Stems and Seeds: Grasses in the Fossil Record

Scientists are beginning to use the broken bits of ancient grasses as important clues in the fossil record

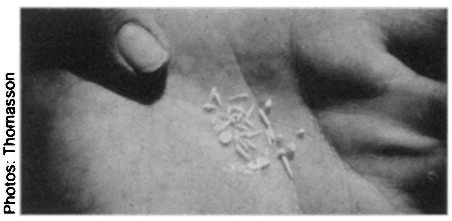
By LISA DAVIS

"I believe a leaf of grass is no less than the journeywork of the stars."
—Walt Whitman, *Leaves of Grass*

Grasses are more than the centerpiece in a cow's dinner: For humans, they are perhaps the most important of plants. A buffer between inhospitable rock and nutrient-seeking life, they transform sunlight into the better part of the world's daily diet. Since they first appeared, grasses have mellowed the atmosphere with oxygen; they temper the climate and, in thatch roofs and bamboo walls, shelter much of the world's population from the weather.

Yet in spite of their great importance, little is known about the evolution of grasses. There have been few studies of grass fossils — almost none in the United States. Part of that may be due to the fact that fossil grass seeds and bits of leaves are easy to overlook next to mammoth tusks, or even maple leaves. And part may be due to the fact that until the last few decades the technology did not exist to glean much information from such scraps. As a result, scientists don't have answers to even the broadest questions about the history of grasses. They don't know, for example, how the grassland ecosystem developed, or even when grasses first diverged from ancestral stock.

"If you go down the hall here," said Joseph Thomasson during a recent international symposium on grasses at the Smithsonian Institution in Washington, D.C., "you'll see an awful lot of vertebrate fossils — fossil horses and fossil rhinoceri and fossil all kinds of things. Then in the display showing, say, the late Miocene, you see the background with all kinds of [grasses] growing there. Yet there's hardly any record of them. [To reflect our current lack of knowledge] that diagram really should be shown without the plants."


Photos: Thomasson

A handful of fossil grass husks from Minium's Quarry. The grasses that bore the round husks are related to living ricegrass in Central America. The long cylindrical husks are related to living needle-and-thread grasses in North and South America, and the oval husk to living millet grasses.

But that situation is slowly changing. At the grasses symposium, Thomasson and other researchers discussed the way the picture of grass evolution is beginning to come into focus — and what the new information reveals about ancient climate and ecology, and the evolution of animals that depend on grasses.

Thomasson, at Ft. Hays (Kan.) State University, is one of what can generously be called a handful of fossil grass researchers in the United States. At a site in northwestern Kansas called Minium's Dead Cow Quarry he has collected seeds and leaf fragments that date back about 7 million years, to the late Miocene. The site, he says, may turn out to be a Rosetta Stone of grasses — the fossils so well preserved, the animal-plant associations so rich, that they tell an unusually complete ecological story.

Under the scanning electron microscope, some of the fossils from Minium's Quarry show as much detail as living plants, with intact vessels visible in cross sections of leaves. "It's as if you found a fossilized rabbit and it still had its eyelashes," Thomasson says. That kind of detail provides a window into the physiological processes of the living leaf of 7 million years ago. It has allowed Thomasson to refine an intriguing problem in plant evolution: When did grasses undergo the split that has resulted in some species using C3 (three-carbon) photosynthetic processes, while others use C4 (four-carbon) processes as well?

C4 photosynthesis provides a plant with enough of an advantage that it has evolved, probably independently, in many plant groups. It involves an entirely new metabolic loop in the process of carbon fixation that turns chemical energy into simple sugars, and its evolution required major anatomical changes.

The leaves of C4 plants characteristically show wreath-like patterns of cells surrounding vessels, an arrangement that allows the plant to separate energy-producing reactions from energy-consuming ones. Unlike C3 grasses, C4 grasses are able to store carbon dioxide, so they can close their pores when the temperature is high, conserving water while continuing with CO_2-dependent metabolism. That makes C4 grasses more efficient at converting sunlight into structure — into more grass — and better adapted to regions of high temperatures and light intensities. (The net photosynthetic rates of C4 grasses — corn, for example — can be two to three times the rates of C3 grasses like wheat or rice, according to a recent text on plants. Think of the ability of C4 crabgrass to overrun a lawn of C3 Kentucky bluegrass during a hot summer.)

"Prior to [the study of] this site," Thomasson says, "we had absolutely no idea when this split in those two phys-

Lower jaw of a hippo-like rhinoceros at Minium's Quarry. "I've got a vial of seeds that I took out of that rhinocerus's jaw," Thomasson says. "You can't get any closer association than that."

iologies occurred" in grasses. In fact, he and his colleagues wrote in the Aug. 22 SCIENCE, hypotheses about the timing of the split have varied wildly. Some researchers suggest that it occurred 100 million years ago; others say it happened as recently as 10,000 years ago.

The fossil C4 grass found at Minium's Quarry "allows us to say that 7 million years ago, positively and without any doubt, that split had already occurred," Thomasson says. Indeed, he adds, the fact that the characteristic C4 anatomy is so well developed in the fossils suggests that the split may have occurred tens of millions of years ago.

Besides filling in gaps in scientists' understanding of grass evolution, Thomasson says, the fossil grasses can provide clues to the climate millions of years ago. The physiology of C4 plants, for instance, is adapted to highly seasonal, warm, wet regions. According to Thomasson, the fossils at Minium's Quarry indicate a subtropical, slightly lusher Kansas, without its familiar extremes of cold — or indeed, any summer or winter at all.

"If you wanted to get a feel for what Kansas looked like 7 million years ago, you'd need to transport yourself to the Serengeti Plains [in Tanzania]," Thomasson says. "You [would] see bears and cats, camels and horses. . . . You'd see huge herds of animals wandering by."

Those vertebrates are represented at the Kansas site; so are zebra, rhinoceri, antelope-like pronghorns, cats and other vertebrates. According to Ft. Hays State University paleontologist Richard Zakrzewski, who worked at the site, the close association of plant and animal fossils at Minium's Quarry is particularly valuable. "In other places, if you find the seeds you don't find the bones; if you find the bones you don't find the seeds. As far as I know, it's unique to find a diversity of both plants and animals in the same sediments."

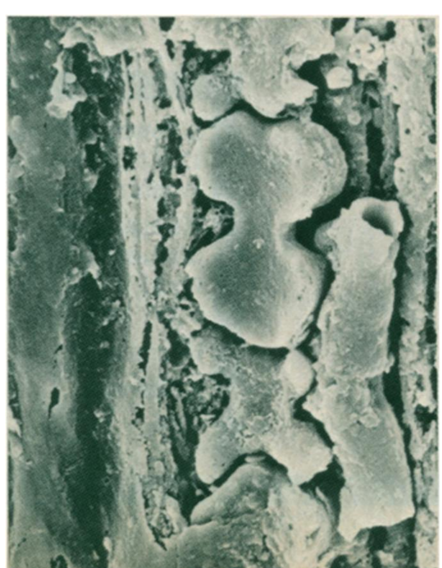
Having flora and fauna together means that vertebrate paleontologists need make fewer speculative leaps about how the animals lived. In the past, Zakrzewski says, paleontologists have relied on anatomical characteristics like tooth architecture as indicators of the diet of fossil animals — extrapolating from high-crowned teeth, for example, that the animal was a grazer, with a diet of gritty, high-silicon grasses. But to make that extrapolation, researchers have had to rely on fossil findings at often widely separated sites.

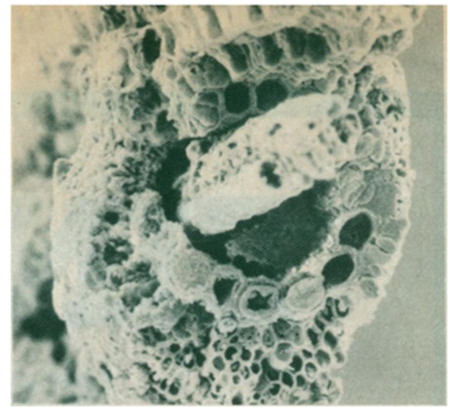
The Kansas site will help researchers correlate plant and animal fossils from disparate sources, Zakrzewski says. And animals and plants at Minium's Quarry can be tied together with much less ambiguity than ever before. "We have a much better handle on who was eating what," Zakrzewski says.

According to Scott Wing, a paleobotanist at the Smithsonian Institution, Thomasson's work is adding much-needed information about grasses. But, he says, what he'd really like to see are fossils that shed some light on the origin of grasses, which botanists speculatively place at about 80 million years ago. The oldest unequivocally identified grass fossils date back to the late Oligocene, about 25 million years ago, according to Thomasson.

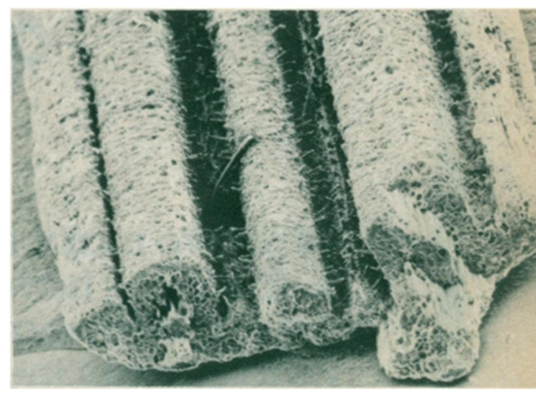
Wing is not sure paleontologists will ever find fossils to fill the gap. "There's a giant hole at the critical time," he says. "Yet there are wonderful fossils of comparable age [80 million years old or older]

Sharp detail is visible on the upper surface of fossil leaf (seen in end-on view, below). The dumbbell-shaped silica body is responsible for the gritty feel of many grasses (silica is a natural grass); the cross-shaped cork cell produces a resilient substance that, Thomasson speculates, may serve as a shock absorber (magnification: 1725x).





Fossil grass researcher Joseph Thomasson was able to pin down the type of photosynthesis used 7 million years ago by the grasses at Minium's Quarry. In this end-on view of a leaf fragment (magnification: 336x), cells surrounding vessel (protruding, open-ended tube) are arranged in a wreath-like pattern, one bit of evidence that the grass used a more advanced style of photosynthesis.



Fossil grass, showing complex ribbing and furrowing of the upper leaf surface. The cells surrounding the vessels in this leaf do not show the radial arrangement seen in grasses using more complex forms of photosynthesis (above) (magnification: 62x).

for many, many groups of plants. My feeling is that if the specimens were there, someone would have twigged to that by now."

Thomasson, on the other hand, thinks the scarcity of grass fossils has more to do with their unprepossessing appearance than with special characteristics that might prevent their preservation. Impressions of leaves of other plants are immediately identifiable, at least on a general level, he says; in contrast, researchers have to focus on microscopic features to begin to identify grass fossils. Now the scanning electron microscope has made that possible — and, says Thomasson, perhaps his work will encourage other researchers to look for similar fossils at their own sites.

"It's as though we've had half the information, and now we'll have the whole," Thomasson says. "I don't think that grasses mysteriously appeared anywhere. I think they're in the fossil record." □