Astrobiology Quotations

Compiled By Paul Nethercott

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1. Current Earth Environments, By Various Authors
Hydrothermal systems on Mars and Europa are possible havens for life because they can supply the requisite water, energy and sources of carbon. Page 335
Astrobiology, Volume 1, Number 3, 2001, Pages 317-349

2. What Will We Find on Mars, Europa, By Jack D. Farmer
Europa has the possibility of harboring a sub-surface liquid ocean, organic compounds, and a heat source from friction generated from tidal action. These potential conditions make Europa a high-priority for exobiological exploration. Page 351

V. What are the plausible models for the origin and evolution of life on Europa? Page 351

Since reduced gases may be released from the ocean bottom at hydrothermal vents, the chemical disequilibrium required for evolution of life within Europa may present even without substantial inputs from photosynthetically active radiation (PAR) at the surface. Europa may therefore represent a new class of habitable objects in the universe – large icy satellites or planets orbiting in intense irradiation environments. Due to the fragility of life often exposed to catastrophic events on the surfaces of planets in the classical 'habitable zone', life forms evolving in protected sub-surface oceans of Europa-like objects might actually be more common in the universe than terrestrial life forms. Page 352

More generally, whether we are considering Earth, Mars, Titan, or Europa in the search for life and its origins the bubblesol cycle, its processes, and its resulting mass objects must be taken into account. Page 366
Astrobiology, Volume 1, Number 3, 2001, Pages 350-380

3. Outside Our Solar System?, By Various Authors
I suggest here that a primarily inorganic form of life is not only possible, but currently in the process of formation. Specifically, in this life form, information storage is carried by digital circuits of inorganic makeup (Si, SiOx, Cu, Au, etc.), and analysis and control functions are orchestrated by computer program software. Energy transduction into electrical power is achieved from solar insolation (solar cells of Si, Ga, As, etc.), nuclear radiation (radioisotope thermoelectric conversion from Pu or Sr, or fission reactor sources of U or Pu), or inorganic electrochemical energy sources (fuel cells and batteries of various, often inorganic, forms). Mutation occurs via software modifications, using self-altering program codes and an influx of new programming material from human sources. All this resides in an artificial machine intelligence entity or network of entities that comprise a single, but possibly distributed life form. Page 421
Astrobiology, Volume 1, Number 3, 2001, Pages 416-426

4. Origin of Homochirality on Earth?, By Evgenii I. Klabunovskii
Although there are numerous enantiomorphic crystals that can initiate asymmetric reactions using the mechanism of autocatalysis, we conclude that enantiomeric crystals did not play a role in the origin of homochirality on Earth. Page 129
Astrobiology, Volume 1, Number 2, 2001, Pages 127–131

5. Life on Other Worlds, By Louis Neal Irwin
Category III applies to worlds where conditions are physically extreme but possibly capable of supporting exotic forms of life unknown on Earth (Titan, Triton). Category IV applies to bodies that could have seen the origin of life prior to the development of conditions so harsh as to make its perseverance at present unlikely but conceivable in isolated habitats (Venus, Io). Page 143

Category IV applies to bodies that could have seen the origin of life prior to the development of conditions so harsh as to make its perseverance at present unlikely but conceivable in isolated habitats (Venus, Io). Page 143

Reasonable inference of past conditions suitable for the Mercury, Venus, Io origin of life prior to the development of conditions so harsh as to make its perseverance at present unlikely but conceivable in isolated habitats. Page 147

Ganymede [Plausibility Of Life]
Favorable—numerous energy sources; likely subsurface water; geochemical cycling. Pages 149, 150

Callisto [Plausibility Of Life]
Moderate—possible subsurface liquid but little energy flux. Pages 149, 150

Enceladus [Plausibility Of Life]
Moderate—possible subsurface liquid water with several energy sources. Pages 149, 150

Titan [Plausibility Of Life]
Moderate—complex organic chemistry and reducing atmosphere. Pages 149, 150

Triton [Plausibility Of Life]
Moderate—complex chemistry and several energy sources, with possible subsurface liquid. Pages 149, 150

The possibility of life on Europa has increased with the discovery of new evidence that indicates a salt-bearing liquid ocean lies beneath the frozen ice crust. Page 151

If water was ever liquid at the surface on Europa, all current theories about the origin of life on Earth could potentially apply to Europa. Page 151

Therefore, the origin of life on Europa is quite plausible. Page 151

Life could have persisted on Europa if water is indeed liquid beneath its icy crust. Page 151

The presence of abundant organic compounds, possibly sufficient to coat the entire surface (Spiker, 1997), provides the strongest stimulant to speculations about the possibility of life on Titan. Page 152

If life formed [Titan], it would have been exotic by Earth standards. Page 152

While conditions on Triton appear to be extreme at present, they were quite possibly amenable to the origin of chemotrophic life at an earlier point in its history, which could still be present if a liquid environment persists below the surface. Page 153
Astrobiology, Volume 1, Number 2, 2001, Pages 143–160

6. Possibility of Life on Venus, By Dirk Schulze-Makuch
During the time period when liquid water was stable on the surface of Venus, life may have evolved independently or been delivered by meteorites from Earth or Mars. Page 197

If so, microbial life may have had time to emerge or establish itself on Venus. Once in existence, life could have retreated to restricted environmental niches for survival, adapting progressively through directional selection to specialized environmental niches (Irwin and Schulze-Makuch, 2002). One such niche is the atmosphere, which, owing to its high pressure, is kept in a thick, liquid-like state. Another possible niche is Venus' subsurface. Page 198

Under the environmental conditions prevailing in the Venusian atmosphere, chemotrophic as well as phototrophic life could be imagined. Page 200

Environmental conditions on the surface of Venus are hostile to life as we know it. However, it is possible that life, whether indigenous or exogenous, established itself early in the planet's history. Life could have gradually adapted to the deep subsurface, where water may exist in the supercritical liquid state, or it could have survived and adapted to live in the atmosphere when the planet warmed and the ocean evaporated into a dense cloud covering. Several observations and measurements in the lower cloud layer of Venus could be explained by the presence of microbial life. Empirical evidence for the existence of living microbes in the midregions of the Venusian atmosphere could be obtained by sample collection and return to Earth, using existing technology patterned after the Stardust Mission. Page 201

Astrobiology, Volume 2, Number 2, 2002, Pages 197–202

7. Liquid Water in Europa, By Krishan K. Khurana

Liquid water, as far as we know, is an indispensable ingredient of life. Therefore, locating reservoirs of liquid water [Europa] in extraterrestrial bodies is a necessary prerequisite to searching for life. Page 193

Astrobiology, Volume 2, Number 1, 2002, Pages 93–103

8. Europa's Ocean, By Dirk Schulze-Makuch

While Europa has emerged as a leading candidate for harboring extraterrestrial life, the apparent lack of a source of free energy for sustaining living systems has been argued. Page 105

Using reasonable assumptions based on known organisms on Earth, our calculations suggest that chemical oxidation–reduction cycles in Europa's subsurface ocean could support life. Page 105

Assumed here is the distinct possibility that life either arose indigenously or was transported to Europa early in its history, given the surface water conditions and water vapor atmosphere that likely prevailed on Europa shortly after its formation. Page 106

It is reasonable to assume that, once established, life would adapt to the sheltered conditions beneath Europa's ice crust and persist (Irwin and Schulze-Makuch, 2001). If hydrothermal vents exist on the ocean floor of Europa, thermophilic organisms like those proposed as early ancestors for life on Earth (Stetter, 1998) could have arisen more recently. Detailed arguments for the possible origin of life on Europa have been made by others (McKay and Davis, 1999; Rummel and Van Dover, 2000) and are beyond the scope of this paper. Page 106

Jupiter's ice-covered satellite Europa now appears to be one of the most likely places in the solar system for harboring extraterrestrial life (Chyba, 1997, 2000; Chela-Flores, 1998; McKay and Davis, 1999, Irwin and Schulze-Makuch, 2001). Page 107

Thus, in principle, chemotrophic, osmotrophic, thermotrophic, kinetotrophic, gravitrophic, and magnetotrophic life could theoretically exist in the subsurface ocean of Europa. Page 108

It follows that arguments made here for the support of life by alternative energy sources on Europa could apply to Ganymede and Callisto as well. Page 108

If life arose early on Europa, it could have originated either in fresh water or in an ocean with a low salinity content since it is unlikely the ocean would have been in chemical equilibrium with the rocky mantle. Life could have maintained a hyposmotic cellular state as the ocean became progressively saltier. Page 111

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. Page 113

Gravitational energy could be harvested in a simplistic fashion by lifting up protons or molecules against the gravitational attraction of a planetary body. Page 115

The only habitat where overlap among the proposed alternative life forms would occur would be geothermal areas near convection cells (thermotrophs and kinetotrophs). The hypothetical organisms and their microenvironments are depicted in Fig. 6. Page 116

Astrobiology, Volume 2, Number 1, 2002, Pages 105–121

9. Life on Earth and Europa, By Stephan Kempe

Biogenesis is one of the most puzzling scientific problems. Given life's biochemical complexity, it is a wonder it ever arose. Even if Panspermia (Hoyle and Wickramasinghe, 1997) is accepted as a way to propagate life, it does not solve the fundamental problem of biogenesis but shifts it from the Solar System to other places in the galaxy. Page 123

Similarly, if our hypothesis of a soda ocean on Europa should prove true, then the biogeochemical window for life to emerge in its ocean could have appeared relatively rapidly. Page 129
Astrobiology, Volume 2, Number 1, 2002, Pages 123–130

10. Life Before RNA, By Stephen J. Sowerby
The hypothesis that life originated and evolved from linear informational molecules capable of facilitating their own catalytic replication is deeply entrenched. However, widespread acceptance of this paradigm seems oblivious to a lack of direct experimental support. Page 231
Astrobiology, Volume 2, Number 3, 2002, Pages 231–239

11. Life Is Common in the Universe?, By Charles H. Lineweaver
Although we do not understand the details of how life originated, we have some useful observational constraints on how long it took. Page 293
Astrobiology, Volume 2, Number 3, 2002, Pages 293–304

12. Pathways to Life, By David W. Deamer
In part, the challenge is to avoid being trapped into "Earth-o-centric" thinking based on familiar terrean biochemistry, without at the same time being lured into fanciful "Star Trek Chemistry", fun to imagine but lacking any chance of reality. To do so requires drawing on every piece of information known in chemistry, and then some, to enforce the discipline needed to ensure reality. Page 433
Astrobiology, Volume 2, Number 4, 2002, Pages 433

13. Exploring for Life in the Solar System, By Various Authors
Mounting evidence for the existence of a liquid water ocean below Europa's icy lithosphere [e.g., 1–3] has increased the potential for the satellite to harbor life, and the future exploration of Europa will need to focus on the identification of sites where signatures of past or present life could be detected and studied. Page 510

Therefore chaos areas, whether derived from diapirs from the base of the lithosphere or from an exposed and refrozen ocean, are windows to Europa's subsurface, its chemistry, and possible life forms. Page 510

If detected, equilibrium lowtemperature relations among these species in Europa's oceanic water would be highly suggestive of the involvement of ancient life. Page 514
Astrobiology, Volume 2, Number 4, 2002, Pages 504-522

14. Origin of Living Systems, By Various Authors
Strong chiral preference for amino acids, sugars and other essential bio molecules is a defining characteristic of biological systems. Abiotic processes that select left handed versus right-handed molecules are thus central to geochemical models of life's origin and evolution. Page 598

It is widely presumed that life's origins are tied to the early oceans, and that the key reactions leading to functioning peptides and polynucleotides were water-based. The story is not without its difficulties, however, with thermodynamic and perhaps kinetic barriers to their formation stemming from the inherent favor of amide and ester hydrolysis relative to formation. This water-based obstacle leads to the consideration of a dry, bulk solid alternative that provides a surprisingly facile route to peptides, while at the same time accounting for the rapid emergence of life after the period of heavy bombardment (PHB). Page 602
Astrobiology, Volume 2, Number 4, 2002, Pages 589-604

15. Exchange of Life Between Stellar Systems?, By H.J. Melosh
In this paper I examine the probability that such interstellar meteorites might be captured into a distant solar system and fall onto a terrestrial planet in that system within a given interval of time. The overall conclusion is that it is very unlikely that even a single meteorite originating on a terrestrial planet in our solar system has fallen onto a terrestrial planet in another stellar system, over the entire period of our Solar System's existence. Although viable microorganisms may be readily exchanged between planets in our solar system through the interplanetary transfer of meteoritic material, it seems that the origin of life on Earth must be sought within the confines of the Solar System, not abroad in the galaxy. Page 207

This translates to only a very slim chance that life can be transported from one stellar system to another. Page 213

When the long transit times from one star to another are added in, the prospect that life hopped from star to star by any natural agency becomes vanishingly small. The bottom line is that the origin of life on Earth must be sought within the confines of the Solar System itself, not abroad in the galaxy. Page 215
Astrobiology, Volume 3, Number 1, 2003, Pages 207-215

16. Detection of Microbial Life, By Roger F. Knacke
In this paper we discuss the feasibility of the direct detection of microbial life outside the Solar System. Microbes, the smallest, but possibly the most abundant life forms on habitable extrasolar planets, may be detectable in the next few decades. Page 532

Experience with satellite remote sensing and projections of future telescopic capabilities suggest that the prospects for searches for algae on extrasolar planets will be challenging, even daunting. Page 539
Astrobiology, Volume 3, Number 3, 2003, Pages 531–541

17. Finding Extraterrestrial Organisms, By Anthonie W.J. Muller
Venus and the gas giant planets. The surface of Venus and the interior of the gas giant planets are at present far too hot to permit living TSOs. The atmospheres, however, are much cooler, and life that could reside in aerosols within convecting clouds has been proposed (Dimmick et al., 1977; Dobson et al., 2000), that would be based on internal heating of the planet (Jones, 1997). Page 559
Astrobiology, Volume 3, Number 3, 2003, Pages 555–564

18. Evaporites, Water, and Life, Part 1, By Susan J. Wentworth
The widespread occurrence of evaporites in extraterrestrial samples may have profound implications for the origin and development of life, simply because the evaporites suggest that conditions favorable to life as we know it may have been fairly common in the Solar System throughout most of its history. Page 582
Astrobiology, Volume 3, Number 3, 2003, Pages 581-582

19. Evaporites, Water, and Life, Part I, By Stephen E. Grasby
Chemolithotrophic bacteria, analogous to those at deep-sea vents, could have survived beneath the ice of "Snowball Earth," and life forms with similar characteristics might exist beneath the ice of Mars or Europa. Page 583

Even at this stage, our work supports the idea that life can exist under extreme environmental conditions in isolated refuges, such as under Snowball Earth conditions, and perhaps even beneath the ice on Mars or Europa. Page 594
Astrobiology, Volume 3, Number 3, 2003, Pages 583–596

20. Earth, Life and the Universe, By David J. Thomas
As with most books and papers on life in the Solar System, most of Keith Tritton's discussion focuses on Mars and Europa as the most likely sites for finding extant or extinct extraterrestrial life. Page 645

Astrobiology, Volume 3, Number 3, 2003, Pages 645, 646

21. Imply a Martian Origin?, By P. C. W. Davies
The foregoing standard scenario—that life established itself rapidly on Earth following an extended hostile period—is certainly open to question in the light of sparse and contentious data concerning the early Solar System. Page 673

The problem of life's origin is bedevilled by the fact that we have access to only one sample of life. Page 678
Astrobiology, Volume 3, Number 4, 2003, Pages 673–679

22. Europa, By Sherwin J. Gormly
Speculations about the extent of life of independent origin and the potential for sustaining Earth-based life in subsurface environments on both Europa and Mars are of current and relevant interest. Page 761

Under some scenarios for the Europan ocean, conditions have close Earth analogs, and thus analog microbial communities may exist. Organisms resident in arctic wastewater treatment or natural brine environments may provide the potential to validate the limits for microbial life under postulated Europa conditions. Page 762
Astrobiology, Volume 3, Number 4, 2003, Pages 761–770

23. Europa Mission, By James Bradley Dalton
It has been postulated that this ocean could have at one time harbored prebiotic compounds or even extraterrestrial life (Sagan et al., 1993; Fanale et al., 1998; McCord et al., 1998; Chyba and Phillips, 2001). Page 772
Astrobiology, Volume 3, Number 4, 2003, Pages 771-784

24. The Search for Life on Europa, By Giles M. Marion
The putative ocean of Europa has focused considerable attention on the potential habitats for life on Europa. Page 785

The potential habitats for life on Europa can be divided into three zones: the ice layer, the liquid ocean, and the seafloor environment. Page 794

Temperatures in the vicinity of seafloor hydrothermal vents, if they exist, are likely the most favorable environments for life on Europa. Unfortunately, there is no direct evidence that such vents exist on Europa. Page 798
Astrobiology, Volume 3, Number 4, 2003, Pages 785-811

25. Ecosystems on Europa, By Louis N. Irwin
The likely presence of a liquid ocean beneath the icy surface of Europa (Carr et al., 1998; Khurana et al., 1998) provides a potential habitat for life based on aquatic biochemistry. Page 813

Though the template is applied here by analogy with known terrean ecosystems, the general strategy could in theory be extended to ecosystems and forms of life unknown on Earth. Page 820
Astrobiology, Volume 3, Number 4, 2003, Pages 813–821

26. Oxidants in Europa's Surface, By R. E. Johnson
The putative subsurface ocean on Europa is of interest to astrobiologists as an environment that might be able to sustain life processes. Page 823
Astrobiology, Volume 3, Number 4, 2003, Pages 823–850

27. Potential Biosignatures on Europa, By Patricio H. Figueredo

Evidence for the existence of a liquid water ocean below Europa's icy shell (e.g., Carr et al., 1998; Khurana et al., 1998; Pappalardo et al., 1999; Kivelson et al., 2000) has increased the potential for the satellite to harbor life (e.g., Irwin and Schulze-Makuch, 2001; Chyba and Phillips, 2002). Page 851

Astrobiology, Volume 3, Number 4, 2003, Pages 851–861

28. Terrestrial Analog of Europa, By Olga Prieto-Ballesteros

Moreover, the characterization of the subsurface microbial community of Lake Tírez, which is dominated by sulfate-reducing bacteria together with methanogenic Archaea, could give some insight into the possible microbial life sustained on the Jovian satellite. Page 866

Astrobiology, Volume 3, Number 4, 2003, Pages 863–877

29. Content of Europa's Ocean, By William B. McKinnon

On the other hand, we argue here that massive (multi kilometer-thick) sulfur beds are a distinct possibility, and they would be an astrobiological disaster from the point of view of hydrothermally hosted life (Shock et al., 2000). Page 893

Astrobiology, Volume 3, Number 4, 2003, Pages 879–897

30. Fossil Life on Mars, By Tomas Hode

Given the recent evidence for water ice on Mars, it is reasonable to assume that any large impacts that generated hydrothermal systems could localize niches for possible thermophilic communities on Mars, supporting the idea that impact structures are suitable places to look for fossil thermophilic organisms on the Red Planet. Page 287

Astrobiology, Volume 3, Number 2, 2003, Pages 271–289

31. Martian Hydrothermal Systems, By B. M. Jakosky

In order to explore further the question of which environments on Mars are most suitable for life, we developed numerical models to investigate the geochemical consequences of mixing martian hydrothermal fluids with ground waters. Page 408

Astrobiology, Volume 3, Number 2, 2003, Pages 407–414

32. Build Living Systems, By William Bains

This has been the subject of some speculation, often based on the idea that, even if life did not originate, for example, on Europa, it could have been transferred from Earth and subsequently flourish there. Page 148

But with at least two energy sources available for biochemistry (and photosynthesis for surface life on Titan), conceiving of the Galilean moons as a home for a non-terrestrial biochemistry is not unreasonable. Page 150

Thus from a kinetic standpoint silicon chemistry, and specifically the chemistry of the silanols, could be a more attractive candidate than carbon for the base chemistry of "life" in extremely cold liquids (specifically in liquid nitrogen, as this is the liquid in which solubility measurements have been carried out, although liquid methane/ethane would be expected to have similar properties). But can silicon chemistry fulfill the structural requirements of a biochemistry? Page 154

As a barrier to using silicon for living systems, however, this is only a problem if we assume that strongly protonating solvents (water, ammonia, hydrogen sulfide, and sulfuric acid in a cosmological context) are the solvent base. Oceans of cold, non-protonating fluids, and specifically liquid nitrogen, would be more favorable for silicon life. In such environments, the inherently greater reactivity of silicon-based chemicals could be an advantage, enabling "living" processes to occur at greater than geological speeds at the relatively lower temperatures where such fluids are stable. Such fluids could also include liquid methane, ethane, neon, or argon. Page 155

So the "builders specification" requirement for life does not rule out silicon as a base element in place of carbon; its chemical and structural flexibility in non-aqueous environments can provide analogues to all the functions of terrestrial biochemistry. Page 156

Astrobiology, Volume 4, Number 2, 2004, Pages 137–167

33. Biological Terraforming of Mars, By James M. Graham

These data, the basis of the search for past or present life on Mars, suggest the possibility of returning Mars to its previous climate by global engineering techniques. Greenhouse gases, such as perfluoro carbons, appear to be the best method for warming Mars and increasing its atmospheric density so that liquid water becomes stable. The process of making Mars habitable for terrestrial organisms is called terra forming or planetary eco synthesis. The process of introducing terrestrial ecosystems to Mars can be compared with a descent down a high mountain. Each drop in elevation results in a warmer, wetter climate and more diverse biological community. Beginning with a polar desert, the sequence of ecosystems passes through tundra, boreal forest, and temperate ecosystems where moisture determines the presence of desert, grassland, or forest. This model suggests a sequence for the introduction of ecosystems to Mars and the communities to search for potential colonizing species for Mars. Page 168

Planetary eco synthesis on Mars will be a long and great adventure. It will yield a vast amount of new knowledge and become one of the great acts of positive creative energy by the human species. Earth is the home of the human species; through planetary eco synthesis humanity may be able to build new homes through the galaxy. Page 193

Astrobiology, Volume 4, Number 2, 2004, Pages 168–195

34. Life in the Venusian Atmosphere, By Dirk Schulze-Makuch

Several observations indicate that the cloud deck of the venusian atmosphere may provide a plausible refuge for microbial life. Having originated in a hot proto-ocean or been brought in by meteorites from Earth (or Mars), early life on Venus could have adapted to a dry, acidic atmospheric niche as the warming planet lost its oceans. Page 11

Thus, life could exist today in the clouds of Venus. Page 11

For water-based life, the discontinuous and cold clouds of Earth represent, in many ways, a more extreme environment than those of Venus. Thus, if microbial life has gained a foothold in Earth's atmosphere, the more favorable conditions of the atmosphere on Venus should certainly make it a suitable habitat for microbial life. If life arose or was transported to Venus at an earlier stage in its planetary history when liquid water may have persisted on the surface (Jakosky, 1998; Owen, 2000), descendents of those early forms could have adapted to the increasingly warm, dry, and acidic atmosphere through directional selection that would have favored retention of characteristics suitable for those conditions (Schulze-Makuch and Irwin, 2004). Page 12

If microbial life exists in the venusian atmosphere, a mechanism has to be employed to cope with high doses of UV radiation. Page 12

Thus, Reaction 1 is a plausible pathway for microbial life on Venus. Page 14

In proposing photosynthesis as the bioenergetic mechanism for the support of putative microbial life in the clouds of Venus, we do not mean to imply the same molecular processes of photosynthesis as they occur in phototrophs on Earth. Indeed, as life has evolved in a much less acidic environment on this planet, selection has favored mechanisms that operate at neutral pH values and are non-functional at high acidity. On Venus, however, forms of life may have evolved a quite different molecular machinery to deal with the progressively acidifying conditions. Page 15

Therefore, instead of life originating independently on Venus, ancestral photoautotrophic or chemoautotrophic organisms from Earth or Mars could have been delivered by impact panspermia, when the planetary environments on all three planets were likely to have been very similar. Early Venus with an ocean most likely would not have been particularly acidic, although it would still have been a harsh UV environment (Kasting et al., 1988; Cockell, 1999, 2000). Page 16

Astrobiology, Volume 4, Number 1, 2004, Pages 11–18

35. A Viable Microbial Community, By Eric Gaidos
Active subglacial volcanoes and their concomitant hydrothermal systems may be especially propitious sites for life. Besides their intrinsic scientific interest as extreme environments, subglacial volcanoes are potential analogs to past or present habitats on an early Snowball Earth, in possible martian glaciers, and in the subsurface ocean of the satellite Europa (Gaidos et al., 1999; Gaidos and Marion, 2003). Page 328
Astrobiology, Volume 4, Number 3, 2004, Pages 327-344

36. Spectra of Distant Jupiters, By D. M. Williams
By taking advantage of this spectral contrast, future space observatories will be able to discern which extrasolar giant planets have Earth-like moons capable of supporting life. Page 400
Astrobiology, Volume 4, Number 3, 2004, Pages 400-403

37. Evaporites, Water, and Life—Part 2, By Russell Scott Shapiro
Because of the physicochemical gradient, biotic precipitation of evaporite minerals could occur at these sites. At Earth’s methane seeps, the primary precipitates are the calcium carbonate minerals aragonite, calcite, and dolomite and sulfide minerals such as pyrite. Elsewhere in the Solar System, a host of other precipitating minerals may substitute. Regardless, the precipitates can point to the localization of prokaryote-like fossils (such as the botryoidal cements of the present study) and can also replace, or form, a microbial mold. Therefore, the analysis of these fabrics should remain a major goal of future astrobiological missions. Page 446, 447
Astrobiology, Volume 4, Number 4, 2004, Pages 438–449

38. Session 3: Origins of Life, By Various Authors
The source of life’s homochirality is one of the central questions of origin of life research. Page 221
Astrobiology, Volume 5, Number 2, 2005, Pages 215-228

39. News & Views, By Kenneth Stedman
The purpose of NAIVIFOG is to foster interest in the study of viruses found in extreme locations on Earth and to apply these results to the development of concepts, instruments, and techniques to search for extreme viruses and similar “life forms” on Earth and elsewhere, specifically Mars and Europa. Page 441
Astrobiology, Volume 5, Number 4, 2005, Pages 441-443

40. Origin of Life on Earth, By Nils G. Holm
Thermal and geochemical activity in hydrothermal systems has persisted since the formation of the planetary crust. Hydrothermal activity has also been discussed in the context of prebiotic chemistry on both Mars and Europa (e.g., Bock and Goode, 1996; Jakosky, 1998). French (1962, 1970) was the first scientist to recognize hydrothermal systems as plausible sites for non-biological synthesis of organic compounds. Page 445
Astrobiology, Volume 5, Number 4, 2005, Pages 444–460

41. Venus, Mars, and the Ices on Mercury, By Dirk Schulze-Makuch
Venus and Mars likely had liquid water bodies on their surface early in the Solar System history. The surfaces of Venus and Mars are presently not a suitable habitat for life, but reservoirs of liquid water remain in the atmosphere of Venus and the subsurface of Mars, and with it also the possibility of microbial life. Page 778

Current conditions at the venusian surface are extremely desiccating and prohibitive in terms of extant life. However, the origin of life on the Venusian surface early in its history is feasible. Page 779

A number of arguments have been advanced in support of the possibility of microbial life in the venusian atmosphere. Page 780

Astrobiology, Volume 5, Number 6, 2005, Pages 778–795

42. Interplanetary Transfer of Photosynthesis, By Charles S. Cockell

We launched a cryptoendolithic habitat, made of a gneissic impactite inoculated with Chroococcidiopsis sp., into Earth orbit. After orbiting the Earth for 16 days, the rock entered the Earth's atmosphere and was recovered in Kazakhstan. The heat of entry ablated and heated the rock to a temperature well above the upper temperature limit for life to below the depth at which light levels are insufficient for photosynthetic organisms (_5 mm), thus killing all of its photosynthetic inhabitants. Page 1

Astrobiology, Volume 7, Number 1, 2007, Pages 1–9

43. How Rare Is Life in the Milky Way?, By Christine Bounama

Today, scientists and engineers mainly concentrate on the exploration of the solar system to find indicators of life on Mars, Jupiter's moon Europa, or Saturn's moon Titan. Page 746

Some scientists hold that, if liquid water, carbon, and some nutrients are available, then simple microbial life is almost certainly going to occur (see, for example, Dick, 1998). By contrast, others suggest that the fraction of habitable planets that may evolve life is extremely low (e.g., Hart, 1995). Page 748

Astrobiology, Volume 7, Number 5, 2007, Pages 745–755

44. Homochirality, By Axel Brandenburg

Homochirality of almost all amino acids (left-handed) and sugars (right-handed) is undoubtedly a striking property of all life on Earth and an essential requirement for the assembly of functional polymers (either polypeptides or nucleic acids). Indeed, the origin of homochirality is often thought to be closely associated with the origin of life itself (Avetisov, 1991; Bada, 1995). Page 725

Astrobiology, Volume 7, Number 5, 2007, Pages 725–732

45. Complete Chiral Purity, By Cristobal Viedma

The origin of this selective chirality has remained a fundamental enigma with regard to the origin of life since the time of Pasteur, some 140 years ago. Page 312

Astrobiology, Volume 7, Number 2, 2007, Pages 312–319

46. The Power of Our Myth, By Jacob D. Haqq-Misra

Religious myths often place humanity as the focus of creation, the masters of the world, in a sense. The discussion surrounding creationism and intelligent design often assumes a Judeo- Christian framework, but many of the assumptions of a religious creation myth are common to other religions as well. In this view, the Universe and the Earth were created especially for people. Humans are not just another animal but have achieved a greater status than animals. Developments such as cognition, civilization, and technology indicate this superiority and attest to the design (and Designer) that placed humans in such an arena. This myth has many forms, but all share a similar expression: the Creator designed the Universe and set everything in place. After making the Sun, Moon, Earth, and stars, the Creator made the land, sea, and air, and then turned to plants, fish, birds, and animals. Finally, the Creator made humans and gave them dominion over all creation. Page 712

Science has also developed its own creation myth, although it rarely is called by this name. In particular, theories such as the big bang and evolution provide scientific explanations for some of the most profound questions about origins. The Universe came into existence at the moment of the big bang. Over billions of years, stars and galaxies formed, one of these being the Milky Way. In this galaxy, the Solar System began to take shape as the Sun and planets formed—including Earth. Around four billion years ago, conditions were favorable on Earth to allow the emergence of simple life. Over time this life developed multi cellular complexity and eventually moved from the sea onto land as amphibians, followed by reptiles and mammals. As life evolved into more complex forms, a certain group of primates developed larger brains than the rest. This superior intelligence allowed humans to invent

agriculture, writing, domestication, and other tools requisite for civilization—a testament to human supremacy over all other animals. Page 712
Astrobiology, Volume 7, Number 4, 2007, Pages 712-713

47. Fossil DNA in Cretaceous Black Shales?, By Marco J. L. Coolen
In a recent paper in this journal, Inagaki et al. (2005) reported the recovery of fossil DNA derived from past microbial communities from Cretaceous marine sediments deposited approximately 112 million years ago as a black shale interval known as Oceanic Anoxic Event (OAE)-1b. Page 299
Astrobiology, Volume 6, Number 2, 2006, Pages 299-302

48. Ice Shell of Europa, By Kevin P. Hand
Our focus on Europa and oxidants is motivated in part by the prospect for finding life on this moon. Page 464

In terms of chemical potential, such regions would be very attractive for any life forms at the ice–water interface. Page 474
Astrobiology, Volume 6, Number 3, 2006, Pages 463–482

49. Ices Relevant to Europa, By Reggie L. Hudson
This suggests that the surface of Europa may be devoid of organic material. Page 483
Astrobiology, Volume 6, Number 3, 2006, Pages 483–489

50. Lithopanspermia Experimentally Tested, By Gerda Horneck
The theoretical possibility of the transfer of life, by meteorites, between early Mars and Earth during the period of heavy bombardment has been proposed (Gladman, 1997; Mileikowsky et al., 2000). Page 18

The Burchell et al. studies were mainly targeted toward the icy satellites of the giant planets and the possible transfer of life between them. Page 38
Astrobiology, Volume 8, Number 1, 2008, Pages 17–44

51. Geological Constraints on Europa, By Kevin P. Hand
Europa is a prime target for astrobiology. The presence of a global subsurface liquid water ocean and a composition likely to contain a suite of biogenic elements make it a compelling world in the search for a second origin of life. Critical to these factors, however, may be the availability of energy for biological processes on Europa. We have examined the production and availability of oxidants and carbon-containing reductants on Europa to better understand the habitability of the subsurface ocean. Page 1006

McCollom (1999), Zolotov and Shock (2003), and Zolotov and Shock (2004), however, analyzed the geochemical possibilities for maintaining chemical disequilibrium in a hydrothermally active Europan ocean and found that energetic niches for microbial life could persist, provided hydrothermal activity is maintained through time. Page 1007

Delivery of radiolytic oxidants to the ocean could mean the difference between an ocean inhabited by single-celled microbes and one that can support complex, multicellular life forms. Page 1007
Astrobiology, Volume 7, Number 6, 2007, Pages 1006–1022

52. Titan's Hydrocarbon Lakes, By Tetsuya Tokano
Moreover, convective mixing may drive suspension of solid acetylene and other sediments on the lake bottom and redistribution of dissolved gases, which might be relevant for putative life-forms that consume hydrogen and solid acetylene. Page 147

Even the possibility of methanogenic life consuming acetylene and hydrogen (McKay and Smith, 2005; Schulze-Makuch and Grinspoon, 2005) or silane-based life in hydrocarbon lakes (Schulze-Makuch and Irwin, 2004) has been speculated. Any consideration of the astrobiological potential of Titan's lakes requires knowledge of the environmental setting of the lakes, as is common in studies of the origin of life on Earth. Page 148

Titan's lakes are also important in terms of putative life forms that may not be based on carbon and may not rely on liquid water. Page 162
Astrobiology, Volume 9, Number 2, 2009, Pages 147–164

53. Life on Extrasolar Planets, By C. S. Cockell,
The discovery of extrasolar planets is one of the greatest achievements of modern astronomy. The detection of planets that vary widely in mass demonstrates that extrasolar planets of low mass exist. In this paper, we describe a mission, called Darwin, whose primary goal is the search for, and characterization of, terrestrial extrasolar planets and the search for life. Page 2

Finding Earth analogues in terms of mass and size will be the focus of many ground and space-based research programs in the coming decade. Finding evidence of habitability and life represents an even more exciting challenge. Page 2

Here, we describe the science program and some of the technological requirements for an ambitious space mission to discover and characterize Earth-like planets and search for evidence of life on them. The Darwin mission will address one of the most fundamental questions: what is humankind's origin and place in the Universe? Page 2
Astrobiology, Volume 9, Number 1, 2009, Pages 1–22

54. Life on Enceladus, By Christopher P. McKay
However, it is possible that a liquid water environment exists beneath the south polar cap, which may be conducive to life. Several theories for the origin of life on Earth would apply to Enceladus. These are (1) origin in an organic-rich mixture, (2) origin in the redox gradient of a submarine vent, and (3) panspermia. Page 909

We base our discussions of the possible origin of life on Enceladus on theories for the origin of life on Earth. For ecosystems on Enceladus, we base our discussions on specific existing ecosystems on Earth that survive in conditions similar to those that may be present in an aquifer on Enceladus. Page 910

Many of the issues related to life on Enceladus mirror previous discussions of life below the ice of Europa, and we make this connection whenever appropriate. Finally, we consider how a signature of biological processes might be present in the plume and detected by the Cassini instruments. Page 910

From an astrobiological perspective, a key question is whether the subsurface aquifer has persisted long enough to allow for the origin of life. Unfortunately, there are no satisfying estimates of the age of the activity on Enceladus although the geologic features and crater density near the plume indicate that they have persisted over several hundred million years (Porco et al., 2006). Page 910

Discussions of life on Enceladus must logically begin with a consideration of the possible origin of life on that world. Unfortunately, we do not know how life originated on Earth, nor have we been able to reproduce it in the laboratory. There is not even a consensus theory for the origin of life on Earth. Nonetheless, considerations of the possible origin of life on another world are based on theories for the possible origin of life on Earth. Page 910

The alternative theory for the origin of life on Earth—the chemosynthetic origin—may apply well to Enceladus. In this scenario, life begins at the interface where chemically rich fluids heated by tidal dissipation emerge from below the sea floor. This approach is motivated by the chemical and biological properties of deep sea vents in Earth's ocean (Corliss et al., 1981; Shock, 1990). Wächtershäuser (1990) [see also Pace (1991), and for a review see Holm (1992)] suggested hydrothermal or geothermal environments as promising sites for the subsurface origins of chemosynthetic life. Page 912

However, Orgel (1998) criticized this result and stated that we do not understand the steps that lead to life; consequently, we cannot estimate the time required. “Attempts to circumvent this essential difficulty are based on misunderstandings of the nature of the problem.” The problem remains unsolvable with the current data. Page 912

To describe a plausible subsurface ecosystem that may exist on Enceladus, consideration must be given to ecosystems on Earth that are completely independent of O2 or organic material produced by surface photosynthesis. Page 913

If life exists on Enceladus and is biochemically and genetically related to life on Earth, then detection of the remains of this biology would be straightforward. Page 917

The discovery of life on Enceladus that is identical to life on Earth would be of interest, but it would not be as interesting as the discovery of evidence for life that is different from life on Earth and, thus, represents a second genesis of life in our Solar System (McKay, 2001, 2004). However, if the remains of life are found in the plume of Enceladus, and they are from an alternate type of biochemistry, it would not be clear how we would detect or characterize this life. Finding alien life would certainly be more challenging than finding Earth-like life. Page 917
Astrobiology, Volume 8, Number 5, 2008, Pages 909–919

55. Alien Life in Our Solar System, By Robert Shapiro
Our priority for investigation is (1) Titan, (2) Mars, (3) Europa. Titan displays a rich organic chemistry and offers several alternative possibilities for the discovery of extant life or the early stages that lead to life. Mars has already been subjected to considerable study through landers and orbiters. Although only small amounts of methane testify to the inventory of reduced carbon on the planet, a number of other indicators suggest that the presence of microbial life is a possibility. Care will be needed, of course, to distinguish indigenous life from that which may have spread by panspermia. Europa appears to contain a subsurface ocean with the possibility of hydrothermal vents as an energy source. Page 335

The opposing viewpoint would hold that no such ‘‘fine tuning’’ of the physical constants exists and that even the appearance of our own form of life represents an extraordinarily improbable event, a near miracle or an authentic miracle. According to this position, no other origins of life may be expected. Page 336

We propose to focus the search for life to those forms of life that are based on carbon but use a set of organic compounds clearly distinct from our own [e.g., one that uses reversed chiral molecules, which, if discovered, would settle a long-standing debate as to whether the existing set of chiralities in Earth life is the result of chance or of some inherent bias in natural law that favors one alternative (Keszthelyi, 1995)]. Page 337

Despite the frigid temperature at Titan’s surface, 95K, it has been speculated that possible life on Titan would use metabolic pathways that involve reactions with photochemical acetylene (Schulze-Makuch and Grinspoon, 2005), hydrogen, and heavier hydrocarbons (McKay and Smith, 2005). A recent National Academy of Sciences report (Baross et al., 2007) concluded that the environment of Titan meets the absolute requirements for life. Page 339

Thus, Titan offers the possibility of encountering truly exotic hydrocarbon-based life or alternative water-based life. For these reasons, we give Titan the highest priority for future mission activities to find alien life (Table 1). As a bonus, such a mission could also investigate the smaller (500km in diameter) moon of Saturn, Enceladus. Page 339

If this model is correct, then Enceladus has the potential for life (McKay et al., 2008). Page 340

Venus has been suggested to harbor life in its acidic lower atmosphere (Grinspoon, 1997; Cockell, 1999; Schulze-Makuch and Irwin, 2002b, 2004). Life could have possibly originated in an early ocean on Venus at about the same time life originated on Earth. As Venus experienced a runaway greenhouse effect, microbial life would have had no other choice than to retreat to the lower atmosphere or face extinction. Schulze-Makuch et al. (2004) pointed out that green and purple sulfur bacteria that use the ancient photosystem I would have fit ideally into an early ocean on Venus and, hypothetically, could be the ancestors of microorganisms that perform a similar metabolism in the lower atmosphere of Venus today. The discovery that life can function in the clouds of Venus would be a remarkable testimony to its resilience, and there would be much to learn by a comparison of that type of organism’s biochemistry to that of ex tremophiles on Earth, though such a comparison might not furnish proof of a separate origin. Venus is the closest planet to Earth, and a panspermia event from Earth to Venus would appear likely. Page 340, 341

Astrobiology, Volume 9, Number 4, 2009, Pages 335–343

56. Implications for Lithopanspermia, By Patricia Fajardo-Cavazos

Although only meteorites representing Moon-to-Earth and Mars-to-Earth transfers have been documented, there are no compelling reasons to rule out meteoritic transfers originating from Earth itself; and, indeed, models that support Earth-to-Mars (Mileikowsky et al., 2000), Earth to Earth (Sleep and Zahnle, 1998), Earth-to-Moon (Armstrong et al., 2002; Crawford et al., 2008), and even Earth-to-Europa or Earth-to-Titan (Gladman et al., 2006) transfers have been postulated. Page 647

Astrobiology, Volume 9, Number 7, 2009, Pages 647–657

57. Life's Origins, By David Deamer

Many current theories for the origin of life rely upon the validity of the hypothesis that RNA came before DNA and coded proteins (the "RNA world" hypothesis). The capacity of RNA to both store information and perform catalysis certainly makes this polymer an attractive candidate as this first polymer of life. However, a major difficulty for the RNA world hypothesis is the problem of how the first RNA polymers formed and replicated without the aid of coded proteins. Page 454

The origin of the use of photochemical energy to drive metabolism (i.e., energy transduction) is one of the central issues in our attempts to understand the origin and evolution of life. When did energy transduction and photosynthesis begin? What was the original system for capturing photochemical energy? How simple can such a system be? It has been postulated that vesicle structures developed the ability to capture and transduce light, providing energy for reactions. It has been shown that pH gradients can be photo chemically created, but it has been found difficult to couple these to drive chemical reactions. Page 455

Astrobiology, Volume 8, Number 2, 2008, Pages 453-455

58. Origin of Life, By Pascale Ehrenfreund

Our current research is focused towards producing Titan tholin under the temperature and pressure conditions high in the atmosphere indicated by the Cassini NIMS results. The absorption characteristics of such a tholin without exposing to laboratory environment have revealed that it absorbs hydrocarbons, ammonia and other molecules. Thus an impact event on the surface of Titan producing a pool of water, combined with desorbed ammonia from tholin will produce conditions favourable for the origin of life. Page 466

Astrobiology, Volume 8, Number 2, 2008, Pages 464-467

59. Evolution of Life on Terrestrial Planets, By A. Brack

However, the synthesis of RNA under prebiotic conditions remains an unsolved challenge, and the direct formation of RNA is not a generally accepted model for the origin of life. This is because some of the steps in the proposed prebiotic synthesis of the activated monomers of RNA are not convincing. Page 71

Astrobiology, Volume 10, Number 1, 2010, Pages 69–76

60. Maintenance of Life on Europa, By Richard Greenberg

For a minimum concentration there (about one-quarter as much), similar calculations show that the delivery time must be less than 10 million years to overcome the endogenic reductants, but even a slightly shorter delivery time allows concentrations great enough to support complex life to accumulate over a billion years. Page 276

Additional support for life would come from the role of active cracks through the ice, which could provide ecological niches of their own, as well as increase the transport of substances between the surface and the ocean (e.g., Greenberg and Geissler, 2002; Greenberg, 2005). These processes could, in principle, only further enhance the prospects for native life on Europa. Page 281

Although the lack of access to oxidants has been considered a dominant constraint on the possibility, or at least the quantity, of life on Europa, it appears that vertical transport through the ice may overcome that restriction. Even if the various proposed alternative metabolic pathways (McCollom, 1999; Zolotov and Shock, 2003, 2004; Hand et al., 2007) are inoperative in that setting, the availability of oxidants would not be a limiting factor for the maintenance of life in the ocean. Page 281

Thus, resurfacing processes on Europa may provide both the anaerobic respite needed for life to become established and then the substantial amounts of oxidants needed for advanced life. Page 282
Astrobiology, Volume 10, Number 3, 2010, Pages 275–283

61. Titan's Primordial Soup, By Catherine D. Neish
This represents the first detection of biologically relevant molecules created under conditions thought to be similar to those found in impact melt pools and cryolavas on Titan, which are at a stage of chemical evolution not unlike the ‘‘primordial soup’’ of the early Earth. Page 337
Astrobiology, Volume 10, Number 3, 2010, Pages 337–347

62. Amino Acids and the Asymmetry of Life, By Radu Popa
Despite spectacular advances in analytic and computational chemistry and a flood of models that attempt to explain the origin of biochirality, this subject remains an unsolved puzzle, an inscrutable modern-day Gordian knot. To solve this riddle, some scholars have preferred out-of-the box stances, which until now have proved more or less fruitless. Most professionals in this field believe that solving this question is a matter of proper balance between an analytical view and one that is unconventional, though no cohesive vision has yet been offered as to how to find this equilibrium. Page 696
Astrobiology, Volume 9, Number 7, 2009, Pages 696

63. Life on Extrasolar Planets, By Christopher E. Doughty
Over the next two decades, NASA and ESA are planning a series of space-based observatories to find Earth-like planets and determine whether life exists on these planets. Previous studies have assessed the likelihood of detecting life through signs of biogenic gases in the atmosphere or a red edge. Biogenic gases and the red edge could be signs of either single-celled or multi cellular life. In this study, we propose a technique with which to determine whether tree-like multi cellular life exists on extrasolar planets. Page 869
Astrobiology, Volume 10, Number 9, 2010, Pages 869–879

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