

At this period agriculture was not entirely unknown. This is proved . . . by the discovery of carbonised cereals at various points. Wheat is most common, having been discovered at Meilen, Moosseedorf, and Wangen. . . . many bushels of it were found, the grains being united in large thick lumps. In other cases the grains are free, and without chaff. . . . while more rarely they are still in the ear. . . . Still more unexpected was the discovery of bread, or rather cakes, for leaven does not appear to have been used. They were flat and round, . . . and, to judge from one specimen, had a diameter of four or five inches

(Lubbock 1865: 153–154).

As Lubbock's observations about waterlogged finds at prehistoric Swiss "lake villages" show, archaeologists have long used remains of plants and plant products as evidence for aspects of ancient societies. Archaeobotany, also known as paleoethnobotany, is the subdiscipline of archaeology concerned with the contributions of plant remains to our understanding of past behaviors, diets, food preparation and culinary practices, environments, and technologies. Both terms differ from paleobotany, which also involves the study of ancient plant remains, but without explicit connection to human history. There are also terms for specialized aspects of archaeobotany, such as archaeoanthracology (study of archaeological charcoals) and archaeological palynology (study of archaeological pollens). Archaeobotany is very collaborative in that a holistic understanding of the botanical traces benefits from allied information from zooarchaeologists, paleoecologists, pottery and lithic specialists, and others.

16.1 Types of Archaeological Plant Remains

Archaeobotanists typically classify plant remains as plant macroremains, microremains, and chemical and isotopic traces, each with distinct roles in our understanding of the past as well as distinct challenges with respect to preservation, data collection, quantification, and interpretation (Madella et al. 2014; Pearsall 2015, 2019).

16.1.1 Macroremains

Macroremains are visible to the naked eye and their identification typically requires no more than low-power magnification. Among this type of evidence are charcoal, nuts and nutshell, tubers (parenchymous organs), fruit endocarps (seeds), or their fragments, plant parts closely associated with seeds (e.g., glumes and awns of cereals), and pieces of wooden artifacts or basketry, each with different probabilities of preservation in various environments.

16.1.2 Microremains

Plant remains that are visible to the naked eye are often less abundant than microscopic pollen, spores, opaline phytoliths, diatom frustules, and starch grains. These microremains also offer different kinds of information than macroremains and have different taphonomic histories. Consequently, they are a good complement to plant macroremains and other kinds of evidence.

Pollen grains are an essential element in the reproduction of flowering plants. Male gametes (sperm cells) occur inside each pollen grain or pollen tube, and the pollen transmits male genetic material to a female gamete during pollination by gravity, wind, water, insects, or human agency. The wall, or *exine*, of the pollen grain contains a substance, called sporopollenin, that is very resistant to decay. This makes it

able to survive for long periods in some cases, providing a very useful record of the past abundances of flowering plants.

Phytoliths result when some plants deposit silica (and sometimes calcium oxalate) that they have taken up from the soil onto cell boundaries. Phytoliths vary considerably in shape, even among different plant parts, and inter-specific differences in cell structure may make phytoliths a good source of evidence for plant taxa (Fig. 16.15). Because the silica survives long after other parts of a plant's anatomy have decayed away, phytoliths can provide archaeological evidence for the use of plants or plant parts that are not represented among charred macroremains. Phytoliths can occur in sediments, but also in dental calculus and on the surfaces of tools and pottery. In the case of calculus on human teeth, they are providing direct evidence of what plants an individual has chewed.

Starch is the material in which plants store carbohydrate for later use to make energy, which is what makes it a potential food source for animals as well. Its granules are composed of two kinds of polymer molecules, called amylose and amylopectin, which occur in alternating crystalline and amorphous layers in the grains. Starch granules can be preserved on the surfaces of pottery or stone tools or that came into contact with plants, and in dental calculus.

16.1.3 Chemical and Isotopic Evidence

Chemical and isotopic evidence for prehistoric plants includes residues of fatty acids and amino acids on surfaces or edges of artifacts or on the surface or in the matrix of pottery (pp. 204; Evershed et al. 1992). It also includes DNA fragments in plant remains, and carbon isotopes and trace elements in bones whose relative abundances in part reflect the plants in an animal's or person's diet.

16.2 Taphonomy, Site-Formation Processes, and the *Chânes Opératoires* of Plant Use

As in zooarchaeology (pp. 242–243), archaeobotanists must concern themselves with the taxonomy of the organisms they study and with the taphonomy of their remains (Beck 1989; Gallagher 2014; Hubbard and al-Azm 1990; Pearsall 2019). Identification of plant remains to genus or species faces challenges because usually only tiny remnants of ancient plants survive in archaeological deposits, where they are preserved at all. By contrast, botanists studying modern plants usually have whole plants at their disposal, and taxonomists have tended to emphasize the characteristics of leaves and flowers, parts that archaeologists are unlikely to find. This often requires archaeobotanists and paleobotanists to create

their own studies of the morphology and structure of the plant parts that survive more regularly, and in the state in which they are typically found. Dry caves and waterlogged sediments are generally favorable for preservation of many kinds of macroremains, because they exclude or impede bacterial decay. Charring in a reducing atmosphere, which may caramelize the sugars in plant materials so they are unattractive to bacteria, enhances preservation in other kinds of sediments. Macroremains may also be preserved in ancient feces (coprolites, e.g., Minnis 1989), as impressions in pottery or bricks or, rarely, as casts in volcanic ash (Farahini et al. 2017).

Much as with tool-making, it is possible to conceive of plant use in a *chaîne opératoire* that includes acquisition, not only of plants through harvest in the wild or in fields, but also of the tools and other materials necessary for their collection, processing, and use. For cultivated plants, the *chaîne opératoire* could even include decisions, activities and technologies related to sowing, planting, and cultivating plants, when and where to sow them, fallow schedules, and which crops to grow together. Just as with lithics, the decisions in this *chaîne opératoire* yield products and by-products that provide clues to processes involved up to and including the plants' use and discard. The *chaîne opératoire* thus influences plant remains' taphonomy.

Hillman (1984) pioneered the idea that the sample assemblages of plant remains we are able to recover archaeologically have an intimate connection, not only to the post-depositional processes that gradually alter deposited assemblages, but also to the harvesting, processing, use and discard decisions and activities that resulted in those deposited assemblages. Focussing mainly on cereals and similar crop plants, such as peas and vetch, he used experiments and ethnographic observations in Turkey to characterize the numerous steps from harvest to use and discard, the most likely products of each step, and the relative probabilities of preservation of each product (e.g., Fig. 16.1).

In this methodology, the "life assemblage" (see p. 242) of plants, or even the absolute amount of plant food consumed, is not typically of much interest and is impossible to reconstruct from the number of macro- or microremains in a sample (Pearsall 2019: 61). Rather, archaeobotanists are more interested in various kinds of deposited assemblages that represent material lost or discarded at different stages of some *chaîne opératoire*. For example, in processing glumed cereals, one possible product is straw waste (Table 16.1). If the straw store is accidentally burned or is used to temper dung fuel, this could result in a deposited assemblage of charred culm nodes, awn segments, basal spikelets, weed heads larger than the grain spikelets, and weed seeds smaller or the same size as grain. Alternatively, there could be plant impressions of these items if the straw was used as temper in pottery or bricks (see also Smith 2001).

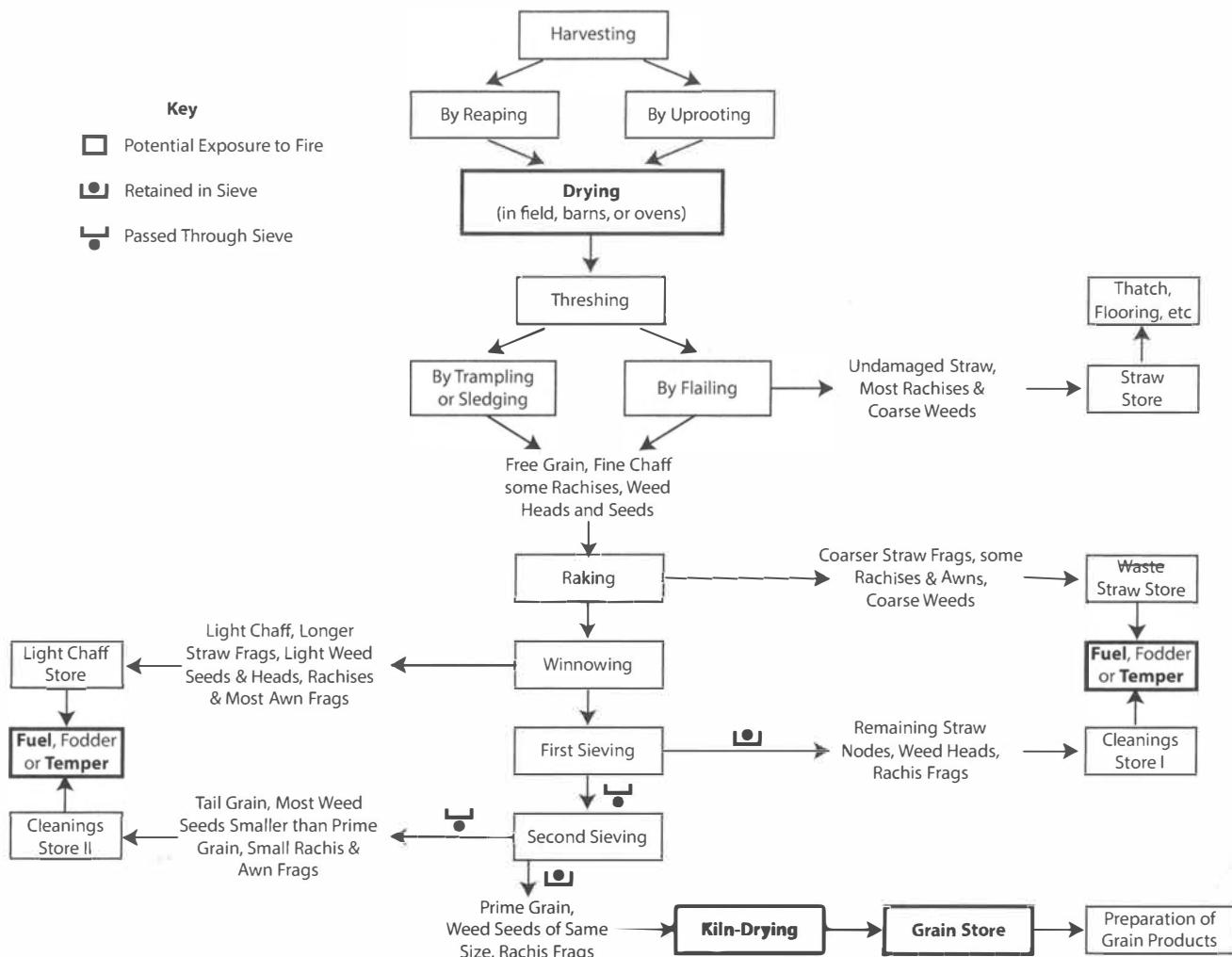


Fig. 16.1 A simplified flow chart of processes involved in the harvest and processing of free-threshing cereals and their straw in traditional agriculture in Turkey. (Modified from Hillman 1984: 4). Note that the

products or by-products that result from some processing steps have some probability of accidental preservation through charring, while others have very little probability of surviving at all

Consequently, Hillman relies, not on counts of plant remains as some indirect measure of the number of plants in a life assemblage or harvested assemblage, but rather on ordinal-scale measures on a variety of plant parts that, in combination, provide clues to the plant-processing activities that probably created the deposited assemblage. These include the seeds of weeds whose sizes would lead to their removal by sieving and others whose sizes are so close to those of crop seeds that they could only be removed by hand-picking.

The *chânes opératoires* of processing other kinds of plants are quite different from those of cereals in the example taken from Hillman's work, and have different taphonomic outcomes. In addition, the deposited assemblages most likely to preserve are different when we look for evidence other than charred macroremains. The conditions that favor phytolith preservation, for example, are imperfectly understood but are not enhanced by fire, and preservation varies among

phytolith types (Cabanes and Shahack-Gross 2015; Cabanes et al. 2011; Piperno 2006: 21–22).

However, for some kinds of plant evidence, especially from pollen and charcoal, it is often the life assemblage that is of interest. The relative abundances of plant taxa as represented by offsite pollen from cores in lakes and bogs and charcoal from archaeological sites can tell us something about the populations of trees and other flowering plants in the vicinity of the site and the much larger region that surrounds it. They thus provide indirect evidence for climate change and forest clearance. However, useful interpretation of pollen abundances requires careful consideration of the processes that transported pollen to the sampling locations and variation in the pollen productivity of the plants, as well as their probabilities of preservation. In the case of charcoal from archaeological sites, we need to consider differential combustion, probable selectivity by humans in their

Table 16.1 Simplified composition of expected contents of crop product types from glume wheats (after Hillman 1984: Table 1). Ordinal scale: items (e.g., glume and rachis fragments) result from the fragmentation of larger items (e.g., spikelets) after charring has occurred

Crop product type		Culm bases	Culm nodes	Awn segments	Intact non-basal spikelets	Intact basal spikelets	Spikelet forks	Glume bases
ΣB	Residue from burning whole sheaves	xx	XX	XX	XXX	XX	XXX	XXX
B1	Straw Waste from raking, winnowing and coarse riddling (threshing floor waste)	xx	XX	XX	r	XX		
B2+B4+B5	Threshed spikelets charred during parching or accidental burning of spikelet store	x	X	X	XXX		XXX	XXX
B2	Coarse sievings (larger than prime grain)	x		X	XX			
B3	Fine sievings (smaller than prime grain)	r	r				XX	XXX
B4	Semi-clean grain in bulk storage charred by sterilization or accidental burning	r	r	r			XX	XXX
B5	Cleanings from hand-sorting before food preparation	r	r	r			X	X
B6	Clean prime grain charred during roasting							

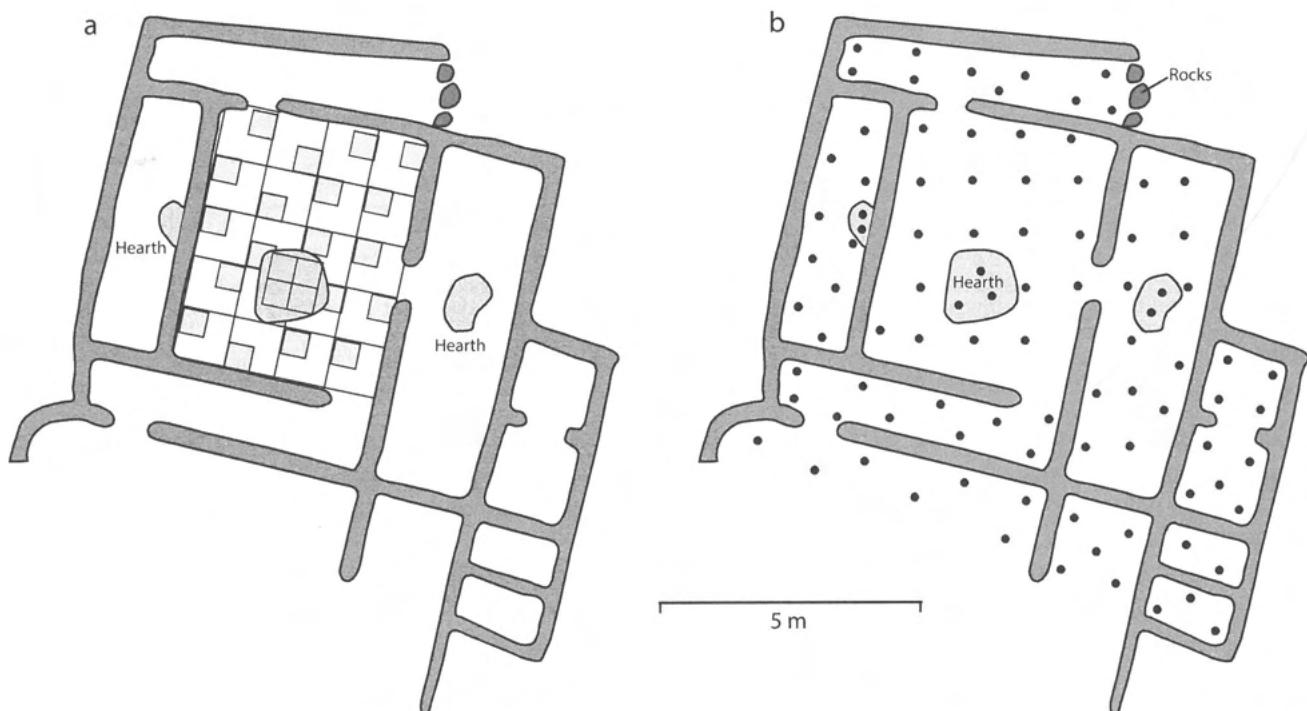


Fig. 16.2 Bulk sampling (a) of an excavation area's deposits and features as compared with pinch sampling (b; plans after Metcalfe and Heath 1990). The bulk sample in (a) is a systematic, stratified, unaligned cluster sample of a population consisting of the floor in one room, with a hearth sampled separately or treated as a stratum in a stratified sample, and sample size of $n = 19$ for the floor or $n = 23$ with the hearth included (see Chap. 6). The pinch sample is also a cluster sample, but in

this case each room floor or hearth is a population and we combine the pinches from dispersed locations (filled circles) to gather sufficient sediment from each room or hearth to ensure adequate numbers of plant remains for statistical purposes. In that case, the sample size for each room or hearth is only $n = 1$. Alternatively, if we treat the whole building as the population, the sample size is $n = 14$ (3 hearths and 11 room floors)

XXX = abundant, XX = common, X = few, r = rare, lower case x means it only occurs when harvest was by uprooting (culm bases). Note that many

Non-basal glume frags	Rachis internode frags	Prime grain	Tail grain	Weed heads > Spikelets	Weed heads ~ Spikelets	Weed heads < Spikelets	Seeds > Prime grain	Seeds ~ Prime grain	Seeds < Prime grain	Most common groupings
XXX	XXX	XXX	X	XX	XX	X	X	XX	XXX	
				XX			X	XX	XXX	
XXX	XXX	XXX	X		XX	X	X	XX	XXX	
						X	r			
	XXX		XX						XXX	
r	XXX	X						XXX	X	
r								XXX	X	
		XXX	X							

collection of wood for fuel or building material, which could include not only wood from nearby forests, but potentially wood imported from elsewhere, natural processes that transport charcoal from offsite or between stratigraphic layers, and archaeologists' own sampling methods (Höhn and Neumann 2018; Jansen and Nelle 2014; Marguerie 2002; Smart and Hoffman 1988: 168–170).

16.3 Archaeobotanical Sampling

As discussed more thoroughly in Chap. 6, ensuring that the sample we use to make inferences about sites, assemblages, features or other “populations” is representative requires careful attention to research design. In archaeobotany, whether the research questions involve determining when certain plants became domesticated in a site or region, inferring the diets or land-use practices of a site's inhabitants, investigating the cultural impacts of climate change, or identifying the processing stage associated with the plant remains in a deposit has a necessary relation to the sampling strategy, which begins in the field but continues in the laboratory. A major consideration is whether investigation of the research problem involves a spatial component (e.g., patterning across a site or differences among houses or features), changes over time, or characterization of whole sites, stratigraphic phases within sites, or the landscapes around sites. Anticipated taphonomic factors and the substantial labor requirements of processing, sorting, and identifying plant remains also have important impacts on sampling strategies.

Not surprisingly, archaeobotanists have given considerable attention to the merits and disadvantages of different kinds of samples. Much of this discussion has focused on the differences between “bulk” and “pinch” samples, usually divorced from an explicitly statistical perspective.

Many archaeobotanists recommend what they call “blanket sampling,” meaning that there should be at least one sample element from every context—layer, floor, or feature—in every excavation unit that was excavated. Statistically, this could be a stratified sample (p. 97), each type of context corresponding to a stratum, and, for most excavations, there would be many strata and disproportionate sampling (i.e. some strata would have larger sampling fractions than others). Each sample element consists of a volume of sediment, and it is generally recommended, as far as possible, to make this a consistent volume, such as 10 L, but it is in any case essential to record what the volume was. One reason for favoring blanket sampling is that, if you sample only contexts where you predict there will be lots of plant remains, such as pits or hearths, your prediction could well be incorrect. Furthermore, estimates based on this sample could be biased, as the pits or hearths may not be representative of all the plant remains in the population of interest. At a minimum, use of a more restrictive sampling strategy should only occur with the recognition of what the population is (the population of hearths, or population of pits). Whether fieldworkers employed blanket sampling or not, there are multiple ways to obtain these sample elements (Pearsall 2019: 41–48).

Bulk sampling, including a version that is sometimes called point sampling, is a form of cluster sampling (see

Fig. 16.3 Schematic of a simple two-bucket flotation system. The upper bucket is pierced in four quadrants to allow water to pass through the bottom mesh and pumping the upper bucket up and down with alternating rotation helps to churn up the sediment and create froth. The upper bucket may have a spout to facilitate decanting the froth into an adjacent screen, as here, or the user may simply skim light fraction from the froth with a small sieve

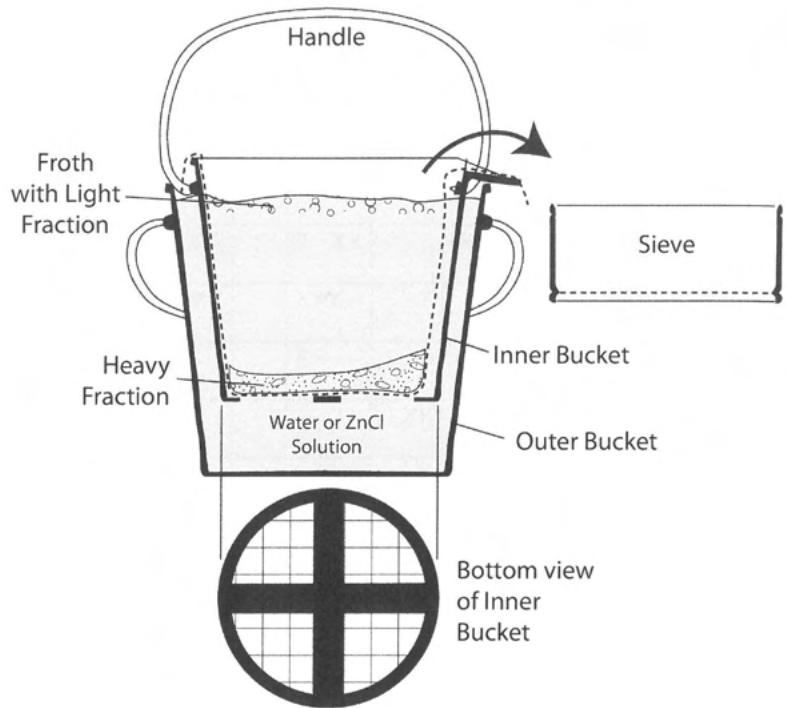
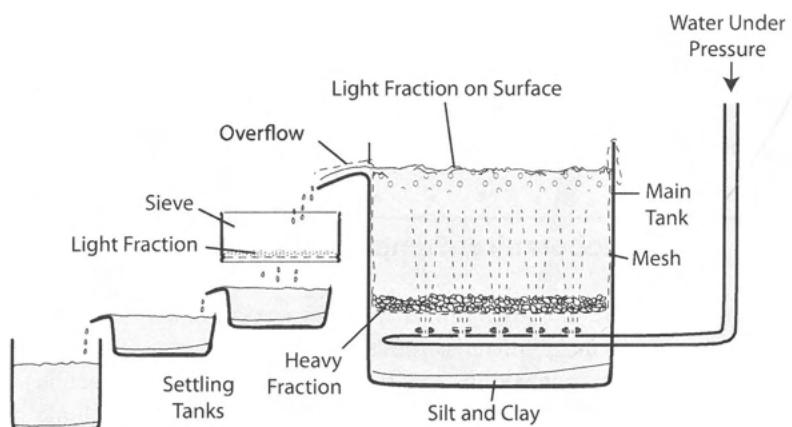


Fig. 16.4 Schematic of a simple froth flotation system with gravity pressure to create underwater jets to agitate the tank, and a series of settling basins to permit recycling of water. (E. Banning and Y. Salama)



pp. 98–100) with sample elements that consist of continuous volumes of sediment, such as all the sediment in a 1 cm layer across a square in a grid, or all the sediment in the bottom of a silo. The selection of volumes for bulk sampling can be purposive, such as targeting features like hearths, pits and silos, or based on probability sampling, such as stratified random sampling with strata that consist of different kinds of deposits and features, although this is not consistent with blanket sampling. Other alternatives are systematic sampling

or systematic, stratified, unaligned sampling of a grid across a room's floor or campsite's or midden's surface (Fig. 16.2a). The statistical assumption of cluster sampling is that each bulk volume is something like a well-mixed microcosm of the population or spatial location it represents and, when the sampling fraction is large, as when the sample element contains most of the sediment that can be securely associated with a 50 cm × 50 cm grid unit, that assumption is probably reasonable. When it is a spatial sample, such as a systematic

sample on a grid, the volume is sometimes taken as representative of a point at the grid unit's center. It is essential to measure the volumes of sediment and best to keep them reasonably consistent in size, but these volumes can be rather small (e.g., 0.6–2 L). Where the individual volumes are used as sample elements for a larger population, such as an entire room or layer in a site, they provide a basis for estimating things like ubiquities, densities, and standard errors.

Composite, scatter, or **pinch sampling** involves attempts to ensure that sample elements are representative by collecting small volumes of sediment from different parts of a context but then mixing them together in the same bag. This might be appropriate in cases where, for example, you want to represent the plant remains over a larger area, like a room floor, but do not have the time or resources to divide it into a grid for bulk or point sampling or to analyze the multiple sample elements that would result from that (Fig. 16.2b). Where possible, fieldworkers should collect enough pinches to fill a standard volume, such as 10 L. We could statistically characterize pinch sampling as either a kind of subsampling or a case of the context—the room floor—being the population and the “pinches” being the sample elements, except that we then mix them to make a single sample element. This may result in a more representative sample of sediment from that context than would a bulk element of equal volume from a single location in the context. However, physically mixing the pinches together prevents us from identifying differences between the pinches that are essential for calculating standard deviations and standard errors. Many archaeobotanists like the ease and time savings of this method, often prefer the larger volumes (~10 L) that result, and are willing to sacrifice the ability to calculate confidence intervals for their data, except in cases where the population consists of multiple contexts sampled in this way. In these last cases, the sample size is the number of contexts or 10 L bags, and *not* the number of pinches.

Column sampling is used in cases where the goal is to identify changes in some characteristics of the plant remains over time. It involves either randomly or, more often, purposively selecting locations in which to take a sequence of sample elements from bottom to top of a series of sediments. Typically, a fieldworker selects a location along a “baulk,” a vertical section through the stratification in an excavation area that includes several superimposed stratigraphic layers (see Chap. 19), and takes a small volume of sediment from each layer with a trowel or spoon, taking care to avoid the boundaries between layers (in contrast to micromorphology sampling, see pp. 295, 302). In such cases, it is important to sample from bottom to top to prevent contamination of lower sample elements with particles falling from above. Another version of column sampling is to take successive sample elements by augering, usually in arbitrary vertical intervals, like 10 cm, or to take sections from cores (see

pp. 294–295). Disadvantages of column sampling include that the volumes of sample elements tend to be very small (~ 0.1 L) and thus unlikely to contain very many macroremains (although they may contain many microremains), and that one column or a small number of columns may not provide a very representative sample of a target population that could be a very extensive layer in a site.

Laboratory Sampling While the most significant sampling decisions may occur in the field, often the sheer volume of material recovered in the field is so large that archaeobotanists need to subsample (multistage sampling). Generally, it is a good idea in these instances to take a stratified random sample that ensures that each category of context contributes to the estimates of population parameters (p. 97). Alternatively, it may be advisable to take a sample or samples that contribute to evaluating very specific research questions, such as whether there was a change in selection of fuels (two or more populations of hearths) or a shift from dry-farming to irrigation-farming (populations of different ages). For charcoal, it is also important to ensure that the sub-sample represents a range of fragment sizes, since charcoal of some taxa may tend to occur in smaller fragments than others (Smart and Hoffman 1988: 174–176). However, there could still be some selection bias, as larger fragments are often easier to identify to a higher taxonomic level.

Sample Size Archaeobotanists have only rarely used statistical methods to determine fixed sample sizes (but see Pearsall 2015: 106–1078; van der Veen and Fieller 1982; and see Case Study: Plant Remains from Sites in Korea) but have often used a form of sequential sampling (p. 101) to provide samples that are adequate for their purposes. This is usually “sampling to redundancy,” which means gradually increasing sample size until the sample’s richness—i.e., the cumulative number of taxa—levels off. What this means is that further increases to sample size are unlikely to yield any taxa not already included in the sample. A similar approach is to increase sample size until the proportions of the main taxa level off, indicating that addition of further sample elements is unlikely to change those proportions substantially (see Fig. 6.6).

In selecting an archaeobotanical sampling method, including both sample size and the size of individual sample elements (see pp. 100–102), it is important to anticipate the likely density of the seeds or other plant materials that are important to the research questions. For quantitative analyses, the sample elements should be large enough that the average counts of at least the more important taxa are not too close to zero, and you can model the expected counts with Poisson distributions (pp. 132–133) to determine whether 0.5 L, 1 L, 5 L or 10 L sample elements will be sufficient for the macroremains or microremains of interest. Alternatively, a period of trial and error may help to decide appropriate volumes. For qualitative

analyses that are based on ubiquity measures (see pp. 122–124) or just the simple presence of certain taxa, density is also the most important determinant of the sample's usefulness. On the basis of estimates of seed densities, for example, you can use the binomial model (pp. 131–132) to decide on the optimum combination of sample size and sample element to provide reasonable assessments of whether a particular taxon is present or not, or the value of its ubiquity.

16.4 Processing Samples of Macroremains

Today, the usual way to retrieve plant macroremains from archaeological sediments is by water separation through a technique called flotation. Captured remains are then sorted and analyzed in the laboratory. Notably, not all of these remains will be plant remains; small bone fragments, snail shells, or stone flakes need to be passed on to the relevant specialists.

Flotation separates charred materials from the mainly inorganic sediment matrix because most charred remains are less dense than water, causing them to float. In combination with agitation, this concentrates them in the “light fraction” for easier analysis. Some heavier charred material, especially fruit stones and larger pieces of charcoal, sink into the “heavy fraction,” which may also contain small artifacts, bone fragments, shells, and stones. Both fractions then require manual sorting to pick out identifiable plant remains.

16.4.1 Water Flotation for Charred Plant Remains

By taking advantage of the lower density of organic as compared to inorganic particles, flotation in water separates charred plant remains from the rest of sediment more effectively than dry sieving in most situations. Some analysts add sodium bicarbonate to the water to improve the removal of clay, calcium carbonate and other minerals that may adhere to the surfaces of plant remains. It may also recover some very small animal bones and lithics.

The simplest kind of flotation—manual **bucket flotation**—is good for processing units of sediment less than about 5 L in volume and, by exposing the plant remains to less prolonged and vigorous wetting, is less destructive than most alternatives (Fig. 16.3). It requires no equipment more sophisticated than several sizes of geological sieves, a small tea-strainer type of sieve, and one or two buckets (Fig. 16.4). In its simplest form, bucket flotation involves putting about a liter sediment into a bucket of water, swirling it around and then decanting the muddy water into the nested sieves. A slightly more sophisticated version involves two buckets, one of which has had most of its bottom cut out and replaced with

a mesh. With the mesh-bottomed bucket nested into the intact one, the user fills them about two-thirds full of water and empties a volume of sediment, typically a liter, into the upper bucket. Grabbing the handle of the mesh-bottomed bucket, the analyst pulls it up, plunges it down, and rotates it back-and-forth to agitate the water, put the sediment into suspension, and release lighter particles from the sediment matrix so that they float while silts and clays sink and pass through the mesh at the bottom, while large, heavy particles, potentially including nutshell or lithics, are caught on the mesh. One either collects floating material with a small sieve or decants the muddy water into nested sieves and then extracts the heavy fraction from the mesh at the bottom before placing the captured material into bags or bundles for drying. Failure to dry samples thoroughly before transporting or analyzing them can result in severe breakage, crushing, or attack by fungi and mildew.

Bucket flotation is tedious for analysis of large volumes of sediment and may have very low yields of plant remains where their density is low. Consequently, many archaeobotanists use flotation machines in which air bubbles or water jets agitate the sediment in water (Hosch and Zibulski 2003; Pearsall 2015, 2019; VanDerwarker et al. 2016). **Machine-assisted flotation** facilitates processing of very large sediment volumes, such as the 10 L that some archaeobotanists favor.

For example, the Ankara-style flotation tank (Fig. 16.4; cf. Shell Mound Archaeological Project, or SMAP-type, flotation, Watson 1976) agitates sediment with jets of pressurized water—gravity is sufficient to provide the pressure through having the source water at a higher elevation than the tank—forced through small holes in interior pipes to agitate water in the tank. A mesh submerged in the tank captures the heavy fraction, and a lip or spout allows overflowing water and any floating material to exit into a series of nested sieves. In regions where water is scarce, the overflow water can pass through a series of settling tanks and be recaptured for reuse. After pouring a sediment sample of known volume and mass into the tank and stirring, the analyst simply collects floating material, most of it organic, on the sieves and then removes the internal mesh bag containing all of the heavier particles too large to pass through the mesh. Flotation thus removes all the finest particles and separates the lightest particles that remain from the rest. The captured light and heavy fractions are then put in separate small gauze or cloth bags or bundles and hung where they will dry slowly.

Flotation is not always the best method to use, as agitation in water may destroy some kinds of delicate bones and plant remains. Users of flotation tanks must also be careful to avoid contamination from previous samples in the tank. In some cases, dry sieving may be preferable.

16.4.2 Dry Sieving

Some archaeobotanists report that dry sieving is less likely than flotation or wet-screening to fragment fragile charred remains, although it may have lower recovery of very small seeds (Chiou et al. 2013). As with microrefuse and sediment analyses (Chap. 17), sieving typically involves use of nested screens, with the largest apertures at the top and smallest at the bottom, to sort sediments by particle size. Often a mechanical screen-shaker helps to make the sediments move downward through these screens, potentially damaging some fragile plant remains and generally creating a lot of dust, so that use of dust masks is a sensible precaution. Archaeobotanists often focus on the screen sizes that are most likely to catch charred seeds or husks of the plants of greatest interest.

16.4.3 Post-separation Analysis

Once plant macroremains have been separated from sediment, a low-power (7x–30x) binocular microscope is used to examine each fraction in small portions on a Petrie dish, where the analyst uses tweezers or a fine brush to sort particles into categories, such as charcoal, nuts, seeds, fruit stones, and unidentifiable or uncertain plant material. There can also be considerable non-plant material, such as lithics, sherds, and stones in the heavy fraction, and shells or insect parts in the light fraction. Sorting can take many hours per kilogram of charred material. Further sorting of each major category to genus or species can be even more time-consuming. Consequently, characterization of macroremains sometimes calls for subsampling, especially where the volumes of sediment sampled are very large.

Identification of macroremains requires a voucher collection with examples of wood, charred wood, seeds, nuts, and other plant items that you might expect to find in the archaeological deposits (Bye 1986; Pearsall 2015). Most archaeobotanists build their own collections, as the specimens in herbarium collections do not typically emphasize the parts that are of greatest archaeological interest, and their curators are understandably protective of specimens. Some kinds of voucher specimens, such as maize kernels, wheat grains, peas and lentils, are easy to obtain, at least in modern varieties, from bulk food stores, while it may be possible to obtain others from carefully identified plants in the wild or in farmers' fields. Wood of the more commercially valuable species may be obtainable from scrap at a lumberyard or carpentry shop, but collecting dead limbs of living trees can often yield a collection more similar to archaeological specimens. As charring changes metric attributes of seeds through shrinkage (Hubbard and al-Azm 1990), it is helpful to char some of the material from each

taxon and plant part in a hearth or lab oven, preferably with an atmosphere that excludes oxygen, to make voucher specimens more comparable to archaeological ones.

16.5 Seeds and Nutshell

The remains of fruit, most often charred or desiccated seeds, nuts or nutshell, or their impressions in clay, have long been the most important type of plant macroremain, both because seeds and nuts have been important human food sources, and because they are more likely to survive archaeologically than many other kinds of plant parts. Plant parts adjacent to seeds, such as glumes and rachis fragments of cereals (Fig. 16.7), may also be preserved. Characteristics of some seeds and nuts or their uses make them good candidates for charring, and thus for enhanced preservation. For example, hulled wheats that need to be parched with heat before threshing are fairly likely to be charred (Harlan 1967). In other cases, preservation depends on intentional or accidental firing, either after discard in a hearth or when a building burned down. Only plant parts that were protected from direct burning are likely to be preserved, with enough heat to char them but not enough to combust them and reduce them to ash (Dimbleby 1967). For example, relatively dense nutshell discarded in fires tends to sink in ash, where it is protected from combustion.

Fruit and seeds of flowering plants are formed from the flowering parts of plants after fertilization of the egg cell (in the ovule) by pollen (Figs. 16.5, 16.6, 16.7, 16.8, and 16.9). As seeds grow, the ovary becomes enlarged, the flower's stamens and petals shrivel and fall off, and the ovary becomes recognizable as a fruit. Fruits vary widely in form, ranging from pods and dry capsules to fleshy, edible fruits, such as apples, tomatoes, cucumbers and bananas. Blackberries and raspberries are actually clusters of many

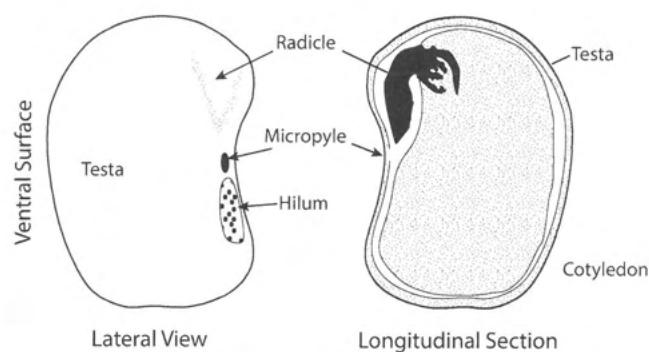


Fig. 16.5 Anatomy of a dicotyledon (dicot) seed. The embryo consists of a root or radicle and a shoot, or plumule, and is attached to two cotyledons. A cotyledon is a modified leaf in the seed, and monocots have one cotyledon, while dicots have two. The cotyledons store food and enclose the embryo. The hilum is a scar marking the place where the seed was attached to its pod

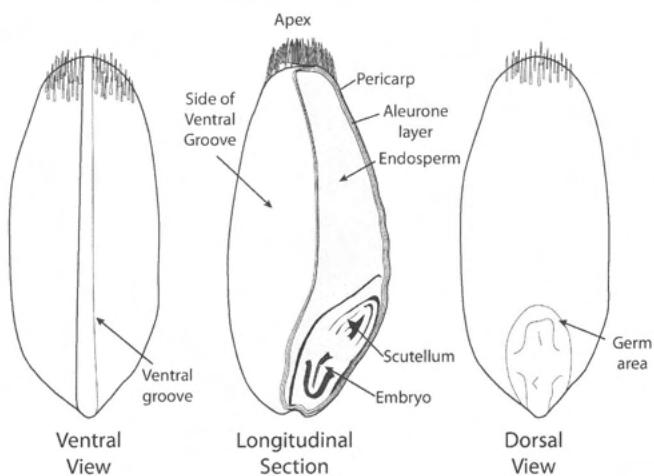


Fig. 16.6 Ventral and dorsal views and longitudinal section through a wheat grain (or caryopsis). As monocots, wheat plants store energy in a tissue called endosperm. (Y. Salama)

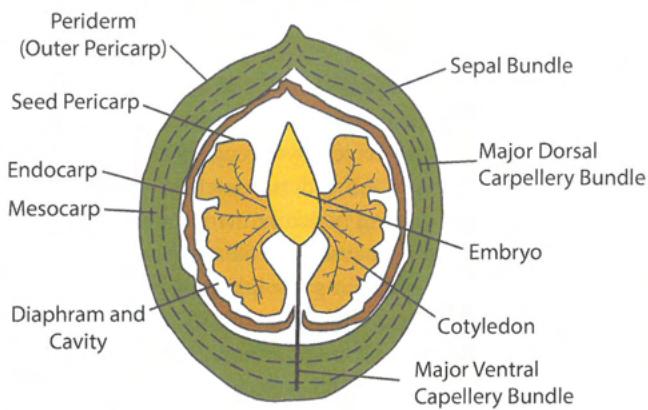


Fig. 16.9 Radial section through a walnut (*Juglans regia*) to show its parts

Fig. 16.7 Anatomy of a cereal spikelet with glumes enclosing florets attached by rachillae (left). The photos at right show both abaxial (away from the axis) and adaxial (toward the axis) views of charred rachis nodes and internode segments of *Triticum dicoccum* (top) and *Triticum durum* (bottom) from Bronze Age sites in the Near East. The *T. dicoccum* is a spikelet fork, as the bases of two glumes are present. The preservation of the *T. durum* at lower right is quite exceptional, with even very fragile hairs present. (Photos courtesy J. McCorriston)

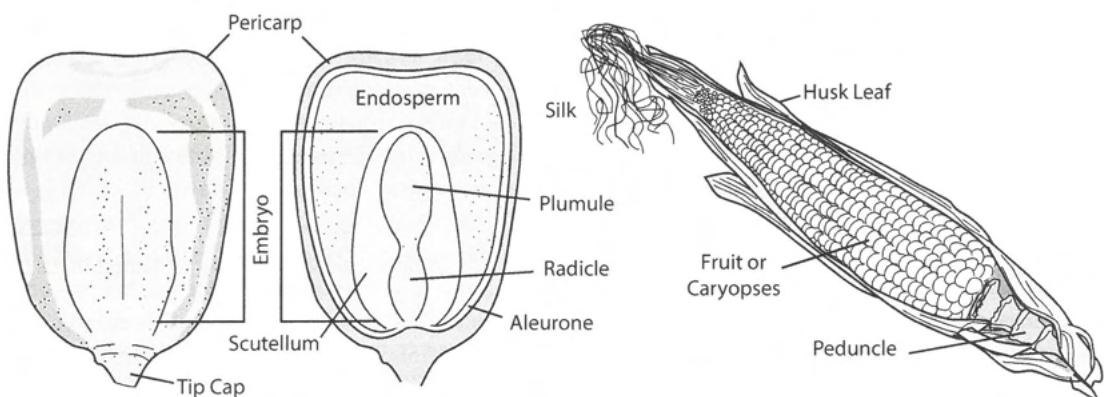
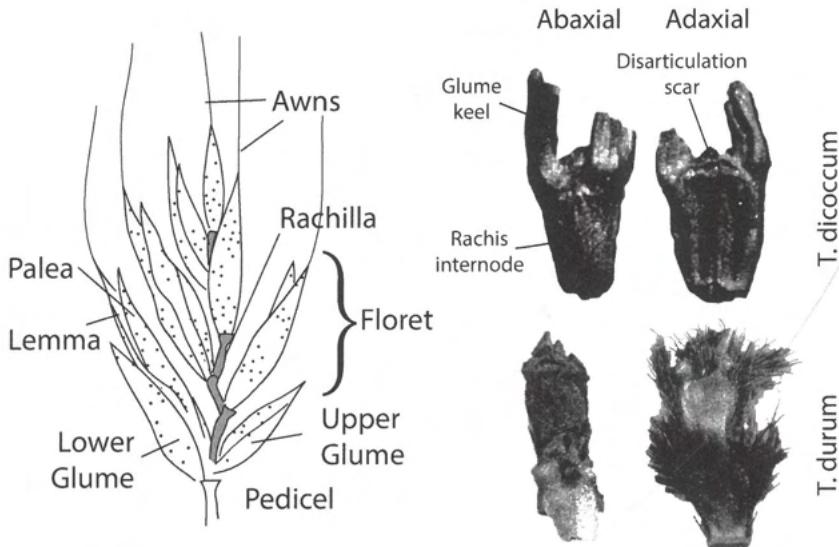


Fig. 16.8 Dorsal view and cross-section of a maize (*Zea mays*) caryopsis (kernel) and, at right, ear with female inflorescence. The endosperm stores energy for the embryo in the form of starch

small fruits. In strawberries, the largest edible portion is actually the flower's receptacle while the fruits are the small pips that cover it.

Sometimes, we are fortunate in finding other parts of a grass plant. Grains grow at the top of a culm (stem) in a spike (e.g., wheat and barley), broad panicle (e.g., oats), or intercalary ear (maize). A spike consists of a central, segmented rachis, with spikelets attached alternately at the nodes. A panicle is the same except that branches at each node are attached to the spikelets. Each spikelet (Fig. 16.7) has two glumes enclosing several florets attached by rachillae. In each floret, a lemma and palea enclose the grain or caryopsis, the lemma on the dorsal side and the palea on the ventral.

Maize (Fig. 16.8) is a highly unusual grass, being the product of humans' domestication of teosinte (Huffman et al. 2012). Here, the axis is a tough cob to which the grains are firmly attached. The glumes, lemma, and palea have become so reduced in size that the grains or kernels are naked and, instead, the entire corn ear is enclosed by leaf bases (husks). These completely preclude natural dispersal of the grains, making the plant completely dependent on humans for reproduction.

Nuts were exploited not only for their oil and meat, which can be made into flour, but also for tannic acid (for tanning hides) and fuel. Use of nutshell for fuel as well as roasting to reduce nuts' tannic acid content accounts for their charring in many archaeological cases. The part of the nut that is most often preserved archaeologically is the shell or **endocarp**, which in many kinds of fruit, such as peaches and walnuts, encloses the seed (endosperm and embryo) and lies beneath the fleshy part or mesocarp (Fig. 16.9).

Some guides to the identification of seeds and nuts include Delorit (1970); Nesbitt (2009), Schopmeyer (1974), and Smith (2018), but reference collections are nearly essential (Fritz and Nesbitt 2014: 130–131). While charring helps to preserve some plant remains, it also modifies their shape. Archaeobotanists can conduct experiments to study the effects of heat on them, and it is important to include both charred and uncharred specimens in the reference collection (Hubbard and al-Azm 1990; Ucchesu et al. 2016).

16.6 Wood Charcoal of Trees and Shrubs

Dry-sieved sediment and heavy fraction from flotation often includes charcoal fragments, which field archaeologists also often pick out for radiocarbon dating or dendrochronology. These are not only useful for dating, but to reconstruct a site's environment and human preferences for fuel and construction materials (e.g., Byrne et al. 2013; Höhn and Neumann 2018). Even microscopic charcoal fragments from sediment samples can reveal the history of forest fires (Moore 2001).

However, taxa represented by charcoal may not be representative of the trees around a site because wood accumulates on the site through many cultural and natural processes that favor particular kinds of wood, while presenting many of the

same taphonomic problems as faunal remains. Some kinds of wood make better fuel, are easier to hew, make straighter timbers, or are easily found lying on the ground within easy reach. Wood that is particularly useful can also be exported from forested regions to places with fewer or poorer trees, while charcoal can also come from driftwood that may have travelled thousands of kilometers on currents. In some instances, however, opportunistic collection of dead wood for fuel may provide a nearly random sample of wood in a site's vicinity. Only attention to site-formation processes and cultural practices can help us distinguish these situations (Théry-Parisot et al. 2010).

Accurate identification of wood or charcoal requires some preparation (Cutler et al. 2008; Stuijts 2006). It is necessary to break pieces so that they show the **transverse** (or cross-sectional), **radial**, and **tangential** planes (Fig. 16.10), using gentle pressure with a razor or scalpel to fracture, rather than slice or saw, the piece in the desired planes (Fig. 16.11). In the transverse section, in reflected light, the rays appear like spokes of a wheel, while in the tangential section, you see the rays end-on, and in the radial section they appear as parallel bands.

Identification depends on recognition of distinctive patterns in the cellular structure of the wood (Crang et al. 2018: 518–540; Crivellaro and Schweingruber 2013; Dubis n.d.; Helmling et al. 2018; Hoadley 1990; Lake 2015; Ruffinatto and Crivellaro 2019; Schweingruber 1990; Wheeler and Baas 1998). Identification to genus or species level requires detailed inspection of minute differences in cell structure, arrangement, and size. Consequently, a reference collection is essential (see Scheel-Ybert 2016). However, distinguishing hardwoods from softwoods more generally is less difficult (Fig. 16.10). Hardwoods have a complex structure with vessels (pores) running longitudinally through them; these appear as tunnel-like, circular features in transverse section. The vessels can be isolated or, as in maples and birches, grouped. Softwoods lack these specialized vessels, mainly showing the band-like variations in cell width (early and late growth) that occur in tree rings, although some genera, including pine, can have longitudinal resin canals that are somewhat similar to pores. They also show pits in radial section that are very useful in identification. Both kinds of wood show rays that radiate out in transverse section. In softwoods, the rays appear in tangential section as single or double strands of cells arranged vertically, but in hardwoods the rays can be multiseriate (have large bundles of cells arranged in vertical lenses). However, small fragment size and other factors sometimes makes it impossible to identify charcoal to one genus, requiring composite identifications, such as *Populus/Salix*.

In addition to taxonomic identification, careful examination of charcoal can inform us about the health of the original tree, branch diameter, and other factors relevant to firewood use and woodland management (Dufraisse 2006).

For reference collections, it is useful to mount thin sections cut from wood or charcoal on slides. This involves

Fig. 16.10 Wedges of hardwood (top left) and softwood (top right) cut along transverse and radial planes, along with magnified transverse cross-sections to show the tubular vessels in hardwood (lower left), and the lack of vessels in softwood (lower right), which has early-wood (**a**) and late-wood (**b**) zones of growth. (Y. Salama)

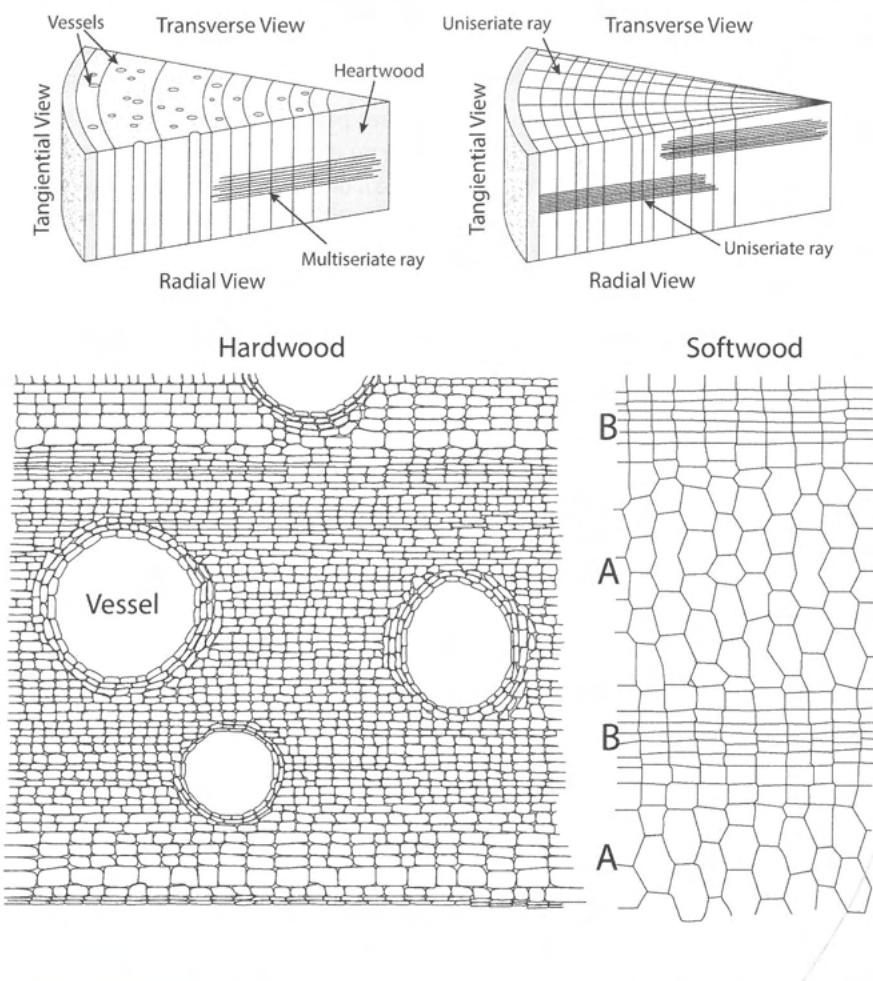


Fig. 16.11 Fracturing a charred branch fragment in the transverse plane by gentle pressure with a sharp scalpel

cutting thin slices in each of the transverse, radial and tangential planes with a microtome or a very sharp razor blade, thin enough that light will show through. A dull blade will tear at the cell structure and ruin your section. You can mount the sections on a microscope slide in a solution of glycerin and alcohol. It is useful to keep one section of each plane on a single slide under three cover slips, with clear label and a consistent orientation and order from one to the other so that it is easy to switch views or slides without becoming

disoriented. Heating the slide on a hot plate at 150 °C for 1–2 min expels air bubbles (Friedman 1978: 2–6).

Wood and its charcoal can also be useful chronologically because, in some species, seasonal and annual environmental variations affect the production of xylem and phloem to create tree rings of varying width (Crang et al. 2018: 516–518). This characteristic is the basis for dendrochronology (see chap. 20).

16.7 Parenchymous Remains

Vegetative remains of parenchymous plant organs (roots, tubers, rhizomes and corms) sometimes survive in archaeological deposits and can be particularly important in regions, like the tropics or Andes, where foods such as yams and potatoes have been staples (Pearsall 2019: 10–13).

Successful recovery of parenchymous tissues from sediments differs from that of seeds and nut fragments. Because they are fragile, machine-assisted water flotation is likely to break fragments into pieces too small for identification and, if water-flotation is necessary, it is better to use bucket flotation with only gentle agitation. Where it is practical, dry sieving is preferable, but without mechanical screen-shakers that would likely cause excessive fragmentation (Hather 2016: 74).

Because of the way they are processed, used, and discarded, large roots and tubers used for food are only likely to be charred and preserved as fragments, rather than whole organs. This presents challenges, and initial sorting by fragment types based on the kinds of tissues they preserve is a first step toward identification (Hather 2016: 72).

While charring or waterlogging can often aid their preservation, they may also distort the structure of parenchymous tissues by shrinking or swelling. Consequently, reference collections of parenchymous organs should be exposed experimentally to the same deteriorating conditions, such as charring, to improve the accuracy of identifications. Tissue

that has dried slowly prior to charring shows the best preservation, while steam expulsion that results from heating moist tissues causes fissures and large vesicles (Hather 1991: 662).

Generally, the identification process for parenchymous tissues is similar to that for other plant remains, and especially charcoals, except that confident identification may require use of Scanning Electron Microscope (SEM), with reflected-light microscopy only serving as a first step (Fig. 16.12). As with charcoals, it is also necessary to cut or break a fresh, reasonably flat plane through each specimen (Hather 2016: 76).

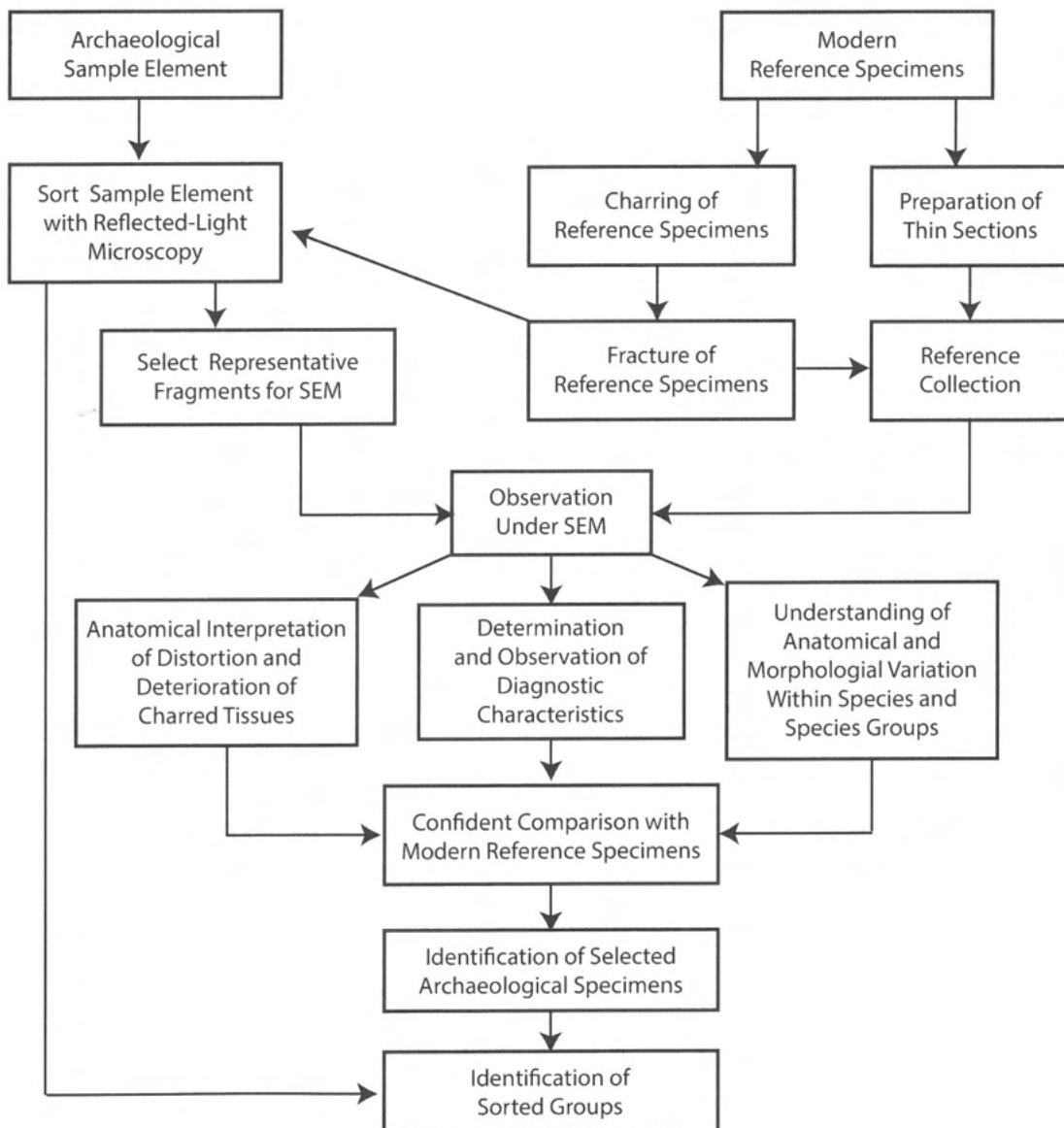


Fig. 16.12 Flow diagram for the identification of parenchymous tissues. (After Hather 2016: 75)

16.8 Processing and Analyzing Samples of Microremains

Microremains require use of separation and concentration techniques to isolate them from surrounding sediment, and high-power magnification for identification. They may also appear in sediment thin-sections.

The usual method for extracting phytoliths, starch grains and pollen from bulk sediments is called heavy-liquid flotation. This involves using a heavy liquid, such as lithium metatungstate, to separate particles of varying density (Chandler and Pearsall 2003; Coil et al. 2003; Horrocks 2005).

Micromorphology (see also pp. 302–303) involves removing blocks of sediment from select locations, consolidating and hardening them with resin, and sawing and polishing thin-sections of the blocks for examination under magnification. Sometimes phytoliths appear in these thin-sections and allow us to identify, for example, thin layers of degraded plant remains from straw stores, bedding, or the floors of livestock enclosures (e.g., Hubbard 2010).

16.8.1 Pollen

Archaeobotanists sometimes use pollen from archaeological contexts (Bryant and Hall 1993; Bryant and Holloway 1983) but off-site pollen records are particularly important as evidence for the vegetational environment and, indirectly, the climate of the region in which archaeological sites are located.

The most common context for recovering ancient pollen is in cores of waterlogged deposits, such as those in swamps and lake bottoms, because anaerobic environments favor pollen preservation and bodies of water are excellent for capturing wind-borne pollen. Pollen preservation is more favorable in sediments with pH no greater than 5.5, but there are other factors that also affect preservation (Havinga 1984).

It is usually necessary to concentrate pollen grains from sediment samples by progressive chemical digestion of the surrounding sediment (Bryant and Holloway 1983; Faegri and Iverson 1989: 72–84; Moore et al. 1991: 41–46). To aid quantification, analysts sometimes introduce a known number of polystyrene spheres, *Lycopodium* spores, or *Eucalyptus* pollen into fixed volumes of sediment (see p. 115). The addition of safranin red stain enhances pollen visibility. A portion of the concentrated pollen can then be mounted on a warm glass slide with a pipette, spread out, covered with a cover slip, and sealed with varnish. Once the slide is labelled, it is ready for examination under a microscope.

Identification of pollen grains depends on the great diversity of shapes that they exhibit (Faegri and Iversen 1989;

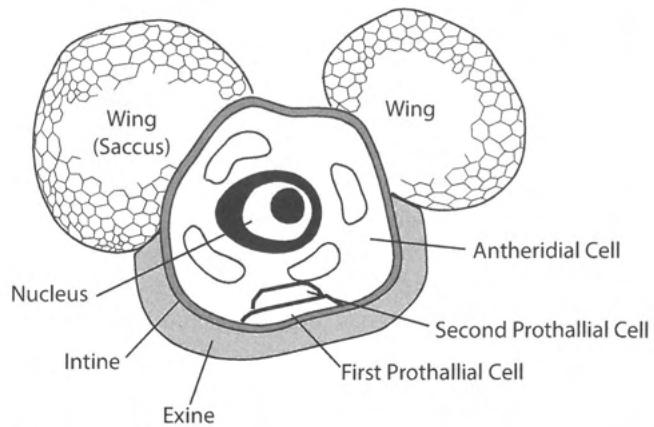


Fig. 16.13 View of a mature exine (decay-resistant outer layer) of Pine pollen, showing its parts

Moore et al. 1991). Both morphology and the relative abundance of pollen are related to the pollen's means of dispersal.

Anemophilous (wind-borne) pollen, such as that of *Pinus*, *Casuarina*, *Poaceae*, and *Typha*, has features that enhance its buoyancy on the wind. For example, pine pollen has large sacs (Fig. 16.13) that make it very light (low in density). **Zoophilous** (animal-borne, including entomophilous or insect-borne) pollen comes from plants that produce less pollen but depend on animal vectors to transport it very effectively from the anthers to the stigmas of flowers. Pollen of this type has features that make it likely to attach to fine hairs on the animal meant to disperse it. **Hydrophilous** (water-borne) and cleistogamous (self-pollinating) pollens rarely occur in archaeological deposits because the former lacks a hard exine and the latter are not transported widely. Understanding pollen frequency distributions is impossible without considering the effects of these dispersal mechanisms (Hevly 1981).

Although there are guides for identification (e.g., Bassett et al. 1978; Moore et al. 1991; Weber 1998), as usual, there is no substitute for a voucher collection. These can be made from pollen collected in the field from confidently identified plants or from herbarium specimens; some are even available from commercial firms. However, pollen that is difficult to identify is typically only identified to a "type" (Greig 1989: 65).

Pollen analysis is a common source of evidence for changes in vegetation cover that might be related to climate change or human impacts. For example, the introduction of maize agriculture triggers relative decreases in tree pollen and increases in the pollen of field weeds (Fig. 16.14). Typically, palynologists examine changes in the pollen of several taxa of environmentally-sensitive trees and shrubs, as well as non-arbooreal pollen—the collective contributions of all non-tree plants. Because of their interest in evidence for climate change and human impacts on landscapes, they can

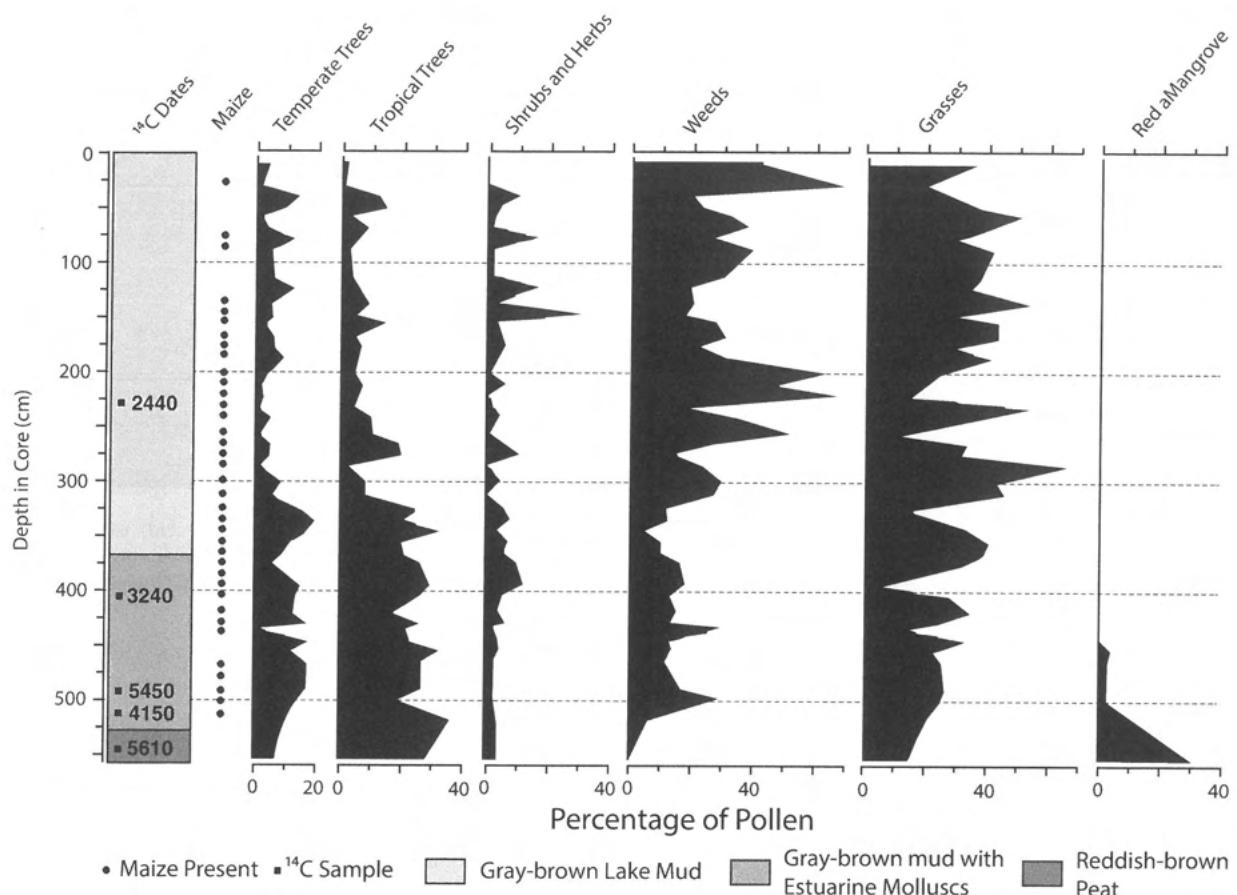


Fig. 16.14 Pollen diagram for a core from a lake in the coastal plain of Veracruz, Mexico, showing relative abundances for a variety of taxonomic groupings along with presence of maize, whose introduction is

associated with a decrease in trees and increase in weed taxa. (Y. Salama, after Sluyter and Dominguez 2006). Radiocarbon determinations are uncalibrated and omit the errors

concentrate on groups of vegetation types that are sensitive to these effects because they are adapted to particular conditions of temperature and humidity. For example, tree cover may be more extensive during warmer, more humid climate, while certain shrubs and herbs that are adapted to steppes or prairies, such as *Artemisia sp.* (wormwood and sagebrush), may make stronger contributions to a pollen distribution when conditions are cooler and drier.

However, interpretation of pollen abundances requires careful consideration of plants' pollen productivity and the transport mechanisms that may have brought the pollen to the deposits that the cores intersected. Pollen that is easily carried on wind can travel many hundreds of kilometers, while zoophilous pollen might hardly be represented in a deposit even when there are thousands of these plants in its immediate vicinity. Consequently, the changing abundances of pollen taxa in a core do not necessarily reflect local changes in vegetation and may be better for interpreting regional-scale vegetation patterns. Interpreters of pollen evidence attempt to calibrate the varying kinds of pollen in light of these production and transport differences.

16.8.2 Phytoliths

The conditions under which phytoliths may be preserved in archaeological sediments are quite different from those for many other types of plant remains. Charring, for example, has negative impacts on phytolith preservation, while the presence of certain iron and aluminum oxides in sediments can enhance preservation. In addition, phytoliths of different taxa and even different plant parts may differ considerably in their stability over time (Cabanes and Shahack-Gross 2015; Cabanes et al. 2011; Pearsall 2014; Piperno 2006: 21–22).

Phytoliths pose unusual challenges of identification and quantification. The cell shapes that they document usually do not vary enough interspecifically to allow identification to species or genus, with rare possible exceptions, and also vary in different parts of the plant (Fig. 16.15). In addition, it is not obvious what counts of phytoliths would be telling us, as hundreds of phytoliths could come from a single stem fragment or from several fragments of unrelated plants. As with other kinds of plant remains, the sampled assemblage is a degraded remnant of a deposited assemblage that originated

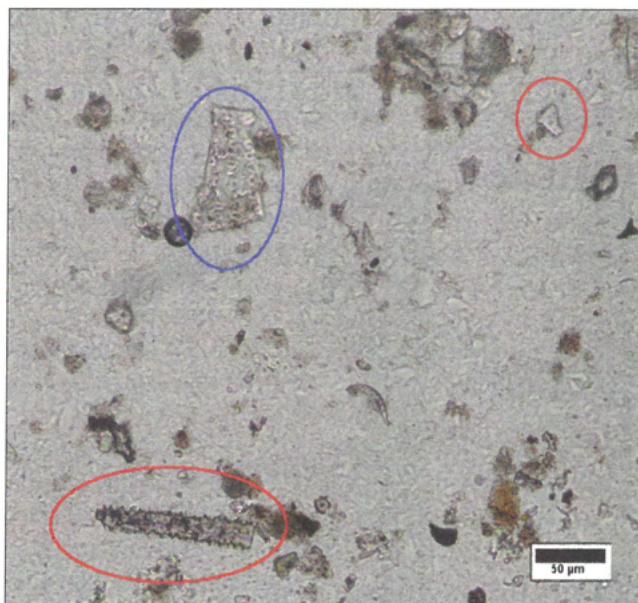


Fig. 16.15 Phytoliths (circled), with a saw-like grass phytolith at lower left. (Courtesy E. Hubbard)

from behaviors that led to plant parts' accidental or intentional discard. Consequently, phytolith analysis tends to be most useful to archaeologists in the context of specific research questions for which phytoliths could provide supporting evidence.

Example

Alison Weisskopf (2017) exploits phytoliths of crop weeds in middens and other cultural deposits to distinguish between dependence on rice or millet agriculture in Neolithic and Early Bronze Age China. It was not possible or necessary to identify the taxa of the phytoliths, all of which came from grass leaves, but the distinction between phytoliths that came from cells genetically predisposed to form phytoliths and those from cells that form phytoliths only under wet conditions allowed her to distinguish wet and dry cycles. Millet could be grown under dry conditions, but rice would only be grown when there was sufficient water.

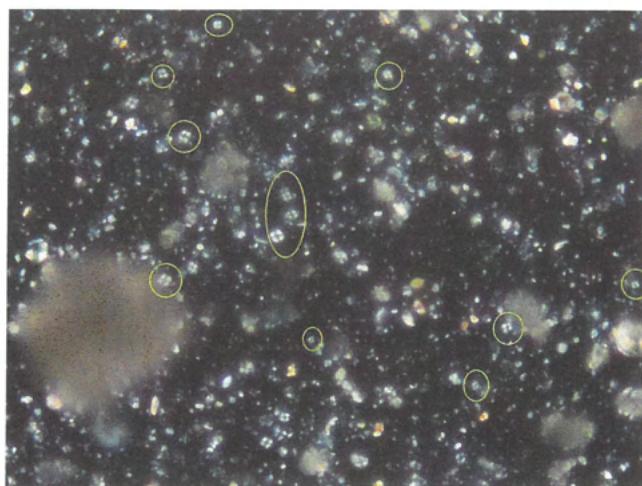


Fig. 16.16 Example of starch granules (circled) extracted from a Neolithic quern, each 5–10 μm in diameter, under polarizing microscopy. Note the cross-shapes that result from birefringence of the crystalline structures in starch. (Courtesy E. Yasui)

"Cross" when viewed under the microscope (Fig. 16.16; Copeland and Hardy 2018; Torrence and Barton 2006), and starch granules also exhibit internal growth rings. Because they vary substantially in size, shape, and molecular structure (Reichert 1913; Torrence et al. 2004), both among species and among plant organs, they provide a valuable complement to other plant evidence, and particularly for plant foods, such as tubers, that are not consistently represented among macroremains. When starch is cooked in water, however, the granules swell and lose their distinctive molecular organization, while processing of foods by grinding and pounding can also damage granules (Lamb and Loy 2005).

Starch analysis requires removal from artifacts, coprolites or dental calculus and separation from soil and other minerals. Sometimes, previous cleaning of artifacts has removed most residues, but starch can sometimes still be present in pores and crevices. Removal methods vary, and include extraction by pipette and distilled water, mechanical removal with sterile tools, washing with water and ultrasonic cleaning. The enzyme, alpha-amylase, can confirm that starch is present, while repeated agitation and centrifuging in a solution of cesium choloride (CsCl , $\rho = 1.8 \text{ g.cm}^{-3}$) and washing with distilled water can separate the starch (e.g., Pagán-Jiménez et al. 2015). A droplet of the more concentrated starch solution is placed on a new slide with a small amount of glycerol to enhance the birefringence of the crystalline layers. Staining, often with CongoRed or Trypan Blue, can also be useful, particularly for identifying damaged grains. For longer-term storage, a cover glass will protect the specimen on the slide to be rehydrated for later analysis after

16.8.3 Starches

Although they are far from immune from degradation or decay (Haslam 2004; Henry 2014), starch granules can sometimes survive for many millennia in sediments, on tool and pottery surfaces, and in dental calculus. The crystalline layer in starch granules causes a distinctive, **birefringent** "Maltese

it dries out (Piperno 2006), or it can be mounted for a permanent collection with glycerol, immersion oil, or similar compounds.

As with other classes of plant remains, identification depends a good deal on the availability of a modern reference collection, although such collections are currently fairly rare. Starch analysis is still in its early stages, and there remains skepticism about the reliability of starch identifications that are based solely on visual examination under the microscope (Akeju et al. 2018).

Other key challenges in starch research are taphonomy and controls for contamination (Barton and Matthews 2006; Barton and Torrence 2015). As with other kinds of plant evidence, it is useful to think in terms of the processes that are more or less likely to result in deposition of starch.

16.9 Chemical and Isotopic Evidence

Chemical residues on the edges of cutting tools or on the use surfaces of grinding stones can provide some of our best evidence for their use. Not only can these sometimes show phytoliths, pollen, or starches, as noted above, but also cellulose and lignin (polymers that give rigidity to cell walls, bark and wood), lipids (molecules in fats and oils), resins, or amino acids. The methods used to detect and identify these residues include gas chromatography (GC), mass spectrometry (MS), a very useful combination of these (GC-MS), gas chromatography-combustion-isotope ratio mass spectrophotometry (GC-C-IRMS), Fourier Transform Infrared Spectroscopy (FTIR), and others. Much of this research has focussed on identification of animal fats (see pp. 257–258), but they have also been successful at identifying proteins and lipids from plants (e.g., sesame oil, Shevchenko et al. 2017).

Isotopic research on the plant component of diet has focussed mainly on the stable carbon isotopes, ^{13}C and ^{12}C (as opposed to radioactive ^{14}C). The ratio of these isotopes in living organisms varies because the photosynthetic pathways of plants differ in how they take them up from carbon dioxide in the atmosphere. This slight preference for one isotope over another is called fractionation, and archaeological analysis of these isotopes depends on differences between two groups of plants with different photosynthetic pathways, C3 and C4 plants. The former group includes trees, shrubs, and temperate grasses; the latter includes tropical grasses, such as maize, and tends to have more ^{13}C relative to ^{12}C . Consequently, when humans consume substantial amounts of maize or other C4 plants, you would expect that to show up in the isotopic composition of the carbon in their bones (Fig. 16.17). Because humans are omnivores, the mixing of isotopic signals in their diets can be very complex, and some researchers are beginning to use Bayesian methods (see pp. 139–140) to try to sort that out (Lewis and Sealy 2018).

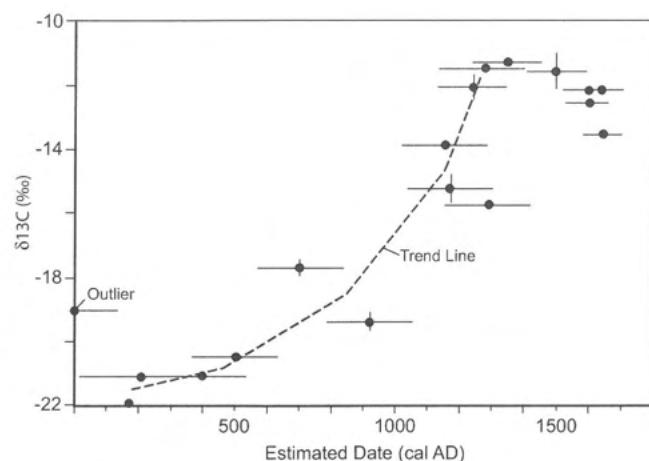


Fig. 16.17 Time-series graph showing variation in the mean $\delta^{13}\text{C}$ to $\delta^{12}\text{C}$ ratio ($\delta^{13}\text{C}$ in ‰) at sites in southern Ontario. (After Katzenberg et al. 1995, error bars estimated by author). Note the rather rapid change in this ratio about 1000 cal AD, marking the introduction of maize as a staple in diet. As the points are means by site, they do not reflect all the variation in the data

16.10 Quantification Issues

As already discussed at length in Chap. 7, quantification is a thorny issue for archaeobotanists. We can count seeds or pollen grains, or measure the mass of charcoal fragments, but what do the resulting measures mean in terms of plant use, environment, or past cultures?

Seeds, glumes, internodes, rachis fragments, and many other plant fragments are amenable to counting, and it is sometimes possible to avoid double-counting of fragments by only counting those that are more than 50% complete or those that preserve a “landmark,” such as the hilum on a dichot seed. Differential fragmentation makes the interpretation of charcoal or parenchymous counts very difficult (Chrzażez et al. 2014), and most researchers prefer to quantify these by mass.

However, there has long been controversy over how we can make use of counts or mass for valid interpretation. The appropriate choice depends on the research questions and the taphonomic processes to which assemblages were probably exposed.

One approach has been to make use of ratios, especially the ratio of charred seed counts to mass of charcoal (pp. 112–113; Marston 2014; Miller 1988: 75–83). The idea here is that charcoal mass normalizes for at least some of the preservation issues, but this depends on the questionable assumptions that habitual use of wood as fuel is rather constant and that preservation rates of charcoal and other charred plant remains are very similar and stable (Kadane 1988: 212; see Orton 2000: 65–66).

Rather than take their absolute magnitudes or their proportions very seriously, many analysts are interested in the implications of various combinations of macroremains for the character of the deposit in which they occur and the processing or discard activity with which they are most likely associated. For example, Hillman's work in Turkey, as described earlier in this chapter, suggests that a plant assemblage in which spikelet forks and tail grains from glumed wheats are fairly common, while glume bases and internodes, and weed seeds smaller in size than prime grain are very abundant, probably resulted from fine sievings during grain processing. The exact quantities of these things are not important, only their ordinal-scale representation and the way they are combined with other plant remains as evidence for the processing stage that could have resulted in a deposited assemblage. These characterizations are also most useful in the context of specific research questions.

Similarly, we can study the distributions of wood charcoal in the context of how people selected wood for fuel or lumber. Fuel wood, of course, is much more likely to be preserved by charring, except in the case of catastrophic or intentional fires that engulfed whole buildings. Where we use charcoal as evidence for the environments around sites, it may be useful to compare the archaeological charcoal distributions, usually quantified by mass, with the distributions of tree taxa in modern environments (Smart and Hoffman 1988: 184). However, selection of wood for household fuels is rarely completely random, since different woods vary in their ease of collection and burning qualities, and fuel suitable for some industrial processes, such as smelting ore or firing pottery, could be even more selective or include imported fuel with no relationship to local forests (Smart and Hoffman 1988: 168–169). Another quantitative aspect of archaeoanthracology (charcoal analysis) is to estimate the mean diameter of the wood from which charcoal fragments originated. This is biased unless bark is routinely present and all fragments are large enough to measure the curvature of growth rings and angles between rays, but it still gives a sense of whether fuel consisted of small branches and coppice shoots, larger branches, or thick portions of tree trunks (e.g., Jansen and Nelle 2014). It can also be useful for estimating the relative merits of fragments for dendrochronology or radiocarbon dating (see Chap. 20).

Pollen and similar microremains have their own quantification challenges. Counting pollen involves making a series of traverses at about 400x across the slide by turning the small "travel knobs" to move the microscope stage in the x- and y-axes by small, fixed increments. To avoid confusion, always begin at the same corner of the slide. Along each traverse, you count and record pollen of various taxa at various grid coordinates. Grains that are not immediately identifiable require closer examination by zooming in at higher magnification, perhaps 1000x (Faegri and Iversen 1989: 65–66).

Pollen quantification is often expressed as number of grains per unit volume or unit mass of sediment (as measured before chemical digestion) rather than simply in number of grains or percentage of grains, although the last is still common. Pollen analysts can use a sampling-resampling approach (p. 115) by placing a known number of "exotics" (microremains that would not occur naturally), such as *lycopodium* (clubmoss) spores in the sample volume. The proportion of "exotics" provides a basis for calibrating the number of pollen grains and providing a reliable estimate for the total number of ancient pollen of each taxon in that sample element (Benninghoff 1966). For example, if you know that you placed 1000 *lycopodium* spores in a volume of sediment that should not have had any *lycopodium* in it, and then find 50 *lycopodium* spores in the sub-sample that you examined, you can multiply the counts of all the ancient pollen grains by 20 (1000/50) to obtain an estimate of the total number of each type of pollen in the volume.

For starches and chemical residues, it is not necessary to count anything. Instead, the mere presence of these residues—after controlling for possible contamination—provides evidence for contact with or consumption of certain categories of plants.

16.11 Archaeobotany and Paleoenvironment

Archaeobotanical evidence, especially from off-site pollen and archaeological wood charcoal, is important for reconstructing prehistoric environments and the place of humans in them (Barker 1985: 15–19; Crawford 2018: 156–158).

A key archaeological interest is interaction of humans with vegetation communities in their habitats. A fairly early paradigm for such research is human ecology (Bruhn 1974; Butzer 1982; Hardesty 1977; Lawrence 2003; Vayda 1969), along with the closely related historical ecology (Crumley 1994; Szabó 2015). Although human ecology is far from being a unified paradigm, it features humans as just one species among many in an ecosystem that involves interspecific exchanges of matter, energy and information. It focuses specifically on the interrelationships between human populations and the other components, both living and non-living, in ecosystems. While archaeobotany can play a large role in human ecology, it is inherently interdisciplinary.

Human Behavioral Ecology (HBE), more a branch of human ecology than a completely different paradigm, is less common in archaeobotany. Like human ecology more generally, it contextualizes human behaviors, including those involving plants and animals, within evolutionary ecology. However, with its connections to ecology and economics, HBE makes use of decision theory and other optimizing functions to determine the "best" combinations of resource use in terms of costs and benefits, as measured in energy or

some other “currency” (e.g., Gremillion 2014; Winterhalder and Smith 2000).

Niche-Construction Theory (NCT) has recently become common in archaeobotany. Odling-Smee (1988; Odling-Smee et al. 2003) introduced the term niche construction to describe an evolutionary process that Lewontin (1983) had already been advocating as a complement to natural selection (Laland et al. 2016). A key feature of niche construction theory is that an organism does not simply adapt to pre-existing conditions through selection, but can itself modify its environment in ways that influence the selection pressures on itself or other organisms so that there is an evolutionary response in at least one species (Matthews et al. 2014). While niche construction itself is fairly obvious—all organisms have some kind of impact on their environments—the difference in NCT is that these impacts alter the nature or intensity of natural selection for one or more organisms. It also tends to be a reciprocal relationship, as adapting organisms can make further alterations to their environments as they respond to an earlier one.

Archaeologists are of course most interested in the implications of NCT for human interactions with their environments, and this is particularly true of research on domestication (see below). Bruce Smith (2012, 2014) argues that NCT provides a much better explanation for plant (and animal) domestication than HBE or human ecology more generally can do, particularly as it does not require the assumption that humans were adapting to adverse climatic changes or population growth that restricted resource availability. We can expect that many of the resource-collecting behaviors and mobility decisions of Pleistocene and early Holocene hunter-gatherers to have had substantial impacts on the distribution and density of both desirable and undesirable plants. Some of these impacts, furthermore, would have been ones that altered selective pressures on the plants, on humans, or on other animals that preyed on the plants. Smith (2012: 264) is particularly interested in humans’ deliberate modifications to their environments to enhance availability of desirable resources, but it is important to note that both deliberate and unintentional modifications can satisfy the criteria for niche construction. For example, humans may deliberately till a field to increase their yield of some crop, while unintentionally creating conditions that change the selective pressures on weeds or non-human animals that also prey on that crop.

16.12 Reconstructing Paleodiets, Foodways and Plant Use

As in zooarchaeology, archaeobotanists place considerable emphasis on the role of plants in ancient dietary choices and increasingly in culinary practices and social relations

(Hastorf 2017; Morehart and Morell-Hart 2015). They are interested not only in staple foods, but in plant use for fuel, construction or clothing material, drugs, condiments, spices, cosmetics, dyes, inks, and poisons (Day 2013; Pearsall 2019: 198–227).

As noted in Chap. 7 and in a previous section, interpreting the quantitative evidence for plant use is complicated, and abundances of plant remains do not just translate into dietary preferences, niche breadths or culinary practices. It is easier to identify the introduction of new plants or their adoption as staples, while the newer research on starch and chemical residues is increasingly useful for identifying actual food-preparation practices. Evidence from dental calculus, in particular, provides our most direct evidence of what people were eating, although with less specificity than we would typically like.

Example

To study diet and its cultural implications, Beck et al. (2016) examine changes in the distributions of plant and animal foods from earlier to later contexts at the sixteenth-century, Spanish colonial site of Fort San Juan de Joara in what is now North Carolina. Counts of charred acorns, hickory nuts, maize, and other food crops and fruit from the Spanish compound just north of the fort strongly suggest that the Spanish soldiers garrisoned there depended on indigenous women for their plant food provisions, rather than provisions brought from elsewhere or crops from imported seed stocks. Statistical analyses show significant differences between early and later contexts in the compound, mainly involving a shift from acorn to hickory that may be due to local women adapting to the Spanish soldiers’ preferences or to the addition of nonlocal slaves to the labor pool. Evidence from animal remains similarly shows a shift from early contexts in which deer and bear contributed almost equally to the soldiers’ diet to later ones in which venison—arguably more sympathetic to European palates—became by far the dominant meat in the Spanish compound and became less likely to come from whole deer carcasses. As in the case of the plant foods, this could be due to local hunters adapting to Spanish demand.

16.13 Plant Domestication and the Origins of Food Production

Archaeobotanists have long focused attention on identifying and understanding the domestication of plants and the dispersal of agricultural ecologies. Domestication is a process

whereby a plant, through natural or artificial selection, or both, becomes dependent on humans for its dispersal just as humans become more dependent on the plant, or one that grows with it, for food or some other use. Crop plants and the weeds that accompany them are both subject to these evolutionary influences (Willcox 2012).

The domestication of wheat, barley, rice, maize, squash, millet and pulses have attracted a great deal of interest (Bestel et al. 2014; Conard 2016; Crawford 2016; Fuller 2007; Fuller et al. 2011; Gross 2012; Milla et al. 2015; Ranere et al. 2009; Sang and Ge 2007; Sonnante et al. 2009; Wang et al. 2005; Willcox 2013; Zheng et al. 2016). However, there has also been interest in the domestication of figs, olives and grapes in the Old World (e.g., Denham 2007; Gismondi et al. 2016; Kislev et al. 2006; Margaritis 2013; McGovern et al. 2017) and of potatoes in the Andes (Spooner et al. 2005). Not surprisingly, studies of domestication have tended to have a human-ecological or evolutionary focus (e.g., Milla et al. 2015; Punugan and Fuller 2009; Rindos 1984), and increasingly a niche-construction one (e.g., Smith 2012), while genetics has had a profound impact on our understanding over the last two decades (e.g., Kovach et al. 2007; Peleg et al. 2011; Pourkheirandish et al. 2015).

Domestication is related to, but distinct from, the human behaviors that involve manipulating and tending plants; in some instances, humans may have been cultivating wild plants for decades or centuries before the plants showed any morphological signs of domestication (e.g., Willcox et al. 2008), although domestication processes can also be rapid. Other kinds of evidence can sometimes allow us to infer behavioral changes associated with cultivation, whether or not morphological changes in crop plants have yet developed, such as the appearance or shift in abundance of weed taxa that typically appear only in assemblages harvested from cultivated fields (Hillman 2000: 384–388).

Some, but not all, of the following changes that plants often undergo in the domestication process are morphological, making them useful evidence for domestication (Rindos 1984: 183):

- The plant loses its ability to disperse seeds. For example, wild grasses have a brittle rachis that shatters when the grain is ripe so that grain will scatter; domestic wheat has a tough rachis that holds grain until after humans harvest it

- The plant part that humans consume becomes larger. In some cases, such as apples, it is not only enlarged, but attracts humans and other predators by signaling ripeness with color changes
- The plant part that humans use may become clustered. Seeds that are clustered in a pod, spike or maize cob are easier to harvest in large quantities, a feature that attracts predators, including humans
- There is often a change in duration, from annual to perennial, or the reverse
- There is a tendency toward polyploidy (increase in chromosome number), often accompanying gigantism
- There is a loss of dormancy. In the wild, only some seeds germinate in their first year, while others lie dormant until later years as a sort of insurance against drought or other poor growing conditions. In an agricultural ecology, where humans seed and tend the plants, this feature usually disappears
- Plants tend to develop simultaneous ripening. In the wild, fruit may ripen at different times over several weeks, again as a sort of insurance against bad weather or predators. Simultaneous ripening is attractive to humans because they can harvest a crop all at once
- Plants tend to lose features, such as thorns and toxins, that protect wild plants from predation. Humans would tend to select less thorny and more palatable plants for their use, and may aid their dispersal and increase, while plants in fields tended by humans have less need for these protective features
- Diversity in plant form tends to increase. Subtle mutations that would not have persisted in the wild may thrive in the protective environment of humans' fields, and humans may even encourage this diversity by intentional propagation
- Because humans provide a dependable means of reproduction, plants tend to change from very opportunistic (r-selected) to more specialized (K-selected) species during the domestication process.

While early domestication events have dominated the literature, domestication is an ongoing evolutionary process. New domesticates can be added to agricultural ecologies long after introduction of the earliest domesticates, while existing domesticates can develop new varieties or even species through selection and hybridization.

Case Study

Plant Remains from Sites in Korea

Gyoung-Ah Lee (2012) provides an example of how archaeobotanists can grapple with the dual problems of taphonomic effects and effective sample size. In large, semi-subterranean houses at several sites of the Early Chulman through Late Mumun periods (ca. 5600–200 BC) in the Nam River valley, Korea, Lee was interested in identifying changes from a foraging to an agricultural economy. The most significant changes in this sequence probably occurred from the Early to Middle Mumun. Given this research question, she hoped to characterize plant remains from whole sites that dated to particular intervals over this long period, rather than, for example, distinguishing differences in plant use among houses or features.

However, the potential numbers of plant remains to analyze were huge and unknown taphonomic effects that had probably affected the sampled assemblages differentially were major challenges.

In an attempt to deal with these problems, while still allowing her to answer her research questions with reasonable confidence, Lee attempted to determine what sample sizes she would need to analyze from the hundreds of sample elements that had been collected from these sites. The sample elements were 10 L of sediment from each 1 m² grid square and from a subsample of pit features. Taking the total of these at each site as the population, and

given the substantial labor costs of counting seeds in such volumes after flotation, Lee estimates the sample size (number of grid squares and features) necessary to achieve a relative standard error (RSE) on seed densities of 20% at 90% confidence ($t = 1.83$ and $r = 0.2$) for each period of occupation. She assumes that these densities will provide a sound basis for estimating the proportions of taxa among the seeds of whole sites. The result was $n = 141$ for the Early Mumun contexts, and $n = 70$ for the Middle Mumun. However, she was actually able to accomplish her goals with even smaller sample sizes, as samples of $n = 76$ and $n = 63$ turned out to meet her objective of 20% RSE at 90% confidence. This strategy provided a basis for inferences at the site level without the cost of having to analyze 10 L volumes from all of the grid squares and features.

She then compares the samples by using the ratio-of-ratios approach (Orton 2000: 65–66). This makes comparisons among sites, contexts or time periods possible when we can plausibly assume that taphonomic differences are such that they still preserve proportionality among taxa (see p. 119 and Fig. 7.3). For example, if Millet was twice as abundant as rice at one site and four times as abundant at another (ratio of 2:1 between sites), that same ratio will be found in the degraded sample that the archaeobotanist analyzes (still 2:1), even though the two sites' preservation environments differ, as long as the probability of survival of millet and rice retains proportionality (e.g., 0.8 to 0.4 at one site and 0.4 to 0.2 at the other).

16.14 Quality in Archaeobotanical Analysis

The previous chapter ended with an example of interobserver studies to evaluate the quality of zooarchaeological identifications. Analyses of plant remains are similarly vulnerable to errors in identification, quantification and interpretation, as well as recovery (e.g., Hosch and Zibulski 2003).

For example, Wright (2005) argues that variations in the ways that different archaeobotanists collect and process sediments for flotation probably have a large impact on quantification and resulting interpretations. She uses an experiment with three 10 L volumes of sediment (sandy loam, silt-loam, and clay-loam) that each contained exactly 25 charred specimens of each of 11 taxa of charred nutshell, wood, and seeds to estimate their recovery rates in both the heavy and light fractions that result from use of a Shell Mound Archaeological Project (SMAP) flotation system, which agitates with water jets, and 1 mm mesh insert.

Wright's findings indicate that, while recovery of charcoal and nutshell was fairly good, recovery of other remains was highly variable and especially poor for small seeds, such as tobacco and chenopod. Clearly, this recovery variability has major implications for the value of reported abundances of plant remains and potentially even for measures of ubiquity and diversity when some taxa are relatively rare. Furthermore, this study does not account for variability among flotation machines or analysts.

16.15 Summary

- Plant evidence consists of macroremains (e.g., charred endocarps and charcoal), microremains (e.g., pollen, starches, and phytoliths), and chemical and isotopic traces
- Differential preservation and recovery are major concerns for archaeobotanists. Orton's ratio-of-ratios approach is a creative attempt to account for this

- Archaeobotany has long made important contributions to the study of human-environmental interactions, sometimes in a human ecological framework, and recently with increasing emphasis on niche construction theory (NCT)
- Archaeobotany has also made contributions to understanding dietary choices and plant use in the past, although the quantitative problems have been challenging. Today, isotopic methods, starch residues and other sources of evidence have provided new and effective tools for this work
- Other major foci of archaeobotany have been agricultural origins, food processing, plant domestication, and the evolution of agricultural ecologies

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