

# MARUM

*Center for Marine Environmental Sciences*



 marum

DFG Research Center  
Cluster of Excellence



# MARUM

Center for Marine Environmental Sciences  
University of Bremen



**A**t MARUM, consistent with the motto »The Ocean in Depth«, we have been studying key processes in the marine environment for over ten years. This slogan is intended to be taken literally. On marine expeditions in shallow coastal waters as well as in the deep, open ocean, scientists investigate deposits and processes at and within the seafloor. Even after many years of intensive research, they make new discoveries on almost every expedition. With this brochure we would like to provide you with a glimpse into our exciting field of work; easy to understand, interesting and, I hope, engagingly presented. While thumbing through and reading it, you will meet a number of our young scientists because, in addition to outstanding research, we place a high value on excellent training.

As one of the first Research Centers, MARUM has been supported by the Deutsche Forschungsgemeinschaft DFG since 2001. Since 2007, our internationally acclaimed work has been funded under the Excellence Initiative. A year earlier the International Graduate School GLOMAR had already become part of the Excellence Initiative. In GLOMAR, young natural and social scientists study global changes in the ocean.

In 2012 we reached an important milestone. In that year the DFG approved the continued funding of the MARUM Excellence Cluster, which was the basis for recognition of the University of Bremen as an »Excellence University«. At that time we also integrated the GLOMAR Graduate School into the Excellence Cluster. Notably, in the same year, MARUM was transformed into the first and only research faculty of the University

of Bremen, and thereby became responsible across all disciplines and departments for the long-term development of the university's scientific focus in the fields of marine, polar and climate research.

An important element in this success story is the close collaboration with other distinguished regional marine research establishments, such as the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research and the Max Planck Institute for Marine Microbiology, just to name two. We will continue on this path of cooperation within and outside of the university in the future.

It is an important goal in MARUM to strengthen the concept of equal opportunity between men and women in science. One step in this effort is the very successful, ongoing mentoring program »plan m«, in which women receive advice in planning their scientific careers from experienced and successful female colleagues.

I wish you an exciting dip into our world of science.

Sincerely,

**Michael Schulz**

Director of MARUM

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# The ocean in the Earth system

## Marine research at MARUM

Our blue planet is a fascinating system: its major components include the atmosphere, oceans and crust, the biosphere inhabited by large and small creatures, as well as sea ice and glaciers, all of which are closely interwoven through complex interactions. Stagnancy never prevails. Storms, earthquakes and volcanic eruptions, rock slides and the current melting of glaciers, all illustrate how dynamically the processes in the Earth System occur. This is especially true of the oceans, which cover approximately 71 per cent of the Earth's surface. Ocean currents that span the world, hot and cold seeps on the seafloor, and many other phenomena make the marine environment an exciting field for researchers.

At MARUM, the Center for Marine Environmental Sciences at Bremen University, scientists and technicians study the critical role of the ocean in the Earth System through systematic investigations. MARUM is active in three general fields of research: exploring relationships between the ocean and climate, closely examining biogeochemical processes on and within the seafloor, and investigating changes in the seafloor itself. The scien-

tists at MARUM actively participate in developing and carrying out international marine-oriented research programs such as IODP, C-DEBI, IGBP-PAGES, and Inter-Ridge. In addition, MARUM operates the largest of the three world-wide core repositories of the International Ocean Discovery Program (IODP).

Over the years, a number of geographical areas of focus have naturally evolved at the Bremen Center. These include the entire Atlantic Ocean, the Mediterranean and Black Seas, and the North Sea. MARUM scientists are as active in shallow coastal waters as they are in the deep ocean.

Coastal seas form the transitional zones between continents and the open oceans. Within these limited areas natural geological, chemical and biological processes, as well as human activities impact the environment. Here, for example, rivers discharge enormous amounts of eroded material from mountains in the hinterland. Viewed in a geological time frame, over millions of years, the amount of eroded material transported into the ocean is ultimately determined by climate changes, mountain-building processes, and sea-level



*MARUM provides the ideal setting to satisfy our enthusiasm for marine research. I am happy that my work contributes to a better understanding of the processes in the ocean, and I continue to be impressed with the diverse but still closely integrated nature of research at MARUM.*



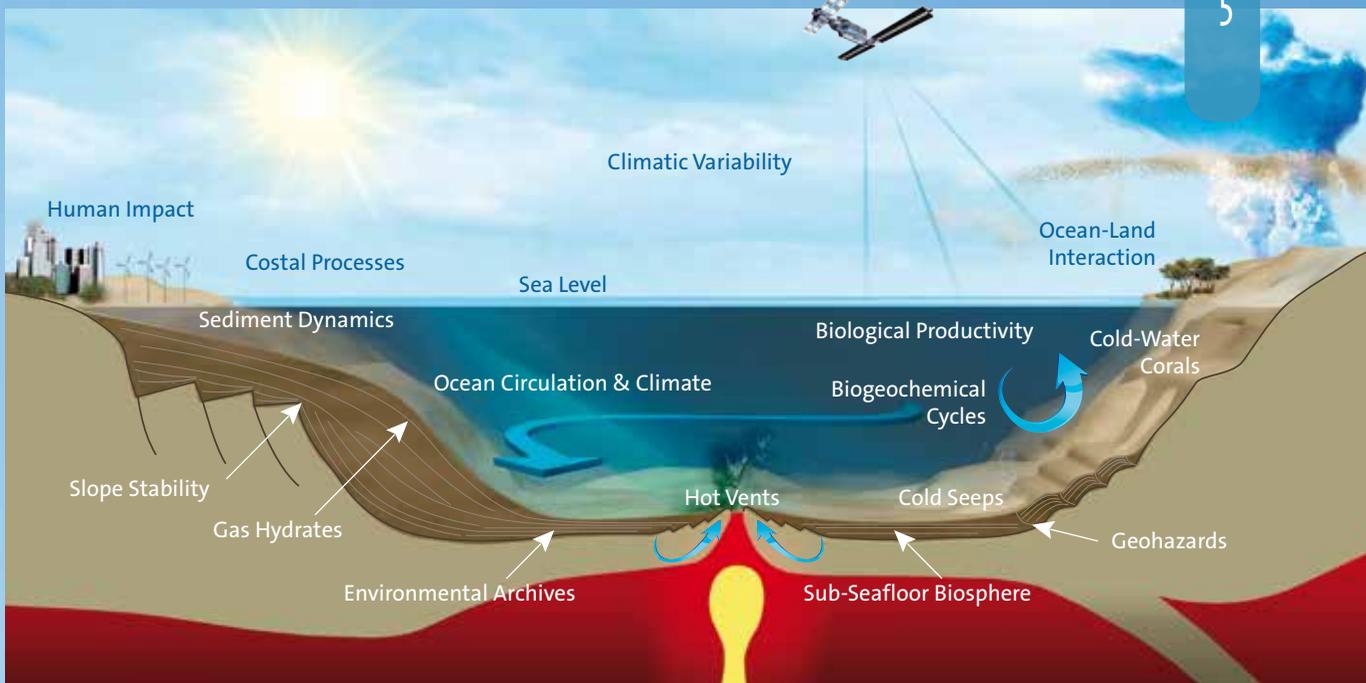
Miriam Römer  
Postdoc at MARUM

fluctuations. At the same time, coastal seas serve as catch basins for pollutant input and as multifaceted resources, which leads to conflicts in many regions. It is no wonder that these regions are regarded as real »hot spots« by researchers in the natural and social sciences.

Hot spots of a completely different kind are found at the mid-ocean ridges. This undersea mountain chain, more than 60,000 kilometers long, forms a boundary between the Earth's plates. At the central cleft, which can be up to several tens of kilometers wide, hot magma flows upward. This is where new ocean floor is produced. Sea water penetrates into the bottom through clefts and cracks. It is estimated that, at any given time, around two per cent of the total ocean water is circulating within this uppermost lithosphere layer. At the mid-

ocean ridges this water is heated up and, loaded with dissolved minerals, it gushes out of the seafloor at hot smokers with temperatures of 400 degrees Celsius or greater. Video recordings taken by submersible vehicles document the proliferation of specialized ecosystems at these hydrothermal systems. White prawns, clams and other organisms thrive in the direct vicinity of the hot seeps. They benefit from symbiotic relationships with bacteria whose metabolism is based on hydrogen sulfide or hydrogen rather than oxygen.

Because of its great expanse, the study of the seafloor is literally a broad field. Large-scale investigations using satellites are only possible to a limited degree, for example, in taking gravity-field measurements. All other observations and measurements must be car-



The role of the ocean in the Earth System – research fields at MARUM

ried out directly on-site. For these, research vessels are used to deploy remotely operated underwater vehicles, autonomous underwater vehicles, seafloor landers and other technological tools for direct measurements and sampling. MARUM is one of only a few institutes in the world that has a fleet of the most modern underwater instruments for deployment in the deep sea. This capability has helped to make it a center of marine research technology and a highly desired partner in international cooperative projects.

In the framework of the German Excellence Initiative geologists, geochemists, microbiologists, physicists and social scientists work at MARUM in close cooperation with colleagues at other marine research institutes in the north-western region. These include the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research in Bremerhaven (AWI), the Max Planck Institute for Marine Microbiology in Bremen (MPI), Senckenberg Research Institute in Wilhelmshaven (SGN), the Leibniz Center for Marine Tropical Ecology in Bremen (ZMT), as well as the private Jacobs University in Bremen and the University of Oldenburg.

# The role of the ocean in the climate system

## MARUM Research Area »Ocean and Climate«

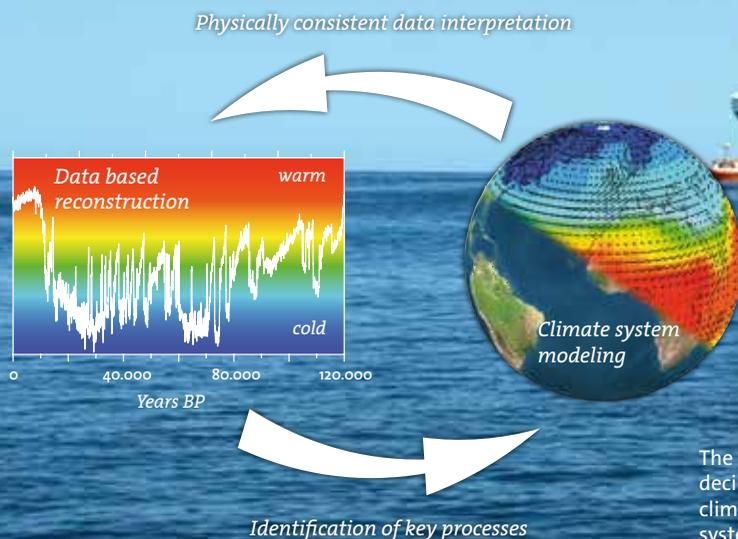
The world ocean stores an immense amount of heat energy. Some of this heat is transported by ocean currents from the equator toward the poles, which helps to provide a mild climate for northern Europe. Many different substances are also dissolved in the ocean. These are distributed and stored in sea water for long durations, and include the important greenhouse gas carbon dioxide. The world ocean thus represents a central component of our climate system.

In order to improve our ability to assess future climate change, it is necessary to have an accurate understanding of the ocean's role in the climate system. With this in mind, MARUM scientists address a wide range of questions, including the following:

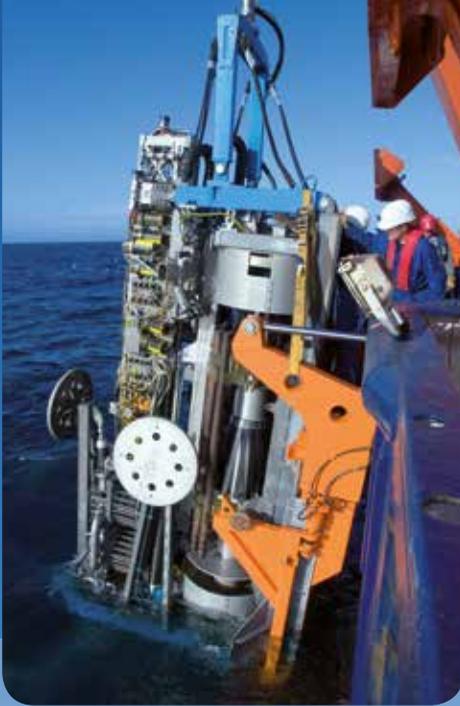
- How do ocean currents change during the transitions between cold and warm climate conditions?

- Are there critical tipping points for the marine currents?
- How do changes in ocean circulation impact the climate on land, particularly the water cycle in low latitudes?
- What are the time frames of large-scale ocean circulation fluctuations?
- What mechanisms determine these fluctuations?
- To what degree are the interrelated biological, geological and chemical processes in the ocean influenced by climate changes?

In this context, measurement series of salinity, temperature, currents or the distribution of materials in the ocean are important for deciphering how the ocean interacts with the other climate-system components – land biosphere, polar ice caps, and atmosphere. An additional factor comprises time series from climate



The dynamics of past climate variation can be deciphered through a combination of geoscientific climate reconstructions and the results from climate system modeling.



Cores up to 70 meters long from the seafloor can be retrieved with the seafloor drilling rig MARUM-MEBo70. This allows the investigation of much longer time series than conventional methods using gravity or piston coring. The new MEBo200 system will allow drilling up to 200 meters into the seafloor.

history. Compared to direct measurements made by instruments, these series extend much further into the past. Moreover, they offer a unique archive for quantitatively tracking natural fluctuations in the ocean as well as their interactions with the other components of the climate system.

Sediment cores taken on various national and international expeditions from the tropics to the polar latitudes, which have been analyzed by micropaleontological, geochemical or physical methods, serve as archives for this work. The time series obtained by these methods extend back thousands to millions of years into the history of the Earth and document global climate conditions that were completely different from those of today, but which may be seen again in the

future. The climate reconstructions are combined with direct observation data from ships and satellites as well as with Earth-system model experiments. This provides scientists with insights into the mechanisms of climate variation and their underlying causal relationships. The results allow them to draw more reliable conclusions about the possible future climate development.

The greater part of our planet is covered by ocean, and it significantly influences climate processes. At MARUM efforts are being made to decipher how it has impacted climate processes in the past and how it will influence them in the future. One of the objectives is to combine direct instrumental measurements, reconstructed climate time series, and computer climate models in order to reveal underlying causal relationships.

*In Ocean and Climate we aim to reconstruct past climate and ocean conditions. The variety of methods used by us at MARUM to fulfil these aims is fascinating. In my case only the combination of two different methods going along with teamwork enabled me to answer my actual research questions.*



Sebastian Hötzel  
PhD student at MARUM

# Climate snapshots from the past

## Corals as archives for ocean salinity and temperature

In contrast to daily changing weather patterns, climate change mostly occurs at time scales that are hardly conceivable to the human imagination. However, short-term climate fluctuations can also impact our lives. Lasting for years to decades, they are the result of ocean-atmosphere interactions, and they influence our weather. One example is the Southern Oscillation climate phenomenon known as El Niño.

**T**he El-Niño phenomenon originates in the tropical Pacific, but causes drought and flooding around the world. At our latitudes, the North-Atlantic Oscillation influences weather and climate. It determines the severity of winters and the intensity of winter precipitation from Scandinavia to the Mediterranean. Furthermore, in recent years extreme events such as hurricanes, tropical cyclones, heavy rains and heat waves have gained increased attention – events that take place over a few days to weeks.

To investigate the natural dynamics of these climate phenomena, scientists study past climate. Instrumental records of weather and cli-

mate, however, reach only about 150 years into the past – not far enough to assess the natural frequency and intensities of extreme events, nor to project future changes in climate phenomena and extreme events in response to global climate change. It is therefore necessary to identify climate archives that extend further back in time, but which also reveal short-term climate fluctuations of months, years or decades.

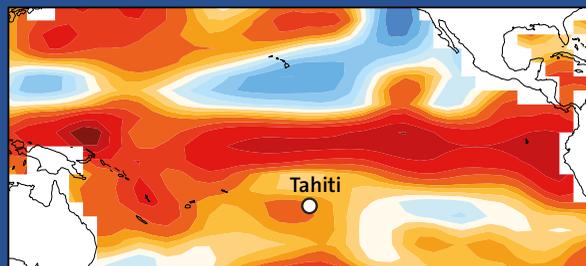
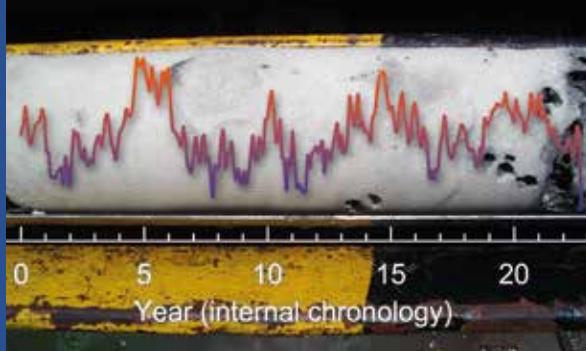
Scientists at MARUM employ archives with high temporal resolution. They sample massive stony corals that thrive in shallow, warm-water tropical to subtropical reefs. Stony corals produce two bands with different densities in their calcareous skeleton each



year. Additionally, they incorporate trace elements and stable isotopes into their skeletons that reflect the environmental conditions of the seawater. Using sophisticated techniques it is possible to reconstruct temperature and salinity of the surface waters based on corals, with a temporal resolution of months to weeks. The annually banded corals, therefore, are ideally suited to providing information about past ocean-atmosphere interactions at time scales that are relevant to humans.

Based on coral analyses, MARUM scientists have been able to reconstruct temperature and salinity of the subtropical Northwest Pacific with an annual resolution back to the year 1873. It was shown that salinity in the Kuroshio Current region off Japan declined considerably within only five years during the early twentieth century. Together with colleagues from the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, it could also be shown that this sea-surface salinity shift was preceded by a weakening of the westerly winds, which transport dry air masses from Asia toward the North Pacific. The possibility of such abrupt fluctuations that are related to ocean-atmosphere interactions should thus be considered in climate projections for the future.

The high-resolution climate archives extend far back into the



Coral core (top left) drilled by the Integrated Ocean Drilling Program off Tahiti in the South Pacific, using the drill ship DP HUNTER (top right), with reconstructed temperature fluctuations for the end of the last glacial period schematically indicated, and climate model results of pronounced tropical Pacific El-Niño activity at that time (bottom left).

Opposite page: Coral reef in the Gulf of Aqaba (northern Red Sea). Small photos: MARUM scientists drilling cores from fossil corals for climate reconstruction at Bonaire (top, southern Caribbean) and Aqaba (bottom, northern Red Sea). Aside: an X-radiograph reveals the annual density bands in a coral core.

Earth's history. A technologically challenging expedition of the Integrated Ocean Drilling Program sampled fossil coral reefs that grew off Tahiti around 15,000 years ago, near the end of the last glacial period. MARUM scientists studied an especially well-preserved fossil coral. This allowed tracing the monthly rhythm of sea-surface temperature changes at that time. The temperature pattern revealed by this climate "snapshot" can have only one surprising explanation: Tahiti at that time lay within the area of influence of El Niño, although the two-to-five year rhythm of temperatures typical of this climate phenomenon today does not extend as far as Tahiti. These results reveal two interesting conclusions: El Niño was active at the end of the last glacial and its influence extended farther into the South Pacific than it does today.

The laboratory analyses are complemented by simulations provided by computer-based climate models. These are used to link findings from different oceans. MARUM scientists were thus able to draw a connection between a weakened North-Atlantic Ocean circulation at the end of the last glacial and the pronounced tropical Pacific El-Niño activity. Be-

cause these climate models are also used to project future climate, the comparison of fossil coral data with

simulations of past climate offers a unique possibility for testing the models.

## Remote Sensing



Satellite measurements are an ideal complement to shipboard measurements of geophysical parameters. Satellites have been providing continuous global measurements of the Earth's atmospheric components for more than two decades. Environmental physicists at MARUM investigate the role of Saharan dust in the climate system. These scientists determine the extent to which dust particles in the atmosphere diminish the strength of solar radiation reaching the Earth's surface. They can estimate how much dust is being transported along various paths toward the Atlantic where it is eventually deposited. These data are then compared to those obtained from sediment traps in the Atlantic as well as to the results of climate models. In light of the current concerns about climate change, many new findings are being obtained regarding climate processes and also about nutrient cycles.

# Small organisms, large implications

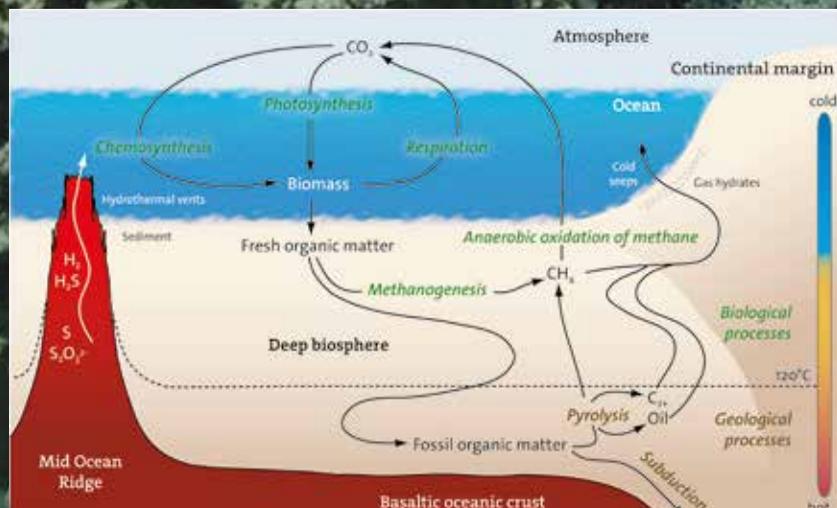
## MARUM Research Area »Geosphere-Biosphere Interactions«

Imagine 3,5 billion years – impossible! The oldest proven traces of life on Earth go back that far. Since that time the face of our blue planet has been shaped not only by geodynamic processes, but also by the existence and activities of living organisms. Their metabolic reactions significantly influence the global cycle of elements. This applies especially to the smallest of them, the bacteria and archaeans, whose importance is often underestimated. These one-celled organisms play a primary role in determining the chemical compositions of the atmosphere, the ocean and groundwater, as well as many rocks. Their metabolic reactions, through which they produce the energy they need for life, are very diverse and linked to one another by complex interactions. At the same time biological processes

are also constantly being influenced by processes of geological transformation. Habitats change; some life forms disappear – others survive, adapt, or go through new stages of evolution.

This MARUM Research Area is dedicated precisely to these kinds of interactions at the interface between the solid Earth and the biological world. The broad spectrum of interdisciplinary projects includes investigations of the cycles of carbon, nutrients and trace matter in the sea as well as studies of the distribution, functionality and diversity of specific groups of organisms. An additional research theme focuses on the various causes of seafloor seeps and the processes occurring at these sites. Characterized by extreme chemical conditions and, depending on the type of seep or vent system,

The deep biosphere within the seafloor is one of the largest contiguous ecosystems on Earth. Its role in the global carbon cycle is being investigated at MARUM.





Indispensable equipment: deployment of the submarine robot MARUM-QUEST



often with temperatures as high as 400 degrees Celsius, these habitats produce unique biological communities. Their study is closely linked with hopes for new knowledge about the origins of life on Earth.

In contrast, the expanses of the abyssal plains and the slopes falling away from the continents seem to be almost completely free of life. This appearance, however, is deceptive because most of the biological activity here takes place within rather than on the seafloor. Working in international cooperative projects and research

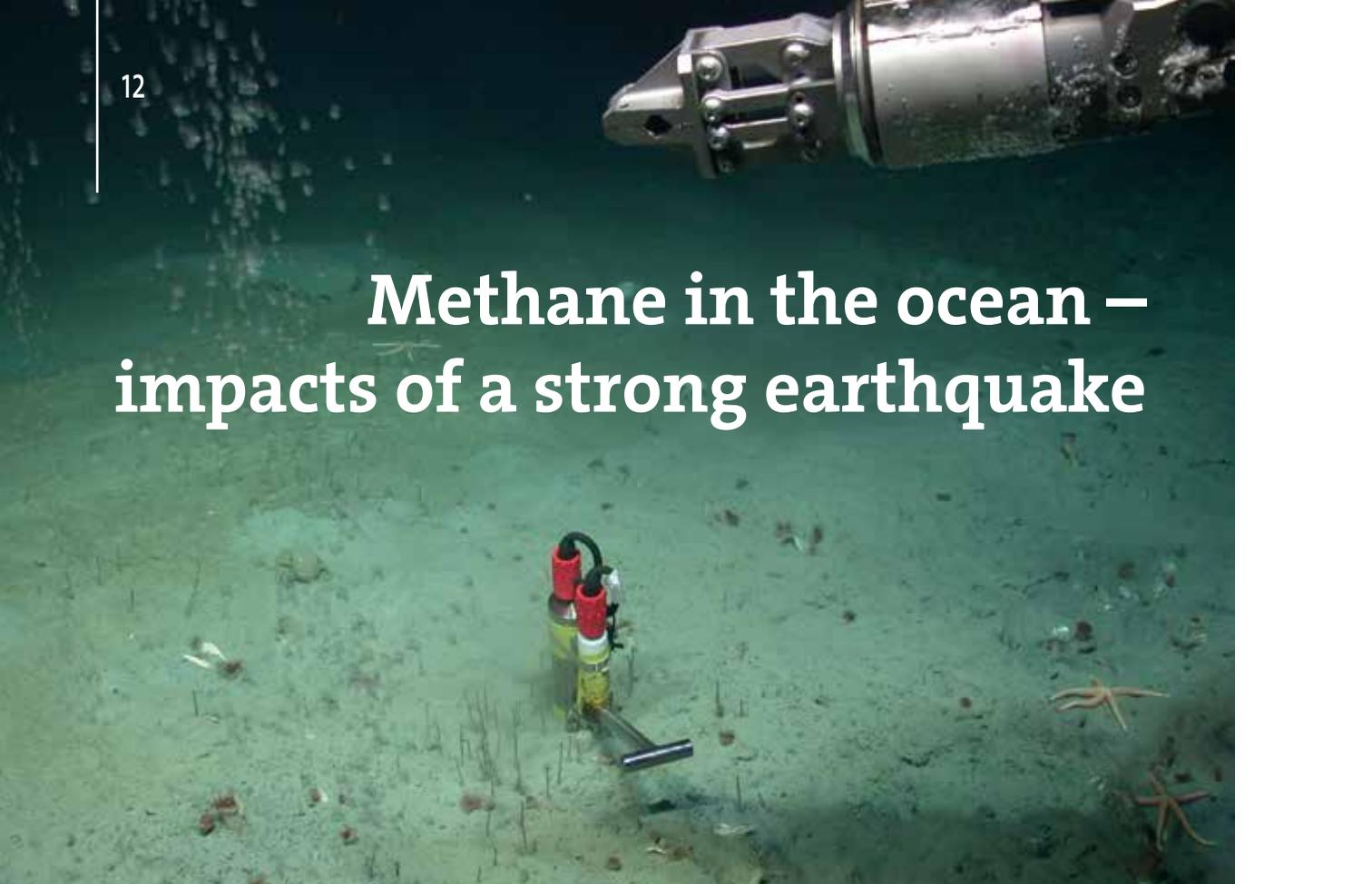
programs, MARUM scientists have been able to verify the presence of microorganisms living in deposits hundreds of meters below the seafloor. Although investigations of this deep biosphere are still in their early stages, there are good indications that the comparatively slow exchange processes between the geosphere and biosphere occurring here could contribute to the Earth's climatic development.

At MARUM scientists investigate the interactions between geological, biological and chemical processes at and below the seafloor, as well as in the water column. Main focal points of this research include understanding the role of microbial communities in material and energy fluxes, describing the driving forces responsible for the formation of seep and vent systems, and quantifying geochemical fluxes on the micro to global scales. Results from these studies are directly related to current issues of global importance, such as the concentration of greenhouse gases in the atmosphere.

*We aim at understanding the highly dynamic interactions between the ocean's geosphere and biosphere, from ultra-fine community structure to global biogeochemical cycles. At MARUM academic and non-academic cooperation partners meet to generate insight into the astonishing diversity of Earth's marine ecosystems.*



Lars Wörmer  
Postdoc at MARUM



# Methane in the ocean – impacts of a strong earthquake

On November 28, 1945 at 5:26 a.m. local time, the Earth shook violently off the coast of Pakistan. The quake, whose epicenter was located at a depth of 15 kilometers and not far from the coastal town of Pashan had an intensity of 8.1 on the Richter scale. The results, not surprisingly, were devastating: A tsunami rolled across the northern Indian Ocean and ravaged the shorelines of the coastal countries. Around 4,000 people died under waves up to eleven and a half meters high. An undersea mud volcano erupted off the Pakistani coastal region of Makran, creating four small islands. The mud eruptions were accompanied by a release of the greenhouse gas methane. According to eyewitness reports, the gas ignited on one of the islands, sending flames hundreds of meters into the sky.

**I**n 2007, 62 years after the catastrophe, a team led by MARUM scientists carried out an expedition to the Makran region on the research vessel *METEOR*. The researchers investigated how the quake had affected the distribution and mobility of methane in the seafloor. Methane occurs in three phases within this realm: dissolved in the water surrounding individual sediment grains, as free gas, and as gas hydrate. Gas hydrates are ice-like compounds composed exclusively of hydrocarbon gases – primarily methane – and water. They form at

low temperatures and high pressure when the methane concentration reaches a saturation level.

Due to density differences, an oceanic tectonic plate is subducting beneath the Eurasian plate at the Makran continental margin. In the process, the continental plate is scraping large amounts of methane-rich sediments off of the submerging plate. These kinds of motions rarely occur without disturbances. The plates lock into one another until the tension is released in the form of an earthquake. In the study area off Pakistan earthquakes with

intensities greater than 8 occur about every 100 to 200 years.

During the expedition the scientists deployed the remotely operated vehicle *MARUM-QUEST*, took sediment cores from the seafloor, and processed geophysical data. This substantiated the fact that earthquakes can mobilize methane in the sediments and that in some cases it can even be released into the sea. The 1945 quake physically fractured the seafloor. The free methane trapped under the gas hydrate layers ascended through cracks toward the sediment surface

and escaped into the ocean. According to conservative estimates, since the earthquake around 7.4 million cubic meters of methane have escaped into the ocean, recalculated for the pressure conditions at sea level. This is approximately equal to the volume of ten large gas tankers and does not include the amount of methane immediately released as a result of the 1945 earthquake.

In the study area off Pakistan methane was released from the seafloor at a water depth of 2,861 meters. Considering current investigations of global climate, this means that methane from the seafloor in shallower marine regions could enter directly into the atmosphere. This appears to be the case, for example, in the Laptev Sea in Siberia.

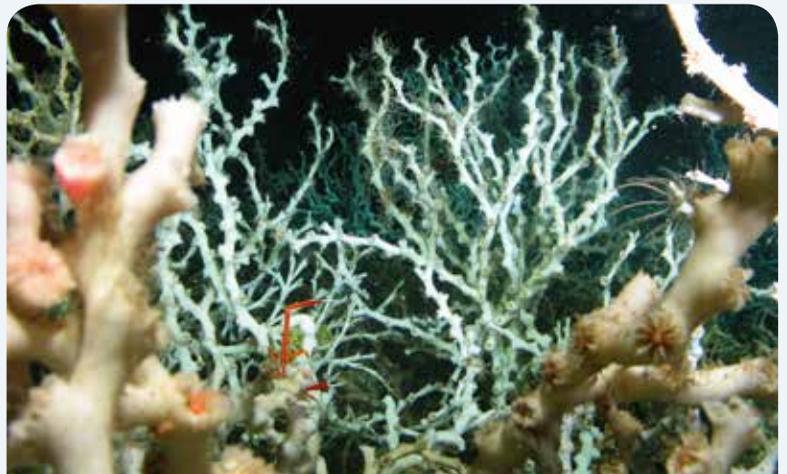
There is an obvious reason why MARUM researchers study the question of whether natural methane from below the seafloor remains in the water column or enters into the atmosphere: As a greenhouse gas in the atmosphere, methane is 20 times as effective as carbon dioxide.

In addition to natural and anthropogenic methane that is produced on the continents, enormous amounts of methane are created in the ocean within the seafloor. This occurs particularly in areas with high biological productivity. These are marine regions where large amounts of carbon and other nutrients are available, which, with the help of light, are transformed into organic material by microscopic plants and animals at the bottom of the food web. When these organisms die, their remains are deposited at the seafloor. The necessary carbon, a main ingredient for the production of methane, is thus available here. These high-productivity regions are usually located on the continental margins, such as the coast of Pakistan, and are thus frequently the goal of MARUM ship expeditions that are working to unlock the secrets of methane.



Methane hydrates are stable under the high-pressure and low-temperature conditions that prevail at the seafloor in water depths greater than 400 meters. Under atmospheric conditions methane hydrate decomposes and large amounts of flammable methane escapes (image above). At certain methane hydrate locations such as offshore Pakistan, methane is seeping out of the seafloor (image, opposite page).

## Ocean and Life



In areas where the continents slope down to the deep sea, cold-water corals form biodiversity hot spots. Primarily in water depths from 200 to 1,000 meters, they build remarkable structures on the seafloor, ranging from reef-like frameworks covering several tens of square kilometers to mounds reaching heights of over 300 meters. MARUM researchers study how these ecosystems have developed over time, particularly with respect to their dependence on climate swings between cold and warm periods. This work includes the use of remotely operated vehicles, whose high-resolution video recordings provide insight into the diverse nature and functioning of these ecosystems. Regionally, the focus of cold-water coral research at MARUM extends from the northeast Atlantic and Mediterranean to the Gulf of Mexico and the Straits of Florida.

# From coast to deep sea

## MARUM Research Area »Seafloor Dynamics«

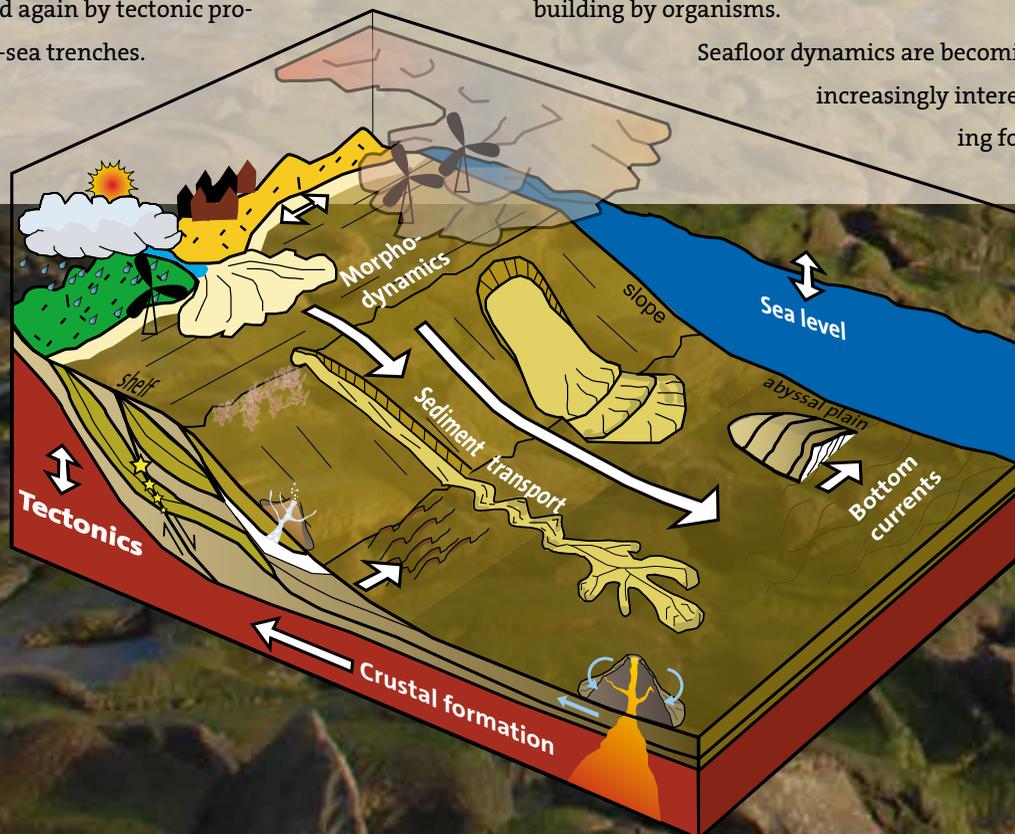
The ocean covers approximately 71 percent of the Earth's surface. Large areas of the seafloor are draped by a sediment cover with a thickness of up to several tens of kilometers, which originates from continental erosion. Water and wind transport these sediments into coastal areas and the shelf seas, where they may be picked up by ocean currents and moved onto the continental slopes and farther down to the abyssal plains. The underlying oceanic crust is being continuously created by dynamic magmatic processes along a 60,000-km long network of mid-ocean ridges before it is recycled again by tectonic processes in the deep-sea trenches.

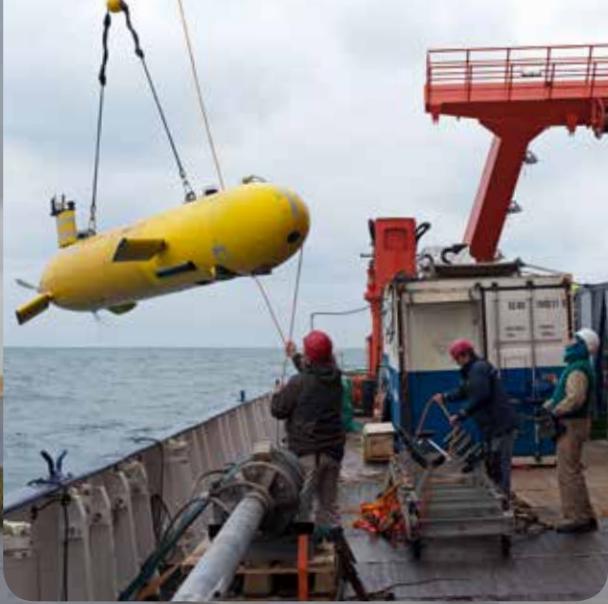
A wide variety of processes

contribute, and often interact, to make the seafloor a very dynamic and geologically diverse environment of the Earth's »surface«. These include sediment erosion, transport and deposition, as well as submarine volcanism and seawater ventilation through the oceanic crust. In addition, tectonic movements associated with earthquakes can generate rapid gravitational mass movement and ensuing tsunamis. Dewatering and mud volcanism can also change the face of the seafloor, as can fluids escaping through hot vents and cold seeps, as well as various biological activities, including reef-building by organisms.

Seafloor dynamics are becoming increasingly interesting for

Seafloor dynamic processes





Deployment of the Autonomous Underwater Vehicle (AUV) MARUM-SEAL from the research vessel FS METEOR. This AUV can dive to a water depth of 5,000 meters and produce highly accurate maps of the seafloor.

commercial endeavours, particularly with regard to offshore construction, harbour extensions, ship navigation, and dredging activities. These all interfere to some extent with sediment dynamics in coastal and shelf seas. Additionally, the seafloor supplies natural resources and may be a site for the triggering, for example, tsunamis, which threaten a worldwide increasing coastal population. All of these issues increase the societal importance of understanding seafloor processes.

In the Research Area Seafloor Dynamics, MARUM scientists study the origin, structure and development of the seafloor worldwide. This is a challenging task as many processes are occurring simultaneously at any given time, on very different time scales and with different spatial extents. Working in cooperation with in-

ternational partners from various disciplines, MARUM scientists tackle these challenges by investigating both the underlying processes as well as their interactions in shaping and changing the seafloor from the coast to the deep-sea. MARUM scientists address these topics by field surveys, lab experiments and modelling approaches, and by developing and employing cutting-edge technologies, such as autonomous vehicles and seafloor drill rigs.

From its formation by volcanic and tectonic processes to its colonization by organisms to – often catastrophic – mass movements at continental margins and in coastal areas, the seafloor is a highly dynamic environment. Here, the oceanic crust, sediments, seawater, and biota vividly interact with each other. The Research Area »Seafloor Dynamics« aims to understand and quantify the driving forces and interconnections of the processes shaping the seafloor.

» My research at MARUM focuses on the highly dynamic sedimentary processes in the world's coastal zones, where land and ocean meet. At MARUM, I enjoy access to a vast range of technological resources, the collaboration within an international team of coastal scientists, and supportive programs for early-career scientists.



Eva Kwohl  
Postdoc at MARUM

# Submarine landslides – an underrated geohazard

Alpine landscapes are well known for their frequently occurring rock falls, debris or mudflows, which can result in significant property damage or sometimes even cost human lives. It is not common knowledge, however, that submarine slopes are also sites for »landslides«. These present a danger for gas and oil pipelines as well as for telecommunications cables and large offshore structures. Furthermore, when large slump masses acquire sufficient momentum they can also trigger tsunamis – like the one on the Mediterranean coast of Nice in 1979, when around five cubic kilometers of sediments slid down to a water depth of 2,000 meters. The result was a local tsunami up to three meters high. Such events illustrate the need for studying submarine landslides in order to better understand their causes as well as their dynamics and, when possible, to mitigate their impacts.



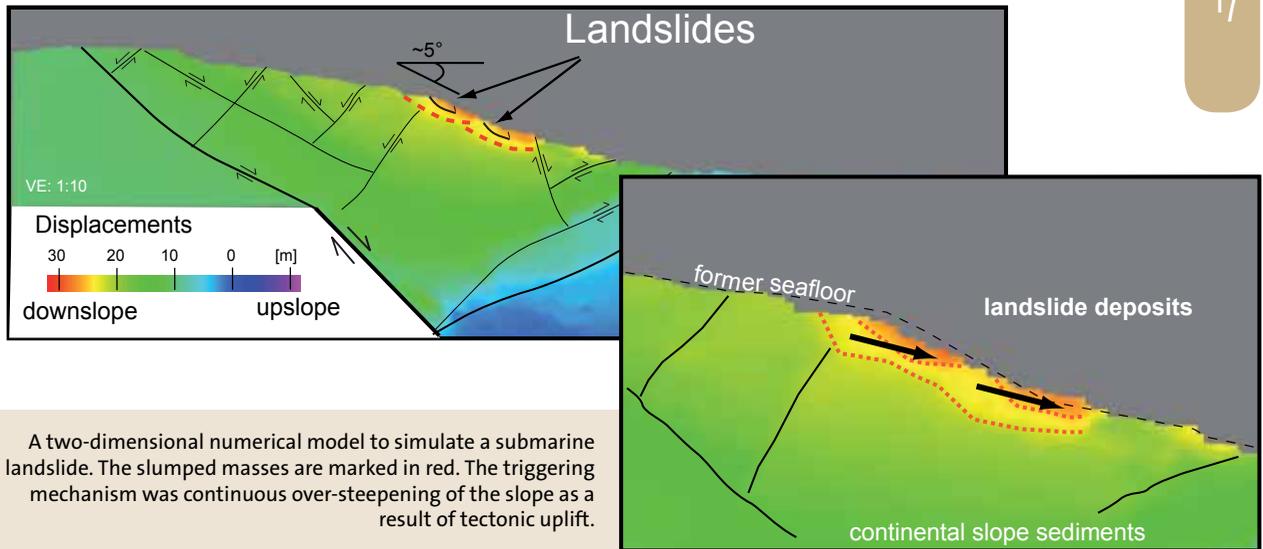
Deployment of the MARUM long-term piezometer from research vessel POSEIDON to monitor indicators for sub-seafloor deformation and fluid flow in the slope offshore Nice, France. This slope collapsed in 1979 and caused a major landslide and tsunami. The governing geoprocesses that caused this catastrophic event are studied by MARUM researchers.

**S**ubmarine landslides have much greater dimensions than mountain slides. In one of the largest European landslides, the Storegga slide, which occurred about 8,000 years ago off the Norwegian coast, sediment packages tens of meters thick were transported more than 600 kilometers down the continental slope. The resulting tsunami brought waves with heights of up to six meters to the east coast of Scotland and over 20 meters to the Shetland Islands. In addition to these giant landslides, many smaller submarine slumps occur around the world. Nonetheless, because of their great number, frequency and wide distribution, these have a great societal significance. This is due to the increasing economic usage of continental slopes in recent decades, such as for oil and gas production. At the same time, the number of people living in coastal regions is increasing. Thus, submarine landslides have poten-

tially much more severe impacts than a few decades ago.

Submarine landslides are being studied around the world. The goals include obtaining a better understanding of the triggering mechanisms as well as the behavior of the slumping material in motion. The latter aspect is presently of particular importance because it is still not completely understood how huge slump masses are transported downslope for many kilometers, although underwater slopes have very low inclines.

The stability of a continental slope is determined by the physical properties of the slope sediments. A slide can be triggered when the shear resistance of the sediment body significantly decreases in a short time, or by a steepening or over-steepening of the slope. The former can be triggered by a rapid increase in pore pressure, which is the fluid pressure in the tiny pockets between the sediment grains.



A two-dimensional numerical model to simulate a submarine landslide. The slumped masses are marked in red. The triggering mechanism was continuous over-steepening of the slope as a result of tectonic uplift.

This could happen, for example, as a result of a rapid increase in sediment load, pulsing groundwater flows, from fluids rising from deeper layers of the seafloor, or as a result of earthquakes. All of these trigger mechanisms are processes by which fluids are released or moved, whereby highly porous materials may liquefy and lose their strength when the fluid pressure increases. Exchange between the geosphere and hydrosphere also has consequences for element fluxes and mass balances, because the fluids could be ion-rich waters from depth or hydrocarbon gases/gas hydrates. These cold seeps play a fundamental role in continental-margin dynamics.

Research on submarine landslides at MARUM provides a better understanding of the preconditions, the trigger mechanisms, the dynamics of slide processes (including the potential danger of tsunamis), and the role of the triggering fluids in geosphere-hydrosphere interactions.

To address these questions, MARUM scientists have collected unique datasets applying modern innovative technologies: high-resolution geophysical mapping; sedimentological and geochemical analyses; on site and laboratory measurements of the physical characteristics; long-term monitoring through seafloor observations; and

computer simulations of landslide processes. Only this combination of a wide variety of investigative techniques enable to test hypotheses

on landslides, develop conceptual models and thus assess risks and impacts on the coastal regions and, if possible, to mitigate their effects.

## Ocean and Society



The human impact on the marine environment and coastal regions is intensifying. Laws and regulations such as the EU Marine Strategy Framework Directive and other legal codes now require the monitoring of marine environments. MARUM scientists develop concepts to assess the condition of the marine environment. Scientific knowledge is transferred to policy and decision makers, administrators, and interested public. Conflicts of interest between environmental protection and use of coastal areas and the seas are investigated in collaboration with colleagues in the social and legal sciences.

*There is no better place for me to carry out my research than at MARUM. The abundance of superb knowledge, the European-wide, if not worldwide unparalleled infrastructure in combination with the IODP core repository, as well as the excellent international contacts provide an ideal environment for research at the highest level.*



Thomas Westerhold  
Senior Scientist at MARUM

# Over 150 kilometers of seafloor

## The Bremen IODP core repository

The largest of the International Ocean Discovery Program's (IODP) three core repositories worldwide is located at MARUM. International research institutes in 27 countries, including the United States, Japan, and a consortium of European countries, have joined together to carry out worldwide expeditions in the oceans using scientific drilling ships and platforms.

There are over two hundred thousand core sections stored in the Bremen IODP facility, all originating from the Atlantic and Arctic Oceans, and the Mediterranean, Black, and Baltic Seas. They were taken since 1968 under the scientific programs of the Deep Sea Drilling Project (DSDP), Ocean Drilling Program (ODP), Integrated Ocean Drilling Program (IODP), and the new International Ocean Discovery Program (also IODP, begun in October 2013).

Initially the core cylinders are split lengthwise. The researchers are allowed to take samples from the des-

ignated working halves, while the archive halves are generally reserved for non-destructive analyses such as color or X-ray fluorescence scanning. During the first year after a drilling expedition, participating scientists have exclusive rights to samples and data. After this moratorium period any investigator from anywhere in the world can request samples. Approximately 200 international scientists visit the IODP Bremen Core Repository each year, while others have the requested samples sent to them. Around 50,000 samples are sent out annually.

Germany is one of the 19 member countries in the European drilling consortium ECORD. This group carries out IODP expeditions in marine regions where the large deep-water drill ships JOIDES RESOLUTION (USA) and CHIKYU (Japan) cannot operate. These areas include the ice-covered regions around the North Pole and shallow coastal regions or seas.



For these kinds of research cruises ECORD charts special ships or drilling platforms. These vessels have no onboard laboratory facilities. Mobile laboratory containers, mostly from MARUM, are therefore installed on these platforms. In these labs, critical initial work that cannot be delayed, such as geochemical measurements or microbiological sampling, is carried out. All additional analyses for ECORD cruises are performed later onshore, in Bremen.

After the end of each expedition a team of around 30 researchers meets in the laboratories of the Bremen Core Repository for the »Onshore Science Party« to carry out the remaining standard IODP measurements on the cores. For several weeks, in two shifts lasting from early morning to late at night, the scientists visually describe and analyze the materials. The measurements include physical properties such as density and thermal conductivity, chemical composition of the pore

waters within the sediments, and age determinations of the samples. The initial results are then summarized in expedition reports. And so, each expedition provides an additional piece to the puzzle of our total concept of the Earth.

In the five-and-a-half-meter high racks of the Bremen Core Repository, 154 kilometers of core (as of mid 2014) are stored in 250,000 plastic boxes. The core sections are each one-and-a-half meters long with a diameter of almost seven centimeters. These are the fruits of more than 45 years of scientific drilling expeditions.

# Navigation in a sea of data

## The PANGAEA data information system

**I**n cooperation with the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI), MARUM operates a data information system in which Earth-system research data are archived and published. Because its goal is to promote a holistic and comprehensive approach to viewing the Earth, the system is named after the supercontinent that, 200 million years ago, contained all of the present-day continents: PANGAEA.

The efficiency of sampling and analytical instruments employed in Earth sciences and the amount of data collected has grown exponentially in recent decades. At the same time, thanks to advances in information technology, it is now possible to store, distribute and process almost unlimited volumes of data. However, due to rapid changes in hardware and software, too

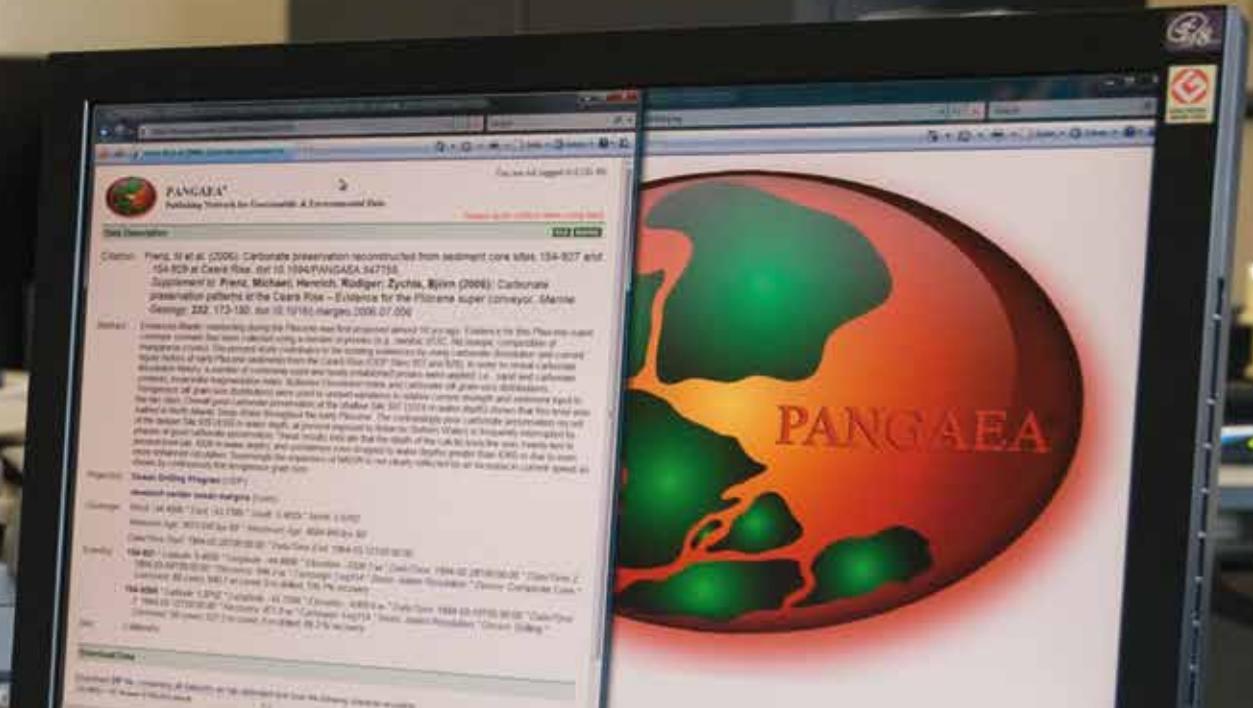
much data is still being lost. This is because the library-style storage of primary data from research projects and their resulting publications have not been considered to be an integral part of the scientific working process in the past.

PANGAEA provides science with a tool for long-term and reliable access to all data types produced in the research of our Earth. This novel electronic library is based on international standards, and is therefore not only smoothly compatible with the globally developing geo-data infrastructure, but also serves as a publication system. It integrates data with the established procedures of scientific publication. Just like articles in professional journals, the data are subject to a review process and can be cited by other scientists in their own work. There is therefore a scientific incentive to publish data.

At MARUM I am involved in the planning of expeditions and the synthesis of new data products, both of which require rapid access to published raw data. For this reason the data base PANGAEA is an indispensable tool for my everyday work.



Stefan Mulitza  
Senior Scientist at MARUM



The publication system is based on a well-defined editorial process. Entered data are linked with all necessary metadata and filed so as to be citable. The metadata include bibliographic information as well as ship's position and time details, and the instruments and methods used for measurements.

PANGAEA can store any conceivable measurement values from all the fundamental disciplines in Earth sciences, from the upper atmosphere to deep below the seafloor. The »data warehouse« is an important part of the system. This allows retrieval of user-defined data subsets from the total database inventory. As one example, the evolution of local sea-water temperature over the past hundred years can be constructed from many different sources. With this capability, PANGAEA can promote investigations of novel scientific questions,

helping Earth scientists to expand our understanding of the complex Earth system.

There are around 350,000 datasets in the PANGAEA data information system. They comprise more than six billion individual measurement values and data objects including 100 terabytes of pictures, seismic profiles and climate modeling data. Around a hundred new datasets are added each day.

Over the past ten years, data from more than a century of Earth sciences has been collected and archived in PANGAEA.

*MARUM technologies provide us with unique opportunities for investigating the seafloor. Long sediment cores drilled with the MARUM-MEBO contain information on climate changes that extend several hundred thousand years into the past.*



Gema Martínez Méndez  
Postdoc at MARUM

# Heavy equipment

## Marine research technology at MARUM

**M**ARUM has been deploying marine technology instruments on marine expeditions for over 20 years. It uses equipment that is available on the open market but also develops new technology itself. A number of underwater vehicles are now available: The cable-controlled remotely operated vehicles (ROVs) include the MARUM-QUEST, with a depth capability of 4,000 meters. In late 2015 another deep-diving ROV, the MARUM-SQUID, with a depth capability of 2,000 meters, will be available. Their high-resolution cameras document the environment with a quality that has never been achieved before. The grabbing arms are video-controlled remotely from the research vessel to optimally take samples or position measurement instruments for experiments on the seafloor.

Remotely operated vehicles can be deployed to address a number of scientific questions, but they can

only investigate a limited area of the seafloor. Multi-beam echosounders installed in the hulls of research vessels are used to record seafloor information over larger areas. Their sound waves are reflected by the bottom to provide maps of the seafloor. But at great water depths the multi-beam image of the seafloor is less clear. MARUM has therefore obtained an autonomous underwater vehicle (AUV) called the MARUM-SEAL. It is also equipped with a multi-beam echosounder and travels a predetermined course within a particular region at a height of around 50 meters above the bottom. This 5.5-meter long device, shaped like a torpedo, can dive down to 5,000 meters and maps seafloor relief with high accuracy. It can even recognize structures that are only a few decimeters in size.



A new underwater vehicle that either operates autonomously or can be remotely controlled in real time from a research vessel is presently being developed for investigations in areas that are difficult to access like regions beneath sea ice. This vehicle will be able to maneuver beneath the ice several kilometers from the ice edge and take samples at selected sites from the base of the sea ice.

MARUM scientists reap benefits from the extremely complementary nature of the various instruments. At locations where the SEAL has precisely mapped the bottom, the underwater vehicle QUEST or the mobile lander MARUM-CMOVE can then investigate specific targeted sites in more detail. CMOVE is an autonomously operating, four-wheel drive vehicle for deployment in water depths down to 3,000 meters. It rolls slowly and energy efficiently along the sea bottom and provides a stable

platform for scientific experiments at the sediment-water interface.

The drill rig MARUM-MEBo70, just under seven meters tall, was developed at MARUM. It is deployed from research vessels in water depths down to 2,000 meters, provided with energy through a copper wire, and is remotely controlled by a fiber optic »umbilical cord«. MEBo70 can retrieve continuous cores to a depth of 70 meters below the sediment surface. It fills a gap between standard coring tools and the drilling ships of the International Ocean Discovery Program (IODP). Starting in 2015, its improved successor MARUM-MEBo200, with the ability to core up to 200 meters into the seafloor in up to 2,700 meters water depth, will be available for expeditions.

*The incredibly modern facilities of the MARUM laboratories and the technological know-how of my colleagues are invaluable to me and my research. Here at MARUM and our cooperating institutes I can discuss my experimental ideas with a number of motivated scientists and then immediately put them to the test.*



Nadine Goldenstein  
PhD student at MARUM

# Revealing the invisible

## The lab infrastructure at MARUM

Marine scientists count on extensive laboratory analyses to reconstruct past climate and environmental conditions and to assess current processes. Highly developed spectrometers, chromatographs, X-ray fluorescence scanners, magnetometers and other modern instruments are working around the clock at MARUM. Firstly, in order to unlock the interdependent biological, geological and chemical processes in the ocean, the abundance of inorganic and organic trace substances in sea water, sediment, rocks, or coral samples are determined. Secondly, isotope analyses play an important role.

If concentrations of chemical elements are to be determined, or their relative proportions assessed, scientists rely on emission spectrometers, allowing high-resolution reconstructions of past environmental

processes in the ocean. Ion chromatography is used if the amount of dissolved nitrate or sulfate in ocean water has to be determined. These compounds serve as indicators for oceanographic and biogeochemical processes.

Organic components dissolved in sea water or preserved in sediments are analyzed with mass spectrometers. MARUM scientists thus obtain extensive information about the distribution of organic materials, past climatic events, and about the interactions between microbial life and element cycles.

The determination of trace substances is complemented by isotope analyses, targeting either the distribution of stable isotopes or isotopes originating from naturally occurring radioactive decay of certain elements.



In order to measure the stable isotopes on corals, scientists acidify the original sample and analyze the resulting gas phase with isotope-ratio mass spectrometers. Individual organic components are prepared and analyzed in a similar way, thus allowing temperature and salinity reconstructions of past climate epochs and a comprehensive understanding of the global carbon cycle.

In order to understand how the environment affects isotope ratios and element cycles, MARUM runs a DNA and culturing facility for marine algae and foraminifera. This approach reveals the hidden diversity of shell-producing planktonic organisms and their growth behavior in respect to climate changes under controlled laboratory conditions.

MARUM researchers also specialize in isotope signals that originate from natural radioactive decay. Here,

chemical trace elements in sediments or rocks are processed in clean laboratories and then analyzed by state-of-the-art mass spectrometers. Researchers thus get information about the geochemical development of our planet or past environmental changes in the ocean.

For investigations of complex organic cell-membrane components, liquid chromatographs are coupled with dedicated mass spectrometers. Intact polar lipids in extracts from sediments, water samples and cell cultures are selectively analyzed. Scientists thus obtain information about the presence, diversity, and mode of life of the various micro-organisms in the samples.

As a GLOMAR associate scientist, I am very proud to support students throughout their PhD. I also appreciate the interdisciplinary environment provided by MARUM/GLOMAR as well as the opportunity to attend a wide variety of courses. I believe that it encourages the students and me to improve our scientific work.



Alice Lefebvre  
GLOMAR Associate Scientist at MARUM

# Perspectives for early career scientists

## Training at MARUM

**M**ARUM provides a stimulating environment for PhD students and post-docs from currently over 30 countries. PhD students at MARUM have the opportunity to become members of GLOMAR, the Bremen International Graduate School for Marine Sciences. This program provides the foundation for a broad spectrum of advanced training courses and creates optimal conditions for PhD students to establish international and interdisciplinary networks, which are important for their long-term careers.

Because GLOMAR covers a wide range of disciplines, the graduate school serves as an interface between MARUM and marine science activities in the region that are not directly related to the MARUM research portfolio. The disciplinary backgrounds of GLOMAR

members range from geosciences to physics, biology, chemistry, human geography, political and social sciences, and also cover economics and legal sciences.

At MARUM, PhD students are offered a variety of state-of-the-art supervision and training approaches. Moreover, GLOMAR supports its PhD students in »going international«, e.g. by presenting their research at international conferences and by spending extended research stays at international research institutes.

One of the central factors in the success of this graduate training program is supervision by an advisory committee of experienced scientists, which ensures optimal support. Regular meetings are held to discuss the PhD project as well as career planning and achievement of key qualifications. Numerous advanced training courses



are available to improve skills in time and project management as well as presentation and communication techniques.

In addition, GLOMAR offers a wide range of introductory and advanced courses that are in part oriented toward the respective scientific subject, but which also focus significantly on interdisciplinary aspects. The success of the program is illustrated by the lively participation of PhD students and postdocs from Bremen as well as external institutes.

While the male-female ratio of PhD students is well balanced in the graduate programs, the proportion of women who move on to higher career-levels, is considerably lower. To sustainably improve this situation, MARUM, in cooperation with the university program

»plan m«, offers a mentoring program for female early career scientists that aims to support women with their career in science.

MARUM hosts two international research training groups, both funded by the Deutsche Forschungsgemeinschaft (DFG). INTERCOAST (Integrated Coastal Zone and Shelf-Sea Research) is a collaboration between the Universities of Bremen (Germany) and Waikato (New Zealand). It started in 2009 and accepted a second cohort of PhD students in 2012. In 2013, the German-Canadian group ArcTrain (Processes and impacts of climate change in the North Atlantic Ocean and the Canadian Arctic) accepted its first cohort of 12 PhD students.

# Communicating the ocean on shore

MARUM's dialog with the public

Public relations work at MARUM is directed at journalists, school students and teachers, decision-makers, as well as the general interested public. An important communication medium is the MARUM website. The homepage has up-to-date announcements on the daily operations of the institute. The »Discover« link takes you to press releases, expedition logbooks, or the Science by Phone question-and-answer project, which was initiated 15 years ago in cooperation with the Hamburg magazine »mare – die Zeitschrift der Meere«.

The MARUM TV project on YouTube has played an important role since April 2008. There are now almost 100 short films available, many of them in both English and German. The channel has over 330 subscribers and to date has registered around 430,000 video plays. A number of the films include dazzling pictures from the

deep sea taken by the submersible vehicle MARUM-QUEST. They are also shown in marine exhibits at distinguished German museums. In addition, the QUEST video material is frequently requested by television programs.

Since 2009 MARUM has taken a novel approach with the traveling exhibition MeerErleben (experiencing the sea), which will continue to visit many large German and European shopping centers through 2015. Mankind and the ocean, Diversity and evolution, Origins of volcanos and earthquakes, and Modern research technologies are just a few of the themes in the seven exhibition modules. A combination of fascinating photos, videos, animations, texts and graphics, as well as entertaining interactive exhibits provide a variety of opportunities to become involved in the exhibition. The highlights of MeerErleben include the high-definition deep-sea movie theater, with

At MARUM I have the chance to explore completely new directions in public relations. The many innovative projects make my work here so varied and exciting. But I enjoy working with the children most of all – they ask the best questions!



Jana Stone  
MARUM PR staff



underwater videos and photos from the submersible MARUM-QUEST, and a cylindrical 2,500 liter aquarium in which visitors can test-pilot a real mini-submersible vehicle.

The MARUM UNISchullabor offers regular courses for children and youth, targeted towards kindergarten, secondary levels I and II, or handicapped children. Teachers can attend courses related to MARUM within the framework of the Summer University program held by the University. In addition, geosciences are a part of the curriculum in the State of Bremen. This improves success within the nation-wide contest Jugend forscht (Youth Research).

MARUM is deeply involved in national and international science communication networks such as public relations at the German Marine Research Consortium or the International Ocean Discovery Program. These

comprehensive efforts are rounded off through by use of social media such as @marum\_de at Twitter.

MARUM is constantly creating new products with target audiences in mind. The MARUM UniSchuollab focuses on co-operation with schools and offers a wide spectrum of courses. Families and children are exposed to science during open house days on the campus or on board research vessels. MARUM co-operates with major German museums to prepare exhibitions, and successfully develops in-house projects. National and international science communication networks are in place to address decision makers or early career scientists attending congresses and conferences.

# Credits

## Editor

Michael Schulz  
MARUM – Center for Marine Environmental Sciences  
University of Bremen  
Leobener Str., 28359 Bremen  
+49 421 218 65500  
mschulz@marum.de

## Photos

Large photo cover and p. 3 small photo 4: Sean Diaz, SDProPho; front page middle and bottom, portraits, and p. 3 small photo 2 and 3, p. 6/7, 7 top, 11 top, 13 top, 15 top, 19 top, 20/21, 22/23, 23 middle, 24/25, 26/27, 27 top: Volker Diekamp; front page top, p. 28/29: Jana Stone (all MARUM); photo foreword: Kai Uwe Bohn, Universität Bremen; p. 2/3: C. Lott, HYDRA; p. 3 small photo 1, p. 14/15, 18/19, 29 bottom: Albert Gerdes, MARUM; p. 4/5: Husemann/Timmermann/Hidde – Architekten und Ingenieure, Braunschweig; p. 8 left, bottom right: Thomas Felis; p. 8 top right: Jürgen Pätzold (all MARUM); p. 9 top left: ECORD/IODP and Felis et al. 2012, doi:10.1038/ncomms1973; X-radiograph: Felis et al. 2009, doi:10.1130/G25581A.1; p. 9 top right: ECORD/IODP; p. 9 bottom: NASA; p. 10/11, 12, 13 and back side: Submarine shots by MARUM-QUEST; p. 16: Achim Kopf; p. 17 bottom, p. 29 top: Frank Schmieder (all MARUM); p. 19 middle: Carlos A. Alvarez Zarikian, IODP; p. 23 top: MARUM; p. 25 top: Xavier Prieto Mollar; p. 25 bottom: Matthias Zabel; p. 27 bottom: Christina Klose (all MARUM)

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## Texts

Wolfgang Bach, Torsten Bickert, Marcus Elvert, Thomas Felis, David Fischer, Albert Gerdes, Lydia Gerullis, Dierk Hebbeln, Sebastian Hötzel, Katrin Huhn, Achim Kopf, Ursula Röhl, Michael Schulz, Gerold Wefer, Christian Winter, Matthias Zabel (all MARUM)

## Editorial Staff

Albert Gerdes, Walter Hale (all MARUM)

## Layout and typesetting

Frank Schmieder, MARUM

## Print

Asco Sturmdruck, Bremen

## Circulation

2<sup>nd</sup> edition, 4,000 copies

Bremen, August 2014





MARUM – Center for Marine Environmental Sciences  
University of Bremen  
Leobener Str.  
D-28359 Bremen / Germany  
[www.marum.de](http://www.marum.de)

 **marum**  
*The ocean in depth!*

MARUM aims at understanding the role of the oceans in the Earth system by employing state-of-the-art methods. It examines the significance of the oceans within the framework of global change, quantifies interactions between the marine geosphere, physical processes and marine biosphere, and provides information for sustainable use of the ocean.

In MARUM, the DFG Research Center and the Cluster of Excellence »The Ocean in the Earth System« are key elements among many additional national and international research projects.