Project Report: Delivery of Organic Materials to Planets

**University of Rhode Island**
**Executive Summary**
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*Life is abundant in Earth's atmosphere, on its surface, and in its seas −− that is, in the biosphere. But scientists are revising and expanding their ideas about the ubiquitousness of Earth's living organisms. Their research has shown that life goes on in what may constitute another biosphere, one in which organisms (collectively called extremophiles) are able to live and thrive in a superhot, superpressure, eternally dark underworld that exists far below deep−ocean bottoms. This subterranean community is known to exist to depths of at least a half mile below the seafloor, and there are estimates that it might account for as much as one−tenth to one−third of Earth's living biomass.*

The study of subsurface life is the principal focus of the NASA Astrobiology Institute's University of Rhode Island (URI) team. Sediments deep beneath the seafloor constitute the team's primary field area. The team's objectives are to understand the subsurface microbial ecosystems of marine sediments, their role in Earth's biogeochemical cycles, and their relevance to the search for life on other planets.

The approach of the URI team is fundamentally interdisciplinary. Team members use advanced techniques from a wide range of fields, including microbiology, molecular biology, organic and inorganic biogeochemistry, geology, and geophysics. Their work is field−, laboratory−, and model−based. URI team members routinely participate in Ocean Drilling Program (ODP) cruises and, in this reporting period, played a leading role in the first ocean drilling expedition to be dedicated to study of life deep beneath the seafloor.

The URI Team is using a variety of biogeochemical techniques to identify metabolic interactions in deeply buried sediments. For example, team members are actively testing thermodynamic hypotheses of microbial competition in deep subseafloor environments. Initial results suggest that in subseafloor sediments, hydrogen concentrations are fixed at the lowest concentrations that provide sufficient free energy for hydrogen−using metabolic reactions to proceed. If these results are shown to apply more generally to subsurface ecosystems, they will demonstrate a key aspect of microbial competition. They may also eventually guide the search for thermodynamic competition (or its absence) on other planetary bodies.

URI team members are also using a variety of techniques to quantify rates of metabolic activity deep beneath the seafloor. For example, in this reporting period, they compiled and computationally modeled biogeochemical data from 25 years of deep−sea drilling expeditions. That study suggested that metabolic activity deep beneath the seafloor is greatest in narrow zones of sulfate−reducing methane oxidation along ocean margins. It also showed that the metabolic activity of life beneath the seafloor is generally orders of magnitude lower than that of life on Earth's surface.

To understand better the phylogenetic composition of buried microbial ecosystems in marine sediments, the team undertook the first community−wide genetic assays of life deep beneath the seafloor. Their pilot study of selected samples from a western Pacific drill site suggests that subseafloor communities are not simply buried oceanic communities, and that distinct communities occur at different sediment depths. Future studies are expected to test the geographic continuity of subseafloor communities and their relation to the physical and biogeochemical structure of deeply buried sediments.

To accomplish their objectives, the team's investigators, post−doctoral researchers, graduate students, and select undergraduate students collaborate with each other, with other members of the NASA Astrobiology Institute, and with scientists at other institutions throughout the world.

Some of these collaborations are within the URI team, but directly serve the broader community. For example, a website (http://deschutes.gso.uri.edu/subsurface) provides community access to global compilations of biogeochemical and physical properties that may define the limits to life in deeply buried marine environments. This website provides ready access to biogeochemical and geothermal information to help scientists assess the nature of microbial communities and activities that are likely to exist in marine sediments of different regions at different depths beneath the seafloor. The ecosystems of these subsurface habitats are potentially representative of ecosystems that may exist on other planets. For example, this website is expected to aid the search for anaerobic communities strongly supported by chemolithotrophy and the search for the upper thermal limit to life in deeply buried deep−sea sediments (fig. 1).

Other collaborations are between individual members of different NAI teams and are closely focused on specific studies of mutual interest. For example, URI team members are collaborating closely with the Marine Biological Laboratory (MBL) team in using multiple biomolecular approaches to document the microbial diversity of near−surface marine hydrothermal sediments (of the eastern Pacific Guaymas Basin). Similarly, a URI team member and a member of the Pennsylvania State University Astrobiology Research Center (PSARC) are collaborating closely with each other and with others in documenting the composition and structure of anaerobic methane−oxidizing microbial communities in near−surface marine sediments. Biogeochemical modeling suggests that such sulfate−reducing methanotrophic communities began to strongly influence Earth's biogeochemical cycles and climate 2.7 billion years ago.

Other collaborations are much broader in scope. URI participation in Ocean

Drilling Program Leg 201 entailed close collaboration with scientists from leading research institutions throughout the world. This 2−month expedition, the first deep−sea drilling expedition to be dedicated to the study of life deep beneath the seafloor, was proposed and co−led by URI Team members. The 26−member shipboard team included scientists from URI, the Max Planck Institute for Marine Microbiology (Germany), and PSARC.

The expedition drilled sites in the open equatorial Pacific, in the Peru Basin, and on the continental shelf of Peru −− sites selected to represent the general range of subsurface environments that exists in marine sediments throughout most of the world's oceans. In water depths as great as 5,300 meters and as shallow as 150 meters, the expedition drilled up to 420 meters into oceanic sediments and the underlying rocky crust. The sediments ranged in temperature from 1°C to 25°C and in age from 0 to almost 40 million years. Microbial cells and a range of metabolic activities were discovered in all sediments at all depths (fig. 2). Many of the samples collected during this cruise, and much of the data generated are being closely analyzed by NAI members and by their collaborators. Their objective is to document the composition, structure, and biogeochemical effects of these subseafloor ecosystems, as well as their relevance to the search for life on other planets.

The success of this expedition required close international funding cooperation, as well as extensive research collaboration. The direct expeditionary costs were borne by the Ocean Drilling Program (ODP), an international partnership of scientists and research institutions organized to study the evolution and structure of the Earth. The ODP is funded principally by the U.S. National Science Foundation, with substantial contributions from its international partners. Much of the pre−cruise development of techniques specific to the expedition was funded by NAI support of URI team members. Post−cruise studies of the samples recovered during the cruise, and of the data generated by the cruise, are sponsored by a number of national organizations in Europe, the United States., Japan, and Australia. Through its support of the URI and PSARC teams, the NAI is currently the principal U.S. sponsor of this post−cruise work.

In short, research by the NAI URI team and its close collaborators is rapidly advancing knowledge of life deep beneath Earth's seafloor, its role in Earth's surface processes, and its relevance to the search for life on other planets.

Figures

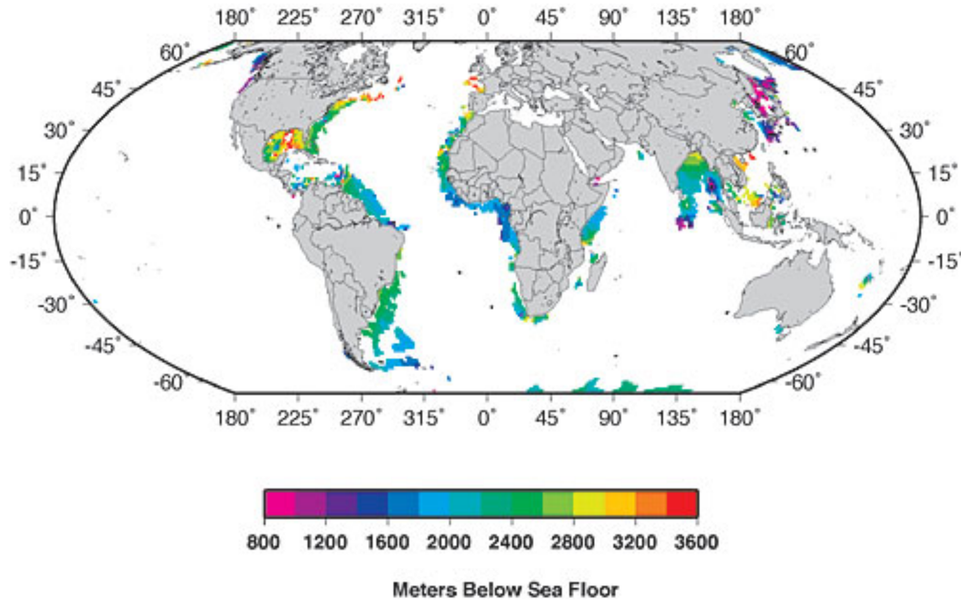


*Figure 1. Global map of the depth of the 120°C isotherm within marine sediments. The isotherm may approximate the depth below the seafloor of the high−temperature limit to life in deep sea sediments. (No microbes are yet known to survive culture temperatures in excess of 113°C.) White marks areas where the 120°C isotherm occurs within the igneous crust that underlies the sediment or where no sediment is present (as at newly formed mid−ocean ridges).*

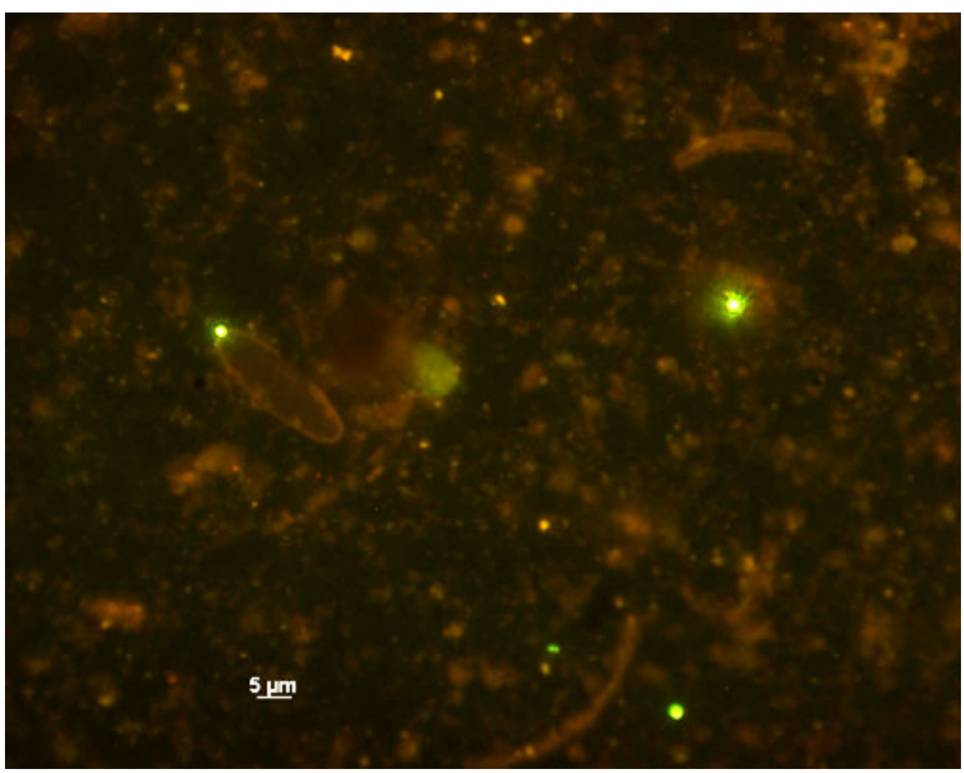


*Figure 2. Photomicrograph of sediment and microbes recovered from approximately 30 meters below the seafloor during Ocean Drilling Program*

*Leg 201. The glowing green dots are the microbes, stained with fluorescent SYBR Green I. (Photomicrograph courtesy of David C. Smith)*