Distribution and Sources of Obsidian in the Rio Grande Gravels of New Mexico

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The obsidian in the gravels deposited by the Rio Grande in New Mexico has interested archaeologists of the region, particularly the use of these gravels by prehistoric populations and the implications for obsidian sourcing studies. Previous investigations of Rio Grande gravel obsidian have focused on obsidian in the archaeological record. This study focuses on the natural occurrence and distribution of obsidian in the gravels and the implications for archaeological investigations. Spatial sampling of the gravels clearly indicate that obsidian, as well as other chipped stone material, is not uniformly distributed across the landscape. Geochemical analysis of the obsidian in the gravels establishes the true source constituents for the obsidian present in the gravels. The main source area for obsidian in the Rio Grande gravels is the Jemez Mountains, although some obsidian comes from Grant's Ridge, Polvadera, and No Aqua sources. Sources south of Mount Taylor, such as Red Hill and Mule Creek, do not occur in the Rio Grande gravels of southern New Mexico. © 2000 John Wiley & Sons, Inc.

INTRODUCTION

The availability of lithic material affects how prehistoric humans procure these materials and, subsequently, the archaeological record (e.g., Andrefsky, 1994a, 1994b; McGregor, 1995; Stone, 1994; Wiant and Hassen, 1985). Many studies, however, rely on empirically derived generalizations to characterize an area as containing either abundant or sparse lithic sources. As McCutcheon and Dunnel point out, "Not knowing the composition and size characteristics . . . greatly limits the analysis of lithics from the area" (McCutcheon and Dunnel, 1993, p. 20). Other studies take into consideration only the primary lithic source of specific materials and do not address the distribution of these materials in secondary deposits. This oversight has obvious implications, as has been pointed out by previous investigations (e.g., Shackley, 1992; Watrall, 1976; Wyckoff, 1993; and most recently, Reid, 1997). The information contained in this article is intended to provide a preliminary baseline against which the archaeological record can be compared. Further and more controlled sampling should be completed up and down the Rio Grande trough so that the relative abundance of the individual sources is determined.

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THE RIO GRANDE

The present day Rio Grande flows 1,887 miles from the San Juan Mountains (elevation more than 12,000 ft) in southwestern Colorado into the Gulf of Mexico. The size of its drainage basin, 246,000 square miles, is second only to that of the Colorado River. It has relatively few major tributaries, including (from north to south) the Conejos, Red, Rio Chama, Jemez, Rio Puerco, Rio Conchos, Pecos, and Rio de San Juan.

Age and Development

During the development of the Rio Grande rift, a series of basins formed, many of which contain deposits of the ancestral Rio Grande (Kelley, 1952). These basins are, from north to south, Espanola (Denny, 1940b), the Santa Domingo (Webster, 1966), the Albuquerque (Lambert, 1968; Lozinsky and Tedford, 1991), the San Marcial, the Engle, the Palomas (Grunwald, 1990; Mack and James, 1993; Mack et al., 1994; Willingham, 1980), the Tularosa (Lozinsky and Bauer, 1991), the Hueco (Gustavson, 1990; Stuart and Willingham, 1984; Uphoff, 1978, Willingham, 1980), the Mesilla (Mack, 1985; Uphoff, 1978; Vanderhill, 1986; Willingham, 1980), the Presido, and others in Texas (Dickerson and Muehlberger, 1994).

The deposits in these basins constitute the Santa Fe Group, which dates from 400,000 to 500,000 years ago (Hawley et al., 1969; McGrath and Hawley, 1987). Within the Santa Fe Group, several formations contain river gravels of the ancestral Rio Grande. These formations are primarily the Palomas (Lozinsky and Hawley, 1986) and the Camp Rice, although other formations of the Santa Fe Group also contain minor fluvial deposits. Leeder et al. (1996) have suggested that the ancestral Rio Grande shifted eastward and out of the Hatch basin in response to faulting about 1.6 million years ago. The later Pleistocene development of the Rio Grande through southern New Mexico may have included two stages (Mack et al., 1993). Initially, the Rio Grande degenerated into a fluvial plain, thus creating the Fort Hancock Formation, following its advancement into several playa lakes at its then terminus in the El Paso area (Kelley, 1952; Seager, 1981:79). These deposits of the Santa Fe Group are complex, and their interpretation varies (Hawley et al., 1969; Riley, 1984).

Later, the northern and southern drainages coalesced to form a through-flowing river creating the Camp Rice Formation (Stuart and Willingham, 1984). During this time, the Rio Grande shifted into a new channel that flowed through the present-day Fillmore Pass (Lovejoy, 1976) and into the Hueco Bolson (Figure 1). The Rio Grande continued to flow through the gap until uplift forced the river back to the western slopes. Eventually these deposits were capped by the La Mesa surface (Mack et al., 1993). Of these older deposits, it is the Camp Rice Formation that contains exotic gravels of chert, obsidian, vein quartz, as well as rhyolite and other volcanic and metamorphic clasts (Gustavson, 1991:29; Hawley et al., 1969). Both the La Mesa surface and Camp Rice Formation have been buried by more recent aeolian deposits and are not generally exposed except in the walls of arroyos;

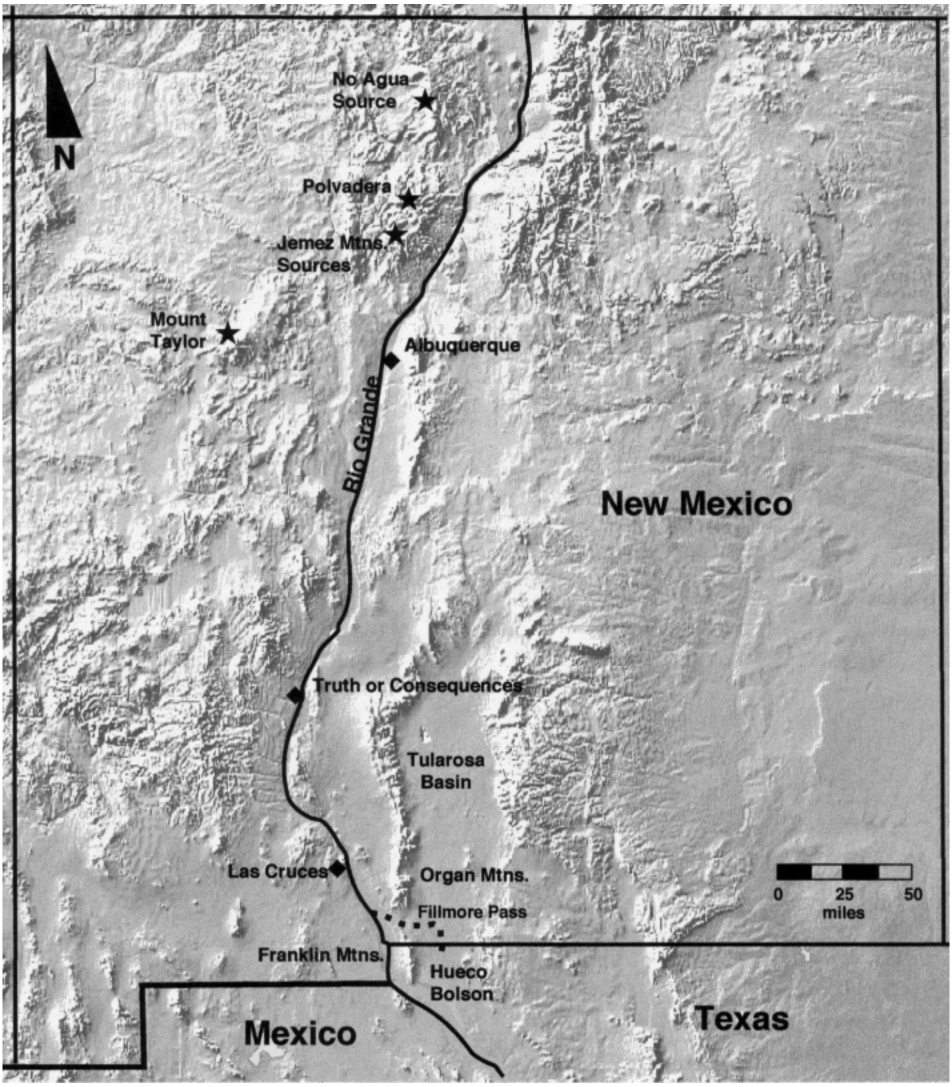

Figure 1. Relevant locations and obsidian sources.

uplifted fault scarps, as much as 79 m in major faults such as the Robledo, (Mack and Seager, 1990); steep erosional slopes of mountain foothills; or in cutbanks of the present day Rio Grande.

Geomorphological and Hydrologic Factors

The hydrological transportation forces and the geomorphological processes affect the distribution and morphology of clasts and have implications for their use as stone tool material. For much of its course, the Rio Grande is a sand-bedded river and has, historically, been subject to rapid avulsions, or channel shifts (Mack and Leeder, 1998). Sand-bedded rivers have several characteristics of note. The first is that they are prone to develop gravel lenses that are subsequently buried by sand (Foley, 1977). Second, clast of all sizes move ten times further in gravel-bed streams than sand-bed streams (Hassan and Church, 1992). Finally, experimental studies indicate that movement of pebbles and cobbles in sand-bed rivers occurs mainly in the upper reaches where high-velocity flow during flood stage is sufficient to initiate movement. Downstream reaches of sand-bed rivers thus contain fewer pebbles and cobbles (Fahnestock and Haushild, 1962).

Obviously, gravels (defined as clasts > 2 mm in length) transported and deposited by rivers are of interest in lithic resource studies. The transportation of these materials results in certain predictable morphological parameters. The type of rock will, to a large degree, dictate the maximum distance from its source that each material will remain in the bedload. Four processes affect the shape of river pebbles. These are abrasion, shape sorting, dilution (the addition of differently shaped materials into the river by tributaries), and breakage (Goede, 1975:711). These processes result in variation in roundness, sphericity, and size over distance. However, Jones and Humphrey (1997) found that experimental studies of abrasion may be misleading, particularly in the case of the Rio Grande, a meandering river.

Ancestral Deposits

Several difficulties are present in any study of the Rio Grande gravels. The first is that the gravel components of the various deposits resulting from Rio Grande deposition are often mapped as a single unit. Therefore, geological maps delimiting these areas often do not differentiate between gravel members and nongravel members. A related problem is the extent of these deposits and the difficulty of differentiating the various gravel-bearing members in the field.

The river gravels contain a variety of rock types, including obsidian. The obsidian clasts in the gravels originated from volcanic fields in northern New Mexico. Small amounts of obsidian clasts have been noted in the axial-fluvial member of the Palomas Formation exposed in arroyo cuts of the Palomas Basin near Truth or Consequences, New Mexico (Grunwald, 1990). North of Las Cruces, the fluvial member of the Santa Fe Group is 100 m thick and up to 5 km wide (Seager and Mack, 1991:19). Further south, subsurface trace amounts of obsidian are reported from well borings in the Mesilla Valley (Mack, 1985). Obsidian and cherts continue to be present in Rio Grande gravel deposits further south (Paz, 1948; Dake, 1952).

Belcher (1975) investigated gravel deposits along the entire course of the Rio Grande, and the deposits were used to plot hypothetical channel development. There was no attempt to identify the geological unit, nor was there any horizontal control. All gravel is assumed to have been deposited by the ancestral Rio Grande. Nevertheless, Belcher's study provides a general picture of the general composition of gravels from a number of localities along the present course of the Rio Grande

(Belcher, 1975:54–63). These data show the general composition of Rio Grande gravels from north to south, with quartzite being present throughout, igneous rocks being slightly less common, and chert becoming a component after the river passes the Caballo Mountains, a source of abundant cherts. A more detailed picture can be reconstructed by piecing together information from a number of geological and archaeological studies along the Rio Grande (see Table I).

Historic Deposits

Recent deposits of the Rio Grande also include "mixed, rounded gravels," and recent coring in the Mesilla Valley near Las Cruces below the present Rio Grande sand bed has revealed a layer of gravel (Hawley and Kottlowski, 1969:98). Deposits containing these gravels include the Tortugas, Picacho, and the Fillmore members of the most recent (2600–4600 yrs B.P.) Fort Selden Formation (Hawley, 1965). It is unclear if the exotic gravels in these younger deposits represent fresh material coming down the river or reworked material eroding out of the Camp Rice Formation north of the study area.

It is also unclear if the exotic gravels from these different aged deposits vary in either composition or morphology. Ruhe (1962:159) reported that river gravels in the Las Cruces area were composed of 25% quartz, 22% rhyolite, 14% andesite and latite, 11% quartzite, 9% chert, 7% granite, 3% monzonite, 2% basalt, with limestone $< 1\%$. Good exposures of the Camp Rice Formation lie north of Las Cruces where the formation appears to thicken (Willingham, 1980). The distribution of ancestral and historic gravel deposits is presented in Figure 2.

GRAVEL COMPOSITION

Mauldin et al. (1998) conducted a study to assess the potential availability of lithic materials in the Rio Grande gravels in the Las Cruces/El Paso area on Fort Bliss military lands. The project area lay in the central Hueco Bolson, 20 km east of the Franklin Mountains. Available lithic material was collected along three transects; within each transect, material was examined within a 100 by 2.5 m unit. Data collected included rock type and size; quality was not assessed. The survey resulted in data for 20,429 items in 150 units. A summary of the Rio Grande gravel materials identified in the sample is presented in Table II.

The available materials were dominated by pieces less than 3 cm (82%) in length, followed by 17% at 3 to 6 cm, with only 1% larger than 6 cm. The presence of obsidian pebbles in the area is also noteworthy because the area lies on the eastern edge of fluvial facies of the upper Santa Fe Group (specifically the Camp Rice Formation).

My investigation of Rio Grande gravels in southern New Mexico was undertaken as part of a lithic source survey (Church et al., 1996). Because of time limitations, spatially controlled sampling was not undertaken. Instead, a series of timed samples done at various locations was completed (Figure 3). The main goal of these timed samples was to determine the procurement cost of these deposits. These samples also provide an indication of the composition of the usable materials in

Table I. Summary of Rio Grande gravels compiled from various sources.

Location	Formation/Deposit	Composition	Morphology	Clast Size	Obsidian Source(s)	Reference Source
Abiquiu	Santa Fe	Volcanic	Pebble	"Few inches in length"	—	Smith, 1938
Espanola Valley	Sante Fe	Quartzites, fine-grained igneous rocks, granites, andesite	Water worn pebbles to boulders	1/2 inch to a foot, with averages ranging from 1 to 8 in.	—	Denny, 1940a
Cochiti Reservoir	Rio Grande terrace deposits	Quartzites, andesites, and basalts dominate with other igneous rocks including obsidian at about 0.2%	—	—	?	Warren, 1979
Albuquerque	Quaternary deposits; Menaul, Edith, Los Duranes, upper Buff gravel, and upper Buff sand (note these are different than those proposed by Webster, 1966).	The upper Buff sand contain volcanic rocks, including obsidian (although Stearns does not mention obsidian in an earlier study).	Cobbles and pebbles	—	?	Lambert, 1968; Stearns, 1953; Webster, 1966

Rio Puerco	Ortiz surface	Silicified wood, basalt, obsidian, schist, sandstone, quartzite, travertine	Cobbles and pebbles	Obsidian cobbles up to 15 cm in length.	Grant's Ridge on Mount Taylor	Warren, 1982; Bryan and McCann, 1936, 1937, 1938
Middle Rio Puerco	Archaeological specimens	—	—	—	67% from Jemez Mt. Sources, 19% from Red Hill, 7% Grants Ridge, 7% No Agua	Bowman, 1987
Elephant Butte Lake	Palomas Formation	Volcanic (including obsidian), and sedimentary rocks	Rounded to subrounded pebbles	Less than 8 cm in length	?	Grunwald, 1990
Rincon Arroyo	Camp Rice Formation	Volcanics (including traces of obsidian), sedimentary, and granite rocks	Subrounded to rounded	Pebbles with some cobbles.	?	Seager and Hawley, 1973
Falcon–Zapata area, Texas	Reynose Formation	Cherts, agates, jasper, quartz, and rhyolite porphyry. No obsidian	—	Pebbles	—	Evans, 1961
Del Rio, Texas	?	Obsidian (originally believed to be tektites).	Rounded	Pebbles	?	Paz, 1948

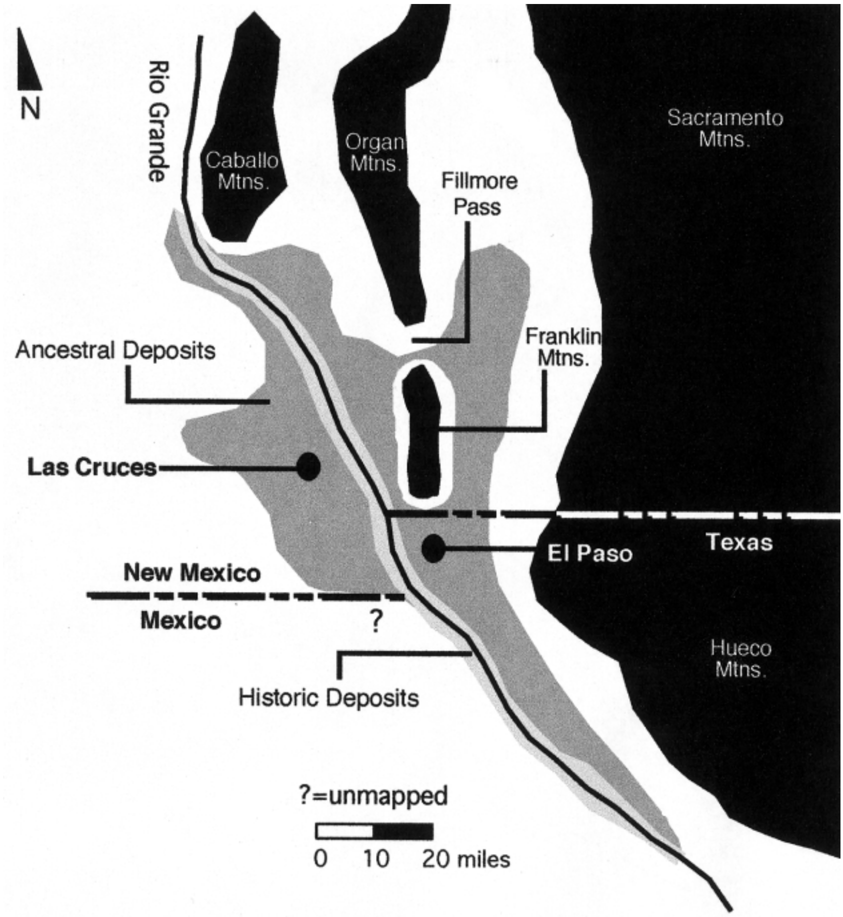

Figure 2. Distribution of ancestral and historic Rio Grande gravels in the study area (from Hawley et al., 1969).

the gravels and their variation across the landscape. Three areas were selected for this sampling, and a fourth area was subjected to grab sampling. The results of these collections are presented in Table III.

The Rio Grande gravels in the Vado area consist of exposures of the Camp Rice Formation. This area is on the western slope of present day Fillmore Pass and is in the hypothesized channel of the ancestral Rio Grande as it entered the Hueco Bolson. Tortugas Mountain lies just to the east of Las Cruces, adjacent to the Organ Mountains, and to the west are deposits of modern Rio Grande gravels of the Fort Selden Formation. Rincon Arroyo materials were selected by grab sampling of

Table II. Summary of Rio Grande gravel lithic materials from 150 transects Hueco Bolson (Mauldin et al., 1998) (local materials are excluded from this table).

Material	Quantity	Percent of Total
Obsidian	144	0.7
Chalcedony	645	3.2
Quartzite	2464	12.1

surface materials exposed on the south side of the arroyo to the northeast of Rincon, New Mexico and represent the Camp Rice correlate, the Palomas Formation.

These data suggest that there is a definite difference between the historic, Fort Selden Formation gravels and the ancestral, Camp Rice/Palomas Formation gravels. Specifically, it appears that the Camp Rice Formation gravels contain more obsidian but less chert than the Fort Selden Formation. Furthermore, while the Fort Selden Formation contains less obsidian, its maximum size is larger. The Rincon Arroyo sample contains larger clasts of chert and quartzite than the other areas, but this might reflect the contribution of larger (less abraded) materials from the nearby mountains through the arroyo.

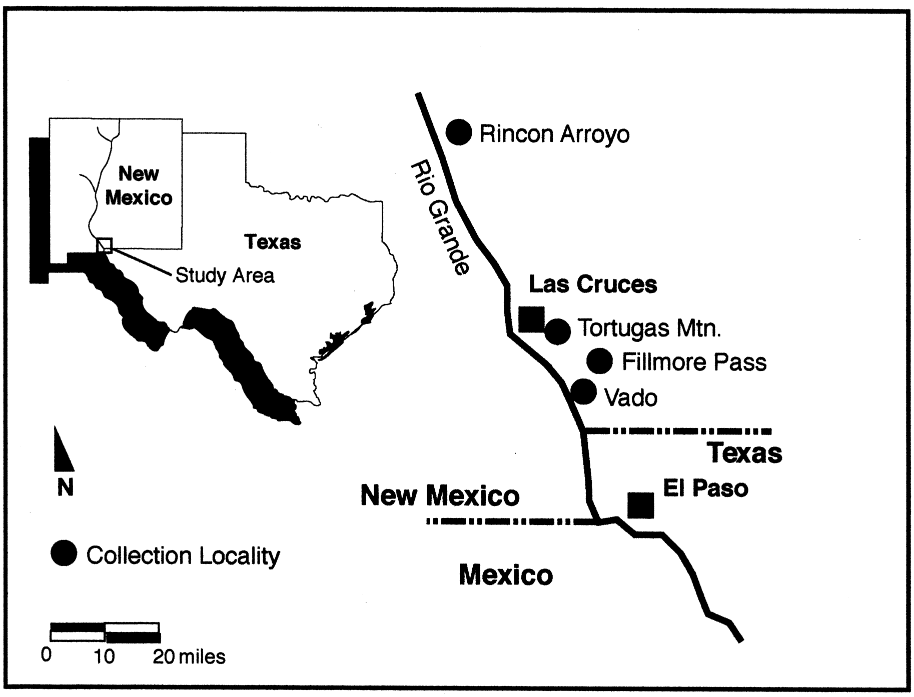

Figure 3. General location of sampling localities.

Table III. Comparison of sampled areas.

	Tortugas Mtn. (Ft. Selden)	Vado Area (Camp Rice)	Fillmore Pass (Camp Rice)	Rincon Arroyo (Camp Rice)
Obsidian %	11	36.5	40.4	28
Max. Size	6.6 cm	5.4 cm	5.0 cm	4.1 cm
Chert %	79.4	55.3	45.6	50
Max. Size	14.1 cm	13.5 cm	14.3 cm	18 cm
Chalcedony %	4.5 cm	8.2	2.2	6
Max. Size	9.7 cm	7.5 cm	9.3 cm	5.5 cm
Quartzite %	4.5	0	1.5	6
Max. Size	11.4 cm		11.0 cm	16 cm
Other % Type	1.3 Rhyolite	0	10.3 Rhyolite	11 Rhyolite
Max. Size	9.5 cm		12.2 cm	11.0 cm

The results of present day sampling of these gravels is arguably biased because long-term prehistoric procurement will have differentially depleted certain materials and material attributes (i.e., larger pebbles). There is always a certain amount of truth in such an argument, and we can never be sure how closely present day conditions mirror those 1000, 5000, or 10,000 years ago. However, these deposits are actively eroding and after a 500-year hiatus from collecting, I suggest that the surfaces from which gravels were collected provide a representative picture of the nature of the gravel distribution.

Obsidian

The presence of obsidian in the Rio Grande gravels has been noted for some time. This obsidian appears to have formed a significant resource for prehistoric populations, particularly for those down river from primary sources. Many investigators have suggested sources for this obsidian. A total of 14 chemical groups assumed to represent materials in the Rio Grande gravels (RGG) have been defined. RGG groups 1–8 were defined by Michels (1983, 1984a, 1984b, 1984c, 1984d, 1984e, 1986) using Atomic Absorption Spectrography (AAS). The RGG groups 9–14 were defined by Stevenson and McCurry (1990) using an inductively coupled plasma-atomic emission spectrometer (ICP). Only two of these have been geochemically correlated with primary sources: RGG II to Obsidian Ridge and RGG VI to Grants Ridge (Stevenson and McCurry, 1990). These correlations have, however, come into question based on more recent work.

However, all previous studies have violated sampling rules to varying degrees. Most of the obsidian used to define these chemical groupings originated not from natural deposits of the gravels themselves, but often from archaeological sites. The assumption was that material being discarded at the sites (the cultural population of obsidian) was representative of the geological population of obsidian in the gravels. In order to more clearly define the true obsidian composition of the gravels, 70 obsidian pebbles were selected from those collected from four collection areas (the Vado area, Tortugas Mountain, Fillmore Pass, and Rincon Arroyo). Of these 70 pebbles, 40 were randomly selected, and 30 were subjectively selected to include a full range of attributes (size, form, etc.). These specimens were provenanced by X-ray fluorescence analysis (Hughes, 1996). The results are presented in Table IV and summarized in Table V.

These most recent data indicate that there are fewer obsidian source areas represented than previously thought. If true, several of the chemical groupings thought to relate to obsidian in the Rio Grande gravels might actually represent as yet undocumented secondary or primary sources.

Examination of these data reveals several surprises. The most striking is the Rincon Arroyo sample, which shows only Polvadera as a source. This sample is small (n = 5), but we had expected to find at least Obsidian Ridge as an additional source because it is the dominant source of materials in the other areas. If this is not the result of sampling error, it may be a result of either depositional or postdepositional processes. During initial deposition, the Rincon Arroyo drainages carrying Polvadera may have been the only, or dominant, tributary entering the ancestral Rio Grande (see Mack and Leeder [1998] for a discussion of Rio Grande channel shifting and Kelson and Wells [1989] on the fluvial hydrology of the Taos Plateau). Postdepositional gravel transportation mechanisms may have, for whatever reason, differentially deposited only Polvadera obsidian pebbles in the Rincon Arroyo deposit. In contrast, Polvadera obsidian is missing from Fillmore Pass samples.

The Vado sampling locality is dominated by material from Obsidian Ridge, with material from Grants Ridge second, and minor obsidian sources of No Agua, Paliza Canyon, Canovas Canyon, and Polvadera. This area also produced the only two specimens of unknown provenance. One of these specimens contains a large number of phenocrysts, rendering it marginal for tool use. The other unknown is a homogeneous, translucent glass with no phenocrysts. The Fillmore Pass sample is again dominated by Obsidian Ridge material, with Grants Ridge the only other source represented. Exposures of historic Rio Grande deposits collected at the Tortugas Mountain locality are dominated by Obsidian Ridge, with Grants Ridge and Polvadera present. Table VI presents the overall obsidian composition from the present study (Figure 4).

These results are comparable to Stevenson's reported frequency of Obsidian Ridge (68%); Grants Ridge (18%); and, Polvadera Peak (8%) (Stevenson and McCurry, 1990). The compositional difference between historic Rio Grande deposits (the Fort Selden Formation collected at the Tortugas Mountain locality) and the ancestral deposits (the Camp Rice Formation collected at all other localities) is similar in terms of the contribution from Obsidian Ridge with 67% in historic deposits and 63% in ancestral deposits. The contributions from both the Grants Ridge and Polvadera Peak sources shows greater variability with 11% from Grants Ridge and 22% from Polvadera Peak in historic deposits compared to 17% and 10%, respectively, in ancestral deposits. Also notable in its absence is the Cerro del Medio source, present in archaeological assemblages throughout the region. LeTourneau

Table IV. XRF results of Rio Grande gravel obsidian.

Specimen LS#	Collection Locality	Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Ti	Mn	Fe_2O_3	Source
240-2-1(R)	V	50 ± 5	22 ± 3	180 ± 4	3 ± 3	30 ± 2	79 ± 3	58 ± 2	0 ± 13	409 ± 17	418 ± 14	.54 ± .12	UK
240-2-2(R)	V	95 ± 4	22 ± 3	201 ± 3	2 ± 3	66 ± 2	182 ± 4	92 ± 2	nm	468 ± 15	556 ± 13	1.15 ± .12	OR
240-2-3(R)	V	84 ± 4	17 ± 3	198 ± 4	0 ± 4	66 ± 2	160 ± 4	94 ± 2	nm	420 ± 16	529 ± 14	1.06 ± .12	OR
240-2-4(R)	V	45 ± 4	19 ± 3	118 ± 3	36 ± 3	22 ± 2	107 ± 3	48 ± 2	341 ± 13	585 ± 17	466 ± 13	.76 ± .12	CC
240-2-5(R)	V	92 ± 5	19 ± 3	198 ± 4	2 ± 3	66 ± 2	167 ± 4	96 ± 2	nm	439 ± 17	525 ± 14	1.08 ± .12	OR
240-2-S3	V	98 ± 5	24 ± 3	208 ± 4	8 ± 3	71 ± 2	179 ± 4	101 ± 2	nm	479 ± 17	523 ± 14	1.09 ± .12	OR
240-2-S4	V	171 ± 5	38 ± 3	612 ± 5	3 ± 3	94 ± 2	129 ± 3	207 ± 2	nm	210 ± 14	876 ± 14	.83 ± .12	GR
240-3-1(R)	V	82 ± 4	24 ± 3	178 ± 3	1 ± 4	58 ± 2	157 ± 3	86 ± 2	nm	434 ± 15	579 ± 13	1.20 ± .12	OR
240-3-2(R)	V	94 ± 4	21 ± 3	214 ± 3	3 ± 3	70 ± 2	184 ± 4	100 ± 2	nm	461 ± 15	583 ± 13	1.15 ± .12	OR
240-3-3(R)	V	101 ± 4	24 ± 3	203 ± 3	3 ± 3	66 ± 2	175 ± 4	96 ± 2	nm	461 ± 16	543 ± 13	1.11 ± .12	OR
2430-3-4(R)	V	79 ± 4	19 ± 3	184 ± 3	1 ± 4	65 ± 2	165 ± 3	92 ± 2	nm	425 ± 14	543 ± 13	1.11 ± .12	OR
240-3-5(R)	V	92 ± 4	21 ± 3	210 ± 3	2 ± 3	66 ± 2	181 ± 4	101 ± 2	nm	516 ± 15	552 ± 13	1.24 ± .12	OR
240-3-6-(R)	V	56 ± 4	11 ± 3	106 ± 3	81 ± 3	27 ± 2	126 ± 3	32 ± 3	1422 ± 14	801 ± 21	582 ± 13	.95 ± .12	PC
240-3-S7	V	44 ± 4	15 ± 3	144 ± 3	6 ± 3	26 ± 2	66 ± 3	41 ± 2	nm	536 ± 14	466 ± 13	.69 ± .12	PP
240-3-S17	V	87 ± 4	19 ± 3	202 ± 3	0 ± 4	65 ± 2	173 ± 3	91 ± 2	nm	449 ± 14	618 ± 13	1.25 ± .12	OR
240-3-S19	V	101 ± 5	27 ± 3	225 ± 4	3 ± 3	77 ± 2	189 ± 4	108 ± 2	nm	482 ± 16	563 ± 14	1.10 ± .12	OR
240-4-1(R)	V	89 ± 4	21 ± 3	196 ± 3	2 ± 3	67 ± 2	165 ± 3	93 ± 2	nm	454 ± 15	599 ± 13	1.21 ± .12	OR
240-4-2(R)	V	87 ± 4	22 ± 3	203 ± 3	32 ± 3	69 ± 2	173 ± 3	94 ± 2	nm	434 ± 14	566 ± 13	1.17 ± .12	OR
240-4-3	V	170 ± 5	39 ± 3	540 ± 5	5 ± 3	103 ± 2	140 ± 4	235 ± 2	nm	196 ± 14	707 ± 13	1.04 ± .12	GR
240-4-4(R)	V	77 ± 3	23 ± 3	290 ± 3	4 ± 3	57 ± 2	86 ± 3	87 ± 2	nm	363 ± 12	1094 ± 13	.66 ± .12	NA
240-4-5(R)	V	168 ± 5	31 ± 3	588 ± 5	4 ± 3	91 ± 2	126 ± 4	206 ± 2	nm	251 ± 15	816 ± 14	.80 ± .12	GR
240-4-6(R)	V	46 ± 4	16 ± 3	119 ± 3	65 ± 3	25 ± 2	84 ± 3	24 ± 2	987 ± 13	602 ± 22	481 ± 13	.70 ± .12	UK
240-4-7(R)	V	90 ± 4	27 ± 3	197 ± 3	0 ± 4	68 ± 2	172 ± 3	94 ± 2	nm	439 ± 14	575 ± 13	1.17 ± .12	OR
240-4-S12	V	87 ± 4	23 ± 3	199 ± 3	7 ± 3	65 ± 2	174 ± 4	95 ± 2	nm	459 ± 15	566 ± 13	1.17 ± .12	OR
240-G-1(R)	V	37 ± 4	17 ± 3	106 ± 3	31 ± 3	22 ± 2	92 ± 3	47 ± 2	307 ± 12	595 ± 17	501 ± 13	.79 ± .12	CC
240-G-2(R)	V	88 ± 4	27 ± 3	210 ± 3	3 ± 3	68 ± 2	179 ± 4	99 ± 2	nm	435 ± 14	555 ± 13	1.13 ± .12	OR
240-G-3(R)	V	101 ± 4	26 ± 3	207 ± 4	3 ± 3	71 ± 2	180 ± 4	100 ± 2	nm	475 ± 16	560 ± 13	1.15 ± .12	OR
240-G-4(R)	V	92 ± 4	29 ± 3	217 ± 4	0 ± 4	73 ± 2	183 ± 4	101 ± 2	nm	479 ± 15	559 ± 13	1.16 ± .12	OR
240-G-5(R)	V	84 ± 4	21 ± 3	197 ± 3	3 ± 3	64 ± 2	167 ± 4	91 ± 2	nm	453 ± 16	618 ± 13	1.23 ± .12	OR
240-G-6(R)	V	157 ± 5	32 ± 3	485 ± 4	4 ± 3	93 ± 2	136 ± 3	224 ± 3	nm	229 ± 14	603 ± 13	.96 ± .12	GR
240-G-7(R)	V	146 ± 4	34 ± 3	466 ± 4	4 ± 3	91 ± 2	128 ± 3	209 ± 2	nm	167 ± 14	706 ± 13	1.06 ± .12	GR
241-1-1(R)	FP	108 ± 5	26 ± 4	224 ± 4	2 ± 3	76 ± 2	195 ± 4	103 ± 2	nm	529 ± 18	511 ± 14	1.10 ± .12	OR

241-1-S20	FP	92 ± 5	24 ± 3	204 ± 4	2 ± 3	66 ± 2	173 ± 4	92 ± 2	nm	446 ± 16	585 ± 14	1.18 ± .12	OR
241-2-2(R)	FP	92 ± 4	19 ± 3	207 ± 3	2 ± 3	72 ± 2	177 ± 4	99 ± 2	nm	424 ± 14	547 ± 13	1.13 ± .12	OR
241-2-3(R)	FP	83 ± 4	21 ± 3	186 ± 3	3 ± 3	62 ± 2	160 ± 4	86 ± 2	nm	461 ± 17	590 ± 14	1.25 ± .12	OR
241-2-4(R)	FP	148 ± 5	31 ± 3	551 ± 5	4 ± 3	86 ± 2	113 ± 3	188 ± 2	nm	149 ± 14	882 ± 14	.83 ± .12	GR
241-3-1(R)	FP	80 ± 5	17 ± 4	67 ± 3	223 ± 4	20 ± 2	196 ± 4	14 ± 2	nm	4696 ± 44	861 ± 15	5.80 ± .12	NO
241-3-2(R)	FP	102 ± 4	24 ± 3	212 ± 3	1 ± 3	70 ± 2	175 ± 2	98 ± 2	nm	476 ± 16	582 ± 13	1.21 ± .12	OR
241-3-3(R)	FP	1.78 ± 5	33 ± 4	540 ± 5	1 ± 3	102 ± 2	144 ± 4	238 ± 3	nm	249 ± 14	667 ± 14	1.01 ± .12	GR
241-3-4(R)	FP	102 ± 5	30 ± 3	224 ± 4	2 ± 3	75 ± 2	189 ± 4	100 ± 2	nm	498 ± 17	575 ± 14	1.19 ± .12	OR
241-3-5(R)	FP	91 ± 4	20 ± 3	194 ± 3	2 ± 3	63 ± 2	177 ± 4	95 ± 2	nm	436 ± 15	524 ± 13	1.09 ± .12	OR
241-3-6(R)	FP	176 ± 6	34 ± 4	589 ± 6	5 ± 3	86 ± 3	120 ± 4	200 ± 3	nm	273 ± 17	795 ± 15	.80 ± .12	GR
241-3-S16	FP	97 ± 4	25 ± 3	216 ± 3	2 ± 3	70 ± 2	189 ± 4	100 ± 2	nm	482 ± 14	577 ± 13	1.18 ± .12	OR
242-1-1(R)	TM	43 ± 4	16 ± 3	143 ± 3	7 ± 3	26 ± 2	68 ± 3	44 ± 2	nm	472 ± 13	465 ± 13	.66 ± .12	PP
242-2-1(R)	TM	97 ± 5	20 ± 4	210 ± 4	3 ± 3	69 ± 2	182 ± 4	98 ± 2	nm	478 ± 18	523 ± 14	1.09 ± .12	OR
242-2-2(R)	TM	178 ± 4	35 ± 3	537 ± 4	6 ± 3	99 ± 2	145 ± 3	234 ± 2	nm	186 ± 13	724 ± 13	1.06 ± .12	GR
242-2-S2	TM	68 ± 4	19 ± 3	45 ± 3	797 ± 5	19 ± 2	212 ± 4	21 ± 2	nm	4035 ± 36	682 ± 14	4.71 ± .12	NO
242-2-S9	TM	78 ± 4	22 ± 3	175 ± 3	3 ± 3	59 ± 2	160 ± 3	89 ± 2	nm	420 ± 15	532 ± 13	1.11 ± .12	OR
242-2-S14	TM	91 ± 4	26 ± 3	200 ± 3	2 ± 3	69 ± 2	175 ± 4	95 ± 2	nm	463 ± 15	552 ± 13	1.15 ± .12	OR
242-2-S15	TM	99 ± 4	22 ± 3	211 ± 3	2 ± 3	67 ± 2	180 ± 4	99 ± 2	nm	472 ± 16	579 ± 13	1.19 ± .12	OR
243-G-1	RA	50 ± 4	20 ± 3	154 ± 3	7 ± 3	28 ± 2	72 ± 3	48 ± 2	nm	478 ± 15	414 ± 13	.61 ± .12	PP
243-G-2	RA	46 ± 4	18 ± 3	150 ± 3	7 ± 3	27 ± 2	70 ± 3	46 ± 2	nm	492 ± 14	432 ± 13	.62 ± .12	PP
243-G2-S10	RA	42 ± 4	14 ± 3	151 ± 3	5 ± 3	24 ± 2	71 ± 3	47 ± 2	nm	419 ± 14	413 ± 13	.61 ± .12	PP
243-G2-S11	RA	44 ± 3	14 ± 3	149 ± 3	5 ± 3	26 ± 2	73 ± 3	47 ± 2	nm	443 ± 14	426 ± 13	.63 ± .12	PP
245-2-1	FP	86 ± 4	24 ± 3	194 ± 3	1 ± 4	62 ± 2	164 ± 3	87 ± 2	nm	430 ± 15	609 ± 13	1.24 ± .12	OR
246-3-1	FP	136 ± 4	33 ± 3	526 ± 4	4 ± 3	82 ± 2	115 ± 3	182 ± 2	nm	160 ± 13	975 ± 14	.89 ± .12	GR
246-3-2	FP	90 ± 4	23 ± 3	197 ± 3	1 ± 3	65 ± 2	168 ± 3	89 ± 2	nm	450 ± 15	610 ± 13	1.26 ± .12	OR
248-2-1	V	83 ± 4	23 ± 3	192 ± 3	1 ± 6	63 ± 2	163 ± 3	89 ± 2	nm	422 ± 14	601 ± 13	1.22 ± .12	OR
249-3-3	V	81 ± 4	21 ± 3	190 ± 3	0 ± 5	66 ± 2	169 ± 3	89 ± 2	nm	408 ± 13	562 ± 13	1.15 ± .12	OR
249-3-4	V	84 ± 4	21 ± 3	193 ± 3	1 ± 3	66 ± 2	162 ± 3	93 ± 2	nm	457 ± 15	611 ± 13	1.25 ± .12	OR
249-3-5	V	85 ± 4	16 ± 3	184 ± 3	2 ± 3	61 ± 2	162 ± 3	86 ± 2	nm	410 ± 14	561 ± 13	1.16 ± .12	OR
250-G-1	V	111 ± 5	23 ± 4	215 ± 4	0 ± 5	66 ± 2	187 ± 4	103 ± 2	nm	496 ± 17	537 ± 14	1.11 ± .12	OR
250-G-1a	V	88 ± 4	25 ± 3	187 ± 3	1 ± 4	63 ± 2	162 ± 3	88 ± 2	nm	431 ± 15	610 ± 13	1.23 ± .12	OR
250-4-1	V	93 ± 4	23 ± 3	214 ± 3	2 ± 3	72 ± 2	184 ± 3	95 ± 2	nm	526 ± 15	600 ± 13	1.20 ± .12	OR
250-4-2	V	157 ± 4	35 ± 3	567 ± 4	4 ± 3	87 ± 2	117 ± 3	192 ± 2	nm	203 ± 13	894 ± 13	.85 ± .12	GR

(Continued)

Table IV. *Continued*

Specimen LS#	Collection Locality	Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Ti	Mn	Fe_2O_3	Source
249-3-2	V	88 ± 5	19 ± 4	182 ± 4	5 ± 3	63 ± 2	170 ± 4	89 ± 2	nm	479 ± 19	598 ± 15	1.13 ± .12	OR
252-2-1	TM	87 ± 5	25 ± 3	217 ± 4	2 ± 3	71 ± 2	179 ± 4	99 ± 2	nm	398 ± 16	533 ± 14	1.11 ± .12	OR
252-2-1a	TM	94 ± 4	22 ± 3	209 ± 3	2 ± 3	67 ± 2	177 ± 4	102 ± 2	nm	412 ± 14	537 ± 13	1.12 ± .12	OR
252-G2-S2	TM	47 ± 4	17 ± 3	154 ± 3	7 ± 3	25 ± 2	71 ± 3	46 ± 2	nm	546 ± 14	460 ± 13	.67 ± .12	PP
253-G2-S1	RA	46 ± 5	13 ± 4	144 ± 3	6 ± 3	22 ± 2	70 ± 3	44 ± 2	nm	517 ± 18	434 ± 14	.64 ± .12	PP

(R) = randomly selected; S# = subjectively selected; V = Vado collection locality; FP = Fillmore Pass collection locality; TM = Tortugas Mtn. collection locality; RA = Rincon Arroyo collection locality; all values in ppm (parts per million); nm = not measured; OR = Obsidian Ridge; GR = Grants Ridge; PP = Polvadera Peak; NA = No Agua; CC = Canovas Canyon; PC = Paliza Canyon; NO = not obsidian; UK = unknown. Analysis done by Dr. Richard Hughes; instrumentation was an energy dispersive X-ray fluorescence spectrometer.

Table V. Obsidian sources represented in the Rio Grande gravels.

	Fillmore Pass Collection Area		Rincon Arroyo Collection Area		Tortugas Mountain Collection area		Vado Collection area		Totals	
									#	%
Obsidian Ridge (random)	7	10.29	0		1	1.47	15	22.06	23	33.82
Obsidian Ridge (selected)	3	4.41	0		5	7.35	12	17.65	20	29.41
Canovas Canyon (random)	0		0		0	0	2	2.94	2	2.94
Canovas Canyon (selected)	0		0		0	0	0		0	
Grants Ridge (random)	3	4.41	0		1	1.47	4	5.88	8	11.76
Grants Ridge (selected)	1	1.47	0		0	0	2	2.94	3	4.41
No Agua (random)	0		0		0	0	1	1.47	1	1.47
No Agua (selected)	0		0		0	0	0		0	
Paliza Canyon ? (random)	0		0		0	0	1	1.47	1	1.47
Paliza Canyon (selected)	0		0		0	0	0		0	
Polvardera (random)	0		2	2.94	1	1.47	0		3	4.41
Polvadera (selected)	0		3	4.41	1	1.47	1	1.47	5	7.35
Unknown (random)	0		0	0	0	0	2	2.94	2	2.94
Unknown (selected)	0		0	0	0	0	0		0	
Total random	10	14.71	2	2.94	3	4.41	25	36.76	40	58.82
Total selected	4	5.88	3	4.41	6	8.82	15	22.06	28	41.18
Total	14	20.59	5	7.35	9	13.24	40	58.82	68[a]	100

[a] Two specimens were determined not to be obsidian and are not included in these tabulations.

Table VI. Rio Grande obsidian gravel composition based on this study.

	Percent of Obsidian
Jemez Caldara sources	
Obsidian Ridge	63.0
Canovas Canyon	3.0
Paliza Canyon	1.0
Polvadera	12.0
Mount Taylor volcanic field	
Grants Ridge	1.60
No Agua peaks	
No Agua	1.0
Unknown source	3.0

et al. (1998) point out that this absence is likely because Valles Caldera containing the Cerro del Medio source is younger than the deposits of the Santa Fe group.

Morphologically, the obsidian pebbles collected ranged in shape from elongated spherical pebbles to round disks and from 1 to > 6 cm. The disk pebbles and those < 5 cm would be difficult or impossible to reduce and would probably not be present in archaeological assemblages. The disk pebbles appear to be confined to Obsidian Ridge specimens. Obsidian Ridge materials were the heaviest at a maximum weight of 65.23 grams (from the Fillmore Pass locality), with Grants Ridge second at 47.78 g (from the Vado locality) with Polvadera and No Agua considerably smaller. Pebble weights from each of the localities are presented in Figures 5, 6, 7, and 8.

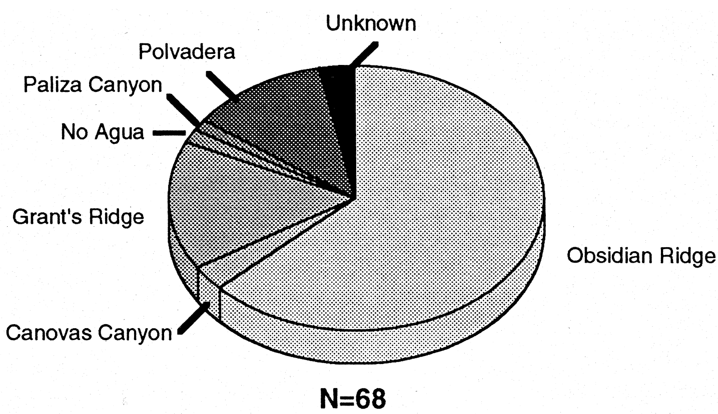

Figure 4. Source composition of submitted Rio Grande pebble obsidian based on XRF analysis.

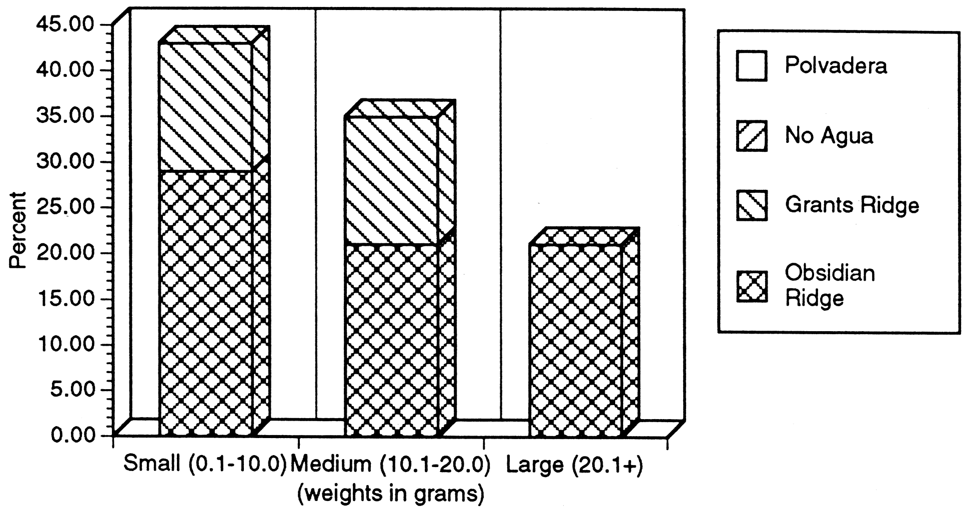

Figure 5. Obsidian pebble weights by source for the Fillmore Pass locality.

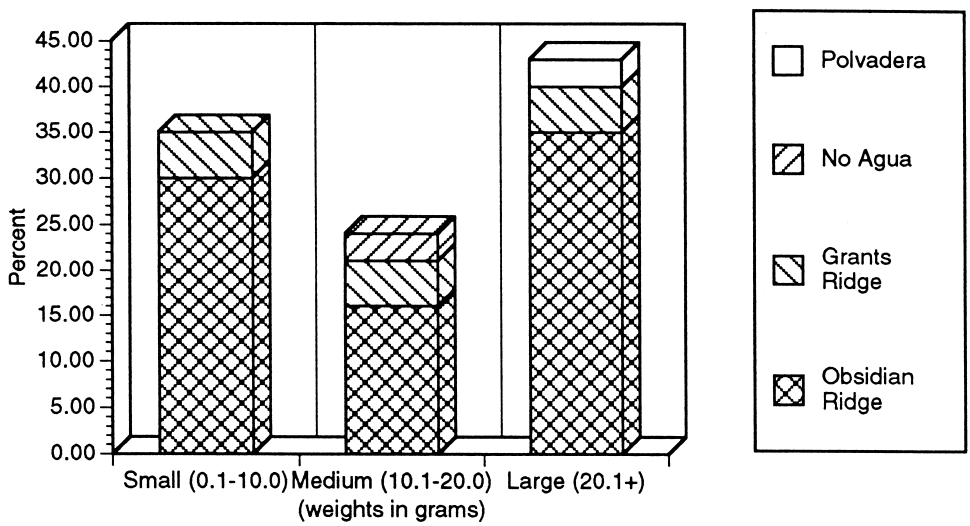

Figure 6. Obsidian pebble weights by source for the Vado locality.

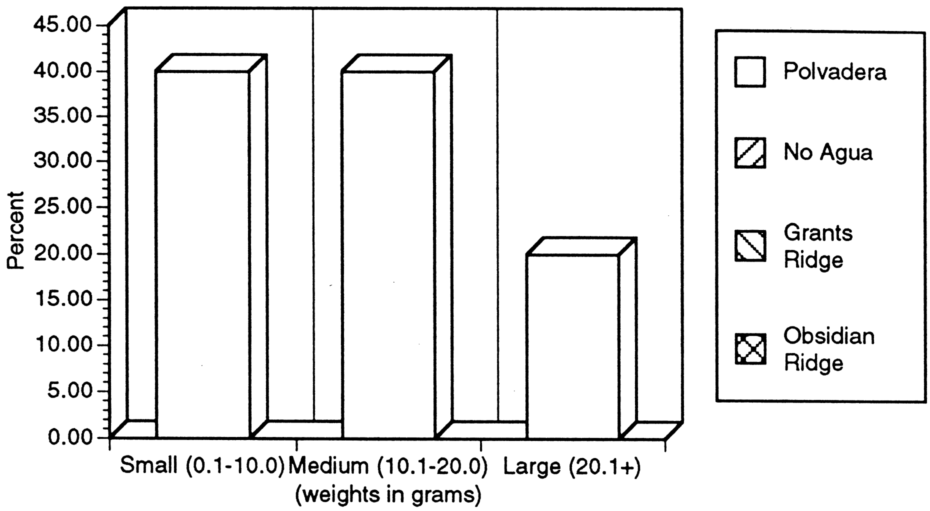

Figure 7. Obsidian pebble weights by source for the Rincon Arroyo locality (Polvadera is only source present).

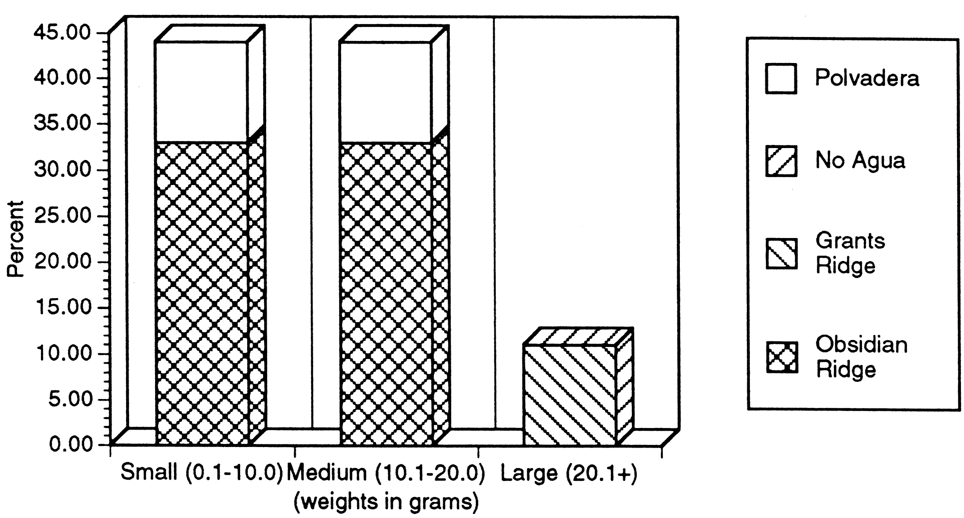

Figure 8. Obsidian pebble weights by source for the Tortugas Mountain locality.

ARCHAEOLOGICAL IMPLICATIONS

Secondary sources of lithic materials contained in stream and glacial deposits have been traditionally scorned by archaeologists because they have been thought of as difficult to investigate, ambiguous, and of less value than primary sources. As McCutcheon and Dunnell (1993, p. 1) state, "Secondary sources are troublesome subjects compared to bedrock sources. Gravel deposits can contain rock from many bedrock sources, a feature that can make them especially attractive as sources to prehistoric consumers. They also display the added complication of transport variables. Consequently, secondary sources are generally understudied." Yet to understand the complexities of lithic procurement, such secondary sources must be examined and their role in the overall procurement system understood. The importance of chipped stone materials from secondary deposits has often been overlooked. Fortunately, the situation has begun to change with the publication or presentation of several archaeological studies of secondary sources (e.g., Lavin and Prothero, 1992; Shelley, 1993).

The reduction of stream gravels has been investigated in a number of areas. Brink (1992) reports the use of large stream boulders in the Northwest Territories of Canada as anvils. These anvil boulders were used as platforms upon which quartzite cobbles could be reduced. Around these anvil boulders lie much resulting debitage. Archaeological investigations of historic and contemporary stream deposits in northern Canada have confirmed that because desirable pebbles and cobbles are scattered throughout stream deposits, much of the reduction debris associated with them consists of a few large testing flakes dispersed over the area (Mason and Polokylo, 1992; Pilon, 1990). One such historic site investigated later by archaeologists was reported by Alexander Mackenzie in 1789. He wrote, "a strong party of Esquimaux occasionally ascends this river, in large canoes, in search of flint stones, which they employ to point their spears and arrows" (Pilon, 1990:258).

The manufacture of usable tools (versus piles of small flakes) from small pebbles presents obvious problems. Prehistoric knappers apparently adopted a nearly uniform reduction method to deal with these problems: the bipolar technique (Shott, 1989). This technique requires the use of an anvil stone upon which the pebble is held and a hammerstone to strike the pebble. Honea's work in northern New Mexico and Texas found that such anvil stone lithologies included sandstone, basalt, and rhyolite and often had a depression or pit on one face. Apparently these depressions were the result of battering during reduction, but in some cases, pitted stones were apparently shaped prior to use. Honea (1965:261) states, "They [the flakes] are usually about three-quarters the length of the pebble core and are commonly longer than they are wide." Sometimes flakes are detached simultaneously from both ends of the core. More often than not, those coming off the distal or lower end of the core are both smaller and shorter than those coming off the top. "Occasionally, a bipolar flake, approximately equal in length to the pebble core, will exhibit a major bulb of percussion on the proximal end and a minor bulb of percussion on the distal end of the inside or flat face" (Honea 1965:261–262). Honea suggests three types of bipolar cores: the single-ended, the double-ended, and the multi-platformed. Honea's (1965:264) experiments "showed that pebble cores were more effectively worked in conjunction with stationary anvils of stone." Magne's (1985) reduction experiments indicate that bipolar reduction of obsidian result in the production, in almost equal quantities, of platform flakes and shatter; more recent work has focused on the debitage variability resulting from bipolar reduction (Kuijt et al., 1995) and how that might be reflected in archaeological assemblages (Kuijt and Russell, 1993:667–680).

There is a general assumption in archaeology that material from primary sources is more costly up front (in procurement) and less costly later (in reduction), while tertiary sources (deposits of discarded artifacts) are less costly to procure but have a higher cost in reduction (reflective of the limitations that the size and shape of these culturally modified materials would impose), while secondary sources offer both a lower procurement cost and a lower reduction cost. However, these general suggestions are subject to a number of variables. For instance, I suggest that reduction costs increase with diminished size. That is, a large cobble is less costly to reduce than a small pebble, simply because a knapping error with a small pebble will render the whole piece useless, while the same error on a larger cobble probably will not.

PREHISTORIC USE OF RIO GRANDE GRAVELS

Two archaeological investigations completed in south-central New Mexico are of particular relevance to this discussion. In a cultural resource survey of the West Mesa area south of Las Cruces, Camilli (1988) found that glassy volcanics formed the highest proportions of Archaic and Formative assemblages. "A high incidence of cortical platforms and dorsal cortex on obsidian flakes, as well as their small size, is evidence for the reduction of local obsidian nodules" (Camilli, 1988:157). Quartzite, another material found in the project area, mainly in the Rio Grande gravels, comprised 5–28% of the dated assemblages and 8% of the undated assemblages (Camilli, 1988: Table 2). Quartzite is not present in primary deposits in the immediate area of Las Cruces.

The second archaeological investigation was excavations undertaken by Giese (1994) at several sites near Tortugas Mountain, in the same area as the gravel collections discussed previously. The data from these excavations provide evidence that the historic Fort Selden Formation gravels[1] were an important source of materials for people of the Rio Grande valley from at least 1910–1050 years ago (Giese, 1994). These sites differ from most sites in the area for their almost total

[1] Giese, based on information supplied to him, wrongly classifies these deposits as "Pleistocene" "deposited by Rio Grande 500,000 years ago" (Giese, 1994:6). The deposits in question are clearly mapped as Fort Selden Formation by Seager et al. (1987). The Fort Selden Formation covers about 11.2 % of Ruhe's study area near Las Cruces, and he concludes that this deposition began about 4900 yr B.P. and extended to less than 1100 yr B.P. (Ruhe, 1967:39). Ruhe's interpretation has been refined but remains accepted by geomorphologists working in the area.

lack of groundstone, including identifiable anvil stones. Further, the results of debitage analysis of one of these sites "is strongly indicative of complete tool manufacturing processes occurring on this site throughout its life" (Giese 1994:68). The artifactual raw materials evident at the same site were 59.8% chert, 8.6% chalcedony, and 7.5% obsidian. Again, sedimentary formations that would contain primary outcrops of chert and chalcedony are not present in the immediate vicinity of the site. Giese (1994:64) sums up his interpretation:

> There is no question that high quality lithic materials were intentionally selected to produce the formal tools manufactured on NMSU 1565 throughout the use-life of the site. This supports a conclusion that the location of the NMSU 1565 and the TMAP sites was dictated by the local abundance of high quality lithic raw materials. That there was continuity in the functional use of these sites, as it pertains to lithic procurement and processing, for over 2,000 years is also strongly suggested.

Because of limited funding, Giese was only able to submit two obsidian specimens for source determination and hydration. Both specimens originated at Obsidian Ridge, the dominant obsidian source present in the Rio Grande gravels (Jackson, 1994).

Amick's (1996: Table 1) recent study of Folsom assemblages in New Mexico seems to indicate that Rio Grande gravels were heavily exploited in the Albuquerque Basin (providing 79% of the materials), moderately exploited in the Jornada del Muerto (providing 39.5%), and least exploited in the Tularosa Basin (providing 26.9%). However, Amick does not provide the classification criteria used to arrive at these figures, nor does he discuss the error rates of his classification, so that the validity of these figures is open to question.

Procurement of material from the Rio Grande gravels in south-central New Mexico would have been limited by several conditions. The first is that access to these deposits is variable because the geomorphic processes are dynamic; they can be subject to repeated cycles of exposure, burial, exposure. Because of their instability and variable access, exposures are only moderately predictable. There is no assurance that a productive exposure will be productive again next visit. However, the general presence and location of the gravels overall (not just usable materials) is much more stable and predictable (long-term access is another issue and is discussed below). In other words, prehistoric populations could count on the gravels exposed in the Fillmore Pass area, for example, as a lithic source terrain, but specific locations within that terrain that were rich in usable materials on one visit might not be productive in a later visit. Further, deposits of the Camp Rice and Palomas Formations, which are otherwise buried, are exposed in fault areas throughout the southern basins and might have provided prehistoric populations with isolated windows for procurement in areas otherwise devoid of exposures of these materials (Mack and Seager, 1990; Collins and Raney, 1990, 1994).

Several specific factors may have influenced the distribution and exposure of gravels in the area around Las Cruces, New Mexico to El Paso, Texas. Paleoclimatic data indicate that this area was dominated by grasslands until 9000 B.P. with a gradual transition to desert shrubs by 7000 B.P. Given this vegetative cover, surface visibility of gravel deposits was probably considerably lower, with ground surface visibility only 10–30% as opposed to 80–95% today. This would mean that procurement of Rio Grande gravels prior to 9000 B.P. would have been more costly, and probably impossible in areas. Therefore, a decrease in visibility of 60% (from 90% to 30%) would result in a proportional procurement cost increase. Finally, beginning about 7000 B.P., alluvial fan building increased, particularly off the Organ Mountains, which could have diminished the surface area of exposed Rio Grande gravels by burying them under these fans. This would have had the greatest impact in the Fillmore Gap area where Camp Rice Formation deposits (laid down by the ancestral Rio Grande) would have been covered by the advance of fans (from Boulder and South Canyons). At the same time, the decrease in grass cover would have exposed considerable areas of gravels. Finally, lithic material deposited in the Fillmore member of the Fort Selden Formation was not available prior to 5000 years B.P., the beginning of deposition for the member. All these factors would have restricted procurement in one way or another and in terms of both short- and long-term temporal access. Given these assumptions, exposures of Rio Grande gravels may have been severely restricted until about 9000 B.P. With the disappearance of the grasslands, exposures of gravels would have increased to their maximum with subsequent reduction in areal exposure due to fan building. If true, we could expect gravel lithic materials to be rare in Paleoindian assemblages and common in Archaic and later assemblages.

Evidence from my own collecting and from data generated by Giese (1994) indicate that the different Rio Grande deposits, ancestral and historic, contain different amounts of the various flaked stone materials. Specifically, the historic Fort Selden Formation contains significantly more usable chert than does the ancestral Camp Rice Formation. Further, prehistoric populations were aware of this differential distribution and placed long-term lithic procurement and processing workshops on the chert-dominated Fort Selden Formation exposures near Las Cruces.

CONCLUSIONS

In southern New Mexico, the amount of obsidian in the Rio Grande gravels is minimal, around 1%. Based on Kuenen's work (1956:340), it appears that obsidian clasts are reduced 33% in weight after being transported 115 km. Obsidian pebbles in the Rio Grande deposits of southern New Mexico must have been transported at least 400 km, suggesting that in order to produce a 20 g pebble, a clast of obsidian originally weighing 60 g would have to enter transport.

The different localities sampled at each of the collection areas showed horizontal variation in the availability of the different materials, as did each of the collector transects done at each locality. For instance, in one area, obsidian pebbles might be noticeably more abundant than at other, nearby areas. Based on observations during these investigations of the Rio Grande gravels, usable materials in the gravels are not uniformly distributed across the landscape; their distribution can be termed patchy. These patches are three-dimensional, having length, breadth, and depth. These patches are not stable but are subject to depletion (collection of surface materials), renewal (erosion or deposition of new material), exhaustion (depletion of the patch), or burial by younger sediments not containing obsidian pebbles.

Several other observations can be made as to surficial and temporal variation in the composition of Rio Grande gravels. First, based on the age of the various deposits reviewed and the absence of certain obsidian sources in younger deposits, obsidian may not have entered the Rio Grande until relatively late, perhaps during the Pleistocene. This may be related to the recent identification of a series of impounded lakes caused by Pleistocene landslides in the foothills of the Jemez Mountains of northern New Mexico (Dethier and Reneau, 1996; Reneau and Dethier, 1996). Five landslide-lake formation sequences have been identified, some resulting in outburst floods when the dams failed. This flood sequence would support Stevenson and McCurry's (1990:156) time estimate of two phases for obsidian from the Jemez sources entering the Rio Grande, the first at about 10 million yr B.P. and the second at about 1 million yr B.P. or less. Secondly, the gravels of the northern stretches of the river are dominated by igneous and metamorphic materials, many of which are unsuitable for chipped stone use, while siliceous sedimentary stone does not become a significant component until somewhere between Albuquerque and Truth or Consequences, New Mexico.

XRF analysis of the obsidian occurring naturally in the Rio Grande gravels in south-central New Mexico clearly shows that only a few volcanic fields, namely Mount Taylor (Grants Ridge source), the Jemez Mountains (Obsidian Ridge, Paliza Canyon, Canovas Canyon, and Polvadera sources), and Mount San Antonio (No Agua source) have contributed to the gravels (Figure 1). Shackley's recent work (1998) at Mount Taylor (the Grants Ridge source) suggests that this volcanic field contains two chemically distinct obsidians, one of which was preferred by prehistoric tool makers.

Interestingly, an analysis of 50 obsidian artifacts from surveys to the west of Las Cruces resulted in 76% being identified as originating from Obsidian Ridge, 18% from Grants Ridge, 4% (two specimens) from unknown sources, and 2% from Polvadera Peak (Camilli et al., 1988). These percentages closely reflect the natural occurrence of obsidian sources in the Rio Grande gravels. Additional sources from these volcanic fields may also be present in very minimal quantities and perhaps restricted to more northerly stretches of the river.

This has several implications for archaeological interpretation of obsidian distribution (in particular for regional trend studies such as Findlow and Bolognese's 1982 study). For confirmed sources of obsidian to the Rio Grande gravels, the range of secondary distribution forms a narrow belt from the primary outcrops southward through New Mexico and into Texas. This means that archaeologists working along the Rio Grande should not automatically assume that all, or even most of the obsidian for obsidian artifacts was procured from Rio Grande gravels. LeTourneau's study of Folsom obsidian illustrates this point (LeTourneau et al., 1998). Often, identification of artifacts as originating from obsidian pebbles is based on the morphology of the obsidian with pebble morphology thought to indicate a Rio Grande gravel origin. However, Shackley's summary (1998) of the morphology of southwestern obsidian sources clearly shows that a number of other sources are also similar in form and size. More recent work in northern Chihuahua has also uncovered several pebble obsidian sources (Miller and Shackley, 1998). Stream pebbles have certain morphological attributes that enable differentiation from other kinds of pebbles (e.g., Link-Chevitch, 1959; Sames, 1966). Unwarranted assumptions may be masking important data that might be useful in mobility and exchange studies in south-central New Mexico.

Finally, in reviewing previous work on obsidian studies along the Rio Grande and Rio Puerco, a recurring problem was noted. Several investigators have established chemical groupings. Michels (1983, 1984a, 1984b, 1984c, 1984d, 1984e, 1986) established the Rio Grande gravel groups I–VIII, Stevenson and McCurry (1990) established the Rio Grande gravel groups IX–XIIII, and Shelley established the Tularosa, Cochiti, and Las Lunas gravels groups (Bowman 1987; Shelley et al. 1988). Doing so has caused much confusion. There must be a clear understanding of the difference between a chemical group and a source. A chemical group is composed of chemically similar specimens, whereas a source is geologically defined (see Hughes and Smith, 1993; and Hughes, 1998 for pertinent discussions of these issues). Archaeologists should not reference chemical groups as sources. Further, while the chemical groups established by Michels (1983, 1984a, 1984b, 1984c, 1984d, 1984e, 1986), and Stevenson and McCurry (1990) are based on chemical similarity, the groups used by Shelley (Tularosa, Cochiti, and Las Lunas Pleistocene Terrace gravels) are geographically based. That is, Shelley's groups in all likelihood represent a mix of obsidian from various primary sources, although they were collected in the same geographical area. The problem stems from the misunderstanding of the term source. In a geological, artifact-provenancing context, source means the geological formation/deposit, primary or secondary, from which the material originated. In an archaeological context, source often designates the geographical point of procurement. Investigators should take care to define secondary deposits both on their geographic location (archaeological source) and the individual primary sources (geological source) present in these deposits.

The sampling of secondary deposits such as the Rio Grande gravels poses a number of problems, particularly with minimally occurring materials, in this case obsidian pebbles. A flexible strategy that addresses both geological and archaeological issues is needed. Geologically, it is important to know the overall composition and distribution of the gravel lithology. Archaeologically, it is important to determine the type, amount, and distribution of archaeologically significant materials such as chipped stone materials for example. It is also important archaeologically to sample these deposits in terms of prehistoric procurement. In other words, we want to determine the geological context (the overall composition and distribution), and within that, what archaeologically meaningful materials are present, their nature, and, finally, how these two populations interact to shape procurement activities.

Geological sampling of secondary deposits can be done using a number of different techniques (e.g., Ashworth and Ferguson, 1989; Denny and Postel, 1964; Ibbeken and Schleyer, 1986; Rice and Church, 1996; Wolman, 1954; Wolcott and Church, 1991), depending on the specific attributes under investigation. Archaeological sampling can follow similar lines (Shelley, 1993). Sampling in order to investigate procurement behavior is another matter. Our own investigations of the time and distance costs of procurement proved valuable in assembling a true picture of the costs and benefits of obtaining lithic material from the Rio Grande gravels. Ideally, all three strategies should be used.

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REFERENCES

Amick, D.S. (1996). Regional patterns of Folsom mobility and land use in the American southwest. World Archaeology, 27, 411–426.

Andrefsky, W., Jr. (1994a). The geological occurrence of lithic material and stone tool production strategies. Geoarchaeology: An International Journal, 9, 375–391.

Andrefsky, W., Jr. (1994b). Raw-material availability and the organization of technology. American Antiquity, 59, 21–34.

Ashworth, P.J., & Ferguson, R.I. (1989). Quantifying gravel deposition on river bars using flexible netting. Journal of Sedimentary Petrology, 59, 623–625.

Belcher, R.C. (1975). The geomorphic evolution of the Rio Grande, Bulletin 29. Waco: Baylor Geological Studies, Baylor University.

Bowman, K.K. (1987). An analytic study of obsidian from the middle Rio Puerco valley, New Mexico, Master's Thesis. Portales: Eastern New Mexico University (unpublished).

Brink, J. (1992). Anvil boulders and lithic reduction on southern Victoria Island, Northwest Territories. Arctic, 45, 138–144.

Bryan, K., & McCann, F.T. (1936). Successive pediments and terraces of the upper Rio Puerco in New Mexico. Journal of Geology, 44, 145–172.

Bryan, K., & McCann, F.T. (1937).The Ceja del Rio Puerco: A border feature of the basin and range province in New Mexico, I. Stratigraphy and structure. Journal of Geology, 45, 801–828.

Bryan, K., & McCann, F.T. (1938).The Ceja del Rio Puerco: A border feature of the basin and range province in New Mexico, II. Geomorphology. Journal of Geology, 47, 1–16.

Camilli, E.L. (1988). Lithic raw material selection and use in the desert basins of south-central New Mexico. The Kiva, 53, 147–163.

Camilli, E.L., Wandsnider, L., & Ebert, J.I. (1988). Distributional survey and excavation of archaeological landscapes in the vicinity of El Paso, Texas. Las Cruces: Bureau of Land Management, Las Cruces District Office.

Church, T., Caraveo, C., Jones, R., & Sirianni, J. (1996). Mountains and basins: The lithic landscape of the Jornada Mogollon, Archaeological Technical Reports 8. El Paso: Anthropology Research Center, University of Texas.

Collins, E.W., & Raney, J.A. (1990). Neotectonic history and structural style of the Campo Grande fault, Hueco Basin, Trans-Pecos Texas, Report of Investigations 196. Austin: Bureau of Economic Geology, University of Texas.

Collins, E.W., & Raney, J.A. (1994). Tertiary and Quaternary tectonics of the Hueco Bolson, Trans-Pecos Texas and Chihuahua, Mexico. In G.R. Keller & S.M. Cather (Eds.), Basins of the Rio Grande rift: Structure, stratigraphy, and tectonic setting, (pp. 265–282), Special Paper 291. Boulder: Geological Society of America.

Dake., H.C. (1952). Texas agate mecca. The Mineralogist, 20, 254–256.

Denny, C.S. (1940a). Tertiary geology of the San Acacia area, New Mexico. Journal of Geology, 48, 73–106.

Denny, C.S. (1940b). Santa Fe Formation in the Espanola Valley, New Mexico. Bulletin of the Geological Society of America, 51, 677–694.

Denny, C.S., & Postel, A.W. (1964). Rapid method of estimating lithology of glacial drift of the Adirondack Mountains, New York. U.S. Geological Survey Professional Paper, 501B, B143–B145.

Dethier, D.P., & Reneau, S.L. (1996). Lacustrine chronology links late Pleistocene climate change and mass movements in northern New Mexico. Geology, 24, 539–542.

Dickerson, P.W., & Muehlberger, W.R. (1994). Basins in the Big Bend segment of the Rio Grande rift, Trans-Pecos Texas. In G.R. Keller & S.M. Cather (Eds.), Basins of the Rio Grande Rift: Structure, stratigraphy, and tectonic setting (pp. 283–297), Special Paper 291. Boulder: Geological Society of America.

Evans, G.L. (1961). Notes on terraces of the Rio Grande, Falcon-Zapata area, Texas. Bulletin of the Texas Archaeological Society, 32, 33–45.

Fahnestock, R.K., & Haushild, V.L. (1962). Flume studies of the transport of pebbles and cobbles on a sand bed. Geological Society of America Bulletin, 73, 1431–1436.

Findlow, F.J., & Bolognese, M. (1982). Regional modeling of obsidian procurement in the American southwest. In J.E. Ericson & T.K. Earle (Eds.), Contexts for prehistoric exchange (pp. 53–81). New York: Academic Press.

Foley, M.G. (1977). Gravel-lens formation in antidune-regime flow: A quantitative hydrodynamic indicator. Journal of Sedimentary Petrology, 47, 738–746.

Geise, R.W. (1994) Human subsistence and adaptation in the Mesilla Valley, New Mexico: 1000 B.C.–A.D. 1000, Master's Thesis. Las Cruces: New Mexico State University (unpublished).

Goede, A. (1975). Downstream changes in shape in the pebble morphometry of the Tambo River, eastern Victoria. Journal of Sedimentary Petrology, 45, 704–718.

Grunwald, T.W. (1990). Depositional environments and paleosols of the Palomas Formation (Plio-Pleistocene), Palomas Basin, southern Rio Grande rift, Master's Thesis. Las Cruces: New Mexico State University (unpublished).

Gustavson, T.C. (1990). Stratigraphy and geomorphic evolution of southern Hueco Bolson, West Texas and Chihuahua, Mexico. West Texas Geological Society, 30, 5–28.

Gustavson, T.C. (1991). Arid basin depositional systems and paleosols: Fort Hancock and Camp Rice Formations (Pliocene–Pleistocene), Hueco Bolson, West Texas and adjacent Mexico, Report of Investigations 198. Austin: Bureau of Economic Geology, University of Texas.

Hassan, M.A., & Church, M. (1992). Virtual rate and mean distance of travel of individual clasts in gravel-bed channels. Earth Surface Processes and Landforms, 17, 616–627.

Hawley, J.W. (1965). Geomorphic surfaces along the Rio Grande Valley from El Paso, Texas to Caballo reservoir, New Mexico. In Guidebook, 16th Field Conference, southwestern New Mexico (pp. 188–198). Socorro: New Mexico Geological Society.

Hawley, J.W., & Kottlowski, F.E. (1969). Quaternary geology of the south-central New Mexico border region. In F.E. Kottlowski & D.V. LeMone (Eds.), Border stratigraphy symposium (pp. 89–115). Socorro: New Mexico Bureau of Mines and Mineral Resources.

Hawley, J., Kottlowski, F.E., Seager, W.R., King, W.E., Strain, W.S., & LeMone, D.V. (1969). The Santa Fe Group in the south-central New Mexico Border region. In F.E. Kottlowski & D.V. LeMone (Eds.), Border stratigraphy symposium (pp. 52–76). Socorro: New Mexico Bureau of Mines and Mineral Resources.

Honea, K.H. (1965). The bipolar flaking technique in Texas and New Mexico. Bulletin of the Texas Archaeological Society, 36, 259–267.

Hughes, R.A. (1996). Geochemical Research Laboratory: Letter Report 95-49. Unpublished report on file at the Directorate of Environment, Fort Bliss, Texas.

Hughes, R.A. (1998). On reliability, validity, and scale in obsidian sourcing research. In A.F. Ramenofsky & A. Steffen (Eds.), Unit issues in archaeology: measuring time, space, and material (pp. 103–114). Salt Lake City: The University of Utah Press.

Hughes, R.A., & Smith, R.L. (1993). Archaeology, geology, and geochemistry in Obsidian provenance studies. In J.K. Stein & A.R. Linse (Eds.), Effects of scale on archaeological and geoscientific perspectives (pp. 79–91). Boulder: Geological Society of American.

Ibbeken, H., & Schleyer, R. (1986). Photo-sieving: A method for grain-size analysis of coarse-grained, unconsolidated bedding surfaces. Earth Surface Processes and Landforms, 11, 59–77.

Jackson, T.L. (1994). Report of X-ray fluorescence analysis of artifact obsidian from NMSU 1624. In R.W. Geise (author), Human subsistence and adaptation in the Mesilla Valley, New Mexico: 1000 B.C.–A.D. 1000 (pp. 157–158), Master's Thesis. Las Cruces: New Mexico State University (unpublished).

Jones, L.S., & Humphrey, N.F. (1997). Weathering-controlled abrasion in a coarse-grained, meandering reach of the Rio Grande: Implications for the rock record. Geological Society of American Bulletin, 109, 1080–1088.

Kelley, V.C. (1952). Tectonics of the Rio Grande depression of central New Mexico. In Guidebook of the Rio Grande country, central New Mexico (pp. 93–105). Socorro: New Mexico Geological Society.

Kelson, K.I., & Wells, S.G. (1989). Geologic influences on fluvial hydrology and bedload transport in small mountainous watersheds, northern New Mexico, U.S.A. Earth Surface Processes and Landforms, 14, 671–690.

Kuijt, I., & Russell, K.W. (1993). Tur Imdai rockshelter, Jordan: Debitage analysis and historic bedouin lithic technology. Journal of Archaeological Science, 20, 667–680.

Kuijt, I., Prentiss, W.C., & Pokotylo, D.L. (1995). Bipolar reduction: An experimental study of debitage variability. Lithic Technology, 20, 116–127.

Kuenen, H. (1956). Experimental abrasion of pebbles: Rolling by current. Journal of Geology, 64, 336–368.

Lambert, P.W. (1968). Quaternary stratigraphy of the Albuquerque area, New Mexico, Doctoral Dissertation. Albuquerque: University of New Mexico (unpublished).

Lavin, L., & Prothero, D.R. (1992). Prehistoric procurement of secondary sources: The case for characterization. North American Archaeologist, 13, 97–113.

Leeder, M.R., Mack, G.H., & Salyards, S.L. (1996). Axial-transverse fluvial interactions in half-graben: Plio-Pleistocene Palomas Basin, southern Rio Grande rift, New Mexico, USA. Basin Research, 12, 225–241.

LeTourneau, P.D., Shackley, M.S., & Baker, T. (1998). Folsom period obsidian use in New Mexico. Paper presented at the 63rd Annual Meeting of the Society for American Archaeology, Seattle.

Link-Chevitch, P. (1959). Beach and stream pebbles. Jounal of Geology, 67, 103–108.

Lovejoy, E.M.P. (1976). A little problem concerning Fort Hancock–Camp Rice–"mixed rounded gravels" correlation in the El Paso–Las Cruces Region, as viewed by a skeptic. In E.V. LeMone & E.M.P. Lovejoy (Eds.), El Paso Geological Society Symposium on the Franklin Mountains (pp. 99–103). El Paso: El Paso Geological Society.

Lozinsky, R.P., & Bauer, P.W. (1991). Structure and basin-fill units of the Tularosa Basin. In J.M. Baker, B.S. Kues, G.S. Austin, & S.G. Lucas (Eds.), Geology of the Sierra Blanca, Sacramento and Capitan Ranges, New Mexico (pp. 7–11). Albuquerque: New Mexico Geological Society.

Lozinsky, R.P., & Hawley, J.W. (1986). Upper Cenozoic Palomas Formation of south-central New Mexico. In Truth or Consequences, New Mexico Geological Society Guidebook, 37th Field Conference (pp. 239–249). Albuquerque: New Mexico Geological Society.

Lozinsky, R.P., & Tedford, R.H. (1991). Geology and paleontology of the Santa Fe Group, southwestern Albuquerque Basin, Valencia county, New Mexico, Bulletin 132. Socorro: New Mexico Bureau of Mines and Mineral Resources.

Mack, P.D.C. (1985). Correlation and provenance of facies within the upper Santa Fe Group in the

subsurface of the Mesilla Valley, southern New Mexico, Master's Thesis. Las Cruces: New Mexico State University (unpublished).
Mack, G.H., & James, W.C. (1993). Control of basin symmetry on fluvial lithofacies, Camp Rice and Palomas Formations (Plio-Pleistocene), southern Rio Grande Rift, USA. In M. Marzo & C. Puigdefabregas (Eds.), Alluvial sedimentation (pp. 439–449), Special Publication 17. Boston: International Association of Sedimentologists, Blackwell Scientific Publications.
Mack, G.H., & Leeder, M.R. (1998). Channel shifting of the Rio Grande, southern Rio Grande rift: Implications for alluvial stratigraphic models. Sedimentary Geology, 117, 207–219.
Mack, G.H., & Seager, W.R. (1990). Tectonic control on facies distribution of the Camp Rice and Palomas Formations (Pliocene–Pleistocene) in the southern Rio Grande rift. Geological Society of America Bulletin, 102, 45–53.
Mack, G.H., Salyards, S.L., & James, W.C. (1993). Magnetostratigraphy of the Plio-Pleistocene Camp Rice and Palomas Formations in the Rio Grande rift of southern New Mexico. American Journal of Science, 293, 49–77.
Mack, G.H., James, W.C., & Salyards, S.L. (1994). Late Pliocene and early Pleistocene sedimentation as influenced by intrabasinal faulting, southern Rio Grande rift. In G.R. Keller & S.M. Cather (Eds.), Basins of the Rio Grande rift: Structure, stratigraphy, and tectonic setting (pp. 257–264), Special Paper 291. Boulder: Geological Society of America.
Magne, M.P.R. (1985). Lithic and livelihood: Stone tool technologies of central and southern Interior British Columbia, Mercury Series 133. Ottawa: National Museum of Man.
Mason, A.R., & Polokylo, D.L. (1992). Now you see it, now you don't—a contemporary stone tool quarry site at Willowlake River, NWT. The Musk-Ox, 39, 335.
Mauldin, R., Graves, T., & Bentley, M. (1998). Small sites in the central Hueco Bolson: A final report on Project 90-11. Fort Bliss, Texas: Conservation Division, Directorate of Environment, U.S. Army Air Defense Artillery Center.
McCutcheon, P.T., & Dunnell, R.C. (1993). Quantifying lithic raw material variability of Crowley's Ridge gravel, southeast Missouri. Paper presented at the 58th Annual Society for American Archaeology Meetings, St. Louis.
McGrath, D.B., & Hawley, J.W. (1987). Geomorphic evolution and soil-geomorphic relationships in the Socorro area, central New Mexico. In V.T. McLemore & M.R. Bowie (Eds.), Guidebook to the Socorro area, New Mexico (pp. 55–59). Socorro: New Mexico Bureau of Mines and Mineral Resources.
McGregor, D.E. (1995). Lithic resource availability in the upper Trinity River Region: The evidence from Joe Pool Lake. Advances in Texas Archeology: Contributions from Cultural Resource Management, 1, 187–202.
Michels, J. (1983). Hydration rate constants for Rio Grande gravels Group 2, Dona Ana County, New Mexico, Technical Report 27. State College, Pennsylvania: MOHLAB.
Michels, J. (1984a). Hydration rate constants for Rio Grande gravels Group 1, Dona Ana County, New Mexico, Technical Report 32. State College, Pennsylvania: MOHLAB.
Michels, J. (1984b). Hydration rate constants for Rio Grande gravels Group 3, Dona Ana County, New Mexico, Technical Report 37. State College, Pennsylvania: MOHLAB.
Michels, J. (1984c). Hydration rate constants for Rio Grande gravels Group 4, Dona Ana County, New Mexico, Technical Report 38. State College, Pennsylvania: MOHLAB.
Michels, J. (1984d). Hydration rate constants for Rio Grande gravels Group 6, Dona Ana County, New Mexico, Technical Report 36. State College, Pennsylvania: MOHLAB
Michels, J. (1984e). Hydration rate constants for Rio Grande gravels Group 7, Dona Ana County, New Mexico, Technical Report 43. State College, Pennsylvania: MOHLAB,
Michels, J. (1986). Hydration rate constants for Rio Grande gravels Group 8, Dona Ana County, New Mexico, Technical Report 58. State College, Pennsylvania: MOHLAB.
Miller, M.R., & Shackley, M.S. (1998). New interpretations of obsidian procurement and movement in west Texas, southern New Mexico, and northern Chihuahua. Paper presented at the 69th Meetings of the Texas Archeological Society, Waco.
Paz, L.L. (1948). The Valverdites: A weathered obsidian form superficially resembling certain tektites. Popular Astronomy, 56, 552–558.

Pilon, J.L. (1990). *Vihtr'iitshik:* A stone quarry reported by Alexander Mackenzie on the lower Mackenzie River in 1789. Arctic, 43, 251–261.

Reid, K.C. (1997). Gravels and travels: A comment on Andrefsky's "Cascade phase lithic technology." North American Archaeologist, 18, 67–81.

Reneau, S.L., & Dethier, D.P. (1996). Late Pleistocene landslide-dammed lakes along the Rio Grande: White Rock Canyon, New Mexico. Geological Society of America Bulletin, 108, 1492–1507.

Rice, S., & Church, M. (1996). Sampling surficial fluvial gravels: The precision of size distribution percentile estimates. Journal of Sedimentary Research, 66, 654–665.

Riley, R. (1984). Stratigraphic facies analysis of the upper Santa Fe Group, Fort Hancock and Camp Rice Formations, far west Texas and south-central New Mexico, Master's Thesis. El Paso: University of Texas (unpublished).

Ruhe, R.V. (1962). Age of the Rio Grande valley in southern New Mexico. Journal of Geology, 70, 151–167.

Ruhe, R.V. (1967). Geomorphic surfaces and surficial deposits in southern New Mexico, Memoir 18. Socorro: New Mexico Institute of Mining and Technology, State Bureau of Mines and Mineral Resources.

Sames, C.W. (1966). Morphometric data of some recent pebble associations and their application to ancient deposits. Journal of Sedimentary Petrology, 36, 126–142.

Seager, W.R. (1981). Geology of the Organ Mountains and southern San Andres Mountains, Memoir 36. Socorro: New Mexico Bureau of Mines and Mineral Resources.

Seager, W.R., & Hawley, J.W. (1973). Geology of Rincon quadrangle, New Mexico, Bulletin 101. Socorro: New Mexico Bureau of Mines and Mineral Resources.

Seager, W.R., & Mack, G.H. (1991). Geology of the Garfield quadrangle, Sierra and Dona Ana Counties, New Mexico, Bulletin 128. Socorro: New Mexico Bureau of Mines and Mineral Resources.

Seager, W.R., Hawley, J.W., Kottlowski, F.E., & Kelley, S.A. (1987). Geology of the east half of Las Cruces and northeast El Paso, Geologic Map 57. Socorro: New Mexico Bureau of Mines and Mineral Resources.

Shackley, M.S. (1988). Sources of archaeological obsidian in the Southwest: An archaeological, petrological, and geochemical study. American Antiquity, 53, 752–772.

Shackley, M.S. (1992). The upper Gila River gravels as an archaeological obsidian source region: Implications for models of exchange and interaction. Geoarchaeology: An International Journal, 7, 315–326.

Shackley, M.S. (1998). Geochemical differentiation and prehistoric procurement of obsidian in the Mount Taylor Volcanic field, northwest New Mexico. Journal of Archaeological Science, 25, 1073–1082.

Shelley, P. (1993). A geoarchaeological approach to the analysis of secondary lithic deposits. Geoarchaeology: An International Journal, 8, 59–72.

Shelley, P.H., Montgomery, J.L., & Bowman, K. (1988). Obsidian sourcing and hydration studies. In T.J. Seaman, W.H. Doleman, & R.C. Chapman (Eds.), The Border Star 85 survey: Toward an archeology of landscapes (pp. 149–162). Albuquerque: Office of Contract Archeology, University of New Mexico.

Shott, M.J. (1989). Bipolar industries: Ethnographic evidence and archaeological implications. North American Archaeologist, 10, 1–24.

Smith, H.T.U. (1938). Tertiary geology of the Abiquiu quadrangle, New Mexico. Journal of Geology, 46, 933–965.

Stearns, C.E. (1953). Tertiary geology of the Galisteo-Tonque area, New Mexico. Bulletin of the Geological Society of America, 64, 459–508.

Stevenson, C.M., & McCurry, M.O. (1990). Chemical characterization and hydration rate development for New Mexican obsidian sources. Geoarchaeology: An International Journal, 5, 149–170.

Stone, T. (1994). The impact of raw-material scarcity on ground-stone manufacture and use: An example from the Phoenix Basin Hohokam. American Antiquity, 59, 680–694.

Stuart, C.J., & Willingham, D.L. (1984). Late Tertiary and Quaternary fluvial deposits in the Mesilla and Hueco Bolsons, El Paso area, Texas. Sedimentary Geology, 38, 1–20.

Uphoff, T.L. (1978). Subsurface stratigraphy and structure of the Mesilla and Hueco Bolsons, El Paso region, Texas and New Mexico, Master's Thesis. El Paso: University of Texas (unpublished).

Vanderhill, J.B. (1986). Lithostratigraphy, vertebrate paleontology, and magnetostratigraphy of Plio-Pleistocene sediments in the Mesilla Basin, New Mexico, Doctoral Dissertation. Austin: University of Texas (unpublished).

Warren, A.H. (1979). Geological and mineral resources of the Cochiti Reservoir area. In J.V. Biella & R.C. Chapman (Eds.), Archeological investigations in Cochiti Reservoir, New Mexico (pp. 47–60). Albuquerque: Office of Contract Archaeology, University of New Mexico.

Warren, A.H. (1982). Prehistoric mineral resources of the lower Rio Puerco. In P.L. Eidenbach (Ed.), Inventory survey of the lower Hidden Mountain Floodpool, lower Rio Puerco drainage, central New Mexico (pp. 67–75). Tularosa, New Mexico: Human Systems Research.

Watrall, C.R. (1976). A note on the Souris gravels. Archae-Facts, 4, 21–23.

Webster, D.A. (1966). A study of the axial and pediment gravels in the eastern part of the Santo Domingo Basin. Albuquerque: University of New Mexico (unpublished).

Wiant, M.D., & Hassen, H. (1985). The role of lithic resource availability and accessibility in the organization of technology. In S.C. Vehik (Ed.), Lithic resource procurement: Proceedings from the second conference on prehistoric chert exploitation (pp. 101–114). Carbondale: Center for Archaeological Investigations, Southern Illinois University.

Willingham, D.L. (1980). Stratigraphy and sedimentology of the upper Santa Fe Group in the El Paso region, West Texas and south-central New Mexico. El Paso: University of Texas (unpublished).

Wolcott, J., & Church, M. (1991). Strategies for sampling spatially heterogeneous phenomena: The example of river gravels. Journal of Sedimentary Petrology, 61, 534–543.

Wolman, M.G. (1954). A method of sampling coarse river-bed material. Transactions of the American Geophysical Union, 35, 951–956.

Wyckoff, D.G. (1993). Gravel sources of knappable Alibates silicified dolomite. Geoarchaeology: An International Journal, 8, 35–58.

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