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Exploring knowledge about microbes living in the extreme environments – the resources review

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Abstract. Extremophiles are organisms that tolerate or require to live the extreme ranges of variation of the environmental factors such as temperature, pH, salinity, concentrations of heavy metals, high hydrostatic pressure, ionizing radiation, ultraviolet, availability of water, light, oxygen, and nutritionally limited environments, etc. Exposure to such diverse factors caused, in the light of evolutionary changes, the appearence of many biochemical adaptations. In most cases, extremophiles are unicellular organisms belonging to the *Archaea* domain, but there are also representatives of other domains (*Bacteria, Eucaryota*) and multicellular organisms. The diversity of the Internet resources and printed materials (scientific publications) reflect areas of this interest. Special characteristics of extremophiles are of interest to researchers in various fields of biological sciences (astrobiology, ecology, biotechnology, biospeleology). The purpose of this article is to review the most representative resources about microorganisms living in extreme environments and indicate the directions of the future research.
Key Words: extremophiles, astrobiology, biological sciences, the Carex project, scientific publications.

Abstrakt. Ekstremofile to organizmy tolerujące lub wymagające do życia skrajnych zakresów zmienności czynników środowiskowych takich jak temperatura, pH, zasolenie, stężenie metali ciężkich, wysokie ciśnienie hydrostatyczne, promieniowanie jonizujące, ultrafioletowe, dostępność wody, światła, tlenu, ograniczonych zasobów odżywczych itp. Ekspozycja na tak zróżnicowane czynniki wytworzyła w toku ewolucji liczne adaptacje na poziomie biochemicznym. W większości przypadków ekstremofile to organizmy jednokomórkowe należące do domeny *Archaea*, ale są wśród nich także przedstawiciele innych grup (*Bacteria, Eucaryota*) oraz organizmy wielokomórkowe. Bogactwo źródeł internetowych oraz materiałów drukowanych (publikacji naukowych) odzwierciedla obszary zainteresowań ekstermofilami. Szczególne właściwości ekstremofili są przedmiotem zainteresowania naukowców różnych dziedzin nauk biologicznych (astrobiologia, ekologia, mikrobiologia, biotechnologia, biospeleologia). Celem niniejszego artykułu jest przegląd najbardziej reprezentatywnych źródeł informacji o mikroorganizmach żyjących w środowiskach ekstremalnych oraz wskazanie przyszłych kierunków badań.
Słowa kluczowe: ekstremofile, astrobiologia, nauki biologiczne, projekt Carex, publikacje naukowe.

Rezumat. Extremofilele sunt organisme care tolerează sau suportă doar zonele extreme ale variaţiei factorilor de mediu precum temperatura, pH-ul, salinitatea, concentraţia metalelor grele, presiunea hidrostatică, radiaţia ionizantă, razele ultraviolete, disponibilitatea apei, lumina, oxigenul, nutrienţii etc. Expunerea la astfel de diverşi factori a determinat în lumina modificărilor evolutive apariţia multor adaptări biochimice. În cele mai multe cazuri, extremofilele sunt organisme unicelulare aparţinând domeniului *Archaea*, dar sunt şi reprezentanţi ai altor domenii (*Bacteria, Eucaryota*) şi organisme multicelulare. Diversitatea resurselor din Internet şi materialele printate (publicaţii ştiinţifice) cuprinde aceste arii de interes. Caracteristicile speciale ale extremofilelor prezintă interes pentru cercetători în diferite domenii ale ştiinţelor biologice (astrobiologie, ecologie, biotehnologie, biospeologie). Scopul acestui articol este acela de trecere în revistă a celor mai reprezentative resurse privind microorganismele care trăiesc în medii extreme şi care pot da viitoare direcţii de cercetare.
Cuvinte cheie: extremofile, astrobiologie, ştiinţe biologice, proiect Carex, publicaţii ştiinţifice.[1]

Introduction. Extremophiles can be defined as the organisms living in extreme environments or 'on the edge'. Pioneering studies has taken a place in June 1965, when T. Brock, a microbiologist discovered in the thermal vents of Yellowstone National Park a

[1] In 1977, C. Woese proposed dividing prokaryotes into the *Bacteria* and *Archaea* (originally *Eubacteria* and *Archaebacteria*) because of the major differences in the structure and genetics between the two groups of organisms. This arrangement of *Eukaryota* (also called 'Eukarya'), *Bacteria*, and *Archaea* is called the three-domain system replacing the traditional two-empire system.

new form of bacteria *Thermus aquaticus*, which can survive at near-boiling temperatures (Brock & Freeze 1969). The word 'extremophile' was coined by B. MacElroy (1974). It originated from the Latin *extremus* and the Greek *philos*, which literally means 'lover of extremes'. From the mid-1970s., the number of these novel microorganisms has been increasing.

Provided definition is not as clear as one might think and many objections have arisen over the years. Extreme is usually taken to refer to physical, chemical, or biological conditions. Those enumerated in the abstract conditions that disrupt the integrity or functions of aqueous solutions of organic compounds are extreme.

On the other hand, it is not necessary for extremophiles to 'love' extreme conditions. They could be also extremotolerant. For many extremes, from pH to radiation, the extremophile organisms grow well, or even grow better, under less-extreme conditions. In addition to that, the ability to thrive under extreme conditions may be limited only to particular life stages after the production of appropriate molecules. In some cases, adaptation requires the location of the ions outside the cell (low pH), in other, more complex mechanisms are involved. Many species can survive extreme conditions in a dormant state but are not capable of growing or reproducing indefinitely under such condition.

There is also an attempt to modify the terminology to be less anthropocentric. Extremophiles inhabit environments considered too harsh and severe for humans. Likewise, conditions suitable for humans are too harsh for survival of many extremophiles.

Today, research into extremophiles has important implications for biology and other sciences. Many of these organisms, despite their high degree of evolutionary adaptation, provide insights into the history of life on Earth and guidance on the range of conditions on other worlds in the solar system (and beyond). Extremophiles have also spawned a huge biotechnology industry devoted to the analysis and extraction of proteins responsible for extremophilic survival for application in a range of industries from medical to cleaning.

The microorganisms have gained popularity as a study matter over recent decades among many scientists. Consequently, a series of International Conferences for Extremophiles has been held since the first in 1998 (Japan); then in Germany 2000; Italy 2002; USA 2004 and France 2006 (Horikoshi 2008). Additionally, in order to promote extremophilic microbiology: taxonomy, physiology, enzymology, molecular biology, genetics and industrial applications, the International Society for Extremophiles (ISE, http://extremophiles.org/) has been set up in 2001.

The variety of accessible resources, both the Internet (websites, databases, webzines) and printed materials (scientific publications, magazines, journals, books) reflect areas of still increasing interest in extremophiles. The most representative resources about microorganisms living in extreme environments will be shortly reviewed as follows: the Carex project, other useful Internet resources, and printed scientific publications.

The Carex project and other useful websites

a) The Carex project

The presence of websites offering comprehensive treatments of microbial diversity is a serious convenience, by its accessibility of course, for any students or investigators who are in need of morphological, physiological, and lifestyle information about extremophilic microbes. The presence in the virtual space facilitates the popularization of research results, and enables the collaboration of international research teams. CAREX, which stands for *Coordination Action for Research Activities on life in Extreme Environment* funded for three years (2008-2010), seems to be the best example of such cooperation. It focuses on the issues of enhancing coordination of life in extreme environments research in Europe by providing networking and exchange of knowledge opportunities to the scientific community and by developing a strategic European research agenda in the field. CAREX involved the European and international experts from 58 European and non-European partners from 23 countries. CAREX was managed by a consortium of nine core

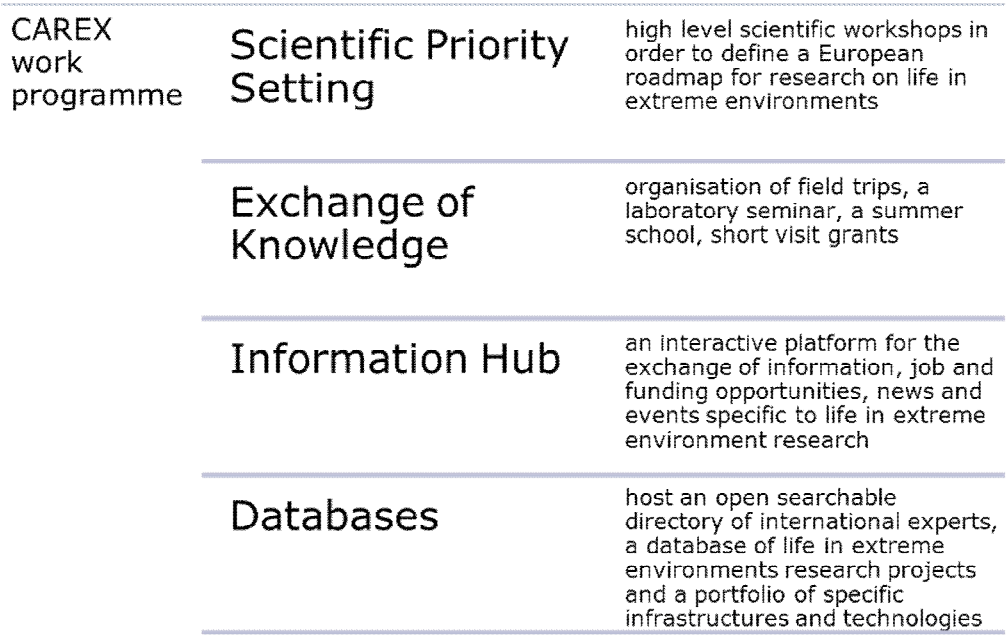

Figure 1. The description of the four lines of actions of the Carex work programme.

partners. The wide range of life in extreme environments research covers microbes, plants and animals evolving in various marine, polar, terrestrial extreme environments as well as outer space (http://carex.hd20.hosting.punkt.de/home.html).
The CAREX project has been designed to fulfil eight main objectives:

- Establish interactions, coordinate activities and promote a community identity.
- Identify the current status of life in extreme environments research within Europe.
- Furthering the scientific knowledge of life in extreme environments on key issues.
- Identify the priorities for future life in extreme environments research within Europe.
- Identify the environment-specific technological challenges and infrastructure necessary to support life in extreme environments research priorities.
- Harmonise protocols and approaches used in life in extreme environments research and promote knowledge transfer across the community.
- Promote the development of young career scientists.
- Establish an interactive information hub to support and develop a dynamic European community.

In order to achieve enumerated above objectives, CAREX work programme has been developed around four lines of actions (see Figure 1). The author would like to draw attention to the databases. These three platforms (experts, projects and infrastructures) allow finding specific expertise, research partners, and information on research projects or on the research capacity available in Europe and beyond. These databases have been structured in order to register specific profiles and to perform detailed targeted search with the use of well-defined criteria.

b) Websites

The great majority of the scientific magazines offer an online access to their contents. Those who are interested in an easy (and environmentally friendly) form can use a free but limited access or take out an online subscription. There are also the so called webzines such as *Astrobiology Magazine*, which is a NASA-sponsored online popular science magazine.
The most important websites are connected with the national space agencies. Almost each of them provides a special news section devoted to extremophiles and the newest results of researches. Just to provide a few examples: NASA (see: *Discovery of 'Arsenic-bug' Expands Definition of Life,* http://science.nasa.gov/science-news/science-at-

nasa/2010/02dec_monolake), ROSCOSMOS (see: *Beer Microbes Live 553 Days Outside ISS,* http://www.federalspace.ru/main.php?id=2&nid=10157&hl=extremophiles).
Other examples on how the information about extremophilic microorganisms are spread through the Internet resources, designed and addressed by adepts and professionals are:

- *Microbiology of Extremophiles*is a website under an investigation of J.M. Gonzalez created by a research group on extremophiles at IRNAS-CSIC, Seville, Spain, which stands for: The Institute for Natural Resources and Agrobiology, which is a centre of the Science Research Council (CSIC), a self-governing body responsible to the Ministry of Education and Science, (originally: *Instituto de Recursos Naturales y Agrobiología- Consejo Superior de Investigaciones Científicas*, http://www.irnase.csic.es/users/micro/extrem/index.html).
- *The Windows to the Universe* website is a richly interlinked ecosystem for learning about the Earth and Space sciences for use by the general public, students, and teachers. It has been in development since 1995. The project started, with support from NASA for a proposal submitted by Dr. R. Johnson, Director of *Windows to the Universe*, to NASA while she was on the Research Faculty at the University of Michigan's Department of Atmospheric, Oceanic, and Space Sciences (http://www.windows2universe.org/earth/Life/extremophile.html).
- *Going to the Extremes: An Inquiry into the Biodiversity of Extremophiles (Microbial Life)* is a wonderful website (a sort of database) for young adepts of extremophilic biodiversity, science teachers, and even professionals seeking the information on a given topic.
  The website contains the variety of resources divided into a several themes and related links to other websites, webzines, articles, images, animations (http://www.folksemantic.com/resources/60554?details=true). The browser allows searching for OCW courses (UMass Boston, MIT, Connections, JHSPH).

Scientific publications

Studies on extremophiles have progressed to the extent that there are now regular international extremophilic symposia, as well as dedicated scientific journals such as *Extremophiles* and *Archaea*, for example. Presented scientific publications are devoted either entirely or partially (issue, chapter, part, column) to microorganisms and their extraordinary features depending on the nature or profile of the publication and a given context (i.e. extremophiles and the origin of life).
Printed materials:

a) Scientific journals

- *Extremophiles*

The journal presents multidisciplinary original research articles, reviews, and method papers on the biology, molecular biology, structure, function, and applications of microbial life at the edges of survivability. Some articles are available online before print publication. Conditions covered include high or low temperature, pressure, acidity, alkalinity, salinity, or oxygen concentration; or in the presence of organic solvents, heavy metals, normally toxic substances, radiation, or host defence mechanisms. First volume was published in 1997. Other data: I.F.: 2.0 (2009). Journal Citation Reports® by Thomson Reuters, http://www.springer.com/life+sciences/microbiology/journal/792.

- *Archaea*

Archaea is a peer-reviewed, open access journal that publishes original research articles as well as review articles dealing with all aspects of research on the archaea, including bioinformatics, biotechnology, environmental adaptation, enzymology, genetics, metabolism, molecular biology, molecular ecology, phylogeny, and ultrastructure. First published in 1999. SCImago Journal Rank Indicator: 0,624 (2008), http://www.hindawi.com/journals/arch/.

- *Astrobiology*

The authoritative, peer-reviewed international journal was created as a forum for scientists seeking to advance our understanding of life's origin, evolution, distribution, and destiny in the Universe. It covers the following scientific branches: astrophysics, astropaleontology, bioastronomy, cosmochemistry, ecogenomics, exobiology, extremophiles, geomicrobiology, gravitational biology, life detection technology, meteoritics, origins of life, planetary geoscience, planetary protection, prebiotic chemistry, space exploration technology, and terraforming. First published in 2000. Astrobiology is the Official Journal of The Astrobiology Society. Other data: I.F.: 3.257 (2009). Journal Citation Reports® published by Thomson Reuters, http://www.liebertpub.com/products/product.aspx?pid=99.

- *International Journal of Astrobiology*

The international peer-reviewed devoted to the practitioners in this exciting interdisciplinary field. Coverage includes cosmic prebiotic chemistry, planetary evolution, the search for planetary systems and habitable zones, extremophile biology and experimental simulation of extraterrestrial environments, Mars as an abode of life, life detection in our solar system and beyond, the search for extraterrestrial intelligence, the history of the science of astrobiology, as well as societal and educational aspects of astrobiology. Also, but occasionally, the keynote plenary research papers from an international meeting. Launched in 2002, the journal publishes articles that encourage interaction between scientists world-wide from a diverse range of disciplines. Other data: the first (2011) I.F. will be published in 2012. It has been recently accepted into the Thomson Reuters database Science Citation Index Expanded ®, http://journals.cambridge.org/action/displayJournal?jid=IJA.

- *Extreme Life, Biospeology & Astrobiology - International Journal of the Bioflux Society*

It is published semi-annually. ELBA Bioflux presents original articles, reviews, minireviews, short notes, letters, opinions and editorials on extremophilic species, cave species or communities, astrobiology, cryopreservation, microbiology and lichenology. Available online. ELBA Bioflux reveal a collaboration of nine countries (from 3 continents): Romania, Poland, India, Iran, Thailand, Japan, Bangladesh, Canada and USA. First printed volume pilot(a) published in 2007, http://www.elba.bioflux.com.ro/.

- *Applied Microbiology and Biotechnology*

Applied Microbiology and Biotechnology addresses a range of topics, presenting full-length papers and mini-reviews of new and emerging products, processes and technologies. Coverage includes prokaryotic or eukaryotic cells, relevant enzymes and proteins; applied genetics and molecular biotechnology; genomics and proteomics; applied microbial and cell physiology; environmental biotechnology; process and products and more. First published in 1975. Other data: I.F.: 2.896 (2009). Journal Citation Reports® by Thomson Reuters, http://www.springer.com/chemistry/biotechnology/journal/253.

- *AMB Express*

AMB Express is a high quality journal that brings together research in the area of *Applied and Industrial Microbiology*, which will be launched soon. Special emphasis is laid on processes employing microorganisms, eukaryotic cell cultures or enzymes for the biosynthesis, transformation and degradation of compounds. This includes fine and bulk chemicals, polymeric compounds and enzymes or other proteins. Downstream processes are also considered. Integrated processes combining biochemical and chemical processes are also published. The journal publishes high-quality, innovative articles and serves as an essential resource for researchers in academia and industry. The journal welcomes also proposals for short reviews which critically summarize and evaluate interesting new developments, processes, products, features of production organisms or industrially relevant enzymes, http://www.springer.com/chemistry/biotechnology/journal/13568.

b) Books

The number of books devoted to extremophiles has flourished over the past decades. The book on *Microbial life in extreme environments* edited by D. Kushner in 1978 still can be considered as an exemplary work. Other valuable references are the 1986 book on *Microbes in extreme environments* (Herbert and Codd, 1986), two books edited by K. Horikoshi and W.D. Grant: *Extremophiles: Microbial Life in Extreme Environments*, 1998, and *Superbugs*, 1991; two books edited by J. Seckbach (see below, COLE series, 1999, 2000), the book by D.A. Wharton (*Life at the limits: organisms in extreme environments*, 2002). In addition, there are many specialized reviews on specific groups of extremophiles (Seckbach and Oren, 2004; Horikoshi and Grant, 1998; Rothschild and Mancinelli, 2001).

The author would like to point out in this part a book series: *Cellular Origin and Life in Extreme Habitats* (COLE) with J. Seckbach as a series editor, and the newest *Extremophiles Handbook* by K. Horikoshi; G. Antranikian; A.T. Bull; F.T. Robb; K.O. Stetter (Eds.).

The *Cellular Origin, Life in Extreme Habitats and Astrobiology* (COLE) Book Series, written by the international competent scientists who are experts in their fields of research, deal with the origin and evolution of life, the nature and general features of the first cells and several aspects of microbial life. A special emphasis is given to the microbial diversity and extremophiles all over the globe. The extremophiles covered in this series' volumes are the hot loving microbes, cold living cells, acid and alkalophiles, hypersaline halophiles, barophiles, desiccation etc.

The microorganisms featured in these books are prokaryotic *Archaea* and *Bacteria* and unicellular eukaryotic *Protista* (protozoa and lower algae). These books cover many fields of biological, biochemical, biophysical and molecular research. Additionally, new views of chemical evolution, astrobiology and the possibilities of life in extraterrestrial celestial bodies are considered. These books are addressed to microbiologists (also animal and plant microbiologists), general biologists, theoretical biologists, ecologists, biotechnologists, micropaleontologists, molecular and marine biologists who will find a lot of information in these volumes. Scientists working in the industry of soaps, detergents and petroleum will find some related information in these volumes. Biologists, students in Microbiology, Ecology, Genetics and Astrobiology as well as anyone interested in the fields of *Archae, Bacteria* (including nanobacteria and cyanobacteria) and *Protista* or obtaining data on algae and fungi. These books may serve as good reference sources and for graduate courses in microbiology and for laboratory active research workers (http://www.springer.com/series/5775).

Some of the volumes examples:

- *From Fossils to Astrobiology*, COLE Vol. 12, Seckbach, Joseph; Walsh, Maud (Eds.) 2008, ISBN 978-1-4020-8836-0
- *Algae and Cyanobacteria in Extreme Environments*, COLE Vol. 11, Seckbach, Joseph (Ed.) 2007, ISBN 978-1-4020-6111-0
- Life as We Know It, COLE Vol. 10, Seckbach, Joseph (Ed.) 2006, ISBN 978-1-4020-4394-9
- *Adaptation to Life at High Salt Concentrations in Archaea, Bacteria, and Eukarya*, COLE Vol. 9, Gunde-Cimerman, Nina; Oren, Aharon; Plemenitaš, Ana (Eds.) 2005, ISBN 978-1-4020-3632-3
- Origins: Genesis, Evolution and Diversity of Life, COLE Vol. 6, Seckbach, Joseph (Ed.) 2004, ISBN: 978-1-4020-1813-8
- *Enigmatic Microorganisms and Life in Extreme Environments*, COLE Vol. 1, Seckbach, Joseph (Ed.) 1999, ISBN 978-1-4020-1863-3
- *Halophilic Microorganisms and their Environments*, COLE Vol. 5, Oren, Aharon 2002, ISBN 978-1-4020-0829-0
- *Journey to Diverse Microbial Worlds*, COLE Vol. 2, Seckbach, Joseph (Ed.) 2000, ISBN 978-0-7923-6020-9

Extremophiles Handbook, by K. Horikoshi et al., its first edition will be in 2011, presents a comprehensive overview on extremophiles research and covers microbial life in the whole range of extreme environments. Undoubtedly, this book will be a useful reference

for finding clues to the origin of life and for exploring the biotechnology potential of these fascinating organisms. It contains the descriptions of alkaliphies, halophiles, thermophiles, piezophiles, psychrophiles, xerophiles, organic solvent tolerant microorganisms, and also so called new frontiers: deep biosphere, radiation resistant organisms, and microorganisms in oligotrophic (http://www.springer.com/life+sciences/microbiology/book/978-4-431-53897-4).

Who and why might be interested in the extremophilic organisms?

Since extremophiles began to be discovered, they have fascinated and attracted scientists from various disciplines:

• **Molecular biology, genetics**. Many different studies have been devoted to understand the molecular adaptations needed to work under conditions that would severely alter, denature or prevent function of non-extremophile's molecules. As a result of these investigations, physiology, molecular biology, and genetics of extremophiles have been developed quickly. Biologists are extensively studying extremophiles by new genomic approaches, such as metagenomics, that prove very useful methods to understand these organisms.

• **Biotechnology, microbiology**. The use of extremophiles in industrial processes has opened a new era in biotechnology. Microbiologists and biotechnologists are interested mainly in discoveries of adaptive mechanisms, practical applications in cosmetology and food technology. Each group of extremophiles has unique features that can be exploited to provide biomolecules for industry. In any organism, enzymes (proteins catalysing transformations of chemical substrates into products) are logically adapted to work optimally at its natural growth conditions. Enzymes from extremophiles are therefore functional at high temperature, high or low pH, high salt concentration, etc. They are normally very stable and resistant to denaturing agents as well, which may be an additional interest for some industrial processes. Enzymes from organisms adapted to very diverse extreme conditions, also called *extremozymes* by some authors, offer a vast choice to industry due to their functionality in media where traditional enzymes cannot work (Horikoshi & Grant 1998; Lee 2002). Furthermore, many extremophiles display novel metabolic pathways, which increase the panorama of possible reactions for biotechnology.

• **Ecology**. Studies in this field have shown the great microbial diversity, discoveries of the new (extreme abiotic factors) environments and certain niches or even ecosystems, where living organisms can still develop strategies for long-term survival. Another task for ecologists might be the quest for new species. In addition to that, many extreme environments occurs naturally, but there are also man-made (anthropogenic environmental factors): nuclear reactor (high radiation), acidic mine water (or acid mine drainage) (high metal content, low pH) which can trigger new challenges.

• **Evolution and phylogeny**. Numerous studies refer to taxa which contain extremophiles or physicochemical conditions on early Earth which could have been similar to those of some contemporary extreme environments are of interest of many evolutionists. It was partly due to the first studies on extremophiles that the third domain of life, *Archaea*, was discovered, with fundamental consequences for evolutionary biology (Woese & Fox 1977; Woese et al 1990[2]). With attention focused on temperature and salt tolerance, biologists tend to equate *Archaea* with extremophiles for a long time. This is inaccurate, as many extremophiles are *Eubacteria* and *Eukarya*, and additionally an increasing number of non-extremophilic *Archaea* are being uncovered (López-García 2005). On the other hand, physicochemical conditions on early Earth could be used as models and helpful set of information leading to discovery of ancient geochemical cycles or the origin of life and its first diversification.

[2] Woese et al 1990: *The system we propose here will repair the damage that has been the unavoidable consequence of constructing taxonomic systems in ignorance of the likely course of microbial evolution, and on the basis of flawed premises that life is dichotomously organized; that negative characteristics can define meaningful taxonomies,* p. 4576

• **Exobiology and astrobiology**. The study extremophiles are significant for defining the boundary conditions for life. The occurrence of extremophiles living under conditions that are similar to those found in other planets raises more realistic hopes about the possibility to discover extraterrestrial life. Astrobiological considerations also include: the future use of extremophiles in space – perhaps for life support or terraforming; the biodiversity of life on Earth, mechanisms to survive extreme environments, and the limits for life in the Universe (Benner et al 2004). It is interesting to note that extremophiles have been used to look for life in the Universe not as a recent construct of astrobiology, but rather as a nineteenth century suggestion of R. Proctor, who was probably the first to connect the study of life in extreme environments and life on other planets (Rothschild 2007).
• **Paleontological and ecological biospeleology**. These studies of preserved traces of prehistoric life and examination of the relationship between the inhabitants of the cave and cave are the youngest areas of researches where presence of extremophiles is also ascertained. Some of the scientists are members of SLIME (*Subsurface Life in Mineral Environments*), a loose affiliation of cave scientists working on geomicrobiological interactions in caves. Their work is based on searching of bacteria that use hydrogen sulphide gas and other noxious chemicals and water in their interactions with surrounding environment (Gonzalez & Saiz-Jimenez 2005; Laiz et al 2003; Macalady et al 2009). Extremophiles that living in caves may hold clues not only to the earliest life on Earth but to the possibility of life in outer space. Some places scientist think might harbour life in the solar system include the permafrost of Mars, hydrothermal vents on Jupiter's moon Europa, the methane and ethane oceans of Saturn's moon Titan and the cloud surface of Venus.

Future perspectives

During recent years, the discovery of extremophiles and marked out the limits of life on Earth caused the appearance of numerous questions about the existence of extraterrestrial life, for example. Future plans should embrace a continuation of exploring the microorganisms colonising extreme environments, particularly those from not entirely accessible biotopes such as the deep subsurface or caves which are still less recognized. Consequently, new extreme environments and novel microbes could be discovered and those existing – could be better explored by the usage of the modern techniques (metagenomics). Extracted organic compounds from extremophiles will find new applications in biotechnology. The results derived from different studies (astrobiology, exobiology) should allow identification of potential habitats for life (as we know it) on other planets. Another important challenge today is the identification of markers of incontestable biogenic origin that could be afterwards detected in other planets, either *in situ* or by direct analysis after an eventual sample return. In the future, exobiology will certainly require a further interdisciplinary approach to identify unambiguously biosignatures and develop methodologies to detect them on Earth or on other planets.

Subsequent researches should give the answers regarding the origin of life; more precisely whether the existing extremophiles have adapted recently to the unusual environments in which they live, or they are vestiges of ancient types of organisms that evolved on early Earth when conditions were much more extreme than they are today.

Conclusions

Research on extremophiles has many important and interesting aspects which can be enumerated as follows: 1) the extremophiles state the limits of life as we know it, and extend our understanding of the biodiversity on Earth, 2) the elucidation of the mechanisms behind the ability of extremophilic microorganisms to withstand otherwise hostile conditions provides not only a more profound insight in the functioning of living cells, but may also lead to interesting biotechnological applications and economic exploitation of the extremophiles, 3) the understanding of the unusual properties of the extremophiles leads to questions about their origin, 4) the understanding of the limits of

life on Earth, as displayed by the extremophiles, may provide us with clues on the possibility of the existence, now or in the past, of similar life elsewhere in the Universe.

The results of studies conducted over extremophiles are reflected in a wide variety of different resources: publications (articles, scientific magazines, handbooks and books), online resources, formed associations and organizations, and even the original international projects. The exchange of scientific information about microorganisms through characterized resources and maintenance of the international cooperation can bring tangible benefits in the future in the form of answers to our most pressing questions enumerated above and once a new answer is given many new questions could arise.

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