# CARBON CYCLING IN THE DEEP CRUSTAL BIOSPHERE

**UNIVERSITY OF THE FREE STATE, BLOEMFONTEIN, SOUTH AFRICA JANUARY 18–22, 2011**

It has been said that mankind knows more about the surface of Mars than the depths of our own oceans. Arguably, with the success of programs such as the Census of Marine Life, the balance has shifted to fill this gap. The fact remains, however, that our understanding of the nature of microbial life in the Earth's subsurface down to several kilometers in the crust, and of the carbon cycle that sustains that biosphere, remains one of the most challenging scientific gaps. This exploration for life in the Earth's subsurface, or so-called "inner space", has profound implications for our understanding of the origin and evolution of life, the search for life on other planets and moons, and the relationship between life below the Earth's surface and the global carbon cycle.

Chemoautotrophs, or microbes drawing their energy for life from geologically produced chemical species rather than from photosynthesis, were discovered in the late 1970s at mid-ocean ridge hydrothermal vents. This discovery sparked a revolution in our understanding of the range of possible mechanisms for sustaining life and hence in our concept of where on this planet life could be found. Since that time, our understanding that life is not simply a thin veneer on the Earth's surface but may permeate several kilometers into the Earth's crust has evolved rapidly. Serpentinization of ultramafic rocks and alteration of basaltic ocean floor have been invoked as mechanisms by which geochemical processes of water–rock interaction may provide energy and reducing power for chemoautotrophic microbial communities on the seafloor. In continental settings, $H_2$-utilizing chemoautotrophic microbial communities have been identified in volcanic hot springs.

## *Beyond the Deep Hot Biosphere*

A major gap remains in our understanding of life in the deep terrestrial biosphere away from major geothermal or volcanic energy sources. Investigations, particularly in the continental or terrestrial deep subsurface, are recognizing that chemosynthetic communities are not restricted to high-temperature hydrothermal vents and springs, but can be sustained under lower-temperature regimes by similar types of water–rock reactions, albeit at slower rates. The implications of this conceptual evolution are profound, as it suggests that much larger volumes of the Earth's subsurface may be habitable. **In just 30 years we have moved from the misconception that life consists of a thin veneer on the surface of the planet driven by the sun's energy alone, to a recognition of deep biosphere oases at vents and hot springs, to the possibility that the Earth's biosphere extends to kilometers depth and may be distributed more widely over the planet's entire circumference.**

## *Workshop Activities*

An international group of more than fifty participants from five continents gathered from January 18 to 22, 2011, at the University of the Free State (UFS), Bloemfontein, South Africa, for the workshop "Carbon Cycling in the Deep Crustal Biosphere." The workshop, which was sponsored by the Deep Carbon Observatory (DCO), was hosted by Drs. Esta van Heerden and Derek Litthauer of the UFS and coorganized by T. C. Onstott (Princeton University), T. Kieft (New Mexico Institute of Technology), and B. Sherwood Lollar (University of Toronto). The meeting was a catalyst for the development of new collaborations and research interactions within the international community for researchers at all levels (students, postdoctoral fellows, professors, senior researchers, and industry partners) working in this research area. In the course of 3 days of meetings, students and researchers in geology, geochemistry, hydrogeology, microbiology, and genomics discussed the latest findings in the investigation of the subsurface biosphere, highlighting examples from marine-crust vents and subseafloor sediments and from terrestrial settings, such as Wyoming's Kane Cave, South Africa's Witwatersrand Basin, and the Precambrian shield rocks of Canada and Fennoscandia. Presentations also addressed new approaches in instrumentation and exploration of Earth's inner space. The group identified opportunities for transformative research provided by boreholes, subsurface mines, and underground research laboratories worldwide, and the means by which deep carbon research in the Earth's subsurface advances the fundamental understanding of the carbon cycle. In particular, participants identified the links between the deep carbon cycle and surface biogeochemical cycles, the role of deep carbon in sustaining chemoautotrophic microorganisms isolated from the surface biosphere, and the potential for research in this area to benefit mankind in applications that include energy exploration, carbon sequestration, and the discovery of novel microorganisms in the Earth's subsurface.

University of Toronto postdoctoral student Ken Voglesonger sampling at 2 km depth in the Canadian Shield

On the final workshop day, participants traveled 100 km northeast and almost 2 km below the Earth's surface to sample the geochemical and microbiological environment of the subsurface, courtesy of a visit to one of the Witwatersrand Basin's gold mines.

In addition to fostering a plethora of individual research collaborations and connections, a major outcome of the workshop was a consensus to work towards solidifying the community around a network for subsurface terrestrial biosphere research (potentially NISO – Network for Inner Space Observatories). For more information on this and other emerging themes in deep carbon research, visit the DCO website (address below).

The DCO is an international multidisciplinary effort dedicated to achieving transformational understanding of carbon's chemical and biological roles in the Earth. The DCO Secretariat at the Carnegie Geophysical Laboratory in Washington, D.C., was established with an initial $4-million investment from the Alfred P. Sloan Foundation. The Secretariat serves as an international clearinghouse for deep carbon research and funding opportunities (www.dco.ciw.edu) and in 2009–2011 sponsored a series of workshops on deep carbon research.

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