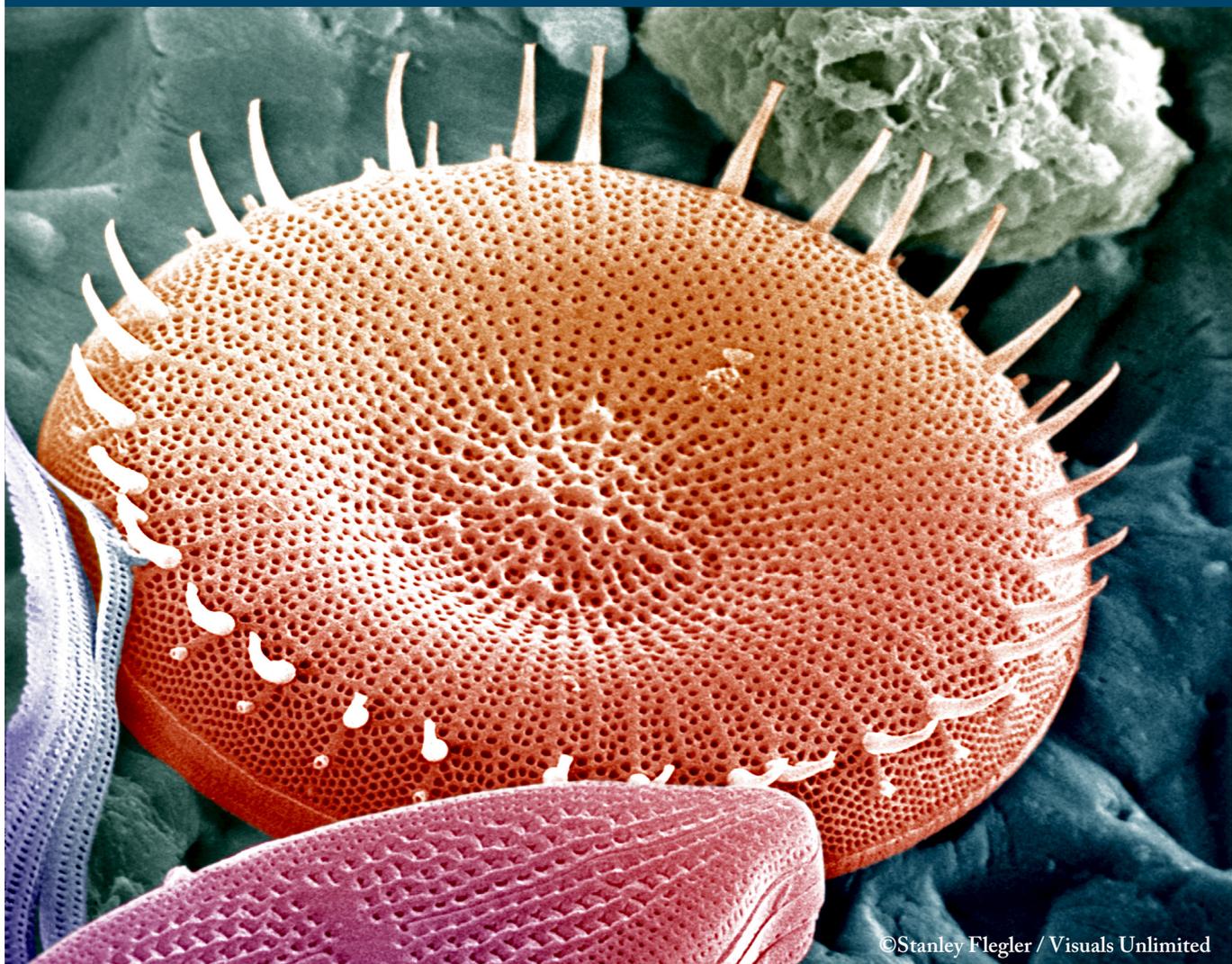


# The Microbial World: A Challenging Frontier



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The physical diversity of microbes reflects a commensurate underlying genetic and functional diversity—yielding a broad range of biochemical capabilities that sustain the planet. Diatoms (pictured above) are photosynthetic microorganisms that play a role in global carbon cycling and sequestration. Famous for their wide variety of intricately shaped silica walls, these organisms are abundant in plankton and in marine and freshwater sediments, often being found in fossil deposits.

# THE MICROBIAL WORLD:

## A Vast and Genetically Rich Resource

**M**icrobes and their communities make up the foundation of the biosphere and sustain all life on earth. These single-celled organisms are masters at living in almost every environment and harvesting energy in almost any form, from solar radiation to photosynthesis-generated organic chemicals to minerals in the deep subsurface.

Microbes have evolved over 3.5 billion years, transforming the atmosphere with oxygen (a by-product of photosynthesis) more than a billion years ago to create the environment for life as we know it. Some microbes can thrive in either aerobic (with oxygen) or anaerobic (without oxygen) conditions. Microbes also capture nitrogen from the atmosphere, make it available to plants (and other life forms), and carry out processes responsible for soil fertility. Most do not cause disease. The unique microbial biochemistries amassed over eons in every niche on the planet now offer a deep and virtually limitless resource of capabilities that can be applied to national needs, including DOE energy and environmental missions.

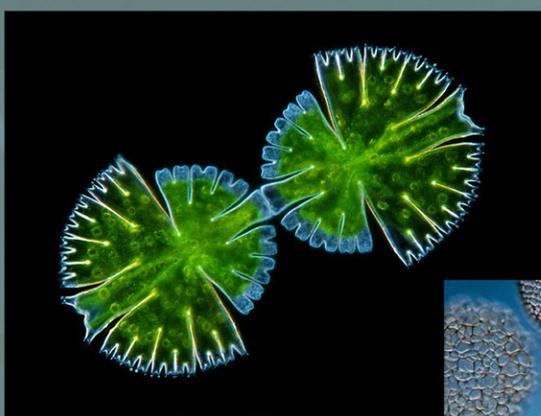
Although immense, the microbial world remains largely unexplored, a frontier of truly astronomical dimensions: The estimated nonillion or  $10^{30}$  individual bacteria on earth are  $10^9$  times more than the number of stars in the universe. The vast majority, however, cannot be studied using standard techniques. While 2000 to 3000 species are estimated to be present in a single gram of soil, we can cultivate for study only some 0.1 to 1% of the species in that or any other environment. About 5700 species have been described thus far.<sup>1-3</sup>

Investigators now are beginning to apply the tools of genomics to studying this enormous untapped natural treasure. Because microbes have modest-sized genomes (averaging 4 to 5 million bases compared with 3 billion bases in the human and other mammalian genomes), they represent a tractable life form we can use to explore and understand life processes at a whole-system level. Already, limited environmental sampling of microbes and their communities has led to the

discovery of millions of previously unknown genes and proteins, thousands of species, and innumerable variations in critical functionalities. As scientists begin to scratch the surface of the microbial world, they are finding analysis an enormous challenge.

Recent discoveries from projects funded by DOE's Biological and Environmental Research program highlight the ubiquitous presence and critical importance of microbes in all ecosystems. For example:

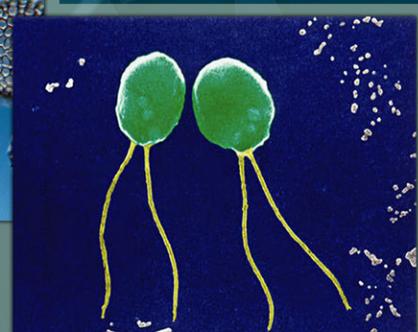
- The cyanobacteria *Prochlorococcus* and *Synechococcus*, along with other ocean phytoplankton, account for about half of global photosynthesis.<sup>4</sup>



***Micrasterias rotata*, a Desmid Undergoing Cell Division or Cytokinesis.** Desmids are attractive unicellular freshwater green algae that have a distinct basic symmetry consisting of two semicells with the nucleus situated in the narrow center. When they divide, two new semicells are formed.  
[© Wim van Egmond / Visuals Unlimited]



***Spumellarian radiolarian*, Skeletons from the Ocean Bottom.** Radiolarians are unicellular protists with strikingly beautiful siliceous skeletons showing radial symmetry.  
[© Wim van Egmond / Visuals Unlimited]



***Chlamydomonas*, Green Algae with Two Flagella for Movement.** These microbes can generate hydrogen from light, water, and basic nutrients.  
[Elias Greenbaum, Oak Ridge National Laboratory]

- Diatoms, ancient and intricately shaped ocean microbes, store an amount of carbon comparable to that in all the earth's rainforests combined. Over geological time, diatoms may have influenced the earth's climate.<sup>5</sup>
- More than a million previously undiscovered genes, possibly representing new biochemical functions, were the surprising find in sequencing DNA fragments from the Sargasso Sea—a region heretofore thought to sustain little life.<sup>6</sup> This discovery also was named one of *Science* magazine's "Breakthroughs of the Year."<sup>7</sup>

# A CHALLENGING FRONTIER

- Microbes thrive deep within the earth's subsurface and at extremes previously thought to extinguish life.<sup>8</sup>

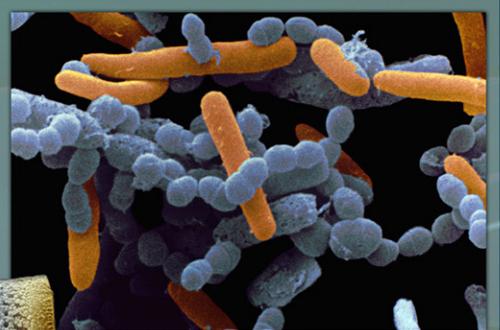
Growing recognition of microbial capabilities and potential applications has made a compelling case for further investigations by DOE and other agencies and institutions.

Before we can harness their capabilities, microbes must be understood in far greater detail and in the realistic context of whole living systems—whether as individuals or communities of interacting microbes—rather than as isolated components such as single genes and proteins. Microbes already can be manipulated at the molecular, cellular, and system levels, but understanding and taking advantage of their complexities and surmounting the technical challenges of whole-systems biology is a daunting prospect.

## Understanding MICROBES and Their Communities

Most microbes live in highly organized and interactive communities that are versatile, complex, and difficult to analyze from many perspectives. Some of these challenges are outlined below.

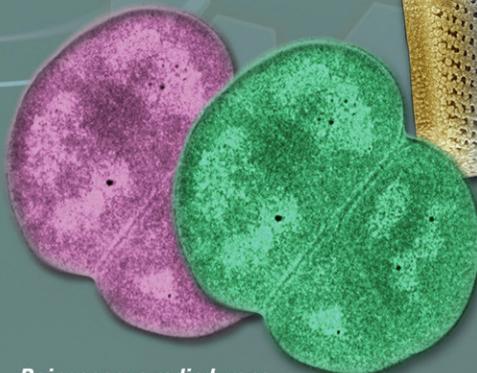
- Microbes are exceedingly small—only 1/8000th the volume of a human cell and spanning about 1/100th the diameter of a human hair. Investigating processes within this size range is challenging.
- The microbial world encompasses millions of genes from thousands of species, with hundreds of thousands of proteins and multimolecular machines operating in a web of hundreds of interacting processes in response to numerous physical and chemical environmental variables. Gene control is complex, with groups or “cassettes” of genes (operons) directing coordinated transcription and translation of genes into interacting proteins.
- Microbes adapt rapidly in response to environmental change, an ability that underlies their survival for billions of years. For example, various species of “extremophile” microbes have adapted to great extremes of pressure, temperature, pH, salinity, and radiation. Their high surface-to-volume ratio enhances interactions and supports adaptation. Unlike animal cells, they have no protective nucleus for their DNA, which leaves it more vulnerable to alteration. Genes move easily among species. Moreover, microbial communities are awash in genetic material from viruses that confer additional genetic properties and expand their range of adaptability.



**Rod-Shaped (Bacilli) and Spherical (Cocci) Bacteria Found in Compost.**

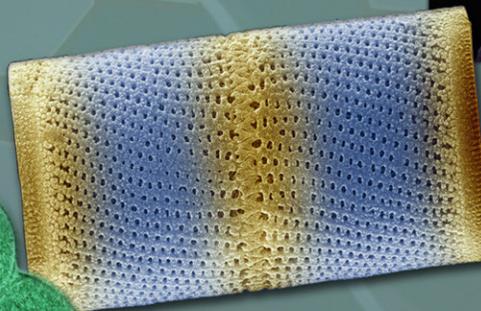
Decomposition of organic matter is an extremely important process in nature and a part of the global carbon and nutrient cycle.

[© Simko / Visuals Unlimited]



***Deinococcus radiodurans*, the Most Radiation-Resistant Microbe Known.**

[Michael Daly, Uniformed Services University of the Health Sciences]



**Diatom, a Unicellular Algae.**

The cell walls of diatoms are made of silica and come in a variety of shapes. These microscopic algae may be either fresh or saltwater, are photosynthetic, and play a role in carbon cycling.

[© Stanley Flegler / Visuals Unlimited]

other natural ecosystems. These “metagenomics” studies have given us a glimpse into the intricacies of these natural ecosystems and their diverse functions.

References noted on these pages are listed on the last page of this section.

- Microbial communities can extend in size from cubic millimeters (or smaller) to cubic kilometers. Even relatively simple communities can have millions of genes, giving them a genetic diversity substantially greater than that of higher life forms, even humans. Recent investigations have focused on collecting DNA fragments from environmental samples in the sea and