microbial communities. One advantage of applying genomic approaches is that they are not reliant on a priori assumptions about the specific organisms, biochemical pathways, or biogeochemical processes that are present and active in any particular habitat or community. Therefore, the community composition, genetic character, and biochemical pathways present can be evaluated in a more unbiased fashion. Discoveries concerning the genetic properties of uncultivated microbes, as well as novel genes and biochemical pathways, are now resulting from environmentally-oriented genomic studies. Examples include the discovery of novel phototrophs in marine plankton, and the genetic dissection of uncultivated methane-oxidizing consortia from anoxic deep-sea methane seeps. Results from these early studies indicate that genomic dissection of naturally occurring microbes is extremely useful for characterizing the microorganisms, biochemical pathways and biogeochemical processes that occur in natural environments.

URL: http://www.tigr.org/tdb/MBMO/

B52C MCC: 132 Friday 1535h

Life and the Evolution of the Earth System: Processes and Theories *(joint with H, OS, GC, PP)*

Presiding: **A Kleidon,** University of Maryland**; S H Schneider,** Stanford University

B52C-01 1545h INVITED

A Metric to Guide the Search for Biosphere-Scale Principles

Tyler Volk (212-998-3736; tyler.volk@nyu.edu)

New York University, Biology Dept. 1009 Main Building, New York, NY 10012

Various metrics have been proposed to measure large-scale structure at the biosphere level, including metrics of mass (such as primary productivity) and energy (such as entropy). Here I suggest a metric called the cycling ratio. It is defined, for any system, as the ratio of the flux of any specified element into the photosynthesizers relative to the flux of that element into the system across its boundaries. In general, the ratio is greater than one because of coordinated processes in which the wastes from some life forms become the food of others. The cycling ratio can be applied across scales of space and time, and across biologically-essential elements. For space, I will show data from Hubbard Brook Forest to the biosphere. For time, I will sketch evidence for the growth of the cycling ratio of carbon over Earth history. And I will compare the cycling ratio for different elements at various scales. The cycling ratio could be used to help develop and focus questions about the coevolution of life and the environment, because it measures the amplification of photosynthesis within a system, compared to the magnitude of photosynthesis if limited to an amount equal to the rate of external supply of an essential element.

B52C-02 1605h

Biogeophysical Effects and the Production of Entropy by the Earth System

Axel Kleidon (301-405-3203; akleidon@geog.umd.edu)

Department of Geography, University of Maryland, 2181 Lefrak Hall, College Park, MD 20742, United States

The Earth is an open thermodynamic system. Incoming solar radiation of low entropy is subsequently converted by diabatic processes into a flux of terrestrial radiation associated with relatively higher entropy. It has been suggested that physical processes within the climate system, such as polar heat transport or vertical exchange processes in the atmosphere, act to maximize entropy production. Here I apply these thermodynamic considerations to the overall climatic effect of terrestrial vegetation. Terrestrial vegetation directly affects land surface functioning, such as the absorption of solar radiation and the rate of evapotranspiration. With climate model simulations of extreme vegetation settings, a "green planet" and a "desert world", I investigate how terrestrial vegetation affects the entropy production budget of the Earth and whether the overall biogeophysical effect can be described as such an entropy-maximizing process. The results are discussed in the context of the Gaia hypothesis, which states that the Earth system is regulated by and for the biosphere.

B52C-03 1620h INVITED

Methane Greenhouses and Anti-Greenhouses During the Archean Era

James F Kasting[1] (814-865-3297; kasting@essc.psu.edu)

Alexander A Pavlov[2] (pavlov@lasp.colorado.edu)

[1] Department of Geosciences Penn State University, 443 Deike Penn State University, University Park, PA 16802, United States

[2] LASP University of Colorado, 392 UCB University of Colorado, Boulder, CO 80309-0392, United States

Climate and life are coupled today through the biogeochemical carbon cycle, but they may have been even more tightly coupled in the distant past when atmospheric O2 levels were lower. The finding of mass-independently fractionated S isotopes in Archean rocks confirms that pO2 was very low, probably <10-13 times the present level, prior to 2.3 Ga (1). The Sun was also some 20 percent less luminous at this time (2). High CO2 levels were initially proposed to solve this 'faint young Sun problem' (3); however, these levels are in conflict in data from paleosols (4). CH4 is an alternative greenhouse gas which could have kept the Archean climate warm if present at concentrations of 0.01-0.1 percent by volume (5).

The primary source of methane is biological. CH4 is produced by methanogenic bacteria that today live in anaerobic environments such as the intestines of ruminants and the water-logged soils underlying rice paddies. During the Archean, however, methanogens should have been widespread, and the methane they produced would have had a long photochemical lifetimes, around 10,000 years (6). Most methanogens are thermophiles or hyperthermophiles, and those which are more thermophilic have shorter doubling times than those that prefer cooler temperatures. This suggests that a positive feedback loop may have existed, whereby methanogens warmed the climate by releasing CH4, which in turn promoted the proliferation of faster-growing methanogens. This positive feedback would have been halted, however, once the ratio of CH4 to CO2 in the atmosphere exceeded unity. At this point, polymerization of CH4 by solar UV radiation would have caused the formation of an organic haze layer similar to that observed today on Titan. Such a haze layer would have cooled the climate by creating an 'anti-greenhouse effect.' This creates an overall negative feedback loop that may have been responsible for maintaining a stable Archean climate. The rise of O2 at 2.3 Ga disrupted this equilibrium and may well have triggered widespread, possibly Snowball, Huronian glaciation.

References: 1) Farquhar, J., Bao, H. & Thiemans, M. Science 289, 756-758 (2000). 2) Gough, D. O. Solar Phys. 74, 21-34 (1981). 3) Walker, J. C. G., Hays, P. B. & Kasting, J. F. J. Geophys. Res. 86, 9776-9782 (1981). 4) Pavlov, A. A., Kasting, J. F., Brown, L. L., Rages, K. A. & Freedman, R. J. Geophys. Res. 105, 11,981-11,990 (2000). 5) Pavlov, A. A., Kasting, J. F. & Brown, L. L. J. Geophys. Res. 106, 23,267-23,287 (2001). 6) Rye, R., Kuo, P. H. & Holland, H. D. Nature 378, 603-605 (1995).

B52C-04 1640h

The Peroxy Challenge to Early Life

Lynn J. Rothschild[1] (650 604-6525; lrothschild@mail.arc.nasa.gov)

Friedemann T. Freund[2] (650 604-5183; ffreund@mail.arc.nasa.gov)

Paul Gosling[3] (410 908-6552; pgosling99@hotmail.com)

[1] Lynn J. Rothschild, NASA Ames Research Center, Moffett Field, CA 94035, United States

[2] Friedemann T. Freund, SJSU/NASA Ames Research Center, Moffett Field, CA 94035, United States

[3] Paul Gosling, Johns Hopkins University, Baltimore, MD 21218, United States

The development of aerobic metabolism was one of the most important breakthroughs in evolution. But the early Earth was anaerobic, with most researchers today attributing the build-up of free O2 to oxygenic photosynthesizers. This reasoning is problematic because photosynthesis invariably produces oxygen radicals as by-products or intermediates. Known collectively as reactive oxygen species, ROS, these radicals damage DNA, damage membranes, and inactivate essential enzymes. In addition, molecular data on the evolution of cytochrome oxidase suggest that early organisms must have learned to detoxify ROS prior to the evolution of aerobic metabolism and oxygenic photosynthesis. A possible way out of this dilemma comes from a study of igneous and high-grade metamorphic rocks, which indicates that a small but significant fraction of the oxygen anions in their minerals exists in the 1 state, forming peroxy links of the type O3Si-OO-SiO3 (J. Geodynamics 33, 543-570, 2002). Water hydrolyzes these peroxy links to hydrogen peroxide, H2O2. As a result, microorganisms that attach themselves to mineral grains will be exposed to a constant trickle of ROS from the production of H2O2. We propose the following scenario: Though the overall conditions on the early Earth were anaerobic, conditions at microsites were not. The hydrolysis of peroxy links in minerals to hydrogen peroxide at the rockwater interface was biochemically challenging for any microbes living in intimate contact with rock surfaces. The generation of ROS placed the microbes under evolutionary stress to develop biochemical defenses against the potentially lethal effects of ROS radicals. Only after these enzymatic defenses were in place, oxygenic photosynthesizers were able to develop and increase the O2 partial pressure in the Earths atmosphere to a high level.

B52C-05 1655h

Kerogen Characterization of Microfossils in Precambrian Cherts: Evidence for Biogenicity

Bradley T De Gregorio[1] (480 218 6150; degregorio@asu.edu)

Thomas G Sharp[1] (tom.sharp@asu.edu)

[1] Arizona State University, Department of Geological Sciences P.O. Box 871404, Tempe, AZ 85287-1404, United States

Currently, much of our oldest evidence of life on this planet has been called into question. It is not enough for a possible microfossil to have bacterial morphology. In addition, it must also be composed of material with an unquestionably biogenic origin. Once an organism dies, the carbon it contains is altered through diagenesis and metamorphism. Most organic material is removed or remineralized, but insoluble amorphous carbon, known as kerogen, may remain. With additional heating and pressure, this kerogen is transformed into graphite, eliminating the structural biosignature of the material. No known biological process creates graphite as a product. Oxides, which form on the external surface of bacterial cell walls, may also remain after fossilization. Many microfossils are defined not by kerogen but by arrangements of small iron or manganese oxide crystals, even though kerogen may still be associated with them. Cherts from Mink Mountain locality of the Gunflint Formation (2.0 Ga) contain black, brown, and red filaments composed of both hematite crystallites up to 1 μm and kerogen. The amount of kerogenous material determines the color of the microfossil. Those with little associated kerogen appear red, the color of hematite, while those with much associated kerogen appear black. Brown microfossils are the result of remnant carbon with little or no hematite. Kerogen is also found abundantly outside of microfossils and may possibly be the remains of ancient biofilm.

The crystallinity of carbon, grading from amorphous carbon to graphite, can be measured via a variety of methods, including X-ray diffractometry (XRD), Raman spectrometry, high-resolution transmission electron microscopy (HRTEM), and electron energy loss spectrometry (EELS) in TEM. However, EELS may be the best method when dealing with small patches of carbon associated with microfossils, especially if high-resolution imaging is not possible. Information about the crystallinity is given by the morphology of the near edge fine structure of the carbon K-edge. Specifically, the relative intensities of smaller structures on the σ* peak and the width of the σ* peak both increase with increased graphitization. EELS analysis has been performed on cherts from Schreiber Beach, which contains typical, well-accepted microfossils of the Gunflint Formation (2.0 Ga). These microfossils are composed entirely of kerogen in a matrix of microcrystalline quartz. The spectrum of this kerogen is very similar to that of amorphous carbon.

The biogenicity of carbon structures within the Apex Chert (3.5 Ga) is in contention. Raman spectra of these structures have been interpreted as either representing highly disordered graphite (Brasier et al. 2001) or partially graphitized kerogen (Schopf et al. 2001). The former implies an abiogenic origin, whereas the latter implies a biogenic origin. We will use EELS and HRTEM to determine the crystallinity of this carbon in the Apex Chert.