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News & Views

Life Up North: Meeting Report: Nordic Astrobiology 2006: Origins & Distribution of Life in the Universe

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Nordic Astrobiology 2006 was held at the Royal Swedish Academy of Sciences May 8–11, 2006, with the bold aim of bringing together researchers in the Nordic countries whose research focus is origins of life and astrobiology. The conference attracted around 100 participants, and, somewhat surprisingly, many of us had not met one another prior to this meeting. So by all accounts a meeting like this was not only well overdue, but also a great success.

Proceedings kicked off with an engaging public lecture, given by Chris McKay (NASA Ames Research Center, Moffett Field, CA). Chris covered everything from the possibility of past and present life on Mars to speculation on recreating a habitable martian climate. His talk attracted a broad cross-section of the local scientific community and a good many members of the public.

Three full days of scientific presentations followed, covering the biological, geological, and space sciences. Keynote presentations were made by Eörs Szathmáry (Collegium Budapest, Budapest, Hungary), Karsten Pedersen (Gothenburg University, Gothenburg, Sweden), Chris McKay, Aivo Lepland (Geological Survey of Norway, Trondheim, Norway), Pascale Ehrenfreund (Leiden University, Leiden, The Netherlands), and Hans Rickman (Uppsala University, Uppsala, Sweden), with a broad range of contributed presentations making for a stimulating and diverse program (abstracts are available online at http://astrobiology.molbio.su.se/).

While it is not possible to do justice to the entire range of material presented, two dominant themes emerged from the conference. First, there is within the Nordic community considerable interest for topics relating to the origin of life. The conference reflected this, with presentations covering topics as diverse as the interstellar medium, early biochemistry, and geological traces of the earliest life. Second, there is significant technological competence in detection of organics and biosignatures, spanning the astronomical, geological, and biological sciences.

The conference began at "the beginning," with the origin of life. Autonomous life as we know it has three key features—metabolism, genetics, and compartmentation. Research that focuses on one of these three features is common, but as Eörs Szathmáry advocated, there needs to be a concerted effort to put the three together. The RNA world theory is considered by many researchers to be a seductive candidate for understanding the emergence of autonomous life in that RNA can both catalyze reactions and store genetic information. Of particular interest here is the recent empirical demonstration that catalytic RNAs can tolerate significant mutational loads without affecting function, thereby downsizing Eigen's paradox of "no enzymes without a large genome

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and no large genome without enzymes" (E. Szathmáry). But RNA falls short with regard to compartmentation, and given what is known regarding transport across modern cell membranes, another paradox could be put forth: no cells without membrane proteins, and no selection for membrane proteins without cells. This is because membranes, even leaky ones, are insufficient for life—cells require specific import of nutrients and export of waste. G-quadruplex RNAs are potentially interesting in this regard as they show all the hallmarks of passive-mediated ion transport. This makes an RNA-based cell a theoretical possibility, but as RNA is not hydrophobic, this would require a novel membrane architecture, not unlike that of the eukaryote cell nucleus (A. Poole, Stockholm University, Stockholm, Sweden). The source of lipids is, of course, still an open issue, though the presence of amphiphilic molecules in meteorites has been long known.

Indeed, building blocks such as these could be formed via geochemical processes and may also have been delivered to the early Earth via cometary impacts. Pascale Ehrenfreund reviewed current astrophysical and astrochemical data pertaining to the origin of life, concluding that the basic building blocks of life as we know it are probably widespread and were likewise present in the early universe. Å. Hjalmarson (Onsala Space Observatory, Chalmers University of Technology, Onsala, Sweden) presented recent searches for prebiotic interstellar molecules using the Onsala 20-m (diameter) millimeter-wave telescope. Sensitive searches for amino acetonitrile (a potential "parent" molecule for glycine) and vinyl acetylene (since vinyl cyanide is known to be abundant) did not yield directly positive results, though a number of unidentified lines resulted, three of which might lead to the first detection of interstellar amino ethanol. Observations of water and ammonia in comets using the Swedish satellite Odin were also presented. Hans Rickman followed up with a critical review of the pros and cons for delivery of volatiles to the terrestrial planets. He concluded that extensive early delivery to the Earth via comets and asteroids appears very likely. However, a clear problem is that these delivered volatiles would have been very vulnerable to degradation subsequent to the Moon-forming impact.

Among the geochemical processes that could produce key building blocks for life, serpentinization of olivine and pyroxene in ultramafic mantle rocks (rocks low in silica) has attracted a great deal of attention in recent years and was discussed extensively at the conference. Serpentinization is a complex series of reactions that occurs at temperatures below 500°C in several active tectonic settings. Biogeochemically, the process is important because it leads to reduction of H_2O to H_2 (P. Crill, Stockholm University). At the same time, catalytically active compounds like magnetite are formed. H_2 may be used together with CO_2 and magnetite as a catalyst in Fischer-Tropsch type reactions. Fischer-Tropsch type processes may lead to the formation of CH_4, as well as heavier hydrocarbons and other abiotic organic compounds. Petrological data of serpentinized mantle of the Iberia Abyssal Plain have been used to constrain the production of CH_4 (P. Crill). The calculations indicate an average annual flux rate of 0.55–5.5 mol of CH_4 exiting the mantle/m^2. Provided water is available on Mars, the rate of serpentinization of the ultramafic rocks and the flux rate of CH_4 on our neighbor planet may be about the same.

As an interesting and related aside, most of the biomass around deep-sea hydrothermal systems is composed of invertebrate species that host symbiotic microorganisms. The energy for these symbioses is provided by geothermal reductants, such as sulfide and methane, which can occur in very high concentrations in hydrothermal fluids. The dilution of these effluents with ambient seawater leads to gradients in sulfide and methane concentrations at vent sites that can be used by different groups of chemosynthetic organisms. These interesting ecosystems, based on the activity of chemosynthetic microbial communities, were only recently discovered on our planet. However, it is likely that microbial communities around hydrothermal systems appeared fairly early in the diversification of life. This raises the possibility that such microbial communities could be found on other planets in our solar system. A hydrothermal vent bio-sampler currently under development by the Luleå University of Technology and NASA's Jet Propulsion Laboratory (J. Jonsson, Luleå University of Technology, Luleå, Sweden) is designed to operate under the extreme conditions associated with hydrothermal systems and will be equipped with sensors that can monitor the chemical conditions around the chemosynthetic communities.

Returning to the topic of serpentinization, it was pointed out that, at temperatures below 300°C, this is associated with high pH (pH 10–12). This is significant because the high pH may promote the formose reaction in natural environments and, hence, the abiotic formation of pentoses like ribose, the carbohydrate constituent of RNA (N.G. Holm, Stockholm University). Pentoses are stabilized by borate that is scavenged from seawater by brucite—a magnesium hydroxide product of serpentinization reactions.

Formation of the building blocks, however, is only one aspect of the problem; an additional hurdle is, of course, that formation of polymers is inhibited in a racemic mixture of monomers. Various physical and chemical processes have been explored that might favor an excess of left-handed amino acids and right-handed sugars. R. Popa (Portland State University, Portland, OR) discussed the empirical evidence in support of one such mechanism. In the presence of a magnetic field of comparable strength to that on the early Earth, solvents with quadrupole moments, such as $^{17}O\text{-}H_2O$, differentially influence the dissociation constants of D- and L-ribose enantiomers. To reach complete homochirality, however, some amplification is still needed. With exponential amplification, even initially minute enantiomeric excess can eventually reach 100%. However, the final handedness may then depend on a tiny initial imbalance in the concentrations of right- and left-handed building blocks. A. Brandenburg [Nordic Institute for Theoretical Physics (NORDITA), Copenhagen, Denmark] discussed autocatalysis together with some inhibitory effect on the opposite handedness as the crucial ingredients in both RNA and protein world scenarios. In the latter, the net effect of dipeptide formation, together with subsequent epimerization and depolymerization, was argued to mimic the effect of autocatalysis.

The prospect of early metabolism on mineral surfaces such as pyrite has gained currency in recent years, and was touched upon in regard to the possibility of radical-induced polymerization. For RNA, the news here is mostly bad—RNA degrades owing to generation of hydroxyl radicals on a host of surfaces, including pyrite (C. Cohn, Stony Brook University, Stony Brook, NY). Interestingly, however, degradation can be abrogated in the presence of lipids, so it may be possible to find viable links between an iron-sulfur surface metabolism and an RNA-lipid world.

Complementing biological and chemical attempts to understand life's earliest beginnings is the search for the earliest traces of life in the geological record. One problem for identifying very early evidence for life on Earth is the lack of well-preserved rocks. Research has thus focused on the island of Akilia and the Isua Supracrustal Belt (southwest Greenland). Both of these locations were once considered to host 3.7–3.8 billion years old sedimentary rocks, in which graphite particles with low $\delta^{13}C$ have been identified, consistent with biological metabolism. However, there has been controversy as to whether the rocks are sedimentary or igneous, and this is particularly so for Akilia. The origin of the graphite is also a controversial topic, and it has been shown that much of the graphite was formed through thermal breakdown of siderite and does not represent metamorphosed organic matter as previously believed (A. Lepland). Nevertheless, some of the isotopically light graphite found in Isua rocks of sedimentary origin was not formed through thermal breakdown of siderite and thus represent the last standing evidence for life older than 3.7 billion years on Earth. The graphite particles were interpreted to have formed through metamorphism of detrital organic matter incorporated in pelagic deposits on the early Earth. However, though clearly sedimentary, the biological origin of the graphite particles was questioned at the conference. There are several mechanisms that can lead to the formation of isotopically depleted graphite, and a new abiological interpretation was presented (T. Hode, Portland State University).

The issue of how to identify geological evidence for life was revisited multiple times. It came as a surprise to many nongeologists that this controversy extends even to fossils of multicellular organisms. Stefan Bengtson (Swedish Museum of Natural History, Stockholm) described recent controversy over claimed fossil bilaterian embryos from the Doushantuo formation (China), demonstrating that in some cases it may be very difficult to differentiate between small metazoan fossils and abiological diagenetic features. As for the origin of metazoans, it is generally thought that they emerged in the late Proterozoic, but ~1.8 billion years old Australian trace fossils have challenged that view (S. Bengtson). The trace fossils were probably formed by motile multicellular organisms (not necessarily metazoans), and even though the interpretation has been questioned, a convincing alternative interpretation still remains to be presented. Here, we were given a taste of the subjectivity inherent in such interpretation in the form of the somewhat satirical "Early Worm Uncertainty Principle" (S. Bengtson), which ran as follows: Critics either accepted these as *bona fide* trace fossils, contending that there was something wrong with the dating, or they agreed that the dating was solid, instead taking issue with the interpretation of the trace fossils. The conclusion was thus drawn that both lines of evidence can be accepted, just not at the same time!

Detecting contemporary life forms is likewise not trivial. One important goal is to develop the necessary tools and expertise to detect novel forms of life, on Mars, for instance (C. McKay), but identifying the full diversity of life on Earth is not by any means straightforward; our catalogue of microbial diversity is far from complete. For instance, it is only relatively recently that diverse, abundant microbial communities have been studied in the deep intraterrestrial biosphere, where they may have remained isolated from surface ecosystems across considerable time scales. Successful detection of independent subsurface ecosystems is, however, hampered by the risk of contamination, and many of the deepest boreholes have not been drilled with biological experiments in mind, meaning they are heavily contaminated and hence unsuitable for such microbiological investigations (K. Pedersen).

A related question, of particular interest for future Mars missions, is how long-lived microbes can be. Can they remain preserved in isolated refugia over geological time scales? Here, DNA offers the most specific and information-rich marker, but comes with a strong caveat. Polymerase chain reaction enables amplification of specific DNA sequences from very little starting material, but this is complicated by the high risk of contamination. Indeed, when strict criteria are applied to reduce the risk of contamination and artifact, the very oldest claims for geologically ancient microbes fail to survive the battery of tests that are now becoming standard in this field. Nevertheless, bacterial DNA sequences from permafrost samples several hundred thousand years old have been successfully recovered (E. Willerslev, University of Copenhagen, Copenhagen, Denmark), and cold and dry regions such as the McMurdo Dry Valleys in the Antarctic may yet yield evidence of cryopreserved bacteria several million years old.

The difficulties in eliminating contamination in Earth-based samples are compounded for searches for extraterrestrial life forms, but such searches first require identification of environments with the potential to support the origin and evolution of life. Several noteworthy contributions examined the issue of habitability. Markus Janson (Max Planck Institute for Astrophysics, Heidelberg, Germany) described advances in ground-based detection of extrasolar planets by means of spectral differential imaging using adaptive optics. We can expect the first unambiguous detection of substellar companions from ground-based surveys in the very near future.

Neighboring Mars is, of course, a closer target for detection of extant life forms. Chris McKay discussed possible sites for further investigation, in particular, the deep old martian permafrost—the value of the Antarctic Dry Valleys as Earth analogs is clear here. Recent Mars Express results are fueling a new paradigm whereby a "Cold, Wet Mars" model that takes into account atmospheric escape and evidence of surface erosion replaces the once widely accepted model of a "Warm, Wet Mars." A sobering conclusion is that there may be little hope of finding extant life at or near the surface of Mars, and future missions may need to go deep to search for convincing evidence of life on the Red Planet (E. Carlsson and S. Barabash, Swedish Institute of Space Physics, Kiruna, Sweden).

That Stockholm was able to host this conference has provided a real boost for the developing astrobiology community in the region; Stockholm University has recently established a Graduate School in Astrobiology, and NORDITA, which is actively promoting astrobiological research in the Nordic countries, is in the process of relocating to Stockholm. Our sincere hope is that we in the Nordic region can build on the momentum generated by this conference and develop a strong astrobiology research base. There is certainly optimism that this will happen; a working group has been formed with the aim of establishing a Nordic Astrobiology Network, and plans are afoot to hold one or more smaller workshops over the coming year in areas where the Nordic community can productively contribute to the development of the field.

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