CONCEPTS AND METHODS IN PALEOBOTANY

At times, evidence from different sources may on the face of it appear to be contradictory. Ultimately, of course, there can be no contradiction.

DIMBLEBY 1985: XI

Not long ago the biosphere encompassed by definition two taxonomic kingdoms: Animals and Plants. Fungi and algae were included in the plant kingdom, and bacteria were somewhere between. The currently dominant **taxonomy** (systematic classification), based in large measure on organic form, recognizes five kingdoms, with bacteria and some algae included in Monera, other algae and simple "eukaryotic" organisms (having discrete nuclei in their cells) in Protista, and Fungi in a kingdom of their own (Margulis and Schwartz 1982). The kingdom of Plantae includes most of what we recognize as plants (vegetation) – trees, shrubs, flowers, mosses, ferns, and so forth. Recent research in microbiology has forced reconsideration of the organization and history of life, and initiated a period of classificatory revisions. An emerging taxonomy based on molecular criteria proposes three "**domains**" at the foundation of life: Archaea (microbes unlike bacteria), Bacteria (with blue-green algae), and **Eukarya** (all organisms with distinct cell nuclei). Members of the newly recognized group, Archaea, are separate from but differentially related to the two other groups, and with bacteria comprise the prokaryotes (organisms lacking cell nuclei). The domain of Eukarya includes plants, animals, fungi, and **protists** (single-celled organisms with cellular nuclei). As the new criteria are tested against extant classifications, the results are likely to rearrange classes even further and modify phylogenetic trees (Pace 1997). Archaeologists can wait for these developments but should be aware of the new uncertainties and alert to the need for clear analytical language.

In Part VI we ignore prokaryotic microbes except for awareness of their positive and negative consequences for the health of more complex organisms. The organisms most central to environmental archaeology are eukaryotic. Plants, some protists, and occasionally some fungi are here discussed under the vernacular term "plants," and their study is called variously botany, plant science, or phytology. When more specificity is needed, technical terms are introduced.

Plants in the widest sense are the foundation for all other forms of complex organisms. Using carbon dioxide and sunlight energy, plants and bacteria synthesize the carbohydrates, amino acids, and fatty acids essential to the proliferation of living things. From soils and water they derive additional chemicals for organic compounds. Plants grow nearly everywhere; with microbes, algae and more complex organisms live in and on the geosphere, within the hydrosphere to great depths, and on ice surfaces. Abundant and widespread plant remains are the basis of our knowledge of paleoenvironments.

Three classes of primary data support studies of past states of the biosphere and of human relationships with plants: **macrobotanical remains** (visible and recognizable pieces and parts of plants); **microbotanical remains** (plant parts and products requiring magnification for study); and molecular and **chemical residues** and traces coaxed out of sediments, charred crusts, or animal tissues. Macrobotanical remains are pieces of wood, seeds and fruits, stems and roots, leaves, buds, cuticle, and so on that are preserved under diverse special conditions. Microbotanical remains include principally pollen and spores, microorganisms such as algae and diatoms, and inorganic intracellular deposits such as opal phytoliths and calcitic crystals. Indirect evidence for past plant **associations** (habitat groups) and species distributions comes from such proxy sources as sediments and soils, animal remains and, for recent millennia, artifacts such as graphic representations and historic texts. This chapter introduces these classes of evidence.

Theory for bioarchaeology

The basic bodies of theory for the life sciences are those of genetics and evolution in the widest sense. Those concepts, which underlie much of what is discussed here, are not considered in detail. Taxonomy (the theory of formal classification and systematics), fundamental to description and identification, is more important in the applied biosciences, including bioarchaeology, than in the academic life sciences today. Ecological theory developed in the study of modern organic systems and **biomes** (regional-scale units of the biosphere) must be modified for application to paleoenvironments that cannot be observed in action; in this chapter and that which

follows, applications and modifications of ecological theory are indicated. The emphasis here is on **synecology** (the study of interrelationships of species within a defined space), rather than on concepts of community ecology. Paleoethnobotany is too young a discipline to have a developed body of theory. It borrows some theory from the biosciences and the rest, properly, from anthropology and archaeology. The emphasis of bioarchaeology today (paleoethnobotany and zooarchaeology/archaeozoology) is on special skills and clear reasoning rather than on advanced theory. As the studies mature and criteria for good work are clarified, theoretical issues will come to the fore.

Taphonomy and sampling

The process by which a living organism is translated from the biosphere to the geosphere is the subject of taphonomy. It begins with the death of an organism and continues through deposition of the remains, possible transportation of all or some of them, to decay and burial, and ends with the remains being either fossilized or disintegrated and recycled (Chapter 2). Because taphonomic processes follow many possible routes and reach many possible outcomes, consideration of taphonomy is essential to interpretation of any organic samples recovered from deposits.

Sequences and agents of transportation, deposition, burial, and preservation are directly relevant to the evaluation of organic remains as representatives of the living populations from which they were derived. Organic remains in archaeological sites present additional taphonomic routes related to human actions and intentions: for example, importation, cultural selection, modification, and discard. Ethnobotanical and ethnoarchaeological studies are important sources of insight regarding the histories of plant materials on archaeological sites.

The archaeologist's choice of recovery and sampling methods further complicates issues of representativeness. Samples recovered during field studies must be defined for congruence with research goals. Sample attributes such as size, distribution, diversity, and frequency are differentially relevant to studies of human behavior and paleoecology, varying with the transport and depositional processes represented.

The archaeological literature on paleobotany leans toward exposition of cultural and behavioral interpretations – paleoethnobotany. In this volume, since paleoenvironmental and ecological interpretations are of paramount interest, cultural information is invoked as a control for understanding taphonomic processes. Clearly, neither cultural nor environmental information can be ignored in the geosciences, and no value judgment is implied by the emphasis presented.

MACROBOTANICAL REMAINS (PLANTAE AND FUNGI)

The gulf between the biophysical environment as perceived by archaeologists through the extant material evidence, and that perceived by a contemporaneous person within that environment is significant and probably unresolvable.

<div align="right">O'CONNOR 1991: 4</div>

Macrobotanical remains are the most identifiable and least ambiguous class of plant remains, being parts and pieces of vegetation, more or less familiar as tissues and structures of plants and fungi. While they are usually recognizable as vegetative remains, their identification and interpretation require training and a special analytical vocabulary (e.g., Körber-Grohne 1991).

A paleobotantist must be familiar with plants in fragments, as those are retrieved waterlogged, desiccated, charred, or fossilized from several preservation contexts. Access to systematic collections such as those in herbaria is essential to identification and interpretation of fragmented remains of plant tissues, organs, and **phytoliths** (Pearsall 1989). Publications that aid the identification of cuticle fragments, fibers, bark, leaves and leaf skeletons, wood, stems, seeds, flowers, fruits and nuts, and underground organs and tissues (roots, bulbs, corms, rhizomes) are scattered and specialized. Most specialists build their own reference collections for the areas in which they work.

Taphonomy and preservation

Plant remains in organic deposits, including Histosols, are likely to have grown locally. Peat deposits are most representative of the plant associations from which the remains are derived, subject mainly to preservation biases. Exceptions proliferate when fluvial transport is involved or charcoal fragments are carried by wind. Macrobotanical remains in geological contexts are subject to post-mortem transportation and secondary deposition; information about their taphonomic histories should be sought before they are removed from context. Far more complex histories may be involved in archaeological sites because plant materials may be derived from great distances, selected according to strong cultural values, nurtured nearby despite being unsuited to the local natural conditions, or deposited where found after site abandonment (Fig. 13.1). All that one can conclude unequivocally about plant remains found in a given place is that they were available by some means to be deposited there. The range of means is then open for investigation (Miksicek 1987; Smart and Hoffman 1988: 176–180).

SELECTION   LOSS
√   Harvest/Collect   √

√   Clean/Strip   √

√   Separate by intended use

√   Prepare/Modify for use   √

√   Store: containers; modifications   √

√   Consume/Use   √

√   Discard waste   √

range of discard sites: pits; midden; sheet waste; water

transformations after discard, relative to type of materials and discard site √

Differential preservation by type, site, age   √

VVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVV

√   Recovery by excavation: selection, sieving, flotation   √

√   Sorting, labelling, and conserving   √

√   Identification and quantification   √

√   Interpretation

Figure 13.1   Taphonomic processes and human behaviors and choices involved in the deposition, reduction, and recovery of plant materials in archaeological contexts. The column on the left highlights human choices; that on the right, the points of loss of material or information. Few materials pass through all stages diagrammed; some may loop through several, repeatedly.

Macrobotanical tissues are preserved through archaeological and geological time spans when they fall into depositional conditions that impede decay and disintegration – when they have been carbonized, deposited and held below the water table in anaerobic conditions, mineralized, frozen, or kept very dry. These special conditions retard decay by limiting either the moisture or the oxygen required by decomposing microorganisms. Plant materials deposited on subaerial surfaces are rarely preserved. Additionally, molds of plant parts, showing very good morphological details

but lacking tissue remains, may be preserved in volcanic ash or as impressions in clay (usually but not essentially baked); these should be expected to be slightly shrunken from heating (J. M. Renfrew 1973: 15). Because preservation conditions are spatially restricted, macrobotanical remains occur sporadically and become rarer with age. Each preservation condition poses special opportunities and challenges for retrieval and study of macrobotanical remains. Appropriate recovery and handling methods are different in each case.

Carbonization (reduction) of organic materials occurs with burning in oxygen insufficient to support complete combustion. Water and fugitive compounds are driven out and the remaining structural materials are converted to a chemically stable mineral state which preserves most aspects of form and is not subject to organic decomposition. Plant macrofossils preserved by carbonization are usually the more massive tissues such as wood, seeds, stems, tubers, and roots, some fruits and nuts, and occasionally fibers. In archaeological sites they occur typically and frequently in pits, hearths, house floors, and middens. They are also recovered in palynological cores as minor components of bog and pond deposits, brought by wind or water after forest or grass fires (Tolonen 1986). The occurrence of carbonized remains in archaeological sites is dependent upon a number of variables related to site function, duration, and mode of burial. Studying charred plant material from a village site in the southeastern United States, Hally (1981) identified five sources of variability related to the presence and recovery of charred plant materials: (1) the duration of occupancy, including the season or seasons; (2) the site's function and the range of activities carried on there; (3) the nature of the abandonment of the site or structures, especially whether houses were burned; (4) the timing of the abandonment (whether precipitous or gradual); and (5) the methods of excavation and sampling. The likelihood of plant materials being burned by intent or accident in the course of normal site activities and materials processing is a primary consideration affecting various classes of materials differently (Hally 1981; Smart and Hoffman 1988).

Natural or archaeological features that intercept the water table, such as bogs, ditches, pits, wells, and cisterns, create anaerobic conditions likely to preserve plant macrofossils. In perennially wet conditions, even large wooden structures and artifacts such as boats and fish weirs, trackways over bogs, even houses, may be preserved essentially intact for millennia. On archaeological sites, wet plant remains are usually accompanied by other organic materials including animal tissues – leather, skins, bone, and insect carapaces.

Macrobotanic remains comprise the Histosols of bogs, swamps, and similar wetlands at the intersection of the geosphere and hydrosphere. Wetlands transgressing

land surfaces in response to rising groundwater are most typically involved with archaeological sites, since only very special and limited classes of sites are formed directly on wet vegetation. Therefore, coastal marshes and terrestrial bogs and fens are most commonly met in the archaeological literature, while swamps, ponds, and such water-based systems are domains of paleobotanists. Particularly in northwestern Europe, there is a large literature on bog investigations involving significant archaeological finds as well as paleoenvironmental research. More typical in the Americas are archaeological sites buried in transgressing coastal marshes and swamps.

Peat deposits, whether coastal or terrestrial, are dynamic environments that may cycle repeatedly between saturated and unsaturated states. It is not uncommon to find horizons in deep peats which represent former forest floors, containing the remains of sizable trees. Frozen environments are a special class of wet; not only are the materials protected from air, but the low temperatures further constrain bacterial decomposition. Frozen sediments in the high Arctic yield plant remains from Late Glacial times, sometimes even mammoths with hair and remains of their last meals.

Permanent dryness is an even better preserver of plant materials than permanent wetness. Deposits of plant materials in dry areas are usually cultural, because natural collecting agents are rare. An exception is the woodrat (packrat; *Neotoma*), which accumulates middens in dry dens and crevices in the American desert West; the plant and other debris collected from the rodents' immediate neighborhoods is cemented by a varnish-like urine and kept dry in sheltered spots. Paleoecologists use the clumps as datable samples of the immediately local flora (Betancourt et al. 1990). Desiccated macrofossils in archaeological contexts are recovered from caves and rockshelters, burials, tombs, and other structures in arid environments. Despite the brittleness that is a characteristic of dried plant materials, the remains are frequently astonishingly complete and easily identified. Woodworking and constructional techniques are well represented in dry archaeological sites, where domestic architecture and household interiors may be studied. Dietary evidence is also dependably preserved; in dry sites food remains reveal all stages of on-site food preparation and consumption in the contents of storage caches, the remains of meals and food preparation, and the composition of coprolites.

Preservation of plant materials in volcanic ash (tephra), while rare, can be spectacular, as sites such as Pompeii, Herculaneum, and Akrotiri attest. In catastrophically buried cities, houses and furnishings may survive in remarkable condition, with meals on tables, and garden plots (Meyer 1980). In tephra, plant materials are preserved by desiccation or molding, or some combination of the two. The phenomenon of molding, in which organic material is leached away but the impression is

preserved in a fine matrix, occurs under special conditions of matrix composition and groundwater. While organic materials themselves disappear, their original form may be faithfully modeled, permitting confident identification.

On geological sites

Non-cultural agents accumulate macrofossils in bogs, pond and lake deposits, animal nests, and perennially frozen ground. Unless rivers were involved in the transportation and deposition of the materials, off-site deposits normally are relevant sources of data for immediately local environments. They preserve parts of plants that grew nearby, although such remains cannot be considered statistically representative of the full diversity or proportions of the living plant communities. When the stratigraphical or chronological resolution of deposits permits close dating, such **assemblages** (suites of remains in a deposit) may be related to human activities nearby. Natural deposits can reveal evidence for human impacts on plant associations; archaeologists should be alert to opportunities to test them for evidence of human effects (e.g., fires, deforestation, removal or introduction of species).

On archaeological sites

The full range of preservation conditions for plant materials is found on archaeological sites; not, of course, all together. Dry caves or tombs, and true desert conditions preserve plant materials superbly, as do deposits in permafrost. Wet macrobotanical remains are restricted to small-scale features that provide good preservation, such as pits, wells, and privies. Archaeological sites within wet natural features such as bogs and transgressing marshy shores, or shipwrecks under water, offer exceptions. Typical of terrestrial sites are carbonized plant remains distributed discontinuously because of their primary association with different kinds of activities. The rare impressions in clay, including plant parts and artifacts such as matting and cordage impressed in pottery or in baked clay floors and hearths, are limited to the appropriate materials. In the southeastern United States, where plant materials are unusual in early sites, mat flooring 8000 years old was revealed in a site buried in alluvium, preserved in burnt clay near a hearth (Chapman and Adovasio 1977). Houses, furnishings, and garden plots may survive under tephra deposits, as noted above.

Recovery

On-site vegetation data are typically retrieved by archaeologists themselves, less often by specialists collaborating with archaeologists. In contrast, off-site data are

generally retrieved by specialists other than archaeologists, with archaeologists sometimes involved. The choice of recovery methods directly affects the quality of data recovered and the range of applicable analytical methods. Advance planning and consultation for recovery and sampling is, therefore, essential to success, as is forethought in providing for appropriate handling and conservation.

Sampling

The quality of the sampling design is crucial for any field investigation. Successful sampling entails an informed awareness of taphonomic biases and of the range and representativeness of the materials preserved (M. K. Jones 1991). The full range of proveniences available in any research locale or site should be evaluated for potential contributions to problem-oriented sampling. Each sample context must be interpreted in the field to identify its cultural or non-cultural origin, depositional agent, and full suite of stratigraphic relationships. The ideal situation for sampling is a specialist taking the samples directly, for specific analyses; failing that, there must be consultation beforehand on the full range of information to be collected. Identification of the depositional agent is essential information regardless of whether the material is cultural or non-cultural. Cultural contexts are appropriate for investigating aspects of human behavior relating to plants, particularly selection for use (Hastorf and Popper 1988; Pearsall 1989). Cultural contexts also provide information about the size, diversity, and quality of the environments utilized for resources (the site catchment; e.g., Jones 1984). Natural contexts, where animal or physical agents have deposited or concentrated plant materials, reveal aspects of environments less directly under human control. In archaeological research, neither of these complementary contexts is complete without the other; confusion between them leads to error.

Retrieval and treatment

Recovery of organic materials from either archaeological or geological field situations is a major subject best dealt with in the specialist literature rather than thinly summarized in a volume such as this. Here, we touch on only the range of problems and situations relevant to macrobotanic specimens. Plant macrofossils are usually recovered from clumps of matrix, ranging from peaty deposits and mucks, coprolites, carbonate crusts, and packrat middens, to food stores and artifacts. Paleobotanical samples are acquired by coring or bulk sampling, from pond and bog sediments (Aaby and Digerfeldt 1986). The enclosing clumps of matrix are then disaggregated to separate the seeds, stems, leaves, and fruits for study.

Except for structural timbers and water craft, which should be uncovered and recorded *in situ*, waterlogged plant materials are best recovered in lumps of wet

matrix, to be washed free in the laboratory where conditions can be controlled and treatment started expeditiously (Körber-Grohne 1991; Schoch 1986; Tolonen 1986). Wet materials may be separated by hand and by washing, with sieving for small items. Wet specimens must be kept wet until treated; they shrink and crack upon exposure to air. Proper treatment can prevent the distortion that reduces interpretive and display values. The special needs of wet materials should be anticipated as part of the planning for any field work that might encounter them. Equipment requirements normally include hoses or sprays to keep things wet during exposure, wet tanks to receive large specimens, and those modern marvels, plastic sheets and bags, to protect them from excessive exposure to air. Special materials and facilities for transport and storage should be provided when required (Cronyn 1992; Sease 1987). Prior to treatment, wet materials may be stored in distilled water or under refrigeration to keep them moist and to reduce bacterial action. Treatment may include the leaching of contaminants such as salts and humic acids.

Carbonized and desiccated materials, because of their fragility, require special care in cleaning and handling prior to identification. Archaeologists typically recover carbonized plant materials by flotation or dry sieving (Pearsall 1989: Ch. 2; Toll 1988; Wagner 1988), more rarely, when pieces are large, by isolation in place. Charred plant materials in pollen cores are usually only counted, or quantified as a ratio of the pollen and spores in the core; charcoal is not usually identified, given the variety and small sizes of fragments involved (Schoch 1986; Smart and Hoffman 1988; Tolonen 1986). Carbonized plant materials are stable if allowed to dry out very slowly and protected from compression or shocks that might further fragment them. Desiccated plant remains must be recovered with great care, taken up in lumps as they occur or cleaned carefully by dry brushing in place or sieving. Being fragile, they require careful packing and support during transport and storage, to prevent sagging, cracking, or compression. They may need no other preparation for museum storage, but it is imperative that they be protected from dampness (Cronyn 1992; Sease 1987). Desiccated coprolites are rehydrated in a chemical solution and then separated as for wet materials (Fry 1985; Reinhard and Bryant 1992).

Recovery of impressions and molds requires mainly alertness on the part of excavators, and appropriate response to the opportunity. In Pompeiian gardens, under ash, molds of tree roots were recovered and identified after being filled with plaster (Jashemski 1979). Recognizing impressions of matting on a clay floor requires another level of responsiveness on the part of excavators; the possibility should be part of every field archaeologist's kit of expectations. Impressions of sticks, seeds, leaves, mats, basketry, and cordage in potsherds, bricks, and mud daub can be examined and recorded in the laboratory if collected in the field.

Study techniques

The first step in analysis and interpretation is identification, in terms of plant taxa and tissue parts, of fragments recovered in altered chemical and physical states. Plant tissues, "complexes of cells of common origin . . . may consist of cells of different form and even different function" (Fahn 1990: 79). Knowledge of cell types and tissue structures is basic to identification of plant remains (Esau 1977). There are no dependable shortcuts to training in systematic botany for that initial task.

Botanical keys and systematic collections are essential for the identification of plant materials. Systematic herbarium collections prepared for the region involved are the only reliable bases for identifications, although special challenges are posed by recovered species that no longer live in an area. The shrinking and distortion characteristic of charred materials require that reference collections include carbonized specimens, prepared for the purpose if not otherwise available (Schoch 1986). Specimens preserved in wet conditions should also be included, to display the chemical and physical changes they undergo. Fragments, so long as their identification is in no way problematical, are valuable components of a study collection, as even breakage patterns may be diagnostic (Bohrer 1986). Intact specimens may be identified from comparative material by the naked eye, provided eye and mind have been trained to observe the crucial determinants of tissues, genera, and species. Because carbonized materials are typically fragmented or distorted, while wet materials may be corroded, distorted or both, microscopic examination may be essential to identification. In some cases thin-sections (along more than one plane) are the best preparation for identification of characteristic structures, as they are of wood. Electron microscopy has proven its value with small macrofossils (Pearcy et al. 1989). The degree of taxonomic specificity attainable varies with the size, condition, and parts preserved, and with the diversity and distinctiveness represented in the native vegetation (Hather 1994; Körber-Grohne 1991; Smart and Hoffman 1988; Sobolik 1994; Wasylikowa 1986). Plant materials modified in the course of early experiments in domestication may be impossible to identify to the species level.

A list of recovered species and plant parts is the beginning of interpretation of a collection. From that beginning, studies proceed toward understanding aspects of ancient environments and human behavior related to management and exploitation of plants.
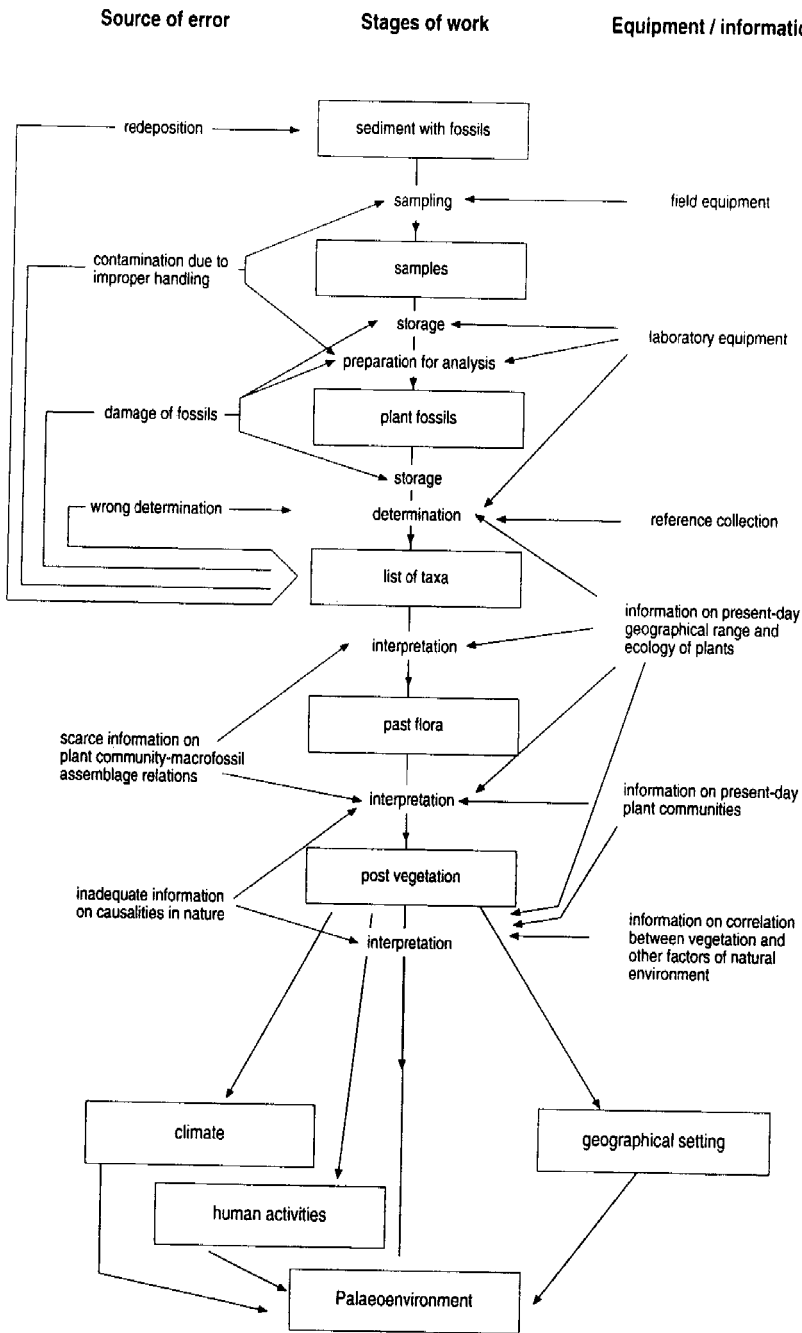
Interpretation

Once plant materials are identified and interpretation has begun, the value of a disciplined sampling design is demonstrated. When every sample can be unambiguously

related to its spatial coordinates and context of origin, its depositional environment interpreted, and its taphonomic history related, interpretation problems are minimized and competing hypotheses are testable.

While study of plant macrofossils was important in the early development of Quaternary paleoenvironmental research, it was superseded before mid-century by pollen analysis. Recently it has again attracted attention from phytogeographers and paleobotanists. Macrofossil interpretation is based on analogies with modern flora and vegetation associations, expanded and circumscribed by paleoenvironmental inferences from as many other sources as can be brought to the task (Fig. 13.2; Wasilykowa 1986). Saturated plant remains and associated materials recovered from pond margins and bogs complement rather than duplicate the palynological data associated with them. Representing species growing on the recovery site or nearby, they typically include some of the insect-pollinated, vegetatively reproducing, or rare species that are poorly represented in pollen deposits. Moreover, macrofossils can be identified to the species level, which is rare with pollen. Large wood specimens offer, in addition to forest composition, data for dendrochronological and dendroclimatological interpretations.

Macrofossils in geological context are direct relics of natural vegetation, offering insights into past environments different from those achieved through the study of similar materials on archaeological sites. They are sounder evidence for the local presence and associations of ancient plants than pollen alone can provide, since pollen can be carried over considerable distances by wind or water. However, macrofossils are not statistically representative of their source populations. Taphonomic processes intervene significantly between the production of plant components and their deposition in preservative environments. Edible plant parts are subject to predation by herbivores of all sizes; the most nourishing may be rarely preserved. Diverse reproductive strategies influence the likelihood of preservable parts being deposited in anaerobic conditions; for example, plants that produce small, lightweight, and numerous seeds are far more likely to be represented in pond sediments than are those producing a smaller number of heavy, hard nuts and seeds that fall close to the parent plant. Similarly, some mechanisms for fruit and seed dispersal may make preservation opportunities exceptional. Transportation of plant parts by animals, wind, or water retains no semblance of original ratios within the source populations. For all these reasons, preserved terrestrial vegetal remains provide only qualitative information about past vegetation at very local scales.

Interpretation of even the same items of vegetation in cultural contexts requires sensitivity not only to issues of representativeness and selective deposition, but also to cultural biases (Fig. 13.1). Charred materials in archaeological sites, for instance,

Figure 13.2 Schematic sequence of steps for retrieval and study of plant macrofossils, from sediment to interpretive reconstruction of paleoenvironments. The top half of the diagram is data collection; the lower half is interpretation. (After Wasilykowa 1986: Fig. 27.1.)

result from a far more complex mixture of events and processes than do those in natural deposits. While identification of large pieces may be relatively straightforward, interpretation of their significance is subject to considerable uncertainty (Smart and Hoffman 1988). Carbonized material may be derived from, and represent, plants growing on or near the site, plants or plant parts brought in by people or other animals from any distance as food and economic resources for occupants of the site, waste and debris of food preparation or other activities, or combinations of the preceding. Desiccated plant remains typically owe their preservation to cultural selection and manipulation; their presence in a deposit is subject to seasonal differences of use and preservation, and to differential selection for special purposes. Without strong contrary evidence, the safest assumption is that on-site plant remains of all classes only distantly reflect the environment of the site and its surroundings. They directly reflect (1) cultural selection for a variety of purposes, (2) special environments in and near human habitations, and (3) special preservation conditions. The biases, always significant, pose problems for the paleoecologist who wants to understand natural associations, and offer opportunities for the archaeologist who is interested in human behavior.

Because of the numerous variables determining plant preservation in archaeological sites, the equifinality issue is pervasive. The number of means and agencies by which a given set of plant remains might have been assembled on a particular spot is very large, and each has implications for interpretation. Rigorous sampling, imaginative testing, and collection of complementary data can help to narrow the scope of responsible interpretations, but in archaeology the temptation to push beyond the data limits is rarely overcome. Thus, statistical treatments of recovered macrofossils appear in the literature, especially when site data are being applied to environmental reconstructions. Investigators presenting such arguments do not always justify the assumptions behind the statistical techniques employed, or establish a priori the representativeness of the remains for either the total site content or the question being investigated. Even frequency counts, dependent as they are upon the degree of fragmentation of the materials, the size and location of samples collected, and the fineness of subdivisions defined within the site (pits, strata, activity loci, etc.), may mislead by implying standards of objectivity and representativeness that cannot be met by the data (G. E. M. Jones 1991). Unless conditions are demonstrably appropriate to numerical treatments, macrofossil data should be interpreted as the qualitative data they typically are.

For all these reasons, therefore, macrobotanical remains are more significant in their presence than in their absence; the interpretation of absence, particularly, must not be pressed. Statistical treatment of the data is only appropriate when sample sizes

are large; this condition is rarely met. With sources of variability deriving not only from the parent plant populations but also from processes of selection, transportation, processing and consumption, deposition, preservation, and recovery, no direct or statistical relationship between any environmental factor and plant macrofossil assemblages can be assumed.

MICROBOTANICAL REMAINS: POLLEN AND SPORES

Tiny and abundant, pollen grains and spores pervade the near-surface zones of the five spheres of the climate system. This ubiquity, in combination with their remarkable resistance to decay and destruction and the relative specificity of their morphologies, is at the foundation of **palynology**, the scientific study of pollen and spores. Pollen grains are produced by the male reproductive organs of flowering plants and conifers; they are dispersed by a variety of mechanisms to fertilize the female organs, which then produce seeds. Spores are the asexual reproductive cells of non-flowering plants (cryptogams) such as mosses and ferns, and of fungi. The size, ruggedness, and morphological specificity of spores are comparable to those of pollen grains but their function is more nearly akin to that of seeds; each can initiate the growth of a new plant, although in an alternative generational form. The genetic matter in pollen grains and spores is protected by a durable outer coat, or exine, made of sporopollenin, a plant polymer highly resistant to enzymes and acids and resilient under stress or abrasion. Exines, therefore, may survive in environmentally favorable deposits for very long periods of time, retaining the identifiable form of the pollen grain or spore (Faegri and Iverson 1989; Moore et al. 1991; Fig. 13.3).

Palynology has dominated paleoenvironmental studies since the second decade of the twentieth century, following its development by the Swedish botanist, Lennart von Post, as a stratigraphic tool to correlate varved lacustrine deposits and layered terrestrial peats. Like other historical sciences including archaeology, palynology has been changed recently by the adoption of quantitative concepts and ecological principles, which initiated creative reconsideration of some of its fundamental assumptions and basic methods (Birks and Gordon 1985; Faegri and Iversen 1989; Moore et al. 1991). Deeper awareness of the complexity of the natural world and of the interdependence of all the environmental sciences entails new standards for data evaluation and demonstration of conclusions. For example, palynologists are increasingly sensitive to evidence implicating human interference in natural systems, even in the distant past, and are increasingly able, in collaboration with archaeologists, to evaluate it. As a consequence of this innovation and growth, papers on theory and method
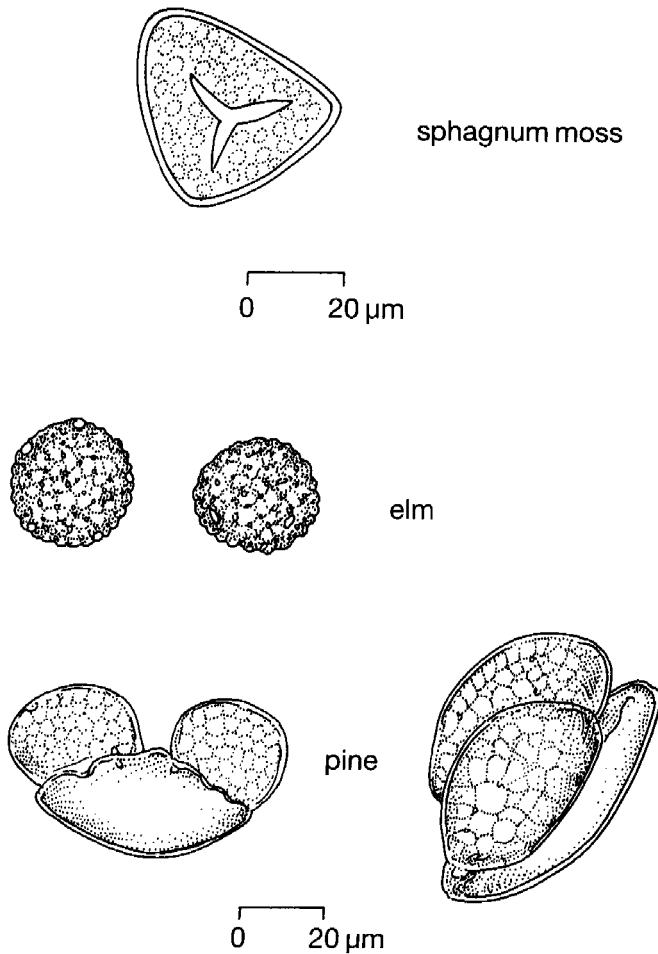
Figure 13.3 Pollen grain morphologies: pine and elm grains, moss spore, with scale. The bladder-like wings on pine pollen facilitate wind dispersal. (After Bradley 1985: Fig. 9.1, and Lowe and Walker 1984: Fig. 4.1.)

dominate the literature, and much of the classic interpretive work of the first half of the twentieth century is under revision.

Pollen grains and spores are adapted for passive dispersal by a variety of means. Some, buoyant in the wind, soar over great distances. Some are adapted for dispersal by animals, having sticky surfaces or small hooks that cling to insects, fur, and feathers. Tough exines permit grains to survive water transport as well, although they may suffer abrasion and some loss of surficial features in the process. The pollen of some aquatic plants is spread exclusively under water. Wind-pollinated species, particularly trees, tend to produce more pollen and disperse it more widely than do the species

relying upon other mechanisms; consequently, tree pollens dominate the deposits typically sampled by palynologists. Because of diverse species-specific specializations for dispersal, pollen grains are produced, and deposited in sediments, in proportions different from the representation of the parent plants in the standing vegetation (see discussions of dispersal in Faegri and Iversen [1989] and Moore et al. [1991]).

Deposits receiving pollen and spores vary in the sizes of their catchments (the areas from which they receive pollen), preservation characteristics, and postdepositional stability. For example, a large lake receives pollen from the air and from its influent streams; it collects grains from considerable distances. Lake-bottom sediments may be seasonally churned by burrowing organisms, and be subject to settling and sliding to the detriment of stratification. In contrast, a small bog will receive most of its pollen from plants that grow on its surface and margins, with less contributed by running water and moving air. Although bog sediments suffer only compaction in place, pollen may trickle down with rainwater through air spaces, blurring the stratigraphic integrity. A lake will yield a generalized picture of pollen rain at the regional scale, while a bog will collect data mainly representing changes in its native and immediately neighboring vegetation (Jacobson 1988; Larsen and MacDonald 1993). Neither lake nor bog presents a truly representative picture of vegetation associations at scales important to people living nearby.

Palynologists collect pollen from lake and pond sediments, peat deposits, and soil for several different research purposes. Collection sites and techniques vary with research goals, and the results will be partly constrained by those choices. Interpretation of the data must be done in full awareness of the biases. At least five different research emphases are represented in contemporary palynological literature: (1) vegetational history, (2) phytogeography, (3) climatic history, (4) plant ecology, and (5) human intervention in and use of natural systems. A sixth emphasis, formerly more important, was using stratified pollen sequences to provide chronological control and stratigraphic correlation for other paleoenvironmental studies. Expansion and improvement in physicochemical dating techniques have superseded this application of biostratigraphy. The optimal sampling locations and techniques for each research emphasis are not mutually exclusive, but nevertheless vary considerably, as does resolution of resulting laboratory analyses. Archaeologists, who frequently select palynological data from the literature on the single criterion of geographical proximity to archaeological phenomena of interest, need to be aware of the original research purposes that shaped the data collection, analysis, and interpretation of published data.

The fundamental limitations of pollen accumulations as environmental data derive from the facts that palynological accumulations record mainly plants that are

wind pollinated, and that pollen is identifiable primarily at the genus level (e.g., Solomon and Webb 1985). Such limitations have many, variously serious, implications for paleoenvironmental studies. Many plants important as human food, both wild and domesticated, are poorly represented in the pollen record. The morphological specificity of pollen grains, which makes it possible to identify many taxa unequivocally, is relevant mainly at the generic level. When a particular genus comprises more than one species, each of which may have very different environmental requirements, such low resolution in the database introduces serious indeterminacies. Moreover, pollen deposits do not faithfully represent the local diversity of plant associations; they are biased by the areal extent (size) and spatial distribution (direction and altitude) of vegetation associations in the catchment. Even extensive vegetation stands contribute differentially to a pollen deposit, according to their composition and location in respect to prevailing winds and to watersheds.

Efforts to refine interpretation of pollen deposits by discriminating among the many factors that contributed to their composition led palynologists to examine plant **community** ecology and to study processes and rates of community development. On Quaternary time scales, rates of species colonization and dispersal, the dynamics of species competition, differential degrees of climatic control of distributions, rates of soils development, occurrence of plant pathogens, and human interference with landscapes must be considered equally with climatic changes in the interpretation of pollen diagrams and **spectra** (the pollen grains associated with a stratigraphic sample). With experience in the description of actual pollen rains came the recognition that many pollen spectra of the past are not matched in modern pollen rain. This is the basis of the no-analog problem: in the absence of good modern matches for fossil pollen spectra, analogous reasoning for interpretation is severely constrained. Analog arguments are weak tools for dealing with differences, but we still lack theoretical principles that can reach beyond analogs. For all these reasons pollen diagrams cannot be directly interpreted in terms of vegetation, and never directly in terms of climate at any scale (Faegri and Iversen 1989; Ritchie 1986). Paleoclimatologists have made their peace with the uncertainties, and continue to work toward refinements that will provide better resolution (Bradley 1999: 363–364).

Preservation conditions

Pollen preservation requires anaerobic (oxygen-free) or acidic environments that hinder decomposing bacteria. In sediments that are aerated, even seasonally, pollen is destroyed by bacteria and oxidation; in neutral or alkaline sediments (pH over 6.0), pollen gradually decays unless the sediments are perennially and thoroughly

desiccated. The best sedimentary environments, therefore, are both anaerobic and acidic, or totally arid. Bogs, the basal sediments of oligotrophic ponds and lakes, archaeological features and deposits below the local water table, acidic soils such as podzols, and dry cave Earths all offer environments variously conducive to the preservation of pollen. Certain metallic salts, such as oxides of copper, inhibit bacterial action and preserve pollen in contact with them. Sediments sheltered immediately under objects such as large stones or bivalve shells may also yield pollen. Thus, the archaeologist has a variety of favorable situations in which to find pollen, and should be alert to recover samples that can illuminate aspects of past plant associations or human exploitation of plants (Bryant et al. 1994; Davis and Overs 1995; Dimbleby 1985; Faegri and Iversen 1989; Gremillion 1997).

Recovery

Palynological investigations have many goals and for each purpose there are optimal and less ideal sites from which to extract pollen samples, because each kind of deposit collects pollen and spores from a different range of sources more or less appropriate to the research aims. Basically, it is essential that the pollen in a given deposit be derived from sources at spatial and temporal scales congruent with the research questions: large catchments (e.g., lakes >1 km^2) for regional paleoenvironmental or paleoclimatic studies, smaller catchments (e.g., bogs and ponds) with fine stratigraphic resolution for studies of plant ecology or human exploitation. When small catchments are used, they are sampled optimally in sets, to intersect a range of microenvironments (Jacobson 1988). In archaeological deposits, each discrete class of contexts which preserves pollen should be sampled, and on habitation sites each member of each class might be examined in order to investigate the full range of variation represented.

The study of pollen in soils, rarely undertaken by palynologists unless they are working with archaeologists, presents special problems because scale factors are not well controlled and stratigraphic integrity is difficult to evaluate. Soils represent an indeterminable span of time for accumulation and chemical and biological modification; soils processes may mask depositional events, and there may be a large range of pollen sources and vectors represented (Dimbleby 1985). Pedoturbation (soil mixing) and pollen percolation further complicate pollen stratigraphy, but their effects may sometimes be discriminated (Kelso 1994).

Pollen samples are typically collected either by coring or by taking a series of discrete samples from an exposed stratigraphic section. Lakes and ponds, for obvious reasons, are sampled by coring, either from boats or from the more stable platform of

ice cover. Bogs may be cored, usually requiring a series of segments through the deposits; they present challenging technical problems because of compaction of sediments during coring. The best results are obtained when sections are exposed so that they can be cleaned and sampled sequentially (bottom-up) through the depth of the deposits. In stratified archaeological deposits, collecting a sequence of small contiguous samples through the section is the recommended procedure; the smaller the sampling interval, and therefore the larger the number of discrete samples, the better the resolution of the stratification during analysis (see Fig. 5.2). In purely archaeological contexts, where individual features and small depositional contexts are sampled, it is best to collect samples as large as possible, being scrupulous in bounding and subdividing them to represent as fully as possible the range of *discrete* depositional incidents. The methods and equipment are discussed in any good palynological handbook (Dimbleby 1985; Faegri and Iversen 1989; Moore et al. 1991).

Palynologists study actual pollen rain in relationship to standing vegetation in order to define biases inherent in sampled deposits of older pollen, as a test of representativeness. Good summaries of these studies are readily available in palynological handbooks. The major biases are only briefly referenced here to indicate the scope of the problems. Pollen and spores are sampled from deposits with good preservation characteristics, but there are always likely to be preservation differentials among taxa and between depositional layers of different ages and chemical and physical composition. In addition, any change in depositional rates will bias the pollen representation, and any physical disturbance of the matrix during consolidation will mix pollen of different ages. We have already seen that plant species produce pollen in widely differing amounts and that different agencies disperse it over diverse spatial scales. Any geomorphological or hydrological changes in the catchment area, such as stream capture, or human action in clearing land and modifying drainage, will change the size and character of the area sampled. Such changes in the pollen source area may be difficult to distinguish from vegetational changes of other kinds if the pollen sample itself provides the only data considered.

A sobering example of the subtleties of pollen contexts has been revealed by research in southern New England, USA. A research program seeking macrofossil remains in Late Glacial and Early Holocene sediments revealed abundant macrofossil specimens in the basal parts of cores, with minimal representation of pollen. The ratios were reversed in the core sections dated later than 9000 B.P. Interpretation of the macrofossil matrix indicated that the earliest deposits were considerably more alkaline than later ones. Alkaline conditions preserve macrofossils but destroy pollen; acidic conditions later had the opposite effect (McWeeney 1994: 186–188). Low pollen concentrations observed in Late Glacial sediments in this region may be

artifacts of sediment chemistry rather than reflections of impoverished vegetation.

Transportation of pollen in moving air introduces further complexities; understory plants release pollen into winds slowed by standing vegetation, while pollen released near the top of the canopy layer may travel far in faster winds, reaching into the upper atmosphere (Moore et al. 1991: 10–21; Tauber 1967). Pine and oak pollen grains, adapted to airborne transport, are notorious travelers; they soar beyond the range of the parent trees to be deposited, for example, beyond the tree line in tundra and sites at high elevations. Heavier pollen such as that produced by beech and larch will settle close to the originating vegetation. One study indicated that 99% of wind-dispersed pollen grains settle within one kilometer of their source (Brasier 1980: 67), well within our local scale, implicating serious underrepresentation of diversity at the regional scale. Pollen carried in water can settle at considerable distances from its source, even onto the continental shelves. Running water can liberate old pollen from sediments and redeposit it with younger material. Spring snow melt and floodwaters flush sediment and pollen into depositional basins, complicating studies of depositional rates. Grains of different sizes and weights entering standing water settle out differentially, the more buoyant being carried by wind and wave action to the shore zones. Sediments under shallow water are subject to resuspension during the seasonal turnover of the waters and to bioturbation in place, mixing the upper layers. Pollen samples taken from lakes deep enough to preserve annual varves, and those from annually laminated snow and firn deposits, are less affected by such disturbances.

Sample preparation and identification

In the laboratory, standard-sized subsamples are taken from cores or box samplers so that each stratum in a sequence is represented by at least one subsample and thick strata are subsampled sequentially at regular intervals. The frequency of subsampling will depend upon the size of the core, the concentration of pollen in respect to other sedimentary materials, and the degree of resolution desirable for the investigation, just as similar decisions are made in the field when an exposed section is being sampled.

The pollen in each subsample is separated from matrix materials and concentrated by a series of chemical treatments and washes and by centrifuging. Humates, carbonates, silica, and cellulose are removed chemically from the matrix. Strong acids are used, including hydrofluoric acid to dissolve silica, testifying to the toughness of pollen exines that survive the treatment intact. The procedures require special equipment to ensure the safety of the handlers; beginners must be fully and

carefully supervised (Moore et al. 1991: 41–44). The concentrated pollen grains from each subsample are fixed to a microscope slide and examined grain by grain under magnification. The grains are identified by comparison with pollen keys and reference collections (e.g., NOAA 1994); like any skill it becomes easier with practice, but always requires painstaking accuracy and patience. The identification of pollen grains that have been damaged or partially decayed is especially challenging, but is now recognized as an important source of information about the integrity of the sample (Kelso 1993). Taxa less susceptible to destruction than others over comparable time spans may dominate deeper parts of a deposit (Hall 1981; Havinga 1984). Typically, specimens more degraded than the rest in a sample are likely to have been secondarily deposited from older or exotic contexts. By identifying and accounting for them, analysts can distinguish between pollen natural to the deposit (autochthonous) and that foreign to the context (allochthonous).

The analyst counts each sample until a predetermined number of grains has been identified. The number is defined in terms of the diversity of pollen in the samples and the completeness of representation required by the research goals. For some purposes, identification of absolutely rare pollen taxa is not important and so counting may be limited at around 200–250 grains per sample. If rare species are sought, as in investigations of sub-regional assemblages or of anthropogenic effects in the vegetation (including domesticates, which rarely disperse pollen very far), then counts as high as 1000 grains or even more may be undertaken (Fig. 13.4). Expanded counts are expensive and must be justified by the research goals (Berglund and Ralska-Jasiewiczowa 1986; Dimbleby 1985). For some purposes, only the pollen of tree species (**AP: arboreal pollen**) is counted; this was the standard procedure during the early years of palynology. Studies of vegetation environments, ecology, or human effects require attention also to the pollen of shrubs, flowers, and grasses (**NAP: non-arboreal pollen**); these are now typically included in pollen diagrams (Table 13.1 displays Latin and common names for some common northern-hemisphere taxa). For archaeological research, rare pollen grains may be extremely informative; even when their presence cannot be easily or immediately interpreted, recognition is important. Again, weighing research goals against costs, counts for pollen samples from archaeological contexts should ideally be on the high end of the range; sometimes this means counting the total sample, especially when, as is frequently the case, the concentration of pollen is low.

Depositional biases, bioturbation, settling, compaction, and sliding of sediments clearly affect the associations of pollen grains, and thus the counts. These random errors are typically ignored once counting begins, with the justification that they affect all samples equally. Of course, random errors are not evenly distributed; their
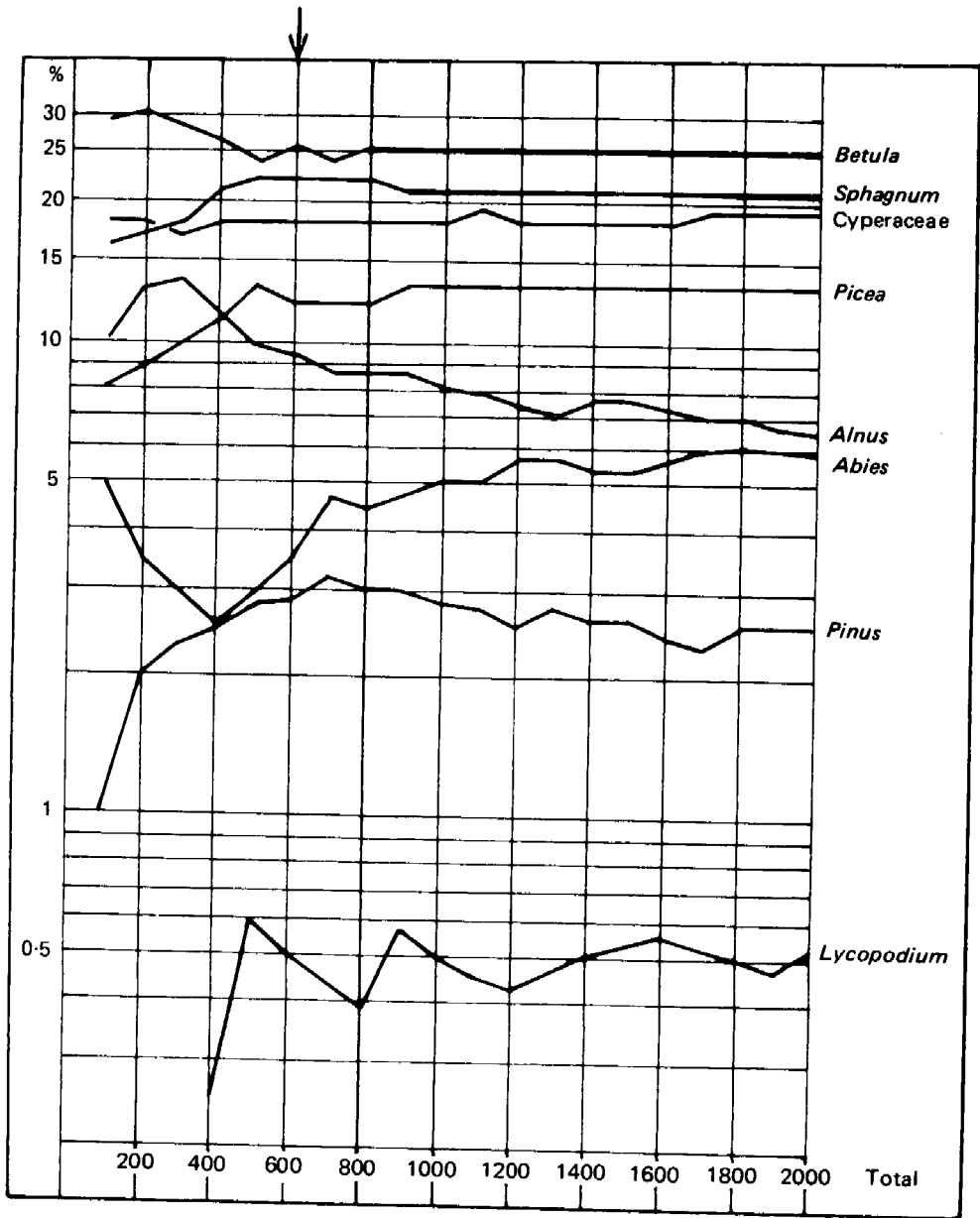
Figure 13.4   Change in pollen percentages and diversity of taxa with larger counts. The numbers on the x axis are total grains counted. (Reproduced from Birks and Birks 1980: Fig. 8.9, with permission of Cambridge University Press.)

Table 13.1 Latin and common names of some major plant taxa in northwest European and eastern North American pollen diagrams

A. Arboreal genera

Abies	Fir	*Myrica*	Myrtle/Bayberry
Acer	Maple/European Sycamore	*Nyssa*	Tupelo
Alnus	Alder	*Ostrya*	Ironwood/Hop-hornbeam
Betula	Birch	*Picea*	Spruce
Carpinus	Hornbeam	*Pinus*	Pine
Carya	Hickory	*Platanus*	Plane/American Sycamore
Castanea	Chestnut	*Populus*	Poplar/Aspen
Corylus	Hazel	*Prunus*	Cherry/Plum/Almond, etc.
Fagus	Beech	*Quercus*	Oak
Fraxinus	Ash	*Salix*	Willow
Ilex	Holly	*Tilia*	Lime/Basswood/Linden
Juglans	Walnut	*Tsuga*	Hemlock
Juniperus	Juniper	*Ulmus*	Elm
Larix	Larch/Tamarack		

B. Non-arboreal genera

Ambrosia	Ragweed	*Phragmites*	Reed
Artemesia	Sagebrush/Wormwood	*Plantago*	Plantain
Calluna	Heather	*Pteridium*	Bracken fern
Dryas	Mountain avens	*Rumex*	Dock, Sorrel
Hedera	Ivy	*Typha*	Cattail

C. Non-arboreal families

Amaranthaceae	Herbs and herbaceous shrubs
Chenopodiaceae	Goosefoot/Lambsquarter, etc.
Compositae	Daisies, Sunflowers, Asters, etc.
Cyperaceae	Sedges
Ericaceae	Heaths (e.g., blueberry, rhododendron)
Gramineae	Grasses, including cereals

Source: various sources.

methodological dismissal affects results. Pollen counts, representative of no vegetational reality, must be interpreted.

Data presentation

The grains identified are summed by **taxon** (discrete class) and each taxon is expressed as a percentage of the total count for each sample. Sometimes the total is the

sum of arboreal pollen only (ΣAP); more usually now the total pollen count (ΣTP) is the sum used. Obviously, any interpretation depending upon relative representation must take account of the reference sum actually used in the calculation; this should always be given with the results. Percentages are presented in **pollen diagrams,** for which several graphic styles are in use (Fig. 13.5; Grimm 1988). Time (or stratigraphy) is represented on the vertical axis; taxa as percentages of the total count are shown separately on the horizontal axis. The total of each sample can be read along the horizontal axis of the diagram, as a pollen spectrum. In this way the relative representation of each taxon is immediately comprehensible, and can be easily compared with any other. However, the use of the percentage statistic means that a real change in the frequency of any one taxon entails a statistical adjustment in the percentage of all others, so that the diagrams conflate actual and statistical representation, introducing serious methodological bias. Moreover, the percentage statistic is a relic of an earlier disciplinary paradigm, in which issues of proportional representation of pollen in the pollen rain and of depositional, preservational, and retrieval biases were ignored (Birks and Gordon 1985; Faegri and Iversen 1989: 149–155). Percentage representation is a convention; its conventional status must be fully understood by anyone intending to interpret or use pollen diagrams. Because percentages of species adjust with every change, interpretation of actual increase or decrease in a *particular* species of interest requires additional data, independent of a single diagram.

An alternative or complement to the percentage calculation is the calculation of "absolute counts," either "absolute pollen concentration or frequency" (APC; AP_{conc}; APF) or "influx" (API; AP_{influx}) statistics. The concentration of pollen grains in samples is measured by counting grains derived from standardized subsamples to which exact numbers of exotic marker grains or spores have been added. Counts of the marker grains yield a percentage of the total added, which is used as a basis to estimate the actual frequency of other counted taxa in the subsample, giving a pollen concentration figure, usually expressed as grains per cubic centimeter of sediment. The deposition rate of the sediment is calculated from a series of direct radiocarbon dates through the sediment column, or by counting annual deposits. Pollen influx is calculated as the number of grains falling on one square centimeter of surface per year. Although the absolute status of such figures is a polite fiction (Colinvaux 1978), concentration and influx calculations are advantageous for some kinds of research. The concentration figures can be weighted in terms of known pollen production rates for different taxa. Such manipulations provide closer approximations to the ratios of various plant taxa in ancient landscapes, and permit displays of the relative frequencies of individual taxa through time with less statistical distortion than percentage diagrams offer. The archaeological applications are especially appealing, as the figures are the best available approximation to biomass estimates.

A POLLEN PERCENTAGE DIAGRAM (SUMMARY)
SAINT MICHAEL ISLAND, ALASKA
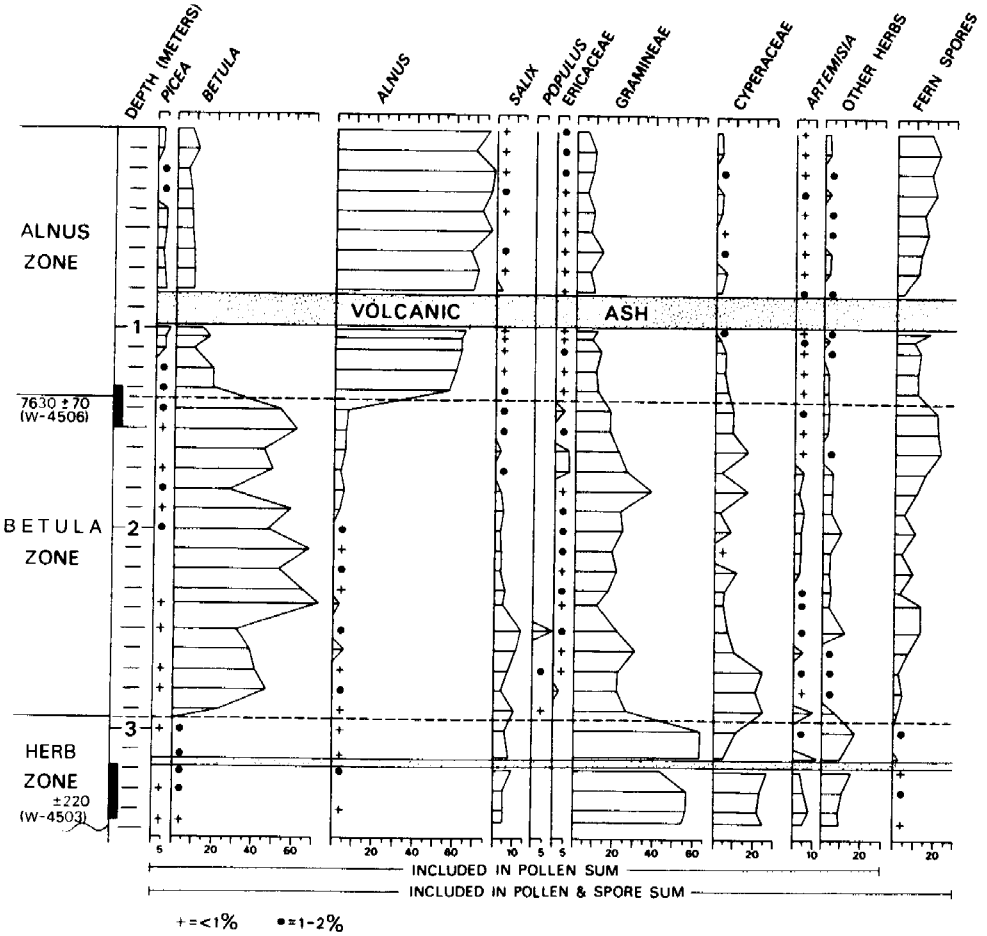## LAKE III (PUYUK LAKE)
CORE 78-2

Figure 13.5   Examples of pollen diagrams; both at 10 cm intervals. A. Percentage diagram with tephra, Puyuk Lake, Alaska. (Reproduced with permission from Ager 1982: Fig. 6.) B. Pollen percentages (a) and influx values (b), at Lateral Pond, Yukon Territory, Canada. Notice how different are the emphases by species between (a) and (b), and the marked change in biodiversity at 12,000 B.P. (Reproduced with permission from Ritchie and Cwynar 1982: Fig. 3. Both © 1982 by Academic Press.)
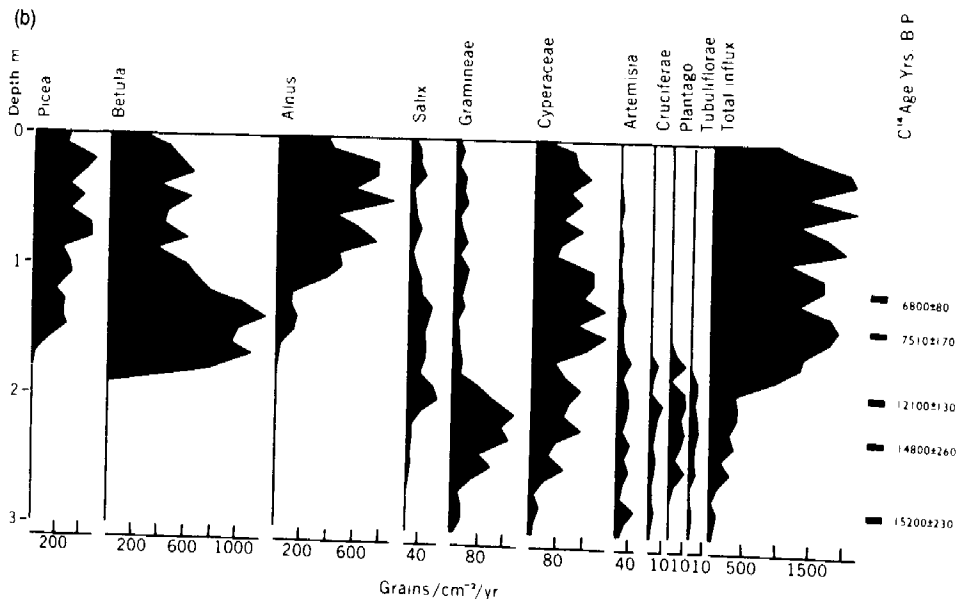
B

(a)
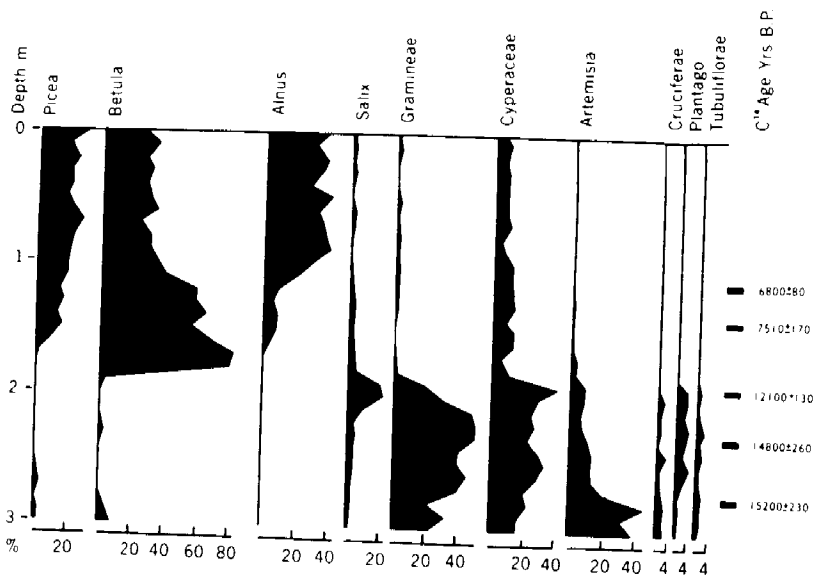
Lateral Pond, Yukon Territory

(b)

The advantages of concentration and influx calculations are, unfortunately, balanced by real problems, the most obvious and least serious of which is that preparation of an influx calculation is much more time-consuming, and therefore more expensive, than preparation of a percentage diagram. The significant problems come with the assumptions that are basic to the method. Calculation of pollen concentrations requires the assumption of a constant rate of deposition between dated points–an expectation that is unrealistic and usually untestable. Influx calculations depend fundamentally on the concentration figure. A number of problems both theoretical and technical make rate calculations conventions of greater or lesser, but in any case untestable, accuracy (Aaby 1988; Prentice 1988). Some of the complications in calculating sedimentation rates, and ways to minimize them, are cogently discussed by Berglund and Ralska-Jasiewiczowa (1986) in an article that has direct relevance for archaeological stratigraphies as well.

Some investigators present both percentage and influx/concentration counts, in order to benefit from their complementary strengths and weaknesses (Fig. 13.5B); there is no question but that such compound diagrams are an advance over simple percentage diagrams. For pollen in soils, influx counts are strongly recommended as alternatives to percentages, since soils mixing and degradation of pollen in such matrices make percentages fundamentally misleading (Dimbleby 1985). In such contexts, however, influx counts may really be equivalent to preservation counts.

To facilitate comparison among pollen diagrams reflecting both very local as well as regional factors affecting pollen frequencies, diagrams are subdivided into zones that group sequential spectra into sets. The zones are defined so that each has a characteristic suite of pollen and they are labeled with numbers, letters, or combinations of both. In this way, a sequence of biostratigraphic units is defined, which can be compared from diagram to diagram across space and time. The drawing of zonal boundaries has been until recently a subjective, even intuitive, activity, lacking rules to guarantee comparability of either criteria or subdivisions. Quantitative computer algorithms are standardizing the definition of zones so that intra- and inter-regional comparisons will not be unduly influenced by arbitrary personal criteria (Berglund and Ralska-Jasiewiczowa 1986; Birks and Gordon 1985; Moore et al. 1991: 178–180). In regions where many pollen studies have been carried out, zonation schemes tend to be self-perpetuating, gradually taking on auras of accuracy and generality that they have not earned on their merits. The schemes become reified, as was the case with the northwest European schemes which initially were equated uncritically with the Blytt–Sernander climatic phases based on bog stratigraphy. Biostratigraphic units should not be assumed uncritically to be determined by climate, or to reflect everywhere the same directionality and timing of change. Relationships among vegetation

change, soils development, climate change, geomorphological and anthropogenic changes must be investigated for each instance, not assumed. They will vary in time and at different spatial scales (see the excellent discussions of various factors affecting pollen production and deposition in *Vegetatio* [vol. 67, no. 2, 1986]). For pollen diagrams representing NAP influx as well as tree pollen, zones may be defined in such a way as to reflect human interference with natural systems – a desirable product for archaeology.

When many dated pollen diagrams are available in a region it is possible to map distributions of pollen in time and space. Taxa may be mapped singly to show their representation at different points in space at one time, using the graphic convention of **isopolls**, contour-like lines connecting points with equal percentages of a pollen taxon (Fig. 13.6A; Huntley and Birks 1983; Jacobson et al. 1987). Pollen concentration or influx data can be mapped the same way, giving patterns that may depart significantly from those of percentages. **Isochrons**, lines delimiting the geographic limits of a taxon at a single point in time, display other kinds of information (Fig. 13.6B; Gaudreau and Webb 1985). Pollen associations defined by the zonation of diagrams can also be mapped spatially, to show large-scale synchronic distributions of gross vegetation types (e.g., Delcourt and Delcourt 1981). These cartographic conventions, based as they are on interpretations of quantitative data, require evaluative interpretation in turn; they are not representations of demonstrable facts. They present *data patterns* relevant to reconstruction of paleoenvironments and phytogeography. Clearly, they are all great favorites with archaeologists, who are eager consumers of patterned data – most particularly dated patterns. Archaeologists must be informed consumers of such patterns, (1) recognizing the methodological, logical, and interpretational complexities that underlie them, and (2) applying them to archaeological problems at congruent scales. Because of the need to extrapolate and generalize in any mapping exercise, but particularly with still scanty pollen data, the best uses of these maps are in environmental studies at regional and larger scales.

Interpretation

Application of data from pollen diagrams and maps to significant research problems in paleoenvironmental studies entails evaluative interpretation for which both theoretical concepts and a responsible sensitivity to logic and limitations are essential. With the growth of palynological research and plant biology in the last few decades much has been learned, and much necessarily unlearned, about the interpretation of pollen data.

The hard-won realization that many Late Glacial and Early Holocene pollen spectra
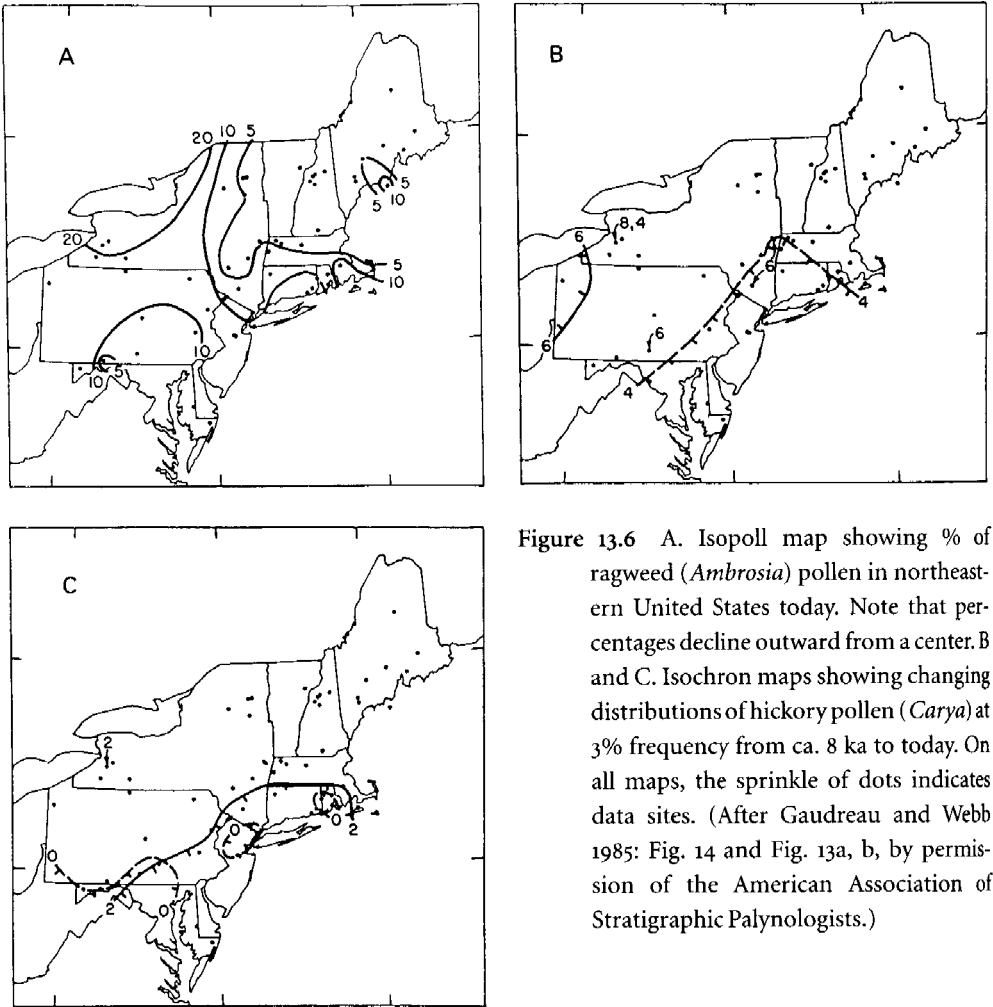
Figure 13.6 A. Isopoll map showing % of ragweed (*Ambrosia*) pollen in northeastern United States today. Note that percentages decline outward from a center. B and C. Isochron maps showing changing distributions of hickory pollen (*Carya*) at 3% frequency from ca. 8 ka to today. On all maps, the sprinkle of dots indicates data sites. (After Gaudreau and Webb 1985: Fig. 14 and Fig. 13a, b, by permission of the American Association of Stratigraphic Palynologists.)

have no modern analogs shook much of palynological reasoning to its foundation. The first victim of obsolescence was the idea that plant communities and regional associations maintained their compositional integrity as they "shifted" toward or away from the poles when Quaternary climates warmed or chilled. As data accumulated at the regional scale, as sampling intervals were reduced and dating achieved finer resolutions, it became clear that the spatial changes in vegetation had been accomplished at the taxon level, each taxon changing its distribution and density in response to many interacting environmental parameters, at rates defined by both biology and ecology. The idea of stable associations was invalidated; equilibrium became a relative concept, and research attention turned to the elucidation of processes.

Once the multiplicity of processes defining pollen representation came under scrutiny, researchers realized that many of the classic questions of palynology, particularly those related to climate, could not be answered with the available methods. With the new emphasis on quantification, issues in sampling theory emerged and it became clear that more questions could be put to the data if scalar distinctions in time and space were carefully respected. Thus, recent palynological studies examine the effects on pollen production and representation of such local factors as topography (relief and elevation), catchment size, depositional environments, soils maturity, disturbance and successions within plant associations, competition, pathogens, consumer effects (herbivory), and human interference with the physical and biological environments. These concepts are not elaborated here, but their promise for expanding paleoenvironmental studies should be clear.

The powerful concepts and methods adopted for studying rates and processes revealed the need for better control of the time dimension in pollen deposits. Beyond the problems of the radiocarbon method itself (Chapter 6) are the complications related to internal dynamics of the deposits sampled, and complications introduced by sampling methods. Collecting organic material for dating from small-diameter cores of sediments with varying proportions of organic material meant that different dated samples represented different *spans* of time; the several radiocarbon dates could be no more than averages of individual, undefined spans. Such data compromise precision, and therefore comparability. In the lake sediments that have been favored for regional pollen studies, mixing of sediments by moving water and bioturbation blends annual pollen deposits into zones representing a decade or more. In combination with the imprecision of dating technologies, the uncertainty complicates and limits correlation among cores and sites (Solomon and Webb 1985). The validity of pollen isochron and isopoll maps, even assemblage maps, depends among other factors upon a reasonable accuracy, if not precision, in correlation among diagrams; that is not easily achieved (Pilcher 1993).

Specification of the spatial dimension represented in pollen deposits is also challenging. In deposits outside of archaeological contexts, the size of the catchment can usually be estimated, according to the characteristics of the depositional basin. One estimate suggests that typical catchment sizes range from 50 to 3000 km² (Solomon and Webb 1985: 63), a range that measures vegetation from the scale of watersheds to landscapes. The selection of sampling sites appropriate to the scale of a problem under investigation is crucial, as is awareness of the relevant scales in any interpretation of the data. Pollen rain on archaeological sites includes elements of local and regional floras, but the special conditions of deposition and preservation on sites are unlikely to preserve representative samples of pollen rain. Interpretation entails

critical consideration of possible or likely sources for all taxa. In particular, pollen that finds its way into features that were once inside an enclosed space may represent very special or temporary conditions within the space itself (room, cave, etc.). Plants and plant materials may be collected and brought to a site by people, animals, or insects, introducing pollen that could not have reached the place naturally. Pollen deposited in fecal matter, especially in cesspits and latrines, may represent a highly diverse, selective, and widespread range of source locations (Greig 1982; Reinhard et al. 1986). In archaeological investigations, where the research problems are fitted to the data as often as the data are selected for the problem, an educated awareness of the spatial scales represented in diverse pollen samples is essential to interpretive success.

The realization that modern plant associations are products of numerous specific and interactive processes shifted attention from pollen zones and assemblages to indicator species as the bases for the study of plant associations (Birks and Birks 1980; Bryson 1985). Field studies reveal the modern parameters of climate, soils, or other factors that seem most determinative for the presence or absence of sensitive species, and the relationships so revealed are used to infer environments of the past on the basis of pollen spectra. This form of analog argument entails assumptions that we have seen are undemonstrated and vulnerable to challenge. First, there is the assumption that the relative importance of constraints on species in modern associations is unchanged through the duration under investigation. The assumption that plants are in equilibrium with climates (now and in the past) is a variant of this. Second is the assumption that consistent and close relationships hold between the observable ecological relationships of a particular species and that species' manifestation in the pollen record. Extrapolation from observations of plant associations to the interpretation of pollen spectra is made more difficult by the fact that field observations are made at the taxonomic level of species, whereas pollen is mainly identifiable at the genus or even family level, where ecological tolerances may be quite broad.

Pollen analysis supports strong inferences about paleoenvironments when they address the state and condition of vegetation mainly at regional (formation) scales (Berglund 1986; Birks and Birks 1980). Such interpretation stays closest to the data, requires the fewest undemonstrated assumptions, and benefits greatly from research on pollen–plant relationships. Excellent work has been done in both North America and Europe mapping the major plant associations of the Holocene (Huntley 1990; Huntley and Birks 1983; Jacobson et al. 1987).

Close-interval sampling and growing interest in sampling and comparing small basins to study local effects is producing excellent results at small scales, where bio-
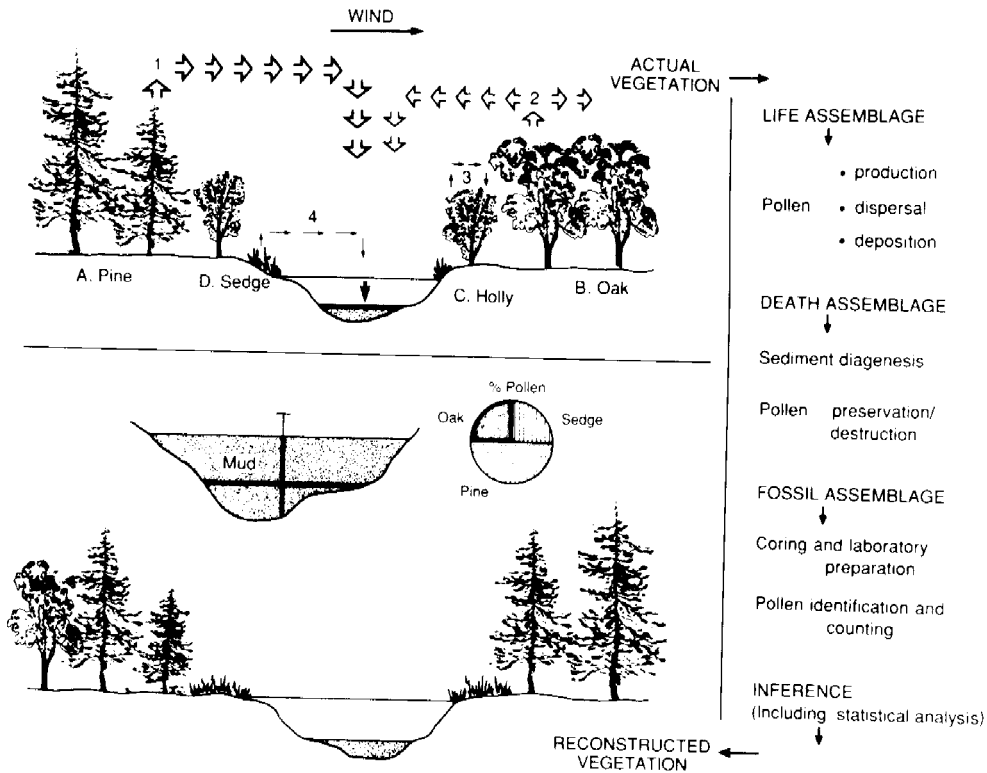
Figure 13.7 Reconstruction of vegetation from pollen analysis, showing biases skewing representation and distribution of species. Factors such as prevailing wind direction (1 & 2), differential pollen production (3), and relative proximity to collecting basin (4) are shown to overrepresent pine and sedge in the pollen spectrum, while underrepresenting oak and eliminating from consideration the insect-pollinated holly. (After Roberts [1989: 24], where more detailed discussion is available; with permission of Blackwell Publishers.)

logical factors dominate over those of the physical world (Peglar 1993; Smith and Cloutman 1988). Despite the possibility of greater precision when sampling intervals and sampled universe are both small, small-scale paleoenvironmental reconstructions may well be necessarily less accurate than the large-scale work. Inaccuracies in the data and assumptions will be more prominent in results at small scales (Fig. 13.7). Archaeologists can benefit from paleoenvironmental reconstructions based on pollen analysis, even when the reconstructions are not done with or for archaeologists, as long as they bear in mind (1) the requirements of scale congruency, (2) the need to be critically aware of the assumptions behind the work, and (3) the inherent limits of resolution or accuracy (King 1985).

Research into human effects on plant associations is intensifying in palynology as phytohistorians become aware of the range and scales of human influences and the antiquity of the phenomenon (Behre 1986; Starkel 1987). Palynologists are providing data on fire regimes, forest clearance, resource management, and introductions of exotic species. Human disturbance of natural systems is now recognized as a major environmental determinant, not confined to the period of industrialization or even of urbanization. The discrimination of anthropogenic effects from other habitat disruptions requires sophisticated analysis not only of pollen data but of other environmental proxies as well. Wherever human activities were concentrated enough to produce a recognizable archaeological context, the crucial distinction between background and cultural sources of pollen is at best difficult. An example of the difficulties is provided by the case study of the elm decline in this section. It is not idle speculation to wonder if Holocene vegetation anywhere in the world developed without some human influence (Roberts 1989). The idea of a "natural" environment or even "wilderness" free from human influence is problematical. Recognition of the antiquity and ubiquity of anthropogenic effects has important implications for the use of proxy data in any paleoenvironmental reconstructions. The biological success of *Homo sapiens* is more than a side issue in the study of Late Quaternary environments at any scale (Dincauze 1993a).

MICROBOTANICAL REMAINS IN MINERAL FORM

Growing plants and algae deposit in their tissues oxides and crystals that may outlast the organic remains and be diagnostic of former vegetation. Non-crystalline silica bodies that form in and between the cells of plants and encase some algae are significant categories of microbotanical remains. Delicately elaborate diatom frustules (box-like cases enclosing cytoplasm) recovered from subaqueous deposits inform about the chemistry and temperature of water bodies. As they rarely occur in archaeological contexts or yield information about terrestrial habitats, they are noted here but not further discussed (see Chapter 8, and discussions in Bradley [1999], Lowe and Walker [1984], and Williams et al. [1993]). Micromorphological studies of archaeological sediments have revealed potentially identifiable plant remains in the form of crystals of calcium oxalate and calcitic ash. These have been observed at high magnifications in floor accumulations and middens in dry climates, and in ash deposits from hearths (Matthews and Postgate 1994; Wattez and Courty 1987).
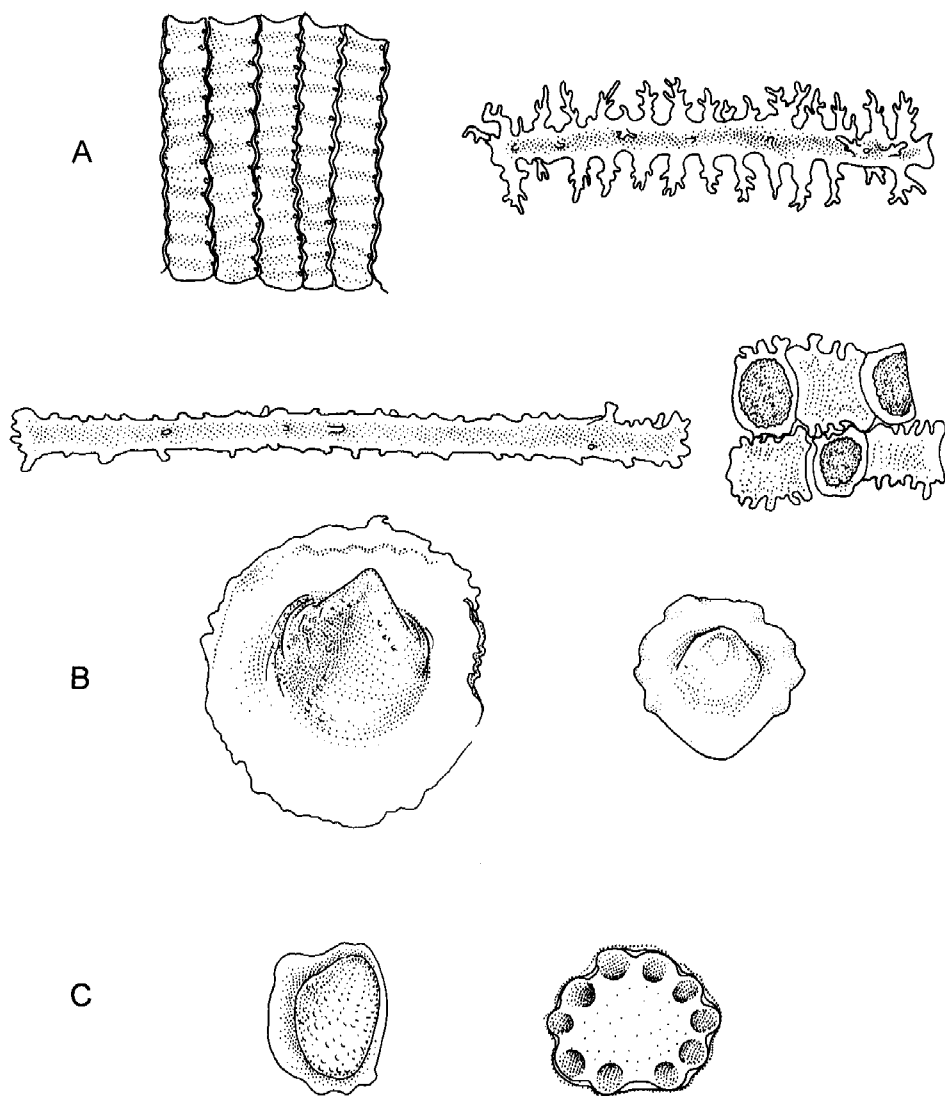
Phytoliths

Phytoliths ("plant stones") are opaline silica bodies formed in and around plant cells from silica (SiO_2) taken up with water. Constrained by the walls of cells, they harden into shapes that are characteristic of some plant taxa. When plant tissues decompose, the inorganic silica bodies typically remain where they fall, to be incorporated into soils and sediments. Their durability is less than that of crystalline silica (quartz) but is not well quantified; they have been shown to degrade with depth in soil (Fisher and Kelso 1987). Radiocarbon dating of organic inclusions in phytoliths showed considerable, but not infinite, age averaged for a set (Wilding 1967). Phytoliths form in many kinds of plant tissues; their sizes and frequencies vary with available moisture and other factors poorly understood (Pearsall 1989: Ch. 5; Piperno 1987; Rapp and Mulholland 1992; Rovner 1983, 1988).

Phytolith shapes, which may be amorphous, generalized, or distinctive, are consistent within taxa and are used for paleobotanical reconstructions within the limits of their specificity (Fig. 13.8; Piperno 1987). While there are several manuals for pollen identification, phytolith systematics is only just developing (Rapp and Mulholland 1992). Phytoliths are best known and therefore most useful among the grasses, and have been successfully applied to studies of domestic landscapes (lawns and meadows), pasturage and grain crops, particularly maize, and successional sequences in grasslands. Because phytoliths are preserved in climates and soils inimical to pollen, they offer advantages worth the development costs in pollen-poor areas such as tropical climates (Piperno 1989), grasslands, and urban deposits. Phytolith research, approached with discipline and imagination, promises a conditionally useful complement to pollen analysis.

Pioneering phytolith studies held out the promise of species-specific shapes; recent work has demonstrated that using suites of phytolith shapes to identify plant associations has a firmer foundation in the reality of phytolith variation and recoveries (Powers-Jones 1994; Rovner and Russ 1992). Research in archaeological middens in the Outer Hebrides shows that degraded cattle and sheep dung, as well as peat, can be identified by discrete phytolith suites (Powers-Jones 1994).

The small size of phytoliths creates difficulties in separating them from sedimentary matrices, where they tend to concentrate in the chemically similar silt fraction. They are separated from other sedimentary components by heavy-liquid flotation and centrifuging with deflocculation to separate them from clays. Pearsall (1989: 356–404) summarized a number of experimental laboratory methods for preparations of phytoliths, leading toward standardization. Counts of identifiable classes and degraded specimens are displayed in formats like those of pollen analysis. In the

Figure 13.8   Selected phytolith shapes from Old World cereals, few of which are strongly diagnostic. A. Sheet elements from epidermal surfaces of oats (2), wheat, and rye-grass; B. Long cell appendages from oats and wheat; C. Epidermal cell elements from rye-grass and wheat. (After Kaplan et al. 1992: Figs. 8.2–9, 19–22, scales diverse. Identification and explanations are in the original source.)

current developing state of phytolith analysis, interpretation is best supported by comparison with patterns of pollen and other paleoenvironmental indicators.

Phytoliths have been recovered from contexts other than sediments, including tooth calculus (Middleton and Rovner 1994), cooking residues (Pearsall 1989: 312), and the working edges of flint tools. In those contexts they have explicitly archaeological implications for human activities and environments.

CHEMICAL TRACES AND PROXY DATA

Subcellular plant remains in the form of ratios of stable isotopes and **chemical residues** also provide data on former vegetation. Chemical analyses of tissue constituents and residues retrieved from sediments, soils, and cooking and storage vessels can indicate the past presence of plant taxa that have left no visible remains.

Stable isotopes

Plants use solar energy to synthesize organic compounds by photosynthesis. There is more than one way to do it. Three photosynthetic pathways are recognized: C_3 (Calvin, with 3 carbon atoms in a primary compound), C_4 (Hatch-Slack, with 4 carbon atoms), and CAM (crassulacean acid metabolism), which involves aspects of the other two, according to available light and moisture. Since the photosynthetic paths involve different degrees of discrimination against heavy carbon isotopes, they are distinguished analytically by their ratios of stable carbon isotopes ($^{13}C/^{12}C$) (O'Leary 1988). C_4 plants discriminate less against ^{13}C (that is, utilize more) than do C_3 plants, and therefore their photosynthetic compounds have higher values of ^{13}C (expressed as less negative $\delta^{13}C$) in comparison to an established standard (Table 8.1). Photosynthetic pathways differ among taxa, reflecting adaptations to diverse regimes of temperature, moisture, and possibly light. "At different temperatures it pays to gather gas in different ways" (Colinvaux 1981: 5). CAM plants are typically desert succulents; C_3 plants characterize temperate regions; subtropical grasses constitute a major C_4 group. Because the pathways differ among environments, isotope ratios in plant tissues are proxies for regimes of temperature and effective moisture.

The ratios of heavy to light isotopes continue through the food chain, from plants to herbivores, to carnivores and omnivores, and can be measured in the tissues of consumers. Fortuitously, the C_4 group includes major subtropical human food plants such as maize, sorghum, millet, rice, and sugar cane. When such plants are introduced and cultivated in temperate environments naturally dominated by C_3 plants, their isotopic signature values can be read in the tissues of consumers.

Significant research in prehistoric human and animal diets is founded on this observation (van der Merwe 1992). Such research, based on animal tissues, is discussed further in Part VII.

Analysis of plant tissue fragments from soils and sediments shows isotope values varying regularly by altitude on the slopes of an African mountain as a result of adaptations to conditions of light and moisture (Tieszen et al. 1979). The phenomenon offers an approach to tracking climate change and vegetation responses (Ambrose and Sikes 1991). Especially where moisture regimes are close to critical values, habitat change would stimulate adaptive response from plants, normally by changes in distribution or proportional representation of species within the vegetation. It is not necessary that the tissues be closely identified to taxa in order to serve as isotope proxies of vegetation changes but, of course, identification improves sampling control.

Chemical residues

Examination of food residues adhering to cooking vessels is a promising line of inquiry into chemical analyses of plant constituents in human foods. After a slow start, the literature is growing in specificity and breadth (Biers and McGovern 1990; Charters et al. 1993; Fankhauser 1994; White and Page 1992). Both wet and dry analytical methods are showing success. Various lipids (fat molecules) have been extracted from ceramics and chemically identified to plant sources (Evershed 1993; Heron and Evershed 1993). For example, analysis of pots from an early medieval site in central England has indicated the cooking of cabbage or turnip leaves and also leeks (Evershed et al. 1992: 203), an indication of recipes to come. Cacao residues have been identified in Maya food vessels (Hall et al. 1990), in an area where plant remains are rare. A glimpse of the future is provided by Hillman and his colleagues (1993), who find that "long-chain lipid systems offer greater potential than proteins and carbohydrates as they are less vulnerable to fungal and bacterial attack." Work continues to refine methods, identify complications, improve experimental controls, and reduce costs and processing time.

Research on trace elements and crucial molecules that can identify vegetatively reproductive plants has achieved preliminary results in Peru (Ugent 1994). The classic trace element suites of nitrogen and strontium ratios in animal bones, long used to distinguish plant from animal dietary emphases, must be refined to escape from some long-standing abuses of interpretation (Radosevich 1993).

Methods under development for utilization of chemical residues in paleoenvironmental research include extraction of DNA from plant residues, and trace chem-

ical analyses. The literature is currently experimental and partly unevaluated, but improving (Andrews 1994). At present, plant DNA seems better preserved and easier to clone (Weising et al. 1995), under many conditions, than animal DNA, which is particularly susceptible to fungal contaminants.

Proxy data for paleobotany

Indirect evidence for past vegetation and human use of plants comes from both natural and purely cultural (artifactual) sources. Gross aspects of plant associations can be inferred from paleosols, since vegetation is a prime soil-forming factor (Chapter 11). Forest soils contrast significantly with soils formed under grasslands; in the absence of identifiable plant remains in soils, such basic differences can usually be distinguished, although chronology is likely to be problematic. The addition of paleoclimatic information can strengthen the inference or at least restrict alternatives. Reconstructed ancient landforms and hydrography help narrow the range of possible vegetation types by implicating constraints such as elevation, slope, and drainage.

When something is known of past faunal associations, analog arguments can suggest likely foods for herbivores and habitats for animals whose ecological requirements are well known. Age is a limiting condition for such inferences, because the further the analogy must be stretched from present conditions, the less likely is a good match to past conditions and therefore the weaker the analogy. For example, insects often have narrow ecological niches, being adapted to particular plant species, but because many are genetically very plastic they are not dependable indicators of past vegetation. Beetles, which apparently rely more on migration to suitable environments than on genetic adaptation, have been a useful exception to the rule on insects. Small herbivorous mammals are comparable to mobile beetles in this respect; they contribute to vegetation reconstructions in many investigations. Herbivores such as terrestrial mollusks may be useful indicators of past vegetation associations. Snail sequences recovered from pits and ditches at the Danebury hillfort, in England, implicated a period of reforestation after site abandonment (Evans 1984). Stable carbon isotope ratios in animal tissues can help refine gross estimates of past vegetation by implicating proportionate consumption of C_3, C_4, or CAM groups.

Artifacts representing identifiable plants are excellent evidence of what the artificer has perceived. Drawings and sculptures of plants from archaeological periods as ancient as the Upper Paleolithic provide such information. As with artifactual data of all kinds, however, the source is not specifiable from the findspot or

associations. Portable plants smaller than shrubs and plant organs such as fruits and seeds may have been accessible to an artist who was never within many miles or hundreds of kilometers of the home soil of a given plant. Depictions of plant associations, such as the marsh panoramas in Egyptian tombs, are excellent evidence of habitats closely observed, whose locations might be inferred from their characteristics.

CODA

Plants and bacteria that make food (autotrophs) are fundamental to life and nearly ubiquitous. Plant remains in great variety are preserved differentially in dry, wet, or charred condition, and as pollen, spores, phytoliths, crystals, molecules, DNA, isotope ratios, and suites of trace elements. Artifacts provide indirect evidence. Archaeologists who maximize the amount and diversity of recovered plant remains, and diversify laboratory analyses, enhance studies of prehistoric human paleoecology and behavior in many disciplines.