Formation Processes of the Archaeobotanical Record
Author(s): Charles H. Miksicek
Source: *Advances in Archaeological Method and Theory*, Vol. 10 (1987), pp. 211-247
Published by: Springer
Stable URL: http://www.jstor.org/stable/20210089
Accessed: 25-08-2015 13:41 UTC

4

Formation Processes of the Archaeobotanical Record

CHARLES H. MIKSICEK

Office of Arid Lands Studies
University of Arizona
Tucson, Arizona 85721

INTRODUCTION

Archaeobotany is the art and science of recovering, identifying, and interpreting plant remains from archaeological sites. Some authors (notably Ford 1979; Renfrew 1973) prefer to call the discipline paleoethnobotany, stressing the relationships between past cultures and the plant kingdom, but both terms will be used synonymously in the following discussion. This article will focus on the preserved traces of ancient food plants but other types of botanical remains including fibers, wood, charcoal, pollen, and plant crystals will also be mentioned briefly.

The formal study of plant remains from archaeological sites can be traced back to at least 1826 when Kunth published an analysis of "mummified" cereals, fruits, and seeds from dry Egyptian tombs (Kunth 1826). Other pioneering efforts in archaeobotany also focused on sites with exceptional organic preservation. These included Heer's (1866) treatise on seeds from waterlogged deposits associated with lake dwellings in Switzerland, examinations of botanical materials in mummy bundles from the arid coast of Peru by de Rochebrune (1879) and Wittmack (1888), and Harshberger's

ADVANCES IN ARCHAEOLOGICAL
METHOD AND THEORY, VOL. 10

(1896) analysis of plant remains preserved in dry rock shelters in southwestern Colorado. A brief paper by Mills (1901) on carbonized seeds from Baum Village in Ohio broadened the domain of archaeobotanical research by demonstrating that even open sites with less than optimal preservation conditions could yield suitable material for careful botanical analysis. During the first half of this century paleoethnobotanical reports gradually became more common, and by the era of the large interdisciplinary projects of the 1950s and 1960s, many archaelogical research teams included one or more botanists in their roster of specialists. [A detailed history of the development of paleoethnobotany is beyond the scope of this article. For a more complete discussion of the development of the discipline from the European perspective see Renfrew (1973: 1-6) or for the American viewpoint, see Ford (1979: 291-297).]

Within the last two decades, archaeobatany has undergone a methodological revolution with the adoption of flotation (water separation) as a tool for recovering small charred plant remains. Although Struever (1968) deserves credit for popularizing flotation, the technique itself was pioneered over a century earlier. In 1860 Professor Unger, an Austrian botanist, dissolved ancient Egyptian adobe bricks in water and examined the residue for traces of cereals and other seeds (Wittmack 1905: 6). Hendry (Hendry and Kelly 1925) and V. Jones (Montgomery *et al.* 1949: 88) used a similar technique to recover plant remains preserved in mud bricks from historic mission buildings in California, Arizona, and northern Mexico. Cutler was one of the first archaeobotanists to apply flotation to general site fill, testing the method at Tularosa Cave, Higgins Flat Pueblo, and Point of Pines in the early 1950s (Watson 1976: 78-79). Matson (1955) experimented with water separation for concentrating charcoal for radiocarbon dating and noted that it also yielded numerous small charred seeds and nutshell fragments. (For a more complete discussion on various flotation techniques and their development see Watson 1976.)

Concurrent with the wider application of flotation, archaeobotany is also undergoing a theoretical revolution. A common theme in many articles published over the last two decades is a careful reexamination of the nature of the prehistoric botanical record. Archaeological sites do not contain pristine samples of all of the plants used by ancient peoples. A plant part may undergo many transformations between the time it was harvested by someone in the past and the time when it is quantified, measured, and reported on in an archaeological monograph. Organic preservation varies in different types of natural environments. Not all types of plant materials are equally well represented in a given site. Environmental processes may introduce more recent material, mix deposits, or destroy fragile plant fragments. Cultural factors such as site type, processing methods, or discard patterns affect the archaeobotanical record. Even the sampling strategies and analytical techniques employed by the paleoethnobotanist may alter the data base. These natural, cultural, and analytical transformations, henceforth called formation processes after Schiffer (1976, 1983), are the focus of this paper.

PRESERVATION ENVIRONMENTS

First of all it is important to consider the natural conditions that favor "the survival of the evidence" (Renfrew 1973). Archaeological sites have been discovered in environmental settings ranging from arctic tundra to tropical rainforest. What kinds of sites in what localities offer the best potential for the preservation of ancient botanical remains? Table 4.1 presents a hypothetical comparison of the preservation potential of different categories of biological remains in various types of sites. Tables 4.2 and 4.3 summarizes the densities of seeds actually recovered from representative sites.

Archaeologists have tended to overlook the contribution of plants to the subsistence of hunters or pastoralists living at high latitudes or elevations. Nevertheless, plants probably provided food for animals, seasonal dietary supplements, and raw materials for tools and shelters. Frozen sites, where the decomposition of organic material is limited by constant temperatures at or below freezing, offer great, almost untapped potential for archaeobotanical research. A cache of hemp seeds was found in association with a copper censer and felt tent in a Scythian tomb in the Altai mountains of Siberia (Rudenko 1970). Lowland tropical plant remains were identified from the unlikely locality of dry, cold rock shelters associated with adze quarries at an elevation of 4205 meters on Mauna Kea in Hawaii (M. S. Allen, personal communication).

Peat bogs are a specialized class of waterlogged sites in which the constantly wet, anaerobic environment, combined with low pH from humic and tannic acids, produce some of the best conditions for the preservation of ancient plant remains. Bogs have long been favored sampling localities for palynologists. Unfortunately for faunal specialists, the acidity of the soil is very deleterious to the preservation of bone and shell (hence the low scores in Table 4.1). On the other hand, hair, hide, and the chitinous exoskeletons of insects may survive in almost pristine condition. The peat bogs of northern Europe, especially Denmark, have yielded a number of remarkably preserved human bodies (Glob 1971). Analyses of the stomach contents of two individuals from Tollund and Grauballe have been completed by Helbaek (1950, 1958) and Hillman (1981). Hillman is currently engaged in similar research on a recently discovered English "bog man" from Cheshire.

TABLE 4.1

Differences in the Preservation of Biological Remains in Various Types of Site Environments[a]

Types of remains	Preservation environment					
	Frozen sites	Peat bogs (wet, acid)	Waterlogged sites (wet, anaerobic)	Open sites (moist soil)	Open sites (dry soil)	Dry caves
Human bone	+ + +	+	+ +	+ +	+ + +	+ + +
Animal bone	+ + +	+	+ +	+ +	+ + +	+ + +
Coprolites	+	+	+	—	—	+ + +
Parasites	+ +	+ +	+ +	—	—	+ + +
Shell	+ + +	+	+ + +	+ +	+ + +	+ + +
Insect remains	+ + +	+ + +	+ + +	—	+	+ + +
Pollen	+ + +	+ + +	+ + +	+	+ +	+ + +
Phytoliths	+ + +	+ +	+ + +	+ +	+ +	+ + +
Other crystals	+ + +	—	—	—	+	+ + +
Wood	+ + +	+ + +	+ + +	—	+	+ + +
Charcoal	+ + +	+ + +	+ + +	+ +	+ +	+ + +
Fresh seeds	+ + +	+ + +	+ + +	—	+	+ + +
Charred seeds	+ + +	+ + +	+ + +	+ +	+ +	+ + +
Basketry or fibers	+ + +	+ + +	+ + +	—	+	+ + +
Leather	+ + +	+ +	+ +	—	—	+ +

[a] Quality of preservation: + + +, excellent; + +, fair; +, poor; —, generally not preserved.

TABLE 4.2

The Density of Carbonized Seeds in Open Archaeological Sites Sampled by Flotation

Site	Age or type of site	Seeds[a]/ liter	Reference
Sites in wet, tropical regions			
Cuello, Belize	Early Formative Maya	0.11	Hammond and Miksicek 1981
	Late Formative Maya	0.94	
Pulltrouser Swamp, Belize	Early Formative Maya	0.58	Miksicek 1983a
	Terminal Classic Maya	0.18	
	Raised fields	0.18	
Sites in moist, temperate regions			
Kameda Peninsula, Japan	Initial Jōmon	0.30	Crawford 1983
	Early Jōmon	0.59	
	Middle Jōmon	1.70	
Koster, Illinois	Middle and Late Archaic	0.05	Asch *et al.* 1972
American Bottoms, Illinois	Late Archaic	0.28	Johannessen 1984
	Middle Woodland	0.69	
	Late Woodland	1.52	
	Mississippian	3.48	
Micheldever Wood, Britain	Iron Age	0.59	Fasham and Monk 1978
Winklebury, Britain	Iron Age	1.82	Keepax 1977
Mirobriga, Portugal	Late Iron Age	1.71	Miksicek 1984c
Coon Dog, Illinois	Middle Woodland	0.65	Lopinot and Brussell 1982
	Late Woodland	1.84	
Little Egypt, Georgia	Protohistoric	1.81	Hally 1981

(continues)

TABLE 4.2 *(continued)*

Site	Age or type of site	Seeds[a]/ liter	Reference
Sites in semi-arid regions			
Tumamoc Hill, Arizona	Late Archaic	1.62	Fish *et al.* 1986
Coronado Project, Arizona	Pueblo I–III Anasazi	6.41	Gasser 1982
Salmon Ruin, New Mexico	Pueblo II–III, Anasazi trash	29.32[b]	Doebly 1981
	Pueblo II–III, Anasazi rooms	11.09[b]	Adams 1980
El Morro Valley, New Mexico	Late Pueblo III, Anasazi	9.96	Miksicek unpublished
Pueblo Las Fosas	Classic Hohokam	6.41	Miksicek 1983c
Nolic, Arizona	Modern Papago	2.55	Miksicek 1983b
Saguaro Camp, Arizona	Modern Papago	8.30	Miksicek and Fish 1981

[a] Includes edible or useful plant parts other than wood.
[b] Not all seeds carbonized.

TABLE 4.3

The Density of Preserved Plant Remains in Sites with Excellent Preservation

Site	Age or type of site	Seeds[a]/ liter	Reference
Sites or features with evidence of catastrophic fires			
Green Bear, Arizona	Pueblo I, Anasazi	125.28	Miksicek 1978
Tanque Verde Wash, Arizona	Hohokam storage structures	287.55	Miksicek 1986a
Dakota Wash, Arizona	Classic Hohokam cremations	487.71	Miksicek 1986b
Homolovi II, Arizona	Proto-Hopi storage rooms	269.01[b]	Miksicek 1985
Hatun Xauxa, Peru	Inca storage rooms	368.80	D'Altroy and Hastorf 1984
Dry sites[c]			
Tehuacan Valley, Mexico	Coxcatlan Phase	150.03	Smith 1967
	Venta Salada Phase	4667.85	
Lurin Valley, Peru	Late Horizon Midden	24.32	Cohen 1975
Waterlogged sites[c]			
Aartswoud, Netherlands	Coastal Neolithic village	14.29	Pals 1984
Clairvaux, France	Neolithic lakeshore village	669.07	Lundstrom-Baudais 1984
Carthage Harbor, Tunisia	Punic deposits	204.76	van Zeist and Bottema 1983
	Roman deposits	119.35	
	Byzantine deposits	781.67	
Lower Rhineland, Germany	Roman cesspits	340.95	Knorzer 1984
	Medieval cesspits	202.51	
	16–18th century cesspits	767.44	

[a] Includes edible or useful plant parts other than wood.

[b] Not all seeds carbonized.

[c] Almost all of the material from the dry and waterlogged sites was uncarbonized.

The more generalized class of waterlogged sites shares many features in common with peat bogs but lacks the acid conditions. The more neutral pH is conducive to the preservation of bone and shell (Table 4.1). Noteworthy analyses have been performed on plant remains from waterlogged deposits including Swiss and French lakeshore dwellings (Heer 1866; Lundstrom-Baudais 1984), the Mesolithic village of Star Carr in Britain (Clark 1954), Roman timber-lined pits and middens below modern London (Willcox 1977), Carthage harbor (van Zeist and Bottema 1983), Neolithic Dutch coastal villages (Pals 1984), German privy pits (Knorzer 1984), and the Olympic Peninsula villages of Ozette and Hoko River in Washington State (Croes and Blinman 1980).

At the other extreme of the moisture scale, a constantly dry environment, such as that found in some caves and rock shelters, is conducive to the preservation of plant remains. Localities with abundant dehydrated botanical refuse include dry passages of Salts and Mammoth caves in Kentucky (Watson 1969, 1974; Yarnell 1974), rockshelters in the Tehuacan Valley of Mexico (Smith 1967; MacNeish 1967), cliffdwellings in southwestern Colorado (Harshberger 1896), Egyptian tombs (Kunth 1826), and the coastal desert of Peru (de Rochebrune 1879; Wittmack 1888; Cohen 1975; Pozorski 1983).

Freezing, acidity, waterlogging, and aridity are macroscale environmental factors that favor botanical preservation. In rare instances uncharred plant remains may persist in open sites due to microscale chemical effects. During recent excavations at the Roman site of Curium on Cyprus, in which this author participated, flax fibers preserved by copper salts leaching from the alloy were discovered during the microscopic examination of bronze objects. The copper salts mineralized the fibers and acted as a strong fungicide. Wooden tools and baskets dating at least to the Roman period have been recovered from ancient copper mines in Cyprus. In the eastern United States, where pollen preservation is often marginal, good recovery was noted from soil adjacent to copper artifacts or bark with high tannin levels (King *et al.* 1975). Using scanning electron microscopy, Keepax (1975) was able to identify wood fragments preserved by corrosion products from iron artifacts such as nails. In soils with a high phosphate content, uncharred seeds may be preserved by mineralization, especially in coprolites or ancient latrines (Green 1979). Fossilization by casting or mineral replacement may also involve silicates, carbonates, gypsum, or calcite. Seeds with naturally high concentrations of calcium carbonate in their seed coats, such as hackberry (*Celtis* spp.) or some sedges such as razorgrass (*Scleria* spp.), will survive for millenia without carbonization. Some types of wood, such as juniper, with a high resin and terpenoid content may persist for over a thousand years in relatively dry, open sites.

Another type of mineralization occurs as a natural result of transpiration. In most members of the plant kingdom, but especially grasses and palms, hydrated silica from groundwater is precipitated in epidermal tissue as silica bodies, plant opals, or phytoliths, as they have been referred to in the paleoecological literature (Rovner 1983). These silica bodies are casts of the epidermal cells, so they can be relatively distinctive to taxonomic groups. As leafy plant material decays in soil, assemblages of phytoliths are left behind. Only strongly alkaline soils seem to be relatively poor environments for the preservation of silica bodies (Rovner 1983). Pearsall (1978) utilized phytolith analysis to attempt to document maize agriculture in early deposits from Real Alto that contained few other preserved plant remains. Pearsall (1983) also suggested early cultivation of *achira* (*Canna edulis*), a root crop, based on the identification of distinctive chains of "phytoliths." These *achira* crystals should more properly be referred to as calcium oxalate druses, which have a different biochemical origin and composition. These oxalate crystals are included in the "Other Crystal" category in Table 4.1, along with calcium carbonate cystoliths, both of which are adversely affected by acidic environments.

PRESERVATION BY CARBONIZATION

Frozen, acidic, waterlogged, permanently dry, or chemically unique localities account for only a small percentage of the sites that archaeologists investigate. The most frequently encountered sites are in open, well-drained areas with alternating wet and dry conditions. Fluctuating moisture levels in well-aerated soil are conditions favorable to the growth of bacteria, fungi, insects, and other decomposers that break down organic matter. In these open sites, plant remains are likely to be preserved for long periods of time only if they have been charred.

Complete carbonization occurs when plant materials are subjected to temperatures between 250 and 500°C under low oxygen conditions (Hillman 1981; Lopinot 1985). Rapid burning at high temperatures with abundant oxygen reduces organic remains to mineral ash. Carbonization reduces a seed or fruit to 50 to 60% elemental carbon (Meyer 1980: 403), which is very resistant to further organic decay. Mechanical damage is about the only process that will destroy a completely charred seed.

Occasionally, whole sites may be destroyed by a catastrophic conflagration. The eruption of Mount Vesuvius in A.D 79 froze the cities of Pompeii and Herculaneum in a moment of time and preserved a fairly complete cross section of Roman food plants by carbonization (Meyer 1980). The explosion of Ilopango Volcano in El Salvador in approximately A.D. 260 buried a Maya farmstead and an associated *milpa* (traditional field) with germinating corn (*Zea*) seedlings in ash (Zier 1980). In the American Southwest, it is not uncommon to find individual structures or occasionally whole sites destroyed by fires. In these rare circumstances, a relatively complete inventory of plants available at one time may be preserved. In sites that have not been destroyed by a catastrophic fire, only certain types of plant remains are likely to be preserved by charring.

The likelihood that a given type of plant remain will be preserved in the archaeological record by carbonization is related to whether or not it is directly exposed to fire during use or processing for consumption or storage.

Munson *et al.* (1971: 427) divided plant foods into three categories based on "preservability" and potential visibility in the archaeological record. This approach has been reiterated and expanded on by many other authors, for example Dennell (1976), Minnis (1981), or Hammond and Miksicek (1981).

The first group includes foods with dense, inedible parts such as nutshells, maize cobs, or olive pits. After the edible part is removed, the waste products may be recycled as a supplemental fuel. Massive quantities of hickory (*Carya*) nutshell have been reported from many sites in the eastern United States. Charred fragments of corncobs are perhaps the most ubiquitous remains in Southwestern sites. Ford and Miller (1978) suggested that the abundance of charred olive (*Olea*) pits in flotation samples from Carthage and other Near Eastern and Mediterranean sites may be due to the use of waste from olive oil presses, which included pits and was used as a fuel in ancient lime kilns, furnaces, ovens, and hearths.

The second group includes plant foods, such as edible seeds, that were commonly parched before consumption or storage. For example, toasting mesquite pods (*Prosopis*) enhances their flavor, makes them easier to grind, and also kills bruchid beetles that could destroy much of the harvest during storage. Many small seeds, such as those of pigweed (*Amaranthus*) and lamb's-quarters (*Chenopodium*), were commonly popped in much the same way as popcorn. Dennell (1976) and Hillman (1981, 1984) suggest that many of the hulled cereals need to be toasted lightly to loosen the adherent glumes before pounding or threshing. Complete carbonization of plant foods in this second category would only be accidental, when a few seeds spilled into a hearth, or a batch of seeds was allowed to get too hot during the parching process.

The third category includes nondense plant foods with a high moisture content, such as leafy greens, pulpy fruits, or edible tubers. Since most of these are either eaten fresh (and often away from sites as snacks) or boiled they are not very likely to be preserved by carbonization. If by chance they did get charred, the fragmentary remains of tubers or greens would be very fragile and difficult to identify except by careful anatomical examination under a scanning electron microscope. This category is only likely to be represented archaeologically by the occasional pit from a fleshy fruit spat into a hearth. Although medicinal herbs are not technically foods, they could be included with this group as they are commonly prepared as teas or poultices and are therefore likely to be very underrepresented in archaeological sites.

Even within the above plant food categories (nuts, seeds, fruits), not all taxa are equally likely to be preserved. Lopinot (1985) experimentally carbonized nine different species of nuts commonly recovered from sites in eastern North America at temperatures ranging from 200 to 900 °C. Thick-shelled nuts such as hickory and walnut (*Juglans*) survived charring better than thin-shelled types such as acorns (*Quercus*) and chestnuts (*Castanea*). Lopinot concluded that because of differential preservation after carbonization and the greater edible meat to shell ratio of acorns and chestnuts, the contribution of these two taxa to Archaic and Woodland subsistence in eastern North America has been greatly underestimated. In a similar test using 12 common types of European weed species and 12 different experimental treatments (varying time, temperature, and moisture content), Wilson (1984) concluded that seeds with oily or mucilaginous endosperm were less likely than starchy or proteinaceous ones to be preserved, recovered, and identified from archaelogical sites.

APPROACHES TO UNDERSTANDING DIFFERENTIAL PRESERVATION

Ethnoarchaeology

Laboratory experiments such as those conducted by Lopinot and Wilson are one approach to understanding differential preservation. Ethnoarchaeology may offer other clues. During the summer of 1980, I had the opportunity to observe traditional Papago saguaro fruit (*Carnegiea*) harvesting and processing in the desert west of Tucson, Arizona. The following spring, Fish and I returned to the saguaro camp to sample various processing loci for pollen and charred seeds (Miksicek and Fish 1981). All of the flotation samples collected produced saguaro seeds, but 44.4% of these samples produced charred seeds. A total of 2088 saguaro seeds were recovered, of which only 11.3% were carbonized. All of the charred seeds were recovered from hearths or ash dumps. During the process of reducing saguaro pulp to syrup or jam by boiling, foam rises to the top of the cooking vessel and is continuously skimmed away. This foam, which contains seeds, is usually tossed into the firepit, where some of the seeds are charred. Each saguaro fruit contains approximately 15 gm of edible pulp and 2000 seeds. During the morning that I observed saguaro processing, approximately 8 kg of pulp, containing over a million seeds, was reduced to syrup and jam. The flotation samples yielded evidence for approximately 0.2% of a morning's work, of which only 0.02% was carbonized. The problem of underrepresentation is even worse if you consider that the same camp may have been used fairly continuously over a 5- to 6-week period during saguaro season (June through July). Our informant's family had been coming to the same locality for over 60 years. A single charred saguaro seed could therefore represent the distilled essence of 0.03 kg (1 day), 0.9 kg (1 season), or 7.6 kg (60 years) of saguaro pulp. In order to be able to estimate that a given plant food accounted for a certain percentage of the prehistoric diet, similar correction factors (transfer functions) would have to be derived for each type of plant remain recovered from an archaeological site. Even so, there would be no way to account for archaeologically invisible categories such as greens or tubers.

Significant amounts of saguaro pollen (higher than levels in control samples collected away from the camp) were recovered from 35.7% of the samples analyzed by Fish. In contrast to the distribution of charred seeds, saguaro pollen counts were lowest in fire pits and ash piles and highest in the area where the initial opening and processing of the fruit occurred. The high frequency of saguaro pollen in this area may be partially explained by the use of the dried saguaro blossom as a natural "can opener" for splitting open the fruit.

An interesting sidelight was noted during this study of a saguaro camp. A pack rat (*Neotoma* sp.) had moved into the roof of one of the ramadas and built a nest after the saguaro harvest was over. This nest contained numerous seeds and other plant parts (as well as associated pollen) that had been collecteld by the pack rat. If the ramada had been destroyed by a fire, the only clue that some of the seeds from this structure were collected by pack rats and not people would have been the presence of charred, rodent fecal pellets. I have noticed similar occurrences of carbonized fecal pellets in a number of Hohokam structures that had burned during or after use. The introduction of seeds by the pack rat is one example of faunalturbation, a topic that will be discussed in a later section.

Ethnoarchaeological experiments such as this will become increasingly more important in understanding the archaeobotanical record. In an examination of plant remains from the Hopi village of Walpi, Gasser and Adams (1981) noted that only 0.3% of the seeds in deposits younger than 60 years were charred, whereas 8.6% of the seeds from rooms over 65 years old were carbonized. Microbial, rodent, and insect activity had destroyed some of the unburned plant material in the older sample. Rodents seemed to prefer oily seeds such as squash (*Cucurbita*), melon (*Citrullus*), juniper (*Juniperus*), pinyon (*Pinus edulis*), peach (*Prunus persica*), and cherry (*Prunus cerasus*). Insect damage was most severe on maize and beans (*Phaseolus*). This study also suggested an additional explanation for the paucity of beans in the archaeobotanical record. Beans, which are usually prepared by soaking and boiling, are rarely ever charred. Gasser and Adams (1981) noted that beans are more susceptible to fungal damage during storage than most other seed types.

In an ethnoarchaeological study of modern cholla (*Opuntia*) roasting pits by Greenhouse *et al.* (1981), five carbonized spine clusters were the only charred evidence for cholla buds, and only a few clumps of *Cylindropuntia* pollen were noted in pollen samples. Cheno-am (Chenopodiaceae and Amaranthaceae) pollen from seepweed (*Suaeda*) utilized during the cooking process was the most conspicuous evidence for cholla roasting.

Dennell (1974, 1976), Hubbard (1976), Hillman (1981, 1984), and Jones (1984) have analyzed samples of modern seeds and chaff from various stages of traditional crop processing methods still practiced in Greece and Turkey. They predict that tailings, the residue left after winnowing or sieving, should contain smaller cereal grains and more weeds than the cleaned end product ready for storage. Measurements on charred seeds from tailings tossed into a fire for fuel would be significantly smaller than samples of clean grain from a granary destroyed by a catastrophic fire. Cereals harvested by uprooting should be mixed with more weed seeds and stem bases than those reaped with sickles. Crops from plowed fields should have different weedy assemblages than those from fields tilled by other methods. Hulled wheats (*Triticum*) or glumed barley (*Hordeum*), which are often processed by parching to loosen the chaff, are more likely to be preserved than bread wheats or naked barley. Based on these ethnographic models, Hillman (1981) has suggested that the stomach contents of the Tollund and Grauballe Men may represent the tailings from a cereal crop, rather than the prime harvest. Jones (*et al.* 1986) was able to identify several different stages of processing in samples of grain from Mycenaean storerooms at Assiros in Greece.

Comparison of Coprolites and Flotation Samples

The comparison of the range and quantities of plant remains in open sites to those recovered from contemporaneous and culturally related deposits with better preservation may offer another approach to understanding preservation differences. Yarnell (1974) pioneered this method in his comparison of taxa in flotation samples and human coprolites from Salts Cave in Kentucky. Yarnell found a fairly close correspondence between the two data sets. Nutshell fragments and *Chenopodium* seeds were more abundant in the flotation samples (large quantities of nutshell were probably not consumed, and ground chenopod seeds may have been almost completely digested).

Gasser (1982) conducted a similar comparison of the results of flotation and coprolite analysis for the Anaszai area of the Southwest. In Gasser's study, squash and beans, prepared by boiling, are grossly underrepresented in flotation samples, while maize is only slightly underrepresented. Fresh fruits are generally underrepresented. Since many spinachlike greens yield a second harvest of edible seeds, they may be indirectly represented in the flotation record. Gasser's data were assembled from many different sites and probably contain biases derived from differences in seasonality, age, or site function.

It may be useful to compare coprolites and macrofossils recovered from a single site. Table 4.4 contains such a comparison for plant remains from the Tehuacan Valley in Mexico. In dry caves, root crops such as pochote or fresh fruits such as sapote, chile, avocado, hogplum, or various cactus fruits may be well represented. The abundance of plant remains in the bulk samples reflects the amount of waste material derived from food processing that is never seen in open sites. Early maize is almost synonymous with the Tehuacan Valley, but it is interesting to note that only 9% of the coprolites produced evidence for maize consumption. Perhaps this is because maize kernels are not very recognizable after they have been ground and passed through the human digestive system. Difficulties with identification may also partially explain the underrepresentation *in coprolites* of many of the Tehuacan plant remains that are well represented as macrofossils. Future comparisons of plant remains from coprolites and flotation samples, or between open and protected sites, may help identify many missing or underrepresented taxa.

CULTURAL TRANSFORMATIONS OF THE ARCHAEOBOTANICAL RECORD

The effects of processing methods on the archaeobotanical record, which has already been discussed, is one example of a cultural transformation. A combination of many other cultural formation processes may produce significant patterns of their own.

At this point, it would be useful to define *de facto,* primary, and secondary refuse as they relate to plant remains. *De facto* refuse is defined as usable material abandoned in an activity locus (Schiffer 1976; Rathje and Schiffer 1982). True examples of *de facto* refuse are relatively rare in the archaeobotanical record. Caches of seeds are occasionally found in sealed, ceramic ollas in dry sites in the Southwest. These caches are so rare that they have inspired an elaborate oral mythology concerning viable seeds germinated from these deposits (Nabhan 1977). Collections of plant remains preserved by catastrophic fires could be considered as *de facto* refuse, although the term "usable" in the definition no longer really applies. Primary refuse is defined as trash discarded at the location of use (Schiffer

TABLE 4.4

A Comparison of Coprolites and Plant Macrofossils from the Tehuacan Valley: The Problem of Differential Preservation[a]

Plant[b]	Samples containing plant material (%)	
	Coprolites (N = 87)	Bulk samples (N = 51)
Almost equal		
Pochote (*Ceiba*)(b,r)	59	61
Millet (*Setaria*)(p)	59	45
Black sapote (*Diospyros*)(f)	26	31
Other grass (p)	25	27
Overrepresented in bulk samples		
Agave (*Agave*)(r)	50	92
Mesquite (*Prosopis*)(p)	16	53
Organ pipe (*Lemaireocereus*)(f)	16	24
Prickly pear cactus (*Opuntia*)(f)	11	61
Chile (*Capsicum*)(f)	11	31
Beans (*Phaseolus*)(b)	11	25
Maize (*Zea*)(p,b,r)	9	72
Squash (*Cucurbita*)(b)	3	47
Coyol palm (*Acrocomia*)(f)	0	33
Amaranth (*Amaranthus*)(p)	0	35
Hogplum (*Spondias*)(f)	0	43
Avocado (*Persea*)(f)	0	45
Cotton (*Gossypium*)(p)	0	47
Underrepresented in bulk samples		
Other cacti (f)	50	33
Groundcherry (*Physalis*)(f)	22	4
Manioc (*Manihot*)(b,r)	11	0

[a] Data from Callen 1967; Smith 1967.

[b] Common method of preparation: b, boiled; f, fresh; p, parched; r, roasted.

1976; Rathje and Schiffer 1982). The charred saguaro seeds recovered from the cooking pits in the saguaro camp example discussed above are botanical examples of primary refuse, as are the cholla spines and pollen from the roasting pit example (Greenhouse *et al.* 1981). Secondary refuse is defined as trash deposited at some location other than the location of use (Schiffer 1976; Rathje and Schiffer 1982). The vast majority of plant remains recovered from archaeological sites should be considered secondary refuse.

One of the most frustrating tasks routinely assigned an archaeobotanist is to figure out the function of a pit from a flotation sample, more often than not, collected somewhere within the fill of that feature. An hypothetical

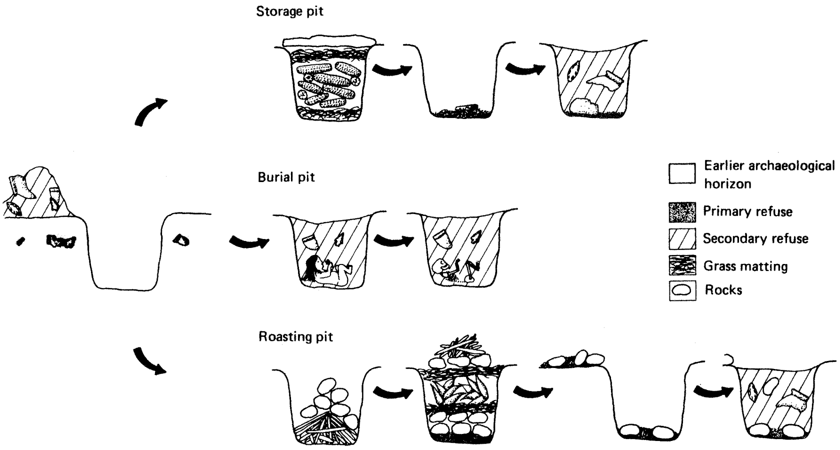

Figure 4.1. Three possible uses of an hypothetical pit, illustrating the deposition of primary and secondary refuse.

example will illustrate some of the problems involved in this task. In Figure 4.1 a "generic" pit with several possible functions was excavated into soil which contained an earlier archaeological stratum. In the first alternative, it was filled with grass matting and ears of corn and used as a storage pit. If it was abandoned at this point, the maize ears and grass would be considered *de facto* refuse, but since they were not carbonized they would soon decompose, leaving behind perhaps some phytoliths and a few grains of pollen. If the ears of maize were removed before they decayed, fragments of grass matting or cobs from which the kernels had been removed might have been left behind as primary refuse. Once again they would probably not be preserved unless they were carbonized. In the end, the storage pit would be filled with a mixture of soil from the initial excavation and any available trash from around the site. This fill would contain a mixture of secondary refuse from both the earlier and current occupations. The fill of this feature, which would probably be identified by an archaeologist as a trash pit, would have no relation at all to the original (storage) function of the pit. Based on experimental studies of replicated Iron Age storage pits at the Butser Experimental Farm in Britain, Reynolds (1979: 71–82) has suggested that most types of grain do not need to be parched for storage in subterranean pits. Residue left after storage might only be burned if there was a desire to sterilize the pit before the next usage.

In the second case, the pit was excavated for immediate use as a burial pit and refilled with the original soil. Secondary refuse from the fill of this burial pit would have little relationship to the burial itself and would actually predate it. Perhaps a few pollen grains or phytoliths from food or floral offerings included with the body would be the only primary material associated with the burial. Leroi-Gourhan (1975) has suggested that unusually high percentages of pollen from insect-pollinated flowers found associated with a Neanderthal grave from Shanidar Cave in Iraq reflect floral offerings intentionally deposited with the burial.

In the third case, the pit was used for roasting agave. A large fire was built in the pit to heat stones. After the fire burned down and the rocks were heated, most of the ashes were removed and the pit was refilled with alternating layers of hot rock, leafy matting, and agave hearts. The pit was then sealed with earth and a second fire was built on top to help complete the roasting process. A few fragments of matting or agave leaves in direct contact with the hot rocks might be preserved by charring. After the cooked agave hearts were removed, some of this charred material and charcoal from the fire would be left behind as primary refuse. Once again, most of the fill of this roasting pit would be secondary refuse, with only a small amount of charred primary refuse at the very bottom of the pit or mixed in with the fill. In recent studies of roasting pits associated with dry farming features northwest of Tucson, Arizona by P. Fish, S. Fish, and myself, agave fibers, thorns, leaf bases, and heart fragments have been identified from every pit sampled by flotation. These agave remains, along with wood charcoal and grass stems, seem to represent primary refuse from the agave roasting process.

How might *de facto*, primary, and secondary refuse appear in real archaeobotanical assemblages? The "Mckellar Hypothesis" (discussed in Rathje and Schiffer 1982) suggests that in areas that are regularly cleaned, small objects are more likely to be left behind as primary refuse. This suggests that flotation samples from hearths that are cleaned or floors that are swept are likely to produce mostly small seeds. Table 4.5 contains size and density data for carbonized seeds from the Tanque Verde Wash site, a small farming village in the eastern Tucson Basin that was occupied between A.D. 1000 and 1100 (Miksicek 1986a). One of the catastrophically burned pit houses was a storage structure with a floor assemblage consisting of 17 reconstructable vessels and over 180,000 charred maize kernels, beans, and squash seeds. Concentrations of predominantly one taxon were associated with some of the vessels, suggesting storage behavior similar to that found by Jones (*et al.* 1986) at Assiros. Two other structures also contained high densities of charred seeds and relatively complete floor assemblages that suggested rapid abandonment. The plant remains from the floors of these pit houses could be considered *de facto* refuse. The seeds were fairly complete (allowing for some damage during excavation and flotation). The overall density of charred material was very high (287.55 seeds/liter) and most of the macrofossils were smaller than 3mm. Structures that were burned

TABLE 4.5

Carbonized Plant Remains from the Tanque Verde Wash Site: Size Sorting and Seed Density

Feature type	Density (seeds/liter)	Large seeds (%)
Castastrophically burned structures	287.55	36.4
Structures burned after abandonment	4.06	42.2
Extramural activity areas	3.41	30.7
Extramural pits	1.95	42.0
Unburned structures	0.69	70.0
Trash mounds	0.52	86.4

after abandonment yielded a much lower density of charred remains (4.06 seeds/liter) with 58% smaller than 3 mm. These small seeds, mostly *Amaranthus,* were probably primary refuse from plant processing that occurred near the hearth. Unburned structures yielded very few charred remains (0.69 seeds/liter) most of which were durable mesquite seeds and maize cob fragments, that is, secondary refuse deposited in the structures after abandonment. This interpretation is strengthened by the similarity with the trash mounds samples. Plant remains from the activity areas and extramural pits were most similar to those from the pit houses that burned after abandonment. Both these categories included hearths and roasting pits, which probably contained primary refuse.

Hally (1981) discovered similar patterns at the Little Egypt site in Georgia. One burned structure yielded a pile of large hickory nutshell fragments next to a hearth (probably to be used as fuel), a cluster of persimmom seeds next to a storage jar, and numerous corncob fragments on the floor (Hally 1981). This patterned floor assemblage, combining a relatively high density of "seeds" (2.28/liter), at least for that site, (see Table 4.3) with the presence of large nutshell fragments (82% were larger than 3 mm), suggests mostly *de facto* refuse. One unburned structure yielded only primary refuse: small cob and nutshell fragments.

Such factors as the overall density of preserved plant remains, their average size, and the degree to which they are complete may help an archaeobotanist recognize the type of deposit from which they originated. Both primary and secondary deposits are likely to contain only limited samples of the potentially preserved range of plants from a site. Secondary trash is likely to be biased toward the larger and more durable end of the scale whereas primary refuse may contain smaller seeds. By sampling both types of contexts, or by taking full advantage of rare *de facto* deposits when they are encountered, a botanical specialist is more likely to identify the total range of taxa preserved in a given site.

The "Schlepp Effect" (discussed in Rathje and Schiffer 1982) was derived from taphonomic studies and has mostly been applied to faunal remains, but it may also have some relevance to archaeobotany. In its original zooarchaeological context, the Schlepp Effect states that the amount of butchering performed on an animal is directly related to the size of the animal and the distance to the place it will be consumed. For a large animal, only the most usable elements will be brought back to the home base. In terms of plant remains, the Schlepp Effect may be interpreted as: the more primary processing of a plant product that occurs at a site, the more waste products will be produced. For example, in Anasazi sites maize seems to have been stored on the cob, but in Hohokam sites maize seems to have been stored in the form of shelled kernels in jars or baskets. Cob fragments are usually only recovered from Hohokam sites situated close to canals or dry farming features. If cotton seeds or calyx fragments are recovered from a Hohokam site, it suggests that cotton was grown and processed nearby. The recovery of only cotton fibers or completed textiles from a dry cave, however, may be interpreted as evidence that the cotton was produced elsewhere and imported to the site.

The "Clarke Effect" (discussed in Schiffer 1983) states that the diversity of artifacts recovered from a site is directly related to the length of occupation of a site. This may be directly applied to archaeobotanical assemblages. Figure 4.2 presents data for the number of types of "seeds" identified from 61 Hohokam sites in southern Arizona. The soild line represents the expected number of taxa for a given number of samples based on a regression of the $\log_{10}$ of the number of samples analyzed against the $\log_{10}$ of the number of taxa identified. The taxon-sample relationship accounts for approximately 41% of the variance in the data set. As more samples are examined the number of rarer taxa encountered increases. It is possible to predict the expected number of taxa from a given number of samples using this log-log relationship. A single 8-liter flotation sample should yield an average of five distinct types of seeds. Each additional five samples should add another taxon. The dashed lines in Figure 4.2 indicate the 95% confidence intervals calculated for 1 to 5, 5–10, 10–20, 20–50, 50–80, and 80–100 samples. Sites were classified as agricultural fields, field houses, farmsteads, hamlets, villages, or primary villages with ceremonial structures such as ball courts or platform mounds based on various archaeological criteria such as number of structures, permancy of construction, amount of accumulated trash, and presence of hearths. Field houses (one or two structures) generally yielded fewer than the expected number of taxa (they tend to fall below the regression line in Figure 4.2). Field house sites also produced lower frequencies of maize and gathered wild plants such as mesquite or saguaro and higher proportions of agricultural weeds. Farmsteads (two to five structures) tend to fall near or below the regression line in Figure 4.2. Hamlets or villages (more than five contemporaneous structures), produced

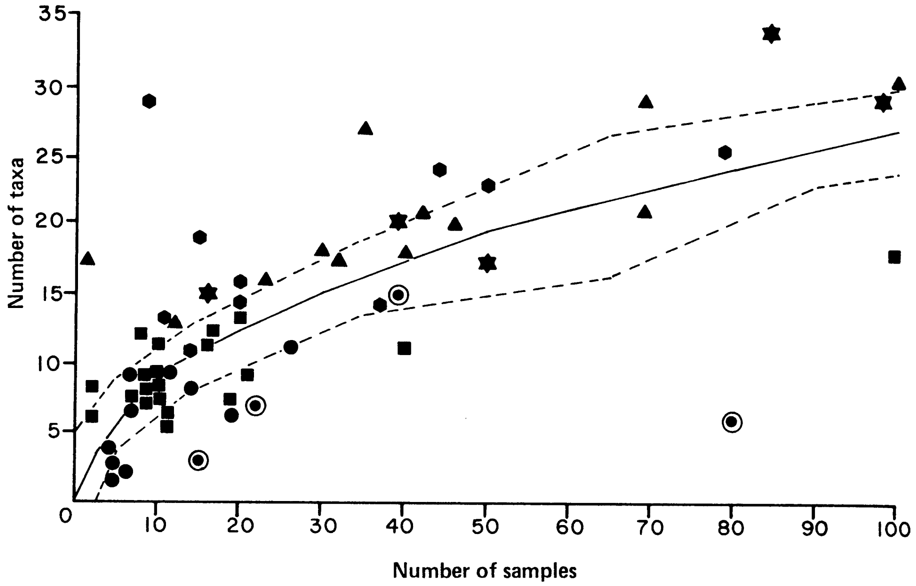

Figure 4.2. The relationship between sample diversity and sample number for 61 sites in southern Arizona. Agricultural fields (⊙); field houses (●); farmsteads (■); hamlets (▲); villages (⬢); villages with ceremonial structures such as ball courts or platform mounds (★).

higher than expected levels of plant diversity, more maize and gathered plants, and fewer agricultural weeds. The villages tended to fall above the regression line in Figure 4.2. These results seem to confirm the Clarke Effect. The longer a site is occupied, the greater the range of activities that will be carried on at that site, and the more diversity of plant remains that will be preserved.

ENVIRONMENTAL TRANSFORMATION PROCESSES

Once charred botanical remains are deposited in an archaeological site, they are subject to any of a number of environmental factors. A very simple relationship is evident from an examination of the data on seed density for various types of open sites presented in Table 4.2. Older sites produce fewer carbonized seeds. Since charred seeds have been reduced to elemental carbon, which is essentially immune to further organic decomposition, it is not age itself that produces this relationship. Small, fragile, carbonized seeds may be mechanically destroyed, mixed, or displaced in the soil by any of the soil formation processes described in Wood and Johnson

(1978). A second relationship is evident in Table 4.2. Sites in more mesic environments produce fewer charred seeds than sites in semi-arid regions. This suggests that these soil formation processes occur more rapidly in moist environments.

Faunalturbation

In the discussion of the saguaro camp example, I mentioned one example of faunalturbation, seeds transported into a site by a pack rat. This is an example of an additive, natural transformation; the addition of new material, completely unrelated to the occupation of a site, by a nonhuman agent. During the excavation of Star Carr, a cache of hazelnuts was uncovered in what appeared to be a good Mesolithic context, but the presence of rodent incisor marks led Clark (1954: 60) to conclude that these nuts had been deposited by squirrels after the occupation of the site. Granivorous rodents or insects may create caches of seeds in sites that completely unrelated to the human occupation of the same site. Since most archaeobotanists working in open sites use the general rule that only carbonized seeds should be considered ancient this should not be too much of problem. Intrusive seeds are not always so easily recognized in waterlogged sites or dry caves. This problem is not limited to seeds. Since leaf harvester ants collect flowers or vegetative material, intrusive microfossils may be an ever-present and not easily recognized problem in pollen and phytolith analysis. Pulliam and Brand (1975) estimate that in the desert grasslands of southern Arizona, granivorous rodents harvest an average of 3,000,000 seeds/hectare each year, while foraging ants may harvest as many as 6,500,000/hectare. This amounts to about 3% of the total annual seed crop. Miller and Smart (1984) described a mechanism for the introduction of carbonized seeds into sites by a combination of animal and human action. They suggested that charred seeds be incorporated into archaeological sites if the dung of domestic animals was used for fuel.

Faunalturbation is not only additive. The action of burrowing animals may mix previously deposited material. Small mammals may burrow to a depth ranging from 0.5 to 2.5 m depending on species and substrate (Kirmiz 1962; Schmidt-Nielsen 1964; Wood and Johnson 1978). Small rodents may mix between 2.5 and 18 metric tons of soil per hectare each year (Wood and Johnson 1978). Tunnels in ant nests have been reported as deep as 2 to 5 m below the surface (Tevis 1958; Wood and Johnson 1978). Earthworms may burrow to a depth of 3 m (Wood and Johnson 1978) and they frequently use seeds or small stones to line their tunnels (Keepax 1977). Earthworms may mix between 0.4 and 9 metric tons of soil per hectare each year (Wood and Johnson 1978). In moist areas with a shallow water table, crayfish may burrow to a depth of 5 to 8 m and bring a metric ton of soil per hectare to the surface each year (Wood and Johnson 1978). Since burrowing animals seem to like the relatively loose, organic, rich soils of archaeological sites, the possibility of mixing of prehistoric plant remains by faunalturbation should always be considered.

Floralturbation

Wood and Johnson (1978) describe floralturbation as the mixing activitiy of soil by plants. As tree roots decay they leave behind cavities that may fill with organic debris. When trees blow over in storms they may churn up and mix large volumes of soil or create depressions that trap organic debris. In the tropical regions of Central America, cohune palms (*Orbignya cohune*) leave behind large conical depressions 0.5 m in diameter and up to 1 m deep when they are blown over or decay. Furley (1975) estimates that this activity could mix 5500 m^3 of soil per hectare (55% of the upper soil volume) each millenium in tropical regions where this species grows. Since slash-and-burn farming is almost synonymous with tropical agriculture, and since modern Maya farmers use cohune palms as indicators of good soil for maize *milpas,* there is a very real danger that modern seeds charred by field burning could go unrecognized in shallow archaeological deposits. The potential for the mixing of soils by treefalls or infilling after the decay of stumps or roots should be considered for archaeological sites in any wooded region.

Argilliturbation

Argilliturbation is defined by Wood and Johnson (1978) as soil disturbance caused by the shrinking and swelling activity of clays as they absorb or lose moisture. The 1981 field season at Pulltrouser Swamp (Miksicek 1983a) was one of the driest periods in recent climatic records in northern Belize. Massive soil cracks that were 10 cm wide and over a meter in depth formed in the upland vertisols away from the Pulltrouser Basin. This cracking action could have mixed earlier deposits or trapped modern seeds charred by slash-and-burn land clearing.

Aeolian and Alluvial Processes

The action of wind (aeroturbation) or water (aquatubation) may alter shallow archaeological deposits by mixing, covering, or eroding them (Wood and Johnson 1978). The announcement of the discovery of Late Paleolithic barley from sites near Wadi Kubbaniya in Egypt appeared to shake established opinions on the antiquity of plant manipulation in the Near East (Wendorf *et al.* 1979). Grinding stones and blade tools were collected from deflated depressions in nearby dunes. The barley grains were described as "carbonized" but "probably not burned" (Wendorf *et al.* 1979: 1345). Although the exact context of the cereal grains was not described, radiocarbon samples that seemed to be in association with the barley dated to between 17,100 and 17,670 radiocarbon years before present. These were collected from depths ranging between 0 and 30 cm. Several years later Hillman (*et al.* 1983) ran electron spin resonance spectroscopic tests on the Wadi Kubbaniya barley grains and determined that the maximum temperature to which they had been heated did not exceed 150° C, which would have been insufficient to char them enough to last the presumed 18 millenia. More recently, these barley grains were dated at the University of Arizona tandem accelerator facility and found to be a maximum of 4850 yr old (Wendorf *et al.* 1984). Shifting sands and other natural processes had mixed more recent barley grains with ancient charcoal. Several factors should have alerted the excavators to the possibility of contamination: the uncharred state of the grains, the shallowness of the deposits, the unstable site context (dunes), and the lack of clear association with grinding stones or similar tools.

Background Seed Rain and Fires

Soil acts as a "seed bank" for natural plant communities. Hopkins and Graham (1983) have reported seed densities of 558 to 1068/m^2 of topsoil for lowland rain forest in Queensland, Australia. Similar densities of 177 to 752 seeds m^2 were noted for abandoned fields and adjacent rain forest in Amazonian Venezuela (Uhl *et al.* 1982). Pulliam and Brand (1975) estimated that annual seed production in the desert grassland of southeastern Arizona averaged 350,000,000 seeds/hectare. Lopinot and Brussell (1982) recovered an average of 38.6 uncharred seeds/liter from flotation samples collected at sites in southern Illinois. Keepax (1977) noted between 74 and 1506 uncharred seeds/kg of topsoil for Iron Age sites in Britain. Minnis (1981) identified 100–2100 modern seeds/liter in control samples collected from offsite areas in southwestern New Mexico. Minnis (1981) refers of these uncharred seeds in archaeological sites as the "modern seed rain." With so many background seeds in soil it is conceivable that a few could be carbonized by natural or man-caused fires.

Sauer (1952) and Lewis (1972) have suggested that fire has been an important tool for hunting or clearing land for almost as long as humans have existed. Slash-and-burn is essentially synonomous with tropical agriculture. The Danish palynologist Iversen (1941) cited the decline of elm pollen and increases in herbaceous pollen in northern European bog sequences as evidence for the use of slash-and-burn clearing by early Neolithic farmers. Recently the use of a "controlled burn" strategy has even been suggested for prehistoric farmers in the American Southwest. Sullivan (1982) proposed that Mogollon peoples could have intentionally burned small plots to increase the foraging and agricultural potential of ponderosa pine forests.

To test for the possibility of a naturally charred seed rain, Minnis (1981) collected surface soil samples from offsite areas in southwestern New Mexico. Although thousands of modern seeds were identified, not a single one was carbonized. Even if the real incidence of naturally charred seeds is rather low, it is a factor that sould be considered by every cautious archaeobotanist.

Evaluating the Origins of Seeds in Sites

In the preceeding sections I have discussed mechanisms for the nonhuman introduction of seeds into sites. An experiment by Minnis (1981) illustrates the relative magnitude of some of these factors. In 1978 he floated floor sweepings from a chicken coop that had served as a dormitory for members of the Mimbres Archaeological Project the previous field season. He identified 684 seeds of 19 different taxa from three flotation samples. Only 0.7% could definitely be attributed to human introduction (chile, tepary beans, sunflower). Approximately 11.2% of the seeds could have been carried into the coop by rodents, but only 5.5% showed definite evidence for rodent gnawing. The remaining 88% could have been introduced by the combined effects of insects, shifting sands, rodents, humans, or other animals.

Various authors haves proposed criteria for evaluating seeds from archaeological sites (Keepax 1975; Minnis 1981; Lopinot and Brussell 1982; Miksicek 1983b). When the is a doubt, the burden of proof is always on the archaeobotanist.

1. What is the state of preservation of the seed? If it is from an open site and it is not carbonized then it may well be a recent introduction. If the seed is not charred and it does not look old, then it probably is not. Black or dark-colored seeds always present a special problem for the archaeobotanist. If a taxon is abundant, it is always worthwhile to break a few seeds open and determine if they are completely charred or if they contain fresh-looking endosperm. Although this technique is destructive (any critical measurements should be taken first) it may save a few headaches.
2. Is this species part of the modern local vegetation and seed rain? Control samples collected away from a site will be useful for determining the diversity and density of background seeds as well as indicating the possible existence of a naturally charred seed rain.
3. Is there any evidence for disturbance in the soil profile such as soil cracks, animal burrows, plowing, or intrusive pits?

4. Even if the seeds are carbonized, is there evidence for ancient animal disturbance such as charred rodent or insect fecal pellets, teeth marks, or charred insect bodies?

5. Is there good ethnographic evidence for the species in question?

6. Is there any size or morphological feature that would distinguish the seed in question from modern populations?

7. Will any of the uncharred seeds germinate? If a flotation sample sprouts while it is drying, then those seeds probably are not very old. A simple germination test may resolve many questions.

8. How abundant is the taxon in question? It is hard to argue with a vessel full of charred seeds or a storeroom full of burned corn. One or two individuals of a species from a large number of flotation samples may not be very significant in the long run.

9. How old is the seed itself? A final, but rather expensive way to resolve any possible problems with critical material would be to date it directly using a tandem accelerator.

ANALYTICAL TRANSFORMATIONS OF THE DATA BASE

In *The structure of scientific revolutions* Kuhn (1970) discussed the relationship between "seeing" and the process of normal science. The theoretical orientation of an investigator and the methods and instruments that he uses influence the interpretation of the results of any research. To paraphrase a contemporary adage, "How you see, affects what you get." In archaeobotany, as well as any other research, how the data are collected influences the final analysis and interpretation. "Laboratory transforms" are just as significant as "natural" or "cultural" transforms in paleoethnobotanical research.

Sampling

There is almost no such thing as a site with no preserved plant remains. If enough samples of sufficient size are collected and analyzed just about any site should yield some data. What is an adequate sample? This must be answered both in terms of sample volume and sample number.

The data in Table 4.2 suggest that there is a very wide range in the absolute abundance of preserved plant remains in sites depending on age, preservation environment, and site history. In archaeobotany, "one size does not fit all." The sample volume must be adjusted according to the specific requirements of each site and project. It would be useful to experiment with various sample volumes to determine the optimal size when working in a new area. The choice of a given volume must be a compromise between adequate recovery and logistic problems involved in handling the samples.

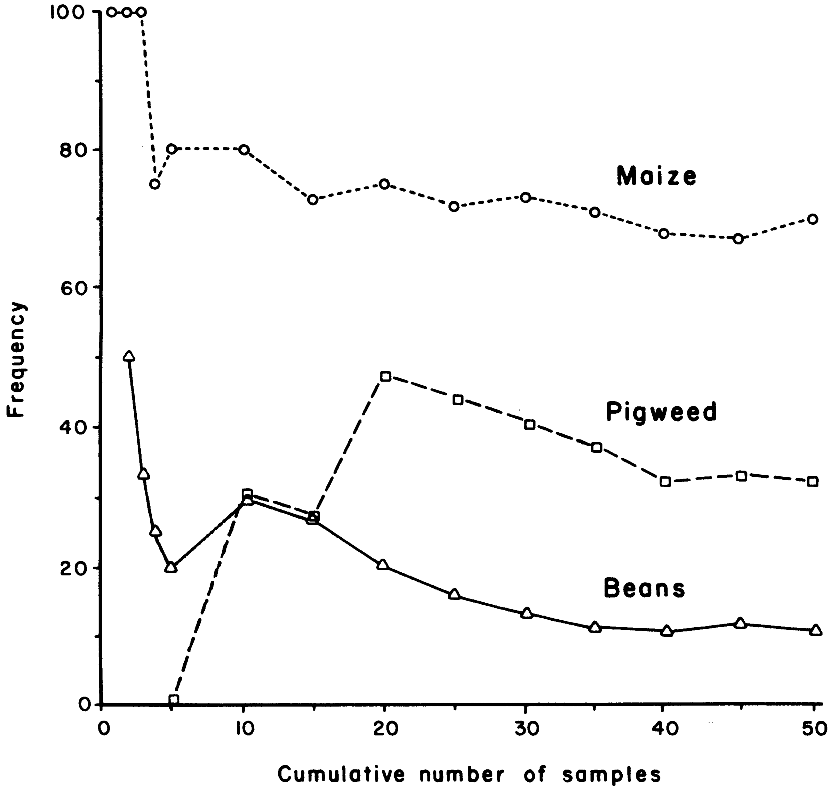

Figure 4.3. A "species–area curve" for determining the adequacy of sampling.

Larger samples produce more plant remains, but they are more difficult to transport, take longer to process and analyze, and require more storage space. The collection of a standard volume sample makes statistical manipulations of the data easier and more reliable.

The next question to consider is, "What is an adequate number of samples?" To answer this question I used data for 69 8-liter flotation samples from Pueblo Las Fosas, a Classic Period Hohokam site near Florence, Arizona. I shuffled the raw data sheets and calculated frequency values for 1, 2, 3, 4, 5, 10, 15, 20, and so forth up to 50 samples at a time for six taxa. The concept of frequency will be discussed further in a later section on quantificaton, but it is defined as "the percentage of analyzed samples that contain a given taxon." The results for three species are plotted in Figure 4.3. The curves for two other taxa (*Trianthema* or false purslane, mesquite seeds) were essentially identical to those for beans and maize, respectively. The sixth species (tobacco) was so rare that it was not drawn until the sixty-ninth try. Figure 4.3 is similar to a species–area curve, a technique that is commonly used to test the adequacy of a sample in quantitative ecology. In Figure 4.3, it is possible to see that between 5 and 10 samples are necessary to produce a reliable estimate of the population frequency for a common taxon such as maize. On the other hand, 25–35 samples are required for rarer types of plant remains such as beans or pigweed. Fasham and Monk (1978) performed similar tests for cereals from Iron Age pits in Britain with essentially the same results. Five or six flotation samples would be an absolute minimum for a feature, temporal phase, or site to identify the more common species preserved, but 30 samples would be much more reliable. More samples will always add a few additional types of plant remains (see Figure 4.2).

The problem of where to sample depends on the specific goals and research design of the individual archaeological project. General guidelines have been presented in Bohrer and Adams (1977) and Adams and Gasser (1980). The development of a sampling design should involve close collaboration between the project director, the archaeobotanist, and other analytical specialists.

Processing

Although many different types of flotation systems are in use today, they generally fall into two major types: tub flotation or continuous-flow machines. These two major systems are described in Watson (1976) along with many of the possible variations. The choice of a system depends on the individual preferences of the project director and analyst as well as logistic factors such as cost, availability of water and materials, and the amount of material to be processed.

When used by an experienced technician, the results of either tub or continuous-flow flotation should be fairly consistent. To test the recovery efficiency of various flotation systems, Kaplan and Maina (1977), Wagner (1982), and Pendleton (1983) have suggested adding charred modern seeds (of various sizes) as tracers and calculating the percentage recovered. This is essentially identical to the use of exotic pollen tracers in palynology to calculate absolute pollen influx. Wagner (1982) reported recovery rates of 84 to 98% for flotation machines and slightly lower values of 6 to 94% for a tub system. The wide variance for the tub system could be attributed to the use of different mesh sizes. When screens with mesh openings smaller than 0.59 mm were used, recovery rates increased to 81 to 94%, comparable to the machine system. In my own work, I tend to use the tub system described in Minnis and LeBlanc (1976). I have tested recovery rates using sample volumes varying from 1 to 15 liters with results ranging from 79 to 100%. The lowest recovery was obtained from a 15-liter sample, which suggests that soil volume may also affect recovery efficiency. Wagner (1982) and

Pendelton (1983) have recommended using various types of tracers to compensate for differences in seed buoyancy. The use of charred tracers may also help monitor cross-sample contamination.

Preprocessing may also affect recovery rates. Soil samples from the most recent excavations at Snaketown in Arizona were all screened in the field before they were given to Bohrer (1970) for flotation. When the results of the Snaketown analysis are compared to botanical data from other Hohokam sites (Gasser an Miksicek 1985), several striking differences are apparent. Maize was not recovered from the Snaketown flotation samples even though it is well represented at all other Hohokam sites and despite the fact that it was identified by Jones from earlier work at Snaketown (Castetter and Bell 1942: 31–32). In contrast to other sites along the Gila River (Gasser and Miksicek 1985: Figure 1), cotton seems conspicuously absent in the Snaketown samples even though it too was reported in the earlier study (Castetter and Bell 1942: 32). Mesquite and saguaro, however seem to be overrepresented at Snaketown in comparison to other Hohokam sites (Gasser and Miksicek 1985: Figure 1). I would strongly advise against prescreening flotation samples. Charred seeds are fragile and it is wise to minimize possible mechanical damage to the seeds. All of the small artifacts or animal bones that are recovered in the heavy fraction may be retrieved by the flotation analyst and sent to the appropriate specialist.

Quantification

The topic of quantification is one area of paleoethnobotany that still needs considerable exploration and research. Various methods have been utilized. In his analysis of plant remains in coprolites recovered from Salts Cave in Kentucky, Yarnell (1969) used a relative scale ranging from E (trace) to A (abundant). Although this system somewhat limits further statistical analysis it may be the most realistic approach considering the vagaries of differential preservation and recovery. Bohrer (1970) used a seed concentration index defined as "the number of seeds, divided by the volume of charcoal recovered." I used a modified concentration index preparing Table 4.2 (seeds/liter of soil). Other authors (for example, Renfrew 1973) have used a relative abundance measure, defined as "the number of seeds of one species divided by the total number of all seeds recovered." Relative abundance is similar to the concepts of relative frequencies used in palynology or relative densities used in plant ecology. Perhaps the most common statistic used today is frequency (defined previously), which has also been referred to as presence value (Hubbard 1980) or ubiquity (Gasser 1982). Frequency or presence value is a statistic borrowed from quantitative ecology. Relative abundance data use absolute counts for different taxa, while frenquency measures how commonly representatives of a taxon occur in independent samples. It would seem useful to borrow another statistic from quantitative ecology and combine both types of information in a summary statistic such as importance value, which is an average of two or more distinct measures (Miksicek 1983c). Importance value should be interpreted as importance in the archaeological record and *not* importance in the diet.

One of the most commonly stated goals of paleoethnobotanical research is the "reconstruction of past diets." In reality this is impossible because of problems with differential preservation, recovery, and many of the aforementioned cultural and environmental transformation processes. An archaeobotanical sample represents only a small portion of the plant remains that are preserved at a site, which are in turn only a small fraction of the plants that were actually utilized by the people who lived there.

When Cohen (1975) analyzed plant remains in a Late Horizon midden from coastal Peru, he identified over 40,000 items of vegetal refuse from a 4.5-m^3 volume. He estimated that this midden was deposited in about 70 yr. Even with such a large, well-preserved sample he felt that it was impossible to calculate relative dietary proportions because certain items such as squash, lima beans, root crops, and certain tropical fruits that had been identified from other parts of the site or other sites in the region were conspicuously underrepresented. Several quantitative dietary reconstructions have been attempted (for example MacNeish 1967; or Pozorski 1983) but in the long run these are probably purely mathematical exercises. It is difficult, if not impossible, to estimate the relative dietary importance of different types of plants. Chronological or spatial trends for a single taxon may be far more realistic. In the final analysis, general trends will be much more meaningful than absolute numbers.

CLOSING THOUGHTS

In the foregoing discussion I have tried to outline some of the principles behind archaeobotanical analysis. Although I am far more familiar with data from the American Southwest, I have tried to bring together examples and ideas from both European and American researchers. I have tried to be comprehensive but I certainly do not assume that this chapter is in any way exhaustive.

The concerns mentioned above are well understood by practicing paleoethnobotanists but they are often intuitive and are not always stated explicitly in every published report. Almost all of these concerns have been expressed somewhere in the published literature but I have tried to bring as many as possible together in one place. I hope that in some way this discussion will prove useful to both specialists and archaeologists alike and that in some small way it may contribute to an understanding of site formation processes and archaeobotanical interpretation.

ACKNOWLEDGMENTS

The seeds of many of the ideas discussed in this paper were planted almost 15 years ago in discussions with Hugh C. Cutler and Leonard W. Blake, and I wish to dedicate this article to them. In some ways, this paper is modeled after a course in Quaternary Palynology taught by Alan Solomon at the University of Arizona in the spring of 1976. I also benefited greatly from a workshop on archaeobotany conducted in 1983 at the University of Arizona by Vorsila Bohrer and Karen Adams. I wish to thank Bruce Benz, David Browman, Gary Crawford, Owen Davis, Bill Doelle, Clark Erickson, Patricia Fall, Richard Felger, Paul Fish, Suzanne Fish, Richard Ford, Robert Gasser, Norman Hammond, Christine Hastorf, Sissel Johannessen, Scott Kwiatkowski, Neal Lopinot, Scotty MacNeish, Naomi Miller, Paul Minnis, Gary Nabhan, Barbara Pickersgill, Virginia Popper, Michael Schiffer, C. Earle Smith Jr., Alan Sullivan, Jill Thompson, Molly Toll, B. L. Turner, Gail Wagner, Patty Jo Watson, Fred Wiseman, Richard Yarnell, and anyone I may have inadvertently forgotten for many stimulating discussions throughout the years.

REFERENCES

Adams, K. R.
1980 Pollen, parched seeds and prehistory: a pilot investigation of prehistoric plant remains from Salmon Ruin, a Chacoan pueblo in northwestern New Mexico. *Eastern New Mexico University Contributions in Anthropology* 9.

Adams, K. R. and R. E. Gasser
1980 Plant microfossils from archaeological sites: research questions, and sampling techniques and approaches. *The Kiva* 45(4): 293–300.

Asch, N., R. I. Ford, and D. L. Asch
1972 Paleoethnobotany of the Koster Site, the archaic horizons. *Illinois State Museum Reports of Investigations* No. 24.

Begler, E. S., and R. W. Keatinge
1979 Theoretical goals and methodological realities: problems in the reconstruction of prehistoric subsistence economies. *World Archaeology* 11(2): 208–226.

Bohrer, V. L.
1970 Ethnobotanical aspects of Snaketown, a Hohokam village in southern Arizona. *American Antiquity* 35(4): 413–430.

Bohrer, V. L. and K. R. Adams
1977 Ethnobotanical techniques and approaches at Salmon Ruin, New Mexico. *Eastern New Mexico University Contributions in Anthropology* 8.

Bottema, S.
1984 The composition of modern charred seed assemblages. In *Plants and ancient man,* edited by W. van Zeist and W. A. Casparie. Boston: A. A. Balkema. Pp. 207–212.

Byers, D. S. (editor)
1967 *The prehistory of the Tehuacan Valley,* Vol. 1, *Environment and subsistence.* Austin: University of Texas Press.

Callen, E. O.

1967 Analysis of Tehuacan coprolites. In *The prehistory of the Tehuacan Valley,* Vol. 1, *Environment and subsistence;* edited by D. S. Byers. Austin: University of Texas Press. Pp. 261-269.

Castetter, E. F., and W. H. Bell

1942 *Pima and Papago Indian agriculture.* Albuquerque: University of New Mexico Press.

Clark, J. G. D.

1954 *Excavations at Star Carr.* Cambridge: Cambridge University Press.

Cohen, M. N.

1975 Some problems in the quantitative analysis of vegetable refuse illustrated by a Late Horizon site on the Peruvian coast. *Nawpa Pacha* 10–12: 49–60.

Conrad, N., D. Asch, N. Asch, D. Elmore, H. Grove, M. Rubin, J. Brown, M. Wiant, K. Farnsworth, and T. Cook

1984 Accelerator radiocarbon dating of evidence for prehistoric horticulture in Illinois. *Nature* 308: 443–446.

Crawford, G. W.

1983 Paleoethnobotany of the Kameda Peninsula Jōmon. *Anthropological Papers, Museum of Anthropology, University of Michigan* No. 73.

Croes, D. R., and E. Blinman (editors)

1980 Hoko River: A 2500 year old fishing camp on the northwest coast of North America. *Washington State University, Laboratory of Anthropology, Reports of Investigations* No. 58.

D'Altroy, T. N., and C. A. Hastorf

1984 The distribution and contents of Inca state storehouses in the Xauxa region of Peru. *American Antiquity* 49(2): 334–349.

Dennell, R. W.

1974 Botanical evidence for prehistoric crop processing activities. *Journal of Archaeological Science* 1: 274–284.

1976 The economic importance of plant resources represented on archaeological sites. *Journal of Archaeological Science* 3: 229–247.

de Rochebrune, A. T.

1879 Recherches d'ethnographie botanique sur la flore des sepultures péruviennes d'Ancón. *Actes de la Sociètè Linnèenne de Bordeaux.* 3: 343–358.

Doebley, J. F.

1981 Plant remains recovered by flotation from trash at Salmon Ruin, New Mexico. *The Kiva* 46:(3): 169–187.

Farnsworth, P., J. Brady, M. DeNiro, and R. S. MacNeish

1985 A re-evaluation of the isotopic and archaeological reconstructions of diet in the Tehuacan Valley. *American Antiquity* 50(1): 102–116.

Fasham, P. J., and M. A. Monk

1978 Sampling for plant remains from Iron Age pits: some results and implications. In *Sampling in contemporary British archaeology,* edited by J. F. Cherry, C. G., and S. Shennan. *BAR British Series* (50: 363–371.

Fish, P. R., S. K. Fish, A. Long, and C. Miksicek

1986 Early corn remains from Tumamoc Hill, southern Arizona. *American Antiquity* 51(3): 563–572.

Ford, R. I.

1979 Paleoethnobotany in American archaeology. In *Advances in archaeological method and theory;* Vol. 2, edited by M. B. Schiffer. New York: Academic Press. Pp. 285–336.

Ford, R. I., and N. Miller

1978 Paleoethnobotany I. In *Excavations at Carthage, 1976, conducted by the University of Michigan* Vol. IV, edited by J. H. Humphrey. Ann Arbor: Kelsey Museum, The University of Michigan. Pp. 181-187.

Furley, P. A.

1975 The significance of the Cohune Palm, *Orbignya cohune* (Mart.) Dahlgren on the nature and in the development of the soil profile. *Biotropica* 7(1): 32-36.

Gasser, R. E.

1982 The specialists' volume: biocultural analyses. *The Coronado Project Archaeological Invesitigations No. 4, MNA Research Paper 23.*

1985 *Archaeological trash mounds and floor features: don't believe everything.* Paper presented to the Society for American Archaeology, Denver, CO.

Gasser, R. E., and E. C. Adams

1981 Aspects of deterioration of plant remains in archaeological sites: the Walpi archaeological project. *Journal of Ethnobiology* 1(1): 182-192.

Gasser, R. E., and C. H. Miksicek

1985 The specialists: a reappraisal of Hokokam exchange and the archaeobotanical record. In Proceedings of the 1983 Hohokam Symposium, edited by A. Dittert and D. Dove. *Phoenix Chapter, Arizona Archaeological Society Occasional Paper* (2): 483-498.

Glob, P. V.

1971 *The bog people: Iron Age man preserved.* New York: Ballantine Books.

Green, F. J.

1979 Phosphatic mineralization of seeds from archaeological sites. *Journal of Archaeological Science* 6: 279-285.

Greenhouse, R., R. E. Gasser, and J. W. Gish

1981 Cholla bud roasting pits: an ethnoarchaeological example. *The Kiva* 46(4): 227-242.

Hally, D. J.

1981 Plant preservation and the content of paleobotanical samples: a case study. *American Antiquity* 46(4): 723-742.

Hammond, N., and C. H. Miksicek

1981 Ecology and economy of a formative Maya site at Cuello, Belize. *Journal of Field Archaeology* 8: 259-269.

Hargrave, L. L.

1938 A plea for more careful preservation of all biological material from prehistoric sites. *Southwestern Lore* 4(3): 47-51.

Harshberger, J. W.

1896 The purposes of ethnobotany. *American Antiquarian* 17: 73-81.

Hastorf, C., and M. DeNiro

1985 Reconstruction of prehistoric plant production and cooking practices by a new isotopic method. *Nature* 315: 489-491.

Helbaek, H.

1950 *Tollund mandens sidste maaltid. Aarbøger* f. Nordisk oldkyndighed og historie 329-341.

1958 *Grauballemandens sidste maaltid. Kuml aarbog f. jysk Ark. Selskab.* 83-116.

Heer, O.

1866 Treatise on the plants of the Lake Dwellings. In *Lake Dwellings of Switzerland and other parts of Europe,* edited by F. Keller, trans. by J. E. Lee, London: Longman Green.

Hendry, G. W., and M. P. Kelley

1925 The plant content of adobe bricks. *California Historical Society Quarterly* 4:361-373.

Hillman, G.

1981 Reconstructing crop husbandry practices from charred remains of crops. In *Farming practice in British prehistory,* edited by R. Mercer. Edinburgh: Edinburgh University Press. Pp. 123-162.

1984 Interpretation of archaeological plant remains: the application of ethnographic models from Turkey. In *Plants and ancient man,* edited by W. Van Zeist and W. A. Casparie. Boston: A. A. Balkema. Pp. 1-41.

Hillman, G., G. Robins, D. Oduwole, K. Sales, and D. McNeil

1983 Determination of thermal histories of archaeological seeds with electron spin resonance spectroscopy. *Science* 222: 1235.

Hopkins, M. S., and A. W. Graham

1983 The species composition of soil seed banks beneath lowland tropical rainforests in north Queensland, Australia. *Biotropica* 15(2): 90-99.

Hubbard, R. N. L. B.

1976 On the strength of the evidence for prehistoric crop processing activities. *Journal of Archaeological Science* 3: 257-265.

1980 Development of agriculture in Europe and the Near East: evidence from quantitative studies *Economic Botany* 34(1): 51-67.

Iversen, J.

1941 Land occupation in Denmark's stoneage. *Denmarks Geologiske Undersogelse* 2(66): 1-67.

Johannessen, S.

1984 Paleoethnobotany. In *American bottom archaeology,* edited by C. J. Bareis and J. W. Porter. Chicago: University of Illinois Press. Pp. 197-214.

Jones, G.

1984 Interpretation of archaeological plant remains: ethnographic models from Greece. In *Plants and ancient man,* edited by W. van Zeist and W. A. Casparie. Boston: A. A. Balkema. Pp. 43-69.

Jones, G., K. Wardle, P. Halstead, and D. Wardle

1986 Crop storage at Assiros. *Scientific American* 254(3): 96-103.

Kaplan, L. and S. L. Maina

1977 Archaeological botany of the Apple Creek Site, Illinois. *Journal of Seed Technology* 2(2): 40-53.

Keepax, C.

1975 Scanning electron microscopy of wood replaced by iron corrosion products. *Journal of Archaeological Science* 2:145-150.

1977 Contamination of archaeological deposits by seeds of modern origin with particular reference to the use of flotation machinery. *Journal of Archaeological Science.* 4:221-229.

King, J. E., W. E. Klippel, and R. Duffield

1975 Pollen preservation and archaeology in eastern North America. *American Antiquity* 40(2): 180-190.

Kirmiz, J. P.

1962 *Adaptation to desert environment.* London: Butterworth.

Knorzer, K. H.

1984 The prospects of the palaeoethnobotanical examination of cesspits. In *Plants and ancient man,* edited by W. van Zeist and W. A. Casparie. Boston: A. A. Balkema. Pp. 331-338.

Kuhn, T. S.

1970 *The structure of scientific revolutions.* Chicago: University of Chicago Press.

Kunth, C.

1826 *Examen botanique.* In *Catalogue raisonnė et historique dė antiquitės dėcouverte en Egypte,* edited by J. Passalaqua. Paris: Musées Nationaux.

Leroi-Gourhan, A.

1975 The flowers found with Shanidar IV, a Neanderthal burial in Iraq. *Science* 190: 562–564.

Lewis, H. T.

1972 The role of fire in the domestication of plants and animals in Southwest Asia: a hypothesis. *Man* 7:195–222.

Lopinot, N. H.

1985 *Archaeobotanical formation processes and late Middle Archaic subsistence.* Ann Arbor: University Microfilms International, 85-10043.

Lopinot, N. H., and D. E. Brussell

1982 Assessing uncarbonized seeds from open-air sites in mesic environments: an example from southern Illinois. *Journal of Archaeological Science* 9: 95–108.

Lundstrom-Baudais, K.

1984 Palaeo-ethnobotanical investigation of plant remains from a Neolithic lakeshore site in France: Clairvaux, Station III. In *Plants and ancient man,* edited by W. van Zeist and W. A. Casparie. Boston: A. A. Balkema. Pp. 293–306.

MacNeish, R. S.

1967 A summary of subsistence. In *The prehistory of the Tehuacan Valley,* Vol. 1, *Environment and subsistence,* edited by D. S. Byers. Austin: University of Texas Press. Pp. 290–309.

Matson, F.

1955 Charcoal concentration from early sites for radiocarbon dating. *American Antiquity* 21: 162–169.

Matthews, M., and B. Benz

1983 *Developing an ecological-behavioral model for the interpretation of pioneer plant remains in archaeological sites.* Paper presented before the Society for American Archaeology, Pittsburgh, PA.

Meyer, F. C.

1980 Carbonized food plants of Pompeii, Herculaneum, and the villa at Torre Annunziata. *Economic Botany* 34(4): 401–437.

Miksicek, C. H.

1978 Basketmaker III-Pueblo I botanical remains from Lupton, Arizona. In *The painted cliffs rest area,* edited by A. Ferg. *Arizona State Museum Contribution to Highway Salvage Arcaheology in Arizona* (50):143–153.

1983a Paleoecology and subsistence at Pulltrouser Swamp: the view from the float tank. *Report to the National Science Foundation on the 1981 Pulltrouser Swamp Project,* edited by P. D. Harrison and B. L. Turner, II.

1983b Plant remains. In *Archaeological and historical investigations at Nolic, Papago Indian Reservation, Arizona,* edited by W. Harper Doelle. *Institute for American Research Anthropological Papers* (2): 147–156.

1983c Archaeobotanical aspects of Las Fosas: a statistical approach to prehistoric plant remains, In *Hohokam archaeology along the Salt-Gila aqueduct, Central Arizona Project,* Vol. VI: *Habitation sites on the Gila River,* edited by L. S. Teague and P. L. Crown. *Arizona State Museum Archaeological Series* (150): 671–700.

1984a Historic desertification, prehistoric vegetation change, and Hohokam subsistence in the Salt-Gila Basin. In *Hohokam archaeology along the Salt-Gila aqueduct, Central Arizona Project,* Vol. VII: *Environment and subsistence,* edited by L. S. Teague and P. L. Crown. *Arizona State Museum Archaeological Series* (150). Pp. 53–80.

1984b *Hohokam adaptation to the chaparral zone: paleoecology and subsistence in the Anamax-Rosemont area of southern Arizona.* Manuscript on file, Arizona State Museum Archives.

1984c Iron age environment and diet. *Muse* 18: 51–53.

1985 Palaeoethnobotany of a 14th century Hopi site: Homolovi II. In *Excavation and surface collection of Homolovi II ruin,* edited by K. Hays and E. C. Adams, Appendix II. Tucson: Archaeology Section, Arizona State Museum.

1986a Plant remains from the Tanque Verde Wash site. In Archaeological investigations at the Tanque Verde Wash Site, edited by M. Elson. *Institute for American Research Anthropological Papers Tucson* 7: 371–394.

1986b Colonial and early classic plant remains from the Dakota Wash site: AZ AA:16:49. Manuscript on file, Pima Community College, Tucson.

Miksicek, C. H. and S. K. Fish

1981 *Understanding prehistoric subsistence activities in southern Arizona.* Paper presented to the Fourth Ethnobiology Conference, Columbia, Missouri.

Miller, N. F., and T. L. Smart

1984 Intentional burning of dung as fuel: a mechanism for the incorporation of charred seeds into the archaeological record. *Journal of Ethnobiology* 3(1): 15–28.

Mills, W. C.

1901 Plant remains from the Baum Village site. *Ohio Naturalist* 1(5): 70–71.

Minnis, P. E.

1981 Seeds in archaeological sites: sources and some interpretive problems. *American Antiquity* 46(1): 143–152.

Minnis, P. E., and S. LeBlanc

1976 An efficient, inexpensive arid lands flotation system. *American Antiquity* 41: 491–493.

Montgomery, R. G., W. Smith, and J. O. Brew

1949 Franciscan Awatovi. *Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University,* Vol. 26. *Reports of the Awatovi Expedition, Peabody Museum, Harvard University Report* (3).

Munson, P. J.

1981 Note on the use and misuse of water separation (“flotation”) for the recovery of small scale botanical remains. *Midcontinental Journal of Archaeology* 6(1): 123–126.

Munson, P. J., P. W. Parmalee, and R. A. Yarnell

1971 Subsistence ecology of Scovill, a terminal Middle Woodland village. *American Antiquity* 36(4): 410–431.

Nabhan, G. P.

1977 Viable seeds from prehistoric caches? Archaeobotanical remains in Southwestern folklore. *The Kiva* 43(2): 143–159.

Osborne, D.

1965 Contributions of the Wetherill Mesa archaeological project. *American Antiquity* 31(2), Part (2).

Pals, J. P.

1984 Plant remains from Aartswoud, a Neolithic settlement in the coastal area. In *Plants and ancient Man,* edited by W. van Zeist and W. A. Casparie. Boston: A. A. Balkema. Pp. 313-322.

Pearsall, D. M.

1978 Phytolith analysis of archaeological soils: evidence for maize cultivation in formative Ecuador. *Science* 199: 177–178.

1983 Evaluating the stability of subsistence strategies by use of paleoethnobotanical data. *Journal of Ethnobiology* 3(2): 121-137.

Pendleton, M. W.

1983 A comment concerning "testing flotation recovery rates." *American Antiquity* 48(3): 615-616.

Pozorski, S.

1983 Changing subsistence priorities and early settlement patterns of the north coast of Peru. *Journal of Ethnobiology* 3(1): 15-38.

Pulliam, H. R., and M. Riley Brand

1975 The production and utilization of seeds in plains grassland of southeastern Arizona. *Ecology* 56(4): 1158-1166.

Rathje, W. L., and M. B. Schiffer

1982 *Archaeology*. New York: Harcourt, Brace.

Renfrew, J. M.

1973 *Palaeoethnobotany*. New York: Columbia University Press.

Reynolds, P. J.

1979 *Iron-age farm: the Butser experiment*. London: British Museum Publications.

Rovner, I.

1983 Plant opal phytolith analysis: major advances in archaeobotanical research. In *Advances in archaeological method and theory* Vol. 6, edited by M. B. Schiffer. New York: Academic Press. Pp. 225-266.

Rudenko, S. I.

1970 *Frozen tombs of Siberia*. Berkeley: University of California Press.

Sauer, C. O.

1952 *Agricultural origins and dispersals*. New York: The American Geographical Society.

Schiffer, M. B.

1976 *Behavioral archaeology*. New York: Academic Press.

1983 Toward the identification of formation processes. *American Antiquity* 48(4): 675-706.

Schmidt-Nielson, K.

1964 *Desert animals: physiological problems of heat and water*. Oxford: University Press.

Smith, C. E., Jr.

1967 Plant remains. In *The prehistory of the Tehuacan Valley*, Vol. 1, *Environment and subsistence*, edited by D. S. Byers. Austin: University of Texas Press. Pp. 220-255.

1985 Recovery and processing of botanical remains. In *The analysis of prehistoric diets*, edited by R. Gilbert and J. Mielke. New York: Academic Press. Pp. 97-126.

Struever, S.

1968 Flotation techniques for the recovery of small-scale archaeological remains. *American Antiquity* 33: 353-362.

Sullivan, A. P.

1982 Mogollon agrarian ecology. *The Kiva* 48(1-2): 1-15.

Taylor, W. W.

1957 The identification of non-artifactual archaeological materials. *National Academy of Sciences, National Research Council, Publication* 565.

Tevis, L., Jr.

1958 Interrelations between the harvester ant *Veromessor pergandei* (Mayr) and some desert ephemerals. *Ecology* 39(4): 695-704.

Uhl, C., H. Clark, and K. Clark

1982 Successional patterns associated with slash and burn agriculture in the upper *Rio Negro* region of the Amazon Basin. *Biotropica* 14(4): 249-254.

van der Veen, M.

1984 Sampling for seeds. In *Plants and ancient Man,* edited by W. van Zeist and W. A. Casparie. Boston: A. A. Balkema. Pp. 193-200.

van Zeist, W., and S. Bottema

1983 Palaeobotanical studies of Carthage. *CEDAC Carthage,* Bulletin 5.

Wagner, G. E.

1982 Testing flotation recovery rates. *American Antiquity* 47(1): 127-132.

Watson, P. J.

1969 The prehistory of Salts Cave, Kentucky. *Illinois State Museum Reports of Investigations* (16).

1974 *Archaeology of the Mammoth Cave area.* New York: Academic Press.

1976 In pursuit of prehistoric subsistence: a comparative account of some contemporary techniques. *Mid-Continental Journal of Archaeology.* 1(1): 77-100.

Wendorf, F., R. Schild, N. Hadidi, A. Close, M. Kobusiewicz, H. Wieckowska, B. Issawi, and H. Haas

1979 Use of barley in the Egyptian Late Paleolithic. *Science* 205: 1341-1347.

Wendorf, F., R. Schild, A. Close, D. Donahue, A Jull, T. Zabel, H. Wieckowska, M. Kobusiewicz, B. Issawi, and N. Hadidi

1984 New radiocarbon dates on the cereals of Wadi Kubbaniya. *Science* 225: 645-646.

Willcox, G. H.

1977 Exotic plants from Roman waterlogged sites in London: *Journal of Archaeological Science.* 4:269-282.

Wilson, D. G.

1984 The carbonisation of weed seeds and their representation in macrofossil assemblages. In *Plants and ancient man,* edited by W. van Zeist and W. A. Casparie. Boston: A. A. Balkema. Pp. 201-206.

Wittmack, L.

1888 *Die Nutzpflanzen der alten Peruanet. Congrês International de Americanistes, Berlin* 7: 325-349.

1905 Our present knowledge of ancient plants. *Transactions of the Academy of Science of St. Louis* XV (1).

Wood, W. R., and D. L. Johnson

1978 A survey of disturbance processes in archaeological site formation. In *Advances in archaeological method and theory* Vol. 1, edited by M. B. Schiffer. New York: Academic Press. Pp. 315-381.

Yarnell, R. A.

1969 Contents of human paleofeces. In *The prehistory of Salts Cave, Kentucky,* edited by P. J. Watson. *Illinois State Museum Report of Investigations* 16: 41-54.

1974 Plant food cultivation of the Salts Cavers. In *Archaeology of the Mammoth Cave area,* edited by P. J. Watson. New York: Academic Press. Pp. 113-122.

1982 Problems of interpretation of archaeological plant remains of the Eastern Woodlands. *Southeastern Archaeology* 1(1):1-7.

Zier, C. J.

1980 A Classic-period Maya agricultural field in western El Salvador. *Journal of Field Archaeology* 7: 65-74.