EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

RESEARCH NETWORKING PROGRAMME

ARCHEAN ENVIRONMENTAL STUDIES: THE HABITAT OF EARLY LIFE (ArchEnviron)

Standing Committee for Life,
Earth and Environmental Sciences (LESC)

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Setting Science Agendas for Europe

The European Science Foundation promotes high quality science at a European level. It acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European research initiatives.

Established in 1974 as an independent non-governmental organisation, the ESF currently serves 78 member organisations across 30 countries.

Objectives

The aim of this Research Networking Programme is to coordinate and encourage research on the environment of the early Earth and on the manner in which life emerged and evolved.

The main research topics are:

- **Composition and temperature of Archean atmosphere and oceans;**
- **The nature of Archean landmasses;**
- **Interaction between Archean surface waters and the oceanic and continental crust;**
- **The search for traces of early life.**

Our main gaol is to obtain a better understanding of the conditions that existed at or near the surface of our planet during the first two billion years of its history. Our approach is based firmly on the earth sciences but we interact with complementary programmes such as molecular biology, genetics and exobiology.

The starting point of the programme is the notion that conditions at the surface of the Archean Earth may have been very different from those at present, but in a manner that is as yet poorly understood.

Most probably the Archean sun was less luminous, the mantle was hotter and the atmosphere contained little oxygen, but we do not know how such differences influenced the way the Earth functioned. Our lack of understanding of the interplay between solar radiation and atmospheric composition means that we are unsure whether the atmosphere and oceans were hotter or colder that those of today. Rates of heat production were higher in the Archean mantle, but because our understanding of mantle convection at that time is rudimentary, we do not know if this difference resulted in internal temperatures that were extremely high, or close to those of the present-day mantle.

We know very little about the environments in which life may have appeared and later evolved. Two commonly cited settings for the cradle of life are hydrothermal springs on the ocean floor and tidal flats on the early continents. Our views on the first are based on studies of black or white smokers on the modern ocean floor, but their Archean counterparts may have been very different. Archean oceanic crust probably was much thicker than modern crust and the thermal gradient across this crust would have been low: temperatures in the shallow interior of Archean oceanic crust may have been lower than those in modern crust, not higher as is commonly assumed. Archean volcanic rocks were more magnesian than their modern counterparts and Archean ocean water more reducing. How did these differences influence conditions in Archean hydrothermal springs and what was their influence on the appearance and early evolution of life?

Our knowledge of the second setting is even more rudimentary. The survival of 4.2-4.4 billion year old zircons for about a billion years on the turbulent surface of the Archean Earth tells us that felsic continents formed very early on and that these continents stayed on the surface throughout the early Archean. 3.8 Ga sediment rocks in Isua, Greenland tell us that this crust was exposed to weathering and erosion: some of the emergent land in the Archean was very similar to that of today. But there may also have been vast “melano” (dark-coloured) continents – emergent volcanic plateaus composed of mafic to ultramafic volcanic rocks. The best modern analogue of an Archean tidal flat may be the shores of a tropical Iceland.
It is probable that the volume of ocean water was greater than today’s. Was the Archean a waterworld in which only a few small landmasses (mafic or felsic) breached the surface of a global ocean; or did higher mantle temperatures and more vigorous convection produce an extensive network of emergent mountain ranges along the mid-ocean ridges?

The main scientific objective of the programme is to answer these questions and many others, all crucial to our understanding of the origin and evolution of life.

Scope of the Programme

Our programme involves scientists and students from at least 20 different institutions in seven European countries. These include university departments, government research centres and the Geology or Natural Science Museums in three different countries. The list is not exhaustive and we welcome the participation of other scientists.

Most of the institutions are in Earth Sciences but through the involvement of multidisciplinary institutions such as the Centre of Molecular Biophysics in Orleans, the Darwin Centre for Biogeology in Utrecht and the Centro de Biología Molecular in Madrid, and our association with the European Space Agency, we interact with scientists of other disciplines. We coordinate our activities with programmes in other major countries, and with international programmes in the fields of Archean studies and geomicrobiology.

The principal goal of the programme is to coordinate the research of those European scientists and students who work on the environment of the Archean Earth. We do this by funding exchange visits between participating laboratories of scientists and upper-level research students, and by organising conferences, workshops at sessions and international congresses.

Archean pillow lava,
Abitibi greenstone belt,
Canada
(photo: N. Arndt)

Banded iron formations,
which probably indicate a
change in atmosphere
composition
around 2.5 Ga
(photo: N. Arndt)

Objectives

The research activities of the proposed programme can be grouped into four main projects.

Project 1: Composition and Temperature of Archean Atmosphere and Oceans

The question of how the composition, and particularly the redox state, of the atmosphere and oceans, changed during the first 3 billion years of Earth history has occupied geologists for the past four decades. Lively debate continues between two firmly entrenched schools, one that argues that the atmosphere was relatively reducing for the period from 4.5 Ga up to about 2.5 Ga, the other that proposes that the change to oxidizing compositions similar to those of the present atmosphere happened before 4.0 Ga. Diverse arguments are used to defend the opposing points of view: geological features that record conditions during the deposition of sediments of formation or soils are particularly important, yet in each case questions remain as to whether the inferred conditions reflect only a local environment or that of the atmosphere/hydrosphere as a whole. Other approaches use geochemical data and depend on issues such as the interpretation of mass-independent fractionation of stable isotopes.

Project 2: Nature of Archean Landmasses

Geological and geochemical investigations in rare localities where subaerial Archean rocks are known constrain the physico-chemical conditions and the topography of the land surface. The nature of weathering and erosion, the types of sediments that resulted from this erosion, the fluxes from land to sea may have been radically different for the two types of land surface that might have existed in the Archean. At one extreme the “continents” of mafic-ultramafic rock were composed of easily altered rocks but had subdued relief that mitigated the rate of mechanical erosion. At the other are granitoid continents with compositions similar to modern continents. However, because of higher temperatures in the mantle and crust itself, due to higher concentrations of heat-producing isotopes, the mountain ranges may have been lower and the topography more subdued. How would these landmasses have reacted to erosion under the more aggressive Archean atmosphere? What types of sediments were deposited around the edges of the early supracrustal masses? What is the origin of the silicification that affects such a high proportion of Archean sedimentary and volcanic rocks? Does the silicification indicate that hydrothermal circulation, both within the oceanic crust and on land, was much more common than now? How did the closer Moon influence tides and their effects on sedimentary structures? How deep was the usual wave-base?

Project 3: Impact of impacts

How was the Earth affected by meteorite impacts? The lunar impact record indicates that large impacts were much more frequent in the Archean, more specifically prior to 3.9 Ga, than at later times. Such frequent and large impact events may have been an important factor in the processes that determined the conditions of early life. Large impacts are thought to have had a devastating effect on life in the more recent history of Earth, such as the KT extinction event. However, in the Archean, meteorite impacts may have influenced the origin and the habitat of early life. Pre-biotic molecules, such as amino acids and polycyclic aromatic hydrocarbons, are abundant in space, and meteorites and comets could perhaps have played an important role in providing the necessary ingredients for life on Earth. The energy of the impact and brecciation of target rocks in the crater results in extensive hydrothermal systems that could provide an ideal habitat for early life.

Project 4:
Interaction between Archean seawater and the oceanic crust

The goal of this project is to establish the physical and chemical characteristics of oceanic hydrothermal systems in the Archean. More specifically, we would aim to establish the size, geometry, and flow rates of the hydrothermal cells and the changing temperature and chemical compositions (Eh, pH, contents of major and trace elements) of the fluids that moved through the system. Particular attention will be paid to the changes in composition that took place as the fluids flowed out of the crust and mixed with Archean seawater.
As with the other projects, we will cooperate closely with groups working on modern hydrothermal systems on land and in the ocean basins.

Project 5:
The Search for Traces of Early Life

A fundamental requirement for life is a steady source of energy commensurate with the requirements of metabolism. The materials and modules required for emerging life must also be delivered at the same time and in the same place. The energy must be sufficient to drive the first cells (e.g. to drive pyrophosphate formation) but not of such power to destroy them. The next fundamental question relates to the formation of RNA, DNA, other polymerised organic molecules and cross-catalytic self-replicating systems. In other words, how could sufficient and sustained concentrations of the building blocks of life be achieved in a prebiotic world?

Field areas

We focus our research on three key field areas chosen using the following criteria: (a) they are the oldest regions in which the geological and tectonic nature of the rock formations can be interpreted in an unambiguous manner; (b) they are regions where European geologists have been particularly active during the past decade and in which firm research collaboration has been established with local geologists; (c) they are regions that are politically stable and readily accessible.

The Pilbara Belt in Western Australia. This 3.0-3.5 Ga region, together with the Barberton belt in South Africa, contains the oldest known well-preserved sequences of volcanic and sedimentary rocks. It is the site of numerous investigations of the habitat of early life and the source of some of most exciting discoveries in the field. Teams of Dutch, French and British geologists have worked extensively in the region and have established firm research contacts not only with Australian geologists, but also with teams from the USA and Japan who are also very active in the region.

The Barberton Belt in South Africa. This region has received rather less attention by research groups in the past decade but contains many sequences that are spectacularly well preserved. It also has provided extremely valuable information on the environment at the surface of the Archean Earth and has yielded some of the best evidence for the existence and nature of early life. Cooperative research programmes are well established between European and South African scientists.

The Abitibi Belt in Canada. Although this belt is considerably younger than Pilbara and Barberton, it has been chosen because the geological setting of the rocks is better understood than any other Archean region. Thanks to concerted and ongoing geological, geochronological, geochemical and geophysical studies, mainly by Canadian geologists, and the remarkable preservation in many parts or the belt, the conditions of sedimentation and volcanism, and the entire tectonic evolution of the belt are well constrained. For example, only in this belt can island arc sequences be unambiguously be distinguished from rocks deposited in mid-ocean settings. Investigations in the Abitibi belt will therefore provide the firmest constraints on the conditions on the ocean floor and at the surface of the Archean earth. Again, firm research links have been established with local geologists.

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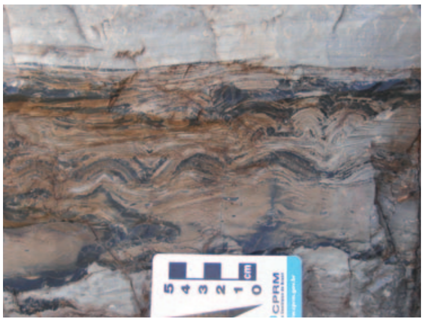
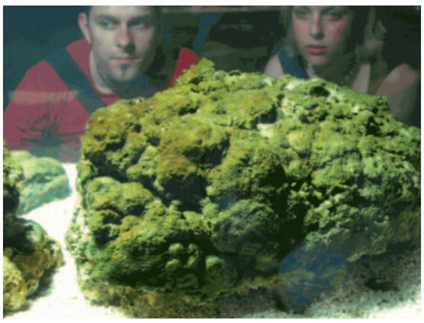
Fossil stromalites from the Barberton Greenstone belt
(photo: N. Arndt)



Living stromalites in the laboratory at ETH Zurich
(photo: C. Vasconcelos)



ArchEnviron Steering Committee

Nicholas Arndt (Chair)
Laboratoire de Géodynamique des Chaînes Alpines
1381 rue de la Piscine
38401 St Martin d'Hères
France
Tel: +33 4 76635931
Email: arndt@ujf-grenoble.fr

Ricardo Amils
Universidad Autonoma de Madrid
Centro de Biologia Molecular del CSIC
Campus UAM
28049 Madrid
Spain
Tel: +34 91 497 5070
Email: ramils@uam.es

David Banks
School of Earth and Environment
University of Leeds
Woodhouse Lane
Leeds LS2 9JT
United Kingdom
Tel: +44 113 343 5244
Email: D.Banks@earth.leeds.ac.uk

Ulrich Riller
Humboldt-Universität zu Berlin
Museum für Naturkunde
Invalidenstrasse 43
10115 Berlin
Germany
Tel: +49 30 2093 8573
Email:
ulrich.riller@museum.hu-berlin.de

Minik Rosing
Geologisk Museum
Oster Voldgade 5-7
1350 Copenhagen K
Denmark
Tel: +45 3532 2368
Email: minik@savik.geomus.ku.dk

Fons Stams
Wageningen University
Laboratory of Microbiology
PO Box 8033
Hesselink van Suchtelenweg 4
6700 EJ Wageningen
Netherlands
Tel: +31 317 483101
Email: fons.stas@wur.nl

Crisogno Vasconcelos
Geological Institute
ETH-Zentrum
Sonneggstrasse
8092 Zurich
Switzerland
Tel: +41 44 632 1030
Email:
crisogono.vasconcelos@erdw.ethz.ch

Martin Whitehouse
Swedish Museum of Natural History
NORDSIM Laboratory for Isotope Geology
Box 50 007
Frescativ. 40
104 05 Stockholm
Sweden
Tel: +46 8 5195 5169
Email: martin.whitehouse@nrm.se

Tanja Zegers
Paleomagnetic Laboratory
Institute of Earth Sciences
Utrecht University
Budapestlaan 17
3584 CD Utrecht
Netherlands
Tel: +31 71 5656585
Email: tanja@geo.uu.nl

ESF Liaison

Arja Kallio
Science

Pat Cosgrove
Administration

European Science Foundation
1 quai Lezay-Marnésia
BP 90015
67080 Strasbourg cedex
France
www.esf.org
Tel: +33 (0)3 88 76 71 06
Fax: +33 (0)3 88 37 05 32
Email: pcosgrove@esf.org

For the latest information on this Research Networking Programme consult the ArchEnviron home page:
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EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

1 quai Lezay-Marnésia | BP 90015
67080 Strasbourg cedex | France
Tel: +33 (0)3 88 76 71 00 Fax: +33 (0)3 88 37 05 32
www.esf.org