friends," Myron Ebell, director of global warming policy at the Competitive Enterprise Institute, a free-market public policy group, wrote in a March 14 e-mail to allies, "We have won a famous victory, and everyone should congratulate themselves on the work they did to achieve this end.

"Although we have won Round Two, Round Three has already started and we are losing," he cautioned. "Round Three is about staffing the key global warming and Kyoto policy positions in the administration...I urge you to take a simple message to your contacts in the Bush-Cheney Administration: everyone appointed to a key job should be fully on board with the president's opposition to [the] Kyoto [protocol] and to regulating carbon dioxide."

Concern Expressed Overseas

The Bush reversal also has drawn concern from some leaders across the globe, including environment ministers from Canada, Germany and elsewhere, as negotiators gear up for climate change talks that restart in July.

"Without U.S. leadership, effective global action on climate change may not be possible," said Klaus Toepfer, who is the executive director of the United Nations Environment Programme. "We know that the U.S. is the world's largest emitter of greenhouse gases and is therefore an important part of the problem. But the U.S. is also our best hope for a solution. Simply put, the U.S. is the world's most technologically innovative country. Its industries are most likely to develop the climate-friendly products and services that must one day soon set the world onto a clean energy path."

For more information, visit the Web sites: http://thomas.loc.gov/cgi-bin/query/z?c107: S.556:

Randy Showstack, Staff Writer

GEOPHYSICISTS

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In Memoriam

Arnold Boris Arons died on February 28, 2001, at age 84. He had been an AGU member (Ocean Sciences) since 1950.

Donald Bower died at age 73. He was a retired life member (Geodesy) who joined AGU in 1966.

William P. Durbin died on February 8, 2001, at age 71. He had been an AGU member (Geodesy) since 1964.

Warren Lincoln Flock died on March 4, 2001, at age 81. He had been an AGU member (Atmospheric Sciences) since 1960.

Shuh-Chai Lee died at age 81. He was a retired life member (Geodesy) who joined AGU in 1954.

Charles Sclar died on January 13, 2001, at age 75. He had been an AGU member (Volcanology, Geochemistry, and Petrology) since 1951.

Honors

Georges L. Weatherly has been elected as a foreign member of the Russian Academy of Natural Sciences in recognition of "great scientific findings and significant contributions to oceanography" and for his "efforts in the development of friendship and cooperation between Florida State University and Russian scientists." Weatherly is also honored for successfully coordinating international scientific projects dedicated to the ecological stability of bodies of waters such as the Black Sea and the Aral Sea.

Weatherly is professor of oceanography at Florida State University, Tallahassee, and has been an AGU member (Physical Oceanography) since 1969.

Recent Ph.D.s

Hydrology

The marching–jury backward beam equation method and its application to backtracking nonreactive plumes in groundwater, **Juliana Atmadja**, Columbia University, Amvrossios C. Bagtzoglou, February 2001.

FORUM

Alternative Energy Sources Could Support Life on Europa

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Energy pervades the solar system in a variety of forms, including electromagnetic and particle radiation, magnetism, heat, kinetic motion, and gravitational interactions. Life on Earth is sustained by the conversion of light and chemical energy into proton gradients across membranes that drive the phosphorylation of high-energy intermediate metabolites.

The use of light and reduced chemical bonds as energy sources is not surprising on Earth, where the intensity of light is strong and an oxidizing atmosphere favors energy-yielding chemical reactions. However, any naturally occurring energy gradient that generates charge separation across boundary layers could theoretically yield the free energy needed to sustain life. Using specific, plausible examples from Jupiter's ice-covered satellite Europa, we propose that alternative energy sources could sustain life where neither light nor an oxidizing atmosphere is available.

Energy Sources on Europa

Estimating the chances of life elsewhere in our solar system includes the challenge of envisioning a specific, feasible energy capture mechanism. Europa now appears to be one of the most likely places in the solar system for harboring extraterrestrial life. The presence of a liquid-water ocean 100 km deep or more beneath Europa's icy crust is now widely assumed. While chemoautotrophy is a possibility on Europa, the lack of abundant oxygen beneath the icy crust means that oxidation-reduction cycles unlike those on Earth would have to be postulated. Photoautotrophy does not appear to be a viable energy capture mechanism for Europa because of the low amounts of light that pass through the icy surface layer several kilometers thick. Photoautotrophy that is solely based on light emitted from black smokers and flange pools, which may exist on Europa, appears unlikely. Nevertheless, the presence of subsurface liquid water and a rich selection of other energy sources make life beneath Europa's icy crust a viable scenario.

Europa most likely possesses a metallic core that provides internal heat through radioactive decay. Observation has shown that endogenic heat flow to the icy surface is indicated by systematic post-sunset temperature variation with latitude: northern latitudes are warmer than equivalent southern latitudes and there is a temperature minimum along the equator. Convection currents in the Europan ocean are likely to be generated from thermal differentials between the ice-covered surface and the geothermally heated ocean floor. Such currents may also be generated within tidal channels, either on the ocean floor or in the ice ceiling, due to Jupiter's strong gravitational attraction, which is in alternating synchrony or opposition to the other Jovian satellites. Thus, both thermal energy and the kinetic energy of convection currents could be harvested by living systems on Europa. In addition, Jupiter's magnetic field, through which Europa makes a complete circuit every 85.2 hours, provides an additional potential energy source.

Life Based on Thermal Energy

Thermotrophic life forms that use thermal gradients may be conceivable, possibly in conjunction with the high heat capacity of water (about 4 kJ/kg*K). If we assume a cell mass of 10–15 g, comparable to the cell mass of microbes on Earth, and further assume that one tenth of the body mass is a vacuole of water within the cell membrane from which the thermotroph could extract energy via the Carnot cycle, 89 eV of usable energy could theoretically be obtained by a temperature change from 20°C to 19°C. This amount of energy is substantially greater than the 2 eV that can be extracted via photoautrophy (per one photon) or chemoautotrophy (from oxidizing one molecule of hydrogen to water). For a cell as large as the giant pan-tropical alga *Valonia macrophysa*, which contains a water vacuole of approximately 10 g, the potential energy yield could be close to 1 Joule. A plausible energy-harvesting mechanism would be the presence of membrane macro-molecules that catalyze high-energy metabolites through temperature-dependent conformational changes.

Life Based on Magnetic Energy

Magnetic fields theoretically can be used to create charge separation and extractable free energy. The physical process may be either based on the principle of the Lorentz force, the movement of a charge within a magnetic field, or by induction of a periodically changing magnetic field. Jupiter's magnetic field of about 450 nT near Europa is most likely too small when using a cell with a diameter in the micro-meter range to create a sufficient amount of energy from the Lorentz force. On the other hand, the constraints of a weak magnetic field could be overcome by a meter-long hair cell clinging to a substrate while Europa is moving through Jupiter's dipolar magnetic field. Charge separation of many orders of magnitude larger than across a microscopic cell would occur. The organism could contain magnetite pigments that would orient themselves to the external magnetic field to optimize the harvest of magnetic energy. Alternatively, organisms of microbial dimensions could also be envisaged that would cling to strips of inanimate conducting material and harvest energy from the magnetically induced electron flow in their substrates.

Life Based on Kinetic Energy

Directly harvesting the kinetic energy of convection cells or tidal currents on Europa's ocean floor or ice ceiling would be another way to sustain life in the absence of light and oxygen. Organisms containing hair cells much like ciliated bacteria or protozoa could adhere to a substrate at the ocean bottom or on the underside of the ice ceiling, where they are exposed to currents of moving water that can bend their hair cells. The cells may enclose protein-like macro-molecules that induce an electrical polarity across the membrane through a Donnan equilibrium mechanism. The hair cells could be surrounded by Na^+ channels whose permeability is proportional to deflection of the hair, with properties like those of sensory hair cells in the vestibular membrane of vertebrates.

By bending the hair cells, the convection currents could lead to the opening of Na^+ channels, allowing Na^+ to flow into the cell passively down its concentration gradient. This thermodynamically favored process could be coupled to the direct formation of high-energy phosphate bonds or to an H^+ transporter across another internal membrane, by analogy with mitochondrial membranes. A steady convection current with a velocity in the centimeter-per-second range would certainly be able to power such a system, and the minimum energy needed may be extremely low. Since this system works essentially like a battery that is charged over time, all that is needed is a minimal energy source and enough time to charge the system high enough to form energy-storing chemical compounds.

Analogy to Earth and General Implications

While these postulated energy sources for life on Europa are admittedly speculative, they don't lack analogs on Earth. Living cells that are sensitive to heat, touch, stretch, convection of air and fluids, gravity, and pressure are well known. Sensitivity to magnetic fields, as in magnetotactic bacteria, is also a well-established mechanism. Theoretically, enough energy can be supplied by all of these postulated processes to generate H^+ gradients across membranes or to power phosphorylation reactions directly.

While the argument given here has focused on Europa as an example, it can be generalized to any planetary ecosystem where energy gradients are available. In particular, collaborative strategies for extracting energy from different types of energy gradients may commonly occur on other worlds, because they provide the means for naturally cycling chemical compounds in a manner specific to a given planetary ecosystem. Organisms may have evolved as chemoautotrophs near hydrothermal vents as on Earth, as thermoautotrophs close to hydrothermal areas, as magnetotrophs near suitable magnetic fields, and as kinetotrophs in colder areas on the bottom of an ocean where convection or tidal currents are present. The possibility of life on other worlds would be enhanced by ecosystem differentiation of living environments, and each would have its own optimal energy source. On worlds such as these, nutrient cycling or even collaborative strategies as far-reaching as symbiosis could evolve.

While speculative, these scenarios are based on reasonable physical, chemical, biological, and geological assumptions. Energy-yielding processes that could be conducive for life, but that are different from those on Earth need to be considered in the search for life on other worlds. Theoretical possibilities such as those proposed here have the benefit of posing specific follow-up questions such as: What would be the minimum energy required to establish a proton pump? Which type of energy is most suitable to be tapped on other specific planets and moons? What are the likely energy-capture mechanisms for specific sources of energy on other worlds? Developing a good understanding of the theoretical possibilities of life will better guide us to the best search parameters and tools for detecting it.

Authors

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BOOK REVIEW

Siliciclastic Sequence Stratigraphy—Concepts and Applications-SEPM Series-Concepts in Sedimentology and Paleontology #7

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Henry W. Posamentier and George P. Allen

SEPM (Society for Sedimentary Geology), Tulsa, Oklahoma, USA, 216 pp., ISBN 1-56576-070-0, 1999, $48 (members), $67 (non-members).

Sequence stratigraphy is branch of stratigraphy that is based upon using stratal patterns and stratal termination patterns to identify groups of strata that were deposited within the same interval and therefore genetically related. Its wide application in the 1980s and 1990s has provided new insight into the history and architecture of basin fill.

In this book, H. W. Posamentier and G. P. Allen take sequence stratigraphic models developed in the 1970s and modified in the 1980s to a higher level. The authors state that their goal is to focus on remaining flexible and pragmatic in their presentation of how to conduct sequence stratigraphic analyses and to operate using the premise that any