Annual Report 2011

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

CENTRE FOR
GEOBIOLOGY

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DIRECTOR'S COMMENT

The Centre for Geobiology (CGB) passed its mid-term evaluation in 2011. The international panel that evaluated the Centre concluded that the establishment of CGB had been successful, and that the Centre's performance in the first three years had been "exceptionally good". For the core group of researchers that have stayed committed to the Centre's development it was rewarding to read the many positive comments by these international experts:

"The Centre has done an exemplary job of focusing in the early years on establishing a strong research group and excellent analytical facilities, as well as participating in international science projects, and attracting a new group of students to participate in integrated and interdisciplinary science".

As in ski jumping, the challenge now is to transform the speed from the take-off ramp into a long and stable flight and then to prepare for a safe landing.

As we approach mid-term there are a number of positive developments. The young researchers now provide a significant lift to the scientific discussions and production at the Centre. Their research papers are being accepted for publication in high-ranking journals. In this report we highlight a paper recently published in Science by one of our young researchers to exemplify this exciting trend.

The curiosity-driven research that forms the basis for the Centre's activities is now resulting in a portfolio of more applied research projects. Only a few years ago deep-sea research was regarded as an exotic academic activity. Today there is a growing demand for knowledge about this environment in order for government leaders to make informed socially relevant decisions. In a wide range of areas from new process-relevant enzymes to new metal source, the deep-sea is becoming the newest frontier for resource prospecting.

As stakeholders and government leaders raise questions about these resources and the environment within the deep-sea parts of the Norwegian exclusive economic zone, the knowledge and know-how that are available at CGB are suddenly relevant. Within the first half of the Centre's lifetime the significant investment in long-term basic research funding provided by UiB and NFR is paying off.

When CGB, in five years' time, ends its term as a Centre of Excellence it is important that the deep-sea competencies and know-how that have been developed are carried on. As we see it, this would best be done through the establishment of a national deep-sea submergence facility. CGB is therefore leading an initiative to establish and develop such a facility. Recently, this initiative was selected to be on the national roadmap for research infrastructure by the Norwegian Research Council. Although funding has yet not been provided, a national deep-submergence facility is now within reach.

A thick succession of Cambrian through Lower Carboniferous marine sedimentary rocks exposed in Montana. These rocks record the coming and going of shallow seas, which this study shows affects both biodiversity and patterns of sedimentation.

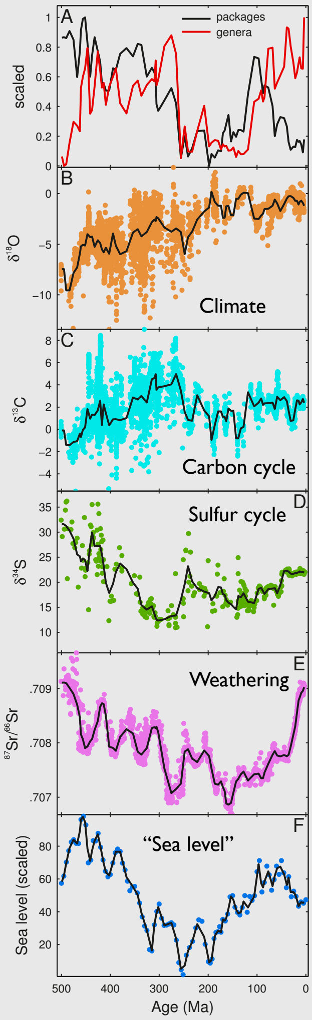
500 MILLION YEARS OF **GEO-BIOSPHERE COEVOLUTION**

In a paper published in the prestigious journal **Science**, CGB research suggests that long-term changes in the diversity of marine animals have been linked to the earth's geological evolution over the last 500 million years.

Charles Darwin, an avid geologist himself, devoted an entire chapter of *The Origin of Species* to "The Imperfection of the Geological record". He thus pre-empted any criticism that the sudden appearance of species in the fossil record would disprove his model of slow, gradual evolution by natural selection. More than a century would pass before fossil compilations were used to reconstruct the evolutionary history of Life on Earth.

Today, the Paleobiology Database (paleodb.org), with over a million fossil occurrences and counting, is the definitive source of data on biodiversity changes in the deep past. Understanding the coming and going of major groups of organisms, including mass extinction events, can help us understand long-term consequences of current and future environmental changes.

Still, Darwin's doubts have lingered. Paleobiologists are legitimately concerned about how biodiversity patterns observed in the fossil record are biased by the fickle nature of sedimentary rock preservation and by our sampling of those rocks. Indeed, direct rock-fossil comparisons show striking



Fossil horn corals. The corals are about 450 million years old and represent an extinct group of marine organisms commonly found in the fossil record. The specimen is part of the collection of the UW-Madison Geology Museum.

similarities that have created a conundrum: does the rock record dictate the fossil record, or have both records responded to the same forcing?

In a recent paper in *Science*, CGB researcher Bjarte Hannisdal and co-author Shanan E. Peters (U. Wisconsin-Madison) argue in favor of the latter explanation: the linkage between marine biodiversity and sediments may have been indelibly woven into the fabric of the evolving Earth System.

The study combines state-of-the-art data sets on fossil diversity, the amount of sedimentary rock, global sea-level change, and seawater chemistry through the last 500 million years (the Phanerozoic Eon). During this period, plate tectonic processes drove the assembly and breakup of the supercontinent Pangaea. This also modulated the long-term, global extent of flooding of the continents, which affected sedimentary environments and the habitat of marine organisms.

Important clues can also be found in geochemical records of the isotopic composition of seawater. Specifically, there seems to be an important link between marine biodiversity and global sulfur cycling, which may in part reflect the biological effects of changing oxygen levels in the marine environment.

Although this study does not target specific mechanisms, it suggests that we need to consider multiple interacting components of the Earth System (solid - fluid - living) in order to understand biodiversity dynamics on geological time scales. For example, the geological sulfur cycle is coupled to the carbon cycle via terrestrial rock weathering and via the burial of biologically produced organic matter in marine sediments.

Intriguingly, the commendable practice of sampling-standardizing the diversity data effectively removes the signal of geological processes such as sea level change, suggesting that sampling variability itself represents more than just noise. Darwin's geological incompleteness may, ironically, carry an important message concerning the evolution of the Earth System.

FROM GEOBIOLOGY TO **BIOTECHNOLOGY**

The Norwegian government has recently launched an ambitious national strategy for Marine Bioprospecting and Biotechnology to explore the untapped potential of the sea's resources.

Recent studies indicate that the enormous marine resources around Norway contain thousands of previously unknown or poorly known species. Norway, with its long tradition of excellence in marine science, aims to play a global role in developing products from the marine environments. We at CGB, have been at the forefront of many of these new initiatives due to our unique, deep-sea discoveries of hydrothermal vents sites along the AMOR (Arctic Mid-Ocean Ridge).

In 2011 Centre researchers received project funding from the Norwegian Research Council to exploit the genetic reservoir in these extreme environments. Hydrothermal vents are considered one of the most challenging environments for life on Earth with extremes in pressure, temperature and pH. Microorganisms living under such extremes are commonly called extremophiles. They are well-known to produce biocatalysts. Already today several commercial products are being made using microbial enzymes obtained from extreme environments. The hydrothermal vent sites along the AMOR is thus believed to be an environment where we will be able to find microorganisms and enzymes with unique characteristics that could be exploited to create different products and processes. This will provide a basis for both Green and Blue Norwegian Biotechnology. Our systematic surveys of identifying what microorganisms are present in our newly discovered habitats, show clearly a large diversity of novel microbial taxa and a vast reservoir of uncultivated microbial lineages. These results imply that there is a sizeable hidden and yet-to-be discovered genetic reservoir in these habitats. These hydrothermal vents at the AMOR, therefore constitute a genetic potential – a potential "blue" gold mine for Norway.

Metagenomics is the study of genetic and genomic information from whole-environmental communities. Metagenomics tools are now well-known and are able to access the pool of genes from a given habitat that encode specific processes such as biocatalytic enzymes. Since CGB was established researchers in the Centre have focused on developing cutting-edge methods in metagenomics to study the adaptations of microorganisms to the extreme conditions in and around the hydrothermal vents. However, as useful biocatalysts may only constitute a minor fraction of the genetic pool in these habitats, a way to increase the probability of identifying particular target enzymes is to expose microbial communities to selective pressure before applying metagenomics. Therefore, we have constructed *in situ* incubators to simulate our extreme environments that will degrade recalcitrant matter relevant to Norwegian industry. During our research cruise in 2011 such *in situ* incubators were placed in the hot sediments in the Jan Mayen vent field. These will be collected in 2012 for detailed metagenomic studies.

We are currently collaborating closely with the newly developed Centre for Applied Biotechnology at Uni Research in Bergen to evaluate the potential commercial use of the genetic reservoir in our already sampled metagenomes from these unique deep-sea environments.

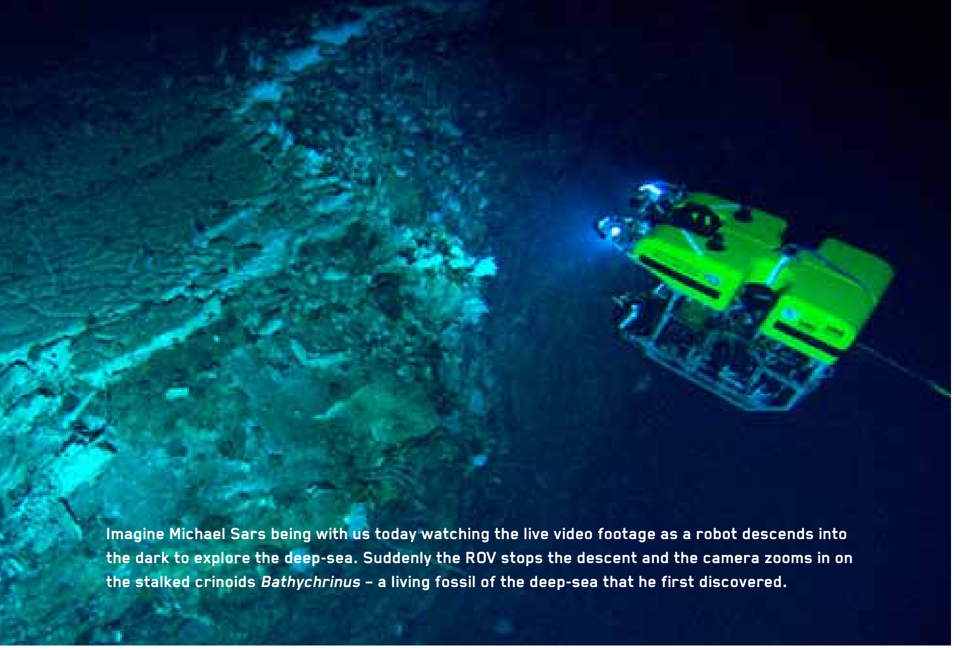
ROV ON THE ROADMAP

Towards a Norwegian Deep Sea Submergence facility

In 1850, Michael Sars, a Norwegian theologian and naturalist from Bergen, documented a diverse deep-water fauna at 800 meters depth outside the Lofoten Islands. This discovery over-threw the Abyssus Theory, which stated that there could be no life in waters deeper than around 500 meters. This, in turn, stimulated academic interest in the deep-sea, which later led to the Challenger expedition of 1872–76 and other similar ventures around the globe.

One hundred and fifty years after Michael Sars' discovery off Lofoten, the deep seafloor is still to a large extent unexplored. It has remained so largely because despite covering more than half of Earth's surface, an average depth of around 4 km has made the deep-sea inaccessible.

However, thanks to developments in technology, this is about to change. Today's deep-sea explorers use sophisticated research vessels and marine robots. The latest remotely operated vehicles (ROV) can be guided to explore Earth's deepest submarine trenches with water depths exceeding 10 000 meters. Using high definition video and photo equipment, they have shown us glimpses of this unexplored world. Researchers have been able to witness new life-forms and geological events such as underwater volcanic eruptions as the seafloor forms. ROVs have robotic arms that enable them to sample both the biology and geology of the new environments their photographic "eyes" reveal: from the superheated, 400°C hydrothermal water as it emanates from the seafloor at deep-sea geysers, to unique new organisms interacting with their environment.



Imagine Michael Sars being with us today watching the live video footage as a robot descends into the dark to explore the deep-sea. Suddenly the ROV stops the descent and the camera zooms in on the stalked crinoids *Bathychrinus* – a living fossil of the deep-sea that he first discovered.

ROV ON THE ROADMAP

Whereas cost limited deep-sea research to the realm of the superpowers 15 years ago, technological advances mean that such capabilities are now within the reach of many nations. Such capacity is increasingly important for coastal nations with deep-sea territories, as it will enable them to explore, defend and potentially exploit the deep-sea resources and environments that are being revealed.

Norway has a vast marine territory that is extremely diverse. It includes volcanic spreading ridges containing potential mineral and genetic resources; a continental shelf and slope with complex sedimentary systems and slope stability challenges; subsurface gas-hydrate reservoirs, and methane seeps with unique chemosynthetic ecosystems that have important but unknown climate links. This latter part of Norway's marine territory encompasses a unique oceanographic environment of first-order importance to future climate conditions; and large sub-seabed aquifers that may become important storage sites for anthropogenic CO_2.

Effective understanding and management of marine resources requires tools and platforms that enable researchers to monitor the environment, collect critical data or samples, deploy and retrieve seafloor instrumentation and experiments, assess the potential for deep-sea resources and predict environmental impacts of industrial activity.

In Norway, the University of Bergen has been pioneering the deep-sea exploration with marine robots. These operations started in 1999 with a first attempt to reach and sample the Mid-Atlantic Ridge using "Aglantha" - a small, UiB-owned ROV. Since then there have been regular deep-sea expeditions, first organised through a Strategic University program, and now through the Centre for Geobiology. Over this period experience and knowledge has accumulated and today it is timely for CGB to spearhead the establishment of a national deep-sea submergence facility.

Recently the Norwegian Research Council endorsed such an initiative by including it on the roadmap for national scientific infrastructures. Although funding is yet not secured, the establishment of such a facility now seems an attainable goal.

EARTH'S MID-LIFE CARBON CRISIS AND **THE RISE OF ATMOSPHERIC OXYGEN**

Planet Earth is 4.54 billion years old, and it has experienced a "mid-life crisis" when between 2.5 and 2.0 billion years, everything went wrong...

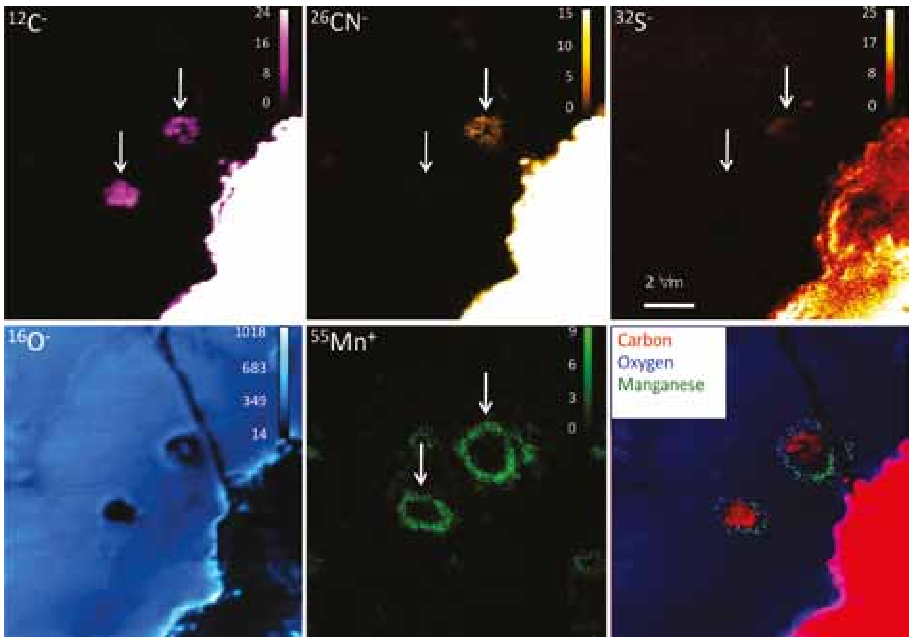
A very stable Archaean period ended 2.5 billion years ago with the rapid onset of a series of unprecedented, global-scale perturbations that modified surface environments on an unprecedented scale not experienced either before or after in Earth's history. One such upheaval was the so-called "Great Oxidation Event" that led to the accumulation of significant levels of oxygen in the Earth's atmosphere, irrevocably changing biogeochemical cycles and setting the stage for the evolution of complex multicellular life forms. Victor Melezhik, a CGB scientist that leads the FARDEEP project has co-authored an article in Science that presents a different view of this "event".

The researchers investigated rock cores from the Fennoscandian Arctic Russia – Drilling Early Earth Project (FAR-DEEP) undertaken in north-west Russia. The drilling operation obtained 3650 meters of core drilled through sedimentary and volcanic formations that span the time interval 2.5-2.0 billion years ago, including the «Great Oxidation Event». Evaluation of the FAR-DEEP core in comparison with the Fransevillian cores from Gabon in Africa, suggests that the appearance of oxygen in the terrestrial atmosphere probably did not occur as a single event (the Great Oxidation Event) but played out over hundreds of millions of years... a prolonged "mid-life crisis".

The rise of oxygen can be traced using different chemical and isotopic indicators that have varying sensitivities to the accumulation of oxygen. First, the oxidation of pyrite or "fools gold" by 2.5 billion years ago suggests that oxygen levels in the atmosphere had crossed the threshold for iron sulphides, but still remained rather low. Subsequently, at 2.4 billion years ago, the oxygen concentration was sufficient to end the mass-independent fractionation of sulphur isotopes, but was still not 'breathable' to multicellular organisms. When at 2.3 billion years ago abundant "red beds" containing oxidised or "rusty" iron appeared worldwide, the oxygen content in the atmosphere was still below 1 percent.

Considering now carbon preserved in the FAR-DEEP cores in particular the $^{13}C/^{12}C$ ratio recorded by c. 2.0 billion-year-old sedimentary rocks and their comparison to contemporaneous sediments from Gabon in Africa, suggests that there were high rates of oxygen accumulation worldwide. At about 1 percent atmospheric oxygen, groundwater becomes strongly oxidised and is capable of oxidising previously buried organic matter, converting it to carbon dioxide, and the latter inherits a low carbon $^{13}C/^{12}C$ ratio. Both the Francevillian cores and the FAR-DEEP cores show large deposits of carbon in the form of petrified oil, and both sets of cores exhibit similar, and dramatic changes in $^{13}C/^{12}C$ ratio through time, indicating that a considerable amount of organic material was oxidised and converted to low-^{13}C carbon dioxide. This was therefore an environmental drama that affected the isotopic composition of both the terrestrial atmosphere and hydrosphere.

Thus, based on the carbon isotopic record as well as many other lines of data presented in the Science article, the oxidation of terrestrial environment is argued not to be a single event, but rather a slow-motion process with oxidative flow that gradually and irregularly crawled deeper and deeper into the inorganic crust, over hundreds of millions of years. The petrified oil deposits found in the FARDEEP core are the subject of a PhD thesis at CGB that is yielding many more interesting secrets.



SUB-SEAFLOOR STORAGE OF CO_2

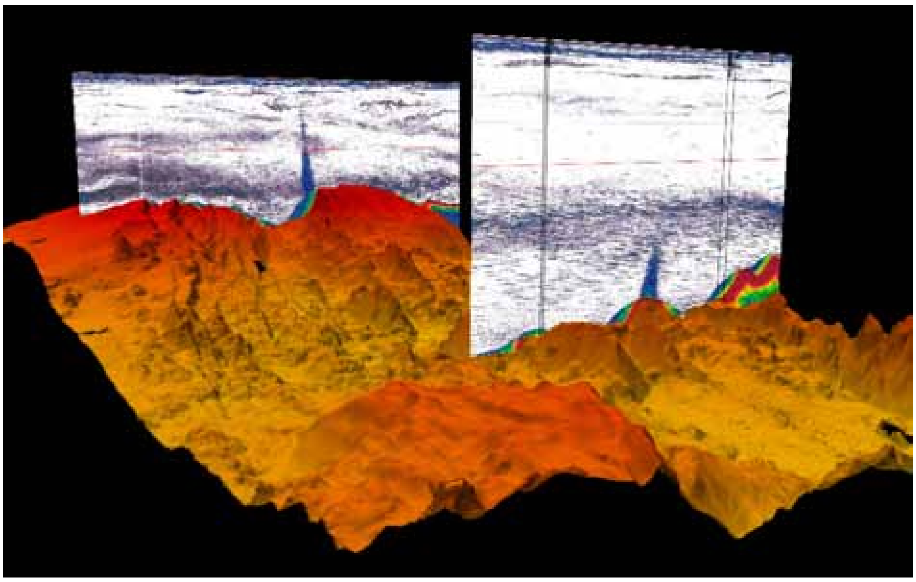
FROM BASIC TO APPLIED RESEARCH

Storage of CO_2 in sub-seafloor rock reservoirs is gradually becoming an accepted method for mitigating anthropogenic release of CO_2 to the atmosphere. Norway is spearheading Carbon Capture and Storage (CCS) by investing in the development of carbon-capture plants and by using the large North Sea database to locate suitable sub-seafloor storage sites. As part of these efforts, the Norwegian Petroleum Directorate (NPD) recently published a CO_2 Storage Atlas for the Norwegian North Sea that outlines the vast storage potential of the North Sea.

Storage of large amounts of CO_2 in the subsurface raises concerns: what is the likelihood of leakage on short- and long-term timescales? What might the environmental consequences of leakage be? Can sub-seabed storage sites be safely monitored, including detecting signs of leakage at an early stage? Centre for Geobiology is now addressing these and other questions in several projects where know-how developed through years of basic research is being applied.

A new EU-project named ECO2 assesses the likelihood of leakage and its corresponding impact on marine ecosystems. In order to do this the project studies sub-seabed storage sites already in operation – such as the Sleipner site in the North Sea, where Statoil annually injects one million tons of CO_2 into the Utsira Formation. In ECO2, new monitoring techniques are being applied to detect and quantify the fluxes of formation fluids, natural gas, and CO_2 from storage sites and to develop appropriate and effective monitoring strategies. These activities are being supported by modelling and laboratory experiments, and are complemented by process and monitoring studies at natural CO_2 seeps. These natural sites serve as analogues for potential CO_2 leaks at storage sites. The Jan Mayen vent fields, which were discovered by CGB researchers in 2005, represent one natural analogue where CO_2 release to the marine environment can be studied.

In the ECO2 project, researchers that specialise in oil and gas reservoirs, work together with marine scientists that are experts on natural seabed fluid-flow systems and their associated ecosystems. Whereas the first group is more familiar with studying petroleum reservoirs that have been sealed for millions of years – the latter group has their experience from areas where fluids (liquids and gases) are leaking naturally from the seafloor. Both backgrounds are needed to understand how and where CO_2 may or may not be stored safely for thousands of years. The project shows how crucial it is to use multi-disciplinary approaches when addressing the global challenges of today and tomorrow.



As part of ECO2, the Centre for Geobiology coordinated two international cruises in 2011. The first was directed to the Sleipner area where the seafloor and water column above the CO_2 storage reservoir was studied using an autonomic underwater vehicle (AUV). By using novel techniques, the seafloor was imaged in unprecedented detail. This allows us to locate areas where even small amounts of fluids seep out of the seafloor. Apart from abandoned oil wells where there are bubbles of methane being discharged into the water column, no signs of seabed fluid flow were detected in the Sleipner area. However, around 20 km to the north, we discovered a several km long structure in the seafloor where fluids are seeping out – highlighting the need for further research in this area.

USING PHYLOGENOMICS TO REVEAL ANCIENT MOLLUSC EVOLUTIONARY RELATIONSHIPS

The phylum Mollusca has the second largest number of species of any animal phyla. Today it includes over 100 000 described species divided into eight major lineages. However, the evolutionary relationships between these lineages is unclear and often debated. This autumn Nature published an article written by an international team of scientists, including CGB researcher Christoffer Schander, that provides solid phylogenomic evidence for some new and interesting conclusions about molluscan evolution and classification.

Led from Auburn University, the international group included scientists from the University of Bergen, the University of Florida, and Johannes Gutenberg University Mainz. Together the researchers compiled a data set that includes more than 300 genes from 49 different mollusc species. It is by far the most comprehensive dataset ever used to describe the phylogeny of molluscs. It also includes major groups of molluscs that have not been taken into account in previous mollusc phylogenies. When the dataset's analysis was completed the scientists were surprised to find a close relationship between snails and mussels, which is in contrast with assumptions that snails and squids, the groups with the most highly developed heads and nervous systems ("brains"), are most closely related. A possible grouping of snails and mussels had previously received little attention, even though these animals make up over 95% of all known species of molluscs.

Their results confirmed the much earlier hypothesis that molluscs were divided into two subphyla: the shell-bearing Conchifera and the spiny Aculifera. Even though they lack an external shell, squids belong to the shell-bearing Conchifera together with mussels and snails. Schander and colleagues therefore proposed the name Pleistomollusca for the grouping, which includes the last common ancestor of Gastropoda (snails) and Bivalvia (mussels), as well as all their descendents. The new results suggest that characteristics such as the centralization of neural and sensory organs in the head region and the development of protective shells may have occurred on several occasions in the evolutionary history of the molluscs.

IN REMEMBRANCE

Professor Christoffer Schander died suddenly on the 21st of February 2012. He was one of the researchers involved in the establishment of the Centre for Geobiology. During the most recent years he was a major driving force in developing the field of marine biodiversity and biosystematics in Bergen, building fruitful cooperation between different research groups and institutions, as well as uniting classical and new methodologies in biosystematics research. He will be deeply missed by friends and colleagues at CGB.

RESEARCH THEMES

The research at Centre for Geobiology is focused on five themes. Below is an update on the research carried out under these themes in 2011.

Geodynamics of the deep seafloor

This theme involves deep-sea exploration and the search for new extreme environments. It therefore provides a foundation for the Centre's geobiological research. In addition it has several independent research objectives relating to hydrothermal systems, seabed fluid flow and the geodynamics of spreading ridges.

In 2011 we have had a continued focus on use of Underwater Autonomic Vehicles (AUV) for deep-sea research. Prior to a cruise to the Jan Mayen Vent Fields, Hugin – an AUV produced by Kongsberg Maritime – was equipped with a synthetic aperture side-scan sonar designed for imaging of the seafloor in great detail. The robot was also equipped with a magnetometer capable of detecting mineral deposits on and below the seafloor, as well as a forward-looking sonar that made Hugin able to safely fly close to the seafloor for photographic imaging. Together with international collaborators, high-resolution photo mosaics were acquired. The synthetic aperture sonar and the photo imaging provided exceptional image resolution that will permit both geologists and biologists to extract important new information from the seafloor.

This return visit to the Jan Mayen vent fields made it possible to carry out additional sampling and investigations of the CO_2-rich hydrothermal fluids emanating from the seafloor at these sites. The hydrothermal deposits and of the young volcanic terrain hosting the vent fields were also re-sampled.

In 2011, CGB also organised a research cruise to the Jan Mayen Ridge. This was done in collaboration with the Norwegian Petroleum Directorate (NPD). The Jan Mayen Ridge represents a micro continent assumed to have rifted off Greenland around 25 million years ago. During the cruise rocks and biota were sampled along steep escarpments and deep submarine canyons using an ROV. These samples demonstrated for the first time that Mesozoic strata are present below the ridge, spurring interest in further petroleum exploration in this area. Sampling of rift-related volcanic rocks that occur together with the sedimentary successions are expected to further advance our understanding of ridge-continent-plume interaction in the North-Atlantic.

Water-rock-microbe interactions & the deep biosphere

The theme has continued to focus on low-temperature water-rock reactions in ultramafic (olivine-rich) systems using the Leka ophiolite complex as a natural laboratory facility in combination with laboratory experiments. The results will indicate if these reactions have the potential to sustain chemolithoautotropic based microbial communities that are independent of solar energy and photosynthesis. Similar experimental studies concerning the synthesis of organic molecules that could serve as the building blocks of life have also been conducted. The geochemical studies have been carried out in parallel with microbial community studies of the ultramafic subsurface environment at Leka. The results strongly suggest that the abiotic generation of hydrogen gas is an important energy-yielding geochemical process in this low-temperature habitat. Furthermore, the presence of hydrocarbon-utilising microorganisms also suggests the abiotic formation of hydrocarbons. Alternatively, such compounds could have been generated at an earlier alteration stage and stored in the rock, and are only now being leached out.

By combining detailed geochemical and microbial community profiles of highly stratified deep-ocean sediments from the Arctic spreading ridge, the theme has also been able to demonstrate a significant correlation between changes in sediment composition and changes in the subsurface microbial community. This makes it possible to make predictions about the energy metabolisms of hitherto uncultured groups of microorganisms. To further explore the deep subseafloor biosphere one of the theme members also joined the IODP expedition 336 "Mid-Atlantic Ridge Microbiology" (Sept. – Nov.). During this expedition subseafloor observatories ("CORKs") were installed in two different drill holes. In addition, several cores of deep-sea sediments and the underlying basaltic basement were collected for further geological and microbiological investigation.

Building on their expertise obtained from the deep-ocean and experimental research, researchers in this theme started to study sulphide and olivine rich mine tailing placements in Norwegian fjords in 2011, as part of a collaborative research project. An important topic is to evaluate the mobility of heavy metals and identify the major biogeochemical processes involved.

Life in extreme environments and roots of life

This theme involves research on microbial community adaptations to chemical gradients and fluctuation in chemical and physical parameters in extreme environments such as cold methane seeps and hydrothermal systems. Furthermore, we aim to learn as much as possible about the metabolic properties of novel and uncultivated microbial taxa from these environments to be able to evaluate their interactions with the geosphere as well as to give us insights into life on early Earth.

Using our developed holistic "eco-system biology" approach we have been able to gain an overview of the structure and function of the microbial communities in cold methane seeps in Nyegga. In cold methane seeps, the microorganisms act as methane sinks, reducing the emission of methane to the water column and subsequently to the atmosphere. We have identified the key players in the consumption of methane at Nyegga and have obtained detailed information about their expressed metabolisms.

Our new insights into the ecosystem functioning of cold seeps are valuable for understanding how present and future climate changes may impact these globally present microorganisms' ability to consume a possibly increased release of methane from subsurface reservoirs. We intend to extend this knowledge further. Interestingly, similar microbial taxa to those found in the Nyegga methane seeps have been identified as dominating in various hot and cold habitats in the Loki's Castle and the Jan Mayen hydrothermal vent fields.

Finally, the research cruise to Jan Mayen this year was very successful for the research theme as we have identified samples enriched in specific microbial taxa that branch off close to the "roots of life". Exploring the metabolic properties of such microbial taxa may give us clues about what metabolisms were operational on the early Earth

Vent and Seep Biota

This theme involves the exploration of fauna associated with reduced habitats 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.

This year 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.

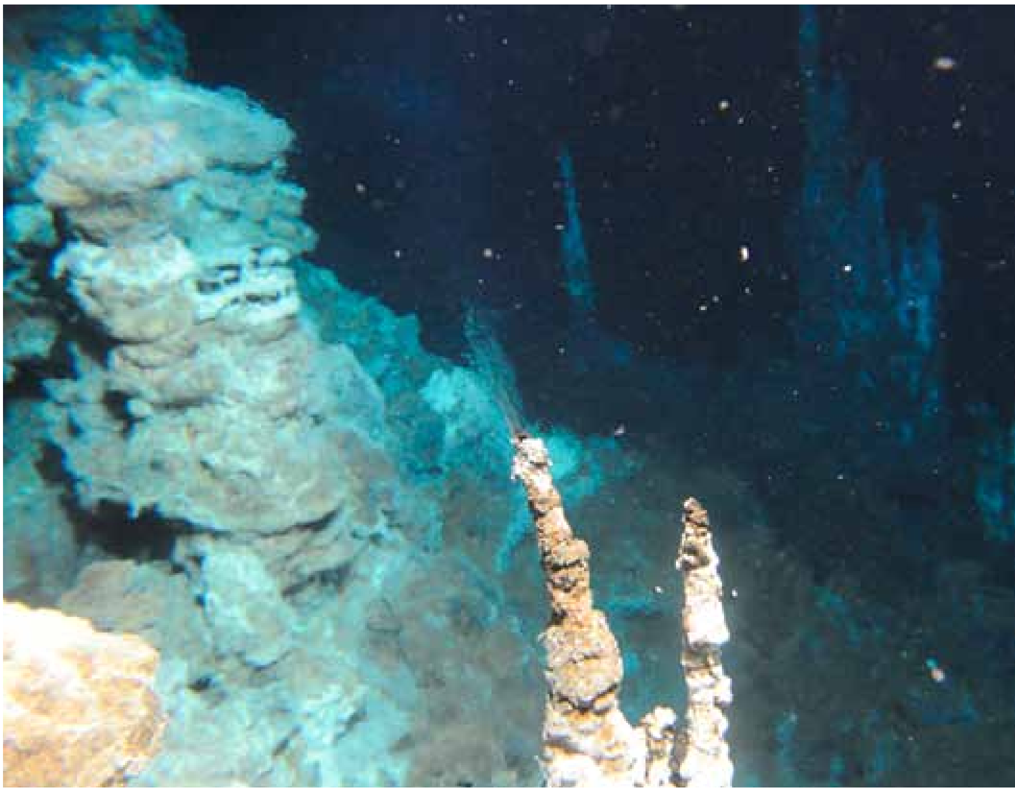
There are obvious similarities between the fauna found at hot vents along AMOR, the fauna of cold seeps along the Norwegian margin, and from wood-falls in the abyssal Norwegian Sea. A shared group of keystone species directly or indirectly dependent on chemosynthetically derived energy has been identified, including rissoid gastropods, maldanid and ampharetid polychaetes, as well as a new genus of melitid amphipods. 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

Investigating the emergence of life on Earth requires both the identification of environments suitable for life and secondly, robust biosignatures to detect early microbial life. In 2011 progress has been made on both these fronts. For example, a study of clastic sediments from the Barberton Scientific Drilling Project used laser ablation-ICP-MS to obtain a depositional age for these sediments and to propose a major tectonic accretion event on the Kaapvaal craton at ca. 3432 Ma (Grosch et al. 2011). This work identified the oldest tectonic basin in the Archean Barberton Greenstone Belt and argued for the formation of a shallow, intra-continental sea; a possible environment for early microbial life. This study was presented at a Nordic Scientific Drilling workshop and forms part of a PhD thesis successfully completed during 2011 in the Early Earth theme.

Studies of altered seafloor volcanic glass from the Norwegian-Greenland Sea using NanoSIMS (nano-scale secondary ion microprobe) found micropores containing carbon and nitrogen and with rims enriched in manganese (McLoughlin et al. 2011). Working together with the water-rock-microbe interaction theme we have proposed a model involving the fossilisation of manganese-oxidising bacteria, and suggested that Mn mapping is a promising biosignature in altered volcanic glass. At the same time we have also been undertaking NanoSIMS investigations of candidate traces of life in Archean metavolcanic glass from the Barberton Scientific drill core to identify robust chemical signatures of life in the subseafloor of the early Earth.

In 2011 the Early Earth group was involved in editing as Special issue of Astrobiology entitled "Volcanism and Astrobiology: Life on Earth and Beyond", which contained several papers from members of the Centre for Geobiology focusing on interactions between volcanic activity and microbial ecosystems. The Early Earth group also contributed to a new encyclopedia of Astrobiology with definitions of the terms: biogenicity, syngenicity and endogenicity, designed for scientists seeking life on other planets (McLoughlin et al. 2011). Future research in 2012 aims to build on recent results with a continued focus on early Earth geodynamics and early life environments, with implications for Astrobiology.



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 Department of Biology and the Department of Earth Sciences.

Although initially organised around research themes, the Centre has since adopted a matrix model 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 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 plan is carried out though a number of external and Centre funded projects. The following long- and short-term projects received funding from the Centre in 2011:

- The subsurface microbiology of sedimented parts of the AMOR rift valley
- Diversity and functioning of archaea in marine methane enriched sediments
- Adaptations of *Archaeoglobus* species to environmental changes
- Biomineralisation and biosignatures in hydrothermal iron hydroxides and barite deposits
- Water-mineral/rock reactions and hydrogen formation
- Whalefalls – phase 2
- Phylogeography of Vent, Seep and Fall Fauna
- Foods webs in hydrothermal plumes
- Macrofauna on hydrothermal vents and cold seeps in the northernmost Atlantic ocean II
- The Barberton Scientific Drilling Programme (post drilling research)
- Geology and geodynamics of AMOR vent fields
- Tectonic and magmatic segmentation of the Mohns Ridge
- Participation in the Dead Sea Drilling project (ICDP)
- Participation in IODP Expedition 329 - South Pacific Gyre (post cruise research)
- Participation in IODP Expedition 336 - Mid-Atlantic Ridge microbiology

RESEARCH PROJECTS 2011

Projects Funded by the Research Council of Norway

DURATION	TITLE	LEADER*/PARTNER**
2008 – 2011	"H2DEEP" Ultra-slow spreading and hydrogen-based biosphere: A site survey proposal for zero-age drilling of the Knipovich Ridge	Rolf Birger Pedersen*
2009 – 2012	"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	The molecular basis for protein degradation and hydrogen production capabilities of Fervidicoccus fontis, a thermophilic crenarchaeon.	Anna Perevalova*/ Ida Helene Steen**
2011 – 2015	«BIOGOLDMINE» Mining of a Norwegian biogoldmine through metagenomics.	Ida Helene Steen*

International projects organised or funded through the European Science Foundation (ESF)/Era-Net

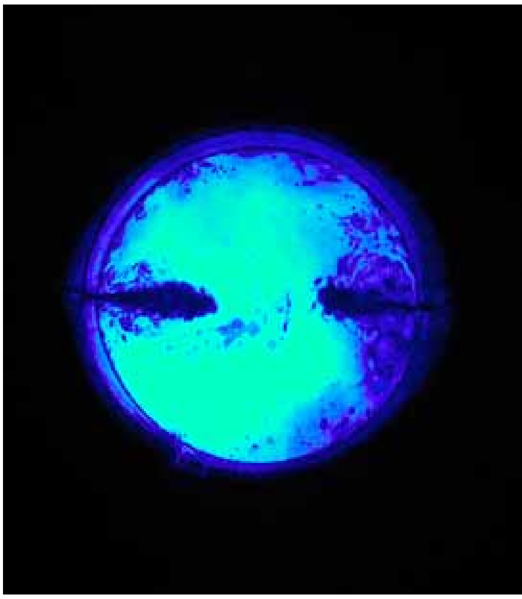
DURATION	TITLE	COORDINATOR*/ PRINCIPAL INVESTIGATOR**/COLLABORATOR***	PROGRAMME
2008 – 2011	"H2DEEP" Ultra-slow spreading and hydrogen-based biosphere: A site survey proposal for zero-age drilling of the Knipovich Ridge. Project 1: The Magmatic, Tectonic and Hydrothermal Architecture of the Southern Knipovich Ridge: Geophysical Survey and Geological/ Geomicrobiological sampling. Rolf Birger Pedersen**/ Ingunn H. Thorseth*** Project 2: Core complex formation and evolution: Geodynamic synthesis, Knipovich Ridge Rolf Birger Pedersen*** Project 3: Linking Hydrothermal Alteration, Serpentinization, and Fluid Fluxes to Biological Niches at the Knipovich Ridge Rolf Birger Pedersen*** Project 4: Sulfide Petrology, Ore Genesis and the Deep Biosphere at Knipovich Ridge Rolf Birger Pedersen***/ Ingunn H. Thorseth*** Project 5: Geomicrobiology: microbial communities and processes associated with basement alteration at the ultraslow spreading Knipovich Ridge Ingunn H, Thorseth**/ Rolf Birger Pedersen***/ Lise Øvreås***	Rolf Birger Pedersen* (Main Coordinator)	ESF/ EuroMARC (EUROCORES)/NFR
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	Sub-seabed CO_2 storage: Impact on Marine Ecosystems	Rolf Birger Pedersen** Ingunn Thorseth**	EU

Projects funded by other sources (Public and Private)

DURATION	TITLE	LEADER*/PARTNER**
2007 – 2011	Biotechnology and microbial diversity of Ethiopian soda lakes	Lise Øvreås* SIU
2009 – 2011	Preparing for sub-sea storage of CO_2	Rolf Birger Pedersen** Gassnova
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
2010-2011	Exploring the geology of the Jan Mayen Ridge using ROV	Rolf Birger Pedersen* Norwegian Petroleum Directorate
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
2011-2013	Taxonomy and distribution of sponges (Porifera) in Norwegian waters	Hans Tore Rapp*, The Norwegian Biodiversity Information Centre
2011-2012	Deep-water sponges in Norwegian waters	Hans Tore Rapp* The Norwegian Academy of Science and Letters, The Norwegian Deep-Sea Program
2011-2014	The Emergence of Life on Earth 3+ billion years ago	Nicola McLoughlin*, UiB-BFS





WORKSHOPS, SEMINARS AND SHORT **COURSES** 2011

The past year has been an active one for CGB researchers in terms of conference activity. They have been involved in more than 80 scientific conference proceedings and have, in addition, been invited or even keynote speakers 26 times.

In August 2011 a 12 day long Nordic course in Geobiology was arranged in Iceland, in collaboration between CGB and universities in Denmark, Sweden, Finland and Iceland. Iceland, with its unique situation on a mid-ocean ridge, and 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. The course was supported by the NORDPLUS programme and focused on geobiology in hydrothermal areas and combined practical field work, laboratory work and lectures. In total 22 masters and PhD students attended the course which included 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.

In August 2011 the centre also organised a two days Detrital zircon U-Pb workshop in the Czech Republic before the Prague Goldschmidt meeting. There were several presentations outlining some of the key problems of U-Pb detrital zircon analysis and data interpretation, followed by discussions. Participants were invited to present their own results at the end of the first day of the workshop which also included a small poster session. The workshop had 51 participants from 14 countries and was sponsored by CGB together with the International Association of Geoanalysts, New Wave Research, Nu Instruments, Australian Scientific Instruments and Photon Machines.

In addition to the above, CGB researchers have organised a number of workshops and short courses at the Centre or at the University of Bergen (UiB).

PUBLIC OUTREACH 2011

In 2011 CGB's communication efforts continued to increase. In addition to a significant number of scientific publications and scientific presentations, CGB researchers were also involved in numerous dissemination measures aimed at other, more public, relevant target groups including public lectures and presentations to government and industry committees.

CGB researchers are generating socially relevant expertise in deep-sea exploration (resource potential of Jan Mayen Ridge), biodegradation (mine tailings) and deep-sea infrastructure (ROV, lander and observer technologies).

In addition, CGB researchers were active in presenting online reports about their field and course activity. These included reports from a month-long stay on Jan Mayen, field work in Siberia, participation in a 2-month IODP research cruise and field testing of new equipment for use in CO_2 detection activity.

STAFF

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Hovland, Martin
Kelly, Deborah
Kosler, Jan
McLoughlin, Nicola
Melezhik, Victor
Pedersen, Rolf Birger
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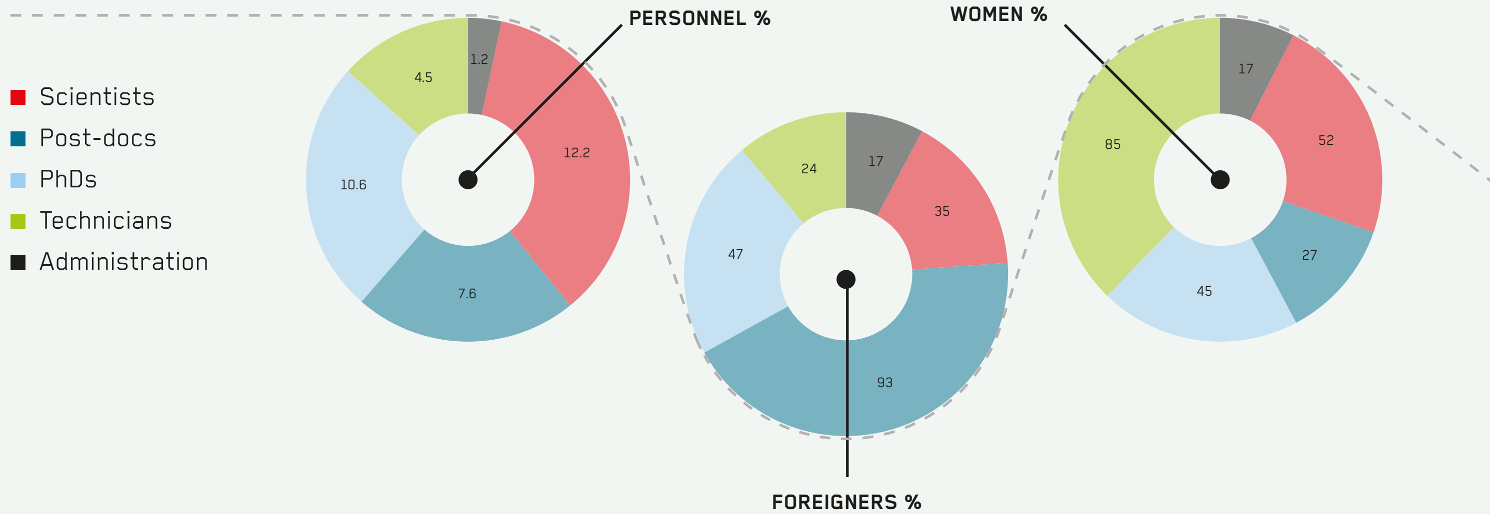
Norheim, Marianne
Ronen, Yuval
Tumyr, Ole

Administration
Bartle, Elinor
Hesthammer, Steinar

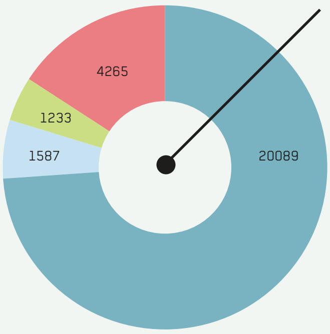
PERSONNEL SUMMARY

CATEGORY	PERSON-YEARS	FOREIGNERS (% PERSON-YEAR)	WOMEN (% PERSON-YEAR)
Scientists	12.2	40	47
Post-docs	7.6	61	30
PhDs	10.6	52	46
Technicians	4.5	0	75
Administration	1.2		
Total	**36.1**	**43**	**49**



FUNDING AND EXPENSES

FUNDING	(1000 NOK)	EXPENSES	(1000 NOK)
Research Council of Norway	10845	Salaries and indirect costs	20089
University of Bergen	18650	Research equipment	1587
		External research services	1233
		Other costs	4265
Total funding	**29495**	**Total expenses**	**27174**



EXPENSES
(1000 NOK)

- Salaries and indirect costs
- Research equipment
- External research services
- Other costs

SELECTED **PUBLICATIONS** 2011

In 2011 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 80 scientific presentations in 2011. Below is a list of some selected publications.

1. Borgonie G, **García-Moyano A,** Litthauer D, Bert W, Bester A, van Heerden E, Möller C, Erasmus M, Onstott TC (2011). Nematoda from the terrestrial deep subsurface of South Africa. Nature 474: 79-82. doi:10.1038/nature09974
2. **Dahle H, Hannisdal B, Steinsbu BO**, Ommedal H, Einen J, Jensen S, Larsen Ø, **Øvreås L,** Norland S (2011). Evolution of temperature optimum in Thermotogaceae and the prediction of trait values of uncultured organisms. Extremophiles 15.(4) p. 509-516
3. **Furnes H,** de Wit MJ, Robins B, Sandsta NR (2011). Volcanic evolution of the upper Onverwacht Suite, Barberton Greenstone Belt, South Africa. **Precambrian Research** 186(1-4):28-50. ISSN:0301-9268 DOI:10.1016/j.precamres.2010.12.007
4. **Grosch EG, Kosler J, McLoughlin N, Drost K, Slama J, Pedersen RB** (2011). Paleoarchean detrital zircon ages from the earliest tectonic basin in the Barberton Greenstone Belt, Kaapvaal craton, South Africa. Precambrian Research 191(1-2): 85-99. ISSN: 0301-9268 DOI: 10.1016/j.precamres.2011.09.003
5. **Hannisdal B,** Peters SE (2011). Phanerozoic Earth system evolution and marine biodiversity. Science 334: 1121-1124. DOI: 10.1126/science.1210695
6. Hellevang H, **Huang S, Thorseth IH** (2011). The potential for low-temperature abiotic hydrogen generation and a hydrogen-driven deep biosphere. Astrobiology 11.(7) p. 711-724
7. Kocot KM, Cannon J, Todt C, Citarella M, Kohn AB, Meyer A, Santos SR, **Schander C,** Moroz LL, Lieb B, Halanych KM (2011). Phylogenomics reveals deep molluscan relationships. Nature 477(7365): 452
8. Kump LR, Junium Ch, Arthur MA, Brasier A, Fallick AE, **Melezhik VA, Lepland A,** Črne AE, Luo G (2011). Isotopic Evidence for Massive Oxidation of Organic Matter Following the Great Oxidation Event. Science 334: 1694-1696
9. **Lanzén A, Jørgensen SL,** Bengtsson MM, Jonassen I, **Øvreås L, Urich T** (2011). Exploring the composition and diversity of microbial communities at the Jan Mayen hydrothermal vent field using RNA and DNA. FEMS Microbiology Ecology 77.(3) p. 577-589
10. **Lepland A, van Zuilen** MA, Philippot P (2011). Fluid-deposited graphite and its geobiological implications in early Archean gneiss from Akilia, Greenland. Geobiology 9(1):2-9. ISSN: 1472-4677 DOI:10.1111/j.1472-4669.2010.00261.x
11. **McLoughlin N, Wacey D,** Kruber C, Kilburn MR, **Thorseth IH, Pedersen RB** (2011). A combined TEM and NanoSIMS study of Endolithic microfossils in altered seafloor basalt. Chemical Geology 154-162
12. **Reigstad LJ, Jorgensen SL,** Lauritzen SE, **Schleper C, Urich T** (2011). Sulfur-oxidizing chemolithotrophic proteobacteria dominate the microbiota in high arctic thermal springs on Svalbard. Astrobiology 11(7):665-78
13. **Roalkvam I, Jørgensen SL,** Chen Y, **Stokke R, Dahle H, Hocking WP, Lanzén A,** Haflidason H, **Steen IH** (2011). New insight into stratification of anaerobic methanotrophs in cold seep sediments. FEMS Microbiology Ecology 78.(2) p. 233-243
14. **Steinsbu BO,** Tindall BJ, **Torsvik VL, Thorseth IH, Daae FL, Pedersen RB** (2011). Rhabdothermus arcticus gen. nov., sp. nov., a novel member of the family Thermaceae isolated from a hydrothermal vent chimney from Soria Moria vent field at the Arctic Mid-Ocean Ridge. Int J Syst Evol Microbiol. 2010 Oct 8. [Epub ahead of print] PMID:20935086

PHOTO CREDITS

Thank you to the generous and talented photographers who have allowed us the use of their photos in the 2011 Annual Report and in other outreach materials. The photos in this annual report may not be copied or reproduced in any form without permission of the photographer.

Eirik Gjerløw (pp. 1, 21 and 24)

Irene Heggstad (p. 3)

Shanan Peters (p. 4)

Ida Helene Steen (pp. 6, 12 and 13)

Håkon Dahle (pp. 6, 12 and 13)

Hans Tore Larsen (pp. 7, 15, 19 and 23)

Rolf Birger Pedersen (pp. 6, 8, 11 and 12)

Victor Melezhik (p. 9)

Hans Tore Rapp (p. 11)

Guri Gunnes Oppegård (p. 11)

Steffen Leth Jørgensen (p. 18)

Courtesy of University of Washington, Institute for Exploration University of Rhode Island, and NOAA (p. 8)

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