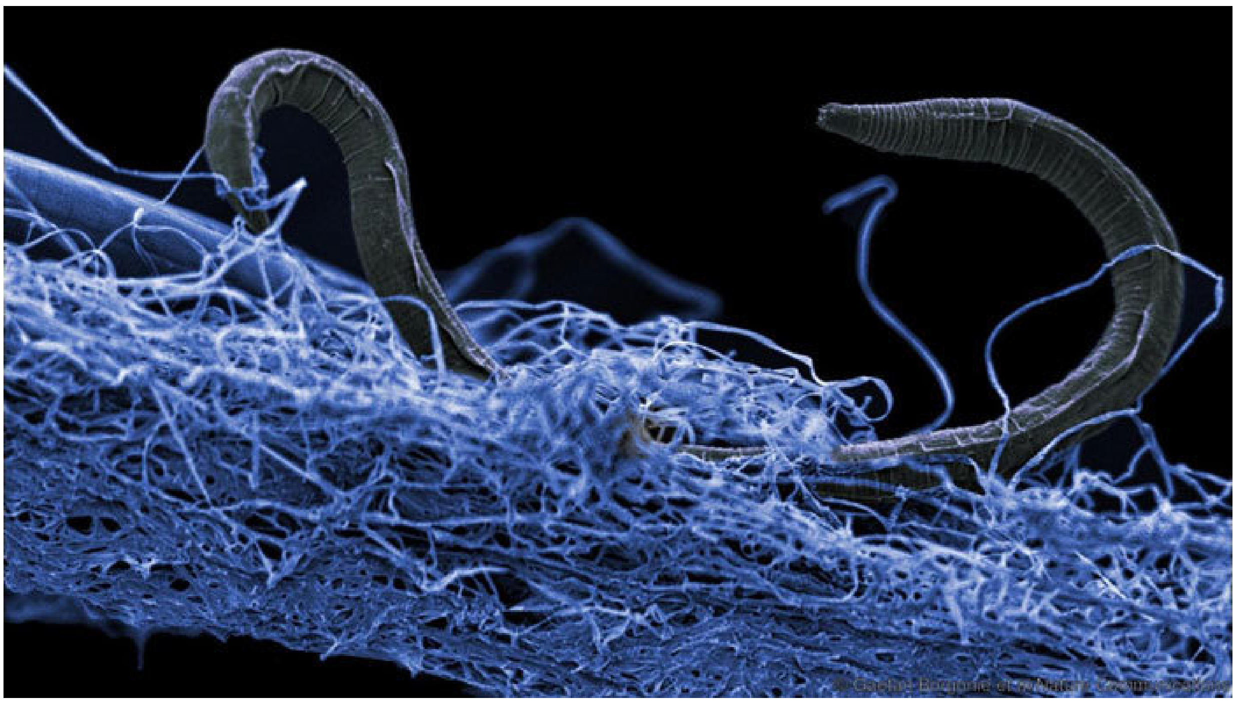
Life in deep Earth totals 15 to 23 billion tons of carbon—hundreds of times more than humans

December 10 2018



A nematode (eukaryote) in a biofilm of microorganisms. This unidentified nematode (Poikilolaimus sp.) from Kopanang gold mine in South Africa, lives 1.4 km below the surface. Credit: Gaetan Borgonie, Extreme Life Isyensya, Belgium

Barely living "zombie" bacteria and other forms of life constitute an immense amount of carbon deep within Earth's subsurface—245 to 385 times greater than the carbon mass of all humans on the surface, according to scientists nearing the end of a 10-year international collaboration to reveal Earth's innermost secrets.

On the eve of the American Geophysical Union's annual meeting, scientists with the Deep Carbon Observatory today reported several transformational discoveries, including how much and what kinds of life exist in the deep subsurface under the greatest extremes of pressure, temperature, and low nutrient availability.

Drilling 2.5 kilometers into the seafloor, and sampling microbes from continental mines and boreholes more than 5 km deep, scientists have used the results to construct models of the ecosystem deep within the planet.

With insights from now hundreds of sites under the continents and seas, they have approximated the size of the deep biosphere—2 to 2.3 billion cubic km (almost twice the volume of all oceans) - as well as the carbon mass of deep life: 15 to 23 billion tonnes (an average of at least 7.5 tonnes of carbon per cu km subsurface).

The work also helps determine types of extraterrestrial environments that could support life.

Among many key discoveries and insights:

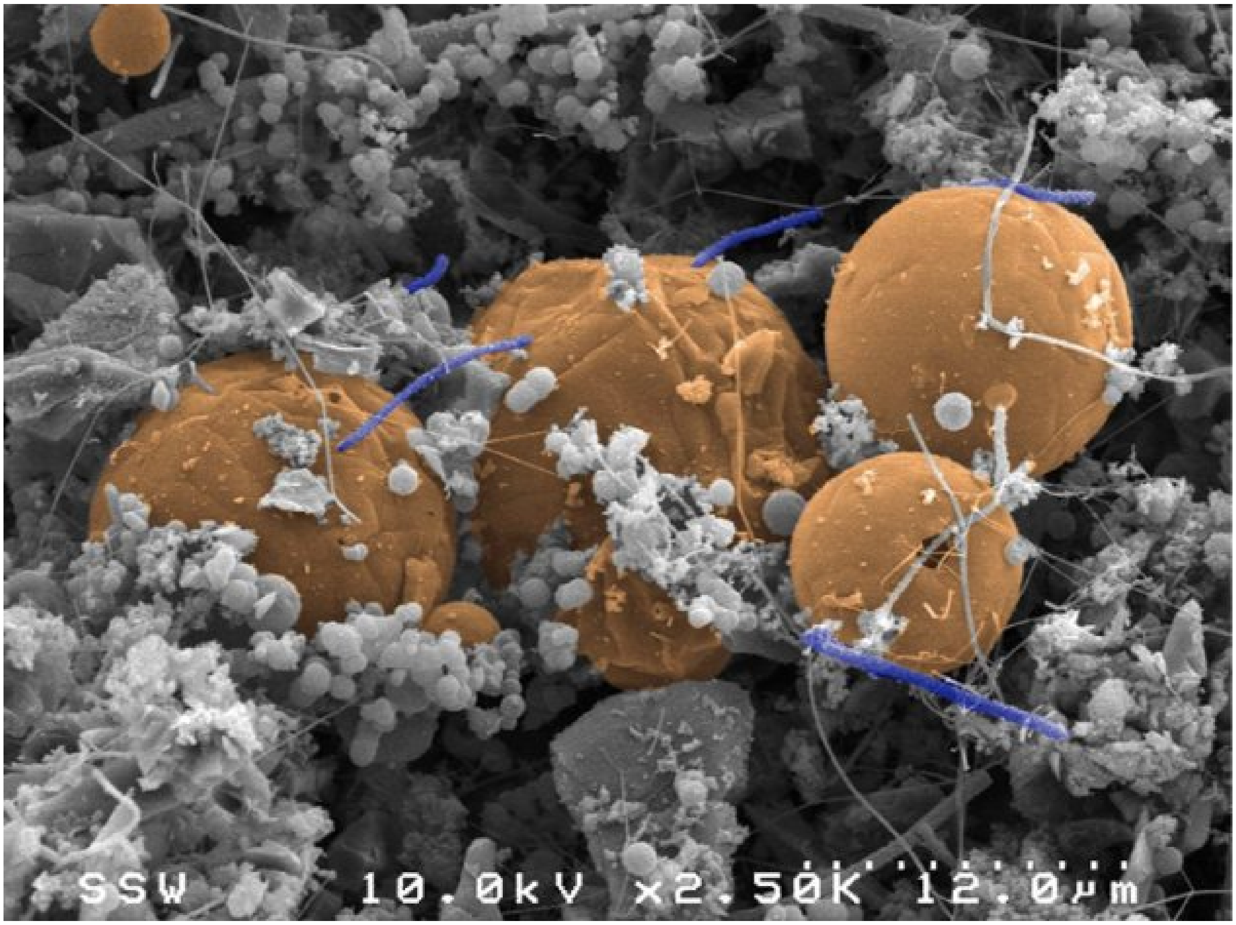
- The deep biosphere constitutes a world that can be viewed as a sort of "subterranean Galapagos" and includes members of all three domains of life: bacteria and archaea (microbes with no membrane-bound nucleus), and eukarya (microbes or multicellular organisms with cells that contain a nucleus as well as membrane-bound organelles)

- Two types of microbes—bacteria and archaea—dominate Deep Earth. Among them are millions of distinct types, most yet to be discovered or characterized. This so-called microbial "dark matter" dramatically expands our perspective on the tree of life. Deep Life scientists say about 70% of Earth's bacteria and archaea live in the subsurface
- Deep microbes are often very different from their surface cousins, with life cycles on near-geologic timescales, dining in some cases on nothing more than energy from rocks
- The genetic diversity of life below the surface is comparable to or exceeds that above the surface
- While subsurface microbial communities differ greatly between environments, certain genera and higher taxonomic groups are ubiquitous—they appear planet-wide
- Microbial community richness relates to the age of marine sediments where cells are found—suggesting that in older sediments, food energy has declined over time, reducing the microbial community
- The absolute limits of life on Earth in terms of temperature, pressure, and energy availability have yet to be found. The records continually get broken. A frontrunner for Earth's hottest organism in the natural world is Geogemma barossii, a single-celled organism thriving in hydrothermal vents on the seafloor. Its cells, tiny microscopic spheres, grow and replicate at 121 degrees Celsius (21 degrees hotter than the boiling point of water). Microbial life can survive up to 122°C, the record achieved in a lab culture (by comparison, the record-holding hottest place on Earth's surface, in an uninhabited Iranian desert, is about 71°C—the temperature of well-done steak)
- The record depth at which life has been found in the continental subsurface is approximately 5 km; the record in marine waters is 10.5 km from the ocean surface, a depth of extreme pressure; at 4000 meters depth, for example, the pressure is approximately

400 times greater than at sea level
- Scientists have a better understanding of the impact on life in subsurface locations manipulated by humans (e.g., fracked shales, carbon capture and storage)

Ever-increasing accuracy and the declining cost of DNA sequencing, coupled with breakthroughs in deep ocean drilling technologies (pioneered on the Japanese scientific vessel Chikyu, designed to ultimately drill far beneath the seabed in some of the planet's most seismically-active regions) made it possible for researchers to take their first detailed look at the composition of the deep biosphere.

There are comparable efforts to drill ever deeper beneath continental environments, using sampling devices that maintain pressure to preserve microbial life (none thought to pose any threat or benefit to human health).



Candidatus Desulforudis audaxviator(the purplish, blue rod-shaped cells straddling orange carbon spheres) is a species of bacteria that survives on hydrogen. Scientists found it living within a fluid and gas-filled fracture 2.8 km beneath Earth's surface at a mine near Johannesburg, South Africa. The genus name Desulforudis comes from the Latin for "from sulfur" and "rod," noting its shape and its ability to get energy from sulfates. And audaxviator? From Jules Verne's Journey to the Center of the Earth, and a message in Latin deciphered by Verne's protagonist, Professor Lidenbrock, which read in part: "descend, bold traveler, and attain the center of the Earth." Credit: Greg Wanger, California Institute of Technology, USA, and Gordon Southam University of Queensland, Australia

To estimate the total mass of Earth's subcontinental deep life, for example, scientists compiled data on cell concentration and microbial diversity from locations around the globe.

Led by Cara Magnabosco of the Flatiron Institute Center for Computational Biology, New York, and an international team of researchers, subsurface scientists factored in a suite of considerations, including global heat flow, surface temperature, depth and lithology—the physical characteristics of rocks in each location—to estimate that the continental subsurface hosts 2 to 6 × 10^29 cells.

Combined with estimates of subsurface life under the oceans, total global Deep Earth biomass is approximately 15 to 23 petagrams (15 to 23 billion tonnes) of carbon.

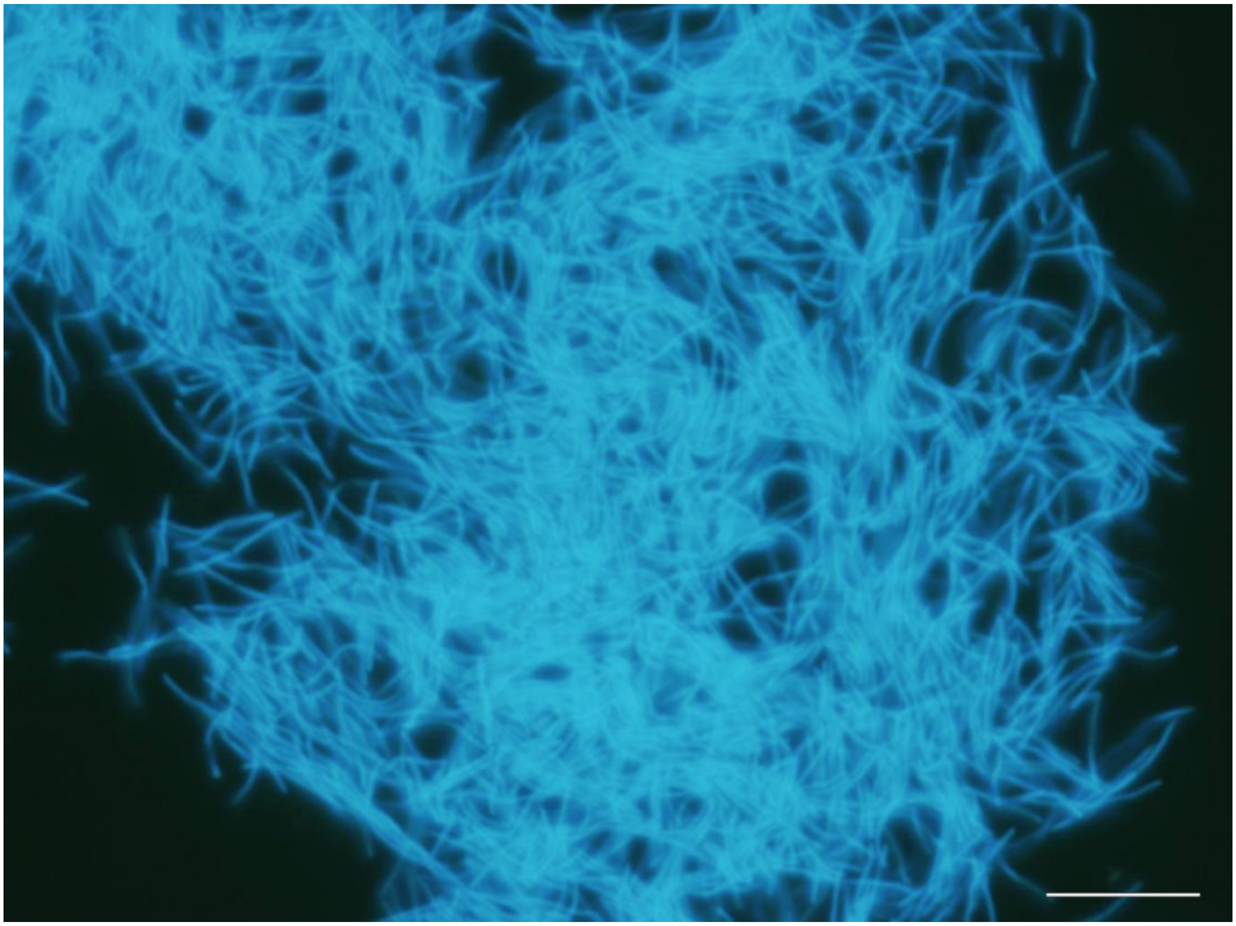
Says Mitch Sogin of the Marine Biological Laboratory Woods Hole, USA, co-chair of DCO's Deep Life community of more than 300 researchers in 34 countries: "Exploring the deep subsurface is akin to exploring the Amazon rainforest. There is life everywhere, and everywhere there's an awe-inspiring abundance of unexpected and unusual organisms.

"Molecular studies raise the likelihood that microbial dark matter is much more diverse than what we currently know it to be, and the deepest branching lineages challenge the three-domain concept introduced by Carl Woese in 1977. Perhaps we are approaching a nexus where the earliest possible branching patterns might be accessible through deep life investigation.

"Ten years ago, we knew far less about the physiologies of the bacteria and microbes that dominate the subsurface biosphere," says Karen Lloyd, University of Tennessee at Knoxville, USA. "Today, we know that, in many places, they invest most of their energy to simply maintaining their existence and little into growth, which is a fascinating way to live.

"Today too, we know that subsurface life is common. Ten years ago, we had sampled only a few sites—the kinds of places we'd expect to find life. Now, thanks to ultra-deep sampling, we know we can find them pretty much everywhere, albeit the sampling has obviously reached only an infinitesimally tiny part of the deep biosphere."

"Our studies of deep biosphere microbes have produced much new knowledge, but also a realization and far greater appreciation of how much we have yet to learn about subsurface life," says Rick Colwell, Oregon State University, USA. "For example, scientists do not yet know all the ways in which deep subsurface life affects surface life and vice versa. And, for now, we can only marvel at the nature of the metabolisms that allow life to survive under the extremely impoverished and forbidding conditions for life in deep Earth."



Species of Methanobacterium, which produces methane. Found in samples from a buried coal bed 2 km below the Pacific Ocean floor off the coast of Japan, this specimen was retrieved during an Integrated Ocean Drilling Program (now the International Ocean Discovery Program) expedition aboard the Drilling Vessel Chikyu. Bar represents 10 µm (micrometers, or 0.0004 inch). Credit: Hiroyuki Imachi (Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Among the many remaining enigmas of deep life on Earth:

Movement: How does deep life spread—laterally through cracks in rocks? Up, down? How can deep life be so similar in South Africa and Seattle, Washington? Did they have similar origins and were separated by plate tectonics, for example? Or do the communities themselves move? What roles do big geological events (such as plate tectonics, earthquakes; creation of large igneous provinces; meteoritic bombardments) play in deep life movements?

Origins: Did life start deep in Earth (either within the crust, near hydrothermal vents, or in subduction zones) then migrate up, toward the sun? Or did life start in a warm little surface pond and migrate down? How do subsurface microbial zombies reproduce, or live without dividing for millions to tens of millions of years?

Energy: Is methane, hydrogen, or natural radiation (from uranium and other elements) the most important energy source for deep life? Which sources of deep energy are most important in different settings? How do the absence of nutrients, and extreme temperatures and pressure, impact microbial distribution and diversity in the subsurface?

"Discoveries regarding the nature and extent of the deep microbial biosphere are among the crowning achievements of the Deep Carbon Observatory. Deep life researchers have opened our eyes to remarkable vistas—emerging views of life that we never knew existed."says Robert Hazen, senior staff scientist, Geophysical Laboratory, Carnegie Institution for Science, and DCO Executive Director.

"They are not Christmas ornaments, but the tiny balls and tinsel of deep life look they could decorate a tree as well as Swarovski glass. Why would nature make deep life beautiful when there is no light, no mirrors?" says Jesse Ausubel of the Rockefeller University, a founder of the DCO.

Provided by Deep Carbon Observatory