Annual Report 2012

DEEP SEAFLOOR • DEEP BIOSPHERE • DEEP TIME & ROOTS OF LIFE

CENTRE FOR
GEOBIOLOGY

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2012 – **INTERDISCIPLINARITY** YIELDING RESULTS

Looking back, the proposal to establish this cross-disciplinary research centre was a bold undertaking. Today, a little over half-way through the 10-year project period, we are seeing the first truly interdisciplinary results, both in terms of the articles now being published and in the kind of students now completing a geo-bio education. These latter represent a brand-new labour resource that will have the integrated, multi-disciplinary background necessary to address the global research challenges of today and tomorrow.

The first Centre internal seminars struggled to bridge the academic gap between the different disciplines. Today, students and researchers alike have gained a cross-disciplinary understanding that increases their ability to use new approaches that were unimaginable just a few years ago. This is clearly demonstrated in the theses of the Centre's latest PhD graduates. The research presented links geochemistry and microbiology in different environments, cold seeps, deep-sea sediments and ultramafic rock formations.

The work in one of the PhD papers focuses on an ultramafic rock system in Leka (see page 8). Rock-water interactions in ultramafic systems may provide insights into the origin of life on Earth. Interestingly, the methodologies developed in that study are also proving relevant for measuring the environmental impact of acid mine tailings (see page 7). This application provides another demonstration of the important but perhaps unexpected benefits of investment in pure research activities.

Among the many papers published in 2012 was one published in the Proceedings of the National Academy of Sciences of the United States of America (PNAS) (see page 5). Produced by a diverse, multi-disciplinary team of authors from the Centre, the paper presents research analysing the correlations between geology, geochemistry and microbiology in deep-sea sediments. The results not only provide testable hypotheses for the cultivation of deep-sea microbial organisms, but will also impact system-level thinking in terms of global element re-cycling. A leading scientist within the field wrote a PNAS commentary on the paper and concluded that the CGB author team "should be thanked for energizing the game". Our ambition is to continue to do so in the years to come.

Rolf-Birger Pedersen
Centre Director

INTERDISCIPLINARY RESEARCH AT THE CGB DEMONSTRATES A GEO-BIO LINKAGE IN DEEP-SEA SEDIMENTS

A multidisciplinary team of researchers at the Centre for Geobiology (CGB) has shed new light on how geochemical stratification within seafloor sediment correlates with stratification of its microbial community.

While this idea was conceptualized many years ago, it has been challenging to demonstrate such a relationship quantitatively. However, the team of researchers was able to capitalize on the special conditions in the sediments near the Loki's Castle hydrothermal vent fields, which Centre researchers discovered in 2008.

In addition to the hydrothermal activity, this area, located at the bend between the Mohns and Knipovich Ridges, has been affected by sediment input from the nearby Bear Island fan. Geological research via seismic and coring activity into the seafloor has revealed a strong layering, or stratification, of the sediments, caused in part by alternating hydrothermal and sediment input.

The microbes living in the seafloor sediments in the deep sea obtain their energy from chemical reactions, in particular from the coupling of reactions that release (oxidation) or gain (reduction) electrons; redox reactions. For example, organisms use materials such as iron oxide as electron acceptors and organic carbon as electron donors. Thus particular layers with sufficient quantities of redox compounds can support the growth of microbial communities: different geochemical micro-environments supporting differently structured microbial communities. At the same time, microbial activities drive the geochemical cycling within the sediment. Knowing something about the geochemistry of particular layers enables researchers to predict the kinds of reactions – and therefore the kinds of microbes – that might be found there.

One of CGB's goals as a centre for research excellence is to develop multidisciplinary research teams that combine approaches from different fields to address large system-scale geo-biological questions. This research was made possible through cross-discipline collaborations between experts in geochemistry, statistics, bioinformatic and microbiology. The results shed light on reactions ongoing in the deep sea and in geological "hot-spots" such as spreading ridges and venting systems, while simultaneously understanding the interaction and impact of this geochemical sphere with the significantly-sized biological sphere of the subseafloor. They will provide new information that is relevant for the understanding of global element re-cycling.

Their article "Correlating microbial community profiles with geochemical data in highly stratified sediments from the Arctic Mid-Ocean Ridge" is featured in November 2012 issue of PNAS (Proceedings of the National Academy of Sciences). The issue also includes a commentary by A. Teske. ■

EARLY SUBSEAFLOOR LIFE
REINVESTIGATED

While previous evidence of carbon linings in ancient microbial fossils is debunked, high-resolution ion microprobe mapping techniques reveal independent isotopic evidence that life may have existed in the Archean subseafloor.

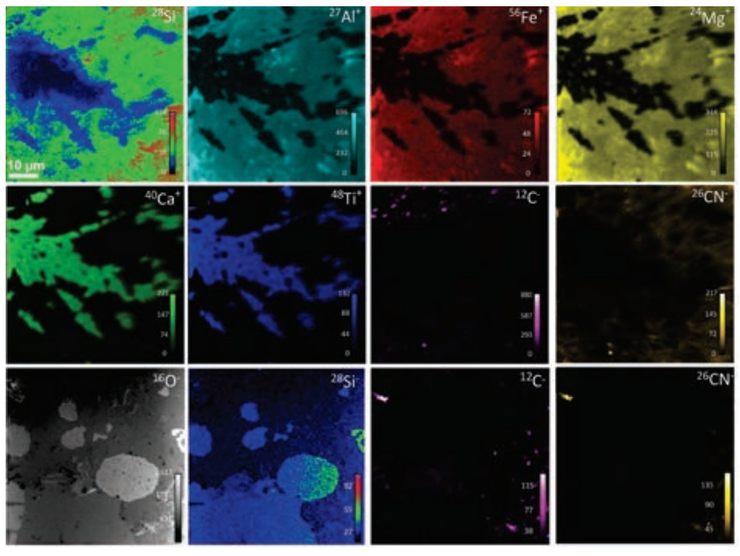
CGB researchers have been investigating candidate biosignatures in pillow lavas that erupted onto the seafloor 3.47-3.45 billion years ago (Ga) found in Barberton Greenstone Belt in South Africa. It is hypothesized that these microtextures may provide insight into processes of the ancient subseafloor biosphere. The Barberton Greenstone Belt pillow lavas are not only some of the most ancient rocks still present on Earth today, but this particular area has undergone relatively little geological change in the 3+ billion years since formation, making them some of the best preserved examples of ancient seafloor.

CGB researchers were the first to present evidence of microbes in volcanic glass from the rims of modern seafloor pillow lavas, for example, from Iceland and the Norwegian-Greenland Sea. When new pillow lava erupts onto the seafloor it cools quickly when it comes into contact with the near-freezing water of the deep sea. Here it has been hypothesized that microbes colonize fractures in the newly formed outer glassy rims of the pillow lavas. Researchers speculate that microbes can obtain chemical energy and nutrients from the newly formed rock. In turn, the microbes leave behind tunnels in the glass that may be annulated, twisted, spiral-shaped or branched.

The scientific community is yet to agree as to when life first emerged on Earth, and the subseafloor represents one possible environment where life may have begun. In 2008 CGB scientists were involved in a scientific drilling project in the Barberton Greenstone Belt that sampled more than 800 meters of core material. This project recovered many different types of rocks with one of the drill holes focusing on a sequence of pillow lavas that was found to contain microtextures in the rims of the basaltic pillow lavas. Given that these rocks have experienced metamorphic temperatures, pressures and fluid flow that have transformed the original volcanic glass into metamorphic minerals these microtextures need to be carefully evaluated. Previously reported evidence of carbon linings to the microtextures from microprobe x-ray maps was earlier taken to support the biogenicity of the microtextures. However reexamination by this CGB study using high-resolution nano-scale ion microprobe (NanoSIMS) has proved those traces of organic material are likely artifacts of the analytical method. This lack of organic linings in the microtextures raises questions about the biogenicity of the microtextures and their formation by Archean microbes.

Although the NanoSIMS results disproved the presence of organic linings, the analysis also revealed an independent biomarker associated with the textures. Using NanoSIMS, the CGB research team found highly variable fractionation of sulfur isotopes in sulfide grains within the samples. Sulfate reduction is a widely accepted microbial mode of life in both modern and ancient ecosystems, especially in sedimentary rocks and is now also becoming apparent in subseafloor rocks. The fractionation measured in these Barberton samples represents the widest range and most negative sulfur isotopic values so far reported from the Archean, and most likely are too drastic to have occurred without microbial input.

The high-resolution investigation of the Barberton Greenstone Belt microtextures is guiding CGB scientists towards new methods for ascertaining the biogenicity of proposed traces of life. It is exciting that an independent analysis method also points to possible microbial life in the Archaean subseafloor, and is leading CGB scientists to ask new questions about the ancient subseafloor metabolic processes and origins. ■



ENVIRONMENTAL IMPACT
OF SUBMARINE MINE TAILINGS

An important objective for carrying out basic science at CGB is for the data we produce to impact our knowledge of significant environmental problems. New information about submarine mine tailings in the Norwegian fjords provides insights into how to approach current mine tailings and future deep-sea mining initiatives.

Mining is one of Norway's oldest export industries and has played an important role in the Norwegian economic sector since the early 1600s. But, extraction of metals, minerals and stone can pose environmental challenges, especially when it comes to the disposal of fine-grained waste, known as tailings.

The composition and characteristics of the tailings depend on the mineralogy of the ore and the process of extraction. Historically tailings have been deposited in landfills within retaining structures. Other alternative disposal methods include in-pit, co-disposal, offshore and submarine tailing placements. Landfills, for example, have had documented retention issues; sand drift in dry weather and leaching of metals when there is heavy precipitation.

Mining of sulfide deposits has also created environmental problems due to the weathering properties of sulfide minerals. When these minerals come in contact with water and air, they oxidize creating acidic compounds and mobilizing metals. These products can enter the environment through drainage. This phenomenon is known as acidic mine drainage, and is a well-known problem. Today there is no active mining of sulfide deposits in Norway, but historical operations have left behind tailings, which remain a serious environmental issue.

In Norway there are around 20 registered marine disposal localities in the fjords. The main reason that mine operations choose marine deposition for their mine tailings is that water provides an oxygen barrier, reducing the weathering process. This advantage, however, has only been verified in fresh water. Seawater's natural buffering capacity supports the belief that the reduction processes of acidic mine drainage and the mobility of toxic elements will be decreased in seawater. Nevertheless, acidic drainage and toxic metal leaching may be occurring in submarine tailing disposal. Increased interest in new mining operations has led to greater pressure from mining companies for further marine storage. The unknown fate of acidic compounds and metals in tailings presents an urgent need for better documentation of the reactivity of marine tailings and stability of toxic elements in the sea.

CGB researchers involved in a pilot project are focusing on three disposal sites with different tailing compositions in Ballangsfjorden (Nordland) and Jøssingfjorden (Rogaland). Geochemical composition, porewater, and microbial diversity in sediment cores from and around the tailing deposit sites have been analyzed. The data from disposal sites will be compared to surrounding sediments to gauge the effect of the tailings deposits in the fjords. The geochemical and geomicrobiological results from the submarine tailings will describe the microbial diversity, reactivity of heavy metals, and effects of biogeochemical processes on the mobility of toxic metals in the sediments, providing a better understanding of marine tailings in Norwegian fjords. The results of these studies will provide critical knowledge for evaluating the environmental impact of new mining initiatives, including those in deep ocean sites. ■

HYDROGEN-BASED LIFE ON EARTH AND OTHER PLANETS

CGB researchers are studying subsurface microbial communities sustained by hydrogen-producing geochemical reactions.

A water-rock environment rich in hydrogen is a proposed environment for the origin of life on early Earth, and is hypothesized as akin to conditions in the subsurface of modern Mars. There is increasing evidence of a hydrogen-based subsurface biosphere on Earth, existing independently of photosynthesis, often referred to as a subsurface lithoautotrophic microbial ecosystems or SLiME. Hydrogen and other reduced compounds formed though water-rock reactions are used as energy sources by microorganisms living in these systems. Ultramafic, olivine-rich rocks are considered to be a particularly promising habitat for SLiME, since water-rock reactions (serpentinization) in ultramafic systems are known to produce large amounts of hydrogen, methane and other light hydrocarbons.

Ultramafic rocks are found in the mantle and lower crust, but due to tectonic processes they may be transported to higher crustal levels such as at slow and ultraslow oceanic spreading ridges. Sections of oceanic crust and mantle rocks that have been emplaced onto continental crust provide easily accessible systems to study such processes. The Leka ophiolite complex in mid-Norway is a beautiful example of this. It contains all the components of the oceanic crust and mantle rocks. CGB researchers are studying on-going low temperature geochemical processes and associated microbial communities in the ultramafic part of the Leka ophiolite complex. These low temperature water-rock reactions have been further investigated in controlled laboratory experiments.

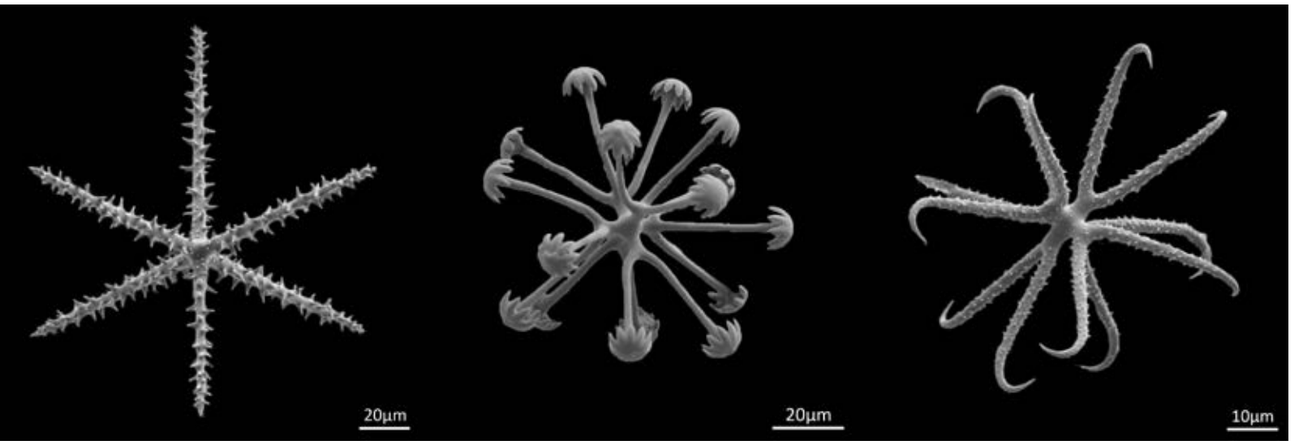
Geochemical and microbial processes within the Leka ophiolite complex are inferred from studies of groundwater, rock and mineral precipitates on fracture surfaces. Hydrogen is produced by the splitting of water molecules. This usually occurs naturally in reduced conditions created by the oxidation of ferrous iron. Surprisingly, we find hydrogen under oxidized conditions in the groundwater at the Leka ophiolite complex. This can be explained by transport and diffusion of hydrogen from the small fractures with reducing conditions where it is produced, to larger fractures that are channels for oxic groundwater.

The groundwater moves through heavily fractured zones of highly altered ultramafic rock, interacting with the rock as it passes through. During these water-rock interactions, the dissolution and oxidation of reduced iron in the minerals of the rock lead to reduction and splitting of water molecules to form hydrogen. This process has been studied both experimentally and in natural environments at elevated temperatures. The mechanism for methane and light hydrocarbon production in ultramafic system is less straightforward, particularly under low temperature conditions, and is still the subject of debate within the scientific community.

Aerobic hydrogen-oxidizing bacteria dominate the microbial community in the groundwater, which fits well with the geochemical analyses of the water. Organisms connected to other reduced compounds are also detected in the groundwater and in the fracture coatings.

Previous studies on hydrogen production through geochemical processes in ultramafic rock have focused primarily on the mineral olivine, and on higher temperature reactions (> 150°C). The results of our low temperature studies show that hydrogen and methane also are formed through low temperature water-rock reactions with ultramafic rocks.

Production of hydrogen and methane through low temperature geochemical processes in altered ultramafic rocks offers a potential energy source for microbial communities in the subsurface environment at temperatures where organisms can thrive. Ultramafic rock appears to be much more common than initially thought in the upper section of the oceanic crust, which means these processes could possibly support a large subsurface biosphere here on Earth and perhaps also on Mars. ■



SPONGES IN NORWEGIAN WATERS

Although sponges in Norwegian waters are rich in species numbers and highly abundant, recent work makes clear that the status of knowledge about species composition and distribution of sponges in the area is generally very low. CGB scientists are filling in these gaps with their research.

Sponges are among the more dominant groups of macro organisms in Norwegian waters both in terms of species and biomass. Around 300 species are known from coastal waters and at least 100 more are added when the entire Norwegian Economic Zone is included. Sponges are highly efficient filter feeders, mainly utilizing the bacterial fraction (normally not used by other organisms), and therefore have a crucial role in the pelagic-benthic relationship. This link is highly important in many of our shelf and fishery bank areas, e.g. the Tromsø-flaket area in the western Barents Sea and on seamounts. Sponges found on sponge grounds in our waters are normally very slow-growing organisms, however, they may grow to one meter in size, weighing 30-40 kg. Specimens of this size are estimated to be several hundred years old. Sponge grounds provide seafloor structure, quite similar to a coral reef and form a very good habitat for other organisms, including fish.

CGB researchers have been working recently with the Norwegian Red List and the Species Database (Artsnavnebasen) compiling and cataloguing known Norwegian sponge species. This work has highlighted the lack of knowledge about sponge species and their corresponding distribution in Norwegian waters. In addition to the Norwegian Research Council, this work was supported by The Norwegian Biodiversity Information Centre (Artsdatabanken) and the Norwegian Academy of Science and Letters.

CGB researchers are finding and cataloguing novel information on some of the most poorly characterized sponge groups. An increasing number of southern species are spreading northwards along the Norwegian coast due to the temperature rise in the NE Atlantic during the last 20-30 years. It is important to track changes in species assemblage over time.

So far almost 20 species of sponges that are new to science have been described, and as least as many have been recorded for the first time in Norwegian waters. Calcareous sponges, previously considered as mainly shallow-water organisms, are exceptionally common in the abyssal (deeper than 2000 m) Norwegian Sea, and as many as 7 of the 10 species encountered there are new to science. Unique and undisturbed hexactinellid sponge grounds on a seamount have been studied in detail, and based on sediment cores and spicule data we can say that these sponge grounds have existed basically unchanged for several thousand years.

This assessment work is based on the comprehensive sponge collections housed by the researchers, Museum collections and samples from a range of ongoing national and international projects. The material comprises unique collections made by manned submersibles and ROVs at very recently discovered hydrothermal vents in the Northern Norwegian Sea as well as cold seeps, deep water coral reefs, and boreal and arctic sponge grounds. The project provides the first overviews of sponge species dominating these special habitats in Norwegian waters.

The project provides species descriptions of all encountered species within these Norwegian sponge groups, species lists with accompanying data on species distributions and identification keys, and contributes to a high standard sponge collection in Bergen Museum with reference material of all species encountered in the project. The CGB plans to organize project workshops as well as an international workshop on sponge taxonomy to further develop a national/Nordic and international cooperation network for sponge research, and the strong focus on the educational aspect of the project enables training of a new generation of sponge taxonomists. ■

INTERNATIONAL SCIENTIFIC DRILLING OF **DEEP PACIFIC CRUST**

CGB researcher Dr. Romain Meyer joined the Integrated Ocean Drilling Program (IODP) Expedition 345, which started in December 2012 at Puntarenas, Costa Rica and ended two months later in Balboa, Panama.

The aim of this particular IODP expedition was to explore the evolution and formation of oceanic crust. The expedition's target was Hess Deep, a 6000 meters deep rift basin that is located approximately 1000 km west of the Galapágos Islands.

The scientists onboard R/V JOIDES Resolution hoped to resolve some key questions on how seafloor spreading forms oceanic crust. The seafloor of Earth's deep oceans, – comprising more than 50 % of Earth's total surface area, is covered by oceanic crust that has been formed during the last 200 million years of Earth's 4.6 billion years long history. For non-geologists, this may seem like an incomprehensibly long time, but for geologists, this reveals how young the ocean basins are, and how fast oceanic crust forms by seafloor spreading.

Since the 1960's, scientific ocean drilling has aimed to better understand the nature and genesis of the deeper layers of the Earth's crust; layers that are relatively inaccessible. This work started with the project MOHOLE, which set out to drill through the entire 6-7 km thick oceanic crust. The technical challenges involved were vastly underestimated and the project ultimately failed. However, overcoming the technical difficulties involved in the process of drilling several kilometer long holes into the oceanic crust spurred the development of alternative approaches. Since that time, seafloor mapping and exploration have demonstrated that in certain areas tectonic processes have exposed the deeper layers of the crust as well as the upper mantle. By targeting such areas, samples of the lower crust and upper mantle can be recovered without the need for drilling extremely deep holes.

Hess Deep is such a "tectonic window". Here the Cocos-Nazca Ridge intersects the East Pacific Rise, where new seafloor forms at a rate of around 10 cm per year. At Hess Deep, the seafloor is rifted apart so that the deep layers of the oceanic crust have become exposed. This locality therefore provides a unique opportunity to learn more about these deep layers of the crust and how the seafloor forms.

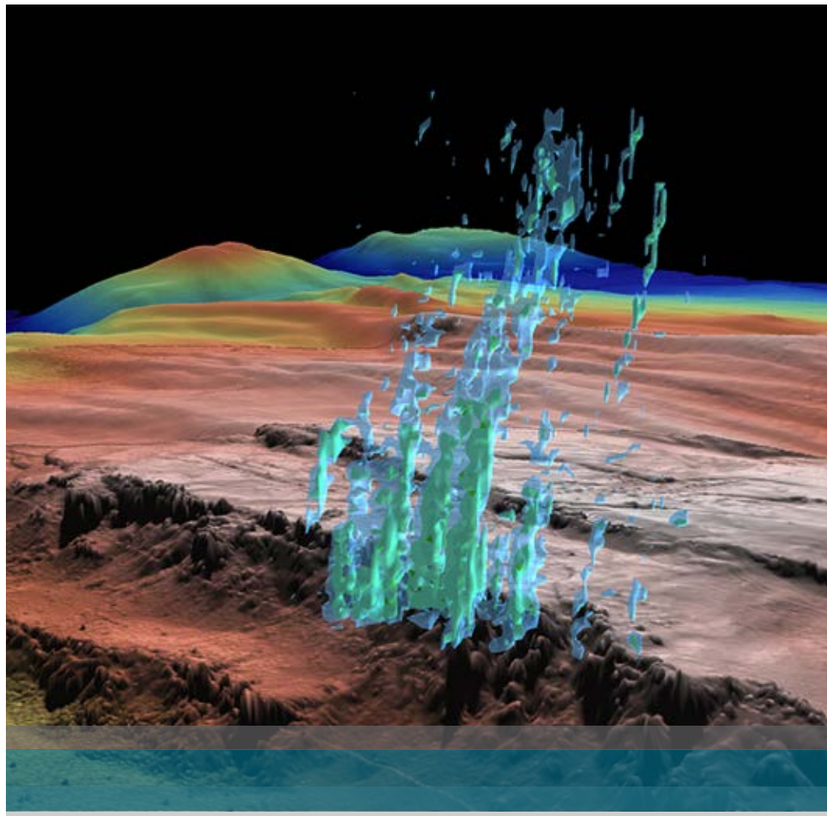
The drilling at Hess Deep was carried out in ~4850 m water under challenging borehole conditions. Despite these challenges, the expedition recovered unique samples from the deepest layer of the oceanic crust. These samples are presently being studied by CGB scientists in collaboration with researchers from France, USA, Germany, Japan, and the UK. The goal is to reveal the processes by which fast-spreading ocean crust forms and, then to study how, once solidified, the crust interacts with hot hydrothermal fluids. For Meyer, being able to be part of the onboard science team was an unprecedented opportunity. Observations of the core once it was on deck gave both Meyer and the other researchers present first insights into the mineralogical and petrologic evolution of these igneous rocks.

The IODP Hess Deep expedition was tremendously successful. The scientific results will provide a whole new reference section of information about fast-spreading lower crust, and underline the continued necessity for ocean drilling to explore and understand the on-going fundamental processes that are evolving and reshaping Earth. ■

RESEARCH THEMES

The research at the Centre for Geobiology is focused on five themes. The following are updates on the research carried out under each of these themes in 2012.

GEODYNAMICS OF THE DEEP SEAFLOOR



This theme involves deep-sea exploration and searching for new extreme environments. It provides a foundation for the Centre's geobiological research by providing knowledge about the geological and geochemical context of the Centre's focus sites. In addition, researchers working in this theme have several independent research objectives relating to hydrothermal systems, seabed fluid flow and the geodynamics of spreading ridges.

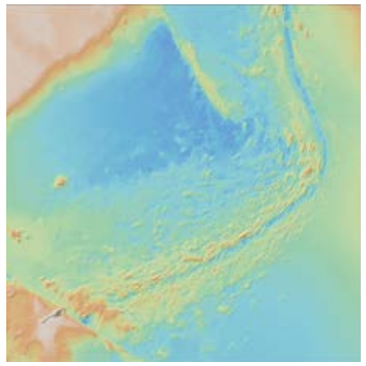
In 2012 we have developed two key acoustic data resources to support the diversity of research at the Centre. The first resource involves developing unified multi-scale bathymetric maps for the entire Arctic Mid-Ocean Ridge system, which provide critical contextual information for all the research done at CGB. These maps integrate bathymetry from satellite observations, CGB and NPD ship-based bathymetric surveys, and super high-resolution AUV acquired multibeam bathymetry. Altogether they span more than three orders of magnitude in resolution and represent the most detailed view of the Arctic Mid-Ocean Ridge system ever compiled. These maps will be used to support geological, geochemical, and biological studies at all the CGB focus sites, and will foster an increased understanding of the interconnection between individual systems.

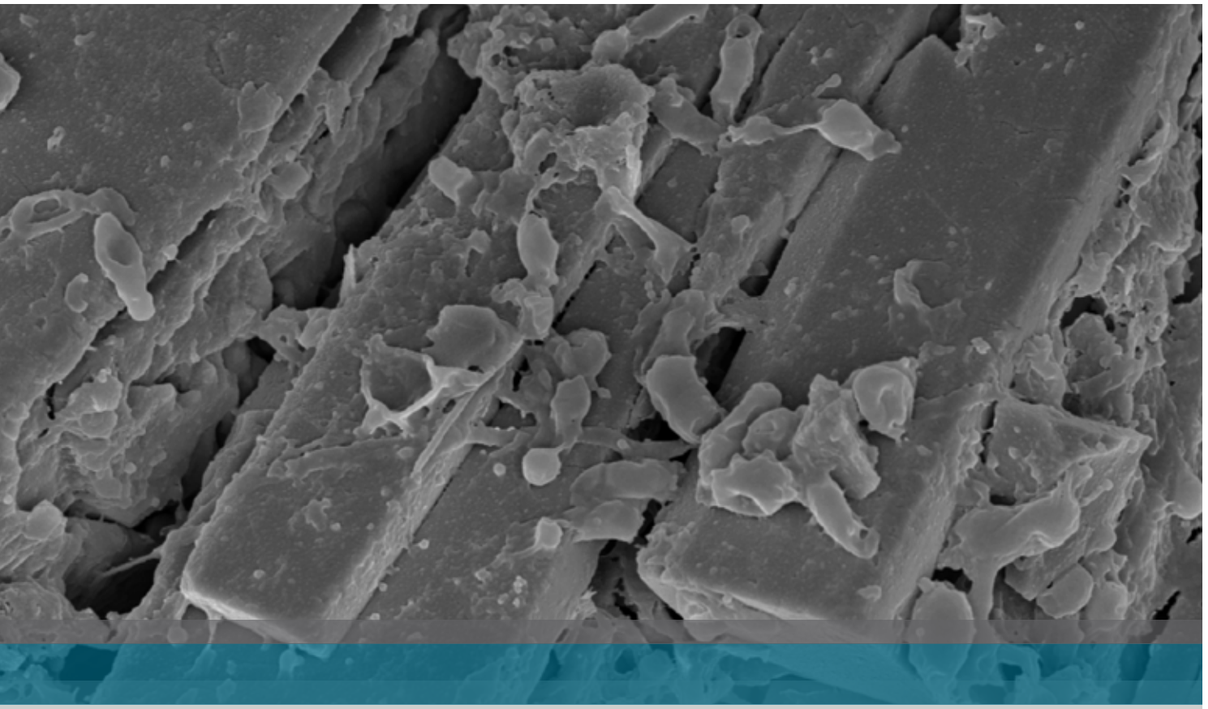
The second acoustic data resource involves further exploration of water column acoustic signatures. The Centre's unique natural laboratory, the CO2 vents at the Jan Mayen vent fields, provided the field site and the water column capability of the R/V G.O.Sars' new EM302 multibeam echosounder was used to collect the data. This state-of-the-art system allowed us to image rising bubbles of CO_2 in 3-D with high spatial resolution. It enables us to study the dynamics of the bubble plumes with future time-series acoustic observations. In this particular setting, where the bubbles rise to at least 150m below the sea surface, these plumes are a potentially important source of CO_2 to the entire water column. Acoustic studies of these and other bubble plumes will significantly enhance our understanding of the dynamic interactions between seafloor gas sources and the overlying water column.

As well as acoustic studies of seafloor dynamics, researchers working in the geodynamics of the seafloor theme are delving into deep crustal and mantle processes at slow spreading ridges. The upper mantle beneath the arctic mid-oceanic ridge is known to present a very unique geochemical signature. Basalts, produced by mantle melting, are relaying this signature to the seafloor surface where the Centre has been collecting samples for a number of years. Using Lu–Hf and Sm–Nd isotope systems, which have proven to be useful in tracking the signatures of ancient mantle events, we trying to understand more about why this atypical mantle is present in the north Atlantic area. These new geochemical data will give us better understanding structure of the upper mantle in the vicinity of the Jan Mayen hot spot and provide more information about the geodynamical history of this region.

In addition, researchers are studying crust-mantle interactions during the birth of an ocean. Particular focus has been on the Jan Mayen micro-continent and its formation as a result of continental rifting and establishment of a ridge system. In collaboration with the Norwegian Petroleum Directorate in-situ rock samples have been collected from the Jan Mayen Ridge using an ROV. Ongoing geochemical and geochronological studies of these sedimentary and igneous samples are now revealing information about the evolution of the Norwegian-Greenland Sea.

Finally, the involvement of CGB scientists in the Hess Deep international drilling campaigns have provided the CGB with a unique sample collection of shallow mantle and the lowest oceanic crust material that will enhance our understanding of crustal accretion at fast spreading ridges (see page 11) ■





WATER-ROCK-MICROBE INTERACTIONS & THE DEEP BIOSPHERE

Low-temperature alteration of ultramafic rocks continued to be a main research focus for this theme in 2012. Experimental laboratory studies using naturally occurring rocks showed that water reactions with not only primary olivine but also with secondary minerals from earlier alteration stages can result in production of significant amounts of hydrogen and methane. Interestingly, the nitrogen-species ammonium, nitrite and nitrate were also found to be produced during these low-temperature water-rock reactions. Further studies are needed, however, to unravel the exact formation mechanisms or sources of these compounds. As low-temperature alteration of ultramafic rocks is likely to be a common process at slow to ultraslow spreading mid-ocean ridges, the associated production of these biological important compounds could potentially support a globally significant deep biosphere in these habitats.

Further studies of barite deposits and their associated low-temperature venting fluids, which occur at the flank of the Loki's Castle black smoker field in the Norwegian-Greenland Sea, have revealed that this is a result of subsurface mixing of rising high-temperature fluids and cold percolating sea water, combined with microbial sulphate reduction. The high hydrogen and methane contents of the high-temperature fluid are likely to fuel the microbial reduction of seawater sulphate. The findings indicate that this may be a major subsurface microbial process not only locally in the hydrothermal mound but possibly also in much larger and deeper parts of the ocean crust were such mixing is going on.

This year researchers from this theme also have been involved in work that shows that geochemical stratification within seafloor sediments correlates with stratification of its microbial community. This work involved sediment cores from the seafloor near the Loki's Castle hydrothermal vent fields, one of the Centre's natural laboratories. It was a truly multi-disciplinary project, where the researchers were able to show that knowing something about the geochemistry of particular layers enables researchers to predict the kinds of reactions – and therefore the kinds of microbes – that might be found in a given layer.

The theme has also continued their research on mine tailings in Norwegian fjords in order to evaluate the stability of toxic elements and the importance of mineral composition of the deposits. Core samples of gabbroic deposits have been collected in addition to the earlier samples of olivine and sulphides rich deposits. Using a combination of geochemical and microbiological studies, on-going submarine biogeochemical processes and their effects on the mobility of heavy metals will be documented. Together with similar weathering studies of deep-sea hydrothermal sulphide deposits, the results will increase our understanding of the environmental challenges connected with marine tailing storage and potential future deep-sea mining in Norwegian territorial waters.

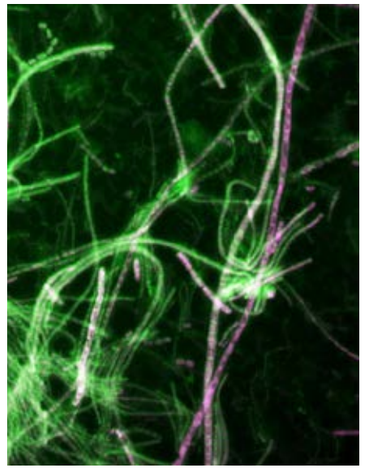
Researchers from this theme have also been working on different aspects of subseafloor CO_2 storage. They have been involved in studies at another of CGB's natural laboratories, the Jan Mayen Vent Fields. Here they have been able to observe effects of CO_2 leakage in a natural setting. ■

LIFE IN EXTREME ENVIRONMENTS AND ROOTS OF LIFE

In this theme we focus on understanding the adaptations and metabolic properties of the microorganisms found in hydrothermal vent fields located along the Arctic-Mid-Ocean Ridge (AMOR). We evaluate their interactions with the geosphere and use this knowledge to gain insights into life on early Earth. During past years researchers in this theme have made great advances in adapting molecular biology technologies to the study of microbiological samples from these sites. We are now in a position to carry out (meta)genomics, metatranscriptomics and metaproteomics analyses of samples with state-of-the-art technology.

This year at the Centre we completed the first whole-genome sequencing of a hyperthermophilic sulphate-reducing archaeon. The data obtained from this project will allow detailed analyses of the organism's metabolic properties and form the basis for comparative genome analyses. We have also determined the metabolic properties of an Epsilonproteobacteria-dominated biofilm on the Loki's Castle hydrothermal chimney. Epsilonproteobacteria are key-players in bio-corrosion processes and this year we received a grant from VISTA to support our work focusing understanding the metabolisms participating in this process.

In this theme we also lead a bio-prospecting project in the Arctic mid-ocean ridge hydrothermal vent fields . The biological material of these deep-sea habitats has exceptional biotechnological potential. We are a member of the management team in a new National biotechnology project, through which we aim to develop a biotechnological pipeline that will enable Norwegian Industry to directly use the genetic reservoir from AMOR. We are also exploring possible new applications from this novel genetic reservoir. ■

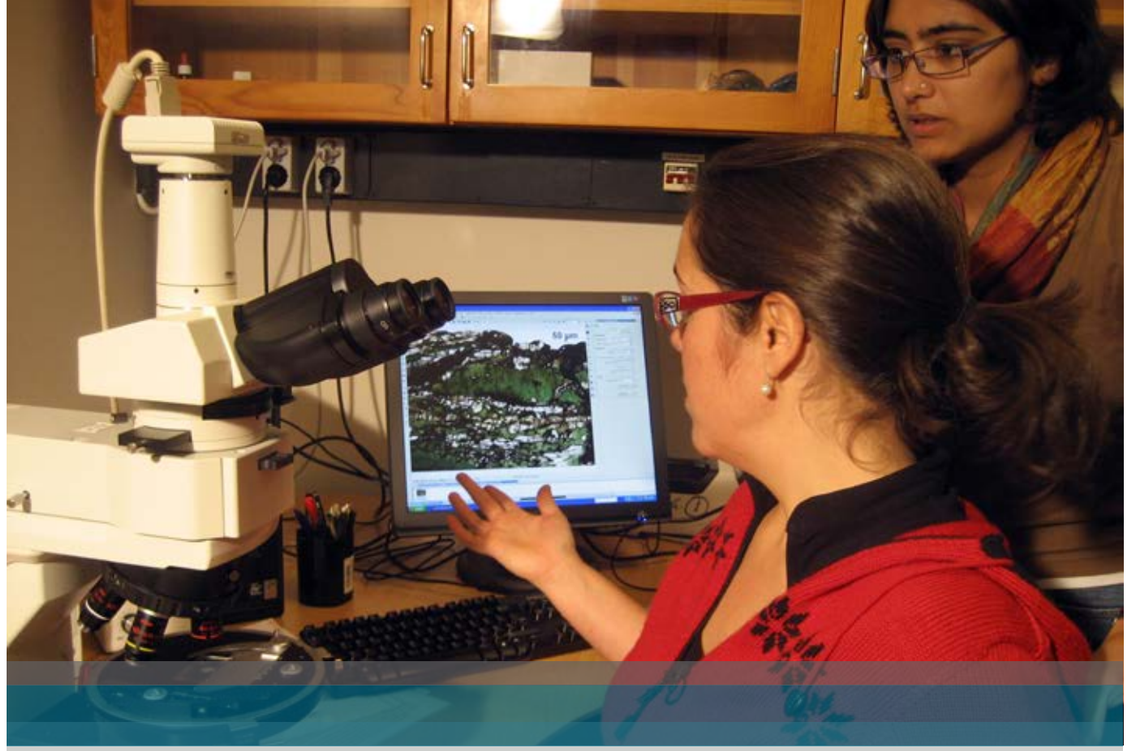


"I carried out my PhD work at the Center for Geobiology. It was a great experience for me from both a scientific and social point of view. CGB has a unique research environment, where both microbiologists and geologists work together to interpret results from the unique sampling material collected during cruises and fieldwork. Also, the future-oriented research at the CGB involves the use of cutting-edge technology, which gives me an excellent start on my scientific career."

Dr. Irene Roalkvam, CGB scientist, defended her PhD thesis in 2012

VENT AND SEEP BIOTA

This theme involves the exploration of fauna associated with reduced habitats and seamounts in the deep sea in the Arctic and the NE Atlantic. Among the main objectives in the ongoing work is to investigate local adaptations and speciation processes, as well as addressing potential ecological and evolutionary connectivity between different chemosynthetic habitats in the area, including hydrothermal vents, cold seeps and sunken wood. We have shown that chemosynthetic habitats in the Norwegian- and Greenland seas host an endemic and highly specialized fauna. More than 90 % of this specialized fauna represents new and undescribed species, and extra effort has therefore been concentrated on describing this novel fauna. There are obvious similarities between the fauna found at hot vents along AMOR, the fauna of cold seeps along the Norwegian margin, and from wood-falls in the abyssal Norwegian Sea. A shared group of keystone species directly or indirectly dependent on chemosynthetically derived energy has been identified, including rissoid gastropods, maldanid and ampharetid polychaetes, as well as a new genus of amphipods. Our most recent work has also shown that the hydrothermal plumes fertilize the adjacent waters, resulting in specialization and adaptation also in the planktonic systems surrounding hydrothermal vents and cold seeps. Molecular tools are now being used to provide more information about the evolutionary history of this special fauna, and to explore the possible connections between the Atlantic and Pacific reduced habitat faunas through time. ■



EARLY EARTH AND BIOSIGNATURES

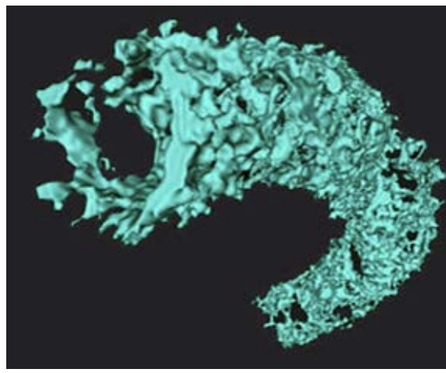
In the year the rover Curiosity landed and began exploring Mars, our group actively pursued detection methods for traces of life in the early rock record and mapped the nature of Archean Earth environments. Planetary scientists believe that 3+ billion years ago Mars may have been more hospitable to life than the early Earth. Studies of the early rock record on Earth are an invaluable baseline for establishing when life began on Earth and for designing how and where to seek potential traces of life in our solar system.

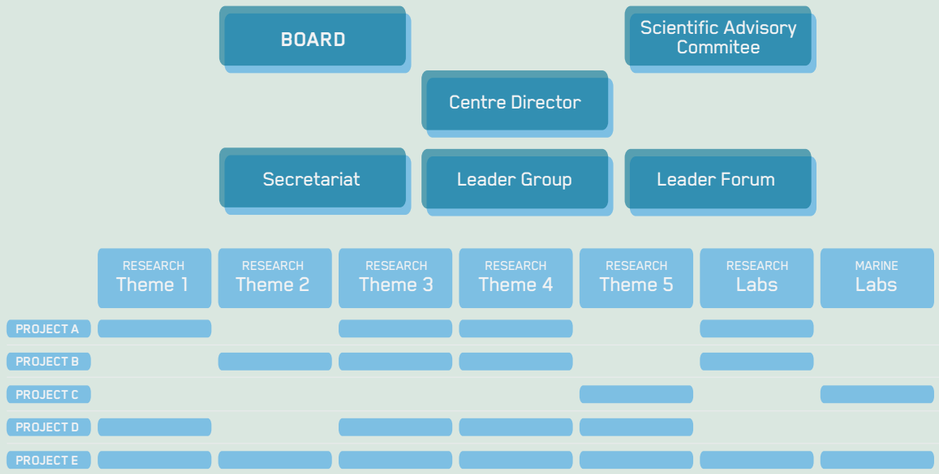
This year our ongoing investigations of titanite microtextures in c. 3.45 billion-year-old subseafloor pillow lavas from the Barberton Greenstone Belt, South Africa yielded important results. Nanoscale chemical mapping (NanoSIMS) concluded that organic linings previously reported to be associated with these candidate traces of life are absent and thus are an unreliable biosignature. Independent of the textural evidence, however, this study found pronounced sulfur isotope fractionations in the ancient subseafloor rocks which may represent a new chemical trace of early microbial life.

A separate study on a classic c. 3.34 billion-year old sequence of oceanic rocks from the Barberton Greenstone Belt combined field and petrographic observations with thermodynamic phase modeling to provide new constraints on their preserved pressure-temperature-fluid conditions. These findings illustrate how the metamorphic history of Archean oceanic rocks can be derived and used to decipher their alteration history in fossil hydrothermal systems, and also to constrain their geodynamic setting. Taken as a whole, this study provided new evidence for plate-tectonic type processes operating on the mid-Archean Earth.

This year CGB scientists and collaborators developed new methods for visualizing fossilized microbial remains in another of our studies investigating ancient microfossil bearing cherts from Northern Canada and West Australia. Using a focused ion beam, researchers made 3D tomographic reconstructions of organic microfossils revealing a wealth of information about their subcellular architecture and preservation processes. We are combining this approach with chemical and isotopic data obtained by NanoSIMS to yield new insights into fossilized microbial ecosystems on the early Earth.

In summary, 2012 was an exciting year for studies of the Archean rock record and came to a close with the presentation of our recent results at the AGU conference in a session entitled “The Early Earth”. The data obtained and methodologies developed this year will underpin continuing work to understand the nature of Archean Earth environments and aid efforts to ratify chemical and textural biosignatures that may one day be discovered on Mars. ■





ORGANISATION

The Centre for Geobiology (CGB) is part of the Faculty of Mathematics and Natural Sciences at the University of Bergen (UiB) and is hosted by the Departments of Biology and Earth Science.

The Centre has adopted a matrix approach that facilitates and promotes the inter- and multi-disciplinarity necessary to attain the Centre's research goals. In this model the Centre activities – the rows in the matrix – are organised as projects. The columns of the matrix are the crosscutting themes of the Centre research plan. In this model the thematic leaders (leader group) are responsible for developing the research themes by initiating new and overseeing existing projects. It allows young, early-stage researchers to acquire leadership training as individual project leaders (leader forum).

SCIENTIFIC ADVISORY COMMITTEE

Antje Boetius	Max-Planck-Institut für Marine Mikrobiologie, Bremen Germany
Cindy Van Dover	Duke University Marine Laboratory, North Carolina, USA
Chris German	Woods Hole Oceanographic Institution, Massachusetts, USA
Frances Westall	Le Centre de Biophysique Moléculaire CNRS, Orléans, France

THE GOVERNING BOARD

Dag Rune Olsen, (leader)	Dean of the Faculty of Mathematics and Natural Sciences
Gunn Mangerud	Head of the Department of Earth Sciences
Anders Goksøyr	Head of the Department of Biology
Svenn-Åge Dahl	Director of the Department of Research Management at UiB
Ole Tumyr	Employee representative from the Department of Earth Sciences
Runar Stokke	Employee representative from the Department of Biology

CENTRE FUNDED PROJECTS

The CGB research is carried out through a number of external projects, and Centre funded projects which fall within the context of the five research themes: Geodynamics of the Deep Seafloor, Water-Rock-Microbe Interactions & the Deep Biosphere, Life in Extreme Environments & Roots of Life, Early Earth and Bio-signatures, and Vent and Seep Biota.

In 2012 the CGB Leader Group also decided to continue the Seed Project initiative whereby Centre researchers engaging in short -term enterprises can apply for funding for 1 - 2 years. Seed projects funded by CGB in 2012 are as follows:

Archean Geodynamics & Environments for Life (Eugene G. Grosch)

Multiple sulfur isotope analysis of microbially-mediated mineral sulfides at the micron scale (David Wacey, Nicola McLoughlin and William Hocking)

Fluid - rock interaction during alteration of mantle lithosphere - an example of the Leka ophiolite complex (Jiri Konopasek, Rolf Birger Pedersen and Jan Kosler)

Developing laser-ablation ICP-MS methods for use in U/Th dating of geological and archaeological samples (Jan Kosler and Elizabeth Farmer)

Is methane oxidation in extreme geothermal environments metal independent (Nils-Kåre Birkeland)

Analysis of 16S rRNA and mcrA genes in cryotubert tundra soil (Vigdis Torsvik)

RESEARCH
PROJECTS 2012

PROJECTS FUNDED BY THE RESEARCH COUNCIL OF NORWAY

DURATION	TITLE	LEADER*/PARTNER**
2009 – 2013	«FarDeep» The Emergence of an Aerobic World – Drilling Early Earth Project	Victor Melezhik*
2009 – 2017	«SUCCESS» Subsurfac CO2 storage – Critical Elements and Superior Strategy	Rolf Birger Pedersen**/ Ingunn H Thorseth**
2010 – 2012	«CryoCARB» Long-term Carbon Storage in Cryoturbated Arctic Soils	Christa Scleper*/ Tim Urich**/Vigdis Torsvik**
2010 – 2013	Hotspot Rift Interaction & Geochemistry of the North Atlantic Mantle: the Aegir Ridge 'Hole' in the Iceland Hotspot	Rolf Birger Pedersen**
2011 – 2013	«IMPTAIL» Improved submarine tailing placements in Norwegian Fjords	Ingunn H. Thorseth**
2011 – 2014	«BIOGOLDMINE» Mining of a Norwegian biogoldmine through metagenomics	Ida Helene Steen*
2011 – 2014	Biological methane oxidation by methanotrophic verrucomicrobia under hot and acidic conditions	Nils Kåre Birkeland*
2012 – 2017	Enzyme development for Norwegian biomass – mining Norwegian biodiversity for seizing Norwegian opportunities in the bio-based economy (NorZymeD)	Ida Helene Steen*

INTERNATIONAL PROJECTS ORGANISED OR FUNDED THROUGH THE EUROPEAN SCIENCE FOUNDATION (ESF)/ERA-NET

DURATION	TITLE	COORDINATOR*/ PRINCIPAL INVESTIGATOR**/COLLABORATOR***	PROGRAMME
2008 – 2013	«H2DEEP» Ultra-slow spreading and hydrogen-based biosphere: A site survey proposal for zero-age drilling of the Knipovich Ridge.	Rolf Birger Pedersen* (Main Coordinator)	ESF/EuroMARC (EUROCORES)/ NFR FREPRO
2010 – 2012	«CryoCARB» Long-term Carbon Storage in Cryoturbated Arctic Soils Individual project 5: High-resolution Microbial Community Structure Christa Schleper**/ Vigdis Torsvik***/ Tim Urich***	Christa Schleper*	ESF/ PolarCLIMATE/ NFR
2010 – 2013	«MicVirEcolHotSprings» Microbial and viral ecology of hot spring environments with emphasis on 454 pyrosequencing and microbial and viral interactions	Lise Øvreås, Ruth-Anne Sandaa	EU/Marine Curie/ International Outgoing Fellowships for Career Development
2011 – 2014	ECO2 – Sub-seabed CO_2 Storage: Impact on Marine Ecosystems	Rolf Birger Pedersen**	EU

PROJECTS FUNDED BY OTHER SOURCES (PUBLIC AND PRIVATE)

DURATION	TITLE	LEADER*/PARTNER**
2009 – 2012	Direct dating of diagenic processes by in-situ analysis of U-Th-Pb isotopes in authigenic phosphate minerals by laser ablation ICP-MS	Jan Kosler* Statoil
2009 – 2012	Metagenomics and metaproteomics of deep arctic hydrothermal systems	Ida Helene Steen* VISTA
2009 – 2012	Subsurface metagenomics, functional microbial diversity analysis and gene discovery in deep and hot petroleum reservoirs	Nils Kåre Birkeland* VISTA
2010 – 2015	Earth System Modelling	Jan Kosler**, Bjarte Hannisdal**, Jiri Slama** Statoil
2010 – 2012	De Novo sequencing of iron oxidising bacteria through reconstruction of microbial genomes from iron hydroxide deposits at the Arctic deep seafloor	Lise Øvreås*, Meltzer Høyskolefond
2010 – 2012	Taxonomy and distribution of sponges (Porifera) in Norwegian waters	Hans Tore Rapp* NTNU/Artsdatabanken
2011 – 2012	OD Jan Mayen Ryggen II	Rolf Birger Pedersen* Oljedirektoratet
2011 – 2013	Deep-water sponges of the Greenland-Iceland-Norwegian Seas	Hans Tore Rapp* Det Norske Videnskapsakademi
2011 – 2014	The Emergence of Life on Earth 3+ billion years ago	Nicola McLoughlin*, UiB/BFS
2012 – 2015	Better handling of microbial induced corrosion during operation	Ida Helene Steen* VISTA
2011 – 2016	Preparing for sub-sea storage of CO2: Baseline gathering and monitoring for the North Sea (CO2 – Base)	Rolf Birger Pedersen** CLIMIT/GASSNOVA

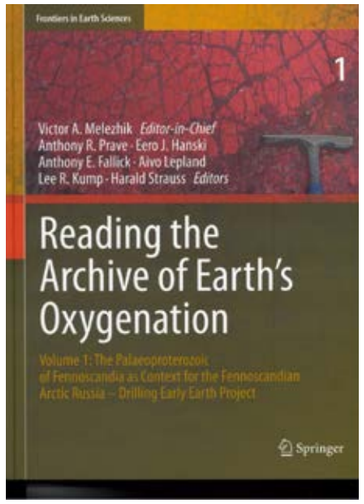
SCIENCE
DISSEMINATION

FIELD COURSE HIGHLIGHT

This summer a group of Nordic geobiology researchers collaborated to hold the second field course of its kind in geobiology in Iceland. Supported by a NordPlus initiative, the course was held in Reykjavík, Iceland, in August 2012. Iceland, with its unique situation on a mid-ocean ridge, and with countless hot springs and other geothermal features teeming with life, constitutes an ideal natural laboratory for the study of the interface between the geosphere and the biosphere.

19 MSc and PhD students from Norway, Denmark, Sweden, Finland and Iceland attended the 2012 course, including 6 Norwegians. The course content includes lectures, field trips as well as practical exercises designed to introduce the students to standard field and laboratory techniques used in microbiology, molecular ecology, biogeochemistry and geology. Another course will be held summer 2013.

ANTHOLOGY HIGHLIGHT



The recently published, three-part book, "Reading the Archive of Earth's Oxygenation" (Springer 2012, edited by CGB adjunct professor Victor Melezhik) is a multinational geologic achievement documenting a key period of Earth's early geobiosphere. Around 2.3 billion years ago, atmospheric free oxygen increased dramatically, altering the previously anoxic Earth atmosphere to an irreversibly oxic environment. The changes in chemical cycling during this period of progressive oxygenation of Earth's surface environments was catastrophic to existing organisms, but also created the modern atmospheric conditions necessary for terrestrial life as we know it.

In 2007, the International Continental Scientific Drilling Project (ICDP) coordinated the FAR-DEEP expedition in response to new initiatives to explore the evolution of the Earth and its ancient biosphere by examining key time intervals. 3560 meters of fresh drill core were recovered and subsequently archived at the NGU.

The book series shows these cores collected during the FAR-DEEP expedition and natural exposures of the Palaeoproterozoic rocks of the Fennoscandian Shield meticulously documented using high-quality photographs. The books extraordinary high-resolution geological photos are associated with geochemical data, maps, and time-slice reconstructions of palaeoenvironmental settings, adding critical information about the Earth system dynamics in reaction to the progressive oxygenation of terrestrial biosphere and geosphere.

The dialogue in these volumes goes far beyond a summation of the work completed in the FAR-DEEP project: invited expert authors delve into a wide-ranging review of knowledge of the Palaeoproterozoic events and put into context the relationship of these events with Earth's oxygenation. The text emphasizes outstanding questions for future researchers to uncover and acts as a field guide to help experienced researchers and geology students alike recognize these rock formations at disparate locations.

The cores from the FAR-DEEP project are publically available at the Geological Survey of Norway in Trondheim. See the ICDP and Geological Survey of Norway websites for more details on the FAR-DEEP project.

CO_2 Bubbles on top of a bacterial mat at a vent in La Palma island.

STAFF

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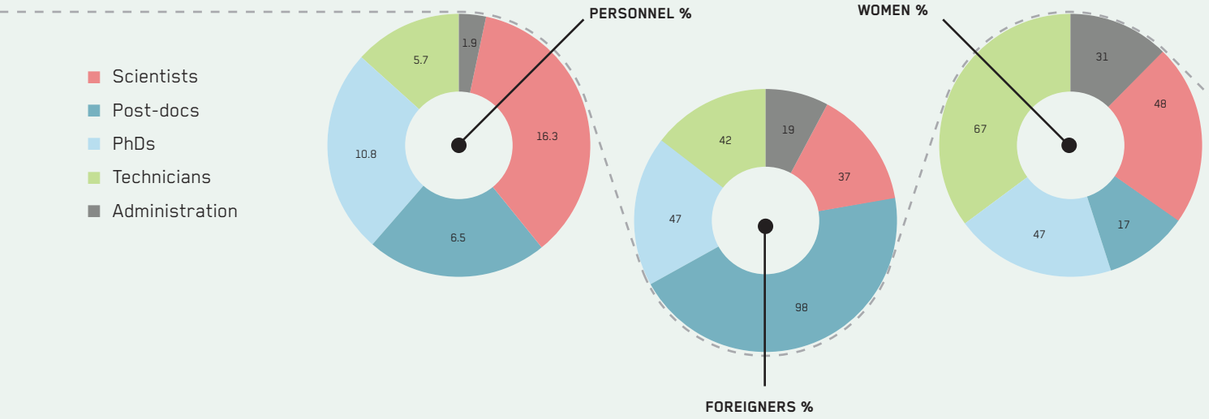
Hesthammer, Steinar
Lappegård, Heidi
Olesin, Emily

PERSONNEL SUMMARY

CATEGORY	PERSON-YEARS	FOREIGNERS (% PERSON-YEAR)	WOMEN (% PERSON-YEAR)
Scientists	16.3	37	48
Post-docs	6.5	98	17
PhDs	10.8	47	47
Technicians	5.7	42	67
Administration	1.9	19	31
Total	**41.2**	**48**	**42**

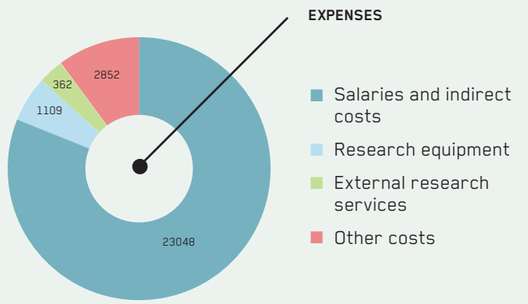


FUNDING AND EXPENSES

FUNDING	(1000 NOK)
Research Council of Norway	9873
University of Bergen	17498
Total funding	**27371**

OTHER PROJECT FUNDING	(1000 NOK)
International projects	2569
Other Research Council projects	8091
Other public funding	4805
Private funding	370
Total	**15835**

EXPENSES	(1000 NOK)
Salaries and indirect costs	23048
Research equipment	1109
External research services	362
Other costs	2852
Total expenses	**27371**



SELECTED **PUBLICATIONS** 2012

In 2012 CGB's communication efforts continued to increase, including activity directed at both scientific and more general public audiences. CGB researchers have produced more than 70 scientific publications and over 120 scientific presentations in 2012. Below is a list of some selected publications.

1. Baskar, Sushmitha; Baskar, Ramanathan; Thorseth, Ingunn Hindenes; Øvreås, Lise; Pedersen, Rolf B. Microbially induced iron precipitation associated with a neutrophilic spring at Borra Caves, Vishakhapatnam, India. Astrobiology 2012; Volum 12.(4) s. 327-346.
2. Connelly, Douglas P.; Copley, Jaonathan T.; Murton, Bramley J.; Stansfield, Kate; Tyler, Paul A.; German, Cristopher R.; Van Dover, Cindy L.; Amon, Diva; Furlong, Maaten; Grindlay, Nancy; Hayman, Nicholas; Hühnerbach, Veit; Judge, Maria; Le Bas, Tim; McPhail, Stephen; Meier, Alexandra; Nakamura, Koichi; Nye, Verity; Pebody, Miles; Pedersen, Rolf B.; Plouviez, Sophia; Sands, Carla; Searle, Roger C.; Stevenson, Peter; Taws, Sarah; Wilcox, Sally. Hydrothermal vent fields and chemosynthetic biota on the world's deepest seafloor spreading centre. Nature Communications 2012; Volum 3.
3. Dahle, Håkon; Roalkvam, Irene; Pedersen, Rolf B.; Thorseth, Ingunn Hindenes; Steen, Ida Helene. The versatile in situ gene expression of an Epsilonproteo-bacteria-dominated biofilm from a hydrothermal chimney. Environmental Microbiology Reports 2012
4. Drost K., Wirth R., Košler J., Fonneland Jørgensen H. (2012): Chemical and structural relations of epitaxial xenotime and zircon substratum in sedimentary and hydrothermal environments – a TEM study. Contributions in Mineralogy and Petrology, DOI 10.1007/s00410-012-0833-6. in press.
5. Fliegel, Daniel; Knowles, Emily; Wirth, Richard; Templeton, Alexis; Staudigel, Hubert; Muehlenbachs, Karlis; Furnes, Harald. Characterization of alteration textures in Cretaceous oceanic crust (pillow lava) from the N-Atlantic (DSDP Hole 418A) by spatially-resolved spectroscopy. Geochimica et Cosmochimica Acta 2012; Volum 96. s. 80-93.
6. Furnes, Harald; Robins, Brian; de Wit, Maarten J. Geochemistry and petrology of lavas in the Upper Onverwacht Suite, Barberton Mountain Land, South Africa. South African Journal of Geology. 2012; Volum 115.(2) s. 171-210.
7. Gittel, Antje; Kofoed, Michael V.W.; Sørensen, Ketil B.; Ingvorsen, Kjeld; Schramm, Andreas. Succession of Deferribacteres and Epsilonproteobacteria through a nitrate-treated high-temperature oil production facility. Systematic and Applied Microbiology 2012; Volum 35.(3) s. 165-174.
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9. Hannisdal, Bjarte; Henderiks, Jorijntje; Liow, Lee Hsiang. Long-term evolutionary and ecological responses of calcifying phytoplankton to changes in atmos-pheric CO2. Global Change Biology 2012; Volum 18.(12) s. 3504-3516.
10. Jaeschke, Andrea; Jørgensen, Steffen Leth; Bernasconi, Stefano M.; Pedersen, Rolf B.; Thorseth, Ingunn Hindenes; Früh-Green, Gretchen L. Microbial diversity of Loki's Castle black smokers at the Arctic Mid-Ocean Ridge. Geobiology 2012; Volum 10.(6) s. 548-561.
11. Jørgensen, Steffen Leth; Hannisdal, Bjarte; Lanzén, Anders; Baumberger, Tamara; Flesland, Kristin; Fonseca, Rita; Øvreås, Lise; Steen, Ida Helene; Thorseth, Ingunn Hindenes; Pedersen, Rolf B.; Schleper, Christa Maria. Correlating microbial community profiles with geochemical data in highly stratified sediments from the Arctic Mid-Ocean Ridge. Proceedings of the National Academy of Science of the United States of America 2012; Volum 109.(42) s.E2846-E2855.
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16. Møller, Kirsten; Schoenberg, Ronald; Pedersen, Rolf B.; Weiss, Dominik; Dong, Shuofei. Calibration of the new certified reference materials ERM-AE633 and ERM-AE647 for copper and IRMM-3702 for zinc isotope amount ratio determinations. Geostandards and Geoanalytical Research 2012; Volum 36.(2) s. 177-199.
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19. Roalkvam, Irene; Dahle, Håkon; Chen, Yifeng; Jørgensen, Steffen Leth; Haflidason, Haflidi; Steen, Ida Helene. Fine-scale community structure analysis of ANME in Nyegga sediments with high and low methane flux. Frontiers in Microbiology 2012; Volum 3. s. 1-13.
20. Slama, Jiri; Kosler, Jan. Effects of sampling and mineral separation on accuracy of detrital zircon studies. Geochemistry Geophysics Geosystems 2012; Volum 13.(5).
21. Stokke, Runar; Roalkvam, Irene; Lanzén, Anders; Haflidason, Haflidi; Steen, Ida Helene. Integrated metagenomic and metaproteomic analyses of an ANME-1-dominated community in marine cold seep sediments. Environmental Microbiology 2012; Volum 14.(5) s. 1333-1346.
22. Tandberg, Anne Helene Solberg; Rapp, Hans Tore; Schander, Christoffer; Vader, Wim; Sweetman, Andrew Kvassnes; Berge, Jørgen. Exitomelita sigynae gen. et sp. nov.: a new amphipod from the Arctic Loki Castle vent field with potential gill ectosymbionts. Polar Biology 2012; Volum 35.(5) s. 705-716.
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24. Wacey, David; Menon, Sarah; Green, Leonard; Gerstmann, Derek; Kong, Charlie; McLoughlin, Nicola; Saunders, Martin; Brasier, Martin D. Taphonomy of very ancient microfossils from the 3400 Ma Strelley Pool Formation and 1900 Ma Gunflint Formation: New insights using a focused ion beam. Precambrian Research 2012; Volum 220-221. s. 234-250.
25. Økland, Ingeborg Elisabet; Huang, Shanshan; Dahle, Håkon; Thorseth, Ingunn Hindenes; Pedersen, Rolf B. Low temperature alteration of serpentinized ultramafic rock and implications for microbial life. Chemical Geology 2012; Volum 318. s. 75-87.

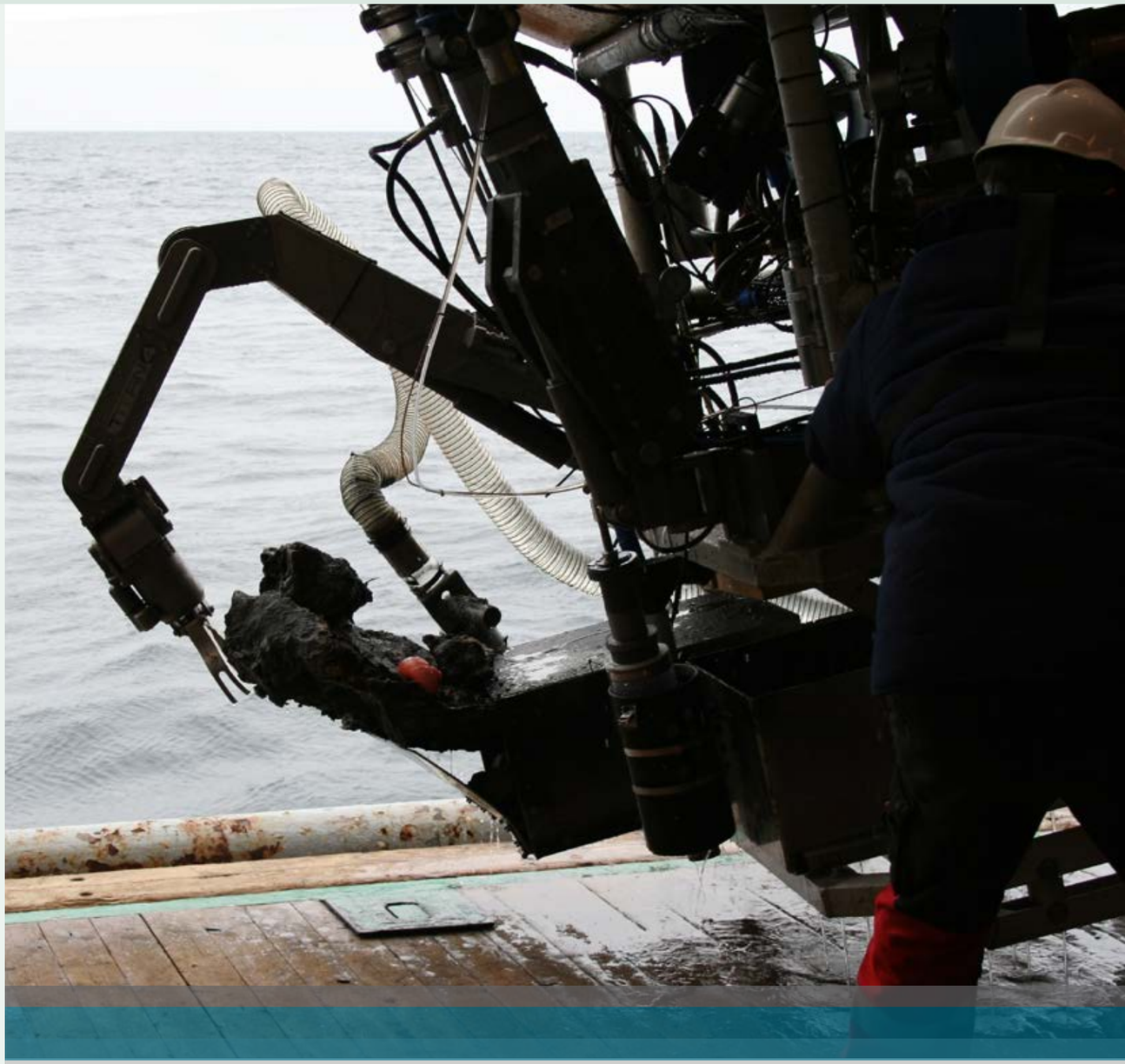

PHOTO CREDITS

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