Global Issues

Astrobiology

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We are studying a sequence of fundamental physicochemical processes that bridge nonliving and living matter. We are seeking to construct a biogeochemical network within a molecular aggregate (a vesicle or micelle) that can derive energy from a simple form of metabolism (a coupled redox complex) and use information carried in a simple form of genes (templating polymers). This proto-organism can self-replicate, use energy and nutrients available from its environment, undergo evolutionary change over time, and ultimately die. All the molecular species we use are either simulated readily in prebiotic geochemical reactions or are present as organic components of carbonaceous chondrites. The species can thus be assumed to have existed on Earth some 4 billion years ago. Although we use such simple building blocks, we are not attempting to reconstruct the origin of life on Earth. Indeed, our focus is on fundamental processes that could lead to the self-organization of matter into functional units, and, thereby, on helping describe the formation of life anywhere in the universe. We are also interested in future technological applications of self-reproducing molecular machines.

We are accomplishing our objectives by integrating, in the laboratory and by simulation, the two experimental systems described below.

(1) A templating polymer (our protogene) with a hydrophobic backbone performs template-directed replication at a lipid interface. This lipid-template complex has a slight energy advantage over the two being independent, so more interface can form. A hybridization reaction between the original template and two complementary oligomers follows that is also thermodynamically downhill. As this new three-component complex sinks into the hydrophobic environment, polymerization becomes thermodynamically possible as a means of generating additional templates. Thus, a weak energetic coupling exists between templating and interface generation. Simulation of the interactions between amphiphilic aggregates (micelles) and templating polymers (peptide nucleic acids, or PNAs) is possible using our newly developed molecular-dynamics lattice-gas technique.

(2) This first system is only using the slight energy advantage associated with lipid/template complexation and polymer templating, so the process is very fragile. Orders of magnitude in speed can be obtained using the chemical energy bound in mineral sulfur or iron compounds, for example, or through photo-induced reactions. As an example, we can design an electron relay system in a vesicle membrane and use sulfur in different oxidation states as the energy source to cause a coupling between the production of PNA dimers and amphiphilic polymers . The result would be a continuous synthesis of surfactant and PNA dimer in a vesicle system. By, for example, functionalizing the PNA backbone, certain PNA strands could enhance the redox reactions, and an autocatalytic cooperation could be established between the templating and surfactant production processes. This feedback also forms the basis for a simple Darwinian evolution of the system.

Although the proposed self-reproducing molecular aggregate does not constitute a contemporary cell, it is the first concrete model of a molecular system that is driven by thermodynamically favorable processes and that combines vesicles, metabolism, and protogenes in a cooperative manner.

Middle Awash Geological and Paleoanthropological Research Project, Southern Afar Rift, Ethiopia

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We have submitted a proposal to the Los Alamos Branch of the Institute of Geophysics and Planetary Physics (IGPP) to join the Middle Awash Geological and Paleoanthropological Research Project, an international, multidisciplinary effort to establish accurate temporal constraints on the geological processes for elucidating human origins and evolution, including other faunal remains, during the terminal Miocene and the Plio-Pleistocene periods. Unique tectonic and volcanic processes of continental and oceanic affinities characterize the main Ethiopian and the Afar Rifts at the northern part of the East African Rift System, respectively.

We plan to evaluate the continental part of the southern Afar Rift and assess the volcanotectonic processes responsible for the widening of the rift system, as well as the changes in the orientation of the rift margins in the vicinity of the Middle Awash region. The Middle Awash region is located along a tectonic transition zone between the northern sector of the Main Ethiopian and the southern Afar Rifts. In our previous field studies, we assessed how the timing of this structural modification influenced subsequent volcanism and sedimentation processes along the western rift margin and adjacent rift floor.

Results of our proposed research will provide stratigraphic and geochronological frameworks for the paleontological and archaeological records, while delineating the tectonic, volcanic, geomorphic processes that shaped the rift system in the vicinity of the Middle Awash region of the southern Afar rift. We plan to collect volcanic rocks interbedded within the fossiliferous sediments and other samples. These samples will undergo geochemical, paleomagnetic, stable isotope, and radiometric analyses, the results of which should help us determine the precise temporal placement of the volcanic, tectonic, and geomorphic processes, and paleoenvironmental features of the most complete fossil-bearing sedimentary sequence, spanning the Neogene and the Quaternary periods.

Our team has collected several hundred volcanic and sedimentary samples from the rift margin and floor during the previous field trips. The samples are being analyzed at Los Alamos using a microprobe and a scanning electron microscope. At Miami University of Ohio, the major and trace element compositions of the bulk samples are being determined. At the Berkeley Geochronology Center, the age of important samples and layers is being determined using the $^{40}Ar/^{39}Ar$ dating technique on single crystals and rocks. We have also collected paleomagnetic samples from fossiliferous sedimentary rocks for age control.