In *The Holocene,* edited by H. E. Wright, Jr., pp. 182–207. Late Quarternary Environment of the United States, vol. 2, H. E. Wright, Jr., general editor. University of Minnesota Press, Minneapolis.
Stuiver, M., G. W. Pearson, and T. Braziunas
1986 Radiocarbon Age Calibration of Marine Samples Back to 9000 Cal Yr BP. *Radiocarbon* 28:980–1021.
Stuiver, M., and P. Reimer
1986 A Computer Program for Radiocarbon Age Calibration. *Radiocarbon* 28:1022–1030.
Sturtevant, W. C., and D. J. Meltzer
1985 The Holly Oak Pendant. *Science* 227:242–244.
Weslager, C. A.
1941 An Incised Fulgar Shell from Holly Oak, Delaware. *Archaeological Society of Delaware Bulletin* 3: 10–15.

PREHISTORIC VEGETATION AND ENVIRONMENT AT CHACO CANYON

Stephen A. Hall

*Pollen analysis of woodrat (*Neotoma*) middens indicates that the local vegetation at Chaco Canyon and the regional vegetation of the San Juan Basin, northwestern New Mexico, have been shrub grassland since at least 10,600 years ago. Plant macrofossils in the same woodrat middens indicate that pinyon pine trees were present in the canyon during much of the Holocene, but low percentages of their pollen grains in both the middens and in adjacent alluvium suggest the trees were few, occurring as small stands or isolated individuals along canyon escarpments. The vegetation at Chaco Canyon during Anasazi times was an arid shrub grassland with a sparse escarpment population of pinyon and juniper. A climate-caused regional increase in pinyon at higher elevation sites occurred approximately at the time of Puebloan abandonment.*

Chaco Canyon, in the San Juan Basin of northwestern New Mexico, has been the focus of archaeological and geologic investigations for more than a century. Extensive Puebloan ruins in the midst of inhospitable aridity have led to conjecture about the environment during Anasazi occupation of the canyon. Some of the first paleovegetation information came from pollen analysis of the alluvial fill, which indicated to Hall (1977) that the local vegetation was a treeless shrub grassland throughout the late Holocene, including the Anasazi period. Subsequent discovery in the canyon of woodrat (*Neotoma*), or packrat, middens containing remains of pinyon pine and single-seed juniper led to a reconstruction of the Holocene vegetation as a pinyon–juniper woodland (Betancourt and Van Devender 1981).

This paper presents the results of pollen analysis of the same 10,600-year series of woodrat middens originally collected and analyzed by Betancourt and Van Devender. The midden pollen is compared with the 7,000-year alluvial pollen record as well as with the midden plant macrofossils. This study provides new information on Chaco Canyon's vegetational history and is the first independent check of the use of pollen and plant macrofossils from woodrat middens for vegetation reconstruction in the southwestern United States.

METHODS

The woodrat midden material was collected by T. R. Van Devender, M. C. Kearns, and J. L. Betancourt in 1977 and 1979. From the 22 midden samples analyzed for plant macrofossils, 19 were made available for pollen studies. Radiocarbon dates on the Chaco Canyon woodrat midden

Stephen A. Hall, Department of Geography, The University of Texas at Austin, Austin, TX 78712

American Antiquity, 53(3), 1988, pp. 582–592.
Copyright © 1988 by the Society for American Archaeology

Table 1. Radiocarbon Dates on Chaco Canyon *Neotoma* Middens Analyzed for Pollen.

Sample Abbreviation	Sample Name[a]	Age (^{14}C years B.P.)[b]	Lab Number	Material Dated
GW3	Gallo Wash 3	460 ± 190	A-1837	*Ephedra torreyana* twigs
MC4	Mockingbird Canyon 4	1,230 ± 60	A-2113	*Neotoma* fecal pellets
WR2	Weritos Rincon 2	1,780 ± 110	A-2128	*Juniperus monosperma* twigs
MC5	Mockingbird Canyon 5	1,860 ± 120	A-2114	*Juniperus monosperma* twigs
MC2	Mockingbird Canyon 2	1,910 ± 90	A-2111	*Juniperus monosperma* twigs
GW4	Gallo Wash 4	1,940 ± 150	A-1834	*Juniperus monosperma* twigs and seeds
CC3	Casa Chiquita 3	1,970 ± 100	A-2125	Miscellaneous twigs
MC1	Mockingbird Canyon 1	1,990 ± 90	A-2110	*Juniperus monosperma* twigs
GW5	Gallo Wash 5	2,070 ± 90	A-1840	*Juniperus monosperma* twigs
GW1	Gallo Wash 1	2,810 ± 90	A-1839	*Juniperus monosperma* twigs
GW6	Gallo Wash 6	2,820 ± 300	A-1838	*Lepus* fecal pellets
MC3	Mockingbird Canyon 3	3,270 ± 90	A-2112	*Pinus edulis* needles
CC1B	Casa Chiquita 1B	3,940 ± 110	A-2129	*Pinus edulis* wood fragments
GW2	Gallo Wash 2	4,480 ± 90	A-1833	*Juniperus monosperma* twigs and seeds
CC2	Casa Chiquita 2	4,780 ± 90	A-2124	*Juniperus monosperma* twigs
CC4	Casa Chiquita 4	4,920 ± 110	A-2126	Miscellaneous twigs
AC4A	Atlatl Cave 4A	5,550 ± 130	A-2115	*Juniperus monosperma* twigs
AC3	Atlatl Cave 3	9,460 ± 160	A-2116	*Pseudotsuga menziesii* wood fragments
		10,500 ± 250	A-2411	*Juniperus scopulorum* twigs[c]
AC4B	Atlatl Cave 4B	10,030 ± 150	A-2123	*Juniperus scopulorum* twigs
		10,600 ± 200	A-2139	*Pseudotsuga menziesii* wood fragments

[a] From Betancourt and Van Devender (1981).
[b] Half-life 5,568 years; dates adjusted for $^{13}C/^{12}C$ ratios.
[c] Listed as *Juniperus monosperma* in Betancourt and Van Devender (1981).

material initially were reported by Betancourt and Van Devender (1981) and are presented in Table 1. Each sample processed for pollen was broken from an indurated interior portion of a midden, excluding the dark brown rind that forms by weathering on the outer surface of middens. Woodrat middens are cemented by dried urine that is soluble in water, facilitating laboratory processing. Following the general techniques outlined by King and Van Devender (1977), these samples were oven dried and weighed, soaked in hot water for 20 to 30 minutes, and sieved through a 150 μm screen. Most of the midden samples contained fecal pellets that did not disaggregate during the brief hot-water wash and were caught in the sieve in an attempt to eliminate the addition of pollen biased toward woodrat diet. Midden material may contain partly disintegrated woodrat fecal pellets, an aspect not investigated in the present study but one that should not be ignored by pollen analysts. The fine material washed through the sieve was treated with hydrochloric acid, hydrofluoric acid, and a mild acetolysis solution. After acetolysis, the residue was washed in 10 percent ammonium hydroxide and stained with safranin O. Each residue contained numerous pollen grains, nearly all excellently preserved.

Five predissolved tablets of *Lycopodium* spores (batch no. 212761; each tablet containing 12,489 ± 491 spores; Maher 1981; Stockmarr 1971, 1973) were added to each sample during the hot water soak. Tabulation of the *Lycopodium* spores during pollen counting permits the calculation of fossil pollen concentrations for each midden sample which, in the case of the Chaco Canyon material, ranged from 17,800 to 281,000 pollen grains per gram of original midden material (Table 2). Pollen concentration is greater when the weight of the intact fecal pellets and plant fragments that did not disaggregate is subtracted from the weight of the original midden sample. Most of the weight of many samples was the soluble fraction.

RESULTS

Analysis of the Chaco Canyon material indicates that *Juniperus* pollen is the most abundant in many of the woodrat middens, one midden containing 96 percent and eight other middens containing

Table 2. Pollen Concentrations and Oven-Dried Sample Weights of Processed *Neotoma* Midden Material and Surface Samples.

Midden	Weight of Original Sample in Grams	Weight of Macroremains >150 μm in Grams	Pollen Concentration per Gram of Original Sample Processed
GW3	20.0	4.8	36,400
MC4	17.8	6.0	48,900
WR2	9.3	3.6	17,800
MC5	26.2	16.6	20,300
MC2	15.1	5.9	79,200
GW4	18.7	.9	81,300
CC3	10.5	3.8	189,000
MC1	21.6	8.5	188,000
GW5	30.2	23.5	281,000
GW1	15.5	6.3	62,100
GW6	19.0	6.7	118,000
MC3	99.4	2.7	80,500
CC1B	27.8	18.9	108,000
GW2	11.1	3.8	39,000
CC2	15.9	3.4	258,000
CC4	23.7	12.3	89,100
AC4A	26.1	15.4	108,000
AC3	28.3	19.9	82,300
AC4B	7.1	1.9	105,000
Surface materials[a]			
A	29.9	–	19,300
B	23.0	–	30,400
C	18.4	–	38,200
D	19.8	–	27,400
E	21.3	–	211,000
F	24.6	–	23,200
G	24.9	–	30,200

[a] Based on Hall (1977) and unpublished data.

more than 50 percent *Juniperus* pollen (Figure 1). Surface duff from Southwest juniper woodlands generally yields 10 to 40 percent *Juniperus* pollen (Bent and Wright 1963; Hevly 1968). Juniper twigs were present in all except the youngest midden analyzed for pollen. The various species of woodrats exhibit wide behavioral differences in plant species preferred for food and den construction (Finley 1958). For example, the Stephen's woodrat (*Neotoma stephensi*) selects den sites within 10 m of a living juniper. In a 12-month study of 317 samples of fecal material from 106 live-trapped woodrats near Flagstaff, Arizona, juniper twigs (evidently from only one tree within each woodrat home range) constituted over 87 percent of an individual woodrat's diet; reliance on juniper was greater in the winter when fewer other plants were available (Vaughan 1980). Since pollen-bearing cones of junipers are terminal on stems, a woodrat midden containing abundant juniper stems is a sure candidate for overrepresentation of *Juniperus* pollen. Both the Stephen's woodrat (*N. stephensi*) and bushy-tailed woodrat (*N. cinerea*) have been trapped at Chaco Canyon, and the white-throated woodrat (*N. albigula*) and Mexican woodrat (*N. mexicana*) are reported elsewhere in San Juan County (Findley et al. 1975:241–251). To eliminate the likely effect of juniper overrepresentation in some of the pollen spectra (Figure 1), counts of *Juniperus* pollen are subtracted from the pollen sum, and frequencies for other pollen types are calculated from the pollen sum excluding *Juniperus*.

Woodrat Midden Pollen Zones

The pollen spectra from the Chaco Canyon series of woodrat middens are divided into three informal pollen zones (Figure 1). *Pinus* pollen grains are differentiated to species using the key of

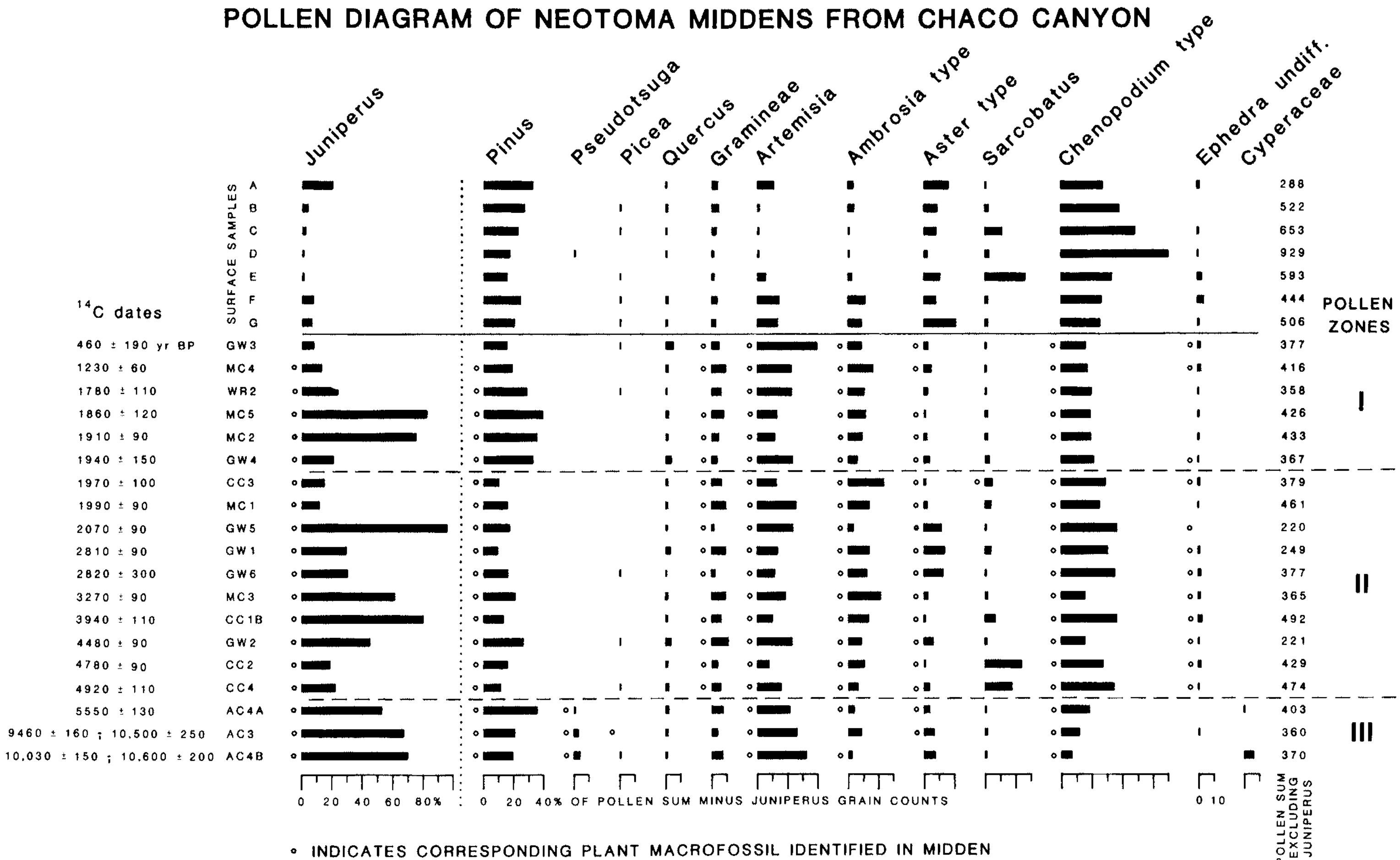

Figure 1. Percentage pollen diagram of *Neotoma* middens from Chaco Canyon; surface-sample spectra are recalculated minus counts of *Juniperus* pollen for comparison with midden-pollen spectra; locations of the seven surface samples A-G are shown in Hall (1977).

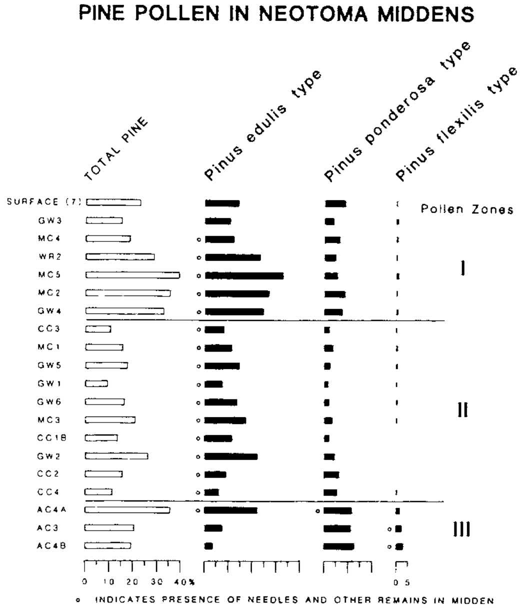

Figure 2. Differentiated pine pollen in *Neotoma* middens from Chaco Canyon; percentages shown are based on more than 100 species-identified *Pinus* grains and are relative to a pollen sum excluding *Juniperus*.

Hansen and Cushing (1973) and reference slides (Figure 2). The pollen zones correspond in general to the previously published pollen zonation of the canyon fill (Hall 1977). The time horizons separating the zones are based on midpoints between radiocarbon dates. However, it should be emphasized that a 4,000-year period, from 9,500 to 5,500 years, is missing from the midden record in zone III. Also, the time boundary between pollen zones II and I may be spurious: The one-sigma ranges of several radiocarbon dates overlap. These shortcomings can be alleviated by future study of additional material.

Pollen Zone III. The only late Pleistocene–early Holocene records from Chaco Canyon are from Atlatl Cave (Figure 3). Pollen zone III, dated from 10,600 to about 5,200 years B.P., is marked by comparatively high frequencies of ponderosa pine (*Pinus ponderosa*) and limber pine (*P. flexilis*), and significant percentages of Douglas fir (*Pseudotsuga menziesii*). The spectra also show comparatively low percentages of Chenopodiaceae-*Amaranthus* (*Chenopodium*-type), and short-spined Compositae (*Ambrosia*-type) and moderate percentages of sagebrush (*Artemisia*). A secondary but

Figure 3. Atlatl Cave, center of view in Cliff House Sandstone (Upper Cretaceous) at northwest end of Chaco Canyon; the three woodrat midden deposits containing late Pleistocene-early Holocene Douglas fir, limber pine, ponderosa pine, Rocky Mountain juniper, and blue spruce were collected here; photographed July 1981.

distinctive characteristic of the Atlatl Cave record is the presence of sedge (Cyperaceae) pollen. Sedges are rare today in Chaco Canyon. Previous analysis of numerous samples of modern and Holocene sediment from the canyon produced only one sedge pollen grain (Chaco Wash II pollen diagram, Hall 1977:1612–1613). The presence of sedge pollen in two of the three Atlatl Cave middens may indicate seeps along the base of the escarpment creating a mesic habitat. The same mesic microhabitat may have contributed to the local survival of some tree species as relicts from the as-yet-undetermined Pleistocene vegetation of the canyon.

Pollen Zone II. The next zone, dated from about 5,200 to about 1,950 years B.P., is characterized by low relative frequencies of ponderosa pine pollen and a generally low abundance of total pine pollen. Macrofossils of pinyon pine and single-seed juniper occur in every midden in pollen zone II. Relatively high frequencies of chenopod and short-spined composite pollen and comparatively low abundances of sagebrush are found in the midden samples, although the nonarboreal taxa exhibit variation in pollen percentages.

Pollen Zone I. The transition from pollen zone II to I is marked by an increase in pollen frequencies of pinyon and ponderosa pine and an increase in total pine pollen. Chenopod abundance in zone I is generally less that in the preceding zone II. The chronology of zone I extends from about 1,950 years B.P. to the present, although gaps in the woodrat midden pollen record prevent detailed vegetation reconstruction for the important period of Anasazi occupation of Chaco Canyon, A.D. 600 to 1150 (Hayes et al. 1981). Indeed, only one woodrat midden falls into the Anasazi period.

VEGETATION RECONSTRUCTION

Pre-Anasazi

Pollen analysis of the late Pleistocene–early Holocene woodrat middens of Atlatl Cave indicates that the vegetation was a shrub grassland with more sagebrush and fewer chenopods than today. The Atlatl Cave middens contain plant macrofossils of Douglas fir, limber pine, ponderosa pine, pinyon pine (*P. edulis*), blue spruce (*Picea pungens*), and Rocky Mountain juniper (*Juniperus scopulorum*) (Betancourt et al. 1983; Betancourt and Van Devender 1981). None of these trees grow in the vicinity today. Pinyon pine can be found in abundance several kilometers to the east on Chacra Mesa at higher elevation. At present the junipers in Chaco Canyon are single-seed juniper (*J. monosperma*), evidently having replaced Rocky Mountain juniper during the Holocene (Betancourt and Van Devender 1981). Since *Juniperus* pollen is likely overrepresented and pollen grains of the two species of juniper essentially are identical, it is not possible to determine by pollen analysis of woodrat middens if Rocky Mountain juniper was a major or minor component of the vegetation.

The spruce–fir–pine vegetation present in the Chuska Mountains during full-glacial time (Wright et al. 1973) was gone by 10,600 years ago. Although the nature of the glacial age vegetation and the transition from glacial to postglacial vegetation at Chaco Canyon have not yet been determined fully, the Douglas fir, limber pine, blue spruce, Rocky Mountain juniper, and ponderosa pine macrofossils may be relicts of the earlier vegetation, surviving for a time near Atlatl Cave in more mesic microhabitats.

A gap in the alluvial and woodrat midden pollen records extends from about 9,500 to 7,000 years B.P. Other middens have been reported more recently (Betancourt et al. 1983) but their pollen contents have not been analyzed. The oldest alluvial deposit from Chaco analyzed for pollen, dating no earlier than 7,000 years B.P., contains relative frequencies of pinyon pine similar to those of today but with a greater-than-modern component of ponderosa pine pollen (Hall 1977).

Between 6,000 and 5,000 years ago the alluvial and midden pollen records both document a marked regional decrease in ponderosa and limber pine; the alluvial record also shows a decrease in pinyon pine abundances. A similar mid-Holocene decrease in pine pollen frequencies is documented at Ashislepah Shelter near Chaco Canyon (Fredlund 1984). Low abundance of ponderosa pine pollen, persisting until about 2,000 years B.P., reflects upslope migration and diminished abundance of regional pine forest vegetation in response to drier climate.

A few pinyon pines, ponderosa pines, and Douglas firs were able to survive locally at escarpment sites along the canyon during the dry period. Twigs of single-seed juniper also occur in the same middens and, together with the pinyon remains, are the evidence for the previous interpretation of a Holocene pinyon-juniper woodland at Chaco Canyon (Betancourt and Van Devender 1981). However, the low percentages of pinyon pine pollen in the same woodrat middens and in alluvium of local origin with the same age as the middens indicate that pines were not a significant component of the local vegetation. The alluvium of local origin also contains low percentages of *Juniperus* pollen (less than 10 percent), suggesting that junipers also were few in numbers. During this time, the desert shrub-grassland vegetation at Chaco Canyon and at lower elevation in the San Juan Basin exhibited increases in chenopods and composites. Furthermore, analysis of charcoal from archaeological sites in the lower Chaco River area shows that a chenopod, probably saltbush (*Atriplex*), and small amounts of rabbitbrush (*Chrysothamnus*) were the only plants used for fuel during the Archaic occupation from 1820 B.C. to A.D. 590 (Toll 1983). The absence of charcoal from pinyons and junipers implies that a pinyon–juniper woodland was not present at lower elevations in the San Juan Basin.

Anasazi

Alluvial pollen assemblages dated between 250 B.C. and A.D. 950, including much of the period of Anasazi occupation of the canyon, are characterized by pinyon and ponderosa pollen frequencies one-third those found in post-Anasazi and modern alluvium at Chaco (Hall 1977). An exception, based on midden pollen, is a period of 200 years, from about 1 B.C. to A.D. 200, when pinyon pollen percentages at Chaco were nearly twice that of modern surface samples, indicating a brief increase in pinyon pine abundance or pollen production.

The pollen records from both woodrat middens and alluvium indicate that the vegetation at Chaco Canyon during Anasazi occupation (about A.D. 600 to 1150) was a desert shrub grassland, similar to that of today, with one notable difference. Macrofossil remains from woodrat middens document the presence of pinyon pines in the canyon where none now exist (Betancourt and Van Devender 1981). Single-seed junipers, which occur today as isolated individuals along the canyon escarpments, also are preserved as fossils in the woodrat middens along with the remains of pinyon pine.

The presence of pinyon pines and junipers at Chaco Canyon is supported by charcoal analysis of Puebloan hearths. Charcoal from six sites, including Pueblo Alto, Una Vida, and a late Basketmaker III–early Pueblo pit house dated about A.D. 700 to 800, shows that pinyon and juniper account for 13.5 and 19 percent, respectively, of hearth materials analyzed. However, greasewood (*Sarcobatus*) and saltbush (*Atriplex*) account for 52 percent of fuel materials (Powers et al. 1983). The moderate use of pinyon and juniper for firewood suggests that these trees were in short supply, a conclusion supported by the woodrat midden and alluvial pollen records.

Anasazi Deforestation at Chaco Canyon?

It is reasonable to consider that, especially with initially low abundances, the numbers of pinyon and junipers would be reduced systematically through constant local harvesting of firewood by the Anasazi population, resulting in local extinction of trees. The plant macrofossil record from Chaco was regarded by Betancourt and Van Devender (1981) as showing a drastic reduction of pinyon and juniper after 1,230 ± 60 years B.P. (A.D. 780, tree-ring calibration, Stuiver and Pearson 1986). Betancourt and Van Devender concluded that the Chaco Puebloans depleted the Holocene pinyon-juniper woodlands, resulting in political and economic instability and, ultimately, abandonment. These conclusions, however, were based on the absence of pinyon and juniper in one midden, dated 460 ± 190 years B.P. (A.D. 1437; tree-ring calibration, Stuiver and Pearson 1986). Later studies of additional middens showed that junipers did not become extinct locally but persisted through Anasazi occupation of Chaco, surviving to today. Pinyon pines, however, appear to drop out of the new woodrat midden record; the last midden from the new series containing pinyon pine is dated 1,070 ± 90 years B.P. (A.D. 980; tree-ring calibration, Stuiver and Pearson 1986; Betancourt et al. 1983). A critical gap in the second collection of woodrat midden material, A.D. 980 to 1414 (Stuiver and Pearson 1986), still leaves us without information for the later periods of Puebloan occupation.

The presence of pinyon and juniper charcoal in Puebloan hearths, however, cited above, implies the presence of those trees nearby during Pueblo III time.

Post-Anasazi

In contrast with the woodrat midden macrofossil data that show a late prehistoric drop-out of pinyon pines from Chaco Canyon escarpment localities, the alluvial pollen record shows a marked increase in regional pinyon-pine populations by about A.D. 1350 (Hall 1977, 1983). Relative frequencies of pinyon pine in alluvium deposited prior to and during Anasazi occupation of the canyon are about 12 percent; alluvium postdating Puebloan abandonment contains about 34 percent pinyon with 38 percent pinyon pollen occurring in historic age alluvium. A similar late-prehistoric increase in pinyon also is documented north of Chaco Canyon at alluvial and archaeological sites along the San Juan River (Schoenwetter 1964). The increase in distribution of pinyons occurred at higher elevations, such as on Chacra Mesa where the pines are abundant today, but did not reach the lower elevations of Chaco Canyon, or did so only in small numbers.

The historic vegetation at lower Chaco Canyon includes numerous widely spaced individuals of single-seed juniper and, in recesses, a few small pinyons that are possible descendents of the sparse late-prehistoric population recorded in woodrat middens and Puebloan hearths. In 1923 two living ponderosa pines on the south side (South Mesa) of Chaco Canyon were photographed and inspected by A. E. Douglass; the outer rings were so narrow as to be scarcely readable. The pines later were cut for firewood (Hawley 1934).

The near absence of pinyons in the lower Chaco Canyon area today probably is due to the cumulative effects of the continuously arid Holocene climate coupled with wood harvesting of an already sparse tree population by pre-Anasazi, Anasazi, Navajo, and Anglo travelers and inhabitants.

ENVIRONMENTAL RECONSTRUCTION

The late Pleistocene–early Holocene climate of the Chaco area, based on the vegetation, was similar to that of today with slightly lower temperatures and perhaps slightly higher precipitation. The transition from glacial to postglacial conditions already had occurred by 10,600 years B.P., the age of the oldest woodrat midden from Chaco Canyon. This general time interval is represented poorly in Southwest pollen records (Hall 1985). However, the interpretation corresponds to the results obtained from the 11,200-year-old Lehner mammoth kill site in southeastern Arizona where it was concluded that the late Pleistocene desert-grassland vegetation was similar to that of the Holocene and was characterized by slightly lower temperatures and several inches of annual precipitation with present seasonality (Mehringer et al. 1971; Mehringer and Haynes 1965).

Middle Holocene pollen records from woodrat middens, from alluvium, and from Ashislepah Shelter at Chaco Canyon indicate the onset of a hot, dry climate by at least 5,800 years ago (Fredlund 1984; Hall 1977, 1983). During the middle Holocene, although beginning at different times in different areas and persisting for varying lengths of time (probably due in part to data resolution), the climate in the Southwest was hotter and drier than either historic or Holocene averages. Additional evidence for this extreme aridity comes from the drying of lakes, upward migration of alpine treelines, deep trenching of alluvial valleys, and soil formation. Also, the interpretation of a wet Altithermal or an Altithermal with increased summer rainfall (Martin 1963) has been shown to be in error; the Double Adobe I alluvial sequence in southeastern Arizona on which the wet Altithermal concept was based is interrupted by an unconformity at which the middle Holocene, dating from about 7,000 to less than 4,000 years B.P., is missing from the record (Haynes 1968; Waters 1986). The Chaco record of the middle Holocene is incomplete as well, and further studies should be made there in order to provide additional information about the nature of Altithermal vegetation and climate in the San Juan Basin.

The late Holocene, including the period of Anasazi occupation of Chaco Canyon, was characterized by a climate slightly drier than that of today, based on low frequencies of pinyon pine pollen—lower than those found in post-Anasazi and historic alluvium. Alluvial pollen sequences, however, can represent a moderately broad scale of paleoclimatic reconstruction, at least when compared with archaeological chronologies. The pollen record at Chaco probably has at best a 100-year resolution, limited by the nature of the alluvial stratigraphy and pollen-sampling interval. Tree-ring records, on the other hand, can show year-to-year fluctuations of precipitation. Tree-ring analyses in northwestern New Mexico show consistent variations in precipitation that may apply to Chaco Canyon: an increase in summer rainfall A.D. 1100–1135 followed by a period of lower summer rainfall A.D. 1135–1179 (data from W. J. Robinson and M. R. Rose, cited in Gillespie 1984:40). These decadal fluctuations, while having a potentially strong impact on Puebloan society, are not recognizable as yet in alluvial-pollen records.

Approximately 1,000 years ago, the climate changed to comparatively moister conditions such as prevail today. This interpretation is not based as firmly as one would like, however, and contrasts with the Murray Springs (Arizona) and Southern Plains records that both indicate a change to the comparatively dry modern climate about 1,000 years ago (Hall 1982; Mehringer et al. 1967).

POLLEN AND PLANT MACROFOSSILS FROM WOODRAT MIDDENS

Preliminary investigations have shown that, in general, pollen spectra from modern and fossil woodrat middens may provide reliable information on regional and local vegetation (King and Van Devender 1977; Thompson 1985). In contrast, plant macrofossils represent a geographically restricted plant community occurring within a few tens of meters of a woodrat nest, matching the home range of individual woodrats.

The present study completes the first independent check of pollen and plant macrofossil data from woodrat middens from the Southwest. At Chaco Canyon, pollen from woodrat middens and from the previously reported alluvial record (Hall 1977) indicates the same history of the local and regional vegetation. Plant macrofossils, on the other hand, have been interpreted as indicating the presence of a pinyon–juniper woodland in the canyon (Betancourt and Van Devender 1981). While the macrofossils provide positive evidence for the presence of pinyons and junipers along canyon escarpments, macrofossils alone do not indicate the abundance of the trees in the escarpment plant community nor do they provide information on whether or not those trees are components of the nonescarpment local or regional vegetation. In arid regions, escarpments may have plant communities that differ markedly from the more widespread vegetation found over broader areas of less-broken terrain. Also, escarpment habitats can be more mesic and may harbor relict plants from former vegetation types and past climatic regimes, such as is likely the case at Atlatl Cave in Chaco Canyon. Because of these and other uncertainties (Hall 1985, 1986), the application of plant macrofossils from woodrat middens to local and regional vegetation and paleoclimatic reconstruction may be unsound. Macrofossils alone cannot be used to judge the representativeness or reliability of the midden plant material for the interpretation of past vegetation. Pollen analysis, however, provides the basis for verifying the significance of the macrofossils. Indeed, pollen and macrofossils together are an unbeatable source of vegetation and floral data that surpass in quality and completeness the information obtained from either pollen or macrofossils alone. The example of Chaco Canyon testifies, not to the limitations of plant remains from woodrat middens, but to the promise of future new insights to come from combined analysis of both pollen and macrofossils.

SUMMARY AND CONCLUSIONS

1. The vegetation at Chaco Canyon and at lower elevations in the San Juan Basin of New Mexico has been a desert shrub grassland since 10,600 years ago.

2. The blue spruce, Douglas fir, Rocky Mountain juniper, limber pine, and ponderosa pine found as plant macrofossils in woodrat middens may be relicts from a former vegetation and imply that earlier local microhabitats were more mesic or cooler.

3. The middle Holocene was marked by extreme aridity. Pine-forest vegetation in the mountains surrounding the San Juan Basin moved upslope, decreasing in abundance. Chenopods and composites, except sagebrush, increased in abundance in low elevations in a vegetation of desert shrub grassland. A few scattered pinyon and juniper trees persisted during the dry period along escarpments at Chaco.

4. The vegetation at the time of Anasazi occupation of Chaco Canyon was a desert shrub grassland, perhaps slightly drier on a broad scale than today, and with pinyon pines and single-seed junipers occurring as isolated individuals or small stands along canyon escarpments. Pollen data indicate that the trees were minor components of the escarpment vegetation.

5. The Anasazi occupants of Chaco Canyon harvested pinyons, junipers, greasewood, and saltbush for firewood. Plant macrofossil evidence, if representative, indicates that pinyon pines may have become more rare in Chaco Canyon sometime after A.D. 980. Small stands and isolated individuals of junipers evidently were present along canyon escarpments before, during, and after Anasazi presence. Whether or not the Anasazi were responsible for the demise of pinyons cannot be determined from current evidence.

6. Pollen data from alluvium indicate a significant increase in regional pinyon-pine populations by about A.D. 1350, although pinyons did not expand into the lower elevation areas of Chaco Canyon where isolated junipers occur today. The regional expansion of pinyons may have been in response to a change in climate to comparatively moister conditions.

Acknowledgments. I thank T. R. Van Devender and J. L. Betancourt for providing samples of the Chaco Canyon woodrat middens for pollen analysis and Walter P. Herriman, past superintendent, who provided access to areas in Chaco Culture National Historical Park (formerly Chaco Canyon National Monument). Previous work discussed in this paper was supported in part by National Science Foundation Grant GA-35448. I thank Paul Delcourt, Edward Cushing, and other reviewers for helpful comments, and Thomas Windes for assistance.

REFERENCES CITED

Bent, A. M., and H. E. Wright, Jr.
1963 Pollen Analyses of Surface Materials and Lake Sediments from the Chuska Mountains, New Mexico. *Geological Society of America Bulletin* 74:491–500.

Betancourt, J. L., P. S. Martin, and T. R. Van Devender
1983 Fossil Packrat Middens from Chaco Canyon, New Mexico: Cultural and Ecological Significance. In *Chaco Canyon Country,* edited by S. G. Wells, D. W. Love, and T. W. Gardner, pp. 207–217. American Geomorphological Field Group, Albuquerque.

Betancourt, J. L., and T. R. Van Devender
1981 Holocene Vegetation in Chaco Canyon, New Mexico. *Science* 214:656–658.

Findley, J. S., A. H. Harris, D. E. Wilson, and C. Jones
1975 *Mammals of New Mexico.* University of New Mexico Press, Albuquerque.

Finley, R. B., Jr.
1958 *The Wood Rats of Colorado: Distribution and Ecology.* University of Kansas Publication 10(6):213–552. Museum of Natural History, Lawrence.

Fredlund, G.
1984 Palynological Analysis of Sediments from Sheep Camp and Ashislepah Shelters. In *Archaic Prehistory and Paleoenvironments in the San Juan Basin, New Mexico: The Chaco Shelters Project,* edited by A. H. Simmons, pp. 186–209. Project Report Series 53. Museum of Anthropology, University of Kansas, Lawrence.

Gillespie, W. B.
1984 The Environment of the Chaco Anasazis. In *New Light on Chaco Canyon,* edited by D. G. Noble, pp. 37–44. School of American Research Press, Santa Fe.

Hall, S. A.
1977 Late Quaternary Sedimentation and Paleoecologic History of Chaco Canyon, New Mexico. *Geological Society of America Bulletin* 88:1593–1618.
1982 Late Holocene Paleoecology of the Southern Plains. *Quaternary Research* 17:391–407.
1983 Holocene Stratigraphy and Paleoecology of Chaco Canyon. In *Chaco Canyon Country,* edited by S. G. Wells, D. W. Love, and T. W. Gardner, pp. 219–226. American Geomorphological Field Group, Albuquerque.
1985 Quaternary Pollen Analysis and Vegetational History of the Southwest. In *Pollen Records of Late-Quaternary North American Sediments,* edited by V. M. Bryant, Jr., and R. G. Holloway, pp. 95–123. American Association of Stratigraphic Palynologists Foundation, Dallas.
1986 Plant Macrofossils from Wood Rat Middens: Vegetation or Flora? In *Program and Abstracts,* p. 136. American Quaternary Association 9th Biennial Meeting, Champaign–Urbana, Illinois.

Hansen, B. S., and E. J. Cushing
1973 Identification of Pine Pollen of Late Quaternary Age from the Chuska Mountains, New Mexico. *Geological Society of America Bulletin* 84:1181–1200.

Hawley, F. M.
1934 *The Significance of the Dated Prehistory of Chetro Ketl, Chaco Canon, New Mexico.* Monograph No. 2. School of American Research, University of New Mexico Press, Albuquerque.
Hayes, A. C., D. M. Brugge, and W. J. Judge
1981 *Archeological Surveys of Chaco Canyon, New Mexico.* Publications in Archeology 18A. Chaco Canyon Studies, National Park Service, Washington, D.C.
Haynes, C. V., Jr.
1968 Geochronology of Late Quaternary Alluvium. In *Means of Correlation of Quaternary Successions,* edited by R. B. Morrison and H. E. Wright, Jr., pp. 591–631. University of Utah Press, Salt Lake City.
Hevly, R. H.
1968 Studies on the Modern Pollen Rain in Northern Arizona. *Journal of the Arizona Academy of Science* 5:116–127.
King, J. E., and T. R. Van Devender
1977 Pollen Analysis of Fossil Packrat Middens from the Sonoran Desert. *Quaternary Research* 8:191–204.
Maher, L. J., Jr.
1981 Statistics for Microfossil Concentration Measurements Employing Samples Spiked with Marker Grains. *Review of Palaeobotany and Palynology* 32:153–191.
Martin, P. S.
1963 *The Last 10,000 Years. A Fossil Pollen Record of the American Southwest.* University of Arizona Press, Tucson.
Mehringer, P. J., Jr., D. P. Adam, and P. S. Martin
1971 Pollen Analysis at Lehner Ranch Arroyo. In *Lehner Early Man-Mammoth Site,* pp. 10–26. American Association of Stratigraphic Palynologists Foundation, Dallas.
Mehringer, P. J., Jr., and C. V. Haynes, Jr.
1965 The Pollen Evidence for the Environment of Early Man and Extinct Animals at the Lehner Mammoth Site. *American Antiquity* 31:17–23.
Mehringer, P. J., Jr., P. S. Martin, and C. V. Haynes, Jr.
1967 Murray Springs, A Mid-Postglacial Pollen Record from Southern Arizona. *American Journal of Science* 265:786–797.
Powers, R. P., W. B. Gillespie, and S. H. Lekson
1983 *The Outlier Survey. A Regional View of Settlement in the San Juan Basin.* Reports of the Chaco Center No. 3. Division of Cultural Research, National Park Service, Albuquerque.
Schoenwetter, J.
1964. The Palynological Research. In *Alluvial and Palynological Reconstruction of Environments, Navajo Reservoir District,* edited by J. Schoenwetter and F. W. Eddy, pp. 63–107. Papers in Anthropology No. 13. Museum of New Mexico, Santa Fe.
Stockmarr, J.
1971 Tablets with Spores Used in Absolute Pollen Analysis. *Pollen et Spores* 13:615–621.
1973 Determination of Spore Concentrations with an Electronic Particle Counter. *Geological Survey of Denmark Yearbook 1972,* pp. 87–89. Amsterdam.
Stuiver, M., and G. W. Pearson
1986 High-Precision Calibration of the Radiocarbon Time Scale, AD 1950–500 BC. *Radiocarbon* 28(2B): 805–838.
Thompson, R. S.
1985 Palynology and *Neotoma* Middens. In *Late Quaternary Vegetation and Climates of the American Southwest,* edited by B. F. Jacobs, P. L. Fall, and O. K. Davis, pp. 89–112. Contribution Series No. 16. American Association of Stratigraphic Palynologists Foundation, Dallas.
Toll, M. S.
1983 Changing Patterns of Plant Utilization for Food and Fuel: Evidence from Flotation and Macrobotanical Remains. In *Economy and Interaction Along the Lower Chaco River,* edited by P. Hogan and J. C. Winter, pp. 331–350. Office of Contract Archeology and Maxwell Museum of Anthropology, University of New Mexico, Albuquerque.
Vaughan, T. A.
1980 Woodrats and Picturesque Junipers. In *Aspects of Vertebrate History. Essays in Honor of Edwin Harris Colbert,* edited by L. L. Jacobs, pp. 387–401. Museum of Northern Arizona Press, Flagstaff.
Waters, M. R.
1986 *The Geoarchaeology of Whitewater Draw, Arizona.* Anthropological Papers No. 45. University of Arizona, University of Arizona Press, Tucson.
Wright, H. E., Jr., A. M. Bent, B. S. Hansen, and L. J. Maher, Jr.
1973 Present and Past Vegetation of the Chuska Mountains, Northwestern New Mexico. *Geological Society of America Bulletin* 84:1155–1180.