by Michael Matz

Where Did the OXYGEN You Breathe Come From?

An exhibit in our *Traits of Life* collection offers clues

Exhibits you see at the Exploratorium are fun and fascinating. But did you know that they're also rooted in current trends in science? Consider *Traits of Life*, our exhibit collection of 30 stand-alone exhibits celebrating the wonder and mystery of life.

"There is currently a great deal of discussion among biologists over what fundamental traits define a living thing," says Charles Carlson, director of life sciences and one of the principal investigators on the project. "Scientists are asking the question, 'What is life?'" According to Carlson, this debate in biology inspired museum staff, who ultimately designed *Traits of Life* as an exhibit collection exploring the elemental traits shared by all living organisms.

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While considering this central biological question, you can also delve into other contemporary scientific issues at individual exhibits in the collection. In one exhibit, called Living Color, several large Plexiglas tanks are filled with colorful microorganisms, including microbes called cyanobacteria. Though you may never have heard of cyanobacteria before, you probably wouldn't exist without them. Many researchers believe that about 3 billion years ago, cyanobacteria's ancestors introduced oxygen gas into the earth's atmosphere, paving the way for oxygen-breathing organisms such as yourself.

As you approach Living Color, you'll see tall, thin tanks filled with a strange, slimy-looking material separated into intricately arranged green, brown, purple, and red layers. Each color is a different species of bacteria, which colonize specific areas of mud in the tanks by the billions. The cyanobacteria are green.

Early life likely existed independent of light in high-temperature hydrothermal environments, using sulfur compounds to sustain them. This sulfur-based biochemistry produced hydrogen sulfide as waste. At that time, scientists believe, the atmosphere contained mostly carbon dioxide, along with hydrogen sulfide, ammonia, nitrogen, and water vapor. Because oxygen is highly reactive—that is, it combines easily with other elements to form compounds—little or no free oxygen existed in the atmosphere. While humans and other oxygen-dependent organisms would die in this atmosphere, ancient microorganisms thrived in it. In fact, oxygen was toxic to them. Many microorganisms today retain the metabolic chemistry of their primitive forebears, living in sulfur-rich hot springs and thermal ocean vents, and shunning oxygen.

But when cyanobacteria first appeared in the oceans, some 2.5 to 3.4 billion years ago, they started using an oxygen-based compound—water—to make what they needed to survive. Taking advantage of sunlight, carbon dioxide, and the water they lived in, cyanobacteria were likely the first living things to use photosynthesis—a chemical reaction using light, water, and carbon dioxide—to make food. Photosynthesis, unlike the sulfur-based chemical reactions, produces oxygen as waste. As cyanobacteria continued to grow and multiply, they eventually produced enough free oxygen to change the earth's atmosphere. Today, all green plants depend on photosynthesis to live and grow.

Exactly how cyanobacteria's oxygen output changed earth's atmosphere is unclear. Some scientists believe that the oxygen first combined with iron dissolved in the oceanwater to form massive reddish iron-oxide sediments, called "banded iron formations." According to this theory, once the oxygen-iron reactions exhausted the supply of dissolved iron—a process that may have taken several hundred million years—oxygen gas saturated the oceans, and then leaked into the atmosphere.

Other evidence suggests that these cyanobacterial oxygen-iron reactions did not occur, and that cyanobacteria pumped oxygen into the atmosphere relatively quickly. However oxygen came to permeate the earth's atmosphere, once there, it set the stage for an ecological revolution. Many species went extinct because oxygen was poisonous to them. Species that lived in mud, sediments, and other habitats without oxygen survived. Still others evolved the biochemical machinery to adapt to oxygen. As oxygen concentrations increased, some oxygen converted to ozone, which eventually formed an ozone layer in the upper atmosphere and shielded the earth's surface from ultraviolet sunlight.

Perhaps the most significant evolutionary outcome of atmospheric oxygen was the appearance of new organisms that used oxygen to extract energy from food. Such organisms needed oxygen for their metabolism and survival. Over the next several billion years, these primordial one-celled oxygen-dependent organisms, protected from the damaging effects of UV radiation, evolved into all the multicellular life we know today (along with untold numbers of others that have gone extinct).

It's impossible to say what life would be like today if cyanobacteria never existed, but it's safe to say these tiny green creatures forever changed the nature of life on earth. ■

Background image of *Microcystis aeruginosa* courtesy of John Patchett (University of Warwick), Mark Schneegurt (Wichita State University), and Cyanosite (www-cyanosite.bio.purdue.edu)

TRY THIS!

by Fred Stein

With just mud, paper, and an egg, you can create your own version of Living Color by growing colonies of multihued microbes!

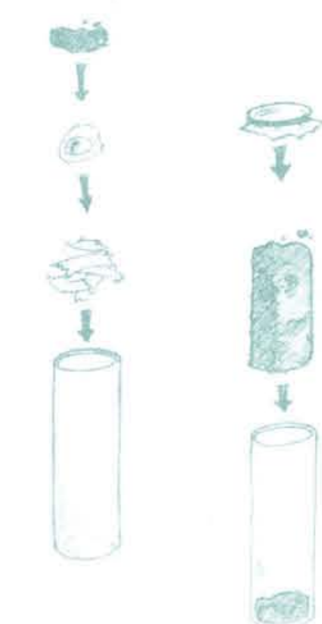
In the 1880s, Russian microbiologist Sergei Winogradsky discovered that watery mud poured into a tall bottle and placed in the sun turned many different colors. He also found that by adding a few simple things, such as cheese or paper, he could control which colors appeared. Here's a recipe for making your own Winogradsky column.

Materials

- Mud from a bay shore or the edge of a shallow pond (the smellier the better)
- Bowl
- Water
- Spoon
- A clear tennis-ball container or plastic soda bottle with the top cut off
- 1/4 newspaper page shredded
- 1 raw egg (without shell)
- Lid, or plastic wrap and a rubber band
- Lamp with a 40-watt incandescent bulb

To Do and Notice

Remove any rocks or sticks from the mud, and put the mud in the bowl. Mix it with water until it's the consistency of heavy cream.



Remove the label from your container. Put in the shredded paper and egg, add an inch of mud, and mix well. Then, fill the container with mud up to an inch from the top and cover it. Wash your hands after you complete the setup.

Put the container about a foot from a 40-watt bulb that you can leave on all the time. Every few days, briefly remove the container's top to vent off gases. (If too much gas is allowed to build up, it can blow the top off.) If the mud at the top is drying out, add a little water. In a few weeks, you'll see areas of brilliantly colored bacteria. Keep watching, and you'll see the colors develop and change during the next several months.

What's Going On?

Many kinds of bacteria live in mud. Some are decomposers that get nutrients by breaking down organic materials—like the egg and paper. During the process of decomposition, all the oxygen near the bottom of the container is used up.

Other bacteria are photosynthetic. Blue-green bacteria near the top of the mud column use light, carbon from carbon dioxide, and hydrogen from water to make carbohydrates, and give off oxygen—just like plants. The carbon dioxide they need is released when the decomposers break down the paper and egg.

Red, orange, and green bacteria that grow near the bottom of the column are less tolerant—or completely intolerant—of oxygen. They're photosynthetic, but they get their hydrogen from hydrogen sulfide, the gas that smells like rotten eggs. In your container, hydrogen sulfide is released when the decomposers break down the protein in the egg.

Your mud already contained some of each of these kinds of bacteria when you collected it. Since you provided the bacteria with ideal growing conditions, their populations exploded. ■

Where in the World Are Our Exhibitions?

Several Exploratorium traveling exhibitions are on the move, rented by other institutions. Here's where you'll find some of our most popular exhibitions. If you're in the neighborhood, be sure to stop by!

Memory
Science Spectrum, Lubbock, TX
(through August 17, 2003)

Turbulent Landscapes
Noorderdierenpark, Emmen, Holland (near Amsterdam)
(until March 30, 2005)