

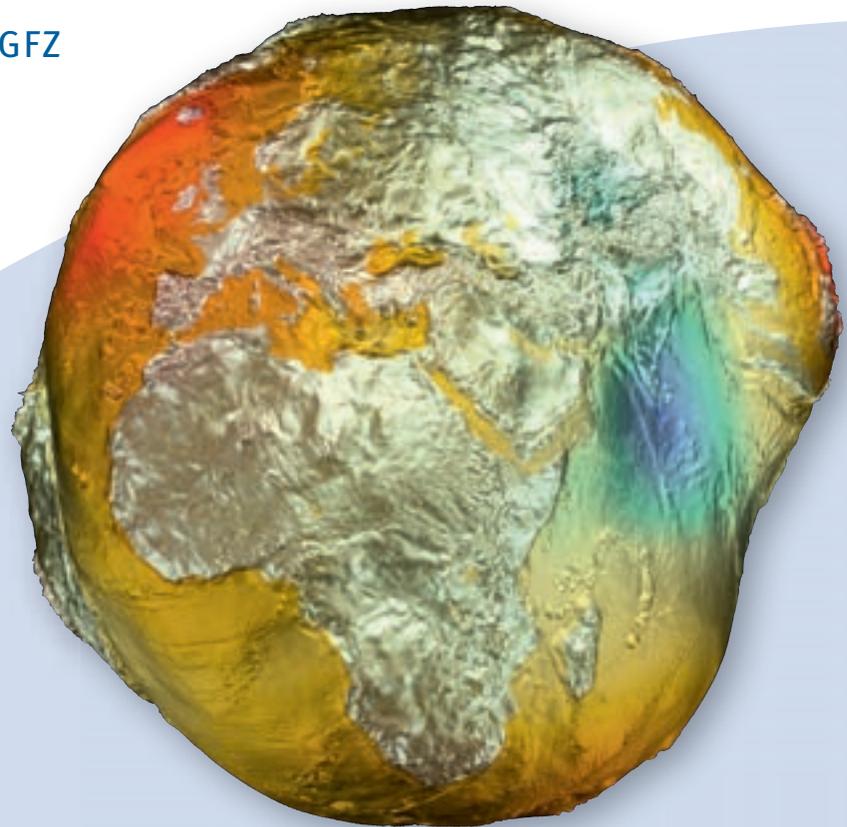
GFZ

Helmholtz Centre
POTSDAM

HELMHOLTZ CENTRE POTSDAM
**GFZ GERMAN RESEARCH CENTRE
FOR GEOSCIENCES**

From Space to the Core of the Earth

The World of the GFZ



GFZ

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POTS DAM

At a Glance:

Name	Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences
Affiliation	Helmholtz Association of German Research Centres
Funding	Federal Ministry of Education and Research (90%); Ministry of Higher Education, Science and Culture (10%)
Employees	Circa 1115, of which 453 scientists and 173 Ph.D. students (December 2012)
Joint Appointments	9 with the University of Potsdam 6 with the Free University of Berlin 4 with the Technical University of Berlin 1 with the Brandenburg University of Technology (Cottbus) 1 with the Humboldt University Berlin
Annual Budget (2011)	€ 47.9 million from programme funding · € 41.2 million from third-party funding
Scientific Infrastructure	Geodetic instrument pool, satellite laser telescope, geophysical instrument pool, Plate Boundary Observatories Chile and Turkey, Global Change Observatories South Africa and Central Asia, Geomagnetic Observatories Niemegk and Wingst, KTB Deep Crustal Laboratory Windisch Eschenbach, drill rig InnovaRig, Ultra-Cleanroom laboratories for isotope geochemistry, laboratories for chemical analyses, facilities for high pressure/ high temperature experiments, scanning und transmission electron microscopy, High Performance Computing

Welcome...

to Potsdam's Telegrafenberg, which has been the home of research institutions for astrophysics and Earth science for more than 125 years. From research geodesy to the science of earthquakes and the investigation of the magnetic field, many Earth science disciplines have their roots here. In the years since the German reunification, the rich tradition and history of this world-renowned scientific site has provided a unique opportunity

to establish a large research centre for the Earth sciences. Here, the experience and knowledge collected in the East and West could be combined in a cutting-edge program for the investigation of our planet. On 1 January 1992, the GFZ German Research Centre for Geosciences was founded as a national research centre for the Earth sciences. In this brochure, we report on some of the activities undertaken at the GFZ, and invite you on a stroll through our departments to see the many facets of our work.



R. Hüttl

S. Schwartze

The focus of the research at the GFZ is the “System Earth” and the influence of humans on our planet. We investigate the history of this system, its characteristics, the processes which take place within it and on its surface, as well as the interactions between the elemental parts: the geo-, hydro-, atmo- and biospheres. The goal of our work is to understand these diverse and complex processes, and thereby lay the foundation for the effective management of the Earth's resources and our environment. In this way, we can provide solutions to problems of global importance, such as developing and implementing preventive measures for natural disasters, determining the availability of natural resources, and pinpointing the effects of human activities on natural cycles, such as the environment and climate. Only since recent years and thanks to the rapid developments in measuring and computing have the geosciences been capable

to put together the puzzle pieces of collected data and information to form an overall picture.

While enabling an in-depth study, the separation of Earth sciences into individual disciplines often makes it difficult to understand the “System Earth” as a whole. Therefore, when the GFZ in Potsdam was founded, an effort was made to overcome the traditional boundaries between various fields by collecting many different geoscientific disciplines into a single research consortium. Thus, the scientific instrumentation ranges from drill rigs to Earth-orbiting satellites (developed in house) and from hundreds of seismometers that measure Earth movements simultaneously to specialized presses to study rock samples under conditions that are otherwise found only deep beneath the Earth's surface.

The GFZ is also a hub for international communication and cooperation in the Earth sciences. By its nature, Earth science research is global and does not recognize national boundaries. As an active partner, the GFZ German Research Centre for Geosciences represents the Federal Republic of Germany in many international programs and cooperative efforts.

We invite you to marvel at the diversity of questions that GFZ researchers are tackling, and the broad spectrum of methods and techniques they apply in their quest. Naturally, only a small selection of our wide-ranging activities can be presented here.

We hope you enjoy reading about our work!

A handwritten signature in blue ink, appearing to read 'R. Hüttl'.

Prof. Dr. Dr. h. c. Reinhard Hüttl

A handwritten signature in blue ink, appearing to read 'S. Schwartze'.

Dr. Stefan Schwartze

A Century of Geosciences at the Telegrafenberg

1832	Construction of an optical telegraph station between Berlin and Koblenz. The hill is given its name.
1870	Founding of the Royal Prussian Geodetic Institute in Berlin, under the direction of Lieutenant General Johann Jacob Baeyer.
1889	First recording of a remote earthquake by Ernst von Rebeur-Paschwitz at the Telegrafenberg.
1890	Founding of the Geomagnetic Observatory in Potsdam.
1892	The official inauguration of the Royal Prussian Geodetic Institute on the Telegrafenberg.
1898 - 1904	Determination of the absolute value of the Earth's gravity. The value ascertained at Potsdam was adopted as the international reference in 1909 and remained valid until 1971.
1930	Transfer of the Geomagnetic Observatory to Niemegek
1933	Commissioning of the first two quartz chronometers for official timekeeping on the Telegrafenberg: a requirement to monitor the fluctuations in the Earth's rotation speed.
1969	The Geodetic and Geomagnetic Institutes in Potsdam are merged with the Geotectonic Institute in Berlin and the Geodynamic Institute in Jena to form the Central Institute for Physics of the Earth (ZIPE) in the former German Democratic Republic (GDR).
1988	An earthquake catalogue for the GDR and its surrounding areas for the years 823 to 1984 is published.
1992	The GeoForschungsZentrum Potsdam GFZ is founded.
1995	The GFZ's first satellite is launched (GFZ-1).
1996	Establishment of the International Continental Scientific Drilling Program (ICDP)
2000	The <i>CHAMP (Challenging Mini-Satellite Payload for Geosciences and Application)</i> georesearch satellite is launched. Founding of the Observatory for Earth Magnetism Wingst (<i>WNG</i>)
2002	Launch of the geosatellite tandem <i>GRACE (Gravity Recovery and Climate Experiment)</i> and founding of the <i>Central-Asian Institute for Applied Geosciences (CAIAG)</i> in Bischkek, Kirgistan.
2005	Request to design a tsunami early warning system for Indonesia (<i>GITEWS</i>) by the BMBF (Transfer to Indonesian Government in 2011)
2006	Establishment of the <i>Plate Boundary (PBO) and Global Change Observatories (GCO)</i> by the GFZ
2008	Renaming in Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences



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From Space to the Core of the Earth: The World of the GFZ

Our planet Earth is still full of secrets. For example, we cannot directly observe the inner life of the planet, such as the extremely slow flow of rocks in the Earth's core and mantle. At its surface, such singular forces are acting at the same time – from wind and weather, through vegetation and mountain building, to the way humans have shaped their environment – that we have not even discovered, much less understood all the interactions between them. Even at the boundary between the atmosphere and space, where the Earth's magnetic field is bombarded by high energy particles from the cosmos and the sun, there are many things to investigate. At the same time, it is important to understand the causes of natural disasters and climate change, to mitigate their respective effects and to develop strategies to adapt to them. Deposits of vital resources like ore, oil and water must be analysed and understood to discover the possibilities for their sustainable use. For scientists investigating the Earth, the secrets our planet hides within, the hazards it exhibits and the resource potential it holds present a huge challenge. At the GFZ German Research Centre for Geosciences in Potsdam, we have responded to this challenge. The GFZ is the only research centre in Germany that is solely devoted to the investigation and research into System Earth in all its details and facets.

As a member of the “Helmholtz Association of German Research Centres”, the GFZ is funded jointly by the German federal government and by the state of Brandenburg. Founded in 1992 after the German reunification, the GFZ builds on the important scientific history of Potsdam's Tel-

egrafenberg. This location became the cradle of the science of geodesy when the Geodetic Institute was formed in 1892. It represents the roots of seismology as a geophysical discipline for investigating the interior of the Earth with the help of earthquakes, and it was here, in the Magnetic Observatory, where the systematic study of Earth's magnetic field and its variability found its beginning. Since its foundation, investigators at the GFZ maintain close contact with researchers at universities and other research centres all over the world. Scientists from Potsdam are among the

*In front of the main entrance:
The pillars made of rocks from
all continents symbolize the
global activities of the GFZ.*





Measurement of ash particles at the Karymsky volcano, Kamchatka. The balloons can be controlled like kites over the crater area. The probe is attached underneath it by a thin steel wire.

leaders in many international projects, and the GFZ is always hosting a large number of foreign researchers. Learning to understand the Earth necessitates solving many more puzzles first. Under the Earth's thin crust lies the much thicker mantle, which is made of heavier rocks. The mantle in turn surrounds the Earth's core, which is made of hot iron – molten on the outside and solid in the centre. The Earth, which is often compared with an onion because of its layered structure, is a heat machine which draws its

energy primarily from two sources. Some of the heat energy develops from the decay of radioactive elements within the Earth. But, the Earth has also retained an enormous amount of heat since its formation. The heat from within the Earth is slowly moving outward toward its surface.

The discovery that the outer shell of our planet is made up of a mosaic of lithospheric plates that float across its surface at a velocity of several centimetres per year changed the Earth sciences completely. The plates grow at the

spreading centres of the mid-ocean ridges. In contrast, ocean trenches mark zones where one plate collides with another. In this collision, one of the two glides downwards into the mantle. Most mountain ranges were formed by collisions of currently active or past plate boundaries. Time and again, large earthquakes occur in regions where plates collide or push past each other.

This process, called plate tectonics, is driven by the transport of heat from the interior of the Earth to its surface. The

rocks in the Earth's mantle are generally poor conductors of heat. Nonetheless, through the physical process of convection, heat is transported upwards. On the core-mantle boundary at a depth of about 2900 kilometres, the deformable rocks of the Earth's mantle are heated more at some locations than at others. The heated rocks become lighter than those above them, and they begin to rise. When they reach a depth of about 200 kilometres beneath the Earth's surface, the pressure has decreased so much that some of the minerals in the mantle rock be-



The campus on Telegrafenberg in Potsdam has more than 125 years of tradition as a scientific location. It is the cradle of modern scientific geodesy and it was here where the world's first teleseismic record of an earthquake was made.



The classic illustration of the tectonic plates. Mid-ocean ridges are highlighted in grey, the red dots show the location of earthquake epicenters over a period of 20 years.

gin to melt. This basaltic melt continues to rise. It pushes most of the rest of the mantle rock aside, rock which then drags the “lithosphere”, or uppermost mantle rock and crust, along with it. The crust, particularly the continental crust, swims along on top, because it is less dense than the material of the mantle. At the spreading centres of the mid-ocean ridges the rising magma reaches the Earth’s surface and becomes part of the two lithospheric plates that are moving away.

Plate tectonics turned out to be a very prolific concept. It has been able to integrate our view of phenomena previously considered separate, such as mountain building and earthquakes, volcanism and the development of mineral deposits. It can even explain some changes in climate. One surprising realization was that the oceans,

which had previously been considered immutable, are continuously being formed and reformed in new constellations and are therefore relatively young. The continents have been torn apart and recombined in the course of the Earth’s history, but their cores have already existed for billions of years. Insights into long spans of geologic history can therefore only be found on land.

The more than one thousand employees at the GFZ have made it their job to study this living, dynamic planet. They view the Earth as a system which includes all the physical, chemical and even biological processes that take place within it and on its surface. They investigate the countless interactions between all parts of the whole: between the solid Earth (geosphere) and the watery regions (hydrosphere), the ice (cryosphere), the air (atmosphere) and



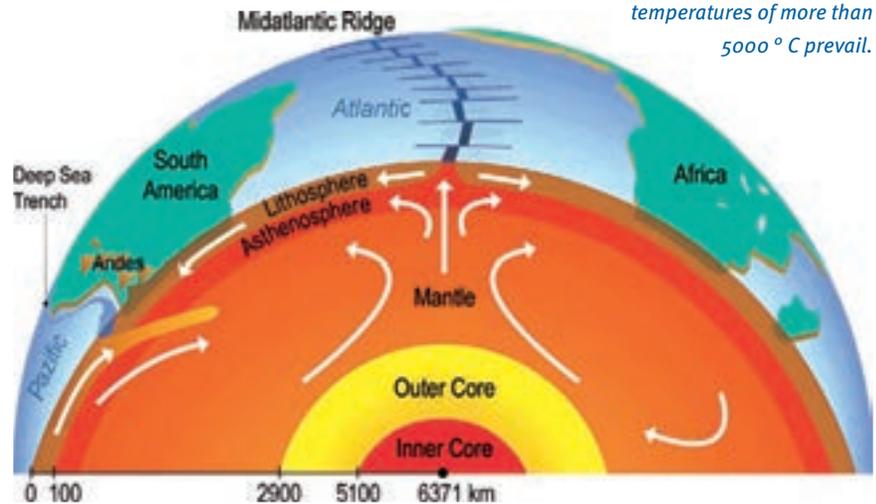
of topics require that the researchers use a broad spectrum of methods and techniques.

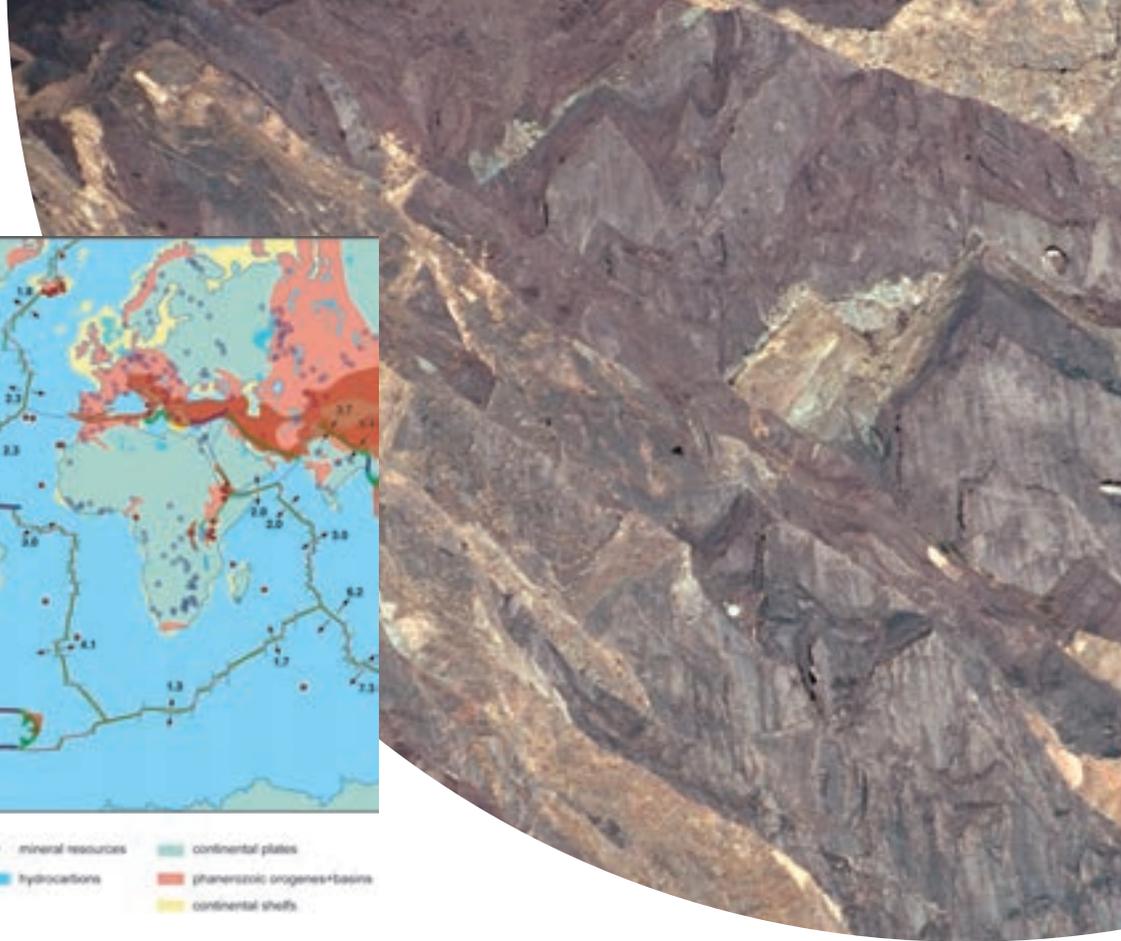
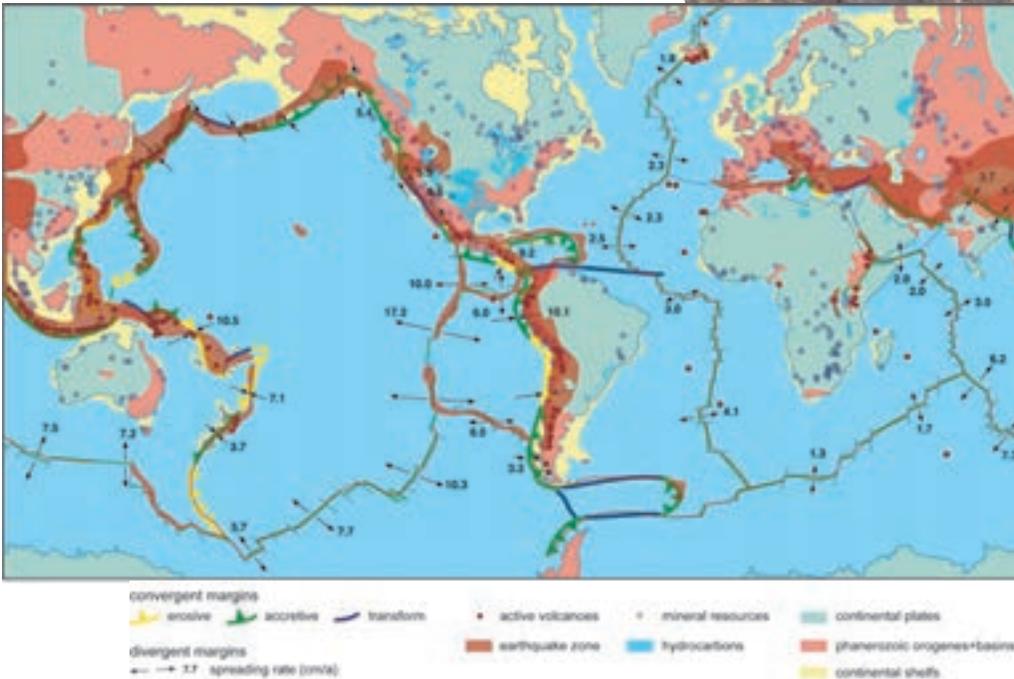
The selection of geoscientific instruments available to researchers at the GFZ ranges from Earth-orbiting satellites developed in-house with systems to measure the Earth's gravitational and magnetic fields ever more precisely from space, to laboratory experiments under the pressure and temperature conditions that reign deep within the Earth. The methods include research drilling and various procedures for geophysical deep sounding, like "x-raying" the Earth with the help of naturally occurring or man-made earthquake waves, or mathematical modelling of geoprocesses. Together with geoinformatics, these are tools that help investigators to understand the processes within the Earth. For expeditions and global field campaigns, the GFZ has set up geodetic, geophysical and geological instrument pools. A team of engineers

Coastal tide gauge off the Indonesian coast as part of the tsunami early warning system

life (biosphere). There is a particularly strong research focus on the way man influences the Earth system. After all, the Earth's surface is not only the place where we live; it is also the sensitive skin of the Earth. The complex interactions of the many processes taking place within and on the Earth are not the only distinction which fundamentally separates the Earth sciences from other branches of the natural sciences. If researchers want to understand the Earth, they have to study phenomena which span vastly differing scales in time and space. The themes and the spectrum of research at the GFZ range from the Earth's core into space, from microscopically small crystals and their atomic structure to the entire body of the Earth, from the billions of years of geologic history to the fragment of a second in which rock fractures during an earthquake. This great variety in the research and the colourful palette

Heat engine Earth: the heat in the Earth's core and mantle is the driving force for plate tectonics. In the inner core, temperatures of more than 5000 °C prevail.





The upthrust of the Andes as a result of the collision of the Nazca plate and the South American plate

The map shows the relationship between tectonic structures, earthquakes, volcanism and deposits. It is conspicuous that the human habitat is in many places threatened by natural hazards.

stands ready to improve existing or develop new geoscientific instruments when they are required.

The researchers at the GFZ see great potential for small, cost-effective satellites with high resolution sensors. These instruments will be good for long term measurements and environmental monitoring from space. Another focus of instrument development is taking advantage of the rapid development in measuring and communication technology to immediately transfer data from measuring stations to a central location for analysis, and then to forward the results of the analysis for response. Such “real time systems” are vital for monitoring earthquake zones and volcanoes. They are the prerequisite for implementing warning systems which will not only warn the endangered population, but will also automatically turn

off industrial plants and close roads and bridges.

The complexity of research problems in the Earth sciences requires interdisciplinary collaboration and organization along new lines. For this reason the GFZ, Potsdam’s Helmholtz Centre, is not structured according to disciplines, but is divided into five departments of responsibility. In each of them scientists from various fields work together. A department may have up to six sections, each of which is working on a range of projects. In addition, in four centres, geoscience expertise on a particular topic is put into practice. The topics include, among others, the development of geothermal energy or developing early warning systems for natural hazards. Some of the scientific research projects at the GFZ are introduced in the following pages.

Like a Potato: The Figure of the Earth

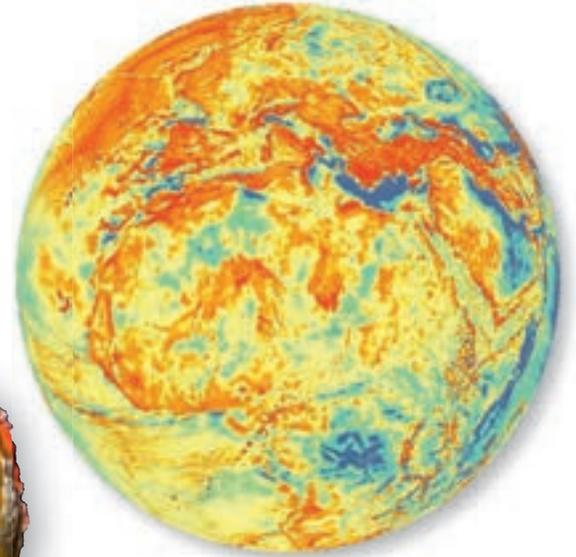
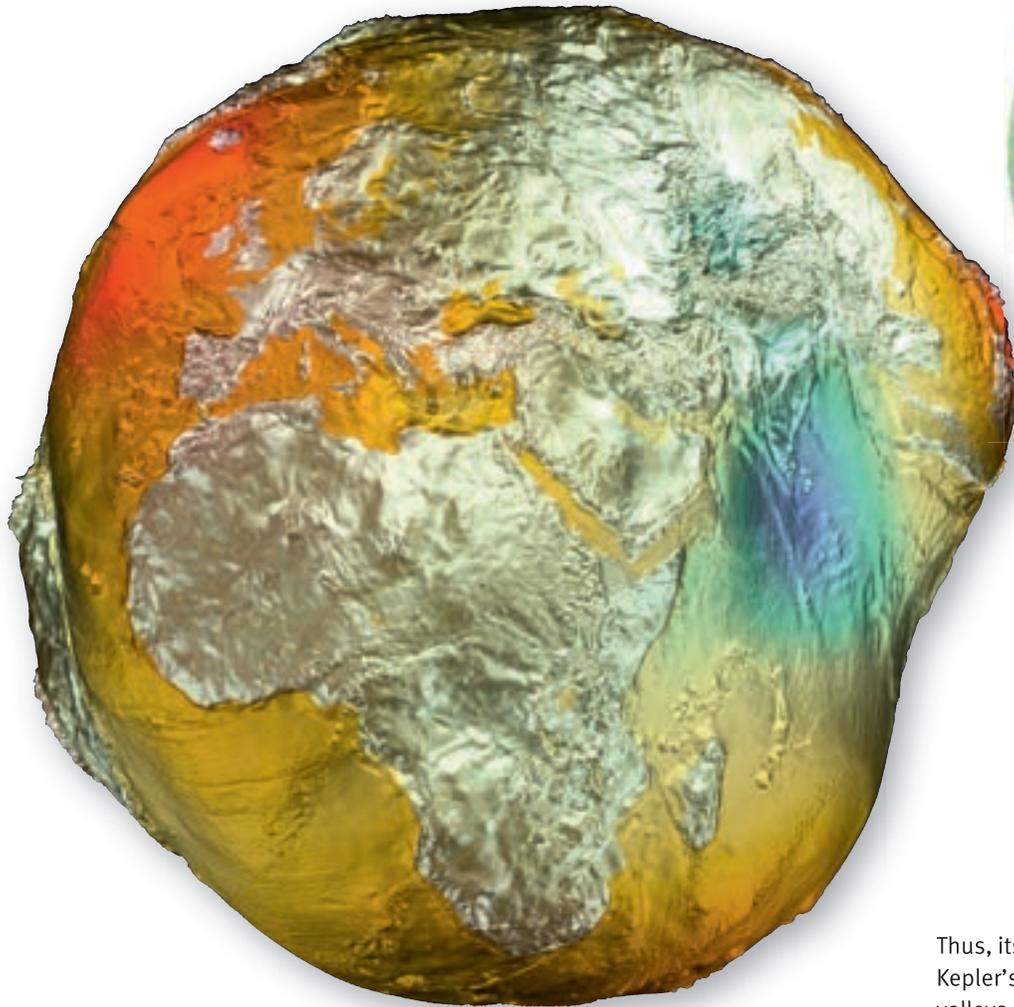
The shape of the Earth is not the perfect sphere that we see on our globes. The topography of the continents reaches different altitudes, and even the surface of the ocean has not the same distance from the centre of the Earth at all locations. In fact, it has extended bumps and depressions. One of the tasks of the GFZ is to determine the irregular shape of our planet as precisely as possible.

Isaac Newton already calculated that the Earth must be thicker at the equator than at higher latitudes, caused by the centrifugal force from its rotation. In fact, the diameter from the North to South Pole is 42 kilometres shorter than in the equatorial plane. That would make the Earth an ellipsoid rather than a sphere. But it is still only an approximation of the Earth's shape, since the "sea level"

can be up to 110 metres higher and down to 85 metres lower than this approximate ellipsoid. These variations are the result of the inhomogeneous interior of the Earth: thick layers of sedimentary rock alternate with huge granite blocks. The roots of high mountain ranges reach deep into its interior, while the crust under the oceans is relatively thin. Changes in the density of the Earth's mantle and core also influence the gravitational field and thereby the shape of the Earth. Experts therefore refer to the figure of the Earth as "Geoid". The surface of this geoid would coincide with the surfaces of the oceans, if they were completely at rest. On the continents, the geoid is beneath the Earth's surface, and is an imaginary sea level derived from gravity measurements. The precise knowledge of the geoid is important for more

The satellite receiving station of the GFZ in Ny Ålesund on Spitsbergen can receive the data of satellites with a polar orbit, such as GRACE, during each overpass.





The geoid representation of the GFZ shows the non-uniform gravitational field of our planet, enhanced by a factor of 15,000. South of India the sea surface slopes into a 110 metre deep valley, north of Papua New Guinea it forms a 85 metre high mound. The small image shows the gravity field anomalies, as measured by the GRACE satellites.

reasons than “only” practical applications in surveying or navigation. Many branches of the modern Earth sciences cannot advance without it. But how can we measure the geoid with high precision? Just as the uneven distribution of dense rocks within the Earth determines the shape of the geoid, a satellite in orbit experiences the variations as small changes in the Earth’s attraction.

Thus, its orbit will not be the perfect ellipse postulated by Kepler’s Laws. Rather satellite orbits will have humps and valleys that we can measure in various ways. One way is to send pulses of laser light from ground stations to special reflectors on the outside of a satellite. By measuring the time the ray needs to travel to the satellite and back to Earth, we can precisely determine the altitude of the satellite and derive the shape of its orbit. A second procedure is to use GPS receivers on board the satellites, which can measure their positions continuously and much more precisely than the navigational instruments used in cars.

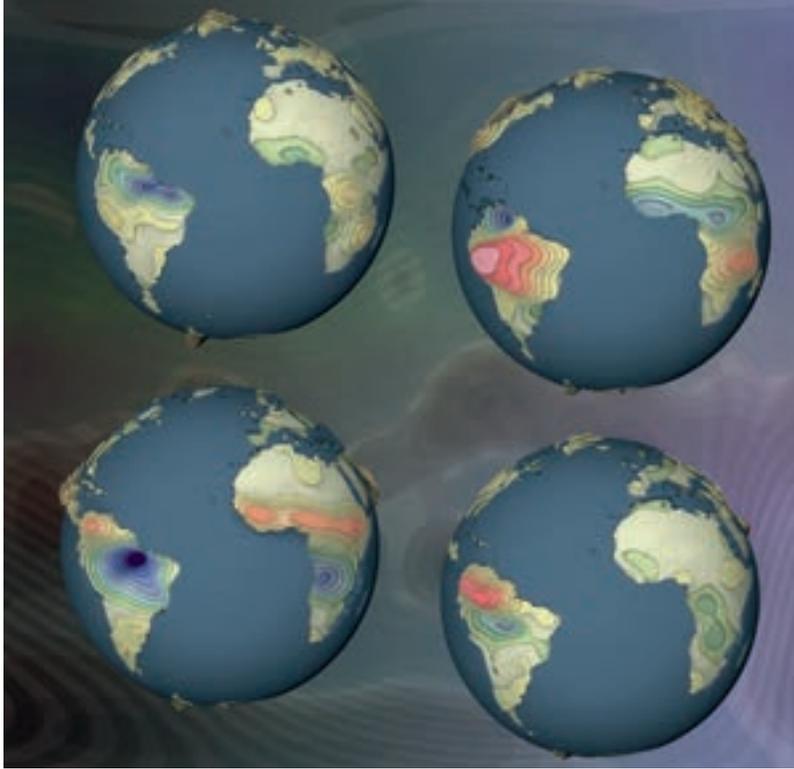
Satellite Mission to Gravity

The determination of the geoid and its relationship to the Earth's gravitational field has a long tradition on Potsdam's Telegrafenberg. In 1892, the Geodetic Institute was founded here and became the cradle of scientific geodesy. For decades, the gravitational force measured here was accepted worldwide as the standard. Potsdam Earth scientists were also pioneers in the precise measurement of orbits and the resulting determination of the shape of the Earth. For example, in 1995, astronauts released the soccer-ball-sized satellite GFZ-1 which was

developed by us. Its surface was equipped with several dozen laser reflectors. After a highly successful mission lasting four years, this mini-satellite burned up like a meteorite upon re-entry into the atmosphere. Its task was continued by the GFZ satellite CHAMP, which has been providing gravity data between 2000 and 2010 with a much higher precision than GFZ-1. In 2002 the twin satellites of the German-American project GRACE were launched. They are flying behind each other in a tandem pair at an altitude of about 470 kilometres and



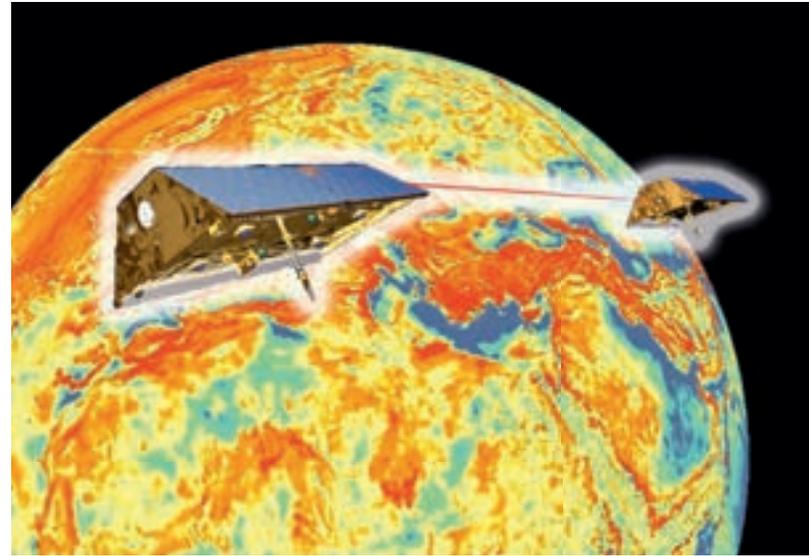
The CHAMP georesearch satellite measured the Earth's gravity, the Earth's magnetic field and the atmosphere from July 2000 to September 2010. The position of a satellite during an overpass over the station can be determined with high precision using laser telescopes.



The GRACE satellite tandem can detect gravity differences based on non-uniform mass distribution with high precision. Thus, the seasonal variation of continental water storage (January, April, July, October 2011, clockwise direction, starting top left) measured in millimetre water column results in a variable signal of Earth's gravity .

separated by a distance of about 220 kilometres. Even the smallest changes in the distance between the two of them are measured with extreme precision. From these data, we can exactly calculate the changes in their orbits and as a result determine the fine structure of the Earth's gravitational field. Since the measurements repeat on a monthly basis, we can even measure seasonal cycles in ground water levels and observe climate-caused changes in the ice masses of Greenland and the Antarctic.

Since March 2009, even higher precision measurements than those of the GRACE twins exist. With the "Gravity Field and Steady-State Ocean Circulation Explorer" or GOCE, the accuracy of the geoid has reached new dimensions. GOCE has a so-called satellite gradiometer on board to measure precisely even the smallest variations in the gravity field. It is sampling the gravitational field of the Earth with a spatial resolution of about 100



kilometres, thereby delivering much more exact gravity data and smaller structures than all previous satellite missions.

One of the most important scientific applications of the GOCE mission is the investigation of global ocean currents. These currents are the cause of the deviations in sea level from the ellipsoid form of the Earth's gravitational field mentioned above. Knowledge of the topography of the ocean surface will allow us to draw conclusions about the circulation of water in the oceans and possible changes in the circulation which may be related to climate change.

When we integrate all the information about how different the geoid is from an ideal sphere, we get a realistic picture of the shape of the Earth. It is a body with an uneven surface, covered with bumps and dents – in short, the shape of the Earth is more like a potato.

Looking through the Earth: Tomography with Seismic Waves

Earth scientists seeking to investigate the interior of the Earth are faced with a dilemma. A “Journey to the Centre of the Earth”, as so eloquently described by the science fiction author Jules Verne, is completely unrealistic. Because it is impossible to visit and directly measure the inside of the Earth, researchers have to find second hand information. For example, recordings of seismic waves from earthquakes can be used to learn about the conditions within the Earth. In fact, these seismic waves contain information about the density and the temperature of the rock deep beneath our feet.

The astronomer Ernst von Rebeur-Paschwitz did not know



Ernst von Rebeur-Paschwitz, who successfully completed the world's first remote recording of an earthquake in 1889 in Potsdam.

about this when he discovered an unusual signal in his records of the Earth tides in Potsdam on 17 April 1889. Instead of swinging quietly in the 12 hour rhythm of the tides, the needle of his instrument wiggled violently back and forth for three hours. The phenomenon was caused by seismic waves from an earthquake 9000 kilometres away, which had occurred in Japan and made the ground of the Telegrafenberg swing back and forth a little while later. This was the first time

that a distant earthquake had been recorded. Since then, seismologists have learned to read earthquake waves like x-ray images. Now, seismic tomography has become one of the most important tools for their investigations of the interior of the Earth.

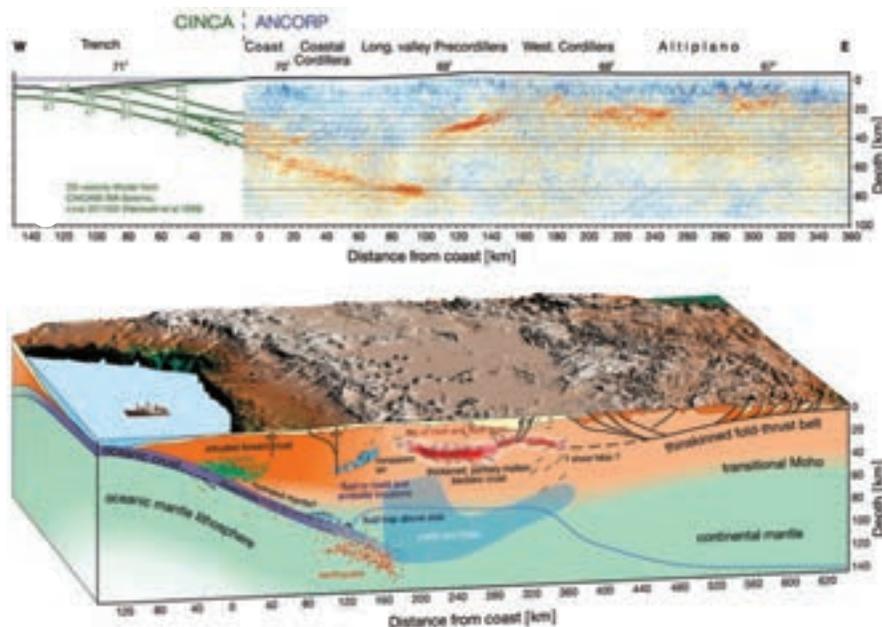
The GFZ researchers apply this method similarly to the way it is used in medical diagnostics. There are some important differences between these two applications, though. For example, X-ray computed tomography (CT) is based on the fact that different types of tissue in the human body absorb electromagnetic waves differently. In seismic tomography, on the other hand, differences in the travel times of seismic waves that are mapped. Those travel times depend on the speed of sound when it travels through rocks. This, in turn, depends on the temperature of the rock. As warmer rocks are more compressible, sound and seismic waves travel more slowly in warm rocks, and more quickly through cooler rock. Since the change in the wave speed is only a few per cent, even when the temperature difference is large, it is hard to measure the differences in the recordings of a single earthquake station. The variations quickly become apparent, however, when the recordings of many earthquakes at hundreds of seismic stations are compared.

This is why tomographic studies examining the Earth's entire mantle have only become possible since seismic stations were distributed more or less evenly over all continents. The network of stations operated through-

out the world by the GFZ, called GEOFON, contributes to these studies. Data from these stations are transmitted directly and immediately to Potsdam. GEOFON is part of an international system in which researchers from many countries exchange their seismic data in real time. This allows the determination of the magnitude of an earthquake and its exact source within a few minutes of its occurrence. The collection of data from these stations has now also become an extensive resource that permits the statistical evaluation of the travel time of seismic waves through various regions of the Earth's mantle.

In tomographic studies, the observed deviations of travel times are shown relative to a fixed model of velocities within the Earth. One resulting discovery was that the mantle is cooler in the subduction zones below South America and under the Malaysian-Indonesian archipelago. Regions of warm rock are found under Africa's rift valley and off the West African coast beneath the volcanoes of the Canary and Cape Verde Islands. Using these methods, Earth scientists for the first time developed realistic three-dimensional models of the interior of the Earth. In spite of the many data, however, the resolution of these tomographic maps is still not good enough for studying details of the Earth's structure. Seismologists of the GFZ have therefore improved existing methods and developed new ones to extract even more information about the interior of the Earth. For example, the paths of seismic waves from earthquakes are strongly disturbed when they reach a boundary within the Earth. In such cases, they may change from one type of wave to another. When such conversions are detected in the seismograms, more can be learned about the structure deep under the wandering continents. Calculations like these have shown, for example, that the Indian subcontinent had been pushed northward several hundred kilometres under Tibet.

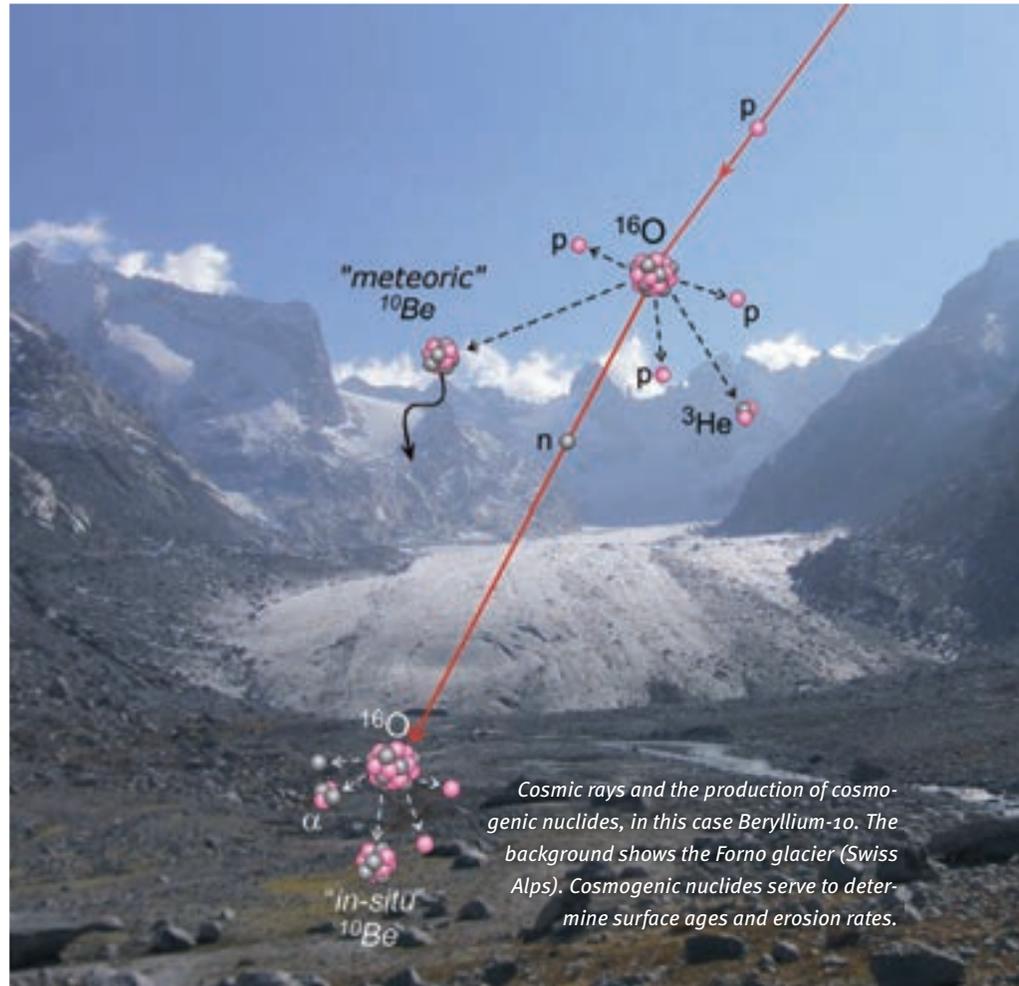
Earthquake damage in the North Anatolian Fault Zone. Seismological investigations use the earthquake distribution in the Chilean Andes to analyse the structure of the subduction zone on the west coast of South America.



Fingerprints from Outer Space: Investigating the Earth's Surface Using Extremely Rare Nuclides.

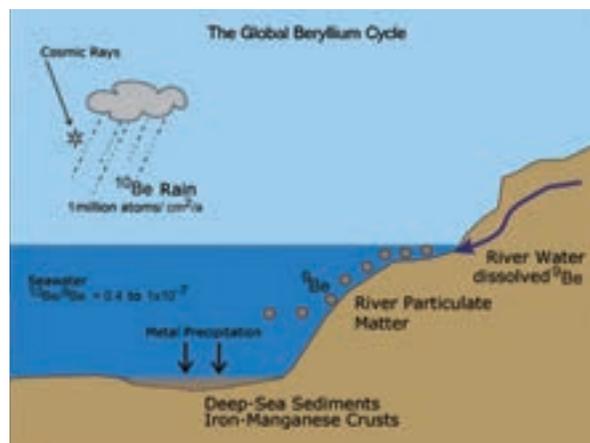
They are extremely rare and very difficult to measure. Within only a few millions years, most have disappeared as a result of radioactive decay. Thus, on our nearly five billion year old planet, they should not even exist. Nonetheless, these *cosmogenic nuclides* now play an important role in studying the uppermost layers of the Earth's surface. These nuclides are formed when cosmic rays interact with the Earth's atmosphere or its surface. Like fingerprints, these extremely rare nuclides are important indicators from which geoscientists can draw new conclusions about the many processes that continually shape the Earth's surface. Investigators at the GFZ are at the forefront of research on these topics.

How is it possible that particles produced by distant cosmic rays can provide new information about our immediate surroundings in the uppermost layers of the Earth's surface? Cosmic radiation consists of high-energy sub-atomic particles that originally formed during the explosions of stars in our Milky Way. In the stratosphere, cosmic rays collide with molecules of the Earth's atmosphere, that is, with oxygen, nitrogen and with the noble gas argon. As a result of these collisions, the nuclei of air molecules are broken apart. The resulting fragments are new nuclides that do not typically occur in the atmosphere, such as the radioactive nuclides beryllium-10, carbon-14 or chlorine-36. Over the course of time, these cosmogenic nuclides reach the Earth's surface. There they become enriched in all soils, in plants, and in some rocks, as well as in rivers, ground-

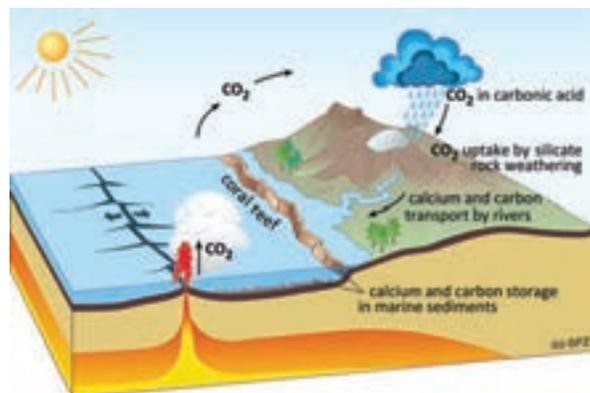


Cosmic rays and the production of cosmogenic nuclides, in this case Beryllium-10. The background shows the Forno glacier (Swiss Alps). Cosmogenic nuclides serve to determine surface ages and erosion rates.

water and in the oceans. In addition, some of the high-energy particles of the cosmic ray cascade reach the Earth's surface. Here they can produce the same radionuclides and the noble gas isotopes helium-2 and neon-21, directly in rocks. Given the extremely low abundances of cosmogenic nuclides, they can only be detected using modern techniques in laboratories,



The global beryllium cycle (top) and the way weathering at the Earth's surface is linked to the inorganic carbon cycle (bottom).



using particle accelerators or dedicated rare gas mass spectrometers.

The best known of these nuclides is without doubt carbon-14, a tool now used in many branches of science to determine the age of materials derived from plants. The research groups at the GFZ, however, are concentrating on other nuclides, in particular on beryllium-10, aluminium-26 and neon-21.

Using the ratio of the cosmogenic nuclide beryllium-10 to that of stable beryllium-9, for example, the age of ocean-bottom sediments can be determined. This dating method is especially valuable, since it can be used to date sediments like manganese nodules and crusts that do not contain dateable fossils. The method can also be used to determine the

age of chemical deposits in the oceans, like manganese nodules. In doing so, the scientists found that these potential raw materials for industry grow at a rate of 1 to 10 millimetres per million years. Likewise, researchers can determine the age of groundwater horizons by measuring the concentration of the cosmogenic nuclide chlorine-36.

The value of cosmogenic nuclides goes far beyond the determination of the ages of soils, sediments or aquifers. For example, by measuring their concentration in certain surface rocks, investigators can establish the timing of the last glacial ice sheet retreat, or to establish when a particular layer of rocks was uncovered by erosion. In addition, by comparing the concentrations of cosmogenic nuclides in soils and river sediments, one can determine both erosion rates, as well as how much material is transferred from the mountains into the rivers. Cosmogenic nuclides in ice cores can be used as proxies for solar activity and indicators of the state of the Earth's magnetic field, these two being the factors that modulate the intensity of the cosmic radiation hitting the Earth.

Using the information obtained from cosmogenic nuclides analyses, scientists can better understand the nature and timing of the processes that have shaped the Earth's surface. Seismologists have used these tools successfully to determine the return intervals of earthquakes. Climate researchers have acquired new insights into changes in the climate before humans began to play an important role. Geomorphologists can better evaluate the development of landscapes, as a result of better insights into the magnitude and timing of surface processes. The investigation of the geochemical fingerprints left behind by cosmic rays is thus an increasingly important and more universally used tool in many disciplines of the Earth sciences.

Earthquakes in the Laboratory: How Does Rock Fracture?

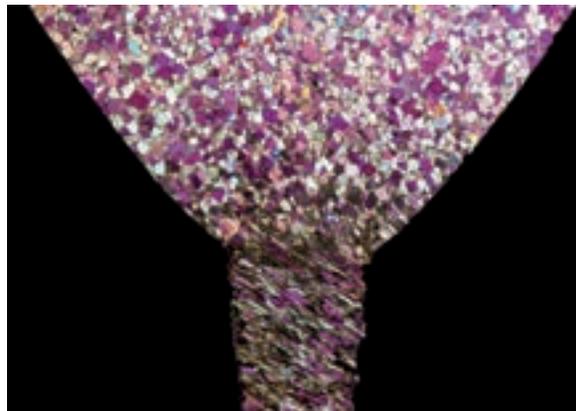
Earthquakes can have a disastrous effect as natural catastrophes. Understanding these sudden movements of the Earth involves challenging studies of extreme mechanical processes: The rupture front, the line along which the rock breaks, zooms at a speed of up to several kilometres per second through the Earth's crust. Geoscientists at the GFZ are investigating the details of what happens during such a rupture. They are also analysing the physical conditions under which rock begins to flow and how it is deformed.

Hard rock is not really as solid and immutable as it appears in everyday life. When it is subjected to large enough mechanical forces, rock can suddenly burst or slowly begin to deform plastically. Such processes are difficult to measure on the surface of the Earth, even with extremely sensitive instruments. When a rock breaks, the process usually occurs very quickly. The plastic deformation deep in the Earth's crust or mantle takes place extremely slowly, on the other hand. In the laboratory, these processes can be investigated on rock samples under controlled conditions using hydraulic or gas-pressure anvils.

The rock laboratory at the GFZ has presses which can subject rock samples to high pressure and temperature. In the process, mechanical stresses increase in the sample until it breaks at a certain level. At low temperatures, brittle failures develop. The same process is responsible for the development of earthquakes in nature. In their experiments, the researchers also break and analyse rocks that have come from an earthquake zone, such as the serpen-

tinite taken from a depth of about three kilometres in a borehole into the San Andreas Fault in California.

These modern presses are also equipped with acoustic sensors which record the elastic waves that are radiated when microfractures grow inside a rock that is subjected to increasing stress. The sounds correspond to small shocks similar to seismic events recorded by seismometers in nature. In order to compare the cracking in the laboratory with real microearthquakes, the scientists from Potsdam also measure in seismically active regions. They have concentrated their investigations along the North Anatolian Fault in western Turkey, one of the most dangerous earthquake regions in the world. On several small islands in the Marmara Sea near the megacity of Istanbul, they have installed a network of seismometers



How the stress in rock is visualized: to the left, the transparent cut image of a twisted Carrara marble, to the right the computed tomography image of a cylindrical quartzite sample in which a shear zone is clearly shown.



Rock under pressure: in the pressure anvils, rock samples are put under strain until they fracture. The resulting acoustic emissions are recorded by small microphones that are attached to the sample. The granite sample shows the state after the fracture.

with which they can record even very small earthquakes occurring in this region. There are also instruments from the GFZ in one of the deepest mines in the world, the 3.5 kilometre deep gold mine Mponeng in South Africa. These sensors record the extremely small rock fractures that occur during the mining process.

With these measurements, the researchers cover a large segment of the spectrum of possible rock fractures. The investigations extend from fractures in rock samples in the laboratory that may be only millimetres long to rock

bursts in the gold mine to the kilometre long ruptures that occur in large earthquakes along a hazardous fault. In their research, they not only study basic topics like the mechanical properties of rock. They also provide physical fundamentals to answer the geomechanical questions that play a role in the use of underground resources, such as the development of geothermal energy or the sequestration of carbon dioxide. Their investigations also contribute to the assessment of a variety of georisks. Earthquakes cannot yet be predicted, but by knowing more about the rupture process and the associated seismicity, we can prepare better for future earthquakes and thereby reduce their consequences.



InnovaRig: The New World of Drilling

The dimensions of the Earth are huge. Its radius alone corresponds approximately to the distance from Berlin to New York. In comparison, even the deepest drill holes in the world, among them the German Continental Deep Drilling Program KTB in the Upper Palatinate with a depth of more than nine kilometres, are only tiny pricks into the skin of the earth. Nonetheless, such deep wells are often the only opportunity scientists have to verify their hypotheses and models about the interior of the Earth against reality – and at the same time to unveil new information about the Earth’s crust. Until now, these investigations used drill rigs designed for the search for oil and gas deposits and for their development. In many cases, these rigs are of limited use for research purposes. Especially the continuous collection of cores from the hole takes a long time with oilfield rigs and as a result is very expensive. Only the analysis of such cores, however, allows conclusions to be drawn about the conditions in the crust at a depth of several kilometres.

To alleviate such shortcomings, the GFZ has its own rig for drilling deep holes, called “InnovaRig”. It was developed and built in close collaboration with the firms Herrenknecht-Vertikal in Schwanaue and H. Anger’s Söhne in Hessisch Lichtenau. This rig can drill to a depth of 5000 metres, satisfying not only research goals but also commercial requirements. For this reason, InnovaRig is particularly flexible. For example, it can drill using any of the modern drilling procedures, such as “directional drilling” or “casing drilling” with diameters up to 70

*The modern drill rig
InnovaRig drilling a geothermal
borehole in the pre-
Alpine Molasse Basin.*



A rotary bit at the end of a drill pipe.



The pipe handler automatically removes the drill pipes from the pipe rack. The “iron roughneck” automatically screws the pipes together, thus replacing this dangerous activity of the rig worker, also known as a “roughneck”.

centimetres. It is also easy to rapidly take rock or fluid samples from the borehole and to take measurements with scientific instruments. In addition, the rig has a suite of integrated measuring devices, such as automatic analysers for the gas content of the drilling mud. The equipment to collect and store the collected data is also integrated into the rig.

As the drill rig was being developed, one of the conditions was to ensure that is environmentally sound.

Thus, during drilling it produces much less waste than conventional rigs, and only biodegradable liquids and lubricants are used. Intensive sound damping allows drilling even in populated areas. The rig is mechanized for the most part, so that the individual elements of the drill pipe are assembled by robots. This was in the past a task for the “roughnecks”, who often had to perform this dirty, dangerous and difficult work on the platform in bad weather.

This mobile rig with a value of about 17 million Euros will be used for drilling under the auspices of the International Continental Scientific Drilling Program (ICDP), as well as for other projects. Since 1996, scientific institutions from more than 19 countries have joined this program, which is coordinated by experts from the GFZ. The goal of the ICDP is to plan and support research drill holes on land. Among other projects, the program has supported drilling into the conduits and deposits of volcanoes in Japan and Hawaii, into the Chicxulub meteorite crater on the Yucatan Peninsula in Mexico, and into the San Andreas Fault in California. In the near future, InnovaRig will be utilized in the volcanically active Phlegrean Fields near Naples. Research holes to investigate the possibility of storing carbon dioxide in the ground and to learn about exploiting geothermal fields are also planned. The drill rig has already passed its first tests in commercial geothermal projects near Munich and Hannover. With its help, holes were successfully drilled that reached a depth of more than four kilometres.

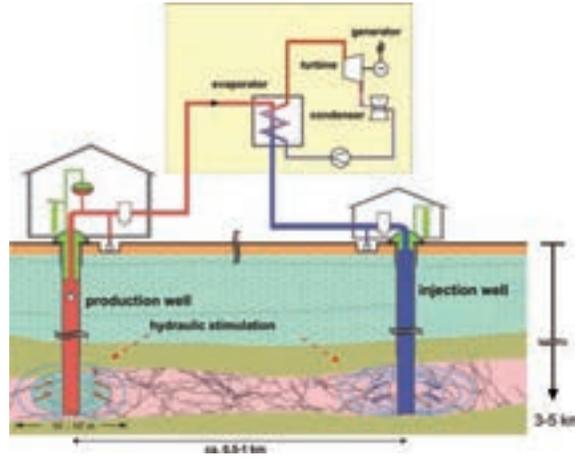
Energy from Below: The Groß Schönebeck Geothermal Laboratory

Geothermal energy has long been used in the volcanic areas of Italy and Iceland. In Central Europe, however, its development is still in its infancy, although there is probably no other source of energy that is as universally available as geothermal heat. Even far from active volcanoes, the heat present in the Earth's crust is independent of season and climate and is almost inexhaustible. In contrast to many other regenerative energy sources, geothermal energy is capable to provide a base load for electricity as well as heat. Using present day procedures and techniques, however, the investment and risks of building and operating a geothermal plant are still relatively high. That is reason enough for GFZ scientists to conduct research to optimize all processes and systems components that are involved in geothermal power production. In the town of Groß Schönebeck in Brandenburg, they have a unique laboratory at their disposal.

There, at a depth of about 4300 metres, two deep boreholes tap into a rock layer saturated with water at a temperature of 150 degrees Centigrade. Such a temperature is necessary if the geothermal heat is to be efficiently converted into electricity. In order to generate electricity it is also important that the hot water can be used at the surface with a reasonable pumping effort. It is important that the hot water can flow uninterrupted. To ensure this, the GFZ researchers stimulated the deposit. They pumped large amounts of water under high pressure into the underground via both holes. This "hydrofracking" widened the already existing crevices into a widespread system of fissures.



Geothermal power generation requires two boreholes, a sustainable thermal water cycle and an above-ground power plant. The water is pumped from the depths via the production borehole, and after its thermal use in the power plant it is returned to the reservoir through the injection borehole. The extracted water transfers its heat via a heat exchanger to a working fluid with a low boiling point, which drives a secondary circuit in the generator to produce electricity.



Production test in the Groß Schönebeck well: hot water from 4300 metres depth.

From one of the two holes, the production borehole, the hot groundwater is now brought to the surface under various operating conditions and back into the rock layer through an injection borehole after flowing through the various components of the research pilot plant. The heat in the water from Groß Schönebeck is to be turned to electricity in a power plant at a later date. In each opera-

tion run, the scientists and engineers monitor the fluid production, the plant performance as well as the reliability of the technical components, particularly the pumps in the well and the heat exchanger at the surface. They also keep an eye on the conditions of the pipes and valves, as the groundwater is corrosive and can cause damage to the technical supply equipment. The gained experience is used as input into model calculations which analyse the performance of the entire circuit system. From these analyses, which are globally unique, the researchers derive recommendations for the operators of geothermal plants which will allow them to improve and optimize their operations. Such time consuming investigations are only possible in a research facility like Groß Schönebeck.

During the construction of the research platform Groß Schönebeck, the fundamental questions for the exploitation and use of geothermal reservoirs were examined carefully. They characterized the reservoir and developed a way to increase the productivity of the reservoir. They are also improving those technical processes that are coupled to the utilization of the underground to the point of converting the energy efficiently into heat and electricity. Finally, in the laboratory, they are investigating how water and fluid move through rock pores, which chemical processes take and how the geothermal heat can be used most efficiently and sustainably for power production.

Therefore, the natural laboratory at Groß Schönebeck is an important project for the development of geothermal energy. Here, new techniques can be tested and improved under conditions that are close to reality. Since the geological conditions are typical for broad regions of Europe, the insights gained and the procedures developed can be transferred to other locations. Geothermal power plants use local energy resources and release almost no carbon dioxide. For these reasons, the increased use of geothermal resources to supply the base loads for electricity and heat opens new possibilities for achieving climate-related goals in Europe.

Seasons under the Microscope: Climate Archives in Lakes and Trees

When the sediment cores pulled up from the floors of deep lakes are finely layered the scientists from the GFZ are satisfied. That is because they have penetrated many annual layers with their unique coring system. Each of these sediment layers, called “varves” (from the Swedish “varvig lera”, meaning for layered clay), contains valuable information about the climate and environmental conditions of the past. Without such natural archives, modern research on climate change would not be possible. Our regular weather records, which only span the past 150 years, are only a snapshot of climate history. The complete range of climate dynamics can only be understood if we succeed in collecting and understanding climate archives which go far back into prehistoric times.

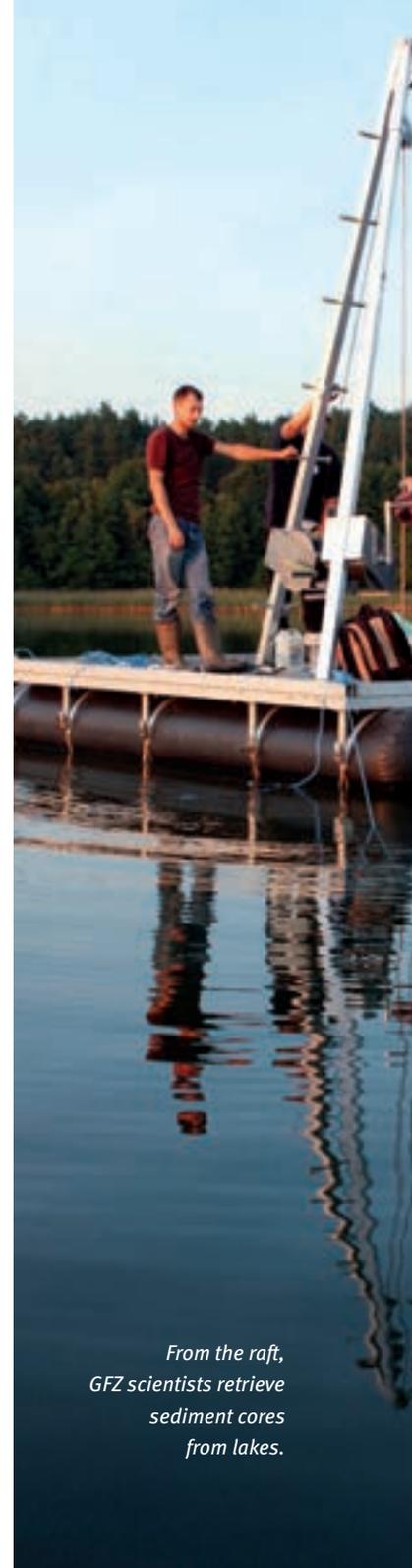
The sediments in the maars (here Pulvermaar, the “Powder Maar” in the Eifel region) are an ideal climate archive for climate researchers.



To do this, researchers carefully count tree rings and the annual layers in the sediments of lakes. Both of these types of archives can be found in regions settled by man, and thus contribute important information about the effects of climate in nearby environments.

GFZ researchers started such investigations in the maar lakes of the Eifel. The bottom of these water-filled remains of extinct volcanoes represents a collection of all kind of algae that grew and died in the lake, everything that was washed into the lake from the slopes, and all that was blown in by the wind. Each year is represented by a light layer consisting of the remnants of a summer’s algae growth and a dark layer of material washed in by the rains of the fall and winter. The analysis of these layers under a microscope is like time travel for the scientists, allowing them to look back many thousands of years into the past. They see hot summers with intense algae growth, cold winters with long ice cover, but also the traces of extreme floods and of volcanic eruptions. In this way, the shifting of the seasons as a consequence of climate change can be observed. One can trace back rare, more extreme and sudden changes in climate, the causes of which are still shrouded in mystery.

GFZ scientists found one of the best sequences of layers covering the last 14000 years in the Meerfelder Maar, which lies protected from the wind in a volcanic crater 180 metres deep. In the continuous varve sequence from this lake they found a special surprise. It includ-



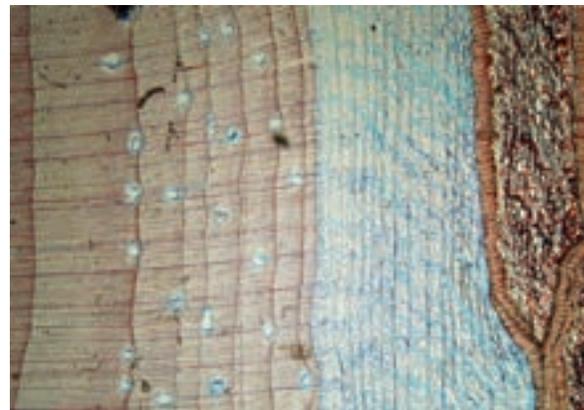
From the raft, GFZ scientists retrieve sediment cores from lakes.



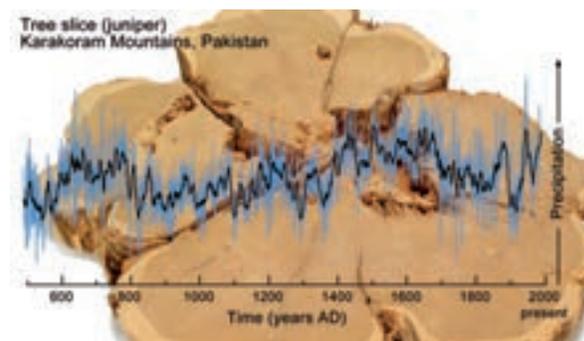
ed what is probably the most extreme climate collapse since the last ice age. The analysis revealed that the 1100 year long cold phase known as the Younger Dryas began in just one decade. This proved that extremely sudden changes in the climate occur not only in the Arctic as was previously assumed- they are also possible in the middle of Europe. The data from the varves from the maar also contained valuable information about the cause of this climate collapse. In contrast to previous assumptions that the weakening of the Gulf Stream was the cause of the abrupt cooling, a sudden change in the wind systems was involved in the initiation of the sudden cooling.

The climate information about prehistoric times collected from the lakes is complemented by the examination of tree rings. Trees absorb carbon dioxide from the atmosphere and water from the soil to build their trunks. In spring, the wood grows more quickly, has larger cells and is lighter. In summer, it grows more slowly and the cells are smaller. This late wood is denser and darker. Together, a layer of early wood and one of late wood make up an annual ring. If one counts the annual rings, one can find the age of the tree. If one looks at the rings more closely, one can learn about the environment and the climate of the tree's habitat. From the thickness of the rings, their colour and form, as well as their chemical signature, researchers can measure how the temperature and precipitation have changed. They can even deduce from the tree rings how long and intensive droughts were, how often forest fires occurred and whether the forests were attacked by insects.

The focus of climate research on the Telegrafenberg is Eurasia. The GFZ scientists investigate, for example, how the west wind systems that determine the weather in Europe and the monsoon in Asia are related and how they influence each other. They also study how global changes in climate affect different regions. For this purpose, re-



*Dyed thin section (60 μm) of an Eastern White Pine (*Pinus strobus*)*



1500 years of climate evolution in the Karakoram Mountains of Pakistan are reflected in the tree disc of a juniper tree.

searchers have jointly analysed lake sediments and tree rings from many places, ranging from the European Atlantic coast to the Pacific Asian shores and from Siberia to the Indian subcontinent. Together these climate archives give a complete history which extends back to the most recent warm period more than 130000 years ago. Never before has such a detailed record of climate history been possible.

The World in the Computer: Modelling System Earth

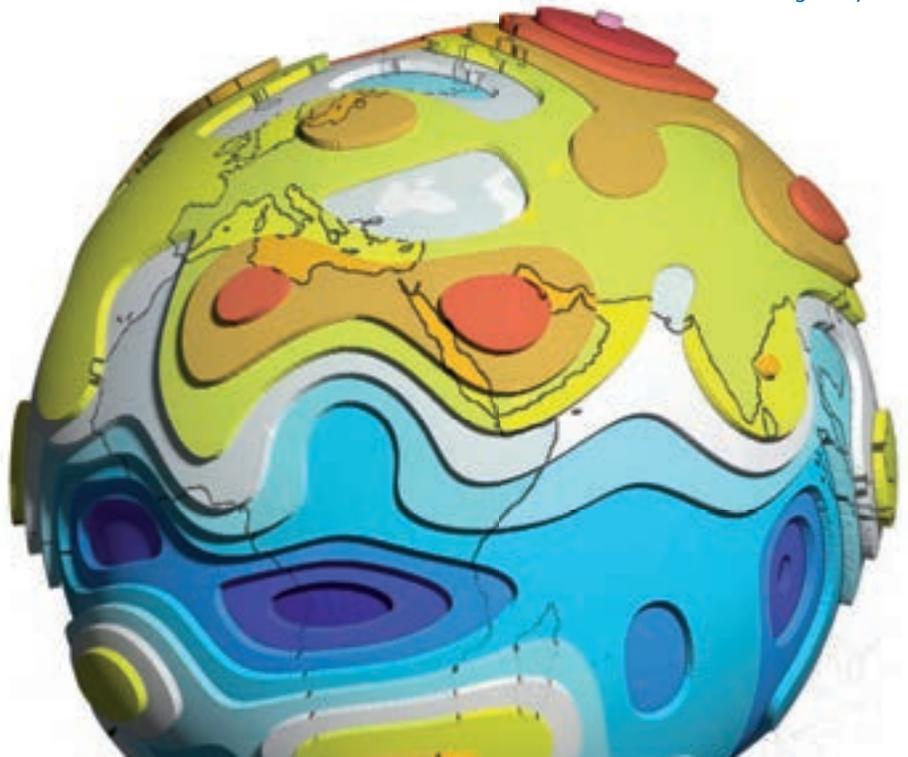
It may be pure coincidence that the most commonly occurring element in the Earth's crust aside from oxygen is the mother of the digital electronic revolution. As a semiconductor, silicon is today at the heart of almost all computer chips. Bound in quartz and many other silicate-based rocks, it is also the material which earth is made of. The digital age, which has been shaped by silicon, has of course not passed by the Earth sciences without leaving its trace – today computers are among the most important tools at the GFZ. They not only make it easier to collect data, they can also be used to model the interior of the Earth and the processes occurring within it. With their computer programs, the researchers on the Telegrafenberg bring the electrons in the silicon chips to model the beginnings of tsunamis, seek out the secrets of sedimentary basins or investigate the influence of wind and ocean currents on the rotation of the Earth.

Much of the world deep below our feet is unknown. Most processes within the Earth take place at timescales far larger than those that humans can experience. For example, the ruptures of earthquakes zoom through faults at about 10,000 kilometres per hour. In contrast, the huge lithospheric plates move more slowly than a fingernail grows. Wherever two or more lithospheric plates meet, such as at transform faults or in subduction zones, the rocks in the Earth's crust and mantle are deformed. This generates heat, which in turn influences the mechanical behaviour of the rocks and at the same time leads to petrological changes in them. GFZ researchers have developed numerical procedures that can simulate on

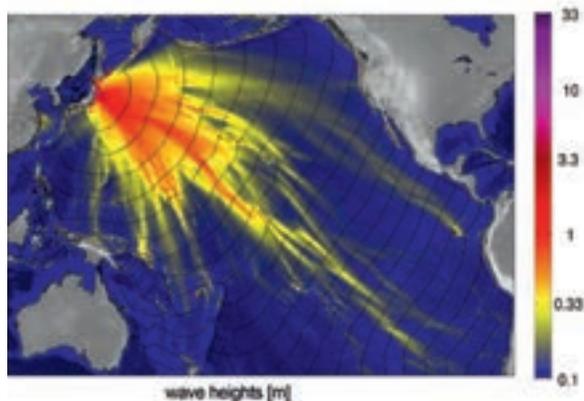
computers dynamic processes that take place at such different rates. By taking both the thermomechanical and petrophysical changes into account at the same time in their simulations, the results of such models are especially realistic. That is why they are the basis *GPS-Shield*, a new warning system for tsunamis based mainly on the measurements of crustal deformation using GPS.

A second work group is modelling sedimentary basins with their computers. Such basins, like the Norddeutsche

Numerical simulation of the Earth's magnetic field



The figure shows maximum tsunami wave heights resulting from a GPS-based model of the Tohoku earthquake. Focusing effects due to bathymetric features are clearly visible, as is the strong increase of wave height close to the coast. Thin black lines depict tsunami travel times in 1-hour steps.



Becken (North German Basin) which underlies the lowlands of northern Germany to depths of more than 12 kilometres, are among the geologically richest landforms of the Earth. Many basins hide large deposits, ranging from coal to oil and natural gas to gravel for the construction industry. How do such basins form, and what pressures and temperatures reign at such depths of a few kilometres beneath the Earth's surface? With their computer models, scientists at the Telegrafenberg investigate how an entire basin would have sunk in the course of the Earth's history, and how it was filled with sediments at the same time. From this, they gain important information for the usage of resources from such a basin, like ground water, hydrocarbons and deep geothermal heat. They also investigate how a basin could be used to store geomaterials, like for carbon sequestration.

The basis for computer models are the large data sets derived from measurements: here, seismometers are ready for field use.



The work of this group does not just involve looking at sedimentary basins on land. They have also developed three-dimensional models of the Vøring- and Møre-basins in the North Atlantic off the Norwegian coast, the Kwanza-basin off of Angola as well as the Orange Basin off the South African coast and its counterpart off the Argentine coast. One of the goals of these models is to study the movement of salt within a basin. The close collaboration between the modellers at the GFZ and their colleagues in the field is demonstrated in a project in Namibia. On land and on the ocean, several work groups have collected seismic refraction profiles of the Orange basin off the coast of this country in southwest Africa. From the results of their measurements, they can draw conclusions about the overall geological layering and the structure of the basin. When the data are fed into a computer model, however, a more complete picture of the basin develops. Basic geological information can then be derived from this picture, such as the history of the basin's sinking and the development of heat flow.

Other researchers model how changes in the atmosphere's large scale wind systems, in the ocean currents and in the water reservoirs of the continents affect the Earth's rotation, its gravitational field and its shape. They investigate the crust's viscoelastic response to changes in the ice masses on the continents and the resulting changes in sea level. Unlike the short term elastic deformation, movement from glacial-isostatic response to the reduced pressure from the ice can still be measured today, thousands of years after the ice has melted. The investigators also model how variations and interactions in the convection currents in the Earth's mantle and in its outer core lead to decadal fluctuations in the Earth's rotation. At the same time, a group of young scientists is combining geodetic observations with numerical simulations to uncover natural contributions to climate variability.

From Orbit to the Core: Details of the Earth's Magnetic Field

The magnetic field of our planet is a surprisingly capricious feature of the Earth, which otherwise appears so solid. Its force is continuously changing, so is its orientation – the magnetic poles move almost one million times faster than the continents. The geomagnetic field is made up of many different contributions. There is the dominating main field, which is generated by the slowly flowing liquid of molten iron in the Earth's outer core. At any particular location, the "lithospheric field" is superimposed on top of it. This localized field varies in strength and is caused by magnetized rocks in the crust and perhaps also in the upper mantle. In addition, the sun also has a strong influence on the Earth's field. The electrically charged particles emitted in the form of solar wind affect the conditions in the magnetosphere which in turn interferes with the magnetic field measured at the Earth's surface. Researchers at the GFZ try to separate the individual components of this confusing interaction as precisely as possible.

Each of the magnetic field's components is of immense practical importance in our lives. The main field protects us from the electrical particles from the sun, like an invisible umbrella. It deflects them and guides most of them around the Earth. The force of the Earth's magnet is not constant, however. In the course of geologic history, there have always been intervals in which the field was weak, and even reversed its polarity. We know this from studies of magnetized rocks. A trend towards a weakening is also apparent in the direct measurements of the magnetic field, which have been recorded regularly

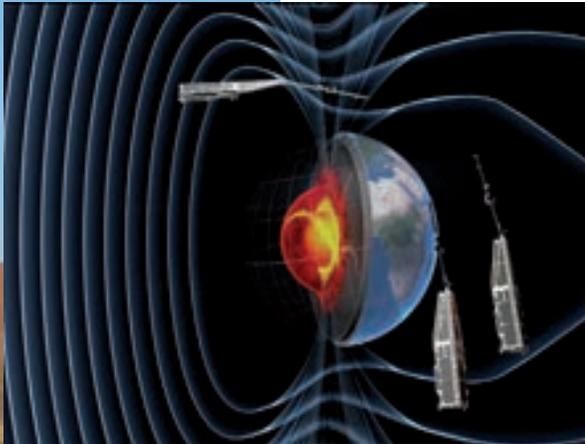
over the past 150 years. On top of these variations, the electrically charged particles emanated from strong solar eruptions produce currents along the lines of the Earth's field and in the ionosphere, which cause an additional, rapidly changing outer field. These currents have a multitude of disturbing effects on power distribution systems and on the many communication and navigation satellites. Our civilization increasingly relies on the proper functioning of these devices. On the other hand, the lithospheric field gives indications about the hidden geological structures within the Earth's crust. Patterns we can now recognize demonstrate relationships between parts of various continents which were previously torn apart by plate tectonics. The lithospheric field also reveals possible geologic deposits. When planning exploration projects for oil, natural gas, ores or water, maps showing the magnetic anomalies of the region are consulted.

All over Earth, the magnetic field and its various components are measured continuously and without interruption. The GFZ plays an important role in this coordinated network of worldwide observations. It operates the Adolf-Schmidt-Observatory for Geomagnetism, which was founded in 1890 in Potsdam and later moved to Niemegk, 45 kilometres to the southwest. The observatory Wingst, north of Hamburg, was added to the network in 2000. Equipped with state-of-the-art instrumentation, they are among the most capable geomagnetic observatories in the world. In cooperation with international partners, the GFZ operates or supports additional observatories in Bolivia, Bulgaria, Namibia, Rumania and Russia, as well as

Magnetic field measurements in southern Africa.



The proposed satellite mission SWARM to measure the Earth's magnetic field consists of three satellites based on the principle of the CHAMP satellite.



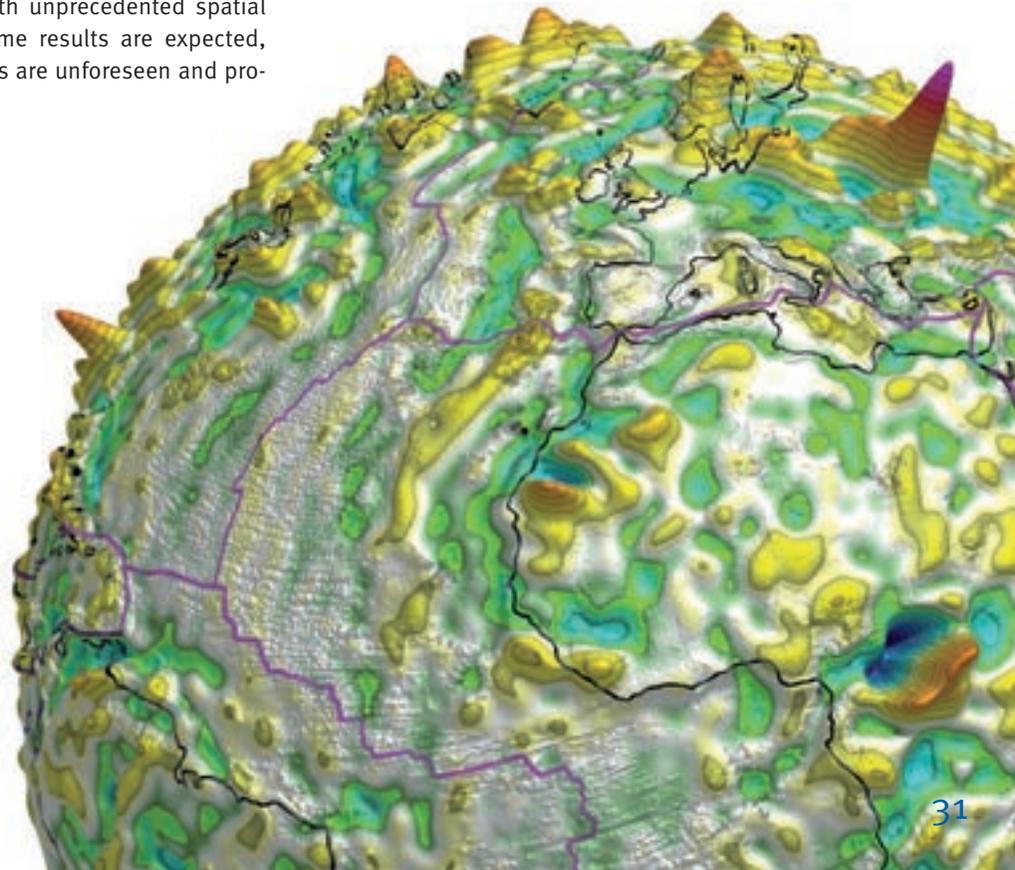
in the South Atlantic Ocean on the island of St. Helena.

A significant achievement in geomagnetic research is the observation of the magnetic field from space, since 2000 with the GFZ satellite CHAMP and in the future with the ESA mission Swarm. An important result from CHAMP's measurements is the preparation of a world map which displays the lithospheric

part of the magnetic field with unprecedented spatial resolution and precision. Some results are expected, which is reassuring, but others are unforeseen and pro-

vide room for suspense. One of the expected observations confirmed previous work that the magnetization of the oceanic plates, particularly that of the Pacific, is much weaker than that of the very old parts of the continents, which is very strong. Among the surprises are an as yet geologically unexplained high in lithospheric field strength near the North Pole, and very weak magnetization of the oldest parts of South America. During the analysis of the data collected by CHAMP, GFZ researchers also discovered that ocean tides and currents generate their own very faint magnetic signals. In this way, magnetic field measurements can also be used to remotely sense dynamic processes of our continuously changing planet.

Three-dimensional representation of the magnetic field signal of the lithosphere at an altitude of 100 km. Clearly visible are the Bangui anomaly in Central Africa and the anomaly near Kursk.



Life below the Surface: The Deep Biosphere

Looking at other heavenly bodies, it is clear that the Earth is a special planet: it harbours life. From space the biosphere appears as extensive green vegetation, the life on Earth's surface. In contrast, the discovery that microbial life is widespread deep under the surface was a big surprise. Almost nobody had expected that life could even be possible under conditions deep underground which are extremely inhospitable compared to the surface. For example, no sunlight penetrates into the Earth's interior, and thus photosynthesis is impossible. In addition, as one goes deeper into the Earth, temperature and pressure increase with each kilometre by 20 to 50 degrees Celsius and by 10 to 20 Megapascal, respectively. Nonetheless, microbial life has been shown to be present at several kilometres depth in apparently hostile surroundings at a pressure of 60 Megapascal and 120 degrees Celsius. Deep below the surface, no oxygen is available;

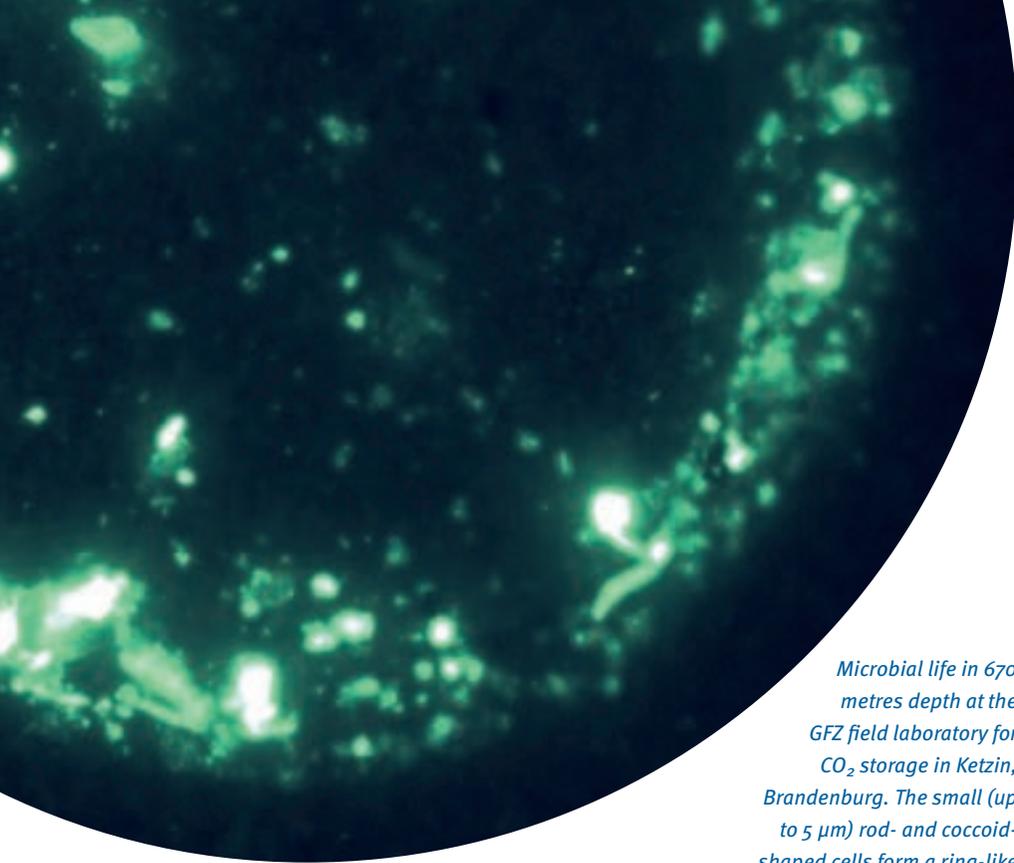
breathing and metabolism of the microorganisms living there take place under anaerobic conditions and are thus fundamentally different from those at the Earth's surface. Earth scientists have come to realize that the biomass of the "deep" biosphere is comparable to that at the surface. The processes that take place within and around these organisms are the subject of intensive research at the GFZ. Here are a few examples.

In sedimentary rocks, the microbes appear to derive their nourishment from algae and plants that were deposited there over the eons. In the process, they derive energy from biochemical reactions. It is suspected that important substrates are released from the organic sedimentary material through microbial and geological processes and then serve as the basic food source for the "deep biosphere". Such coupled bio-geosystems can occur at different depths in the Earth's crust. Their metabolic products reach the surface through cracks and fractures. In addition, microorganisms were discovered in rocks that, in contrast to sedimentary layers, are completely separated from the biosphere at the Earth's surface and its remnants. These organisms are capable of producing the materials necessary for an autonomous life with only the basic ingredients water, carbon dioxide, hydrogen and nitrogen.



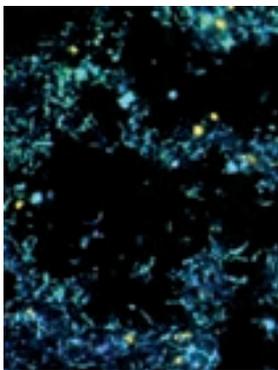
Drill site in Huntly, New Zealand. The drill core (left) contains pieces of coal, a potential food source for microbial communities in depth.





Microbial life in 670 metres depth at the GFZ field laboratory for CO₂ storage in Ketzin, Brandenburg. The small (up to 5 µm) rod- and coccoid-shaped cells form a ring-like structure.

Fluorescence microscopic photo of the microbial communities in the fluid of the injection well (670 metres) at the pilot site Ketzin, one year after the start of the CO₂ injection.



In a South African gold mine, GFZ researchers discovered some life forms of that nature. At a depth of 2.8 kilometres, they found bacteria which had survived millions of years without energy from the sun. While some near-surface microbes can double their numbers within minutes, the bacteria in the gold mine need up to 300 years to do so. Such “life in the slow lane” ensures that the microbes can survive in these apparently inhospitable depths, because the rate at which nutrients and the associated energy resources are supplied is very low. But what do the bacteria in the gold mine live on? They use a source of energy that is completely independent of the Sun. Instead they biochemically reduce sulfate to sulfide with the hydrogen that naturally forms at depth from the radioactive decay of elements

like uranium, thorium and potassium. Thus, these microbial communities live solely from geologically produced nutrients.

In a research bore hole in the permafrost of northwest Canada, GFZ researchers also found clear signs of life at a depth of more than one kilometre. The signs were lipid membranes, organic molecules from the cell walls of bacteria that rapidly decompose when a microorganism dies. Finding traces of these molecules in deep sediments is thus an important indicator of the presence of underground ecosystems. When scientists simulate the geological development of the investigated region with computer models to better understand the thermally controlled processes over time, they can then decode the history of the deep biosphere in this region. By combining bio-geochemical analyses and geological process modelling, they found that intact lipids can exist in sediments that are up to 15 million years old and have been buried to depths of more than 5.5 kilometres. A coupled biogeosystem is capable of life even under high pressures and temperatures.

Microbes are active even in oil and natural gas deposits, since some microorganisms long ago recognized that hydrocarbons are ideal sources of energy. They process the hydrocarbons in their metabolism, producing enormous amounts of carbon dioxide and methane. These gases would have a strong influence on the global climate if they were to get into the Earth’s atmosphere. The major part of all globally known oil reserves have been more or less altered by such biological processes. As this happens, the amount of available energy resources and their economic value decrease. The changes also make it more difficult to produce the oil and natural gas using environmentally friendly methods. This is why GFZ scientists pursuing the questions of how microbes change such deposits and what role they play in the global carbon cycle.

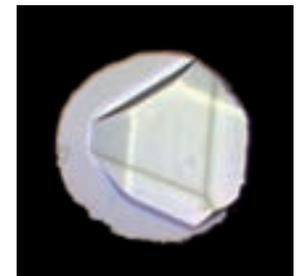
High Pressure: Diamonds Bring the Earth's Mantle into the Laboratory

The samples are not much larger than a speck of dust, the experimental chambers have the volume of a tip of a needle – despite this, GFZ researchers can create conditions within them that simulate those at depths of hundreds to thousands of kilometres below our feet in the Earth's mantle. At these depths the temperature can reach several thousand degrees Celsius and the pressure can be more than a million times higher than the air pressure at the Earth's surface. The goal of the experiments in the various high pressure devices on the Telegrafenberg is to learn about the conditions at these unreachable depths and to discover how various rocks react to the conditions there.

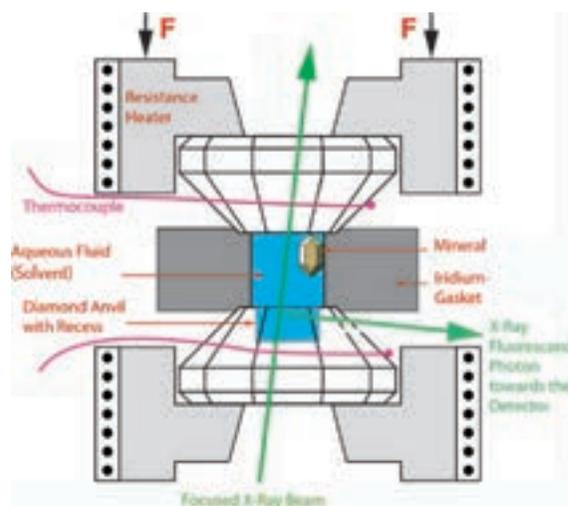
Even if we could drill deep enough into the Earth's mantle, we would need to investigate the physical and chemical behaviour of high pressure minerals with laboratory methods. This is because many of the exotic rocks that exist deep inside the Earth change into everyday minerals relatively quickly when the pressure decreases. The measurements must therefore take place as long as the usually tiny samples are heated and under extreme pressure. To accomplish this, the tiny experimental chambers are usually surrounded by comparatively huge apparatuses: Lasers to heat the samples, microscopes, X-ray machines and spectrometers to collect the results.

The centre pieces of these experiments are the diamond anvil cells, which can be used in many different ways. In them, high pressures are generated by compressing the sample chamber between two diamonds with sharp

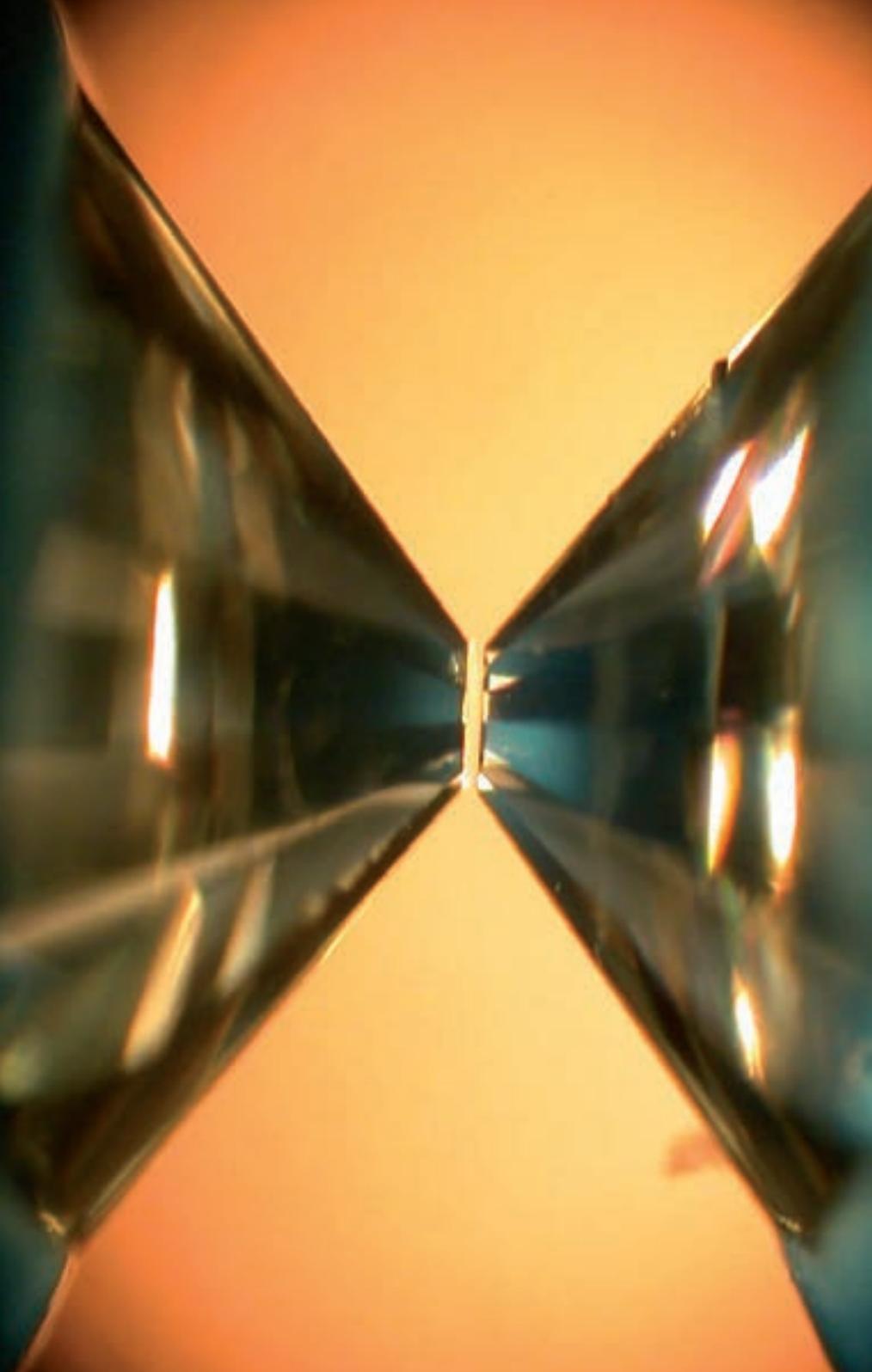
tips. At the same time they are heated and analysed. Diamonds are ideal for such experiments: Of all known materials, they have the highest hardness, the highest thermal conductivity, they are electrical insulators and do not react with the sample materials under most conditions. They are transparent not only for light, but also for rays in a broad range of the electromagnetic spectrum as well as for ultrasound. Thus, during experiments, samples can be investigated with a variety of optical, spectroscopic and X-ray methods as well as with ultrasound interferometry.



Under high pressure water takes the form of ice VI.



Principle of a diamond anvil cell



*Diamond anvil cell,
viewed from the side*

Investigations of the unreachable regions of the Earth with such difficult experiments are more than just pure research. At depth, dynamic processes are taking place that influence what happens at the surface. For example, the Earth's mantle is heated from below by its core. As a consequence, the rocks lose their stiffness and begin to flow as an extremely viscous mass. Convection currents are the result, which are considered to be the motor of plate tectonics, as well as the causes for the formation of mountain ranges, for volcanism and even of earthquakes.

The details of these processes are not even close to being understood, and many important questions remain unanswered, like: How well do rocks at depth conduct heat? How is their electrical conductivity influenced? How do the travel times of seismic waves from earthquakes change? What happens to the pore space between the minerals and thus their permeability for fluids? How do rock melts behave? Many investigations are looking at how minerals change as the pressure and temperature increase. And the researchers can directly observe through a microscope what is happening in the diamond cell- for example, how a homogenous melt separates into partial melts as it cools, and which elements are enriched.

The high pressure experiments are also of immediate value for practical applications, such as determining the heat flow from the inside of the Earth, and with it the capability of determining the potential of geothermal energy more exactly. The investigations also produce insights into reactions that can lead to the formation of ore deposits. In short the experiments between the tips of these valuable gemstones open new windows into the Earth's interior.

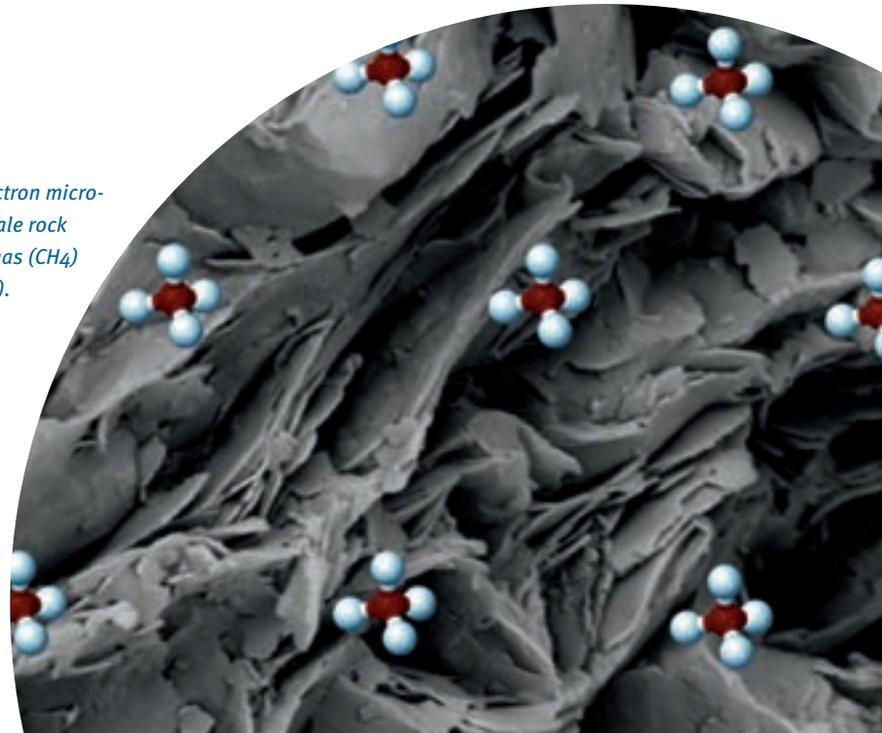
A New Energy Source: Gas from Black Shales

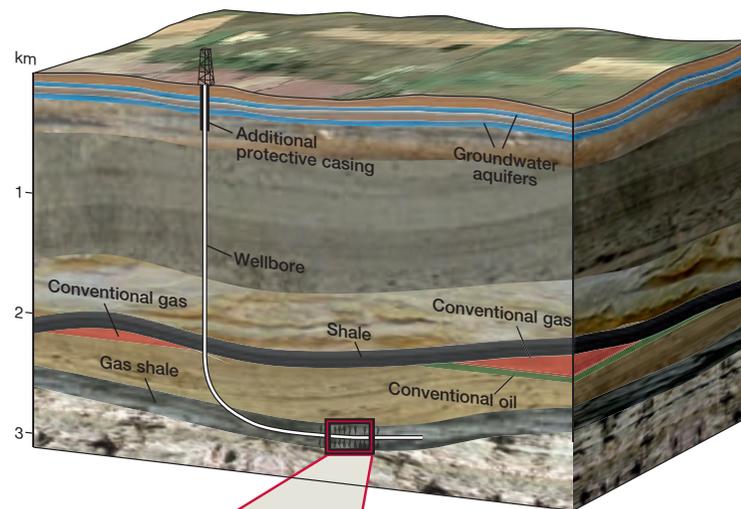
What do the wonderfully preserved fossils of sea lilies in the “Urweltmuseum Hauff” in the German city of Holzmaden have to do with the many drill rigs you see when landing at DFW airport in Dallas, Texas? At first glance there seems to be no connection at all between the hectic drilling activity surrounding the Texan metroplex and the sleepy town on the edge of the Swabian mountains. A glimpse below the ground, however, shows why researchers of the GFZ are enthusiastic about both locations. Under both Holzmaden and Dallas there are thick beds of a dark, clay-rich rock. The reason for the enthusiasm is not only the well-preserved fossil record in these rocks, known as black or bituminous shales. It is also the fact that the shales may contain huge amounts of natural gas. Indeed, shales are the newest source of fossil fuels that has until recently remained untapped. Researchers from Potsdam are leading a cooperative project, alongside other European earth scientists and the industry, to examine how the energy potential of these “gas shales” can be realised.

Until recently only very little natural gas could be produced economically from shales using conventional drilling methods. This is because of the rocks’ dense structure. Shales are usually nearly impermeable to liquids and gases, which is in stark contrast to conventional gas reservoirs, usually sandstones, where gas flows easily through their well connected pores. However, a technology has now evolved that allows us to effectively release the natural gas locked in the black shales. By pumping water at high pressures into the rock via boreholes it is possible to create artificial fractures in the

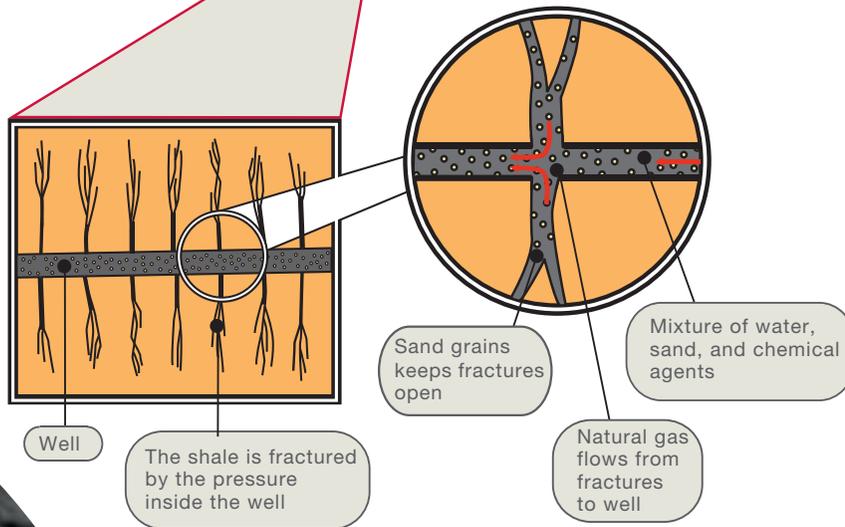
rock to increase permeability and thus to allow gas to flow to the wellbore (hydraulic fracturing). The borehole itself is vertical from the surface until the shale is reached, and is then steered horizontally for up to about 1 kilometre, thereby penetrating the shale layer, and not moving outside of it. This technology is used in north Texas, drilling into the Barnett shale. We now know that this shale deposit is likely to be the second largest natural gas field in the United States. It has reserves of more than 850 billion cubic metres.

Scanning electron micrograph of a shale rock with natural gas (CH₄) molecules (M).





Since shales have a very low permeability, the natural gas trapped in the rock is not easily released. Shale gas wells are drilled and completed horizontally. The shale is hydraulically fractured with water containing sand to keep the fractures open and chemicals to aid the fracturing process. After fracturing, a portion of the water is removed from the well and the natural gas is being produced.



black shales. If the current provisional estimates are correct, there are more than 40 trillion cubic metres of natural gas beneath Western Europe. That is in fact comparable with one third of the proven conventional natural gas reserves in Russia. The GFZ researchers aim to find out how such shale gas deposits in geological sedimentary basins actually originated and how natural gas can remain stored for millions of years in such dense rock.

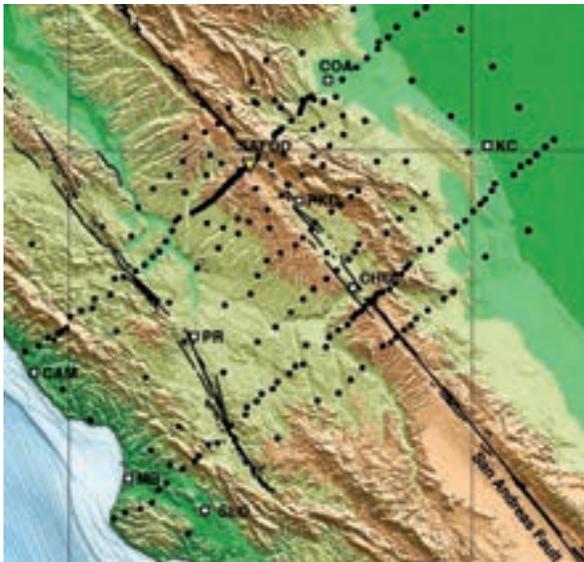
Notwithstanding the advance of renewable energies, fossil energy resources will stay important in the German, European and world wide energy mix for decades. Natural gas plays a key role, since it is the cleanest fossil fuel when combusted, is affordable as well as being abundant. However, experience in the USA has shown that alongside economic advantages and an increased security of energy supply there are also risks to the environment and to health involved in shale gas production. Such risks need to be investigated and must of course be minimised in Europe through scientific and technological developments as well as regulation so that possible future shale gas production can be economically successful and environmentally friendly at the same time. GFZ researchers are therefore actively examining how much gas is contained in European gas shales and how it can be efficiently produced under safe and environmentally friendly production practices.

Black shales are also found in Germany and in other European countries, for example the Posidonia shale, which formed some 175 million years ago. Beneath Great Britain and large areas of the Netherlands there are similar shale formations, which were deposited about 320 million years ago in the Carboniferous era. Under some regions of Sweden the Alum shale exists which is even older, dating back to the Cambrian. To date, nobody has yet investigated the true energy potential of Europe's

Magnetotellurics: Illuminating the Earth with Electrical Currents

It is impossible to imagine our daily lives without electricity. It provides us with light, runs our washing machines and refrigerators, brings our computers to life and, in the future, will increasingly propel our cars. The flowing electrons make our lives much, much easier. Electrical currents can also be used to investigate the interior of the Earth where we cannot otherwise go – and over the years, scientists at the GFZ have perfected ways to illuminate the Earth under our feet using electricity.

Magnetotelluric data points perpendicular to the San Andreas Fault, California

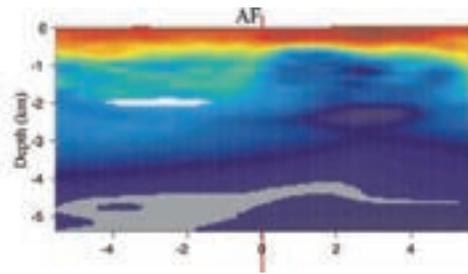


How well a current flows depends primarily on the electrical resistance. Some metals like copper or aluminium provide little resistance to flowing currents. Other materials, for example granite or marble, practically do not conduct electrical charge at all. Salt water is full of dissolved ions which, in contrast, make it a good conductor. Deep within the Earth the layers also have different conductivity. How well individual rock layers conduct a current depends on their water content, their chemical composition and in particular on their mineralization. Thus, rocks that contain ores, graphite and sulfides are very good underground conductors. Since one cannot directly measure the conductivity of rocks deep within the Earth, researchers record the electrical and magnetic field at the Earth's surface with probes. Their "current sources" are the sun and lightning, since the continuously blowing solar wind and thunderstorms cause alternating electric currents in the magnetosphere and the ionosphere. The magnetic fields from these currents induce electrical currents in the Earth's layers. They can be measured with probes at the Earth's surface. The measurements are then evaluated using computer programs, which produce as a result a model of the distribution of the electrical conductivity with depth. In scientific terminology such measurements are called magnetotelluric depth soundings or MT for short.

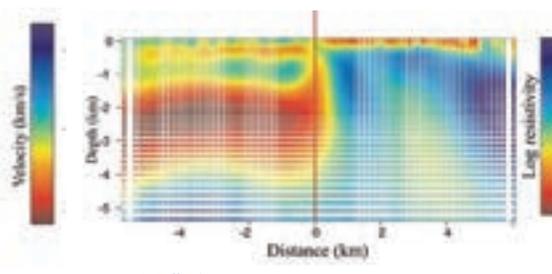
Researchers from the GFZ have used these methods to survey a range of geologically interesting regions. They paid special attention to the so-called shear zones, those regions of the Earth's crust in which two plates push past each other. In their investigations of one of the

Setup of a magnetotelluric experiment for the Plate Boundary Observatory in Chile.

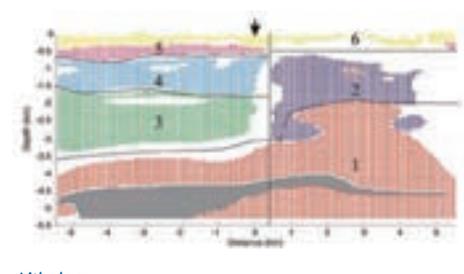




Seismics



Magnetotelluric



Lithology

The section across the Jordan Rift Valley shows, in the synopsis of seismology, magnetotellurics and lithological profile, clearly the shear zone as the boundary between the African and the Arabian plate.



most famous shear zones of the world, the San Andreas Fault in California, they found, for example, a nearly vertical zone of high conductivity on one side of the fault. Beneath the surface, this zone broadens out and seems to be connected with a broad anomaly of high conductivity in the upper mantle. It is now considered to be almost certain that the high conductivity is caused by fluids that rise from the mantle. At high pressure it is possible that these fluids contribute to a reduction in the stress along the fault by causing micro earthquakes or by allowing the two flanks of the fault to creep past each other aseismically.

In other investigations of shear zones, the GFZ researchers did not find fluids but instead they found graphite, an unusually good electrical conductor. The reason for this is that movement of the plates under high pressure converts the carbon in the rocks to graphite which is then deposited between them. Such graphite shear traces are often preserved for hundreds of millions of years and thus allow conclusions to be drawn about the processes which took place in the early times of plate tectonics. The geoscientists from Potsdam used

their MT-probes to investigate what is possibly the oldest preserved collision zone between continents. About 3.5 billion years ago, two continents collided in what is now South Africa and left behind graphite shear traces. Thus, the electrical illumination of the Earth not only allows a view of deeper layers, it also opens a window into the early years of the Earth.

As part of a comprehensive study of the Jordan rift zone in the border region between Israel, Palestine and Jordan, GFZ scientists also deployed their probes in the region around the Dead Sea. Like the San Andreas Fault, the Jordan rift zone is also a shear zone where the Arabian and the African plates are displaced against each other horizontally. Although they did not find such a clear anomaly in the conductivity as in California, the salt deposits under the surface associated with the Dead Sea and the upwardly bulging domes from salt layers were clearly apparent in the measurements.

The Potsdam research group does not only use their MT methods for pure geophysical research. Using Magnetotellurics, they have investigated the subsurface in areas of ongoing geothermal projects. Even before the first wells are drilled, one can use this method to get a glimpse of the electrical conductivity of the reservoir and collect clues about its potential for geothermal energy production. In MT active signal sources are also used to provide answers in exploration geophysics. In addition to geothermal research, CO₂ sequestration and unconventional natural gas deposits are fields for such applications.

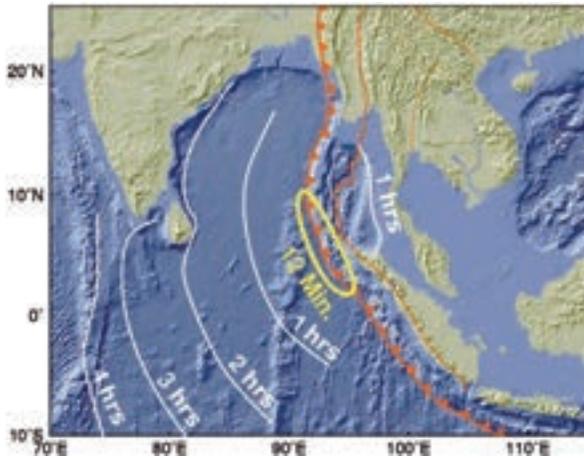
Warning of the Killer Waves: Tsunami Research

No one will forget the dramatic pictures that circled the world at the end of 2004. A large earthquake off shore of the Indonesian island of Sumatra caused a devastating tsunami, which affected the entire Indian Ocean within a few hours. From Sumatra to Sri Lanka, from India to Kenya, the monster wave sucked people to their deaths and destroyed hundreds of coastal villages. At the time, the German government provided more than just immediate disaster aid. Berlin promised a warning system for killer waves like that of 2004 to the country that was most affected by the disaster, Indonesia. This system was to be developed by German scientists specifically for the conditions in the island nation. In contrast to the Pacific Ocean, which has had tsunami warnings for more than 50 years, the wave caused by the great underwater earthquake off Sumatra caught the countries surrounding the Indian Ocean completely unprepared. Of these countries, Indonesia, with more than 81,000 kilometres of coastline, is the most endangered by tsunami. The core of the “German-Indonesian Tsunami Early Warning Systems” (GITEWS) was officially inaugurated by Indonesian President Yudhoyono a scant four years after the Great Sumatra earthquake, in November 2008. After a joint phase of operation Germany officially handed over the Tsunami Early Warning System to Indonesia in March 2011. Since then the responsible operator is the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) in Jakarta. Since operation started, thousands of earthquakes and more than ten tsunamis have been successfully registered.

More than 120 scientists from seven German research institutions participated in the development, implementation and construction of the system. Personnel from the GFZ coordinated the project and contributed fundamentally to all its individual components. In the worst case, the time between an earthquake and the run-up of the wave on the coast will only be about twenty minutes. The core of the early warning system therefore consists of the rapid and reliable characterization of earthquakes. To do this, German researchers together with scientists from Indonesia, Japan and China set up a dense network of 160 seismic stations. Unfortunately, seismic measurements alone are not enough to decide if a quake has caused a tsunami or not. For this reason, the scientists set up sensitive GPS stations on land and on islands off

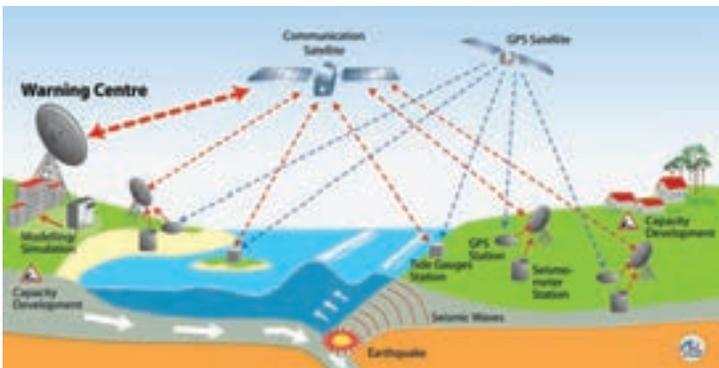
*View into the control room of
the GITEWS warning
centre in Jakarta.*





The propagation of the tsunami of December 2004

Schematic structure of the GITEWS with its subcomponents.



the coast of Indonesia. These stations can detect ground movement of just a few centimetres. These measurements contain important information about the mechanism of the earthquake and are therefore an important indicator for the formation of a tsunami. Additional gauges for the continuous monitoring of the water level have also been installed in coastal areas.

The collected data from a total of more than 300 sensors are transferred in real-time via satellite, radio or telephone to a data centre in Jakarta. There, software developed by the GFZ collects all the incoming data and analyses them automatically. The computers also receive as input the results of a program especially developed for the warning system. The program simulates tsunami waves in the waters off of Indonesia and has produced a digital library that currently contains more than three thousand different tsunami scenarios. From all these data, the computer develops a situation map which shows the expected

height and arrival time of a tsunami for each section of coast. This map is the basis for specific warning messages that can be sent to each individual district in Indonesia.

The construction of the warning system for Indonesia and other Indian Ocean nations was not the only task within the framework of this project. During the development of GITEWS, many other problems were studied that could only be answered with basic geoscientific research. For example, GFZ researchers discovered that a new GPS technique is especially well suited to determine whether a particular earthquake could have caused a tsunami when it is combined with detailed model calculations.

Despite the official handing over of the Warning System to Indonesia the project is still far from complete. Alongside a comprehensive academic and technical training programme for Indonesian scientists and engineers, German scientists are also working on concepts and strategies for the prevention and management of natural disasters. Comprehensive Capacity Development in the field of Disaster Reduction and community preparedness has been practised in three pilot regions (Sumatra, Java, Bali) and is now widespread over Indonesia.

At the GFZ, a Tsunami Early Warning Unit was also established to transfer scientific know-how into corresponding technologies. In the meantime, it has been discovered that not only the shores of the Pacific and Indian Oceans are endangered by tsunamis. These killer waves also, although more seldom, occur in the Atlantic Ocean, and even in the Mediterranean Sea. Between Gibraltar and the Suez Canal, however, tsunami warning is particularly difficult, since the Mediterranean is relatively small compared to the major oceans, and warning times would be correspondingly short. Despite all the research and development, GFZ scientists are aware that the occurrence of natural events such as tsunami cannot be prevented. Even if alarm systems work perfectly, such catastrophes will still take their toll in damage and human lives. Nonetheless, the goal of their work is to minimize the consequences of such catastrophic events with the early warning system.

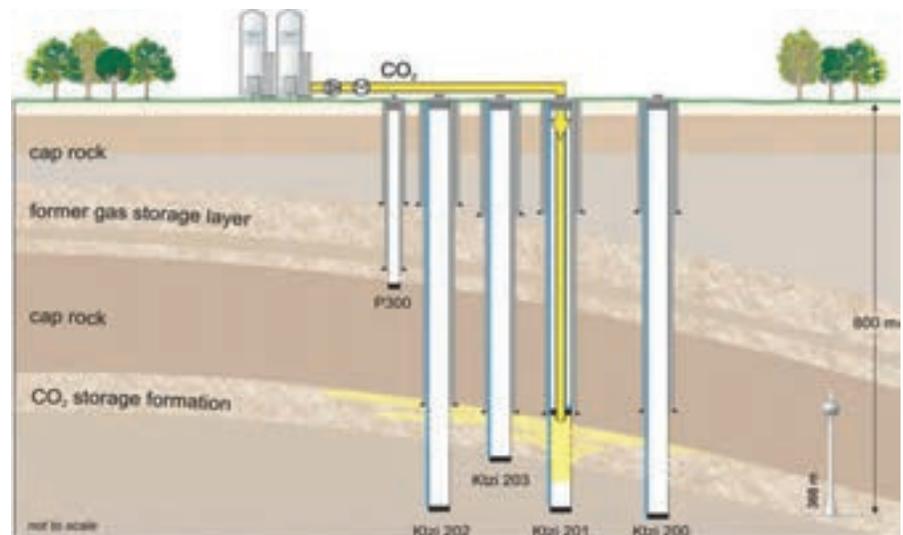
Protecting the Climate from Deep in the Earth: Underground CO₂ Storage

How can we counteract the continuous increase in the concentration of carbon dioxide in the atmosphere that began with the industrial era? One possibility for reducing the emissions of this greenhouse gas is to scrub the CO₂ from the smoke stacks of coal and biomass power plants, steel factories and cement plants, and then put it underground into safe and long term storage. The fine pore spaces of sandstone formations in the Earth's crust are considered to be very promising locations for such storage. Such pores are often filled with highly saline water. Near the town of Ketzin, in Havelland, west of Berlin, researchers from the GFZ are investigating the fundamentals of such storage in a large-scale field experiment, and are testing its practical realization. In the first such project on the European continent, carbon dioxide has been reliably and safely pumped to a depth of 650 metres underground and stored since June 2008.

At first glance, it seems illogical to want to store a gas underground. Because of its very low density compared to the formation water in the rocks, gas in the Earth's crust tends to rise. Through cracks and fractures which are widespread in the crust, it could then escape to the surface. In natural gas deposits, however, nature shows us the way that gases can remain underground for millions of years. There are rock layers that are essentially impermeable to liquids and gases. When they are above gas-containing rocks, they prevent the gas from rising and hold it in place. In rock, though, CO₂ behaves differently than natural gas. That is why extensive research is necessary before carbon dioxide can be pumped into

underground stores on a large scale. This idea to pump CO₂ underground is not completely new, since this gas is pressed into oil and natural gas fields to increase the level of production. The Ketzin field laboratory is unique in the world. Under the leadership of the GFZ, scientists from more than 20 countries are investigating open questions about the storage of carbon dioxide. The partners include large research institutions, universities and industry, as well as governmental agencies and the International Energy Agency of the United Nations.

Layout of the pilot project for the geological storage of CO₂ in Ketzin.





Work on the injection system

CO₂ in the transition from liquid to gaseous state.



From earth science investigations, the researchers first discovered that a sand stone layer saturated with salt water below Ketzin lies beneath nearly impermeable layers of anhydrite and claystone. These layers prevent the undesired emergence of gases. Next, a demonstration plant was built in which CO₂, delivered in liquid form, is heated to 50 degrees Celsius and then, as a gas, is pumped into the sandstone layer at high pressure. The gas then displaces the salt water present in the rock pores and spreads into the sandstone. Over the course of time, the CO₂ is fixed in the rock, for example by capillary forces, by solution of the gas into the salt water, and by precipitation of carbonate minerals. All in all, researchers want to inject up to 60,000 tons of CO₂ into the reservoir under Ketzin.

The CO₂ storage is accompanied by an extensive research program. In it, researchers not only investigate how tight the reservoir really is. They also want to find out in detail how the rocks and fluids in the Earth's crust interact with the CO₂. In addition, they are observing whether and how the rich microbial life in the underground rock layers is influenced by the pumping and storage of carbon dioxide. From the Earth's surface, geophysicists are using a variety of measuring technologies to investigate how the CO₂ spreads into the rock formation comprising the reservoir, and to what extent it can actually fill the rock pores. Until now, no researchers anywhere on Earth have had such an opportunity to observe the migration of carbon dioxide within a porous sandstone formation so close to the actual injection location. That is why the system for observation and monitoring installed at Ketzin is the most extensive of any in the world. This system includes two additional observation drill holes which allow scientists to measure and observe the injection of CO₂ at depth and not just from the surface.

All the information recorded in this field laboratory is entered into computer models which can represent and quantify the underground geology as well as the physical and chemical processes. With extensive measurements, researchers evaluate how well the models describe the movement of the carbon dioxide in the reservoir and how precisely they can calculate its behaviour. It is only when the models satisfy these tests in reality that they can be used as tools to predict whether long term, underground storage of CO₂ without any leakage may be possible.

Burning Ice: The Investigation of Gas Hydrates

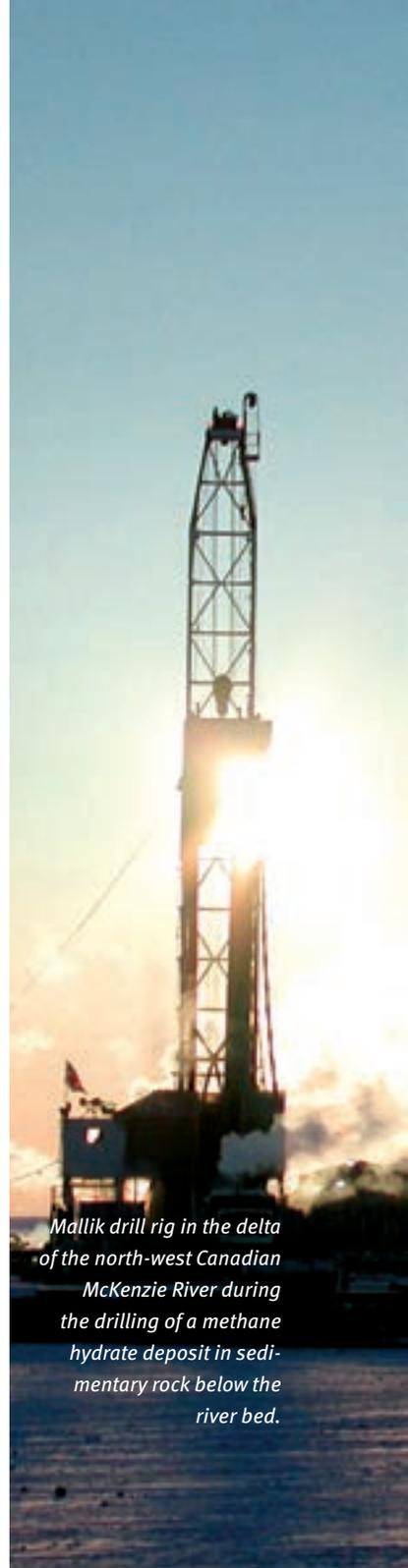
It is made of water and gas, but is nonetheless solid. At atmospheric pressure, it decays with a loud hissing noise, when ignited, it burns with a yellow flame. At first glance this appears to be a strange scientific brain teaser. If we look closer, however, these attributes describe real substances. They are called gas hydrates, and not only do they have unusual characteristics, but they also represent an energy resource that is twice as large as all of the known oil and natural gas reserves in the world together. In addition, they stabilize the continental slopes. They are also considered to be an effective climate regulator that has strongly influenced the green house effect more than once in the course of the Earth's history. These reasons are more than sufficient for researchers in several sections of the GFZ to study these unique molecules intensely.

In gas hydrates, water molecules form a cage structure in which guest molecules like hydrocarbons are enclosed. In most cases, it is methane that combines with water into so-called clathrates. They can also form with higher order hydrocarbons or carbon dioxide. Gas hydrates are only stable at high pressure and low temperature, otherwise they decay. They are often called methane ice, since they superficially appear to be similar to normal water ice.

In nature, gas hydrates primarily occur in two regions, in the permafrost of the Arctic and in ocean sediments. In the permafrost, gas hydrates form below the permanently frozen layer if the pressure and temperature con-

ditions are suitable. The sources of the methane are deeper seated natural gas reservoirs, from which a little methane continuously escapes into the sediment layers above. If the pressure in those layers is high and the temperature is low enough, the methane will combine with pore water to form the gas hydrates. Yet, most of the gas hydrates are found in ocean sediments in water depths of 500 metres or more. There the hydrostatic pressure is so large that gas hydrates can form even at temperatures above the freezing point. The methane may also be contributed by deeper natural gas deposits. In many cases, however, it may also be the fresh decay product of organic material in young sediments. Gas hydrates in ocean sediments can act like cement, since they displace water from the pore spaces and solidify the mud.

The total amount of hydrocarbons stored in methane ice all over the world is enormous. A cubic metre of gas hydrate consists of about 80 percent water molecules. Despite this fact, there is so much methane in the rest that, at room temperature and at atmospheric pressure, this volume would expand to about 160 cubic metres. Since gas hydrates are so ubiquitous in ocean sediments, it is estimated that the amount of carbon bound there is about three thousand times that currently present as methane in the atmosphere. If it could be commercially exploited, the underwater methane ice would be a gigantic resource of hydrocarbons. In contrast, if it were released by warming of the oceans, the methane would contribute strongly to the green house gas effect.

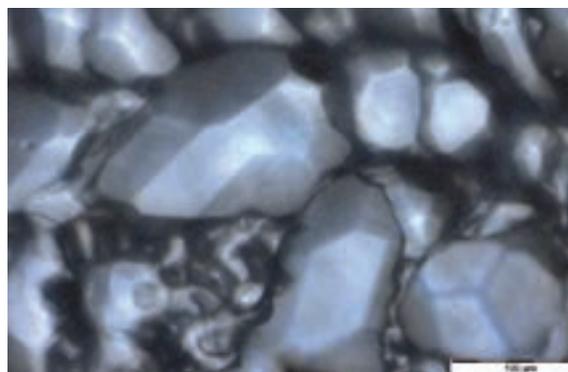


Mallik drill rig in the delta of the north-west Canadian McKenzie River during the drilling of a methane hydrate deposit in sedimentary rock below the river bed.

Synthetically produced gas hydrate being tested in the laboratory. The methane is trapped in a water cage and burns.



Methane hydrate under the microscope



Extensive research is still necessary in order to understand the unique characteristics of methane ice. The researchers in GFZ laboratories are determining the thermodynamic, kinetic and physical parameters of samples of naturally occurring gas hydrates, and of synthetic, mixed hydrates. In their work, they are concentrating particularly on determining how these materials form, under which conditions they decay, and how much energy is necessary to decompose naturally occurring hydrates if gas were to be extracted from hydrate-containing sediments. Such fundamental investigations also have practical applications. For example, investigators at the GFZ are looking for innovative methods to extract natural gas. In a pilot plant, these methods are tested be-

fore they are applied in field experiments. Another, more applied research direction is investigating how carbon dioxide emitted from industrial plants can be stored in gas hydrates. Ideally, these two applications could be combined with each other. In addition to the experimental work, simulations are carried out in which results are scaled from the small dimensions of the laboratory to the greater dimensions of the natural environment. This is important to understand the role that gas hydrates play in the complex system of the Earth.

At the GFZ, work on methane ice is not limited to the laboratory or the computer. In the framework of an international research program, scientists from Potsdam are also investigating gas hydrates under the permafrost. In the Mackenzie Delta in the far northern regions of Canada, a gas hydrate deposit is being drilled into, sampled and methods for gas extraction are being investigated.

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2.3 Earth's Magnetic field
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4.3 Organic Geochemistry
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5.3 Hydrogeology
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Centre for Integrated Hydrocarbon Research CIHR (in development)
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• TERENO-Northeast / Geocological Research
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Detailed information on the GFZ is also available on the GFZ website at <http://www.gfz-potsdam.de>

Texts and images for teachers and students are also available, albeit mostly in German:

<http://schule.gfz-potsdam.de>

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