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May 16, 2006

HQ 06-164

Mr. John Greenewald, Jr
[redacted]

Dear Mr. Greenewald:

This is our final response to your Freedom of Information Act request for records pertaining to "the study of life on Europa."

After review of the responsive material provided to this office, we have enclosed those documents, in full without any redactions or pages withheld under the exemptions listed in Title 5, United States Code, §552 of the Freedom of Information Act.

I trust this will be of assistance to you.

Sincerely,

Original Signed

Kellie Robinson
Headquarters, FOIA Public Liaison Officer

[used when providing citations from RECONplus in response to information requests]

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Life on Europa
Unrestricted Materials

1
Exploring Europa with a Surface Lander Powered by a Small Radioisotope Power System (RPS)
Author and Affiliation: Abelson, Robert D.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA United States
Shirley, James H.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA United States
Abstract: Europa is a high-priority target for future exploration because of the possibility that it may possess a subsurface liquid ocean that could sustain life. Exploring the surface of this Galilean moon, however, represents a formidable technical challenge due to the great distances involved, the high ambient radiation, and the extremely low surface temperatures. A design concept is presented for a Europa Lander Mission (ELM) powered by a small radioisotope power system (RPS) that could fly aboard the proposed Jupiter Icy Moons Orbiter (JIMO). The ELM would perform in-situ science measurements for a minimum of 30 Earth days, equivalent to approximately 8.5 Europa days. The primary science goals for the Europa lander would include astrobiology and geophysics experiments and determination of surface composition. Science measurements would include visual imagery, microseismometry, Raman spectroscopy, Laser Induced Breakdown Spectroscopy (LIBS), and measurements of surface temperature and radiation levels. The ELM spacecraft would be transported to Europa via the JIMO spacecraft as an auxiliary payload with an extended duration cruise phase (up to 13 years). After arriving at Europa, ELM would separate from JIMO and land on the moon's surface to conduct the nominal science mission. In addition to transportation, the JIMO mothership would be used to relay all lander data back to Earth, thus reducing the size and power requirement of the lander communications system. Conventional power sources were evaluated and found to be impractical for this mission due to the extended duration, low level of solar insolation ([approx]3.7% of Earth's), the low surface temperatures (as low as 85K), and the 1.75 days of eclipse every Europa day. In contrast, a small-RPS would enable the ELM mission by powering the lander and keeping all key instrumentation and subsystems warm during the cruise and landed phases of the mission. The conceptual small-RPS is based on the existing General Purpose Heat Source (GPHS) module using thermoelectric conversion. This would generate 225 Wt (thermal) and 10.1 We (electric) at the end of the mission, and would provide an energy margin exceeding 100%. A small rechargeable lithium-ion battery would be used to handle peak load demands during the short-duration communication events and while using the higher-power instrumentation (LIBS and Raman). In summary, small-RPS technology could enable an exciting, scientifically valuable Europa lander mission designed to verify the existence of a subsurface ocean, and to search for signs of past or present life. [copyright] 2005 American Institute of Physics
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Source Publication: AIP Conference Proceedings (ISSN 0094-243X) / Volume 746; no. 1; 303-317
Financial Spons. Info.: Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA United States
Meeting Information: SPACE TECHNOLOGY AND APPLICATIONS INT.FORUM-STAIF 2005: Conf.Thermophys in Micrograv;Conf Comm/Civil Next Gen.Space Transp; 22nd Symp Space Nucl.Powr Propuls.;Conf.Human/Robotic Techn.Nat'l Vision Space Expl.; 3rd Symp Space Colon.; 2nd Symp.New Frontiers; 13-17 February 2005; Albuquerque, New Mexico; United States
Document Language: English
Subj. Category Text: Spacecraft Instrumentation and Astrionics

NASA Major Term: SPACECRAFT; THERMOELECTRIC GENERATORS
Non-NASA Terms: space vehicles; power systems; radioisotope thermoelectric generators; aerospace instrumentation; space research
Available From: Other Sources
Database Load Date: Mar 22, 2005

2
Lunar and Planetary Science XXXVI, Part 18
Abstract: Topics discussed include: PoDS: A Powder Delivery System for Mars In-Situ Organic, Mineralogic and Isotopic Analysis Instruments Planetary Differentiation of Accreting Planetesimals with 26Al and 60Fe as the Heat Sources Ground-based Observation of Lunar Surface by Lunar VIS/NIR Spectral Imager Mt. Oikeyama Structure: First Impact Structure in Japan? Central Mounds in Martian Impact Craters: Assessment as Possible Perennial Permafrost Mounds (Pingos) A Further Analysis of Potential Photosynthetic Life on Mars New Insight into Valleys-Ocean Boundary on Mars Using 128 Pixels per Degree MOLA Data: Implication for Martian Ocean and Global Climate Change; Recursive Topography Based Surface Age Computations for Mars: New Insight into Surficial Processes That Influenced Craters Distribution as a Step Toward the Formal Proof of Martian Ocean Recession, Timing and Probability; Laser-induced Breakdown Spectroscopy: A New Method for Stand-Off Quantitative Analysis of Samples on Mars; Milk Spring Channels Provide Further Evidence of Oceanic, >1.7-km-Deep Late Devonian Alamo Crater, Southern Nevada; Exploration of Martian Polar Residual Caps from HEND/ODYSSEY Data; Outflow Channels Influencing Martian Climate: Global Circulation Model Simulations with Emplaced Water; Presence of Nonmethane Hydrocarbons on Pluto; Difference in Degree of Space Weathering on the Newborn Asteroid Karin; Circular Collapsed Features Related to the Chaotic Terrain Formation on Mars; A Search for Live (sup 244)Pu in Deep-Sea Sediments: Preliminary Results of Method Development; Some Peculiarities of Quartz, Biotite and Garnet Transformation in Conditions of Step-like Shock Compression of Crystal Slate; Error Analysis of Remotely-Acquired Mossbauer Spectra; Cloud Activity on Titan During the Cassini Mission; Solar Radiation Pressure and Transient Flows on Asteroid Surfaces; Landing Site Characteristics for Europa 1: Topography; and The Crop Circles of Europa.
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NASA Goddard Space Flight Center; Greenbelt, MD, United States
Meeting Spons. Info.: NASA Johnson Space Center; Houston, TX, United States
Lunar and Planetary Inst.; Houston, TX, United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration

NASA Major Term: ASTEROIDS; EUROPA; EXTRATERRESTRIAL LIFE; LUNAR SURFACE; QUANTITATIVE ANALYSIS; SOLAR RADIATION; MARS (PLANET); MARS ENVIRONMENT; MARS SURFACE
NASA Minor Term: CASSINI MISSION; DAMAGE ASSESSMENT; ERROR ANALYSIS; GAMMA RAYS; LANDING SITES; MARINE METEOROLOGY; MOSSBAUER EFFECT; SPACE WEATHERING; TOPOGRAPHY; VALLEYS; ATMOSPHERIC CIRCULATION; CLIMATE CHANGE; CLIMATOLOGY; HEAT SOURCES; HYDROCARBONS

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Database Load Date: Jun 09, 2005

3

Mars Geochemical Instrument (MarGI): An instrument for the analysis of the Martian surface and the search for evidence of life

Author and Affiliation: Kojiro, Daniel R.; NASA Ames Research Center; Moffett Field, CA, United States
Mancinelli, Rocco; Search for Extraterrestrial Intelligence Inst.; Moffett Field, CA, United States
Martin, Joe; Equinox Interscience, Inc.
Holland, Paul M.; Thorleaf Research, Inc.; Santa Barbara, CA, United States
Stimac, Robert M.; Ion Applications, Inc.; Lake Worth, FL, United States
Kaye, William J.; Ion Applications, Inc.; Lake Worth, FL, United States
Abstract: The Mars Geochemical Instrument, MarGI, was developed to provide a comprehensive analysis of the rocks and surface material on Mars. The instrument combines Differential Thermal Analysis (DTA) with miniature Gas Chromatography-Ion Mobility Spectrometry (GC-IMS) to identify minerals, the presence and state of water, and organic compounds. Miniature pyrolysis ovens are used to both, conduct DTA analysis of soil or crushed rocks samples, and pyrolyze the samples at temperatures up to 1000 degrees C for GC-IMS analysis of the released gases. This combination of analytical processes and techniques, which can characterize the mineralogy of the rocks and soil, and identify and quantify volatiles released during pyrolysis, has applications across a wide range of target sites including comets, planets, asteroids, and moons such as Titan and Europa. The MarGI analytical approach evolved from the Cometary Ice and Dust Experiment (CIDEX) selected to fly on the Comet Rendezvous Asteroid Flyby Mission (CRAF).
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Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
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Meeting Spons. Info.: American Chemical Society; United States
Meeting Information: 229th American Chemical Society National Meeting; 13-17 Mar. 2005; San Diego, CA; United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration

NASA Major Term: GEOCHEMISTRY; MARS SURFACE; EXTRATERRESTRIAL LIFE; EXOBIOLOGY
NASA Minor Term: SOIL SAMPLING; COMET RENDEZVOUS ASTEROID FLYBY MISSION; GAS CHROMATOGRAPHY; EUROPA; PYROLYSIS
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Jul 05, 2005

4
Astrobiological and Geological Implications of Convective Transport in Icy Outer Planet Satellites; Final Report

Author and Affiliation: Pappalardo, Robert T.; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
Zhong, Shi-Jie; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
Barr, Amy; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States

Abstract: The oceans of large icy outer planet satellites are prime targets in the search for extraterrestrial life in our solar system. The goal of our project has been to develop models of ice convection in order to understand convection as an astrobiologically relevant transport mechanism within icy satellites, especially Europa. These models provide valuable constraints on modes of surface deformation and thus the implications of satellite surface geology for astrobiology, and for planetary protection. Over the term of this project, significant progress has been made in three areas: (1) the initiation of convection in large icy satellites, which we find probably requires tidal heating; (2) the relationship of surface features on Europa to internal ice convection, including the likely role of low-melting-temperature impurities; and (3) the effectiveness of convection as an agent of icy satellite surface-ocean material exchange, which seems most plausible if tidal heating, compositional buoyancy, and solid-state convection work in combination. Descriptions of associated publications include: 3 published papers (including contributions to 1 review chapter), 1 manuscript in revision, 1 manuscript in preparation (currently being completed under separate funding), and 1 published popular article. A myriad of conference abstracts have also been published, and only those from the past year are listed.

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Org. Source Info.: Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: CONVECTIVE FLOW; BUOYANCY; ICE; ICY SATELLITES; SATELLITE SURFACES; TIDES; CONVECTION
NASA Minor Term: EXTRATERRESTRIAL LIFE; EXTRATERRESTRIAL OCEANS; TEMPERATURE EFFECTS; EUROPA
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A01
Database Load Date: Aug 05, 2005

5
Medusa Sea Floor Monitoring System
Author and Affiliation: Flynn, Michael; NASA Ames Research Center; Moffett Field, CA, United States
Abstract: This paper presents viewgraphs on the development of an instrument to enable fundamental research into understanding the potential for and limits to chemolithoautrophic life. The topics include: 1) Background; 2) Relevance to NASA Missions; 3) Technology Requirements; 4) Medusa System Description; 5) Medusa Components; 6) Medusa Science Capabilities; 7) Medusa Capabilities; and 8) Schedule
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Project/Task No.: 131-20-10
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Meeting Information: Palo Alto Colloquia; 14 Apr. 2005; Palo Alto, CA; United States
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NASA Minor Term: PHOTOSYNTHESIS; EUROPA; TECHNOLOGY UTILIZATION; BIOSPHERE; SYSTEMS INTEGRATION
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6
Lunar and Planetary Science XXXVI, Part 16
Abstract: Contents include the folowing: Experimental Study of Fe-, Co- and Ni-partitioning Between Forsterite and low-Co Fe,Ni-Alloys: Implications for Formation of Olivine Condensates in Equilibrium with Primitive Metal. Channels and Fan-like Features on Titan Surface Imaged by the Cassini RADAR. The Oxygen Isotope Similarity of the Earth and Moon: Source Region or Formation Process? The Mn-53-Cr-53 System in CAIs: An Update. Comparative Planetary Mineralogy: Valence State Partitioning of Cr, Fe, Ti, and V Among Crystallographic Sites in Olivine, Pyroxene, and Spinel from Planetary Basalts. CAI Thermal History Constraints from Spinel: Ti Zoning Profiles and Melilite Boundary Clinopyroxenes. Noble Gas Study of New Enstatite SaU 290 with High Solar Gases. A Marine Origin for the Meridiani Planum Landing Site? A Mechanism for the Formation and Evolution of Tharsis as a Consequence of Mantle Overturn: Large Scale Lateral Heterogeneity in a Stably Stratified Mantle. Endolithic Colonization of Fluid Inclusion Trails in Mineral Grains. Microbial Preservation in Sulfates in the Haughton Impact Structure Suggests Target in Search for Life on Mars. Ascraeus Mons Fan-shaped Deposit, Mars: Geological History and Volcano-Ice Interactions of a Cold-based Glacier. Weathering Pits in the Antarctic Dry Valleys: Insolation-induced Heating and Melting, and Applications to Mars. Mineralogy and Petrography of Lunar Mare Regolith Breccia Meteorite MET 01-210. Geological Mapping of Ganymede. A Quantitative Analysis of Plate Motion on Europa: Implications for the Role of Rigid vs. Nonrigid Behavior of the Lithosphere. Comparison of Terrestrial Morphology, Ejecta, and Sediment Transport of Small

Craters: Volcanic and Impact Analogs to Mars. An Integrated Study of OMEGA-Identified Mineral Deposits in Eastern Hebes Chasma, Mars. Global Spectral and Compositional Diversity of Mars: A Test of CRISM Global Mapping with Mars Express OMEGA Data. On Origin of Sedna. Processing ISS Images of Titan s Surface. LA-ICP-MS Study of Trace Elements in the Chaunskij Metal.
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Meeting Spons. Info.: Lunar and Planetary Inst.; Houston, TX, United States
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Meeting Information: Lunar and Planetary Science XXXVI; 14-18 Mar. 2005; Houston, TX; United States
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NASA Minor Term: IMAGE PROCESSING; COMPUTER ASSISTED INSTRUCTION; GEOLOGY; ANTARCTIC REGIONS; BASALT
Available From: CASI
Format and Price Code: CD-ROM - Price Code: C01
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7
High Power Instruments for Astrobiology Investigations at Europa
Author and Affiliation: Sharma, Shiv K. (Principal Investigator)
McKay, Christopher P. (Technical Monitor)
Abstract: No abstract available
Grant Number: NNA04CL09A
Contract/Grant Date: 20040915
Document ID (CASI): 20040129674
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Authorized Users: Publicly available
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Org. Source Info.: Hawaii Univ.; Honolulu, HI, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Miscellaneous Notes: Reports Expected
Document Language: English
NASA Major Term: EUROPA; EXOBIOLOGY

Database Load Date: Oct 13, 2004

8

Possible and False Biomarkers from Space

Author and Affiliation: Bernstein, Max P.; NASA Ames Research Center; Moffett Field, CA, United States

Abstract: The Search for life in the Solar System is one of NASA's main goals for the coming decade. We may never observe alien life directly; we or our robotic craft may always be removed from it by many years, or meters of crust. If we do find evidence of Life elsewhere in the Solar System it will probably be in form of chemical biomarkers, quintessentially biological molecules that indicate the presence of micro-organisms. What molecules would be truly indicative of alien life? Chlorophyll fragments, which are often used by geochemists are probably far too specific. Simpler molecules, such as fatty acids, amino acids and nucleo-bases might seem to be biomarkers, but they can form non-biotically in space. Alkyl substituted aromatics in ALH 84001 have been invoked as biomarkers, but they are not strong evidence in and of themselves. Understanding the range of nonbiological organic molecules which could act as false biomarkers in space is a prerequisite for any reasonable search for true biomarkers on other worlds. When simple organics arrive at the surface of a body like Europa, either from below or from space, how long do they survive and what do they make? How can we distinguish these from real biomarkers? In this talk I will present some ideas about what might be useful qualities to consider in a potential biomarker, and will ask for advice from the attendant geochemists.

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Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States

Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States

Meeting Information: Gordon Research Conference on Organic Geochemistry; 8 Aug. 2004; Plymouth, NH; United States

Document Language: English

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NASA Major Term: BIOMARKERS; EXTRATERRESTRIAL LIFE

NASA Minor Term: ORGANIC COMPOUNDS

Available From: Other Sources

Availability Notes: Abstract Only

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9

High Power Instruments for Astrobiology Investigations at Europa

Author and Affiliation: Winebrenner, Dale P. (Principal Investigator)

McKay, Christopher, P. (Technical Monitor)

Abstract: No abstract available

Grant Number: NNA04CK84A

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NASA Major Term: EUROPA; EXOBIOLOGY
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10
The Role of Distributed Deformation on Europa: Implications for the Interpretation of Geologic Features and the Transport of Biogenic Elements
Author and Affiliation: Head, James (Principal Investigator)
Blanding, Katie (Technical Monitor)
Abstract: No abstract available
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Contract/Grant Date: 20040701
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Org. Source Info.: Brown Univ.; Providence, RI, United States
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Miscellaneous Notes: Reports Expected
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NASA Major Term: DEFORMATION; STRUCTURAL PROPERTIES (GEOLOGY); EUROPA; BIOLOGICAL EVOLUTION; EXTRATERRESTRIAL LIFE
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11
Ice Radiation Chemistry as a Source of Potential False Biomarkers on the Surface of Europa
Author and Affiliation: Bernstein, Max P.; Search for Extraterrestrial Intelligence Inst.; Mountain View, CA, United States
Sandford, Scott A.; Search for Extraterrestrial Intelligence Inst.; Mountain View, CA, United States
Allamandola, Louis J.; Search for Extraterrestrial Intelligence Inst.; Mountain View, CA, United States
Abstract: If we find evidence of Life elsewhere in the Solar System it will probably be in form of chemical biomarkers, quintessentially biological molecules that indicate the presence of micro-organisms. While molecules such as amino acids and nucleo-bases might seem to be biomarkers, and alkyl substituted aromatics have been invoked as such, they are not necessarily. These molecules are present in some meteorites and are expected to be present on the surface of other planets even in the absence of life. Understanding the range of non-biological organic molecules which could act as false biomarkers in space is a prerequisite for any reasonable search for true biomarkers on other worlds. Our experiments have shown that some organic molecules in meteorites that appear biological in nature are formed by energetic processing of extraterrestrial ices can account for amino acids, quinones and other functionalized aromatic compounds. In the past, such molecules have been proposed as biomarkers. For example, alkylated aromatics were invoked as biomarkers in the Alan Hills 84001 'Martian meteorite.' When simple organics arrive at the surface of a body like Europa,

either from below or from space, how long do they survive and what do they make? How can we distinguish these from real biomarkers?

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Project/Task No.: 344-30-21-01
Org. Source Info.: Search for Extraterrestrial Intelligence Inst.; Mountain View, CA, United States
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Subj. Category Text: Exobiology
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NASA Minor Term: SATELLITE SURFACES; ORGANIC COMPOUNDS
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Sep 01, 2004

12

Human Missions to Europa and Titan - Why Not?

Author and Affiliation: International Space Univ., Inc.; Strasbourg Central Campus; France

Abstract: This report describes a long-term development plan to enable human exploration of the outer solar system, with a focus on Europa and Titan. These are two of the most interesting moons of Jupiter and Saturn, respectively, because they are the places in the solar system with the greatest potential for harboring extraterrestrial life. Since human expeditions to these worlds are considered impossible with current capabilities, the proposal of a well-organized sequence of steps towards making this a reality was formulated. The proposed Development Plan, entitled Theseus, is the outcome of a recent multinational study by a group of students in the framework of the Master of Space Studies (MSS) 2004 course at the International Space University (ISU). The Theseus Program includes the necessary development strategies in key scientific and technological areas that are essential for identifying the requirements for the exploration of the outer planetary moons. Some of the topics that are analysed throughout the plan include: scientific observations at Europa and Titan, advanced propulsion and nuclear power systems, in-situ resource utilization, radiation mitigation techniques, closed life support systems, habitation for long-term spaceflight, and artificial gravity. In addition to the scientific and technological aspects of the Theseus Program, it was recognized that before any research and development work may begin, some level of program management must be established. Within this chapter, legal issues, national and international policy, motivation, organization and management, economic considerations, outreach, education, ethics, and social implications are all considered with respect to four possible future scenarios which enable human missions to the outer solar system. The final chapter of the report builds upon the foundations set by Theseus through a case study. This study illustrates how such accomplishments could influence a mission to Europa to search for evidence of life in its subsurface oceans. The future remains unpredictable, as does the realization of any of these possibilities. However, projects such as this remind us that the final frontier for humans is truly outer space, and only our imagination will determine where the frontier stops. We can dream of visiting other planetary systems and perhaps

even galaxies, but we must begin closer, and considering the scope of our known universe, Europa and Titan are very close indeed.

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Org. Source Info.: International Space Univ., Inc.; Strasbourg Central Campus; France
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NASA Minor Term: SPACECRAFT DESIGN; TITAN ATMOSPHERE; CLOSED ECOLOGICAL SYSTEMS; IN SITU RESOURCE UTILIZATION; PROPULSION SYSTEM PERFORMANCE; ARTIFICIAL GRAVITY
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Database Load Date: Oct 05, 2005

13
Microorganisms on Comets, Europa and the Polar Ice Caps of Mars
Author and Affiliation: Hoover, Richard B.; NASA; Washington, DC
Pikuta, Elena V.

Abstract: Microbial extremophiles live on Earth wherever there is liquid water and a source of energy. Observations by ground-based observatories, space missions, and satellites have provided strong evidence that water ice exists today on comets, Europa, Callisto, and Ganymede and in the snow, permafrost, glaciers and polar ice caps of Mars. Studies of the cryoconite pools and ice bubble systems of Antarctica suggest that solar heating of dark rocks entrained in ice can cause localized melting of ice providing ideal conditions for the growth of microbial communities with the creation of micro-environments where trapped metabolic gasses produce entrained isolated atmospheres as in the Antarctic ice-bubble systems. It is suggested that these considerations indicate that several groups of microorganisms should be capable of episodic growth within liquid water envelopes surrounding dark rocks in cometary ices and the permafrost and polar caps of Mars. We discuss some of the types of microorganisms we have encountered within the permafrost and snow of Siberia, the cryoconite pools of Alaska, and frozen deep within the Antarctic ice sheet above Lake Vostok.

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NASA Major Term: EARTH (PLANET); GLACIERS; MICROORGANISMS; SNOW; TECHNOLOGY UTILIZATION
NASA Minor Term: COSMIC RAYS; FUNGI; ROCKS
Non-NASA Terms: Microorganisms; Earth (planet); Space applications; Glaciers; Snow; Rocks; Fungi; Cosmic rays; Microbials extremophiles; Comets; Europa; Astrobiology
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14
Empirical Determination of Radiolytic Products in Simulated Europan Ices
Author and Affiliation: Hand, P.; Stanford Univ.; Dept. of Geological and Environmental Sciences; Stanford, CA, United States
Carlson, R. W.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Chyba, C. F.; Stanford Univ.; Dept. of Geological and Environmental Sciences; Stanford, CA, United States
Abstract: The chemical composition of Europa's surface is strongly influenced by energetic charge particle bombardment from Jupiter's magnetosphere. Here we report on progress in experimental work designed to address: 1) The production of radiolytic products in thermodynamic disequilibrium that could be utilized by known terrestrial microorganisms, and 2) The modification of complex organic molecules and degradation of biological material by the simulated Europan surface radiation environment.
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Copyright Indicator: No Copyright
Document Type: Conference Paper
Description: 1p
Source Publication: Workshop on Europa's Icy Shell: Past, Present, and Future/ 33; LPI-Contrib-1195/ (SEE 20040055312, 20040055312)
Org. Source Info.: Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
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Subj. Category Text: Astronomy
NASA Major Term: EUROPA; RADIOLYSIS; COMPUTERIZED SIMULATION; EXOBIOLOGY; ICY SATELLITES; SATELLITE SURFACES
NASA Minor Term: CHEMICAL COMPOSITION; IRRADIATION; MICROORGANISMS; ENERGETIC PARTICLES; WATER VAPOR; BIOMARKERS
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15

Convection in Icy Satellites: Implications for Habitability and Planetary Protection

Author and Affiliation: Barr, A. C.; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States

Pappalardo, R. T.; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States

Abstract: Solid-state convection and endogenic resurfacing in the outer ice shells of the icy Galilean satellites (especially Europa) may contribute to the habitability of their internal oceans and to the detectability of any biospheres by spacecraft. If convection occurs in an ice I layer, fluid motions are confined beneath a thick stagnant lid of cold, immobile ice that is too stiff to participate in convection. The thickness of the stagnant lid varies from 30 to 50% of the total thickness of the ice shell, depending on the grain size of ice. Upward convective motions deliver approximately 10(exp 9) to 10(exp 13) kg yr(sup -1) of ice to the base of the stagnant lid, where resurfacing events driven by compositional or tidal effects (such as the formation of domes or ridges on Europa, or formation of grooved terrain on Ganymede) may deliver materials from the stagnant lid onto the surface. Conversely, downward convective motions deliver the same mass of ice from the base of the stagnant lid to the bottom of the satellites ice shells. Materials from the satellites surfaces may be delivered to their oceans by downward convective motions if material from the surface can reach the base of the stagnant lid during resurfacing events. Triggering convection from an initially conductive ice shell requires modest amplitude (a few to tens of kelvins) temperature anomalies to soften the ice to permit convection, which may require tidal heating. Therefore, tidal heating, compositional buoyancy, and solid-state convection in combination may be required to permit mass transport between the surfaces and oceans of icy satellites. Callisto and probably Ganymede have thick stagnant lids with geologically inactive surfaces today, so forward contamination of their surfaces is not a significant issue. Active convection and breaching of the stagnant lid is a possibility on Europa today, so is of relevance to planetary protection policy.

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Org. Source Info.: Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
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Subj. Category Text: Exobiology
NASA Major Term: CONVECTION; EXOBIOLOGY; GALILEAN SATELLITES; HABITABILITY; ICY SATELLITES; PLANETARY PROTECTION
NASA Minor Term: CALLISTO; TERRAIN; GRAIN SIZE; MASS TRANSFER; CONTAMINATION; BUOYANCY; GANYMEDE
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16

Geology of Europa

Author and Affiliation: Greeley, R.; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
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Head, J. W.; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
McCord, T.; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
McKinnon, W. B.; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
Pappalardo, R. T.; Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
Abstract: Europa is a rocky object of radius 1565 km (slightly smaller than Earth s moon) and has an outer shell of water composition estimated to be of order 100 km thick, the surface of which is frozen. The total volume of water is about 3 x 10(exp 9) cubic kilometers, or twice the amount of water on Earth. Moreover, like its neighbor Io, Europa experiences internal heating generated from tidal flexing during its eccentric orbit around Jupiter. This raises the possibility that some of the water beneath the icy crust is liquid. The proportion of rock to ice, the generation of internal heat, and the possibility of liquid water make Europa unique in the Solar System. In this chapter, we outline the sources of data available for Europa (with a focus on the Galileo mission), review previous and on-going research on its surface geology, discuss the astrobiological potential of Europa, and consider plans for future exploration.
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Copyright Indicator: No Copyright
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Description: 1p
Source Publication: Jupiter: The Planet, Satellites and Magnetosphere/ 329-362
Org. Source Info.: Colorado Univ.; Lab. for Atmospheric and Space Physics; Boulder, CO, United States
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Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: EUROPA; EXOBIOLOGY; PLANETARY GEOLOGY; SATELLITE ATMOSPHERES; PLANETARY MAGNETOSPHERES; JUPITER (PLANET)
NASA Minor Term: GALILEO PROJECT; WATER; ECCENTRIC ORBITS
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17

Lunar and Planetary Science XXXV: Astrobiology

Abstract: The presentations in this session are: 1. A Prototype Life Detection Chip 2. The Geology of Atlantis Basin, Mars, and Its Astrobiological Interest 3. Collecting Bacteria Together with Aerosols in the Martian Atmosphere by the FOELDIX Experimental Instrument Developed with a Nutrient Detector Pattern: Model Measurements of Effectivity 4. 2D and 3D X-ray Imaging of Microorganisms in Meteorites Using Complexity Analysis to Distinguish Field Images of Stromatoloids from Surrounding Rock Matrix in 3.45 Ga Strelley Pool Chert, Western Australia 4. Characterization of Two Isolates from Andean Lakes in Bolivia Short Time Scale Evolution of Microbiolites in Rapidly Receding Altiplanic Lakes: Learning How to Recognize Changing Signatures of Life 5. The Effect of Salts on Electrospray Ionization of Amino Acids in the Negative Mode 6. Determination of Aromatic Ring Number Using Multi-Channel Deep UV Native

Fluorescence 7. Microbial D/H Fractionation in Extraterrestrial Materials: Application to Micrometeorites and Mars 8. Carbon Isotope Characteristics of Spring-fed Iron-precipitating Microbial Mats 9. Amino Acid Survival Under Ambient Martian Surface UV Lighting Extraction of Organic Molecules from Terrestrial Material: Quantitative Yields from Heat and Water Extractions 10. Laboratory Detection and Analysis of Organic Compounds in Rocks Using HPLC and XRD Methods 11. Thermal Decomposition of Siderite-Pyrite Assemblages: Implications for Sulfide Mineralogy in Martian Meteorite ALH84001 Carbonate Globules 12. Determination of the Three-Dimensional Morphology of ALH84001 and Biogenic MV-1 Magnetite: Comparison of Results from Electron Tomography and Classical Transmission Electron Microscopy 13. On the Possibility of a Crypto-Biotic Crust on Mars Based on Northern and Southern Ringed Polar Dune Spots 14. Comparative Planetology of the Terrestrial Inner Planets: Implications for Astrobiology 15. A Possible Europa Exobiology 16. A Possible Biogeochemical Model for Titan
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Document Language: English
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NASA Major Term: BIOGEOCHEMISTRY; DETECTION; EXOBIOLOGY; MICROORGANISMS; ORGANIC COMPOUNDS; SIGNATURES; EXTRATERRESTRIAL LIFE; PLANETARY ENVIRONMENTS
NASA Minor Term: METEORITES; MICROMETEORITES; MINERALOGY; SNC METEORITES
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18
Near-infrared detection of potential evidence for microscopic organisms on Europa
Author and Affiliation: Dalton, J. Brad; NASA Ames Research Center; Moffett Field, CA United States
Mogul, Rakesh
Kagawa, Hiromi K.
Chan, Suzanne L.
Jamieson, Corey S.
Abstract: The possibility of an ocean within the icy shell of Jupiter's moon Europa has established that world as a primary candidate in the search for extraterrestrial life within our Solar System. This paper evaluates the potential to detect evidence for microbial life by comparing laboratory studies of terrestrial microorganisms with measurements from the Galileo Near Infrared Imaging Spectrometer (NIMS). If the interior of Europa at one time harbored life, some evidence may remain in the surface

materials. Examination of laboratory spectra of terrestrial extremophiles measured at cryogenic temperatures reveals distorted, asymmetric nearinfrared absorption features due to water of hydration. The band centers, widths, and shapes of these features closely match those observed in the Europa spectra. These features are strongest in reddish-brown, disrupted terrains such as linea and chaos regions. Narrow spectral features due to amide bonds in the microbe proteins provide a means of constraining the abundances of such materials using the NIMS data. The NIMS data of disrupted terrains exhibit distorted, asymmetric near-infrared absorption features consistent with the presence of water ice, sulfuric acid octahydrate, hydrated salts, and possibly as much as 0.2 mg cm(-3) of carbonaceous material that could be of biological origin. However, inherent noise in the observations and limitations of spectral sampling must be taken into account when discussing these findings.

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Subj. Category Text: Exobiology
NASA Major Term: ABIOGENESIS; CHEMICAL EVOLUTION; EUROPA; EXTRATERRESTRIAL ENVIRONMENTS; INFRARED SPECTROPHOTOMETERS; JUPITER (PLANET); MICROORGANISMS; SPECTROPHOTOMETRY
NASA Minor Term: FREEZING
Non-NASA Terms: Biogenesis; Extraterrestrial Environment; Jupiter; Life; Spectrophotometry, Infrared/instrumentation/methods; Freezing; Research Support, Non-U.S. Gov't
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19
Chemical and Astrobiological Investigations of Mars and Europa Analogs
Author and Affiliation: Quinn, Richard C. (Principal Investigator)
Zent, Aaron P. (Technical Monitor)
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Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
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Org. Source Info.: Search for Extraterrestrial Intelligence Inst.; Mountain View, CA, United States
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Miscellaneous Notes: Reports Expected
Document Language: English
NASA Major Term: EXOBIOLOGY; EUROPA; MARS (PLANET); ANALOGS; CHEMISTRY
Database Load Date: Jul 20, 2003

20

Astrobiology: The Case for Venus

Author and Affiliation: Landis, Geoffrey A.; NASA Glenn Research Center; Cleveland, OH, United States

Abstract: The scientific discipline of astrobiology addresses one of the most fundamental unanswered questions of science: are we alone? Is there life elsewhere in the universe, or is life unique to Earth? The field of astrobiology includes the study of the chemical precursors for life in the solar system; it also includes the search for both presently existing life and fossil signs of previously existing life elsewhere in our own solar system, as well as the search for life outside the solar system. Two of the promising environments within the solar system being currently considered are the surface of the planet Mars, and the hypothesized oceans underneath the ice covering the moon Europa. Both of these environments differ in several key ways from the environments where life is found on Earth; the Mars environment in most places too cold and at too low pressure for liquid water to be stable, and the sub-ice environment of Europa lacking an abundance of free energy in the form of sunlight. The only place in the solar system where we know that life exists today is the Earth. To look for life elsewhere in the solar system, one promising search strategy would be to find and study the environment in the solar system with conditions that are most similar to the environmental conditions where life thrives on the Earth. Specifically, we would like to study a location in the solar system with atmospheric pressure near one bar; temperature in the range where water is liquid, 0 to 100 C; abundant solar energy; and with the primary materials required for life, carbon, oxygen, nitrogen, and hydrogen, present. Other than the surface of the Earth, the only other place where these conditions exist is the atmosphere of Venus, at an altitude of about fifty kilometers above the surface.

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Description: 14p
Project/Task No.: WBS 22-755-60-02
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Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: EXOBIOLOGY; VENUS (PLANET); SOLAR SYSTEM; EXTRATERRESTRIAL LIFE; PLANETARY ENVIRONMENTS; FOSSILS; MARS (PLANET)
NASA Minor Term: LIFE DETECTORS; AEROSPACE ENVIRONMENTS; ICE ENVIRONMENTS; PLANETARY SURFACES
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Database Load Date: Sep 23, 2003

21

Identification and Characterization of Extremophile Microorganisms with Significance to Astrobiology

Author and Affiliation: Bej, Asim K.; Alabama Univ.; Dept. of Biology; Birmingham, AL, United States

Abstract: It is now well recognized that microorganisms thrive in extreme ecological conditions such as geothermal vents, polar region, acid and alkaline lakes, and the cold pressurized depth of the ocean floor of this planet. Morphological, physiological, biochemical and genetic adaptations to extreme

environments by these extremophile microorganisms have generated immense interest amongst astrobiologists who increasingly believe in the existence of extraterrestrial life. The evidence collected by NASA's space probe Galileo suggested the presence of liquid water and volcanic activity on Mars and Jupiter's satellite Europa. Volcanic activity provides some of the heat necessary to keep the water on Europa from freezing that could provide important dissolved chemicals needed by living organisms. The possibility of the existence of hypersaline alkaline lakes and evaporites confined within closed volcanic basins and impact craters on Mars, and a layer of liquid water under the ice on Europa provide sufficient 'raison d'etre' to study microorganisms in similar extreme environments on Earth, which could provide us with a model that would help establish the existence of extraterrestrial life on other planetary bodies. The objectives of the summer research project were as follows: (1) application of molecular approaches to help establish new species of extremophile microorganisms isolated from a hypersaline alkaline lake; and (2) identification of a major cold-shock gene (cspA) homolog from a psychrotolerant microorganism, PmagG1.

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Financial Spons. Info.: NASA Marshall Space Flight Center; Huntsville, AL, United States
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NASA Major Term: EXTRATERRESTRIAL LIFE; BIOCHEMISTRY; MICROORGANISMS; GENES; COLD TOLERANCE; SALINITY; ALKALINITY
NASA Minor Term: EXTRATERRESTRIAL OCEANS; LAKES; MARS; EUROPA; EXOBIOLOGY
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22

Cratering Rates in the Outer Solar System

Author and Affiliation: Zahnle, Kevin; NASA Ames Research Center; Moffett Field, CA, United States

Abstract: We have constructed a self-consistent study of cratering rates in the outer solar system. Two papers were written, one on cratering asymmetries on synchronously rotating satellites and the other on the cratering rates themselves. The first addresses the well-founded expectation that the leading hemisphere of a synchronously rotating satellite should be more heavily cratered than the trailing hemisphere, and how our solar system has avoided showing much sign of this. We conclude that Ganymede has in the past rotated nonsynchronously, which may imply that it once harboured a thicker inner ocean than it does now. The other study began as an attempt to determine the age of the surface of Europa at a time when Europa was regarded as a major Exobiological target. In keeping with changing times the study expanded to the point that it now recommends cratering rates for worlds as diverse as Charon and Pluto, and includes the contributions of several invaluable co-authors, none of whom would agree with all of my conclusions. The nexus of the work is the size-frequency distribution of comets striking Jupiter (Figure). This was determined using the historically

observed record of comets striking or nearly striking Jupiter; the size-frequency distributions of craters on lightly cratered surfaces of Europa, Ganymede, and Triton; and the size-frequncy distribution of Kuiper Belt objects. Extreme reductionists will be happy to know that the surface of Europa probably has an age of around 50 million years. Perhaps more intriguing is that Neptune's moon Triton, by origin a giant comet and by capture and orbital evolution a once fully melted giant comet, has a surface that is probably no older than Europa's.

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Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
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Meeting Information: Exobiology PI Conference; 25-29 Aug. 2003; Moffett Field, CA; United States
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Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: CRATERING; SIZE DISTRIBUTION; FREQUENCY DISTRIBUTION; EXOBIOLOGY; CRATERS
NASA Minor Term: EUROPA; SOLAR SYSTEM; CAPTURE EFFECT; ROTATION
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23

A Case for Microorganisms on Comets, Europa and the Polar Ice Caps of Mars

Author and Affiliation: Hoover, Richard B.; NASA Stennis Space Center; Stennis Space Center, MS, United States
Pikuta, Elena V.; NASA Stennis Space Center; Stennis Space Center, MS, United States

Abstract: Microbial extremophiles live on Earth wherever there is liquid water and a source of energy. Observations by ground-based observatories, space missions, and satellites have provided strong evidence that water ice exists today on comets, Europa, Callisto, and Ganymede and in the snow, permafrost, glaciers and polar ice caps of Mars. Studies of the cryoconite pools and ice bubble systems of Antarctica suggest that solar heating of dark rocks entrained in ice can cause localized melting of ice providing ideal conditions for the growth of microbial communities with the creation of micro-environments where trapped metabolic gasses produce entrained isolated atmospheres as in the Antarctic ice-bubble systems. It is suggested that these considerations indicate that several groups of microorganisms should be capable of episodic growth within liquid water envelopes surrounding dark rocks in cometary ices and the permafrost and polar caps of Mars. We discuss some of the types of microorganisms we have encountered within the permafrost and snow of Siberia, the cryoconite pools of Alaska, and frozen deep within the Antarctic ice sheet above Lake Vostok.

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NASA Major Term: COMETS; EUROPA; MARS SURFACE; MICROORGANISMS; POLAR CAPS; EXOBIOLOGY
NASA Minor Term: GLACIERS; WATER; METABOLISM; ANTARCTIC REGIONS; SOLAR HEATING; CALLISTO; GANYMEDE
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Availability Notes: Abstract Only
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24
Chiral Determination of Amino Acids Using X-Ray Diffraction of Thin Films
Author and Affiliation: Dragoi, D.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Kulleck, J.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Kanik, I.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Beegle, L. W.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Abstract: The astrobiological search for life, both extinct and extant, on other solar system bodies will take place via several planned lander missions to Mars Europa and Titan. The detection and identification of organic molecules that have been associated with life is a major technical challenge. Terrestrial life utilizes organic molecules, such as amino acids, as its basic building block. Amino acids can be synthesized by natural processes as is demonstrated by their detection in meteoritic material. In this process, the organic molecules are produced roughly in a even mixture of D and L forms. Biological process, however, can utilize almost uniquely one form or the other. In terrestrial biology, only the L-amino acids is common in biological processes. If signature of life existed elsewhere in the D form it then be concluded that life had evolutionary beginning on that body. Detection of an enantiomeric excess of L over D would also be a powerful sign that life had existed on that body at one time.
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Distrib. Authorization: Distribution under U.S. Government purpose rights; under cooperative agreement NCC5-679
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Description: 2p ; Original contains color illustrations
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NASA Major Term: CHIRALITY; DETECTION; AMINO ACIDS; EXOBIOLOGY
NASA Minor Term: X RAY DIFFRACTION; THIN FILMS; METEORITIC COMPOSITION; MOLECULES
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25
High-Resolution Electrospray Ionization/Ion Mobility Spectrometer for Detection of Abiotic Amino Acids
Author and Affiliation: Beegle, L. W.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Terrell, C. A.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Kim, H.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Kanik, I.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Abstract: One of the primary goals of the current NASA thrust in Astrobiology is the detection and identification of organic molecules as part of an in-situ lander platform on the surface of Mars or Europa. The identification of these molecules should help determine whether indigenous organisms exist on the surface of Mars or in an undersea environment on Europa. In addition, a detailed organic chemical inventory of surface and near surface molecules will help elucidate the possibilities of life elsewhere in the Universe. Terrestrial life has, as its backbone, the family of molecules known as the amino acids (AA), and while AA can be found in the terrestrial environments as part of more complex molecules, such as peptides, and proteins, they also exist as individual molecules due to of the hydrolyses of biopolymers. In terrestrial biochemistry, there are 20 principal amino acids which are necessary for life. However, some forms of these molecules can be found in nature synthesized via abiotic process. For example, they are known to exist extraterrestrially as a component of carbonaceous meteorites. The idea that amino acids are readily created by abiotic means has been demonstrated by their positive identification in the Murchison CM2 meteorite, which fell in 1969. This meteorite was analyzed before contamination by terrestrial microbes could result. Three laboratories individually tested parts of the meteorite and concluded that the amino acids present in them were indigenous to the meteorite because, among other reasons, they had equal L- and D-enantiomers. Final identification of the constituents of the Murchison included 33 amino acids which have no known biotic source, 11 amino acids which have limited distribution and 8 (Glycine, Alanine, Valine, Proline, Leucine, Isoleucine, Aspartic Acid, and Glutamic Acid), which readily occur in terrestrial proteins.
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Subj. Category Text: Exobiology
NASA Major Term: AMINO ACIDS; ION MOBILITY SPECTROSCOPY; DRIFT RATE; EXTRATERRESTRIAL LIFE; PROTEINS
NASA Minor Term: CARBONACEOUS METEORITES; MURCHISON METEORITE; BIOPOLYMERS; ION MOTION
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Format and Price Code: Hardcopy - Price Code: A01
Availability Notes: Available from CASI on CD-ROM only as part of the entire parent document
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26
Searching for Alien Life Having Unearthly Biochemistry
Author and Affiliation: Jones, Harry; NASA Ames Research Center; Moffett Field, CA, United States
Abstract: The search for alien life in the solar system should include exploring unearth-like environments for life having an unearthly biochemistry. We expect alien life to conform to the same basic chemical and ecological constraints as terrestrial life, since inorganic chemistry and the laws of ecosystems appear to be universal. Astrobiologists usually assume alien life will use familiar terrestrial biochemistry and therefore hope to find alien life by searching near water or by supplying hydrocarbons. The assumption that alien life is likely to be based on carbon and water is traditional and plausible. It justifies high priority for missions to search for alien life on Mars and Europa, but it unduly restricts the search for alien life. Terrestrial carbon-water biochemistry is not possible on most of the bodies of our solar system, but all alien life is not necessarily based on terrestrial biochemistry. If alien life has a separate origin from Earth life, and if can survive in an environment extremely different from Earth's, then alien life may have unearthly biochemistry. There may be other solvents than water that support alien life and other elements than carbon that form complex life enabling chain molecules. Rather than making the exploration-restricting assumption that all life requires carbon, water, and terrestrial biochemistry, we should make the exploration-friendly assumption that indigenous, environmentally adapted, alien life forms might flourish using unearthly biochemistry in many places in the solar system. Alien life might be found wherever there is free energy and a physical/chemical system capable of using that energy to build living structures. Alien life may be discovered by the detection of some general non-equilibrium chemistry rather than of terrestrial biochemistry. We should explore all the potential abodes of life in the solar system, including those where life based on terrestrial biochemistry can not exist.
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Authorized Users: Publicly available
Copyright Indicator: Copyright
DAA-File Indicator: Yes
Distrib. Authorization: Distribution as joint owner in the copyright
Document Type: Preprint
Description: 6p
Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
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Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: BIOCHEMISTRY; EXTRATERRESTRIAL LIFE; SOLVENTS; WATER; CARBON
NASA Minor Term: INORGANIC CHEMISTRY; SOLAR SYSTEM; MARS (PLANET); HYDROCARBONS
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A02
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27
A Search for Signs of Life and Habitability on Europa
Author and Affiliation: Fonda, Mark (Technical Monitor); NASA Ames Research Center; Moffett Field, CA, United States
McKay, Christoper P.; NASA Ames Research Center; Moffett Field, CA, United States
Eicken, H.; NASA Ames Research Center; Moffett Field, CA, United States
Neuer, S.; NASA Ames Research Center; Moffett Field, CA, United States
Sogin, M.; NASA Ames Research Center; Moffett Field, CA, United States
Waite, H.; NASA Ames Research Center; Moffett Field, CA, United States
Warmflash, D.; NASA Ames Research Center; Moffett Field, CA, United States
Abstract: Europa is a key target in the search for life beyond the Earth because of consistent evidence that below the icy surface there is liquid water. Future missions to Europa could confirm the presence and nature of the ocean and determine the thickness of the ice layer. Confirming the presence of an ocean and determining the habitability of Europa are key astrobiology science objectives. Nevertheless, the highest priority objective for astrobiology will be a search for life. How could a search for life be accomplished on a near-term mission given the thick ice cover? One answer may lie in the surface materials. If Europa has an ocean, and if that ocean contains life, and if water from the ocean is carried up to the surface, then signs of life may be contained in organic material on the surface. Organics that derive from biological processes (dead organisms) are distinct from organics derived from non-biological processes in several aspects. First, biology is selective and specific in its use of molecules. For example, Earth life uses 20 left-handed amino acids. Second, biology can leave characteristic isotopic patterns. Third, biology often produces large complex molecules in high concentrations, for example lipids. Organic material that has been on the surface of Europa for long periods of time would be reprocessed by the strong radiation field probably erasing any signature of biological origin. Evidence of life in the ocean may be found on the surface of Europa if regions of the surface contained relatively recent material carried up from the ocean through cracks in the icy lithosphere. But organic material that has been on the surface of Europa for long periods of time would be reprocessed by the strong radiation field probably erasing any signature of biological origin. Thus, the detailed analysis required may not be possible via remote sensing but direct sampling of the material below the radiation processed upper meter is probably required.
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Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: Copyright
DAA-File Indicator: Yes
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Description: 1p

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Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Meeting Spons. Info.: American Geophysical Union; Washington, DC, United States
Meeting Information: AGU Fall 2003 Meeting; 8 Dec. 2003; San Francisco, CA; United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: EUROPA; EXTRATERRESTRIAL LIFE; EXTRATERRESTRIAL OCEANS; WATER; ORGANIC MATERIALS
NASA Minor Term: EXOBIOLOGY; ISOTOPES; LIPIDS; REMOTE SENSING; SAMPLING; EXTRATERRESTRIAL RADIATION
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Nov 20, 2003

28
Space Science Reference Guide, 2nd Edition
Author and Affiliation: Dotson, Renee (Editor); Lunar and Planetary Inst.; Houston, TX, United States
Abstract: This Edition contains the following reports: GRACE: Gravity Recovery and Climate Experiment; Impact Craters in the Solar System; 1997 Apparition of Comet Hale-Bopp Historical Comet Observations; Baby Stars in Orion Solve Solar System Mystery; The Center of the Galaxy; The First Rock in the Solar System; Fun Times with Cosmic Rays; The Gamma-Ray Burst Next Door; The Genesis Mission: An Overview; The Genesis Solar Wind Sample Return Mission; How to Build a Supermassive Black Hole; Journey to the Center of a Neutron Star; Kepler's Laws of Planetary Motion; The Kuiper Belt and Oort Cloud ; Mapping the Baby Universe; More Hidden Black Hole Dangers; A Polarized Universe; Presolar Grains of Star Dust: Astronomy Studied with Microscopes; Ring Around the Black Hole; Searching Antarctic Ice for Meteorites; The Sun; Astrobiology: The Search for Life in the Universe; Europa and Titan: Oceans in the Outer Solar System?; Rules for Identifying Ancient Life; Inspire ; Remote Sensing; What is the Electromagnetic Spectrum? What is Infrared? How was the Infrared Discovered?; Brief History of Gyroscopes ; Genesis Discovery Mission: Science Canister Processing at JSC; Genesis Solar-Wind Sample Return Mission: The Materials ; ICESat: Ice, Cloud, and Land Elevation Satellite ICESat: Ice, Cloud, and Land; Elevation Satellite ICESat: Ice, Cloud, and Land Elevation Satellite ICESat: Ice, Cloud, and Land Elevation Satellite ICESat: Ice, Cloud, and Land Elevation Satellite Measuring Temperature Reading; The Optical Telescope ; Space Instruments General Considerations; Damage by Impact: The Case at Meteor Crater, Arizona; Mercury Unveiled; New Data, New Ideas, and Lively Debate about Mercury; Origin of the Earth and Moon; Space Weather: The Invisible Foe; Uranus, Neptune, and the Mountains of the Moon; Dirty Ice on Mars; For a Cup of Water on Mars; Life on Mars?; The Martian Interior; Meteorites from Mars, Rocks from Canada; Organic Compounds in Martian Meteorites May be Terrestrial Contaminants; Bands on Europa;Big Mountain, Big Landslide on Jupiter's Moon, Io; Cratering of the Moon; Europa's Salty Surface; The Europa Scene in the Voyager-Galileo Era; Explosive Volcanic Eruptions on the Moon; Ice on the Bone Dry Moon; Jupiter's Hot, Mushy Moon; The Moon Beyond 2002 ; Phases of the Moon; The Ph-D Project: Manned Expedition to the Moons of Mars; and Possible Life in a Europan Ocean.
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Contract Number: NASW-4574
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Authorized Users: Publicly available
Copyright Indicator: Copyright
Distrib. Authorization: Distribution under U.S. Government purpose rights; under contract NASW-4574 and cooperative agreement
Document Type: Collected Works
Description: Original contains color and black and white illustrations
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Org. Source Info.: Lunar and Planetary Inst.; Houston, TX, United States
Financial Spons. Info.: NASA; Washington, DC, United States
NASA Goddard Space Flight Center; Greenbelt, MD, United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: LUNAR GEOLOGY; MARS SURFACE
NASA Minor Term: LUNAR EXPLORATION; EUROPA; IO; ICE; IMAGE ANALYSIS; EXTRATERRESTRIAL LIFE; METEORITE CRATERS; PLANETARY GEOLOGY; VOLCANOES
Available From: CASI
Format and Price Code: CD-ROM - Price Code: C01
Database Load Date: Feb 06, 2004

29
Life Detection: Mars and Beyond - A Summary as it Relates to JIMO

Author and Affiliation: Flynn, M. T.; NASA Ames Research Center; Moffett Field, CA, United States
Abstract: This paper provides a focused summary of the results of the Life Detection: Mars and Beyond workshop. Specifically, it addresses the Astrobiology derived science and technology requirements for the near and far term exploration of Europa. The stated objectives of the workshop was to examine potential technological focus areas for Astrobiology payload development and integration into future missions. The product was a set of recommendations concerning Astrobiology science objectives as they relate to Solar System exploration. In addition, recommendations were developed concerning how best to integrate emerging concepts and technologies for life detection into the design of a new generation of flight experiments for detecting life in other planetary environments. A primary focus of this workshop was to develop Astrobiology objectives for the exploration of Europa. As it relates to the exploration of Europa, the workshop resulted in a set of very specific recommendations which are relevant to the JIMO mission. The most significant of these is the need to incorporate a surface lander into the existing mission architecture. It was widely agreed that a JIMO mission with only an orbiter would generate limited interest and support from Astrobiology researchers.
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Document ID (CASI): 20030066054
Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: Copyright
Distrib. Authorization: Distribution under U.S. Government purpose rights
Document Type: Conference Paper
Description: 1p
Source Publication: Forum on Concepts and Approaches for Jupiter Icy Moons Orbiter/ 24; LPI-Contrib-1163/ (SEE 20030066012, 20030066012)
Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
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Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: EUROPA; EXOBIOLOGY; PAYLOAD INTEGRATION; PAYLOADS; SPACEBORNE EXPERIMENTS; EXTRATERRESTRIAL LIFE
NASA Minor Term: MISSION PLANNING; SPACE EXPLORATION; RESEARCH AND DEVELOPMENT; SURFACE VEHICLES
Availability Notes: Abstract Only; Available from CASI only as part of the entire parent document
Database Load Date: Aug 28, 2003

30
Forum on Concepts and Approaches for Jupiter Icy Moons Orbiter
Abstract: The papers presented at this conference primarily discuss instruments and techniques for conducting science on Jupiter's icy moons, and geologic processes on the moons themselves. Remote sensing of satellites, cratering on satellites, and ice on the surface of Europa are given particular attention. Some papers discuss Jupiter's atmosphere, or exobiology.
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Authorized Users: Publicly available
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Distrib. Authorization: Distribution under U.S. Government purpose rights
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Financial Spons. Info.: Lunar and Planetary Inst.; Houston, TX, United States
NASA; Washington, DC, United States
NASA Goddard Space Flight Center; Greenbelt, MD, United States
Meeting Information: Forum on Concepts and Approaches for Jupiter Icy Moons Orbiter; 12-14 Jun. 2003; Houston, TX; United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: REMOTE SENSING; SPACECRAFT INSTRUMENTS; ICY SATELLITES; JUPITER SATELLITES; PLANETARY GEOLOGY
NASA Minor Term: SPACE EXPLORATION; JUPITER (PLANET); CRATERING; EUROPA; EXOBIOLOGY; JUPITER ATMOSPHERE
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A06
Database Load Date: Sep 02, 2003

31
MALDI TOF MS: An Exobiology Surface-Science Approach for Europa
Author and Affiliation: Gerakines, Perry A.; Alabama Univ.; Astro- and Solar-System Physics; Birmingham, AL, United States
Wdowiak, Thomas J.; Alabama Univ.; Astro- and Solar-System Physics; Birmingham, AL, United States
Abstract: If Europa is to be of primary exobiological interest, namely as a habitat for extant life, it is obvious that: (i) a hydrosphere must prevail beneath the cryosphere for a long time, (ii) internal energy sources must be present in a sufficient state of activity, and (iii) a reasonable technical means

must be available for assessing if indeed life does exist in the hypothesized hydrosphere. This discussion focuses on technological issues, because the compounding evidence about Europa indicates that the first two are highly likely to be true. We present a consideration of time-of-flight mass spectroscopy (TOF MS) conducted in-situ on the cryosphere surface of Europa during a landed robotic mission. We assert that this is a reasonable technical means not only for exploring the composition of the cryosphere itself, but also for locating any biomolecular indicators of extant life brought to the surface through cryosphere activity. We also describe a MALDI (MAtrix Laser Desorption and Ionization) TOF MS system that we are constructing as a proof-of-concept prototype for conducting TOF MS measurements on Europa.

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Security Classif.: Unclassified

Restriction on Access: Unlimited

Authorized Users: Publicly available

Copyright Indicator: No Copyright

Document Type: Conference Paper

Description: 4p ; Original contains black and white illustrations

Source Publication: Proceedings of the NASA Laboratory Astrophysics Workshop/ 249-252; NASA/CP-2002-211863/ (SEE 20030058868, 20030058868)

Org. Source Info.: Alabama Univ.; Astro- and Solar-System Physics; Birmingham, AL, United States

Financial Spons. Info.: NASA Advisory Council Task Force on Issues of a Mixed Fleet; Washington, DC, United States

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Document Language: English

Subj. Category Text: Lunar and Planetary Science and Exploration

NASA Major Term: EUROPA; MASS SPECTROSCOPY; TIME OF FLIGHT SPECTROMETERS; CRYOSPHERES; EXOBIOLOGY

NASA Minor Term: ICE ENVIRONMENTS; INTERNAL ENERGY

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32

Infrared Spectra of Hydrated Magnesium Salts and their Role in the Search for Possible Life Conditions on Jupiter Moons

Author and Affiliation: Chaban, Galina; NASA Marshall Space Flight Center; Huntsville, AL United States

Huo, Winifred M.; NASA Marshall Space Flight Center; Huntsville, AL United States

Lee, Timothy J.; NASA Marshall Space Flight Center; Huntsville, AL United States

Kwak, Dochan (Technical Monitor)

Abstract: Recent observations from the Galileo satellite indicate that three of the Jupiter moons, Europa, Ganymede, and Callisto, may have subsurface oceans. Possible existence of such ocean and the nature of its composition are of great interest to astrobiologists. Data from Galileo's NIMS spectrometer indicate the possibility of hydrated salts on Europa's surface. To aid in the design of future missions, we investigated infrared spectra of MgSO4-nH20, n=1-3 using ab initio calculations. Geometry, energetics, dipole moments, vibrational frequencies and infrared intensities of pure and hydrated MgSO4 salts were determined. Significant differences are found between vibrational spectra of water molecules in complexes with MgSO4 and pure water. Some of the O-H stretching frequencies in the complexes are shifted to the red by up to 1,500 - 2,000 per cm. In addition, the SO2 stretching vibrations are found at lower frequency regions than the water vibrations. The calculated

bands of water and SO2 fragments can serve as markers for the existence of the salt-water complexes on the surface of Jupiter's moon.
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Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
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Document Type: Preprint
Description: 1p
Project/Task No.: RTOP 274-50-00-06
Org. Source Info.: NASA Marshall Space Flight Center; Huntsville, AL United States
Financial Spons. Info.: NASA Marshall Space Flight Center; Huntsville, AL United States
Meeting Spons. Info.: American Chemical Society; United States
Meeting Information: 224th ACS Meeting; 20 Aug. 2002; Boston, MA; United States
Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: INFRARED SPECTRA; INFRARED ASTRONOMY; MAGNESIUM SULFATES; SALTS; EXOBIOLOGY; GALILEAN SATELLITES
NASA Minor Term: OCEANS; GALILEO SPACECRAFT; SPECTROMETERS; JUPITER (PLANET); APPLICATIONS OF MATHEMATICS; DIPOLE MOMENTS; VIBRATIONAL SPECTRA
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Jan 03, 2003

33
Identification, Characterization, and Exploration of Environments for Life on Mars; Final Report
Author and Affiliation: Acevedo, Sara E.; Search for Extraterrestrial Intelligence Inst.; Center for the Study of Life in the Universe; Mountain View, CA United States
Abstract: A bibliography (18 references) listing the publications during the current grant period of The Center for the Study of Life in the Universe, part of the SETI (Search for Extraterrestrial Intelligence) Institute is presented. The publications, from the Period of Performance September 1, 2000 to February 28, 2002, primarily cover Mars and its potential for life, as well as extreme environments and primitive life forms on Earth. One of the publications covers Europa and the Galileo spacecraft.
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Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Technical Report
Description: 4p
Org. Source Info.: Search for Extraterrestrial Intelligence Inst.; Center for the Study of Life in the Universe; Mountain View, CA United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA United States
Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: MARS (PLANET); EXOBIOLOGY; BIBLIOGRAPHIES
NASA Minor Term: PROJECT SETI; MARS LANDING SITES; EUROPA; BACTERIA; GALILEO SPACECRAFT

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Format and Price Code: Hardcopy - Price Code: A01
Database Load Date: Aug 02, 2002

34
Bacterial Silicification and Its Relevance in Astrobiological Research
Author and Affiliation: Toporski, J.; Carnegie Institution of Washington; Geophysical Lab.; Washington, DC United States
Steele, A.; Carnegie Institution of Washington; Geophysical Lab.; Washington, DC United States
Westall, F.; Centre National de la Recherche Scientifique; Centre de Biophysique Moleculaire; Orleans, France
Thomas-Keprta, K. L.; NASA Johnson Space Center; Houston, TX United States
McKay, D. S.; NASA Johnson Space Center; Houston, TX United States
Abstract: Silicified bacteria are the earliest evidence of life on Earth. If life evolved on Mars or Europa, its traces may have been silicified. Detailed knowledge on silicification therefore helps refine our search parameters for extraterrestrial life. Additional information is contained in the original extended abstract.
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Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Conference Paper
Description: CD-ROM contains the entire conference proceedings presented in PDF format
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Org. Source Info.: NASA Johnson Space Center; Houston, TX United States
Financial Spons. Info.: NASA Johnson Space Center; Houston, TX United States
German Academic Exchange Service; Germany
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: BACTERIA; EXOBIOLOGY; EXTRATERRESTRIAL LIFE; MARS (PLANET); SILICIDES
NASA Minor Term: MICROORGANISMS; TRANSMISSION ELECTRON MICROSCOPY; DEOXYRIBONUCLEIC ACID; CELLS (BIOLOGY)
Availability Notes: Abstract Only: Available from CASI only as part of the entire parent document
Database Load Date: Jun 14, 2002

35
Life Beneath the Ice: Earth(!) Mars(?) Europa(?)
Author and Affiliation: Allen, C. C.; NASA Johnson Space Center; Houston, TX United States
Grasby, S. E.; Geological Survey of Canada; Calgary, Alberta Canada
Longazo, T. G.; Hernandez Engineering, Inc.; Houston, TX United States
Lisle, J. T.; NASA Johnson Space Center; Houston, TX United States
Beauchamp, B.; Geological Survey of Canada; Calgary, Alberta Canada
Abstract: Life exists in subsurface refuges despite surface temperatures less than 0 deg C (analogs Snowball Earth, Mars, Europa). Water discharged from such refuges brings to the surface living microbes, as well as mineralogical/isotopic indications of subsurface life. Additional information is contained in the original extended abstract.
Publication Date: April 2002
Document ID (CASI): 20020045675

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Restriction on Access: Unlimited
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Document Type: Conference Paper
Description: CD-ROM contains the entire conference proceedings presented in PDF format
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Org. Source Info.: NASA Johnson Space Center; Houston, TX United States
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Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: EUROPA; EARTH (PLANET); ICE; MARS (PLANET); EXTRATERRESTRIAL LIFE
NASA Minor Term: SURFACE TEMPERATURE; SCANNING ELECTRON MICROSCOPY; SURFACE WATER; BACTERIA
Availability Notes: Abstract Only: Available from CASI only as part of the entire parent document
Database Load Date: Jun 14, 2002

36
Anaerobic Psychrophiles from Alaska, Antarctica, and Patagonia: Implications to Possible Life on Mars and Europa
Author and Affiliation: Hoover, Richard B.; NASA Marshall Space Flight Center; Huntsville, AL United States
Pikuta, Elena V.; Alabama Univ.; Astrobiology Group; Huntsville, AL United States
Marsic, Damien; Alabama Univ.; Astrobiology Group; Huntsville, AL United States
Ng, Joseph; Alabama Univ.; Astrobiology Group; Huntsville, AL United States
Abstract: Microorganisms preserved within the permafrost, glaciers, and polar ice sheets of planet Earth provide analogs for microbial life forms that may be encountered in ice or permafrost of Mars, Europa, Callisto, Ganymede, asteroids, comets or other frozen worlds in the Cosmos. The psychrophilic and psychrotolerant microbes of the terrestrial cryosphere help establish the thermal and temporal limitations of life on Earth and provide clues to where and how we should search for evidence of life elsewhere in the Universe. For this reason, the cold-loving microorganisms are directly relevant to Astrobiology. Cryopreserved microorganisms can remain viable (in deep anabiosis) in permafrost and ice for millions of years. Permafrost, ice wedges, pingos, glaciers, and polar ice sheets may contain intact ancient DNA, lipids, enzymes, proteins, genes, and even frozen and yet viable ancient microbiota. Some microorganisms carry out metabolic processes in water films and brine, acidic, or alkaline channels in permafrost or ice at temperatures far below 0 C. Complex microbial communities live in snow, ice-bubbles, cryoconite holes on glaciers and ancient microbial ecosystems are cryopreserved within the permafrost, glaciers, and polar caps. In the Astrobiology group of the NASA Marshall Space Flight Center and the University of Alabama at Huntsville, we have employed advanced techniques for the isolation, culture, and phylogenetic analysis of many types of microbial extremophiles. We have also used the Environmental Scanning Electron Microscope to study the morphology, ultra-microstructure and chemical composition of microorganisms in ancient permafrost and ice. We discuss several interesting and novel anaerobic microorganisms that we have isolated and cultured from the Pleistocene ice of the Fox Tunnel of Alaska, guano of the Magellanic Penguin, deep-sea sediments from the vicinity of the Rainbow Hydrothermal Vent and enrichment cultures from ice of the Patriot Hills of Antarctica. The microbial extremophiles recovered from permafrost, ice, cold pools and deep-sea sediments may provide information relevant to the question of how and where we should search for evidence of extant or extinct microbial life elsewhere in the Cosmos.
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Security Classif.: Unclassified
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Document Type: Reprint
Description: 14p
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Org. Source Info.: NASA Marshall Space Flight Center; Huntsville, AL United States
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Meeting Spons. Info.: International Society for Optical Engineering; Bellingham, WA United States
Meeting Information: Instruments, Methods and Missions for Astrobiology IV; 29-30 Jul. 2001; San Diego, CA; United States
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Subj. Category Text: Life Sciences (General)
NASA Major Term: ANTARCTIC REGIONS; EUROPA; EXOBIOLOGY; EXTRATERRESTRIAL LIFE; MARS (PLANET); PSYCHROPHILES; ANAEROBES
NASA Minor Term: EARTH (PLANET); ICE ENVIRONMENTS; CULTURE TECHNIQUES; MICROORGANISMS; DEOXYRIBONUCLEIC ACID; LIPIDS; PERMAFROST; ENZYMES
Available From: Other Sources
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37
Astrobiology
Author and Affiliation: DesMarais, David; NASA Ames Research Center; Moffett Field, CA United States
DeVincenzi, D. (Technical Monitor)
Abstract: Astrobiology is the study of the origins, evolution and distribution of life in the universe. It provides a biological perspective to many areas of NASA research, linking such endeavors as the search for habitable planets beyond our solar system, exploration missions to Mars and Europa, and efforts to understand the origin and early evolution of life. Astrobiology addresses three fundamental questions: How does life begin and develop? Does life exist elsewhere in the universe? What is the future of life on Earth and beyond? This talk will address our concepts about the definition of life, how life might have begun, and how our blaspheme and planet have co-evolved for billions of years. The talk will explore how the perspectives gained from interdisciplinary research in the biological, geological and space sciences will prepare us to search for habitable environments and biospheres elsewhere in the Universe.
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Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
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Description: 1p
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Org. Source Info.: NASA Ames Research Center; Moffett Field, CA United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA United States
Meeting Information: Burpee Museum's Paleo Festival; 22-24 Feb. 2002; Rockford, IL; United States

Document Language: English
Subj. Category Text: Astrophysics
NASA Major Term: EXOBIOLOGY; UNIVERSE; BIOLOGICAL EVOLUTION; SPACE EXPLORATION
NASA Minor Term: MARS MISSIONS; EUROPA; EXTRATERRESTRIAL LIFE; HABITABILITY
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Jul 19, 2002

38
Astrobiology
Author and Affiliation: DesMarais, David; NASA Ames Research Center; Moffett Field, CA United States
Abstract: Astrobiology is the study of the origins, evolution and distribution of life in the universe. It provides a biological perspective to many areas of NASA research, linking such endeavors as the search for habitable planets beyond our solar system, exploration missions to Mars and Europa, and efforts to understand the origin and early evolution of life. Astrobiology addresses three fundamental questions: How does life begin and develop? Does life exist elsewhere in the universe What is the future of life on Earth and beyond? This talk will address our concepts about the definition of life, how life might have begun, and how our blaspheme and planet have co-evolved for billions of years. The talk will explore how the perspectives gained from interdisciplinary research in the biological, geological and space sciences will prepare us to search for habitable environments and blasphemes elsewhere in the Universe.
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Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA United States
Meeting Information: Burpee Museum's Paleo Festival; 22-24 Feb. 2002; Rockford, IL; United States
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Subj. Category Text: Exobiology
NASA Major Term: LIFE SCIENCES; BIOLOGICAL EVOLUTION; AEROSPACE ENGINEERING; EXOBIOLOGY
NASA Minor Term: SOLAR SYSTEM; SPACE EXPLORATION; MARS MISSIONS; PLANETS
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Aug 02, 2002

39
Life In Extreme Environments
Author and Affiliation: McKay, Christopher; NASA Ames Research Center; Moffett Field, CA United States
DeVincenzi, Donald (Technical Monitor)
Abstract: All life on Earth requires water as liquid to grow or reproduce. However many environments on Earth with mean temperatures well below freezing sustain life, due to the physical properties of water

and ice. In addition to being interesting examples of environmental physics, these environments may provide analogs for life on other cold worlds: Mars and Europa.

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Security Classif.: Unclassified
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Copyright Indicator: No Copyright
Document Type: Preprint
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Project/Task No.: RTP 344-38-82-04
Org. Source Info.: NASA Ames Research Center; Moffett Field, CA United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA United States
Meeting Information: Space Science Telescope Inst. Meeting; 7 May 2002; United States
Document Language: English
Subj. Category Text: Life Sciences (General)
NASA Major Term: LIFE SCIENCES; FREEZING; EXTRATERRESTRIAL LIFE
NASA Minor Term: WATER; ICE
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Aug 16, 2002

40

Exobiological Exploration of Europa (E3) Europa Lander

Author and Affiliation: Stillwagen, F. H.; NASA Langley Research Center; Hampton, VA United States
Manvi, Ramachandra; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA United States
Seywald, Hans; Analytical Mechanics Associates, Inc.; Hampton, VA United States
Park, Sang-Young; Swales Aerospace; Hampton, VA United States
Kolacinski, Rick; Swales Aerospace; Hampton, VA United States

Abstract: The search for life outside Earth's protected atmosphere is a compelling testament to the quest by mankind to determine if "we" are alone in the universe. The phenomenal success of the NASA Galileo spacecraft has indicated that the moons of Jupiter, and most notably Europa, may indeed contain subsurface liquid under an icy surface. This speculation of a salty liquid subsurface fuels expert opinions that biological products may exist. The Revolutionary Aerospace Systems Concepts (RASC) effort at Langley Research Center, initiated by NASA Headquarters, pushes NASA and the Aerospace/Science community to target advanced evolutionary technology usage to provide a Europa Lander concept targeted for completion within the next 50 years. The study effort indicates the use of certain advanced technologies to achieve a subsurface penetrator and liquid explorer in the approximately 2040 timeframe.

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Security Classif.: Unclassified
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Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Technical Report
Description: 20p ; Original contains color illustrations
Org. Source Info.: NASA Langley Research Center; Hampton, VA United States
Financial Spons. Info.: NASA Langley Research Center; Hampton, VA United States
Meeting Spons. Info.: International Astronautical Federation; Unknown

Meeting Information: 53rd International Astronautical Congress; 10-19 Oct. 2002; Houston, TX; United States
 The World Space Congress - 2002; 10-19 Oct. 2002; Houston, TX; United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: EUROPA; EXOBIOLOGY; GALILEO SPACECRAFT; PLANETARY SURFACES; EXPLORATION; PLANETARY MAPPING
NASA Minor Term: EARTH ATMOSPHERE; ICE; LIQUID FUELS; JUPITER SATELLITES; UNIVERSE; SALINITY; RADIO FREQUENCIES
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A03
Database Load Date: Feb 14, 2003

41
Vibrational Spectroscopy and Astrobiology
Author and Affiliation: Chaban, Galina M.; NASA Ames Research Center; Moffett Field, CA United States
Kwak, D. (Technical Monitor)
Abstract: Role of vibrational spectroscopy in solving problems related to astrobiology will be discussed. Vibrational (infrared) spectroscopy is a very sensitive tool for identifying molecules. Theoretical approach used in this work is based on direct computation of anharmonic vibrational frequencies and intensities from electronic structure codes. One of the applications of this computational technique is possible identification of biological building blocks (amino acids, small peptides, DNA bases) in the interstellar medium (ISM). Identifying small biological molecules in the ISM is very important from the point of view of origin of life. Hybrid (quantum mechanics/molecular mechanics) theoretical techniques will be discussed that may allow to obtain accurate vibrational spectra of biomolecular building blocks and to create a database of spectroscopic signatures that can assist observations of these molecules in space. Another application of the direct computational spectroscopy technique is to help to design and analyze experimental observations of ice surfaces of one of the Jupiter's moons, Europa, that possibly contains hydrated salts. The presence of hydrated salts on the surface can be an indication of a subsurface ocean and the possible existence of life forms inhabiting such an ocean.
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Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Preprint
Description: 1p
Project/Task No.: RTOP 274-50-00-06
Org. Source Info.: NASA Ames Research Center; Moffett Field, CA United States
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Meeting Information: Irvine, CA; United States
Document Language: English
Subj. Category Text: Astrophysics
NASA Major Term: VIBRATIONAL SPECTRA; BIOLOGICAL EVOLUTION; INFRARED SPECTROSCOPY; INTERSTELLAR MATTER; MOLECULES; EXOBIOLOGY
NASA Minor Term: QUANTUM MECHANICS; ELECTRONIC STRUCTURE; PEPTIDES
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Apr 26, 2002

42

Europa Surface-Subsurface Material Interchange: Astrobiology Implications of the Session

Author and Affiliation: Meyer, M. A.; NASA; Washington, DC United States

Abstract: This paper will seek to identify key parameters, and critical measurements needed to determine exchange rates of surface-subsurface materials of Europa and to anticipate their implications for the astrobiological studies NASA will plan. Additional information is contained in the original extended abstract.

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Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Conference Paper
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Org. Source Info.: NASA; Washington, DC United States
Financial Spons. Info.: NASA; Washington, DC United States
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Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: EUROPA; JUPITER (PLANET); SATELLITE SURFACES; SURFACE PROPERTIES
NASA Minor Term: EXOBIOLOGY; EXTRATERRESTRIAL LIFE
Availability Notes: Abstract Only: Available from CASI only as part of the entire parent document
Database Load Date: Jun 02, 2001

43

Energetic Ion and Electron Irradiation of the Icy Galilean Satellites

Author and Affiliation: Cooper, John F.; Raytheon Information Technology and Scientific Services; Greenbelt, MD United States
Johnson, Robert E.; Virginia Univ.; Dept. of Engineering Physics; Charlottesville, VA United States
Mauk, Barry H.; Johns Hopkins Univ.; Applied Physics Lab.; Laurel, MD United States
Garrett, Henry B.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA United States
Gehrels, Neil; NASA Goddard Space Flight Center; Greenbelt, MD United States

Abstract: Galileo Orbiter measurements of energetic ions (20 keV to 100 MeV) and electrons (20-700 keV) in Jupiter's magnetosphere are used, in conjunction with the JPL electron model (less than 40 MeV), to compute irradiation effects in the surface layers of Europa, Ganymede, and Callisto. Significant elemental modifications are produced on unshielded surfaces to approximately centimeter depths in times of less than or equal to 10(exp 6) years, whereas micrometer depths on Europa are fully processed in approximately 10 years. Most observations of surface composition are limited to optical depths of approximately 1 mm, which are indirect contact with the space environment. Incident flux modeling includes Stormer deflection by the Ganymede dipole magnetic field, likely variable over that satellite's irradiation history. Delivered energy flux of approximately 8 x 10(exp 10) keV/square cm-s at Europa is comparable to total internal heat flux in the same units from tidal and radiogenic sources, while exceeding that for solar UV energies (greater than 6 eV) relevant to ice chemistry. Particle energy fluxes to Ganymede's equator and Callisto are similar at approximately 2-3 x 10(exp 8) keV/square cm-s with 5 x 10(exp 9) at Ganymede's polar cap, the latter being comparable to radiogenic energy input. Rates of change in optical reflectance and molecular composition on Europa, and on Ganymede's polar cap, are strongly driven by energy from irradiation, even in relatively young regions. Irradiation of nonice materials can produce SO_2 and CO_2, detected on Callisto and Europa, and simple to complex hydrocarbons. Iogenic neutral atoms and meteoroids

deliver negligible energy approximately 10(exp 4-5) keV/square cm-s but impacts of the latter are important for burial or removal of irradiation products. Downward transport of radiation produced oxidants and hydrocarbons could deliver significant chemical energy into the satellite interiors for astrobiological evolution in putative sub-surface oceans.
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Authorized Users: Publicly available
Copyright Indicator: Copyright
Document Type: Reprint
Description: 27p
Source Publication: Icarus (ISSN 0019-1035) / Volume 149; 133-159
Org. Source Info.: Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA United States
Financial Spons. Info.: NASA Goddard Space Flight Center; Greenbelt, MD United States
NASA; Washington, DC United States
National Academy of Sciences - National Research Council; United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: RADIATION CHEMISTRY; EUROPA; GANYMEDE; CALLISTO; ION IRRADIATION; ELECTRON IRRADIATION; SURFACE LAYERS
NASA Minor Term: ENERGETIC PARTICLES; FLUX DENSITY; MAGNETIC FIELDS; SPUTTERING; EXOBIOLOGY; OXYGEN
Available From: Other Sources
Database Load Date: Dec 21, 2001

44

Anaerobic Psychrophiles from Alaska, Antarctica, and Patagonia: Implications to Possible Life on Mars and Europa

Author and Affiliation: Hoover, Richard B.; NASA Marshall Space Flight Center; Huntsville, AL United States
Pikuta, Elena V.; Alabama Univ.; Astrobiology Group; Huntsville, AL United States
Marsic, Damien; Alabama Univ.; Astrobiology Group; Huntsville, AL United States
Ng, Joseph; Alabama Univ.; Astrobiology Group; Huntsville, AL United States
Six, N. Frank (Technical Monitor)

Abstract: Microorganisms preserved within the permafrost, glaciers, and polar ice sheets of planet Earth provide analogs for microbial life forms that may be encountered in ice or permafrost of Mars, Europa, Callisto, Ganymede, asteroids, comets or other frozen worlds in the Cosmos. The psychrophilic and psychrotolerant microbes of the terrestrial cryosphere help establish the thermal and temporal limitations of life on Earth and provide clues to where and how we should search for evidence of life elsewhere in the Universe. For this reason, the cold-loving microorganisms are directly relevant to Astrobiology. Cryo-preserved microorganisms can remain viable (in deep anabiosis) in permafrost and ice for millions of years. Permafrost, ice wedges, pingos, glaciers, and polar ice sheets may contain intact ancient DNA, lipids, enzymes, proteins, genes, and even frozen and yet viable ancient microbiota. Some microorganisms carry out metabolic processes in water films and brine, acidic, or alkaline channels in permafrost or ice at temperatures far below 0 T. Complex microbial communities live in snow, ice-bubbles, cryoconite holes on glaciers and ancient microbial ecosystems are cryopreserved within the permafrost, glaciers, and polar caps. In the Astrobiology group of the NASA Marshall Space Flight Center and the University of Alabama at Huntsville, we

have employed advanced techniques for the isolation, culture, and phylogenetic analysis of many types of microbial extremophiles. We have also used the Environmental Scanning Electron Microscope to study the morphology, ultra-microstructure and chemical composition of microorganisms in ancient permafrost and ice. We discuss several interesting and novel anaerobic microorganisms that we have isolated and cultured from the Pleistocene ice of the Fox Tunnel of Alaska, guano of the Magellanic Penguin, deep sea sediments from the vicinity of the Rainbow Hydrothermal Vent and enrichment cultures from ice of the Patriot Hills of Antarctica. The microbial extremophiles recovered from permafrost, ice, cold pools and deep sea sediments may provide information relevant to the question of how and where we should search for evidence of extant or extinct microbial life elsewhere in the Cosmos.

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Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Preprint
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Org. Source Info.: NASA Marshall Space Flight Center; Huntsville, AL United States
Financial Spons. Info.: NASA Marshall Space Flight Center; Huntsville, AL United States
Meeting Spons. Info.: International Society for Optical Engineering; United States
Meeting Information: 4th SPIE Conference on Instruments, Methods and Missions for Astrobiology; 29 Jul. - 3 Aug. 2001; San Diego, CA; United States
Document Language: English
Subj. Category Text: Life Sciences (General)
NASA Major Term: ANAEROBES; BACTERIA; EXOBIOLOGY; PERMAFROST; PSYCHROPHILES
NASA Minor Term: MARS (PLANET); EUROPA; POLAR REGIONS; ACTIVITY (BIOLOGY)
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Mar 01, 2002

45

Synthesis of Organic Molecules in the Fracture Zone of Meteorite Impacts on Europa

Author and Affiliation: Borucki, Jerome G.; NASA Ames Research Center; Moffett Field, CA, United States
Khare, Bishun N.; NASA Ames Research Center; Moffett Field, CA, United States

Abstract: This work studies the synthesis of organic molecules that occurs as a result of meteorite impacts into planets with icy surfaces, such as Europa. Meteorite impacts into icy surfaces cause a large zone of fracturing under the impact crater. Very large voltages are generated during this fracturing, and that energy is, in effect, "stored" in the ice as electrostatic charges spread over a large area of the ice for substantial periods of time. Over time, the electro-static charges can accumulate until a critical level ("the breakdown potential of ice") is reached, at which time electrical arcing occurs. In the presence of water-ice, methane, and ammonia, this arcing the ice at a temperature of -170 C. At projectile impact, light emission, high voltage, and a large magnetic field that lasted about 5 milliseconds (ms) were recorded; then after a pause of 280 ms, a secondary light, voltage, and magnetic field occurred. The voltage and light had four spikes in a 10-ms timeframe, and the emissions correlated with each other, indicating that arcing was occurring in the fracture zone under the impact.

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Security Classif.: Unclassified

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Copyright Indicator: No Copyright
Document Type: Technical Report
Description: 2p
Source Publication: Research and Technology 1999/ 90-91; NASA/TM-2000-209618/ (SEE 20040077048, 20040077048)
Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: GAS FLOW; BIOGEOCHEMISTRY; DETECTION; EMITTANCE; MICROORGANISMS
NASA Minor Term: ATMOSPHERIC COMPOSITION; ECOLOGY; EXTRASOLAR PLANETS; INFRARED SPECTROSCOPY; PLANETARY ATMOSPHERES; TERRESTRIAL PLANETS
Available From: CASI
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Database Load Date: Jul 01, 2004

46
TOF MS In Situ Planetary Science and Exobiology on Europa
Author and Affiliation: Wdowiak, Thomas (Principal Investigator)
Betts, Bruce (Technical Monitor)
Grant Number: NAG5-9424
Contract/Grant Date: 20000430
Document ID (CASI): 20010006186
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Restriction on Access: Unlimited
Authorized Users: Publicly available
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Document Type: Contract
Project/Task No.: RTOP 344-36-00-01
Org. Source Info.: Alabama Univ.; Birmingham, AL United States
Financial Spons. Info.: NASA Goddard Space Flight Center; Greenbelt, MD United States
Miscellaneous Notes: Reports Expected
Document Language: English
NASA Major Term: EUROPA; EXOBIOLOGY; TIME OF FLIGHT SPECTROMETERS; PLANETOLOGY; CELESTIAL BODIES; SPACE EXPLORATION; PLANETARY ENVIRONMENTS
Database Load Date: Jan 19, 2001

47
MALDI for Europa Planetary Science and Exobiology
Author and Affiliation: Wdowiak, T. J.; Alabama Univ.; Astro and Solar System Physics Program; Birmingham, AL United States
Agresti, D. G.; Alabama Univ.; Astro and Solar System Physics Program; Birmingham, AL United States
Clemett, S. J.; NASA Johnson Space Center; Houston, TX United States
Abstract: TOF MS for Europa landed science can identify small molecules of the cryosphere and complex biomolecules upwelling from a subsurface water ocean. A matrix-assisted laser-desorption ionization (MALDI) testbed for cryo-ice mixtures is being developed.
Publication Date: March 2000

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Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Conference Paper
Description: CD ROM: CD ROM contains the entire conference proceedings presented in PDF format
Source Publication: Lunar and Planetary Science XXXI/ LPI-Contrib-1000/ (SEE 20000080557)
Org. Source Info.: NASA Johnson Space Center; Houston, TX United States
Financial Spons. Info.: NASA Johnson Space Center; Houston, TX United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: BIOCHEMISTRY; EUROPA; EXOBIOLOGY; MASS SPECTROSCOPY; TIME OF FLIGHT SPECTROMETERS; CRYOGENICS
NASA Minor Term: LASER SPECTROMETERS; ICE ENVIRONMENTS
Availability Notes: Available from CASI only as part of the entire parent document
Database Load Date: Sep 01, 2000

48
Fossil Record of Precambrian Life on Land; Final Report
Author and Affiliation: Knauth, Paul; Arizona State Univ.; Tempe, AZ United States
Abstract: The argument that the earth's early ocean was up to two times modern salinity was published in 'Nature' and presented at the 1998 Annual Meeting of the Geological Society of America in Toronto. The argument is bolstered by chemical data for fluid inclusions in Archean black smokers. The inclusions were 1.7 times the modern salinity causing the authors to interpret the parent fluids as evaporite brines (in a deep marine setting). I reinterpreted the data in terms of the predicted value of high Archean salinities. If the arguments I presented are on track, early life was either halophilic or non-marine. Halophiles are not among the most primitive organisms based on RNA sequencing, so here is an a priori argument that non-marine environments may have been the site of most early biologic evolution. This result carries significant implications for the issue of past life on Mars or current life on the putative sub-ice oceans on Europa and possibly Callisto. If the Cl/H2O ratio on these objects is similar to that of the earth, then oceans and oceanic sediments are probably not the preferred sites for early life. On Mars, this means that non-marine deposits such as caliche in basalt may be an overlooked potential sample target.
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Grant Number: NAG5-4860
Document ID (CASI): 20010047676
Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Technical Report
Description: 2p
Org. Source Info.: Arizona State Univ.; Tempe, AZ United States
Financial Spons. Info.: NASA Goddard Space Flight Center; Greenbelt, MD United States
Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: FOSSILS; MARINE ENVIRONMENTS; OCEANS; PRECAMBRIAN PERIOD; EXTRATERRESTRIAL LIFE
NASA Minor Term: MARS (PLANET); SALINITY; ISOTOPE RATIOS; BASALT

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Format and Price Code: Hardcopy - Price Code: A01
Database Load Date: Jun 08, 2001

49
Microbiological Sensing System for a Europa Probe Application
Author and Affiliation: Powers, Linda (Principal Investigator)
Flynn, Michael (Technical Monitor)
Contract Number: NCC2-5325
Contract/Grant Date: 19990515
Document ID (CASI): 20000004935
Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Contract
Org. Source Info.: Utah State Univ.; Logan, UT United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA United States
Miscellaneous Notes: Reports Expected
Document Language: English
NASA Major Term: DETECTION; EUROPA; MICROBIOLOGY; EXOBIOLOGY; EXTRATERRESTRIAL LIFE
Database Load Date: Jan 14, 2000

50
Gas Chromatographic Detectors for Exobiology Flight Experiments
Author and Affiliation: Kojiro, Daniel R.; NASA Ames Research Center; Moffett Field, CA United States
Humphry, Donald E.; Search for Extraterrestrial Intelligence Inst.; Mountain View, CA United States
Takeuchi, Nori; TMA/Norcal; Richmond, CA United States
Chang, Sherwood (Technical Monitor)
Abstract: Exobiology flight experiments require highly sensitive instrumentation for in situ chemical analysis of the volatile chemical species that occur in the atmospheres and surfaces of various bodies within the solar system. The complex mixtures encountered place a heavy burden on the analytical instrumentation to detect and identify all species present. Future missions to Mars', comets, or planetary moons such as Europa, will perform experiments with complex analyses. In addition, instrumentation for such missions must perform under severely restricted conditions with limited resources. To meet these analytical requirements, improved methods and highly sensitive yet smaller instruments must continually be developed with increasingly greater capabilities. We describe here efforts to achieve this objective, for past and future missions, through the development of new or the improvement of existing sensitive, miniaturized gas chromatographic detectors.
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Security Classif.: Unclassified
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Authorized Users: Publicly available
Copyright Indicator: Copyright
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Meeting Spons. Info.: American Chemical Society; United States

Meeting Information: American Chemical Society; 7-11 Sep. 1997; Las Vegas, NV; United States
Document Language: English
Subj. Category Text: Life Sciences (General)
NASA Major Term: EXOBIOLOGY; GAS CHROMATOGRAPHY; DETECTORS
NASA Minor Term: EUROPA; MARS MISSIONS; SOLAR SYSTEM
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Jul 08, 2002

51
Europa: Prospects for an ocean and exobiological implications
Author and Affiliation: Oro, John; Houston Univ.; TX., United States
Squyres, Steven W.; Cornell Univ.; Ithaca, NY., United States
Reynolds, Ray T.; NASA Ames Research Center; Moffett Field, CA, United States
Mills, Thomas M.; Houston Univ.; TX., United States
Abstract: As far as we know, Earth is the only planet in our solar system that supports life. It is natural, therefore, that our understanding of life as a planetary phenomenon is based upon Earth-like planets. There are environments in the solar system where liquid water, commonly believed to be a prerequisite for biological activity, may exist in a distinctly non-Earth-like environment. One such location is Europa, one of the Galilean satellites of Jupiter. The possibility that liquid water exists on Europa presents us with some interesting exobiological implications concerning the potential of the satellite to support life. Topics include the following: an ocean on Europa; thermal evolution of Europa; Europa's three models; exobiological implications; early conditions of Europa; low-temperature abiotic chemistry; possibility of the emergence of life on Europa; prerequisites for the habitability of Europa; energy sources for biosynthesis and metabolic activity; habitability of Europa by anaerobic life; and habitability by aerobic life.
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Publication Date: Aug 1, 1992
Accession Number: 93N18552
Document ID (CASI): 19930009363
Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Conference Paper
Description: 24p ; Original contains color illustrations
Source Publication: Exobiology in Solar System Exploration/ p 103-126/ (SEE N93-18545 06-51)
Imprint and Other Notes: In its Exobiology in Solar System Exploration p 103-126 (SEE N93-18545 06-51),Original contains color illustrations
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Document Language: English
Subj. Category Text: LIFE SCIENCES (GENERAL)
NASA Major Term: EUROPA; EXOBIOLOGY; EXTRATERRESTRIAL ENVIRONMENTS; EXTRATERRESTRIAL LIFE; OCEANS; WATER
NASA Minor Term: BIOLOGICAL EVOLUTION; BIOSYNTHESIS; HABITABILITY; METABOLISM; SPACE EXPLORATION
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A03
Database Load Date: Dec 28, 1995

52
On the origin and early evolution of biological catalysis and other studies on chemical evolution; Abstract Only
Author and Affiliation: Oro, J.; Houston Univ.; TX., United States
Lazcano, A.; Universidad Nacional Autonoma de Mexico; Mexico City., United States
Abstract: One of the lines of research in molecular evolution which we have developed for the past three years is related to the experimental and theoretical study of the origin and early evolution of biological catalysis. In an attempt to understand the nature of the first peptidic catalysts and coenzymes, we have achieved the non-enzymatic synthesis of the coenzymes ADPG, GDPG, and CDP-ethanolamine, under conditions considered to have been prevalent on the primitive Earth. We have also accomplished the prebiotic synthesis of histidine, as well as histidyl-histidine, and we have measured the enhancing effects of this catalytic dipeptide on the dephosphorylation of deoxyribonucleotide monophosphates, the hydrolysis of oligo A, and the oligomerization 2', 3' cAMP. We reviewed and further developed the hypothesis that RNA preceded double stranded DNA molecules as a reservoir of cellular genetic information. This led us to undertake the study of extant RNA polymerases in an attempt to discover vestigial sequences preserved from early Archean times. In addition, we continued our studies of on the chemical evolution of organic compounds in the solar system and beyond.
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Publication Date: Oct 1, 1991
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Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Conference Paper
Description: 1p
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Imprint and Other Notes: In NASA, Washington, Fourth Symposium on Chemical Evolution and the Origin and Evolution of Life p 53 (SEE N92-13588 04-55)
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Document Language: English
Subj. Category Text: SPACE BIOLOGY
NASA Major Term: CATALYSIS; CATALYSTS; CHEMICAL EVOLUTION; COENZYMES; DEOXYRIBONUCLEIC ACID; EXOBIOLOGY; GENETIC CODE; METEORITIC COMPOSITION; RIBONUCLEIC ACIDS
NASA Minor Term: AMINO ACIDS; EUROPA; HISTIDINE; HYDROLYSIS; HYPOTHESES; MOLECULES; PRECAMBRIAN PERIOD; SEQUENCING; SOLAR SYSTEM
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A01
Database Load Date: Nov 07, 1995

53
Chemical evolution: A solar system perspective
Author and Affiliation: Oro, J.; Houston Univ.; TX, United States
Abstract: During the last three decades major advances were made in the understanding of the formation of carbon compounds in the universe and of the occurrence of processes of chemical evolution in the solar system and beyond. This was made possible by the development of new astronomical

techniques and by the exploration of the solar system by means of properly instrumented spacecraft. Some of the major findings made as a result of these observations are summarized.

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Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Conference Paper
Description: 4p
Source Publication: NASA, Ames Research Center, Exobiology and Future Mars Missions/ p 46-49/ (SEE N89-26334 20-51)
Imprint and Other Notes: In NASA, Ames Research Center, Exobiology and Future Mars Missions p 46-49 (SEE N89-26334 20-51)
Org. Source Info.: Houston Univ.; Dept. of Biochemical and Biophysical Sciences.; TX, United States
Financial Spons. Info.: NASA; United States
Document Language: English
Subj. Category Text: ASTROPHYSICS
NASA Major Term: ASTEROIDS; CARBONACEOUS CHONDRITES; CHEMICAL EVOLUTION; COMETS; EXOBIOLOGY; EXTRATERRESTRIAL LIFE; PLANETARY ATMOSPHERES; SOLAR SYSTEM
NASA Minor Term: ABUNDANCE; EARTH (PLANET); EUROPA; JUPITER (PLANET); MARS (PLANET); MICROWAVE SPECTROMETERS; RADIO ASTRONOMY; TITAN
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A01
Database Load Date: Nov 06, 1995

54
Europa - The prospects for an ocean

Author and Affiliation: Reynolds, R. T.; NASA Ames Research Center; Moffett Field, CA, United States
Mckay, C. P.; NASA Ames Research Center; Moffett Field, CA, United States
Kasting, J. F.; NASA Ames Research Center; Moffett Field, CA, United States
Squires, S. W.; Cornell University; Ithaca, NY, United States

Abstract: Tidal dissipation in the satellites of a giant planet may provide sufficient heating to maintain a liquid water ocean below a thin ice layer. In the solar system, Europa, one of the Galilean satellites of Jupiter, may have such an ocean. Both theoretical calculations and certain observations support its existence, although proof is lacking. The putative ocean would probably have temperatures, pressures, and chemistry conducive to biologic activity. However, the environment would be severely energy limited. Possible energy sources include transient transmission of sunlight through fractures in the ice and hydrothermal activity on the ocean floor. While temporary conditions could exist that are within the range of adaptation of certain terrestrial organisms, origin of life under such conditions seems unlikely. In other solar systems, however, larger satellites with more significant heat flow could provide environments that are stable over an order of aeons and in which life could perhaps evolve.

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Document Type: Conference Paper
Description: 8p
Source Publication: (SEE A88-55201, A88-55201)
Imprint and Other Notes: IN: Bioastronomy - The next steps; Proceedings of the Ninety-ninth IAU Colloquium, Balaton, Hungary, June 22-27, 1987 (A88-55201 24-88). Dordrecht, Kluwer Academic Publishers, 1988, p. 21-28.
Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
Cornell Univ.; Ithaca, NY, United States
Financial Spons. Info.: NASA; United States
Meeting Spons. Info.: IAU and Magyar Tudomanyos Akademia
Meeting Information: Bioastronomy - The next steps; June 22-27, 1987; Balaton; Hungary
Document Language: English
Subj. Category Text: SPACE BIOLOGY
NASA Major Term: EUROPA; EXTRATERRESTRIAL ENVIRONMENTS; OCEANS; SOLAR SYSTEM; WATER
NASA Minor Term: ALGAE; BIOLOGICAL EVOLUTION; EXOBIOLOGY; EXTRASOLAR PLANETS; PLANETARY ORBITS; TIDES
Available From: Other Sources
Database Load Date: Nov 28, 1995

55
Under the ice in Antarctica
Author and Affiliation: Wharton, R. A. Jr; NASA Ames Research Center; Moffett Field CA United States
Wharton RA, J. r. (Principal Investigator)
Abstract: The 1985 Antarctic Scientific Research Expedition to Lake Hoare in Taylor Valley is briefly described. Of particular interest to to the expedition is the nature of the lake's perennial ice cover and its role in concentrating dissolved gases. Also, the algal mats and sediment found on the bottom of the lake were studied. Antarctic lakes have been cited as possible analogs for possible biological habitats on Mars and on Europa.
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Publication Date: Jun 1986
Document ID (CASI): 20040089113
Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: Copyright
Document Type: Journal Article
Source Publication: Explorers journal (ISSN 0014-5025) / Volume 64; 2; 62-5
Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: ANTARCTIC REGIONS; COLD WEATHER; FRESH WATER; ICE; MICROBIOLOGY; SEDIMENTS
NASA Minor Term: ALGAE; EXOBIOLOGY; MARS (PLANET)
Non-NASA Terms: Cold Climate; Fresh Water/analysis/microbiology; Geologic Sediments/analysis/microbiology; Ice; Water Microbiology; Algae; Antarctic Regions; Exobiology; Mars; NASA Center ARC; NASA Discipline Exobiology
Available From: Other Sources
Database Load Date: Sep 07, 2004

56
Diatoms on earth, comets, Europa and in interstellar space
Author and Affiliation: Hoover, R. B.; NASA Marshall Space Flight Center; Huntsville, AL, United States
Hoover, M. J.; NASA Marshall Space Flight Center; Huntsville, AL, United States
Hoyle, F.; NASA Marshall Space Flight Center; Huntsville, AL, United States
Wickramasinghe, N. C.; NASA Marshall Space Flight Center; Huntsville, AL, United States
Al-Mufti, S.; University College; Cardiff, United Kingdom
Abstract: There exists a close correspondence between the measured infrared properties of diatoms and the infrared spectrum of interstellar dust as observed in the Trapezium nebula and toward the galactic center source GC-IRS 7. Diatoms and bacteria also exhibit an absorbance peak near 2200 A, which is found to agree with the observed ultraviolet absorbance properties of interstellar grains. The observational data are reviewed, and the known properties of diatoms and bacteria are considered. It is suggested that these characteristics are consistent with the concept of a cosmic microbiological system in which these or similar microorganisms might exist on comets, Europa and in interstellar space.
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Publication Date: May 1, 1986
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Document ID (CASI): 19860059616
Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: Copyright
Document Type: Journal Article
Description: 27p
Source Publication: Earth, Moon, and Planets (ISSN 0167-9295) / 35; 19-45
Imprint and Other Notes: Earth, Moon, and Planets (ISSN 0167-9295), vol. 35, May 1986, p. 19-45.
Org. Source Info.: NASA Marshall Space Flight Center; Huntsville, AL, United States
University Coll.; Cardiff, United Kingdom
Financial Spons. Info.: NASA; United States
Document Language: English
Subj. Category Text: SPACE BIOLOGY
NASA Major Term: ALGAE; GALACTIC NUCLEI; INFRARED SOURCES (ASTRONOMY); INTERSTELLAR MATTER; MILKY WAY GALAXY; NEBULAE
NASA Minor Term: ABSORPTION SPECTRA; BACTERIOLOGY; EARTH ATMOSPHERE; EUROPA; EXOBIOLOGY; INFRARED SPECTRA
Available From: Other Sources
Database Load Date: Nov 28, 1995

57
On the habitability of Europa
Author and Affiliation: Reynolds, R. T.; NASA Ames Research Center; Moffett Field, CA, United States
Squyres, S. W.; NASA Ames Research Center; Moffett Field, CA, United States
Colburn, D. S.; NASA Ames Research Center; Moffett Field, CA, United States
Mckay, C. P.; NASA Ames Research Center; Theoretical Studies Branch, Moffett Field, CA, United States
Abstract: It is pointed out that the Voyager flybys of Jupiter produced remarkable images of Europa, one of the four large Galilean satellites. Taking into account information provided by these Voyagers flybys and other data and investigations, a study is conducted regarding the suitability of Europa as a

habitat for living organisms. The performed calculations indicate, that for a plausible physical model of Europa, the general conditions for the survival of biological organisms could exist, at least in some regions, highly restricted in both space and time.
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Publication Date: Nov 1, 1983
Accession Number: 84A14682
Document ID (CASI): 19840031895
Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: Copyright
Document Type: Journal Article
Description: 9p
Source Publication: Icarus (ISSN 0019-1035) / 56; 246-254
Imprint and Other Notes: Icarus (ISSN 0019-1035), vol. 56, Nov. 1983, p. 246-254.
Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
Financial Spons. Info.: NASA; United States
Document Language: English
Subj. Category Text: LUNAR AND PLANETARY EXPLORATION
NASA Major Term: EUROPA; EXOBIOLOGY; EXTRATERRESTRIAL LIFE
NASA Minor Term: BIOGEOCHEMISTRY; HABITABILITY; SOLAR PLANETARY INTERACTIONS; THERMAL ENERGY
Available From: Other Sources
Database Load Date: Nov 28, 1995

58
Consideration of probability of bacterial growth for Jovian planets and their satellites
Author and Affiliation: Taylor, D. M.
Berkman, R. M.
Divine, N.; California Institute of Technology, Jet Propulsion Laboratory, Pasadena; Calif., United States
Abstract: Environmental parameters affecting growth of bacteria (e.g., moisture, temperature, pH, and chemical composition) were compared with current atmospheric models for Jupiter and Saturn, and with the available physical data for their satellites. Different zones of relative probability of growth were identified for Jupiter and Saturn, with the highest in pressure regions of 1-10 million N/sq m (10 to 100 atmospheres) and 3-30 million N/sq m (30 to 300 atmospheres), respectively. Of the more than two dozen satellites, only the largest (Io, Europa, Ganymede, Callisto, and Titan) were found to be interesting biologically. Titan's atmosphere may produce a substantial greenhouse effect providing increased surface temperatures. Models predicting a dense atmosphere are compatible with microbial growth for a range of pressures at Titan's surface. For Titan's surface the probability of growth would be enhanced if (1) the surface is entirely or partially liquid (water), (2) volcanism (in an ice-water-steam system) is present, or (3) access to internal heat sources is significant.
Publisher Info.: German Democratic Republic
Publication Date: JAN 1, 1975
Accession Number: 75A44139
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Document ID (CASI): 19750060067
Security Classif.: Unclassified
Restriction on Access: Unlimited
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Copyright Indicator: Copyright
Document Type: Conference Proceedings

Description: 8p
Source Publication: (SEE A75-44126 22-51, A75-44126 22-51)
Imprint and Other Notes: In: Life sciences and space research XIII; Proceedings of the Seventeenth Plenary Meeting, Sao Paulo, Brazil, June 17-July 1, 1974. (A75-44126 22-51) Berlin, East Germany, Akademie-Verlag GmbH, 1975, p. 111-118.
Financial Spons. Info.: NASA; United States
Meeting Information: Life sciences and space research XIII; Seventeenth Plenary Meeting; 17th; June 17, 1974-July 1, 1974; Sao Paulo; Brazil
Document Language: English
Subj. Category Text: SPACE BIOLOGY
NASA Major Term: ATMOSPHERIC MODELS; BACTERIA; EXTRATERRESTRIAL LIFE; JUPITER (PLANET); NATURAL SATELLITES; SATURN (PLANET); TITAN
NASA Minor Term: ATMOSPHERIC TEMPERATURE; ENVIRONMENT EFFECTS; PROBABILITY THEORY; REPRODUCTIVE SYSTEMS; TEMPERATURE EFFECTS
Available From: Other Sources
Database Load Date: Dec 01, 1995

59
Consideration of probability of bacterial growth for Jovian planets and their satellites
Author and Affiliation: Taylor, D. M.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Berkman, R. M.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Divine, N.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Abstract: Environmental parameters affecting growth of bacteria are compared with current atmospheric models for Jupiter and Saturn, and with the available physical data for their satellites. Different zones of relative probability of growth are identified for Jupiter and Saturn. Of the more than two dozen satellites, only the largest (Io, Europa, Ganymede, Callisto, and Titan) are found to be interesting biologically. Titan's atmosphere may produce a substantial greenhouse effect providing increased surface temperatures. Models predicting a dense atmosphere are compatible with microbial growth for a range of pressures at Titan's surface. For Titan's surface the probability of growth would be enhanced if: (1) the surface is entirely or partially liquid; (2) volcanism is present; or (3) access to internal heat sources is significant.
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Publication Date: Jun 1, 1974
Report Number: NASA-CR-140807; PAPER-V.4.4
Accession Number: 75N10712
Contract Number: NAS7-100
Document ID (CASI): 19750002640
Security Classif.: Unclassified
Restriction on Access: Unlimited
Authorized Users: Publicly available
Copyright Indicator: No Copyright
Document Type: Conference Paper
Description: 18p
Imprint and Other Notes: Presented at Joint Open Meeting of the Panel on Planetary Quarantine and Working Group 5, 17th Planetary Meeting of COSPAR, Sao Paulo, Brazil, 17 Jun. - 1 Jul. 1974
Org. Source Info.: Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Financial Spons. Info.: NASA; United States
Meeting Information: Joint Open Meeting of the Panel on Planetary Quarantine and Working Group 5; 17 Jun. - 1 Jul. 1974; Sao Paulo; Brazil
Document Language: English

Subj. Category Text: SPACE BIOLOGY
NASA Major Term: BACTERIA; ENVIRONMENT EFFECTS; GROWTH; PLANETARY ATMOSPHERES
NASA Minor Term: ATMOSPHERIC MODELS; EXOBIOLOGY; JUPITER ATMOSPHERE; NATURAL SATELLITES; SATURN (PLANET); TITAN
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A03
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Life on Europa
Restricted Materials

1
Molecular Level Interactions between Organisms and Environment
Author and Affiliation: Brown, Mark V.; Hawaii Univ.; Inst. for Astronomy; Honolulu, HI, United States
Boal, Andrew K.; Hawaii Univ.; Inst. for Astronomy; Honolulu, HI, United States
Glazer, Brian T.; Hawaii Univ.; Inst. for Astronomy; Honolulu, HI, United States
Binsted, Kim; Hawaii Univ.; Information and Computer Sciences Dept.; Honolulu, HI, United States
Gaidos, Eric; Hawaii Univ.; Dept. of Geology and Geophysics; Honolulu, HI, United States
Abstract: Microbial survival in extreme environments requires specific adaptation at the molecular level, selected to maintain functionally stable protein structures under potentially denaturing conditions. Such adaptations are known to include alterations in peptide residue frequencies and preferential utilization of specific protein motifs (patterns of amino acid sequences within a protein structure). Our work aims to couple environmental conditions with specific molecular adaptations to investigate whether a physico-chemical determinant for structural motifs can be established. As well as utilizing available structural and sequence databases, novel molecular data will be obtained from environments considered to be analogous to potential ecosystems on Mars and Europa (subseafloor material, sub-glacial lake water, tephra and sediment). Local adaptation may require a trade off between the ability to survive in an extreme environment and an organism's ability to successfully disperse across environments to which it is not adapted, potentially leading to populations evolving in isolation. Examination of analogous but geographically or physiochemically isolated populations will provide us with further insights into the mechanisms by which environmental conditions shape molecular structures (e.g. co-evolution, endemicity) and determine the potential to predict which structures are stable in an environment of a given set of physical parameters. In parallel to this study, we will computationally derive sets of peptides predicted to be the "most stable" in a given environment and confirm predictions through systematic laboratory studies of synthetic peptides.
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Document ID (CASI): 20050176564
Security Classif.: Unclassified
Restriction on Access: Limited Distribution
Authorized Users: NASA personnel only
Copyright Indicator: No Copyright
DAA-File Indicator: No
Document Type: Conference Paper
Description: 2p
Org. Source Info.: Hawaii Univ.; Inst. for Astronomy; Honolulu, HI, United States
Financial Spons. Info.: Hawaii Univ.; Inst. for Astronomy; Honolulu, HI, United States
Meeting Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Meeting Information: NAI 2005; 10-14 Apr. 2005; Boulder, CO; United States
Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: MOLECULAR INTERACTIONS; BIOGEOCHEMISTRY; MARINE CHEMISTRY; EXTRATERRESTRIAL OCEANS; EXTRATERRESTRIAL LIFE
NASA Minor Term: MICROORGANISMS; MARS (PLANET); EUROPA; EXTRATERRESTRIAL ENVIRONMENTS
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Jun 14, 2005

2

An Energy Criterion for Habitability

Author and Affiliation: Hoehler, Tori M.; NASA Ames Research Center; Moffett Field, CA, United States

Abstract: The concept of habitability offers a means of constraining the possible distribution of life in any system, and can thereby greatly aid in narrowing the field of possible targets in astrobiological search strategies. Energy is fundamentally required by all life, and its availability therefore represents a potential constraint on habitability. For terrestrial life, this conceptual constraint takes the form of a quantitative boundary condition, because the nature (and unity) of our biochemistry imposes shared and discrete minimum requirements on the levels and flux of energy that can be biologically exploited. This boundary condition applies in principle to both light and chemical energy sources. While seldom tested in the terrestrial surface biosphere, these requirements can be significant in comparison to the rates and levels at which subsurface geochemical processes can liberate energy in useful forms. Energetic habitability may thus be among the most important factors constraining the potential distribution of life in subsurface environments, and therefore carries particular significance for the astrobiology of Mars, Europa, and even the Earth during potential periods of uninhabitable surface conditions. If the factors underlying the existence of biological minimum energy requirements are not specific to terrestrial biochemistry, but fundamental to chemical life in general, the energetic habitability concept would represent a broadly applicable criterion in the search for extraterrestrial life.

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DAA-File Indicator: No
Document Type: Conference Paper
Description: 1p
Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Meeting Information: NAI 2005; 10-14 Apr. 2005; Boulder, CO; United States
Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: HABITABILITY; BIOCHEMISTRY; EXOBIOLOGY; ENERGY REQUIREMENTS
NASA Minor Term: EXTRATERRESTRIAL LIFE; CHEMICAL ENERGY; EUROPA; MARS (PLANET)
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Jun 06, 2005

3

Titan's Surface Environment: A Target for Astrobiological Exploration

Author and Affiliation: Lorenz, Ralph D.; Arizona Univ.; Lunar and Planetary Lab.; Tucson, AZ, United States
Lunine, Jonathan I.; Arizona Univ.; Lunar and Planetary Lab.; Tucson, AZ, United States

Abstract: Titan's surface is being revealed in detail by the NASA/ESA Cassini-Huygens mission, and early results point to a young surface, with evidence of possible fluid flow and cryovolcanic activity. Titan's organic photochemistry yields abundant hydrocarbons and nitriles - these may react with

liquid water in cryovolcanic flows to yield amino acids, purines and other important prebiotic molecules. Thus Titan is a more appealing astrobiological target than Europa, which lacks abundant organics. Furthermore, Titan's thick atmosphere makes it easy to deliver instrumentation to its surface, perhaps in a mobile aerial platform such as an airship or helicopter, able to traverse long ranges across Titan's diverse landscape and select specific spots for sampling and prebiotic assay. Recent developments in Titan mission and instrumentation concepts will be discussed in the light of early results from Cassini-Huygens.

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Security Classif.: Unclassified
Restriction on Access: Limited Distribution
Authorized Users: NASA personnel only
Copyright Indicator: No Copyright
DAA-File Indicator: No
Document Type: Conference Paper
Description: 1p
Org. Source Info.: Arizona Univ.; Lunar and Planetary Lab.; Tucson, AZ, United States
Financial Spons. Info.: Arizona Univ.; Lunar and Planetary Lab.; Tucson, AZ, United States
Meeting Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Meeting Information: NAI 2005; 10-14 Apr. 2005; Boulder, CO; United States
Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: TITAN; SATELLITE SURFACES; EXOBIOLOGY
NASA Minor Term: EXTRATERRESTRIAL ENVIRONMENTS; CASSINI MISSION; HUYGENS PROBE
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Jun 14, 2005

4

Heavily Hydrated Salts on Europa

Author and Affiliation: Dalton, J. Brad; Search for Extraterrestrial Intelligence Inst.; Moffett Field, CA, United States

Abstract: Recent laboratory studies have quantified the infrared spectral character of heavily hydrated sulfates and other salts proposed as major surface components on Europa. At temperatures relevant to the surface of Europa, the spectral signatures of these materials are markedly different than at room temperature. Comparison to Galileo Near Infrared Mapping Spectrometer (NIMS) observations indicate that heavily hydrated sulfate salts, such as mirabilite (Na2SO4(raised dot)10H2O) and magnesium sulfate dodecahydrate (MgSO4(raised dot)12H2O), provide a better explanation of the unique infrared signature observed in the reddish, disrupted terrains than less hydrated salt compounds under consideration, such as bloedite (Na2Mg(SO4)2(raised dot)4H2O) and epsomite (MgSO4(raised dot)7H2O). However, slight discrepancies which may go unnoticed in room temperature laboratory measurements are magnified at Europa temperatures, and suggest that the surface spectra cannot be explained by a single compound. The infrared signature of hydrated sulfate salts arises from the waters of hydration and is not intrinsic to the host compound. Therefore, alternative materials bearing waters of hydration must also be considered. Some of the materials considered thus far include sulfuric acid hydrate, chloride, carbonate, and sulfide hydrates, and hydrated metabolites in extremophile organisms trapped in ice or evaporite mineral crystals. Each material has separate implications for the formation and evolution of the near-surface environment, with ramifications for the evaluation of astrobiological potential at Europa from current and planned spacecraft observations. Consideration of the chemical, physical, and infrared behaviors of these

materials leads to specific questions concerning acceptable definitions of biosignatures to be applied in the search for life in the Solar System.

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Restriction on Access: Limited Distribution
Authorized Users: NASA personnel only
Copyright Indicator: No Copyright
DAA-File Indicator: No
Document Type: Conference Paper
Description: 1p
Org. Source Info.: Search for Extraterrestrial Intelligence Inst.; Moffett Field, CA, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Meeting Information: NAI 2005; 10-14 Apr. 2005; Boulder, CO; United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: EUROPA; HYDRATES; SALTS; EXOBIOLOGY
NASA Minor Term: BLOEDITE; CARBONATES; CHLORIDES; MAGNESIUM SULFATES; METABOLITES; MINERAL DEPOSITS; SULFURIC ACID; SPECTRAL SIGNATURES; ROOM TEMPERATURE
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Jun 07, 2005

5

Astrobiology Penetrates the Public Consciousness: Mission Accomplished?

Author and Affiliation: Wilmoth, Krisstina; NASA Ames Research Center; Moffett Field, CA, United States

Abstract: Boiling mud travels around America's heartland, Europa gives oceans a whole new definition, and Mars finally reaches its cold, rocky, icy destiny- in American consciousness that is. After six short years, Astrobiology has permeated into our living rooms, theaters, and museums. In September 2004, NOVA airs its four part series, Origins, narrated by Neil deGrasse Tyson, prominently featuring 9 different members of the NAI. Two months later, the New York Hall of Science opens an $88 million expansion featuring a 5000 square foot exhibit on The Search for Life Beyond Earth. In January 2005, director James Cameron and Disney release the high-resolution, 3-D IMAX film, Aliens of the Deep, connecting hydrothermal vent research on Earth to the possibility of life on Europa. And in February, the Space Science Institute launches Alien Earths, a 3000 square foot traveling exhibit to small and mid-size museums and science centers around the country. OPM, other people s money, bore these projects to completion, but NAI played a noteworthy role. From providing content ideas and connections to researchers to developing supporting materials, providing critical letters of support, and occasionally small amounts of funding, NAI's Education and Public Outreach (E/PO) program has leveraged the millions of dollars invested in these projects, communicating NASA s work in the core aspects of astrobiology and showcasing the NAI in particular. These are the fruits of NAI s public outreach these past six years. What next? Is public attention a benefit to astrobiology? These are the questions before us, all of us, now.

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Document Type: Conference Paper
Description: 1p
Org. Source Info.: NASA Ames Research Center; Moffett Field, CA, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Meeting Information: NAI 2005; 10-14 Apr. 2005; Boulder, CO; United States
Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: EDUCATION; EXOBIOLOGY; NASA PROGRAMS
NASA Minor Term: HIGH RESOLUTION; EXTRATERRESTRIAL LIFE; EUROPA; MARS (PLANET)
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Jun 07, 2005

6
Origins in a Europan Ocean; Progress Report
Author and Affiliation: Hand, K. P.
Carlson, R.
Abstract: The prospect of a large sub-surface Ocean beneath the ice shell of Europa harbors much interest for the astrobiology and origin of life communities. While the putative ocean may be habitable, conditions through time may not have been conducive for an independent origin of life. Here we examine the question of origins in a Europan Ocean by addressing three issues: 1) surface radiation chemistry as a mechanism for prebiotic chemistry, 2) Ocean salinity and ions in the role of vesicle formation, and 3) the redox state of the ocean. Experimental work addressing the first issue will be presented and theoretical models of the later two issues will be discussed.
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Contract Number: NASW 02005
Document ID (CASI): 20040161148
Security Classif.: Unclassified
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Authorized Users: NASA personnel only
Copyright Indicator: No Copyright
DAA-File Indicator: No
Document Type: Preprint
Org. Source Info.: Raytheon Technical Services Co.; Greenbelt, MD, United States
Financial Spons. Info.: NASA; Washington, DC, United States
Document Language: English
Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: BIOLOGICAL EVOLUTION; EUROPA; EXOBIOLOGY; OCEANS; RADIATION CHEMISTRY
NASA Minor Term: CHEMICAL REACTIONS; HABITABILITY; MATHEMATICAL MODELS; SURFACE REACTIONS
Available From: Other Sources
Availability Notes: Abstract Only
Database Load Date: Nov 15, 2004

7
Mars in Situ Biological/Mineral Native Fluorescence Microscope with Co-Registered UV/Vis Raman Spectrometer; Final Report

Author and Affiliation: Schmidt, Greg (Technical Monitor); NASA Ames Research Center; Moffett Field, CA, United States
Hug, William F.; Photon Systems; Covina, CA, United States
Reid, Ray D.; Photon Systems; Covina, CA, United States
Abstract: A number of instrumental techniques are available for identification and characterization of biogenic materials when materials handling and preparation and use of reagents are possible and when these materials are plentiful. What is needed for the in situ, robotic, search for biogenic materials that are sparsely distributed, as would be expected on Mars, Europa or elsewhere in the Solar system, is a robust, non-contact, non-destructive, instrumental suite that combines discovery and identification phases. This contract addresses the need with a UV laser induced native fluorescence detection and UV Raman spectrometer coregistered with a microscopic CCD array camera for both reflectance and fluorescence imaging. The laser induced native fluorescence spectral response can then be compared to a spectral library of biogenic and non-biogenic terrestrial minerals, organic materials, and intact microorganisms. Based on these comparisons, the probability that a given structure or portion of a structure is of biological origin can be determined. More detailed chemical characterization of selected regions can then be accomplished with an integrated and co-registered deep UV Raman spectrometer. The goal of this contract is to demonstrate all of the features that make this instrument feasible and to build a breadboard instrument.
Publication Date: August 06, 2004
Report Number: NAS2-02066-8-Final; NRA-00-01-ASTID-014
Contract Number: NAS2-02086
Document ID (CASI): 20040112029
Security Classif.: Unclassified
Restriction on Access: Limited Distribution
Authorized Users: NASA personnel only
Copyright Indicator: No Copyright
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Document Type: Technical Report
Description: 61p
Org. Source Info.: Photon Systems; Covina, CA, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Document Language: English
Subj. Category Text: Instrumentation and Photography
NASA Major Term: LIFE DETECTORS; MICROSCOPES; RAMAN SPECTROSCOPY; ULTRAVIOLET SPECTROMETERS; LASER INDUCED FLUORESCENCE; ULTRAVIOLET LASERS
NASA Minor Term: EXTRATERRESTRIAL LIFE; IN SITU MEASUREMENT; CCD CAMERAS
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A04
Database Load Date: Oct 01, 2004

8
Deep UV Semiconductor Radiation Source for In Situ Astrobiology Exploration; Final Report
Author and Affiliation: Hug, William F.; Photon Systems; Covina, CA, United States
Reid, Ray D.; Photon Systems; Covina, CA, United States
Schmidt, Gred (Technical Monitor); NASA Ames Research Center; Moffett Field, CA, United States
Abstract: This proposal addresses the need for deep ultraviolet radiation sources to be employed for in situ native fluorescence and UV resonance Raman detection of life biomarkers on Mars Surveyor Missions as well as missions to Europa, Titan and comets. The proposed light source technology is needed to enable compact, rugged, light-weight, high efficiency in situ native fluorescence and Raman life detection instruments for a wide range of extraterrestrial and terrestrial life exploration

research. The proposed development is a proof of concept development of a AlGaN-based semiconductor radiation source emitting in the 225nm range and includes development of improved methods of providing contamination-free hermetic seals of deep ultraviolet optics which are needed both for the AlGaN sources and deep UV narrow linewidth lasers such as HeAg and NeCu lasers. The proposed development addresses the need to improve size, weight, power consumption, and robustness of in situ life detection instruments.

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Copyright Indicator: No Copyright
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Document Type: Technical Report
Description: 55p
Org. Source Info.: Photon Systems; Covina, CA, United States
Financial Spons. Info.: NASA Ames Research Center; Moffett Field, CA, United States
Document Language: English
Subj. Category Text: Optics
NASA Major Term: SEMICONDUCTORS (MATERIALS); FAR ULTRAVIOLET RADIATION; RADIATION SOURCES; LIFE DETECTORS
NASA Minor Term: FLUORESCENCE; RAMAN SPECTROSCOPY; ULTRAVIOLET LASERS
Available From: CASI
Format and Price Code: Hardcopy - Price Code: A04
Database Load Date: Aug 20, 2004

9

Photolysis And Radiolysis Of Ice As A Source Of False Biomarkers On Europa

Author and Affiliation: Bernstein, Max; NASA Ames Research Center; Moffett Field, CA, United States
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Abstract: If we find evidence of Life elsewhere in the Solar System it will probably be in form of chemical biomarkers, quintessentially biological molecules that indicate the presence of micro-organisms. While certain functionalized PAHs have been invoked as biomarkers, and some people think of molecules such as amino acids as good candidates, these molecules are produced non-biotically in abiotic radiation experiments and thus could be present on the surface of other planets even in the absence of Life. Understanding how components of proteins and other molecules can form in sterile space environments is relevant to our search for life elsewhere in the Solar System (Astrobiology Roadmap Goal 7). Understanding the range of non-biological organic molecules that could act as false biomarkers in space is a prerequisite for any reasonable search for true biomarkers on other worlds We will present the results of laboratory experiments that show that UV photolysis and MeV proton irradiation of extraterrestrial ice analogs produce seemingly biotic organic molecules such as and amino acids , quinones, and other functionalized aromatic compounds. In the past, molecules of these types have been invoked as biomarkers.

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NASA Minor Term: AMINO ACIDS; MOLECULES; EUROPA; PROTON IRRADIATION
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10
Astrobiology And The Jupiter Icy Moons Orbiter (JIMO): Results Of The NASA Science Definition Team
Author and Affiliation: Greeley, Ronald; Arizona State Univ.; Tempe, AZ, United States
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Abstract: The Jupiter Icy Moons Orbiter (JIMO) is planned as the first in a series of missions in the NASA Prometheus project. JIMO would use nuclear-electric propulsion and nuclear power systems to enable unprecedented exploration in the outer solar system. A NASA Science Definition Team for JIMO, co-chaired by T, Johnson and R. Greeley, consisted of 38 scientists and was appointed to formulate the science objectives for the mission. The SDT drew on previous studies by NASA, various National Academy of Sciences reports, and results from a community-wide "Forum" held in the summer of 2003 and attended by 130 scientists. SDT recommendations include a mission statement for JIMO to: Explore the icy moons of Jupiter and determine their habitability in the context of the Jupiter system, which includes three crosscutting themes: Oceans (finding their locations, studying the structure of their icy crusts, and assessing active internal processes), Astrobiology (determining the types of volatiles and organics on and near the surfaces, and the processes involved in their formation and modification), and Jovian System Interactions (studying the atmospheres of Jupiter and the satellites and the interactions among Jupiter, its magnetosphere, and the surfaces and interiors of the satellites, including Io). The SDT has formulated four equally important goals for the JIMO mission. Within each goal, the objectives, investigations and measurements were identified and prioritized. The goals and the means to meet them are summarized as follow: a) Surface Geology and Geochemistry Goal: to determine the evolution and present state of the Galilean satellite surfaces and subsurfaces, and the processes affecting them. b) Interior science Goal: to determine the interior structures of the icy satellites in relation to the formation and history of the Jupiter system, and the potential "habitability" of the moons. c) Astrobiology Goal: to search for signs of past and present life and to characterize the habitability of the Jovian moons with emphasis on Europa. d) Jupiter System Science Goal: to determine how the components of the Jovian system operate and interact, leading to the diverse and possibly habitable environments of the icy moons.
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Document Language: English
Subj. Category Text: Exobiology
NASA Major Term: ICY SATELLITES; JUPITER SATELLITES; JUPITER ATMOSPHERE; EXOBIOLOGY; GEOCHEMISTRY; HABITABILITY
NASA Minor Term: GAS GIANT PLANETS; SATELLITE SURFACES
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11
The Lunar Astrobiology Sample Return Mission: Searching For Planetary Material On The Moon
Author and Affiliation: Armstrong, John C.; Weber State Univ.; Ogden, UT, United States
Beegle, Luther W.; Jet Propulsion Lab., California Inst. of Tech.; Pasadena, CA, United States
Gonzalez, Guillermo; Iowa Univ.; IA, United States
Abstract: Space flight missions to study Astrobiologically interesting objects including Comets, Mars, Europa and Titan are either currently in route (Cassini/Huygens bound for Titan) on site (Spirit and Opportunity on Mars), in the developmental phase (Comet Surface Sample Return, Mars Science Laboratory) or in the Early planning phases (Jupiter Icy Moons Orbiter for Europa and Post MSL Mars missions). One mission with potentially large Astrobiology relevance that is not currently under study is a lunar mission specifically to return astrobiologically interesting samples originating from other bodies that have collected there since the lunar crust solidified. We have begun to define and develop a sample return mission concept that will identify non-lunar material, cache it, and return it to Earth for further in-depth study in terrestrial laboratories. This non-lunar material could consist of samples of early Venus and Mars released through impacts, meteoritic & comet material and, most promising, early Earth samples which could have retained the chemical signatures of ancient terrestrial environments (Armstrong et al. 2002). This material, removed from the geological and biological weathering processes of the host planet, could be sequestered and protected on the Moon. We will discuss viability of sample deposition on the surface, lunar site selection, and sample processing strategies for a future sample return mission.
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Subj. Category Text: Exobiology
NASA Major Term: EXOBIOLOGY; MOON; SAMPLE RETURN MISSIONS; LUNAR GEOLOGY
NASA Minor Term: LUNAR CRUST; SITE SELECTION; WEATHERING; METEORITIC COMPOSITION

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12
Undergraduate Educational Opportunities In Astrobiology
Author and Affiliation: Abrams, Sam S.; NASA Ames Research Center; Moffett Field, CA, United States
Morrison, David; NASA Ames Research Center; Moffett Field, CA, United States
Abstract: Undergraduate astrobiology courses have begun to take form at many different colleges and universities. We conducted a web-based search of these courses to determine the subject matter being taught. From the posted course outlines and the contents of newly published astrobiology texts, it is possible to suggest a standard framework for an introductory course in astrobiology. Overall, 1364 prospective departments were sent an email inquiry, yielding detailed information on 42 courses on life in the universe . These are offered by departments of physics/astronomy, biology, or geology in the ratio 8:2:1. We found that that 76% of the astrobiology courses are for non-science majors and 67% require no prerequisite. These 42 courses used a remarkable 39 different texts, highlighting the diversity of course offering. From these 2002-3 data, The Search for Life in the Universe by Donald Goldsmith and Tobias Owen is the most popular text, although Life in the Universe by Bennett, Shostak, and Jakosky is a close second and is a new book that has had less time for exposure. The majority of these courses are large-scale lecture courses with enrollments of 60 or more students. From the posted syllabus for these courses, we can suggest a standard example of astrobiology course content for non-science majors. The course is organized into 11 broad topics as follows: History of the Universe; Formation and History of the Earth; the Nature of Life; Evolution of Life; Extraterrestrial Life; Life in Extreme Environments; Life in Our Solar System (Mars); Life in Our Solar System (Europa); Aliens, Science Fiction, and Society; SETI; The Future of Humankind in the Universe. Notable by its absence is the topic of habitable planets in other planetary systems, but this may reflect the newness of the subject of extrasolar planets.
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Subj. Category Text: Social and Information Sciences (General)
NASA Major Term: EDUCATION; EXOBIOLOGY; LECTURES; EXTRATERRESTRIAL LIFE
NASA Minor Term: UNIVERSITIES; SOLAR SYSTEM; PLANETARY SYSTEMS; EXTRASOLAR PLANETS; EUROPA
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13
Taphonomy Of Europa: A Paleobiologic Search Strategy
Author and Affiliation: Rieboldt, Sarah; California Univ.; Berkeley, CA, United States
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Abstract: If life occurs on Europa (Chyba & Phillips, 2002), it likely is or was distributed in discrete habitats. These habitats, in benthic, water column, and ice environments (Lipps et al. 1977, 1979),

would be distributed heterogeneously and preserved in near-surface ice. If they were preserved over geologic time, a record of past and present life may reside in the icy crust. Various processes anchor ice flotation (Isham & Webb, 2003), freezing grounded ice, ice ploughing, cyrovolcanism, diapir formation, for example may transport habitats to the crust where they are preserved. Ice dynamics and tectonics might expose them at the surface where detailed study and exploration will be possible. Likely exposures would be at ridges, bands, blocks and matrix of chaotic terrains, and diapirs. Modern organisms might be preserved too. Ice habitats like pores, channels, and the water-ice interface (Krebs et al., 1982), might be preserved in place. Floating or motile ones in the water column have a greater chance of being incorporated into the ice, if water from below fills openings. While radiation and chemistry preclude extant life on the surface, organisms or biosignatures may be found in ice sheltered by outcrops, ledges, or under ice blocks. Exploration for life requires imaging likely sites with resolutions of 10cm/pixel or better; for example, with Lockheed Martin s MIDAS instrument (Pitman et al., 2004) to look for cracks, sediment, layering, and possible larger organisms.

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Subj. Category Text: Lunar and Planetary Science and Exploration
NASA Major Term: EUROPA; PALEOBIOLOGY; GEOCHRONOLOGY
NASA Minor Term: ICE ENVIRONMENTS; ORGANISMS; TERRAIN; SEDIMENTS; IMAGING TECHNIQUES; EXTRATERRESTRIAL LIFE; BIOMARKERS
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14

Compact high-resolution 3-D imaging spectrometer for discovering oases on Mars; Final Report

Author and Affiliation: Ge, Jian; Pennsylvania State Univ.; Dept. of Astronomy and Astrophysics; PA, United States
Lunine, Jonathan; Arizona Univ.; Lunar and Planetary Lab.; Tucson, AZ, United States
Brown, Robert; Arizona Univ.; Lunar and Planetary Lab.; Tucson, AZ, United States
Yelle, Roger; Arizona Univ.; Lunar and Planetary Lab.; Tucson, AZ, United States
Soderblom, Larry; Geological Survey; Astrogeology Program; Flagstaff, AZ, United States

Abstract: This project started on May 1, 2002 and ended on April 30 2004 (with one year no-cost extension) to develop a prototype compact, robust and light-weight 3D near-IR imaging spectrometer for future Mars orbital remote sensing missions targeted to examine closely astrobiologically promising sites, and also possible surface landing missions. The instrument is designed to detect and characterize possible organic compounds on the martian surface, and identifl promising possible oases of extant and extinct life for further exploration by landed instruments. This new instrument approach takes advantage of the emerging silicon immersion grating and integral field optics developed at Penn State to enable an order of magnitude improvement in spectral resolution with high dispersing silicon grisms and observing efficiency with the integral field optics and also large wavelength coverage (1.2-4.8 micrometers) with commercially available large IR detector arrays. Our

approach enables more than an order of magnitude reduction in volume, mass and cost for infrared spectroscopic instruments with better performance than what has been achieved before. This instrument is well suitable for other missions to Europa and Titan for astrobiological studies.

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Financial Spons. Info.: NASA Goddard Space Flight Center; Greenbelt, MD, United States
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NASA Major Term: HIGH RESOLUTION; MARS SURFACE; OASES; THREE DIMENSIONAL MODELS; EXOBIOLOGY
NASA Minor Term: COSTS; SURFACE ROUGHNESS; SILICON; GRATINGS; ETCHING; WAVE FRONTS; INFRARED SPECTROSCOPY
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15

Influence of Methanogens on Mineral Weathering

Author and Affiliation: Hausrath, Elisabeth M.; Pennsylvania State Univ.; University Park, PA, United States
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Brantley, Susan L.; Pennsylvania State Univ.; University Park, PA, United States

Abstract: Methanogens are microorganisms in the domain Archaea that produce methane from carbon dioxide and hydrogen, acetate, or one-carbon compounds. They have played an important role in the carbon cycle and global climate throughout Earth's history through the production of methane, which is a potent greenhouse gas. Additionally, it has been proposed that life in the subsurface of Mars and Europa might consist mainly of methanogens, similar to communities which have been found on Earth in deep, subsurface environments which lack organic carbon. We have conducted experiments to determine whether methanogens enhance the dissolution of mineral analogs in batch experiments in the laboratory, or form characteristic biomarkers on mineral analog surfaces. This information could contribute to the interpretation of paleosols from early Earth, or potential biomarkers from Mars or Europa. We have determined that methanogens do enhance dissolution of mineral analogs in the laboratory, which may be due to pH changes, production of cell lysates or exudates. Experiments are currently ongoing to distinguish between these mechanisms. We have not observed any characteristic biomarkers formed by methanogens.

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NASA Minor Term: BIOMARKERS; BIOGEOCHEMISTRY; ANALOGS
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16
Development of an Extremophile Microbial Digester for Astrobiology Relevant Biomass Production
Author and Affiliation: Gormly, Sherwin; Nevada Univ.; Reno, NV, United States
Adams, V. Dean; Nevada Univ.; Reno, NV, United States
Marchand, Eric; Nevada Univ.; Reno, NV, United States
Abstract: Large volume digester/chemostat studies are not normally associated with extremophile microbiology. This is particularly true for psychrophilic (low temperature), halophilic (high salt adapted) anaerobic communities. The low rate of culturing success and long culturing times required discourages the use of large volume culturing techniques for these communities. This is unfortunate for astrobiology, because low temperature brine environments are particularly attractive possibilities for extending water, and thus the potential for biologically viable habitats into otherwise unfavourable locations and conditions (like subsurface Europa and Mars). The digester developed in this study provides two significant advantages over normal culturing techniques by developing: An operational instrument test chamber (8.5 litre volume) with active, monitored and controlled psychrophilic and halophilic, anaerobic metabolism in situ. A substantial quantity of biomass product, under astrobiology relevant conditions, for development of biosignature target material. The initial proof of concept target culture habitat used was a high sulfate brine environment that was moderately halophilic (2.5% salt as NaCl) and psychrophilic (4 C). Robust sulphate reduction, substrate utilization, and target biomass production is currently being observed and reported.
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NASA Minor Term: SULFATES; MICROORGANISMS
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17

NAI Contributions to NASA Flight Missions

Author and Affiliation: Morrison, David; NASA Ames Research Center; Moffett Field, CA, United States
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Abstract: One of the long-term objectives of the NASA Astrobiology Institute (NAI) is to provide astrobiology input to the planning and execution of NASA flight missions. The NAI includes many members with diverse technical backgrounds, both scientists and engineers, who can focus their unique expertise on flight mission opportunities. From the foundation of the NAI, we have all agreed that one metric of the success of this Institute should be the degree that astrobiology is infused into and affecting NASA flight missions. Part of the NAI contribution is provided by the mission-related Focus Groups. The Mars Focus Group has played a critical role as a forum for discussion of martian astrobiology in the context of the current mission planning, for encouraging astrobiologists to participate in a variety of Mars mission teams and planning groups, and especially in focusing attention on the selection of landing sites of high astrobiology potential. The Europa Focus Group has concentrated on long-term science questions concerning Europa and the search for life there. At present, when there are no other active Europa mission studies, this Focus Group plays a unique role in planning and advocating future Europa missions. The new Titan Focus Group will provide a mechanism for building bridges between the Cassini-Huygens flight team and the astrobiology community. Finally, several of the NAI Focus Groups are dealing with scientific issues that will eventually be critical for planning the search for biomarkers on distant planets using the Terrestrial Planet Finder (TPF) and Darwin missions.

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18

The Classification of Biosignatures

Author and Affiliation: McKay, David S.; NASA Johnson Space Center; Houston, TX, United States
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Clemett, Simon; Lockheed Martin Corp.; Houston, TX, United States
Gibson, Everett K.; NASA Johnson Space Center; Houston, TX, United States

Abstract: If we are trying to detect extant or extinct life on Mars, Europa, or another planetary body, we must first identify biosignatures and then infer from the biosignatures that life is or was present. This

is true for robotic missions with remote instruments, remote sensing sensors, and returned samples analyzed in our laboratories on Earth. We therefore need to be concerned with biosignatures: What are they? Can we identify them? Are they proof of life? How reliable are they? We propose the following definition: A biosignature is any measurable property of a planetary object, its atmosphere, its oceans, its geologic formations, or its samples that suggests that life is or was present. A short definition is a "fingerprint of life". Biosignatures are sometimes termed biomarkers, but the term biomarker has long been used in the geological literature to refer specifically to organic compounds derived from once-living material and now found in geologic formations. This usage has precedence and should be retained. Biosignatures as defined above include biomarkers as a subset.
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19

Humans and robots collaborating in the search for life beyond Earth

Author and Affiliation: Allen, Carlton C.; NASA Johnson Space Center; Houston, TX United States
McKay, David S.; NASA Johnson Space Center; Houston, TX United States

Abstract: The search for life beyond Earth, carried out by humans and robots, is one of the key drivers for space exploration. Rocks and soils returned by the Apollo astronauts were initially quarantined and studied for any evidence of lunar microbes; none were found, with most of the research done by workers using controlled-atmosphere gloveboxes. The robotic Viking landers deliberately searched for organic chemistry and metabolism in Martian soil, again with negative results. Intensive laboratory research is currently underway to understand possible signs of ancient microorganisms in meteorites from Mars. All of these meteorites have been found by human searches, but experiments with a robot meteorite hunter have recently shown promise. Future samples returned by spacecraft from the Martian surface may require initial robotic handling until questions of possible indigenous life and biohazard can be answered. Robots and specialized vehicles will certainly be required to support future human exploration of Mars. Jupiter's satellite Europa may have a liquid ocean beneath its ice crust. Robots are being designed to explore this ocean for evidence of ecosystems based on chemical energy, like those found on the terrestrial seafloor by robots and humans in deep submersibles. Optical telescopes are revealing ever-increasing numbers of planets orbiting other stars, and space observatories may achieve the sensitivity to detect chemical signs of life in the atmospheres of these extrasolar planets. Automated searches of nearby stars for signs of radio communication are

currently underway. If any of these investigations provides evidence of life, in our solar system or beyond, it will rank as one of the most important discoveries in human history.
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NASA Minor Term: ORGANIC CHEMISTRY; LUNAR EVOLUTION; EUROPA; RADIO COMMUNICATION
Non-NASA Terms: SPACE ROBOTS
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Database Load Date: Nov 02, 2001

20
Astrobiology at Arizona State University: Program Overview and Research/Outreach Highlights
Author and Affiliation: Davis, Rebecca; Arizona State Univ.; Dept. of Geological Sciences; Tempe, AZ, United States
Unser, Leslee; Arizona State Univ.; Dept. of Geological Sciences; Tempe, AZ, United States
Farmer, Jack; Arizona State Univ.; Dept. of Geological Sciences; Tempe, AZ, United States
Abstract: ASU's Astrobiology Program is an interdisciplinary program of study and research that offers exciting opportunities for both undergraduate and graduate students who seek a high-level academic experience at a Research One University. The current program includes faculty researchers and students at all levels from the Departments of Geological Sciences, Chemistry and Biochemistry, Biology, Plant Biology, and Microbiology. We also are supported by affiliated programs in Astronomy, Aerospace Engineering, and Biotechnology. The current program supports 15 funded ASU Co-Investigators across these disciplines with collaborative ties to the College of William & Mary, University of Alaska, University of Arizona, University of Connecticut, University of Puget Sound, University of Tennessee, Indiana University, and the National University of Mexico (UNAM), Mexico City. At last count, ongoing research projects are providing training opportunities for 19 graduate and 7 undergraduate students. Active research areas include the 1) cosmochemistry of carbonaceous meteorites, 2) organosynthesis in seafloor hydrothermal systems, 3) the origins and evolution of photosynthesis, 4) studies of the microbial fossil record, 5) environmental conditions on Archean Earth, 6) the structure, function and persistence of complex ecosystems in extreme environments, 7) the effects of impact processes on planetary habitability and evolution, and 8) the exploration for habitable environments and life on Mars and Europa. In this presentation we will review the present current research highlights and review recent Education and Public Outreach activities from the past year.
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NASA Minor Term: MICROORGANISMS; OCEAN BOTTOM; PRECAMBRIAN PERIOD; EXTRATERRESTRIAL LIFE; PHOTOSYNTHESIS; HABITABILITY; EUROPA; BIOTECHNOLOGY; BIOCHEMISTRY; MARS (PLANET); CARBONACEOUS METEORITES; COSMOCHEMISTRY
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21
Mission to Europa's sub-surface ocean and search for possible biological traces
Author and Affiliation: Akiyama, H.; Nishimatsu Construction Co., Ltd., Kanagawa; Japan
Shiraishi, A.; NASDA; Tsukuba Japan
Haruyama, J.; NASDA; Tsukuba Japan
Terazono, J.; Japan Space Forum, Tokyo
Yano, H.; NASA Johnson Space Center; Houston, TX United States
Abstract: A strategy to explore the surface ice of Europa, a Jovian satellite, is proposed as a feasible mission for the next decade. The plan is based on the assumption that sufficient evidence for life in Europa could be obtained from its surface ice, and it is not necessarily required to reach the environment of the thermal vents located at the bottom of the subsurface ocean to find life. The required observations and instruments are briefly discussed.
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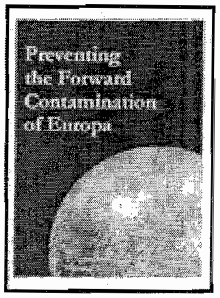

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Preventing the Forward Contamination of Europa

Space Studies Board
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Preventing the Forward Contamination of Europa

Task Group on the Forward Contamination of Europa
Space Studies Board
Commission on Physical Sciences, Mathematics, and Applications
National Research Council

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Foreword

Jupiter's moon Europa is widely regarded as the most promising extraterrestrial habitat for life in the solar system. This view is based on recent evidence suggesting the presence of a water ocean beneath Europa's fractured icy surface together with studies of microbial life in extreme environments on Earth, which suggest that living organisms emerge wherever liquid water and some form of usable energy are found.

Naturally, there is now great interest in learning much more about Europa, primarily through a series of space probes to survey and eventually to land on the surface. But any spacecraft that transports scientific instruments can also carry terrestrial microbes. This report deals with the important issue of how to protect Europa from such inadvertent biological contamination.

To reach their conclusions, the task group had to consider many dimensions of the question. These included techniques for cleaning a spacecraft, the resilience of terrestrial organisms, the space environment at Jupiter, and cost implications of alternative planetary protection approaches. The complexity of these issues, no doubt, contributed to the fact that the task group could reach consensus on some, but not all, aspects of their charge.

The task group's deliberations illuminate several thorny questions dwelling on the boundary of science and ethics and point the way for further study of both technical and ethical considerations. Although one might have wished for an unequivocal answer, the complexity of the recommendations appropriately reflects the complexity of the underlying issues. In that sense, the report gives NASA's Planetary Protection Officer a very clear message.

Claude R. Canizares, *Chair*
Space Studies Board

Preface

Europa, a planetary satellite of Jupiter, is a solar system body that may have a significant potential for past or present life. Europa has a radius of about 1,600 km, slightly less than the Moon's, and it is probably mostly silicate and metal by mass. It has an upper layer, on the order of 80 to 170 km deep, rich in water ice. There is evidence for liquid water beneath the icy crust, first surmised from Voyager data and reinforced by Galileo data. The investigation of Europa's biological potential forms much of the rationale for continued investigation of the satellite.

In accordance with international treaty obligations, the National Aeronautics and Space Administration (NASA) maintains a policy of planetary protection to limit the contamination of extraterrestrial bodies by terrestrial microorganisms and organic compounds during spaceflight missions. Thus, preventing the contamination of Europa's environment by terrestrial organisms will be required during upcoming spaceflight missions such as the orbiter that is currently scheduled for launch later in this decade.

The planetary protection procedures applied to a given spacecraft are currently determined by the nature of its mission (e.g., flyby, orbiter, or lander) and the biological interest posed by the celestial object that is its destination. A lander targeted at an object of great biological interest must undergo careful cleaning, and heat sterilization may be required if it is carrying life-detection experiments. These requirements are, however, specifically tied to the historical development of our understanding of Mars and its biological potential. Given Europa's unique environment, applying the criteria developed for Mars may not be appropriate, and a separate assessment is warranted of the levels of cleanliness and sterilization required to prevent the contamination of Europa by spacecraft missions.

Against this background, NASA's Planetary Protection Officer requested that the Space Studies Board undertake a study to evaluate the planetary protection requirements and methods used to prevent contamination of Europa by terrestrial organisms in future orbiter and lander missions and that it recommend any necessary changes. In particular, the Space Studies Board was asked to do the following:

- Assess the levels of cleanliness and sterilization required to prevent the forward contamination of Europa by future spacecraft missions (orbiters and landers), given Europa's unique environment and our current understanding of terrestrial microorganisms;
- Review methods used to achieve the appropriate level of cleanliness and sterilization for Europa spacecraft and recommend alternatives in light of recent advancements in science and technology; and
- Identify scientific investigations that should be accomplished to reduce the uncertainty in the above assessment.

In response to this request, the Space Studies Board established the Task Group on the Forward Contamination of Europa.

The work of the task group began in early April 1999 and proceeded with a series of meetings and associated presentations, discussions, and deliberations. Despite its best efforts, however, the task group was unable to reach complete agreement on a number of issues. This report describes the majority and minority viewpoints resulting from the task group's deliberations. In particular, it describes their areas of agreement and disagreement and the implications for implementation of planetary protection requirements for future Europa missions.

The work of the task group benefited from contributions, presentations, or comments made by Amy Baker (Technical Administrative Services), Mark Guman (Jet Propulsion Laboratory), Torrence Johnson (Jet Propulsion Laboratory), Harold Klein (SETI Institute), Robert Koukol (Jet Propulsion Laboratory), Jan Ludwinski (Jet Propulsion Laboratory), Christopher McKay (NASA Ames Research Center), William McKinnon (Washington University), Chris Paranicas (Applied Physics Laboratory, Johns Hopkins University), Pericles Stabekis (Lockheed Martin Life Sciences), David Relman (Stanford University), John Rummel (NASA headquarters), Partha Shakkotai (Jet Propulsion Laboratory), Norman Wainwright (Marine Biological Laboratory), and Wayne Zimmerman (Jet Propulsion Laboratory).

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee.

The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. The task group thanks reviewers John Battista (Louisiana State University), Russell Doolittle (University of California, San Diego), John Kerridge (University of California, San Diego, retired), Krishan Khurana (University of California, Los Angeles), Leslie Orgel (Salk Institute for Biological Studies), Robert Pappalardo (Brown University), and M. Elisabeth Paté-Cornell (Stanford University) for their many constructive comments and suggestions. Responsibility for the final content of this report rests solely with the authoring task group and the NRC.

Contents

Executive Summary

Planetary protection is an essential consideration for exploration of planets or satellites that may have experienced prebiotic chemical evolution or that may have developed life. Recent observations of Jupiter's satellite Europa indicate that it has been geologically active in the relatively recent past and that liquid water might exist beneath a surface ice shell some 10 to 170 km thick. Moreover, water might exist closer to the surface on an intermittent basis if the ice shell is cracked or otherwise punctured owing to the action of internal and external forces.

We know that life arose rapidly on Earth, perhaps in ancient hydrothermal systems. In these systems, cold ocean water is taken up and circulated through a geothermally heated zone, where it interacts chemically with minerals, and is then released back into the ocean. Its high temperature and dissolved mineral content result in a state of physical and chemical disequilibrium when it mixes again with the cold water. On Earth, the subsequent reactions to reestablish equilibrium were able to provide energy to support metabolism. Europa may also have such geothermal zones if a global ocean of liquid water exists below the surface.

Terrestrial microorganisms provide the only available reference point for evaluating whether life might already be present on Europa or whether it could be introduced by a contaminated spacecraft. On Earth, life is found in some of the most extreme environments. These include extreme heat, cold, pressure, salinity, acidity, dryness, and radiation. Microorganisms are remarkably resilient and have survived exposure to the space environment for more than 5 years aboard the Long Duration Exposure Facility and for millions of years in permafrost regions on Earth's surface. Moreover, in some circumstances, the ability to survive one form of environmental stress may confer the ability to survive in another stressful environment. Many common bacteria are, for example, desiccation resistant, and there is evidence suggesting that the mechanisms that evolved to permit survival in very dry regions also confer resistance to irradiation. Organisms capable of surviving a particular set of extreme conditions cannot, therefore, be assumed to be necessarily confined to environments possessing those conditions.

Even though current information is not sufficient to conclude whether Europa has an ocean, native life, or environments compatible with terrestrial life, it is also insufficient to dismiss these possibilities at this time. Thus, future spacecraft missions to Europa must be subject to procedures designed to prevent its contamination by terrestrial organisms. This is necessary to safeguard the scientific integrity of future studies of Europa's biological potential and to protect against potential harm to europan organisms, if they exist, and is mandated by obligations under the United Nations' *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies* (U.N. Document No. 6347 January 1967).

Current NASA requirements for the protection of other planetary environments are based on categorizing the mission as to type and the target object as to its likelihood of harboring life. The current procedures for planetary protection use protocols derived from those originally developed for the Viking missions to Mars in the 1970s. Determining whether or not this methodology is applicable to Europa missions was the central facet of the task group's deliberations.

The Task Group on the Forward Contamination of Europa concluded that current cleaning and sterilization techniques are satisfactory to meet the needs of future space missions to Europa. These techniques include Viking-derived procedures such as cleaning surfaces with isopropyl alcohol and/or sporicides and sterilization by dry heating, as well as more modern processes such as sterilization by hydrogen peroxide, assuming that final sterilization is accomplished via exposure of the spacecraft to Europa's radiation environment. The technological drawbacks of current prelaunch sterilization techniques are such that the use of such techniques is likely to increase the complexity and, hence, the cost of a mission.

The task group also concluded that the current spore-based culturing techniques used to determine the bioload on a spacecraft should be supplemented by screening tests for specific types of extremophiles, such as radiation-resistant organisms. In addition, modern molecular methods, such as those based on the polymerase chain reaction (PCR), may prove to be quicker and more sensitive for detecting and identifying biological contamination than NASA's existing culturing protocols for planetary protection.

The task group recommends a number of studies that would improve knowledge of Europa and that would better define the issues related to minimization of forward contamination. These include studies on the following topics:

- Ecology of clean room and spacecraft-assembly areas, with emphasis on extremophiles such as radiation-resistant microbes;
- Detailed comparisons of bioload assay methods;
- Desiccation- and radiation-resistant microbes that may contaminate spacecraft during assembly;
- Autotroph detection techniques; and
- Europa's surface environment and its hydrologic and tectonic cycles.

The task group was unable to reach complete agreement on the central issue of the planetary protection standards that must be met by future missions to Europa. The majority if its members believe that Europa's potential importance to studies of chemical evolution and the origin of life is great but that detailed understanding of the europan environment and the survival of terrestrial organisms in extreme conditions is so limited that the current planetary protection methodology is not readily applicable to Europa missions. Uncertainties demand conservatism, and, thus, the very first mission to Europa must meet the highest reasonable level of safeguard.

In practice, this means that the bioload of each Europa-bound spacecraft must be reduced to a sufficiently low level at launch that delivery of a viable organism to a subsurface ocean is precluded at a high level of probability. This approach allows mission planners to take advantage of the bioload reduction likely to occur en route, particularly while in Jupiter's radiation environment. One consequence of this view is that Europa must be protected from contamination for an open-ended period, until it can be demonstrated that no ocean exists or that no organisms are present. Thus, we need to be concerned that over a time scale on the order of 10 million to 100 million years (an approximate age for the surface of Europa), any contaminating material is likely to be carried into the deep ice crust or into the underlying ocean.

Thus, the task group's majority concluded that spacecraft sent to Europa must have their bioload at launch reduced to such a level that, taking into account the natural additional reduction that occurs after launch, the probability of contaminating a europan ocean with a viable terrestrial organism at any time in the future should be less than 10^{-4} per mission. How this standard might be implemented by a combination of Viking-level cleaning and sterilization, accompanied by bioload reduction in the europan radiation environment, is illustrated by a probabilistic calculation offered by the task group (Appendix A).

In addition to the majority view, this report presents two independent minority viewpoints that argue for less stringent planetary protection requirements.*

* The minority viewpoints supporting less-stringent planetary protection procedures than those advocated by the majority are based on two independent arguments. One subset of the task group argued that the planetary protection provisions for Europa should be broadly consistent with the current policies, practices, and protocols. The other subset argued that studies of the organisms found in extreme terrestrial environments suggest that no known terrestrial organism has a significant probability of surviving and multiplying in a europan ocean. The practical consequences of both of these views is that Europa missions should be subject to essentially the same planetary protection requirements that are currently applied to Mars missions. That is, spacecraft (including orbiters) without biological experiments should be subject to at least Viking-level cleaning, but sterilization is not necessary.

1
Planetary Protection Policies

HISTORY

Planetary protection concerns were first raised in 1956 in a discussion of the nascent field of space law at the International Astronautical Federation's 7th Congress, held in Rome.[1] Planetary protection became an issue for the scientific community in December 1957 when Joshua Lederberg wrote a letter to the National Academy of Sciences. He was concerned that it would not be possible to test the panspermia hypothesis for the origin of life if the Moon became contaminated with terrestrial organic matter as a result of spacecraft missions.

The Moon was soon found to be barren, however, and interest in panspermia waned.[2] Nevertheless, the importance of preserving extraterrestrial environments from terrestrial biological and organic contamination was generally recognized and ultimately enshrined in resolutions issued by the Committee on Space Research (COSPAR) of the International Council for Science and in the provisions of the United Nations Outer Space Treaty.[3]

As a signatory to the Outer Space Treaty, the United States is obliged to ". . . pursue studies of outer space, including the moon and other celestial bodies . . . so as to avoid their harmful contamination. . . ."[4] To abide by the treaty's imperatives, NASA has developed detailed planetary protection procedures in accordance with general requirements outlined in recommendations in various reports provided by the Space Studies Board. NASA implementation plans are then submitted to COSPAR for that organization's approval in its de facto role as the international court of scientific opinion with respect to the Outer Space Treaty's noncontamination policies.

It is generally acknowledged that minimizing the risk of forward contamination is motivated by two different imperatives.[5] The first is preservation of the scientific integrity of the planetary body under study. That is, terrestrial organisms introduced into an extraterrestrial environment may cause false positives in life-detection experiments and may generally impede the study of indigenous life, if it exists. The second imperative is to preserve and protect indigenous organisms from possible harm by introduced terrestrial life.

For much of the history of the implementation of planetary protection regulations, the protection of future scientific experiments has been assigned the most weight in determining planetary protection requirements. Indeed, planetary protection policies have centered on the concept of a period of biological exploration, during which particular planetary bodies are accorded protection from contamination so that studies of their biological potential can proceed unhindered by terrestrial contamination. Following the expiration of this exploration period, contamination controls are then relaxed or abandoned altogether.

Over the past 15 years, however, ethical and philosophical papers have been published on the rights of alien beings, no matter how simple those beings. Combined with the emergence of environmental and animal-rights groups, this is a potential area for future debate. Indeed, a 1992 report of the National Research Council's (NRC's) Space Studies Board, *Biological Contamination of Mars: Issues and Recommendations*,[6] recognized these issues and emphasized the need to encourage public discussion and dissemination of information concerning the steps taken to prevent planetary cross-contamination.

PROTECTING MARS

Mars has been the focus of the search for extraterrestrial life for most of the last 40 years. As such, the development and implementation of planetary protection policies have evolved in close concert with the evolution of our understanding of the martian environment and its biological potential. Before the Viking missions of the mid-1970s, the severity of the martian environment was not completely known. The subsequent improvement in understanding is reflected in the fact that the value adopted for the probability of growth of imported terrestrial microbes on Mars (P_g) used in the probabilistic approach to contamination control applicable at that time fell from 1 in 1964 to 10^{-10} in 1978.

The clarification of the biological potential of the martian surface had a major impact on planetary protection policies for Mars and, by extension, other solar system bodies. NASA's current planetary protection requirements and those for Mars, in particular, derive from a policy adopted at COSPAR's 25th General Assembly, held in Graz, Austria, in 1984,[7] as refined in a 1992 NRC report on the topic.[8] The key feature of COSPAR's 1984 policy was the abandonment of the quantitative, statistical approach used in the Viking era and the adoption of a simpler, more straightforward methodology based on the type of mission (e.g., flyby, orbiter, lander, or sample return) and the degree to which the mission's destination is of interest to the process of chemical evolution.

The 1992 NRC report refined the COSPAR approach by drawing a distinction between Mars missions that carry instruments designed to search for evidence of life and those that do not carry them. Since terrestrial organisms are unlikely to grow on the martian surface, the report argued, they do not pose a significant contamination hazard. They could, however, confound the results from life-detection experiments. Thus, the report recommended that landers carrying instrumentation for in situ investigation of extant martian life "should be subject to at least Viking-level sterilization procedures" (see Box 1.1).[9] Orbiters and landers without biological experiments, on the other hand, "should be subject to at least Viking-level presterilization procedures—such as clean-room assembly and cleaning of all components—for bioload reduction, but such spacecraft need not be sterilized."[10] The NRC's recommended distinction between Mars landers with and without life-seeking experiments was later codified and adopted by COSPAR.[11,12]

NASA's implementation of these policies, described in *Planetary Protection Provisions for Robotic Extraterrestrial Missions*, involves adherence to the following procedures:[13]

- *Spacecraft that fly by or enter orbit around Mars* are subject to planetary protection requirements designed to control contamination and to reduce the risk that spacecraft or its boosters will impact the planet. This is achieved by assembling the spacecraft in clean rooms rated at Class 100,000 or better (i.e., no more than 100,000 particles larger than 0.5 μm in any one cubic foot of air) and by ensuring that the probability of impact by the launch vehicle and the flyby spacecraft does not exceed 10^{-4} and 10^{-2}, respectively. The lifetime of an orbiter must be such that it remains in orbit for a period in excess of 20 years from launch, and the probability of impact for the next 30 years must be no more than 0.05. If the lifetime requirements cannot be met, then the surface microbial bioburden must meet the Viking presterilization limit. Following bioassay, such spacecraft must be protected against recontamination.
- *Spacecraft that land on Mars but are not equipped with life-detection experiments* are subject to planetary protection requirements designed to control the lander's bioburden and to prevent accidental impact by hardware not intended to land. The total probability of any accidental impacts by any hardware other than the lander must be no more than 10^{-4}. Bioburden control involves assembly in a Class 100,000 or better clean room, periodic microbiological assays, and maintenance of hardware cleanliness. Bioburden reduction to the Viking presterilization level is required. The mission team is also required to inventory, document, and archive samples of organic compounds used in the construction of the lander and associated hardware that might accidentally impact the planet. Finally, the locations of landing sites and impact points must be determined as accurately as possible, and the condition of the hardware at each site must be estimated to assist in determining the potential spread of organic compounds.
- *Spacecraft that land on Mars and are equipped with life-detection experiments* are subject to all of the requirements outlined above and must, in addition, undergo a Viking-level sterilization process.

Although the bioburden reduction employed for all types of landers may be measured by any microbiological assay, it is incumbent on the project to prove the equivalency between its assay and that employed on Viking. Moreover, no allowance can be made for burden reduction in flight or associated with surface conditions on Mars.

The central question to be addressed in this report concerns the degree to which Europa can be incorporated into the planetary protection framework developed in light of 40 years of experience with the exploration of Mars. In other words, is our current knowledge of Europa and its ability to sustain terrestrial organisms analogous to our understanding of martian conditions before the Viking missions or after them? In an attempt to answer this question, Chapter 2 focuses on current understanding of Europa and Chapter 3 discusses the limits of terrestrial life.

BOX 1.1 Viking's Approach to Bioload Reduction

Viking employed a twofold approach to controlling the population of terrestrial organisms that might find their way to Mars. First there was a careful cleaning of the spacecraft, and then the bioload was reduced still further by heat sterilization.

Presterilization

The Viking landers were assembled in Class 100,000 clean rooms. During assembly, thousands of microbial assays were conducted, and these established that the average spore burden per square meter was less than 300 and the total burden of spores on the lander's surface (i.e., the exposed exterior and those parts of the interior communicating directly with the exterior) was less than 300,000.[14] The spore-forming microbe *Bacillus subtilis* was used as the indicator organism in the microbiological assays on the basis of its enhanced resistance to heat, desiccation, and radiation.

Sterilization

Once the landers had been assembled and sealed inside their bioshields, their bioload was further reduced by dry heating. The landers were heated at a humidity of 1.3 mg/liter such that at the coldest point a temperature of 111.7 °C was maintained for some 30 hours. In other words, much of the lander was subject to a higher temperature for a longer period of time. Once sterilized, the landers were no longer accessible for additional microbial assays. Thus the efficacy of the sterilization procedure was estimated indirectly on the basis of the known heat-survival characteristics of *B. subtilis* and was credited with reducing the lander's bioburden by a factor of 10^4.

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2
Europa

Interest in Jupiter's moon Europa has intensified with exciting new findings in the last few years from NASA's Galileo mission, currently in orbit around Jupiter, which has made numerous close passes by Europa. This summary of our understanding of Europa, the proposed strategy for its exploration, and the possibility for indigenous life there follows closely the 1999 NRC report *A Science Strategy for the Exploration of Europa*.[1] The task group quotes and paraphrases liberally from that report in the next sections, and the reader is directed to it for greater detail.

Perhaps the most exciting facet of Europa is that an ocean of liquid water may lie beneath its surface covering of ice. Although there is currently no direct evidence for such an ocean, intriguing indirect evidence has been seen from various spacecraft. Europa's reflectance characteristics indicate that its surface is composed of water ice. Local- and global-scale ice tectonics dominates the geology, with a very large number of cracks crisscrossing its surface. Galileo's gravity measurements show that Europa has a differentiated interior, with the outermost 80- to 170-km layer predominantly water and/or water ice. Europa's magnetic signature suggests the presence of an electrically conducting layer near the surface. The likely explanation is that the water layer is liquid, with dissolved salts providing the ions for electrical conduction. Europa also has an extremely thin atmosphere composed of gases derived from its surface.

High-resolution images of the surface show features that are best or most easily explained as resulting from the presence of at least partially melted material at shallow depths.[2] These features include plates of ice that appear to have rafted to new locations and then frozen in place (Figure 2.1)[3,4] and cycloidal cracks that can be interpreted as being due to the effects of diurnal tidal stresses on a surface ice shell decoupled from Europa's interior (Figure 2.2).[5]

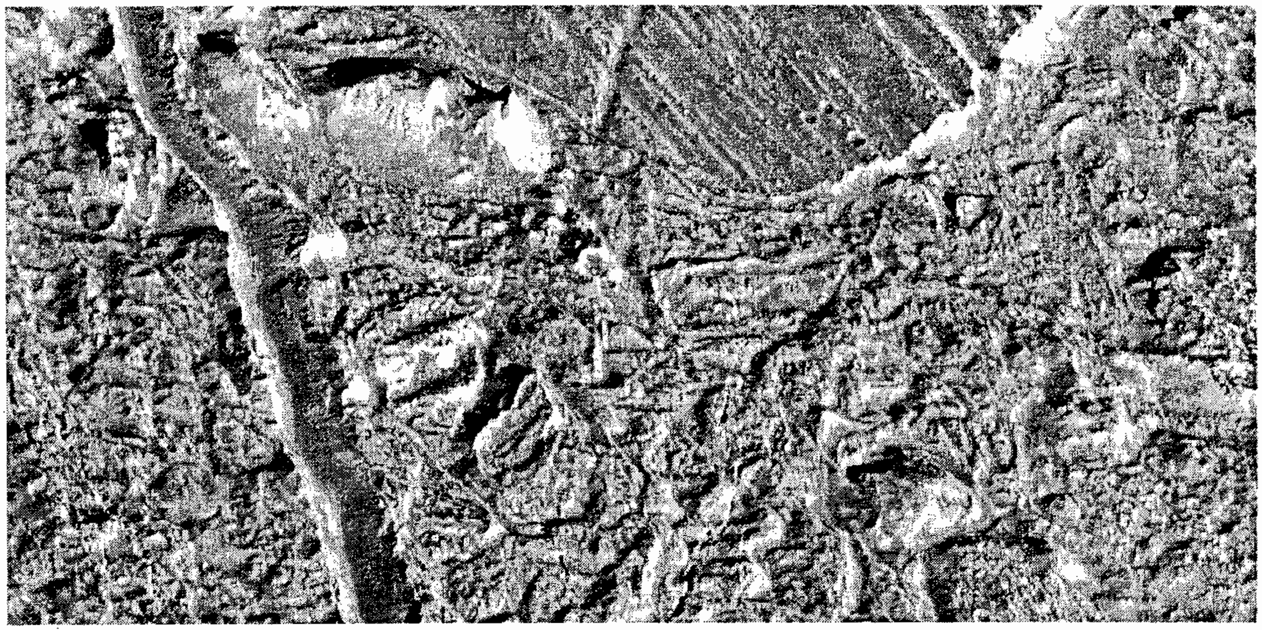

FIGURE 2.1 This view of the Conamara Chaos region of Europa shows an area where the icy surface has been broken into many separate plates that have moved laterally and rotated with respect to each other. North is at the top right of this image, and the Sun illuminates the surface from the east. The area covered by this image, whose center is approximately 8 degrees north and 274 degrees west, is approximately 4 by 7 km. The resolution is 9 m/pixel. Courtesy of the Jet Propulsion Laboratory.

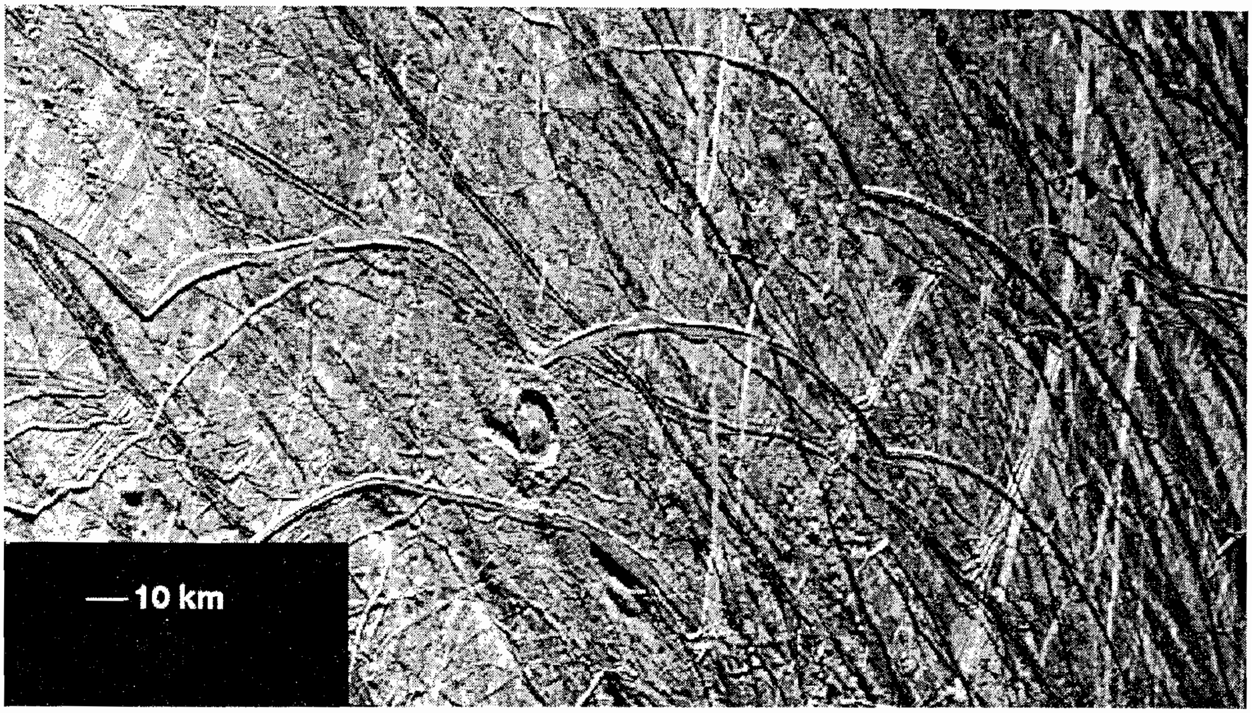

FIGURE 2.2 Europa's cycloidal ridges, such as these seen at 60 degrees north and 80 degrees west, may be the surface expression of diurnal tidal stresses propagating through a thin shell of ice overlying a subsurface ocean. Courtesy of the Jet Propulsion Laboratory.

Because of the likely existence of liquid water, at least as a transient or intermittent species, life could exist within or below Europa's icy shell. The other requirements for life—access to biogenic elements and access to a source of energy—may be available at the water-rock boundary at the bottom of the water layer.[6] Some researchers have argued against this idea on the grounds that Europa's ocean is a closed system and, therefore, its water would rapidly become chemically reduced as the result of interactions with hot rocks in hydrothermal systems,[7] which would mean that a europan ocean would not be an energetically favorable environment for life. This contrary view has, however, been challenged on the grounds that even if the ocean is reducing, abundant redox chemistry could still take place, providing an energy source for metabolism.[8]

Another possibility is that life exists not in the deep oceanic interior of Europa but near the surface. If this is the case, then the ultimate power source for a europan biosphere may be chemical species created by interactions between the surface ice and energetic particles in the jovian radiation environment.[9] While no evidence for life exists, it is the potential for life that makes Europa an exciting target for further exploration.

The most important questions about Europa include whether liquid water exists and whether it has lubricated the motion of surface blocks seen in the Galileo images. Researchers also seek to learn the composition of the deep interior and the non-icy parts of the surface. The nature of the tectonic processes and the abundance of geochemical energy sources are important as well for learning about the potential for—or the history of—life on Europa.

EUROPA EXPLORATION STRATEGY

The important questions about Europa that are outlined above can be addressed through a series of spacecraft missions that carry out the following key measurements, extracted from the 1999 NRC report by the Committee on Planetary and Lunar Exploration (COMPLEX):[10]

- Measuring Europa's global topography and gravity, and determining how Europa's shape changes as it orbits Jupiter;
- Characterizing Europa's geology and surface composition on a global scale;
- Mapping the thickness of Europa's ice shell and determining the interior structure;
- Distinguishing between any intrinsic europan magnetic field and induction and/or plasma effects; and
- Sampling the geochemical environment of Europa's surface and possible ocean.

COMPLEX concluded that Europa is an exciting object for further study, with the potential for major new discoveries in planetary geology and geophysics, and the potential for studies of extraterrestrial life. In addition, COMPLEX concluded that the results obtained by Galileo (revealing geologically recent or ongoing geologic activity, regarding the possible presence of liquid water, and indicating the potential for present or past biological activity) make Europa a high-priority target for further exploration.

The two highest-priority overall science goals identified in the 1999 report by COMPLEX for Europa exploration reflect the emphasis on the potential for life as a major driver in Europa's exploration. They are the following:

1. Determining whether liquid water has existed in substantial amounts subsequent to the period of planetary formation and differentiation, whether it exists now, and whether any liquid water that is present is globally or locally distributed; and
2. Understanding the chemical evolution that has occurred in the liquid-water environment and the potential for an origin and the possible continued existence of life on Europa.

Even if there turns out to be no life or no sophisticated prebiotic chemistry, these goals remain legitimate drivers for a better understanding of Europa's geologic history.

The particular scientific goals of the first mission are expected to be determination of whether a global ocean of liquid water exists beneath the icy surface, determining, if possible, the spatial and geographical extent of liquid water, determining the bulk composition of the surface material, and characterizing the global geologic history and the nature of any ongoing surface and atmospheric processes. These science objectives can best be met by one or more near-polar-orbiting spacecraft.

EUROPA'S RADIATION ENVIRONMENT

The intense radiation near the surface of Europa is a key factor governing the viability of organisms that might be carried to Europa on spacecraft. Ionizing radiation causes biological effects, such as genetic damage, that result in significant morbidity or death once sufficient damage accumulates. The intensity of the radiation environment in the Jupiter system has been measured by several spacecraft, and its variation with depth below the surface of the ice can be predicted. Accordingly, the rate at which microorganisms with a specified radiation tolerance would succumb in the vicinity of Europa can be determined.

Europa lies deep within the magnetosphere of Jupiter, which is the volume of space above Jupiter's atmosphere that is affected by Jupiter's magnetic field. This magnetosphere extends up to 10 million km from Jupiter (i.e., it encompasses a volume 1,000 times that of the Sun) and is filled with ionizing, magnetically trapped particle radiation. The mechanism of magnetic trapping of radiation at Jupiter is the same as that which operates in Earth's van Allen belts. Jupiter's magnetosphere is, aside from the Sun, the dominant source of energetic charged particles and radio emissions in the solar system.

First discovered as a radio source, the magnetosphere of Jupiter interacts strongly with the innermost Galilean satellite Io, as evidenced by the modulation of decametric radio emissions at the orbital period of Io. The study of Jupiter's decimetric radio emissions led to the first determinations of the approximate strength and direction of the jovian magnetic moment. The first spacecraft visits to Jupiter, in 1973 and 1974 by Pioneer 10 and Pioneer 11, respectively, confirmed the existence of the magnetosphere and revealed its disklike configuration, which rotates approximately with the planet itself. The later visits by Voyager 1 and Voyager 2 in 1979 revealed the importance of Io's plasma torus, a region of sulfur- and oxygen-dominated plasmas maintained by the escape of SO_2 and other S- and O-bearing molecules from Io. The plasma torus mediates the interaction of Io with the jovian magnetosphere. The Ulysses spacecraft also encountered Jupiter in 1992 and explored the high-latitude, dusk-side magnetosphere whose configuration appears to reflect its interaction with the solar wind. The latest spacecraft to explore Jupiter is Galileo, which began its orbital tour in 1995 and has provided detailed measurements of the interactions of the magnetosphere with Jupiter's satellites as well as synoptic views of global dynamics.

Europa orbits Jupiter at a distance of 671,000 km and is continually bombarded by magnetically trapped, ionizing radiation. This magnetospheric particle flux is the dominant component of the radiation environment at Europa. Galactic cosmic radiation and solar particle radiation cannot access Europa because of Jupiter's magnetic field except at energies exceeding ~90 GeV, where fluxes are negligible.

The radiation flux in the vicinity of Europa varies on many time scales. There are fluctuations that can exceed an order of magnitude with magnetospheric activity over times of minutes. Similarly, smaller fluctuations, typically by a factor of less than two, occur with the 11.2-hour synodic Jupiter rotation period as seen by Europa, because of the variations of trapped particle intensities with magnetic latitude (Jupiter's rotational and magnetic axes are misaligned by 10 degrees). Moreover, variations of up to roughly an order of magnitude have been observed over the 25-year time span between the Pioneer spacecraft encounters with Jupiter and the Galileo mission.

Galileo magnetic field and charged-particle data also imply that the radiation environment varies across the surface of Europa, being only one-fifth as high over the leading hemisphere as over the trailing hemisphere. This happens because the ice surface of Europa absorbs trapped particles as magnetic flux tubes drift across the moon from trailing side to leading side (owing to magnetospheric rotation), depleting the particle population on the leading side.

Data on the radiation environment of Europa have been compiled from information gathered by the Pioneer 10 and 11, Voyager 1 and 2, and Galileo missions. Available measurements include electron intensities in the energy range 30 keV to >10 MeV and ion intensities from 30 keV to >100 MeV. Data on ion composition—separation of protons from helium and from ions with atomic number $Z > 6$—are available above about 500 keV/nucleon. These data are input to standard radiation-dose models that calculate the rate of energy deposition versus depth below the target surface.

The results are summarized in Figure 2.3, which shows the radiation dose accumulated at various depths in the europan ice as a function of exposure time. Contributions from jovian electrons, electron bremsstrahlung, and ions are shown. The electron-bremsstrahlung component consists of X rays generated by the high-energy electrons at depth as they are stopped by the target material. The contribution from ions and electrons with energies below 30 keV may safely be ignored even though their energy flux may be significant. This is because particles with such very low energies penetrate Europa's surface to a depth of only about 10 μm for the electrons and even less for the ions.

The units of radiation dose are the rad or the gray (1 rad is 100 erg/g and 1 gray is 1 joule/kg) of energy deposition in the target material. No corrections have been made for the relative biological effectiveness (RBE) of different forms of ionizing radiation, based on the rates of linear energy transfer (LET). In higher organisms, such as humans, it is well established that high-LET radiation (e.g., stopping protons, heavy ions) has a greater biological effect than does low-LET radiation (e.g., electrons and X rays), as reflected by RBE values as high as 20 depending on the specific biological end point. However, no experimentally established RBE values for microbes are available.

Figure 2.3 shows that the radiation environment at 10-cm depth in europan ice is ~5 krad per month. The radiation dose is dominated by electrons and bremsstrahlung over depth values down to approximately 1 meter, below which protons dominate. At greater depths, the radiation environment continues to decrease, reaching values similar to those in Earth's biosphere below depths of 20 to 40 m (not shown). Hence, once microorganisms are transported below a shallow depth at Europa—at most a few tens of meters below the surface—radiation is no longer a significant environmental factor.

For comparison, the natural radiation environment at the surface of Earth gives an average dose of about 0.1 rad per year. The ionizing radiation exposure limits for astronauts are 25 rad per month and 50 rad per year, not to exceed 100 to 400 rad total in a career, depending on age and sex (these are whole-body doses). Many microorganisms tolerate far more radiation; *D. radiodurans*, for instance can grow and reproduce in a 6-krad/hour environment.

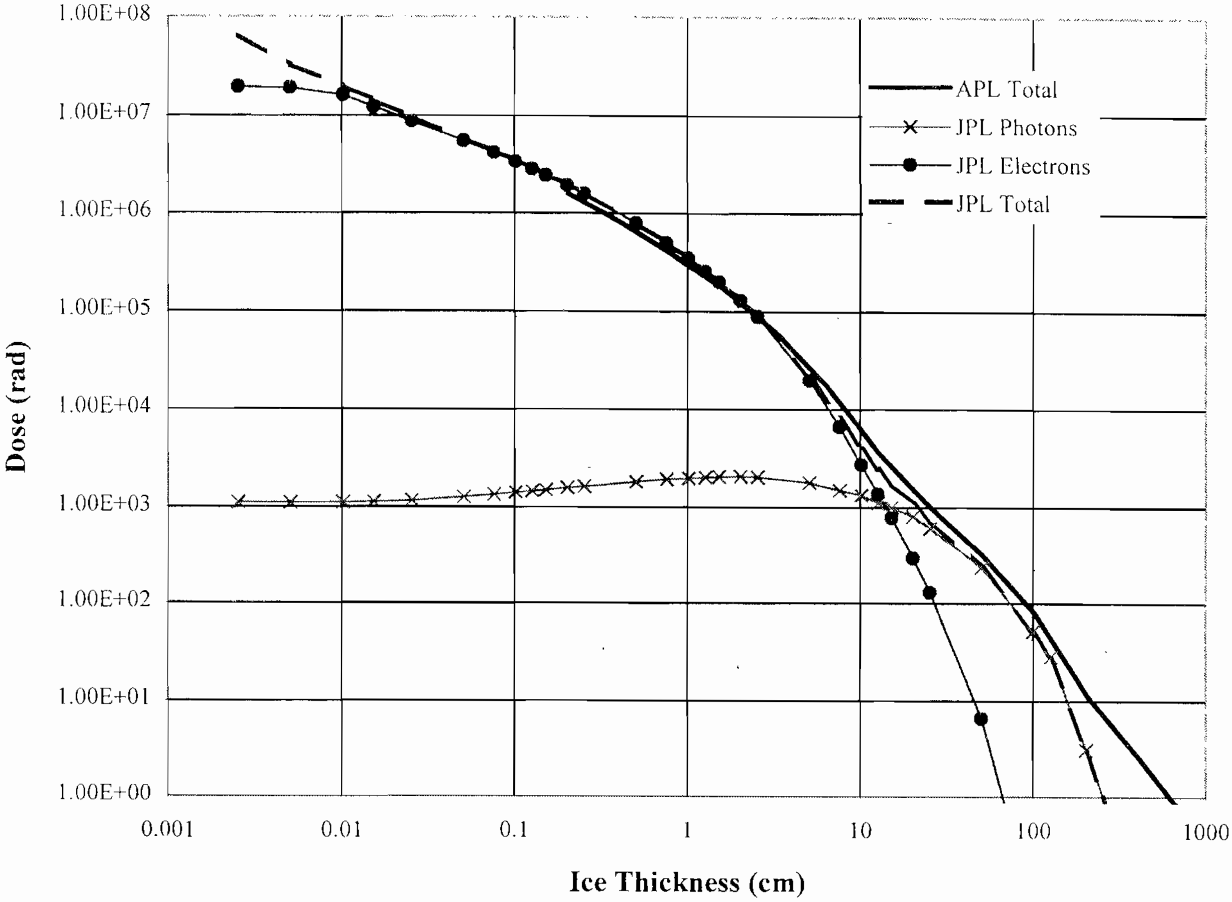

FIGURE 2.3 Radiation dose models for Europa, in rad [water] per month (30.4 days) of exposure below varying thicknesses of ice. The results of two independent evaluations are given, "JPL Total" and "APL Total." For the JPL Total model, the separate contributions of electrons and photons (bremsstrahlung) are shown. The APL Total model has higher proton fluxes at very high energies. In addition to the theoretical uncertainties in Europa's radiation environment (as indicated by the differences between the APL and JPL models), natural variations of up to an order of magnitude have been observed in Jupiter's trapped-particle intensities over the 25-year span between the Pioneer and Galileo missions. Information provided by J.M. Ratliff of the Jet Propulsion Laboratory and C.P. Paranicas of the Applied Physics Laboratory, Johns Hopkins University.

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3
Life in Extreme Environments

A wide variety of extreme environments is known to exist on Earth, including those characterized by, for example, physical conditions such as extreme temperatures and pressures and chemical conditions such as salinity, acidity, or alkalinity. These environments are different from the preferred environment to which we human beings are adapted, yet they are inhabited by organisms that have successfully adapted to them. This chapter discusses some of these organisms, collectively known as extremophiles, and some of the environments they inhabit. Such information can provide insights into the types of terrestrial organisms that might survive and grow on Europa.

EXTREMOPHILES

Extremophiles can be categorized according to the physical characteristics of the environments in which they live. Thus, for example, the thermophiles and barophiles are found in regions characterized by high temperatures and pressures, respectively.[1] The organisms most relevant to an assessment of the probability of the contamination of Europa are those capable of surviving in environments characterized by some combination of low temperatures, high pressures, and a high background radiation.

Psychrophiles and psychrotrophs are types of microorganisms that inhabit cold environments. Psychrophiles have a maximum growth temperature of 20 °C, an optimum growth temperature of 15 °C or lower, and a minimum growth temperature of 0 °C or lower,[2] whereas psychrotrophs have somewhat warmer optimum and maximum growth temperatures. While both are found in many cold environments, only psychrotrophs are found where the temperature can exceed the maximum growth temperature of the psychrophiles in question. In many polar environments, for example, radiant energy can increase the temperature above the maximum growth temperature for psychrophiles, and as a result they expire. This is probably the main reason no psychrophiles are found in the terrestrial portions of Antarctica. Their abnormal susceptibility to warm temperatures means that they are unlikely to be present in a spacecraft-assembly environment and are therefore unlikely to contaminate a spacecraft.

Psychrotrophs, on the other hand, can be found in any environment, and most of the early research on these organisms was carried on by food microbiologists. Various species of psychrotrophs are in well-known genera such as *Pseudomonas, Flavobacterium, Achromobacter, Alcaligenes, Bacillus, Arthrobacter,* and *Vibrio*. Microbial ecologists have found them in most cold environments, even in the harsh desert environments of Antarctica.[3] These organisms can also be found in permafrost as well as in the deeper layers of ice cores, indicating that they have the ability to survive for extremely long periods of time. Laboratory studies indicate that not all species can survive the freezing and thawing process, and many species are killed when frozen, especially if they are in the exponential growth phase.

The best estimate for the minimum temperature of microbial growth is −10 to −12 °C (although there are a few reports of growth at lower temperatures), and this low temperature has been recorded for only a few bacteria. This minimum temperature for growth appears to be determined by the fluidity of cell membranes and the availability of liquid water. If an organism cannot desaturate its membrane lipids, the cellular transport of substrates ceases. The freezing property of the liquid within and immediately adjacent to the cell also comes into play. Either factor can prevent the cell from growing. It is extremely doubtful that any organism can grow at 100 K, but survival remains a possibility at any depth in Europa's ice.

Psychrotrophs may survive at the surface temperatures of Europa, as indicated by current techniques that employ freezing for preserving microbial cells. Europa's geologic conditions may not change significantly for a long period of time and so the microbes might have to stay in this survival state for millions of years. Surviving microbes might have extreme difficulty initiating growth owing to the absence of organic matter for heterotrophic growth and their inability to metabolize at 100 K. The absence of an organic matter energy source does not, however, rule out the possibility of psychrotrophic chemoautotrophic growth if the organism can reach subsurface liquid water.

Barophiles are microorganisms that thrive under conditions of high hydrostatic pressure, and all known examples inhabit marine environments. Europa's ice shell may be 10 to 170 km thick, and thus the pressure in the upper layers of a hypothetical europan ocean would have to be 13 to 210 MPa (130 to 2,100 bars), assuming that the ice has the same density as water. Studies indicate that most organisms cannot grow when the pressure exceeds 60 MPa, and many are indeed killed at that pressure. Known terrestrial organisms could withstand the pressure near the top of Europa's putative ocean, especially if the ice shell is relatively thin. A combination of high pressure and low temperature would, however, decrease the molecular volume of a microbe's macromolecules and would probably bring about its death. For example, *Bacillus subtilis,* one of the indicator organisms currently used to determine the bioload on a spacecraft (see Chapter 5), can survive pressures of 30 MPa provided that the temperature is greater than 20 °C.

Radiation-resistant organisms are of particular relevance to any discussion of the forward contamination of Europa. The bacterium *Deinococcus radiodurans*, for example, can grow continuously, without mutation or any effect on its growth rate, in the presence of 6,000 rad/hr (a dose rate found 1 mm beneath Europa's surface ice).[4] This organism can also survive acute exposures to ionizing radiation of 3 Mrad (at –70 °C) without lethality—a dose that induces about 130 double-strand breaks (DSBs) per chromosome. Furthermore, viable cells are readily recovered from cultures even after exposure to 8 Mrad (at –70 °C).[5] This ability is extraordinary since most cells cannot survive irradiation at more than 500 to 100,000 rad[6] or 1 to 3 DSBs per haploid chromosome.[7] Recent advances have led to insights into this bacterium's exceedingly efficient DNA repair capabilities,[8,9] which have been shown to be partly responsible for its resistance to radiation.[10,11]

Because there are no known radioactive environments that can explain the evolution of *D. radiodurans*'s resistance to radiation, there is general agreement that this organism's resistance to radiation is a secondary characteristic developed in response to some other environmental stress. The consensus view is that the mechanisms that evolved to permit survival in very dry environments also confer resistance to radiation.[12]

It is possible that other desiccation-resistant microorganisms, not yet described as radiation-resistant, could pose a threat to the europan biosphere. Such organisms can only pose a threat if they can survive a multi-year journey to Europa. Despite the discrediting of the oft-repeated claim that live bacteria were recovered from Surveyor 3's camera after surviving on the Moon's surface from April 20, 1967, to November 20, 1969, experiments conducted aboard a variety of spacecraft including the European Retrievable Carrier and the Long Duration Exposure Facility indicate that a variety of common terrestrial bacteria are able to withstand the space environment for periods as long as 6 years.[13,14] Since the radiation-resistance characteristics of many common organisms (and most extremophiles) are unknown, it is conceivable that many bacteria classified as desiccation- and/or radiation-resistant will survive in extraterrestrial environments.

On Europa, life-sustaining, near-surface environments may exist within or under regions of water ice, since ice will provide microbes with some degree of radiation protection. In addition to requiring water in the liquid state, genetic repair would certainly also be dependent on the presence of a source of carbon and energy. There is currently little or no evidence for any organic matter on Europa's surface due to the lack of observable spectral features of CH bonds in Galileo's infrared spectra of Europa. Nevertheless, the presence of carbon in material recycled from the interior via geologic processes or in cometary and meteoritic debris cannot be discounted.[15]

EXTREME ENVIRONMENTS

The ability (or inability) of terrestrial organisms to adapt to, and survive and multiply in, extreme terrestrial environments reveals much about the resilience of life in stressful circumstances. Given that these organisms have had millions of years to come to terms with their particular physical and chemical environments, their ability to cope provides some insight into the problems facing terrestrial organisms suddenly introduced into extraterrestrial environments. Earth's polar regions present two particularly telling examples, the cryptoendolithic environments found in the polar deserts and permafrost.

Antarctic cryptoendolithic environments exist where communities of microorganisms have colonized the surface layers of porous rocks to depths of a few millimeters. Photosynthetic members of the community utilize sunlight that penetrates the translucent rock crust. The ambient air in the Antarctic desert is rarely above 0 °C, but the near-surface regions of rocks exposed to the Sun are warmed by solar radiation. The cryptoendolithic colonies obtain water from snow, which melts when it falls on warm and dry rock surfaces.

The cryptoendolithic environments are good examples of absolute extreme environments, i.e., regions where the physical conditions are beyond adaptability. The organisms colonizing the rocks are not adapted to their environment; they survive by tolerating it. While all metabolic activity occurs at $\sim\pm 10$ °C, the optimum temperatures for organisms, as measured in the laboratory, range from 15 to 25 °C, temperatures rarely reached in the Antarctic. Thus microorganisms in Antarctic rocks live near the lower limits of their physiological potential, and they have no reserves to compensate for changes in the environment, should conditions deteriorate. As a consequence, even a minor change in climate can result in local extinctions. In fact, close to 80 percent of the cryptoendolithic communities in Antarctica are dead or fossilized.[16]

Permafrost microorganisms have been studied most extensively in Siberia[17] and have recently been found in Antarctica.[18] Permafrost microorganisms originate in the soil where they have been immobilized by freezing, while new soil continues to be formed on the surface. In Siberia, the oldest permafrost is 3.5 million to 5 million years old. Recent drilling in Antarctica revealed permafrost some 8 million years old. Permafrost temperatures are extremely stable, around −10 °C in Siberia and down to about −30 °C in Antarctica.

The number of viable bacteria (up to 10 million colony-forming units per gram of dry weight) and the abundance of species found in permafrost decrease with increasing depth (i.e., with increasing age). The viable microbial community in permafrost—mostly psychrotrophs and only very few psychrophiles—is dominated by prokaryotes (organisms whose cells lack a nucleus). Eukaryotic algae (i.e., algae whose cells contain a nucleus) do not survive beyond 5,000 to 7,000 years, but viable yeasts are found in 3 million-year-old permafrost. The composition of bacterial communities found in permafrost mirrors that of the soil from which they originate. Most bacteria isolated from permafrost are aerobes; only a few are anaerobes, mostly methanogens. Permafrost at −10 °C and below is frozen solid. Yet a thin film of unfrozen water envelopes both the inorganic soil particles and microorganisms. The thickness of this unfrozen water film is temperature-dependent and is reduced to about 0.5 nm at −5 °C and below.

In permafrost, microbial growth is in a stationary phase and cell division probably does not occur. This, together with the fact that the number of species decreases with age, suggests that in permafrost a slow selection process takes place, and bacteria that are not able to tolerate the physical conditions of their environment eventually become extinct. In permafrost there is no adaptation, only selection.

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4
Sterilization and Cleaning Methods

The procedures used to ensure spacecraft cleanliness and, ultimately, to achieve the desired sterilization standards begin during the design and manufacturing of spacecraft components. Afterward, when the components are being assembled, further cleaning and sterilization protocols are implemented. Unfortunately, it is not currently practical to sterilize an entire spacecraft at one time, post-assembly, while at the same time protecting all of its diverse components and sensors from damage or failure. The different sensitivities of internal components to sterilizing procedures require that many of the parts be sterilized individually, using a procedure compatible with their function. For complex scientific missions, therefore, whole-spacecraft sterilization is not an option—a single sterilization procedure would be limited by the spacecraft's most sensitive component. As a result of this constraint, many spacecraft components are sterilized individually and then assembled in clean rooms using rigorous procedures that minimize recontamination.

CLEANING AND STERILIZATION STANDARDS

NASA's current planetary protection requirements for Mars missions are derived from the procedures applied to the Viking landers. Missions not carrying life-detection experiments must be cleaned to ensure that the spacecraft's total bioload does not exceed 300,000 spores and that the density of spores on the spacecraft's surfaces does not exceed 300 m^{-2}. Missions with life-detection experiments must undergo additional procedures to ensure that the total bioload does not exceed 30 spores. The effectiveness of the various procedures currently used by NASA and its contractors to meet these bioload standards is determined by the use of reference organisms, including *Bacillus subtilis* (var. *niger)*, *Bacillus pumilis*, and *Bacillus stearothermophilus*. *Bacillus spp.* (endospore formers) were originally selected as a microbiological indicator of sterilization success on the basis of their enhanced resistance to heat, desiccation, and radiation.

ACHIEVING THE STANDARDS

The twofold approach to the control of forward contamination used by the Viking mission—careful cleaning of the spacecraft, followed by active bioload reduction through heat sterilization (see Box 1.1 in Chapter 1)—forms the basis for the procedures currently in use. All missions are carefully cleaned and then those with life-detection experiments undergo sterilization.

The Viking landers were assembled in clean rooms (see Box 4.1 for a description of current clean-room procedures). During assembly, microbial assays (see Chapter 5) were conducted to establish that the average and total burden of spores on the lander's accessible surfaces were 300 m^{-2} and 300,000, respectively.[1] Current practice requires that those parts of the spacecraft not meeting the requisite bioload standards be washed with isopropyl alcohol and/or a sporicide (ethanol, 65 percent; isopropanol, 30 percent; and formaldehyde, 5 percent) to reduce their bioburden. Decontaminated surfaces are then retested for their contaminating microbiological burden.

Once the landers had been assembled and sealed inside their bioshields, the bioload was further reduced by dry heating the whole spacecraft to at least 111.7 °C for some 30 hours. This procedure was credited with reducing the lander's bioburden by a factor of 10^4. Future spacecraft can be designed to maximize accessibility of their components for pre- and post-assembly bioload reduction. However, some components are hermetically sealed before assembly, so cleaning/sterilizing procedures must be conducted before sealing to prevent recontamination. The sterilization procedures commonly applied in a variety of applications to sealed and unsealed components are listed in Table 4.1. It is worth noting that many of these procedures can have negative impacts on spacecraft performance and may increase mission cost.

TABLE 4.1 Common Sterilization Procedures

Procedure—Target	Technique—Problems
Dry heat—exterior/interior	105-180 °C for 1 to 300 hours—Problems caused by thermomechanical incompatibility between materials can lead to the failure of electronic components.
Wet heat—exterior/interior	120-134 °C for 3 to 20 minutes—Problems can be caused by steam (e.g., corrosion and water absorption).
Alcohol wipes—exterior surfaces	Isopropyl or ethyl alcohol swabbing—Problems arise because interior and encased surfaces (e.g., electronic components) are inaccessible.
Ethylene dioxide—exterior/internal exposed surfaces	Toxic gas, 40 to 70 °C—Problems arise because the gas can only reach exposed surfaces and because it is absorbed by some types of polymers (e.g., rubbers and polyvinyl chloride).
Gamma radiation—exterior/subsurface	Typically, 2.5 Mrad—Problems encountered include optical changes in glasses and damage to electronics and solar cells.
Beta radiation—exterior/near-surface	1 to 10 MeV—Problems arise because of limited penetration.
Hydrogen peroxide plasma—exterior/internal exposed surfaces	6 mg/l H_2O_2 concentrated at 58%—Problems can be encountered because the unexposed surfaces remain untreated.
Ultraviolet—exterior surfaces	5,000 to 20,000 J/m^2—Problems arise because unexposed surfaces remain untreated.
Methyl bromide—exterior/internal exposed surfaces	Toxic gas—Problems can be encountered because unexposed surfaces remain untreated and because the gas catalyzes chemical reactions between metal and other components.

These treatments can be highly effective, but they have their limitations in certain circumstances. Important factors influencing germicidal activity include the following: the types of microorganisms; the number of organisms; the intrinsic resistance of the organisms; the amount of organic soil on the item to be sterilized; the type and concentration of germicide; the time and temperature of exposure; and the compatibility between of the device being sterilized and the technique being used.

BOX 4.1 Current Clean-Room Procedures

Clean rooms are highly controlled environments accessible only to trained personnel following strict and unambiguous cleanliness protocols. Representative standard NASA clean-room protocols include the following:

- During assembly, workers are required to wear full face shield suits;
- No human contact directly with spacecraft is permitted. Latex gloves are worn in the clean room, and spacecraft are *not* seeded with tracer organisms to facilitate monitoring;
- Cameras are used to observe and monitor assembly;
- Clean-room air passes through high efficiency particulate air (HEPA) filters and dehumidifiers to minimize airborne microbial contamination and corrosion, respectively;
- Surface particles are removed by vacuuming;
- Witness plates are regularly collected and stored;
- Contact between hardware and biologically relevant materials is minimized; and
- Surface areas of the spacecraft are monitored periodically for their microbiological burden, during and after assembly. Sterile cotton swabs are used to collect contaminating surface microorganisms, which are subsequently cultured and counted.

Unfortunately, clean rooms do not guarantee contamination-free assemblies. Mistakes happen, and clean hardware may not remain clean. Thus, good in-process cleaning procedures are necessary.

REFERENCE

[1] Viking '75 Project, *Pre-launch Analysis of Probability of Planetary Contamination,* Volumes II-A and II-B, M75-155-01 and M75-155-02, Jet Propulsion Laboratory, Pasadena, Calif., 1975.

5
Microbial Detection and Identification

A key aspect of planetary protection is the determination of the bioload on the spacecraft prior to launch. From the Viking era to the present day, the bioload has been monitored by a routine and ongoing procedure that continues until shortly before launch. The monitoring entails swabbing accessible external and internal surfaces of the spacecraft with cotton and then determining the number of culturable bacteria from a known surface area. The standard procedure is to transfer the cells from a swabbed surface to a liquid medium, which is then heat shocked at 80 °C for 8 minutes. The surviving cells are then cultured to determine the number of colony-forming units (cfu). A cfu is defined as a colony on a culture plate (using a standard growth medium) that develops from a cell that survived heat shock.

Although the techniques employed in NASA's planetary protection protocols have remained virtually unchanged for the last 25 years, the methods now available for bioload characterization have changed dramatically thanks to advances in biotechnology. It is now possible to survey with good confidence the microbial diversity on a spacecraft or within its assembly area using explicit molecular criteria. A molecular approach circumvents many of the problems associated with culture-based characterization (e.g., delays caused by the time needed to grow the microbial colonies or by the inability to successfully culture most microbes).

The most established methods are based on selective recovery and sequencing of genes encoding the ribosomal ribonucleic acids (RNA).[1] In addition to new technologies such as high-density deoxyribonucleic acid (DNA) hybridization arrays,[2] refinements of existing molecular methods (e.g., the polymerase chain reaction (PCR)) and analytical methods (e.g., mass spectrometry and immunochemistry) provide improved detection capability using a variety of diagnostic cellular biopolymers, including proteins, lipids, and carbohydrates. A variety of advanced detection methods are now in common use.[3,4] Improvements in the sensitivity and specificity of microbial detection should be incorporated into new assessment standards.

It is important to bear in mind that most DNA-based techniques do not necessarily distinguish between living and dead materials. The preservation of DNA in some noncellular contexts is well known, and DNA bound to surfaces such as clay is resistant to degradation.[5] Nevertheless, other biopolymers, such as RNA and phospholipids, are much less stable and generally degrade rapidly following cell death.[6] For example, reverse transcriptase PCR (RT-PCR) has been used to confirm that microbial populations detected at the DNA level are metabolically active.[7] Also, viable microbes have an intact membrane that contains phospholipids. Cellular enzymes hydrolyze the phosphate group from phospholipids within minutes to hours of cell death.[8] Therefore, determination of the total amount of phospholipid ester-linked fatty acids (PLFA) in a particular sample provides a quantitative measure of the viable or potentially viable biomass.[9] Research is needed to develop other techniques able to discriminate between living and dead material.

Acceptable bioburden standards for spacecraft should consider both total abundance and the presence of specific physiological groups. Standards should be defined that take into account the likelihood of survival during transit from Earth and dispersal following landing or impact. Of concern is the possible transport of viable cells to environments supportive of growth of particular classes of terrestrial organisms.

Among the terrestrial microorganisms of most concern are those deriving all of their carbon and energy requirements from inorganic compounds (the chemolithoautotrophs), since they would be most likely to proliferate in a europan ocean. Given current understanding of Europa, it is not unreasonable to suggest that reduced chemical species (e.g., H_2, HS^-, and Fe^{+2}) might be produced by geothermal processes within an ocean and that oxidized species (e.g., O_2, CO_2, SO_3^-, and SO_4^-) might be transported by geologic activity from the surface to an ocean. A variety of recognized chemoautotrophs are capable of growth using these chemical species as substrates for energy generation and growth.

Represented by Archaea and Bacteria, chemoautotrophs are phylogenetically diverse. Although some lineages are composed solely of chemoautotrophic representatives (e.g., methanogens), others (such as the homoacetogens) are intertwined with heterotrophic lineages and could not be easily recognized by phylogenetic affiliation alone. The identification of these lineages may therefore need to consider the presence of key enzymes or genes required for chemoautotrophic growth. For example, genes encoding enzymes for CO_2 fixation (e.g., ribulose bisphosphate carboxylase or carbon monoxide dehydrogenase) are possible diagnostic targets.

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[3] C.J. Hurst, G.R. Knudsen, M.J. McInerney, M.V. Walter, and L.D. Stetzenbach (eds.), *Manual of Environmental Microbiology,* ASM Press, Washington, D.C., 1996.

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[5] A.J. Alvarez et al., "Amplification of DNA Bound on Clay Minerals," *Molecular Ecology* 7: 775, 1998.

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[7] M.M. Moeseneder et al., "Optimization of Terminal-Restriction Fragment Length Polymorphism Analysis for Complex Marine Bacterioplankton Communities and Comparison with Denaturing Gradient Gel Electrophoresis," *Applied Environmental Microbiology* 65: 3518, 1999.

[8] D.C. White et al., "Determination of the Sedimentary Microbial Biomass by Extractable Lipid Phosphate," *Oecologia* 40: 51, 1979.

[9] D.L. Balkwill et al., "Equivalence of Microbial Biomass Measures Based on Membrane Lipid and Cell Wall Components, Adenosine Triphospate, and Direct Counts in Subsurface Sediments," *Microbial Ecology* 16: 73, 1988.

6
Recommended Planetary Protection Strategy for Europa

The task group considered and discussed the history of planetary protection, the particular characteristics of Europa, and the variety of life on Earth in order to develop a set of requirements for the planetary protection of Europa. Unfortunately, the task group was unable to reach a complete consensus on these requirements. Although a majority of the members did agree on a specific requirement, a rationale, and a proposed procedure for meeting that requirement, two significant independent minority views were also expressed.

This chapter outlines the task group's recommended planetary protection strategy for Europa and goes on to explain the areas of general agreement as well as the points on which the views of the two minority subsets diverged from that of the majority. The consequences of these viewpoints are described along with the arguments pro and con.

The task group is in complete agreement that planetary protection is an important goal for all space missions. Limiting the forward contamination of Europa is necessary to preserve the scientific integrity of future biological studies and to protect any indigenous life forms. NASA has a scientific, moral, and legal responsibility to take this task seriously, even if living up to these responsibilities is costly. The task group is also in complete agreement that the current evidence for the existence of a global ocean is persuasive but not definitive. And, of course, even if there were definitive evidence for an ocean, it would still be premature to assume the presence of indigenous biota on Europa.

PLANETARY PROTECTION STRATEGY FOR EUROPA

Given the uncertainties in our knowledge of the diversity of life on Earth and the recent discoveries of organisms living in extreme environments, the majority of the task group believes that a conservative approach must be taken to protecting the europan environment. Furthermore, since Europa, unlike Mars, may have a global ocean, a viable organism could colonize the entire subsurface via the ocean connection.

Although it is premature to conclude that either an ocean or biota exist on Europa, it is prudent to implement planetary protection procedures that assume the existence of both. In this case, we are obliged to protect the europan environment for an open-ended period, until it can be demonstrated that no oceans or organisms are present. This viewpoint mandates that the bioload on *any* spacecraft sent to Europa must be reduced to such a level that the probability of inadvertent contamination of a europan ocean by viable organisms is very low, either in the next 100 years or at any time in the future.

The task group therefore recommends the following standard: for every mission to Europa, the probability of contaminating a europan ocean with a viable terrestrial organism at any time in the future should be less than 10^{-4} per mission. This standard calls for explicit calculation of the probability of contamination posed by each particular mission. It allows spacecraft designers to take advantage of the bioload reduction that occurs from radiation in the jovian environment (see Chapter 2). The value of 10^{-4} was chosen because of its historical precedents in the planetary protection resolutions issued by COSPAR.[1]

NASA must devise a method for carrying out this calculation. An example of how such a calculation might be done is given in Appendix A. The task group's suggested methodology subdivides the bioload into common microorganisms, spores, radiation-resistant spores, and highly radiation-resistant nonspore microorganisms (e.g., *Deinococcus radiodurans*; see Chapter 3). Assays of the spacecraft and its assembly environment would determine the abundance of these organisms. Multiplying the various survival factors by the probability that an organism will reach the global ocean and grow provides an overall probability that must be less than 10^{-4} in order for a mission to meet this standard.

The task group emphasizes that the sample calculation is intended purely to illustrate a methodology NASA could use to certify that a particular mission meets the 10^{-4} standard. The task group lacks the time, the resources, and the expertise to establish definitive values for each and every parameter considered in the calculation. Instead, the task group has chosen plausible but conservative values for each parameter considered in the calculation. Similarly, it makes no attempt to include either the uncertainties associated with the parameters entering into the calculation or the possibility that some parameters may be correlated. Indeed, the task group explicitly assumes that all factors are independent.

NASA may decide that more detailed calculations and considerations are necessary or that the calculations for a particular mission show that the probability threshold of 10^{-4} is exceeded at some high level of confidence, given the error bars estimated for the various factors. Future studies such as those recommended in Chapter 7 will naturally change the numerical values in the required calculation.

MAJORITY AND MINORITY VIEWPOINTS

The task group was unable to reach complete consensus on a number of issues relevant to determining the appropriate planetary protection requirements for Europa. Two independent minority viewpoints were expressed by two subsets of the task group. Recognizing that reasonable people may disagree on the interpretation of complex scientific issues, the task group presents here the majority viewpoint and both minority viewpoints so that they may be discussed and retained for the historical record.

Applicability of the Current Planetary Protection Strategies to Europa

The first point of disagreement concerned the applicability to Europa of the current approach to planetary protection as recommended in NRC reports, as adopted by NASA, and as ratified by the international scientific community, embodied by COSPAR. According to this approach, the planetary protection measures applicable to a particular spacecraft depend on the type of mission envisioned and the degree to which its destination is of interest to studies of the processes of chemical evolution and/or the origin of life (see Chapter 1). Application of this methodology requires some detailed knowledge about the object to which the spacecraft is being sent.

One minority subgroup expressed the view that the current strategy of protection via categorization is broad enough to be applicable to Europa. Indeed, this approach has already been applied to recommendations for the prevention of back contamination when europan sample are returned to Earth.[2] The implication of this minority view is that the first missions to Europa should be subject to a somewhat augmented version of the protocols currently applied to Mars missions. Thus, orbiters and simple landers would be subject to Viking-level cleaning, while landers with life-detection experiments and/or deep penetrators would be subject to a stricter Viking-level sterilization procedure. Suggested augmentations to the existing cleaning protocols for Mars missions would include assaying for radiation-resistant microbes in addition to spores and the use of molecular-based, cell-detection methods in addition to conventional culturing techniques.

The majority viewpoint is more conservative and argues that Europa must be treated as a special case. The basis for this viewpoint is the current relative ignorance of Europa's possible biology, its possible subsurface ocean—which could allow life to be globally connected—and its possible geologic activity, which may recycle surface material into the ocean on a time scale comparable to the age of the surface, and may also provide a source of chemical energy in the form of organic debris and inorganic substrates entrained from the surface. The majority viewpoint is also based on the possibility that an impacting spacecraft could implant debris sufficiently deep within the ice that it would be protected from radiation.

Survival of Terrestrial Microbes on Europa

The second point of disagreement within the task group concerned the likelihood of the survival and proliferation of a terrestrial organism that might reach a europan ocean (see F_7 in the sample calculation contained in Appendix A).

This minority subset of the task group argued that while it is just conceivable that a terrestrial organism might survive in an oceanic environment on Europa, experience from studies of extreme terrestrial environments suggests that such an organism's ability to grow *and* multiply—the real danger to future scientific studies and, potentially, to the survival of indigenous organisms, if they exist—is indistinguishable from zero.

This second subset asserted that no known terrestrial organisms could survive the successive assaults of cold, aridity, and radiation likely to be experienced in transit from Earth to Europa and then finally proliferate in a saline, oceanic environment under extreme hydrostatic pressure. They believe that the combination of physical and chemical extremes on Europa has no counterpart on Earth, so that no terrestrial organism could have adapted simultaneously to all of them.

Although less than 1 percent of all living species have been characterized to date, both the physiological ecology and the behavior of microbial communities, as well as the environments to which terrestrial microorganisms can adapt, are reasonably well studied. The minority maintained that the known facts are sufficient to form scientifically valid conclusions about the survival and proliferation of terrestrial organisms on Europa.

It argued further that even if organisms that had simultaneously adapted to all the extreme environmental parameters on Europa did exist on Earth, the probability that a spacecraft would be contaminated with significant numbers of these organisms is infinitesimally small. This minority subset would nonetheless be willing to subject future Europa missions of all types to the Viking-level cleaning procedures, so as to significantly reduce their initial bioload.

A majority of the members of the task group did not accept these views. They recommended a more conservative approach and set the probability of proliferation at the relatively small, but finite, value of 10^{-6} (see F_7 in the Appendix A). They argued that prudence is necessary given the variety of life seen in extreme environments on Earth, our ignorance of the extremes of life's adaptability, and our lack of knowledge of the europan ocean. As we learn more, F_7, like the other probability factors discussed in Appendix A, may be updated.

CONCLUSIONS

The majority viewpoint is that a common standard should be set according to which, for every mission to Europa, the probability of contaminating a europan ocean with a viable terrestrial organism at any time in the future should be less than 10^{-4} per mission. NASA would establish the assays and calculations for confirming this figure. The two independent minority viewpoints would both allow future missions to Europa to be governed by the (possibly updated) standards for planetary protection of Mars.

REFERENCES

[1] See, for example, COSPAR, "Resolution 26 COSPAR Position with regard to the Florence Report of its Consultative Group on Potentially Harmful Effects of Space Experiments," Article 5, *COSPAR Information Bulletin* No. 20, 1964, page 26.

[2] Space Studies Board, National Research Council, *Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies*, National Academy Press, Washington, D.C., 1998.

7
Conclusions and Recommendations

As a result of its deliberations, the task group was able to reach the following conclusions on appropriate planetary protection measures for future missions to Europa. All statements express consensus views unless noted otherwise.

1. To meet planetary protection requirements and obligations, each Europa-bound spacecraft must be cleaned, sterilized, and/or subjected to sufficient radiation prior to contact with Europa's surface so that the probability of contaminating a possible europan ocean with a viable terrestrial organism at any time in the future is less than 10^{-4}.[*]

2. Current cleaning and sterilization techniques are satisfactory to meet the needs of future space missions to Europa. These techniques include Viking-derived procedures such as washing surfaces with isopropyl alcohol and/or sporicides and sterilization by dry heating, as well as more modern processes such as sterilization by hydrogen peroxide, assuming that final sterilization is accomplished via exposure of the spacecraft to Europa's radiation environment. The technological drawbacks of current prelaunch sterilization techniques are such that the use of these techniques is likely to increase the complexity and, hence, the cost of a mission.

3. The current culture-based method used to determine the bioload on a spacecraft should be supplemented by screening tests for specific types of extremophiles, such as radiation-resistant organisms.

4. Modern molecular methods, such as those based on the polymerase chain reaction (PCR), may prove to be quicker and more sensitive for detecting and identifying biological contamination than NASA's existing culturing protocols for planetary protection.

Knowledge of the planetary protection requirements for Europa will be enhanced by the data returned from future missions and the continuing analysis of Galileo observations. The task group recommends that, in addition, a series of scientific and technical investigations be conducted to reduce uncertainty in calculating the probability of contaminating Europa as a result of spacecraft missions. These investigations include targeted research in the following areas:

- *Ecology of clean room and spacecraft-assembly areas, with emphasis on extremophiles such as radiation-resistant microbes*—Research on the variety and abundance of such organisms in these areas will allow targeting bioload-reduction techniques to the specific organisms present in these artificial environments.
- *Detailed comparisons of bioload assay methods*—What are the strengths and weaknesses of the various types of molecular-based techniques? Quantitative results should be compared in order to determine which methods can best extend current culturing techniques. Can quick PCR methods replace culture-based assays? Can improved detection techniques be developed to readily distinguish between living and dead organisms?

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[*] Two minority views were expressed by two subsets of the task group. Both would allow future missions to meet (possibly updated versions of) the planetary protection standards currently applied to Mars missions. These minority viewpoints are based on two different arguments. One minority subset argued that the planetary protection provisions for Europa should be broadly consistent with the current practice of categorization based on the type of mission (e.g., flyby, orbiter, or lander) and the degree to which the spacecraft's target is of interest to studies of processes related to chemical evolution. The other minority subgroup argued that studies of the organisms found in extreme terrestrial environments suggest that no known terrestrial organism has a significant probability of surviving and multiplying in a europan ocean. The practical consequence of both of these views is that Europa missions should be subject to essentially the same planetary protection requirements that are currently applied to Mars missions. That is, spacecraft (including orbiters) without biological experiments should be subject to at least Viking-level cleaning, but sterilization is not necessary.

- *Desiccation- and radiation-resistant microbes*—These are the microbes most likely to survive the trip to Europa. What is their abundance, their survivability, and their capacity for growth in possible europan environments?
- *Autotroph detection techniques*—Chemoautotrophs are the terrestrial organisms most likely to colonize a deep ocean on Europa. Since these organisms are not easily cultured, which methods give the most sensitive and reliable estimates of their abundance?
- *Europa's surface environment, and its hydrologic and tectonic cycles*—What are the chemical, thermal, and radiation characteristics of Europa's surface? What are the transport mechanisms and their time scales? Does recycling occur, and on what spatial and temporal scales? Does Europa possess a groundwater or hydrothermal system? These studies may provide information on the locations where contamination is unlikely and the prime locations in which to search for indigenous life.

Appendixes

A
Calculating the Probability of Contamination, P_c

In the main text of this report the task group concluded that for each mission to Europa the probability of contaminating a europan ocean with a viable terrestrial organism at any time in the future should be less than 10^{-4} per mission. The task group offers the following calculation as an example of a methodology NASA can use to certify that a particular mission meets the 10^{-4} standard. The calculation is based on several important assumptions and caveats, including the following:

- The values assigned to individual parameters are not definitive;
- Parameter values are plausible, but err on the side of conservatism;
- No attempt was made to account for uncertainties in the parameters;
- All parameters are assumed to be independent and uncorrelated; and
- The values of particular parameters will change as new information is gathered.

NASA may decide that more detailed calculations and considerations are necessary or that the calculations for a particular mission show that the probability threshold of 10^{-4} is exceeded at some high level of confidence. Whichever the case may be, the onus is on NASA to determine values of the various parameters in the calculation and to certify them as part of the planetary protection plan for each Europa mission.

Expressing the 10^{-4} standard in terms of the delivery of viable organisms to an ocean allows spacecraft designers and mission planners to take advantage of the bioload reduction attributable to the high radiation environment that occurs naturally in transit to Jupiter, in orbit around Jupiter while the spacecraft maneuvers to rendezvous with Europa, in orbit around Europa, and at and near Europa's surface following a controlled or uncontrolled landing. In this context, it is expected that the requirement will be satisfied by meeting a level of bioload reduction prior to launch that depends on the mission plan, with landers or short-lived orbiters requiring a more stringent level of cleanliness than long-lived orbiters.

A SAMPLE METHODOLOGY

The task group suggests that this analysis consider four main types of organisms:

- *Type A*—Typical, common microorganisms of all types (bacteria, fungi, etc.);
- *Type B*—Spores of microorganisms that are known to be resistant to environmental insults (such as desiccation, heat, and radiation);
- *Type C*—Spores that are especially radiation-resistant; and
- *Type D*—Rare but highly radiation-resistant nonspore microorganisms (e.g., *Deinococcus radiodurans*).

The basis for the above categorization is radiation sensitivity. Although each species will have a somewhat different survival response to ionizing radiation, these are the four general categories that can be readily distinguished by straightforward assay protocols.

Calculation of N_{Xs}, the number of organisms of type X that survive to grow in the europan ocean environment, functionally depends on the initial assayed contamination level (bioload) of the spacecraft, expressed as N_{X0} organisms of type X as follows:

$$N_{Xs} = N_{X0}\, F_1\, F_2\, F_3\, F_4\, F_5\, F_6\, F_7.$$

In this equation, the variables F_1 through F_7 reflect the various factors that affect the bioload and the survival and growth of organisms for the Europa mission. These factors are explained in detail below.

If the sum of all N_{X_s} is found to be much less than one, it is known by the Poisson statistic that this sum is equal to the probability of any organism being successful. Hence,

$$P_c = \text{Sum}\ (N_{X_s}) \text{ in the limit of a small value (e.g., } 10^{-4}\text{).}$$

Microbial Populations On Spacecraft

To begin the calculation, it is important to recognize that different classes of organisms are critical to these calculations, and methods must be devised to estimate their abundances. It is assumed that the spacecraft will be cleaned and/or treated to reduce its bioburden of organisms. As a starting point, the current procedures for cleaning and validating a Mars lander that does not carry life-detection experiments will be assumed. Under these procedures, the lander spacecraft is certified to be carrying a total *available* bioload of not more than 300,000 culturable "spores," where the "spores" are defined to be heat-shock-resistant organisms. However, some portions of a Mars spacecraft are solid materials, encapsulated components, and occluded surfaces, and they are not included in the above levels of bioload because they are not "available" for release to the martian environment. For the sake of argument, however, the task group considered a worst-case scenario, in which the long-term corrosive action of ocean water ultimately liberates *all* organisms, wherever they reside. To adjust the estimate of bioload, typical values for surface and buried microbial density on items manufactured inside and outside of controlled environments (e.g., clean rooms) must be taken into account. These values are given in current planetary protection guidelines.[1]

From a series of many thousands of samplings of the Viking landers and subsequent culture studies, information is available on the types of organisms present under clean room assembly conditions. Chemolithoautotrophic organisms were not specifically tested for because at the time, it was widely expected that organic compounds would be present in the martian soil.

The Viking planetary protection studies characterized only the aerobic, mesophilic organisms that grow on trypticase soy agar (TSA) plates. The ratio of total culturable cells to "spores" was found to be quite variable but typically ranged from 3:1 to 60:1.[2] Under present protocols the spacecraft assay is for heat-shock-resistant organisms, presumed to be spores. To be safe, the task group assumed a value of 50 (see the next paragraph) as the factor by which to multiply the number of heat-shock-resistant organisms measured for a given spacecraft to estimate the actual number of organisms that could grow in culture. This value is significantly higher than the average observed. More than 55 percent of the organisms were gram-positive cocci (*Staphylococcus* and *Micrococcus*), characteristic of organisms found in the human body. *Bacillus* organisms accounted for about 24 percent, the *Corynebacterium-Brevibacterium* group accounted for about 15 percent, and *Actinomycetes* and yeasts constituted the remaining few percent.[3]

In studies done on the Surveyor spacecraft before they were sent to the Moon, aerobes outnumbered anaerobes by 5 to 1, both overall and for just the "spore" fraction.[4] Even though autotrophy was not assayed, a search was made for psychrophilic microorganisms, but none were detected on spacecraft surfaces.[5] The factor-of-50 multiplier (see preceding paragraph) takes into account these additional anaerobic microorganisms, which were not assayed in the Viking studies.

In summary, the number of chemolithotrophic organisms on spacecraft is small compared to the number of more common heterotrophs. Since organic compounds may be present in the putative europan ocean, the task group accepts the nominal spacecraft assays that use TSA as the growth medium and assumes them to be indicative of the overall population of organisms that pose a contamination threat.

Type A organisms are all those organisms that are culturable using the standard TSA plating technique. Type B are those known as "spores" in the standard protocol, as determined by their resistance to heat shock. Type C are a subset of Type B and are resistant to higher radiation doses. Type D are a subset of Type A and are also resistant to high radiation doses. To avoid unnecessarily elaborate testing and analysis procedures, the task group suggests that Types C and D be determined by a simple screening test using exposure to ^{60}Co or by some other well-established procedure for dosing with ionizing radiation. The classification criteria suggested at this time are as follows:

- *Type C*—Organisms with 10 percent or greater survival above 0.8 Mrad; and
- *Type D*—Organisms with 10 percent or greater survival above 4.0 Mrad.

For this example, the task group took a level of 10 times the Mars available "spore" bioburden, or 3×10^6 culturable heat-shock-resistant organisms for the total spacecraft bioload, based on typical spacecraft sizes and proportions of high-technology components for which cleanliness precautions are taken during manufacture. For an actual spacecraft, this level will be determined by both assays and careful inventory of nonassayable parts and their mode of manufacture.

In this calculation, starting populations for each type were estimated as follows: Type B was 3×10^6 "spores." Type A was estimated as 50 times that of Type B, based on previous experience in spacecraft assembly areas (see discussion above). Since data on the radiation resistance of spacecraft microbes are not available at this time, Type C was arbitrarily taken as 0.1 percent of Type B and Type D as 0.1 percent of Type A. All of these population values should be determined by actual measurements of the spacecraft microorganisms. As will be seen in this and most examples, the Type D organisms are the largest problem, although all four types must be analyzed.

F_1—Total Number of Cells Relative to Cultured Cells

It is now recognized, through the use of molecular probes, that of the organisms in any given ecological environment, laboratory cultivation is successful for only a very small fraction of those present. Thus, unsuccessful laboratory cultivation does not imply that the organisms are not viable. Indeed, only 0.2 percent to 0.3 percent of the organisms found in sediments and soils can be cultured using current techniques.[6,7] In eutrophic samples of activated sludge, the fraction is not so small,[8,9] but in seawater the fraction of successfully cultivated microorganisms is very small.[10,11] Because a significant component of spacecraft contamination is known to come from soil (the other major component comes from organisms associated with the human body), the task group assumed conservatively that laboratory cultivation underestimates actual microbial abundance by a factor of 1,000, for each type of microbial subpopulation.

F_2—Bioburden Reduction Treatment

This factor accounts for any treatment of the entire spacecraft, after assembly, that reduces bioload. For example, the Viking lander spacecraft were heat treated and the value of bioload reduction was specified to be 10^{-4}. Other approaches would be to expose the spacecraft to penetrating ionizing irradiation to destroy all microorganisms, or to chemicals such as hydrogen peroxide or ethylene oxide gas to kill many surface organisms. For this sample calculation, no special treatments are assumed, so no credit for bioload reduction can be taken and this factor must be set to 1.0.

F_3—Cruise Survival Fraction

During the cruise phase of the journey from Earth to Europa, the spacecraft is exposed to the ultrahigh vacuum and ultraviolet irradiation environment of deep space. However, since spacecraft are generally wrapped in opaque thermal protection blankets, it is only these outermost surfaces that are exposed to ultraviolet irradiation.

Bacterial spores are known to be generally resistant to high vacuum, even for long periods of time. For this reason, no credit is taken for this remediating factor for organisms of Type B and C (i.e., $F_3 = 1.0$). Ordinary vegetative cells, Type A, are often susceptible to inactivation by extreme vacuum, so the task group took a value of 0.1 for the survival of these cells. Type D cells are radiation-resistant vegetative microorganisms, with some species being highly resistant to desiccation and others not. Hence, for Type D cells the task group assumed a survival fraction of 0.5.

F_4—Radiation Survival

A mission to Europa might place a spacecraft in Europa orbit for several weeks before its orbit decayed and the spacecraft impacted Europa's surface. During orbit, and later, on the surface, the spacecraft components and any microorganisms on board could be exposed to up to several megarads of radiation from Jupiter's radiation belts. The longer the spacecraft stayed in orbit, the higher the radiation dose it would receive. Once impact occurred, spacecraft debris would be exposed to radiation on the surface at a dose rate of 10 to 100 Mrad per month (see Figure 2.3 in Chapter 2). Notwithstanding the possibility of some radiation shielding on board the spacecraft or of burial in the Europa surface, it is highly probable that many contaminant microorganisms transported to the surface would ultimately accumulate several megarads of radiation damage.

Microorganisms exhibit exponential declines in survival at high doses of ionizing radiation according to the following relationship:

$$N = N_o \exp(-D/D_o)$$

where N_o = the initial cell number, N = the number of survivors that form colonies, D = the radiation dose, and D_o = the D37 dose (at which 37 percent of the population survives). This equation indicates that increasing the dose by a factor of 10 should reduce the survival of microorganisms by a factor of 22,000.

The survival of the bacterium *Escherichia coli* falls to 0.1 percent at 1×10^5 rad;[12] for *B. subtilis*, it falls to 0.1 percent at 6×10^4 to 3×10^5 rad;[13,14] for *Bacillus pumilus*, at 9×10^5 rad;[15] and for *D. radiodurans*, at 1.8×10^6 rad.[16] The physiologic state of the cells, determined by the nutrient conditions at the time of irradiation, is an important factor in determining radiation resistance. Similarly, the presence of oxygen and water greatly potentiates the effect of ionizing radiation on living systems. In general, dry and/or anoxic cells are much more difficult to inactivate than is a fully hydrated cell growing aerobically. Thus, it should be noted that the nutrient conditions of the test subjects in the studies mentioned above were not equivalent.[17,18,19,20] The reported numbers, therefore, are not absolute—they only reflect a trend of resistance.

The radiation sensitivity of all cell types is increased during rapid, exponential growth. In the exponential growth phase, *D. radiodurans*'s viability falls to less than 0.1 percent after a dose of 1 Mrad. By contrast, during the stationary phase (after the growth nutrients have been depleted) this vegetative bacterium is very much more resistant to radiation. Numerous reports show that in the stationary physiologic state, its D37 is 1.75 Mrad (at 5 to 22 °C). At lower temperatures (–70 °C), the D37 of *D. radiodurans* is even more dramatic: 3.0 Mrad.[21] And, remarkably, it was shown that the bacterium can grow at >6,000 rad per hour without any effect on viability.[22] It should be noted that a combination of radiation-resistant and mildly thermophilic characteristics has been identified in two members of the Deinococcal family, *D. geothermalis* and *D. murrayi*.[23]

Table A.1 presents the current best estimates of the radiation sensitivities that should be assumed for the four types of organism when assessing the effect of exposure to radiation in space. When the predicted survival fraction is below 10^{-10}, no lower value is assumed because of the difficulty of verification in practical laboratory experiments. For Type A and Type B organisms, the survival fractions are purely exponential with dose. For Type C and Type D organisms, there is a significant "shoulder" of high survivability until a pure exponential curve comes into play at higher doses.

TABLE A.1 Radiation Sensitivity of Microorganisms

Dose (Mrad)	Type D	Type C	Type B	Type A
0.1	9.90×10^{-1}	9.00×10^{-1}	3.53×10^{-1}	1.15×10^{-2}
0.3	9.50×10^{-1}	8.00×10^{-1}	4.39×10^{-2}	1.53×10^{-6}
1.0	8.00×10^{-1}	3.63×10^{-2}	3.00×10^{-5}	1.00×10^{-10}
4.0	1.00×10^{-1}	2.30×10^{-9}	1.00×10^{-10}	1.00×10^{-10}
6.0	1.00×10^{-3}	1.00×10^{-10}	1.00×10^{-10}	1.00×10^{-10}
7.0	1.00×10^{-5}	1.00×10^{-10}	1.00×10^{-10}	1.00×10^{-10}
8.0	1.00×10^{-8}	1.00×10^{-10}	1.00×10^{-10}	1.00×10^{-10}

F_5—Probability of Landing at an Active Site

Much of the europan surface is considered geologically young, with some parts showing evidence of relatively recent activity. The factor F_5 represents the likelihood of landing at a geologically active site on the europan surface. Landing at such a site could allow geologic activity to transport some or all of the spacecraft to a depth sufficient to shield it from the sterilizing effect of the surface radiation environments and eventually allow it to reach a europan ocean. Since a lethal radiation dose at a depth of 1 meter below the surface is accumulated in 7,000 years (see factor F_6), F_5 is the probability that the spacecraft will land at a site where burial to a depth of significantly more than 1 meter will occur in less than 7,000 years. Extrusive volcanic activity could bury the spacecraft and protect it against the radiation environment, and the spacecraft, or some of its parts, eventually could be carried to a depth where it could interact with a global ocean.

Assuming an average age of 50 million years, resurfacing models give the probability of activity at any location as on the order of 10^{-3} in 7,000 years.[24] Nonetheless, highly active areas are of particular concern and may cover as much as 10 percent of Europa's surface. Thus, the task group assigned the very conservative value of 0.1 to factor F_5, the probability of landing at a site where activity might bury the spacecraft or a significant part of it within 7,000 years, allowing eventual access to a global ocean.

F_6—Burial Fraction

Once a spacecraft is on the europan surface, the probability of an organism reaching the ocean would depend on the lag time until the spacecraft was buried at depths greater than about 10 meters to totally protect it from radiation. It would also depend on the intrinsic shielding within the spacecraft and the extent to which a portion of the spacecraft was buried into the near surface upon coming into contact with it (e.g., in the case of a crash of an orbiter, or a purposeful penetration by a hard lander). The dose profile within the surface ice is a strong function of depth (approximately, inverse square), as shown in Figure 2.3 in Chapter 2. For example, if a portion of the spacecraft is buried to 10 cm, it will take only 90 years to accumulate 7 Mrad of dose, but if it is buried to 1 meter the time to 7 Mrad will be 7,000 years. For this illustrative calculation, 50 percent of the spacecraft was assumed to be protected by being buried in ice to a depth of 1 meter or more.

F_7—Probability That an Organism Survives and Proliferates

It is the consensus of all members of the task group that the likelihood that some terrestrial organism can survive and proliferate in an arbitrary environment on some other body is intrinsically small. However, because such extreme diversity is found among terrestrial microorganisms, this probability cannot be assumed to be zero. As difficult as it is to make such an estimate, the task group hazarded a guess by considering four factors that are pertinent to the survival and growth of any organism in any environment:

- It must survive the physicochemical properties of all environments to which it is exposed on the way to a final environment in which it can prosper;
- The final environment must provide key nutrients;
- A source of energy that the organism can exploit must be available; and
- The organism must be able to grow and reproduce in the final environment in which these nutrients and energy resources are available.

As is indicated in the following considerations, this probability may well be as low as 10^{-6}. Yet, because every spacecraft possesses a certain bioload, the extremely low probability is not per se sufficient to eliminate a need to maintain cleanliness and to control the bioburden. The task group analyzed this probability by breaking it down into four separate components (subfactors 7a, 7b, 7c, and 7d), each of which must be satisfied for an organism to survive and multiply once it reaches the europan ocean.

F_{7a}—Survivability of Exposure Environments

Other than the correlation between radiation and desiccation resistance, very little is known about the survival of terrestrial organisms in combinations of environmental extremes. Given this lack of information, the task group assumes that the ability to survive in one set of physical and chemical conditions does not predispose an ability to survive in other conditions. The factors relevant to survival on Europa include pH, ionic strength, toxic ions, cold temperatures throughout the ocean, and the high pressures at depth. Organisms that do not lyse or become poisoned in this environment and are psychrotolerant and barotolerant could survive in a dormant state as currents move them to different regions of the hydrosphere. For this calculation, 20 percent of organisms are assumed to survive. This conservative value may need to be revised downward if recent suggestions that both hydrogen peroxide and sulfuric acid are relatively abundant in Europa's surface ice are confirmed.[25,26]

F_{7b}—Availability of Nutrients

Elemental nutrients are needed by organisms to synthesize key biomolecules. Especially important are carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur. Other elements, such as sodium, potassium, chlorine, magnesium, and calcium, are needed to maintain electrolyte balance. Virtually all of these are likely to be available in a salty ocean, in various forms of dissolved compounds or—in some cases—as gases. Trace ions, such as the transition elements needed as enzyme cofactors, are generally present in terrestrial seawater and should be present in a europan ocean. The balance of ions, or the potential nonavailability of some key resource such as phosphorus or nitrogen, could, however, be limiting. Certain molecular nutrients are required by many organisms. The task group took the probability that the entire suite of needed components are present as 50 percent.

F_{7c}—Suitability of Energy Sources

If life already exists on Europa, primary production by chemoautotrophs might support a food web that produces organics and hence contains heterotrophic populations. The task group made a few a priori estimates of the likelihood that an Earth microbe, either heterotrophic or autotrophic, would grow in a novel chemosphere or the likelihood that it would displace indigenous microbiota in a novel biosphere. This lack of fundamental knowledge requires a conservative approach to europan exploration.

Chemolithotrophic microorganisms include both aerobes and anaerobes. Energy sources for aerobic varieties include hydrogen, ammonia, reduced iron, and sulfur. These serve as electron donors for the respiration of oxygen. Anaerobic chemolithotrophs have the capacity to use these same energy sources when there is an appropriate electron-accepting species other than oxygen, such as nitrate, nitrite, or carbon dioxide. Both anaerobes and aerobes are widespread in soils and are therefore expected to be potential contaminants in assembly areas that have unfiltered conduits to outside air.[27] Since anaerobic chemolithotrophs may be more suited to a europan ocean whether or not indigenous biota are present, the task group discussed only this group in more detail.

Although their requirement for an oxygen-free environment for growth would seem to suggest that anaerobes would be less likely contaminants in an assembly area, it has been well documented in numerous studies that viable anaerobic bacteria are present in oxic, well-drained soils.[28,29] Recoverable anaerobes include non-spore-forming autotrophic types such as methanogens as well as many spore-forming varieties, most notably the acetogens. Both methanogens and acetogens have the capacity to grow on molecular hydrogen and carbon dioxide, using these substrates for carbon and energy, yielding either methane or acetate as the main end product of metabolism. In addition, many acetogens also have the capacity to grow heterotrophically. Sulfate reducers combine sulfate salts and reducing species such as molecular hydrogen as an energy source and produce reduced compounds such as elemental sulfur or hydrogen sulfide.

The relative and absolute abundance of anaerobic species has been estimated for a variety of soils using culture-based methods. The task group emphasizes, as discussed above, that these methods have probably greatly underestimated the abundance of most chemolithotrophic populations.[30] For example, a study of autotrophic H_2/CO_2-consuming methanogens showed that the numbers determined by culturing were about an order of magnitude lower than the numbers estimated by direct microscopic examination.[31] Facultative anaerobes generally constitute about 10 percent of the total aerobic population and are several orders of magnitude more common than the obligate anaerobes. In one study of the soil in a beech forest, the concentration of H_2/CO_2-utilizing anaerobes ranged from approximately 10 to 1,000 cells/g. Since these results are culture-based, they are almost certainly significant underestimates.[32]

The task group also noted that people can harbor significant numbers of autotrophs, including methanogens and acetogens, in their gut.[33] Thus, autotrophic anaerobes are anticipated to be common contaminants in most spacecraft assembly environments.

The probability that for any given assembly of organisms found on a spacecraft there will be a species that is capable of utilizing the exact energy couples available in the europan ocean is, of course, small because of the natural diversity of these populations; this factor is taken as 0.001.

F_{7d}—Suitability for Active Growth

Here the task group considered the two most likely growth environments: the rock-water interface at the bottom of an ocean and the water-ice interface at the top of the ocean. At the rocky boundary, rock-water hydrothermal conditions analogous to Earth's deep-sea hydrothermal vents may occur and produce energy couples that can be exploited. However, because of the extreme depth of Europa's ocean (~80 to 170 km) compared to Earth's, which is only a few kilometers deep, the environment will be at a much higher pressure, even given the lower gravitational attraction of this smaller body. To prosper here, organisms would have to be highly barophilic.

Alternatively, psychrophilic organisms might inhabit the water-ice interface just below the surface ice layer, exploiting the reaction of chemically reduced components in the ocean water with oxidized species from the ice surface or utilizing organic or other compounds in the water itself. Such organisms would have to be highly psychrophilic, however, because of the near-freezing temperatures that would prevail.

For this sample calculation, the task group took the likelihood of a suitable organism to be no more than 1 percent of the organisms that are preadapted to the other environmental factors given previously.

Joint Probability for F_7

The four subfactors that make up F_7 are summarized in Table A.2, along with the calculated joint probability.

TABLE A.2 Basis of F_7

Subfactor	Probability
F_{7a} – Survivability of exposure environment	2.0×10^{-1}
F_{7b} – Availability of nutrients	5.0×10^{-1}
F_{7c} – Suitability of energy sources	1.0×10^{-3}
F_{7d} – Suitability for active growth	1.0×10^{-2}
F_7	1.0×10^{-6}

Conclusions from the Illustrative Calculation

The conclusion from this admittedly highly approximate type of calculation are given in Table A.3. They indicate that sterilization of a relatively clean spacecraft by the natural radiation environment can be sufficient to protect the europan ocean environment. The task group notes that the 10^{-4} standard is met if all portions of the spacecraft receive a radiation dose of 7 Mrad. But a 6-Mrad dose would fall far short of being sufficient to achieve the 10^{-4} standard. On the other hand, an 8-Mrad exposure would appear to give extremely favorable results regardless of most other assumptions.

TABLE A.3 Probability of Contamination

	Type D	Type C	Type B	Type A
Number of Culturable Organisms on Spacecraft	1.5×10^{5}	3.0×10^{3}	3.0×10^{6}	1.5×10^{8}
F_1—Total cells/CFUs	1.0×10^{3}	1.0×10^{3}	1.0×10^{3}	1.0×10^{3}
F_2—Bioburden reduction treatment	1.0	1.0	1.0	1.0
F_3—Cruise survival fraction	0.50	1.0	1.0	0.10
F_4—Radiation survival fraction*	1.0×10^{-5}	1.0×10^{-10}	1.0×10^{-10}	1.0×10^{-10}
F_5—Probability of landing at an active site	0.10	0.10	0.10	0.10
F_6—Fraction buried under more than 1 m of ice	0.50	0.50	0.50	0.50
F_7—Probability of survival and proliferation	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}
Product of Factors and Organisms	3.8×10^{-5}	1.5×10^{-11}	1.5×10^{-8}	7.5×10^{-8}
Sum	3.8×10^{-5}			

* Values for 7-Mrad dose

Another conclusion reached from this particular sample analysis is that to meet the requirement that $P_c \leq 10^{-4}$, it will be necessary to do at least one of the following:

1. Demonstrate that no Type C or Type D organisms are on the spacecraft; or
2. Demonstrate that the probability of impacting the surface is less than 10^{-4} for the entire time the spacecraft is in the vicinity of Europa (regardless of whether the spacecraft is operational or not); or
3. Show by probabilistic calculations that the 10^{-4} standard can be met through a combination of spacecraft cleaning, selective and/or whole-spacecraft sterilization, and exposure of the spacecraft to the radiation environment at Europa for a long enough period of time to reduce the bioload to the required level ("near sterilization").

Option 1 is not practical because only a small fraction of microorganisms are culturable. Option 2 may not be possible because of the chaotic perturbations on spacecraft orbits near Europa. Option 3 is achievable using current practices.

Any given mission will need to be individually analyzed. The illustrative calculation presented here indicates that the administration of a dose of at least 7 Mrad to all portions of the spacecraft that have not been previously sterilized and protected from in-flight recontamination is needed to complete sterilization of the most radiation-resistant organisms (Type D). If Type D organisms are present at lower levels than assumed in the example, a lower exposure will be adequate.

To achieve the desired final value, additional approaches could be taken, including the following:

- *Bioburden reduction*—The task group's calculation assumed that no pre-launch sterilization procedures are administered to reduce the bioburden of the spacecraft (i.e., F_2 was assumed to be 1.0). Many technologies could be applied to reduce the bioburden, including heat treatment of the entire spacecraft after cleaning (as was done for Viking), exposure to gaseous chemicals, ultraviolet irradiation of various surfaces, and so forth.
- *Clean-room ecology*—Research to elucidate the populations of organisms in the four categories may show that the assumed number is higher than the number of organisms present in actual assembly conditions for Europa spacecraft.
- *Impact circumstances*—Another factor that could significantly affect the outcome of such calculations are the analyses of how an orbiter spacecraft might impact the surface and to what depths it would be buried. Resurfacing rates at various locations on Europa, and the fractional areas covered, are also highly relevant to this problem.

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B
Glossary

Aerobe—An organism that requires oxygen to grow. See **Anaerobe.**

Anaerobe—An organism with the capacity to grow in the absence of oxygen. See **Aerobe.**

Archaea—Organisms making up one of the three branches on the phylogenetic tree of life. Their cells do not contain a defined nucleus and they are genetically and biochemically distinct from the Bacteria. See **Eukaryotes** and **Bacteria.**

Autotroph—Organisms than can use carbon dioxide as their sole source of carbon. See **Heterotroph.**

Back contamination—The biological contamination of Earth with material returned from another planetary body. See **Forward contamination.**

Bacteria—Organisms making up one of the three branches of the phylogenetic tree of life. Their cells do not contain a defined nucleus and they are genetically and biochemically distinct from the Archaea. See **Eukaryotes** and **Archaea.**

Barophiles—Microorganisms that require high (hundreds of megapascals) hydrostatic pressure for growth.

Bremsstrahlung—Electromagnetic radiation generated when high-energy, charged particles rapidly decelerate during impact with a target.

Cfu (colony-forming unit)—An individual cell that can be grown on a culture plate to form a colony of microorganisms.

Chemoautotroph—Organisms with the ability to synthesize organic nutrients directly from simple inorganic compounds using the energy derived from chemical rather than photochemical reactions.

Chemolithoautotroph—Organisms deriving all of their carbon and energy requirements from inorganic compounds. The "litho" component of the name implies that they derive energy from the oxidation of hydrogen.

Chemosynthesis—The process by which certain organisms use the energy derived from chemical reactions to sustain their metabolism. See **Photosynthesis.**

Cryptoendoliths—Organisms, typically bacteria and lichens, living just below the translucent surfaces of porous rocks found in Antarctica.

DNA (deoxyribonucleic acid)—A polymer of nucleotides connected via a sugar-phosphate backbone. This complex biomolecule encodes genetic information in all terrestrial organisms.

Eukaryotes—Organisms making up one of the three branches on the phylogenetic tree of life. Their characteristic feature is that their cells have a defined nucleus containing most of the organism's DNA. See **Archaea** and **Bacteria.**

Extremophiles—Microorganisms capable of growing under extreme physicochemical conditions such as high temperatures, pressures, and acidity.

Facultative anaerobe—An organism with the capacity to grow in both the presence and the absence of oxygen. See **Aerobe** and **Anaerobe**.

Forward contamination—The biological contamination of an extraterrestrial body by terrestrial organisms inadvertently carried aboard a spacecraft. See **Back contamination**.

Gram-positive bacterium—A bacterium that shows a purple color from Gram's stain procedure. The structure of the bacterium's cell wall determines its ability to retain the dye used in the Gram-stain procedure.

Gray—A measure of radiation exposure defined in terms of the total amount of energy absorbed per unit mass of the absorbing material. One gray is equal to 1 joule of energy deposition per kilogram of the target material. Because the amount of energy absorbed depends on the nature of the target material, the unit is often qualified to indicate the nature of the target. One gray is equal to 100 rad.

Heterotroph—An organism that survives by the ingestion and breakdown of complex organic materials. See **Autotroph**.

Homoacetogen—A bacterium that produces acetate as an end product and can live as both a chemoautotroph (like methanogens) and a chemoheterotroph.

Hydrothermal vents—Springs of hot seawater on the deep ocean floor. They are formed when cold seawater seeps through cracks in the ocean floor, circulates through volcanically heated rock, and returns to the seafloor rich in dissolved minerals.

LET (linear energy transfer)—The energy lost per unit length of path when ionizing radiation passes through a material.

Magnetosphere—The volume of space surrounding a planetary body that is under the dynamical influence of that body's magnetic field.

Methanogen—A prokaryote that produces methane via the reduction of either carbon monoxide or carbon dioxide in an anerobic environment.

Panspermia—A theory suggesting that life on a given planet may have been seeded by life originating on another planetary body.

PCR (polymerase chain reaction)—A relatively quick and sensitive technique used to detect and generate copies of specific DNA fragments. See **DNA**.

Photosynthesis—The process by which certain organisms use the energy derived from sunlight to sustain their metabolism.

Phylogenic—Pertaining to the relationships between different organisms. Such relationships are typically based on comparisons between the DNA sequences of different organisms.

Prokaryotes—Organisms such as the Bacteria and the Archaea whose cells lack a nuclear membrane and other organelles. See **Eukaryote**.

Psychrophiles—Organisms that have a maximum growth temperature of 20 °C, an optimal growth temperature of 15 °C or lower, and a minimum growth temperature of 0 °C or lower.

Psychrotrophs— Organisms that have a maximum growth temperature above some 25 to 30 °C and a minimum growth temperature of 5 °C or lower.

Rad—A measure of radiation exposure defined in terms of the total amount of energy absorbed per unit mass of the absorbing material. One rad is equal to 100 erg of energy deposition per gram of the target material. Because the amount of energy absorbed depends on the nature of the target material, the unit is often qualified to indicate the nature of the target, e.g., 5 krad [water] per month.

Radiation-resistant organisms—Organisms that can survive and grow following acute exposure to radiation.

RBE (relative biological effectiveness)—A numerical factor used to compare the biological effectiveness of different types of ionizing radiation. It is defined as the inverse of the amount of absorbed radiation of a particular type required to produce a given effect relative to the absorbed dose of a reference radiation (e.g., X rays or gamma rays) required to produce the same effect.

RNA (ribonucleic acid)—A polymer of nucleotides connected via a sugar-phosphate backbone. It plays an important role in protein synthesis and other chemical activities in cells.

Stationary phase—The period in the growth of a microbial culture after available nutrients have been depleted and population growth ceases.

Sterilization—A procedure that destroys all living microorganisms, including vegetative forms and spores. In practice, a completely sterile state is rarely achieved.

Thermophiles—Organisms that can survive and grow in high-temperature environments.

TSA (trypticase soy agar)—A solid growth media used to culture microorganisms.