FROM FOSSILS TO ASTROBIOLOGY
From Fossils to Astrobiology
Records of Life on Earth and Search for Extraterrestrial Biosignatures

Edited by

Joseph Seckbach
The Hebrew University of Jerusalem, Israel

and

Maud Walsh
Louisiana State University, Baton Rouge, Louisiana, USA

Springer
# TABLE OF CONTENTS

Foreword/Joseph Seckbach and Maud Walsh ............................. ix

Introduction/A Roadmap to Fata Morgana Wladyslaw Altermann ... xv

List of Authors and Their Addresses ................................. xxix

## GEOLOGY

### PART 1: FOSSILS AND FOSSILIZATION


Disentangling the Microbial Fossil Record in the Barberton Greenstone Belt: A Cautionary Tale [Walsh, M.M. and Westall, F.] .......................................................... 25

Looking Through Windows onto the Earliest History of Life on Earth and Mars [Wacey, D. et al.] ................................. 39


Microfossil Phosphatization and Its Astrobiological Implications [Shuhai Xiao and Schiffbauer, J.D.] ..................... 89

Proterozoic Unicellular and Multicellular Fossils from India and Their Implications [Tewari, V.C.] ................................. 119

### PART 2: STROMATOLITES, MICROBIAL MATS, AND BIOFILMS

Microbial Communities of Stromatolites [Brendan, B.P. et al.] .... 143

Biosedimentological Processes That Produce Hot Spring Sinter Biofabrics: Examples from the Uzon Caldera, Kamchatka Russia [Goin, J.C. and Cady, S.L.] ................................. 159

Cyanobacterial Mat Features Preserved in the Siliciclastic Sedimentary Record: Paleodeserts and Modern Supratidal Flats [Porada, H. and Eriksson, P.G.] ................................. 181

---

1 The editors thank Professor Julian Chela-Flores for his suggestions for sections and chapter arrangements.
Deciphering Fossil Evidence for the Origin of Life and the Origin of Animals: Common Challenges in Different Worlds
[Antcliffe, J. and McLoughlin, N.] ........................................... 211

**BIOLOGY**

**PART 3:**
**TERRESTRIAL MICROBES AS ANALOGS FOR LIFE ELSEWHERE IN THE UNIVERSE**

Microorganisms in the Ancient Terrestrial Subsurface – And in Outer Space? [Stan-Lotter, H. et al.] .......................... 233
Evidence of Ancient Microbial Life in an Impact Structure and Its Implications for Astrobiology:
A Case Study [Hode, T. et al.] ........................................... 249
Endoliths in Terrestrial Arid Environments: Implications for Astrobiology [Stivaletta, N. and Barbieri, R.] .......................... 319
Magnetotactic Bacteria and Their Potential for Terraformation [Ardelean, I.I. et al.] .......................... 335

**PART 4:**
**EVOLUTION AND ASTROBIOLOGY**

Cosmic Life Forms [Grandpierre, A.] .......................... 369

**SPACE SCIENCES**

**PART 5:**
**ASTRONOMICAL AND COSMOLOGICAL CONSIDERATIONS IN ASTROBIOLOGY**

<table>
<thead>
<tr>
<th>Title</th>
<th>Authors</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Big Bang at Time Zero</td>
<td>Bahn, P.R. and Pravdo, S.H.</td>
<td>443</td>
</tr>
<tr>
<td>Molecular Imprints of Reaction Network: Living or Non-living</td>
<td>Matsuno, A.</td>
<td>453</td>
</tr>
<tr>
<td><strong>PART 6:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>THE SEARCH FOR EVIDENCE OF LIFE ON MARS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The ALH84001 Case for Life on Mars</td>
<td>Davila, A.F. et al.</td>
<td>471</td>
</tr>
<tr>
<td>Preservation Windows for Paleobiological Traces in the Mars Geological Record</td>
<td>Fernández-Remolar, D.C. et al.</td>
<td>491</td>
</tr>
<tr>
<td><strong>PART 7:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OUTLOOK AND SUMMARY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summary, Final Comments and Conclusions</td>
<td>Seckbach, J. et al.</td>
<td>515</td>
</tr>
<tr>
<td>Organism Index</td>
<td></td>
<td>521</td>
</tr>
<tr>
<td>Subject Index</td>
<td></td>
<td>523</td>
</tr>
<tr>
<td>Author Index</td>
<td></td>
<td>531</td>
</tr>
</tbody>
</table>
FOREWORD

From Fossils to Astrobiology: Records of Life on Earth and Search for Extra-terrestrial Biosignatures

Astrobiology, the study of life in the universe, draws on many traditional areas of scientific study, including astronomy, chemistry and planetary science. This volume, number 12 in the Cellular Origin, Life in Extreme Habitats and Astrobiology series (published by Springer) focuses on the study of the record of life on planet Earth, which is critical in guiding investigations in the rest of the cosmos, as well the evidence for and likelihood of extraterrestrial life. The 30 contributors to this volume are experts from 16 different countries: Australia; Austria; France; Germany; Hungary; India; Israel; Italy; Japan; Mexico; Norway; Romania; South Africa; Spain; Sweden, United Kingdom; the United States of America.

The editors thank the authors for their contributions and their cooperation during the compilation of this volume. We acknowledge the efforts of many individuals for their careful reviews of the chapters in this volume. Their names are listed in alphabetical order: Wlady Altermann, Peter Bahn, Stefan Bengston, Oliver Botta, Gary Byerly, Zachary Byerly, Jeffrey Chiaranzelli, Brent Christner, Alexandra Davatzes, Stephen Dornbos, J. Peter Gogartner, Jessica Goin, Richard Hugo, Hidrim Idriss, Carolina Keim, Joseph Lambert, Thomas Lindsay, Charles Lineweaver, Andrew Melott, Lori Marino, Harold Morowitz, Jared Morrow, Nora Noffke, Aharon Oren, Mary Parenteau, Russell Shapiro, Giovanni Strazzulla, Jan Toporski, Sergey Tsokolov, Peter Ward, and Frances Westall. We thank Shellie Miller and Maeghan Reese of Louisiana State University for their assistance with organization and proofreading of manuscripts. MMW acknowledges the support of the Louisiana Board of Regents/LaSPACE under the NASA Space Training Grant award NNG05GH22H.

Joseph Seckbach
Hebrew University of Jerusalem
Jerusalem, Israel

Maud M. Walsh
Louisiana State University
Baton Rouge, LA, USA

June 21, 2008
Biodata of Joseph Seckbach, editor of this volume and author of “Foreword” (both with M.M. Walsh) and the author with other coauthors of the “Summary and Outlook”

Professor Joseph Seckbach is the founder and chief editor of Cellular Origins, Life in Extreme Habitats and Astrobiology (COLE) book series. See: www.springer.com/series/5775. He is the author of several chapters in this series. Dr. Seckbach earned his Ph.D. from the University of Chicago, Chicago, IL (1965) and spent his post-doctoral years in the Division of Biology at Caltech (Pasadena, CA). Then he headed at the University of California at Los Angeles (UCLA) a team for searching for extraterrestrial life. He has been appointed to the faculty of the Hebrew University (Jerusalem, Israel) performed algal research and taught biological courses until his retirement. He spent his sabbatical periods in Tübingen (Germany), UCLA and Harvard University, and served at Louisiana State University (LSU) (1997/1998) as the first selected occupant of the John P. Laborde endowed Chair for the Louisiana Sea Grant and Technology transfer, and as a visiting Professor in the Department of Life Sciences at LSU (Baton Rouge, LA). Recently (2006) he spent three months in Ludwig Maximilians University in Munich with a DAAD fellowship from the German service of exchange academicians, where several forward steps of this volume have been performed.

Among his publications are books, scientific articles concerning plant ferritin (phytoferritin), cellular evolution, acidothermophilic algae, and life in extreme environments. He also edited and translated several popular books. Dr. Seckbach is the co-author (with R. Ikan) of the Chemistry Lexicon (1991, 1999) and other volumes, such as co-editor for the Proceeding of Endocytobiology VII Conference (Freiburg, Germany, 1998) and the Proceedings of Algae and Extreme Environments meeting (Trebon, Czech Republic, 2000); see: http://www.schweizerbart.de/pubs/books/bo/novahedwig-051012300-desc.ht). His new volume entitled Divine Action and Natural Selection: Science, Faith, and Evolution, has been edited with Richard Gordon and published by World Scientific Publishing Company. His recent interest is in the field of enigmatic microorganisms and life in extreme environments.

E-mail: seckbach@huji.ac.il
Biodata of Wladyslaw Altermann, author of “From Fossils to Astrobiology – A Roadmap to Fata Morgana?”

**Professor Wladyslaw (Wlady) Altermann**, obtained the Diploma (M.Sc.) in Geology and Paleontology in 1983 and the Dr. *rer. nat.* degree in 1988, from the Free University of Berlin. He spent several years of research at the University of Stellenbosch, R. South Africa; at the Center for the Studies of the Evolution of Life, University of California, Los Angeles; and at the Centre Biophysique Moléculaire, CNRS, Orléans, France. In 1998 he received the Dr. *rer. nat. habil.* degree and the *venia legendi* in geology and sedimentology from the Ludwig-Maximilians University of Munich (LMU), where he is currently serving as geology professor. Dr. Altermann is interested in all aspects of Precambrian sedimentology and biogeology and of biosedimentary processes and habitats of early life on Earth. His interests also extend to sediment-hosted mineral deposits, geochemistry, and geological remote sensing. Wlady Altermann has participated in research projects and fieldwork around the world, from Australia to South America, Southeast Asia, India, and China. He currently holds an Honorary Professorship in Geology at the University of Pretoria, R.S.A., and at the Shandong University of Science and Technology, in Huangdao, Quing Dao, P.R. China.

E-mail: wlady.altermann@iaag.geo.uni-muenchen.de
1. Introduction

Joseph Seckbach, the editor of the present book series, invited me to write the introduction to “From Fossils to Astrobiology” during his 3 months visit to my Institute at the Ludwig-Maximilians-University under the fellowship of DAAD (German Academic Exchange Foundation) in 2006. Of course I felt honoured by his choice, but being sceptical towards the youngest and most multidisciplinary, flourishing and extremely fascinating of all science disciplines, astrobiology, I was also somewhat uncomfortable. Now, after extensive literature research and while writing, I realise how courageous it was of Joseph to entrust a notorious sceptic, like myself, with this work. I took up the challenge because I liked the idea of writing an introduction to a book on “Fossils and Astrobiology” as an essay, not necessarily complying with strict scientific rules and the dictatorship of a peer review process, but rather expressing a personal “qualified point of view” of a concerned scientist. I was eager to demonstrate the low chance for success of the endeavour to find extraterrestrial life. For me, a lot of fantasy and wishful, model driven thinking is associated with this new science discipline. The cases of reporting of Martian fossils and carbonates are good examples of how desire may influence scientific investigations.

It has always been a dream of mankind to find extraterrestrial life, intelligent life, of course, technically much more advanced than our civilisation, so we can learn from the aliens, discuss and explain our religious believes and perhaps demonstrate our religious and moral superiority. Next to these Hollywood-inspiring dreams, some researchers in astrobiology hunt for the evidence that terrestrial life has been introduced to the Earth from the infinite cosmos, riding on meteorites, comets and smaller impactors. The hypothetical proof of the theory of Panspermia, however, clearly will not explain any of the intriguing questions of the origin of life and its physical and chemical circumstances, but only
shift the problems to different unknown and less readily explicable environments. As an astrobiology-agnostic and scientist, I find the rise of expectations and promises suggested by astrobiology in the society alarming. They almost compel the researchers involved to turn up with positive, extraordinary results, in justification of the investments made in astrobiology. There can not be, however, compulsion for spectacular results when objectivity of interpretations is expected in science.

Astrobiology has been extremely successful in uncovering extraterrestrial environments and contributing to the knowledge of the history of the early Earth and life. This contribution over the last dozen of years is tremendous and fills almost uncountable pages of highly cited international astrobiology journals, volumes of conference abstracts and scientific and popular science books. Nevertheless, the young multidisciplinary science, especially when combined with paleobiology, Precambrian geology and geochemistry (the fossil aspect), requires humble and modest reports and should prescind from the temptation to impress with fast and spectacular shots and boulevard-type result reporting. Spectacular, extraordinary research interpretations need critical evaluation and extraordinary proof because of the difficulty in interpretation of indirect observations and measurements of events and environments extremely remote in time and distance. Fallacies, like P. Lowell’s observation of a network of canals on Mars and their interpretation as evidence of advanced Martian civilisation more than a century ago are easily possible also with technically advanced, modern scientific equipment, allowing us to explore new, hitherto unreachable dimensions down to atomic scale and up to unimaginable distances in time and space.

2. What Is Astrobiology?

Astrobiology – a discipline fascinating and stimulating our thoughts but also being disparaged as “the science without an object” to investigate and thus illusive. If there is no life out there or it is too remote to be proven, astrobiology may be an expensive road to a fata morgana. However, astrobiology has undoubtedly boosted the research in Precambrian geology and paleobiology, biogeology, planetary geology, geochemistry, microbiology, and many other scientific disciplines, mediating between them and molecular biology, astrophysics, astronomy, oceanography and bringing together scientists that rarely spoke to each other before. These disciplines experienced a revitalising injection of funding that allowed them to combine forces and develop new research techniques, appoint many young and enthusiastic scientists, and turn up with intriguing results. These results and the pledge to find new worlds and perhaps extraterrestrial life brought astrobiology into the centre of public interest and called for ethical, philosophical and even religious assessment of this science.

Many respected scientific societies like the International Society of the Origin of Life (ISSOL) that has recently extended its name to “ISSOL – the International Astrobiology Society” or the SETI program (Search for
Extraterrestrial Intelligence) are very successful in mobilising researchers worldwide. Panels and commissions of scientists, politicians and social and religious activist have been set up to plan for the case of the discovery of extraterrestrial life or even possible contacts to extraterrestrial intelligence. Such panels not only prepare the necessary emergency plans against contamination of terrestrial and extraterrestrial environments, but also speculate on the possible impact on the society of such discoveries. All these activities are in spite of the hitherto absolute lack of any biological object or any, even equivocal, sign for life from outside of the physical boundaries of our planet Earth.

So, if astrobiology has no extraterrestrial biological objects to study, what is it exploring? According to the National Aeronautics and Space Administration (NASA) web page (2007) http://astrobiology.arc.nasa.gov/, “Astrobiology is the study of life in the universe. It investigates the origin, evolution, distribution, and future of life on Earth and the search for life beyond Earth. Astrobiology addresses three fundamental questions: How does life begin and evolve? Is there life beyond Earth and how can we detect it? What is the future of life on Earth and the universe?” – This is truly a universal subject of investigations, particularly when we consider the difficulties in the definition of life, despite of hundreds of years of research of life and living objects, and more than 60 years after Schrödinger’s, 1944 book “What is Life?”. Next to alleged extraterrestrial life and its fossilised remains hidden in the endless space, the above universal definition of astrobiology embraces all life sciences and all studies of terrestrial life. The major questions asked by this science, but especially the one on the future of life, require a truly prophetic capacity far beyond any responsibility and specialisation of natural sciences. They open ample space to unwholesome suppositions and religious disputes. In my atheistic opinion, however, astrobiology should be strictly restricted to natural sciences.

The dictum and the title of the present book “From Fossils to Astrobiology” demarcates a logical scientific philosophy for the search of extraterrestrial life. It follows the assumption that life in different worlds, on other planets, should obey the same chemical and physical rules as life on Earth. It must have evolved under conditions similar to those that prevailed on the early Earth and are witnessed by the oldest fossils and the environments recorded in rocks where these fossils are found. Like life on Earth, extraterrestrial life must be based on the reactivity and chemical properties of water, carbon and other crucial elements like nitrogen, phosphorus, iron, oxygen and few others. Thus, in order to set off through chemical reactions and thrive, extraterrestrial life also requires an environment of temperatures roughly between zero and few tens of degrees Celsius, although life on Earth can survive temperatures far beyond these boundaries. It also requires a rocky, silicate-oxide based environment, providing nutrients, a stable sources of energy, and shelter from extreme fluctuations of temperature and pressure and from damaging short wave radiation. From our knowledge of the life on Earth, we expect that within such conditions the emerging extraterrestrial life will undergo some kind of evolution, thus gradually changing its environment via its
metabolic products, just like it did on Earth. Actually, this expectation brings us to a new search strategy: Instead of directly searching for extant or fossilised organisms, extremely difficult to recognise from the distance, metabolic products of life and their environmental influence on the planets are sought.

Extraterrestrial life, therefore, is most likely to be found on planetary bodies with chemo-physical conditions similar to those prevailing on Earth during its long, 4.6 billion years of history. The second strategy of astrobiology appears thus logical: Life on Earth emerged under the conditions of the young Archean Earth, before 3.5 billion years ago, under presumably reducing atmosphere, perhaps elevated temperatures and oceans of different chemistry than today. Such conditions may prevail on other planets. It is therefore crucial to investigate the Precambrian Earth as a possible analogue to habitats of putative extraterrestrial life. A logical consequence from this strategy is that such planets could *vice versa* serve as analogues of the earliest conditions of the Hadean Earth, not preserved in the geologic record. The Earth is a dynamic planet driven by the internal forces as expressed through the plate tectonics, which are destructive to old rocks and preservation of organic matter. On planets devoid of plate tectonics, the chance of preservation of the very early steps of planetary evolution or perhaps even of the very first steps of genesis of life might be significantly higher than on Earth. But will such planets be akin enough to the Earth to offer conditions suitable for life, and will life have a chance to develop there?

3. Where To Search?

The above discussed conditions for the genesis and survival of life limit the seemingly endless number of candidates for a fertile environment in the Universe. Even if we take into account the myriads of stars in remote galaxies (which we will never be able to explore or to communicate with), planetary systems like our Sun and its satellites seem to be extremely rare. The chance to find a planet just like the Earth seems just a mathematical illusion, barren of any degree of certainty.

Some time ago, I was speculating together with Roger Buick, one of the Editors of the journal “Geobiology” and a supreme Precambrian geologist and geobiologist, about the “ten reasons why life probably evolved only on Earth”. Equipped with the excellent Bavarian Augustiner beer brewed since AD 1294, sitting in a traditional nineteenth century pub in Munich, we were certain that life elsewhere must obey the same physical and chemical laws as on Earth and thus the factors listed above, such as solution chemistry (free availability and abundance of water, C, H; O; N; P; Fe; S ...), temperature boundaries and bearable energy levels) were among our primary preconditions for the genesis of life. Further requirements in our discussion were gravity conditions similar to those on Earth, proportionally similar distance of the given planet to its star, cyclic changes of environment caused by orbital forcing and climatic fluctuation. To these necessities can be added an efficient shield from UV and cosmic radiation, sufficient atmospheric pressure, long
term equilibrium of planets internal and external energy budget (the lower luminosity of our Sun in the early Archean was buffered by Earth’s higher energy flux and greenhouse gases), and last but not least, the necessary interplay of the right proportions of these preconditions, just as it was on the Archean Earth. Many of the above conditions are influenced by the internal dynamo and consequently by plate tectonic processes that regulate the energy budget of the Earth and allow geochemical cycles to operate. Plate tectonics significantly influenced the early atmospheric composition through degassing processes. Of course, the above requirements followed from life as we know it. We were wondering whether we would be able to recognise life if it is dramatically different.

Reaching out to other stars appears not very realistic considering the distances to overcome. Nevertheless, astronomers have discovered several stars orbited by planetary bodies and each of these discoveries (over 200 exoplanets since 1995) has been announced in the media as a possible site for life and as an “Earth-like” body. Exoplanets are discovered mainly by observation of a periodic shift in wavelength of a star caused by the gravitational pull of the invisible orbiting planet or by observing a periodical slight decrease in light intensity of a star when an orbiting planet passes in front of it. As far as researchers can say, all up to now discovered planets are gas giants composed mostly of hydrogen and helium, similar to Jupiter or Saturn. Only in April 2007, a newly discovered exoplanet was reported as “Earth-like” (Udry et al., 2007) and a possibly habitable “oasis in space”. On a closer reading, however, it turns out that this possibly rocky planet of the mass of five times that of the Earth is orbiting the cold red dwarf, Gliese 581, in a distance of 10.7 million kilometres, which is just 0.07 Astronomical Units (AU = the distance between the Sun and the Earth). Every orbit is completed in 13 days (Schilling, 2007). Although modelling implies that giant rocky planets of five to ten times the mass of the Earth (often dubbed “Super-Earth”) would inevitably have plate tectonics (Valencia et al., 2007), such planets can be called anything not “Earth-like”. Nonetheless, it seems likely that with improved instruments and new spacecraft missions, eventually, somewhere an Earth-like planet will be discovered in the universe. Certainly, the speculations about its possible biology will be outmost.

Carbon and water are abundant in space. Carbonaceous matter in varying molecular forms, ranging from amorphous carbon, polycyclic aromatic hydrocarbons, to fullerenes is present in interstellar dust, meteorites and comets. H\textsubscript{2}O, N, H and C-O compounds are ingredients of comets. Aminoacids and other prebiotic organic molecules have been detected in meteorites. Iron and sulphur are equally universally present, but all extraterrestrial bodies investigated up to date turned out to be sterile, although for some, like our neighbour planet Mars, big hopes for discovery of life still exist.

The above considerations make the genesis of life on other planets than Earth barely probable, but the universal adaptation ability of life to extreme conditions makes it possible that terrestrial life could survive on other planets. That allows for science-fiction scenarios of colonialized planetary bodies and thus,
literature on “Directed Panspermia”, “Planetary Engineering” and the “Ethics of Terraforming” is profuse (e.g. Sagan, 1973; Friedmann et al., 1993; York, 2007, and many others). Experiments in which primitive life and its molecules are exposed to cosmic radiation on mineral shielded panels, carried on board of satellites, seemingly demonstrate that life could survive and travel in space. However, over long time cosmic radiation and other space conditions during such an interplanetary journey and the shock of an impact would certainly eradicate any living cell. “Lithopanspermia” experiments in which dry layers of biological test materials like bacterial endospores, endolithic cyanobacteria or lichens are sandwiched between gabbro discs and impact shock pressures are simulated, apparently determining the ability of the organisms to survive the harsh conditions (Horneck et al., 2008), indeed barely reflect the whole range of realistic circumstances and processes of an asteroid to planet collision and meteoritic interplanetary travel and impact. For this reason Panspermia both ways is not an option.

Despite of this unlikelihood, the most probable candidates for life (and colonization) within our Solar system would be our neighbour planetary bodies Mars and although very improbable, the Jovian moon Europa (next to Io, Ganymede, and Callisto) and Saturn’s largest moon, Titan. However, all these moons are tidally locked to their central planets and their energy balance depends rather on their distance to the Jupiter and Saturn than on their mass and distance to the Sun. Even if microbial life could survive the conditions of Mars, Europa or Titan, survival still is a big difference to the possibility of life’s genesis.

The best of the above candidates for extraterrestrial life is the planet Mars. Our direct neighbour, the fourth planet from the Sun, more closely resembles the Earth than any other planet. The Martian day has a length of 24.6 hours and the Martian year a length of 669 days. The distance from the Sun ranges between 206 and 249 million kilometres. Mars has about half the diameter of the Earth’s diameter and about 1/3rd of Earth gravity. Martian surface temperatures range between −125°C and + 25°C and the atmosphere contains about 95% of carbon dioxide next to 3% nitrogen, 1.5% argon and traces of water, with a surface atmospheric pressure of about 6 mb on average. It would be an interesting experiment to implement some bacterial strains on Mars and closely watch their fate after liberation.

Water on Mars must have been abundant during the early period of this planet’s history, the Noachian (c.4,500 to 3,500 million years ago). Some argue however, that liquid CO₂ has formed the suspicious drainage landscapes of Mars. Nevertheless, preference for liquid water is mounting and there are good hints for episodic, minor water flows expelled from the subsurface throughout the post-Noachian (Hysperian and Amazonian) history of Mars (Fig. 1). It is controversial whether the Noachian occurrence of liquid water was conditional on the dense Martian atmosphere and the atmospheric greenhouse effect and lasted for millions of years or if it was only episodic, following enhanced volcanic activity or subsequent to giant meteorite impacts. Most interpretations postulate an ocean covering the Martian Northern Plains, about one third of the planets surface, during the Noachian. Remote sensing
images from the various Mars orbiters clearly show ancient coastlines. The Martian rovers have found mounting evidence for water-lain sedimentary rocks on Mars. However, the laterally continuous shorelines of the postulated Martian ocean show large topographic fluctuations, on an order of more than 2.5 km difference in elevation. This has been discussed as the result of deformation of the ancient coastlines after the loss of the oceans. Because of its small size and mass the internal dynamo of Mars was shut down early in the planet’s history and led to the loss of the protective magnetic shield and to ionic erosion of Martian atmosphere by solar winds and made surface life on Mars impossible. The unweathered Noachian-Hysperian “olivine fields” (Hoefen et al., 2003) evidence thin and dry atmosphere since the Hysperian. However, if life existed on Mars during the Noachian, it might have migrated to the subsurface that still probably bears frozen water and to the ice-capped Martian polar regions.

4. What To Search For?

The search for life on Mars concentrates simultaneously on several strategies. The search for suitable habitats is mainly focused on the search for water and carbonate rocks. Carbonate sedimentary rocks on Earth that date from the early
Precambrian are biogenic precipitates and contain organo-sedimentary structures – stromatolites. Thus finding carbonates on the bottom of ancient Martian lakes and oceans or in Martian soil would be a good hint for ancient life. However, organic substances and metabolic products of life were directly searched for with negative results.

A pioneering direct approach to detection of biological activity was the 1975/76 Viking mission to Mars. The two Viking landers were equipped with a gas chromatograph mass spectrometer (GCMS) constructed to identify organic molecules in the Mars soil. However, no such molecules were found. Another experiment carried on board of the two landers was the Labelled Release (LR) life detection experiment designed to stir some Martian soil with a carried nutrient solution containing radioactive $^{14}$C. It was envisaged that any living organism in the soil would digest the radioactively labelled carbon rich solution and release $^{14}$C rich gas, as the organism metabolised the nutrients. In both Viking experiments, $^{14}$C labelled gas was indeed detected but the results were discarded because no organic molecules were detected. It was assumed that the measured gas must thus have been released by an abiotic reaction with some unknown oxidant. The designers of this experiment, however, claim until today that their experiment has possibly found life on Mars, but the GCMS experiment missed the organic molecules. There is evidence for magnetic minerals in Martian soil, which could not last in the presence of strong oxidants because magnetic iron minerals would be turned into oxidised forms. Thus, they argue that in the absence of oxidants, the measured gas must have been produced by biological activity.

The fast loss of water on the surface of Mars also has important geochemical implications. It has been long assumed that the fast evaporation of Mars' oceans and lakes must have left a widespread crust of carbonate rocks on the planet surface. The CO$_2$-rich Martian atmosphere must have reacted with the rocks and liberated abundant Ca from Martian basalts. These calcium should have been left over on the surface when the oceans disappeared. From the 1980s on, a plethora of articles speculating on Martian carbonates was published. Eventually, Bandfield et al. (2003), in a paper in Science, identified carbonate minerals in the Martian dust by Thermal Emission Spectrometer (TES) orbiting the planet. These findings had tremendous implications, as on Earth carbonate rocks are clear evidence for biological activity and thus analogously, the images of possible Martian stromatolites and microbial deposits seemed an edge breaking discovery. However, some researcher did not “buy the story” for simple technical reasons.

Spectral analyses from the orbit do not detect minerals but measure radiance, which is then interpreted based on comparisons to terrestrial standards. The identification of 2–3 wt% carbonate minerals in the Martian dust, with calculated particle sizes of $<10 \mu$m, was based on comparison of the Martian emissivity bands to laboratory spectra of labradorite standards. In general, the emissivity depends on the chemical composition of the dust or rock, mineral mixture, crystal orientation, grain size distribution and surface roughness, at that time all unknowns in the Martian soil. For the quantification of the spectral signatures of
minerals of up to 2–5% weight, the sensitivity of the sensor and the calculated particle size are essential; however, detection limits of TES for carbonate concentrations in weight percent were poorly specified. Earlier work by Bandfield et al. (2000) specified detection limits for the Martian TES spectra of 10–15 vol%. The comparison of TES and laboratory spectra is only possible at the same spectral and radiometric resolution for accurate definition of the position and spectral contrast of emissivity minima, not characterised in the report by Bandfield et al. (2003). Particle sizes and the concentration of mineral mixtures are important for the spectral response in the Thermal Infra Red (TIR). Particle sizes \( \leq 63 \mu m \) were used for the calculations, although the high albedo surfaces on Mars were considered \( \leq 10 \mu m \) particle size. The spectral bands \( (>1,350 \text{ cm}^{-1}) \) thus did not necessarily indicate non-hydrous carbonates, as were believed to have been detected. Particle sizes \(<5 \mu m \) are responsible for spectral differences in the wavelength regions of \(<10 \mu m \), due to the combination of surface and volume scattering effects, hence, the quantification of the presented spectra was ambiguous as well. All criticism, however, was in vein and our attempt of publication of this discussion was rejected (Altermann et al., 2004).

Thus far the extremely successful and long operating Mars Exploration Rover missions that landed in January 2004 has not encountered carbonate rocks. The Opportunity Rover that landed in the Gusev impact-crater, a former lake, discovered fields of small haematitic concretions dubbed “blueberries”, probably formed in the presence of water and rocks composed of up to 40% evaporitic sulphate minerals instead of carbonates. The presence of sulphates indicates that the climate of the Noachian Mars was influenced by SO\(_2\), where dilute sulphuric acids must have formed and prevented the precipitation of carbonates (even at traces of 0.1% of SO\(_2\) in the atmosphere). A whole different story of the Martian atmosphere was revealed calling for caution with model driven thinking.

Carbonate minerals were also reported from the famous Martian meteorite ALH 84001. In tiny microscopic cracks in this meteorite, carbonate minerals were found and reported as “globules” and veinlets, filling fractures. However, the morphology of these carbonate “globules” is that of discs, as can be expected in cracks, and not globular. A Rb-Sr age of 3.9 ± 0.04 billion years (Ga) and an Pb-Pb age of 4.04 ± 0.1 Ga were measured on leachates from a 1.0 g chip containing c.5% carbonate (Borg et al., 1999) from these veinlets. On the other hand, a Rb-Sr 1.39 ± 0.10 Ga age on shock melted feldspathic glass and carbonate, thought to be in isotopic equilibrium, was measured by Wadhwa and Lugmair (1996). These carbonates are clearly not minerals within a “sedimentary system” and are not comparable with biogenic carbonates. They are formed from high temperature fluids during impact driven metasomatism or by impact melting of pre-existing carbonates rather than from low temperature fluids, as discussed by Borg et al. (1999). Elevated building temperatures of 80–200°C are suggested by \( \delta^{13}C \) (\( &\text{permile;} \)) and by \( \delta^{18}O \) (\( &\text{permile;} \)). The carbonates are zoned, with Ca-rich centres, Fe-rich mantles and Mg-rich margins. The zoning may be in isotopic equilibrium, but the isotopic composition has been differently interpreted and even claims of terrestrial led isotopy in these carbonates were raised. The zoning
might be the effect of high temperature crystallisation, but perhaps also of terres-
trial alteration processes. Isotopic equilibrium of different zones would be, never-
thless, unlikely in the latter case. Which ever interpretation is correct, these
carbonates can not be regarded as traces of the Martian Noachian ocean.

5. Martian Fossils

So how about looking directly for life or at least for fossilised life? Because life on
Mars had little time to develop and flourish on the surface of the planet, possible
fossil life will certainly be primitive, prokaryotic (Fig. 1). The earliest microfossils
on Earth display already a very high degree of complexity. However, their authen-
ticity and age and metabolic significance have been vigorously questioned in the
recent years, showing how much uncertainty is connected to the business of mor-
phological recognition of ancient and thermally altered microfossils. Finding and
interpreting microfossils on Mars will be certainly, by orders of magnitude, more
difficult.

Yet, the questioning of the authenticity of the Earth’s oldest microfossils
(Brasier et al., 2002, 2004) resulted in additional evidence that the Earth’s oldest,
3.46–3.45 Ga, microfossils (Walsh, 1992; Schopf, 1993; Ueno et al., 2001) are
indeed cellularly preserved remains of Archean microbial life (Altermann, 2005).
They are closely associated with stromatolitic structures of the same ancient age
and with various geochemical “biomarkers”. Even Brasier et al. (2006) claim now
to have found evidence of microbial (endolithic) life in sand-sized grains from the
3.4 Ga Strelley Pool Chert in Western Australia. The discussion on the authentic-
ity of the Earth’s oldest fossils led to the introduction and development of new
investigation techniques like Raman spectroscopy, analysis of molecular biomar-
kers, atomic force microscopy (AFM) techniques and new, stable isotope methods
into Archean paleontology. All these methods and the classical morphological
studies on petrographic thin sections will have to be applied to putative candi-
dates for Martian microfossils. Such complicated investigations require a sample
return to Earth mission and will not be possible to perform on an automated,
remotely controlled rover vehicle.

Considering that only few samples containing Archean microbial remains
were found on Earth, despite intensive mapping and sampling campaigns, how
big would be the chance to find Martian Noachian fossils in the few Martian
meteorites collected on Earth? Such a claim was made by a group of NASA sci-
entist for the same ALH 84001 meteorite, from which the above discussed carbon-
ate minerals were detected (McKay et al., 1996). The meteorite found 1984 in the
Allan Hills region of Antarctica appears to be essentially free of terrestrial weath-
ering, after at least 13,000 years exposure to ice. The examination of surface
textures of the cracked carbonate discs, at magnifications of 50,000 and greater,
revealed the occurrence of ovoid to elongated structures. The straight forward
interpretation was that the tiny elongated structures 20–100 nm in length, represent
fossilised Martian bacteria and the above discussed carbonate “globules” are of biogenic origin! From the occurrence of polycyclic aromatic hydrocarbons (PAHs) and the coexistence of carbonate minerals with Fe-sulphide phases and magnetite within partially dissolved carbonate, biomediated mineralisation in chemical disequilibrium was proposed, as is known to occur in some anaerobic bacteria. A resemblance of this magnetite to magnetite in magnetotactic bacteria was pointed out as additional evidence for Martian microbial activity. The nanooscopic structures shown in SEM microphotographs indeed strongly resemble single bacterial rods. A direct comparison to the size and shape of “nanobacteria in travertine and limestones” was made. Although the mere existence of nanobacteria is highly disputed because metabolic activity is impossible in such a tiny volume space, and no laboratory until today has succeeded in their cultivation, this report became a sensation.

This spectacular interpretation was diluted in an accompanying “News” article in the same issue of Science, by Richard Kerr (1996). It was clear that no single part of the above arguments would be acceptable evidence for life on Mars. PAHs and magnetite crystals, for instance, are found also in carbonaceous chondrites and in interplanetary dust particles or can be formed during hydrothermal decomposition of FeCO₃ (siderite), a common carbonate mineral. However, voices calling for caution like that of Bill Schopf, who, at the organised news conference, in the presence of the US president, suspected the findings as of low probability for truth, were not well received. The detailed arguments pro and contra the life on Mars interpretation are listed in his 1999 book “The Cradle of Life”.

6. The Book “From Fossils to Astrobiology”

In my opinion, life is not a logical unavoidable consequence of the early Earth’s conditions but rather a highly improbable coincidence of circumstances. The common assumption by astrobiologists that ‘wherever there is water there should be life’ is not even true on Earth, where life is indeed present almost everywhere. The most probable conditions for the origin of life and the most probable ingredients of life were experimentally brought together in countless attempts in the most sophisticated laboratories and still the coincidence was not reproduced. Excellent, equally educating and entertaining reading on such experiments can be found in R.M. Hazen’s (2005) book “Genesis”.

The book in front of you, contrary to this introduction, is not a popular science book. It is addressed at scientists seeking precise information in various aspects of astrobiology. Perhaps the major paradox of life sciences and astrobiology is that after so many years of research, we still can not agree on an universal definition of life. The chapters of the book treat major problems in recognition of life on early Earth and discuss the habitats of life and problems in their comparison to extraterrestrial environments. New technologies as used for microfossil
recognition and the opening new perspectives for their application are considered, and general aspects of astrophysics and astrobiology are elucidated.

The young science of astrobiology remains controversial. Probably none of the authors of this book would agree unconditionally with the major synthesis of this introduction that life on Earth is matchless. On the other hand, I see little sense in discussing “non-protein based life,” and I disagree with the criticism of the Earth’s earliest fossils and their debate. I also see no signs for (astro)biological imprints on lunar regoliths. Although I trust that scientists, not long from now, will be able to reconstruct the first living cell in vitro, as they learn to better understand the circumstances of life’s genesis, I radically doubt whether we will be ever able to reach far enough to have a chance to discover extraterrestrial life, if it ever exists or existed. But perhaps, and indeed hopefully, my scepticism towards astrobiology will soon be proven wrong. Life or fossil life will be found on Mars or another planet, and controversies will arise as to its origin on this planet or somewhere else in the Universe and as to its authenticity and criteria for recognition. And we will still be dreaming of finding intelligent life somewhere in the infinity of the Universe.

7. References


**to Fata Morgana?** This painting of the life on the “Red Planet” Mars, by the 7 years old Hanna Altermann, elucidates the desire of finding extraterrestrial intelligent life. Science fiction and serious research programs result from this desire, but even microbial life will be an enormous exception in space. Life is not a logical and unavoidable consequence of ‘suitable physicochemical’ conditions but rather a highly improbable physico-chemical coincidence.
LIST OF AUTHORS FOR “FROM FOSSILS TO ASTROBIOLOGY”

All Senior Authors Are Underlined

ALTERMANN WLADYSLAW
DEPARTMENT OF EARTH-AND ENVIRONMENTAL SCIENCES, LUDWIG-MAXIMILIANS-UNIVERSITY & GEOBIOCENTERLMU, LUISENSTR, 37, D-80333 MUNICH, GERMANY.

AMILS RICARDO
CENTRO DE ASTROBIOLOGÍA, INTA-CSIC, CTRA AJALVIR KM. TORREJÓN DE ARDOZ, SPAIN, AND UNIDAD DE MICROBIOLOGÍA, CENTRO DE BIOLOGÍA MOLECULAR, UNIVERSIDAD AUTÓNOMA DE MADRID, SPAIN.

ANTCLIFFE JONATHAN
DEPARTMENT OF EARTH SCIENCES, UNIVERSITY OF OXFORD, PARKS ROAD, OXFORD, OX1 3PR, UK.

ARDELEAN IOAN I.
CENTER OF MICROBIOLOGY INSTITUTE OF BIOLOGY 060031 BUCHAREST, ROMANIA AND “OVIDIUS” UNIVERSITY FACULTY OF NATURAL SCIENCES CONSTANTZA, ROMANIA.

BAHN PETER R.
BAHN BIOTECHNOLOGY. 10415 E. BOYD RD., MT.VERNON, IL 62864, USA.

BARBIERI ROBERTO
DIPARTIMENTO DI SCIENZE DELLA TERRA E GEOLOGICO-AMBIENTALI UNIVERSITÀ DI BOLOGNA, VIA ZAMBONI 67, I-40126 BOLOGNA, ITALIA.

BLANK CARRINE E.
DEPARTMENT OF GEOSCIENCES, UNIVERSITY OF MONTANA, MISSOULA, MT 59812, USA.

BRASIER MARTIN D.
DEPARTMENT OF EARTH SCIENCES, UNIVERSITY OF OXFORD, PARKS ROAD, OXFORD, OX1 3PR, UK.
BURNS BRENDAN P.
AUSTRALIAN CENTRE FOR ASTROBIOLOGY, SCHOOL OF
BIOTECHNOLOGY AND BIOMOLECULAR SCIENCES AND THE
UNIVERSITY OF NEW SOUTH WALES, 2052 AUSTRALIA.

CADY SHERRY L.
DEPARTMENT OF GEOLOGY, PORTLAND STATE UNIVERSITY,
PORTLAND, OR 97201, USA.

CAVALAZZI BARBARA
DIPARTIMENTO DI SCIENZE DELLA TERRA E GEOLOGICO-
AMBIENTALI UNIVERSITÀ DI BOLOGNA, VIA ZAMBONI 67, I-40126
BOLOGNA, ITALIA.

CHACON ELIZABETH B.
FACULTAD DE CIENCIAS DE LA TIERRA, UNIVERSIDAD
AUTÓNOMA DE NUEVO LEÓN. EX-HACIENDA DE GUADALUPE-KM
8, LINARES, NUEVO LEÓN, MEXICO.

CHELA–FRLORES JULIAN
THE ABDUS SALAM ICTP, STRADA COSTIERA 11, 34014 TRIESTE,
ITALIA AND INSTITUTO DE ESTUDIOS AVANZADOS, IDEA,
CARACAS 1015A, REPÚBLICA BOLIVARIANA DE VENEZUELA.

COLIN-GARCIA MARIA
INSTITUTO DE CIENCIAS NUCLEARES, UNIVERSIDAD NACIONAL
AUTÓNOMA DE MÉXICO, CIRCUITO EXTERIOR, CD.
UNIVERSITARIA, 04510, MÉXICO, D. F. MÉXICO.

DAVILA ALFONSO F.
NASA AMES RESEARCH CENTER, MOFFETT FIELD, CA. USA.

DORMNAYR-PFAFFENHUEMER MARION
UNIVERSITY OF SALZBURG, DIVISION OF MOLECULAR BIOLOGY,
DEPARTMENT OF MICROBIOLOGY, BILLROTHSTR. 11, A-5020
SALZBURG, AUSTRIA.

ERIKSSON PATRICK G.
DEPARTMENT OF GEOLOGY, UNIVERSITY OF PRETORIA,
PRETORIA 0002, SOUTH AFTRICA.

FAIREN ALBERTO G.
NASA AMES RESEARCH CENTER, MOFFETT FIELD, CA. USA.
FENDRIHAN SERGIU
UNIVERSITY OF SALZBURG, DIVISION OF MOLECULAR BIOLOGY. DEPARTMENT OF MICROBIOLOGY, BILLROTHSTR. 11, A-5020 SALZBURG, AUSTRIA.

FERNÁNDEZ-REMOLAR DAVID C.
CENTRO DE ASTROBIOLOGÍA, INTA-CSIC, CTRA AJALVIR KM. TORREJÓN DE ARDOZ, SPAIN.

GERBL FRIEDRICH
UNIVERSITY OF SALZBURG, DIVISION OF MOLECULAR BIOLOGY. DEPARTMENT OF MICROBIOLOGY, BILLROTHSTR. 11, A-5020 SALZBURG, AUSTRIA.

GIBSON EVERETT K.
ASTROMATERIALS RESEARCH AND EXPLORATION SCIENCE DIRECTORATE, NASA-JOHNSON SPACE CENTER, HOUSTON, TX, USA.

GOIN JESSICA C.
DEPARTMENT OF GEOLOGY, PORTLAND STATE UNIVERSITY, PORTLAND, OR 97201, USA.

GÓMEZ FELIPE
CENTRO DE ASTROBIOLOGÍA, INTA-CSIC, CTRA AJALVIR KM. TORREJÓN DE ARDOZ, SPAIN.

GÓMEZ-ORTIZ DAVID
ÁREA DE GEOLOGÍA, UNIVERSIDAD REY JUAN CARLOS, C/ TULIPÁN S/N, MADRÍD, SPAIN.

GRANDPIERRE ATTILA
KONKOLY OBSERVATORY OF THE HUNGARIAN ACADEMY OF SCIENCES, H-1525 BUDAPEST, P.O. BOX 67, HUNGARY.

GRUBER CLAUDIA
UNIVERSITY OF SALZBURG, DIVISION OF MOLECULAR BIOLOGY. DEPARTMENT OF MICROBIOLOGY, BILLROTHSTR. 11, A-5020 SALZBURG, AUSTRIA.

HODE TOMAS
DEPARTMENT OF GEOLOGY, PORTLAND STATE UNIVERSITY, PORTLAND, OR 97201, USA.
JERSE GIOVANNA  
DEPARTMENT OF PHYSICS, UNIVERSITY OF TRIESTE, VIA A. VALERIO 2, 34127, TRIESTE, ITALIA.

KOLB VERA M.  
DEPARTMENT OF CHEMISTRY, UNIVERSITY OF WISCONSIN-PARKSIDE, KENOSHA, WI 53141-2000, USA.

KRISTIANSSON PER  
DEPARTMENT OF NUCLEAR PHYSICS, LUND INSTITUTE OF TECHNOLOGY, LUND UNIVERSITY, P.O. BOX 118, S-221 00 LUND, SWEDEN.

LEGAT ANDREA  
UNIVERSITY OF SALZBURG, DIVISION OF MOLECULAR BIOLOGY. DEPARTMENT OF MICROBIOLOGY, BILLROTHSTR. 11, A-5020 SALZBURG, AUSTRIA.

LIESCH PATRICK J.  
DEPARTMENT OF CHEMISTRY, UNIVERSITY OF WISCONSIN-PARKSIDE, KENOSHA, WI 53141-2000, USA.

LINEWEAVER CHARLES H.  
PLANETARY SCIENCE INSTITUTE, RESEARCH SCHOOL OF ASTRONOMY AND ASTROPHYSICS, RESEARCH SCHOOL OF EARTH SCIENCE, AUSTRALIAN NATIONAL UNIVERSITY, CANBERRA, ACT 0200 AUSTRALIA.

MATSUNO KOICHIRO  
NAGAOKA UNIVERSITY OF TECHNOLOGY, NAGAOKA 940-2188, JAPAN.

MCKAY CHRISTOPHER P.  
NASA AMES RESEARCH CENTER, MOFFETT FIELD, CA. USA.

MCKAY DAVID S.  
ASTROMATERIALS RESEARCH AND EXPLORATION SCIENCE DIRECTORATE, NASA-JOHNSON SPACE CENTER, HOUSTON, TX, USA.

MCLoughlin Nicola  
DEPARTMENT OF EARTH SCIENCES, UNIVERSITY OF OXFORD, PARKS ROAD, OXFORD, OX1 3PR, UK AND DEPARTMENT OF EARTH SCIENCE AND CENTRE FOR GEOBIOLOGY, THE UNIVERSITY OF BERGEN, ALLEGATEN 41, BERGEN-5007, NORWAY.
MEIBOM ANDERS
LABORATOIRE D’ETUDE DE LA MATIÈRE EXTRATERRESTRE,
MUSEUM NATIONAL D’HISTOIRE NATURELLE, PARIS, FRANCE.

MENOR-SALVÁN CÉSAR
CENTRO DE ASTROBIOLOGÍA, INTA-CSIC, CTRA AJALVIR KM.
TORREJÓN DE ARDOZ, SPAIN.

MESSEROTTI MAURO
DEPARTMENT OF PHYSICS, UNIVERSITY OF TRIESTE, VIA A.
VALERIO 2, 34127, TRIESTE, ITALIA AND INAF-TRIESTE
ASTRONOMICAL OBSERVATORY, LOC. BASOVIZZA N. 302, 34012,
TRIESTE, ITALY.

MOISESCU CRISTINA
CENTER OF MICROBIOLOGY, INSTITUTE OF BIOLOGY 060031
BUCHAREST, ROMANIA.

MOSTEFAOUI SMAIL
LABORATOIRE D’ETUDE DE LA MATIÈRE EXTRATERRESTRE,
MUSEUM NATIONAL D’HISTOIRE NATURELLE, PARIS, FRANCE.

NEGRON-MENDOZA ALICIA
INSTITUTO DE CIENCIAS NUCLEARES, UNIVERSIDAD NACIONAL
AUTÓNOMA DE MÉXICO, CIRCUITO EXTERIOR, CD.
UNIVERSITARIA, 04510, MEXICO, D. F. MEXICO.

NEILAN BRETT A.
AUSTRALIAN CENTRE FOR ASTROBIOLOGY, SCHOOL OF
BIOTECHNOLOGY AND BIOMOLECULAR SCIENCES AND THE
UNIVERSITY OF NEW SOUTH WALES, 2052 AUSTRALIA.

OEHLER DOROTHY Z.
ASTROMATERIALS RESEARCH AND EXPLORATION SCIENCE
DIRECTORATE, NASA-JOHNSON SPACE CENTER, HOUSTON, TX,
USA.

OREN AHARON
DEPARTMENT OF PLANT AND ENVIRONMENTAL SCIENCES, THE
INSTITUTE OF LIFE SCIENCES, AND THE MOSHE SHILO MINERVA
CENTER FOR MARINE BIOGEOCHEMISTRY, THE HEBREW
UNIVERSITY OF JERUSALEM, 91904 JERUSALEM, ISRAEL.
POPOVICIU DAN RAZVAN
“OVIDIUS” UNIVERSITY FACULTY OF NATURAL SCIENCES
CONSTANTZA, ROMANIA.

PORADA HUBERTUS
DEPARTMENT OF APPLIED GEOLOGY, GEOWISSENSCHAFTLICHES
ZENTRUM GÖTTINGEN, UNIVERSITY OF GÖTTINGEN,
GOLDSCHMIDTSTRASSE 3, D-37077, GÖTTINGEN, GERMANY.

PRAVDO STEVEN H.
JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF
TECHNOLOGY, PASADENA, CA 91106, USA.

PRIETO-BALLESTEROS OLGA
CENTRO DE ASTROBIOLOGÍA, INTA-CSIC, CTRA AJALVIR KM.
TORREJÓN DE ARDOZ, SPAIN.

PROTHERO DONALD
DEPARTMENT OF GEOLOGY, OCCIDENTAL COLLEGE, LOS
ANGELES, CA 90041, USA.

RAMOS-BERNAL SERGIO
INSTITUTO DE CIENCIAS NUCLEARES.UNIVERSIDAD NACIONAL
AUTÓNOMA DE MÉXICO. CIRCUITO EXTERIOR, CD.
UNIVERSITARIA, 04510, MEXICO, D. F. MEXICO.

RAULIN FRANÇOIS
LISA UMR CNRS 7583 UNIVERSITÉS PARIS 12 & PARIS 7, 61 AVENUE
DU GENERAL DE GAULLE F 94010 CRETEIL CEDEX, FRANCE.

ROBERT FRANÇOIS
LABORATOIRE D’ETUDE DE LA MATIÈRE EXTRATERRESTRE,
MUSEUM NATIONAL D’HISTOIRE NATURELLE, PARIS, FRANCE.

RUÍZ-BERMEJO MARTA
CENTRO DE ASTROBIOLOGÍA, INTA-CSIC, CTRA AJALVIR KM.
TORREJÓN DE ARDOZ, SPAIN.

SCHIFFBAUER JAMES D.
DEPARTMENT OF GEOSCIENCES, VIRGINIA POLYTECHNIC
INSTITUTE AND STATE UNIVERSITY, BLACKSBURG, VA 24061, USA.
SCHULZE-MAKUCH DIRK
SCHOOL OF EARTH AND ENVIRONMENTAL SCIENCES.
WASHINGTON STATE UNIVERSITY, PULLMAN, WA, USA.

SECKBACH JOSEPH
P.O. BOX 1132, MEVO HADAS 20, EFRAT 90435, ISRAEL.

SELO MADELEINE
LABORATOIRE D’ETUDE DE LA MATIÈRE EXTRATERRESTRE,
MUSEUM NATIONAL D’HISTOIRE NATURELLE, PARIS, FRANCE.

STAN-LOTTER HELGA
UNIVERSITY OF SALZBURG, DIVISION OF MOLECULAR BIOLOGY.
DEPARTMENT OF MICROBIOLOGY, BILLROTHSTR. 11, A-5020
SALZBURG, AUSTRIA.

STIVALETTA NUNZIA
DIPARTIMENTO DI SCIENZE DELLA TERRA E GEOLOGICO-
AMBIENTALI UNIVERSITÀ DI BOLOGNA, VIA ZAMBONI 67, I-40126
BOLOGNA, ITALY.

TEWARI VINOD CHANDRA
WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN 248 001,
UTTARAKHAND, INDIA AND INTERNATIONAL CENTER FOR
THEORETICAL PHYSICS, MIRAMARE 34100 TRIESTE, ITALY.

TUNIZ CLAUDIO
THE ABDUS SALAM ICTP, STRADA COSTIERA 11, 34014 TRIESTE,
ITALY.

VON DALWIGK ILKA
DEPARTMENT OF GEOLOGY AND GEOCHEMISTRY, STOCKHOLM
UNIVERSITY, SE-106 91, STOCKHOLM, SWEDEN.

WACEY DAVID
DEPARTMENT OF EARTH SCIENCES, UNIVERSITY OF OXFORD,
PARKS ROAD, OXFORD, OX1 3PR, UK.

WALSH MAUD M.
SCHOOL OF PLANT, ENVIRONMENTAL AND SOIL SCIENCES,
LOUISIANA STATE UNIVERSITY, BATON ROUGE, LA 70803, USA.
WALTER MALCOLM R.
AUSTRALIAN CENTRE FOR ASTROBIOLOGY, SCHOOL OF BIOTECHNOLOGY AND BIOMOLECULAR SCIENCES AND THE UNIVERSITY OF NEW SOUTH WALES, 2052 AUSTRALIA.

WEIDLER GERHARD
UNIVERSITY OF SALZBURG, DIVISION OF MOLECULAR BIOLOGY. DEPARTMENT OF MICROBIOLOGY, BILLROTHSTR. 11, A-5020 SALZBURG, AUSTRIA.

WESTALL FRANCES
CENTRE DE BIOPHYSIQUE MOLÉCULAIRE. CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, 45071 ORLEANS CEDEX France.

XIAO SHUHAI
DEPARTMENT OF GEOSCIENCES, VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY, BLACKSBURG, VA 24061, USA.