Publications of the Exobiology Program for 1991

A Special Bibliography

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# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Cosmic Evolution of Biogenic Compounds</td>
<td>5</td>
</tr>
<tr>
<td>Prebiotic Evolution</td>
<td>15</td>
</tr>
<tr>
<td>Early Evolution of Life</td>
<td>29</td>
</tr>
<tr>
<td>Evolution of Advanced Life</td>
<td>43</td>
</tr>
<tr>
<td>Solar System Exploration</td>
<td>47</td>
</tr>
<tr>
<td>Exploration Exobiology</td>
<td>51</td>
</tr>
<tr>
<td>Search for Extraterrestrial Intelligence (SETI)</td>
<td>57</td>
</tr>
<tr>
<td>Planetary Protection</td>
<td>63</td>
</tr>
<tr>
<td>APPENDIX: Principal Investigators</td>
<td>67</td>
</tr>
</tbody>
</table>
Introduction

The Exobiology Program, located within the Solar System Exploration Division, Office of Space Science and Applications of the National Aeronautics and Space Administration, is an integrated program designed to investigate and understand those processes related to the origin, evolution, and distribution of life in the universe.

This report contains a listing of 1991 publications resulting from research supported by the Exobiology Program. Our intent in compiling this bibliography is twofold: to provide the scientific community with an annual publication listing (as we have done since 1975) of current NASA-supported research in this field, and to stimulate the exchange of information and ideas among the scientists working in the different areas of the program.

The Exobiology Program is broad in scope, covering the following subject areas: Cosmic Evolution of Biogenic Compounds, Prebiotic Evolution, Early Evolution of Life, Evolution of Advanced Life, Solar System Exploration, Exploration Exobiology, Search for Extraterrestrial Intelligence, and Planetary Protection.

**Cosmic Evolution of Biogenic Compounds** focuses on understanding the cosmic history of the biogenic elements (C, H, N, O, P, S) and their compounds in the galaxy and early solar system and understanding the mechanisms of their incorporation (evolution) into organic compounds. This includes: (1) tracing the physical and chemical pathways of the biogenic elements and their compounds from their origins in stars to their incorporation in pre-planetary bodies; (2) determining the kinds of measurements that can be made on the biogenic elements and their compounds to develop theories about solar system formation and prebiotic evolution, and the origin of life; and (3) determining the ways in which the physical and chemical properties of the biogenic elements and their compounds may have influenced the course of events during the formation of the solar system and component bodies.

**Prebiotic Evolution** seeks to understand how the evolutionary sequence leading from simple chemicals to living systems occurred during the development of the Earth and other planets. Research and analysis falls into two major areas: (1) the consequences of planetary evolution on the physical environment of the Earth and planets, including the importance of the physical-chemical processes associated with the development of dynamic planetary surfaces, and (2) the evolution of molecules and molecular systems focusing on energetics, dynamics, and synthesis of chemicals and chemical systems to determine mechanisms by which these systems acquired biological attributes under the constraints imposed by the physical environment.

**Early Evolution of Life** focuses on the nature and history of primitive organisms, relating their evolution to those forces that shaped the evolution of the Earth. The evolutionary record occurs in two forms: the familiar fossil record in rocks, in which phylogeny is deduced from morphology, and in the genome of extant organisms, where mutational events, the driving force of evolution, are expressed in sequences found in the organism's nucleic acids, or the gene products. Thus, studies use the geological record and the molecular record in living organisms to determine when and in what setting life first appeared, to determine the characteristics of the first successful living organisms, to understand the phylogeny and physiology of primitive organisms, to understand the evolution of energy-transducing systems, and to understand what determines the rate of mutation (evolution).

**Evolution of Advanced Life** examines the influence of astrophysical, stellar, and solar system impact events on the evolution of advanced life on Earth, with specific regard to their role in species extinctions. Research in this area focuses on understanding the role of extinction in evolution and the physical conditions that cause extinction of species.
Cosmic Evolution of Biogenic Compounds
Allamandola*, L.J.
Analysis of frozen volatiles.

Allamandola*, L.J.
Interstellar organics and possible connections with the carbonaceous components of meteorites and IDPs (Abstract).

Allamandola*, L.J.
The nature of interstellar/precometary ices.

Allamandola*, L.J.; Sandford, S.A.; Tielens, A.G.G.M.; Herbst, T.
Methanol in the sky with diamonds (Abstract).

Allamandola*, L.J.; Sanford, S.A.; Schutte, W.A.; Tielens, A.G.G.M.
Laboratory and observational study of the interrelation of the carbonaceous component of interstellar dust and solar system materials (Abstract).

Anicich*, V.G.; Arakelian, T.; Hanner*, M.S.
Quantification of UV stimulated ice chemistry: CO and CO$_2$ (Abstract).

Banin*, A.; Blake*, D.F.; Benshlomo, T.
Detection of nanophase lepidocrocite ($\gamma$-FeOOH) in iron-smectite Mars soil analog materials (MarSAM) (Abstract).

Imaging Jupiter's aurorae from H$_3^+$ emissions in the 3-4 $\mu$m band.

Battlo, F.; LeRoy, R.C.; Parvin, K.; Freund*, F.; Freund, M.M.
Positive holes in magnesium oxide: Correlation between magnetic, electric, and dielectric anomalies.

Battlo, F.; Desgranges, L.; Freund*, F.
Anomalous thermal expansion and large polaron conductivity in magnesium oxide single crystals (Abstract).
Eos. Transactions, American Geophysical Union 72(44, Suppl.): 529-530, 1991. (GWU 16095)

Physical conditions along the Orion Molecular Cloud ridge (Abstract).

Clathrate hydrate formation in amorphous cometary ice analogs in vacuo.
Fredericks, J.R.; Gibson*, E.K., Jr.; Hartmetz, C.P.
Trapped lunar volcanic gases within Apollo 15 glass spherules (Abstract).

Freund*, F.; Battlo, F.; LeRoy, R.C.
Electrical conductivity of olivine revisited (Abstract).
_Eos. Transactions, American Geophysical Union_ 72(44, Suppl.): 529, 1991. (GWU 16096)

Crystal-field-driven redox reactions: How common minerals split H2O and CO2 into reduced H2 and C plus oxygen (Abstract).

Freund*, F.; Masuda, M.M.; Freund, M.M.
Highly mobile oxygen hole-type charge carriers in fused silica.

Gibson*, E.K., Jr.; Hartmetz, C.P.
Carbon-bearing phases and volatiles in interplanetary dust particles (Abstract).

Gibson*, E.K., Jr.; Hartmetz, C.P.
Volatiles in interplanetary dust particles and aerogels (Abstract).

Gibson, J.E.; Pillinger, C.T.; Gibson*, E.K., Jr.
Carbon content of silica aerogel: A material proposed as a medium for collection of cosmic dust grains (Abstract).

Griffith, C.A.; Owen*, T.; Wagener, R.
Titan's surface and troposphere, investigated with ground-based, near-infrared observations.

Hartmetz, C.P.; Gibson*, E.K., Jr.; Blanford, G.E.
Analysis of volatiles present in interplanetary dust and stratospheric particles collected on large area collectors.

Hartmetz, C.P.; Gibson*, E.K., Jr.; Blanford, G.E.
_In situ_ extraction and analysis of volatile elements and molecules from carbonaceous chondrites.

Herbst, E.; DeFrees*, D.J.; Talbi, D.; Pauzat, F.; Koch, W.; McLean, A.D.
Calculations on the rate of the ion-molecule reaction between NH3+ and H2.

Interstellar HNO: Confirming the identification.
Madden, S.C. (Irvine, W.M. = P.I.)
Results of a galactic survey for the ring molecule cyclopropenylidene (C$_3$H$_2$).

McConville, P.; Reynolds, J.H.; Epstein*, S.; Roedder, E.
Implanted $^3$He, $^4$He, and Xe in further studies of diamonds from Western Australia.


Minh, Y.C.; Irvine*, W.M.
Interstellar H$_2$S: Probe of grain surface chemistry.

Minh, Y.C.; Irvine*, W.M.

Minh, Y.C.; Irvine*, W.M.; Brewer, M.K.

Minh, Y.C.; Zirurs, L.M.; Irvine*, W.M.; McGonagle, D.


The ortho to para ratio for ketene in TMC-1.
In: *Atoms, Ions, and Molecules: New Results in Spectral Line Astrophysics* (Haschick, A.D., Ho, P.T.P., Eds.).


Owen*, T.; Bar-Nun, A.; Kleinfeld, I.
Cometary impacts on the early Earth: Evidence from heavy noble gases (Abstract).
*Eos. Transactions, American Geophysical Union* 72(44, Suppl.): 59, 1991. (GWU 16098)

Owen*, T.; Bar-Nun, A.; Kleinfeld, I.
Noble gases in terrestrial planets: Evidence for cometary impacts?

Pauzat, F.; Ellinger, Y.; McLean, A.D. (DeFrees, D.J.; Loew, G.H. = P.I.)
Stone, J.; Hutcheon, I.D.; Epstein*, S.; Wasserburg, G.J.
Si, C and N isotopes in SiC from Orgueil and Murchison: H- and He- burning components in presolar grains (Abstract).

Talbi, D.; DeFrees*, D.J.
Ab initio study of C + H$_3^+$ reactions.

Talbi, D.; DeFrees*, D.J.; Egolf, D.A.; Herbst, E.
Calculations concerning the reaction C + H$_3^+$ → CH$^+$ + H$_2$

Tarter*, J.; Saykally, R.
Measurement of the spectral signature of small carbon clusters at near and far infrared wavelengths (Abstract).

Tielens, A.G.G.M.; Allamandola*, L.J.; Sandford, S.A.
Laboratory, observational and theoretical studies of interstellar ices.

Interstellar solid CO: Polar and nonpolar interstellar ices.

Trafton, L.M.; Lester, D.F.; Ramseyer, T.F.; Salama, F.; Sandford, S.A.; Allamandola*, L.J.
A new class of absorption feature in Io's near-infrared spectrum.

Trice, J.P.; Becker, J.F.; Sauke, T.B.; Freund*, F.
Kinetic $^{12}$C/$^{13}$C fractionation during isothermal degassing of arc-fusion grown magnesium oxide (Abstract).
Eos. Transactions, American Geophysical Union 72(44, Suppl.): 523, 1991. (GWU 16097)

Chemical gradients in the Orion Molecular Cloud (Abstract).

Villar, H.O.; Loew*, G.H.
Properties of selective type-I benzodiazepine receptor ligands.

Watson, L.L.; Ihinger, P.D.; Epstein*, S.; Stolper*, E.M.
Hydrogen, carbon and oxygen isotopic composition of volatiles in Nakhla (Abstract).

Whang, E.-J.; Freund*, F.
Carbon segregation from calcium oxide single crystals (Abstract).
Eos. Transactions, American Geophysical Union 72(44, Suppl.): 530, 1991. (GWU 16094)
Prebiotic Evolution
Arrhenius*, G.
Sources and geochemical evolution of cyanide and formaldehyde (Abstract).

Barak, D.; Shibata, M.; Rein*, R.
Structural investigation of protein kinase C inhibitors.

Evolution of isotopic signatures in lunar-regolith nitrogen: Noble gases and N in ilmenite grain-size fractions from regolith breccia 79035 (Abstract).

Betts, J.N.; Holland*, H.D.
The oxygen content of ocean bottom waters, the burial efficiency of organic carbon, and the regulation of atmospheric oxygen.

Bishop, J.L.; Pieters, C.M.; Edwards, J.O.; Coyne*, L.M.; Chang*, S.
Spectroscopic analyses of Fe and water in clays. A Martian surface weathering study (Abstract).

Blank, J.G.; Stolper*, E.M.; Zhang, Y.
Diffusion of CO₂ in rhyolitic melt (Abstract).
Eos. Transactions, American Geophysical Union 72(17, Suppl.): 312, 1991. (GWU 16105)

Chu, B.C.F.; Orgel*, L.E.
Binding of hairpin and dumbbell DNA to transcription factors.

Chyba, C.; Sagan*, C.
Electrical energy sources for organic synthesis on the early Earth.
Origins of Life and Evolution of the Biosphere 21: 3-17, 1991. (GWU 14820)

Chyba, C.F. (Sagan, C. = P.I.)
The heavy bombardment and the origins of life (Abstract).
Eos. Transactions, American Geophysical Union 72(44, Suppl.): 59, 1991. (GWU 14818)

Chyba, C.F.; Sagan*, C.; Brookshaw, L.; Thomas, P.J.
Terrestrial accretion of prebiotic volatiles and organic molecules during the heavy bombardment.

Chyba, C.F.; Sagan*, C.; Thomas, P.J.; Brookshaw, L.
Terrestrial production vs. extraterrestrial delivery of prebiotic organics to the early Earth (Abstract).

Coyne*, L.
Reflectance signature of trapped holes in montmorillonites using near infrared reflectance analysis (NIRA) and EPR.
Egli, M.; Williams, L.D.; Gao, Q.; Rich*, A.
Structure of the pure-spermine form of Z-DNA (magnesium free) at 1-Å resolution.

Egli, M.; Williams, L.D.; Gao, Q.; Rich*, A.
X-ray crystal structures of nucleic acids and their complexes with mono and bis-intercalators (Abstract).

Ferris*, J.P.; Guillemin, J.C.

Fox*, S.W.
Nonrandom protein in prelife \rightarrow life transition (Abstract).

Fox*, S.W.
Origins of life and biomedicinals from thermal proteins (Abstract).
Abstract of paper presented at the 201st National Meeting of the American Chemical Society, Biopolymers Symposium, Atlanta, GA, April 18-19, 1991, 1 p. (GWU 15073)

Fox*, S.W.
Synthesis of life in the lab? Defining a protoliving system.

Fox*, S.W.; Bahn, P.R.
Self-sealing artificial skin comprising copoly-alpha-amino acid (Patent).

Fox*, S.W.; Ruecknagel, P.; Braunitzer, G.
Molecular bases for unity and diversity in organic evolution (Abstract).

Gao, Q.; Williams, L.D.; Egli, M.; Rabinovich, D.; Chen, S.-L.; Quigley, G.J.; Rich*, A.

Harada, K.; Orgel*, L.E.
The cyclization of arabinosyladenine-5'-phosphorimidazolide.

Harang, E.A.; Baltscheffsky, H.; Deamer*, D.W.
Production of ATP and PPI in R. rubrum chromatophores using ferrocyanide illumination to produce chemiosmotic proton gradients (Abstract).

Hefu, F.; Junard, E.O.; Knüsel, B.; Strauss, W.L.; Strang, P.F.; Przybylski, A.; Vaughan, G.; Fox*, S.W.
Promotion of neuronal survival in vitro by thermal proteins and poly(dicarboxylic) amino acids.
Kanavarioti*, A.; Rosenbach, M.T.
Catalysis of hydrolysis and nucleophilic substitution at the P-N bond of phosphoimidazolide-activated nucleotides in phosphate buffers.

The structural studies of endotoxin neutralizing protein (Abstract).

Kerridge*, J.F.
Interstellar precursors in synthesis of meteoritic organic matter (Abstract).

Kerridge*, J.F.
Isotopic analysis of cometary organic matter.

Kerridge*, J.F.
Isotopic constraints on the origin of meteoritic organic matter (Abstract).

Kerridge*, J.F.; Bochsler, P.; Eustein, O.; Geiss, J.
Modelling the evolution of N and 15N/14N in the lunar regolith (Abstract).

Optical properties of tholin from H2O/C2H6 (6:1) ice, and comparison with Titan tholin, kerogen and meteoritic organics (Abstract).

Khare*, B.N.; Thompson, W.R.; Sagan*, C.; Arakawa, E.T.; Meisse, C.; Gilmour, I.
Optical constants of kerogen from 0.15 to 40 μm: Comparison with meteoritic organics.

Lacey*, J.C.; Thomas, R.D.; Staves, M.P.; Watkins, C.L.
Stereoselective formation of bis(α-aminoacyl) esters of 5'-AMP suggests a primitive peptide synthesizing system with a preference for L-amino acids.
*Biochimica et Biophysica Acta* 1076: 395-400, 1991. (GWU 12269)

Lacey*, J.C., Jr.
Chemistry of aminoacylation of 5'-AMP and the origin of protein synthesis (Abstract).

Landry, B.; Allen, M.; Yung*, Y.L.
Troposphere-stratosphere interactions in a one-dimensional model of Jovian photochemistry.

Levine*, J.S.
The biosphere as a driver for global atmospheric change.
Morowitz*, H.J.
A window in time for the first evolutionary radiation (Abstract).

Morowitz*, H.J.; Deamer*, D.W.; Smith, T.
Biogenesis as an evolutionary process.

Interaction between the left-handed Z-DNA and polyamine: The crystal structure of the d(CG)$_3$ and N-(2-aminooethyl)-1,4-diamino-butan complex.

Orgel*, L.E.
Template polymerization of nucleotide analogues (Abstract).

Oró*, J.
Origen y evolucion de la vida. (Spanish)

Oró*, J.; Lazcano, A.
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Pohorille*, A.; Benjamin, I.
Molecular dynamics of phenol at the liquid-vapor interface of water.

Pohorille*, A.; Wilson, M.; MacElroy*, R.D.
Structure and functions of water-membrane interfaces and their role in proto-biological evolution (Abstract).

Ponnamperuma*, C.
Studies on the origin of the genetic code (Abstract).

A possible relationship between enantiomeric structure of an amino acid and its association with its anticodonic nucleotide (Abstract).


Zuotein-1, a putative Z-DNA binding protein in yeast Saccharomyces cerevisiae (Abstract).

Zhang, X.; Kang, C.-H.; Rich*, A.
The structural studies of left-handed Z-DNA (Abstract).

Zhang, Y.; Stolper*, E.M.
Water diffusion in a basaltic melt.

Zhang, Y.; Stolper*, E.M.
Water diffusion in a basaltic melt (Abstract).
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Diffusion of a multi-species component and its role in oxygen and water transport in silicates.

Zhang, Y.; Stolper*, E.M.; Wasserburg, G.J.
Diffusion of water in rhyolitic glasses.
Early Evolution of Life
Allen, M.E.; Friedmann*, E.I.
Scanning electron microscopy of cryptoendolithic microorganisms in Antarctic rocks: Distribution along ecological gradients (Abstract).
In: Abstracts, 91st Annual Meeting of the American Society for Microbiology, Dallas, TX, 1991, p. 190. (GWU 14803)

Asmerom, Y.; Jacobsen, S.B.; Knoll*, A.H.; Butterfield, N.J.; Swett, K.
Strontium isotopic variations of Neoproterozoic seawater: Implications for crustal evolution.

Awramik*, S.M.
Nonmarine stromatolites and the search for early life on Mars (Abstract).

Bauer, J.E.; Haddad, R.I.; Des Marais*, D.J.

Blankenship*, R.E.; Causgrove T.P.; Alden, R.G.; Trost, J.T.
Primary photochemistry in heliobacterial reaction centers (Abstract).

Blankenship*, R.E.; Causgrove, T.P.; Cheng, P.; Brune, D.C.; Trost, J.T.; Alden, R.G.
Energy transfer and trapping in green photosynthetic bacteria and heliobacteria (Abstract).

Heliobacterial reaction centers as models for photosystem (Abstract).

Buchanan*, B.B.
Regulation of CO2 assimilation in oxygenic photosynthesis: The ferredoxin/thioredoxin system.

Buchanan*, B.B.
Thioredoxin and evolution (Abstract).

Buchanan*, B.B.
Thioredoxins: Photosynthetic proteins as regulatory prototypes for nonphotosynthetic systems (Abstract).
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Des Marais*, D.J.; Canfield*, D.E.
Have stromatolites recorded changes in atmospheric carbon dioxide levels? (Abstract)
_Eos. Transactions, American Geophysical Union_ 72(17, Suppl.): 165, 1991. (GWU 14885)

Des Marais*, D.J.; Truesdell, A.H.
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The primary structure of cytochrome c-554 from the green photosynthetic bacterium _Chloroflexus aurantiacus_.

Eglinton, T.I.; Fry, B.D.; Freeman, K.H.; Hayes*, J.M.
Stable carbon isotopic composition of individual products from flash pyrolysis of kerogens (Abstract).
_Abstracts of Papers of the American Chemical Society_ 201: 103-FUEL, 1991. (GWU 15071)

Fairchild, I.J.; Knoll*, A.H.; Swett, K.
Coastal lithofacies and biofacies associated with syndepositional dolomitization and silicification (Draken Formation, Upper Riphean, Svalbard).

Fox*, G.E.
Exploration of RNA structure spaces (Abstract).

Francois, L.M.; Walker*, J.C.G.
Modelling the Phanerozoic carbon cycle and climate: Constraints from the $^{87}$Sr/$^{86}$Sr isotopic ratio of seawater (Abstract).
_Eos. Transactions, American Geophysical Union_ 72(17, Suppl.): 158, 1991. (GWU 16107)

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The relationship between $^{13}$C in organic carbon and atmospheric pCO$_2$ and estimation of pre-Miocene CO$_2$ levels (Abstract).
_Eos. Transactions, American Geophysical Union_ 72(17, Suppl.): 166-167, 1991. (GWU 16108)

Freeman, K.H.; Wakeham, S.G.; Hayes*, J.M.
Predictive isotopic biogeochemistry of lipids from the Black Sea and Cariaco Trench (Abstract).
_Abstracts of Papers of the American Chemical Society_ 201: 38-GEOC, 1991. (GWU 15065)

Friedmann*, E.I.; Ocampo-Friedmann, R.
Strategies of xerophytic algae (Abstract).

Grant, S.W.F.; Knoll*, A.H.; Germs, G.J.B.
Probable calcified metaphytes in the latest Proterozoic Nama Group, Namibia: Origin, diagenesis, and implications.

Green, L.S.; Yee, B.C.; Buchanan*, B.B.; Kamide, K.; Sanada, Y.; Wada, K.
Ferredoxin and ferredoxin-NADP reductase from photosynthetic and nonphotosynthetic tissues of tomato.

31
Huppe, H.C.; Picaud, A.; Buchanan*, B.B.; Miginiac-Maslow, M.
Identification of an NADP/thioredoxin system in Chlamydomonas reinhardtii.
*Planta* 186: 115-121, 1991. (GWU 14750)

Jahnke*, L.L.
The effects of oxygen on the evolution of microbial membranes (Abstract).

Jasper, J.P.; Hayes*, J.M.; Prahl, F.G.
Photosynthetic fractionation of $^{13}$C and estimates of pCO$_2$ on the scale of $10^3$-$10^8$ years (Abstract).

Jasper, J.P.; Hayes*, J.M.; Prahl, F.G.; Mix, A.; Wakeham, S.G.; Crusius, J.; Anderson, R.F.
Isotopically-driven estimates of dissolved CO$_2$ and equilibrium pCO$_2$ from late Quaternary sedimentary records in the equatorial Pacific and Black Sea (Abstract).
*Eos. Transactions, American Geophysical Union* 72(44, Suppl.): 272, 1991. (GWU 16103)

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*Eos. Transactions, American Geophysical Union* 72(17, Suppl.): 167, 1991. (GWU 16110)

Jukes*, T.H.
Random Walking: Chimps, gorillas, orangs and us.

Jukes*, T.H.
Early development of the neutral theory.

Jukes*, T.H.
Mars as a new abode for microbial life.
*Journal of Molecular Evolution* 32: 355-357, 1991. (GWU 14911)

Jukes*, T.H.; Osawa, S.
Recent evidence for evolution of the genetic code.

Jurtshuk, R.J.; Blick, M.; Bresser, J.; Jurtshuk, P., Jr.; Fox*, G.E.
16S rRNA in situ hybridization technique for differentiating closely related gram positive organisms, *Bacillus polymyxa* and *Bacillus macerans* (Abstract).
In: *Abstracts, 91st Annual Meeting of the American Society for Microbiology*, Dallas, TX, 1991, p. 244. (GWU 15367)

Kasting*, J.F.
Box models for the evolution of atmospheric oxygen: An update.

Kasting*, J.F.
CO$_2$ condensation and the climate of early Mars.
Lanyi*, J.K.
Archaebacterial rhodopsin sequences: Implications for evolution (Abstract).

Liebl, U.; Blankenship*, R.E.; Vermaas, W.F.J.
Cloning of the reaction center gene from Heliot Bacillus mobilis (Abstract).

Lowe*, D.; Byerly, G.
Powerline Road section across the central Barberton Greenstone Belt.

Lowe*, D.R.
Geology of the Barberton Greenstone Belt: An overview.

Lyons, W.B.; Des Marais*, DJ.
The stable isotope biogeochemistry of carbon and nitrogen in Lake Hoare, Antarctica (Abstract).
Eos. Transactions, American Geophysical Union 72(17, Suppl.): 109, 1991. (GWU 14888)

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Plant thioredoxin h: An animal-like thioredoxin occurring in multiple cell compartments.

Margulis*, L.
Big trouble in biology: Physiological autopoiesis versus mechanistic Neo-Darwinism.

Margulis*, L.
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Margulis*, L.
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Gaian Science May/July: 11-12, 1991. (GWU 14792)

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_Eos. Transactions, American Geophysical Union_ 72(17, Suppl.): 158, 1991. (GWU 16112)

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Phylogenetic diversity in the genus Bacillus as seen by 16S rRNA sequencing studies.

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Schopf*, J.W.
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Schopf*, J.W.
The oldest evidence of photosynthesis in the fossil record (Abstract).

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Nucleotide protectable labeling of SH groups in subunit I of the ATPase from Halobacterium saccharovorum.
In: _Abstracts, 91st Annual Meeting of the American Society for Microbiology_, Dallas, TX, 1991.
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Kinetic and spectroscopic evidence for an irreversible step between deprotonation and reprotonation of the Schiff base in the bacteriorhodopsin photocycle.

Váró, G.; Lanyi*, J.K.
Thermodynamics and energy coupling in the bacteriorhodopsin photocycle.

Walker*, J.C.G.
Degassing.

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DeVincenzi*, D.L.; Klein*, H.P.; Bagby, J.R. (Eds.)
Appendix
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