

Creationist Funhouse, Episode 7

Lynn Margulis and the Great Convergence That Didn't Happen

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When I was a sophomore at the University of California, Santa Barbara, in 1977, I was excited to attend my first real science seminar. I was on my way to hear Lynn Margulis, one of the greatest biological thinkers of modern times. First, I ran into the wrong room and sat down, only to realize that it was a psychology class, and I had to run back out. By the time I got to the lecture hall where hundreds of people had come to hear Margulis, the only place to sit was on the floor.

After one of the professors gave her an off-color introduction, Margulis proceeded to tell us all about undulipodia. Perhaps you've never heard of undulipodia. They are the cilia (motile hairs) and flagella (motile whips) of complex eukaryotic cells. (Eukaryotic cells have nuclei in which they store their DNA.) These are the hairs and whips that allow complex single cells to swim around and that allow the cells of your respiratory passages to keep themselves clean by shoving bits of goop back out so that you can cough them away. In all four of the kingdoms that have eukaryotic cells, cilia and flagella have the same structure: a ring of nine pairs of motile fibers around a central pair. This implies they had a single evolutionary origin. But what was that origin?

Margulis tried to convince all of us—professors, postdocs, graduate students, and undergrads—that undulipodia had evolved from spirochete bacteria. She had some nice photographic evidence. For example, a kind of single-celled eukaryote, *Mixotricha paradoxa*, appears to have a lot of cilia emerging from its membranes, allowing it to swim. Only they aren't cilia; they are spirochetes that have embedded themselves in the host cell membranes. If spirochetes can look and act so much like cilia, maybe cilia evolved from spirochetes. Margulis never succeeded in convincing the scientific world of this hypothesis. When I met with her in 2006, as I gathered information for my *Encyclopedia of Evolution*, she was still trying to convince everyone, including me. She died, perhaps disappointed in her quixotic quest, in 2011.

Disappointment is not what Margulis should have felt, and perhaps she didn't. This was because, quite possibly, only Charles Darwin provoked more of a shift in scientific thinking than Margulis did.

Margulis's breakthrough paper was "On the Origin of

Mitosing Cells," published in 1967 in the *Journal of Theoretical Biology* after over twenty rejections from other journals. In this paper, she claimed that mitochondria (the complex cellular structures that consume sugar and produce chemical energy) and chloroplasts (the complex green structures in plant cells that make all the food in the world through photosynthesis) did *not* evolve by gradual evolution from simpler structures. She said that mitochondria and chloroplasts were both the *evolutionary descendants of bacteria*: mitochondria from respiring bacteria, and chloroplasts from photosynthetic bacteria. What this means is that the evolution of mitochondria and chloroplasts was not a gradual *increase* in complexity but instead was *sudden* and involved *simplification*.

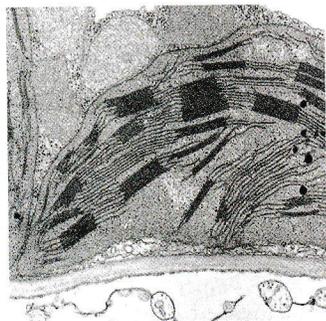
Both mitochondria and chloroplasts are much simpler in structure than the bacteria that Margulis said they evolved from. This means that the bacteria invaded a larger, complex cell and stayed there. They then evolved into simpler—not more complex—forms. Today, mitochondria and chloroplasts



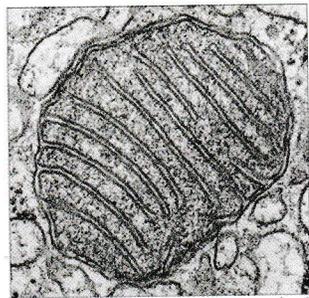
Lynn Margulis (Photo by Boston University Photography)

have degenerated so much that they cannot live outside of cells except under very careful laboratory conditions.

Here is the scenario: Bacteria moved into the host cell. At this point, three outcomes are conceivable. The host cell could have digested the bacteria, or the bacteria could have eaten the host cell from the inside. The third possibility is that the invaders and the host reached a stable balance of mutual benefit. The host cell provided sugar, and the respiring bacteria consumed it, providing cellular energy to the host. The host cell provided carbon dioxide and mineral nutrients, and the photosynthetic bacteria consumed them, providing sugar in return. They formed stable, mutualistic partnerships. From that point, the bacteria and cyanobacteria lived in a simple environment inside the host cells and had all their needs taken care of. They lost the complexity that they needed to survive by themselves in the outside world. This is the *endosymbiotic* theory: *endo* for “inside” and *symbiotic* for “life together,” or mutual cooperation between species. *Symbiogenesis* means the origin (genesis) of new life forms through symbiotic merger.



Transmission electron micrograph of a chloroplast



Transmission electron micrograph of a mitochondrion

Today's eukaryotic cells are therefore the products of two of the most successful mergers in the history of the planet. You can think of it this way: The main function of a leaf is to keep its chloroplasts safe and happy so that they can make food through photosynthesis. Chloroplasts need to be kept wet and cool, something that would be impossible for them on dry land. The main function of the stems and roots is to provide water and minerals to the leaves, to feed the chloroplasts and to keep them cool. Viewed in this way, a whole tree exists just to keep the chloroplasts happy. The fact that most of the land surface of the earth is green is evidence of the striking success of this symbiotic partnership. Earth, seen from outer space, is a green planet because of symbiogenesis. Photosynthesis also produces almost all the oxygen in the air. Take a deep breath and thank a plant that you are alive—and thank the process of symbiogenesis.

Before Margulis, almost every scientist, except a few obscure researchers in Russia and the United States, believed a naive version of evolution: that everything started simple and evolved, a bit at a time, into greater complexity. This was undoubtedly one of the reasons there was so much initial resistance to Margulis's endosymbiotic theory. There was also a

little bit, or perhaps more than a little bit, of sexist resistance. There were and are many women in science, but at the time women played more of a supporting role while men were the thinkers and leaders, the movers and shakers. Think of Watson and Crick getting almost deified for their discovery of the structure of DNA in 1953, while Rosalind Franklin died in relative obscurity soon thereafter. As often happens in science, there was a quick transition straight from “This is crazy” to “Everybody has always known this” regarding Margulis's theory.

Margulis explained the origin of eukaryotic cells in terms of the serial endosymbiotic theory. First, the eukaryotic cell nucleus evolved as a result of a merger between two microbes. Some kind of small microbe—maybe an archaean, maybe a mimivirus, nobody knows—moved into a larger microbe and became the nucleus. Second came the undulipodia. Third, the mitochondria. These things happened in the ancestors of all eukaryotic cells and organisms. Fourth and finally, in the ancestors of some of the eukaryotic cells and organisms, photosynthetic bacteria moved in and became chloroplasts of modern plant cells. And there it is: life on earth in all its dizzying and astonishing complexity.

Margulis saw this story as being typical of the way life works. Instead of “survival of the fittest,” with organisms striving against one another for the greatest fitness, organisms often (perhaps usually) cooperate with one another, and in the process the two cooperators both achieve greater success than either would alone. She thought that many scientists, even though they grudgingly admitted she was right about mitochondria and chloroplasts, believed her story was the exception rather than the rule. But she looked around and saw symbiogenesis everywhere. She was especially enthusiastic about James Lovelock's Gaia hypothesis, in which the earth as a whole kept itself in balance rather than being the arena in which all of its species fight one another.

Many of us have caught Margulis's spirit of excitement about this view of life. The earth is alive, not just the third rock from the Sun that happens to have life. There is nothing mystical involved here—Margulis made sure I understood that Gaia was not a goddess. Even though many mystics have embraced the Gaia view, the spiritual form of the Gaia hypothesis has been rightly skewered in the pages of books and magazines such as this one. I wrote more about this in my book *Life of Earth: Portrait of a Beautiful, Middle-Aged, Stressed-Out World*, a book that Margulis particularly liked. *Life of earth, not life on earth.*

The interconnections of life, the basis of Gaia theory, might be the reason that conditions on earth are relatively stable. For example, the billions of tons of leaves remove carbon dioxide from the air, preventing (at least until recently) a massive greenhouse effect. Back during the Precambrian time, before the earth was covered with plants, it lurched back and forth between extreme heat and extreme cold. But ever since plants started covering the land about 400 million years ago, photosynthesis partially stabilized the climate. The symbiogenetic origin of chloroplasts allowed plants to evolve and

eventually cover the land and stabilize the earth.

But here is the point: Creationists don't believe that this symbiotic convergence ever happened. They believe that God made the eukaryotic cells and organisms all at once about 6,000 years ago, the same time he made bacteria. As a result, creationists miss the whole point of what makes this view exciting: the symbiogenetic view reveals an earth in which cooperation between species leads to continual evolutionary renewal.

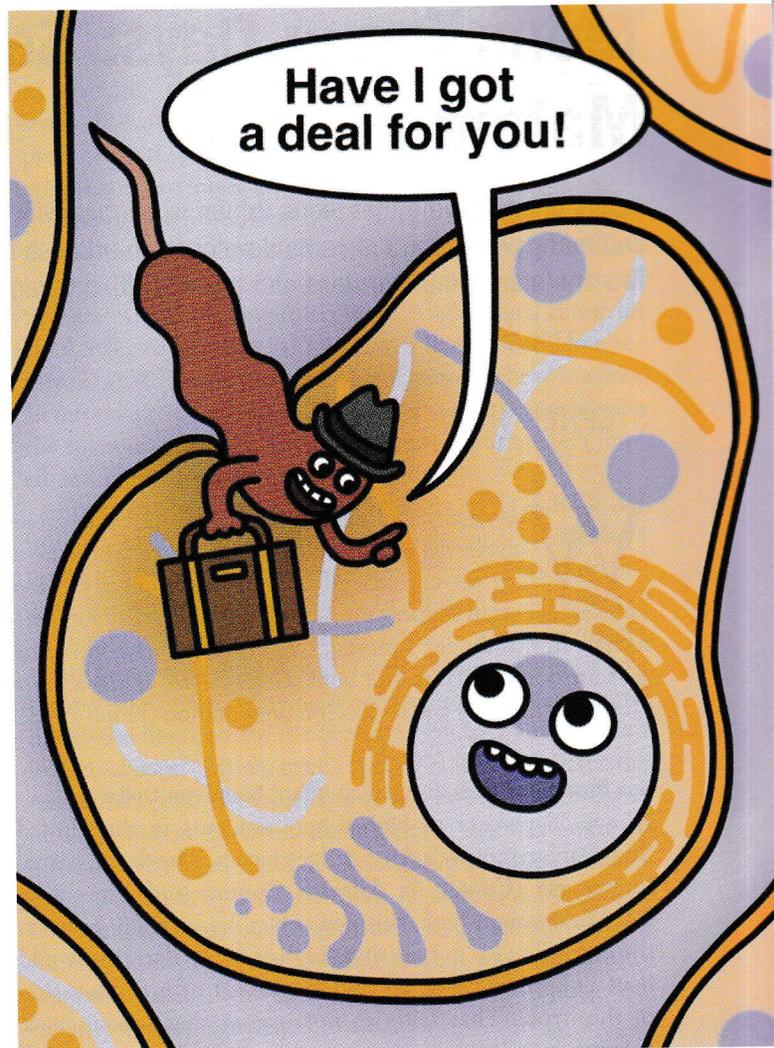
Not only that, but creationists believe that God planted many deceptive pieces of evidence that falsely suggest that symbiogenesis occurred. Mitochondria and chloroplasts *have their own DNA* and even their own machinery for using it. These are relics of their bacterial ancestry. Their DNA resembles circular bacterial DNA, not the linear DNA of eukaryotic chromosomes. Did God make mitochondria and chloroplasts look like *they used to be bacteria* even though they did not?

Perhaps most intriguingly, some eukaryotic cells have very complex chloroplasts. In most cells, chloroplasts are the evolutionary descendants of photosynthetic bacteria; they are cells inside of cells. But some green and red algae have chloroplasts that evolved not from bacteria but *from other algae*. That is, they are cells inside of cells inside of cells. They have extra membranes not found in ordinary chloroplasts. Some of them even have little degenerate nuclei. Did God make these algae look like they were the products of *two* symbiogenetic mergers, when in fact not even one had occurred?

Symbiogenetic mergers might be happening all around us, and we just don't see them. One scientist, Kwang Jeon at the University of Tennessee, studied amoebas and was set to finish his obscure career as an amoeba expert. Then one day a bacterial disease broke out in his cultures. *There goes my career*, he might have thought. But he found that some of the amoebas survived—with bacteria living inside of them. These bacteria-filled amoebas died if they were treated with an antibiotic that killed the bacteria. It appeared that, right in his lab, a symbiogenetic merger had happened in which the amoebas and bacteria had reached a balance and required one another for their very survival. A couple decades later, one kind of eukaryotic single-celled algae was observed moving into another, and it stayed there. Scientist Noriko Okamoto caught it on film.

Symbiogenesis might make you never view a forest the same way again. When you look at a forest, you see trees. The trees each appear to be individuals all struggling against one another for light, water, and minerals. But biologists have discovered that many of the tree roots are connected; in particular, the symbiotic fungi within the tree roots connect one tree with another. This may even allow the trees to communicate and coordinate with one another, according to botanist Peter Wohlleben and fungus expert Paul Stamets. I've closely observed trees all my life, but I now have a whole new view of forests.

This exciting view of evolution is one that creationists cannot allow themselves to believe. It is one for which they cannot praise God. They believe that the world is running



Cartoon by Loraine Thompson

down and has no hope unless God rescues it—which he won't—which means that God planted fake evidence of symbiogenesis in all species. It sounds like they want us, despite all the evidence, to see the natural world as damned and fallen.

The symbiogenetic view is one that would eventually have been discovered anyway, just as Wallace would have revealed natural selection even if Darwin were never born. But we owe a lot to the brilliance and perseverance of Lynn Margulis. One of her early supervisors described her as being the only staff member at Boston University who was paid half time and worked time and a half. She never gave up. ■



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