Methane-eating 'Borgs' have been assimilating Earth's microbes

October 19 2022

A digital illustration inspired by methane-eating archaea and the Borgs that assimilate them. Credit: Jenny Nuss/Berkeley Lab

In Star Trek, the Borg are a ruthless, hive-minded collective that assimilate other beings with the intent of taking over the galaxy. Here on nonfictional planet Earth, Borgs are DNA packages that could help humans fight climate change.

Last year, a team led by Jill Banfield discovered DNA structures within a methane-consuming microbe called Methanoperedens that appear to supercharge the organism's metabolic rate. They named the genetic elements "Borgs" because the DNA within them contains genes assimilated from many organisms. In a study published today as the cover item in *Nature*, the researchers describe the curious collection of genes within Borgs and begin to investigate the role these DNA packages play in environmental processes, such as carbon cycling.

First contact

Methanoperedens are a type of archaea (unicellular organisms that resemble bacteria but represent a distinct branch of life) that break down methane (CH_4) in soils, groundwater, and the atmosphere to support cellular metabolism. Methanoperedens and other methane-consuming microbes live in diverse ecosystems around the world but are believed to be less common than microbes that use photosynthesis, oxygen, or fermentation for energy.

Yet they play an outsized role in Earth system processes by removing methane—the most potent greenhouse gas—from the atmosphere. Methane traps 30 times more heat than carbon dioxide and is estimated to account for about 30 percent of human-driven global warming. The gas is emitted naturally through geological processes and by methane-generating archaea; however, industrial processes are releasing stored methane back into the atmosphere in worrying quantities.

Banfield, a faculty scientist at Lawrence Berkeley National Laboratory (Berkeley Lab) and professor of Earth & Planetary Science and Environmental Science, Policy & Management at UC Berkeley, studies how microbial activities shape large-scale environmental processes and how, in turn, environmental fluctuations alter the planet's microbiomes.

As part of this work, she and her colleagues regularly sample microbes in different habitats to see what interesting genes microbes are using for survival, and how these genes might affect global cycles of key elements, such as carbon, nitrogen, and sulfur. The team looks at the genomes within cells as well as the portable packets of DNA known as extra-chromosomal elements (ECEs) that transfer genes between bacteria, archaea, and viruses. These elements allow microbes to quickly gain beneficial genes from their neighbors, including those that are only distantly related.

While studying Methanoperedens sampled from seasonal wetland pool soil in California, the scientists found evidence of an entirely new type of ECE. Unlike the circular strands of DNA that make up most plasmids, the most well-known type of extra-chromosomal element, the new ECEs are linear and very long—up to one-third the length of the entire Methanoperedens genome.

After analyzing additional samples from underground soil, aquifers, and riverbeds in California and Colorado that contain methane-consuming archaea, the team uncovered a total of 19 distinct ECEs they dubbed Borgs.

Using advanced genome analysis tools, the scientists determined that many of the sequences within the Borgs are similar to the methane-metabolizing genes within the actual Methanoperedens genome. Some of the Borgs even encode all the necessary cellular machinery to eat methane on their own, so long as they are inside a cell that can express the genes.

"Imagine a single cell that has the ability to consume methane. Now you add genetic elements within that cell that can consume methane in parallel and also add genetic elements that give the cell higher capacity. It basically creates a condition for methane consumption on steroids, if you will," explained co-author Kenneth Williams, a senior scientist and Banfield's colleague in Berkeley Lab's Earth and Environmental Sciences Area.

Williams led research at the Rifle, Colorado site where the best characterized Borg was recovered, and is also chief field scientist of a research site on the East River, near Crested Butte, Colorado, where some of Banfield's current sampling takes place.

The East River field site is part of the Department of Energy's Watershed Function Scientific Focus Area, a multidisciplinary research project led by Berkeley Lab that aims to link microbiology and biochemistry with hydrology and climate science. "Our expertise is bringing together what are often thought of and treated as completely disparate fields of inquiry—big science that links everything from genes all the way up to watershed and atmospheric processes."

Resistance is futile

Banfield and her fellow researchers at UC Berkeley's Innovative Genomics Institute, including co-author and longtime collaborator Jennifer Doudna, hypothesize that the Borgs could be residual fragments of entire microbes that were engulfed by Methanoperedens to aid metabolism, similar to how plant cells harnessed formerly free-living photosynthetic microbes to gain what we now call chloroplasts, and how an ancient eukaryotic cell consumed the ancestors of today's mitochondria.

Based on the similarities in sequences, the engulfed cell could have been a relative of Methanoperedens, but the overall diversity of genes found in the Borgs indicates that these DNA packages were assimilated from a wide range of organisms.

Jill Banfield and Kenneth Williams collect a sample of water from the East River in Colorado to study the ecosystem's microbial life. Credit: Roy Kaltschmidt/Berkeley Lab

No matter the origin, it is clear that Borgs have existed alongside these archaea, shuttling genes back and forth, for a very long time.

Notably, some Methanoperedens were found with no Borgs. And, in addition to recognizable genes, the Borgs also contain unique genes encoding other metabolic proteins, membrane proteins, and extracellular proteins almost certainly involved in electron conduction required for energy generation, as well as other proteins that have unknown effects on their hosts.

Until the scientists can culture Methanoperedens in a laboratory environment, they won't know for sure what capabilities the different Borgs confer, why some microbes use them, and why others don't.

One likely explanation is that Borgs act as a storage locker for metabolic genes that are only needed at certain times. Ongoing methane monitoring research has shown that methane concentrations can vary significantly throughout the year, usually peaking in the fall and dropping to the lowest levels in early spring. The Borgs therefore provide a competitive advantage to methane-eating microbes like Methanoperedens during periods of abundance when there is more methane than their native cellular machinery can break down.

Plasmids are known to serve a similar purpose, quickly spreading genes for resistance to toxic molecules (like heavy metals and antibiotics) when the toxins are present in high enough concentrations to exert evolutionary pressure.

"There is evidence that different types of Borgs sometimes coexist in the same host Methanopreredens cell. This opens the possibility that Borgs could be spreading genes across lineages," said Banfield.

Boldly exploring the (microbial) universe

Since posting their article as a pre-print last year, the team has begun follow-up work to better understand how Borgs may affect biological and geological processes. Some researchers are combing through data sets of genetic material from other microorganisms, looking for evidence that Borgs exist in association with other species.

While her colleagues are using lab-based methods, co-author Susan Mullen, a graduate student in Banfield's lab, will be getting her feet wet with some very picturesque field work. She recently started a project to sample microbes from the floodplains of the East River throughout the year to assess how seasonal changes in Borg abundance and other microbes known to be involved in methane cycling correlate to seasonal fluxes of methane.

According to the authors, years down the line, carefully cultured microbes chock full of Borgs could be used to reduce methane and curb global warming. It's all to benefit the collective—life on Earth.

More information: Jillian Banfield, Borgs are giant genetic elements with potential to expand metabolic capacity, *Nature* (2022). DOI: 10.1038/s41586-022-05256-1

Provided by Lawrence Berkeley National Laboratory