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UNUSUAL HOLOCENE ALLUVIAL RECORD FROM RIO DEL OSO, JEMEZ MOUNTAINS, NEW MEXICO: PALEOCLIMATIC AND ARCHAEOLOGIC SIGNIFICANCE

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Abstract — The lower Rio del Oso valley is characterized by a single Holocene terrace that is formed by 3 to 5 m of largely overbank fine quartz sand dated by 22 radiocarbon dates between 4610 and 640 ^{14}C yrs BP making this one of the best dated sequences in the region. The alluvium contains seven cumulic A horizon paleosols, 5 to 62 cm thick, a remarkable feature seldom seen in other alluvial records. The thickest paleosol "F" formed ca. 3000 to 2000 ^{14}C yrs BP and was a valley-wide floodplain soil while the other paleosols were only local in extent. The paleosols are dark brown to very dark grayish brown in contrast to the light to pale brown nonpaleosol alluvium. The paleosols are characterized by 0.3 to 0.5% organic carbon and 8 to 9% silt, the silt originating in part by atmospheric dust influx. The alluvial sedimentation rate is 0.075 cm per calendar year, r = 0.98. The Rio del Oso record of deposition and erosion correlates with other records on the Pajarito Plateau that in turn contrast sharply with regional sequences. Specifically, southwest-southern plains alluvial valleys were trenched 1000 ^{14}C yrs BP while the Oso and Pajarito-area valleys were not and alluviation continued to 600 ^{14}C yrs BP. Since regional downcutting was a response to a shift from moist to dry climate and the Oso and other Jemez area streams were evidently not significantly influenced by this episode of climate change, the Jemez Mountains may be providing a local mesic environment, resulting in local alluvial sequences that differ from those in the greater Southwest. Several in situ prehistoric features were observed at 2 to 4 m depth in the alluvium and are dated about cal BC 3500 to BC 800. After ca. 600 ^{14}C yrs BP, the Oso valley floodplain was incised and the broad floodplain was largely removed by erosion; the Holocene terrace is a remnant of that surface. Late prehistoric agriculture on the Oso valley floodplain, whether or not irrigated, would have been dramatically changed by incision and erosion of the floodplain.

INTRODUCTION

The Rio del Oso is a near-permanent stream fed by snow melt, rainfall, and numerous springs in the Jemez Mountains of north-central New Mexico. Its narrow watershed covers 108 km^2 and begins on the north slope of Chicoma Mountain at 3524 m elevation, the highest peak in the volcanic Jemez Mountains. The Rio del Oso flows 26 km northeasterly through the Jemez, dropping to 1743 m elevation where it enters the Rio Chama at the community of Chili, southeastern Rio Arriba County, along U.S. Highway 84 (Fig. 1). Detailed weather records in Los Alamos County south of Rio del Oso indicate that annual rainfall ranges from about 280 to 890 mm from low to high elevations along the eastern slope of the Jemez Mountains (Reneau and McDonald, 1996).

The upper Rio del Oso drainage is developed in the Tschicoma Formation dacite, a series of extrusive flows and domes of Pliocene volcanic rock at the northeastern margin of the Jemez Mountains (Smith et al., 1970). The lower Oso valley is cut into the weakly indurated Miocene Ojo Caliente Sandstone Member of the Tesuque Formation (Santa Fe Group) (Dethier and Manley, 1985). Lobato Mesa in the upper watershed and north-south trending dikes in the lower Oso valley are outcrops of black vesicular basalt of the Lobato Formation (Koning et al., 2005) and are the source for the basalt gravels in the Oso alluvium. Previous investigations of Rio del Oso alluvium are reported by Dethier and Demsey (1984) and Periman (2001, 2005).

HIGH PLEISTOCENE TERRACE

Superimposed on eroded Tertiary bedrock are thick deposits of Pleistocene gravels occurring at different elevations along the valley margins of the Rio Chama. The gravels represent former channel positions of the Rio Chama and its tributaries. The ages of the terraces are established by amino-acid dating of fossil land-snail shells (Dethier and McCoy, 1993) and the presence of the Lava Creek B volcanic ash in the highest terrace (Dethier et al.,

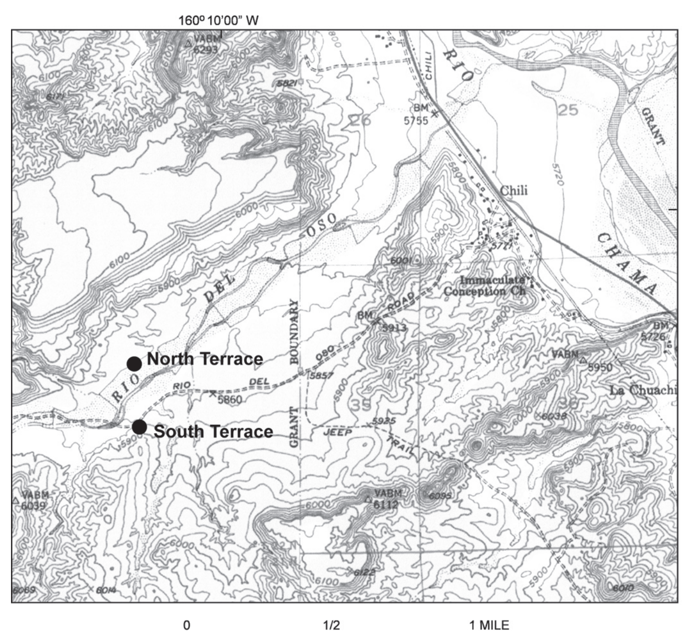

FIGURE 1. Map of Rio del Oso terrace localities, from USGS Chili 7.5 minute quadrangle, 1953, photo-revised 1977; prehistoric pueblos, pebble-garden agricultural fields, and other archeological sites occur here but are not shown for reasons of land owner privacy and, where sites are on public lands, cultural resource management.

1990), indicating that the Rio Chama valley has been down cut 120 m in the past 640,000 yrs (Dethier et al., 1988). Along the north slope of the lower Oso valley, Dethier and Demsey (1984), Dethier and Manley (1985) and Koning et al. (2005) mapped a Pleistocene gravel deposit that forms a prominent terrace about 42 m above the Oso floodplain; the high Pleistocene gravel is not a part of this investigation.

RADIOCARBON DATING

Twenty samples for radiocarbon dating were collected from the thick alluvial section at the south terrace (by RDP) and two from alluvium at the north terrace locality (by SAH) (Table 1). The close-interval samples from the terrace alluvium were analyzed for radiocarbon dating as bulk sediment in which the solid and soluble organic matter was dated. Some of the sediment samples have a high charcoal content, perhaps of cultural origin. The radiocarbon dates were obtained by both conventional and accelerator mass spectrometry (AMS) methods after pretreatment to remove carbonates. The conversion of corrected radiocarbon dates to calendar years is performed by the CALIB rev 5.0.1 program (Stuiver and Reimer, 1993; Reimer et al., 2004). Discussions of geochronology in this study will specify whether radiocarbon years "^{14}C yrs BP," or dendro-calibrated calendar years "cal yrs BP" and "cal BC/AD," or true historic ages "BC/AD" are being referred to.

MODERN CHANNEL AND FLOODPLAIN

The modern channel-floodplain of Rio del Oso is 90 to 215 m wide in the lower 4 km of the stream valley before it joins the Rio Chama. The floodplain, with various low benches formed by deposition and scouring of the floodplain surface, is about a meter above the channel and is vegetated by grasses and small scattered trees of cottonwood, salt cedar, Russian olive, willow, and elm. Water in the Oso flows through the primary (north) channel. During high discharge events, excess water is carried by two connecting channels that are incised through the floodplain deposits. The two ancillary channels are maintained by seasonal flow, originating in the early spring by melt water from snow in the Jemez and in the late summer by runoff from convectional monsoonal rainstorms (Fig. 2). The primary channel is 55 to 120 cm deep. During a flood event in August 2006, the floodplain sediments separating the middle channel and north channel were scoured out, merging the two into one wide channel. Sediments in the primary channel consist of very pale brown, fine to very coarse quartz sand, and include basalt clasts ranging from fine to very coarse sand and to granule-cobble-boulder gravels. The

TABLE 1. Radiocarbon dates, Rio del Oso alluvium, Rio Arriba Co., New Mexico.

Depth (cm)	Lab no.[A]	Measured ^{14}C age[B]	δ^{13}C[C]	Corrected ^{14}C age	Calibrated age, calendar yr BP[D]
South Terrace Alluvium (coll. by RDP)					
18-22	Beta-104591	640 ± 80	---	640 ± 80	648, 576
38-42	Beta-104590	730 ± 70	---	730 ± 70	674
58-62	Beta-104589	950 ± 60	---	950 ± 60	910, 844, 806
88-92	Beta-104588	1100 ± 60	---	1100 ± 60	1046, 974
114-116	Beta-104587	1520 ± 50*	-24.4	1530 ± 50	1400
148-152	Beta-104586	1710 ± 80	---	1710 ± 80	1680, 1607, 1577
173-177	Beta-104585	2120 ± 60	---	2120 ± 60	2117, 2074
214-216	Beta-104417	2930 ± 60*	-20.3	3010 ± 60	3228, 3174
239-241	Beta-104416	2900 ± 50*	-12.4	3110 ± 50	3352
249-251	Beta-104584	2930 ± 50*	-23.9	2950 ± 50	3136, 3042, 3009
258-262	Beta-104583	2810 ± 100	---	2810 ± 100	2940, 2903
264-266	Beta-104582	3120 ± 60*	-23.9	3140 ± 60	3370
278-282	Beta-104581	3510 ± 60	---	3510 ± 60	3827, 3778, 3738
293-297	Beta-104580	3570 ± 80	---	3570 ± 80	3867
309-311	Beta-104579	3800 ± 50*	-25.4	3800 ± 50	4213, 4173, 4156
319-321	Beta-104415	4000 ± 60*	-11.0	4230 ± 60	4832
348-352	Beta-104578	3780 ± 50	-25.9	3760 ± 50	4145, 4117, 4098
358-362	Beta-104577	2780 ± 100	---	2780 ± 100	2914, 2867
399-401	Beta-104414	4520 ± 60*	-19.7	4610 ± 60	5428, 5315
459-461	Beta-104576	3540 ± 50*	-25.4	3540 ± 50	3846, 3784
North Terrace Alluvium (coll. by SAH)					
105-110	Beta-224146	1990 ± 50*	-20.5	2060 ± 50	2028, 2002
165-170	Beta-104419	2540 ± 50*	-19.2	2630 ± 50	2752

A = material dated is bulk sediment except Beta-104419 that is charcoal

B = radiocarbon ages with asterisk (*) are by AMS; others by conventional radiocarbon; Libby half life (5568 years)

C = $^{13}C/^{12}C$ ratios not determined and radiocarbon age not corrected where $\delta^{13}C$ values not given

D = intercept of radiocarbon age with calibration curve, ages in calendar years BP (0 yr BP = AD 1950); calculated by CALIB Rev 5.0.1(Stuiver and Reimer, 1993; Reimer et al., 2004)

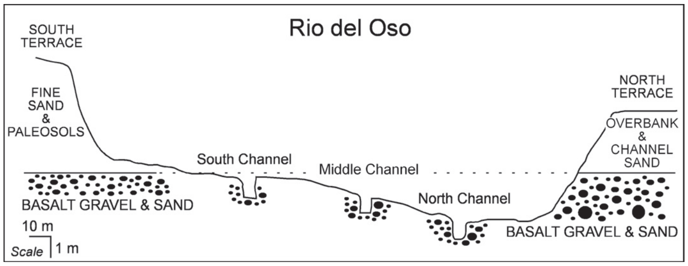

FIGURE 2. Cross-section of Rio del Oso valley showing undated sandy basalt gravel and overlying late Holocene alluvium; south terrace is 5 m above the basalt gravel and the north terrace is 3 m above the gravel; surveyed June, 1999.

sand grains are subrounded, poorly sorted, and form weak laminae and some small crossbeds in floodplain deposits adjacent to the channel.

HOLOCENE TERRACE

Only one Holocene terrace is preserved in the lower Rio del Oso valley, and it is composed of late Holocene overbank and channel deposits of fine quartz sand. Field surveying shows that the terrace on the north side of the valley is 3 m above the modern channel, while the terrace on the south side is 5 m above the present channel (Fig. 2). The slope of the terrace surface, with the south terrace surface higher than the north terrace surface, parallels the slope of the modern channel-floodplain, indicating that the fluvial-geomorphic process that resulted in the north-sloping Holocene valley fill remains active today. The radiocarbon age of the north and south terrace alluvium is the same (discussed below).

ALLUVIAL STRATIGRAPHY

The late Holocene alluvium of the lower Rio del Oso consists of 3 to 5 m of fine to very fine and medium quartz sand with a number of cumulic A-horizon paleosols. Upstream, the valley narrows and the terrace and late Holocene alluvium are largely removed by erosion except for local terrace remnants. The age of the alluvial deposits ranges from 4600 to 640 ^{14}C yrs BP, based on 22 radiocarbon dates. After 600 ^{14}C yrs BP, fluvial aggradation in the valley halted, and, subsequently, the valley fill was incised and largely removed, forming the Holocene terrace.

Basal gravels

Underlying the late Holocene alluvial sand is pebble-cobble-boulder sandy gravel composed largely of basalt clasts derived from upstream outcrops of the Lobato basalt (Fig. 3). The basalt gravel at one time extended across the valley. The top of the gravels exhibit an absence of soil development and may be eroded. The late Holocene fine-grained alluvium was deposited on the eroded surface of the gravels. Today, the modern channel of the Oso is downcut into the gravel, exhuming large basalt clasts that have been incorporated in the historic floodplain and channel deposits.

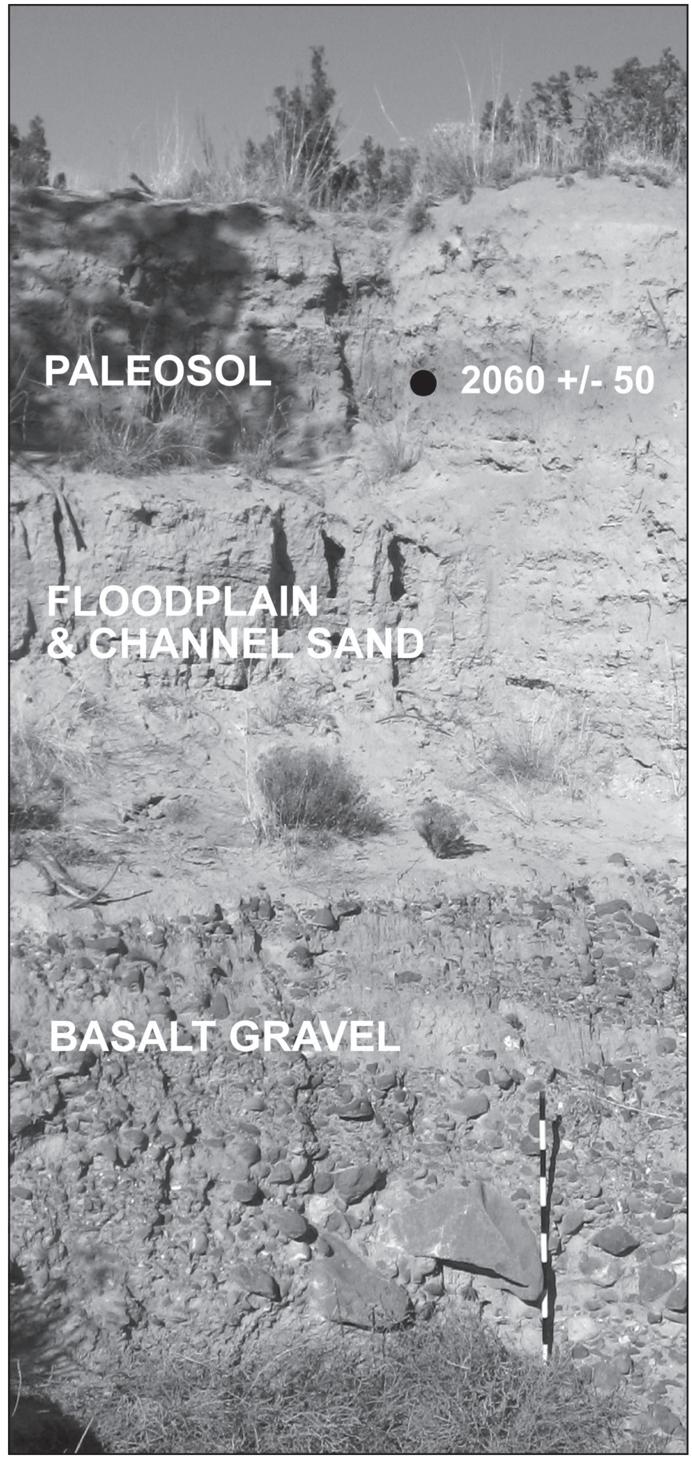

FIGURE 3. North terrace locality with undated coarse basalt gravel and overlying channel and floodplain sand and cumulic paleosol (late Holocene); eolian sand deposits occur locally on the terrace alluvium;1 m scale.

South terrace alluvium

The late Holocene alluvium is a massive light brown-pale brown-yellowish brown fine to very fine quartz sand with small amounts of silt and clay but without gravel (Table 2). The south

TABLE 2. Sediment data from late Holocene alluvium, South Terrace locality, Rio del Oso, Rio Arriba Co., New Mexico; numbers are percentages; Wentworth scale; Munsell Soil Color Chart.

SAMPLE DEPTH (cm)	SAND (mm) 2.0-1.0 v. coarse	1.0-0.5 coarse	0.5-0.25 medium	0.25-0.125 fine	0.125-0.0625 very fine	RECALCULATED SAND	SILT	CLAY <3.9μm	OC	$CaCO_3$	DRY COLOR
South Terrace alluvium											
Non-paleosol											
15-20	0.0	0.1	14.9	60.8	24.2	87	6	7	0.27	2.0	10YR 4/4
33-38	0.0	0.2	11.1	58.4	30.3	86	6	8	0.19	2.4	7.5YR 4/4
Paleosol G											
71-76	0.0	0.2	14.5	59.7	25.6	83	8	9	0.33	3.0	7.5YR 4/2
89-94	0.0	0.1	14.9	58.9	26.1	82	8	10	0.40	2.8	7.5YR 4/2
Non-paleosol											
120-125	0.0	0.1	13.3	61.5	25.1	83	7	10	0.22	3.0	10YR 5/3
140-145	0.0	0.2	13.3	62.8	23.7	87	5	8	0.15	2.3	10YR 4/3
Paleosol F											
170-175	0.0	0.2	16.0	62.5	21.3	85	8	7	0.35	2.0	10YR 3/2
200-205	0.0	0.4	17.5	60.0	22.1	82	9	9	0.41	2.1	10YR 3/2
Non-paleosol											
265-270	0.0	0.2	19.1	61.9	18.8	89	5	6	0.06	2.0	7.5YR 6/4
Paleosol D											
295-300	0.0	0.5	17.9	58.1	23.5	77	9	14	0.54	3.8	10YR 3/2

"0.0" = measured but zero percent; OC = % organic carbon (Walkley-Black); % carbonates determined by chittick method; sedimentology by Milwaukee Soil Laboratory, 6917 W. Oklahoma Ave., Milwaukee, Wisconsin 53219

terrace alluvium is 470 cm thick and rests directly on undated channel sands and basalt gravel. The sediment is soft, well sorted, and lacks any trace of visible bedding or erosional unconformities. The sediment is weakly to moderately calcareous with 2 to 4% calcium carbonate probably derived from local calcareous sandstone bedrock. Visible carbonates are generally lacking although occasional faint carbonate filaments are present; thin carbonate coats are generally less than 5% of sand grain surfaces. The south terrace stratigraphic sequence was deposited in a slowly aggrading floodplain environment and incorporates a remarkable succession of seven cumulic A paleosols (Figs. 4, 5). The age and sedimentation rate of the south terrace alluvium are documented by 20 radiocarbon dates. Four distinct horizons of archaeological features are also found in the alluvium. Numerous cicada insect burrow fills 6 to 18 mm wide occur throughout the sediment column; individual burrows can be traced as much as 10 cm (Fig. 6).

North terrace alluvium

The north terrace alluvium differs considerably in detail from the sequence on the south side (Fig. 7). The north terrace alluvium is light yellowish brown to very pale brown medium-fine-coarse quartz sand and silty sand and lacking gravels. The alluvial sand is 305 cm thick and rests directly on undated basalt gravel; the gravel/sand contact is an erosional unconformity. The lower half of the alluvium below approximately 135 cm is poorly sorted sand with several layers of clayey silt 1 to 5 cm thick, all exhibiting laminae and small crossbeds. The bedded sand is strongly calcareous with carbonate filaments; bioturbation is largely absent. The upper 135 cm is medium to fine quartz that is massive, lacking primary bedding. One 25 cm-thick cumulic A paleosol occurs in the massive sand at about 1 m depth. The alluvium above the paleosol is marked by numerous burrow fills and rodent-carnivore bioturbation. The poor sorting, alternating sand and silt layers, and presence of laminae and cross beds together indicate floodplain and channel-related sedimentation during deposition of the lower half of the sequence. The upper half of the sequence is characterized by massive unbedded sand and the cumulic paleosol indicating overbank sedimentation. During the late Holocene, the Rio del Oso channel may have been closer to the north side of the valley than the south, similar to the situation today.

CUMULIC A-HORIZON PALEOSOLS

One of the remarkable aspects of the Oso alluvial record is the presence of seven cumulic A horizon paleosols, ranging from 5 to 62 cm thick and representing collectively 41% of the south terrace stratigraphic record. The paleosols are all developed in fine to very fine quartz sand and are very dark grayish brown to brown and, in contrast to the light brown sand between paleosols, are visibly prominent in outcrop exposures because of their dark color. The dark color of the paleosols is due to levels of organic carbon, 0.33 to 0.54%, that are twice the amount found in nonpaleosol sediment (Fig. 8; Table 1). None of the paleosols exhibit secondary pedogenic B horizon properties. The paleosols are moderately calcareous, some carbonates occurring as filaments that follow small roots, although the paleosols are generally no more calcareous than are the intervals of sandy alluvium between paleosols. The basal and top boundaries of the paleosols are commonly obscured by cicada insect burrow fills that have mixed the

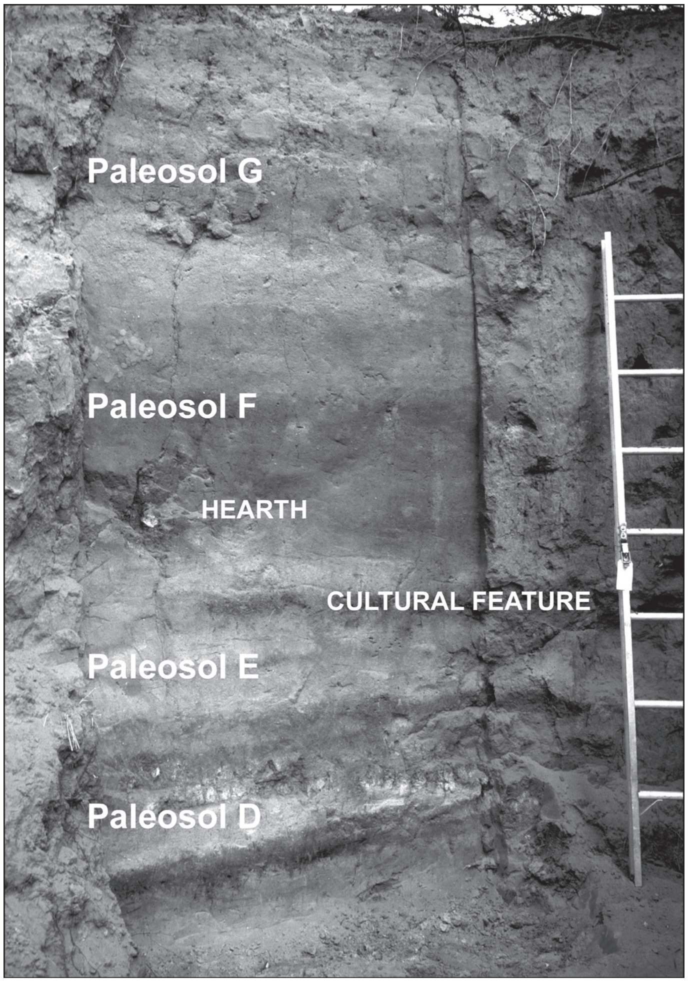

FIGURE 4. South terrace fine sand alluvium with four cumulic A paleosols and prehistoric cultural features; section shown is approximately 300 cm thick and is the upper portion of the south terrace sequence.

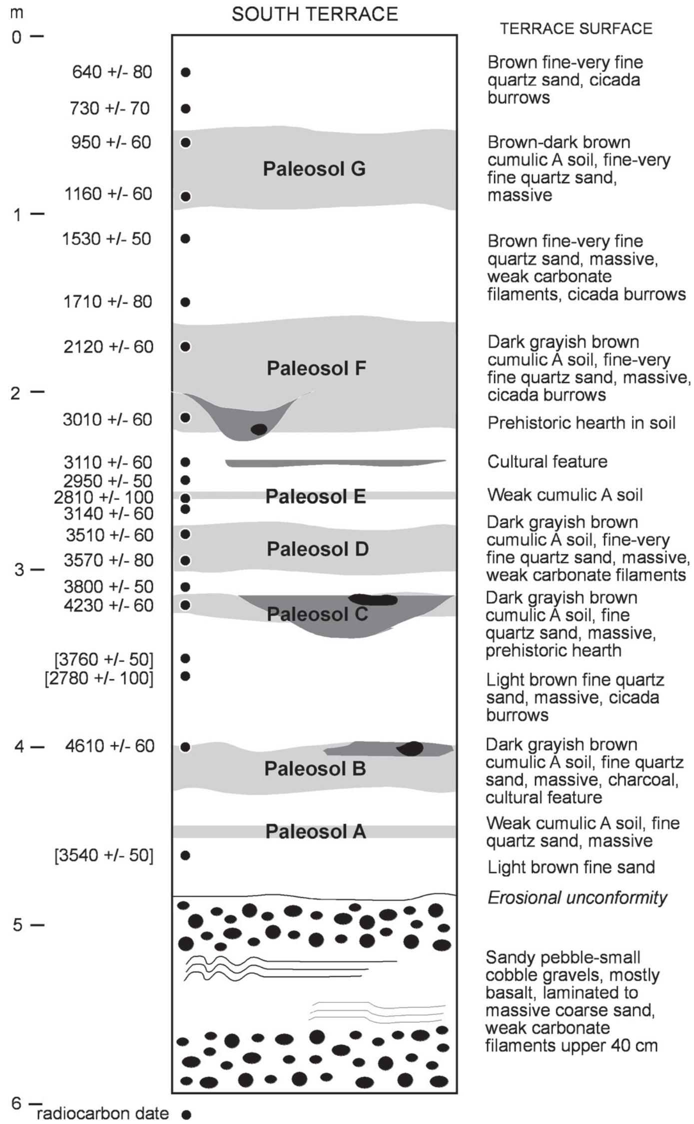

FIGURE 5. South terrace composite section with radiocarbon dates in ^{14}C years BP (Table 1); three dates in brackets are stratigraphically reversed; the upper 4.7 m consists of three separate offset sections within less than 4 m of each other; paleosols A-B-C-D are directly traceable from one section to another; the sandy basalt gravel below 4.7 m depth is exposed in a soil pit approximately 30 m east of the upper sections; the base of the sandy gravel below 6 m depth was not exposed.

dark paleosol and the lighter-colored nonpaleosol sediment. The seven paleosols are labeled A through G from the bottom to top of the sequence (Fig. 5).

One cumulic A horizon paleosol occurs in the upper alluvial sequence at the north terrace (Fig. 7). A single radiocarbon date, 2060 ± 50 ^{14}C yrs BP, indicates that it correlates to paleosol F in the south terrace. Paleosol F, thickest of the paleosols (62 cm), may have been a valley-wide floodplain soil, while the others were only local in extent. The age of paleosol F is ca. 3000 to 2000 ^{14}C yrs BP. Farther downstream along the bank of the north terrace, paleosol F is eroded and missing although another cumulic paleosol, undated, occurs at a stratigraphically lower position in the terrace alluvium.

Carbon isotopes

The cumulic paleosols with their comparatively high organic carbon content likely represent floodplain soils characterized by grasses and sedges. Inspection of the $\delta^{13}C$ values from the radiocarbon dates (Table 1), however, shows that the organic matter present in the paleosols and nonpaleosol alluvium has $\delta^{13}C$ values of -19.7 to -25.9‰ that are characteristic of C_3 plants; only two samples with $\delta^{13}C$ values of -11.0 and -12.4‰ suggest a dominance of C_4 grasses and wet-meadow plants (Boutton, 1991). If the carbon isotopes are significant and representative, the organic carbon content of the alluvium and paleosols is derived primarily from grasses, herbs, shrubs, and trees in the upland landscape and less from wet ground plants on the floodplain.

Atmospheric silt influx

While the chronology of the alluvial sequence at the south terrace is well established, insufficient geochronologic control exists to determine differences in sedimentation rates between paleo-

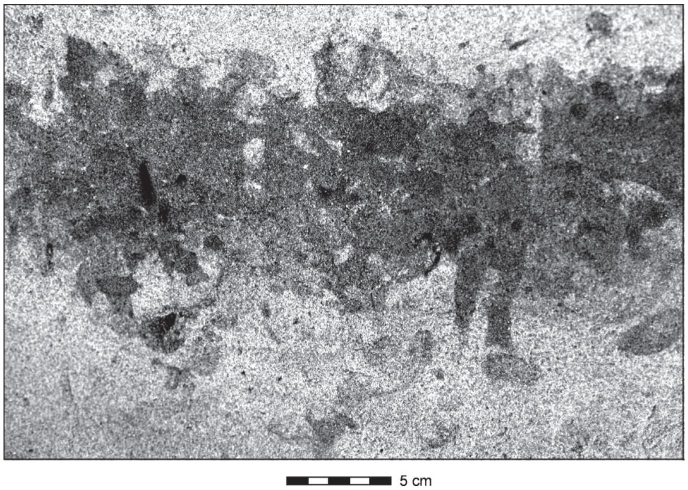

FIGURE 6. Cicada insect burrow fills at the 5 cm-thick cultural feature dated 3110 ± 60 ^{14}C yrs BP at 240 cm depth in south terrace alluvium; the burrows are visible because of the contrasting dark color of charcoal particles in the fills against the light colored sand; cicada insect burrows are present throughout the alluvial section.

sol and nonpaleosol alluvium. Nevertheless, it has been shown elsewhere that cumulic A paleosols are a result of periods of slowed sedimentation (Hall, 1990a). At Oso, the paleosols have higher percentages of silt than does non-paleosol alluvium (Fig. 8). Canyon streams on the Pajarito Plateau carry abundant silt (Malmon et al., 2004). However, in Oso alluvium the percentages of silt and very fine sand are unrelated (Table 2); if the silt were fluvial in origin, the high percentages of silt would correspond to higher amounts of very fine sand, a situation that is not the case. Thus, the data suggest that the elevated amounts of silt in the paleosols are eolian in origin. An eolian silt component of soils has been documented elsewhere (Eberly et al., 1996; Reneau et al., 1996; Muhs and Benedict, 2006).

SEDIMENTATION RATE

A remarkable series of 20 radiocarbon dates from 4.7 m of massive overbank alluvium shows a near-uniform sedimentation rate for a period of 5000 cal yrs at Oso (Table 1). A net rate of sedimentation of 0.075 cm per calendar year has been determined by linear regression of depth versus age in calendar years BP of the thick alluvial section at the south terrace (Fig. 9). The correlation coefficient is strong, r = 0.98. Three incongruous radiocarbon dates (discussed below) were omitted from the sedimentation rate calculations.

Close inspection of the plot of depth versus age shows that the three uppermost ages indicate a more rapid net sedimentation rate in the upper meter of the south terrace alluvium since about 1000 cal yrs BP. We interpret this departure from the net sedimentation rate as a consequence of the increased influx of colluvial sand from the immediately adjacent hillslope above the terrace to the site of floodplain deposition. The increase in sedimentation rate and possible increased sheet erosion rates may be due to local changes in climate and vegetation. Late prehistoric agriculture,

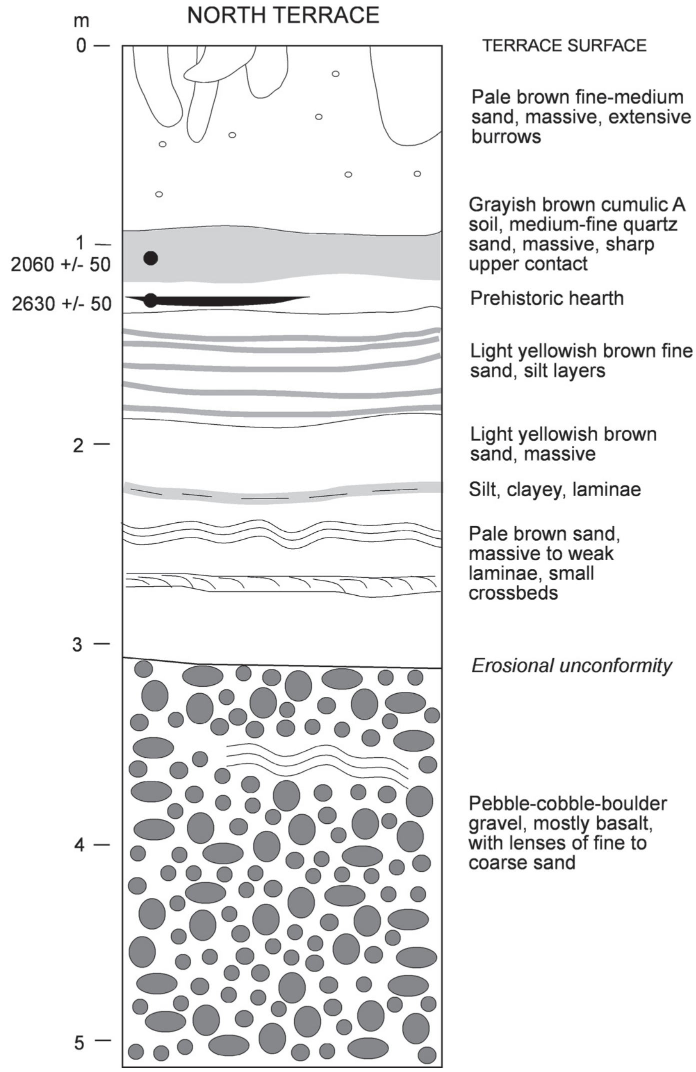

FIGURE 7. North terrace alluvial stratigraphy; see photo in Fig. 3; the dated prehistoric hearth occurs downstream and is physically correlated to the level shown; the single cumulic paleosol correlates to paleosol F in the south terrace sequence (Figs. 4, 5).

fuel harvesting, and general land use by puebloans in the immediate area may have contributed as well to increased sheet erosion and valley sedimentation.

STRATIGRAPHICALLY REVERSED RADIOCARBON DATES

Linear regression analysis of the large number of radiocarbon dates on bulk sediment from the south terrace allows us to identify three stratigraphically reversed dates that, because of their magnitude, cannot be explained by cicada bioturbation. The incongruous dates (Beta-104578, -104577, -104576) are all younger than their stratigraphic position would indicate by ca. 500, 1900, and 2300 cal yrs, respectively. The stratigraphic equivalents of these incongruous ages are approx. 40, 140, and 170 cm of vertical section or depth. There is no apparent explanation for the disharmonious dates. It should be pointed out, however, that the ability to

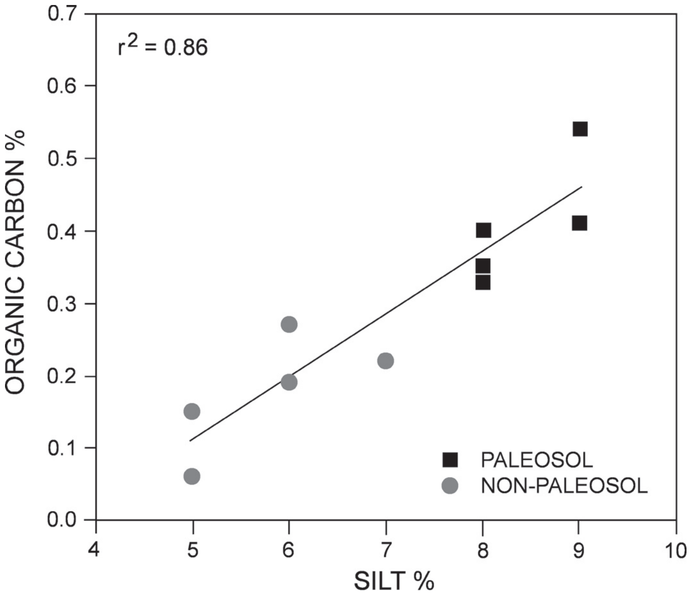

FIGURE 8. Linear regression plot of organic carbon % versus silt % from paleosol and non-paleosol sediment, south terrace; data from Table 2; the results shows that the cumulic paleosols have a higher organic carbon and a higher silt content than non-paleosol alluvium.

recognize coarse-scale stratigraphic-age inversion of radiocarbon dates is only possible in this case because of the large number of dates from successive stratigraphic levels. If, instead, only a few radiocarbon dates had been obtained from widely spaced intervals, erroneous dates, if any, might not be identified.

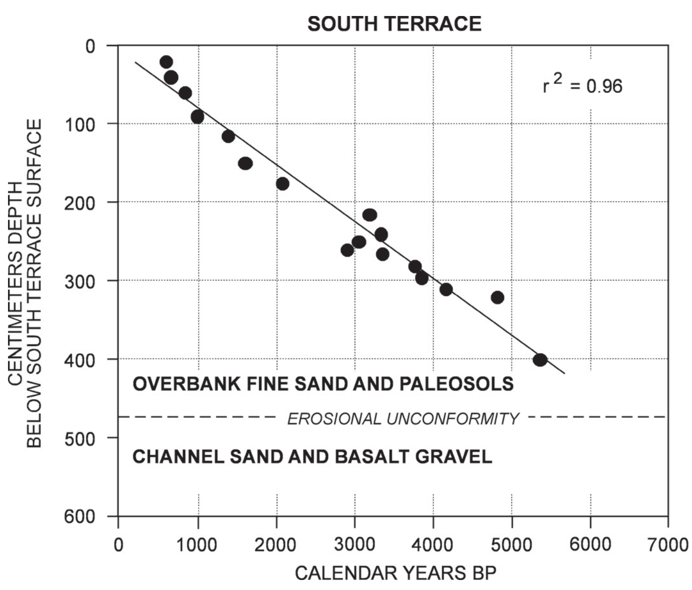

FIGURE 9. Linear regression plot of depth in cm below top of terrace versus calendar years BP (intercepts of radiocarbon ages with calibration curve); south terrace locality; excludes three stratigraphically inverted dates; net sedimentation rate is 0.075 cm per calendar year; data from Table 1.

CORRELATION OF OSO ALLUVIAL RECORD

The Rio del Oso valley fill consists of undated basalt gravels overlain by 3 to 5 m of late Holocene alluvium dated between 4600 and 600 ^{14}C yrs BP. Early Holocene sediments are missing from the local record, unless represented by the underlying basalt gravel. The late Holocene alluvium is massive fine quartz sand and does not exhibit erosional unconformities although it contains a number of cumulic A horizon paleosols.

Recent studies on the Pajarito Plateau focus on alluvial terraces and soils developed on the terraces and provide a valuable basis for comparison with the Rio del Oso record. In Ancho and Sandia canyons, sequences of alternating floodplain and channel deposits represent a period of general aggradation between 4900 and 1200 ^{14}C yrs BP (Reneau and McDonald, 1996, p. 46-48, 68-69). In contrast, rapid downcutting in Rendija Canyon has led to a series of stepped terraces, each inset into and at lower elevation than the other. The four younger terraces are Holocene. Basal sediments from the Qt5 terrace are dated 8800 and 8900 ^{14}C yrs BP at two different localities, sediment in the 5 m-high Qt6 terrace is dated 6900 to 5200 ^{14}C yrs BP, the inset younger 3 m-high Qt7 terrace is dated 3200 ^{14}C yrs BP, and the youngest terrace Qt8, which forms the canyon floor about 1 m above the modern channel, is dated 1580 to 490 ^{14}C yrs BP (Reneau and McDonald, 1996, p. 118; McDonald et al., 1996). The late Holocene alluvial records from Ancho and Sandia somewhat match that from Oso: fluvial sedimentation beginning ca. 5000 ^{14}C yrs BP and ending after 1200 ^{14}C yrs BP. The Rendija Canyon record of deposition and downcutting seems anomalous, however, and may be a response to local fluvial conditions not found at Ancho, Sandia, or Oso.

The Oso record of channel incision after 600 ^{14}C yr BP is unusual. Except for some cases from the Jemez area (Reneau and McDonald, 1996; McDonald et al., 1996; Riihimaki and Dethier, 1998), other alluvial records in the south-central and southwestern United States show widespread channel erosion beginning 1000 ^{14}C yrs BP, and most of these records, such as Chaco Canyon, Zuni, and Tesuque, show renewed alluvial deposition by ca. 800 ^{14}C yrs BP (Miller and Wendorf, 1958; Hall, 1977, 1990a, b), very different from the Oso record (Fig. 10).

OSO ALLUVIUM AND PAST CLIMATE

One of the grand issues in geomorphology concerns the relationship of fluvial aggradation and downcutting to climate and climate change. It is generally agreed that climate is the primary influence on fluvial processes and stream history in the Jemez Mountains (Reneau, 2000). Local stream histories of aggradation and incision in the Jemez exhibit a great deal of variability. For example, the multiple episodes of Holocene incision and terrace formation in Rendija Canyon have been interpreted as the consequence of unusually high magnitude flood events (Reneau and McDonald, 1996, p. 140). In contrast, the alluvium in Ancho Canyon, Sandia Canyon, and Rio del Oso indicate floodplain deposition during the late Holocene without evidence of high

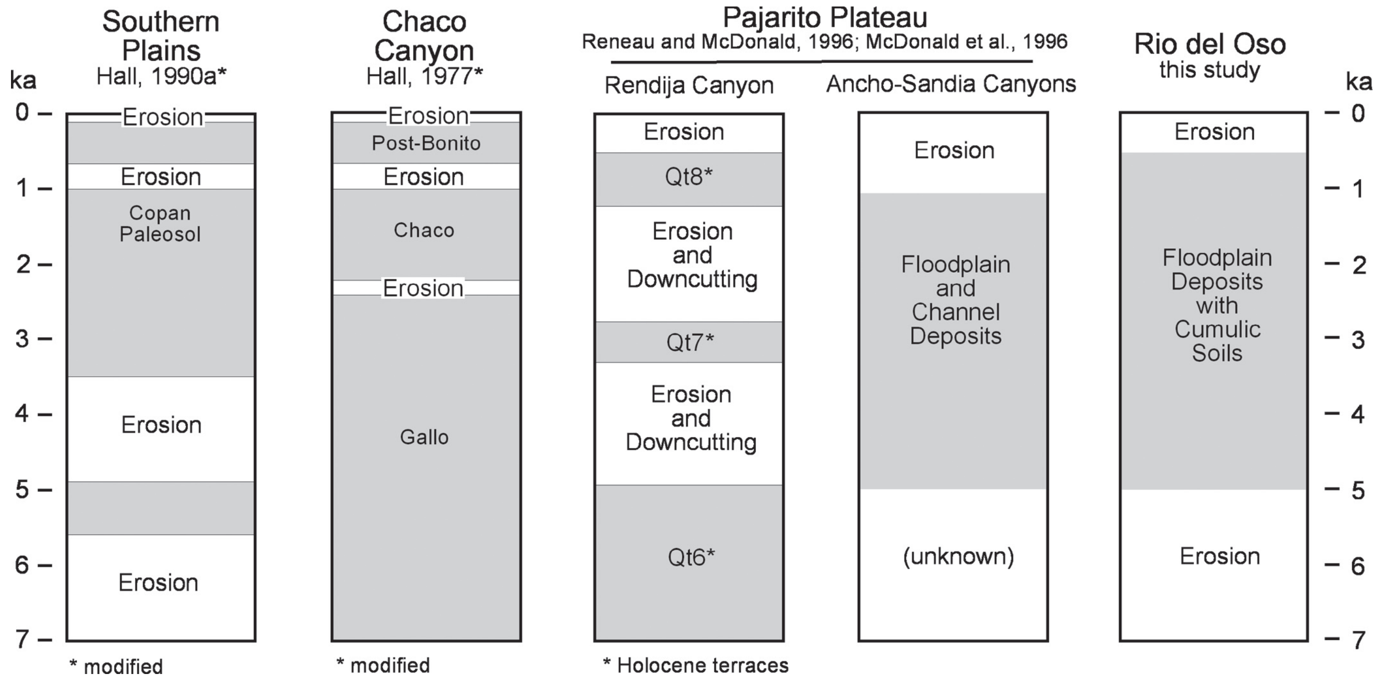

FIGURE 10. Correlation chart of Rio del Oso alluvium with dated alluvial records from the Pajarito Plateau (Reneau and McDonald, 1996; McDonald et al., 1996), Chaco Canyon (Hall, 1977), and the Southern Plains (Hall, 1990a); historic channel incision has been followed in some cases by modest channel alluviation.

magnitude flood events or downcutting. As indicated by Reneau (2000), however, Jemez stream histories are variable, the differences related to local conditions. We suspect that the Rendija Canyon record is indeed a local case and that the alluvial records of Ancho, Sandia, and Oso are more representative. Regardless, further studies of alluvial stratigraphy, sedimentology, and geochronology will allow us to differentiate streams that are responding predominantly to local conditions versus streams that are responding to a broader pattern of Jemez climate.

One emerging pattern suggests that the alluvial history of the Jemez Mountains differs from that of the broader region, especially for the late Holocene period where numerous high-resolution records are in hand. The episode of erosion about 1000 ^{14}C yrs BP that characterizes the southwest and southern plains evidently did not occur everywhere in Jemez mountain streams. Instead, downcutting of the Oso valley occurred after ca. 600 ^{14}C yrs BP at a time when other alluvial valleys in the greater Southwest were aggrading. The regional downcutting documented about 1000 ^{14}C yrs BP is a response to a broad-based change in climate from comparatively moist to dry conditions (Hall, 1990a). The continued alluviation at Oso suggests that the local climate of the Jemez Mountains may have continued to be comparatively moist and was not significantly affected by the regional shift to drier conditions that occurred elsewhere about 1000 ^{14}C yrs BP.

ARCHAEOLOGY

The archaeology of the Oso-Chama area is moderately well known; a large number of preceramic and ceramic-age sites have been documented in the Oso valley (Anschuetz, 1998). Virtually all of these sites occur on old eroded surfaces and lack stratigraphic context, making them nearly impossible to date. The discovery of in situ prehistoric cultural features in the Oso alluvium provides a unique opportunity to obtain radiocarbon ages of the prehistoric occupation of the valley, especially for sites from the Archaic period where diagnostic ceramics are absent.

In this study, five individual cases of buried prehistoric features are radiocarbon dated from ca. cal 3500 BC to 800 BC (Table 3). The dated features occur in both north and south terrace alluvium and are buried at 2 to 4 m depth. The features are mostly hearths with associated charcoal and burned rock. Four features occur in the south terrace alluvium and are stratigraphically distinct from each other, each representing a different site of different age. While artifacts were not observed in place, numerous flakes of obsidian and chert are present on talus slopes below the features. Other buried archaeological features were observed in the Oso alluvium elsewhere but were not studied.

The abundance of buried sites indicates that the Oso valley has been a focus of occupation by prehistoric people during at least the past 5500 cal yrs. More recently, between ca. AD 1250 and 1600, several pueblos were constructed along the Chama River valley and its tributaries including the Rio del Oso (Hewett, 1906). Agricultural fields may have been present on the lower Oso floodplain but are now eroded away by downcutting. On a south-facing slope formed by Pleistocene gravels above the Oso, stone-lined agricultural fields were planted in corn and cotton sometime during the period ca. AD 1250 to 1500 (K. Anschuetz, G. Dean, personal commun., 2007). The Oso-Chama valley was intensely occupied during the past millennium by puebloans and, later, the Spanish. The relationship of cultural activities to the

TABLE 3. Radiocarbon-dated archaeological features buried in alluvium, Rio del Oso, Rio Arriba Co., New Mexico.

Corrected Radiocarbon Date[A]	Calibrated Calendar Years[B]	Description and Comments[C]
North Terrace Alluvium		
2630 ± 50	BC 839 to 772	Hearth with basalt cobble and obsidian flake, exposed in left bank of gully eroded into terrace alluvial sand; hearth about 90 cm wide and 20 cm deep; it occurs about 230 cm depth and 70 cm below the top of a 20-cm thick cumulic A paleosol but not associated with the paleosol; feature disturbed by numerous cicada burrows; the radiocarbon date is on charcoal collected directly from the hearth
South Terrace Alluvium		
3010 ± 60	BC 1377 to 1337 BC 1321 to 1192	Hearth with 5-cm dia. burned sandstone and charcoal about 215 cm depth in terrace alluvial sand; it is bowl-shaped and measures 28 cm wide and 14 cm deep and is associated with the lower half of cumulic A paleosol; the hearth extends about 3 cm below the base of the paleosol; the outline of the hearth is disturbed by cicada insect burrows
3110 ± 60	BC 1442 to 1309	Thin zone of charcoal about 5 cm thick at 240 cm depth; it extends about 250 cm laterally in the exposure and pinches out in the fine sand; a burned rock occurs in the fine alluvial sand at the exact position of the charcoal zone
4230 ± 60	BC 2910 to 2855 BC 2812 to 2746	Large bowl-shaped hearth extending 23 cm deep associated with cumulic A paleosol at 320 cm depth;incorporates burned sandstone 9 cm dia.; numerous charcoal particles ranging to 8 mm dia.; charcoal from the hearth is scattered throughout the paleosol
4610 ± 60	BC 3515 to 3423 BC 3384 to 3336	Hearth with burned sandstone and charcoal particles ranging to 5 mm dia.; hearth occurs in fine alluvial sand at about 400 cm depth; associated with a dark grayish brown cumulic A paleosol; numerous cicada insect burrows

[A] Radiocarbon dates from Table 1, this study
[B] Calibrated ages in calendar years from CALIB Rev 5.0.1 (Stuiver and Reimer, 1993; Reimer et al., 2004); 1-sigma age range
[C] None of the archaeological features have been surveyed or given Laboratory of Anthropology (LA) numbers

surface processes in the Oso valley of alluviation and downcutting has been addressed by Periman (2005).

Late prehistoric irrigation farming

Our conclusion that the Jemez Mountains may not have been significantly affected by the climate shift to drier conditions ca. AD 1000 and that some Jemez streams may have continued to aggrade without downcutting at that time has strong implications for local prehistoric farming. If regional streams were downcutting after AD 1000 but some Jemez streams were not, Jemez area floodplains could be used for agriculture, including irrigation, continuously without the interruption that affected other areas (Damp et al., 2002). The fine sand of the comparatively wide floodplain of the Oso would have been a good substrate for agriculture. After ca. AD 1400, however, downcutting of the Oso, and possibly other streams in the Jemez area, would have dramatically affected the local practice of irrigation agriculture.

CONCLUSIONS

The remarkable Rio del Oso alluvial record with its slow rate of aggradation, cumulic soils, absence of erosional unconformities, abundance of buried archaeological sites, and late persistence of its alluviation, may all be related to its comparatively large, high-elevation watershed and near-permanent year-round flow. The local mesic climate of the Jemez Mountains has evidently resulted in stream behavior that exhibits a great deal of variability as well as alluvial chronologies of erosion and deposition that are unlike alluvial sequences elsewhere in the greater Southwest. The generally mesic late Holocene climate may also have played a role in late prehistoric irrigation agriculture in the Oso-Chama valley.

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