

## Society for American Archaeology

---

Plains-Pueblo Interdependence and Human Diet at Pecos Pueblo, New Mexico

Author(s): Katherine A. Spielmann, Margaret J. Schoeninger, Katherine Moore

Source: *American Antiquity*, Vol. 55, No. 4 (Oct., 1990), pp. 745-765

Published by: Society for American Archaeology

Stable URL: <http://www.jstor.org/stable/281248>

Accessed: 02/10/2008 13:11

---

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at <http://www.jstor.org/page/info/about/policies/terms.jsp>. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at <http://www.jstor.org/action/showPublisher?publisherCode=sam>.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

JSTOR is a not-for-profit organization founded in 1995 to build trusted digital archives for scholarship. We work with the scholarly community to preserve their work and the materials they rely upon, and to build a common research platform that promotes the discovery and use of these resources. For more information about JSTOR, please contact [support@jstor.org](mailto:support@jstor.org).



*Society for American Archaeology* is collaborating with JSTOR to digitize, preserve and extend access to *American Antiquity*.

<http://www.jstor.org>

## PLAINS-PUEBLO INTERDEPENDENCE AND HUMAN DIET AT PECOS PUEBLO, NEW MEXICO

Katherine A. Spielmann, Margaret J. Schoeninger, and  
Katherine Moore

*Using bone-chemistry data, this project sought to assess the degree of dietary change that occurred among eastern border Pueblo populations due to prehistoric food exchange with hunter-gatherers on the Plains and to the arrival of Spanish colonists. In so doing we introduce a technique for dietary reconstruction that determines the range of diets compatible with bone-chemistry data from a particular population. The data are derived from samples of modern and archaeological plants and animals collected from the area surrounding Pecos Pueblo, and from archaeological humans recovered from Pecos itself. Bone-strontium concentrations were measured to monitor the relative proportions of meat to vegetables in the diet. Carbon and nitrogen stable-isotope ratios in food items and in bone collagen were measured to monitor the dependence on maize and bison meat. The results do not provide support for the hypothesis that bison replaced mule deer in the diet during the period of significant Plains-Pueblo trade. If bison, whose diets are relatively enriched in  $^{13}\text{C}$  had replaced mule deer, an increase in average  $\delta^{13}\text{C}$  values should have occurred. This, however, was not observed. A decrease in carbon-isotope values in the historic period suggests that either bison meat or maize or both decreased in importance in the Pecos diet and that dependence on wild plants increased.*

*En base a datos químicos de fragmentos óseos se intentó determinar el grado en el que cambió la dieta entre las poblaciones Pueblo del este, debido al intercambio con cazadores y recolectores prehistóricos y al impacto de la llegada de colonizadores españoles. Con esto se presenta una técnica para reconstruir dietas que permite determinar un cierto rango de dietas compatibles con la composición química de fragmentos óseos de una población determinada. Los datos fueron obtenidos del análisis de flora y fauna contemporáneas al igual que de especímenes encontrados en localidades arqueológicas en el área circunvecina a Pecos Pueblo. Además, se analizaron restos óseos humanos de la misma zona arqueológica de Pecos. Se midieron las concentraciones de Estroncio para controlar las proporciones relativas de carne y vegetales en la dieta. Así mismo fueron medidas las proporciones de los isótopos estables de Nitrógeno y Carbono en productos alimenticios y calógeno óseo para determinar la dependencia de la dieta en maíz y carne de bisonte. Los resultados no dan soporte a la hipótesis de que la carne de bisonte sustituyó a la del venado cariacú en la dieta durante el período en el cual el comercio entre los pobladores de los llanos y los indios Pueblo fue significativo. Como la dieta de bisonte está relativamente enriquecida en  $^{13}\text{C}$ , un aumento del promedio en  $\delta^{13}\text{C}$  debería haber ocurrido en caso de que éste sustituyera al venado cariacú. Pero éste no es el caso. El decrecimiento de las proporciones de los isótopos de Carbono durante el período histórico sugiere una disminución en importancia de la carne de bisonte, o del maíz, o ambos en la dieta de los habitantes de Pecos, mientras que la dependencia en plantas silvestres se incrementó.*

Since 1973, when A. B. Brown used strontium data to address the issue of dietary differences within prehistoric human populations, archaeologists have marshaled isotopic and trace-element data to address several research issues concerning dietary change and social relations. Prominent among these issues in New World archaeology have been the development of dependence on maize agriculture (e.g., Bender et al. 1981; Farnsworth et al. 1985; Lynott et al. 1986; Norr 1981; Schwarcz et al. 1985; van der Merwe and Vogel 1978; Vogel and van der Merwe 1977), and the existence of status differences among members of a single population (e.g., Hatch and Geidel 1985; Lambert et al. 1979; Schoeninger 1979). While bone-chemistry analysis is by no means an infallible technique for the reconstruction and analysis of prehistoric diets (see Price 1989; Sillen et al. 1989), nonetheless,

---

Katherine A. Spielmann, Department of Anthropology, Arizona State University, Tempe, AZ 85287  
Margaret J. Schoeninger, Department of Anthropology, University of Wisconsin, Madison, WI 53706  
Katherine Moore, Department of Behavioral Sciences, Bentley College, Waltham, MA 02154

American Antiquity, 55(4), 1990, pp. 745–765.  
Copyright © 1990 by the Society for American Archaeology

in conjunction with floral and faunal data, bone-chemistry data can be informative in addressing questions like these concerning prehistoric food consumption.

The purpose of the study presented here is to expand the area of inquiry of archaeological bone-chemistry studies in two directions. First, we address an issue of dietary change that involves food exchange rather than in situ changes in subsistence production. Exchange of food is notoriously difficult to address with archaeological data; bone-chemistry analysis holds some promise in this area. Second, we introduce a technique for dietary reconstruction that determines the range of diets compatible and not compatible with bone-chemistry data for a particular population. This technique expands the utility of bone-chemistry information and can be applied easily to any human bone-chemistry data set for which there is isotopic information concerning locally available plant and animal foods.

Our case study concerns the impact that trade for food products between late prehistoric Plains and Pueblo populations in the American Southwest had on Pueblo diet, and whether Spanish colonization affected Pueblo diet. The study focuses on the analysis of archaeological materials from Pecos Pueblo, New Mexico.

Pecos Pueblo, a large farming village in north-central New Mexico (see Figure 1), was occupied by roughly 1,000 people between A.D. 1300 and 1846. The pueblo's location in a pass connecting the Rio Grande Valley and the western High Plains made it an ideal focus for trade between Puebloan and Plains groups. The earliest Spanish documents for New Mexico record that hunters from the Plains came annually in the fall to trade primarily foodstuffs: bison meat and fat in exchange for maize (Hammond and Rey 1953, 1966; Winship 1896). Archaeological data indicate that this interaction appears to have evolved in the mid-fifteenth century and persisted well into the historic period (Kidder 1932; Spielmann 1982, 1983). Neither archaeological nor documentary data indicate the significance of this traded meat to the Pueblo diet, yet such information would provide a means of monitoring the degree of interdependence between the two populations. For this reason, an estimate of the contribution of bison meat to Pueblo diet is needed.

Due to the differential preservation of floral and faunal resources, archaeological data are seldom adequate to quantify contributions of various foods to prehistoric diets (see Klein and Cruz-Urbe 1984; Minnis 1985). For example, historical-period documents indicate that bison meat usually was made into jerky at processing sites to lighten the transported load (e.g., Catlin 1965; Denig 1930; Weltfish 1965). Thus, much bison meat could have arrived at Pecos without bone. In such a case, nothing would be preserved archaeologically. The occasional bison bones in the Pecos midden cannot indicate the quantity of bison meat brought to Pecos, or the significance of bison meat to the Pueblo diet, which may have been considerable.

In addition, field methods may not be adequate to recover those food resources that have been preserved. At Pecos, the only extensive excavations in the prehistoric middens were carried out by Alfred Kidder in the teens and early twenties of this century. At that time, techniques for the recovery of faunal and floral material had not been developed. Those faunal remains that were collected were reported briefly and the majority discarded; floral materials were not saved at all (Kidder 1932).

One means of circumventing the problems of the prehistoric floral and faunal records in the reconstruction of diet is to turn to human skeletal material. Barring diagenesis (postmortem chemical alterations in bone), the composition of bone reflects aspects of the diet of an individual (Schoeninger 1979, 1981, 1989; Schoeninger and DeNiro 1984; Sillen and Kavanagh 1982). Kidder's excavations at Pecos produced a large number of human burials. A sample of these was used for this project.

## RESEARCH PROBLEM

This project has sought to determine whether changes occurred in the composition of the diet of the Pecos population over time with respect to two developments in Pecos' interaction with non-Puebloan peoples. The first development was the evolution of the exchange system between Pecos and various bison-hunting populations occupying the Plains of eastern New Mexico and west Texas, which was discussed above. Computer simulation of maize production at Pecos and bison pro-

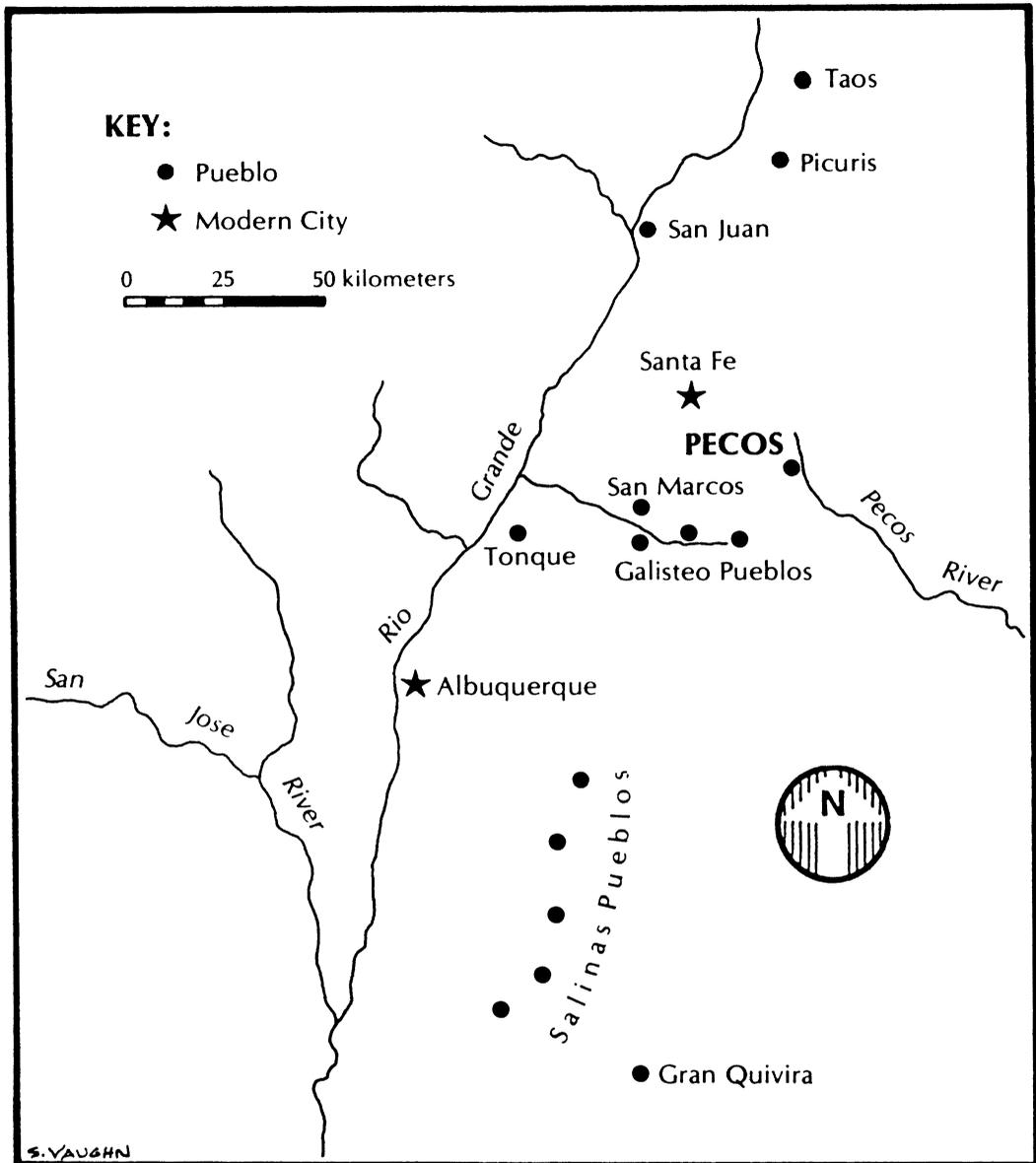


Figure 1. Map of the area within New Mexico where Pecos and other eastern border prehistoric pueblos are located.

curement on the Plains has demonstrated that prehistoric Pecos farmers annually could supply Plains hunter-gatherers with a significant caloric contribution (three months of calories), while Plains populations could supply Pecos with most of their meat protein (Spielmann 1982).

Specifically, the hypothesis tested in this study is that traded bison meat replaced rather than supplemented local mule deer as the primary animal protein source in the Pecos diet. This hypothesis was generated from results of the simulation and from faunal data from Pecos and Gran Quivira, another eastern-border trading pueblo. The simulation indicated that trade for meat was not particularly beneficial for the Pecos population in terms of reducing risk or procurement costs, unless

local meat resources were being stressed (i.e., over hunted), and were consequently not available in adequate quantities.

Faunal data are also suggestive. Kidder mentions that bison bone increased substantially at Pecos beginning in deposits dating to about A.D. 1475 (Kidder 1932:196). Unfortunately, Kidder does not quantify this increase or discuss whether mule deer bone decreased as bison increased.

At Gran Quivira, there is an increase in bison bone similar to that at Pecos in the late fifteenth-early sixteenth-century middens (Spielmann 1988). Further, Gran Quiviran bison bone increases in frequency as antelope, the local large game animal, decreases. Even so, bison bone is never abundant at Gran Quivira, and is comprised primarily of ribs, bones that could have been riders on slabs of jerked meat (see Binford 1978).

The second development that affected the Pecos food supply was the arrival of Spanish colonists in the 1600s and the establishment of a system of land grants. The recipients of a grant were given access to the labor and products of Pueblo populations on their land. One aspect of the system that could have affected Pueblo subsistence significantly was the exaction of Pueblo labor for various projects directed by the Spaniards. This significantly curtailed Pueblo labor in their own fields (Kessell 1979; Scholes 1936-1937; Spielmann 1989), reducing crop production both for Pecos itself and for trade with Plains populations. Compounding this problem was the fact that tribute payments of goods to the Spaniards were exacted in hides, especially bison hides. It is hypothesized that this demand would have shifted the Plains-Pueblo exchange system from an emphasis on the acquisition of meat to an emphasis on hides in those years that the Pueblo farmers had enough surplus maize to trade. Possible support for this shift can be found in statements referring to Plains-Pueblo trade in the 1660s, which report that Apaches came to the Pueblos to trade *hides* (Kessell 1979). Meat is not mentioned at all, in stark contrast to documents from the mid-sixteenth to the early seventeenth centuries, which always listed meat and fat as Plains trade items (e.g., Hammond and Rey 1953, 1966; Winship 1896). Moreover, Spanish participation in Plains trade also disrupted the prehistoric Plains-Pueblo trade system (Spielmann 1989).

The hypothesis we tested with regard to Spanish changes in the Pecos subsistence system is that the combination of demands for labor and bison hides reduced both the amount of meat and also the amount of maize in the Pecos diet after A.D. 1600, forcing the population to rely on gathered foods such as pinyon nuts and wild seeds. While the Spaniards did introduce domestic animals into New Mexico, domestic livestock was raised largely by the Spanish friars for export to northern Mexico to pay for church furnishings (Scholes 1936-1937; Spielmann 1989).

In order to address these issues, several aspects of bone composition were used. An estimation of whether the relative contribution of meat and vegetables to Pecos diets changed over time was made by measuring the concentration of strontium in the mineral portion of bone tissue (Schoeninger 1979; Sillen and Kavanagh 1982). Since animals discriminate against strontium in favor of calcium during passage of the two elements across the wall of the gut, the concentration of strontium in the bones of an herbivore is approximately four times lower than in the equivalent amount of plant tissue. Of the strontium that crosses the gut, over 90 percent is stored in bone (Comar and Wasserman 1964), thus, the flesh of a herbivore has far less strontium than is stored in its skeleton. Therefore, a carnivore eating herbivore flesh has lower strontium levels in its skeleton than occur in herbivore bone due to the reduced amounts in the carnivore diet and the continued discrimination in favor of calcium. Omnivores such as humans are expected to manifest concentrations of strontium in bone that are intermediate between those of herbivores and carnivores, in proportion to the relative amounts of plant and animal foods in their diet.

Since the absolute amount of strontium incorporated in bone ultimately is dependent upon the baseline levels in soil, those soils with low baseline levels produce plants and fauna with strontium concentrations significantly lower than are produced in the same species in areas with higher baseline levels (Comar and Wasserman 1964). Analyses of *modern* fauna from several regions around the world indicate that in some cases the bone-strontium levels are around 100 ppm (Schoeninger 1981), while in others they may exceed 1,000 ppm (Schoeninger 1989). Thus, use of bone-strontium levels as estimators of *absolute* percentages of dietary components must be restricted to areas in which the baseline strontium levels are known and in which the flora and fauna have been analyzed

(Schoeninger 1979; Sillen et al. 1989). This is especially critical in the United States Southwest where baseline levels are known to vary markedly (Sillen and Kavanagh 1982). Because baseline soil levels were not measured for the area surrounding Pecos, and because only a few fauna were available for analysis, our interpretations of the bone-strontium data necessarily were limited to investigation of changes between time periods. If the relative amount of meat vs. plants in the human diet at Pecos changed between time periods, it was assumed that the strontium in human bones also would change through time.

Another method that has been proposed for estimating the meat to vegetable proportions in human diet involves a comparison of the nitrogen stable-isotope ratios in human bone collagen with those ratios in bone collagen of known carnivores and herbivores (Schoeninger 1985). This proposal was based on the well-documented trophic-level separation in marine vertebrates (Schoeninger and DeNiro 1984; Wada 1980), and on data suggesting that the same separation occurs in terrestrial vertebrates (Schoeninger 1985; Schoeninger and DeNiro 1984). The isotopic data presented in Table 1, however, indicate that those plants eaten by the people at Pecos do not differ from faunal values in nitrogen-isotope ratios. Further, there was no difference in nitrogen-isotope ratios between the carnivores and herbivores analyzed in this study. This suggests a complexity in nitrogen cycling recognized in other studies (Ambrose and DeNiro 1986; Sealy et al. 1987). As an aside, it is interesting to note that even though the animals in the present study live in an area of restricted rainfall, they do not display the extremely high  $\delta^{15}\text{N}$  values reported from similar areas in Africa (Heaton et al. 1986). Clarification of this discrepancy obviously will require additional research. In any case,  $\delta^{15}\text{N}$  values cannot be applied in estimating the meat:vegetable proportions of diet and are presented here in partial refutation of the original proposal (Schoeninger 1985).

Carbon stable-isotope ratios ( $^{13}\text{C}/^{12}\text{C}$ ) were used to evaluate whether changes in the quantity of maize in the diet actually occurred. Maize is relatively enriched in the  $^{13}\text{C}$  isotope relative to  $^{12}\text{C}$  when compared with edible wild plants (with the exception of amaranth) in the Pecos area (see Table 1). Amaranth is not thought to have been a significant component in the Pecos diet (see Wetterstrom [1986:59] and diet reconstruction discussion below). Bison meat also is relatively enriched in this isotope due to the fact that bison graze on grasses that in this area are enriched in  $^{13}\text{C}$  (Boutton et al. 1980; L. Tieszen, personal communication 1984). In contrast, over 80 percent of antelope diet consists of forbs (Van Dyne 1973:189), and mule deer diet mixes a focus on grasses in the spring with browse at other times of the year (Rue 1978). Thus, both mule deer and antelope diets are dominated by species not enriched in  $^{13}\text{C}$ . Consequently, changes in the ratio of  $^{13}\text{C}$  to  $^{12}\text{C}$  can be used to monitor changes in the quantities of maize and/or bison in the Pecos diet. In theory, strontium data can be of assistance in determining whether carbon-isotope differences among periods are due to changes in maize as opposed to changes in bison consumption.

## MATERIALS AND METHODS

The population recovered from Pecos Pueblo consisted of approximately 500 skeletons excavated from the trash mounds and rooms under the direction of A. V. Kidder (1924, 1932). Of these, over 100 skeletons were included in the present study. The skeletons are housed at the Peabody Museum, Harvard University. They are in an excellent state of preservation, in part because the burials as a group were fairly well preserved, but also due to the fact that E. A. Hooton, the person in charge of the initial analyses of the burials, had only the well-preserved burials sent to Harvard for study (Hooton 1930:16). Both sexes and all age groups were represented in the burial population. The best preserved were those of adults, therefore only adults were used for this analysis.

Several tests for diagenetic alteration were performed following protocols developed recently (Moore et al. 1989; Schoeninger et al. 1989). The bone chosen for analysis had not been treated with preservatives. Thin sections were prepared from a representative set of the skeletons following Stout (1978) and Hanson and Buikstra (1987). When viewed under plane and also polarized light, the sections exhibited good histological structure; none of the sections displayed alteration to any great extent. Powder X-ray diffraction patterns indicated that little alteration in crystal size had occurred. The preceding, in conjunction with the observation that the majority of samples retained over 25

Table 1. Elemental and Isotopic Composition of Flora and Fauna from Pecos.

	Sr (ppm)			$\delta^{15}\text{N}(\text{AIR})\%$			$\delta^{13}\text{C}(\text{PDB})\%$		
	N	$\bar{X}$	Range	N	$\bar{X}$	Range	N	$\bar{X}$	Range
<b>Fauna<sup>a</sup></b>									
Mule deer ( <i>Odocoileus hemionus</i> )	1	427	—	3	3.9	3.5–5.0	3	-20.7	-22.1–-19.5
Pronghorn antelope ( <i>Antilocapra americana</i> )	2	600	486–713	3	8.0	6.3–9.0	3	-20.2	-20.5–-19.9
Bison ( <i>Bison bison</i> )	1	583	—	2	6.8	6.4–7.1	6	-11.5	-13.9–-9.8
Dog ( <i>Canis</i> sp.)	1	304	—	1	8.8	—	1	-10.6	—
Cat ( <i>Felis</i> sp.)	1	379	—	2	6.9	6.0–7.7	2	-19.7	-19.7–-19.6
<b>Flora</b>									
Maize kernels ( <i>Zea mays</i> )	—	—	—	2	7.0	6.3–7.6	2	-11.2	-11.3–-11.2
Beans ( <i>Phaseolus vulgaris</i> )	—	—	—	2	5.4	5.3–5.6	2	-24.8	-25.1–-24.6
Amaranth seeds ( <i>Amaranthus</i> sp.)	—	—	—	1	9.0	—	1	-11.3	—
Chenopodium seeds	—	—	—	1	8.1	—	1	-25.5	—

<sup>a</sup> The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values given are estimated flesh values based on measured bone-collagen values. For N, flesh and collagen values are very similar, thus, the measured bone-collagen values are presented as flesh values. For C, the original measurements by DeNiro and Epstein (1978) on laboratory rats suggested that flesh values are approximately 4‰ less positive than bone-collagen values. More recent work on large-bodied, free-ranging herbivores (Medaglia et al. 1989; van der Merwe, personal communication 1986), however, suggests the difference is closer to 2‰. The latter is used here, i.e., mule deer flesh, listed here as -20.7, is estimated from a value of -18.7 measured on mule deer collagen.

Table 2. Summary Statistics for Pecos Pueblo.

Period	N	Average $\pm$ s.d.	V <sup>a</sup> (%)	Range
Sr (ppm) in Bone Ash				
VI	12	364 $\pm$ 49	13	293–448
V	18	364 $\pm$ 50	16	239–414
IV	16	340 $\pm$ 48	14	269–429
III	17	352 $\pm$ 77	22	210–447
II	16	365 $\pm$ 57	18	289–502
I	15	319 $\pm$ 64	20	223–459
Black-on-white	9	360 $\pm$ 68	19	289–463
$\delta^{15}\text{N}(\text{AIR})\text{‰}$				
VI	8	9.3 $\pm$ .5	5	9.2–10.1
V	11	9.2 $\pm$ .7	8	7.8–10.0
IV	9	9.0 $\pm$ .6	7	8.2–10.0
III	10	8.8 $\pm$ .6	7	8.2–10.0
II	7	8.9 $\pm$ .6	7	7.9–9.7
I	8	9.3 $\pm$ .8	8	8.5–10.0
Black-on-white	8	9.1 $\pm$ .7	7	8.3–10.4
$\delta^{13}\text{C}(\text{PDB})\text{‰}$				
VI	8	-8.5 $\pm$ .7	8	-9.3–-7.7
V	11	-7.6 $\pm$ .3	4	-7.9–-7.0
IV	9	-7.8 $\pm$ .5	6	-8.2–-7.2
III	10	-7.7 $\pm$ .3	4	-8.1–-7.0
II	7	-7.5 $\pm$ .3	4	-7.9–-7.1
I	8	-7.7 $\pm$ .4	6	-8.6–-7.1
Black-on-white	8	-7.5 $\pm$ .3	4	-8.2–-7.2

<sup>a</sup> V refers to the coefficient of variation.

percent of the original collagen, indicate that it is unlikely that significant diagenetic alteration had occurred in these samples.

The Pecos burials can be divided into seven chronological periods based on the types of pottery that were included in the graves. These periods are roughly A.D. 1200–1300 (Black-on-white); A.D. 1300–1400 (Period I); A.D. 1400–1450 (Period II); A.D. 1450–1550 (Period III); A.D. 1550–1600 (Period IV); A.D. 1600–1675 (Period V); and post-A.D. 1675 (Period VI). A sample of burials was taken from each of these periods (see Table 2). For some of the discussion, however, the samples are combined into three longer periods. These periods are A.D. 1200–1450 (Black-on-white, I, and II), which includes the centuries predating the development of Plains–Pueblo interaction; A.D. 1450–1600 (III and IV), which includes the period of prehistoric Plains–Pueblo interaction; and A.D. 1600–1850 (V and VI), which encompasses the centuries of European contact.

### Strontium

Bone samples were taken from 103 human skeletons in the Pecos collection. Samples containing large quantities of cancellous bone were avoided, but no limitation was placed on the kind of bone sampled. Although there is variation in strontium levels among the bones of an individual (reviewed in Sillen and Kavanagh [1982] and Grupe [1988]), it is insignificant when compared to the variation due to metabolic differences among individuals (Schoeninger 1981), and both sources of variation are small relative to those produced by different diets. Moreover, the results from studies of variation among bones of individual rabbits (Schoeninger 1981) and individual humans (Schoeninger 1989) indicate that the choice of bone should not affect the results of this study.

Cancellous bone was removed mechanically from each bone sample because it tends to trap soil. The remaining cortical bone was then cleaned with double distilled water in an ultrasonic cleaner. After drying to a constant weight at room temperature, the bone was ground in a ball mill grinder or by hand with a mortar and pestle, taking care to avoid heating the bone. Sample preparation

was the same as described previously (Schoeninger 1981). Bone samples were analyzed for strontium and calcium by nitrous oxide/acetylene flame atomic absorption spectrometry using a Perkin-Elmer 403 spectrophotometer.

#### *Carbon and Nitrogen Stable-Isotope Analysis*

Over 80 samples of human bone, faunal bone, and plants were prepared for isotopic analysis. The human and faunal bones were recovered during excavations at Pecos Pueblo. The plant samples are modern specimens collected from nonfertilized areas near the site of Pecos (Wilma Wetterstrom, personal communication 1986). Organic material (referred to as collagen in this paper) was extracted from bone following procedures described previously (Schoeninger and DeNiro 1984). Only bone samples with organic residues that were over five percent of the original bone weight (fresh bone yields about 25 percent organic residue) and that had atomic carbon:nitrogen ratios between 2.6 and 3.4 were analyzed. Bone samples with lower percentage organic residue and different C:N ratios have been shown to have delta values that are not reflective of biological values (Schoeninger and DeNiro 1982).

Collagen samples and dried plant samples (listed in Table 1) were combusted in quartz tubes at 800°C with excess cupric oxide, elemental copper, and silver wire. The resulting CO<sub>2</sub> and N<sub>2</sub> were separated and purified in a vacuum system by cryogenic distillation prior to determination of their isotope ratios by mass spectrometry. Because the concentration of <sup>13</sup>C in the biosphere is very low, the ratio (<sup>13</sup>C/<sup>12</sup>C) cannot be measured directly. Rather, in the manner followed in this paper, the ratio is represented as a delta (δ) value in parts per thousand (read as "per mil," represented by the symbol ‰). This value is calculated by comparing the isotope ratio in the sample with the same ratio in an internationally recognized standard. The equation is shown below:

$$\delta^{13}\text{C} = \frac{^{13}\text{C}/^{12}\text{C sample}}{^{13}\text{C}/^{12}\text{C standard}^*} - 1 \times 1,000\text{‰}$$

\* Standard = Peedee Belemnite (PDB) carbonate.

As is true for <sup>13</sup>C, the concentration of <sup>15</sup>N in the biosphere is very low, thus, the results of the analyses are presented as delta (δ) values in parts per mil (‰) as:

$$\delta^{15}\text{N} = \frac{^{15}\text{N}/^{14}\text{N sample}}{^{15}\text{N}/^{14}\text{N standard}^*} - 1 \times 1,000\text{‰}$$

\* Standard = atmospheric nitrogen (AIR)

## RESULTS

### *Strontium*

The results of the strontium analyses are presented in Table 2 and Figure 2. Figure 2 illustrates the data grouped into three culturally meaningful clusters (pretrade, trade, and Spanish Contact) as discussed previously. There is virtually no difference in bone-strontium concentrations among the grouped ceramic periods. All of the means from the individual periods fall within one standard deviation of one another. The average of the bone-strontium levels in the total sample (N = 103) is 340 ppm (s.d. = 60, coefficient of variation = 17 percent, range = 200–500 ppm). The range of variation is about 150 ppm larger than that observed within a single population of mink all raised on the same diet. The range is also larger than that observed in a set of 44 Dutch whalers (range = 210 ppm Sr), who presumably had somewhat more dietary variation than was true for the mink (Schoeninger 1989). Even so, the similarity of the mean strontium concentrations among ceramic periods suggests that for the population as a whole, little change occurred through time in the amount of meat vs. vegetable material in the human diet.

The variation that does exist cannot be attributed to differences in diet of males vs. females. Of those burials that have been sexed (n = 68; identification taken from Ruff [1981], personal com-

munication 1984; R. Tague, personal communication 1985), the difference between males and females in bone-strontium content is not significant. In sum, these results are consistent with a hypothesis predicting no change in overall meat intake as traded bison replaces depleted local mule deer in the Pecos diet.

#### *Carbon and Nitrogen Isotope Ratios*

As seen in Table 2 and in Figure 3, there is virtually no change in the stable-isotope ratios through time at Pecos Pueblo. The average  $\delta^{15}\text{N}$  value is around 9‰ in each of the 7 ceramic periods. The range of variation in each period is about 2‰, which is the same magnitude as that previously observed in animals on monotonous diets (2‰; DeNiro and Schoeninger 1983). The small coefficients of variation (labeled V in Table 2) support the interpretation of dietary consistency both within and between cultural periods.

The same can be said of the carbon-isotope data. With the exception of ceramic Period VI, the average  $\delta^{13}\text{C}$  value is around  $-7.6\text{‰}$ . Again, the range of variation is virtually identical to that previously observed in animals raised on monotonous diets (DeNiro and Schoeninger 1983). As shown in Figure 3, however, the human samples from Period VI have carbon delta values that are less positive than those from earlier periods; the distribution is also different. The possible significance of this will be discussed later.

The uniformity of the carbon-isotope data indicates an absence of significant change in overall meat consumption and in the type of meat (bison vs. mule deer) from the pretrade period (A.D. 1200–1450) to the trade period (A.D. 1450–1600). If bison (with diets enriched in  $^{13}\text{C}$ ) had replaced mule deer, an increase in the carbon-isotope averages would be expected. These results are explored further in the following section.

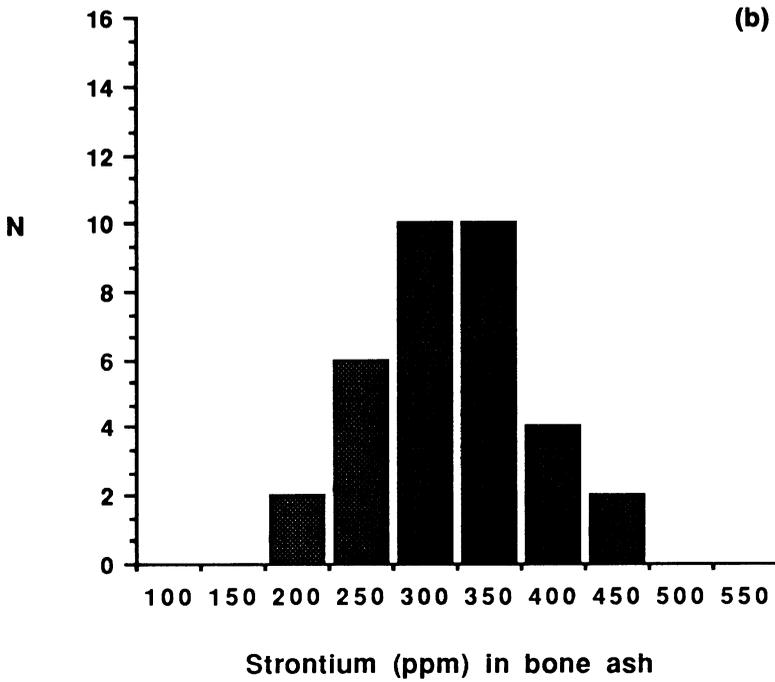
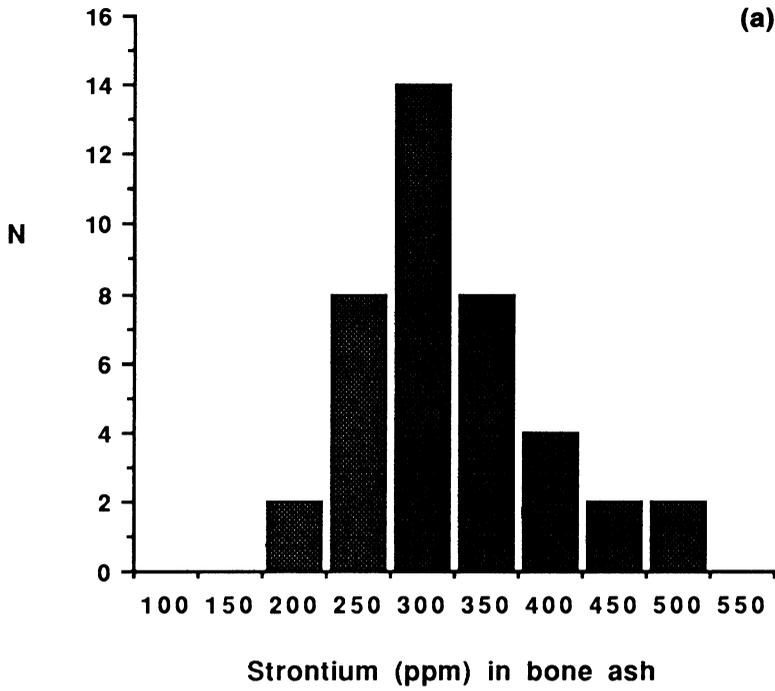
### DIET RECONSTRUCTION USING FOOD-COMPONENT DATA

The purpose of this section is to provide an estimate of the combinations of food items available to the Pecos inhabitants that could have produced the bone-composition results measured by our analyses. In addition, the significance of the apparent shift in the carbon-isotope ratio in Period VI is evaluated.

A basic technique for dietary reconstruction using isotope values for foods from the Pecos area was developed. It is likely that a number of hypothetical diets could produce the same stable-isotope values measured in the Pecos skeletal material. Thus, the aim in the present study is to define ranges of quantities of particular dietary items (e.g., maize, mule deer) that would be compatible with the bone-composition data. In addition, identification of foods and food quantities that are clearly incompatible with the isotopic values in bone also is attempted. Finally, those dietary items that appear to change significantly in quantity by Period VI in Pecos' occupation are identified. The conclusions derived from this portion of the analysis are to be considered hypotheses for further testing using archaeological data from Pecos and additional chemical and isotopic analyses of Pecos skeletal material.

Diets were modeled by varying percentages of four food items that previous research by Wetterstrom (1986) suggested were important for populations living near Pecos Pueblo. Wetterstrom's research focused on Arroyo Hondo, a pueblo located about 24 km west of Pecos. Arroyo Hondo is an ideal analog for Pecos given marked similarities in climate, elevation, growing season, and vegetation. In their study of the tree-ring series from Arroyo Hondo, Rose et al. (1981:41) note that the Arroyo Hondo series of tree-ring values is highly correlated with that from Pecos. The two precipitation series are homogeneous and could have been drawn from a single population. Both sites are near 2,130 m in elevation, both are characterized by 120-day growing seasons (Cordell 1979), and both are set in pinyon-juniper woodland.

Using estimates of amount of available arable land, the land's productivity, and of population size, Wetterstrom calculated the percent caloric contribution for each cultivar grown in the area around Arroyo Hondo. Using a similar technique based on the population density of each species of animal living in the area and the densities of wild plant foods, she calculated the calories that



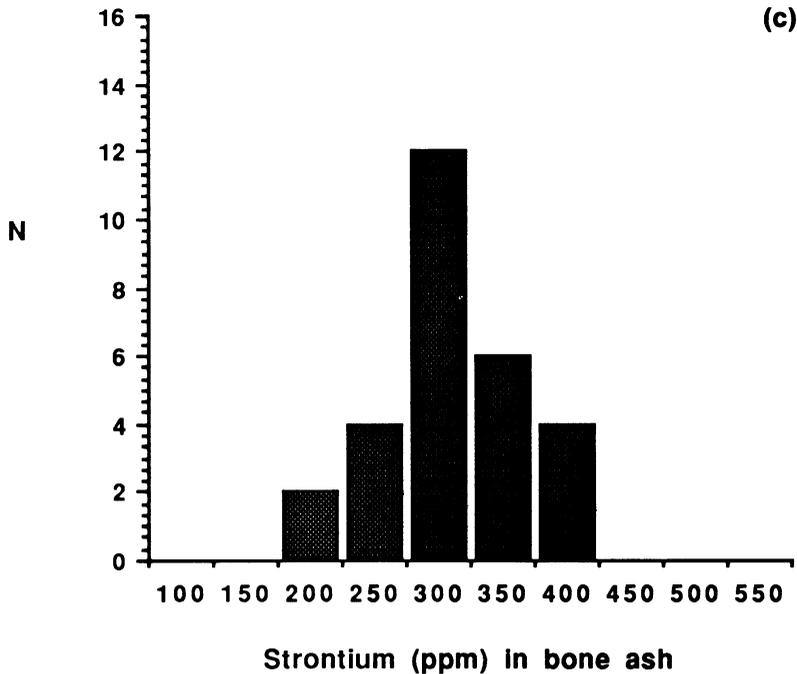


Figure 2. Strontium concentrations in human bone ash from (a) pretrade, (b) trade, and (c) historic periods of occupation at Pecos Pueblo. As a comparison, the range of values obtained in the analysis of a population of mink all raised on a single diet was 150 ppm. When compared with the range of values from Pecos, it appears that no major differences in diet occurred between people. The precision of the analysis is  $\pm 25$  ppm.

could have been contributed to the Arroyo Hondo diet by each type of animal and each species of wild plant. Her estimates are summarized and presented in Table 3 as a list of food items expected at Pecos Pueblo.

Wetterstrom concluded that at Arroyo Hondo, maize could have been produced in sufficient quantities to provide up to 100 percent of required calories during years with moderate rainfall. Thus, it is reasonable to assume that in most years the inhabitants at Pecos could have produced sufficient maize to meet energy needs. In fact, as discussed above, the people of Pecos produced enough maize to use in trading for bison meat with Plains-dwelling hunter-gatherer groups. This is not a suggestion that maize actually provided all of the calories in the diet of the inhabitants at Pecos. Given the well-documented nutritional insufficiencies of a total maize diet, it is considered unlikely that the inhabitants of Pecos subsisted on a monotonous diet of maize.

Wetterstrom's (1986) estimates for other food items are used here as suggestions for potential quantities of cultivated and wild items in the Pecos diet. However, our diet-reconstruction calculations evaluated a wide range of quantities of different food types (see below). Wetterstrom (1986) reports that enough beans could have been grown to provide up to 20 percent of total required calories, yet she cites ethnographic evidence arguing against the consumption of such a large amount of beans. For this reason, she suggests that only a small fraction of the calories would have come from beans. Wetterstrom considers that squash is "unimportant" (less than 1 percent of total calories) because it does not grow well in the area surrounding Arroyo Hondo. She suggests that some of the weedy annuals (e.g., chenopodium, amaranth, and beeweed) could have provided between 2.5 and 15 percent of total calories because they are ubiquitous in disturbed environments in the area. Sunflower, wild cactus fruits, and Indian rice grass are thought to be unimportant based on ethnographic evidence, even though they probably were eaten in certain seasons. In contrast, pinyon could have been a substantial source (up to 15 percent) of calories. Even though good yields can be expected only once every four to seven years, the nuts can be stored and thus used over a period

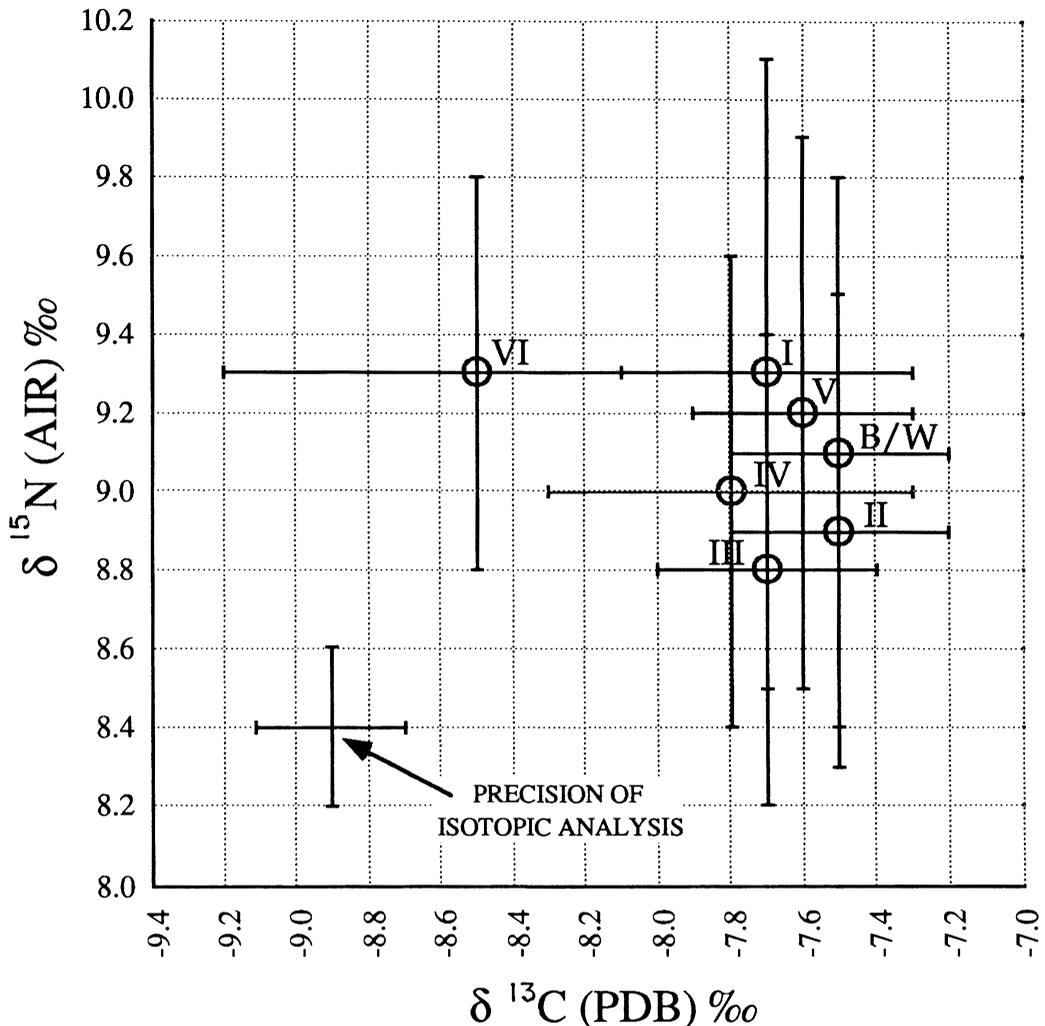


Figure 3. Carbon and nitrogen stable-isotope ratios in human bone collagen from all periods of occupation at Pecos Pueblo (Black-on-white-VI). There appears to be no variation in nitrogen stable-isotope ratios associated with time period, which is probably due to the lack of variation in nitrogen-isotope ratios among food items (see Table 1). Most of the samples have carbon stable-isotope ratios within the range of  $-8.0$  and  $-7.0$ ‰ with the exception of samples from Period VI. The carbon stable-isotope ratios indicate a diet in which a great majority of the calories is derived from a food enriched in  $^{13}\text{C}$  such as bison and/or maize.

of years. These are the most abundant wild plants available in the Arroyo Hondo area. Although a number of others may have been used periodically, their effect on bone chemistry is likely to have been negligible. Overall, Wetterstrom (1986:84, 85, Table 17) estimated that wild plants could have provided Arroyo Hondo residents with between 9 and 30 percent of calories, and suggests an average wild plant contribution of 20 percent of calories.

Of the various types of fauna, Wetterstrom considered only mule deer to have contributed significantly to the diet at Arroyo Hondo. The faunal data from Arroyo Hondo support this assumption (Lang and Harris 1984:47). Mule deer were by far the most abundant fauna in the Pecos middens (Kidder 1932:196). Wetterstrom argues that in the area surrounding Arroyo Hondo (and similarly for Pecos), turkey, rabbit, and hare probably provided less than 1 percent of total calories. Bison

Table 3. Calories (C) and Protein (P) of Food Items at Pecos Pueblo.

Food Items in Diet	C	C/100 g <sup>a</sup>	P/100 g <sup>a</sup>	P/100 C
<b>Cultivated Plants</b>				
Maize ( <i>Zea mays</i> )	up to 100%	348	8.9	2.6
Beans ( <i>Phaseolus vulgaris</i> )	up to 20%	118	7.8	6.6
Squash ( <i>Cucurbita</i> sp.)	unimportant	—	—	—
<b>Wild Plants: Weedy Annuals (ChenoAms)</b>				
Amaranth ( <i>Amaranthus</i> sp.) and chenopodium ( <i>Chenopodium</i> sp.) seeds	up to 15% total	340	3.5	9.7
Sunflower ( <i>Helianthus</i> sp.)	unimportant	—	—	—
<b>Other Wild Plants</b>				
Prickly Pear ( <i>Platyopuntia</i> sp.)	unimportant	—	—	—
Cholla ( <i>Cylindropuntia</i> sp.)	unimportant	—	—	—
Indian rice grass ( <i>Oryzopsis hymenoides</i> )	unimportant	—	—	—
Pinyon ( <i>Pinus edulis</i> )	up to 15%	635	13.0	2.0
<b>Fauna</b>				
Hares ( <i>Lepus californicus</i> ) and rabbits ( <i>Sylvilagus auduboni</i> )	unimportant	—	—	—
Mule deer ( <i>Odocoileus hemionus</i> )	up to 10%	126	21.0	16.7
Turkey ( <i>Meleagris gallopavo</i> )	unimportant	—	—	—
Pronghorn antelope ( <i>Antilocapra americana</i> )	up to 5%	126	21.0	16.7
Bison ( <i>Bison bison</i> )	up to 10%	138	25.0	18.1

Note: Identification and % calories based on Wetterstrom's (1986) study at Arroyo Hondo, a pueblo near Pecos.

<sup>a</sup> Values taken from Watt and Merrill (1973), Styles (1986), and Sokolov (1986).

has been added to the list of diet items at Pecos because the faunal remains from Pecos indicate that bison could have been an important meat component in the diet.

Representative samples of modern plant dietary items were obtained from areas near Pecos and Arroyo Hondo Pueblos. Samples of faunal materials were obtained from archaeological collections from Pecos. These samples were analyzed and the results are presented in Table 1. The only plant of potential dietary importance that is not included is pinyon. Virginia and Delwiche (1982) present nitrogen stable-isotope values of around 1‰ from analyses of *Pinus* leaves. These values suggest that species (such as pinyon) in this genus can fix atmospheric nitrogen. If true, pinyon nuts could have  $\delta^{15}\text{N}$  values close to zero. In response to reviewers' comments, we analyzed one pinyon nut sample, and the nitrogen results are in line with those of terrestrial plants. Thus, in this analysis pinyon was considered to have  $\delta^{15}\text{N}$  values typical of other terrestrial plants (>5‰) that use soil rather than atmospheric nitrogen. Running further samples will be necessary, however, before firm conclusions concerning pinyon's contribution to the Pecos diet can be made.

A couple of interesting points arose in compiling these data. First, in previous reports beans have been expected (though not analyzed in most cases) to have a  $\delta^{15}\text{N}$  value near 0‰ (DeNiro and Epstein [1981], among others) because legumes have the ability to fix atmospheric nitrogen with a delta value of zero whereas other plants utilize nitrogen in soil with an average value of +6‰ (Wada 1980; Wada et al. 1975). The beans analyzed in the present study have an isotope ratio of +5‰, close to that of other plants, which indicates that they were using soil nitrogen rather than fixing atmospheric nitrogen. Thus, the consumption of beans at Pecos will not be reflected in the nitrogen-isotope ratio of human bone collagen because they cannot be distinguished isotopically from other plants. Second, the range of carbon-isotope values in the bison collagen samples is unexpectedly large (-11.9 to -7.8‰ in collagen; Note, the values given in Table 1 are for bison meat, not collagen). The six samples analyzed were obtained from three sites: Pecos, Henderson, and Tierra Blanca. In the following discussion, the average of the six collagen values (-9.5) was used in estimating the stable carbon-isotope ratio in bison meat as -11.5‰.

From Table 1, it can be seen that certain plants are isotopically similar to each other, and cannot

Table 4. Isotope Ratios Predicted for One Diet at Pecos

Food Item	% Calories	Weighted $\delta^{13}\text{C}$ (‰)	Protein (g)	% Protein	Weighted $\delta^{15}\text{N}$ (‰)
Maize	75	-8.4	58	34	2.4
Nonmaize plants	5	-1.2	10	6	.3
Mule deer	10	-2.1	50	31	1.2
Bison	10	-1.2	54	29	2.0
Diet $\delta$ value		-12.9			5.9
Collagen $\delta$ value (expected)		-7.9			8.9

*Note:* Predicted isotope values based on 3,000 calories per day; in calculating weighted  $\delta^{15}\text{N}$  values, grams of protein per 100 calories were taken from Watt and Merrill (1973) as shown in Table 3.

be distinguished from one another using bone collagen stable-isotope ratios. For the purposes of modeling, the contribution of these plants (chenopodium, beans, and pinyon) was grouped into a single, nonmaize plant category. Thus, the diets constructed include four items: maize ( $\delta^{13}\text{C}$ : -11.2,  $\delta^{15}\text{N}$ : +7.0), nonmaize plants (-25.0, +5.6), mule deer (-20.7, +3.9), and bison (-11.5, +6.8). Although antelope was not considered important in either the Arroyo Hondo or Pecos diets based on faunal data, as a test we included it in an initial run in place of bison and in place of mule deer. The resulting diet-isotope values were quite different from the Pecos bone-composition values, confirming the dietary insignificance of antelope.

Using the data in Table 1, it is possible to estimate the stable-isotope ratios of nitrogen and carbon that would be produced in the bone collagen of humans eating particular combinations of these four food items. For example, a diet in which the caloric distribution was 75 percent maize, 5 percent nonmaize plants, 10 percent mule deer, and 10 percent bison would produce the weighted  $\delta^{13}\text{C}$  and weighted  $\delta^{15}\text{N}$  values listed in Table 4. The weighted  $\delta^{13}\text{C}$  value expected for this diet is calculated by adding:  $.75(-11.2) + .05(-25.0) + .10(-20.7) + .10(-11.5)$ , or  $(-8.4) + (-1.2) + (-2.1) + (-1.2)$  as shown in Table 4. The delta value of each food item is multiplied by the percent calories in the diet in order to estimate the relative contribution of that food item to the  $\delta^{13}\text{C}$  value of the total diet. In theory, carbon atoms can be obtained through the metabolism of carbohydrates, lipids, and proteins, since all these molecules contain carbon. We are following Lehninger's (1975: 372) model of metabolism in which a limited number of precursors produced during catabolism of all three components are used in biosynthesis. For this reason, the weighting used for estimating the carbon delta value is calculated using total calories, though we recognize that the sources of carbon atoms included in collagen are in need of further investigation.

The carbon stable-isotope ratio in bone collagen is not identical to the diet-isotope ratio; rather, a fractionation occurs between diet and bone collagen. This results in a  $\delta^{13}\text{C}$  value in bone collagen that is more positive than the value in the diet. There remains some uncertainty concerning the actual magnitude (Vogel [1978] vs. DeNiro and Epstein [1978] and Bender et al. [1981]), and whether the fractionation factor is constant across all diets (Bumstead 1983). For the purposes of this study, in making rough estimates of diet composition, the fractionation factor is assumed to be 5‰. This value was observed in field studies (Vogel 1978), and commonly is used in human diet studies. The fractionation value of +5‰ is added to the diet value to obtain the delta value expected in the bone collagen of a person eating such a diet as shown at the bottom of Table 4.

The estimate for nitrogen was made in a different way. Nitrogen atoms are located only in protein. For that reason, the protein contribution of each food item to the total diet was estimated from a nutrition table (Watt and Merrill 1973). In calculating expected  $\delta^{15}\text{N}$  values, the delta value of each food item was multiplied by the percent protein in the food type in order to estimate the contribution of that food item to the diet as a whole. Thus, the calculation was:  $.34(+7.0) + .06(+5.6) + .31(+3.9) + .29(+6.8)$ , or  $2.4 + .3 + 1.2 + 2.0$  as shown in Table 4.

As with carbon-isotope ratios, the bone collagen nitrogen-isotope ratio is not identical to the diet

Table 5. Stable-Isotope Ratios Expected from Hypothetical Pecos Diets.

Maize (%)	Non-maize Plants (%)	Bison (%)	Mule Deer (%)	Predicted $\delta^{13}\text{C}$ (‰)	Predicted $\delta^{15}\text{N}$ (‰)	Score
<u>Period II</u>						
75	5	14	6	-7.5	9.2	.57
75	5	12	8	-7.7	9.1	.66
85	5	5	5	-7.4	9.2	.67
75	5	16	4	-7.3	9.4	1.06
75	5	10	10	-7.9	8.9	1.20
75	10	14	1	-7.7	9.6	1.28
80	10	10	0	-7.6	9.7	1.28
80	10	8	2	-7.8	9.4	1.28
<u>Period VI</u>						
75	15	8	2	-8.5	9.4	.12
75	15	6	4	-8.6	9.2	.36
75	15	10	0	-8.3	9.6	.59
75	15	5	5	-8.7	9.1	.61
75	10	9	6	-8.2	9.1	.62
75	10	10	5	-8.1	9.2	.65
75	10	8	7	-8.3	9.0	.67
70	20	10	0	-9.0	9.5	.72

nitrogen-isotope ratio. A fractionation of 2.5–3‰ occurs (DeNiro and Epstein 1981; Wada 1980), which results in the bone collagen having more positive delta values than those found in the average diet. In Table 4, a fractionation value of +3‰ is added to the diet value to obtain the delta value expected in the bone collagen of a person eating such a diet.

The actual values obtained in the analyses of the collagen were close to the collagen values expected from a diet like that illustrated in Table 4. In all but Period VI, the average  $\delta^{13}\text{C}$  values fall between -7.8 and -7.5‰, and in all periods the average  $\delta^{15}\text{N}$  value falls in a range of +8.8 to +9.3‰.

In order to determine which other hypothetical diets also closely match with the bone values, and to identify which diets clearly mismatch with the bone values, a technique was developed to evaluate diets. Hypothetical diets were constructed by systematically varying maize from 50 to 90 percent of the diet in 5 percent increments, nonmaize plants from 0 to 40 percent in 5 percent increments, and bison and mule deer from 0 to 20 percent of the diet in 1 and 2 percent increments. Total meat never fell below 10 percent of the dietary calories. We then calculated the degree to which diet-isotope values deviated from the bone mean stable-isotope values. Diets were ranked from most similar to most divergent based on this deviation. We have assumed that diets within approximately one deviation of the bone-chemistry values are most likely to have been characteristic of the Pecos population. The specifics of this approach are discussed in the Appendix.

Comparisons were made between diet and bone composition values for Periods II and VI of occupation at Pecos. As Table 2 indicates, Period II is representative of the pre-Period VI diets. Table 5 lists the eight hypothetical diets that produced isotope values closest to the bone-chemistry values for Periods II and VI. In Period II, the diets with carbon- and nitrogen-isotope values most similar to the bone values consist of 75–85 percent maize, 5–10 percent nonmaize plants, and various combinations of bison and mule deer. The diets include from 10 to 20 percent meat. In contrast, diets least compatible with both Periods II and VI contained relatively low amounts of maize (50–70 percent), high proportions of nonmaize plants, and little meat.

Dietary changes appear to have occurred by Period VI. In particular, the nonmaize plant contribution in compatible diets might have been as high as 20 percent. As discussed above, Wetterstrom argues that beans are not likely to approach 20 percent of a Pueblo diet. This dietary change, then, may indicate an increase in the wild portion of the plant component of the Pecos diet. This increase

is at the expense of either maize or meat, or both. The minimum maize contribution to the diet drops to 70 percent (from 75 percent), and the maximum contribution of meat to these diets decreases to 15 percent (from 20 percent). Given that strontium values do not change from Period II through Period VI, however, we hypothesize that increasing quantities of wild plants make up for a shortfall in maize.

## DISCUSSION

Returning to the original hypotheses to be tested, it was proposed that (1) bison largely replaced mule deer in the Pecos diet in the fifteenth century, and (2) seventeenth-century Spanish occupation in New Mexico had severe repercussions on the Pecos subsistence system. The results do not provide support for the former hypothesis because neither the average strontium nor average  $\delta^{13}\text{C}$  values change from the pretrade (A.D. 1200–1450) to the trade period (A.D. 1450–1600). If bison, whose diets are relatively enriched in  $^{13}\text{C}$ , replaced mule deer, an increase in the  $\delta^{13}\text{C}$  averages would be expected. Interestingly, both bison and mule deer appear present in the diet throughout the occupation of Pecos, based on similarities between dietary and bone stable-isotope data. This conclusion is consistent with the observation by Kidder (1932:196) that bison bone was present throughout the Pecos middens, but contradicts his statement that bison bone increased substantially in those middens beginning in the late 1400s. Further work in the Pecos middens will be necessary to resolve the contradiction between Kidder's data and the modeled Pecos diets.

The data do provide some support for the latter hypothesis. The carbon-isotope values from Period VI indicate that either meat or maize or both may have decreased in importance in the Pecos diet as use of nonmaize plants increased. As discussed above, given the uniformity in strontium values throughout the occupation of Pecos, we expect that maize is the food item that decreases. This could have occurred as the result of Spanish demands for food and/or labor. Spanish demands for food would have depleted Pecos' stores, while demands for labor would have resulted in less time for crop production (Spielmann 1989). In either case, less maize would have been available to the Pecos inhabitants.

It should be noted that we do not expect that climatic deterioration was the cause of reduced maize availability to Pecos. A severe, prolonged drought in the latter half of the 1500s, as well as a number of prior droughts in the 1200s and 1400s (Dean and Robinson 1977), are not reflected in changes in maize consumption in the Pecos skeletal material.

In conclusion, using bone-chemistry data, we have tested two hypotheses concerning changes in Pecos Pueblo diet that were derived from a computer simulation model, ethnohistoric data, and a minimum of archaeological information. The hypothesis concerning the impact of Spanish colonization was supported, while the hypothesis concerning the effect of Plains–Pueblo trade was not supported by the human skeletal data. Some clarification of the discrepancy between the bone-chemistry data and the data upon which the trade hypothesis was based would be possible with quantified floral and faunal information from Pecos. A comprehensive dietary analysis necessitates all three components: floral, faunal, and human skeletal data.

In the near future a study of another large, eastern border pueblo, Gran Quivira, will be undertaken. Fortunately, recent excavation and analyses of floral and faunal material at this site will allow more direct comparisons between food remains and human skeletal data than was possible at Pecos. As with Pecos, there is an extensive skeletal sample spanning its entire 300-year occupation. Research will be designed to test the hypotheses developed during the Pecos study, and also to determine whether the diet of the Gran Quivirans was similar in content to that of Pecos.

Issues that bone-chemistry analysis can address in the Southwest are by no means limited to the Plains-Pueblo border area. For example, comparisons between Plains border pueblos, such as Pecos and Gran Quivira, and pueblos to the west can be made. Preliminary faunal (Spielmann, unpublished data) and human bone-chemistry data (Schoeninger et al. 1983) suggest that western Pueblo populations may have had less access to animal protein than did those to the east. If true, this would have implications both for differences in nutritional health and strategies of protein acquisition

across the Southwest. Thus, bone-chemistry analyses will be significant in defining new research avenues concerning diet and nutrition for archaeological consideration.

*Acknowledgments.* We are grateful to Wilma Wetterstrom for plant samples, to the staff at the Peabody Museum, Harvard University, for help in obtaining human bone samples, and the staff at Pecos National Monument for graciously and quickly providing faunal samples. Discussions with Wilma Wetterstrom, Paul Minnis, John Speth, and Richard Ford helped in clarifying the probable sources of food available to these prehistoric people. Keith Kintigh generously provided his time in consulting on the diet modeling. Renee Robinson (Harvard University) and Mark Schurr (Indiana University) did some of the mass spectrometry. Claus Siebe translated the abstract into Spanish. Funds were provided by an NIH Biomedical Research Support Grant (University of Iowa) to K. Spielmann and by NIH Biomedical Research Support Grant #RR5378 (John Hopkins University School of Medicine) to M. Schoeninger. The paper has benefited from the comments of five anonymous reviewers.

#### REFERENCES CITED

- Ambrose, S. H., and M. J. DeNiro  
1986 The Isotopic Ecology of East African Mammals. *Oecologia* 69:395–406.
- Bender, M. M., D. A. Baerreis, and R. L. Stevenson  
1981 Further Light on Carbon Isotopes and Hopewell Agriculture. *American Antiquity* 46:346–353.
- Binford, L. R.  
1978 *Nunamiut Ethnoarchaeology*. Academic Press, New York.
- Boutton, T. W., A. T. Harrison, and B. N. Smith  
1980 Distribution of Biomass of Species Differing in Photosynthetic Pathway Along an Altitudinal Transect in Southeastern Wyoming Grassland. *Oecologia* 45:287–298.
- Brown, A. B.  
1973 *Bone Strontium Content as a Dietary Indicator in Human Skeletal Populations*. Unpublished Ph.D. dissertation, Department of Anthropology, University of Michigan, Ann Arbor.
- Bumstead, M. P.  
1983 Adult Variation in <sup>13</sup>C: Pre-Columbian North America. *American Journal of Physical Anthropology* 60:178–179.
- Catlin, G.  
1965 *Letters and Notes on the Manners, Customs, and Conditions of the North American Indians*. Ross and Haines, Minneapolis.
- Comar, C. L., and R. H. Wasserman  
1964 Strontium. In *Mineral Metabolism*, vol. 2, part A, edited by C. L. Comar and F. Bronner, pp. 523–572. Academic Press, New York.
- Cordell, L. S.  
1979 *Cultural Resources Overview, Middle Rio Grande Valley, New Mexico*. Submitted to USDA Forest Service, Bureau of Land Management, Albuquerque. Copies available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.
- Dean, J. S., and W. J. Robinson  
1977 Dendroclimatic Variability in the American Southwest, A.D. 680 to 1970. Laboratory of Tree-Ring Research, University of Arizona. Submitted to the National Park Service, Contract No. CX-1595-5-0241. Copies available from Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85721.
- Denig, E.  
1930 Indian Tribes of the Upper Missouri. *Bureau of American Ethnology Bulletin* No. 46:375–628. U.S. Government Printing Office, Washington, D.C.
- DeNiro, M. J., and S. Epstein  
1978 Influence of Diet on the Distribution of Carbon Isotopes in Animals. *Geochimica et Cosmochimica Acta* 42:495–506.  
1981 Influence of Diet on the Distribution of Nitrogen Isotopes in Animals. *Geochimica et Cosmochimica Acta* 45:341–351.
- DeNiro, M. J., and M. J. Schoeninger  
1983 Stable Carbon and Nitrogen Isotope Ratios of Bone Collagen: Variations Within Individuals, Between Sexes, and Within Populations Raised on a Monotonous Diet. *Journal of Archaeological Science* 10:199–203.
- Farnsworth, P., J. E. Brady, M. J. DeNiro, and R. S. MacNeish  
1985 A Re-evaluation of the Isotopic and Archaeological Reconstruction of Diet in the Tehuacan Valley. *American Antiquity* 50:102–116.
- Grupe, G.  
1988 Impact of the Choice of Bone Samples on Trace Element Data in Excavated Human Skeletons. *Journal of Archaeological Science* 15:123–129.

- Hammond, G. P., and A. Rey  
 1953 Don Juan de Oñate, Colonizer of New Mexico. *Coronado Cuarto Centennial Publication*, vols. 5 and 6. University of New Mexico Press, Albuquerque.  
 1966 *The Rediscovery of New Mexico, 1580-1594*. University of New Mexico Press, Albuquerque.
- Hanson, D., and J. E. Buikstra  
 1987 Histomorphological Alteration in Buried Human Bone from the Lower Illinois Valley: Implications for Palaeodietary Research. *Journal of Archaeological Science* 14:549-563.
- Hatch, J. W., and A. A. Geidel  
 1985 Status-Specific Dietary Variation in Two World Cultures. *Journal of Human Evolution* 14:469-476.
- Heaton, T. H. E., J. C. Vogel, G. von la Chevallerie, and G. Gollett  
 1986 Climatic Influence on the Isotopic Composition of Bone Nitrogen. *Nature* 322:822-823.
- Hooton, E. A.  
 1930 *The Indians of Pecos Pueblo*. Yale University Press, New Haven.
- Kessell, J. L.  
 1979 *Kiva, Cross, and Crown*. National Park Service, Washington.
- Kidder, A. V.  
 1924 *An Introduction to the Study of Southwestern Archaeology*. Papers of the Southwestern Expedition 1. Phillips Academy, Andover.  
 1932 *Artifacts of Pecos*. Papers of the Southwestern Expedition 6. Phillips Academy, Andover.
- Klein, R. G., and K. Cruz-Uribe  
 1984 *The Analysis of Animal Bones from Archaeological Sites*. University of Chicago Press, Chicago.
- Lambert, J. B., C. B. Szpunar, and J. E. Buikstra  
 1979 Chemical Analysis of Excavated Human Bone from Middle and Late Woodland Sites. *Archaeometry* 21:115-129.
- Lang, R. W., and A. H. Harris  
 1984 *The Faunal Remains from Arroyo Hondo Pueblo, New Mexico*. Arroyo Hondo Archaeological Series Vol. 5. School of American Research Press, Santa Fe.
- Lehninger, A. L.  
 1975 *Biochemistry: The Molecular Basis of Cell Structure and Function*. Worth, New York.
- Lynott, M. J., T. W. Boutton, J. E. Price, and D. E. Nelson  
 1986 Stable Carbon Isotopic Evidence for Maize Agriculture in Southeastern Missouri and Northeastern Arkansas. *American Antiquity* 51:51-65.
- Medaglia, C., E. A. Little, and M. J. Schoeninger  
 1989 Late Woodland Diet on Nantucket Island (Massachusetts): A Study Using Stable Isotope Ratios. Paper presented at the 54th Annual Meeting of the Society for American Archaeology, Atlanta.
- Minnis, P. E.  
 1985 *Social Adaptations to Food Stress*. University of Chicago Press, Chicago.
- Moore, K., M. Murray, and M. J. Schoeninger  
 1989 Effects of Preservatives on Trace Element and Stable Isotope Analysis of Bone. *Journal of Archaeological Science* 16:437-446.
- Norr, L.  
 1981 Prehistoric Costa Rican Diet as Determined from Stable Carbon Isotope Ratios in Bone Collagen. *American Journal of Physical Anthropology* 54:258-259.
- Price, T. D. (editor)  
 1989 *Chemistry of Prehistoric Human Bone*. Cambridge University Press, Cambridge.
- Rose, M. R., J. S. Dean, and W. J. Robinson  
 1981 *The Past Climate of Arroyo Hondo New Mexico, Reconstructed from Tree Rings*. Arroyo Hondo Archaeological Series Vol. 4. School of American Research Press, Santa Fe.
- Rue, L. L.  
 1978 *The Deer of North America*. Outdoor Life Books, Crown, New York.
- Ruff, C. B.  
 1981 A Reassessment of Demographic Estimates for Pecos Pueblo. *American Journal of Physical Anthropology* 54:147-151.
- Schoeninger, M. J.  
 1979 Diet and Status at Chalcatzingo: Some Empirical and Technical Aspects of Strontium Analysis. *American Journal of Physical Anthropology* 51:295-309.  
 1981 The Agricultural "Revolution": Its Effect on Human Diet in Prehistoric Iran and Israel. *Paleorient* 7: 73-92.  
 1985 Trophic Level Effects on  $^{15}\text{N}/^{14}\text{N}$  and  $^{13}\text{C}/^{12}\text{C}$  Ratios in Bone Collagen and Strontium Levels in Bone Material. *Journal of Human Evolution* 14:515-525.  
 1989 Reconstructing Prehistoric Human Diet. In *Chemistry of Prehistoric Human Bone*, edited by T. D. Price, pp. 38-67. Cambridge University Press, Cambridge.
- Schoeninger, M. J., and M. J. DeNiro  
 1982 Diagenetic Effects on Stable Isotope Ratios in Bone Apatite and Collagen. *American Journal of Physical Anthropology* 57:225.

- 1984 Nitrogen and Carbon Isotope Ratios of Bone Collagen Reflect Marine and Terrestrial Components of Prehistoric Human Diet. *Geochimica et Cosmochimica Acta* 48:625–639.
- Schoeninger, M. J., M. J. DeNiro, and H. Tauber  
1983  $^{15}\text{N}/^{14}\text{N}$  Ratios of Bone Collagen Reflect Marine and Terrestrial Components of Prehistoric Diets. *Science* 220:1381–1383.
- Schoeninger, M. J., K. M. Moore, and M. L. Murray  
1989 Detection of Bone Preservation in Archaeological and Fossil Samples. *Journal of Applied Geochemistry* 4:281–292.
- Scholes, F. V.  
1936–1937 Church and State in New Mexico, 1610–1650. *New Mexico Historical Review* 11(1):9–76, 11(2):145–178, 11(3):283–294, 11(4):297–349; 12(1):78–106.
- Schwarcz, H. P., J. Melbye, M. A. Katzenberg, and M. Knyf  
1985 Stable Isotopes in Human Skeletons of Southern Ontario: Reconstructing Paleodiet. *Journal of Archaeological Science* 12:187–206.
- Sealy, J. C., N. J. van der Merwe, J. A. Lee Thorp, and J. L. Lanham  
1987 Nitrogen Isotopic Ecology in Southern Africa: Implications for Environmental and Dietary Tracing. *Geochimica et Cosmochimica Acta* 51:2707–2717.
- Sillen, A., and M. Kavanagh  
1982 Strontium and Paleodietary Research: A Review. *Yearbook of Physical Anthropology* 25:67–90.
- Sillen, A., J. C. Sealy, and N. van der Merwe  
1989 Chemistry and Paleodietary Research: No More Easy Answers. *American Antiquity* 54:504–512.
- Sokolov, R.  
1986 The Good Seed. *Natural History* 4/86:102–105.
- Spielmann, K. A.  
1982 *Inter-Societal Food Acquisition among Egalitarian Societies: An Ecological Analysis of Plains/Pueblo Interaction in the American Southwest*. Unpublished Ph.D. dissertation, Department of Anthropology, University of Michigan, Ann Arbor.  
1983 Late Prehistoric Exchange Between the Southwest and Southern Plains. *Plains Anthropologist* 28:257–272.  
1988 Changing Faunal Procurement Strategies at Gran Quivira Pueblo, New Mexico. Paper presented at the 53rd Annual Meeting of the Society for American Archaeology, Phoenix.  
1989 Colonists, Hunters, and Farmers: Plains-Pueblo Interaction in the Seventeenth Century. In *Columbian Consequences*, vol. 1, edited by D. H. Thomas, pp. 101–113. Smithsonian Institution Press, Washington, D.C.
- Stout, S.  
1978 Histological Structure and Its Preservation in Ancient Bone. *Current Anthropology* 19:601–604.
- Styles, R.  
1986 *Faunal Exploitation and Resource Selection*. Scientific Papers No. 3. Archeological Program, Northwestern University, Evanston, Illinois.
- van der Merwe, N. J., and J. C. Vogel  
1978  $^{13}\text{C}$  Content of Human Collagen as a Measure of Prehistoric Diet in Woodland North America. *Nature* 276:815–816.
- Van Dyne, G. M.  
1973 *Analysis of Structure, Function and Utilization of Grassland Ecosystems*, vol. 2. Progress Report submitted to the National Science Foundation. Ms. in possession of authors.
- Virginia, R. A., and C. C. Delwiche  
1982 Natural  $^{15}\text{N}$  Abundance of Presumed  $\text{N}_2$ -fixing and Non- $\text{N}_2$ -fixing Plants from Selected Ecosystems. *Oecologia* 54:317–325.
- Vogel, J. C.  
1978 Isotopic Assessment of the Dietary Habits of Ungulates. *South African Journal of Science* 74:298–301.
- Vogel, J. C., and N. J. van der Merwe  
1977 Isotopic Evidence for Early Maize Cultivation in New York State. *American Antiquity* 42:238–242.
- Wada, E.  
1980 Nitrogen Isotope Fractionation and Its Significance in Biogeochemical Processes Occurring in Marine Environments. In *Isotope Marine Chemistry*, edited by E. D. Goldberg, V. Horibe, and K. Saruhashi, pp. 375–398. Uchida Rokakuho, Tokyo.
- Wada, E., T. Kadonaga, and S. Matusuo  
1975  $^{15}\text{N}$  Abundance in Nitrogen of Naturally Occurring Substances and Global Assessment of Denitrification from Isotopic Viewpoint. *Geochemical Journal* 9:139–148.
- Watt, B. K., and A. L. Merrill  
1973 *Handbook of the Nutritional Contents of Foods*. Dover, New York.
- Weltfish, G.  
1965 *The Lost Universe: Pawnee Life and Culture*. University of Nebraska Press, Lincoln.

Wetterstrom, W.

1986 *Food, Diet, and Population at Prehistoric Arroyo Hondo Pueblo, New Mexico*. Arroyo Hondo Archaeological Series Vol. 6. School of American Research Press, Santa Fe.

Winship, G. P.

1896 *The Coronado Expedition, 1540-1542*. Bureau of American Ethnology Annual Report, part 2. Smithsonian Institution, Washington, D.C.

## APPENDIX

The technique used to compare bone-isotope values with diet-isotope values involved calculating the degree to which diet-isotope values deviated from bone values. The steps for this calculation are illustrated with the first hypothetical diet listed in Table 5 and the Period II bone values from Table 2 ( $\delta^{15}\text{N} = +8.9\text{‰}$ ;  $\delta^{13}\text{C} = -7.5\text{‰}$ ):

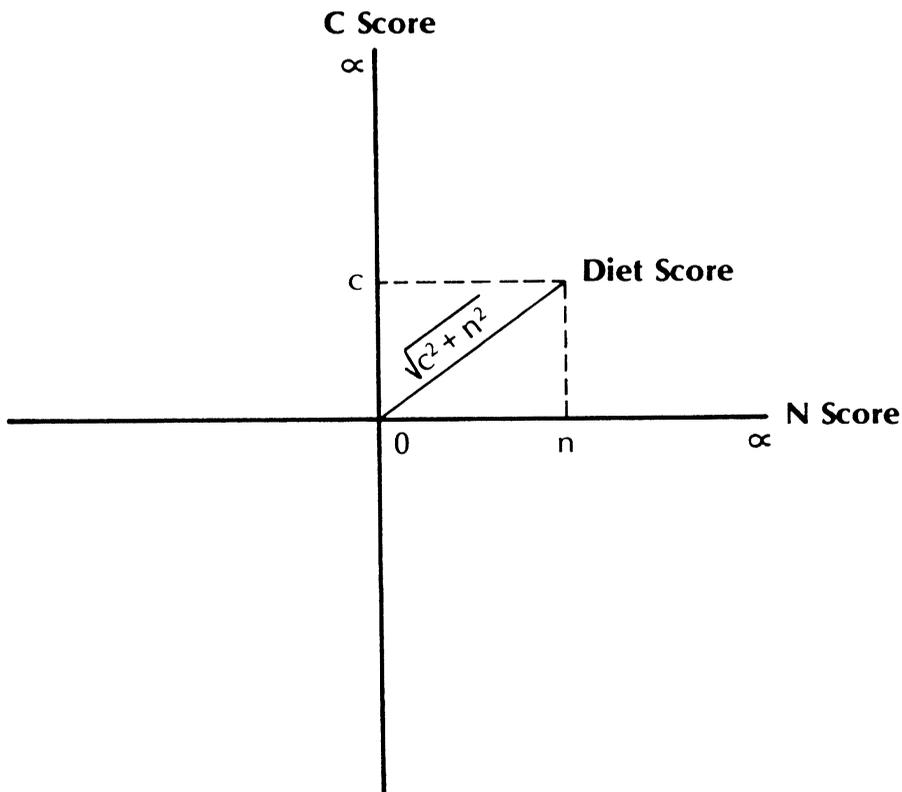
(1) For each period, the bone stable-isotope mean was subtracted from each corresponding diet-isotope value—for N:  $9.24 - 8.9 = .34$ ; and for C:  $-7.49 - (-7.5) = .01$ .

(2) The remainder was divided by the standard deviation for the bone stable-isotope mean. This resulted in a separate "score" for carbon and nitrogen for each diet—for N:  $.34/.6 = .57$ ; and for C:  $.01/.3 = .03$ .

(3) The next step combined the carbon and nitrogen scores into a single deviation measurement, or diet score. This was done by calculating the distance from a point defined by the carbon and nitrogen scores of a diet to the origin of a graph of carbon and nitrogen scores (see Appendix Figure 1.):

$$\sqrt{(.57)^2 + (.03)^2} = .57.$$

(4) The diets then were sorted on the basis of the diet score from lowest to highest, thereby providing a ranking of diets from most likely to least likely, given the human values. Table 5 lists those hypothetical diets that were most compatible with the Pecos bone collagen stable-isotope data for Periods II and VI. Column 7 in this table contains the diet score computed in step 3 above.



Appendix Figure 1. Graph illustrating the calculation of the diet score.

We have assumed that diets with diet scores, or deviations, that are less than one are most likely to have been characteristic of the Pecos population. Thus, once rankings were made, rather than focusing on the single diet with the lowest score, we looked for commonalities among diets most compatible with the bone-chemistry data. For example, in Table 5 it is clear that the most compatible diets for Period II all contain 75–85 percent maize (not 90, or 50–70 percent); 5–10 percent nonmaize plants (not 15–40 percent); and often 15–20 percent meat (not 10 percent). The least-compatible hypothetical diets that we modeled (not illustrated in Table 5) contained 50–60 percent maize, 30–40 percent nonmaize plants, and 10 percent meat.

---

*Received May 11, 1990; accepted July 30, 1990*