Max Planck Research Group
Organic Paleobiogeochemistry

We study the co-evolution of life and environmental conditions on the early Earth by analyzing the sedimentary hydrocarbon remnants of biological lipids. The distribution and stable isotopic composition of such molecules in Precambrian rocks carry clues to organismic diversity, metabolism, and depositional redox conditions. This path of investigation might ultimately explain how a 'modern' planet Earth that is habitable to complex life, including our own species, came to exist.

The Phanerozoic Eon, which spans the last 541 million years, contains most of the commonly studied geological and paleontological events, yet covers only 15 % of Earth history. Despite its variation in environmental conditions, the Phanerozoic Earth can be largely designated as a 'modern' system. This was very different during the preceding 4 billion years. The Precambrian witnessed not only the origin of life, but Earth also went through a number of transitions in terms of atmospheric oxygen budget, marine redox chemistry, nutrient cycling and climatic extremes, before reaching its Phanerozoic state that is habitable by complex organisms. This progression was mediated by - and reciprocally steered - a continuously evolving microbiosphere.

We aim to understand the details of Precambrian Earth system evolution by analyzing molecular fossils, or biomarkers, in sediments. These molecules are the preserved hydrocarbon remnants of lipids once produced in the ancient water column and/or sediment. Taxonomic specificity of select compounds allows the reconstruction of past organismic diversity, while their stable carbon isotopic composition can point towards certain metabolisms.

Our methodological approach starts with geological fieldwork and drilling campaigns to obtain the freshest possible sample material, whereafter we use organic and carbonate carbon isotope stratigraphy for intraregional stratigraphic correlations. The principal work component consists of wet chemical methods to extract and separate trace abundances of hydrocarbons and to analyze these using superbly sensitive gas chromatography and tandem mass spectrometry.

While asking questions pertaining to the co-evolution of life and environments throughout geological history, our lab focuses on three key areas of research.

Portrait of the Group Leader

Christian Hallmann leads the Max Planck Research Group "Organic Paleobiogeochemistry" since 2012 and holds a secondary appointment as a staff scientist at the University of Bremen, where he and his team are located. Christian received a Diploma in geology and palaeontology from the University of Cologne in 2005 and a PhD in applied chemistry from Curtin University in 2009. Before joining the Max Planck Society, he worked as an Agouron Geobiology Fellow and postdoctoral associate at the Massachusetts Institute of Technology.

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Focus 1. Earth's oldest sedimentary hydrocarbons

The late Archean and Paleoproterozoic sedimentary sequence records (most likely) the biological invention of oxygenic photosynthesis and the initial rise of oxygen in Earth's atmosphere, termed the Great Oxidation Event. Our knowledge of biological diversity around this time, as well as the effect that rising O_2 levels had on existing biota is scant. Sedimentary biomarkers can carry such information but most sedimentary basins of this age have experienced a metamorphic overprint beyond the theoretical thermal stability of polycyclic terpenoid molecules. Furthermore, indigenous hydrocarbon concentrations can be expected to be very low, making any sample material highly vulnerable to contamination during sampling, handling and storage. We use advanced sampling (ultra-clean drilling) and work-up protocols (slicing experiments and sequential extraction-digestion techniques) to distinguish contaminants from indigenous biomarkers and determine the oldest sedimentary hydrocarbons that can provide clues to the nature of life on the early Earth. In this context we also aim to determine biomarker breakdown products that still carry diagnostic value.

Focus 2. The Emergence of complex life

Most of the Precambrian was dominated by simple unicellular and later multicellular organisms. But it was the advent of the metazoan kingdom with their differentiated multicellularity that would lead to todays organismic diversity. After more than a billion years of apparent evolutionary stasis, the Cambrian (~541 to 485 Ma) witnessed a period of accelerated evolutionary pace and diversification, mainly within the metazoa (*i.e.* the 'Cambrian explosion'). We are interested in the first appearance of this complex life. Demospongiae are the most basal representatives of the metazoan kingdom. While the oldest sponge spicules are found in Cambrian strata, molecular clocks place the appearance of demosponges deep in the Neoproterozoic Era, which was characterized by strong perturbations of the marine carbon cycle, varying ocean redox chemistry and severe climatic events. We trace the appearance and radiation of metazoa using a characteristic steroid (24-isopropylcholestane) and try to gain an integrated understanding of this evolutionary innovation in light of changing environmental conditions and its spatiotemporal distribution.

Focus 3. Nutrient cycling and redox structure in Precambrian oceans

While currently a rare environmental condition, stratified and sulfidic marine waters were much more common during the Proterozoic Eon. Initially fuelled by the onset of oxic continental weathering and a consequently growing marine sulfate pool, such euxinic conditions not only stripped the Proterozoic ocean of its vast Fe (II) reservoir but likely also depleted redox-sensitive bioessential elements such as molybdenum (Mo). Debilitation of Mo nitrogenase enzymes could have led to nitrogen-limiting conditions, allover reduced productivity and prokaryote-dominated marine ecosystems. We are interested in the interplay between marine redox structure, nitrogen cycling, and the strength of the biological pump. Our approach to these questions involves studying the structure and stable isotopic composition of tetrapyrrole-pigment degradation products, the comparison of intrabasinal distal and littoral facies, and the identification of different sedimentary carbon pools that were sourced at varying palaeo-water depths.

Paleoproterozoic stromatolites. Elsewhere such lithified bacteriogenic structures represent the oldest traces of life on our planet.

One of our field sites on the Belcher Islands, Nunavut, Canada.

Organic geochemistry in the field – 1500 km to the nearest lab.