Journal of Archaeological Method and Theory, Vol. 3, No. 4, 1996

Mano Size, Stable Carbon Isotope Ratios, and Macrobotanical Remains as Multiple Lines of Evidence of Maize Dependence in the American Southwest

Robert J. Hard,[1] Raymond P. Mauldin,[2] and Gerry R. Raymond[3]

While the level of agricultural dependence affects many aspects of human adaptation, estimating levels of dependence on maize through traditional archaeological techniques is problematic. Here we compare various measurements of manos (e.g., grinding surface area), macrobotanical evidence of maize use, and human collagen stable carbon isotope values from six regions of the American Southwest, encompassing 16 phases, as a means of assessing the power and limits of each approach for considering agricultural dependence. The analysis of each data class is considered separately, taking into account formation processes and arguments linking data and inferences. Correlations among the three data classes suggest that mano area and maize ubiquity can be considered ordinal measures of agricultural dependence, but Southwestern stable carbon isotope data have the analytical potential only to discriminate between little or no maize use and substantial maize use. The formation processes and linking arguments associated with each method must be considered when multiple lines of evidence are integrated in order to make sound behavioral inferences. Our results suggest that there were at least three patterns in the adoption of farming in the Southwest: early substantial use followed by continuous increasing maize dependence, initial intensive dependence with little change in later periods, and a long period of minor use followed by substantial dependence.

KEY WORDS: maize; ground stone; stable carbon isotope analysis; paleoethnobotany; prehistoric subsistence; American Southwest; multiple lines of evidence; formation processes.

---

[1] Center for Archaeological Research and Division of Behavioral and Cultural Sciences, The University of Texas at San Antonio, San Antonio, Texas 78249.
[2] Anthropological Research Center, Department of Sociology and Anthropology, University of Texas at El Paso, El Paso, Texas 79931.
[3] Department of Anthropology, University of New Mexico, Albuquerque, New Mexico 87131.

INTRODUCTION

The shift from a subsistence economy based on hunting and gathering to one dependent on agriculture has occupied archaeologists working in the Americas, Africa, Asia, and Europe for well over a century. This subsistence shift had major implications for all aspects of cultural systems, directly influencing the form and scale of land use, aspects of labor and social organization, and population growth. This shift involved the initial adoption or domestication of cultigens and increases in their dependence, both of which correlate with changes in the other aspects of organization. Investigators continue to examine the many dimensions of this subject, including the conditions surrounding the earliest domesticates and the establishment of farming economies (e.g., Cowan and Watson, 1992; Gebauer and Price, 1992; Hard, 1986; MacNeish, 1992; Matson, 1991; Price and Gebauer, 1995; Redding, 1988; Rindos, 1984; B. D. Smith, 1992, 1995; Stark, 1986; Wills, 1988, 1992). Yet methods that are able to infer different levels of agricultural dependence, rather than just presence–absence, are still in their infancy. Archaeologists have used an array of indirect indicators of agricultural dependence including studies of settlement patterns, paleopathology, storage capacity, ceramic vessels, and architecture, as well as the three we evaluate here, ground stone morphology, bone chemistry, and archaeobotanical studies (e.g., El-Najjar *et al.*, 1976; Gilman, 1987; Hard *et al.*, 1994; B. Huckell, 1995; Schiffer, 1972b, 1988; Stark, 1986; Whalen, 1981). In this paper we contrast the results obtained from studies of attributes of manos, the analysis of stable carbon isotopes from human bone collagen, and macrobotanical remains recovered from flotation and coprolite samples. The analysis of diachronic data from six regions in the American Southwest—Black Mesa in northeastern Arizona, Cedar Mesa in southeastern Utah, Mesa Verde in southwestern Colorado, the Sierra Blanca in south central New Mexico, the Southern Jornada in the vicinity of El Paso, Texas, and the Texas Panhandle region—involves consideration of 16 phases.

We suggest procedures that allow for the systematic integration of diverse lines of evidence to make behavioral inferences. This integration is an independent analytical process deserving methodological attention (Schiffer, 1988). We are able to document significant variability in the rate and timing in increases in the dependence on maize among our sample areas.

GRINDING SURFACE AREA AND MAIZE DEPENDENCE

The apparent low level of variability in ground stone tools, their overt function, minimal stylistic information (cf. J. Adams, 1994), and an anticuration bias against these bulky tools have conspired to deny ground stone tools all but superficial attention by both traditional and processual archaeologists. Recently, researchers have turned their attention to ground stone tool variability arguing that their mechanical life histories are latent with functional meaning. Prescient early workers suggested that the morphological changes that did occur in ground stone tools are related to the change between a hunting and gathering and agricultural economy (e.g., Bartlett, 1933; Martin and Rinaldo, 1947). New developments on the nature of this relationship have focused on the mechanics of the grinding process and the nature of maize processing in attempts to develop inferences concerning levels of agricultural dependence. These inferences involve consideration of the nature of maize and maize processing.

Drying fresh maize cobs transforms the kernels' disaccharides into starch or polysaccharides such that kernels become 74.5% starch (Katz *et al.*, 1974, p. 763). These starch molecules are largely unavailable to the human digestive system without extensive processing (Braun, 1983; Hard, 1986; Katz *et al.*, 1974; Marshall and Whelan, 1979, p. 125). Cooking, either parching or steeping, breaks down the polysaccharides into simpler, more digestible forms. Grinding usually follows cooking and serves to reduce particle size, allowing the digestive system to reduce the kernel more rapidly and completely and thereby making more nutrients available to the consumer (Braun, 1983; Hard, 1986; Rylander, 1994, p. 131; Snow, 1990).[4]

Grinding with hand-operated stones involves a complex set of mechanical variables between the transformation of human energy to particle size reduction that have yet to be systematically analyzed from an energetic or mechanical perspective. Engineers, however, are attentive to the variables affecting the time and energy costs involving the comminution of ore, coal, flour, and other industrial products. While the complex mechanical relationships involved in crushing and grinding have yet to be incorporated into well-established theoretical principles (e.g., Prasher, 1987), engineers have conducted empirical studies of the variables affecting comminution and are involved in modeling the relationships among moving grinding surfaces and ground particles. Comminution engineers have examined variables including ground particle size, shape, and surface configuration; the fineness of ground output; the ease or difficulty of grinding different products (grindability); the physics of particle breakage and fracturing; wet grinding versus dry grinding; and the characteristics of specific types of grinding machines (e.g., Lowrison, 1974; Prasher,

---

[4] Steeped, unground maize hominy was consumed by ethnographic groups, although recipes involving grinding or pounding were more commonly used (see Hard, 1986; Cushing, 1920).

1987). However, one of the most critical variables affecting the amount of a given product which can be ground to a given fineness in a given amount of time (mill capacity) is the size of the grinding surfaces. *Capacity* is expressed as a function of the length of the grinding surface by the formula

$$\text{capacity} = PL^3/T$$

where P is the particle density, L is the length of the grinding surface, and T is the grinding time (Prasher, 1987, p. 235). For a given particle density and grinding time, capacity increases as a *cubic* function of grinding surface length (Andreasen, 1957, p. 105; Prasher, 1987). In fact, a standard tool of comminution engineers is scaling laws (e.g., Andreasen, 1957), which assume that a host of variables affecting grinding (e.g., mass, revolutions, force, time) are all functions of the length of the grinding surfaces of the equipment. Scaled-down mill prototypes are built to study time and energy efficiencies of various mill designs since the efficiencies of full-scale equipment are a function of the model's scale (Prasher, 1987, p. 235).

While input and output studies of traditional grinding technologies are just beginning (e.g., Mauldin, 1993a; Wright 1990), in the field of comminution it is a law that grinding capacity increases with grinding surface length. Hard (1986, pp. 108–113, 1990) and Lancaster (1983, pp. 75–86) argued that since grinding with hand tools involves many of the same mechanical relationships as found in industrial comminution equipment, the capacity[5] of hand-operated grinding mills should also be a function of the grinding surface size. Figure 1 contrasts mano area with grinding rates for 16 sessions in which one kg of dried maize was reduced to flour using recent ethnoarchaeological observations on traditional maize grinding from Bolivia (Mauldin, 1993a, 1995; Mauldin and Tomka, 1988, 1989). Four mano and metate sets were used. Clearly, as the grinding surface areas of manos and metates increased, the same amount of maize was ground in less time. In short, this study of traditional maize processing demonstrated that a strong relationship existed between grinding area and grinding rates (Lancaster, 1983, pp. 79–82; Hard, 1986, 1990), which is consistent with empirical studies in industrial comminution.

Ethnographic accounts from the Southwest and Mesoamerica reveal that grinding maize with manos and metates was a labor-intensive task that often involved from 2 to 5 hr per day (Bauer, 1990; Bartlett, 1933; Christenson, 1987; Cushing, 1920; Foster, 1967, p. 52; Hard, 1990; Hayden

---

[5] Increased capacity for ancient grinding equipment is an increase in the output of a given ground product per unit of time. We use the term *capacity* in the same sense that J. Adams (1993, p. 334) uses the term *efficiency*.

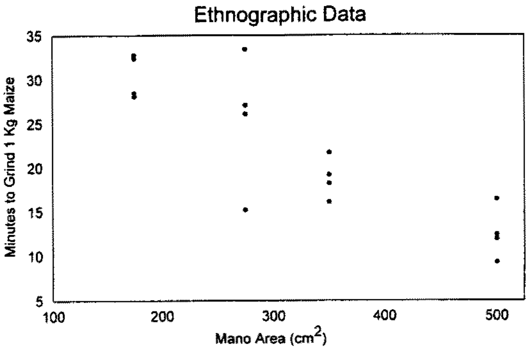

Fig. 1. Mano area compared to grinding rates for 16 sessions of ethnoarchaeological maize grinding.

and Cannon, 1984, p. 68; Horsfall, 1987, p. 348; Lancaster, 1983; Morris, 1990, pp. 188–189; for Old World grains see Molleson, 1989). As the dependence on agricultural products increased, so would the amount of time required for grinding. At some point this task began to conflict with others. One solution to this time conflict was to modify the technology to gain increases in capacity. As suggested by both industrial and ethnoarchaeological studies, increasing the grinding surface area of the manos and metates used in grain preparation provided one of the most significant gains in capacity.[6]

Yet mano and metate design remained static through millennia of hunting and gathering adaptations on several continents (Morris, 1990). This ancient technology involved a small round or oval handstone or mano, averaging 85 to 90 cm^2 in area, used in circular and pounding motions on

---

[6] Other variables that also probably affect traditional grinding capacity include wet versus dry grinding and the fineness of the ground particles. Industrial experimental data suggest that there is only a 10 to 20% increase in capacity with wet versus dry grinding for a given product output and energy input (Prasher, 1987, pp. 38–40). This increase is related to the effect the wet product has in reducing the inefficient contact between grinding surfaces. Other experiments have found that both linear and curvilinear increases in energetic costs occur with finer particle size reductions (Prasher, 1987, pp. 213–215). Increased particle fineness yields higher ratios of particle surface area to volume. For maize this allows the chemical reactions of digestion to proceed at a faster rate, enhancing digestibility and nutrient availability (Rylander, 1994). Higher levels of maize consumption are likely to enhance the desire for increased fineness, particularly for some maize preparations. Other variables that have been suggested to affect the efficiency of traditional grinding include stone material type, downward force on the mano, individual skill differences, maize race, grinding tool shape, and corresponding differences in motor habits (J. Adams, 1993; Morris, 1990). Experimental examination of all these factors using traditional milling equipment will be needed to assess their significance.

a slab or basin metate (Hard, 1986; Morris, 1990). In the Greater Southwest small manos and basin metates were used for over seven millennia before design changes occurred in both tools. Similar grinding technologies persisted during the Archaic in Mesoamerica, South America, Australia, and the North American Great Basin; all locations where the native inhabitants processed nondomesticated, small, hard seeds (Cane, 1987; Euler and Dobyns, 1983; Haury, 1950; Jennings *et al.*, 1980; Pearsall, 1987). Larger manos and slab or trough metates apparently had little adaptive advantage under this subsistence regime. Perhaps the added energetic costs related to manipulating the larger stone against a lower stone render them impractical for the crushing and grinding required for small, wild seeds[7] (J. Adams, 1993; Hard, 1986; Mauldin, 1993a, p. 319).

Industrial studies demonstrate that energetic costs increase as size increases. Power, which is force times velocity, is expressed as:

$$\text{power} = SL^2(L/T)$$

where S is stress, L is the grinding surface length, and T is time (Prasher, 1987, p. 235). Thus, for a fixed stress and grinding time, power increases as a function of grinding surface length. In effect, the human effort required to grind with larger manos and metates increases as grinding surface length increases, all other conditions being equal. It appears that populations throughout the New World did not significantly modify their grinding technology until the increased processing requirements of dried maize presented such a need. This technological redesign involved modifications in the size and shape of both the upper and the lower stone tools accompanied by modifications in motor habits (e.g., J. Adams, 1993; Bartlett, 1933; Morris, 1990). One of the dominant characteristics of this design change involved increasing the grinding surface areas of the manos and metates. Manos were made longer with flatter grinding surfaces. Mano widths, constrained by the size of the human grip, increased only slightly. Design changes in metates included use of slab or trough metates that were appropriate for the reciprocal grinding motion that tended to accompany grain processing (e.g., Bartlett, 1933; Morris, 1990).[8]

---

[7] Euler and Dobyns (1983, p. 253) observed that small manos are used "primarily for pounding and crushing and only partially for grinding" among recent Walapai Indians in northwestern Arizona. However, Cane (1987) reports his recent observations of Australian Aborigines show that wild seed grinding was labor intensive and seeds were ground into a paste.

[8] While these evolutionary changes in ground stone morphology have long been recognized, our work has focused on the utility of using mano grinding surface area as an indirect indicator of agricultural dependence. We have not been able to systematically examine changes in metate grinding surface area because of the difficulty of obtaining measurements from published literature.

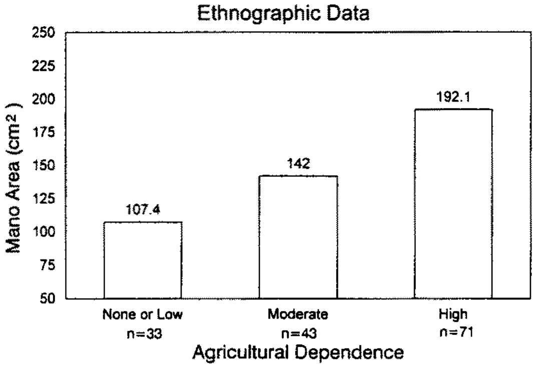

Fig. 2. Correlation of ethnographic mano area and agricultural dependence, based on Hard (1990).

Utilizing ethnographic mano collections in museums, Hard (1990) found a strong correlation between mano length, used as a proxy for mano area, and agricultural dependence for 19 ethnographic cases from western North America. Here the original data (Hard, 1990) were reanalyzed to calculate mano area (length times width) in place of length. Figure 2 shows that mano area increases with agricultural dependence. Further support for the relationship between grinding intensity and mano size is provided by Mauldin and Tomka (1988) and Mauldin (1991, 1993a). Grinding *intensity,* the proportion of each day spent in grinding (but cf. J. Adams, 1993), is related to the quantity of product output. Using ethnoarchaeological data these studies demonstrate that measurements of mano area at a site provide a measure of the intensity of grinding at that location. At Bolivian villages where grinding was more intensive, mano areas averaged 421 cm^2 ($SD = 99.5\ cm^2$; $n = 42$). At camps with less intensive grinding, the average mano area was 337 cm^2 (SD = 66.1 cm^2; $n = 16$).

While the results of these initial studies are encouraging, several issues related to using mean mano area of a site or occupation phase as an indicator of agricultural dependence need further attention. The initial question involves mano function. Manos in the Southwest have traditionally been divided into two classes: small manos, referred to as "one-hand," and larger "two-hand" forms.[9] This classification has had direct

---

[9] The term "one-hand" is somewhat misleading since ethnographic data indicate that they were frequently used with two hands (Christenson, 1987, p. 47; Euler and Dobyns, 1983, p. 254; Hard, 1986; Morris, 1990) and the exact separation point between the two classes varies from researcher to researcher.

functional implications. One-hand manos are assumed to have been used for nondomesticated seed grinding and two-hand manos are assumed to have been used for maize. While in a general diachronic sense in the Southwest, this is correct, but in any particular case a variety of functions, particularly of one-hand manos, is expected. Use-wear studies (J. Adams, 1988, 1989, 1994; Lancaster, 1983) and ethnoarchaeological observations (Hayden, 1987; Mauldin, 1993a; Mauldin and Tomka, 1988) suggest that manos served many functions, including processing nonfood items. J. Adams (1988), for example, argues that many small manos at the Hopi pueblo village of Walpi were used in moccasin manufacture. Both large and small manos also served to grind items such as clay, pigment, bone, salt, ore, and meat (DeGarmo, 1975; Euler and Dobyns, 1983; Hard, 1983c; Hard and Yener 1991; Logan and Fratt, 1993). Furthermore, ethnographic observations indicate that, on occasion, small manos were used to grind maize and large manos were used to grind nondomesticated seeds. For example, Morris (1990, pp. 183–184) notes that both the Navajo and the Northern Tepehuan ground maize with small manos as did the Walapai (Euler and Dobyns, 1983, p. 254). Further, a single mano may serve many functions throughout its use life (Euler and Dobyns, 1983; Horsfall, 1987; Mauldin and Tomka, 1988). This functional variability, including discriminating between maize processing tools and other food and non-food processing functions, remains a difficult issue, although detailed use-wear studies offer some potential (e.g., J. Adams, 1988, 1989).

Our work relies on reported data and seeks to determine if this internal variability is subsumed by a general trend in which mano area correlates with agricultural dependence across a large geographic space. We refer to manos 15 cm or greater in length as "large" manos and those less than 15 cm as "small" manos. Histograms of mano length frequently show bimodal distributions with breaks at about this point. We emphasize that this dichotomous classification does not account for all the functional and morphological variability that exists within these classes. In order to proceed with our analysis, however, we included small manos in our measurements of mean mano area as including them should appropriately reflect low maize usage, but we also include the mean size data for just the large manos as other studies have (e.g., Diehl, 1996; Mauldin, 1993a). We recognize that inclusion of small manos from contexts in which they played no role in food processing would inappropriately deflate estimates of maize use. In order to observe the mano class ratios we also calculated the proportion of large manos in the assemblages (large manos/all manos).

In addition, standard analytical issues, such as sampling, site function, and site formation processes, are relevant to any evaluation of mano data. Schlanger (1991), for example, considered ground stone procurement, manufacture, use, maintenance, and discard (*sensu* Schiffer, 1976, 1987) and the consequent relationships between depositional context and the archaeological distribution of ground stone. While an understanding of the depositional contexts of ground stone tools is important, our study depends upon previously reported data, for which little consideration was given to such issues.

One potential problem which could affect our analysis is the selective removal of manos from sites through collecting or scavenging (Schiffer, 1987, pp. 118–119). With generation-long use-lives, ground stone may be particularly susceptible to collecting (see Cook, 1982, p. 309; Hayden and Canon, 1984, p. 69; Horsfall, 1987, p. 342). For example, Simms (1983) argues that the collecting of ground stone from archaeological sites was common in the Great Basin and that this practice resulted in a concentration of ground stone in the later time periods. Schlanger (1991) indicates collecting was an important factor structuring the formation of ground stone assemblages in the Southwest, and ethnographic accounts of the collection of ground stone from archaeological sites are common (see Deal, 1985; Horsfall, 1987, p. 340; Hough, 1901; Kelly, 1964, p. 37). Collecting that targeted a particular size class, particularly large manos, was likely given their high manufacturing costs (Schlanger, 1991, p. 461). This differential collection could significantly bias the mean mano area measurement as well as the ratios of small to large manos from a site or phase.

We therefore devised a strategy for correcting for the potential effect of post-occupation collecting by examining mano fragment data. Although fragments of large manos were occasionally recycled into small manos, fragments were unlikely to have been scavenged in significant quantities as their use-lives were essentially exhausted. In many instances a mano fragment can be identified as originating from either a small or a large mano. Our approach uses the frequency of mano fragment size classes as indirect indicators of the frequency of whole mano size classes present prior to collecting. This approach assumes that the proportion of small to large mano fragments at a location is the same as the proportion of small to large whole manos deposited in the archaeological record prior to collecting (see Schlanger, 1991, pp. 467–469).[10] It further assumes that frag-

---

[10] Schlanger (1991), using data from the Dolores project in Colorado involving Anasazi sites dating to the seventh to ninth centuries A.D., suggests that broken large manos were discarded at only a slightly higher rate than broken small manos, although she indicated that her data were not clearly supportive of this proposition.

ments were not scavenged in significant quantities. Therefore, if no size-biased collection occurred, the ratio of small to large fragments, after estimating the minimum number of individual manos represented by the fragments, would be equal to the ratio of small to large whole manos at a site.

A minimum number of individual manos (MNIM) estimate, analogous to that calculated for faunal analyses, compensates for the probability that several mano fragments may have derived from a single mano. We calculated the MNIM by first calculating the surface area of each mano fragment that could be identified as deriving from either small or large mano class. Fragments of unknown class were excluded. Next, the areas of fragments were summed by size class. Finally, the total area of each class (small and large) was divided by the mean area of *complete* manos for its respective class. These complete mano areas were derived from whole mano data for each region and phase. The resulting quotient represents the MNIM for each class represented by the fragments. Therefore the MNIM represents the number of whole manos the fragments could produce, based on their total surface area, if all fragments could be refitted into complete manos. The MNIM was then added to each class count of whole manos; these total counts were used to calculate two variables used in the analysis, the proportion of large manos in the total mano assemblage and the weighted mean mano area of all manos by region and period. The weighted mean area of all manos was calculated by weighting with the total counts for each class.

While the assumptions involved prevent this approach from providing an exact correction to postoccupational collecting, the use of fragment data will reduce the magnitude of the error introduced by collecting. If little collecting had occurred at a location, inclusion of the fragment data will have a minimal effect on the ratio of small to large manos or the weighted mean area of all whole manos. However, if substantial collecting occurred and it was biased toward a particular size class, then the fragment data will *reduce the magnitude* of the lowered mano frequency brought about by collection.

Even if the assumption that the proportion of the small to large mano (MNIM) is equivalent to the proportion of small to large unscavenged whole manos is incorrect, use of the fragment data is unlikely to result in the *overestimation* of the frequency of a particular class and by extension agricultural dependence. An overestimate would occur only if the MNIM represented by fragments was substantially greater than the whole mano count and the MNIM class ratio was grossly different from the unscavenged whole mano class ratios. In the two data sets with mano fragment data available (Cedar Mesa and Black Mesa), whole mano frequencies, are greater than the MNIM frequencies suggesting that overestimatation has not occurred and that the use of this measure is justified.[11]

In previous publications, the mean area of all manos, mean mano length, and mean area of large manos have been used as indices of maize dependence (Diehl, 1996; Hard, 1990; Mauldin, 1993a). Here we calculate Spearman's correlation coefficients between mean mano area, mean mano length, mean area of large manos only, and percentage of large manos in an assemblage to evaluate the relationships among these measures. These diachronic data, ranging between 6000 B.C. and A.D. 1400 from six Southwestern regions totaling 16 phases, are listed in Tables III–VIII. These data include complete specimens only. Mean mano grinding surface area is measured as overall mano length times width. Since we are concerned with the grinding surface area in contact with the ground product, we did not attempt to control for manos with multiple grinding surfaces, as presumably each surface has about the same area. Errors introduced from manos with surfaces that are not rectangular or grinding surfaces that do not quite reach to the edge of the stone are negligible. Mean mano area correlates with mean mano length ($r_s = 0.962$, $P = 0.0001$; $n = 16$), mean area of large manos ($r_s = 0.82$, $P = 0.0003$; $n = 14$), and percentage of large manos in an assemblage ($r_s = 0.932$, $P = 0.0001$, $n = 16$). Despite the bimodal and sometimes multimodal frequency distribution of mano area, the mean area of complete specimens is the best characterization of mano size, as it reflects both the frequency of small manos and the variability in the size of large manos.

Mano grinding surface areas are related to grinding capacity and indirectly to levels of agricultural dependence. The theoretical underpinnings

---

[11] A brief reexamination of Schlanger's (1991, p. 471) data further supports our use of mano fragment data. The shorter access sites ($n = 4$) in her study received less collecting than the longer access sites ($n = 8$). On the little-scavenged sites the ratio of whole large to whole small manos from floor assemblages was 7.13 (57/8). If the fragments from floors are added, without regard for the MNIM correction as the fragment size data are unavailable, the large-to-small mano ratio becomes 6.6 (66/10). There is little difference between the two ratios. The close similarity between the whole mano ratio versus the whole-plus-fragment ratio supports the contention that these shorter-access assemblages have suffered little collecting loss. In contrast, the more heavily scavenged, longer-access sites contained a ratio of 4.71 (33/7) whole large to whole small manos. The lower ratio suggests that the scavengers preferred large manos. Adding the fragment counts to the whole mano counts raises the ratio to 6.57 (46/7). While this figure is almost identical to the ratio of 6.6 found on the little-collected sites, more important is the significant difference between the whole tool ratio versus the whole-plus-fragment ratio, indicating that the addition of the fragments on the more heavily scavenged, longer-access sites corrects the size bias introduced from the heavier collecting that depleted the large rather than the small manos. Presumably, if the fragment counts could have been adjusted for MNIM, the trend would be the same, only slightly less. This experiment supports our procedure of using the fragment data to offset mano collecting, particularly when it was biased toward large manos.

of the arguments relate to comminution scaling laws (e.g., Andreasen, 1957; Prasher, 1987), which are tied to the mechanical properties of grinding. Increases in mano grinding surface areas substantially increase the output of ground product per unit of time of an extraordinarily labor-intensive process. As dependence on dried maize increased, households would alter the designs of their manos and metates to increase grinding surface areas, achieving rapid increases in capacity.

STABLE CARBON ISOTOPES AND MAIZE DEPENDENCE

When introduced 20 years ago, stable carbon and nitrogen isotope studies appeared to give archaeologists a means of quantifying dietary intake (e.g., Vogel and van der Merwe, 1977; for recent reviews see Pate, 1994; Schoeninger and Moore, 1992; Schwarcz and Schoeninger, 1991). While nitrogen isotope studies potentially reflect trophic position and marine resource intake, our focus is on stable carbon isotope data, as they have been used to determine the degree of maize use.

The carbon isotope technique is based on the observation that plants incorporate carbon from the atmosphere using one of three photosynthetic pathways, each of which results in distinct carbon stable-isotope ratios ($^{13}C/^{12}C$) (Bender *et al.*, 1973; Pate, 1994; B. N. Smith, 1971, 1972). These isotopic signatures are then incorporated into the bone collagen of animals that eat those plants (DeNiro, 1987; DeNiro and Epstein, 1978; Schoeninger and Moore, 1992; Schwarcz and Schoeninger, 1991; Pate, 1994). The time needed for the replacement of the carbon in adult bone collagen, or turnover rate, is between 10 and 30 years (Stenhouse and Baxter, 1979, p. 339; Bumstead, 1985, p. 544; Krueger and Sullivan, 1984, p. 210). Presumably the collagen stable isotope record reflects an average of the stable isotope ^{13}C intake levels during this period. Most plants, including all trees, most herbs and shrubs, and temperate cool-season grasses, use the C_3 or Calvin pathway to assimilate CO_2 (Pate, 1994). This results in the plants having isotopic ^{13}C values that range between -20 and -35‰, with a mean of -27.1 ± 2.0‰ (Ehleringer, 1989, p. 41; O'Leary, 1988, p. 334). While considerable variation exists in the isotopic signatures of plants using this pathway, no overlap occurs between the carbon isotopic signatures of C_3 and the other major plant pathway, the C_4 or Hatch/Slack pathway. Plants such as amaranth, portulaca, tropical and warm-season grasses, maize, millet, sugarcane, and some shrubs in the Euphorbiaceae and Chenopodiaceae families use the C_4 pathway (Pate, 1994, p. 172). C_4 plants have an isotopically heavier ^{13}C value, with a mean of -13.1 ± 1.2‰ (O'Leary, 1988, p. 334) and a range of -7 to -16‰ (Ehleringer, 1989, p. 41; Pate, 1994,

p. 173). That is, these plants are enriched in ^{13}C. A third pathway, crassulacean acid metabolism (CAM), is characteristic of arid-land succulents, including cacti, agave, and some euphorbs. Depending if growth and uptake of atmospheric CO_2 occurs at night or during the day, CAM species use, respectively, either a C_4-like or a C_3 pathway (O'Leary, 1981, p. 554, 1988, p. 331; Pate, 1994, p. 173). CAM plants have isotopic signatures that range between -10 and -22‰, but they cluster into nocturnal and diurnal CO_2 respiring groups (Ehleringer, 1989, p. 41; O'Leary, 1981, 1988; Pate, 1994, p. 173). The range of $\delta^{13}C$ values of the day-growing CAM group is from -24 to -30‰ and that of the nocturnal CAM group is between -10 and -14‰, within the range of C_4 species (Pate, 1994, p. 173).

When animals consume plants the isotopes are incorporated into their bone collagen, with an additional fractionation or enrichment in ^{13}C relative to the values for plants in the diet (DeNiro and Epstein, 1978; Habicht-Mauche, 1994; Spielmann *et al.*, 1990). While the actual fractionation value is under debate,[12] Schwarcz and Schoeninger (1991, p. 306) estimate that the difference, or spacing, between human diet and collagen is approximately +3 to 5‰, and in this study, we use the +5‰ values (Bender *et al.*, 1981; DeNiro and Epstein, 1978; Vogel, 1978; Spielmann *et al.*, 1990). Therefore, a herbivore subsisting only on C_3 plants (-27.1‰) would have a bone collagen value of around -22.1‰, while a herbivore feeding only on C_4 plants (-13.1‰) would have collagen values of about -8.1‰.

Modeling the diets of omnivores is problematic, as they consume both plants and animals. Omnivores, including humans, may not derive the carbon chains for collagen synthesis in direct proportion to their occurrence in the bulk diet, which has been the standard model (e.g., van der Merwe, 1982; Spielmann *et al.*, 1990). Recent work suggests that the carbon molecules in fats are not available for tissue synthesis (Schoeninger and Moore, 1992, p. 277). Instead of representing the total diet, the carbon molecules in collagen may be routed or derived largely from specific dietary components. Krueger and Sullivan (1984) suggest that even small amounts of animal protein may satisfy collagen amino acid requirements and that carbohydrates may not be significantly involved in collagen synthesis. Controlled experiments suggest that dietary protein, including maize protein, rather than fats, carbohydrates, or an amalgamation of the entire diet, may play the largest role in collagen synthesis in rats and mice (Ambrose and Norr, 1993; Tieszen and Fagre, 1993a). Tieszen and Fagre's experiments (1993a, Fig. 7) found an r^2 of 0.91 for a correlation between the carbon

[12] Recent experiments indicate that the range may be as large as +0.6 to 8.1‰, apparently depending on the size of the subject animals and whether the diet is primarily C_3 or C_4 plants (Ambrose and Norr, 1993, Table I; Pate, 1994, p. 175; Tieszen and Fagre, 1993a, pp. 122–123).

isotope values of collagen and dietary protein but an r^2 of only 0.62 between collagen and bulk diet (see also Cargill, 1996; Katzenberg, 1989 Schoeninger and Moore, 1992). Clearly, further research is required to understand the routing of carbon molecules in collagen, as this critical issue undermines the use of the bulk diet model that appeared to allow quantified estimates of C_3 and C_4 intake.[13]

Diet–collagen isotope spacing may be dependent upon the isotope values of the actual dietary carbon molecules involved in collagen formation (Ambrose and Norr, 1993; Hare *et al.*, 1991; Krueger and Sullivan, 1984; Tieszen and Fagre, 1993a,b). Hare and his colleagues (1991) have examined the diet-to-collagen spacing for seven specific amino acids. They found with an experimental maize diet that the amino acid glycine in pig collagen had an isotopic signal that was enriched 7.4‰ above the isotopic composition of the bulk C_4 diet (Hare *et al.*, 1991, p. 283). If glycine, which makes up 33% of the amino acids in collagen and is abundant in maize, provided the carbon molecules for collagen, it would account for the markedly high isotopic values seen in the human collagen of maize agriculturalists (Tieszen and Fagre, 1993b, p. 37).

In spite of these potential problems, the results of stable-carbon isotope studies on human bone collagen have consistently identified the transition between hunting and gathering and maize agriculture in areas such as the interior Eastern Woodlands where influences of marine resources and alternative C_4 plants do not confound the results. Maize uses a C_4 photosynthetic pathway. When incorporated into noncoastal environments dominated by C_3 plants and animals that feed on C_3 plants, any radical increase in collagen ^{13}C values relates to the increased use of maize (e.g., Ambrose, 1987; Boutton *et al.*, 1984; Buikstra *et al.*, 1987; Katzenberg, 1989; Katzenberg *et al.*, 1993; Schoeninger and Moore, 1992, p. 266).

While the technique of stable carbon isotope analysis has considerable value in such C_3 settings, its use in hot, semiarid environments where C_4/CAM plants are common encounters difficulties (e.g., Farnsworth *et al.*, 1985). Samples from animals that feed on C_4 plants, such as Southern Plains bison, will also yield a C_4 signature (Habicht-Mauche *et al.*, 1994; Tieszen, 1994). The increasing frequency of C_4 grasses correlates strongly with increasing diurnal July minimum temperatures across North America

---

[13] In some costal marine settings, the isotopic signals may be heavily weighted toward dietary protein, as extremely positive human collagen values have been reported for a number of studies where the only C_4 resources available were marine-based, suggesting that the intake of these aquatic resources was substantial (Schoeninger and Moore, 1992, p. 278). Because of nutritional limitations, however, marine-protein intake was unlikely to have formed 100% of the diet. Yet the protein may have provided all of the carbon molecules used in collagen synthesis. However, high protein intake does not always affect the stable isotope signature (see Schwarcz *et al.*, 1985; Katzenberg, 1989; Cargill, 1996).

Table I. $\delta^{13}C$ Values for C_4 and CAM Food Plants in the Southwest

Family	Genus species	Path	$\delta^{13}C$ (‰)[a]	Reference
Agavaceae	*Yucca baccata*	CAM	−15.7	Szarek and Troughton (1976)
Cactaceae	*Opuntia Fulgida*	CAM	−14.8	Szarek and Ting (1977); Mooney *et al.* (1974)
Cactaceae	*Opunita phaeacantha*	CAM	−12.5	Szarek and Troughton (1976)
Cactaceae	*Echinocereus Engelmannii*	CAM	−13.8	Black and Williams (1975) Mooney *et al.* (1974)
Amaranthaceae	*Amaranthus graecizans*	C_4	−12.4	Katzenberg and Kelley (1991)
Amaranthaceae	*Amaranthus hybridus*	C_4	−11.4	Katzenberg and Kelly (1991)
Chenopodiaceae	*Atriplex canescens*	C_4	−13.8	Katzenberg and Kelly (1991)
Gramineae	*Panicum obtusum*	C_4	−12.7	Black (1971)
Gramineae	*Sporobulus cryptandrus*	C_4	—	Kemp (1983)
Gramineae	*Erogrostis mexicana*	C_4	—	Smith and Brown (1973)
Gramineae	*Zea mays* (prehistoric)	C_4	-8.7 to −12.6	Chisholm and Matson (1994); Katzenberg and Kelley (1991); Pate (1994); Schwarcz *et al.* (1985); Tieszen and Fagre (1993b)
Portulacaeae	*Portulaca oleracea*	C_4	−12.1	Amundson *et al.* (1988)
Portulacaeae	*Portulaca retusa*	C_4	−11.8	Katzenberg and Kelly (1991); Welkie and Caldwell (1970)

[a] Some $\delta^{13}C$ values are the means of reported values.

(C. Black, 1973; Teeri, 1988; Teeri and Stowe, 1976). Therefore, bison from more northern latitudes, where C_3 grasses dominate, yield a C_3 collagen signature (Tieszen, 1994). In addition, the increasing frequency of C_4 dicot species strongly correlates with growing-season evaporation rates (Stowe and Teeri, 1978; Teeri, 1988). In settings such as the Southwest, plants that use the C_4 and CAM pathways as well as animals feeding on them are common, and C_4 and CAM pathway plants have less negative $\delta^{13}C$ values. Human dependence on these plants, or animals which feed on these plants, would result in a concentration of ^{13}C in bone collagen and heavier delta values. Such diets may yield essentially the same collagen $\delta^{13}C$ pattern as one dependent on maize.

Table I is a list of some commonly occurring Southwestern economic C_4 and CAM food plants with their photosynthetic pathway and $\delta^{13}C$ value identified. Table II presents bone collagen $\delta^{13}C$ values for a number of Southwestern economic mammals. These delta values tend to be lighter or more negative. With the exceptions of some dog, bison, and jack rabbit

Table II. Bone Collagen $\delta^{13}C$ Values for Several Animals in the Southwest

Animal	$\delta^{13}C$ (‰)[a]	Location	*N*	Range	Source[b]
Dog	–8.6	Pecos	1		1
Bison	–9.5	Pecos	6	–11.9 to –7.8	1
Bison	–10.5	Sierra Blanca	—	–12.8 to –8.0	2
Jackrabbit	–14.0	Sierra Blanca	—	–15.3 to –12.8	2
Jackrabbit	–16.9	S. Jornada	12	–21.3 to –13.3	3
Cottontail	–18.8	Sierra Blanca	—	–19.9 to –17.8	2
Mt. Sheep	–17.0	Cedar Mesa	7	–19.2 to –15.0	4
Mule Deer	–18.7	Pecos	3	–20.1 to –17.5	1
Mule Deer	–18.5	Sierra Blanca	—	–20.2 to –17.2	2
Mule Deer	–20.6	N. Colorado	55	–30.4 to –19.9	5
Pronghorn	–17.6	Sierra Blanca	—	–19.8 to –15.6	2
Pronghorn	–18.2	Pecos	3	–18.5 to –17.9	1

[a] Flesh values are estimated to be 2‰ less than collagen, therefore if bison collagen is -9.5‰, then bison flesh would be -11.5‰ (Spielmann *et al.*, 1990; Tieszen, 1994, p. 277).

[b] (1) Spielmann *et al.* (1990); (2) Katzenberg and Kelley (1991); (3) Mauldin (1993b); (4) Chisholm and Matson (1994); (5) Hobson and Schwarcz (1986).

samples, values from animals indicate that their diets are primarily C_3 plants. Many of these samples, however, are from higher elevations in the Southwest. These elevations, being characterized by lower temperatures, should have a lower percentage of C_4 plants. Values for these same animals in desert settings may vary considerably. The bison samples, with a collagen value of around -9.5‰, suggest a dietary focus on C_4 grasses (see Spielmann *et al.*, 1990).[14]

Another factor affecting the interpretation of stable carbon isotope values is that modern samples are depleted about 1.5‰ relative to ancient samples owing to desertification and the presence of fossil fuels (Tieszen and Fagre, 1993b). Prehistoric maize samples range between -8.7 and –12.6‰, with a mean of -9.1 ± 0.3‰, about 2‰ more positive than the mean for modern maize (Chisholm and Matson, 1994, p. 244; Katzenberg and Kelley, 1991, Table II; Pate, 1994, p. 191; Schwarcz *et al.*, 1985, Table III; Tieszen and Fagre, 1993b, p. 36).

With the ambiguities surrounding fractionation values, collagen synthesis, isotope values of dietary sources, and the addition of fossil fuels to the modern environment, the maximum collagen end value, with 100% ancient maize dependence, is not known but probably varies between -7.5

---

[14] Flesh values are estimated to be 2‰ more negative than bone collagen (Schoeninger and Moore, 1992, p. 278; Spielmann *et al.*, 1990, Table I; Tieszen, 1994, p. 277).

Table III. Black Mesa—Flotation, Stable Carbon Isotope, and Mano Data

	BM II, 200 B.C.–A.D. 200	SD	E. Pueblo, A.D. 800–1050	SD	L. Pueblo, A.D. 1050–1150	SD
Zea mays ubiquity	35%[a]		59%[b]		70%[c]	
	(n = 308)		—		—	
$\delta^{13}C$ (‰)[d]	-7.6	—	-8.6	—	-7.5	—
$\delta^{13}C$ (‰)n	2		5		5	
All manos n[e]	45		60		40	
Mean mano area all whole (cm^2)	85.4	44.1	126.6	77.4	187.8	99.2
Mean mano length all whole (cm)	10.9	3.5	13.9	5.8	17.6	6.9
Large whole n/all whole n	6/45		25/60		24/40	
	13%		42%		60%	
Large whole + MNIM/all whole + MNIM	31/75		51/91		66/83	
	41%		56%		80%	
Mean area large whole (cm^2)	166.6	34.1	206.8	45.2	253.5	68
Mean length large whole (cm)	17.6	1.8	20.0	3.0	22.3	4.4
Mean mano area incl. MNIM (cm^2)	111.6	—	146.4	—	219.8	—

[a] Sites: 11:2126, 11:3131, 11:3133 (Wagner *et al.*, 1984); 11:0449, 11:1410 (Ford *et al.*, 1985).

[b] Sites: 7:23, 7:134, 7:135, 7:707, 7:1118, 11:73, 11:338, 11:814, 11:1153, 11:1158 (Powell, 1983, pp. 145–147). Note: unweighted mean; number of samples not available.

[c] Sites: 7:18, 7:19, 7:704, 7:708, 7:725, 11:97, 11:275, 11:298, 11:324, 11:348, 11:352, 11:354, 11:356, 11:409, 11:879, 11:1081, 11:1170 (Powell, 1983, pp. 145–147). Note: unweighted mean, number of samples not available.

[d] Source: Martin *et al.* (1991).

[e] Source: Ground stone data for 1982 and 1983. Data file, Black Mesa Archaeological Project Laboratory, University of Southern Illinois, Carbondale.

and -4.0‰. Similarly, diets based on 100% dependence on C_3 plants would probably produce mean collagen values of about -22‰ (Pate, 1994, p. 191).

MACROBOTANICAL REMAINS AND MAIZE DEPENDENCE

The archaeological recovery of macrofloral remains has provided archaeologists concerned with prehistoric diet the most direct evidence of plant-related subsistence. However, the complex array of formation processes (after Schiffer, 1976, 1983) affecting the recovery of plant remains has frustrated attempts to translate archaeobotanical data into quantified dietary proportions (for a review see Miksicek, 1987). Here, we are concerned with two primary sources of archaeobotanical data, flotation and coprolite samples.

Flotation

Since its popularization by Struever (1968), the recovery of charred seeds from archaeological contexts by means of water separation has provided a rich source of data regarding prehistoric plant use [see Miksicek (1987) and M. Jones (1991) for New World and Old World histories, respectively]. However, developing an understanding of the complex processes that affect the ultimate archaeological recovery of seeds has impeded the analytical utility of flotation data (e.g., Ford, 1979; Fritz, 1994; Hastorf, 1988; Miksicek, 1987; Sobolik, 1994). Understanding the relationships among the processes of carbonization, preservation, recovery, and the importance of a plant in the subsistence regime is critical if these data are to be used in any subsistence analysis.

The preservation of plant material in open, well-drained sites depends on the exposure of plant materials to 250 to 500°C temperatures with little oxygen, resulting in carbonization. Carbonized seeds are 50 to 60% elemental carbon and, while resistant to further biological deterioration, they can be destroyed through mechanical means (Miksicek, 1987, p. 219). A number of workers divide plant remains into three categories, depending on their potential preservation and recovery from the archaeological record (e.g., Miksicek, 1987, p. 220). The most visible, the nut and maize group, have dense inedible parts (shells and cobs) that were used for fuel following the removal of the edible portion. Next in visibility are seeds that were frequently parched or roasted for consumption or storage, such as amaranth, chenopodium, hulled cereals, and mesquite pods, thus enhancing their potential for accidental carbonization (Gasser, 1982, p. 48; Miksicek, 1987, p. 220). The plant group with the lowest preservation probability is those species with a high moisture content that are not parched but are eaten raw or boiled, such as greens, flowers, tubers, and pulpy fruits (Donoghue, 1989; Gasser, 1982; Miksicek, 1987). For example, Gasser (1982) found that pollen studies yielded evidence for common use of squash, cholla cactus, prickly pear, cattail and yucca, yet these species were rare or absent in flotation data from northeastern Arizona.

Depositional contexts affect the natural and cultural transformations of botanical material as well as the number of events or length of time it has taken for a deposit to form. Structures burned in use have the greatest potential for the occasional recovery of *de facto* botanical material, or usable material abandoned where it is being processed, such as storage vessels burned with their contents (Schiffer, 1976; Miksicek, 1987, p. 224). These deposits are likely to represent short units of time, perhaps reflecting a single event. Primary refuse is trash deposited at the location of use, such as carbonized seeds recovered from cooking pits. Such contexts do not yield particularly high plant recovery rates (Miksicek, 1987, pp. 227–228) but may also represent rather few behavioral episodes occurring over a short span of time. Rather, the vast majority of botanical material is recovered as secondary refuse or material deposited at a location other than where it is used (Schiffer, 1972a, 1976; Miksicek, 1987). This includes trash found in abandoned houses, pits, dumps, and mounds. Among these, houses burned after abandonment tend to yield high densities of charred seeds, presumably due to the burning of trash deposits containing seeds (Lennstrom and Hastorf, 1995; Miksicek, 1987; Popper and Hastorf, 1988). These deposits may represent the amalgamation of numerous behavioral events over long periods of time. Unburned secondary deposits, such as houses and trash mounds, contain low densities of charred material (Miksicek, 1987, pp. 228–229). Lennstrom and Hastorf (1995) compared archaeobotanical samples from features with adjacent nonfeature samples to assist in determining if feature contents are primary or secondary deposits at a Peruvian site. Popper and Hastorf (1988) note that ephemeral sites yield low quantities of charred material, perhaps since burned secondary deposits are usually not found on such sites. Shorter occupation sites tend to produce both a lower frequency and diversity of charred seeds than longer occupied sites (Miksicek, 1987, pp. 229–230). Donoghue (1989) reported that open Australian hunter-gatherer sites offer poor preservation of plant material as they contain few clear features. Central and west Texas open hunter-gatherer sites with small hearth features normally contain little charred material, although large burned rock middens and roasting features are sometimes the exception (S. Black, 1995; Dering, 1995; Holloway, 1983; Mauldin, 1994).

The preservation of charred material, once deposited, depends on multiple environmental transformation processes. Animals, roots, soil movement, and wetting and drying can destroy the charred seeds or mix the deposits (G. Jones, 1991; Miksicek, 1987, pp. 231–233). These noncultural taphonomic processes that affect the preservation and distribution of plant material have recently begun to receive attention (Diehl, 1996; Donoghue, 1989; Ford, 1988; Gasser, 1982, p. 48; G. Jones, 1991; M. Jones, 1991; Lennstrom and Hastorf, 1995; Miksicek, 1987). Numerous investigators have noted that the diverse sampling, recovery, analyses, and reporting protocols currently in use hinder comparisons among sites (M. Jones, 1991; Lennstrom and Hastorf, 1995; Rocek, 1995; Toll, 1988; Wagner, 1988). This situation is exacerbated when processing details go unreported.

Awareness of the numerous and seemingly unpredictable factors that affect the recovery of plant remains has, until recently, impeded most ethnobotanists and archaeologists from undertaking quantitative analysis of their data. Conclusions are often limited to presence/absence statements, supported by ethnographic analogies regarding plant use. Recent attempts at more quantified treatments of flotation data include careful sampling, and use of measures such as seed counts, species richness, ubiquity or presence indices and sample volumes. These indices, coupled with nonparametric statistics, may enhance the analytical power of archaeobotanical data (Dering, 1995; Hanson, 1994; Hastorf, 1988; Johannssen, 1988; G. Jones, 1991; M. Jones, 1991; Lennstrom and Hastorf, 1995; Miksicek, 1987; Minnis, 1985, p. 106; Pearsall, 1988; Popper and Hastorf, 1988; Rocek, 1995). Careful selection of samples and analytic approaches can reduce some differences in formation processes and preservation (however cf. Kadane, 1988).

Two macrobotanical values are used in our analysis: maize ubiquity (also known as frequency or presence analysis), and the ratio of the number of C_3 to C_4/CAM taxa found in the site or sites representing a phase. Maize ubiquity, calculated as the proportion of all samples that contain maize parts, has the advantage of offsetting some preservation and recovery biases, although we are only now beginning to understand these formation processes (Diehl, 1996; Gasser, 1982; Hastorf, 1988; Minnis, 1985; Pearsall, 1988; Popper, 1988; Rocek, 1995; Wagner, 1988).

Ubiquity measures reduce samples with large numbers of maize parts so that they become analytically equivalent to samples containing only a single piece of maize. Therefore, the variables that determine why a sample contains maize, whether they were cultural, postdepositional, or recovery induced, are eliminated from the analysis. The net effect of these biases is unknown (G. Jones, 1991, p. 64; Kadane, 1988). Until recently, investigators had neither the tools nor the reason to examine ubiquity, so many archaeobotanical reports do not contain sufficient information to derive this measure. However, ubiquity analysis does not eliminate the preservation and recovery biases affecting samples that do not contain maize (M. Jones, 1991, pp. 58–59; Kadane, 1988). Therefore, small matrix sample volumes or poor preservation biases may deflate ubiquity in a way unrelated to maize dependence. Use of seed counts as a measure needs to be explored further as well, but sufficient data were unavailable for this study without substantially reducing the number of study areas we included. The large number of samples we treat with the ubiquity measure may compensate for the errors inherent in this approach. We used our second measure, the ratio of the number of C_3 to C_4/CAM taxa recovered in flotation samples from the sites representing a phase, to examine the relative use of nondomesticated C_4/CAM species. Whenever possible we selected sites with pithouse or pueblo architecture to obtain flotation data as a way of enhancing preservation potential and controlling for site function, and we used all reported flotation samples from those sites.

Coprolites

The analysis of macrobotanical material recovered from desiccated human feces or coprolites has become, like flotation, an important line of evidence in the reconstruction of prehistoric human diets. Although researchers first began to examine ancient coprolites over a century ago, in the 1960s Callen and others demonstrated the potential of coprolite studies for dietary reconstruction using improved analytical techniques (Bryant, 1974; Callen, 1967; Martin and Sharrock, 1964; Reinhard and Bryant, 1992; Sobolik, 1988). Within the last 25 years researchers have further refined the study of faunal, mollusk, pollen, phytolith, insects, and the parasites found in coprolites (for a review see Reinhard and Bryant, 1992). However, coprolite studies have been limited by the rarity of samples encountered in excavations, as their preservation is restricted to dry sheltered settings or other uncommon preservation conditions.

Because the dietary components comprising coprolites have been ingested, the recovered material is the most direct evidence of prehistoric human diet. Coprolites are a diverse mixture of ingested but undigested remains, with seeds being one component that is usually recovered and analyzed. Seeds have a hard outer covering (the testa) that results in excellent preservation during digestion. Seeds are thus readily identified and quantified and provide a basis upon which to make comparisons with other techniques such as flotation and stable isotope analyses (Gasser 1982; Hastorf, 1988; Miksicek, 1987; Reinhard and Bryant, 1992; Yarnell, 1974).

Coprolite analysis has inherent biases that limit the interpretation and application of the data. Watson (1974) estimates, given individual variability, that one coprolite sample contains from two to four meals consumed and digested in the preceding 20–26 hr. Coprolite data are unusual in archaeology in that they offer archaeologists fine-grained data reflective of a few consumption events. However, issues that continue to confound coprolite analysis are those of the differential effect of the digestive system on food material, quantification techniques, and seasonality. Since coprolite samples consist only of the undigested dietary material, the samples generally do not reflect the soft food component of the diet, such as beans, leaves, roots, and tubers (Fry, 1985; Reinhard and Bryant, 1992). Further, the techniques for quantifying the remains (i.e., counts, weights, volumes) remain problematic and without standardization. Because coprolites are frequently found in caves, rock shelters, and cliff-dwellings, and such sites may represent seasonal occupations rather than year-round habitation, the issue of seasonality arises. Coprolites recovered from these sites may represent only the diet

Table IV. Cedar Mesa—Coprolite, Stable Carbon Isotope, and Mano Data

	Archaic, 6800–4800 B.C.	SD	BM II, A.D. 200–400	SD	Pueblo II/III A.D. 1060–1270	SD
Zea mays ubiquity	0%[a] (n = 97)		89%[b] (n = 28)			
δ^{13}C (‰)[c]	−13.9	—	−7.7	0.19	−7.3	.15
δ^{13}C (‰)n	1		4		3	
All manos n	4[d]		33[e]		25[e]	
Mean mano area all whole (cm^2)	90[f]	—	133.2	55	179.3	89.3
Mean mano length (cm)	11[f]	—	14.2	4.0	16.7	5.8
Large whole n/all whole n	0/4 0%		13/33 39%		14/25 56%	
Large whole + MNIM/all whole + MNIM	0/4 0%		17.8/40.1 44%		24.3/40.2 60%	
Mean area large whole (cm^2)	—		187.4	41.7	237.8	70.6
Mean length large whole (cm)	—		18.2	2.4	20.8	4.0
Mean mano area incl. MNIM (cm^2)	—		156.3	—	186.0	—

[a] Source: Van Ness (1986).
[b] Source: Aasen (1984).
[c] Source: Matson and Chisholm (1991).
[d] Source: Lindsay *et al.* (1968).
[e] Source: WDL and RGM.
[f] Estimate; see text.

from the occupation season, rather than the entire yearly diet cycle (Farnsworth *et al.*, 1985; Minnis, 1989; Reinhard and Bryant, 1992; Sobolik, 1988). However, in spite of these methodological and interpretive problems, Minnis (1989, p. 545) asserts that coprolite data provide the least ambiguous evidence on prehistoric plant consumption.

A few investigators have made comparative studies between flotation and coprolite data from contemporaneous and culturally related contexts. Yarnell (1974, pp. 119–121), using samples from Salts Cave in Kentucky, found near quantitative correspondence between the two sample types based on seed bulk. Gasser (1982, pp. 43–53) compared 417 flotation samples with 155 coprolite samples from a wide geographic region across the northern Southwest. Maize was the most commonly recovered macrofossil in both sample types, present in 60% of the flotation and 85% of the coprolite samples (Gasser, 1982). Squash, beans, pinyon, and cactus were significantly underrepresented in the flotation data relative to the coprolite data. The processing requirements of these taxa do not enhance their probability of being carbonized. Miksicek (1987) also compared coprolite

Table V. Mesa Verde—Coprolite, Stable Carbon Isotope, and Mano Data

	BM III, A.D. 620–700	SD	P II, A.D. 900–1000	SD	P II/III, A.D. 1050–1200	SD	P III, A.D. 1200–1300	SD
Zea mays ubiquity[a]	65% (*n* = 20)						77% (*n* = 77)	
$\delta^{13}C$ (‰)[b]	–8.3	—	–8.6	0.32	–8.4	0.69	–8.3	0.35
$\delta^{13}C$ (‰)[n]	1		9		15		4	
All manos *n*	12[c]		11[d]		229[e]		262[f]	
Mean mano area all (cm^2)	205	37.1	235.1	59.2	208.5	—	304.5	—
Mean mano length all (cm)	18.2	1.7	19.5	3.7	19.1	—	25.1	—
Large whole *n*/all whole *n*	12/12 100%		10/11 91%		172/229 75%		247/262 94%	
Mean area large (cm^2)	205	37.1	252.5	35.2	255	—	318.2	—
Mean length large (cm)	18.2	1.7	20.5	2.0	22	—	26	—

[a] Source: Minnis (1989); Stiger (1977, 1979).
[b] Source: Decker and Tieszen (1989).
[c] Sites: 1937 and 1940 (Birkedal, 1976).
[d] Sites: 2347 and 2344 (Hallisy, 1974).
[e] Sites: Big Juniper House (Swannack, 1969); 499 (Lister and Lister, 1964); 1088 (Lister and Smith, 1968); 1104 (Lister and Breternitz, 1968).
[f] Site: Mug House (Rohn, 1971).

samples with the uncarbonized plant remains from bulk samples representing most phases from the Tehuacan Valley caves. He found that the taxa most common in coprolites were also common in the bulk samples. However, a number of consumable taxa were well represented in the bulk samples but relatively rare in the coprolite samples, including maize. The substantial disparity between the common presence of maize in the bulk samples and its rarity in coprolites was attributed to the extensive maize grinding required in the production of tortillas and other preparations (Callen, 1967, p. 276; Miksicek, 1987, p. 224). It appears, then, that our use of coprolite samples, in lieu of flotation maize ubiquity values, is likely to yield similar results, unless extensive processing destroyed the kernels (e.g., Farnsworth *et al.*, 1985). If that were the case coprolite data may *underrepresent* maize use. However, Gasser's (1982) and other southwestern coprolite studies (e.g., Rylander, 1994) suggest that maize was not processed to that extreme extent in the Southwest.

Flotation data were not available for the Cedar Mesa and Mesa Verde regions, therefore coprolite data were employed to derive maize ubiquity and taxa counts for two periods in each region. In the four cases that we use coprolite data, sample sizes ranged between 20 and 97, and each case included samples from multiple proveniences (Tables IV and V). These data meet or exceed Reinhard and Bryant's (1992) recommended criteria for coprolite sample size and diversity to reflect the general patterns of consumption. Further, our analysis does not attempt detailed dietary reconstructions but rather assesses the dietary importance of maize. Therefore, coprolite and flotation maize ubiquities and taxa counts are comparable as we are concerned largely with differences in order of magnitude which mitigate the variability inherent in the two techniques.

ARCHAEOLOGICAL REGIONS

Mano attributes, macrobotanical, and stable carbon isotope data from six Southwestern regions, crosscutting 16 phases, were examined to determine their degree of concordance for evaluating dependence on maize. All data were extracted from published and unpublished reports, except for a portion of the Southern Jornada Mogollon data which was taken from our own field work. The selected regions consist of all Southwestern study areas for which stable carbon isotope data and at least one of the two other lines of evidence were available. Figure 3 presents these locations and Tables III through IX summarize these data.

Black Mesa

Black Mesa is in northeastern Arizona, about 125 km east of the Colorado River, within the Colorado Plateaus physiographic region. The plant communities consist of sage at lower elevations, while juniper and piñon pine dominate the sandstone slopes and hills, and Douglas fir and ponderosa pine forests cover the upper elevations (Fig. 3, No. 1). Black Mesa covers an area 120 km east–west × 80 km north–south and slopes up from 1830 m in the south to 2700 m to the north and east (Plog, 1986). This territory includes part of the divide between two major rivers, the San Juan River to the north and east and the Little Colorado River to the southwest. The normally dry arroyos drain into the four principal stream systems on the mesa, and subsurface water is only a few feet below the stream channels. The mean annual precipitation ranges between 25 and 38 cm per year and the growing season averages 120 days (Parry *et al.*, 1985; Plog, 1986). The principal prehistoric occupations reported by the Black Mesa Archaeological Project include Archaic, Basketmaker II, Early Pueblo, and Late Pueblo periods and represent the Kayenta branch of the Anasazi cultural area (e.g., Christenson and Parry, 1985; Martin *et al.*, 1991; Nichols and

Smiley, 1984; Parry and Christenson, 1987; Plog, 1986; Plog and Powell, 1984; Powell, 1983; M. Smith, 1994). Table III lists the mano, isotope, and macrobotanical data.

Cedar Mesa

Located in southeastern Utah, 45 km north of the Arizona border, Cedar Mesa (Fig. 3, No. 2) is a moderately level mesa down cut by steep canyons. The higher altitudes support piñyon–juniper forests, while the lower elevations are dominated by sage, grasses, and blackbrush. Precipitation ranges from 25 to 33 cm annually (Matson *et al.*, 1988). The mesa top slopes up from the south at 1500 m to 2270 m in the north, which drains into the San Juan River. The growing season ranges from 144 to 129 days, depending on elevation (Aasen, 1984). Also belonging to the Kayenta Anasazi cultural area, the prehistoric Cedar Mesa occupations consisted of relatively low population densities and small settlements, with

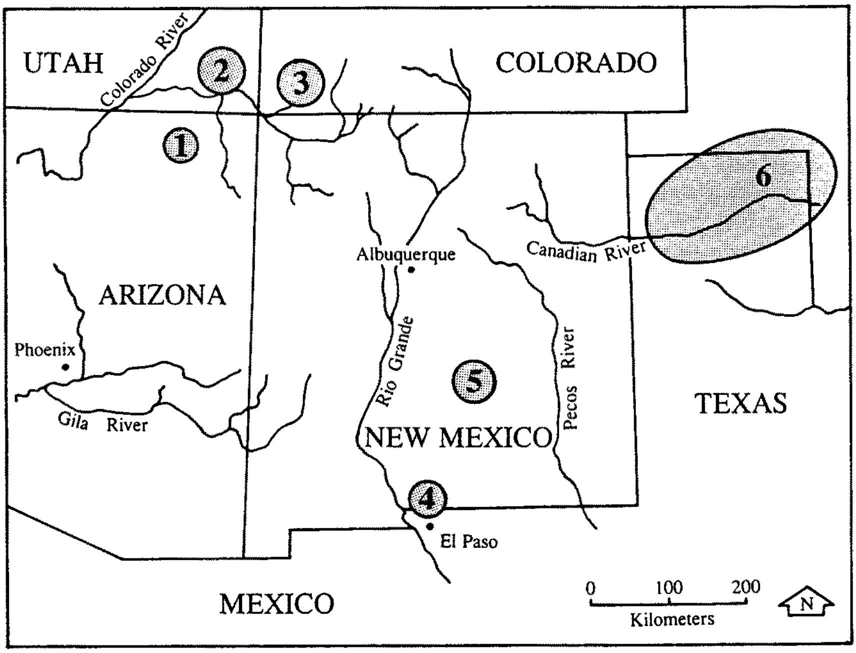

Fig. 3. Map of the Southwest showing the six regions used. (1) Black Mesa; (2) Cedar Mesa; (3) Mesa Verde; (4) Southern Jornada; (5) Sierra Blanca; and (6) Texas–Oklahoma Panhandles.

intervals of little or no occupation (Camilli, 1983; Dohm, 1988; Lipe, 1970, 1978; Matson, 1991; Matson and Chisholm, 1991; Matson and Lipe, 1978; Matson *et al.*, 1988; Mills, 1989). Table IV presents the mano, isotope, and macrobotanical data collected by the Cedar Mesa project. The mano dimensional data for the Basketmaker II and Pueblo II/III are from project field notes [W. D. Lipe and R. G. Matson (WDL and RGM), 1974 Field and Analysis Forms, Department of Anthropology, Washington State University, Pullman]. The temporal site assignments are from WDL and RGM's field notes and Dohm (1988, Appendix A).

Archaic data from Cedar Mesa were not available. Following Chisholm and Matson (1994), we used data from the early Archaic period Desha Complex (ca. 6800–4800 B.C.) from Sand Dune and Dust Devil caves, both near Navajo Mountain, 70 km southwest of Cedar Mesa (Lindsay *et al.*, 1968; Van Ness, 1986). Recently Geib and Davidson (1994) also reported Desha Complex strata from Old Man Cave located on the northern edge of Cedar Mesa. Apparently the Desha Complex deposits from all three caves represent the same archaeological culture (Hanson, 1994, p. 27). A Desha Complex burial from Sand Dune Cave was sampled for a stable isotope assay by Chisholm and Matson (1994) that we include in our analysis. We also use Van Ness's (1986) study of 97 coprolite samples from similar-aged deposits from Dust Devil Cave. Recently Hanson (1994, pp. 104–111) completed the examination of 28 additional Desha Complex coprolites from Old Man Cave and reported their contents to be similar to the coprolites from Dust Devil Cave. A single small mano was associated with the Sand Dune Cave burial and three other small manos were recovered from the Desha strata, although dimensions were not reported (Lindsay *et al.*, 1968). The average length of all small manos from a number of Archaic Southwestern contexts is 10–11 cm and the mean area is 85–90 cm^2 (Hard, 1986; Morris, 1990, p. 186). These dimensions are used in lieu of actual measurements from the Sand Dune Cave manos.

Basketmaker II period macrofloral data were obtained from 28 coprolite samples from Turkey Pen Cave, where a 50 × 50-cm column was excavated and radiocarbon dated to about 2000 B.P. These data are listed in Table IV (Aasen, 1984; Chisholm and Matson, 1994; Matson and Chisolm, 1991, p. 449). Unfortunately no PII/III macrobotanical data are available to compare with the Basketmaker II material.

Mesa Verde

Located in southwestern Colorado at between 2100- and 2300-m elevation, Mesa Verde (Fig. 3, No. 3) topography is dominated by flat mesas broken by deep narrow canyons, steep slopes, and vertical cliffs (J. Smith, 1987). The vegetation is piñyon-juniper woodland with an understory of sage, yucca, and grasses; cacti and succulents are present in small numbers (Mierau and Schmidt, 1981). Rainfall averages 44.4 cm annually at an elevation of 2155 m and the growing season averages 165 days (National Oceanic and Atmospheric Association, 1982; J. Smith, 1987). A number of summaries of Mesa Verde archaeology are available (Cordell, 1984; Plog, 1979; Rohn, 1963, 1977). The Mesa Verde isotope, botanical, and mano data extracted from the literature are summarized in Table V. Few Mesa Verde flotation data are available, and so coprolite data are used.

Southern Jornada

The Southern Jornada region (Fig. 3, No. 4) includes much of south central to southeastern New Mexico, far west Texas, and northern Chihuahua, Mexico (Lehmer, 1948). The data are primarily from the desert basins in the vicinity of El Paso, where elevations range from 1200 to 1350 m. In this northern Chihuahuan Desert setting, rainfall averages 22 cm annually and the growing season averages about 240 days. The vegetation in the lowland basins is dominated by mesquite, yucca, grasses, and broom snakeweed. Prehistorically, grasslands would have been more prevalent. The principal mountain ranges in the area include the Franklin, Organ, Hueco, and Sacramento Mountains that support a gradient of elevationally related ecozones. The past 20 years of cultural resource management work around El Paso has fostered a rapidly growing body of literature documenting a long sequence of adaptation to the Chihuahuan desert (Carmichael, 1986; Doleman *et al.*, 1991; Hard, 1983a,b; Mauldin, 1994, 1995; Whalen, 1977, 1978, 1981, 1994a,b). Table VI lists the isotope, botanical, and mano data for the Southern Jornada region. All data were extracted from published and unpublished reports, although we collected the Conejo site data and all the ground stone data.

Antelope Creek

The Antelope Creek region defines a series of late prehistoric sites (ca. A.D. 1200–1500) located along major drainages in the Texas and Oklahoma panhandles (Fig. 3, No. 6). This southern high plains country has an elevation of between 750 and 1350 m; the slight relief is created by overlapping alluvial fans and shallow basins. Playa lakes dotting the region form during the 198-day growing season, when 98% of the 50 cm of annual pre-

Table VI. Southern Jornada—Flotation, Stable Carbon Isotope, and Mano Data

	Archaic, 2500 B.C.–A.D. 1	SD	Mesilla, A.D. 300–1100	SD	Doña Ana, A.D. 1100–1200	SD	ElPaso, A.D. 1200–1400	SD
Zea mays ubiquity	0[a] (n = 29)		3%[b] (n = 503)		29%[c] (n = 45)		54%d (n = 37)	
δ^{13}C (‰)[e]	−16.5[a]	—	−9.5	—			−7.8	0.48
δ^{13}C (‰)n	1		1				6	
All manos n[f]	43		75		39		48	
Mean mano area all (cm^2)	75.7	26.7	111.5	68.6	131.4	90.3	158.9	87.6
Mean mano length all (cm)	8.9	—	12	—	14.9	—	16.4	—
Large whole n/all whole n[f]	2/43 5%		22/75 29%		13/39 33%		25/48 52%	
Mean area large (cm^2)	146.5	13.5	191.8	72.4	229.4	92.5	225.7	58.6
Mean length large (cm)	17.2	—	20.6	—	26.1	—	23.3	—

[a] Keystone Dam Site: O'Laughlin (1980).

[b] Conejo site: Goldborer (1988). Huesito site (3:739): Wetterstrom (1978). Turquoise Ridge: Minnis and Goldborer (1991).

[c] Meyer Pithouse Village: O'Laughlin (1989). Gobernadora site: Miller (1989).

[d] Three Lakes site: Ford (1977). Hot Wells site: O'Laughlin (1989). Motr site: Browning *et al.* (1992).

[e] Macneish and Marino (1993).

[f] Various sites—data collected by Mauldin, area measured with planimeter.

[g] Three additional Late Archaic, mean = −12.7, SD = 0.57 (Macneish and Marino, 1993).

cipitation falls. The vegetation is primarily buffalograss, needlegrass, and bluestem and gramma grasses, with mesquite, shinnery oak, juniper, hackberry, sagebrush, and yucca also present (Albert and Wyckoff, 1984; Brooks, 1994; Lintz, 1986). Archaeological syntheses are provided by Brooks (1994), Krieger (1947), and Lintz (1976, 1986). Antelope Creek phase structures have stone-slab wall foundations and range from single-room dwellings to multiroom communities of over 35 rooms. Site types include villages, isolated hamlets, bison kill and processing stations, and temporary camps (Brooks, 1994, p. 36).

Researchers consistently note the dominance of small manos on Antelope Creek phase sites (e.g., Krieger, 1947; Lintz, 1984, 1990). We used comparative quantitative material from the McGrath site (Lintz, 1976) in the Oklahoma panhandle and the Two Sisters site in the Texas panhandle (Lintz, 1972, unpublished field notes). Bison remains were the most frequently occurring fauna on the Landergin Mesa site in Oldham County, Texas. On most Antelope Creek phase sites bison represent the highest usable meat weight (Habicht-Mauche *et al.*, 1994, pp. 298–299; Lintz, 1986, p. 242, 1990).

Macrobotanical subsistence data from Antelope Creek phase sites are limited. The most systematic ethnobotanical data are from the Landergin Mesa site (Dean, 1986; Lintz, 1990). Although standard flotation data are not available, Dean (1986) fine-screened the soil from 45 pollen samples to extract charred macrobotanical remains. Although the small soil volumes of these pollen samples could reduce the ubiquity levels, the analysis was systematic. Table VII lists the flotation, mano size, and stable isotope data for Antelope Creek.

Sierra Blanca

The Sierra Blanca region (Fig. 3, No. 5) of southeastern New Mexico lies in the uplands of the Sacramento, Sierra Blanca, and Capitan mountain chains and is part of the Northern Jornada Mogollon culture area. The western sides of these ranges drain into the Rio Grande 150 km to the west and the eastern sides drain into the Pecos River 100 km to the east. These uplands range from 1700 m to a peak of almost 3750 m. The growing season ranges from 195 to 140 days and precipitation ranges from 30 to 50 cm (National Oceanic and Atmospheric Association, 1982; Kelley, 1984; Rocek, 1995). Piñon and juniper forests are bordered by grasslands at lower elevations and by ponderosa pine forests at higher altitudes. The major

Table VII. Antelope Creek—Flotation, Stable Carbon Isotope, and Mano Data

	Antelope Creek, A.D. 1200–1500	SD
Zea mays ubiquity[a]	4% (n = 45)	
δ^{13}C (‰)[b]	-8.0	1.0
δ^{13}C (‰)n	25	
All manos n[c]	33	
Mean mano area all (cm^2)	112.3	30.3
Mean mano length all (cm)	12.7	2.2
Large whole n/all whole n	7/33 21%	
Mean area large (cm^2)	151.4	30.0
Mean length large (cm)	15.9	0.7

[a] Source: Dean (1986).

[b] Source: Habicht-Mauch *et al.* (1994).

[c] McGrath site, Oklahoma (Lintz, 1976); Two Sisters site 34TX32 (Lintz, 1972, unpublished field notes).

east-flowing drainages form wide alluvial valleys dominated by grasslands. The culture history of these uplands prior to A.D. 1000 is poorly known, but the later occupations have been summarized (Hard, 1995; Hard *et al.*, 1996; Kelley, 1984; Lehmer, 1948; Sebastian and Larralde, 1989). Most residential sites occur in the piñon–juniper forest or transitional grasslands between 1645 and 1890 m (Kelley, 1984). Table VIII lists the isotope, botanical, and mano data for the Sierra Blanca region; they derive from published and unpublished material from the Capitan North project directed by Kelley (1991).

ANALYSIS AND MULTIPLE LINES OF EVIDENCE

One of archaeology's principal methodological strengths is the use of multiple lines of evidence to support (or reject) an argument or hypothesis. Although the use of multiple lines of evidence is a long-accepted component of archaeological methodology, its use, underlying logic, processes of integration, and varying applications have yet to be fully explored (Schiffer, 1988). Identifying correlations is perhaps one of the best analytical tools available (Dean, 1978; Whallon, 1975) for evaluating multiple lines of evidence.

Table VIII. Sierra Blanca—Flotation, Stable Isotope, and Mano Data

	Lincoln phase, A.D. 1200–1400	SD
Zea mays ubiquity[a]	89% (n = 38)	
δ^{13}C (‰)[b]	−8.4	0.6
δ^{13}C (‰)n[b]	20	
All manos n[c]	104	
Mean mano area all (cm^2)	152	67.7
Mean mano length all (cm)	17.2	7.1
Large whole n/all whole n	52/104 0.50	
Mean area large (cm^2)	206.8	49.6
Mean length large (cm)	23.1	5.0

[a] Source: K. Adams (1987, 1991).

[b] Source: Katzenberg and Kelley (1991).

[c] Robinson pueblo: excavation catalog manos found near looters' holes, and manos from a private collection (J. H. Kelley, 1986, Field Catalogues, Capitan North Project, manuscript on file, Archaeology Department, University of Calgary, Alberta, Canada).

Aggregate Correlations

Our first analytical step is to seek correlations among the three lines of evidence using the aggregated data set. The occurrence of correlations among these data will allow examination of the strengths and weaknesses of each line of evidence. The Spearman's correlation coefficient was selected to evaluate relationships among mano area, maize ubiquity, and stable carbon isotope values, as assumptions of normality are not required of the data and it is suitable for ranked (ordinal) data sets (Shennan, 1988; Thomas, 1986). Mean mano area and maize ubiquity data for 13 phases from all six regions are used (Tables III–VIII). For the Black Mesa and Cedar Mesa regions, mano area data are calibrated to include the MNIM as represented by the mano fragments as discussed above. Mano fragment data were unavailable for the other phases.

The resulting r_s value between the mean area of all manos and the ubiquity of maize is 0.882, with a P value of 0.0001 ($n = 13$), indicating a strong, direct, and statistically significant relationship (Fig. 4). This correlation is based on flotation data as well as coprolite samples from Mesa

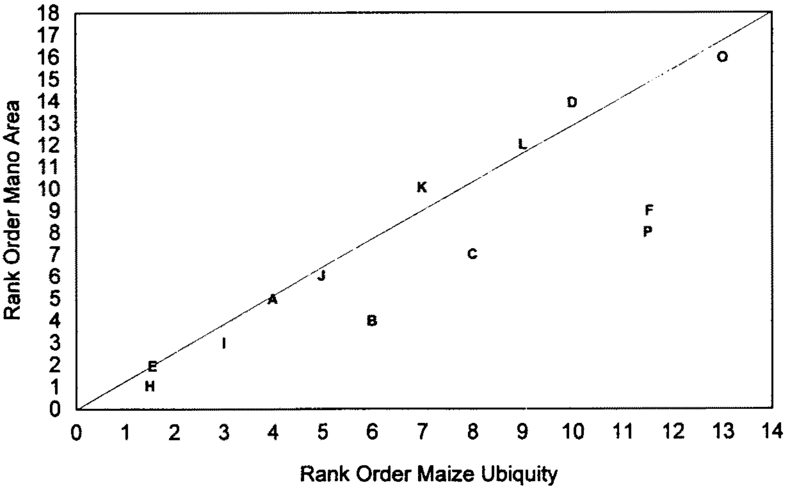

Fig. 4. Correlation between rank order of maize ubiquity and rank order of mean mano area: $r_s = 0.882$, $P = 0.0001$, $n = 13$. (A) Antelope Creek; (B) Black Mesa BM II; (C) Black Mesa Early Pueblo; (D) Black Mesa Late Pueblo; (E) Cedar Mesa Archaic; (F) Cedar Mesa BM II; (H) Southern Jornada Archaic; (I) Southern Jornada Mesilla; (J) Southern Jornada Doña Ana; (K) Southern Jornada El Paso; (L) Mesa Verde BM III; (O) Mesa Verde Pueblo III; (P) Sierra Blanca.

Verde and Cedar Mesa (including the nearby Desha Complex). Because some of the coprolite data points are at both ends of the distribution, there is a possibility that they have a determining affect on the correlation. Eliminating the coprolite data from the analysis produces an r_s value of 0.867 ($P = 0.003$; $n = 9$), indicating a positive, statistically significant relationship. Clearly, the strong correlation in the overall data set is not dependent on the coprolite data, despite its different formation processes and better preservation potential. Mean mano area and maize ubiquity are strongly correlated and independent of one another, yet both are ultimately related to the use of maize.

Is this correlation between mano area and archaeobotanical data based on changing levels of maize use or simply the presence or absence of farming? To resolve this issue we eliminated four cases where hunting and gathering was the primary mode of subsistence even though minor levels of farming were present in two of them. These include the preagricultural Desha Complex in the vicinity of Cedar Mesa (6800–4800 B.C.), the Southern Jornada Archaic (2500 B.C. to A.D. 1) and Mesilla phase (A.D. 300–1100), and the Texas Panhandle Antelope Creek phase (A.D. 1200–1500). The Southern Jornada Archaic, Antelope Creek, and Southern Jornada Mesilla phases, all have only a minor level of maize use, as the manos remained small (<113 cm^2), the proportion of large manos remained low ($<30\%$), and maize ubiquity was low ($<4\%$). After removing these four primarily hunting and gathering occupations, there is still a positive, statistically significant correlation between maize ubiquity and mano area ($r_s = 0.678$, $P = 0.04$; $n = 9$). This correlation suggests that changes in maize ubiquity and mano area are reflecting continuous variability in levels of agricultural dependence, rather than reflecting simple dichotomous differences between hunting-and-gathering and farming adaptations.

While mano area and macrobotanical remains indirectly reflect maize use, $\delta^{13}C$ values reflect the use of C_4/CAM species. Using all available data, there is a positive, statistically significant correlation between $\delta^{13}C$ values and maize ubiquity ($r_s = 0.607$, $P = 0.036$; $n = 12$); however, this correlation exists only because the $\delta^{13}C$ values are simply discriminating between largely hunting and gathering and farming adaptations (Fig. 5). If the correlation is recalculated with only the farming adaptations (eliminating the two Archaic periods and the Mesilla and Antelope Creek phases) the correlation disappears ($r_s = -0.193$, $P = 0.65$; $n = 8$). Our results indicate that Southwestern $\delta^{13}C$ values are unable to distinguish among degrees of agricultural dependence but can segregate farming from nonfarming subsistence bases. Further, the analytical weakness of Southwestern $\delta^{13}C$ values for detecting levels of maize dependence can be seen with a final correlation. A positive, but statistically insignificant, correlation between mano

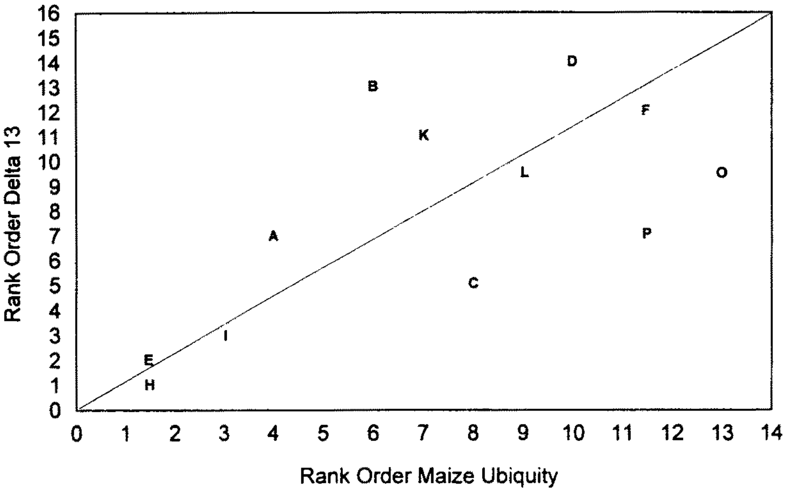

Fig. 5. Correlation between δ^{13}C values and maize ubiquity, $r_s = 0.607$, $P = 0.036$, $n = 12$. Lower left cluster (points E, H, I, and A) represents largely hunting-and-gathering adaptation, and upper right cluster represents farming adaptations. The correlation disappears when only the farming phases are used in the calculation: $r_s = -0.193$, $P = 0.65$, $n = 8$. (A) Antelope Creek; (B) Black Mesa BM II; (C) Black Mesa Early Pueblo; (D) Black Mesa Late Pueblo; (E) Cedar Mesa Archaic; (F) Cedar Mesa BM II; (H) Southern Jornada Archaic; (I) Southern Jornada Mesilla; (K) Southern Jornada El Paso; (L) Mesa Verde BM III; (O) Mesa Verde Pueblo III; (P) Sierra Blanca.

area and δ^{13}C values ($r_s = 0.481$, $P = 0.07$; $n = 15$) exists when all available data are used (Tables III–VIII). Figure 6 plots all δ^{13}C values against time; note that these values show little variation and only the two Archaic points fall outside of the cluster.

All the agricultural phases form a tight cluster that falls between -7.3 and -8.6‰, despite substantial variation in the level of maize dependence among these phases. Three of the four hunting and gathering phases are more negative than -8.6‰. Two of these, the Desha Complex and Southern Jornada Archaic period, have δ^{13}C values of -13.9 and -16.5‰, respectively, and reflect a mix of both C_4/CAM and C_3 nondomesticated foods (Fig. 6).

The single Southern Jornada Mesilla phase δ^{13}C value is -9.5‰, which falls on the outer edge of the agricultural cluster of values (Fig. 6). This mixed subsistence base was dominated by hunting and gathering but included minor maize use. If maize played only a minimal role in the diet, what accounts for its substantially more positive value from the earlier Southern Jornada Archaic value of -16.5‰? This may possibly be ex-

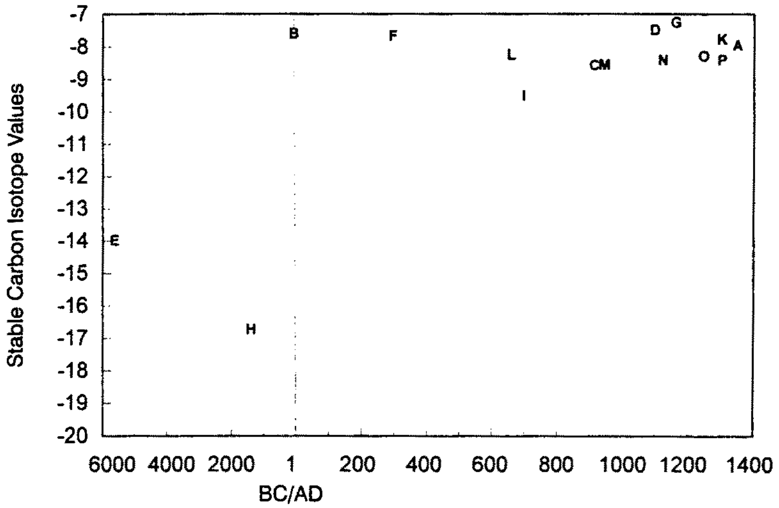

Fig. 6. All Southwestern mean $\delta^{13}C$ values plotted against time. Little difference exists among these values, except those from the Archaic period. (A) Antelope Creek; (B) Black Mesa BM II; (C) Black Mesa Early Pueblo; (D) Black Mesa Late Pueblo; (E) Cedar Mesa Archaic; (F) Cedar Mesa BM II; (G) Cedar Mesa PII/PIII; (H) Southern Jornada Archaic; (I) Southern Jornada Mesilla; (K) Southern Jornada El Paso; (L) Mesa Verde BM III; (M) Mesa Verde Pueblo II/III; (O) Mesa Verde Pueblo III; (P) Sierra Blanca.

plained by a trend of increasing use of CAM succulents, particularly agave, as roasting features for these plants were common during the Mesilla phase (Hard, 1983a; Whalen, 1977, 1994a). Note that there is an additional Southern Jornada Late Archaic value of -12.7*‰* that falls, both chronologically and numerically, between the other two values (Table VI).

The final, primarily hunting-gathering adaptation, the Antelope Creek phase, has an agricultural-like $\delta^{13}C$ value of -8.4*‰*, probably due to the dietary importance of high-protein bison that consumed C_4 grasses, as bison flesh is -11.5*‰* (Table II). On most Antelope Creek phase sites bison bones represent the highest usable meat weight (Habicht-Mauche *et al.*, 1994, pp. 298–299; Lintz, 1986, p. 242, 1990). Bison were absent during the other three primarily hunting and gathering phases in the data set. Other key fauna, such as deer and rabbits, have more negative flesh $\delta^{13}C$ values, -22 to -16*‰* (Table II) and would not yield a C_4, agricultural-like signature, as bison do. Our results indicate that $\delta^{13}C$ values can discriminate between hunting-and-gathering and farming adaptations when combined with other subsistence data.

An examination of the data indicate that not only did individual nondomesticated C$_4$/CAM species become staples in the diet, as bison and perhaps succulents did, but an array of C$_4$/CAM species was consistently exploited throughout the Southwest. An average of 49% (25–64%, SD = 12%; *n* = 13) of all nondomesticated taxa recovered from the flotation and coprolite samples were C$_4$/CAM species for both hunting-and-gathering and agricultural phases (Table IX). Twenty-five percent of the Desha Complex (6800–4800 B.C.) coprolite samples contained C$_4$/CAM taxa (Van Ness, 1986), a level that coincides with the δ^{13}C collagen value of −13.9‰, reflecting a diet containing about 40% C$_4$/CAM species in pre-maize times (Matson and Chisholm, 1991). The other pre-maize collagen sample dating to 1490 ± 80 B.C. from the Southern Jornada region had a δ^{13}C value of −16.5‰, indicating 25% reliance on C$_4$/CAM species (MacNeish and Marino, 1993, p. 118). The seeds recovered from Southern Jornada Archaic flotation samples contained 55% C$_4$/CAM taxa (Table IX). Once maize became a significant dietary component, δ^{13}C values cannot discriminate among differing degrees of maize consumption owing to the constant use of nondomesticated C$_4$/CAM resources in all phases. Considering only the farming occupations, an average of 50% of all nondomesticated plant taxa recovered (SD = 12%; *n* = 9) were C$_4$/CAM species, compared to 45% (SD = 12%; *n* = 4) among the hunting-and-gathering phases (Table IX). Clearly, nondomesticated C$_4$/CAM taxa, as well as maize, continued to be a significant portion of the diet and contributed to the more positive δ^{13}C values seen in the farming phases relative to the Archaic phases. Once any C$_4$/CAM species became a staple, whether it is maize, bison, or possibly succulents, the use of other nondomesticated C$_4$/CAM taxa is great enough to preclude the use of δ^{13}C values as anything other than a nominal variable that indicates the use of a C$_4$/CAM staple. Note also that some nondomesticated C$_4$/CAM plants including amaranth, purslane, and prickly pear seeds and fruits are all high in protein (Cummings, 1995, Table 21.4a) and there is some evidence that proteinacious dietary carbon plays a large role in determining collagen δ^{13}C values (Ambrose and Norr, 1993; Tieszen and Fagre, 1993a).

The strong correlation between maize ubiquity and mano area values, even while excluding the data from largely hunting-and-gathering adaptations, suggests that these two methods can discriminate finer degrees in changes in maize dependence than can stable carbon isotope values. Maize ubiquity and mano area variables, despite also being continuous, ratio-level data, are best treated as ordinal variables that can rank-order levels of agricultural dependence. As ordinal variables, the degree of difference is largely unknown between two ranked measures (Shennan, 1988; Thomas,

Table IX. Number of Plant C_3 and C_4/CAM Taxa Recovered from Flotation and Coprolite Samples

Period	Taxa: Wild C_3	Taxa: Domestic C_3	Taxa: Wild C_4 or CAM	Taxa: Domestic C_4	C_4 wild/ total wild (%)
Black Mesa					
Basketmaker II	8	0	7	1	47
Early Pueblo	4	2	6	1	60
Late Pueblo	5	2	8	1	62
Cedar Mesa					
Archaic	9	0	3	0	25
Basketmaker II	5	1	3	1	38
Mesa Verde					
Basketmaker III	6	2	4	1	40
Pueblo III	11	2	5	1	31
Southern Jornada					
Archaic	5	0	6	0	55
Mesilla Phase	6	1	6	1	50
Doña Ana Phase	7	1	12	1	63
El Paso Phase	4	2	7	1	64
Antelope Creek	2	0	2	1	50
Sierra Blanca	5	0	4	1	44
Average	5.9	1	5.6	0.85	49

1986). However, our data suggest that ranked mano area and maize ubiquity values are related to levels of agricultural dependence.

We can link the mano area end-point values with approximate levels of agricultural dependence. Mano assemblages with a mean area of about 90 cm^2 (the size of small or one-hand manos) represent little or no maize dependence and values greater than ca. 175 cm^2 represent high levels of agricultural dependence [greater than ca. 65% of the diet (Hard, 1990)]. While potential problems remain, including the function of small manos, the effects of collecting, and maize use that did not involve flour preparation, increasing mean mano area apparently reflects increasing agricultural dependence.

What magnitude of difference in recovery of maize translates into a greater degree of maize dependence? Unfortunately, this is unknown at present. Charred maize has a greater probability of recovery in flotation samples than most other taxa because of its size, processing requirements, morphological characteristics, and potential use as fuel. As a result, ubiquity comparisons across taxa need to be viewed with caution. Rank ordering of maize ubiquity measures can provide an approximation of relative levels of agricultural dependence. Yet comparisons should be made by controlling depositional and preservation contexts. For example, secondary deposits within architectural features tend to have the best recovery potential. Assessment of sample size is also a significant consideration in assessing ubiquity ranks.

Inferential Considerations

The considerations summarized above outline the strengths and weaknesses of each type of data. To use these diverse data sets to investigate patterns of agricultural development in the Southwest, however, we must also grapple with the problem of integrating these multiple lines of evidence for particular regional cases. Isotope, mano, and coprolite evidence are all ultimately grounded in principles of mechanics, biochemistry, and physiology. Each is integrally linked to noncultural processes that are within the sphere of existing or developing bodies of principles and theories with uniformitarian characteristics (Binford, 1981, pp. 27–28). For example, understanding varying stable carbon isotope values in human collagen involves numerous principles of biochemistry; mano area is linked to principles of comminution; and coprolite formation is the ultimate product of the physiology of digestion.

Making inferences regarding past phenomena involve not just a single identification (sensu Binford, 1981, p. 26), but a complex series of interlinked inferential arguments that bridge the physical and chemical characteristics of objects to degrees of agricultural dependence. Schiffer (1988) has subdivided these classes of arguments into reconstruction and methodological theories. Reconstruction theory is further broken down into correlates, c-transforms, and n-transforms and methodological theory is subdivided into recovery theory, analytic theory, and inferential theory. Each sequence of inferences is warranted with a mix of low-level principles (sensu Schiffer, 1988), empirical generalizations, interpretive conventions (sensu Binford, 1989, p. 14), and assumptions, resulting in varying degrees of probability that the consequent inference is true.[15] Frequently aspects of inferential arguments involve assumptions and conventions that have yet to be demonstrated or are poorly understood. For example, mano area is related to grinding capacity through principles of comminution. However, the relative importance of maize processing methods that do not involve significant grinding, such as hominey preparations and green maize con-

[15] See Tschauner (1996) for a comparison of Binford's and Schiffer's approaches.

sumption, is unknown. Our understanding of the recovery of charred macrobotanical remains is dependent on principles of recovery theory (Schiffer 1988) and empirical generalizations concerning the charring of particular taxa. Further, their recovery is a function of an array of complex natural, cultural, and recovery formation processes that we are only just beginning to be understand.

The complexities of these linking arguments are daunting but Binford's (e.g., 1978, 1981, 1983) and Schiffer's (e.g., 1987) appeals to develop inferential tools in ethnoarchaeological and experimental settings have been well taken, and remarkable progress is being made on many fronts. Despite the fact that only a fraction of the necessary middle-range theory (*sensu* Binford, 1981) is currently in place, archaeologists continue to make progress in understanding the past through using complex chains of linking arguments that vary in their probability of being true (see M. Salmon, 1982).

Ambiguity is present in most chains of inference about past phenomenon. If there were a perfect, direct linear correlation between an observed archaeological variable and a past phenomenon and if this relationship were understood in terms of independent bodies of theory and all intervening formation processes left the correlation unaffected, then perhaps a single line of evidence is sufficient (Whallon, 1975, pp. 131–132). At our current level of methodological sophistication, such conditions are rare at best. The relationships between an archaeological variable and a past phenomenon are usually only partially understood, resulting in an incomplete measure of the past (Whallon, 1975, p. 132). The use of multiple lines of evidence offers a strategy by which the weight of the combined evidence may overshadow the ambiguities in the methodological or recovery theory of any single inferential sequence.

What contributes to the success or failure of the use of multiple lines of evidence and how does their use differ from that of any single line of evidence? Certainly both require relevant evidence. The degree that a hypothesis is supported is related to the frequency of confirming cases as well their variety (W. Salmon, 1967, pp. 130–131). Additional evidence offered in support of a past phenomenon may increase the probability that the inference is true. Bayes' theorem provides a framework by which additional lines of evidence can be qualitatively assessed and a priori and posterior probability values assigned to each. A combined probability value can then be calculated that estimates the probability that the proposition is true (see W. Salmon, 1967; M. Salmon, 1982). However, simply enumerating additional lines of evidence, without attention to their quality and relevance, may not enhance the overall probability.

A variety of archaeological evidence serves to evaluate a hypothesis within its domain. Obtaining a relevant variety of instances requires sampling different, but relevant aspects within the domain (W. Salmon, 1967, p. 130). Changing agricultural dependence may affect ground stone, macrobotanical content, stable carbon isotope levels, settlement patterns, paleopathologies, storage technology, and ceramic assemblages, but there is little reason to expect it to affect, for example, fishing technology.

Archaeologists investigate not one, but many linked past phenomena that take the form of a model (e.g., Carneiro 1970). However, evaluation procedures frequently incorporate only one line of evidence for each past phenomenon. Challenges to the validity of any single line of evidence are relatively easy to mount, given the ambiguities in our methods. It is not surprising, then, that in 30 years we have accumulated a plethora of abandoned models and a mere handful of supported ones. More importantly, it is frequently unclear if the models or the inferential methods were inadequate (see Binford, 1983, pp. 196-197).

Independence among each line of evidence prevents challenges to one from affecting the other. In addition, Binford (e.g., 1981) has stressed the development of methods with uniformitarian, theoretical underpinnings based on existing principles and theory. In addition, such middle-range theories can be developed through present-day observations, such as carnivore gnawing behavior or the relationships between mano area and grinding capacity. Implementation requires independence of another sort; the theoretical underpinnings of the methods need to be independent of the past phenonomenon being inferred (e.g., Binford 1981).

Regional Patterns

Armed with an improved understanding of the power that each variable represents, as well as how these multiple lines of evidence may be integrated to evaluate propositions, we can now analyze the regional data. The results of our analysis suggest that the timing of the transition between maize as a minor resource to a dependence on maize varied substantially from region to region across the Southwest. In the four regions with sufficient diachronic data, three different developmental trajectories are present. Two regions, Black Mesa and Cedar Mesa, seem to have an early, substantial use followed by gradual, slow increases in dependence. The Mesa Verde pattern is one of a substantial and sustained heavy dependence. Finally, the Southern Jornada area demonstrates a long period of minor use followed by substantial use late in the sequence.

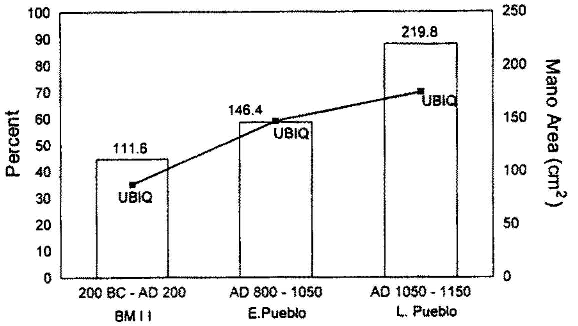

Fig. 7. Black Mesa data. The maize ubiquity points are plotted against the left *Y* axis and mano area bars refer to the right *Y* axis.

Black Mesa

Figures 7–10 show maize ubiquity on the left *Y* axis and the bars represent mean mano area on the right *Y* axis with time periods plotted on the *X* axis for each region. The Black Mesa data are plotted in Fig. 7 and the mean mano area includes the estimated MNIM based on mano fragments combined with the whole mano data.

Mean mano area increased from 112 cm^2 during the Basketmaker II period, to 146 cm^2 in the Early Pueblo period, and to 219.8 cm^2 in the Late Pueblo period (Fig. 7). The steady increase in the mean mano area over time is confirmed by a corresponding increase in the percentage of large manos in the ground stone assemblage: large manos increased from 41% of the assemblage during Basketmaker II, to 56%, and then to 80% in the Late Pueblo period (Table III). The lower-than-anticipated mean mano area of 112 cm^2 for Basketmaker II was derived by adding the MNIM-derived frequency values of the small and large manos, to the counts of whole small and large manos respectively. These total frequencies of small and large manos are then used as weighting factors to obtain a weighted mean area of all manos. Unfortunately only six whole, large manos were in the assemblage, a sample that may not have been representative and therefore may account for the aberrantly low mean mano area figure. Proportionally, large mano fragments were far more common than complete large manos. The proportion of large manos for the Basketmaker II period, based on the MNIM of fragments, was 41%, a substantial increase over the unmodified whole mano value of 13% (Table III). The mano assemblage apparently suffered loss of whole large manos through collecting. Christenson (1987, Table 3-1), based on a different set of sites, indicated that 38% of 21 whole manos for 12 Basketmaker II sites were large. His data compare closely with our MNIM-derived 41% large manos, suggesting that our MNIM corrections provide reasonable estimates. This proportion is similar to the average proportion of large manos in the phases which appear to be involved in farming: nine cases average 61% large manos (ranging between 33 and 91%), suggesting that the Black Mesa Basketmaker II adaptation is dependent on farming.

The Basketmaker II maize ubiquity value is 35% for 308 flotation samples (Fig. 7, Table III). While at the low end of the range of all farming adaptations (29 to 89%, mean = 63%, SD = 21.3%), this ubiquity value is substantially greater than the 3 to 4% for the largely hunting-and-gathering Mesilla and Antelope Creek phases. A review of Black Mesa field reports indicates that maize was found on 22 of 31 (71%) Lolomai phase sites for which data were available. In addition, maize was recovered from virtually all site types, functions, and locations. In sum, with 41% of manos in the large class and with a maize ubiquity value of 35%, these data strongly suggest that maize was a staple during Basketmaker II times at Black Mesa.

Black Mesa researchers have readily recognized that maize was a component of the Basketmaker II (Lolomai phase) diet owing to its consistent recovery. However, the proportion of maize in the diet has remained problematic. Nichols and Smiley (1985, p. 60) characterized agriculture as "an important aspect" of the subsistence system, while Plog (1986, p. 68) suggested that the economic adaptation was "largely based on hunting and gathering . . ." and that cultigens were not a significant dietary component until the Pueblo period (Plog, 1986, p. 312). It appears that these evaluations are in need of revision based on our analysis.

Following the Basketmaker II period, further increases in mano size and maize ubiquity indicate increasing maize utilization through the Early and Late Pueblo periods. However, the δ^{13}C values reflect little change from Basketmaker II through the Late Pueblo period, probably due to the significant use of nondomesticated C_4/CAM taxa through all periods. Forty-seven to 62% of all nondomesticated taxa recovered from the Black Mesa flotation samples were C_4/CAM (Table IX). The increased use of maize as indicated by the mano and flotation evidence from the Early Pueblo and Late Pueblo periods is consistent with interpretations by Plog (1986) that the subsistence base was agriculturally centered by the pueblo periods. While Powell (1983, pp. 44–45) argued that the use of maize fluctuated through time, her analysis was based on the use of the shorter phases, while our analysis uses the longer periods. It is possible that our analysis does not reveal short-term fluctuations—although the gross trends are similar.

Powell (1983) notes, however, a significant decrease in the use of maize during the Toreva phase, the last occupation (A.D. 1100–1150) of the Late Pueblo period. While it is apparent that dramatic changes in adaptation occurred immediately prior to the abandonment of the region, we were unable to isolate the needed Toreva phase data to determine if these changes were reflected in the mano and botanical data.

Additional indicators of the degree of maize use, including storage (Powell, 1987), settlement pattern (Plog, 1986; Plog and Powell, 1984; Powell, 1983), vessel form (Smith, 1994), and paleopathology (Martin *et al.*, 1991), have been analyzed by the Black Mesa project. While each of these has its own methodological complexities, the results are consistent with our analysis, which indicates that maize had reached moderate levels of use by Basketmaker II times and increased in use until just prior to the end of the Pueblo occupation.[16]

Cedar Mesa

The Cedar Mesa data share some similarities with the Black Mesa patterns with regard to the proportion of large manos (Table IV). Using estimates of MNIM derived from fragments, the proportion increased from

---

[16] Powell's (1987) calculations indicate that per capita storage volumes for Basketmaker II were greater than expected. Early Pueblo storage volumes were similar to Basketmaker II volumes, but sharp increases occurred in the Late Pueblo period. In evaluating the settlement patterns, Plog (1986), Plog and Powell (1984), and Powell (1983) conclude that during the Basketmaker II period both lowland and upland sites were seasonally occupied. The lowlands are associated with more arable locations such as drainages and the suggested seasonal occupation of agricultural locations is not inconsistent with the use of maize as a staple (Hard and Merrill, 1992; Powell, 1983). Ceramic assemblages have also been used as indirect indicators of maize use (e.g., Hard *et al.*, 1994). During the Pueblo periods at Black Mesa, maize was probably also prepared by steeping in large cooking jars, as it was in much of the New World (Katz *et al.*, 1974; Mills, 1989). M. Smith (1994, p. 130) argues that, throughout both Pueblo periods, but prior to the Toreva phase, the increasing size of liquid-related jars is related to increasing maize intensification and/or increasing household size. A recent osteological study (Martin *et al.*, 1991) indicates that all seven Basketmaker II burials recovered from Black Mesa exhibit stress-induced dental hypoplasia and three exhibited porotic hypertosis from iron-deficiency anemia. Martin *et al.* (1991, pp. 246–247) suggest that these Basketmaker II health patterns were part of the continuum of pathologies seen throughout Pueblo times. Dental hypoplasia results from various stressors occurring between birth and age 6, including dietary intake and disease. These are associated with intensification of agriculture, nutritional stress, disease, weanling diarrhea, and other conditions (Goodman, 1991; Goodman and Rose, 1991; Martin *et al.*, 1985; Price *et al.*, 1985). Finally, iron-deficiency anemia may be due to weanling diarrhea, infectious disease, poor diet, parasitic infestation, and a heavy maize diet (El-Najjar *et al.*, 1976; Martin *et al.*, 1991; Stuart-Macadam, 1991; Walker, 1985); in fact, a heavy maize diet can indirectly contribute to all these pathologies. In addition, researchers have recently suggested that sedentism brings about increases in disease rates that can then cause iron deficiency anemia (Kent and Dunn, 1993). Clearly, increased levels of maize consumption and increased sedentism are related.

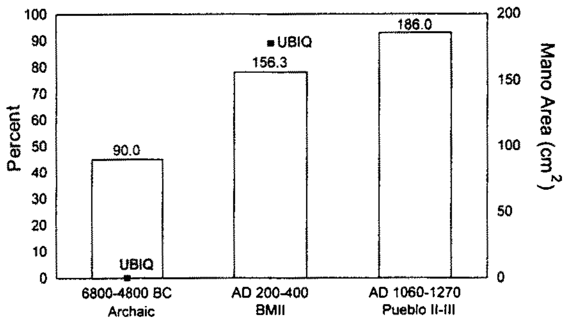

Fig. 8. Cedar Mesa data. The maize ubiquity points are plotted against the left *Y* axis and mano area bars refer to the right *Y* axis.

zero during the Archaic, to 44% for Basketmaker II, and then to 60% during the Pueblo period. Figure 8 shows that the mean mano area increased from 90 to 156.3 cm^2 for the Basketmaker II period and then to 186 cm^2 during the Pueblo period.[17]

While no Pueblo period macrobotanical samples have been analyzed, Fig. 8 demonstrates that maize ubiquity, based on coprolite data, increased from zero during the Archaic period to almost 90% for the Basketmaker II period. The $\delta^{13}C$ values increased sharply from the Archaic to Basketmaker II contexts, but no significant change occurred between the Basketmaker II and the Pueblo periods (Table IV). The sum of the Basketmaker II data clearly indicates that maize was a staple, an interpretation in agreement with that of Chisholm and Matson (1994) and Matson and Chisholm (1991). However, the mano data indicate that further substantial increases in maize utilization occurred during the Pueblo period, a pattern not reflected in the $\delta^{13}C$ values (Fig. 8). The ^{13}C values reflect little change between Basketmaker II and Pueblo times, which led Matson and Chisholm to suggest that there was no increase in the consumption of maize in the following Pueblo period. However, as previously argued, Southwestern $\delta^{13}C$ values cannot detect differing levels of maize consumption once maize has become a staple. The coprolite samples from the Archaic Desha complex deposits contained 25% nondomesticated C_4/CAM species, and 38% in the Turkey Pen Cave Basketmaker II coprolites were C_4/CAM species (Table IX). Clearly, C_4/CAM taxa were a significant proportion of the diet at Cedar Mesa and the surrounding region. Lagomorphs, with mean flesh values be-

---

[17] Note (Table IV) that this mano assemblage has little evidence of scavenging, as the uncorrected values and the MNIM corrected values are similar.

tween approximately -20.8 and -16‰, were a widely used Southwestern resource and may have contributed to the more positive collagen $\delta^{13}C$ values (Table II; Chisholm and Matson, 1994, p. 246; Flint and Neusius, 1987, pp. 257–260; Neusius, 1985, p. 115; Szuter, 1991). Turkeys, which feed on maize, may also have contributed to the more positive collagen $\delta^{13}C$ values (Chisholm and Matson, 1994, p. 246; Matson and Chisholm, 1991). Given these patterns of consumption of nondomesticated C_4/CAM species, it is unlikely that changes in the level of maize intake should be reflected in the stable carbon isotope values, particularly if maize was being substituted for nondomesticated C_4/CAM species. Future excavations of both Basketmaker II and Pueblo sites in the Cedar Mesa region could recover additional macrobotanical, as well as other data, which would shed further light on the changes in adaptation between Basketmaker II and Pueblo occupations.

Mesa Verde

While no Archaic or Basketmaker II data are available, the Basketmaker III and Pueblo data from the Mesa Verde region (Fig. 9 and Table V) indicate a consistently high level of maize use. The percentage of large manos fluctuates between 75 and 100%, maize ubiquity from coprolite samples increased slightly between Basketmaker III and Pueblo III periods, and $\delta^{13}C$ values maintained constant positive levels (Fig. 9, Table V). The mean mano area also fluctuated between 200 and 235 cm^2 between Basketmaker III and Pueblo II/III, then sharply increased to 304.5 cm^2 during Pueblo III times (Fig. 9). The sharp increase in Pueblo III mano size is not well understood. Increases in Southwestern ethnographic mano sizes beyond approximately 200 cm^2 do not necessarily result in a concomitant increase in maize dependence (Hard, 1990, Fig. 10.1). However, Bolivian ethnographic data reflect increases in both grinding capacity (amount ground per unit of time) and maize processing intensity (proportion of day spent grinding) with increasing mano size (Fig. 1) at similar and greater mano size ranges (Mauldin, 1993a, p. 319; Mauldin and Tomka, 1988). If maize consumption is already approaching a maximal level, further increases in the size of large manos should continue to yield increasing maize processing capacity.

Virtually all indicators suggest that Mesa Verde populations were consuming high levels of maize during Basketmaker III times and maize consumption remained high throughout the sequence. Based on isotopic data, Decker and Tieszen (1989) reached a similar conclusion. Although 38 and 44% of all taxa, in Basketmaker III and Pueblo III coprolites, respectively, were C_4/CAM plants (Table IX), the mano and macrobotanical data indi-

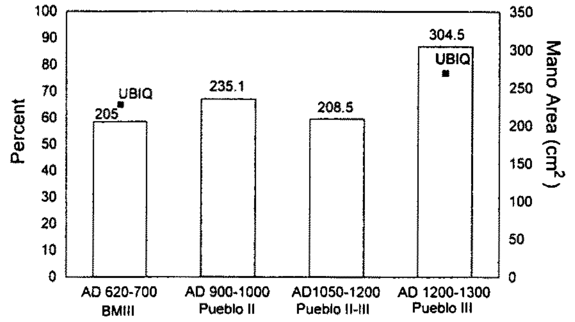

Fig. 9. Mesa Verde data. The maize ubiquity points are plotted against the left *Y* axis and mano area bars refer to the right *Y* axis.

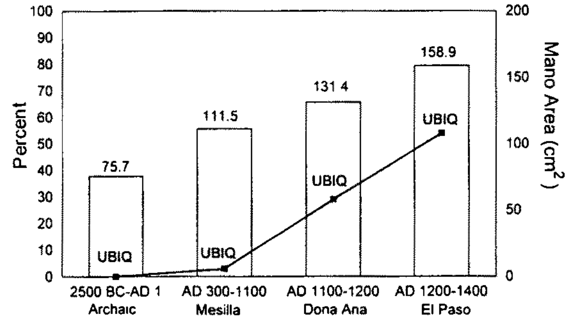

Fig. 10. Southern Jornada data. The maize ubiquity points are plotted against the left *Y* axis and mano area bars refer to the right *Y* axis.

cate that maize was the principal resource. After analyzing these coprolite data, Minnis (1989) and Brand (1994) also concluded that maize was the most important resource for all time periods (see also Cummings, 1995). The Mesa Verde data are all in concordance, and unlike the other regions, the mano data do not suggest a gradual increase in maize dependence. Instead maize consumption was high by Basketmaker III times and remained so throughout the sequence.

Southern Jornada

The Southern Jornada diachronic evidence indicates increasing maize utilization through time. Mano area, maize ubiquity, the percentage of large manos, and the δ^{13}C values all increased between the Archaic period and the El Paso phase (A.D. 1200–1400) (Fig. 10 and Table VI). MacNeish and Marino (1993, p. 118) report that the premaize Archaic $\delta^{13}C$ value, which dated to 1490 ± 80 B.C., is −16.5‰, reflecting a substantial contribution of C_4/CAM species (Table VI). The flotation data that dated to 2500 to 1800 B.C. indicate that 55% of the recovered taxa were C_4/CAM species (Table IX). MacNeish and Marino (1993) report three additional Southern Jornada Late Archaic stable carbon isotope samples which date between 850 and 400 B.C., about 350 to 800 years after the introduction of maize (Upham *et al.*, 1987). These $\delta^{13}C$ values averaged −12.7 ± 0.57‰, reflecting increased use of C_4/CAM-based resources. Unfortunately, no corresponding botanical or ground stone data were available for this Late Archaic period. The single Mesilla phase $\delta^{13}C$ value of −9.5‰, although significantly more positive than the Archaic samples, is more negative than any other maize-bearing phase in our analysis (Fig. 6). It may be more positive due to substantial use of succulents and lagomorphs (Hard, 1983; Whalen, 1977, 1994a) rather than maize consumption. With a maize ubiquity of only 3%, a small mean mano area of 111.5 cm^2, and only 29% of the manos of the large variety, it appears that maize remained a minor part of the diet. Of the 12 nondomesticated macrobotanical taxa recovered, 50% were C_4/CAM taxa species, reflecting continued exploitation of these taxa.

As increases in maize ubiquity and mano size occurred in the Doña Ana phase (A.D. 1100–1200), it appears that maize became a staple at this time, but only as one of a number of important food sources (Fig. 10). Further increased use of maize occurred in the El Paso phase as reflected in higher maize ubiquity, larger manos, and increases in the proportion of large manos. Compared to the Mesilla phase, El Paso phase $\delta^{13}C$ values were more positive as well; unfortunately, there were no Doña Ana phase $\delta^{13}C$ data. By the El Paso phase a clear agricultural adaptation had become established. However, as over 60% of the nondomesticated taxa recovered in the macrobotanical sample were C_4/CAM species, nondomesticated C_4/CAM plants also contributed to the El Paso phase $\delta^{13}C$ value.

In the Southern Jornada, then, congruence among the stable carbon isotope, mano, and macrobotanical data indicates that the transition to a maize-based economy did not occur until ca. A.D. 1100, much later than in most other regions of the Southwest. Our conclusion is consistent with settlement pattern, ceramic, and storage data, as archaeologists working in the Southern Jornada have suggested previously that maize remained a minor part of the diet until the Doña Ana phase (e.g., Hard, 1983b; Hard *et al.*, 1994; Whalen, 1981). Archaic and Mesilla phase site and feature distributions indicate that the interior basins were heavily used, probably for exploitation of wild resources, as they have a low farming potential (Whalen, 1981), although the organization of the use of the basin and its resources shifted between A.D. 700 and A.D. 900 (Mauldin, 1994, 1995). By the Doña Ana and El Paso phases, residential site distributions reflected a dramatic shift toward the more arable rainfall runoff zones at the basin margins, although the interior of the basins continued to be exploited. This marked shift reflects a sharp increase in farming activities (Carmichael, 1986; Mauldin, 1994; Whalen, 1981, 1994b). The ceramic assemblage also reflects these shifts. Tecomates and small jars, which would be appropriate as a transportable ceramic toolkit, dominated the Mesilla phase assemblage.[18] By the El Paso phase tecomates were replaced by large jars more appropriate for steeping quantities of maize (Hard *et al.*, 1994). Excavated El Paso phase rooms filled with burned maize have also been found (Vermillion, 1939), a situation that has not been seen on Mesilla or Doña Ana phase sites (Hard *et al.*, 1994).

Antelope Creek

The Antelope Creek phase data include a mean mano area of 112.3 cm^2, 21% large manos, and 4% maize ubiquity. This pattern indicates an adaptation in which maize played a minor role, yet it has a δ^{13}C value of -8.0‰, similar to that of a farming adaptation (Table VII). Habicht-Mauche and her colleagues (1994) interpreted the isotope data to mean that the Antelope Creek phase diet emphasized nondomesticated C_4/CAM plants, with some bison. They concluded that maize production was limited by marginal environmental conditions. The mano and macrobotanical data do reflect a diet in which maize is a minor component. Therefore, the elevated δ^{13}C value may relate more to the nondomesticated plant and animal C_4-based resources than to maize. In addition to small amounts of maize, 50% of all nondomesticated plant taxa from the Antelope Creek phase macrobotanical study were C_4/CAM species. Bison were the most commonly recovered fauna from the Antelope Creek phase sites (Brooks, 1994; Habicht-Mauche *et al.*, 1994; Lintz, 1986). The flesh of Southern Plains bison has a high δ^{13}C value, averaging -11.2‰ (Table II), the most positive value of any nondomesticated fauna listed. Researchers (e.g., Speth and Spielmann, 1983) have argued that there are severe limitations on the maximum dietary proportion of lean meat that can be consumed without suffering severe health consequences. However, recent experimental work by Ambrose and Norr (1993) and Tieszen and Fagre (1993a) suggests that the δ^{13}C value of dietary protein may influence the collagen value to a greater extant than its actual proportion in the diet. Bison meat may not have been

---

[18] Tecomates, also known as seed jars, are small, hemispherical neckless jars with inward-pointing rims.

the major source of calories but, indeed, may have heavily influenced the $\delta^{13}C$ values. Thus bison, coupled with the use of C_4/CAM nondomesticated plant species and minor use of maize, may account for the elevated $\delta^{13}C$ values during the Antelope Creek phase. Both the mano and the macrobotanical data, coupled with consideration of the isotope and faunal data, indicate that maize played a minimal role in the diet, a conclusion that supports the findings of Habicht-Mauche and her colleagues (1994).

Sierra Blanca

The Lincoln phase data from the Sierra Blanca region of south-central New Mexico, with a maize ubiquity of 89%, a mean mano area of 152 cm^2, 50% large manos, and a $\delta^{13}C$ value of -8.4‰, clearly indicate a farming adaptation (Table VIII). However, despite heavy use of maize, 44% of all nondomesticated taxa from the flotation samples were C_4/CAM species, suggesting a level of nondomesticated C_4/CAM use that would have contributed to the C_4-like bone collagen signatures (Table IX). Although isotope and ground stone data are lacking, recent work on two pre-A.D. 1000 sites have yielded significant flotation data. Site LA 89652, a tenth century A.D. site with storage features, located 25 km south of Robinson pueblo, yielded high maize ubiquity levels (80%; $n = 33$) (Hard, 1994, 1995; Hard *et al.*, 1996). In addition, storage pit volume and ceramic assemblages suggest an agrarian adaptation (Durst, 1995; Hard *et al.*, 1996). Rocek (1995) reported that the sixth- to tenth-century A.D. Dunlap-Salazar pithouse site, yielded maize ubiquity levels (86%; $n = 14$) that are similar both to LA89652 and to those found at Robinson pueblo, 30 km to the northwest. These data suggest that maize dependence was high well before the occupation of Robinson Pueblo, although there are insufficient data to suggest whether there were changes in the levels of maize consumption between the pithouse and the pueblo periods.

CONCLUSIONS

Previous conclusions regarding the timing and rates of change in maize dependence in the Southwest are highly varied. The earlier and more widespread view was that substantial use of maize occurred in the early centuries A.D., with increasing reliance in the following centuries (Amsden, 1949; Haury, 1962; Glassow, 1972, 1980; LeBlanc, 1982; Lightfoot, 1984, pp. 86–87; Lightfoot and Feinman, 1982; Martin and Plog, 1973; Woodbury and Zubrow, 1979). Alternative views suggested that substantial maize dependence did not emerge until the later part of the first millennium (Cordell and Plog, 1979; Gilman, 1987; Plog, 1979; Rice, 1975, 1980; Stafford, 1980). Recent excavations of Late Archaic sites have resulted in evidence for substantial maize dependence as early as ca. 500 B.C. in southern Arizona (e.g., J. Adams, 1996; B. Huckell, 1995; L. Huckell, 1996).

Using multiple lines of evidence, our analysis indicates that the timing of the transition between maize as a minor resource to that of a staple varied substantially from region to region. For example, in the Black Mesa and Cedar Mesa regions, maize had clearly become important by Basketmaker II times. Although Basketmaker II data are lacking, the Basketmaker III occupation in Mesa Verde was heavily agricultural. However, in the Southern Jornada region, maize—though present—did not become a staple until approximately A.D. 1100. While this variability is not well understood, a cross-cultural ethnographic pattern is suggestive of some underlying conditions. Hunn and Williams (1982, p. 6; see also Mauldin 1983, p. 49) plotted Murdock's (1967) degree of maize dependence for a sample of 200 societies on a histogram and found a distinctly bimodal distribution, with few societies in the 5 to 35% agricultural dependence range. Farming activities, at this level of dependence, may be problematic in many environments and conflict with hunting and gathering. Caring for a maize crop, even a small one, and relying on stored maize usually involve reduced residential mobility that may have conflicted with the mobility required for substantial hunting and gathering. Perhaps maize could be either an incidental resource or a staple in the Southwest.

Once the commitment to producing maize as a staple was made, and organizational changes in the society occurred, then ever greater agricultural utilization may have followed. In the Black Mesa and Cedar Mesa regions, additional increases in maize dependence apparently occurred throughout most of the pueblo occupation. In contrast, following the heavy use of maize in Mesa Verde Basketmaker III, further significant increases in maize dependence apparently did not occur. In the Southern Jornada region, it appears that the El Paso phase (A.D. 1200–1400) represents a rapid, albeit relatively late, adoption of substantial maize use. Therefore, from the four regions for which we have diachronic data, three distinctly different patterns emerge: early substantial use with slow increases in dependence as seen at Black Mesa and Cedar Mesa; early substantial use with continuing full use as seen in Mesa Verde, and a long period of minor use followed by substantial use late in the sequence as seen in the Southern Jornada region.

Given these results, we can no longer assume that pithouse occupations indicate either a largely hunting and gathering or a farming adaptation, but must acquire the data and conduct independent analyses in order to evaluate the economic adaptation for each region. With such results we would then be poised to assess the underlying processual conditions affecting these diverse patterns and Southwestern adaptive variability. We suggest that, at the present time, this is best done by using multiple, independent lines of evidence.

Seeking correlations among multiple, independent lines of evidence is a powerful procedure (Whallon, 1975) but the true difficulty occurs when conflicting results are obtained. There is no accepted, explicit, logical system for assessing the weight of often conflicting evidence (Nagel, 1961, p. 591). While the Bayesian approach provides a means by which probability values can be assigned to different types of evidence, the assignment of these values is highly subjective and related to a priori probabilities (Nagel, 1961, p. 591; M. Salmon, 1982). The a priori probabilities of a hypothesis are, in part, a function of the biases and preconceived opinions of the investigator (M. Salmon, 1982). These biases may lead the investigator to challenge the assumptions, particularly involving the formation processes, of evidence that conflicts with a preferred alternative hypothesis that has a higher a priori probability.[19] When multiple, independent lines of evidence are brought to bear on a problem, conflicting results may be more profitably viewed as research opportunities to explore the source of the conflicts (Binford, 1989). Does the ambiguity arise from the methodology or weaknesses in the proposition? Lack of correlations can sharply define research priorities, making clear when substantial investment in the development of particular middle-range theory is needed.

Clearly, our analysis demonstrates that stable carbon isotope data, ground stone assemblages, and macrobotanical remains all warrant further methodological research. Our analyses suggest that mano size is principally related to degree of maize utilization, but additional variables may affect this relationship. For example, Nelson and Lippmeier (1993) proposed a correlation between the regularity of occupation and mano form, Stone (1994) suggested that access to raw materials for ground stone manufacture may affect mano size, Calamia (1991) suggested that mobility may also affect mano size, J. Adams (1996) suggested that Late Archaic farmers were heavily dependent on nonflour maize preparations, and Wright (1990) showed that maize variety affects grinding capacity as does the level of

---

[19] Investigator biases have many origins, but one is the existence of an acceptable theory that accommodates the inferred past phenomena. Wegener supported his 1912 proposition that the continents had drifted apart with multiple, independent lines of evidence. He and his idea were harshly ridiculed and dismissed, primarily because there was no acceptable theory to explain how continents could move. It was not until the 1960s and the arrival of the theory of plate tectonics that the idea of drifting continents was accepted with supporting evidence from many arenas including some of the same evidence marshaled in 1912 (Marvin, 1973).

grinding experience. Improvements in our ability to detect the functions of small manos may be made by further development of use-wear, residue, and pollen analyses (J. Adams, 1988, 1989; Christenson, 1987, p. 49; Yohe *et al.*, 1991). The organization of maize grinding, the ratio of food processors to consumers, the amount of flour ground at a single interval, the difference between wet and dry grinding, and the fineness of the ground meal are all factors that may impinge on the proposed relationship between grinding capacity and mano size, all variables that could be profitably investigated ethnoarchaeologically or experimentally.

Efforts at quantified analyses of macrobotanical data are in their infancy and further attempts are warranted. Not only are taphonomic studies in order (e.g., Donoghue, 1989; Ford, 1988; Gasser, 1982, p. 48; Lennstrom and Hastorf, 1995; Miksicek, 1987; Popper, 1988), but comparisons between coprolite and flotation data sets from the same occupation would be profitable (e.g., Gasser, 1982; Miksicek, 1987; Yarnell, 1974). Further advances in assessing the internal reliability of flotation data could be developed through consideration of taxa recovered, sample context, sample size, and total seed counts.

Archaeologists, biologists, and geochemists are making substantial advances in stable carbon isotope research, and continued laboratory experimental studies designed to follow the carbon isotope pathways between diet and bone are critically needed (e.g., Ambrose and Norr, 1993; Tieszen and Fagre, 1993a). It may be that bone apatite yields a measure of bulk diet superior to collagen, since collagen may be influenced by dietary protein (Ambrose and Norr, 1993), assuming that problems with diagensis can be avoided (Schwarcz and Schoeninger, 1991). Recent work indicates that tooth enamel apatite appears to be less affected by diagenesis than bone apatite (Quade *et al.*, 1995). Elemental analyses, especially of barium, lead, zinc, and strontium, may indicate relative dependence on plant and animal resources (e.g., Ezzo, 1992; Pate, 1994; Schwarcz and Schoeninger, 1991). Stable nitrogen isotope studies are also a powerful tool that can potentially be used to assess the role of meat or aquatic species in the diet (Schoeninger and Moore, 1992; Schwarcz and Schoeninger, 1991). Advances in both stable carbon and nitrogen isotope studies can be made by determining the isotope values for the components of the prehistoric human food web at the local level. Other approaches include further examination of the relationships among increasing maize dependence, increasing use of stored, dried maize, and increasing storage volume per person (e.g., Powell, 1987; Schiffer, 1972b). Changes in vessel form and function, as well as technology, may also correlate with major shifts in levels of maize use (e.g., Arthur, 1993; Braun, 1983; Hard *et al.*, 1994, 1996; M. Smith, 1994). Paleopathological indicators such as porotic hypertosis, caries, and dental hypoplasia have also been used as indicators of diet, dietary stress, anemia, and infections that may be ultimately highly correlated with population density and maize dependence.

All of these various data sets can and should be brought to bear on the question of the variation in the timing and developmental trajectory of agriculture. Our results, comparing stable carbon isotope, macrofloral, and ground stone data sets from a variety of regions and time periods across the Southwestern United States, indicate that agricultural development varied. Other data sets, such as those summarized above, should also be used to consider this problem. The use of multiple, independent lines of evidence both highlights research opportunities and affords archaeology a chance to learn about the past as well as about the methodologies we use to investigate the archaeological record.

ACKNOWLEDGMENTS

Several people generously shared their unpublished data, papers, and knowledge with us. Karen Adams, R. G. Matson, Bill Lipe, Jane Holden Kelley, and Christopher Lintz all allowed us to use their unpublished data. Jenny Adams, Karen Adams, Jeff Huebner, Anne Katzenberg, Christopher Lintz, and Margaret Schoeninger kindly sent unpublished papers. Britt Bousman, Karen Dohm, Eileen Camilli, Jeff Huebner, Steven LeBlanc, Barbara Mills, Shirley Powell, and Larry Tieszen shared their knowledge with us. Wirt Wills, Angela Linse, Paul Lukowski, James Mayberry, and Sue Sitton provided comments on an early draft of this paper. Jenny Adams, Brian Chisholm, George Gumerman, R. G. Matson, Donald Pate, Michael Schiffer, and John Speth provided many useful comments on the manuscript prior to publication. Kimberly B. Rydel assisted with the preparation of the graphs and Cynthia Tennis and Bruce Moses drafted the map. Michael Schiffer and Marcie Renner provided editorial assistance. Ward Bramlett and Johanna Hunziker assisted with the references section. Finally, thanks go to June-el Piper, Ron Kneebone, and Lewis Binford for originally encouraging this project and Michael Schiffer for bringing it to fruition and encouraging us to examine explicitly the procedures involved in working with multiple lines of evidence. A University of Texas at San Antonio Faculty Research Award and the Lincoln National Forest provided funding for Hard's fieldwork in the Sierra Blanca region. Kimberly Rydel (Hard) and Julia Raymond forgave our chronic household absenteeism to pursue this effort.

REFERENCES CITED

Aasen, D. K. (1984). *Pollen, Macrofossil and Charcoal Analyses of Basketmaker Coprolites from Turkey Pen Ruin, Cedar Mesa, Utah,* Unpublished master's thesis, Department of Anthropology, Washington State University, Pullman.

Adams, J. L. (1988). Use-wear analysis on manos and hide-processing stones. *Journal of Field Archaeology* **15**: 331-344.

Adams, J. L. (1989). Methods for improving the analysis of ground stone artifacts: Experiments in mano wear pattern analysis. In Amick, D. S., and Mauldin, R. P. (eds.), *Experiments in Lithic Technology,* BAR International Series 528, Oxford, England, pp. 259–276.

Adams, J. L. (1993). Toward understanding the technological development of manos and metates. *Kiva,* **58**(3): 331-344.

Adams, J. L. (1994). The *Development of Prehistoric Grinding Technology in the Point of Pines Area, East-Central Arizona,* Unpublished Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.

Adams, J. L. (1996). Refocussing the role of food grinding tools as correlates for the subsistence strategies of gatherers and early agriculturalists in the American Southwest. Paper presented at the Society for American Archaeology Meetings, New Orleans, April. 1996.

Adams, K. R. (1987). Domesticated and native plants recovered from the robinson pueblo and other regional sites in the Capitan, New Mexico area. Manuscript in possession of author, Crow Canyon Archaeological Center, Cortez, CO.

Adams, K. R. (1991). Domesticated and native plants recovered from Robinson Pueblo and other regional sites in the Capitan area of New Mexico. In Beckett, P. H. (ed.), *Mogollon V,* COAS, Las Cruces, NM, pp. 220-228.

Albert, L. E., and Wyckoff, D. G. (1984). Oklahoma environments: Past and present. In Bell, R. E. (ed.), *Prehistory of Oklahoma,* Academic Press, New York, pp. 1–43.

Ambrose, S. H. (1987). Chemical and isotopic techniques of diet reconstruction in eastern North America. In Keegan, W. F. (ed.), *Emergent Horticultural Economies of the Eastern Woodlands,* Center for Archaeological Investigations, Occasional Paper No. 7, Southern Illinois University, Carbondale, pp. 78-107.

Ambrose, S. H., and Norr, L. (1993). Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In Lambert, J. B., and Grupe, G. (eds.), *Prehistoric Human Bone—Archaeology at the Molecular Level,* Springer-Verlag, Berlin, pp. 1-37.

Amsden, C. A. (1949). *Prehistoric Southwesterners from Basketmaker to Pueblo,* Southwest Museum, Los Angeles.

Amundson, R. G., Chadwick, O. A., Sowers, J. M., and Doner H. E. (1988). Relationship between climate and vegetation and the stable carbon isotope chemistry of soils in the eastern Mojave Desert, Nevada. *Quaternary Research* **29**: 245–254.

Andreasen, A. H. M. (1957). The principle of similarity applied to mills and to the grinding process. *Transactions of the Institution of Chemical Engineers* **35**: pp. 104–110.

Arthur, J. W. (1994). *Ceramic Function During the Early Pithouse Period in the Mimbres River Valley,* Unpublished master's thesis, University of Texas at San Antonio, San Antonio.

Bartlett, K. (1933). *Pueblo Milling Stones of the Flagstaff Region and Their Relation to Others in the Southwest,* Museum of Northern Arizona Bulletin 3, Northern Arizona Society of Science and Art, Flagstaff.

Bauer, A. J. (1990). Millers and grinders: Technology and household economy in Meso-America. *Agricultural History* **64**: 1-17.

Bender, M. M., Rouhani, I., Vines, H. M., and Black, C. C. (1973). ^{13}C/^{12}C ratio changes in crassulacean acid metabolism plants. *Plant Physiology* **52**: 427–430.

Bender, M., Baerreis, D. A., and Stevenson, R. L. (1981). Further light on carbon isotopes and hopewell agriculture. *American Antiquity* **46**: 346–353.

Binford, L. R. (1978). *Nunamiut Ethnoarchaeology,* Studies in Archaeology Series, Academic Press, New York.

Binford, L. R. (1981). *Bones: Ancient Men and Modern Myths,* Academic Press, New York.

Binford, L. R. (1983). *In Pursuit of the Past:Decoding the Archaeological Record,* Thames and Hudson, London.

Binford, L. R. (1989). Researching ambiguity: Frames of reference and site structure. In Binford, L. R. (ed.), *Debating Archaeology,* Academic Press, San Diego, pp. 223–263.

Birkedal, T. (1976). *Basketmaker III Residence Units: A Study of Prehistoric Social Organization in the Mesa Verde Archaeological District,* Unpublished Ph.D. dissertation, University of Colorado, Boulder.

Black, C. C. (1971). Ecological implications of dividing plants into groups with distinct photosynthetic production capacities. In Cragg, J. B. (ed.), *Advances in Ecological Research, Vol 7,* Academic Press, New York, pp. 87–114.

Black, C. C. (1973). Photosynthetic carbon fixation in relation to net CO_2 uptake. *Annual Review of Plant Physiology* 24: 253–286.

Black, C. C., and Williams, S. (1975). Plants exhibiting characteristics common to crassulacean acid metabolism. In Burris, R. H., and Black, C. C. (eds.), *CO_2 Metabolism and Plant Productivity,* University Park Press, Baltimore, pp. 407–424.

Black, S. (1995). Hot rocks, black holes, and fruitful dirt: burned rock midden sites on and near the Edwards Plateau. Paper presented at the 66th Annual Meeting of the Texas Archaeological Society, Nacogdoches.

Boutton, T. W., Klein, P. D., Lynott, M. J., Price, J. E., and Tieszen, L. L. (1984). Stable carbon isotope ratios as indicators of prehistoric diet. In Turnlund, J. R., and Johnson, P. E. (eds.), *Stable Isotopes in Nutrition,* ACS Symposium Series 228, American Chemical Society, Washington, DC, pp. 191–204.

Brand, M. J. (1994). *Prehistoric Anasazi Diet: A Synthesis of Archaeological Evidence,* M.A. thesis, Department of Anthropology and Sociology, University of British Columbia, Vancouver.

Braun, D. P. (1983). Pots as tools. In Moore, J., and Keene, A. (eds.), *Archaeological Hammers and Theories,* Academic Press, New York, pp. 107–134.

Brooks, R. L. (1994). Southern plains cultural complexes. In Owsley, D. W., and Jantz, R. L. (eds.), *Skeletal Biology in the Great Plains: Migration, Warfare, Health, and Subsistence,* Smithsonian Institution Press, Washington, DC, pp. 33–50.

Browning, C., Sale, M., Kirkpatrick, D. T., and Laumbach, K. W. (1992). Motr site: Excavation at site LA 72859, An El Paso phase structure on Fort Bliss, Otero County, New Mexico. White Sands Missile Range Archaeological Report No. 92-10, Human Systems Research, Inc., Tularosa, NM.

Bryant, V. M., Jr. (1974). The role of coprolite analysis in archeology. *Bulletin of the Texas Archeological Society* 45: 1–28.

Buikstra, J. E., Bullington, J., Charles, D. K., Cook, D. C., Frankenberg, S. R., Konigsberg, L. W., Lambert, J. B., and Xue, L. (1987). Diet, demography, and the development of horticulture. In Keegan, W. (ed.), *Emergent Horticultural Economies of the Eastern Woodlands,* Center for Archaeological Investigations, Occasional Paper No. 7, Southern Illinois University, Carbondale, pp. 67–85.

Bumstead, M. P. (1985). Past behavior from bone chemical analysis—respects and prospects. *Journal of Human Evolution* 14: 539–551.

Calamia, M. A. (1991). Ground stone variability among Jornada Mogollon sites and its implications for interpreting residential mobility. In Beckett, P. H. (ed.), *Mogollon V,* COAS, Las Cruces, NM, pp. 119–132.

Callen, E. O. (1967). Analysis of the Tehuacan coprolites. In Byers, D. S. (ed.), *The Prehistory of the Tehuacan Valley, Vol 1: Environment and Subsistence,* University of Texas Press, Austin, pp. 261–289.

Camilli, E. L. (1983). *Site Occupational History and Lithic Assemblage Structure: An Example from Southeastern Utah,* Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque.

Cane, S. (1987). Austalian aboriginal seed grinding and its archaeological record: A case study from the western desert. In Harris, D. R., and Hillman, G. C. (eds.), *Foraging and Farming: The Evolution of Plant Exploitation,* One World Archaeology Series 13, Unwin Hyman, London, pp. 99–119.

Cargill, D. A. (1996). *Stable Isotope Analysis at Mission San Juan De Capistrano, San Antonio, Texas,* M.A. thesis, Division of Behavioral and Cultural Sciences, University of Texas at San Antonio, San Antonio.

Carmichael, D. (1986). *Archaeological Survey in the Southern Tularosa Basin of New Mexico,* Publications in Anthropology No. 10, El Paso Centennial Museum, University of Texas at El Paso, El Paso.

Carneiro, R. L. (1970). A theory on the origin of the state. *Science* **169**: 733–738.

Chisholm, B., and Matson, R. G. (1994). Carbon and nitrogen isotopic evidence on Basketmaker II diet at Cedar Mesa, Utah. *Kiva* **60**: 239–255.

Christenson, A. L. (1987). The prehistoric tool kit. In Parry, W. J., and Christenson, A. L. (eds.), *Prehistoric Stone Technology on Northern Black Mesa, Arizona,* Occasional Paper No. 12, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 43–93.

Christenson, A. L., and Parry, W. J. (eds.) (1985). *Excavations on Black Mesa, 1983: A Descriptive Report,* Research Paper No. 46, Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Cook, S. (1982). *Zapotec Stoneworkers: The Dynamics of Rural Simple Commodity Production in Modern Mexican Capitalism,* University Press of America, Lanham.

Cordell, L. S. (1984). *Prehistory of the Southwest,* Academic Press, New York.

Cordell, L. S., and Plog, F. (1979). Escaping the confines of normative thought: A reevaluation of Puebloan prehistory. *American Antiquity* **44**: 405–429.

Cowan, C. W., and Watson, P. J. (1992). *The Origins of Agriculture: An International Perspective,* Smithsonian Institution, Washington, DC.

Cummings, L. S. (1995). Agriculture and the Mesa Verde area Anasazi diet: Description and nutritional analysis. In Toll, H. W. (ed.), *Soil, Water, Biology, and Belief in Prehistoric and Traditional Southwestern Agriculture,* New Mexico Archaeological Council, Special Publication 2, Albuquerque, pp. 335–352.

Cushing, F. H. (1920). Zuni breadstuff. *Museum of the American Indian Notes and Monographs* **8**.

Deal, M. (1985). Household pottery disposal in the Maya highlands: An ethnoarchaeological interpretation. *Journal of Anthropological Archaeology* **4**: 243–291.

Dean, G. (1986). The Archeobotany of Landergin Area. Manuscript on file, Office of the State Archeologist, Texas Historical Commission, Austin.

Dean, J. S. (1978). Independent dating in archeological analysis. In Schiffer, M. B. (ed.), *Advances in Archaeological Method and Theory, Vol. 1,* Academic Press, New York, pp. 223–255.

Decker, K. W., and Tieszen, L. L. (1989). Isotopic reconstruction of Mesa Verde diet from Basketmaker III to Pueblo III. *Kiva* **55**: 33–46.

DeGarmo, G. D. (1975). *Coyote Creek, Site 01: A Methodological Study of a Prehistoric Pueblo Population,* Ph.D. dissertation, Department of Anthropology, University of California, Los Angeles.

DeNiro, M. J. (1987). Stable isotopy and archaeology. *American Scientist* **75**: 182–191.

DeNiro, M. J., and Epstein, S. (1978). Influences of diet on the distribution of carbon isotopes in animals. *Geochemica et Cosmochemica Acta* **42**: 495–506.

Dering, J. P. (1995). Plant remains from a late archaic crescent midden in Hinds Cave (41VV456), Val Verde County, Texas. Texas Archaeological Society Meeting, Nacogdoches, Nov.

Diehl, M. W. (1996). The intensity of maize processing and production in upland Mogollon pithouse villages A.D. 200-1000. *American Antiquity* **61**: 102–115.

Dohm, K. M. (1988). *The Household in Transition: Spatial Organization of Early Anasazi Residential-Domestic Units, Southeastern Utah,* Unpublished Ph.D. dissertation, Department of Anthropology, Washington State University, Pullman.

Doleman, W. H., Chapman, R. C., Schutt, J. A., Swift, M. K., and Morrison, K. D. (eds.)(1991). *Landscape Archaeology in the Southern Tularosa Basin, Vol 2. Testing, Excavation, and Analysis,* WSMR Archaeological Report No. 91-9, Office of Contract Archaeology, University of New Mexico No. 185-324E, Prepared for U.S. Army Engineer District, Fort Worth, Contract No. DACA63-91-C-0100.

Donoghue, D. (1989). Carbonised plant macrofossils. In Beck, W., Clarke, A., and Head, L. (eds.), *Tempus: Archaeology and Material Culture Studies in Anthropology, Vol 1. Plants in Australian Archaeology,* Watson Ferguson, Brisbane, pp. 90–110.

Durst, J. (1995). A comparative analysis of pit features in the Jornada Mogollon. Paper presented at Jornada Mogollon Conference IX, El Paso, Tx.

Ehleringer, J. R. (1989). Carbon isotope ratios and physiological processes in aridland plants. In Rundel, P. W., Ehleringer, J. R., and Nagy, K. A. (eds.), *Stable Isotopes in Ecological Research,* Springer Velag, New York, pp. 41–54.

El-Najjar, M. Y., Ryan, D. J., Turner, C. G., III, and Lozoff, B. (1976). The etiology of porotic hyperstosis among the prehistoric and historic Anasazi indians of southwestern United States. *American Journal of Physical Anthropology* **44**: 477–488.

Euler, R. C., and Dodyns, H. F. (1983). The ethnoarchaeology of Pai milling stones. In Fox, N. L. (ed.), *Collected Papers in Honor of Charlie R. Steen, Jr.*, Papers of the Archaeological Society of New Mexico No. 8, Albuquerque, pp. 253–267.

Ezzo, J. A. (1992). A test of diet versus diagenesis at Ventana Cave, Arizona. *Journal of Archaeological Science* **19**: 23–37.

Farnsworth, P., Brady, J. E., DeNiro, M. J., and MacNeish, R. S. (1985). A re-evaluation of the isotopic and archaeological reconstructions of diet in the Tehuacan Valley. *American Antiquity* **50**: 102–116.

Flint, P. R., and Neusius, S. W. (1987). Cottontail procurement among Dolores Anasazi. In *Dolores Archaeological Program: Supporting Studies: Settlement and Environment*, University of Colorado Dolores Archaeological Program, United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver, pp. 257–273.

Ford, R. I. (1977). Archeobotany of the Fort Bliss Maneuver Area II, Texas. In Whalen, M. (ed.), *Settlement Patterns of the Eastern Hueco Bolson*, Anthropological Papers No. 4, Centennial Museum, University of Texas at El Paso, El Paso, pp. 199-205.

Ford, R. I. (1979). Paleoethnobotany in American archaeology. In Schiffer, M. B. (ed.), *Advances in Archaeological Method and Theory, Vol. 2,* Academic Press, New York, pp. 285–336.

Ford, R. I. (1988). Commentary: Little things mean a lot-quantification and qualification in paleoethnobotany. In Hastorf, C. A., and Popper, V. S. (eds.), *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains,* University of Chicago Press, Chicago, pp. 215–227.

Ford, R. I., Werf, P. V., Goland, C., and Trigg, H. B. (1985). Paleoethnobotany of Anasazi sites. Appendix G. In Christenson, A. L., and Parry, W. J. (eds.), *Excavations on Black Mesa, 1983: A Descriptive Report,* Center for Archaeological Investigations, Research Paper No. 46, Southern Illinois University, Carbondale, pp. 469–487, Tables G.3–18.

Foster, G. M. (1967). *Tzintzuntzan: Mexican Peasants in a Changing World,* Little, Brown, Boston.

Fritz, G. J. (1994). The value of archaeological plant remains for paleodietary reconstruction, In Sobolik, K. D. (ed.), *Paleonutrition: The Diet and Health of Prehistoric Americans,* Center for Archaeological Investigations, Occasional Paper No. 22, Southern Illinois University at Carbondale, pp. 21–33.

Fry, G. F. (1985). Analysis of fecal material. In Gilbert, R. I., Jr., and Mielke J. H. (eds.), *The Analysis of Prehistoric Diets,* Academic Press, Orlando, pp. 127–154.

Gasser, R. E. (1982). Anasazi diet. In Gasser, R. E. (ed.), *The Coronado Project Archaeological Investigations, the Specialists' Volume: Biocultural Analyses,* Coronado Series 4, Museum of Northern Arizona Research Paper 23, Museum of Northern Arizona Press, Flagstaff, pp. 8–95.

Gebauer, A. B., and Price, T. D. (eds.) (1992). *Transitions to Agriculture in Prehistory,* Monographs in World Archaeology No. 4, Prehistory Press, Madison, WI.

Geib, P. R., and Davidson, D. (1994). Anasazi origins: A perspective from preliminary work at Old Man Cave. *Kiva* **60**(2): 191–202.

Gilman, P. A. (1987). Architecture as artifact: Pit structures and pueblos in the American Southwest. *American Antiquity* **52**: 538-564.

Glassow, M. A. (1972). Changes in the adaptations of Southwestern basketmakers: A systems perspective. In Leone, M. P. (ed.), *Contemporary Archaeology: A Guide to Theory and Contributions*, Southern Illinois University Press, Carbondale, pp. 289–302.

Glassow, M. A. (1980). *Prehistoric Agricultural in the Northern Southwest: A Study in Changing Patterns of Land Use*, Anthropological Papers No. 16, Ballena Press, Socorro, NM.

Goldborer, S. E. (1988). Botanical remains from the Conejo site (FB46). In Settlement and Subsistence Patterns During Pithouse Occupations in the Chihuahua Desert. Manuscript on file, Archaeology Program, Environmental Management Office, Ft. Bliss, TX.

Goodman, A. H. (1991). Stress, adaptation, and enamel developmental defects. In Ortner, P. J., and Aufderheide, A. C. (eds.), *Human Paleopathology: Current Synthesis and Future Options*, Smithsonian Institution Press, Washington, DC, pp. 280–287.

Goodman, A. H., and Rose, J. C. (1991). Dental enamel hypoplasias as indicators of nutritional status. In *Advances in Dental Anthropology*, Wiley-Liss, New York, pp. 279–293.

Habicht-Mauche, J. A., Levendosky, A. A., and Schoeninger, M. J. (1994). Antelope Creek subsistence: The bone chemistry evidence. In Owsley, D. W., and Jantz, R. L. (eds.), *Skeletal Biology in the Great Plains: Migration, Warfare, Health, and Subsistence*, Smithsonian Institution Press, Washington, DC, pp. 291-304.

Hallisy, S. J. (1974). Salvage excavations of sites 5MT UMR 2344 and 5MT UMR 2347 in Mancos Canyon, Southwest Colorado. Manuscript on file, Mesa Verde Research Center, Department of Anthropology. University of Colorado, Boulder.

Hansen, E. (1994). *Early Archaic Diet at Old Man Cave: A Perspective on Archaic Subsistence in Southeastern Utah*, Unpublished M.A. thesis, Department of Anthropology, Northern Arizona University, Flagstaff.

Hard, R. J. (1983a). *Excavations in the Castner Range Archeological District in El Paso, Texas*, Publications in Anthropology No. **11**, El Paso Centennial Museum, University of Texas at El Paso, El Paso.

Hard, R. J. (1983b). A model for prehistoric land use, Ft. Bliss, Texas. In *Proceedings 1983*, American Society for Conservation Archaeology, New York, pp. 41–51.

Hard, R. J. (1983c). Fieldnotes: Tarahumara Ethnoarchaeological Project. Manuscript in possession of author.

Hard, R. J. (1986). *Ecological Relationships Affecting the Rise of Farming Economies: A Test from the American Southwest*, Unpublished Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque.

Hard, R. J. (1988). Settlement and subsistence patterns during pithouse occupations in the Chihuahuan Desert, Manuscript on file, Archaeology Program, Environmental Management Office, Ft. Bliss, TX.

Hard, R. J. (1990). Agricultural dependence among the mountain Mogollon. In Minnis, P., and Redman, C. (eds.), *Perspectives on Southwestern Prehistory*, Westview Press, Boulder, CO, pp. 135–149.

Hard, R. J. (1994). Agricultural intensification in the Sacramento Mountains of south central New Mexico. Paper presented at the 59th Annual Meeting of Society for American Archaeology, Anaheim, CA.

Hard, R. J. (1995). Formative Jornada Mogollon subsistence variability. Paper presented at the Jornada Mogollon Conference IX, El Paso, TX.

Hard, R. J., and Merrill, W. J. (1992). Mobile agriculturalists and the emergence of sedentism: Perspectives from northern Mexico. *American Antropologist* **94**: 601–620.

Hard, R. J., and Yener, A. (1991). The function of anatolian ground and battered tools. Paper presented at the 56th Annual Meeting of the Society for American Archaeology, New Orleans.

Hard, R. J., Graeber, P., Manasco, J., Tennis, C., and Thuesen, K. (1994). Dona Ana phase ceramics and cultural evolution in the southern Jornada Mogollon. *Bulletin of the Texas Archeological Society* **62**: 267–283.

Hard, R. J., Raymond, G. R., and Durst, J. (1996). Farmers or foragers? Upland exploitation on the eastern periphery of the Southwest. Paper presented at the 61st Annual Meeting of the Society for American Archaeology, New Orleans.

Hare, P. E., Fogel, M. L., Stafford, T. W., Jr., Mitchell, A. D., and Hoering, T. C. (1991). The isotopic composition of carbon and nitrogen in individual amino acids isolated from modern and fossil proteins. *Journal of Archaeological Science* 18: 277–292.

Hastorf, C. A. (1988). The use of paleoethnobotanical data in prehistoric studies of crop production, processing, and consumption. In Hastorf, C. A., and Popper, V. S. (eds.), *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains,* University of Chicago Press, Chicago, pp. 119–144.

Haury, E. W. (1950). *The Stratigraphy and Archaeology of Ventana Cave,* University of Arizona Press, Tucson.

Haury, E. W. (1962). The greater American Southwest. In Braidwood, R. J., and Willey, G. R. (eds.), *Courses Toward Urban Life,* Viking Fund Publications in Anthropology, No. 32, New York, pp. 106–131.

Hayden, B. (1987). Past to present uses of stone tools and their effects on assemblage characteristics in the Maya highlands. In Hayden, B. (ed.), *Lithic Studies Among the Contemporary Highland Maya,* University of Arizona, Tucson, pp. 160–234.

Hayden, B., and Cannon, A. (1984). *The Structure of Material Systems: Ethnoarchaeology of the Maya Highlands,* Society for American Archaeology Papers No. 3.

Hobson, K., and Schwarcz, H. P. (1986). The variation in $\delta^{13}C$ values in bone collagen for two wild herbivore populations: Implications for paleodiet studies. *Journal of Archaeological Science,* 13: 101–106.

Holloway, R. G. (1983). Appendix B, Charcoal and Pollen Analysis. In Hard, R. J., *Excavations in the Castner Range Archaeological District in El Paso, Texas,* El Paso Centennial Museum Publications in Anthropology No. 11, University of Texas at El Paso, El Paso, pp. 81–83.

Horsfall, G. (1987). A design theory perspective on variability in grinding stones. In Hayden, B. (ed.), *Lithic Studies Among the Contemporary Highland Maya,* University of Arizona Press, Tucson, pp. 332–377.

Hough, W. (1901). *Archaeological Fieldwork in Northeastern Arizona,* Report of the United States National Museum for the Year Ending 1901, Smithsonian Institution Press, Washington, DC.

Huckell, B. B. (1995). *Of Marshes and Maize: Preceramic Agricultural Settlements in the Cienega Valley, Southeastern Arizona,* Anthropological Papers of the University of Arizona No. 59, University of Arizona Press, Tucson.

Huckell, L. W. (1996). Paleoethnobotany of late preceramic/early ceramic sites in Tucson, Arizona. Paper presented at the 61st Annual Meeting of Society for American Archaeology, New Orleans.

Hunn, E. S., and Williams, N. M. (1982). Introduction. In Williams, N. M., and Hunn, E. S. (eds.), *Resource Managers: North American and Australian Hunter-Gatherers,* Westview Press, Boulder, CO, pp. 1–16.

Jennings, J. D., Schroedl, A. R., and Holmer, R. N. (1980). *Sudden Shelter,* Anthropological Papers No. 103, University of Utah Press, Salt Lake City.

Johannessen, S. (1988). Plant remains and cultural change: Are paleoethnobotanical data better than we think? In Hastorf, C. A., and Popper, V. S. (eds.), *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains,* University of Chicago Press, Chicago, pp. 145–166.

Jones, G. E. M. (1991). Numerical analysis in archaeobotany. In Van Zeist, W., Wasylikowa, K., and Behre, K. E. (eds.), *Progress in Old World Palaeoethnobotany,* Balkema, Rotterdam, pp. 63–80.

Jones, M. K. (1991). Sampling in palaeoethnobotany. In Van Zeist, W., Wasylikowa, K., and Behre, K. E. (eds.), *Progress in Old World Palaeoethnobotany,* Balkema, Rotterdam, pp. 53–62.

Kadane, J. B. (1988). Possible statistical contributions to paleoethnobotany. In Hastorf, C. A., and Popper, V. S. (eds.), *Current Paleoethnobotany: Analytical Methods and Cultural In-*

terpretations of Archaeological Plant Remains, University of Chicago Press, Chicago, pp. 206–214.

Katz, S. H., Hediger, M. L., and Valleroy, L. A. (1974). Traditional maize processing techniques in the New World. *Science* **184**: 765–773.

Katzenberg, M. A. (1989). Stable isotope analysis of archaeological faunal remains from southern Ontario. *Journal of Archaeological Science* **16**: 319–329.

Katzenberg, M. A., and Kelley, J. H. (1991). Stable isotope analysis of prehistoric bone from the Sierra Blanca region of New Mexico. In Beckett, P. H. (ed.), *Mogollon V,* COAS, Las Cruces, NM, pp. 207-219.

Katzenberg, M. A., Sanders, S. R., and Fitzgerald, W. R. (1993). Age differences in stable carbon and nitrogen ratios in a population of prehistoric maize horticulturists. *American Journal of Physical Anthropology* **90**: 267–281.

Kelley, J. H. (1984). *The Archaeology of the Sierra Blanca Region of Southeastern New Mexico,* Anthropological Papers No. 74, Museum of Anthropology, University of Michigan, Ann Arbor.

Kelley, J. H. (1991). An overview of the Capitan North Project. In Beckett, P. H. (ed.), *Mogollon V,* COAS, Las Cruces, NM, pp. 166–176.

Kelly, I. (1964). *Southern Paiute Ethnography,* University of Utah Anthropological Papers No. 69, Salt Lake City.

Kemp, P. R. (1983). Phenological patterns of Chihuahuan Desert plants in relation to the timing of water availability. *Journal of Ecology* **71**: 427–436.

Kent, S., and Dunn, D. (1993). Etiology of hypoferremia in a recently sedentary Kalahari village. *American Journal of Tropical Medicine and Hygiene* **48**(4): 554–567.

Krieger, A. D. (1947). *Cultural Complexes and Chronology in Northern Texas with Extension of Puebloan Dating to the Mississippi Valley,* University of Texas Publication No. 4640, Austin.

Krueger, H. W., and Sullivan, C. (1984). Models for carbon isotope fractionation between diet and bone. In Turnlund, J. R., and Johnson, P. E. (eds.), *Stable Isotopes in Nutrition,* ACS Symposium Series 228, American Chemical Society, Washington, DC, pp. 205–220.

Lancaster, J. (1983). *An Analysis of Manos and Metates From the Mimbres Valley, New Mexico,* Unpublished master's thesis, Department of Anthropology, University of New Mexico, Albuquerque.

LeBlanc, S. A. (1982). The advent of pottery in the Southwest. In Southwestern ceramics: A comparative review, *The Arizona Archaeologist* **15**: 27–51.

Lehmer, D. J. (1948). *The Jornada Branch of the Mogollon,* University of Arizona Bulletin 19, Social Science Bulletin 17, Tucson.

Lennstrom, H. A., and Hastorf, C. A. (1995). Interpretation in context: Sampling and analysis in paleoethnobotany. *American Antiquity* **60**: 701–721.

Lightfoot, K. G. (1984). *The Duncan Project: A Study of the Occupation Duration and Settlement Pattern of an Early Mogollon Pithouse Village,* Anthropological Field Studies Number 6, Office of Cultural Resource Management, Arizona State University, Tempe.

Lightfoot, K. G., and Feinman, G. M.(1982). Social differentiation and leadership development in early pithouse villages in the Mogollon region of the American Southwest. *American Antiquity* **47**: 64–86.

Lindsay, A. L., Ambler, J. R., Stein, M. A., and Hobler, P. M. (1968). *Survey and Excavations North and East of Navajo Mountain, Utah, 1959-1962,* Museum of Northern Arizona Bulletin No. 45, Northern Arizona Society of Science and Art, Flagstaff.

Lintz, C. (1976). The McGrath site of the Panhandle aspect. *Bulletin of the Oklahoma Anthropological Society* **25**: 1–110.

Lintz, C. (1984). The plains villagers: Antelope Creek. In Bell, R. E. (ed.), *Prehistory of Oklahoma,* Academic Press, New York, pp. 325–346.

Lintz, C. (1986). *Architecture and Community Variability Within the Antelope Creek Phase of the Texas Panhandle,* Oklahoma Archeological Survey, No. 14, Norman, OK.

Lintz, C. (1990). Landergin Mesa: The 1984 Phase II results. Manuscript on file, Office of the State Archeologist, Texas Historical Commission, Austin.

Lipe, W. D. (1970). Anasazi communities in the Red Rock Plateau, southeastern Utah. In Longacre, W. A. (ed.), *Reconstructing Prehistoric Pueblo Societies,* University of New Mexico Press, Albuquerque, pp. 84–139.

Lipe, W. D. (1978). Archaeological work in the Grand Gulch region, southeastern Utah, 1969. In *National Geographic Society Research in 1969,* National Geographic Society, Washington, DC, pp. 389–397.

Lister, R. H., and Breternitz, D. A. (1968). The salvage excavation of Site 1104, Wetherill Mesa. In Lister, R. H. (ed.), *Contributions to Mesa Verde Archaeology: V. Emergency Archaeology in Mesa Verde National Park, Colorado, 1948–1966.* University of Colorado Studies/Series in Anthropology No. 15, University of Colorado Press, Boulder, pp. 69–88.

Lister, R. H., and Lister, F. (1964). *Contributions to Mesa Verde Archaeology: I. Site 499, Mesa Verde National Park, Colorado,* Series in Anthropology No. 9, University of Colorado Press, Boulder.

Lister, R. H., and Smith, J. E. (1968). Salvage excavations at Site 1088, Morfield Canyon. In Lister, R. H. (ed.), *Contributions to Mesa Verde Archaeology: V. Emergency Archaeology in Mesa Verde National Park, Colorado, 1948–1966*; University of Colorado Studies/Series in Anthropology No. 15, University of Colorado Press, Boulder, pp. 5–32.

Logan, E. N., and Fratt, L. (1993). Pigment processing at Homol'ovi III: A preliminary study. *Kiva* **58**: 415–428.

Lowrison, G. C. (1974). *Crushing and Grinding: The Size Reduction of Solid Materials,* Butterworths, London.

MacNeish, R. S. (1992). *The Origins of Agriculture and Settled Life,* University of Oklahoma Press, Norman.

MacNeish, R. S., and Marino, B. (1993). Section 4. Carbon 13/12 and nitrogen 15/14 isotope ratios on skeletons from the Jornada area. In MacNeish, R. S. (ed.), *Preliminary Investigations of the Archaic in the Region of Las Cruces, New Mexico,* Historic and Natural Resources Report No. 9, United States Army Air Defense Artillery Center, Fort Bliss, pp. 117–122, TX.

Marshall, J. J., and Whelan, W. J. (1979). Some aspects of dietary starch utilization in the mammalian digestive tract. In Yagi, K. (ed.), *Biochemical Aspects of Nutrition,* University Park, Baltimore, pp. 125–130.

Martin, D. L., Goodman, A. H., and Armelagos, G. J. (1985). Skeletal pathologies as indicators of quality and quantity of diet. In Gilbert, R. L., and Mielke, J. H. (eds.), *The Analysis of Prehistoric Diets,* Academic Press, San Diego, pp. 227–279.

Martin, D. L., Goodman, A. H., Armelagos, G. J., and Magennis, A. L. (1991). *Black Mesa Anasazi Health: Reconstructing Life from Patterns of Death and Disease,* Occasional Paper No. 14, Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Martin, P. S., and Plog, F. (1973). *The Archaeology of Arizona: A Study of the Southwest Region,* Doubleday/Natural History Press, Garden City, NY.

Martin, P. S., and Rinaldo, J. B. (1947). *The SU Site, Excavations at a Mogollon Village, Western New Mexico: Third Season, 1946,* Anthropological Series Vol. 32, No. 3, Field Museum of Natural History, Chicago.

Martin, P. S., and Sharrock, F. W. (1964). Pollen analysis of prehistoric human feces: A new approach to ethnobotany. *American Antiquity* **30**: 168–180.

Marvin, U. B. (1973). *Continental Drift: The Evolution of a Concept,* Smithsonian Institution Press, Washington, DC.

Matson, R. G. (1991). *The Origins of Southwestern Agriculture,* University of Arizona Press, Tucson.

Matson, R. G., and Chisholm, B. (1991). Basketmaker II subsistence: Carbon isotopes and other dietary indicators from Cedar Mesa, Utah. *American Antiquity* **56**: 444–459.

Matson, R. G., and Lipe, W. D. (1978). Settlement patterns on Cedar Mesa: Boom and bust on the northern periphery. In Euler, R., and Gumerman, G. (eds.), *Investigations by the Southwestern Anthropological Research Group: An Exercise in Archaeological Cooperation,* Museum of Northern Arizona Bulletin No. 50, Flagstaff, pp. 1–12.

Matson, R. G., Lipe, W. D., and Haase, W. R. (1988). Adaptational continuities and occupational discontinuities: The Cedar Mesa Anasazi. *Journal of Field Archaeology* **15**: 245–264.

Mauldin, R. P. (1983). *An Inquiry into the Past: Basketmaker II Settlement on Northeastern Black Mesa, Arizona,* Unpublished Master's thesis, Department of Anthropology, University of Texas at Austin, Austin.

Mauldin, R. P. (1991). Thumping and grinding: Ethnographic observations on ground stone in the Andes. Paper presented at the 56th Annual Meeting of the Society for American Archaeology, New Orleans.

Mauldin, R. P. (1993a). The relationship between ground stone and agricultural intensification in western New Mexico. *Kiva* **58**: 317–330.

Mauldin, R. P. (1993b). Exploring the potential of variation in jackrabbit carbon isotopic signatures as an indicator of seasonality on archaeological sites in the Chihuahuan Desert. Manuscript on file, Archaeology Program, Environmental Management Office, Ft. Bliss, TX.

Mauldin, R. P. (1994). Small sites in western Texas and southern New Mexico. *Bulletin of the Texas Archeological Society* **65**: 185–206.

Mauldin, R. P. (1995). *Groping for the Past: Investigating Archaeological Patterns Across Space and Time in the Southern Southwestern United States.* Unpublished Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque.

Mauldin, R. P., and Tomka, S. A. (1988). Informe preliminar sobre experimentos en el uso de moledoras de piedra (Khona) en la communidad de Alota, Nor Lipez, Potosi, Bolivia. Manuscript submitted to the National Museum of Ethnography and Folklore, La Paz.

Mauldin, R. P., and Tomka, S. A. (1989). An ethnoarchaeological assessment of grinding efficiency and ground stone size. Paper presented at the 54th Annual Meeting of the Society for American Archaeology, Atlanta.

Mierau, G. W., and Schmidt, J. L. (1981). The mule deer of Mesa Verde National Park. *Mesa Verde Research Series Paper No. 2,* Mesa Verde National Park, CO.

Miksicek, C. H. (1987). Formation processes of the archaeobotanical record. In Schiffer, M. B. (ed.), *Advances in Archaeological Method and Theory,* Vol. **10**, Academic Press, New York, pp. 211–247.

Miller, M. R., III (1989). *Archaeological Excavations at the Gobernadora and Ojasen Sites: Dona Ana Phase Settlement in the Western Hueco Bolson, El Paso County, Texas,* Center for Anthropological Research Report No. 673, New Mexico State University, Las Cruces.

Mills, B. (1989). *Ceramics and Settlement in the Cedar Mesa Area, Southeastern Utah: A Methodological Approach,* Unpublished Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque.

Minnis, P. E. (1985). *Social Adaptations to Food Stress,* University of Chicago Press, Chicago.

Minnis, P. E. (1989). Prehistoric diet in the northern Southwest: Macroplant remains from Four Corners feces. *American Antiquity* **54**: 543–563.

Minnis, P. E., and Goldborer, S. E. (1991). Botanical remains from the Turquoise Ridge site. Manuscript on file, Department of Anthropology, University of Tulsa, Tulsa, OK.

Molleson, T. (1989). Seed preparation in the Mesolithic: The osteological evidence. *Antiquity* **63**: 356–362.

Mooney, H., Troughton, J. H., and Berry, J. A. (1974). *Arid Climates and Photosynthetic Systems,* Carnegie Institution of Washington Year Book, 1973, pp. 793–805.

Morris, D. H. (1990). Changes in groundstone following the introduction of maize into the American Southwest. *Journal of Anthropological Research* **46**: 177–194.

Murdock, G. P. (1967). *Ethnographic Atlas,* University of Pittsburgh Press, Pittsburgh.

Nagel, E. (1961). *The Structure of Science: Problems in the Logic of Scientific Explanation,* Harcourt, Brace and World, New York.

National Oceanic and Atmospheric Administration (1982). *Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1951–80, Colorado,* Climatography of the United States No. 81, National Oceanic and Atmospheric Administration, Asheville, NC.

National Oceanic and Atmospheric Administration (1982). *Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1951–80, New Mexico,* Climatography of the United States No. 81, National Oceanic and Atmospheric Administration, Asheville, NC.

Nelson, M. C., and Lippmeier, H. (1993). Grinding-tool design as conditioned by land-use pattern. *American Antiquity* **58**: 286–305.

Neusius, S. W. (1985). Faunal resource use: Perspectives from the ethnographic record. In *Dolores Archaeological Program: Studies in Environmental Archaeology*, University of Colorado Dolores Archaeological Program, United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver, pp. 101–115.

Nichols, D. L., and Smiley, F. E. (1985). An Overview of Northern Black Mesa Archaeology. In Christenson, A. L., and Parry, W. J. (eds.), *Excavations on Black Mesa, 1983: A Descriptive Report*, Research Paper No. 46, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 49–81.

Nichols, D. L., and Smiley, F. E. (eds.) (1984). *Excavations on Black Mesa, 1982: A Descriptive Report*, Research Paper No. 39, Center for Archaeological Investigations, Southern Illinois University, Carbondale.

O'Laughlin, T. C. (1980). *The Keystone Dam Site and Other Archaic and Formative Sites in Northwest El Paso, Texas*, Publications in Anthropology No 8, Centennial Museum, University of Texas at El Paso, El Paso.

O'Laughlin, T. C. (1989). Botanical remains from Meyer Pithouse Village. Appendix 5 in Excavations at Meyer Pithouse Village, by Scarborough, V., Ms on file, Archaeology Program, Environmental Management Office, Ft. Bliss, TX.

O'Leary, M. H. (1981). Carbon isotope fractionation in plants. *Phytochemistry* **20**(4): 553–567.

O'Leary, M. H. (1988). Carbon isotopes in photosynthesis: Fractionation techniques may reveal new aspects of carbon dynamics in plants. *BioScience* **38**(5): 328–336.

Parry, W. J., Renken, L. A., and Nichols, D. L. (1985). Cultural resource summary of the 1983 Research area. In Christenson, A. L., and Parry, W. J. (eds.), *Excavations on Black Mesa, 1983: A Descriptive Report*, Research Paper No. 46, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 1–46.

Parry, W. J., and Christenson, A. L. (1987). *Prehistoric Stone Technology on Northern Black Mesa, Arizona*, Occasional Paper No. 12, Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Pate, D. F. (1994). Bone chemistry and paleodiet. *Journal of Archaeological Method and Theory* 1(2): 161–205.

Pearsall, D. M. (1987). Adaptation of prehistoric hunter-gatherers to the high Andes: The changing role of plant resources. In Harris, D. R., and Hillman, G. C. (eds.), *Foraging and Farming: The Evolution of Plant Exploitation*, One World Archaeology Series 13, Unwin Hyman, London, pp. 99–119.

Pearsall, D. M. (1988). Interpreting the meaning of macroremain abundance: The impact of source and context. In Hastorf, C. A., and Popper, V. S. (eds.), *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains*, University of Chicago Press, Chicago, pp. 97–118.

Plog, F. (1979). Prehistory: Western Anasazi. In Ortiz, A. (ed.), *Southwest, Handbook of North American Indians, Vol. 9* (Sturtevant, W. C., gen. ed.), Smithsonian Institution Press, Washington, DC, pp. 108–130.

Plog, S. (ed.) (1986). *Spatial Organization and Exchange: Archaeological Survey on Northern Black Mesa*, Southern Illinois University Press, Carbondale.

Plog, S., and Powell, S. (eds.) (1984). *Papers on the Archaeology of Black Mesa, Arizona, Vol. II*, Southern Illinois University Press, Carbondale.

Popper, V. S. (1988). Selecting quantitative measurements in paleoethnobotony. In Hastorf, C. A., and Popper, V. S. (eds.), *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains*, University of Chicago Press, Chicago, pp. 53–71.

Popper, V. S., and Hastorf, C. A. (1988). Introduction. In Hastorf, C. A., and Popper, V. S. (eds.), *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains*, University of Chicago Press, Chicago, pp. 1–16.

Powell, S. (1983). *Mobility and Adaptation: The Anasazi of Black Mesa, Arizona*. Southern Illinois University Press, Carbondale.

Powell, S. (1987). Food storage and environmental uncertainty: An example from Black Mesa, Arizona. In Gaines, S. W. (ed.), *Coasts, Plains and Deserts: Essays in Honor of Reynold J. Ruppe*, Anthropological Research Papers No. 38, Arizona State University, Tempe, pp. 213–225.

Prasher, C. L. (1987). *Crushing and Grinding Process Handbook*, John Wiley and Sons, New York.

Price, T. D., and Gebauer, A. B. (eds.) (1995). *Last Hunters First Farmers: New Perspectives on the Prehistoric Transition to Agriculture*, School of American Research Press, Santa Fe, NM.

Price, T. D., Schoeninger, M. J., and Armelagos, G. J. (1985). Bone chemistry and past behavior: An overview. *Journal of Human Evolution* **1985**: 419–447.

Quade, J., Cerling, T. E., Andrews, P., and Alpagut, B. (1995). Paleodietary reconstruction of Miocene faunas from Pasalar, Turkey, using stable carbon and oxygen isotopes of fossil tooth enamel. *Journal of Human Evolution* **28**: 373–384.

Redding, R. W. (1988). A general explanation of subsistence change: From hunting and gathering to food production. *Journal of Anthropological Archaeology* **7**: 56–97.

Reinhard, K. J. and Bryant, V. M., Jr. (1992). Coprolite analysis: A biological perspective on archaeology. In Schiffer, M. B. (ed.), *Archaeological Method and Theory, Vol 4*, University of Arizona Press, Tucson, pp. 245–288.

Rice, G. E. (1975). *A Systemic Explanation of Mogollon Settlement Pattern Changes*, Ph.D. dissertation, Department of Anthropology, University of Washington, Seattle.

Rice, G. E. (1980). An analytical overview of the Mogollon tradition. In Stafford, C. R., and Rice, G. E. (eds.), *Studies in the Prehistory of the Forestdale Region, Arizona*, Anthropological Field Studies No. 1, Office of Cultural Resource Management, Arizona State University, Tempe, pp. 9–40.

Rindos, D. (1984). *The Origins of Agriculture*, Academic Press, New York.

Rocek, T. (1995). Sedentarization and agricultural dependence: perspectives from the pithouse-to-pueblo transition in the American Southwest. *American Antiquity* **60**: 218–239.

Rohn, A. H. (1963). Prehistoric soil and water conservation on Chapin Mesa, Southwestern Colorado. *American Antiquity* **28**: 441–445.

Rohn, A. H. (1971). *Mug House*, Archaeological Research Series No. 7-D, U.S. Department of the Interior, National Park Service, Washington, DC.

Rohn, A. H. (1977). *Cultural Change and Continuity on Chapin Mesa*, The Regents Press of Kansas, Lawrence.

Rylander, K. A. (1994). Corn preparation among the Basketmaker Anasazi: A scanning electron microscope study of *Zea mays* remains from coprolites. In Sobolik, K. D. (ed.), *Paleonutrition: The Diet and Health of Prehistoric Americans*, Center for Archaeological Investigations, Occasional Paper No. 22, Southern Illinois University, Carbondale, pp. 115–133.

Salmon, M. A. (1982). *Philosophy and Archaeology*, Academic Press, New York.

Salmon, W. C. (1967). *The Foundations of Scientific Inference*, University of Pittsburgh Press, Pittsburgh.

Schiffer, M. B. (1972a). Archaeological context and systemic context. *American Antiquity* **37**: 156–165.

Schiffer, M. B. (1972b). Cultural laws and the reconstruction of past lifeways. *Kiva* **37**: 148–157.

Schiffer, M. B. (1976). *Behavioral Archaeology*, Academic Press, New York.

Schiffer, M. B. (1983). Toward the identification of formation processes. *American Antiquity* **48**: 675–706.

Schiffer, M. B. (1987). *Formation Processes of the Archaeological Record*, University of New Mexico Press, Albuquerque.

Schiffer, M. B. (1988). The structure of archaeological theory. *American Antiquity* **53**(3): 461–485.

Schlanger, S. H. (1991). On manos, metates, and the history of site occupations. *American Antiquity* **56**: 460–474.

Schoeninger, M. J., and Moore, K. (1992). Bone stable isotope studies in archaeology. *Journal of World Prehistory* 6(2): 247–296.

Schwarcz, H. P., and Schoeninger, M. J. (1991). Stable isotope analysis in human nutritional ecology. *Yearbook of Physical Anthropology* 34: 283–321.

Schwarcz, H. P., Melbye, F. J., Katzenberg, M. A., and Knyf, M. (1985). Stable isotopes in human skeletons of southern Ontario: Reconstructing paleodiet. *Journal of Archaeological Science* 12: 187–206.

Sebastian, L., and Larralde, S. (1989). *Living on the Land: 11,000 Years of Human Adaptation in Southeastern New Mexico,* Cultural Resources Series No 6., Bureau of Land Management, Roswell District.

Shennan, S. (1988). *Quantifying Archaeology,* Academic Press, San Diego.

Simms, S. R. (1983). The effects of grinding stone reuse on the archaeological record in the eastern Great Basin. *Journal of California and Great Basin Anthropology* 5: 98–102.

Smith, B. D. (1992). *Rivers of Change: Essays on Early Agriculture in Eastern North America,* Smithsonian Institution Press, Washington, DC.

Smith, B. D. (1995). *The Emergence of Agriculture,* Scientific American Library, New York.

Smith, B. N. (1971). Carbon isotope ratios of respired CO_2 from castor bean, corn, peanut, pea, radish, squash, sunflower, and wheat seedlings. *Plant and Cell Physiology* 12: 451–455.

Smith, B. N. (1972). Natural Abundance of the stable isotopes of carbon in biological systems. *Bioscience* 22: 226–231.

Smith, B. N., and Brown, W. V. (1973). The Kranz syndrome in the Gramineae as indicated by carbon isotopic ratios. *American Journal of Botany* 60: 505–513.

Smith, J. E. (1987). *Mesas, Cliffs, and Canyons: The University of Colorado Survey of Mesa Verde National Park 1971–1977,* Mesa Verde Research Series No. 3, Mesa Verde Museum Association, Mesa Verde National Park, CO.

Smith, M. F., Jr. (ed.) (1994). *Function and Technology of Anasazi Ceramics from Black Mesa, Arizona,* Occasional Paper No. 15, Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Snow, D. H. (1990). Tener comal y metate: Protohistoric Rio Grande maize use and diet. In *Perspectives on Southwestern Prehistory,* Westview Press, Boulder, CO.

Sobolik, K. D. (1988). Diet change in the lower Pecos: Analysis of Baker Cave coprolites. *Bulletin of the Texas Archeological Society* 59: 111–127.

Sobolik, K. D. (1994). Introduction. In Sobolik, K. D. (ed.), *Paleonutrition: The Diet and Health of Prehistoric Americans,* Center for Archaeological Investigations, Occasional Paper No. 22, Southern Illinois University, Carbondale, pp. 1–18.

Speth, J. D., and Spielmann, K. A. (1983). Energy source, protein metabolism, and hunter-gather subsistence strategies. *Journal of Anthropological Archaeology* 2: 1–31.

Spielmann, K. A., Schoeninger, M. J., and Moore, K. (1990). Plains-Pueblo interdependence and human diet at Pecos Pueblo, New Mexico. *American Antiquity* 55: 745–765.

Stafford, C. R. (1980). A consideration of settlement-subsistence systems in the Forestdale region. In Stafford, C. R., and Rice, G. E. (eds.), *Studies in the Prehistory of the Forestdale Region, Arizona,* Anthropological Field Studies No. 1, Office of Cultural Resource Management, Arizona State University, Tempe, pp. 41–75.

Stark, B. L. (1986). Origins of food production in the New World. In Meltzer, D. J., Fowler, D. D., and Sabloff, J. A. (eds.), *American Archaeology Past and Future: A Celebration of the Society for American Archaeology 1935–1985,* Smithsonian Institution Press, Washington, DC, pp. 277–321.

Stenhouse, M. J., and Baxter, M. S. (1979). The uptake of bomb ^{14}C in humans. In Berger, R., and Suess, H. E. (eds.), *Radiocarbon Dating,* University of California Press, Berkeley, pp. 324–341.

Stiger, M. (1977). *Anasazi Diet: The Coprolite Evidence,* Master's thesis, Department of Anthropology, University of Colorado, Boulder.

Stiger, M. (1979). Mesa Verde subsistence patterns: From Basketmaker to Pueblo III. *Kiva* 44: 133–144.

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

Stowe, L. G., and Teeri, J. A. (1978). The geographic distribution of C4 species of the Dicotyledonae in relation to climate. *The American Naturalist* **112**: 609–623.

Struever, S. (1968). Flotation techniques for the recovery of small scale archaeological remains. *American Antiquity* **33**: 353–362.

Stuart-Macadam, P. (1991). Porotic hyperstosis: Changing interpretations. In Ortner, D. J., and Aufderheide, A. C. (eds.), *Human Paleopathology: Current Synthesis and Future Options*, Smithsonian Institution Press, Washington, DC, pp. 36–39.

Swannack, J. D., Jr. (1969). *Big Juniper House*, Archaeological Research Series No. 7-C, U.S. Department of the Interior, National Park Service, Washington, DC.

Szarek, S. R., and Ting, I. P. (1977). The occurrence of crassulacean acid metabolism among plants. *Photosynthetica* **11**: 330–342.

Szarek, S. R., and Troughton, J. H. (1976). Carbon isotope ratios in crassulacean acid metabolism plants: Seasonal patterns from plants in natural stands. *Plant Physiology* **58**: 367–370.

Szuter, C. R. (1991). *Hunting by Prehistoric Horticulturalists in the American Southwest*, The Evolution of North American Indians (Thomas, D. H., Ser. ed.), Garland, New York.

Teeri, J. A. (1988). Interaction of temperature and other environmental variables influencing plant distribution. In Long, S. P., and Woodward, F. I. (eds.), *Plants and Temperature*, Symposia for the Society for Experimental Biology No 42, Company of Biologists, Cambridge, England, pp. 77–89.

Teeri, J. A., and Stowe, L. G. (1976). Climatic patterns and the distribution of C4 grasses in North America. *Oecologia* **23**: 1–12.

Thomas, D. H. (1986). *Refiguring Anthropology: First Principles of Probability & Statistics*, Waveland Press, Prospect Heights, IL.

Tieszen, L. L. (1994). Stable isotopes on the plains: Vegetation and diet determinations. In Owsley, D. W., and Jantz, R. L. (eds.), *Skeletal Biology in the Great Plains: Migration, Warfare, Health, and Subsistence*, Smithsonian Institution Press, Washington, DC, pp. 261–282.

Tieszen, L. L., and Fagre, T. (1993a). Effect of diet quality and composition on the isotopic composition of respiratory CO_2, bone collagen, bioapatite, and soft tissues. In Lambert, J. B., and Grupe, G. (eds.), *Prehistoric Human Bone-Archaeology at the Molecular Level*, Springer-Verlag, Berlin, pp. 121–155.

Tieszen, L. L., and Fagre, T. (1993b). Carbon isotopic variability in modern and archaeological maize. *Journal of Archaeological Science* **20**: 25–40.

Toll, M. S. (1988). Flotation sampling: Problems and some solutions, with examples from the American Southwest. In Hastorf, C. A., and Popper, V. S. (eds.), *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains*, University of Chicago Press, Chicago, pp. 36–52.

Tschauner, H. (1996). Middle range theory, behavioral archaeology, and postempiricist philosophy of science in archaeology. *Journal of Archaeological Method and Theory*, **3**: 1–30.

Upham, S., MacNeish, R. S., Galinat, W. C., and Stevenson, C. M. (1987). Evidence concerning the origins of maize de ocho. *American Anthropologist* **89**: 410–419.

van der Merwe, N. J. (1982). Carbon isotopes, photosynthesis, and archaeology. *American Scientist* **70**: 596–606.

Van Ness, M. A. (1986). *Desha Complex Macrobotanical Fecal Remains: An Archaic Diet in the American Southwest*, Master's thesis, Department of Anthroplogy, Northern Arizona University, Flagstaff.

Vermillion, J. H. (1939). The structure of the El Paso polychrome culture. Manuscript on file, El Paso Archaeological Society, El Paso, TX.

Vogel, J. C. (1978). Isotopic assessment of the dietary habits of ungulates. *South African Journal of Science* **74**: 298–301.

Vogel, J. C., and van der Merwe, N. J. (1977). Isotopic evidence for early maize cultivation in New York State. *American Antiquity* **42**: 238–242.

Wagner, G. E. (1988). Comparability among recovery techniques. In Hastorf, C. A., and Popper, V. S. (eds.), *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains*, University of Chicago Press, Chicago, pp. 17–35.

Wagner, G., Smart, T., Ford, R. I., and Trigg, H. (1984). Ethnobotanical recovery, 1982: Summary of analysis and frequency tables. In Nichols, D. L., and Smiley, F. E. (eds.), *Excavations on Black Mesa, 1982: A Descriptive Report,* Center for Archaeological Investigations, Research Paper No 39, Southern Illinois University, Carbondale, pp. 613–632.

Walker, P. L. (1985). Anemia among prehistoric Indians of the American Southwest. In Merbs, C. F., and Miller, R. J. (eds.), *Health and Disease in the Prehistoric Southwest,* Anthropological Research Paper No. 34, Arizona State University, Tempe, pp. 139–161.

Watson, P. J. (ed.) (1974). Theoretical and methodological difficulties encountered in dealing with paleofecal material. In *Archeology of the Mammoth Cave Area,* Academic Press, New York, pp. 239–241.

Welkie, G. W., and Caldwell, M. (1970). Leaf anatomy of species in some dicotyledon families as related to the C3 and C4 pathways of carbon fixation. *Canadian Journal of Botany* **48**: 2135–2146.

Wetterstrom, W. E. (1978). Plant remains from Mesilla and El Paso phase sites of the Hueco Bolson: A preliminary report on plant foods. In *Settlement Patterns of the Western Hueco Bolson* (Whalen, M. E.), Publications in Anthropology No. 6, Centennial Museum, University of Texas at El Paso, El Paso, pp. 230–242.

Whalen, M. E. (1977). *Settlement Patterns of the Eastern Hueco Bolson,* Publications in Anthroplogy No. 4, El Paso Centennial Museum, University of Texas at El Paso, El Paso.

Whalen, M. E. (1978). *Settlement Patterns of the Western Hueco Bolson,* Publications in Anthropology No. 6, El Paso Centennial Museum, University of Texas at El Paso, El Paso.

Whalen, M. E. (1981). Cultural-ecological aspects of the pithouse-to-pueblo transition in a portion of the Southwest. *American Antiquity* **46**: 75–92.

Whalen, M. E. (1994a). *Turquoise Ridge and Late Prehistoric Residential Mobility in the Desert Mogollon Region,* Anthropological Papers No. 118, University of Utah Press, Salt Lake City.

Whalen, M. E. (1994b). Moving out of the Archaic on the edge of the Southwest. *American Antiquity* **59**: 622–638.

Whallon, R. (1975). Variables and dimensions: The critical step in quantitative typology. In Whallon, R., and Brown, J. A. (eds.), *Essays on Archaeological Typology,* Center for American Archaeology Press, Evanston, IL, pp. 127–161.

Wills, W. H. (1988). *Early Prehistoric Agriculture in the American Southwest,* School of American Research, Sante Fe, NM.

Wills, W. H. (1992). Plant cultivation and the evolution of risk-prone economies in the prehistoric American Southwest. In Gebauer, A. B., and Price, T. D. (eds.), *Transitions to Agriculture in Prehistory,* Monographs in World Archaeology No. 4, Prehistory Press, Madison, WI, pp. 153–176.

Woodbury, R. B., and Zubrow, E. B. W. (1979). Agricultural beginnings, 2000 B.C.–A.D. 500. In Ortiz, A. (ed.), *Southwest,* Handbook of North American Indians, Vol. 9 (Sturtevant, W. C., gen. ed.), Smithsonian Institution Press, Washington, DC, pp. 43–60.

Wright, M. K. (1990). *Sandstone and Cornmeal: Experimental Use of Early Pueblo Maize Grinding Tools from Southwestern Colorado,* Unpublished Master's thesis, Department of Anthropology, Washington State University, Pullman.

Yarnell, R. A. (1974). Plant food and cultivation of the Salts Cavers. In Watson, P. J. (ed.), *Archaeology of the Mammoth Cave Area,* Academic Press, New York, pp. 113–122.

Yohe, R. M., II, Newman, M. E., and Schneider, J. S. (1991). Immunological identification of small-mammal proteins on aboriginal milling equipment. *American Antiquity* **56**: 659–666.