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See back cover for new *Park Science* phone, FAX & address.

Cover: An electron micrograph shows a dry sandstone crust interlaced with cyanobacteria, enlarged 90 times. (Story pages 3,4).

Microbiotic Crusts: Their Role In Past and Present Ecosystems

By Jayne Belnap

Microbiotic crusts are found throughout the world, from the hottest deserts to polar regions. Most of these crusts are dominated by cyanobacteria, and also include lichens, mosses, green algae, microfungi, and bacteria. The crusts are critical components of these ecosystems, significantly modifying the surfaces on which they occur. In the cold deserts of the Colorado Plateau region (parts of Utah, Arizona, Colorado, and New Mexico), these crusts are extraordinarily well-developed, and may represent 70-80 percent of the living ground cover.

Cyanobacteria, previously called blue-green algae, are the oldest form of life known. The earliest fossils found, called stromatolites and dating back more than 3.5 billion years, are extremely thick mats of these prokaryotic organisms. It has been suggested that it was these marine organisms that converted the earth's original carbon dioxide-rich atmosphere into the oxygen-rich atmosphere necessary for the evolution of life as we know it today. Stromatolites are still being formed along the coasts of Baja California, Africa, and Australia, where meters-thick mats of cyanobacteria such as *Microcoleus chthonoplastes* and *Lyngbya* can be found in various stages of fossilization.

Cyanobacteria occur as single cells or as filaments. The most common form found in desert soils is the filamentous type. The cells, or filaments, are surrounded by a sticky mucilaginous sheath that is made of polysaccharides and other compounds that can be extremely persistent in these soils.

Their Soil Binding Role

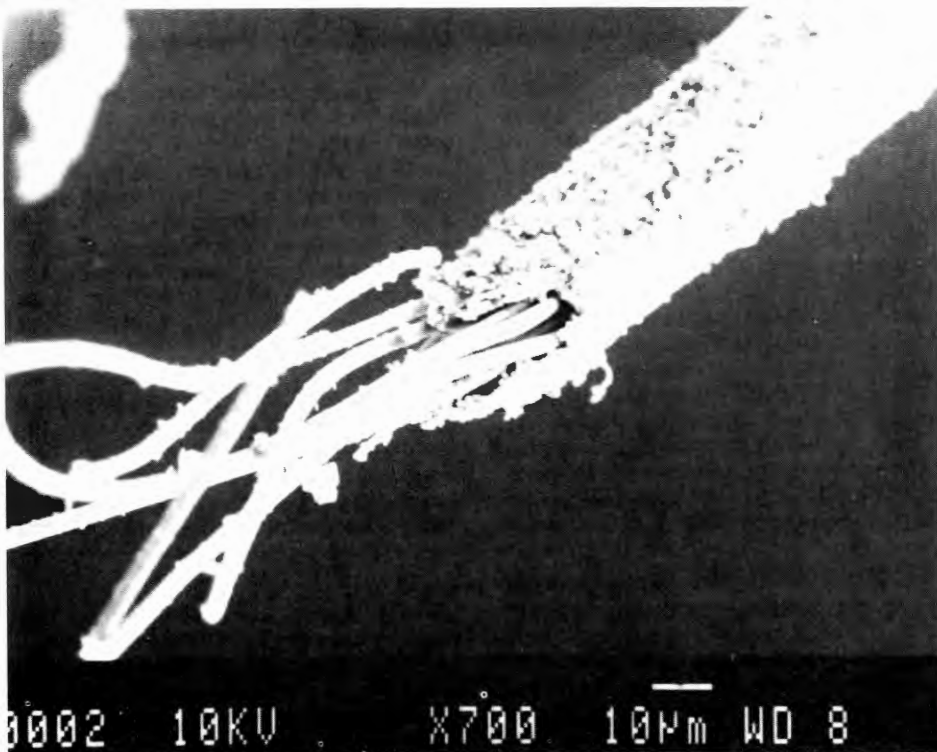
One ubiquitous species, *Microcoleus vaginatus*, not only has sheaths around each filament, but has filaments occurring in bundles that are surrounded by a common sheath. When moistened, these cyanobacteria become active, moving through the soil and leaving a trail of sticky mucus behind. The sheath material sticks to surfaces such as rock or soil particles with which it comes into contact. Since many of these cyanobacteria occur in long filaments, the result is an intricate webbing of fibers throughout the soil, joining soil particle to soil particle, like beads on a string.

As with fiberglass, this webbing gives the soil great stability and tensile strength, and enhances resistance to erosional forces such as wind and water. Of considerable significance is the fact that this binding action is not dependent on the presence of living filaments: layers of abandoned sheaths, built up over long periods of time, can still be found clinging tenaciously to soil particles at depths greater than 15 cm in sandy soils. These sheaths provide cohesion and stability, even at depth, to otherwise highly erodible soils.

The sheaths have other functions as well. They are extremely hydrophilic, swelling up to as much as 10 times their dry size when moistened. Consequently, the sheaths become a way of intercepting and storing water, especially important in arid areas where rainfall is sporadic and intense. This enables the cyanobacteria, which are active only when wet, to remain active longer.

Their Nutrient Holding Role

Recent research also shows that vascular plants grown in crusted areas have much higher levels of essential nutrients than plants grown in areas without



Microcoleus vaginatus is a major constituent of soil crusts on the Colorado plateau. This 700 times enlargement shows the filaments clustered in their common sheath, like a bundle of optical fibers. When moistened, they move through soil and weave it together with their sticky, mucilaginous trails.

crusts. Electron micrographs of *Microcoleus* suggest a mechanism for this nutrient enriching property. Pictures show the outer sheath of cyanobacteria covered with fine clay particles. Both the sheaths themselves and the adhering clay particles are negatively charged; therefore, they attract and bind important positively-charged nutrients, keeping them from being leached out of the upper soil horizons or becoming bound in a form unavailable to plants.

This circumstance benefits the crustal organisms, since attached nutrients are thus readily available, and also the surrounding vascular plants. As with soil stability, this soil-enriching function is not dependent on the presence of living filaments, but only on the presence of sheath material.

Sheaths also offer protection to the organism from both abrasion and desiccation – especially important in dry, unstable soils. Perhaps equally important, the sheaths and the organisms they surround contribute a great deal of organic matter to soils in which they occur.

Their Nitrogen Fixing Role

Nitrogen fixation is another significant capability of many cyanobacteria. Vascular plants are unable to utilize nitrogen as it occurs in the atmosphere and are dependent on microbial organisms to reduce atmospheric nitrogen to a form they can use. This is especially important in desert ecosystems, where nitrogen levels are low and often limiting to the system's productivity. Cyanobacteria play an even more critical role in cold desert ecosystems, where symbiotic and heterotrophic bacterial fixers – often important contributors of fixed nitrogen – do not perform well.

Cyanobacteria, then, are basically nutritionally independent organisms, needing only light, atmospheric nitrogen, a few minerals, and water to survive. This, along with sheaths that give them the ability to stick to surfaces, stabilize soil particles, capture nutrients, and hold water, enables them to colonize areas of bare rock and soil, such as newly-formed land masses.

Their Role As Colonizers

This capacity of cyanobacteria can be seen today in areas such as Iceland and Hawaii, where they are the first to colonize lava flows and cinder cones. For all the above reasons, it is thought that these organisms probably were the first colonizers of earth's early land masses and were integral in the formation and stabilization of earth's earliest soils.

Production of weak acids by the cyanobacteria, as well as the trapping and holding of water next to the rock, would have accelerated the weathering of the parent material and the production of soil particles. The binding of newly-formed particles by the cyanobacteria's sticky sheaths, greatly increasing resistance to water and wind erosion, would have aided the formation of small soil pockets. These small pockets of soil would further accelerate the weathering process, as more water would be trapped and more substrate would be available for colonization by more cyanobacteria.

Unfortunately, human activities are generally incompatible with the presence and well-being of cyanobacterial crusts, whether the disruption comes directly through construction and recreational activities, or

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indirectly through domesticated grazing animals or pollutants. The cyanobacterial fibers that confer such tensile strength to these crusts are no match for the compressional stress placed on them by footprints (cows or people) or by machinery, especially when the fibers are dry, and therefore brittle. Air pollutants, both from urban areas and from coal-fired power plants, significantly affect the physiological functioning of these crusts.

Human Needs Pose Threat

The arid West, where the crusts play such a critical role, is facing expanding human presence. With that, comes ever-increasing pressure to provide energy resources (such as coal, and oil shale), to provide locations for energy production (such as coal- and oil-fired power plants), and to provide locations for waste disposal (whether incinerators or landfills). These activities can be devastating to the microbiotic crusts, which are, in essence, the topsoil of most of the West. No research has been done on recovery rates of crusts after physiological disturbances by pollutants and so this remains unknown.

There is information on recovery from mechanical disturbances, of which there are two types: trampling, like that from hoof or foot traffic, that breaks up the crust but leaves pieces in place that may re-establish themselves; and total removal, as in road construction.

Recovery from trampling depends on the extent of trampling and the time of year it occurs. When they are dry, crusts are very brittle and easily broken up; the problem is not that anything is killed, but that the impacted area is destabilized. Fiber connections are broken, both in sheaths containing living filaments and in those that are abandoned. For living filaments, repair and re-stabilization is possible only when moisture is present, so that if impacts occur just before or during dry times (of which there are plenty in the desert), re-establishment can be difficult.

Large Disturbances Hurt Most

All this is exacerbated when large areas are destabilized, as with grazing or wildfires, or when destabilization occurs as a continuous strip, such as

vehicular or bicycle tracks. These situations leave areas highly susceptible to wind and water erosion. Wind not only blows pieces of the pulverized crust away, thereby preventing reattachment of pieces, but it also blows around the underlying loose soil, covering nearby crusts. Overland water flows carry loose material as well. Since crustal organisms need to photosynthesize, burial can mean death.

When large sandy areas are impacted in dry periods, previously stable areas can become a series of moving sand dunes in a matter of only a few years. Continuous strips, e.g. those left by bicycles and motor vehicles, are highly susceptible to water erosion and channels form quickly, especially on slopes. These areas may never recover fully.

In situations where crusts have been removed, re-establishment is very slow and depends on the size of the disturbance. In sandy areas, under the best of circumstances and where the disturbance areas are small, a thin veneer – 2-4 mm thick – consisting of one or two species of cyanobacteria, may return in five to seven years. This compares to an undisturbed crust 50-100 mm or more thick, that may consist of 14-15 species of cyanobacteria, along with lichens, green algae, and other organisms. It is not known how resistant this thin layer is to erosion, especially those tremendous overland water flows that can occur in the desert. Damage to abandoned sheath material beneath the surface cannot be repaired but must be rebuilt slowly through years of cyanobacterial growth.

Artificial inoculation can significantly increase recovery rates, and should be an integral part of recovery plans for these areas.

Impacts on crusts occur in all arid land parks. Crusts in some parks are affected directly by livestock grazing allowed in those parks. All parks are affected by people, foot traffic, and various types of construction. Most parks, if not currently threatened by air pollution problems, could be in the near future. It poses a real challenge for managers of these parks to find ways to protect these crusts, given the host of factors that affect them and the important contributions they make.

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