Ages of Quaternary Rio Grande terrace-fill deposits, Albuquerque area, New Mexico

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Quaternary fluvial terrace-fill deposits of the Rio Grande contain a wide variety of clasts, reflecting the diverse geology of the drainage basin and the recycling of material from the Tertiary Santa Fe Group sediments. We systematically collected clast-composition data from sites (number in parentheses) representative of the Primero Alto terrace-fill (7), Segundo Alto terrace-fill (7), Tercero Alto terrace-fill (4), and Cuarto Alto terrace-fill (6) throughout the area of Fig. 2A. For comparison, we also collected clast-composition data for the Ceja Formation (6), representing the youngest basin-filling sediments of the Tertiary Santa Fe Group that accumulated before regional integration of the modern Rio Grande and incision of the through-flowing drainage (Williams and Cole 2007).

We summarize clast-composition data in this section for the fluvial deposits of each basin- or terrace-filling cycle. For each of the above, we collected data from deposits east and west of the modern Rio Grande to evaluate effects of local source-area contributions. We also collected data separately for representative populations of pebble-sized clasts (roughly 0.7–2 inches median diameter) and populations of cobble-sized clasts (greater than approximately 3 inches median diameter) to assess compositional biases related to fracture and weathering characteristics of the source rocks. We also present general statistics for rounding characteristics of various compositions in the cobble-sized populations sampled.

Regardless of clast size or site location, we determined that more than 80% of all clasts consist of one of three general (and related) rock types: (1) Precambrian quartz-rich metamorphic rocks, including massive or banded quartz-rich rocks (light brown or gray), true metasedimentary quartzite, or metamorphosed quartz-pebble conglomerate (all colloquially referred to in the literature as "quartzite"; Williams and Cole 2007); (2) Precambrian granite, pegmatite, or mylonitic granite gneiss; and (3) microporphyritic volcanic rocks of intermediate or felsic composition (probably Tertiary). The most common other clast types consist of (in approximate order of declining abundance) multi-colored aphanitic chert; so-called "Pedernal chert" (possible silicified calcrete eroded from the Pedernal Chert Member of the Abiquiu Formation north of the Jemez Mountains; Williams and Cole 2007); calcite-cemented quartzose sandstone (probably Cretaceous); basalt; feldspathic, biotite-bearing volcanic sandstone; fine-grained, fossiliferous limestone (probably Paleozoic, from Sandia Mountains area); obsidian; petrified wood; Bandelier Tuff pumice; or Precambrian biotite schist or hornblende schist.

The bar graphs in this section (Fig. S-1) display the clast-composition data for deposits of several ages in terms of the four main compositional groups, normalized to 100%: Precambrian quartz-rich metamorphic rocks (PC QTZ); Precambrian granitic and mylonitic rocks (PC GR/MY); porphyritic volcanic rocks (VLC PHY); and all OTHER clast types. Each bar graph is labeled E or W, if the sample was collected east or west of the Rio Grande, and similarly labeled C or P if the sample consisted of cobbles or pebbles, respectively.

Inspection of these bar graphs illustrates several general observations about the clast-composition data. The older deposits (Ceja Formation and Cuarto Alto terrace fill) contain the most lithologically diverse clast populations, as well as the greatest number of clasts that are not physically durable (volcanic sandstone, limestone, and quartz sandstone). The percentage of Precambrian quartz-rich metamorphic rocks generally increases (especially in the cobble-sized populations) as the age of the deposit decreases. Similarly, the percentage of Precambrian granitic and mylonitic rocks plus volcanic porphyries increases (most notable in the pebble-sized populations) as the age of the deposit decreases. These two trends are consistent with progressive winnowing of less durable clasts as the terrace-fill deposits are repeatedly recycled during progressive downcutting of the Rio Grande. These progressive trends are most notable in the cobble-sized classes for the quartz-rich metamorphic rocks because they form a higher percentage of cobble-sized clasts, overall. Similarly, the progressive trends are most notable in the pebble-sized classes for the granites and volcanic porphyries because they form a higher percentage of pebble-sized clasts, overall.

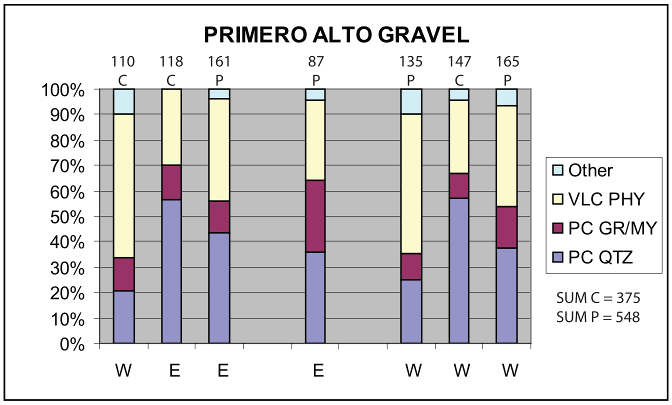
Clast rounding also increases with progressive decrease in the age of the deposit (Fig. S-2). Cuarto Alto terrace-fill clasts are commonly more angular and subangular than any of the younger terrace-fill deposits. Primero Alto terrace-fill clasts are commonly more rounded and subrounded than any of the older terrace-fill deposits.

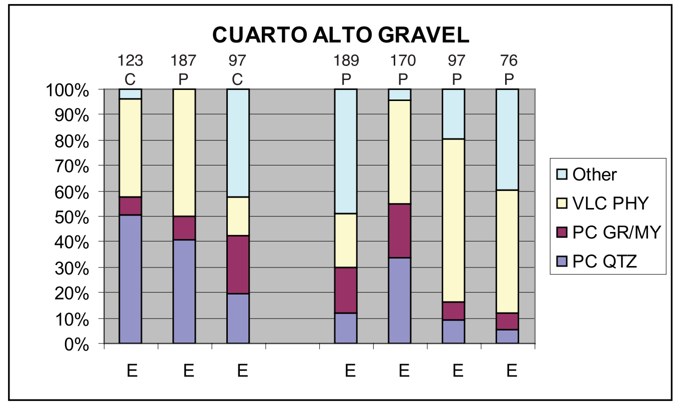
Some of the relatively minor clast constituents show some patterns that appear to be attributable to local source-area variations. For example, "Pedernal chert," quartz sandstone, and petrified wood are rare or absent in the four northernmost localities because these clast types chiefly entered the Rio Grande drainage from sources west and south of the Jemez River (Wright 1946; Lambert 1968; Kelley 1977). Fossiliferous limestone (probable Madera Limestone) only occurs in sample sites east of the Rio Grande, consistent with its limited outcrop in the Sandia Mountains (Kelley 1977). Basalt is only common in the oldest deposits (Ceja Formation and Cuarto Alto terrace fill), which probably reflects the fact that basalt was widely erupted in the basin near the end of Ceja deposition, and that the Cuarto Alto fill was the first fluvial deposition following nearly a million years of basin-wide drainage incision between about 2.5 Ma and 1.6 Ma (Cole et al. 2001a, b; 2002; Williams and Cole 2007). The fact that basalt is rare in younger deposits suggests either that it is winnowed during recycling due to weathering, or that it was not easily moved across the landscape due to its density. Biotite-bearing, feldspathic volcanic sandstone was only detected in the Ceja Formation and the Cuarto Alto terrace-fill deposits, probably because it is relatively fragile and did not survive repeated recycling; its source was probably local to the southern Jemez Mountains.

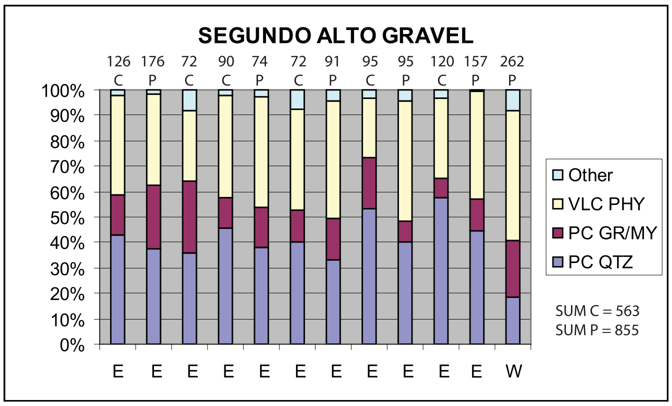
Previous summaries of clast-composition data have tended to characterize the clast populations as representative of "western fluvial" sources, "central-basin axial-fluvial" sources, or "eastern piedmont" sources (Bryan and McCann 1938; Lambert et al. 1982; Hawley and Haase 1992; Connell 2001), without much definition of the discriminating criteria. With minor exceptions, our data do not support these categories.

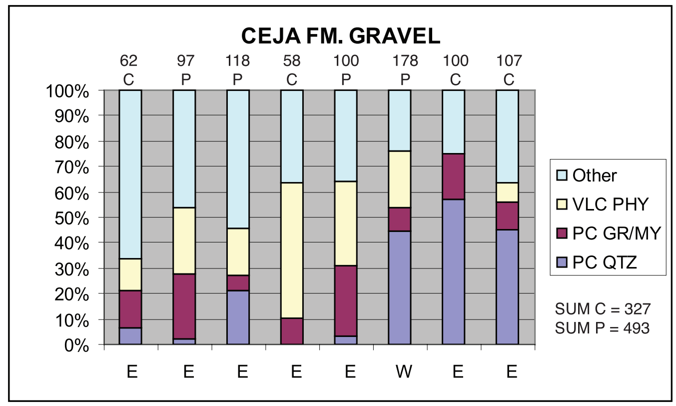
The quartz-rich Precambrian metamorphic rocks (colloquially referred to as "quartzite") have commonly been cited as indicators of the "central-basin axial-fluvial" sediment stream, but they are not restricted to the central valley area. Quartz-rich metamorphic rocks are very abundant in the Ceja Formation at sites on

Supplemental material—clast compositions in Rio Grande terrace-fill deposits









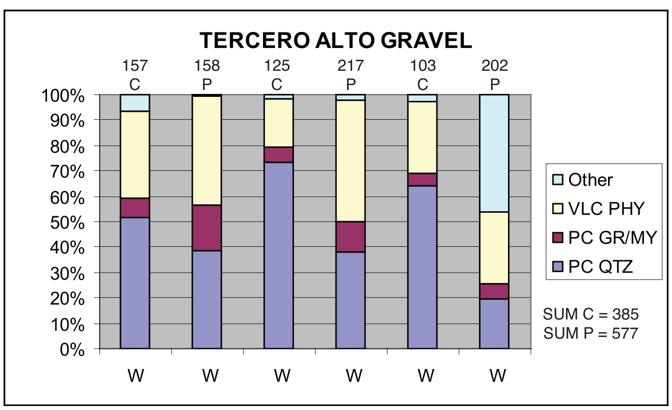
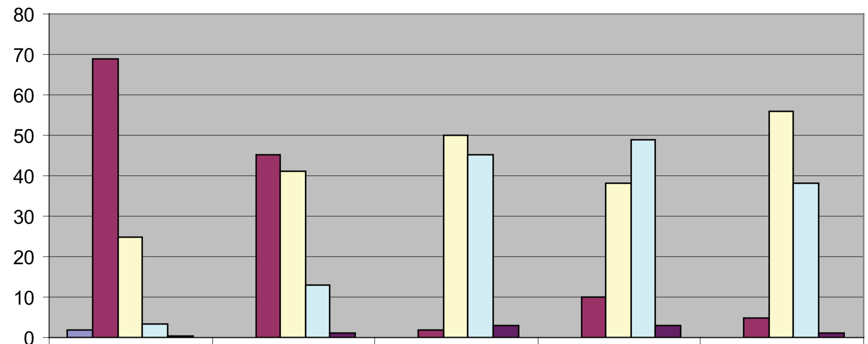


FIGURE S-1—Clast-composition data for pebbles and cobbles in Quaternary fluvial gravel deposits and the Pliocene Ceja Formation in the Albuquerque area.

PC QTZ = Quartz-rich Precambrian metamorphic rocks
PC GR/MY = Precambrian granite, pegmaite, and mylonite gneiss
VLC PHY = Porphyritic volcanic rocks of felsic and intermediate composition
Other = May include basalt, limestone, chert, “Pedernal chert,” quartzose sandstone, petrified wood, or volcanic sandstone

Top of bar chart shows number of clasts counted (C = cobbles greater than 3 inches median diameter; P = pebbles roughly 0.7–2.0 inches median diameter).
Bottom of bar chart indicates sample site east (E) or west (W) of the Rio Grande floodplain.
SUM C = total number of cobbles identified
SUM P = total number of pebbles identified

Supplemental material—clast compositions in Rio Grande terrace-fill deposits



	PRIMERO	SEGUNDO	TERCERO	CUARTO	CEJA FM.
VR	2	0	0	0	0
R	69	45	2	10	5
SR	25	41	50	38	56
SA	3.5	13	45	49	38
A	0.5	1	3	3	1
SUM	375	563	385	220	327

FIGURE S-2—Summary rounding characteristics for cobbles in Quaternary fluvial gravel deposits and the Pliocene Ceja Formation in the Albuquerque area. Bar chart shows percent of clasts in five classes of rounding (after Lewis 1984); table below lists the same data in numerical form. SUM = total number of cobbles measured at all sample sites. VR = very rounded; R = rounded; SR = sub-rounded; SA = sub-angular; A = angular.

the far northwest of the Albuquerque valley. We have concluded that these rocks are so durable that they have been repeatedly recycled throughout the region and throughout the Cenozoic Era. Their presence or absence does not seem to indicate any particular source areas, but they are clearly concentrated in the youngest, most recycled deposits due to attrition of softer clasts.

"Pedernal chert," petrified wood, and quartzose sandstone appear to be more common on the west side of the Rio Grande valley. These observations are consistent with the widespread occurrence of quartzose sandstone and petrified wood in the Cretaceous and Jurassic rocks of the Colorado Plateau west of the Albuquerque valley (Kelley 1977). Similarly, the "Pedernal chert" source appears to be located north of the modern Jemez Mountains; early Cenozoic drainage seems to have transported clasts westward into the San Juan Basin, from which they were recycled southeastward into the Rio Grande rift of the Albuquerque valley (Kelley 1977; Connell 2001).

The one clast type that clearly indicates a northern source area and transport by the through-flowing Rio Grande is Bandelier Tuff, whose source is uniquely defined as the Valles caldera in the Jemez Mountains. Clasts and tephra of the Bandelier Tuff eruptions (as well as related Valles caldera eruptions) are most common in the Cuarto Alto terrace-fill deposits, which were accumulating at the same time as the volcanic activity. Such clasts have been found, although in rarer quantities, in all of the younger terrace-fill deposits of the Rio Grande as a result of recycling. These clasts from Valles caldera sources are certain indicators of Quaternary inset deposits, and clearly distinguish the inset deposits from basin-fill fluvial deposits of the Tertiary Santa Fe Group (Cole et al. 2002; Williams and Cole 2007).

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TABLE S-1—Location and clast-composition data for samples of Quaternary Rio Grande terrace-fill deposits and the Pliocene Ceja Formation, Albuquerque area, New Mexico. Abbreviations follow the table.

Clast counts	UTM North NAD 83	UTM East Zone 13	Cobbles	Pebbles	p€ Qtz	p€ QPCg	p€ Gr/My	Volc IntPhy	Volc FelPhy	Volc Bslt	Sed FslLs	Sed Qss	Cht	PedCht	SUM	Other clasts
MODERN																
Bern'lo bridge, bar gravel	3909900	358360		145	19	12	42	38	24	4	2				141	2 obsidian, 2 volc ss
PRIMERO ALTO																
Hyatt-Tamaya resort	3912060	358830	110		13	10	14	62			10	1			110	
Edith Blvd at Roy	3897280	354730	118		54	13	16	35							118	
Edith Blvd	3895030	353870		161	32	38	20	65						4	159	2 obsidian, 2 volc ss
	ditto	ditto		87	12	19	25	21	6		2	2			87	
All Saints Church @ PDN	3894260	347780		135	23	11	14	44	30	8		1	2	2	135	
Arenal Blvd	3880200	343180	147		36	48	14	43			2	2	1		146	1 petwd
	ditto	ditto		165	48	14	27	38	27		7		2		163	1 volc ss; 1 petwd
SEGUNDO ALTO																
I-25 N of Sandia Wash	3904270	358380	126		26	28	20	49			2		1		126	
[3-SWL]	ditto	ditto		176	53	13	44	38	25		3				176	
Balloon Park #1	3895790	354890	72		18	8	20	15	5		4	1		1	72	
Balloon Park #2 [7-BPL]	3895770	354940	90		34	7	11	24	12			2			90	incl Bandelier, biot schist
	ditto	ditto		74	17	11	12	24	8		1	1			74	1 volc brxx
Balloon Park #3 [8-BPU]	3895760	355000	95		20	18	12	27	11		3	1		3	95	
	ditto	ditto		91	19	11	15	28	14		3			1	91	
Balloon Park #4	3895750	355060	60		17	15	12	14				1		1	60	
	ditto	ditto		95	25	13	8	33	12		2	1			94	1 volc brxx
Old pit, S of PDN	3893240	353770	120		41	28	9	38			1		3		120	
	ditto	ditto		157	20	50	20	66			1				157	
Oxbow Lane	3888530	345470		262	36	12	59	85	48		10	6		3	259	3 obsidian
TERCERO ALTO																
Las Lomata Negras	3904980	351540	157		46	35	12	54		5		4		1	157	
	ditto	ditto		158	30	31	28	68					1		158	
Calle Bursura	3894110	345700	125		71	21	7	22	2					2	125	
	ditto	ditto		217	36	46	27	103				1	4		217	
NW Isleta quad	3875780	340850	103		52	14	5	8	21			2		1	103	
	ditto	ditto		202		40	12	42	15	4			5	5	123	

CUARTO ALTO																
1-25 @ San Felipe Pblo	3919760	371560	123		37	25	9	47					3		121	2 petwd
	ditto	ditto		187	42	34	18	93							187	
Journal Pavilion Park	3873350	349740	97		19		22	10	5	17	2	9		13	97	
	ditto	ditto		189		23	34	28	12	2	3	11	16	9	138	7 petwd
N Tijeras Arroyo top	3876160	350810		170	46	11	36	54	16				4		167	3 volc ss
N Tijeras Arroyo bottom	3875500	350530		97	9		7	45	17	1			4	3	86	11 volc ss
S Tijeras Arroyo bottom	3873180	349540		76	4		5	25	12			1	3	6	56	20 volc ss
CEJA FORMATION																
I-40 west of 98th Street	3882800	338710	62		4		9	6	2	1		11		6	39	8 hb volc ss, 14 bi ss, 1 petwd
	ditto	ditto		97	1	1	25	9	16			4		14	70	18 bi ss, 8 hb volc ss, 1 lapilli
Loma Colorado del Abajo	3904560	348070		118	15	10	7	15	7	2	1		43	10	110	7 bi ss, 1 bi gneiss
Loma Barbon at Hwy 44	3914590	352080	58				6	28	3	5	2	8		6	58	
	ditto	ditto		100		3	28	16	17	2	4	4	2	19	95	4 bi ss, 1 mica schist
E of Isleta, Hwy 47	3865510	347540		178	79		17	39		2		13	25	3	178	
NW Ceja, water tanks	3912500	330740	100		26	31	18	0	0	0	0	13	0	0	88	2 volc ss, 3 amph, 3 volc brxx, 1 petwd, 3 metarhy
NW Ceja, end of road	3921350	332530	107		15	33	12	8	0	0	0	27	2	3	100	3 volc ss, 2 petwd, 2 gneiss

Abbreviations

Major clast constituents

p€Qtz	Precambrian quartzose, aphanitic metamorphic rocks
p€QPCg	Precambrian metaquartzite and quartz-pebble conglomerate
p€Gr/My	Precambrian granite, pegmatite, and mylonite gneiss
IntPhy	Volcanic porphyry, intermediate composition
FelPhy	Volcanic porphyry, felsic composition
Bslt	Basalt
FslLs	Fossiliferous limestone (probably Madera Limestone)
Qss	Quartzose sandstone (likely Cretaceous, but may include Sandia Formation)
Cht	Aphanitic chert, various colors (black, orange, red, white)
PedCht	“Pedernal chert,” vernacular term for dense, banded, siliceous, concretion-like material that forms lumpy and convolute shapes. Source material may be the Miocene Pedernal Chert Member of the Abiquiu Tuff deposited north of the Jemez Mountains (Williams and Cole 2007)

Other clasts

Volc ss	Sandstone with common feldspar, biotite, and volcanic rock fragments
Petwd	Petrified wood
Volc brxx	Volcanic breccia
Bi ss	Sandstone rich in detrital biotite
Hb volc ss	Volcanic sandstone containing conspicuous hornblende
Bi gneiss	Biotite-bearing granitic gneiss
Lapilli	Volcanic rock containing conspicuous lapilli
Amph	Amphibolite
Metarhy	Metamorphic volcanic rock, rhyolitic composition