MEETING BRIEFS

Earth Scientists Assemble Atop an Ancient Rift

At the annual meeting of the Geological Society of America in Cincinnati at the end of October, discussions ranged over every scale. At the small end was microscopic evidence of the earliest life on land. On the macroscopic scale, plant fossils spoke of how the flowering plants achieved dominance. And on the megascale, geologists reported a vast scar, right beneath the meeting site, that records the near-rupture of North America.

A Slow Start for the Flowering Plants?

Flower power was quick to win the world, most paleobotanists think. After the flowering plants began rapidly evolving into an array of new species about 100 million years ago, their energy-efficient life cycles and ability to attract wide-ranging insect pollinators presumably gave them such a marked advantage that they crowded out the once abundant ferns and gymnosperms—the conifers, ginkgoes, and palm-like cycads so often seen as the backdrop for dinosaurs. By 80 million years ago, in the conventional view, the ferns and gymnosperms had been pushed off center stage by the flowering angiosperms. But a bonanza of fossil plants recently found in Wyoming suggests that the angiosperms may not have been so quick to triumph.

The conventional view is based on fossil deposits that reveal the diversity of plant species but may not give a clear picture of each species' abundance. Now paleobotanist Scott Wing of the Smithsonian Institution has found the remains of a 72-million-year-old fern meadow dotted with palms—the first reported site where a head count could be made of fossil plants still rooted to the spot where they grew. The results of the census, presented at the meeting, show that flowering plants were indeed there in all their splendid diversity, but individual angiosperms were few and far between. It was the ferns that reigned in this field. If Wing's site is typical—and some paleobotanists aren't sure it is—the angiosperms' triumph must have been delayed until some external factor tipped the evolutionary scales.

Discovering this snapshot of an ancient landscape took two bits of luck. The first fortuitous event came 72 million years ago in what is now Wyoming, when volcanic ash sifted down on an open, fern-covered field. Only a few centimeters fell from the sky, but then a slurry of ash flowed across the field from higher ground and encased most of the plants to a depth of 30 centimeters. But even that would not have been enough to entomb the plants for good; what ultimately preserved them was the blocking of a stream that drained the wet, subtropical meadow, gently flooding it with water carrying another 4 or 5 meters of ash.

The second piece of luck came in 1990, when Wing happened to be driving along a Wyoming back road on Big Cedar Ridge, watching the roadside with a geologist's eye. Pulling off to see if a 5-meter-thick layer of volcanic ash-turned-to-clay might be dated isotopically, he dug into the base of the volcanic layer and "plants just started to fly out of the [rock]. There were plants anywhere you wanted to dig. It's the best-ever deposit for plants."

SCOTT WING

In death as in life. A fossilized *Gleichenites* fern appears much as it does today.

In order to date the site and analyze the flora, Wing enlisted geochronologist Carl Swisher of the Institute of Human Origins in Berkeley and paleobotanists Leo Hickey of Yale University and Robyn Burnham of the University of Michigan. In the completed census, the angiosperms lived up to expectations only in their diversity—not their numbers. Of the 146 species found, 68% were angiosperms. Sixty-one percent were dicots, the dominant type of angiosperm. But when Wing, Hickey, Burnham, and a small army of 30 field assistants measured the area covered by each species, they found that ferns and gymnosperms covered 56% of it, while angiosperms took up only 43%. The dicots covered only 12% of the area. Only one angiosperm—a palm—was abundant, accounting for 25% of cover. "This place really set me back," says Wing. "I didn't realize how much I was seeing one side of the flora."

To Wing, the eye-opening results from Big Cedar Ridge suggest that fossil sites elsewhere have been giving paleobotanists a distorted view of the rise of angiosperms. Most of the fossil troves paleobotanists rely on were formed when plant remains—pollen, spores, leaves, and even logs—were swept off by wind or flowing water, then deposited and buried by sediments. Wing notes that, especially in the case of leaves, the plant materials most likely to be preserved in this way are those from near streams and rivers—areas particularly favored by angiosperms because they do well where erosion and sedimentation frequently disturb the soil.

The suggestion that more conventional sites have inflated the apparent abundance of angiosperms drew a sharp response from paleobotanist Garland Upchurch of Southwest Texas State University. He argued that pollen from other sites shows that by 72 million years ago angiosperms were dominant both north and south of Wyoming. The flora at Big Cedar Ridge, he insisted, was simply a last holdout. Wing conceded he only has one, isolated record, but he thinks evidence from plants preserved in place deserves greater weight. In his view, Big Cedar Ridge is "one more data point than we have from anywhere else."

Getting more such data points is clearly the next order of business if paleobotanists are to settle the timing of angiosperms' rise and home in on a final trigger—whether climate change, asteroid impact, or something else. Wing and Hickey have already found two smaller sites in Wyoming, and Aureal Cross of Michigan State University has discovered a small patch of forest buried in place in New Mexico. All three sites are about the same age as Big Cedar Ridge, and preliminary counts support a continued dominance of gymnosperms. Any further contributions would be much appreciated.

A Half-Billion-Year Head Start For Life on Land

Paul Knauth is out to shake up some preconceptions about when life first appeared on land. "The notion we've always had is that somewhere around 500 million years ago the [higher] land plants got established and then things crawled out of the sea to eat them. The idea was that [before then] the land was just bare rocks," says the Arizona State University isotope geochemist. But in a poster presentation Knauth and microfossil specialist Robert Horodyski of Tulane University presented evidence of life on land long before familiar plants managed to conquer the

ROBERT HORODYSKI

First on land? Minerals outline micrometer-wide tubes that may record blue-green algae.

continents half a billion years ago.

Their findings, from an isotopic analysis of ancient bedrock and from microscopic fossils, "represent the oldest evidence of life on the land surface," says Horodyski. "We're pushing it back 400 million to 500 million years to 1.2 billion years." Knauth adds that the isotopes point to "a massive amount of green stuff on the land." But this was no primordial jungle: The researchers are talking about a slimy coating of cyanobacteria, popularly known as blue-green algae. That's the photosynthesizing stuff that turns damp spots on building stone green and was abundant in the sea as far back as 3.5 billion years ago.

That the land stayed barren for billions of years after the greening of the oceans had long seemed implausible to Knauth: "Some of us were bothered with the story that nothing was happening on the land." So, 7 years ago, he and graduate student Mark Beeunas, who is now at Chevron Oil in New Orleans, began taking a closer look in ancient rocks for a signature of photosynthesizing organisms—their subtle tendency to favor the lighter of the two stable isotopes of carbon as they take up carbon dioxide to form their organic matter. When green plants or cyanobacteria decay, they release some of that lightened carbon as carbon dioxide, which dissolves in ground water. And in the rocks Knauth and Beeunas were examining—the 1.2 billion-year-old Mescal formation of central Arizona—the telltale isotopic signal should have been locked up in the particularly porous underlying rock. The ground water there would have percolated into the underlying limestone, allowing the carbon dioxide to form carbonates that filled in pore spaces and cemented the rock together.

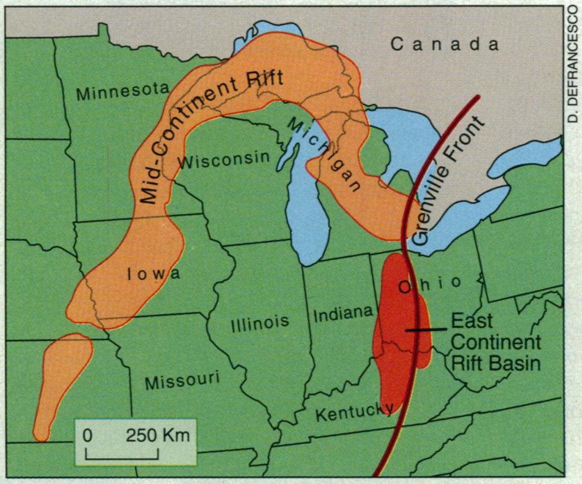
Early analyses of the pore carbonates were suggestive of photosynthesis but "not compelling, even to me," says Knauth. The carbon in the cements was 4 parts per 1000 lighter than the surrounding limestone. But since then he and graduate student Ray Kenny (now at the University of Colorado) have analyzed outcrops of a similar ancient surface in southeastern California that is roughly 700 million to 800 million years old. There the isotopic signature is up to 10 parts per thousand. It is seen all along the ancient surface but is strongest at sinkholes, where the largest volumes of water would have percolated through the rock. "That's an enormous signal," says Knauth. "There's just no way [other than photosynthesis] to do that. I think it's an extremely compelling argument."

Many of the visitors to the poster seemed to agree. And for the doubters, Horodyski had some images of potential culprits. In a microscopic examination of silica from the two sites, he had found tubular microfossils 1 to 2 micrometers thick that look like bacteria. The original organisms lived at or near the surface, say Knauth and Horodyski. And with the big isotopic signal to explain, they think the microfossils are most likely the photosynthesizing cyanobacteria.

A cover of green on the continents a billion years ago would have done more than add a touch of color to an otherwise dreary world. A healthy layer of cyanobacteria would probably have been enough to accelerate weathering of the rock and thus the formation of soils and the release of nutrients. All of which could have softened up the terrestrial environment for its next immigrants from the sea—the true plants. After that, there were only a half-billion years of evolution to go before you could dine on a big, juicy tomato.

A Near-Miss for North America

When geologists from the Ohio Geological Survey began drilling a bore hole about 60 kilometers northeast of Cincinnati in 1987, they weren't expecting any surprises beneath the hundreds of meters of sediments that blanket the state. The Geological Survey drillers simply wanted to confirm the predicted 1-kilometer depth of the sediment cover and retrieve a bit of the granite thought to make up the basement rock. But when they hit a previously unsuspected layer of pink sandstone instead of granite, they opened a new window on a billion-year-old chapter of North American history—a chapter that covers a period when the continent almost split apart.



D. DEFRANCESCO

The big split. A serendipitous discovery beneath Ohio has led to a 600-kilometer extension of an ancient rift.

The discovery, like a missing piece of a puzzle, made sense of a host of under-appreciated data from earlier studies. And at a session on the rifting of continents, the state survey geologists from Ohio, Kentucky, and Indiana described the picture that has emerged: An ancient rift system once thought to peter out north of Ohio actually runs right through the state and into Kentucky. Besides pointing to a narrow escape for ancient North America, the new picture suggests that beneath the sediment blanket spreading across most of the central United States, the bedrock may have many more tales to tell.

The first clue that this particular foray to bedrock was not going as planned came as the 1-kilometer target depth passed without any sign of the layer of granite that is so pervasive in drill holes to the west of Ohio. When the drillers hit sandstone—ancient sediment that had eroded off that granite and collected in some sort of basin—they knew something had gone awry. "We had run out of money and didn't have any idea what we were doing, so we suspended drilling," recalls Douglas Shrake of the Ohio Geological Survey.

But the mystery was too compelling to abandon, so the survey joined ranks with the University of Cincinnati and Wright State University and began probing the strata below the well with seismic waves. As the waves were reflected from deeper formations, they brought back a further surprise, says Shrake. "There was structure beneath the core site," and it bore no resemblance to a layer of granite. Instead, the sedimentary layers continued downward for kilometer after kilometer.

In search of an explanation, geologists at the Ohio Survey banded together with colleagues at the Kentucky Geological Survey and the Indiana Geological Survey to form the Cincinnati Arch Consortium, which then attracted private funding from industry and began amassing existing subsurface data on the surrounding region. Hidden in the data—and not fully appreciated until then—were signs that the newly recognized sedimentary basin extended for hundreds of kilometers. For one thing, 15 of 360 oil and gas wells sunk in the three-state study area had actually penetrated the pink sandstone—though company geologists, perhaps seeing what they expected to see, had pronounced the chips of drilled sandstone to be granite. Subtle variations in Earth's gravity pointed to the same conclusion: A deep, sediment-filled basin lies beneath the region.

Not everybody was startled by the discovery. "We looked on it as a confirmation of our [earlier] hypothesis," says geophysicist G. Randy Keller of the University of Texas, El Paso. In 1983 Keller and geophysicist colleagues had proposed that the great buried rift that 1.2 billion years ago had cracked open 2200 kilometers of the continent from Kansas to Lake Superior and down through Michigan didn't end there, as most researchers thought. Instead, Keller and his colleagues had drawn on gravity data suggesting that dense, iron-rich lavas had erupted to the south of Michigan. The lavas, they proposed, erupted along an eastern extension of the rift that continued another 600 kilometers to the Tennessee border. "It looked like the continent just about broke apart," says Keller.

The three-survey consortium is suggesting that their sedimentary basin is part of the that rift scar. Although other researchers differ on the details, the consortium's history of North America has the continent rifting open 1.2 billion years ago along a great arc from Kansas to Tennessee, quite near what was then the eastern margin of the continent. What drove the rifting is unclear, but some geophysicists think a plume of hot mantle may have been rising below Lake Superior, stretching the continent. In any case, huge eruptions were spewing lavas all along the rift when, almost miraculously, the rifting stopped. North America was saved. Its salvation may have been a squeeze by the approaching Grenville Province, a chunk of continent that shortly thereafter collided with North America east of Ohio.

That may have been an even closer call for North America than the Ohio discovery suggests. At the meeting Donald Adams of the University of Texas, El Paso, and Keller suggested that the western arm of the rift may have extended well beyond Kansas into New Mexico. Thank goodness for colliding continents.

–Richard A. Kerr

CELL BIOLOGY

A New Kind of Organic Gardening

Biophysicist David Stenger of the Naval Research Laboratory (NRL) has developed a passion for precision gardening. Don't expect any prize tomatoes from his plots, though; what he and his colleagues grow are cells, and their gardens are culture dishes. By combining clever surface chemistry with fabrication techniques adapted from the microelectronics industry, they lay out patterns of molecular soil that encourage cells to take root and grow only in certain places. Other researchers had demonstrated the possibility in the late 1980s, but last month Stenger and his collaborators reported a new level of precision: They can now coax cells to grow in molecular flower beds of almost arbitrarily fine geometries.

Stenger, chemist James Hickman of Science Applications International Corp., and their co-workers aren't just imposing order for its own sake. By regimenting cells in precise networks, they and others hope to create a range of devices for basic science and technology. As a means of spreading out neurons so that their behavior and interactions can be more precisely monitored, the networks promise to serve as test beds for neuroscience and perhaps as sensitive detectors of chemical and biological warfare agents. And by mimicking the organized growth patterns of capillaries in the body, these artificial arrangements of cells could also play a role in medicine—as a kind of vascularized cellular gauze for wound repair.

The inspiration is biology's own artful cellular organization. During development, for example, cell adhesion molecules act like lighted aisles, directing migrating cells to their proper locations. Scientists had already known they could roughly control the wanderings of cultured cells by patterning surfaces with substances such as polylysine and fibronectin, which interact with molecules on the cells' surfaces. But David Kleinfeld of AT&T and two colleagues get credit for showing in 1988 that finer control could be achieved by enlisting the photolithographic techniques of microelectronics to create intricate patterns of cell-attracting and cell-shunning molecules.

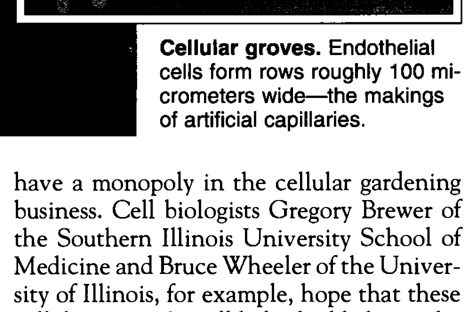
Kleinfeld's original technique included multiple steps, but in the 26 April 1991 *Science*, Stenger and collaborators from the NRL and other institutions presented what they hoped was a simpler strategy. In their method, ultraviolet light shines through a stencil-like mask onto films of organosilane—a compound to which cells will not stick. The light, however, chemically alters the exposed regions, and a subsequent chemical step converts them into a hydrophilic, and thus cell-friendly, form. The result, as Stenger, Hickman, and co-workers now report in the 21 October *Journal of the American Chemical Society*, is "precise geometric control of the adhesion and growth of mammalian neural and endothelial cells." In one striking demonstration, the workers laid down cell-friendly molecules in a pattern reminiscent of minute chicken wire, then watched rat hippocampal cells stitch themselves to the nodes of the mesh and grow neural projections along its strands.

Such feats have been turning heads. In January, for example, the Marine Corps began funding Stenger and colleagues in a project to test the potential of patterned neuroblastoma cells, which react to a menagerie of toxins, as sensing elements for chemical and biological warfare agents. Tiny electrodes or other detectors arrayed directly underneath the cells would register toxin-related changes in cell behavior. Meanwhile, the Office of Naval Research is supporting Stenger's group to study the computer-like features of single neurons, which can integrate and process many inputs. And groups at NRL and Cornell University are working with Stenger's team to develop ways of preforming endothelial cells into networks of artificial capillaries. One goal is to lace these networks of ersatz blood vessels into biodegradable polymers to form a prevascularized, skin-like material for treating burns and other serious wounds.

Stenger and his many collaborators don't have a monopoly in the cellular gardening business. Cell biologists Gregory Brewer of the Southern Illinois University School of Medicine and Bruce Wheeler of the University of Illinois, for example, hope that these cellular networks will help shed light on the behavior of small sets of neurons. Scientists already have tools such as EEG recorders for monitoring whole brain activity and microelectrodes for eavesdropping on single neurons, Brewer says. But by growing networks of neurons, he adds, "we can now work between these levels [of brain structure]."

Cellular gardening, it would seem, promises some bountiful harvests.

–Ivan Amato

BARRY SPARGO

Cellular groves. Endothelial cells form rows roughly 100 micrometers wide—the makings of artificial capillaries.