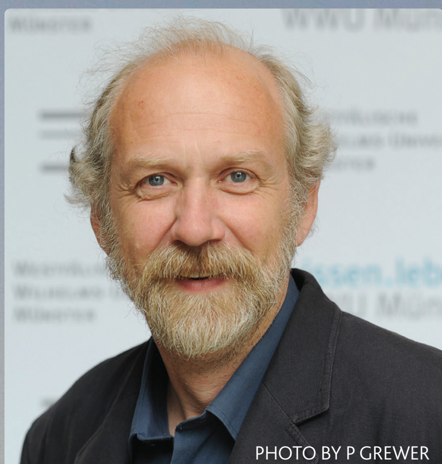
Using sulphur isotopes to explore the early Earth

Through multiple sulphur isotope analyses, **Professor Harald Strauss** is helping to characterise important environmental conditions and identify different metabolic pathways of microbial sulphur cycling



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From what context did your investigation into sulphur isotopes emerge?

Sulphur is an interesting element found in high- and low-temperature rocks. It participates in redox processes and these are generally associated with sometimes sizeable changes in sulphur isotopes. We make use of these isotope effects for tracing potential sulphur sources. More so, however, characteristic variations in the sulphur isotopic composition allow us to identify and differentiate chemical and biological processes.

What is the significance of the Barberton Greenstone Belt (BGB) in South Africa?

The BGB is unique in many ways. As a whole, the BGB exhibits rock successions that are quite complete, well preserved and very diverse in the number of represented environments. The BGB has witnessed a long history of geological research, driven by the understanding that a superbly preserved part of Earth's early history has been archived but also by the numerous mineral deposits present in these rocks. Moreover, the BGB hosts some of the earliest traces of microbial life.

How are you using innovative equipment or approaches to obtain results?

Although the application of multiple sulphur isotope analyses to rocks that formed very early in Earth history at the Earth's surface commenced in 2000, there are still many uncertainties that we need to explore further. Moreover, few working groups worldwide have the respective analytical capabilities. I still consider this a reasonably novel and innovative approach, definitively in the context of our multidisciplinary research that we are currently pursuing.

Can you share the major challenges of your research; how are you looking to overcome these?

The overall scientific objectives of this research project are also its greatest challenge. Aiming to identify and characterise early habitats and early forms of life on Earth requires multiple viewpoints. The task is in some ways like a big jigsaw puzzle. All specialists are pursuing their own disciplinary research which will already advance our understanding about individual research questions. But it is the collection of bits and pieces of information coming from the different disciplines that will ultimately allow us to peer into the cradle of life.

Why is a multidisciplinary approach important in this line of investigation?

Successful research requires interdisciplinary collaboration. This is most obvious when thinking about the great variety of analytical instrumentation or the collective expertise required to successfully uncovering information on the beginning of life on Earth. Equally, if not more important, is the fact that a fellow colleague from a neighbouring discipline might ask the 'unusual' question that makes you think in a different way that might be more fruitful and productive. We study the element sulphur, which is a recorder of inorganic as well as biologically mediated processes. Consequently, multiple links exist to other teams in this multidisciplinary research project.

In what ways are you supported by the resources and opportunities available through the International Continental Scientific Drilling Program (ICDP)?

One of the key objectives of scientific drilling is the acquisition of continuous and complete records of Earth's evolution archived in rocks. Respective rock samples did not suffer from surficial weathering that normally obscures our view. Hence, they allow uncovering primary information that was archived during the time of rock formation. This is particularly important when studying early life. ICDP provides partial financial support to pursue drilling and an excellent platform for international collaborative research.

In your opinion, what have been the project's most significant achievementsto date?

The great variability in multiple sulphur isotope results obtained so far points to a complex sulphur cycle. This includes abiological aspects as well as different microbially driven metabolic pathways, supporting our view that microbial sulphur cycling is an ancient form of metabolism and that early habitats were already populated by a diverse microbial ecosystem.

At what stage is the project currently and where will you be focusing your research efforts over the coming years?

Our geochemical research on the Barberton drill cores commenced last summer. My initial project will run until Autumn 2014. Results will provide a good overview of early sulphur cycling and it will further allow the identification of more detailed research questions for a follow-up project. I anticipate that the superb drill core material will keep me busy for a few more years.

A CRISP WINTER MORNING WELCOMES THE DRILLING CREW

Life on **Earth**

By characterising important environmental conditions and identifying metabolic pathways of microbial sulphur cycling, geochemists at the University of Münster, Germany are helping resolve some of unanswered questions about primitive environments on Earth through the **Peering into the Cradle of Life** project

THE QUESTION OF how early life on Earth began has been pondered by scientists with ever growing enthusiasm. Clear traces have been found in well preserved sediments that are around 3,500 million years old. These microscopic structures are comprised of carbonaceous material. Together with a range of different geological and geochemical features, these structures indicate that a highly rich microbial ecosystem existed on Earth already during its early period. A project led by the University of Münster in Germany, which is analysing multiple sulphur isotopes, aims to shed new light on these early environmental conditions and on early sulphur metabolism.

The Peering into the Cradle of Life project is using the particular isotopes of sulphur and complementary geochemical analysis to look more deeply at these processes. Research Leader Professor Harald Strauss explains that, among isotopic evidence, multiple sulphur isotopes provide a prime biosignature, particularly in some of the oldest, best preserved geological sequences in the world. In addition, mass-independent sulphur isotope fractionation offers some valuable knowledge about the atmospheric composition of Earth during such early times, especially the absence of free oxygen.

EXAMINING NEWLY OBTAINED CORES

The main goal of this multidisciplinary collaborative research initiative is to build a better picture of how the early Earth functioned and the conditions in which life emerged and evolved. The team has chosen the Barberton Greenstone Belt in South Africa as the main site for their study. This is a small, cusp-shaped succession of volcanic and sedimentary rocks surrounded and penetrated by intrusive igneous rocks of granitic composition, known as granitoid plutons.

This location is valuable to the team because these rocks have the potential to unlock some of the many deeply held secrets of early life locked up in rock formations. "The quest for unravelling Earth's early evolution and, in particular, life's early evolution is a truly challenging project," ponders Strauss. "The Barberton Greenstone Belt exhibits a set of superbly preserved rock successions that no doubt include some of the early habitats in which life emerged and evolved on our planet." Thus, Barberton is a very promising place for studying sulphur isotopes – one of the integral components of the project.

Beds of barite have archived the composition of ancient seawater (red pocket knife for scale = 10cm).

Collaborating scientists are also looking at the temperature and geodynamic activity in the Archean mantle, as well as the geodynamic setting and thermal structure of Archean continental and oceanic crust. They are keen to understand more about the nature of the earliest volcanism, how fluids circulated through Archean volcanic crust and the microbial habitats and metabolic activity of organisms in volcanic and sedimentary settings. The study is based on newly obtained drill cores from the Barberton Greenstone Belt.

The drilling project was approved by the International Continental Scientific Drilling Program in 2009 – drilling started in mid-2011 and was completed a year later. Five holes were drilled and respective drill cores, totalling some 3,000 m in length, were retrieved. There were two main targets for the drilling. First, sedimentary sequences afforded data about the conditions in sedimentary basins, such as how erosion and sedimentary processes took place and the composition and temperature of Archean seawater. Second, komatiite-basalt successions enable the group to investigate volcanic processes, mantle dynamics, crustal evolution and the interaction of the oceanic volcanic crust with the hydrosphere and biosphere.

COMBINING MULTIPLE CHEMICAL ANALYSES

The multiple sulphur isotope analysis on this core helps to answer two main questions: first, to identify and distinguish the environmental conditions that defined the early habitats of life on Earth; second, to study processes of microbial sulphur cycling, which are among the earliest metabolic pathways, and identify some of the earliest life forms on Earth. As well as the geochemical and isotopic analyses, detailed petrographic examination of samples, including pyrite morphology, are being completed to help explain the depositional and diagenetic history of the different sedimentary sulphur

INTELLIGENCE

PEERING INTO THE CRADLE OF LIFE: MULTIPLE SULPHUR ISOTOPES REVEAL INSIGHTS INTO ENVIRONMENTAL CONDITIONS AND EARLY SULPHUR METABOLISM SOME 3.5 GA AGO

OBJECTIVES

- Characterising the atmosphere-ocean system and its evolution
- Identifying processes of microbial sulfur cycling

KEY COLLABORATORS

Dr Paul Mason, Utrecht University, Utrecht, The Netherlands

Professor Dr Nick Arndt, Université de Grenoble, Genoble, France

Professor Dr Allan Wilson, University of Witwatersrand, Johannesburg, South Africa

Professor Dr Axel Hofmann, University of Johannesburg, Auckland Park, South Africa

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PROFESSOR HARALD STRAUSS received his PhD from the University of Göttingen, Germany, in 1985. He applies stable isotopes of sulphur and carbon in order to study Earth System Evolution with a strong focus on the early part of Earth's history.

A STEEL PLUG SEALS THE DRILL HOLE

STRAUSS AND HIS PHD STUDENT AT A DRILL SITE

phases. "Collectively, we are aiming to peer into the cradle of life and multiple sulphur isotopes are a powerful geochemical tool for this," elucidates Strauss.

The team is characterising the chemical state of the atmosphere and the ocean. Their measurements also include chemical compositions of carbon and iron which it is hoped will further characterise redox conditions in these early habitats as well as other metabolic pathways. Other working groups are focusing on looking at redox-sensitive metals and their abundances and isotopic compositions. Colleagues from different research groups in Switzerland, Belgium and Germany are studying how important redox-sensitive elements, such as molybdenum and uranium, impact on the very same samples – ultimately maximising the output from the project and improving knowledge. Together this work will help to create a detailed platform of information about the environmental conditions on early Earth. Additional areas that inform Strauss' specific work on multiple sulphur isotopes include the older Isua Supracrustal Belt in south west Greenland and other slightly younger successions in South Africa and northern Russia.

SHARING EXPERTISE

Since the project's inception, the researchers have uncovered some surprising facts while applying multiple sulphur isotopes. For the rock types investigated to date, they expected to identify a particular pattern in the multiple sulphur isotope results, however Strauss points out that while different rock types and potential habitats still exhibit distinctly different isotope variations, results turned out to be far different from what was anticipated by the researchers. These findings have been disseminated at a number of national and international events, such as the recent presentation given by Strauss' PhD student Alice Montinaro at the European Geosciences Union (EGU) Meeting in Vienna, Austria. Results from the drilling and subsequent research will be presented to the scientific community as well as the general public.

> Mass-independent sulphur isotope fractionation offers some valuable knowledge about the atmospheric composition of Earth during such early times

Strauss' project has been underway for two years now and is due to be completed in the latter part of 2014. Early next year, a workshop will once again bring together all of the groups currently studying these particular rocks in order to discuss what has been achieved, to pursue further sampling, and to initiate new research projects. Strauss is confident that their work will help to advance understanding of where and how life began and advanced on this planet: "We hope to be able to provide new insights that will refine our picture of planet Earth during its early time". In addition, he believes that the results gathered will support the search for life beyond the Earth in particular because they are identifying and developing robust geochemical fingerprints.

The drilling project further underlines the importance of this unique geological site and research will improve the overall knowledge of the geological attractions within the proposed heritage site. It is also recognised that this effort to address how life emerged in such extreme conditions holds much value during a time of growing concern about how the Earth's present environment will respond to climate change.

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VIEW INTO THE BARBERTON MOUNTAINLAND – THE CRADLE OF LIFE