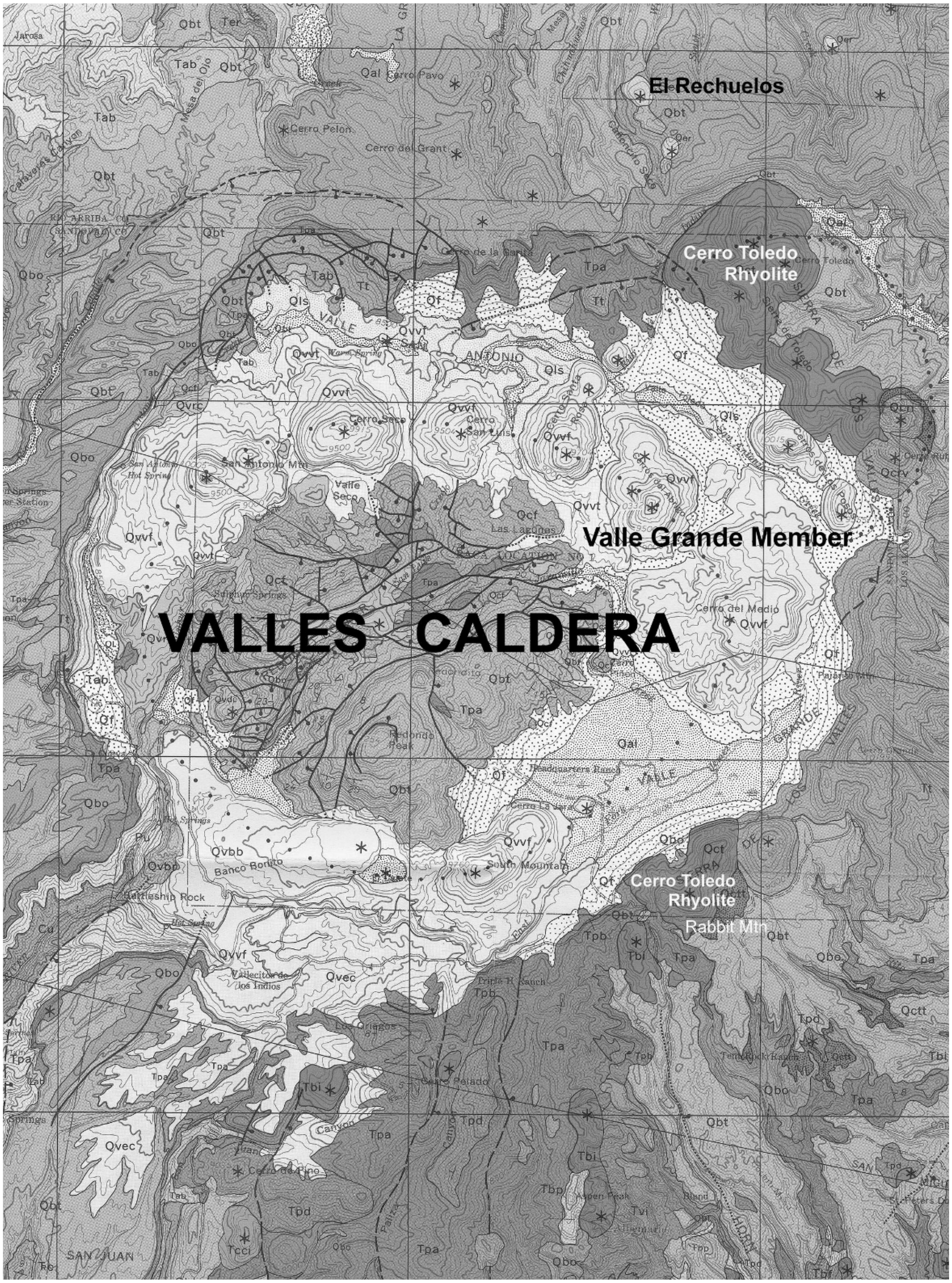

Figure 1. Topographical rendering of a portion of the Jemez Mountains, Valles Caldera, and relevant features (from Smith et al. 1970; formation explanations in Smith et al. 1970).

BEDROCK AND ALLUVIAL DEPOSITION OF THE SIERRA DE LOS VALLES

Due to continuing tectonic stress along the Rio Grande, a lineament down into the mantle has produced a great amount of mafic volcanism during the last 13 million years (Self et al. 1986). Similar to the Mount Taylor field to the west, earlier eruptive events during the Tertiary more likely related to the complex interaction of the Basin and Range and Colorado Plateau provinces produced bimodal andesite-rhyolite fields, of which the Paliza Canyon (Keres Group) and probably the Polvadera Group (El Rechuelos) is a part (Broxton et al. 1995; Shackley 1998a; Smith et al. 1970; Figure 1 here). While both these appear to have produced artifact quality obsidian, the nodule sizes are relatively small due to hydration and devitrification over time (see Hughes and Smith 1993; Shackley 1990, 1995). Later, during rifting along the lineament and other processes not well understood, first the Toledo Caldera (ca. 1.45 Ma) and then the Valles Caldera (1.12 Ma) collapsed causing the ring eruptive events that were dominated by crustally derived silicic volcanism and dome formation (Self et al. 1986). The later eruptive sequence of the Valle Grande Member is significant for the prehistoric procurement of the obsidian as discussed below. The Cerro Toledo Rhyolite and Valle Grande Member obsidians are grouped within the Tewa Group due to their similar magmatic origins. The slight difference in trace element chemistry is probably due to evolution of the magma through time from the Cerro Toledo event to the Valle Grande events (see Hildreth 1981; Mahood and Stimac 1990; Shackley 1998a, 1998b). Given the relatively recent events in the Tewa Group, nodule size is large and hydration and devitrification minimal, yielding the best natural glass media for tool production in the Jemez Mountains.

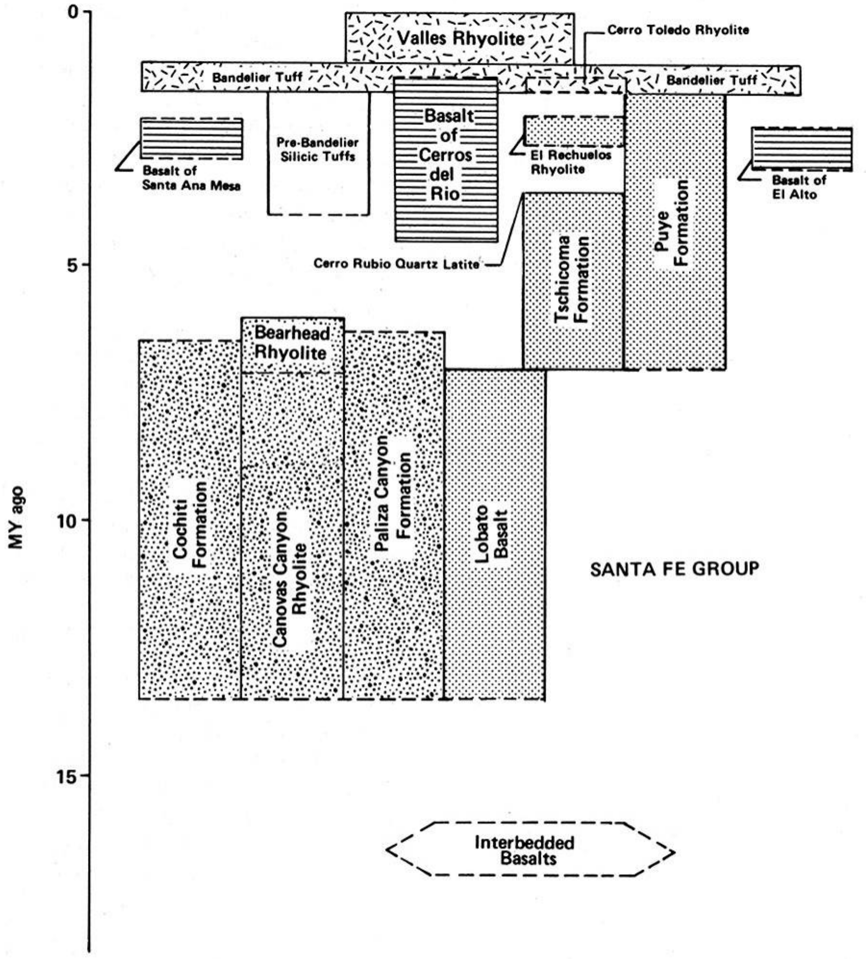

Figure 2. Generalized stratigraphic relations of the major volcanic and alluvial units in the Jemez Mountains (from Gardner et al. 1986). Note the near overlapping events at this scale for the Cerro Toledo and Valles Rhyolite members, and the position of Cerro Toledo Rhyolite at the upper termination of the Puye Formation.

Some of the potentially minor sources of archaeological obsidian from the Jemez Mountain area such as the glass from the Bland Canyon area, appear to be better artifact quality obsidian than previously reported. My recent survey in Bland Canyon (August 1999) below Bearhead Rhyolite yielded a sample of over 100 marekanites of which a sample of 15 analyzed matched the Cerro Toledo Rhyolite signature, not the “Bland Canyon/Apache Tears” signature reported by Glascock et al. (1999:Table 1). The exact sampling location for the Glascock et al. (1999) samples is apparently unknown (see also Wolfman 1994). The Bland Canyon data reported could be rare nodules from an earlier eruptive event contemporaneous with the pre-caldera Polvadera Group, since obliterated by subsequent volcanism and thus making the nodules rare. While this discrepancy could be sampling error in this study, it certainly suggests by this research that the eruptive history and trace element chemistry of artifact quality obsidian from the Jemez Mountains is somewhat more complex than originally described and warrants more intensive geoprospection, a major stimulus for the LLNL project here.

SECONDARY DEPOSITION AND PREHISTORIC PROCUREMENT IN NORTHERN NEW MEXICO

Recent research by this lab investigating the secondary depositional regime from the Jemez Mountains (Sierra de los Valles), indicates that: 1) Valle Grande Member rhyolite and obsidian in the Jemez Mountains, the result of the most recent eruptive event that produced glass in the caldera, does not erode out of the caldera in nodules of any workable size; 2) During the Pleistocene, Cerro Toledo Rhyolite and glass, mainly the result of the Rabbit Mountain ash flow eruption deposited vast quantities of ash and quenched rhyolite through erosion in the Rio Grande River basin as discussed above (Shackley 1998a, 2000). While Cerro Toledo Rhyolite obsidian is found in secondary contexts in the Puye Formation along the northeastern margin of the caldera (see Figures 3 and 4), the greatest quantity of obsidian found today in the Rio Grande River alluvium most likely came from the Rabbit Mountain ash flow event.

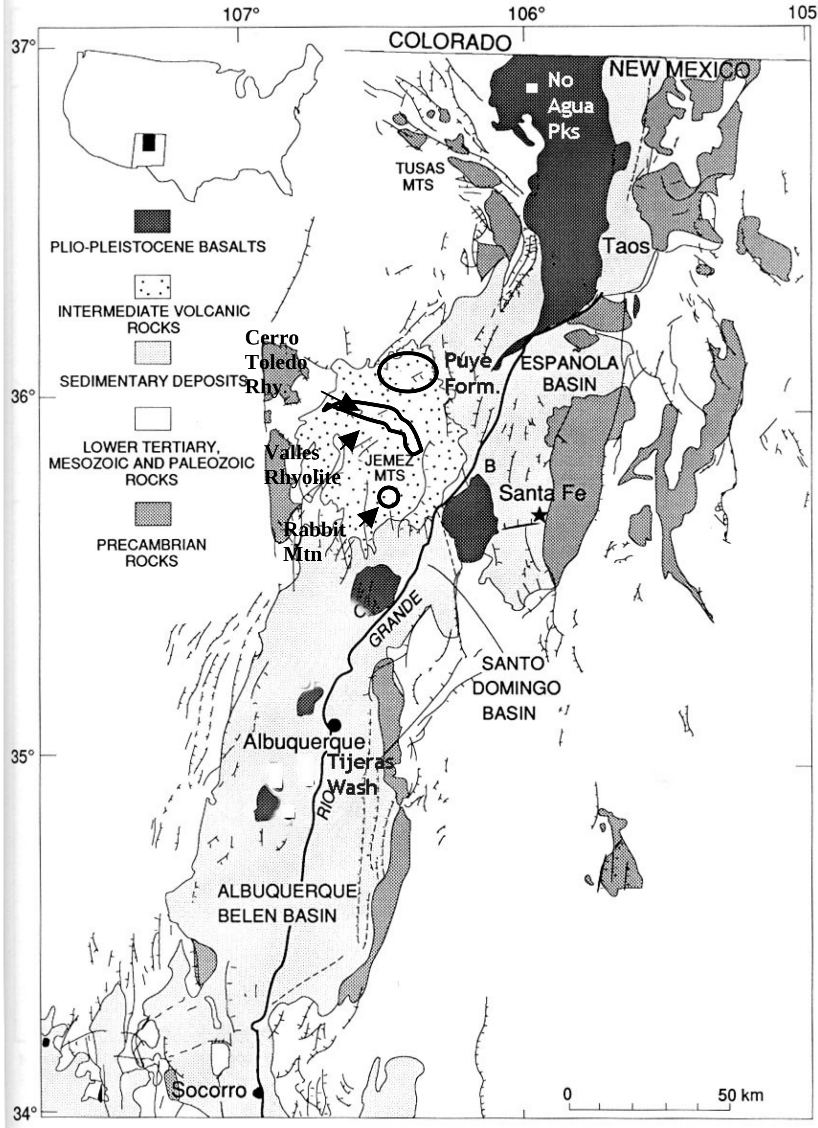

Figure 3. Generalized large scale view of major obsidian source areas and relevant secondary depositional features in north-central New Mexico (adapted from Heiken et al. 1986).

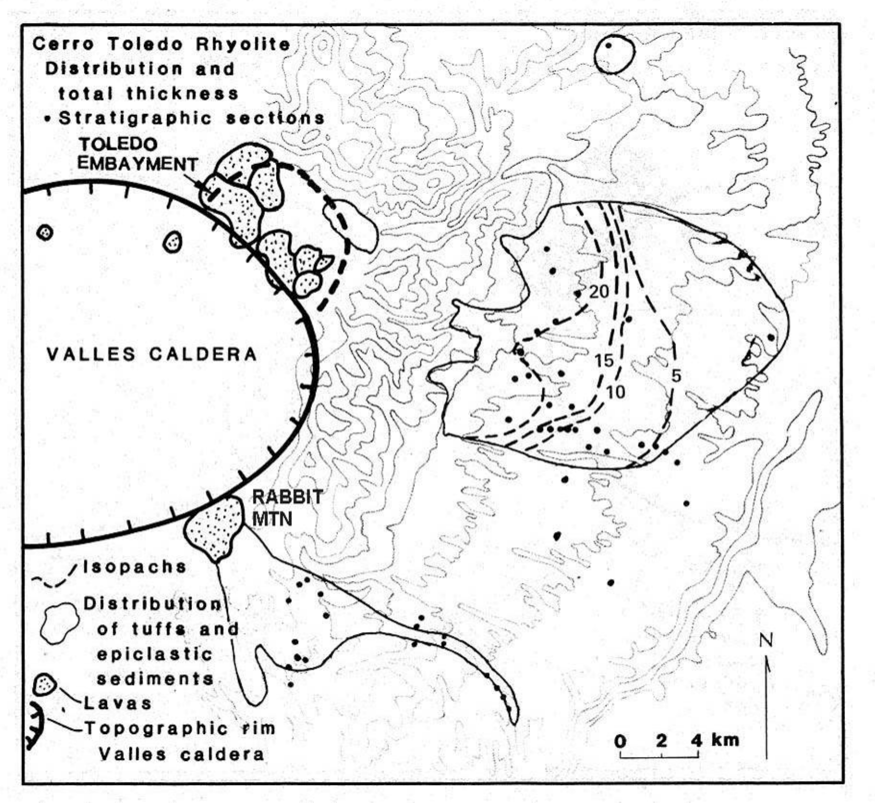

Figure 4. Distribution of tuffs and epiclastic sediments derived from Toledo Embayment and Rabbit Mountain eruptions (from Heicken et al. 1986).

There were six pyroclastic eruptive events associated with the Cerro Toledo Rhyolite:

> All tuff sequences from Toledo intracaldera activity are separated by epiclastic sedimentary rocks that represent periods of erosion and deposition in channels. All consist of rhyolitic tephra and most contain Plinian pumice falls and thin beds of very fine grained ash of phreatomagmatic origin. Most Toledo deposits are thickest in paleocanyons cut into lower Bandelier Tuff and older rocks [as with the Rabbit Mountain ash flow]. Some of the phreatomagmatic tephra flowed down canyons from the caldera as base surges (Heiken et al. 1986:1802).

Two major ash flows or ignimbrites are relevant here. One derived from the Toledo embayment on the northeast side of the caldera is a 20 km wide band that trends to the northeast and is now highly eroded and interbedded in places with the earlier Puye Formation from around Guaje Mountain north to Santa Fe Forest Road 144. This area has eroded rapidly and obsidian from this tuff is now an integral part of the Rio Grande alluvium north of Santa Fe. The other major ash flow is derived from the Rabbit Mountain eruption and is comprised of a southeast trending 4 km wide and 7 km long “tuff blanket” interbedded with a rhyolite breccia three to six meters thick that contains abundant obsidian (Heiken et al. 1986; see also Broxton et al. 1995). All of this is still eroding into the southeast trending canyons toward the Rio Grande. The surge deposits immediately south of Rabbit Mountain contain abundant obsidian chemically identical to the samples from the ridges farther south and in the Rio Grande alluvium. Heiken et al. NAA analysis of Rabbit Mountain lavas is very similar to those from this study (1986:1810; Table 1 here).

Table 1. Selected WXRF oxide values (wt.%) for the three archaeological obsidian source standards from the Jemez Mountains. Sample prefix “CDM” is from the Wolman (1994) sample collected from Cerro del Medio and designated as Valle Grande Rhyolite here. Samples analyzed whole after polishing to present a flat surface to beam as in Shackley (1998a).

Sample Locality	Source Name	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_3
081199-1-7	Cerro Toledo Rhyolite	74.44	0.09	10.74	1.07	0.06	0.00	0.19	4.06	3.93	0.02
CDM3-B	Valle Grande Rhyolite	75.07	0.10	11.56	1.19	0.05	0.20	0.43	4.10	4.75	0.04
080999-2-1	El Rechuelos Rhyolite	74.51	0.10	11.20	0.54	0.06	0.00	0.36	3.79	4.07	0.02

Both the Cerro Toledo Rhyolite glass and Mount Taylor glass is common in Quaternary alluvium of the Rio Grande as far south as Chihuahua, and was frequently used as a toolstone source in prehistory (Shackley 1997). It is impossible to determine, however, in a finished artifact whether the raw material was procured from the primary or secondary sources, unless the artifact is very large (>5-10 cm), when it can be assumed that the artifact was procured from nearer the source.

COLLECTION LOCALITIES

The collection localities discussed here are not the result of a systematic survey to collect and record all the potential sources in the Jemez Mountains, but the result of an attempt to understand the secondary depositional regime of the sources flowing out from the Jemez Mountains into the surrounding stream systems, as noted above. The emphasis here was on understanding the secondary distribution of the major sources that appear in the archaeological record in the northern Southwest; El Rechuelos, Cerro Toledo Rhyolite, and Valle Grande. Additionally, the obsidian sample collection localities for those sources submitted by LANL are not described here specifically, but are plotted on Figure 5, and discussed in general below. The results of the analysis will be discussed below.

El Rechuelos

El Rechuelos is mistakenly called “Polvadera Peak” obsidian in the archaeological vernacular (see also Glascock et al. 1999). Polvadera Peak, while a rhyolite dome, did not produce artifact quality obsidian. The obsidian artifacts that appear in the regional archaeological record are from El Rechuelos Rhyolite as properly noted by Baugh and Nelson (1987). Indeed, El Rechuelos obsidian is derived from a number of small domes north, west, and south of Polvadera Peak as noted by Baugh and Nelson (1987) and Wolfman (1994; see also Figure 5 here). Collections here were made at two to three small coalesced domes near the head of Cañada del Ojitos and as secondary deposits in Cañada del Ojitos (collection locality 080999 in Table 2). The center of the domes is located at UTM 13S 0371131/3993999 north of Polavadera Peak on the Polvadera Peak quadrangle. The three domes are approximately 50 meters in diameter each and exhibit an ashy lava with rhyolite and aphyric obsidian nodules up to 15 cm in diameter, but dominated by nodules between 1 cm and 5 cm. Core fragments and primary and secondary flakes are common in the area.

Small nodules under 10-15 mm are common in the alluvium throughout the area near Polvadera Peak. It is impossible to determine the precise origin of these nodules. Presumably they are remnants of various eruptive events associated with El Rechuelos Rhyolite. The samples analyzed, the results of which are presented in Table 2 are statistically identical to the data presented in Baugh and Nelson (1987) and Glascock et al. (1999).

El Rechuelos obsidian is generally very prominent in northern New Mexico archaeological collections. Although it is not distributed geologically over a large area, it is one of the finest raw materials for tool production in the Jemez Mountains. Its high quality as a toolstone probably explains its desirability in prehistory. Cerro Toledo Rhyolite and Valle Grande Rhyolite, while present in large nodule sizes, often have devitrified spherulites in the glass, so more careful selection had to be made in prehistory. In nearly 500 nodules collected from the El Rechuelos area, few of the nodules exhibited spherulites or phenocrysts in the fabric. Additionally, El Rechuelos glass is megascopically distinctive from the other two major sources in the Jemez Mountains. It is uniformly granular in character, apparently from ash in the matrix. Cerro Toledo and Valle Grande glass is generally not granular and more vitreous.

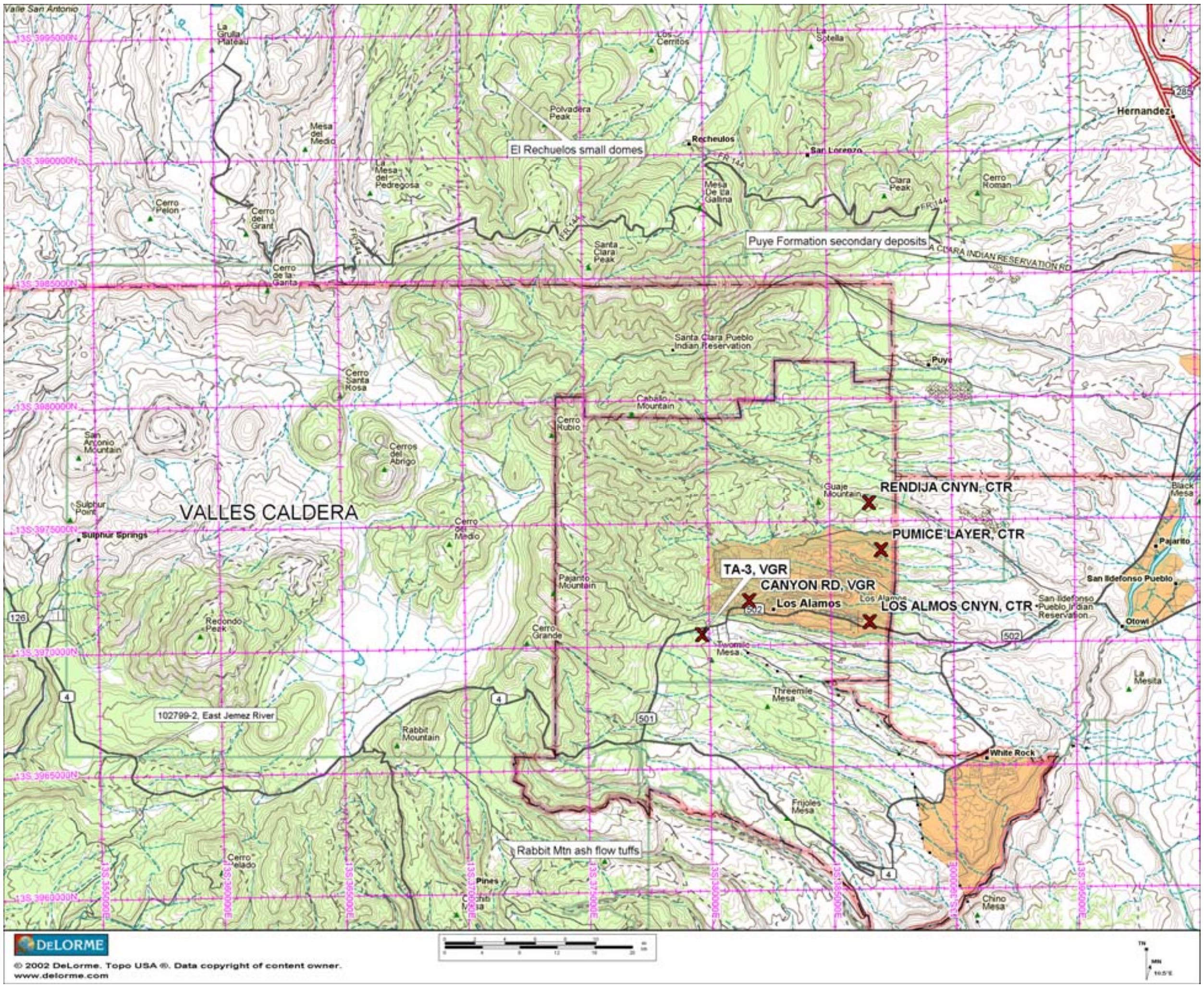

Figure 5. Obsidian collection localities in the Jemez Mountain region. Localities marked with an "X" are LLNL marekanite collections as analyzed in the tables here. The others are collection localities by this lab as discussed here.

Table 2. Source standard elemental concentrations for El Rechuelos Rhyolite obsidian. Samples with "PP" prefix are those from the Wolfman collections as discussed in Wolfman (1994) and Glascock et al. (1999), and analyzed with EDXRF at Berkeley. Those with a "080999" prefix are from this study and locality discussed above and analyzed with WXRF at Berkeley (instrument settings as in Shackley 1998a).

SAMPLE	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Ba
PP-1[1]	543	451	6538	160	9	21	76	48	51
PP-2	560	434	7055	165	10	22	79	52	51
PP-3	526	430	6362	157	9	23	76	48	50
PP-1B	588	436	6504	149	4	25	68	49	n.m.
PP-2B	689	420	6922	156	2	23	75	45	n.m.
080999-2-1				151	11	23	79	46	16
080999-2-2				157	11	24	80	48	20
080999-2-3				154	11	24	81	47	21
080999-2-4				148	11	24	78	46	17
080999-1-1				147	10	23	78	45	16
080999-1-2				150	10	23	79	46	20
080999-1-3				146	10	23	77	45	15
080999-1-4				147	10	23	78	45	11
080999-1-5				146	10	22	77	45	17
080999-1-6				148	10	23	78	46	10

[1] Ti, Mn, and Fe not measured with WXRF; n.m= no measurement.

Rabbit Mountain Ash Flow Tuffs and Cerro Toledo Rhyolite

Known in the vernacular as "Obsidian Ridge", this obsidian is derived from the Cerro Toledo Rhyolite eruptions, and following Baugh and Nelson (1987) and the geological literature are all classified as Cerro Toledo Rhyolite (Bailey et al. 1969; Gardner et al. 1986; Heiken et al. 1986; Self et al. 1986; Smith et al. 1970; Figures 1 and 5 here).

While Obsidian Ridge has received all the "press" as the source of obsidian from Cerro Toledo Rhyolite on the southern edge of the caldera, the density of nodules and nodule sizes on ridges to the west is greater by a factor of two or more. The tops of all these ridges, of course, are remnants of the Rabbit Mountain ash flow and base surge, and the depth of canyons like Cochiti Canyon is a result of the loosely compacted tephra that comprises this plateau. At Locality 081199-1 (UTM 13S 0371337/3962354), nodules on the ridge top are up to 200 per m^2

with over half that number of cores and flakes (Figures 6 and 7). This density of nodules and artifacts forms a discontinuous distribution all the way to Rabbit Mountain. The discontinuity is probably due to cooling dynamics and/or subsequent colluviation. Where high density obsidian is exposed, prehistoric production and procurement is evident. At the base of Rabbit Mountain the density is about 1/8 that of Locality 081199-1, and south of this locality the density falls off rapidly. At Locality 081199-1 nodules range from pea gravel to 16 cm in diameter (Figures 6 and 7 and Table 3). Flake sizes suggest that 10 cm size nodules were typical in prehistory.

Figure 6. Locality 081199-1 south of Rabbit Mountain in the ash flow tuff. This locality has the highest density of artifact quality glass of the Rabbit Mountain ash flow area. The apparent black soil is actually all geological and archaeological glass; one of the highest densities of geological and archaeological obsidian in the Southwest.

Figure 7. Mix of high density geological obsidian and artifact cores and debitage (test knapping) at Locality 081199-1 south of Rabbit Mountain. Nodules ≈200/m^2, cores and debitage ≈100/m^2, some of the latter could be modern. Elemental concentrations for samples from this locality in Appendix under Cerro Toledo Rhyolite.

Cerro Toledo Rhyolite obsidian both from the northern domes and Rabbit Mountain varies from an excellent aphyric translucent brown glass to glass with large devitrified spherulites that make knapping impossible. This character of the fabric is probably why there is so much test knapping at the sources – a need to determine the quality of the nodules before transport. While spherulites in the fabric occur in all the Jemez Mountain obsidian, it seems to be most common in the Cerro Toledo glass and may explain why Valle Grande obsidian occurs in sites a considerable distance from the caldera even though it is not secondarily distributed outside the caldera in any quantity while Cerro Toledo obsidian is common throughout the Rio Grande alluvium. Indeed, in Folsom period contexts in the Albuquerque basin, *only* Valle Grande obsidian was selected for tool production even though Cerro Toledo obsidian is available almost on-site in areas such as West Mesa (LeTourneau et al. 1996). So, while Cerro Toledo Rhyolite obsidian is and was numerically superior in the Rio Grande Basin, it wasn't necessarily the preferred raw material.

Table 3. Elemental concentrations for Cerro Toledo Rhyolite obsidian in the Jemez Mountains. All measurements in parts per million (ppm). Samples with numeric designations from Shackley's surveys. Those with alpha-numeric surveys from the Wolfman and Los Alamos National Laboratory collections. Samples with Ti, Mn, and Fe concentrations analyzed by EDXRF. All others analyzed by WXRF. Instrumental conditions for both instruments discussed in Shackley (1998a).

SAMPLE	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Ba
BCC-1	429	600	10616	217	5	66	192	97	44
BCC-3	552	552	9986	215	5	66	187	97	49
BCC-4	583	547	10102	214	5	62	183	99	42
OR-1	543	550	10278	222	0	66	192	103	43
OR-2	432	425	8727	190	4	59	175	94	42
OR-3	531	534	9921	216	6	65	188	97	42
OR-4	457	577	10218	218	5	69	188	99	42
OR1B	491	536	9810	214	0	63	182	103	
OR2B	633	408	8242	179	1	58	162	92	
CCA-1	341	499	9446	197	4	60	174	90	39
CCA-2	338	516	9714	211	6	66	189	98	0
CCA-3	317	529	9759	208	0	60	184	97	41
081199-1-1				199	7	62	178	96	0
081199-1-2				198	7	61	177	94	1
081199-1-3				200	7	62	179	96	1
081199-1-4				207	6	63	187	99	1
081199-1-5				204	6	63	181	98	4
081199-1-6				204	7	63	184	99	9
081199-1-7				205	6	63	182	99	0
081199-1-8				217	7	67	193	105	15
080900-1				205	8	63	177	100	19
080900-2				204	7	62	175	99	3
080900-3				201	7	62	172	97	3
080900-A1				203	8	62	177	99	73
080900-A2				204	7	63	175	99	14
080900-A4				203	6	63	176	98	0
080900-A5				209	6	65	184	103	5
080900-A6				210	7	62	171	97	1

Valle Grande Rhyolite

While the primary domes like Cerro del Medio of Valle Grande Rhyolite were not visited for this study due to restrictions on entry to the caldera floor, surveys of the major stream systems radiating out from the caldera were examined for secondary deposits; San Antonio Creek and the East Jemez River, as well as the canyons eroding the outer edge of the caldera rim.

In 1956 two geology graduate students from the University of New Mexico published the first paper on archaeological obsidian in the American Southwest, a refractive index analysis of Jemez Mountains obsidian (Boyer and Robinson 1956). In their examination of the Jemez Mountain sources, they noted that obsidian did not occur in the alluvium of San Antonio Creek where it crosses New Mexico State Highway 126, but did occur “in pieces as large as hen’s eggs, but the material is not plentiful and must be searched for with care” in the East Jemez River alluvium where it crosses State Highway 4 (Boyer and Robinson 1956:336). A return to the latter locality (Locality 102799-2) exhibited about the same scenario as that recorded 43 years earlier. The alluvium exhibits nodules up to 40 mm in diameter at a density up to 5/m^2, but generally much lower. Boyer and Robinson did find nodules up to 15.5 cm in diameter along the upper reaches of San Antonio Creek as shown in their plate reproduced here (Boyer and Robinson 1956:337; Figure 8 here).

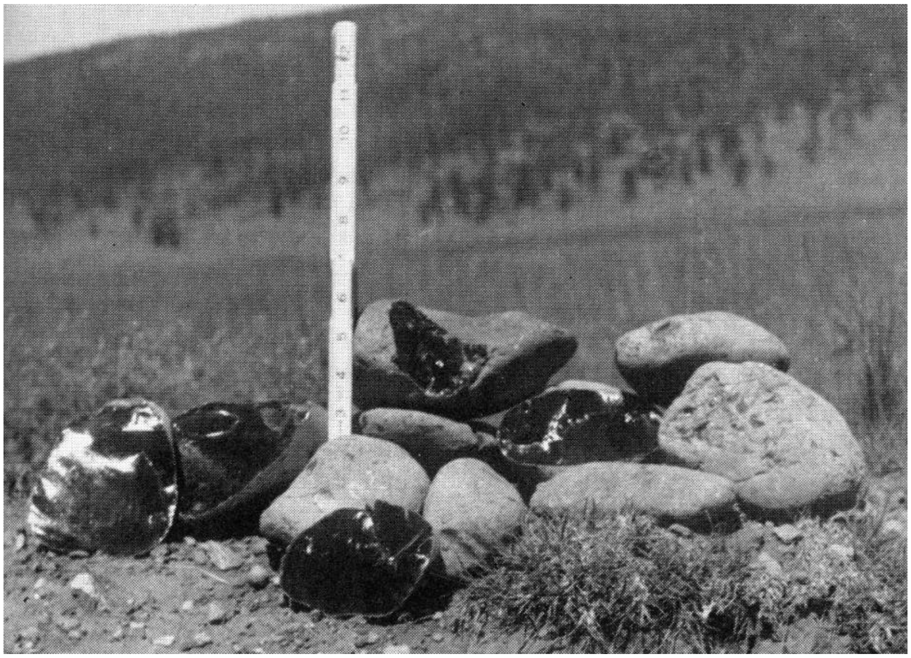

Figure 8. Valle Grande Rhyolite obsidian nodules photographed by Boyer and Robinson collected along San Antonio Creek in the caldera (1956:337).

My survey along San Antonio Creek from its junction with State Highway 126 for two miles upstream did not reveal any obsidian, as in the Boyer and Robinson study. It appears then that Valle Grande Rhyolite obsidian does not enter secondary contexts outside the caldera, at least in nodules of any size compared to Cerro Toledo Rhyolite.

Valle Grande Rhyolite obsidian exhibits a fabric that seems to be a combination of El Rechuelos and Cerro Toledo. Some of the glass has that granular texture of El Rechuelos and some has devitrified spherulites similar to Cerro Toledo, and much of it is aphyric black glass. Flakes of Valle Grande obsidian can be indistinguishable from El Rechuelos or Cerro Toledo in hand sample. An elemental analysis of samples collected by Dan Wolfman from Cerro del Medio and the nodules in San Antonio Creek in this study are identical indicating that Cerro Toledo glass does not enter the East Jemez River system (see Table 4).

Table 4. Elemental concentrations for Valle Grande Rhyolite obsidian in the Jemez Mountains. All measurements in parts per million (ppm). Samples with numeric designations from Shackley's surveys. Those with alpha-numeric surveys from the Wolfman and Los Alamos National Laboratory collections. Samples with Ti, Mn, and Fe concentrations analyzed by EDXRF. All others analyzed by WXRF. Instrumental conditions for both instruments discussed in Shackley (1998a).

SAMPLE	Ti	Mn	Fe	Rb	Sr	Y	Zr	Nb	Ba	La	Ce
102799-2-1				155	10	43	168	54	30		
102799-2-2				157	10	44	172	55	25		
102799-2-3				159	10	44	169	55	35		
102799-2-4				158	10	43	171	55	27		
102799-2-5				160	9	43	170	54	41		
102799-2-6				154	10	42	167	54	39		
102799-2-7				159	9	43	174	54	47		
102799-2-8				162	10	44	168	55	41		
102799-2-9				158	10	43	170	55	45		
102799-2-10				166	10	43	168	54	23		
102799-2-11				176	10	43	168	55	29		
102799-2-12				140	11	40	178	53	26		
102799-2-13				154	11	42	164	54	42		
102799-2-14				144	10	41	179	55	25		
102799-2-15				172	10	44	177	55	23		
CM-3-D	912	486	11600	184	5	47	181	52	30	38	76
CM-2-A	729	341	9030	158	5	40	173	52	26	34	67
CDMA-1				160	10	44	173	56	31		
CDM3B				159	10	44	174	56	39		
CDMV-1				158	10	44	173	55	32		
CDMA-2				158	10	43	174	55	34		
CDMA-3-B				156	10	43	172	54	35		
CDM 3-1				178	10	42	170	54	62		
CDM 3-2				158	10	44	174	55	38		
CDM 3-3				156	10	43	171	54	27		
CDM 1A				156	10	43	172	54	31		
CDM CM1				159	10	44	174	56	28		
CDM CM-3-E				161	11	43	172	54	55		

MAGMATIC RELATIONSHIP BETWEEN THE GLASS SOURCES

The relatively short time period of eruptive events that produced artifact quality obsidian in the Jemez Mountains from El Rechuelos to Valle Grande Rhyolite is reflected in the elemental chemistry as reported by a number of others discussed above (i.e. Baugh and Nelson 1987; Broxton et al. 1995; Gardner et al. 1986; Glascock et al. 1999). This relationship is readily evident in three dimensional and biplots of the incompatible elemental composition of these sources as shown in Figures 9 and 10, the analysis of major and minor elements shown in Tables 2 through 4. Rubidium and yttrium are most sensitive in separating these sources, with zirconium nearly so. Indeed, a biplot of the elemental concentrations Rb versus Y can effectively separate these sources, although it is NOT sufficient to eliminate the possibility that the analyzed artifacts could be from outside the Jemez Mountains group (Figure 10).

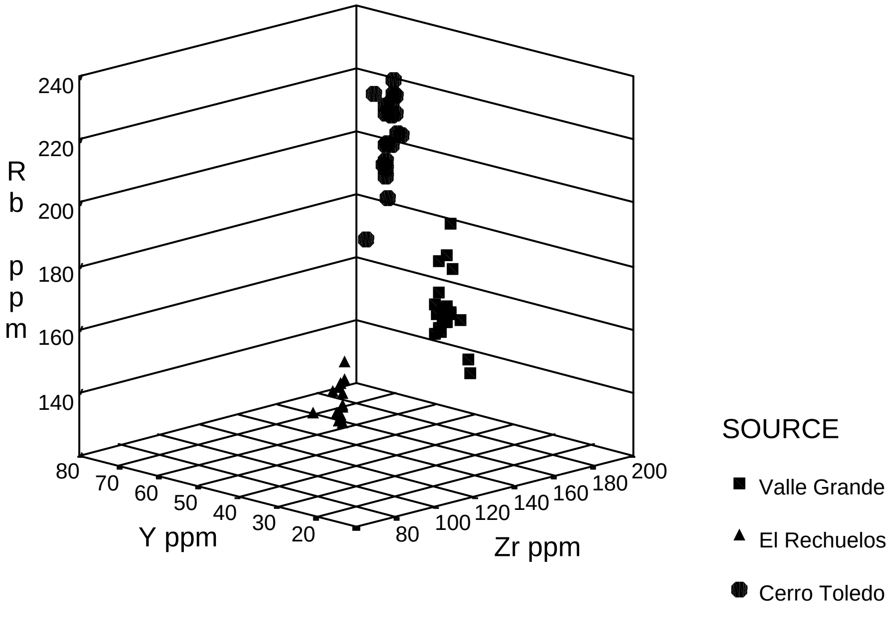

Figure 9. Rb, Y, Zr three dimensional plot of Valle Grande, El Rechuelos and Cerro Toledo Rhyolite obsidian source standards. High variability in Valle Grande and El Rechuelos data are the result of the analysis of small secondary distribution nodules (see Davis et al. 1998).

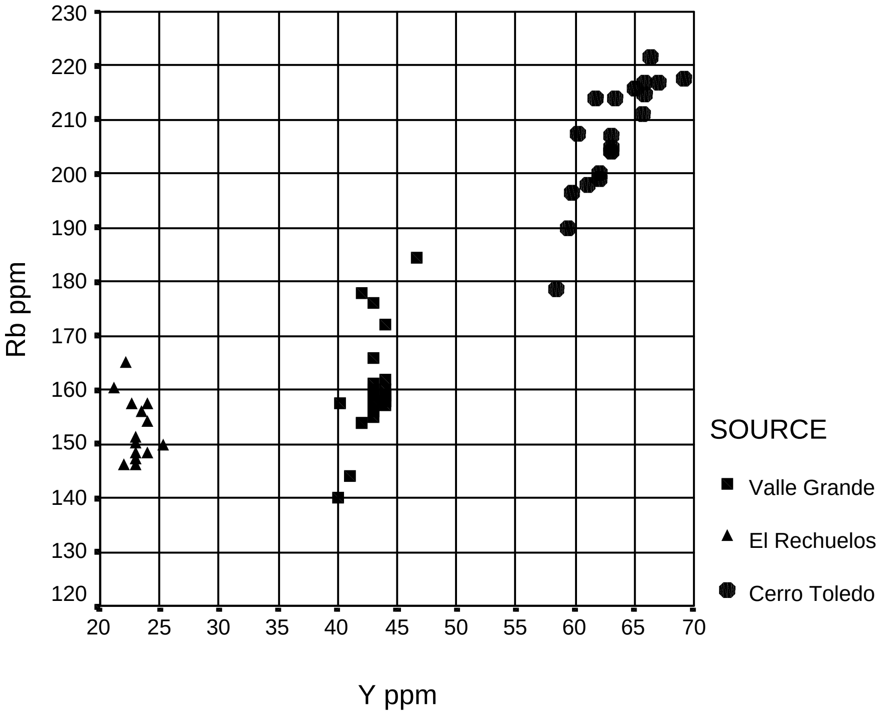

Figure 10. Rb versus Y biplot of the elemental concentrations for Valle Grande, El Rechuelos and Cerro Toledo Rhyolite obsidian source standards. High variability in Valle Grande and El Rechuelos data are the result of the analysis of small secondary distribution nodules (see Davis et al. 1998).

THE LLNL STUDY

A number of marekanite (obsidian), and ignimbrite or tephra samples were submitted for non-destructive WXRF analysis, in part to enlarge the secondary depositional study, and in part to determine the relationship between the marekanites and the ignimbrite or tuff that they are contained within (Table 5 and Figures 11 and 12). While this non-destructive study is certainly not as thorough as a more intensive analysis with prepared pellets and WXRF, the results are revealing. Most of these localities have been described by David Broxton in field notes from July 2002.

Table 5. WXRF non-destructive elemental analysis of obsidian and other rock samples from the LLNL collection. Some samples submitted were too friable for non-destructive analysis.

Sample	Locality	Rb	Sr	Y	Zr	Nb	Ba	Source
Marekanites (obsidian)								
LCT-1-1	Los Alamos Cn	183	7	58	164	91	55	Cerro Toledo Rhy
LCT-1-2		168	6	54	149	83	63	Cerro Toledo Rhy
RC-4-1	Rendija Cn	202	6	61	169	97	4	Cerro Toledo Rhy
RC-4-2		199	5	62	170	98	4	Cerro Toledo Rhy
RC-4-3		203	7	63	173	99	13	Cerro Toledo Rhy
RC-4-4		205	6	64	178	102	8	Cerro Toledo Rhy
TA-3-1	TA-58	154	9	43	166	55	31	Valle Grande Rhy
TA-3-2		155	9	42	160	54	12	Valle Grande Rhy
PL-5-1	pumice near Rendija Cn	200	6	63	169	99	5	Cerro Toledo Rhy
PL-5-2		197	6	62	171	98	0	Cerro Toledo Rhy
PL-5-3		191	6	60	166	95	12	Cerro Toledo Rhy
BV07-02-16-1	Canyon Road	145	10	40	155	51	1	Valle Grande Rhy
BV07-02-16-2		149	9	43	161	53	26	Valle Grande Rhy
BV07-02-16-3		150	9	43	164	54	53	Valle Grande Rhy
Rock and Ignimbrite samples								
BV07-02-13-1	SR 502 road cut	16	479	27	132	16	516	
BVO7-02-10-1	Los Alamos Cn	153	25	52	200	67	37	
BVO7-02-11-1	Los Alamos Cn	125	28	43	202	55	40	
BVO7-02-14-1	SR 502 road cut	360	11	104	255	195	18	
BVO7-02-16-1	Canyon Road	145	48	50	161	49	835	
BVO7-02-17-1	Canyon Road	141	26	44	175	55	195	
BVO7-02-17-2	Canyon Road	146	29	46	173	55	639	
BVO7-02-18-1	Ski Hill Road	137	222	45	145	42	1493	
BVO7-02-18-2	Ski Hill Road	131	172	51	160	47	874	
BVO7-02-5-1	Los Alamos	311	27	108	284	160	92	
BVO7-02-8-1	Los Alamos	209	31	77	199	103	26	
RGM-1		145	102	24	215	8	769	standard
BHVO-1		10	405	27	177	20	134	standard

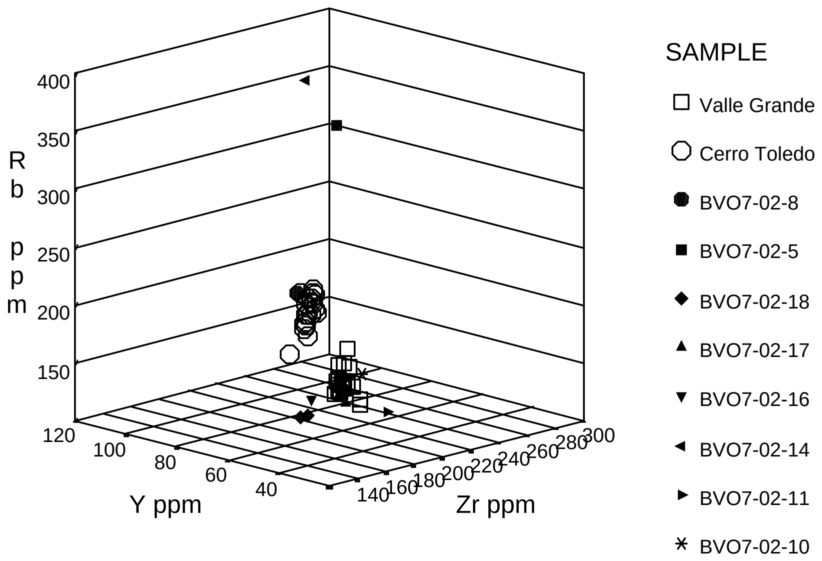

Figure 11. Rb, Y, Zr three-dimensional plot of Valle Grande Rhyolite and Cerro Toledo Rhyolite obsidian source standards and rock samples submitted by LLNL. Samples from localities 5 and 14 are probably not rhyolite based on these elements analyzed.

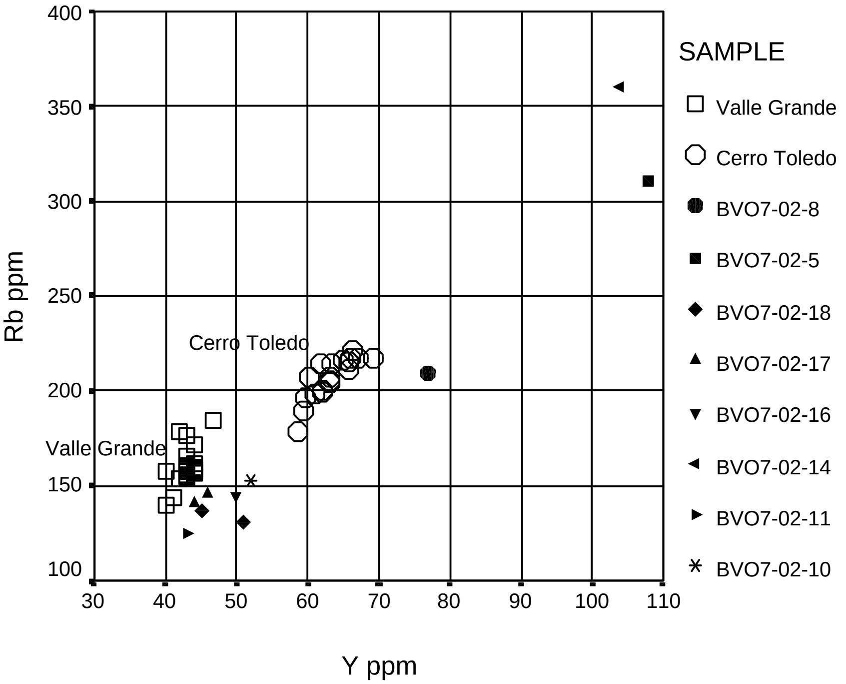

Figure 12. Rb, Y biplot of Valle Grande Rhyolite and Cerro Toledo Rhyolite obsidian source standards and rock samples submitted by LLNL. Samples from localities 5 and 14 are probably not rhyolite based on these elements analyzed.

Obsidian Samples

Obsidian marekanite samples from five localities were submitted for analysis as shown in Table 5. While most of the samples were obsidian associated with the Cerro Toledo Rhyolite events and the Bandelier Tuff, a few of the samples appear to be post-Bandelier, and exhibit an elemental composition consistent with Valle Grande Rhyolite obsidian (TA-3 and BV-07-02-16 localities; see Table 5, and Figure 11). While the sample is small here, it does appear that Valle Grande obsidian occurs in what Broxton designates as "post-Bandelier" sediments and these are in the western portion of the lab property closest to Cerro del Medio. Importantly, although this is the first example of Valle Grande obsidian *outside* the caldera rim, the nodule sizes are quite small, possibly representing small pieces of rhyolite lava quenched as pyroclastics during the eruption. I would stand by the conclusion that no archaeologically significant Valle Grande obsidian has eroded outside the caldera.

Rock Sample Analysis

Figures 10 and 11 exhibit the Rb, Y, and Zr plots of Cerro Toledo Rhyolite and Valle Grande Rhyolite obsidian source standard data and the submitted tephra samples, without the basalt lava included. Immediately apparent is that the vast majority of samples, based on these three elements, are most similar to Valle Grande, the post-Bandelier event, although none of the rock samples plot within the range of variability of the glass. This is typical of rhyolite versus obsidian, where post-emplacement weathering and other processes affect the crystalline lava more than glass (Shackley 1990; Zielinski et al. 1977). Additionally, concentration of Ba and Sr in feldspars, such as sanidine in rhyolites will often elevate the concentration of these elements relative to the obsidian produced by the same event in XRF analyses. This appears to be the case in this data set in the obsidian recovered from locality BV-07-02-16 where the obsidian, consistent with Valle Grande glass is relatively low in Ba and Sr, while the tephra sample is high in Ba and Sr (Table 5). I would, however, if given these samples as a blind test suggest that they were somehow related to the Valle Grande Rhyolite.

Prehistoric Procurement and Secondary Deposition

The LLNL study expands the range of the larger secondary depositional study. While some very small Valle Grande Rhyolite marekanites occur outside the caldera, their small size makes them insignificant as a raw material source. Cerro Toledo Rhyolite obsidian is a much more viable raw material source, apparently, in association with the Bandelier Tuff all around the perimeter of the caldera, including the LLNL area and sediments further south and east. While it is impossible to determine whether obsidian artifacts recovered from sites in the LLNL property were produced from primary or secondary sources, for Valle Grande at least, if the artifacts are larger than about 15 or 20 mm, the raw material probably came from the caldera floor near Cerro del Medio. With artifacts produced from Cerro Toledo Rhyolite obsidian, inferences about procurement are more difficult. Since large nodules (> 30 mm) are common in sediments outside the caldera, these artifacts could be procured anywhere.

This study and the greater secondary depositional study reveals that an understanding of both primary and secondary sources of raw material are crucial in reconstructing procurement, exchange, and group interaction, and simple conjecture that obsidian is located somewhere in the Jemez Mountains yields but simple conclusions.

REFERENCES CITED

Bailey, R.A., R.L. Smith, and C.S. Ross

1969 Stratigraphic Nomenclature of Volcanic Rocks in the Jemez Mountains, New Mexico. *U.S. Geological Survey Bulletin* 1274-P:1-19.

Baugh, Timothy G., and Fred W. Nelson

1987 New Mexico Obsidian Sources and Exchange on the Southern Plains. *Journal of Field Archaeology* 14(3):313-329.

Boyer, W.W., and P. Robinson

1956 Obsidian Artifacts of Northwestern New Mexico and their Correlation with Source Material. *El Palacio* 63(11-12):333-345.

Broxton, D.E., G.H. Heiken, S.J. Chipers, and F.M. Breyers, Jr.

1995 Stratigraphy, Petrography, and Mineralogy of Bandelier Tuff and Cerro Toledo Deposits. In *Earth Science Investigations for Environmental Restoration—Los Alamos National Laboratory Technical Area 21*, edited by D.E. Broxton, and P.G. Eller. Los Alamos MS LA-12934, Los Alamos National Laboratory, New Mexico.

Davis, M.K., T.L. Jackson, M.S. Shackley, T. Teague, and J.H. Hampel

1998 Factors Affecting the Energy-Dispersive X-Ray Fluorescence (EDXRF) Analysis of Archaeological Obsidian. In *Archaeological Obsidian Studies: Method and Theory*, edited by M.S. Shackley, pp. 159-180. Kluwer Academic/Plenum Press, New York and Amsterdam.

Gardner, J. N., F. Goff, S. Garcia, R. Hagan

1986 Stratigraphic Relations and Lithologic Variations in the Jemez Volcanic Field, New Mexico. *Journal of Geophysical Research* 91:1763-1778.

Glascock, M.D., R. Kunselman, and D. Wolfman

1999 Intrasource Chemical Differentiation of Obsidian in the Jemez Mountains and Taos Plateau, New Mexico. *Journal of Archaeological Science* 26:861-868.

Heicken, G., F. Goff, J. Stix, S. Tamanyu, M. Shafiqullah, S. Garcia, and R. Hagan

1986 Intracaldera Volcanic Activity, Toledo Caldera and Embayment, Jemez Mountains, New Mexico. *Journal of Geophysical Research* 91:1799-1816.

Hildreth, W.

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

Hughes, R. E., and Smith, R.L.

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

Mahood, G., and Stimac, J.A.

1990 Trace-Element Partitioning in Pantellerites and Trachytes. *Geochimica et Cosmochimica Acta* 54:2257-2276.

Ross, C.S., and R.L. Smith

1955 Water and Other Volatiles in Volcanic Glasses. *American Minerologist* 40:1071-1089.

Self, S. F. Goff, J. N. Gardner, J.V. Wright, and W. M. Kite
1986 Explosive Rhyolitic Volcanism in the Jemez Mountains: Vent Locations, Caldera Development and Relation to Regional Structure. *Journal of Geophysical Research* 91:1779-1798.

Self, S., G. Heiken, M.L. Sykes, K Wohletz, R.V. Fisher, and D. P. Dethier
1996 *Excursions to the Jemez Mountains, New Mexico*. New Mexico Bureau of Mines and Mineral Resources Bulletin 134, Soccorro.

Shackley, M. S.

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* 60:531-551.

1997 An Energy-Dispersive X-Ray Fluorescence (EDXRF) Analysis of Kaake and Phelps Collection Obsidian Cruciforms From Texas and Chihuahua. Report prepared for Jeff Kaake and Arizona State Museum. Ms. in possession of author.

1998a Geochemical Differentiation and Prehistoric Procurement of Obsidian in the Mount Taylor Volcanic Field, Northwest New Mexico. *Journal of Archaeological Science* 25:1073-1082

1998b Intrasource Chemical Variability and Secondary Depositional Processes in Sources of Archaeological Obsidian: Lessons from the American Southwest. In *Archaeological Obsidian Studies: Method and Theory*, edited by M.S. Shackley, pp. 83-102. Kluwer Academic/Plenum Press, New York and Amsterdam.

2000 The Southwest Archaeological Obsidian Project in The Northern Region. Workshop presented at the 73rd Pecos Conference, Dolores, Colorado.

Smith, R.L., R.A. Bailey, and C.S. Ross
1970 Geologic Map of the Jemez Mountains, New Mexico. Miscellaneous Investigations Series, Map I-571. U.S. Geological Survey, Denver.

Wolfman, Daniel

1994 Jemez Mountains Chronology Study. Report prepared by the Office of Archaeological Studies, Museum of New Mexico for the USDA Forest Service, Contract No. 53-8379-9-14.

Zielinski, R.A., P.W. Lipman and H.T. Millard

1977 Minor-Element Abundances in Obsidian, Perlite and Felsite of Calc-Alkalic Rhyolites. *American Minerologist* 62:426-437.