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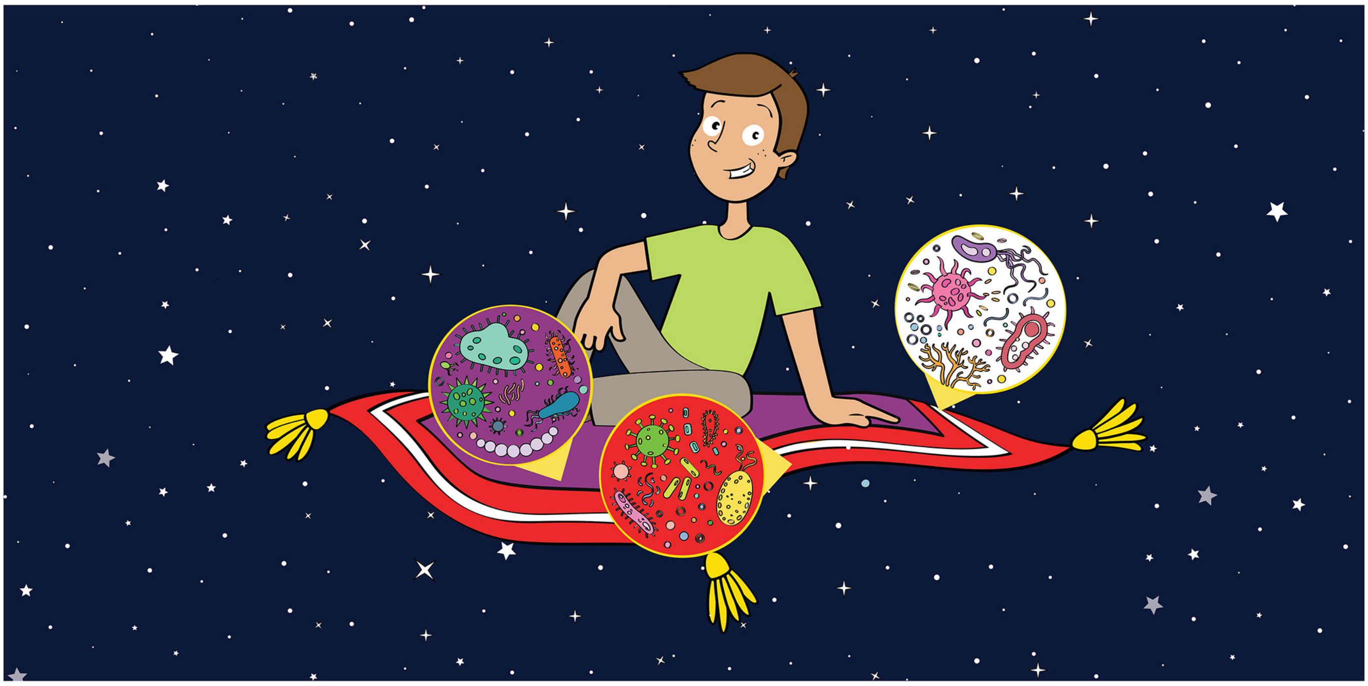

MICROBIAL MATS: PRIMITIVE STRUCTURES THAT COULD HELP US FIND LIFE ON OTHER WORLDS

***Santiago Cadena*[1,2], *Paula Maza-Márquez*[3], *Sandra I. Ramírez Jiménez*[2], *Sharon L. Grim*[3], *José Q. García-Maldonado*[1*], *Leslie Prufert-Bebout*[3] and *Brad M. Bebout*[3]**

[1] *Departamento de Recursos del Mar, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Mérida, Mexico*

[2] *Centro de Investigaciones Químicas, Universidad Autónoma del Estado de Morelos, Cuernavaca, Mexico*

[3] *Exobiology Branch, National Aeronautics and Space Administration (NASA) Ames Research Center, Mountain View, CA, United States*

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AGE: 12


AVANI
AGE: 10


SANSKRITI
AGE: 15

Some microscopic organisms grow together to build structures known as microbial mats. These mats are formed from several layers with different colors, and their structure depends on environmental conditions such as sunlight, humidity, and available food. Microbial mats are found in oceans, lakes, and coastal lagoons, as well as in extreme environments like deserts, polar regions, and hot springs. The study of fossils indicates that microbial mats were a common form of life on early Earth, and they have persisted on our planet ever since! Therefore, the study of modern mats helps us to understand microbial life in the past, and how they might help to regulate the Earth's climate. Scientists believe that microbial mats can prosper on rocky planets like Earth, so they are studying mats in different terrestrial environments to help them to recognize evidence indicating the presence of mats on other worlds.

MICROORGANISMS CAN FORM LARGE STRUCTURES!

Microorganisms are tiny living things that cannot be seen with the naked eye, as most of them are made up of only one cell. We need to use a microscope to see them. They live in and on our bodies, and in our surroundings, including the soil, water, and air. Sometimes microorganisms work together to build big structures that are observable without microscopes. Lichens, for example, look like plants, but they result from an interesting relationship between algae and fungi, which form flakes or leafless branches on trees or rocks. Yogurt, vinegar, cheese, and bread are produced by fermentation processes, which are performed by groups of particular microorganisms. Some plants built small structures called root nodules, where microorganisms can live. Thanks to the microorganisms in these nodules, the plants can obtain more food from the environment and thanks to the plants, the microorganisms have a place to live and a lot of sugar to feed on. Commonly, when your food spoils in the refrigerator, you can observe a layer of microorganisms known as a **biofilm** growing on it.

BIOFILM

A layer of microorganisms that are stuck to one another and stuck to (or floating on) a surface.

In nature, many microorganisms live in the ground. Using soil, water, and minerals these microorganisms can form big, solid structures. When high-quality food is present, some microorganisms can reproduce by the millions, attached to grains of soil or sand, creating structures that look like normal rocks or mud, but that are actually living structures built by multitudes of microscopic organisms. There are different types of rocky microbe structures. They have names like microbialites, endoevaporites, oncolites, and stromatolites (Figure 1) [1]. These structures can have diverse shapes and colors, which are strongly influenced by the environmental conditions present during their formation. **Microbial mats** are a specific example of a structure built by microorganisms.

MICROBIAL MAT

A large structure build by microorganisms, that grow on the top of sediments. It is usually composed by grands of soil, minerals, nutrients, and microbes.

WHAT ARE MICROBIAL MATS AND WHAT DO THEY DO?

Microorganisms need energy and water to build a microbial mat. Water can be provided by hot springs, lagoons, or a coastal shoreline, and many microorganisms use solar light as their main energy source. With enough energy and water, microorganisms can flourish on a surface, sticking together with food and grains of sand or soil, and building mats that can be up to a few centimeters thick (Figure 1C). In some cases, a new living mat grows on top of an older, dead mat, creating thick layers (Figures 1G,H). As the name suggests, mats resemble carpets or rugs, in the way that they cover surfaces of various sizes. When seen up close, mats also have interesting vertical layering (Figure 2). Microorganisms can be distributed in green, orange, red, and purple layers, with each layer representing a different community of microorganisms that needs different amounts of sunlight and oxygen (Figure 1I). All the

Figure 1

Figure 1

Examples of structures made by microorganisms using soil, water, rocks, and minerals. **(A)** Oncolites from Casey Falls locality, Canning Basin, Western Australia (photograph credit: Heidi Allen). **(B)** Endoevaporite. **(C)** Microbial mat. **(D,E,G,H)** Microbial mats in the Yucatán Peninsula in Mexico. **(F)** Microbial mats from the Middle Island Sinkhole, Lake Huron in North America (photo credit: John Bright, NOAA Thunder Bay National Marine Sanctuary). **(I)** A cross-section of a microbial mat from Guerrero Negro, Mexico.

microorganisms in the mat work together to sustain themselves and to interact with their surrounding environment.

Studies have shown that microbial mats are important for the functioning of **ecosystems**. For example, when mats colonize the ground, they contribute to the health of soils and sediments, producing nutrients that enrich them. Mats participate in the recycling of some chemical elements, including carbon, nitrogen, and sulfur. They can also clean the water and they both take up and release gases from the atmosphere, such as oxygen, hydrogen, carbon dioxide, and methane. Mats are also a food source for animals. Some flies, snails, worms, crabs, and birds feed on small pieces of microbial mats, and larger organisms can then feed on those smaller ones [2]. Because they are continuously eaten, mats often do not grow much, except in extreme environments[1].

ECOSYSTEM

A community of organisms living in a certain area, and the non-living components of their environment (weather, landscapes).

[1] If you want to explore deeper into microbial mats, watch this video: https://youtu.be/VpCkgvb41Ag

MICROBIAL MATS AROUND THE WORLD

Nowadays, microbial mats can be found in tropical coastal lagoons, estuaries, and bays, but they may be difficult to spot because they can only grow large when they have enough food and when they are protected from grazing organisms. However, mats are found extensively in the **fossil record**, indicating that, billions of years ago, these structures were abundant on the early Earth. Just think about it! Dinosaurs originated 0.245 billion years ago (BYA), fishes 0.530 BYA and aquatic plants 1.2 BYA, but microbial mats were present on Earth

FOSSIL RECORD

The history of life on Earth, documented by fossils, remains, or imprints of organisms that lived many years ago.

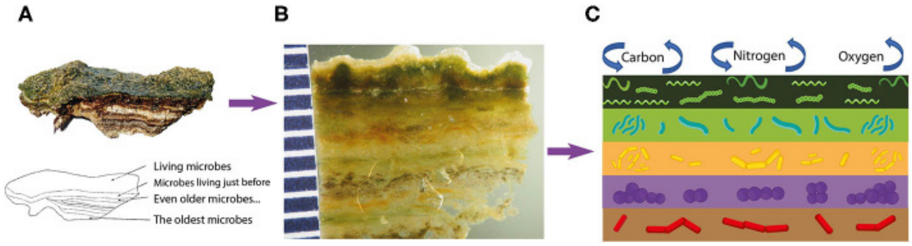

Figure 2

Figure 2

Zoom to the top first centimeter of a microbial mat. **(A)** Structure of a classic microbial mat. Living microbes are found in the top layer, while older mat is below. **(B)** A close-up look at a cross-section of the first centimeter of a mat, showing the different layers formed. **(C)** Different types of microorganisms live in the different layers of a microbial mat. Important elements such as carbon, nitrogen, and oxygen are recycled by microorganisms.

even 3.5 BYA, long, long before any other forms of life existed. On early Earth, these microbial structures proliferated on rocky or sandy surfaces worldwide. Imagine that! Today, microbial mats usually get eaten by other organisms, but billions of years ago, those higher lifeforms had not yet evolved, so the mats just kept growing! Microbial mats are one of the oldest forms of organized life and the study of today's mats helps scientists to understand their contribution to ecosystems on both modern and early Earth.

Geological data and laboratory studies have revealed the importance of microbial mats in the history of Earth. It is believed that, in the past, the abundance and high activity of mats created the atmosphere that we breathe today. Furthermore, as ancient mats released carbon dioxide and methane, they also contributed to the regulation of Earth's climate, helping to create the warm atmosphere that made the Earth a habitable planet [3].

MATS AS MODELS FOR EXTRATERRESTRIAL LIFE

Microbial mats have been observed in extreme ecosystems, such as in extremely salty areas around coasts and in deserts soils. Also, they can form in the polar regions attached to permafrost, which is soil that never thaws. Mats have been discovered at high temperatures, close to volcanoes and hot springs. They have also been found in the deep ocean, under harsh conditions of light and pressure.

Since mats can grow under extreme variations of sunlight, water, temperature, and salinity, scientists believe that microbial mats might exist beyond Earth, growing on other rocky planets or moons. Most planets and moons in our solar system are not suitable places for life, due to the high amounts of ultraviolet light or cosmic radiation they receive, and their lack of a life-supporting atmosphere. But evidence suggests that some planets and moons in the solar system may have water, sometimes protected by ice layers. If there is life in those remote places, it is likely to be microbial life, not big animals, or plants. Therefore, by studying the characteristics of microbial mats, scientists can discover the microbial mats' **biosignature**. A biosignature is like an identification card that suggests the presence of life. For example, the

BIOSIGNATURE

Any feature, molecule, substance, or characteristic that strongly suggest evidence of life.

gases produced by microorganisms or the structures they built in rocks and sand could be their biosignatures. Using cameras and instruments on spacecrafts, large structures produced by microorganisms would be far easier to detect than would microorganisms themselves. If we observe the biosignature of microbial mats on another planet using a spacecraft's cameras, it will indicate that microorganisms could be living on that planet.

Currently, scientists are looking for live or fossilized mats in our solar system. The planet Mars and two moons of the planet Saturn (Titan and Enceladus), have geological characteristics that are promising for the formation of microbial mats. Mars has a rocky, dry surface but recently, NASA's Mars Reconnaissance Orbiter provided strong evidence of liquid water on the planet [4]. The Cassini-Huygens and Voyager spacecraft missions studying Saturn and its moons found evidence of water and polar ice on Titan and Enceladus, probably similar to the ice and water found in the polar ice caps on Earth [5]. There is no evidence yet of any kind of life prospering beyond our planet, but the study of extreme ecosystems on Earth helps us to predict the conditions needed for microbial life elsewhere in the Universe, and to design strategies and devices that will help us to find it. For example, we must know which instruments to send on space missions to detect gases produced by microorganisms, and we must know how to identify microbial mats in photographs.

HOW ARE MICROBIAL MATS STUDIED?

Microbial mats are everywhere on Earth, in both mild and extreme environments, and in both accessible and hard-to-reach places. Some of the most famous microbial mats are found at Yellowstone National Park, California (USA), where they grow near hot springs and geysers. However, you can find mats on some shallow coasts, where seawater rises and falls with the tides. For example, mats can grow in mangrove forests, salt marshes, wetlands, or at the edges of rivers and lakes. Sometimes, in other places where the water is not cleaned regularly, bits of biofilm or small mats can grow—for example, in birdbaths, fountains, or fish tanks (Figures 3A–H).

Current microbial mat research is conducted through field trips and expeditions that investigate the ability of mats and microorganisms to survive in various ecosystems, under diverse environmental conditions. This information helps scientists to understand the role of mats in ecosystems, and the limits of sunlight, water, temperature, and other conditions under which these microorganisms can function. In addition to studying mats in their natural locations, pieces of mats are transported to laboratories, where long-term experiments can be performed, and various laboratory tools can be used to learn about the lives of the microorganisms. For example, we can grow mats in the laboratory and use instruments to measure how much

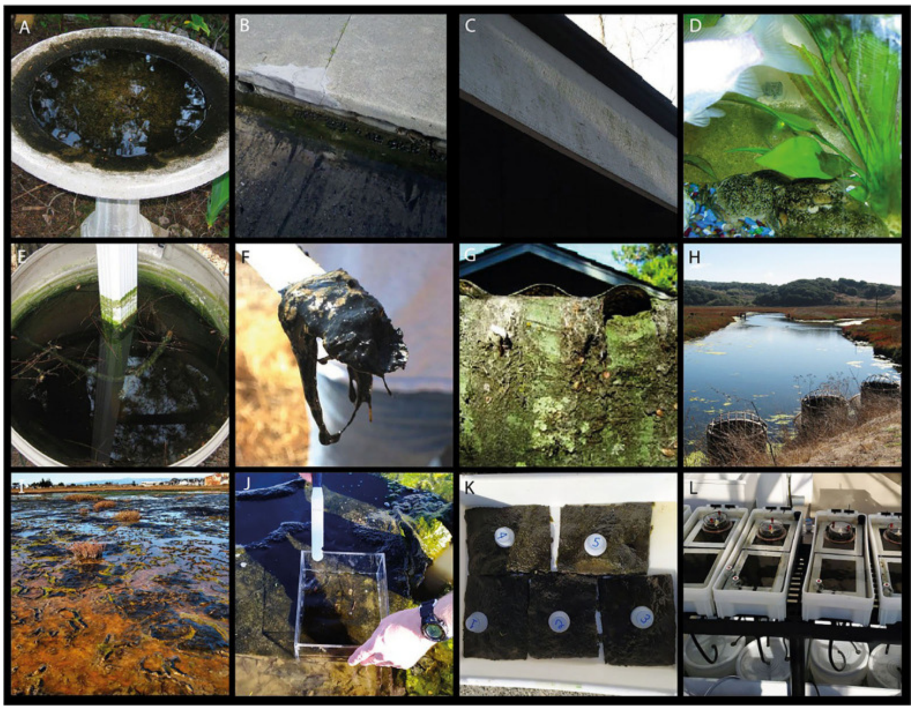

Figure 3

Figure 3

Algae and mat-like biofilms growing in familiar places, such as **(A)** a bird bath, **(B)** a street gutter, **(C)** an exterior roof board, **(D)** the bottom of a fish tank, **(E)** a water collector from a roof drain, **(F)** the waters of an estuary, and **(G)** a board found under a shed. **(H)** Floating algae in an upstream area of Elkhorn Slough, California. **(I)** A view of the microbial mat collecting area. **(J)** Sampling microbial mats. **(K)** Transporting mats from the field site. **(L)** Mats incubating in a greenhouse at NASA's Ames Research Center.

oxygen they produce and how much carbon dioxide they consume (Figures 3I–L).

CONCLUSION

In conclusion, microbial mats are complex systems that provide an excellent opportunity to study microbial diversity, ecology, and evolution. Mats are found all over Earth in many kinds of ecosystems, and they come in a wide variety of shapes and sizes. Just like the mats themselves, scientist interested in studying microbial mats can be found all around the world. Do you know, or have visited any place where mats would grow?

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ANHAD, AGE: 12

Hello my name is Anhad and I like writing about topics (sometimes). I also love watching tv and playing video games on my console and also love hanging out with my friends and family. I like waching netflix in my free time and cooking.

AVANI, AGE: 10

Hello, I am Avani, I like to play a lot of games of every type. I also like playing with my puppy and video games. I like animals and nature a lot! So, in warm weather, I go outside and look at my beautiful surroundings and nature around me! And in cold weather, I ski and play in the snow! Those are some things about me!

SANSKRITI, AGE: 15

Hello, my name is Sanskriti. I am 14 years old and am going into 9th grade. I love Computer Science and hope to see more girls showing interest in that field in the next few years.

AUTHORS

SANTIAGO CADENA

I am a marine biologist dedicated to the study of marine and hypersaline microorganisms. I am very interested in geomicrobiology, astrobiology, and biotechnology. I have experience in the study of the methane and sulfur cycles in microbial mats. Also, we are studying the microorganisms living in mangrove forests. In brief, I am interested in studying the role of microorganisms in nature and their potential use for biotechnological purposes.

PAULA MAZA-MÁRQUEZ

I am a postdoctoral researcher in the Exobiology Branch at NASA's Ames Research Center. I study the structure and function of microbial mats. I am particularly interested in genes that control nitrogen cycling, to explore the hypothesis that key features of the modern biological nitrogen cycle evolved in microbial mat systems.

SANDRA I. RAMÍREZ JIMÉNEZ

I am an astrobiologist at Centro de Investigaciones Químicas, Universidad Autónoma del Estado de Morelos, interested in microorganisms from extreme ecosystems, specifically, bacteria living in high salt concentrations. I study the adaptation strategies bacteria use in environments mimicking the salty water of the satellite Europa or the subsurface of the planet Mars, to understand the limits of terrestrial life and the potential for life on other bodies in the solar system.

SHARON L. GRIM

I am a postdoctoral fellow at NASA's Ames Research Center. I study cyanobacteria, which are photosynthetic microorganisms that have shaped Earth's atmosphere for billions of years by producing oxygen. I use computational tools to understand the genes and biogeochemistry of cyanobacteria and other microorganisms in extreme microbial mats.

JOSÉ Q. GARCÍA MALDONADO

I am a research scientist working at the Marine Resources Department in the Center for Research and Advanced Studies of the National Polytechnic Institute (CINVESTAV), in Mexico. My investigations are mainly related to the ecology and biotechnology of complex microbial communities in marine and extreme environments. *jose.garcia@cinvestav.mx

LESLIE PRUFERT-BEBOUT

I am a microbial ecologist and geobiologist. I am interested in how the sedimentary mineral environment characteristics affect colonization by different populations of microorganisms. I focus on cyanobacterial species and how they distribute themselves in their environments. I am also very interested in how much and what colors of light exist inside of sands and rocks.

BRAD M. BEBOUT

I am a scientist at NASA's Ames Research Center now, but I have been studying microbial mats since I was a graduate student; that was 30 years ago! I am mostly interested in how mats help recycle carbon and nitrogen in the environments where we find them, but also in the biosignatures that they produce so that we, at NASA, can see if they occur in places other than Earth.