PALAIOS

An International Journal of SEPM (Society for Sedimentary Geology)

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VOL. 13, NO. 5 OCTOBER, 1998

ONLINE

Love's Labour Lost? Or the tragic story of a young paleontologist who chooses fossil plants as his life's work only to discover at age 50 that his mother thinks he should have studied dinosaurs ("Why aren't you ever on TV?")

On a hot day in August of 1990, I followed Scott Wing up a hill somewhere in the Bighorn Basin of Wyoming. At the top, Wing stretched out his arm like a biblical prophet and in a grand sweep presented me, a visitor from the heavily vegetated coal basins of the east, with a vision of more bare terrestrial-rock outcrop than I had ever seen in one place. Hosana. I have thought a lot about the lesson of that day and what it means for the recurring image of the terrestrial paleontologist, supposedly staggering across state lines to get from one postage stamp sized outcrop to the next while compiling the "hopelessly gappy" record of continental organisms. Niklas, Knoll and Tiffney, in their 1980 compilation of plant diversity trends through geologic time, computed an area of terrestrial outcrop in the USA and Canada of approximately 2,550,000 km^2, or roughly an area the size the US east of the Mississippi River. Most of this outcrop area does not hold plant macrofossils, or even fossil pollen and spores. A large fraction of it is paleosols, which offer a huge reservoir of information on ancient vegetation and climatic conditions, but nothing about the species that grew there. Nonetheless, that is a huge piece of real estate that at times and in places permits paleobotanists to address some interesting and important questions.

So what? In this brief essay, I wish to pose a couple of questions that I am certain almost all of us know the answers to, but gloss over when generalizing. How many fossil records are there? Do generalities drawn from any one of these records apply equally to the others? And, to the point, what are the characteristics of the fossil record of plants?

Generalities are borne of experience and come understandably from those centers of study that employ the most scientists and appeal to the most members of the general public. Thus, two records rightly dominate both professional and general interest thinking—the record of fossil vertebrate skeletal remains and the record of marine invertebrate macrofossils. Of course there are other fossil records with different strengths and biases—marine microfossils, terrestrial spores and pollen, plant macrofossils, trace fossils, and more.

There really are plenty of plant fossils. Finding plant macrofossils can be a considerably different experience from finding either fossil vertebrates or

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marine macroinvertebrates. Most importantly, it is hard to find plants by searching the surface for remains, and there are few lithologies that are reliably fossiliferous. Coal balls, for example, which are calcium carbonate permineralizations of peat rarely found in coal beds, most often are discovered in the course of mining. So, it is usually by luck that we find out about them through contacts with staff at the mine or through geologists at a geological survey. In contrast, compressions and impressions (known collectively as "adpressions") are present in the shales associated with many coal beds; hence, mines are a good place to look and simply stopping in often can turn up fossils for relatively easy collecting. However, working in areas without coal requires development of a depositional environment search image, which serves as the starting point for test excavations. Lacking that search image, one must be developed by hit or miss digging in promising looking beds.

We recently have made large collections from Permian "red beds" in north-central Texas. The search image of earlier workers was based largely on color and focused on the rare gray beds under the assumption that red beds are too highly oxidized to have plant fossils. Serendipitously, museum paleontologist Dan Chaney found plants by digging in an unusual deposit that attracted his attention while looking for surface bone. A search image was born—channel-form, 'U'- shaped deposits filled with finely layered claystones of any color. With that to look for, we discovered plant fossils at dozens of places in a large geographic area. In another part of the section, dominated by thick evaporite beds and, thus, a place we would have passed by, plants have turned up in channel fills associated with copper mineralization. The first deposits were found by a rancher who kindly showed us the spot.

The lesson here is that what you don't see may still be there. Notes of field geologists that record "plant scraps" frequently provide leads to excellent material once a big enough hole is put in the ground. The apparent "gaps" in the fossil record of plants are in many cases simply gaps in sampling because of the lack of persistently reliable search images for fossiliferous deposits and small numbers of people out there looking.

Achieving critical mass. One of the important ways paleobotany differs from vertebrate and invertebrate paleontology is in the smaller number of practitioners both professional and amateur. This difference can be assessed crudely by comparing membership lists in the major societies through which scientists self-segregate. Based on the Bibliography of American Paleobotany, there are roughly 250 people in the Canada, Mexico, and the USA interested enough in paleobotany to join its major professional association, the Paleobotanical Section of the Botanical Society of America. Only about a half of these regularly attend professional botanical meetings and publish original research articles on fossil plants in peer reviewed journals. By tradition, most are trained as botanists, although some have always joined their fellow paleontologists for annual exchanges of ideas. This group includes few of the many palynologists working in the Quaternary.

By contrast, the directory of the Society of Vertebrate Paleontology includes over 1250 entries from Mexico, Canada, and the USA. The Paleontological Society, home to most of the invertebrate paleontologists (as well as some others), includes nearly 1500 names from North America. Most of these scientists have strong backgrounds in geology and often degrees from geology departments. In addition, unlike paleobotany, vertebrate and invertebrate paleontology have large followings of academically inclined non-professional collectors who out number those practicing for a living and inflate society memberships. A fair number of these amateurs have made discoveries of significant specimens or fossiliferous horizons in the course of building private collections or working in association with academic scientists.

Time averaging and time scales. Commonly heard mantras in ecology, paleoecology and taphonomy: The fossil record is irreducibly time averaged. The fossil record cannot resolve spatio-temporal patterns below about 10^3 years due to time averaging. Paleontologists work on long time scales, millions of years, whereas neobiologists work on short time scales, less than 100 years.

The fossil record of plant adpression fossils is insignificantly time averaged. I imagine the same is true of trace fossils—it seems as if it would be difficult to rework millipede footprints on a lake varve surface. Once deposited, the organic film that is a plant leaf becomes brittle and thin. Storm generated reworking of sediment will turn buried leaves into coffee-grounds or lead to their complete oxidation. Depending on the specific environment of deposition, however, leaves can be moved around spatially prior to burial. Truely autochthonous deposits are relatively uncommon but not rare. Examples include the record of in-place tree stumps preserved in the roof shales of coal mines, the occasional vegetation buried by volcanic ash preserving a veritable temporal snap-shot, or the spectacular mummified forests of Eocene age that have been discovered above the Arctic circle. Most adpression deposits are parautochthonous, which means transported but within the original community of growth. Allochthonous deposits, those that mix specimens from different plant communities, either form under special circumstances or are composed mostly of wear resistant parts because of the fragility of most plant remains. In large lakes or active channel deposits, taphonomic studies tell us that the flora is drawn from the banks of the stream or lake in which the sediments were deposited. There are important allochthonous deposits in marine or lagoonal settings, such as the Pennsylvanian age Mazon Creek biota or the Eocene age London Clay flora, that represent a broad area of land surface and encapsulate hundreds to thousands of years, although not due to reworking but rather through continued input of organic material over an extended period of depositional time.

Lack of time averaging permits paleobotanists to make reasonable estimates of original vegetation. Actualistic studies have shown rank order and quantitative correspondence between the dominance-diversity pattern of litter and that of the standing forest. Consequently, it is possible to sample many plant deposits with techniques used in the study of modern vegetation. These include quadrat analysis, line-intercept methods, point or grid counts, and transects. As a result, analyses of ancient vegetation often proceed in much the same manner as a study of a modern ecosystem, and produce similar results. Estimates of plant biomass, productivity, community structure, and short-term dynamics can be analyzed and compared fruitfully among assemblages of similar age or across long spans of time.

The down side to this temporal homogeneity is spatial restriction. Taphonomic studies suggest that the average 2 m^2 excavation samples something between one-third to one-half hectare. Because of the difficulty of tracing any one instantaneous time horizon very far from its point of exposure, lateral sampling must include several close, but not identical time horizons and thus introduce "analytical" time averaging if spatial patterns are to be investigated on anything more than the smallest scales. Without intense sampling, therefore, the diversity of the plant record tends to be locally underestimated.

There also are myths about certain parts of the record as they relate to the issue of time and resolution, especially in ecological analysis. For example, the Quaternary record of plant microfossils has been touted as the only source of paleontological information to bridge the time gap between the long time scales, on which pre-Quaternary paleontologists supposedly work, and the short time spans of neo-ecologists. While ^{14}C dating certainly permits Quaternary patterns to be resolved better spatially than is generally possible with older material, much of the dating of cores is based on interpolation and sediment-accumulation rates between the widely spaced C-14 dates. It is a gross misrepresentation, probably based on lack of familiarity, to imply that the fossil record of pre-Quaternary spores and pollen cannot be resolved at the very same "meso" temporal scales by vertical incremental sampling of coals and clastic rocks. In fact, there are very few scales of temporal resolution that cannot be accessed with the deep fossil record of plants. Certainly, the autochthonous assemblage at the 10^0 year scale is not seen commonly, but it is not rare enough to be counted out as an important source of information.

As a consequence of the wide range of spatial and temporal scales on which the plant fossil record can be sampled, it is critical that we stop sending the message that "paleontologists work on the time scales of 10^6 years". Do we work on those scales? Yes. Are we restricted to those scales? No. The scale of time and space resolution can be chosen to fit a wide range of interesting and important questions in evolution and ecology.

The problem of the parts. Dead organisms tend to fall apart. This is as true of vertebrates and invertebrates as it is of plants, but the consequences for interpretability of the results are different. Vertebrate paleontologists seem to be able to reconstruct a whole organism from a couple of teeth or a few bones, perhaps because vertebrates are more stereotyped in their organization and modes of feeding. Plants, on the other hand, are less functionally integrated than vertebrates and most invertebrates. Strongly modular construction and "open" growth give plants considerable flexibility in the way organs are arrayed and in the way an individual plant responds to damage (try pruning your cat, or your pet clam). When dispersed, it may be difficult to put these parts back together. It is not possible to describe the subtle and not so subtle differences in the shapes and sizes of oak species from either their leaves or their reproductive organs, although a general idea can be had by linking fossils to closest modern relatives. For the deep past this is a problem that is difficult to overcome without the fortunate find of a preserved whole plant. However, the method of reconstructing whole plants from statistical patterns of association of parts is frowned upon by many, who focus on a few mistaken associations as examples of the weakness of the practice and call for attachment as the only evidence of association (as if attachment of A to B insures that A also cannot be attached to C—it is all probabalistic in the end). The problem of organ association is one of the reasons why paleobotanists insist on so many different names for isolated parts of the same whole plant. Furthermore, there are phenotypic convergences that can cause great confusion, such leaves of virtually identical morphology borne on ferns and seed plants. Separate names for each fossil plant organ can be carried to extremes, however, and not all paleobotanists, myself included, favor the attribution of separate names to organs otherwise known in attachment (yes, this is still done routinely, no kidding).

Even though the record of plants is in bits and pieces, it does preserve with remarkable fidelity the spectrum of tissue and organ types, even if they cannot always be associated confidently at every level of taxonomy. Various forms of mineralization of wood, leaves, and even soft tissues, have produced an excellent record of most of the functional, above ground parts of plants from a large proportion of the fossil record. Roots generally are not as well known, although this is certainly not the case for all groups and is changing as interest in paleosols grows.

Plants and the future. I attended my first professional meeting in 1976. At that time most macrofossil paleobotanical research focused on morphology and systematics. That line of research remains the core of the discipline and if you want to know about it, you've got to learn the jargon (but then how is "lophophore" any more intuitive than "nucellus"). Biostratigraphy played a small but important role and remains the purview of a few. The breadth of the field has enlarged greatly since that time, however. Paleoecology is now a major research program, and itself has broken down into many subdisciplines, including the study of plant-animal interactions. Plants serve the paleoclimate industry in important ways, ground truthing models and providing primary information on rainfall and temperature patterns. The sophistication of phylogenetic analyses has led to several cycles of study of relationship patterns and has refined considerably evolutionary scenarios. Although the number of practitioners is few, modeling has developed as a major tool to study fossil plant biomechanics and developmental biology, and has become an important way of gaining insight into the evolutionary process. It is through these advances and by using the data of paleobotany to address general problems of evolution and ecology that the discipline will insure its survival in the future.

—Bill DiMichele