ORIGINS OF LIFE

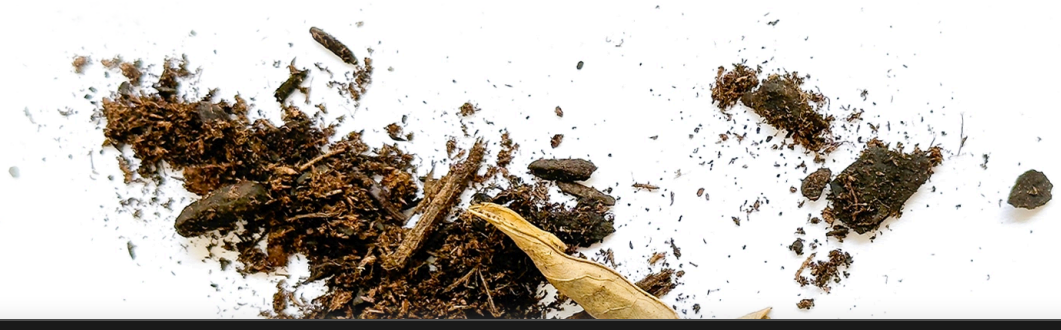
The Dirt That Refused To Die

Lifelike biochemistry continued to unfold in sterilized soil for six years, pointing to a metabolic theory for how biology began.

Samuel Velasco/*Quanta Magazine*

For 15 years, Sébastien Fontaine has been trying to kill dirt. The biochemist, who runs a lab at the French National Institute for Agriculture, Food, and Environment, wanted to know how much carbon is released by soil — just dirt alone, completely devoid of life. His team sealed dirt into jars and blasted them with

Fontaine's lab repeated the experiments and produced the same results. Finally, convinced that they weren't dealing with an artifact of the experimental setup, they set out to find the source of breath in dead soil.

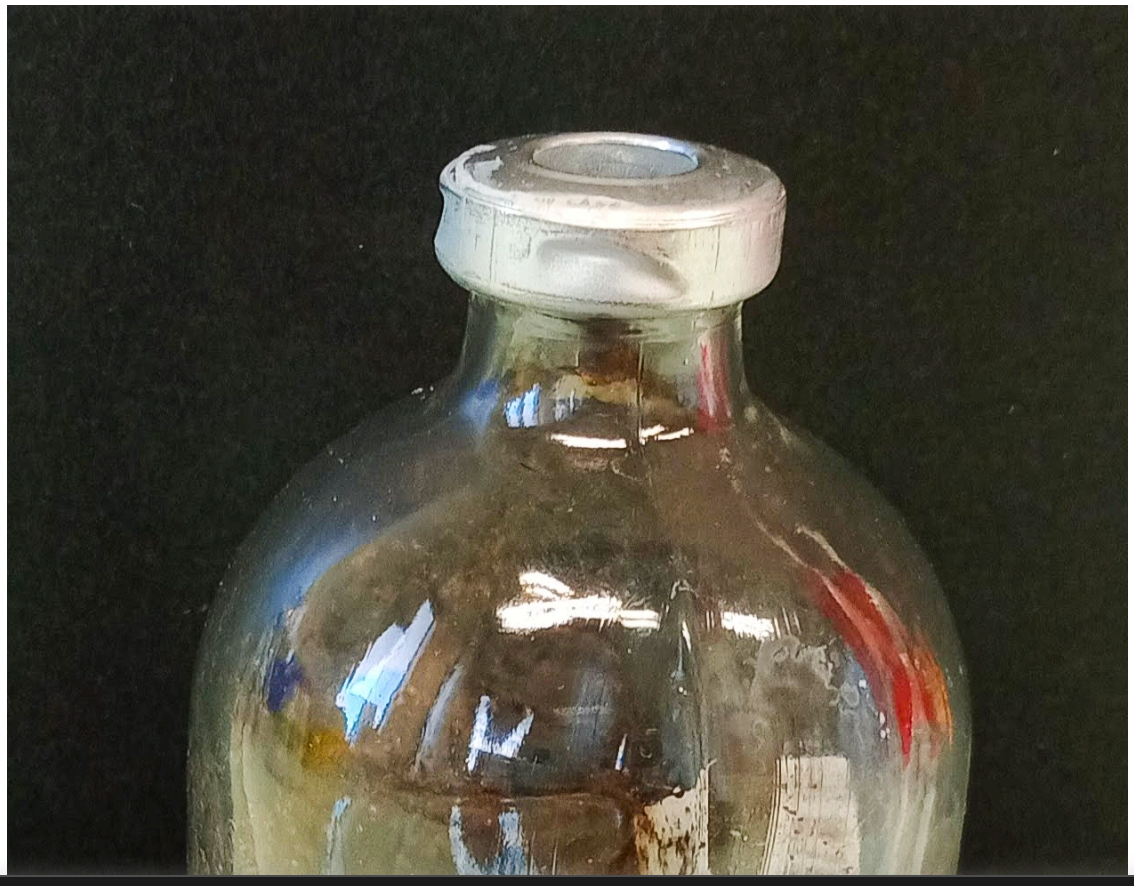


dirt, absent the living proteins that would typically organize it. If they're right, some biochemical reactions, such as those that release the energy of carbon-rich sugar molecules, may not be unique to living things. Such reactions — known as metabolism when performed by cells — could even predate life on Earth, Fontaine said.

The experiments show "what happens to

When he made this accidental discovery, Fontaine was trying to establish a baseline for carbon in lifeless soil. Using a sterile syringe, the researchers periodically sampled the air in a hermetically sealed jar containing soil and measured its carbon content using a mass spectrometer. After radiation wiped out the soil microbes, the carbon emission rate declined

quickly but didn't disappear. It remained stable for over 100 days.



The type of soil-filled vessel used for the lab's experiments "represents the microcosms in which the whole story unfolded," Bouquet said.

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Clémentin Bouquet

When he shared the results with other researchers, they advised him to treat it as an experimental artifact — a source of error not

speculated, was because the enzymes had ramped up a reaction that was already happening.

Convincing the scientific community, however, was an uphill battle. When Fontaine submitted the manuscript to journals for publication, some reviewers “were highly positive, and others were really suspicious, especially concerning the sterility of the soil,” he recalled.

more radiation, pressure, and heat. Still, the soil continued to emit carbon for months.

Through an electron microscope, Benoit Kéraval, then a graduate student in Fontaine's lab, found cells in the irradiated soil. But staining showed no RNA or DNA molecules, indicating that the cells were definitely dead. When they experimentally added microbes to simulate contamination, the cells rapidly

Dirty Electrons

For six years, Bouquet and Kéraval studied two sets of sealed, irradiated soil samples — one of

When they measured the samples again, at days 1,606 and 2,442, the emissions had slowed further, but the soil was still breathing. The glucose-augmented samples showed higher emission rates, which strengthened Fontaine's suspicion that nonbiological catalysts in soil can induce reactions that resemble the metabolic breakdown of sugar.

During metabolism, sugar is broken down into

He devised a fuel cell that could detect electrons zipping through soil in the form of a current. His team added soil that had been irradiated almost five years earlier, and then closed the circuit. A current passed through the soil that was several times higher than in a control setup involving a saltwater solution. According to Fontaine, the experiment demonstrated that sterile soil supports a flow of electrons indicative of processes that resemble the

oxygen-dependent metabolism of the Krebs cycle.

that lifelike biochemistry takes place even in sterile soil.

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Öykü Ataytür

It was once thought that the Krebs cycle cannot occur outside the controlled confines of a cell, which teems with enzymes that keep everything ticking along and increases the

reactions without the presence of life.

An Origin of Life?

For Joshua Schimel, a soil ecologist at the University of California, Santa Barbara, Fontaine's findings were not too surprising. "Glucose naturally, in the process of being oxidized, is going to form some of these Krebs-cycle intermediates," he said. Many soils are

reactions before life emerged. Studies, including his, suggest that the chemical reactions that break down and construct glucose derivatives, which are normally associated with life, might have existed before the enzymes and genes that enable them in living cells.

“There’s a handful of researchers like myself that think, actually, we should organize our thoughts about life in a different way — that we

“This fits a bit into my thinking about how metabolism started in evolution,” he said of the new work. “If it would be very hard to do, then the planet would not be full of life now.” This idea is complicated, however, by the low-oxygen conditions in which life arose.

reactions, said Sudha Rajamani, an astrobiologist at the Indian Institute of Science Education and Research, Pune who wasn't involved in the study.

Ralser agrees with her. "My gut feeling is they still have a lot of enzymes there [in Fontaine's irradiated soil], even after six years," he said. To know whether metals and minerals in soil could spontaneously carry out these reactions, the

recently dead cells contribute to carbon emissions in real-world soils, but the long-term experimental results make it “very unlikely that the respiration we observed is due to enzymes,” he said.

For Bouquet, chasing this years-long obsession has highlighted that “even in a context as close and familiar to us as terrestrial soil, we are not always able to distinguish or recognize

itself," Bouquet said, "right there under our feet."