EVOLUTIONARY BIOLOGY

Animal Oddballs Brought Into the Ancestral Fold?

Life can take on odd forms, as any *National Geographic* program illustrates. But the oddest animals of all go back in time—way back. These are the Ediacara, frond- or disc-shaped blobs of living matter that inhabited Earth millions of years before the Cambrian Period, more than 540 million years ago. So strange are these creatures—a few ranged up to a meter in size but lacked an obvious mouth or anus—that their very nature remains in dispute 50 years after their discovery. Some paleontologists think that the Ediacara may be a part of the evolutionary path leading to later animal life. Others argue that they couldn't be: They believe the strange creatures were just a failed experiment in how to make an animal that ended before the Cambrian Period's explosion of evolutionary innovation—which created the basic animal shapes we see today—even got started. But now, excluding the Ediacara from the evolutionary chain of animal life has just gotten harder.

On page 598 of this issue of *Science*, geologist John Grotzinger and geochronologist Samuel Bowring of the Massachusetts Institute of Technology (MIT) and their colleagues describe new evidence indicating that instead of disappearing tens of millions of years before the Cambrian explosion, the Ediacara persisted at least up to the beginning of the Cambrian, if not into it. If so, they were around during the early stages of the Cambrian explosion and may have contributed to it. This conclusion, which is based on the researchers' dating of tiny mineral grains from volcanic ash layers interspersed among the Ediacaran fossils, is already winning plaudits from paleontologists. "If Grotzinger and company are correct, that's excellent news," says Cambrian paleontologist Simon Conway Morris of the University of Cambridge, in the United Kingdom. "It's not easy to trace simple connections between the Ediacaran and Cambrian fossils, yet if they are effectively cheek by jowl, then it's got to focus our attention on a proper understanding of the Ediacaran fossils."

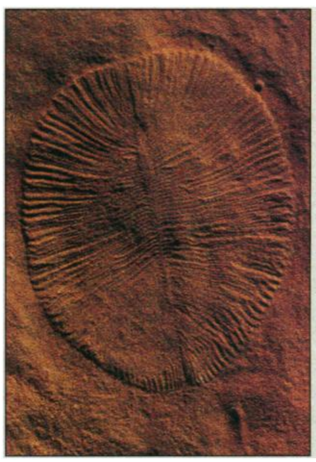
Paleontologists have been trying to understand the Ediacaran fossils since they were first found in the Ediacara Hills of southern Australia in 1946. The flat, often quilted-looking fossils have been called almost every name in the book. Because the fossils show no obvious signs of characteristic features of higher animals, such as circulatory and digestive systems, Adolf Seilacher of Tübingen University in Germany has argued that the Ediacara were enormous single cells. That would warrant their classification into a kingdom of their own, a kingdom that died out when the Ediacara fossils disappeared from the geologic record, apparently well before the Cambrian.


BEVERLY Z. SAYLOR / MIT

Ediacaran heaven. Southern Namibia's rugged terrain has proven an ideal place to search for animals' early ancestors.

Paleontologist Gregory Retallack of the University of Oregon agrees that Ediacarans weren't animals, but he thinks they were primitive lichens—symbiotic combinations of algae and fungi. Examining some Ediacaran fossils, Retallack concludes that the original organism resisted compression after burial about as well as sturdy tree ferns, making the Ediacara far tougher and less compressible than the jellyfish and worms they have been compared to. Lichens would meet that standard of toughness as well as feed themselves without circulatory or digestive systems.

Then there are the traditionalists, such as Conway Morris. They argue that many, although not necessarily all, of the Ediacara fossils strongly resemble animals that follow, such as corals, jellyfish, segmented worms, and arthropods. This is evidence, they believe, that Ediacara gave rise to at least some of the animals seen today. But their line of reasoning had a big a hole in it: "A consensus had begun to emerge," says Conway Morris, "that there's some sort of gap" between the last of the Ediacara and the first of the Cambrian animals. The youngest Ediacaran fossils ever found still seemed older than the oldest Cambrian fossils. There was even talk of their dying out in a Precambrian mass extinction.


BRUCE RUNNEGAR/UCLA

A dead end? Was this Ediacaran any animal's ancestor?

Enter Grotzinger, Bowring, geologist Beverly Saylor of MIT, and geochemist Jay Kaufman of Harvard University. To get a fix on when the Ediacara died out, they went to rock outcrops in southern Namibia that hold a rich load of Ediacaran fossils. Linking those or any other Ediacaran fossils found around the world to fossils in Cambrian rocks has been difficult because any one outcrop exposes only a short segment of the late Precambrian and Cambrian record. So, to determine whether a particular rock layer's fossils are younger or older than another's, researchers had to try to tie together outcrops that are many kilometers—even thousands of kilometers—apart. Such relative dating has recently hinted that the Ediacara approached or even overlapped the Cambrian fauna. But the relative dates cannot approach the reassuring directness of absolute dates, and that is what the new work provides.

Geochronologist Bowring determined the absolute age of beds of volcanic ash by measuring the amount of lead produced in zircon mineral grains through the radioactive decay of uranium. The uranium-lead method has been refined in recent years to the point that even rocks a half-billion years old can be dated with a precision of a million years or less. And when the MIT team applied the method to the Namibian rocks, they uncovered several surprises.

The period of highest Ediacaran diversity lasted not tens of millions of years, as previously estimated, but just 6 million years. And that 6 million years carried the Ediacara right up to the Precambrian-Cambrian boundary in southern Namibia. The youngest Ediacaran fossils found there were laid down just after an ash bed dated at 543.3 ± 1 million years ago; Bowring had already dated the Precambrian-Cambrian boundary in Siberia at 543.9 million years in the course of squeezing the Cambrian explosion down to less than 8 million years (*Science*, 3 September 1993, p. 1274).

As an added bonus, the dates on the four ash beds that span the 6 million years of high Ediacaran diversity came out in the same chronological order as predicted by the geological ordering of the beds. That supports both the geological analysis and the accuracy of the dating, says Bowring. "It used to be that plus or minus 5 million years was great. Now the question is: Can we split hairs at the 200,000- or 300,000-year level?" Bowring intends to find out by dating more ash beds in Namibia.

The new high-precision dating argues against a gap that would keep the Ediacara from contributing to animal evolution in the Cambrian, but Grotzinger and his colleagues concede that their new dating does not rule out most of the proposed scenarios. The Ediacara could have continued to evolve into more familiar animals; they could have perished at or very near the boundary and not contributed anything to later evolution; or they could have been a sister group of the Cambrian animals, as Seilacher is now suggesting, sharing a common ancestor that was not preserved in the fossil record. The MIT-Harvard group's discovery of Ediacaran fossils in some of the youngest strata in southern Namibia, younger than any Ediacarans known elsewhere, is a reminder of how spotty the ancient fossil record can be. More fossil collection is needed to resolve the Ediacarans' role, paleontologists say. Namibia, they add, looks like a good place to start.

–Richard A. Kerr

NEUROBIOLOGY

New Clue to Brain Wiring Mystery

The most complicated wiring task in the world occurs right inside our heads. During brain development, many billions of neurons must make precisely the right connections for our brains to work as they should. Developmental neurobiologists have learned in recent years that both the electrical activity of neurons and the presence of neuron-nurturing proteins called neurotrophic factors appear to be key to the final sculpting of neural connections. But they have not been able to figure out just what characteristics allow neurons to respond to those nurturing proteins.

Now, in a paper in the October issue of *Neuron*, Barbara Barres and her colleagues at Stanford University School of Medicine provide a clue. In their studies of the survival of neurons in culture dishes, they discovered that pure preparations of neurons from rats' eyes must be in an activated state to be susceptible to the neurotrophic factors' effects.

The paper provides a "missing link," by connecting neural activity and neurotrophic factors, says Washington University neurobiologist William Snider. "It is a striking result," adds developmental neurobiologist Carla Shatz, of the University of California (UC), Berkeley, whose own work has implicated neurotrophic factors in the activity-dependent wiring of the visual cortex. The revelation that active neurons respond better to neurotrophic factors, she says, "may help interpret a lot of [other] results."

Barres's team was not directly addressing the problem of brain wiring, but rather was trying to determine the best conditions for growing cultures of purified retinal ganglion neurons, which in the developing embryo send their axons from the retina of the eye along the optic nerve to the brain. Central nervous system neurons such as these are notorious for dying when they are maintained in culture for any length of time, and sure enough, the retinal neurons died even though the researchers fed them an elaborate cocktail of trophic factors that they would be expected to encounter en route to the brain.

They tried stimulating the neurons, because other groups had shown that electrically activated nerve cells are more likely to survive in culture. That alone didn't do the trick, but when the researchers combined activation and trophic factors, the neurons at last survived. Apparently, activity raised levels of the intracellular signaling molecule, cyclic AMP, and that somehow enabled the neurons to respond to the trophic factors. Earlier studies had suggested activity may play such a role, but Barres is the first to verify it with pure cultures of neurons.

That finding caught the interest of developmental neurobiologists who study the remodeling that occurs during brain development. Developing neurons in the brain first make somewhat imprecise links with other neurons that must later be rearranged to create the specific wiring patterns needed for the brain to carry out its numerous functions. In the past decade, work from many research teams has shown that neurons whose electrical signals arrive simultaneously at a spot in the brain will add more connections in that area, while neurons that are inactive when others in the area are active tend to lose the connections they've already made. And in the past year, several groups have shown that neurotrophic factors may also play a role in this activity-dependent remodeling (see Article by Hans Thoenen on p. 593).

B. BARRES/NEURON

Survivor. Retinal ganglion neurons, such as this one, can live in culture when appropriately stimulated.

Now the Barres team has shown—at least in the culture dish—that it is the electrical activity itself that is the key to the selective effect of the neurotrophic factors. And these findings "fit together as a nice story" with another neuron culture study published last year, says UC San Francisco developmental neurobiologist Michael Stryker. In that study, Harvard University neurobiologist Michael Greenberg and postdoc Anirvan Ghosh showed that cultured neurons from the cerebral cortex of embryonic rats produce more of the neurotrophic factor BDNF when they are electrically active, and that the BDNF in turn enhances the cells' survival in culture (*Science*, 18 March 1994, p. 1618). But, says Ghosh, who's now at Johns Hopkins University, when the researchers simply added BDNF to the cultured neurons without stimulating them, it did little to help the neurons survive. Barres's work suggests that "not only did the cell need the BDNF it was making," says Ghosh, "but it actually needed to be in the [activated] state" to respond to the BDNF.

Together those papers suggest a model, says Stryker, in which a neuron receiving a signal produces more neurotrophic factor, and that factor in turn has a growth-promoting effect on nearby neural connections that are active at the same time.

While intrigued by the Barres paper, many neurobiologists caution that going from studies of neuron survival in a culture dish to predictions about synapse formation in a developing brain is a major conceptual leap that may not be justified by the Barres results alone. But despite his caution, Larry Katz of Duke University says his "gut feeling" is that the hypothesis will turn out to be right. Indeed, preliminary work, which will be presented next month at the annual meeting of the Society for Neuroscience by members of his lab and that of his Duke colleague Don Lo, shows that blocking the activity of neurons in slices of rat cerebral cortex blocks the growth-inducing effects of neurotrophic factors on those neurons. And that is just one of many related findings that are in the works in a number of labs, says Katz.

If these upcoming results continue to support the conceptual leap from the culture dish to the developing brain, researchers will be a bit closer to understanding how nature has solved the toughest wiring problem around.

–Marcia Barinaga