Supersoil

Before grasses and trees emerged, microbial soils may have made Earth more hospitable for life

By RICHARD MONASTERSKY

WATCH YOUR STEP! That bold warning appears at the entrance to many trails wending their way through Utah's Canyonlands National Park. In this harsh environment, a misplaced footstep can kill.

The signs are not meant to save hikers. Rather, they aim to protect tiny organisms that form a dark, knobby soil called cryptogamic crust. Looking like lumpy mounds of brown sugar spread over the landscape, cryptogamic crust represents a partnership of sand and clay particles, fungi, moss and cyanobacteria, one of the oldest life forms on Earth. According to the warning posters, these fragile organisms collectively merit protection because they resist erosion and provide nutrients for other plants in the arid habitat.

The living soil may also deserve appreciation for a more ancient accomplishment. If an unusual hypothesis devised by two geoscientists proves correct, humans may owe their very existence to such simple forms of life.

Tyler Volk from New York University and David W. Schwartzman from Howard University in Washington, D.C., have turned their thoughts back billions of years, to a time when microbial communities such as cryptogamic crusts were the only life on land. According to their calculations, these types of organisms may have transformed Earth from a hostile hell into a haven for more complex life.

Before land microbes developed, the researchers propose, Earth was too hot to support complex forms of life. Volk and Schwartzman suggest the early organisms would have played a large role in cooling the continental surface. "This [cooling] would have been a necessary first step before the higher forms of life could come in," Volk says.

Scientists do not know at what point in Earth's 4.5-billion-year history the first organisms began to establish themselves on land. Fossil evidence indicates the oceans were teeming with cyanobacteria, often called blue-green algae, by at least 3 billion years ago. But land rocks do not preserve microbial evidence nearly as well as marine rocks do, so scientists can only guess when organisms first gained a grip on the dry, lifeless continents.

The textbook history of life holds that the land surface remained barren until relatively recently, less than half a billion years ago. But many scientists suspect land life evolved much earlier, perhaps as far back as 3 billion years ago, says Stjepko Golubic, an evolutionary biologist at Boston University. Adding to the uncertainty is the fact that no one knows what the earliest land organisms looked like.

Though lacking direct evidence, some scientists say they have reasons to suspect cyanobacteria were the first inhabitants of the land surface. Biologist Susan E. Campbell of Boston University notes that certain forms of ancient cyanobacteria lived in tide pools, which could be salty, filled with freshwater or dry depending on changing conditions. With these preadaptations to land life, the tide pool microbes could have spawned the first colonizers of the continents, Campbell speculates.

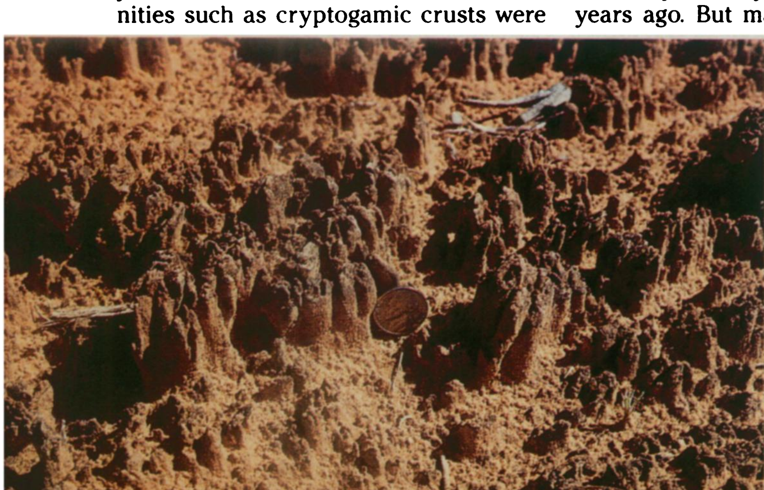
Some find it difficult to believe that such simple organisms once turned Earth's climate inside out, as Volk and Schwartzman suggest. But a close look at some modern cryptogamic soils illuminates how ancient microbes might have altered the climate. While most soils contain different types of living microbes, ecologists use the terms cryptogamic soil or crust to describe ones that contain a high concentration of microorganisms.

Cryptogamic is actually a misleading label, Campbell says. The word, which literally means "having hidden reproductive cells," describes nonflowering plants, such as mosses, that appear in some of the crusts. Yet mosses do not make up the bulk of the material, and some so-called cryptogamic crusts do not contain any organism that would fit under the name cryptogam.

Cyanobacteria represent the vast majority of the living matter in the crusts, and some crusts are made almost entirely of such microbes. Ecologists originally called cyanobacteria blue-green algae because, like other kinds of algae, they use sunlight to photosynthesize carbohydrates from carbon dioxide and water. But they also share characteristics with bacteria, including the absence of a nuclear membrane. For that reason, taxonomy experts in the 1970s placed them in a subdivision of their own. Many, but not all, scientists now use their newer name, cyanobacteria.

Some crust-forming cyanobacteria are unicellular, but other types, such as the extremely widespread genus *Microcoleus*, create filaments out of cells strung end on end. *Microcoleus* filaments bundle together and secrete a sticky polysaccharide that becomes a protective sheath around the bundle when the environment dries out. Trapping sand and clay, the polysaccharide acts as a microbiological mortar, creating a strong matrix that forms the cryptogamic crust.

In arid regions such as Utah's high



Photos: Campbell

Cryptogamic soils can assume many forms, including the knobby crust seen in Canyonlands National Park. In addition to preventing erosion, organisms in these crusts enrich the soil with nitrogen and other nutrients.

desert, *Microcoleus* and the other crustal microbes live a boom-and-bust lifestyle. During dry times, which last most of the year, cyanobacteria rest in a quiescent state, hardly alive. But within seconds after a rainfall, they kick into metabolic action. During that period, *Microcoleus* filaments burst through the end of the protective sheath and propel themselves forward. Leaving their old sheaths behind, the filaments move ahead and secrete fresh polysaccharide slime.

Studies have shown that these and other polysaccharide-producing cyanobacteria drastically limit soil erosion in an arid environment, says Jayne Belnap, an ecologist with the National Park Service in Moab, Utah. The cryptogamic crust forms a hard, resistant covering that prevents sand and clay particles from washing away when infrequent thunderstorms pound the dry ground. The organic material in the crust also tends to soak up water that would otherwise wash over the surface.

"Without the cryptogamic soils, there's tremendous amounts of erosion. It's just amazing to me," says Belnap.

These properties play a special role in Schwartzman and Volk's analysis. In particular, the researchers have explored how early microbes, such as the ancestors of cryptogamic crusts, might have contributed to the chemical weathering of rocks. The term chemical weathering describes certain reactions that leach minerals out of rock. Because these reactions absorb carbon dioxide from the atmosphere, the global rate of chemical weathering helps determine the strength of the Earth's greenhouse effect and ultimately the surface temperature of the planet.

Volk and Schwartzman envision the continents of early Earth as desolate places practically devoid of soil. Before organisms first began living on land, rainwater would have washed all loose pieces of rock into low-lying basins, they suggest. Microbes could have transformed the continents by stabilizing the loose rock and allowing the first widespread accumulation of soil.

This step would have increased weathering rates for several reasons, according to Schwartzman and Volk. Before soils developed, air and water could reach only a limited amount of rock – the bare bedrock surface and rock pieces exposed at the tops of basins. Soil formation altered the weathering process by preventing small rock chips from washing away, thus exposing a tremendously large total surface area for chemical reactions.

Soils would have added a second bonus, Schwartzman and Volk suggest. Before the first land life emerged, water would have run right off bedrock surfaces. Thus, weathering reactions requiring water could occur for only a brief time after a rainstorm. When soil built up with microbial assistance, it would have absorbed water, providing a longer time for contact among the water, air and rock particles within the soil. Microbes also added organic matter to the soil, further increasing water absorption.

Resembling a bundle of optical fibers, Microcoleus *filaments typically cluster together in a group. Each filament measures 5 microns in diameter.*

These changes would have dramatically hastened the chemical weathering rate, according to Volk and Schwartzman's calculations, which they describe in the Aug. 10 NATURE (SN: 8/19/89, p. 127). The development of microbial communities on land could have boosted worldwide weathering by a factor of 20 to 200, Volk told SCIENCE NEWS. If his estimate is accurate, heightened weathering reactions would have lowered Earth's surface temperature by as much as 30°C (54°F) by pulling carbon dioxide out of the atmosphere. Geologic changes such as the growth of the continents and the slowdown of plate tectonics also helped lower temperatures.

Schwartzman and Volk suggest the continents were extremely hot when life first evolved there – too hot to support any but the most basic organisms. The early cooling caused by microbes and geologic factors, they say, would have paved the way for the development of more complex life forms.

The researchers also think the development of trees, grasses and other vascular plants that increase chemical weathering would have further cooled the Earth. But this later temperature drop would have paled in comparison with the earlier change, they contend. "Most of it, maybe 80 percent of the total cooling [caused by life], would have come from those early soils," Volk says.

The arrival of microbes on land would not represent the only occasion in which simple organisms radically changed Earth's living conditions. The oxygen we breathe attests to that. Originally, the atmosphere contained very little oxygen, but as early ocean organisms developed the ability to break apart water molecules for photosynthesis, oxygen levels started building in the atmosphere, gradually rising toward their present value.

Schwartzman and Volk admit their dramatic scenario travels into highly speculative territory. In the first place, scientists do not even know whether the early Earth was especially hot when land life first evolved. While some have gathered evidence that it was significantly warmer than today, others point to data supporting the opposite stance.

Indeed, researchers know precious little about this ancient period in Earth's history. "So you sort of grasp at small straws and hope they're telling you the truth," says Heinrich D. Holland, a geochemist from Harvard University who studies the early Earth.

Given the lack of data, Holland and others express skepticism concerning Schwartzman and Volk's scenario. "The notion that the first life that colonized land brought the temperature down dramatically – I think it's an interesting idea. But I'm not overwhelmed by the chances that it's true," Holland says.

To test the hypothesis, Schwartzman is now trying to measure how much certain microorganisms boost weathering rates.

But James F. Kasting, an atmospheric scientist from Pennsylvania State University at University Park, says it will be difficult to determine whether microbes can actually enhance weathering as much as Schwartzman and Volk claim. "We're not liable to come up with an answer for this very quickly," he says.

The two researchers say they realize their scenario may not describe what really unfolded on the early Earth. Nonetheless, their calculations about life and weathering have opened a new topic for scientists to examine. "At worst," Schwartzman says, "I think our paper is a fruitful error. If we're wrong, at least we think we've stimulated some thinking on this. We haven't seen that anybody has really thought about these questions before."

Whatever their role in the planet's past, microbial crusts remain a dominant force in the Utah desert, where they continue to function much as they have for hundreds of millions of years, their craggy peaks and valleys creating a miniature canyonland that keeps the underlying soil from washing away. In appreciation of their ecological contribution, Belnap says, "These little guys have not gotten credit over all these years. They're the glue holding this place together." □