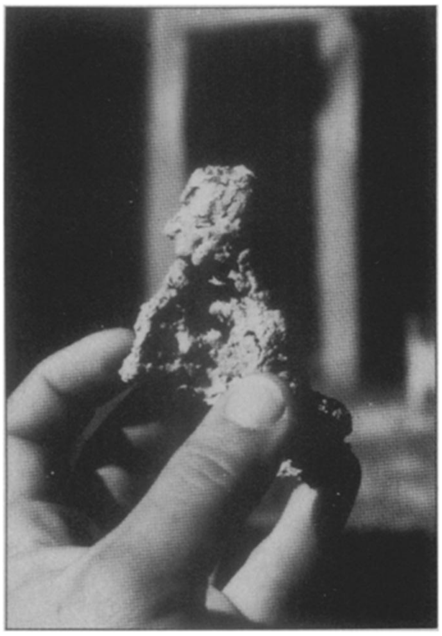
Living Fossils

By CHERYL SIMON

In frigid Antarctic lakes, microbial mats and modern stromatolites offer a glimpse into Precambrian ecosystems



Gordon Love, VPI

Wedged between the Ross Sea and the ice-covered Trans-Antarctic Mountains, the Dry Valleys span a thousand square miles of barren Antarctic landscape. The unearthly vista presented by the terrain seems an unlikely host for even the most primordial forms of life. But lichens have established a cozy dwelling inside rocks in this polar desert, and scientists find that the bottoms of Dry Valley lakes are rife with teeming microbial communities, living much as their predecessors may have 600 million years ago.

The presence of blue-green algae, or cyanobacteria, in Antarctica has long been known from water samples taken at the lakes' edges. In the last few years though, scientists from the Virginia Polytechnic Institute (VPI) and State University in Blacksburg melted holes through the perennial ice that covers Lakes Bonney, Fryxell, Hoare and Vanda. Divers lowered into the icy waters found that lush carpets of microbes mat the lake floors (SN: 7/28/79, p. 71), and in Lake Fryxell last year, observed biogenic structures called stromatolites. The presence of these features can be attributed primarily to the activity of blue-green algae, the microscopic life form that pervades the lakes. The stromatolites, which usually occur in shallow, hypersaline waters, are the first discovered in deep, cold waters. The structures are described in the Feb. 4 NATURE and in BIOSCIENCE, Vol. 31, No. 9.

Stromatolites are fossilized remnants of ancient microbial mats. In the Antarctic lakes, blue-green filamentous algae, *Phormidium frigidum,* precipitate calcium carbonate and then trap and bind sediments, including diatoms, that settle onto the mat. Diatoms are microscopic, single-celled aquatic plants. As the microbial activity continues, the mats grow through the coating of sediments. Over time, the layers of laminations become lithified into domed rocks or columns a few inches wide. A cross section shows thin horizontal layers — alternating sequences of mat and sediments that may be preserved for the geologic record.

Boston University biologist Lynn Margulis, during a session on "The Planet Earth" at the January meeting of the American Association for the Advancement of Science, described microbial mats as seen through an electron microscope: "... the microorganisms are packed elbow-to-elbow. If we section through one of these mats, we find alternating layers of sediment and organic [matter] where the organic layer is produced by these filamentous blue-greens. On a level of just a few millimeters, you have a completely well-developed and well-defined community just the way you have in an Amazon forest—but on the meter scale."

Photosynthetic, oxygen-producing bacteria played a critical role on earth starting more than 3.5 billion years ago when life was beginning to grip and shape the planet's surface. These tiny bits of life exerted tremendous influence on both the deposition of sediments and the production and fixing of gases, including oxygen, in the early atmosphere. Scientists studying early earth history think that microbial mats may provide an analog for the earliest ecosystems. Stromatolites, in fact, offer the fossil record some of its oldest traces of life. Bacterium-like filaments found in rocks 3.5 billion years old are known from Western Australia, while stromatolites of similar age from southern Africa suggest that bacterial communities were common as soon as 1.5 billion years after the earth was formed. For as long as 3 billion years, bacteria were the dominant form of life on earth. Only in the last 600 million years, when higher organisms evolved to graze and disrupt the tranquil realm, did the supremacy of bacteria come to an end.

The VPI group calls the Dry Valley stromatolites "living fossils" because the cyanobacteria are generating features that will be preserved. Wet, the stromatolites are slimy to the touch; dry, they feel crusty "like tapioca," says George Simmons, a VPI aquatic ecologist. If you taste one, he says, you would notice the grit—a legacy of the sediments and abundant carbonate. Stromatolites, such as the club-shaped specimens found in Shark Bay, Australia, that grew in different environments have different forms and structures.

With botanist Bruce C. Parker, Simmons discovered the Dry Valley microbial mats four years ago. With funding from the National Science Foundation's Division of Polar Studies, the two men return to Antarctica each Austral summer along with a multidisciplinary research team. The scientists study various aspects of stromatolite formation, such as productivity rates, geological properties, physiology and adaptation. The intent is to mimic the ancient environment and "then see how the microorganisms function under those kinds of conditions," says Kenneth G. Sea-

Opposite page: A stromatolite from Lake Fryxell, Antarctica.

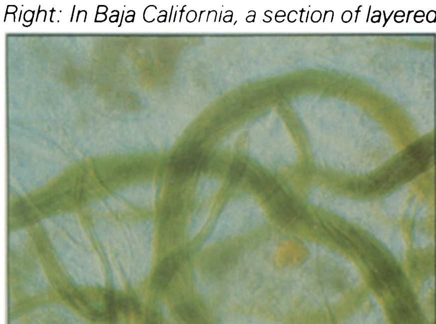
Top left: Close-up of lift-off mat 20 to 33 feet beneath the perennial ice cover of Lake Hoare, Antarctica.

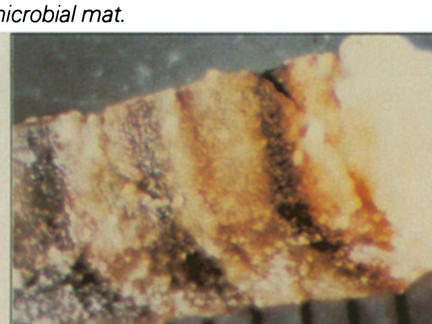
Below: Diver receives last-minute instructions before plunging through the hole melted in the 10-foot-thick layer of ice covering Lake Vanda.

All Antarctica shots: Gordon Love, VPI

Protrusions caused by entrapped air bubbles in lift-off mat in Lake Bonney, Antarctica.

Left: High-powered light microscopy magnification of filamentous blue-green algae, Microcoleus, *from Baja California.*
Right: In Baja California, a section of layered microbial mat.





Baja California photos: Boston Univ.

Gordon Love, VPI

P. F. Hoffman, Geological Survey of Canada

Top: Unlithified microbial mat draped over recent stromatolites in Lake Fryxell, Antarctica.

Below: recent stromatolites in Shark Bay, Western Australia.

burg of VPI. By simulating in a laboratory environment the ecological conditions under which the microbial mats survive, scientists hope to learn what physiological adaptations microorganisms may have made long ago in order to live and function in extreme circumstances.

Most microbial mats are ephemeral features because they occur in environments also populated by higher organisms eager to burrow through or eat them. Today, however, there are a few isolated places where bacteria are dominant. Microbial mats still thrive in alkaline or highly saline environments such as hot springs or salt ponds. Such habitats welcome the bacteria but are inhospitable to organisms and higher plants that would compete with the microbes.

One such bacterial stronghold is Laguna Figueroa in Baja California, 155 miles south of San Diego. Margulis is studying the varied microbial communities in the layered mat sediments in the enclosed, hypersaline lagoon. Evaporation rates are high in the semi-desert region. Very few animals or higher plants are able or willing to brave the extreme salinity, drying conditions, and high temperatures.

The scientists believe these conditions, described in PRECAMBRIAN RESEARCH, Vol. 11, 1980, are conducive to the formation of sedimentary structures such as those formed during the Precambrian. In fact, comparisons suggest parallels between the anaerobic microbial communities so prevalent at Baja California and the microfossils and 3.4-billion-year-old carbon-rich laminated sediments that may be traces of anaerobic microbial communities that evolved during the lower Precambrian period.

For several reasons, the VPI scientists believe that the Antarctic stromatolites are modern analogs for ancient aquatic communities. Blue-green algae are morphologically conservative, changing little even over long periods. Though most modern stromatolites and microbial mats are known in tropical climes and in shallow waters, perhaps their ancient counterparts also lived, like the Antarctic specimens, in cold temperatures (0°C-3°C) and under light conditions best described as "dim." In Lake Hoare, for instance, only one percent of the light that strikes the surface manages to penetrate the 18-foot-thick coating of ice. Of the light that does penetrate, only one-tenth reaches the microbial mats 82 feet beneath the surface. These hardy photosynthesizers make do, though, using the scant light energy to convert water and carbon dioxide into usable organic compounds.

In fact, during the four-month Austral summer, the blue-green algae photosynthesize so vigorously that the resulting oxygen fuels the annual "lift off" — a process by which bits of mat, as well as concentrated salts, carbonate and large quantities of sediment begin a ten-year odyssey from shallower lake waters to the ice surface.

This is what happens: Oxygen so abundant that the water containing it fizzes when exposed to surface air forms gas bubbles that become entrapped in the mat. Buoyed by the bubbles, pieces of mat tear loose and rise to the underside of the ice cover. With summer's end, temperatures drop and new ice forms, entombing the mat fragments. All the while, the surface of the lake is losing water, mostly through evaporation. The microbes, as well as the other components, progress through the thick ice sheet. Finally, the mat fragments reach the surface and blow away.

Parker and Simmons estimate that through this process each of the lakes studied loses 2,200 to 22,000 lbs. of such material per year. While the scientists are not sure how long the exodus has been in progress, its effect on the geochemistry of the lakes is profound because it provides a route by which nutrients and salts can leave the lakes. A similar process occurs in lakes and ponds in more temperate latitudes, but it was long assumed that because there is no outflow from the Dry Valley lakes, and no melting, that the lakes were closed ecosystems. The lift-off process alters that view. It also explains two long-standing puzzles: why nutrients do not build up in the lakes, and how the blue-greens, still viable after their years in ice, move from one Antarctic habitat to another.

Part of the significance of the microbial mats and stromatolites in the Antarctic lakes is that they help solve a long-standing question. Did stromatolites form in deep water? Three and a half billion years ago, there probably was too little oxygen to shield communities in shallow and intertidal waters from the searing effects of ultraviolet radiation. Eventually, Simmons explains, bacteria developed the ability to photosynthesize, or convert light into usable energy and to produce oxygen. For several million years, the oxygen produced was taken up by such metals as iron, manganese and magnesium. These and other metals were in a reduced form then, ready to be oxidized by the new gas making inroads on the young planet. As they accepted electrons from the oxygen, the metals settled onto the mats of filamentous blue-greens, only to be trapped and bound by the growing microbial communities. After a million years or so, the metals were oxidized, the oxygen demand of the ocean was satisfied, and free oxygen gradually began to accumulate in the atmosphere.

"The bacteria had to start the photosynthetic process of producing oxygen to generate the ozone layer to provide a protective envelope around the world," Simmons says. "Then, after several million years, things could begin to grow around the edge of the ocean in shallow water." □