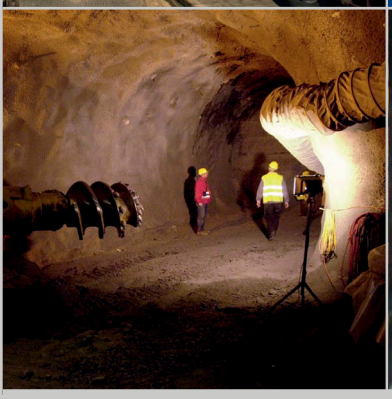
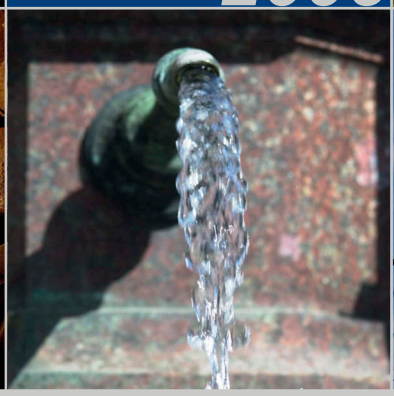
Biennial Report

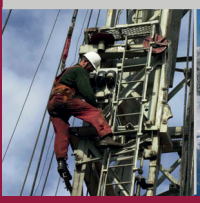
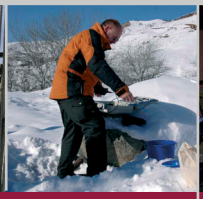
of the Federal Institute for Geosciences and Natural Resources

2005

2006





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Biennial Report 2005/2006

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Foreword

Dear Readers,

The global economy has received an enormous boost in recent years from the rapidly expanding economies of some emerging countries. More than half of German exports consist of goods requiring a significant input of metals and industrial minerals.

This development has again raised the question of how much longer our commodity reserves will last, and the price we will have to pay to satisfy the future demand for natural resources. One of the more important tasks for which BGR is responsible is providing policy makers and industry with advice on all natural resource supply issues, with the ultimate goal of safeguarding our prosperity.

The German Ministry for Economics and Technology used BGR data to present a comprehensive report as early as July 2005 on the current economic implications of the natural resource situation, and to propose recommendations. BGR makes a major contribution to understanding the many facets of the commodity markets and commodity industry relationships by maintaining comprehensive natural resource databases and conducting detailed market analyses.

The use of domestic sources of minerals and energy sources is again capturing the attention of politicians at an international level after many years on the sidelines. "The continually growing global population will also be forced in future to make use of primary resources despite increased efforts to find substitutes and implement savings", writes the German Ministry for Economic Co-operation and Development: "The availability of natural resources in adequate quantities and quality, and at calculable prices, is one of the primary conditions for the continuation of industrial societies, and socio-economic further development in developing countries."

Developing countries producing natural resources are just as strongly affected by the changes in global commodity markets. Within the framework of German development co-operation, BGR contributes to the work aimed at turning national geopotential into development factors. It recommends, promotes and encourages the implementation of processes leading to the closer integration of resource suppliers and resource users. It is engaged in the transfer of expertise to strengthen the capacities of developing countries to optimise the exploitation of their own resources at the same time as complying with urgent environmental protection needs.

BGR's work in the technical co-operation field is an integral part of the German government's obligations to fight poverty around the world: BGR's input provides tangible support in areas such as "good national governance", "crisis prevention", "environmental sustainability" and the setting up of global "development partnerships". BGR staff have worked on assignments to assess the resource potential (mineral resources, energy resources, soil, water) in BGR's partner countries. They support the creation and implementation of legislative frameworks (mining laws, water framework directives, natural disaster management regulations). BGR has also participated in regional development decisions by setting up "round tables" to bring together investors and the people affected by projects, and to improve the participation of the inhabitants in regional development decision making. It therefore makes a valuable contribution to establishing legislative frameworks which not only satisfy the economic interests of the globalised markets, but also provide a voice for the social needs of societal stakeholders.

With its research activities, the Federal Institute for Geosciences and Natural Resources makes a contribution to securing the future commodity supplies for our country, and therefore participates in the strategic effort to satisfy future resource demand. These activities also include the continuous exploration for new deposits of ores and industrial minerals. Success here crucially depends on the proper interaction of investment, technology, expertise and the creativity of exploration geologists.

In the face of the considerable rise in commodity prices, the manganese nodules in the Pacific Ocean are again moving into the spotlight as they did back in the 1970s and 80s when they were first recognised as an important natural resource. At that time, during the "Cold War", new approaches were sought to reduce our country's major dependence on imported resources. The manganese nodules found on the deep ocean floor were discovered and identified as a new previously unexploited source of a range of metals including copper, cobalt and nickel.

On the basis of the scientific findings elaborated at the time, and comprehensive data from an archive acquired from Preussag, BGR has now launched a new exploration campaign for manganese nodules in the Pacific. This involved the submission of a research application to the United Nations International Seabed Authority which is responsible pursuant to the Law of the Sea Treaty for all issues concerning exploitation of natural resources outside of territorial waters. The German application was received positively by the UN policy making committees, and a research agreement between BGR and the International Seabed Authority was signed accordingly in Berlin on 19.07.2006.

This assigns Germany a 75.000 km^2 maritime concession for a period of 15 years with exclusive rights for the exploration of manganese nodules. The detailed exploration of this area will now be specifically elaborated and implemented in phases by BGR.

The rise in prices for energy resources, the Renewable Energy Act (EEG) and government subsidies for renewable energies, are making it increasingly attractive for industry and local authorities to use geothermal energy – which benefits from being continuously available. Depending on the geological conditions, geothermal energy can be used to either provide heat or to generate power. BGR carries out research on suitable geological structures for geothermal energy plants. The risks to which potential investors are exposed can be reduced by carrying out detailed studies on deep underground geology, improving structural geological models, and increasing the amount of information available on the fluids present underground.

BGR intends to construct a demonstration plant within its own office complex to harness geothermal energy and use the heat to centrally heat its own buildings. The go-ahead for implementing the demonstration project at the Geozentrum Hannover was given after the successful conclusion of the preliminary tests. The project kicked off in May 2005 and the framework working plan was approved in December 2005. Preparatory work is currently being carried out prior to drilling the well.

Germany has signed international treaties (Kyoto Protocol) and national agreements committing it to obligatory reductions in the emissions of the greenhouse gas CO_2. One of the technical fixes for reducing emissions of CO_2 from industrial facilities is disposing of the gas underground. BGR participates in various European research programmes aimed at maintaining Europe's leading role in the scientific research and implementation of underground CO_2 sequestration.

A major Tsunami crashed into coasts around the Indian ocean on 26 December 2004. BGR was involved in detailed consultancy work with the governments of the affected countries. This involved a range of projects concerned with reconstruction in the regions affected by the disaster. Other serious natural disasters also occurred during the same period. This shows that the earth is undergoing continuous – sometimes sudden – change. We can identify these changes early enough under favourable conditions to enable the implementation of effective protective measures.

The disastrous earthquake offshore Sumatra has boosted the interest of the public in the installation of earthquake alarm and information systems.
I would like to describe two examples below in which BGR made major contributions:

Example 1:
The Sunda Strait is one of the most important transport routes in Southeast Asia. It passes close to some of the most densely populated parts of Indonesia and is also exposed to considerable seismic and volcanic risks. For these reasons, the Federal Institute for Geosciences and Natural Resources began its "Krakatau Monitoring Project" (KrakMon) at the beginning of 2004 to assess and gave early warnings of volcanic risks in the Sunda Strait. The scientific urgency of realistically assessing georisks in the region was tragically highlighted by the serious consequences of the earthquake offshore Sumatra which generated the deadly Tsunami in 2004, not to mention the continuous activity of the volcano which forced the Indonesian authorities to close the volcano to tourists.

As a direct consequence of these events, work is now being carried out to integrate the KrakMon system within a Tsunami early warning system currently being set up in the Indian Ocean. The intention is to link it in future to proposed global multi-hazard early warning systems.

Example 2:
Although Germany is not exposed to major seismic risks, it has been affected by serious damaging earthquakes in the past. Germany therefore needs fast, reliable and comprehensive information on damaging earthquakes as well as smaller earthquakes. Information of this kind helps organisations such as the police, fire brigade and the Interior Ministry Crisis Centres to rapidly and objectively assess the situation after an earthquake and to implement the necessary measures. This also includes passing on information to worried inhabitants with the aim of calming the situation if an event is not expected to cause any damage.

To gather and deliver this information, Germany set up the ALISE system: Alarm and Information System for Earthquakes in Germany. The system can be used to rapidly and comprehensively inform the responsible authorities about the event after an earthquake in Germany or the surrounding area.

ALISE consists of three components: a seismometer grid, evaluation software and a user interface to visualise the findings. The seismometer grid incorporates the digital seismic broadband stations of the German Regional Seismic Network (GRSN), other stations such as the GERES array in the Bavarian Forest, and some stations in neighbouring countries. They supply continuous waveform data which is transmitted to BGR almost in real time, to guarantee rapid localisation.

The BGR's research activities in polar regions are tied up in some cases to long-term international co-operation agreements and treaties. Working together with the Alfred-Wegener Institute for Polar and Marine Research (AWI), BGR helps maintain Germany's consultative status within the Antarctic Treaty – and does this by conducting regular research expeditions in the Antarctic. The work involved is delegated between AWI and BGR: BGR being responsible for terrestrial geoscientific aspects of the Antarctic research. In addition, numerous geoscientific programmes conducted by university groups and funded by the German Research Society as part of its "Antarctic Research" priority programme, are only possible because of the support they are given by the BGR logistics infrastructure.

Following on from the eight previous GANOVEX expeditions which first started in 1979, GANOVEX IX took place in the southern summer of 2005/06. It focussed on geological and geophysical surveys of the crustal structure and tectonic development in North Victoria Land, the Ross Sea and the Pennell Coast. The scientific focus of the expedition was the reconstruction of the early break-up of Gondwana, the opening of the ocean floor between Australia and the Antarctic, and the associated isolation and climatic development of the present day continent of Antarctica.

BGR's work in the Antarctic makes a major contribution to clarifying the role of the polar regions in the global changes affecting the earth from the past and into the future, and their effect on natural ecosystem services supporting human life.

The foundation committee of the Hans-Joachim-Martini Foundation managed by the BGR Board of Trustees only awarded the Hans-Joachim-Martini Junior Science Prize during the reporting period. Ms Martina Klingenberg received the Hans-Joachim-Martini Junior Science Prize in 2005 for her excellent scientific work on "The Identification of Wyoming bentonites using the rapid infrared spectrometry method".

I hope that we will again be able to award both prizes in the years to come to successful earth scientists, with the aim of also highlighting the importance of the earth sciences overall.

As in previous years, I would like to warmly thank the members of the BGR Board of Trustees for their support and advice. I would also like to thank the German ministries and our domestic and international co-operation partners. Most importantly, I would also like to thank all of the BGR staff for their friendly and professional co-operation, and their commitment to the fulfilment of our important tasks.

Prof. Dr. rer. nat. habil. Alfred Hollerbach
President

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The German Minister for Economics and Technology, the former Minister for Economics and Labour, established a Board of Trustees to provide the Minister and the BGR President with advice on all of the important aspects affecting the work of the BGR. The Board of Trustees is made up of geoscientific representatives from industry and commerce, universities and non-university research organisations.

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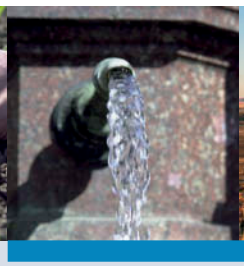


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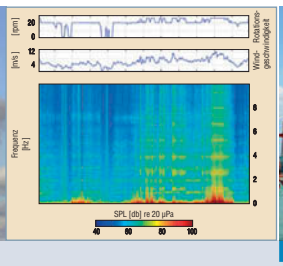



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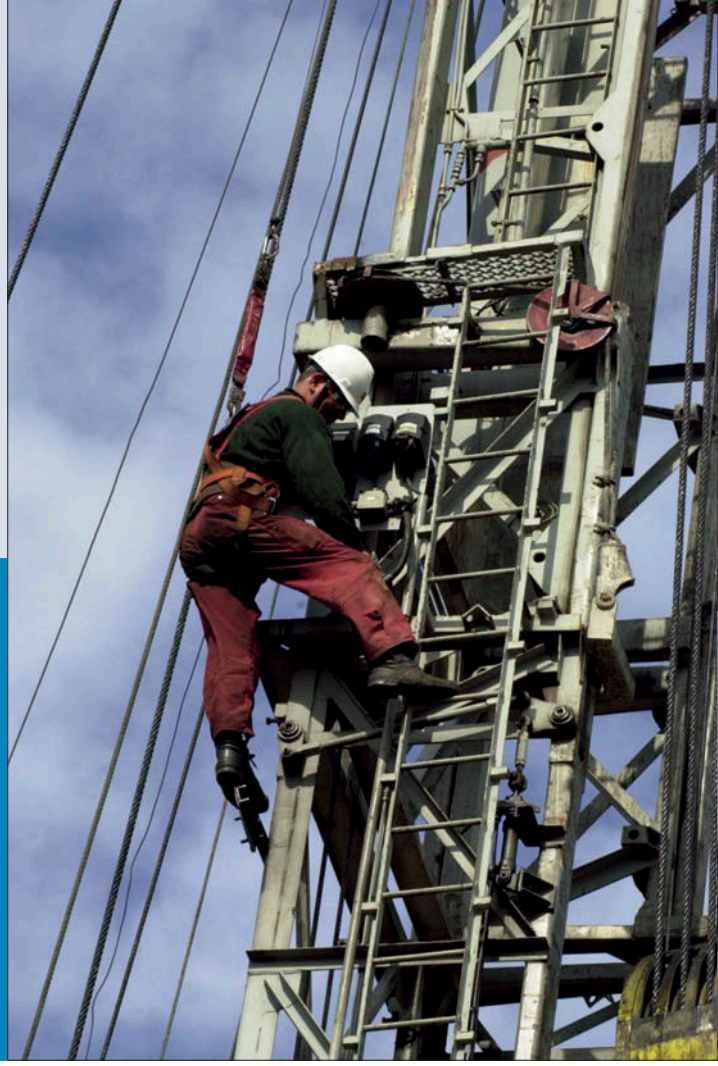
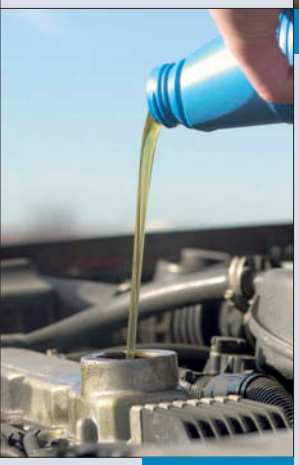


Is the **availability of crude oil** just a question of adequate investment?

Crude oil continues to be the most important energy source worldwide, accounting for 36 % of primary energy demand. This situation is not expected to change significantly in the coming decades because no adequate alternative energy source has yet been found. But oil prices have risen five-fold since the end of the 1990s. What does this tell us? Does the price merely reflect a simple free market equilibrium between supply and demand? Or are we now – as suggested by some pundits – already on the down slope beyond maximum possible global production, called peak oil?

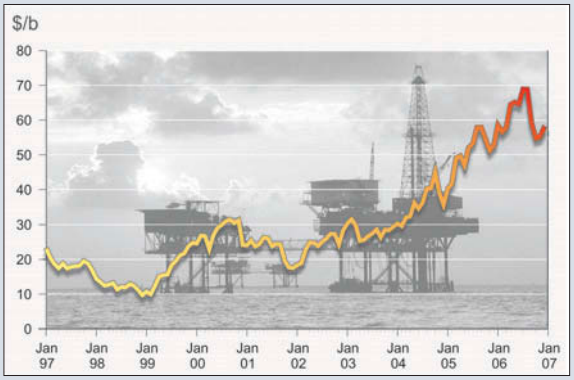
The oil prices are undoubtedly indicators of the short-term availability of this natural resource. But how do we explain the rise in oil prices in the last 6 years? One of the crucial factors is the lack of investment in this sector in the late 1990s due to a low oil price. This lead to a shortage in adequate reserve production capacities at the beginning of this decade when the global economy recovered and boosted the demand for crude oil. This situation was also exacerbated by China's exorbitant hunger for energy. For some time, the only reserve production capacity on the supply side was held by Saudi Arabia – the dominant swing



producer – which still had one million barrels of oil per day up its sleeve – albeit low quality oil. What made the problem worse in this case was that oil of this type cannot be processed by every refinery. Moreover, the refineries in the USA and Europe were already operating at over 90 % of maximum capacity.

Nevertheless, the current high prices also have a positive effect on the production side because fields already producing a relatively high volume of water alongside the oil can be kept in production profitably instead of being shut down. This is good news because once an oilfield is shut down and the infrastructure has been dismantled, certain oilfields – particularly those offshore – will probably never ever see any revival of production activity.

Another aspect affecting the availability of crude oil is transport. Because of the uneven distribution of oilfields around the world – around 70 % of conventional oil reserves are found in the "strategic ellipse" between the Persian Gulf and NW Siberia – more than two thirds of local oil production is exported. Oil within continents is usually transported by pipeline, whilst transport from continent to continent usually involves tankers, possibly in combination with pipelines. Tanker transport currently dominates, and probably accounts for around 75 – 80 %. It does not require much imagination to deduce from this fact that the current price volatility in the oil market will also drive up oil tanker freight rates. The charter prices for super tankers with lengths of up to 350 metres and displacements of up to 500.000 t (very large crude carriers – VLCC), as primarily used on the routes from the Arabian Gulf to North America and the Far East, are booming. Because smaller shipping companies have problems in buying the double-hulled tankers whose use is now mandatory on many oceans around the world, or even in chartering VLCCs at today's prices, the market share of the major shipping companies has doubled since 1999 and now accounts for over one third of the market. Another factor in the equation concerns those shipping lane bottle necks at critical locations such as the Straits of Hormuz and Malacca, or the passage through the Red Sea – the Achilles heels of the oil tanker business.



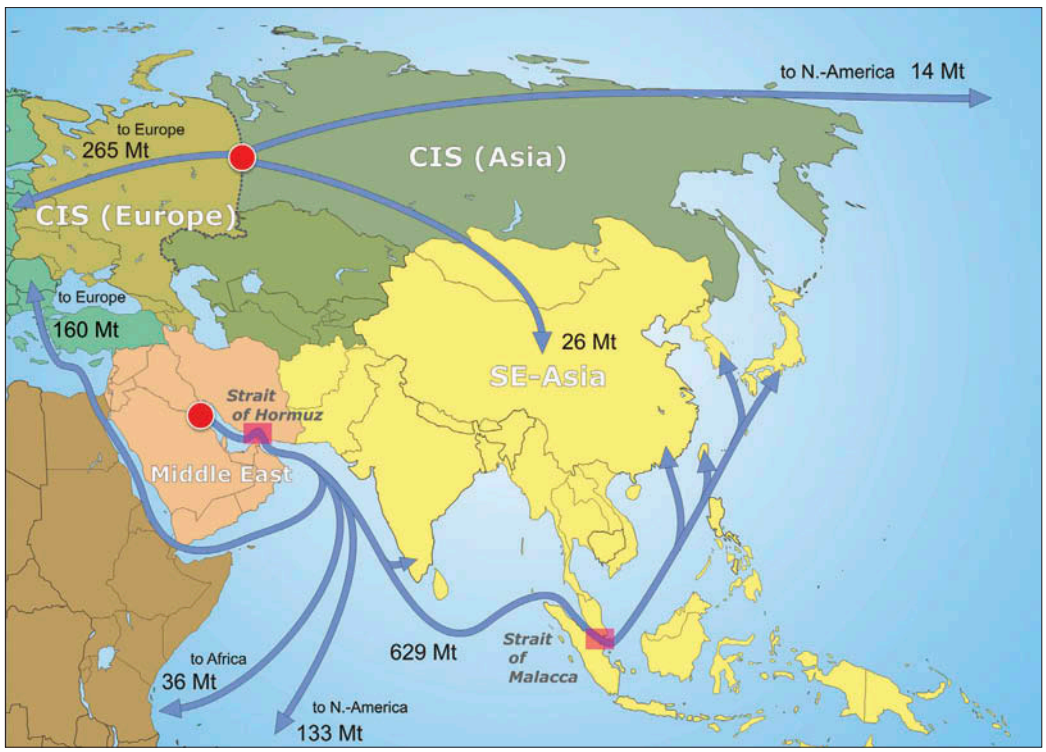
Oil price development during the last 10 years.

Notwithstanding all the factors described above, the most crucial aspect for the availability of crude oil is the existence of the right geological conditions for oil generation, migration and accumulation. The key aspects involved here are:

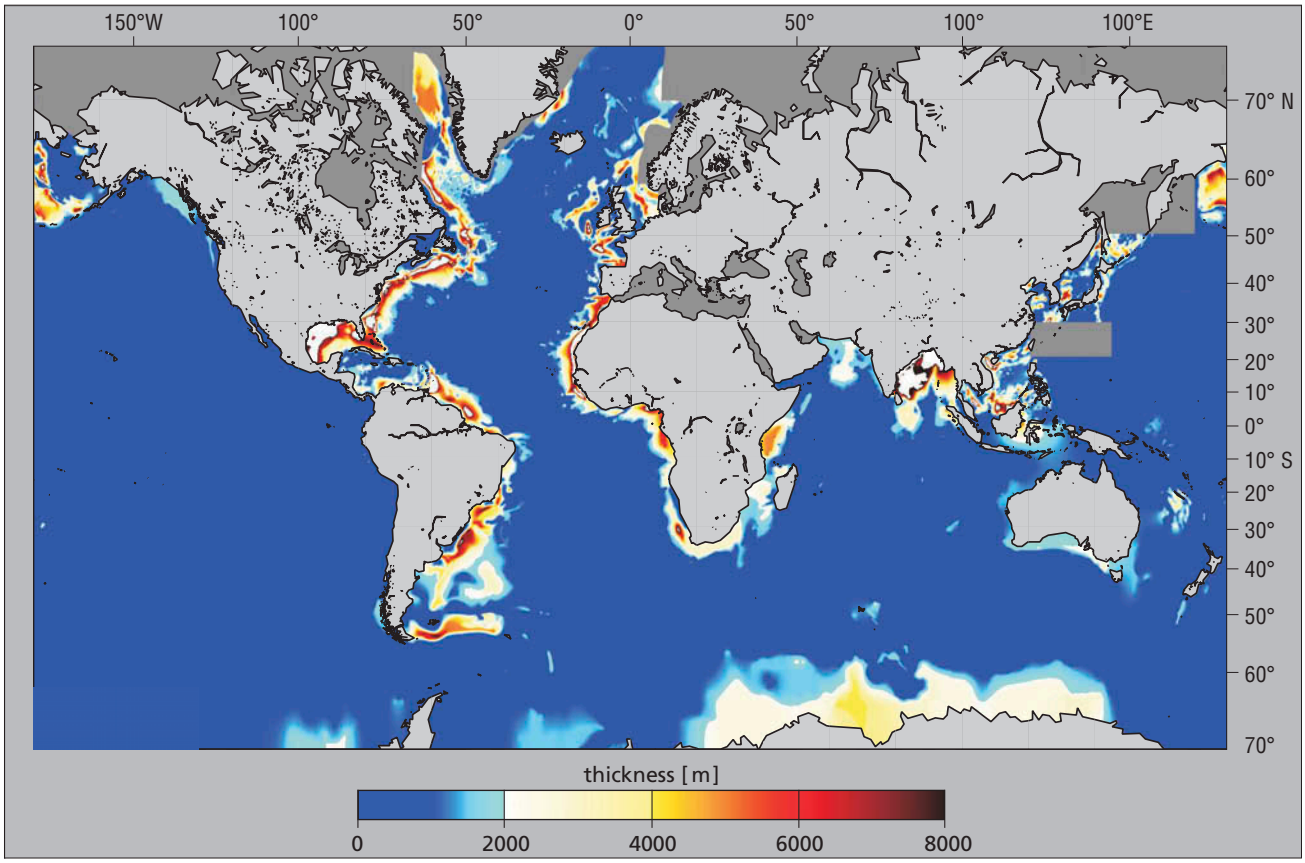
- Crude oil is only generated in a limited depth range within the earth's crust – around 1500 to 3500 m. Above this depth range the rocks are too cold, deeper, the rocks are too hot. This depth interval has largely been explored in all relevant sedimentary basins around the world.
- The geological conditions (sedimentary thicknesses) in around 90 % of all marine regions are inadequate for oil generation. Only the continental margins of the Atlantic Ocean are considered to be prospective for oil.
- The largest oilfields are found first because – put simply – it is much easier to find a big field than a small field.
- The uneven distribution of deposits: only 1 % of all oilfields contain 75 % of all crude oil.
- An oilfield is a very sensitive system of gas, oil and water. Only the very fine tuning of production conditions guarantees the highest possible recovery rates. It therefore makes no sense to produce oil from a field too quickly.
- The amount of oil actually recovered from an oilfield (recovery rate) ranges around 35 % worldwide due to the petrography of the reservoir rock and the reservoir physics.
- Every year since 1980, more oil has been consumed than has been found in new fields.

What does all this tell us about future availability? With the exception of a few regions on deep continental slopes and circum-arctic zones, no unexpectedly large discoveries are expected to help maintain oil supplies around the world. Nevertheless, higher oil reserves are still being reported year after year. Most of this is due, however, to technical innovations such as horizontal wells, or secondary or tertiary production measures.

This raises the question of whether all of the facts described above are adequately reflected in the oil price? There is justification for doubting this: the crude oil market has been largely characterised since 1990 by the intrinsic dynamics of the market itself affecting supply, demand, prices and investment. The ever expanding level of trading on future markets (paper barrels) fosters speculation and price volatility. This means that the fundamental trading data – the actual supply/demand situation for physically existing oil (wet barrels) – is being pushed more and more into the background.



Crude oil transport routes from the Persian Gulf and NW Siberia.



Sediment thicknesses below 2000 m indicate insufficient oil generation conditions in most marine areas.

The facts reveal that the production or supply graph actually runs much more smoothly than the price volatility curve. The price of crude oil today is crucially influenced by a range of different forecasts of future availability and demand. Differences in the assessment of geosupply shortages resulting from rising demand and limited reserves, the effects of terrorism and political unrest, as well as expectations regarding new technologies, are also used as additional input and give rise to different forecasts on which futures transactions are based. The fact that the volume of traded oil is around 100 times the amount of actually physically existing oil production highlights the importance of the futures market as a pricing factor.

Is this situation causing us to lose sight of the geological availability of crude oil?

Hard coal – a tolerated evil or an evergreen energy source?

Next to crude oil, coal is the world's most important energy resource. Coal accounted for 28 % of global primary energy consumption in 2005. 93 % of this was supplied by hard coal and 7 % by lignite. Total coal consumption in 2005 was 5 billion t or 26 % of global energy consumption. The proportion of coal in world energy consumption has hardly changed since 1980. In absolute terms, however, coal consumption has risen by around 79 % (1980: 2.8 billion t), with a rise of 34 % alone since 2001.

Coal has three major advantages compared to oil and gas:

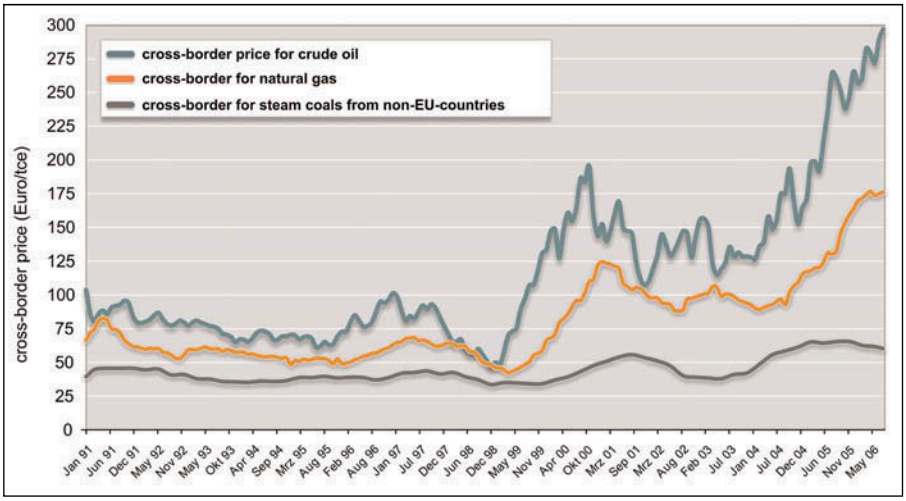
- Its world-wide distribution is relatively uniform.
- The reserves will last for several hundred years.
- Its price, in terms of energy content, is decoupled from oil and gas prices.

The current, and in particular, the future importance of coal for global energy supplies, make a more detailed look at this resource, its properties and future trends, a worthwhile exercise.

Coal is divided up technically into steam coal, coking coal and injection coal, depending on its properties. Steam coal is purely used for electricity generation. The crucial property is therefore a high calorific value. The desirable properties are low sulphur contents and low proportions of water and ash. Coking coal is largely used for the production of coke (smelting coke), which is used in the steel industry for the production of pig iron. Coking coal therefore needs good coking properties, and must swell up when heated. Injection coals are low ash and sulphur coals with a high proportion of volatiles which although lacking coking properties, can be injected into blast furnaces to replace some of the expensive smelting coke. Injection coals usually consist of anthracite.

Hard coal reserves

The world consumes large quantities of fossil fuels every year. Stockpiling is necessary to ensure that adequate volumes of natural resources are always available – in the same way as the stocking of private houses with provisions or the maintenance of inventories by companies. Mining companies therefore safeguard their annual production for several decades by exploring and developing deposits.



Since 1999, German cross-border prices of hard coal have been decoupled from those of crude oil and natural gas.

These developed stocks – the amounts economically extractable at today's prices using present day technology – are referred to as reserves.
Resources are the amounts of discovered coal which currently are not economically exploitable, as well as those amounts currently only assumed to be present but whose existence is probable. Coal resources are converted into reserves every year due to improvements in the information available on coal deposits, and the development of new mines or parts of mines. This conversion of resources into reserves replaces some of the reserves lost as a result of annual extraction.

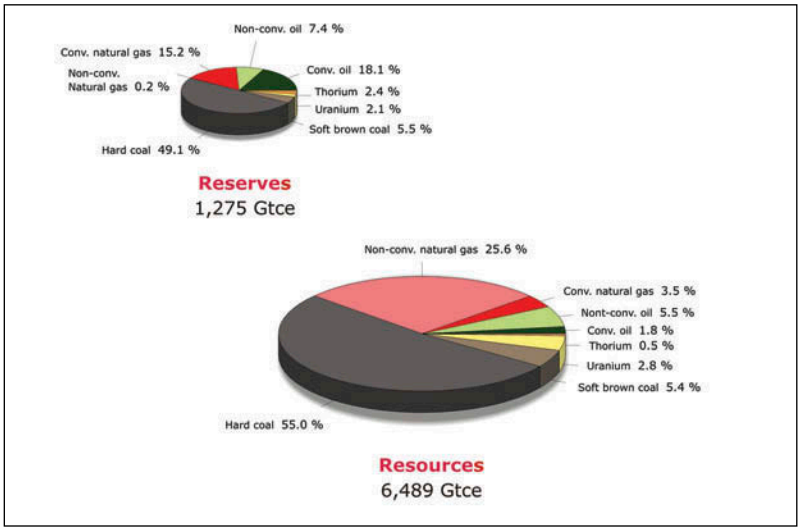
Global hard coal consumption

84 % of hard coal is used in the country in which it is mined. The regional distribution of consumption has significantly shifted into Asia since 1980. The strong rise in the demand for electricity in China and neighbouring countries in particular meant that Asia accounted for 58 % (2 882 million t) of global coal consumption in 2005 – and its proportion is still increasing. China alone accounts for 42 % of global demand. North America 22 %, Europe 8 % and CIS 6 %. Africa accounts for almost 4 % of global hard coal demand (primarily South Africa), whilst Oceania uses around 2 % and Central and South America approx. 1 %.

Coal is used in three sectors: in power plants for the generation of electricity, in the heat market (combined heat and power plants, industry, private households), and in the steel industry for the production of pig iron. The global shares applicable to each of the sectors has shifted strongly since 1980: unlike 1980 when only 36 % of coal was used in power stations, 43 % in the heating market, and 21 % in the steel industry, the proportions today have been completely reversed with 70 %, 10 % and 20 % respectively. This means that almost three quarters of coal production world-wide is used in power stations generating electricity (mainly steam coal).

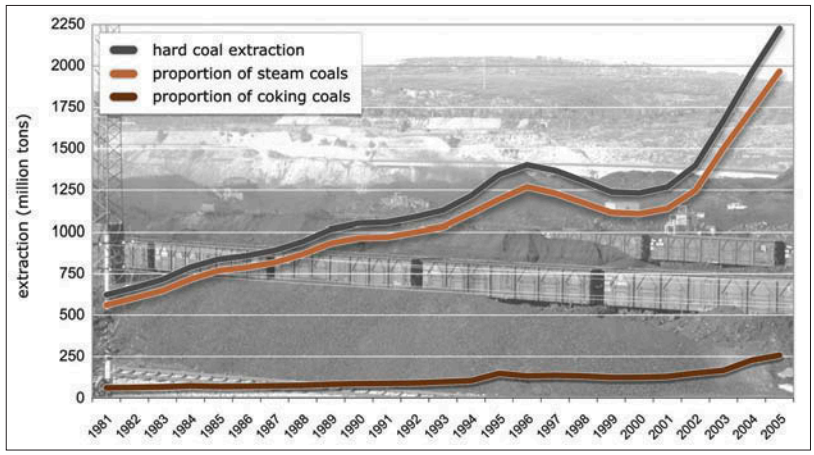
China stands out

With around 7 % of the earth's surface, PR China is the fourth largest country in the world. Its population in 2006 was 1.32 billion – approx. 20 % of the global population. Behind the USA (22.2 %), PR China was the second largest consumer of primary energy in 2005. Around 70 % of Chinese primary energy consumption is based on domestic coal. This proportion is extremely high compared with the global figure of 28 % for 2005, and only 17 % in the EU-25.



Hard coal is the predominant geogenic fossil fuel (ce = coal equivalent, measure for energy content of fossil fuels. 1 kg ce = 29,308 kJ = 8.14 kWh)

Development of Chinese hard coal production. Please note the remarkable increase since 2001.



With a total amount of 2 179 million t, PR China consumed around 44 % of global hard coal production in 2005. This represents a major growth since 1981, in both absolute terms (+ 1 555 million t) and relative terms (+ 249 %).

With production of 2 225.6 million t, PR China accounted for around 45 % of global hard coal production in 2005. Chinese hard coal production has risen by around 258 % in the last 25 years, of which 59 % alone since 2002. 95 % of this was produced in deep mines in 2005.

The rise in Chinese energy consumption will continue to grow in the near future and will primarily be covered by coal. Despite a strong increase in domestic coal production, Chinese hard coal imports rose 12-fold between 2000 and 2005. Only as recently as June 2006, the International Energy Outlook published by EIA forecast that PR China would export 88 million t of hard coal in 2015 and 96 million t in 2030. Chinese hard coal imports in 2030 are now estimated at 128 million t, which would turn PR China from a net coal exporter into a net coal importer. However, the development in Chinese imports and exports in the last three years indicates that it will become a net importer much earlier.

Can coal be used in an environment-friendly way in future?

Coal suffers from the stigma that it produces relatively high emissions of greenhouse gases during combustion. However, this resource has real chances of continuing at full steam in the future if it is possible to significantly curtail the emissions of greenhouse gases during coal combustion. The signs of achieving this are optimistic. By integrating most efficient power plant technologies, implementing CO_2 capture technologies in power stations, and subsequent underground storage, this natural resource will provide us with the time necessary to establish a fossil-free global economy. Successful implementation of the climate protection targets however require a world-wide implementation of this technology.

Coal as an oil substitute

In addition to its use in power generation and in the steel industry, coal can as well be gasified or liquefied for future use as an alternative transport fuel. This potential is becoming increasingly important because the number of cars world-wide is set to more than double by 2030 to approx. 1.5 billion.

Largely only the preserve of South Africa in the past, which has a long tradition of coal liquefaction – converting around 40 million t in 2004 – wide ranging initiatives have now been launched in China and the USA in particular. Seven coal liquefaction pilot plants were built in Germany between 1977 and 1980 after the first oil crisis. But they were all shut down again by 1985 because they proved uneconomic.

Coal gasification will acquire more importance in the eyes of the market, in particular when the fuel cells so often touted in the media will be used in cars on a mass scale.

Reducing the risks of **geothermal plant operation –** Using **CO_2-free energy** from the ground economically

Rising energy prices, the Renewable Energy Act, and grants from the German government made it more attractive and more secure for investors to spend money on geothermal heat and energy production in Germany. Depending on the geological settings and the temperatures, geothermal energy sources can be used in different ways. One is the direct use of geothermal water for district heating or for industrial processes, the second is power generation mostly in a combined heat and power plant. In spite of the growth in the renewable energy market, and wide possibilities, the technique still has to prove its efficiency to establish itself in the German energy market.

The geological conditions for geothermal heat and power production in Germany are not as good as in other countries like Italy or Turkey. In Germany, the reservoirs are usually located at depths of more then 2000 m, and the produced water is often corrosive. Both reasons increase the expense of drilling and plant construction at the beginning of a project. Investors can be exposed to significant economic risks, which vary depending on the level of exploration of the geothermal field. Detailed studies on deep geological formations, the structural geology and the thermal water geochemistry, reduce the risk.

Well head installation of the Neustadt-Glewe production well.

The geothermal plant in Neustadt-Glewe has operated for 12 years and demonstrates that district heating using geothermal heat production can compete with fossil fuels. The most important economic advantage is that, in common with all renewable energy sources, geothermal energy production does not depend on oil markets. The heat prices are more stable then for other energy sources. Furthermore, geothermal energy production does not emit CO_2 or any other greenhouse gases. With emission trading, this aspect makes the technology more attractive for business.

Operational experience in Germany is limited to low enthalpy geothermal fields with temperatures of about 100°C or below. A number of plants with much higher temperatures are under construction or planned for the future. There is still only a minor amount of information available on the influence of e.g. high gas content in thermal water and the varying formation water types in Germany. In Germany, the composition of thermal water ranges from almost drinking water quality in the region around Munich, to brines with extremely high salt concentrations accompanied by high gas contents in the north or in the Rhine Graben. Higher amounts of dissolved gas in the produced water may complicate the operation of a geothermal plant. Also, the formation of scale and the reliability of different parts of the plant may influence the economic performance.

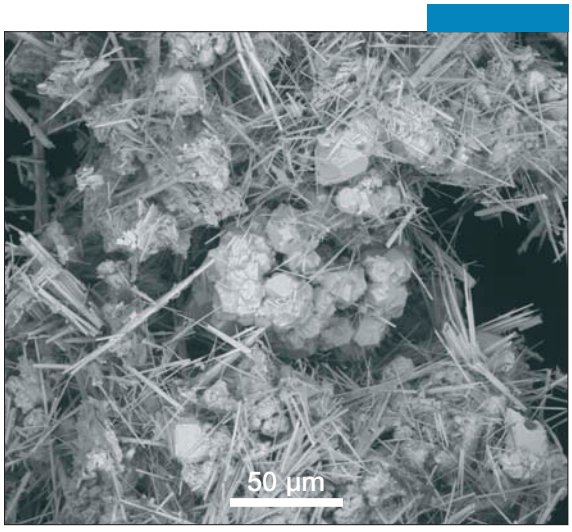
The project "Long Term Reliability of Geothermal Plants" is run by BGR and co-operation partners from industry and science. The main topics are the long term alteration of geothermal reservoirs, the origin of hydrocarbons in thermal waters, corrosion processes, and the formation of scale within critical parts of geothermal plants. BGR runs a wide research programme covering thermal water and reservoir geochemistry, and dissolved gases and scale formation processes.

At the Neustadt-Glewe geothermal heat and power plant, a thermal water bypass was built, enabling in-situ experiments to be carried out since January 2006. The bypass is designed for material testing and online gas monitoring.

The formation of scale within piping and equipment is of particular interest to the industry. Scale and corrosion may cause failures, which give rise to additional costs. After reconstruction work in Neustadt-Glewe, scale from different locations was sampled and the chemical and mineralogical compositions were analysed.

Composition of the scale

Analysis of the solid samples showed that certain minerals precipitate at preferred locations within the plant: lead-bearing deposits were found in uncoated and rubber-coated steel pipe. Barium and strontium sulphates occur where the temperatures are lower. The figure at page 23 shows the wellhead of the production well in Neustadt-Glewe, and the figure at this page shows an SEM micrograph (scanning electron microscope) of a solid sample taken from a wellhead installation pipe: cubic lead sulphide crystals are present combined with lead needles. Such precipitates may form thin coatings which do not affect the operation of the plant. But they can also form thick scale which significantly reduces the section of the piping, disrupting the operation of the plant.



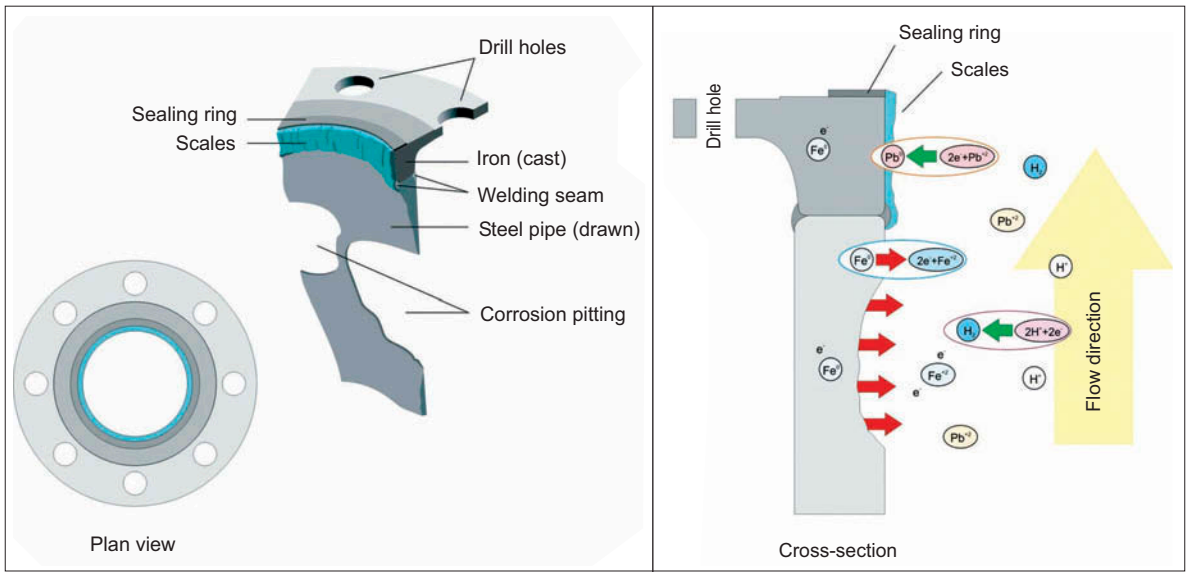
Scanning electron micrograph of a solid sample from the inside of a casing showing cubic lead sulphite crystals and lead needles.

The initial results show that the formation of elemental lead for example seems to depend on the presence of uncoated steel pipes, because of electrochemical processes. The sketch in the figure at the top of next page shows the corrosion of a steel pipe and the formation of lead scale. This process may lead to leakages in the piping and the scale can significantly reduce the pipe section. Corrosion and scale formation is not only a problem in steel pipes; however, uncoated steel pipes are quite rare in geothermal systems. Within coated pipes, scale was also observed, although the coating should protect the pipe from corrosion. The precipitation of solids is not a specific problem of the Neustadt-Glewe plant. The kind of scale depends on the chemical composition of the thermal water and the geological setting of the reservoir. The reasons for the precipitation of solids are mostly local changes in water chemistry, e.g. rising pH.

Gas measurements

BGR monitors the gas online at Neustadt-Glewe, measuring the gas content and the composition of the dissolved gases in the produced thermal water. Data on the gas content is important for operating a geothermal plant: the gas has to be kept dissolved in the water. Free gas may cause the formation of scale, as well as reducing the performance of the geothermal plant because the gas phase lowers the heat capacity of the thermal water.

The produced water in Neustadt-Glewe contains 10 % dissolved gases, i.e. 1 l gas in 10 l water under atmospheric pressure. The individual components are 77 % CO_2, 12 % N_2, 10.5 % CH_4 as well as 0.5 % C_2H_6. Furthermore, traces of other hydrocarbons, hydrogen, argon and helium were measured. In addition to the ongoing monitoring at Neustadt-Glewe, short term measurements are planned for other locations. The knowledge of the gas content, the thermal water chemistry and the gas composition will help to detect the potential for corrosion and scale formation early on.



Simplified diagram of corrosion in a steel pipe.

The potential formation of solid deposits within the plant has to be kept as small as possible to prevent failures, and to protect the geothermal reservoir. To what extent geothermal energy will contribute to the German energy mix in future depends on how efficient the technique can be made in the long term. Possibly the largest potential for geothermal energy production is not power production but heat production, or a combination of both.

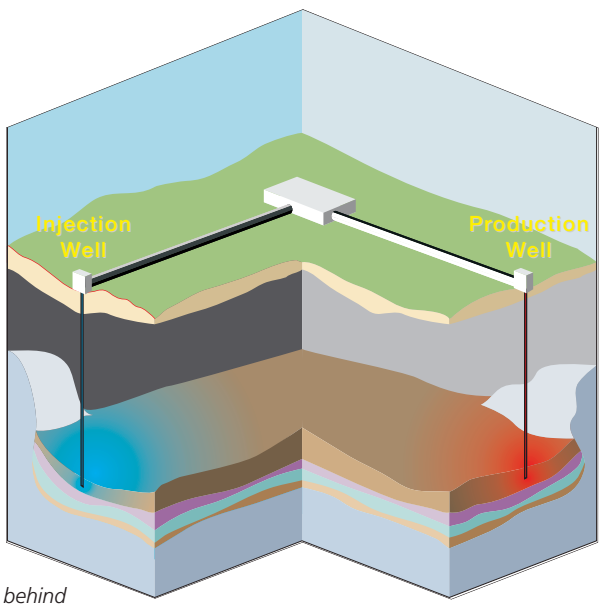


Diagram showing the principle behind a geothermal power station.

Joint research projects on CO_2 storage

Natural CO_2 seep within the Laacher See, Eifel.

Germany has signed the Kyoto Protocol and other national and international agreements for the reduction of CO_2 greenhouse gas emissions. According to the Deutsches Institut für Wirtschaftsförderung (DIW), the aimed reduction targets will not be achieved without additional reduction efforts.

One of the technical options for the reduction of emissions from technical installations is the underground storage of CO_2. The expensive separation of CO_2 is limited to large stationary sources, such as power plants. The underground storage of CO_2 for climate protection purposes is currently only being implemented at a few places around the world.

Many sites are required if CO_2 storage is to make a significant contribution to the envisaged storage targets. Because of the limited practical experience, the preliminary evaluation of the opportunities and risks of this mitigation option still involves some uncertainties. Separation, transport and storage are interlinked. This chain can only form a viable option if all of these links are robust technologies per se. The challenge is combining, adapting and optimising existing equipment and processes. This interdisciplinary task cannot be solved by engineers and economists alone, but only in co-operation with geoscientists. Thus, BGR participates in national and international joint research projects designed to bridge the gaps in scientific and engineering knowledge. A comprehensive understanding of the different aspects of CO_2 storage is fundamental for our responsibility to provide objective advice to the federal government, German industry and the general public. Some examples of joint research and development projects are described in the following to illustrate BGR's contribution to current research topics.

CO_2GeoNet

Monitoring buoy for submarine CO_2 seeps.

In its 6th Framework Programme, the European Commission established a new funding instrument: networks of excellence. One of these networks, CO_2GeoNet, is focussed on the various geoscientific aspects of underground CO_2 sequestration. This network has been set up to maintain Europe's leading position in the research and practical application of CO_2 storage.

CO_2GeoNet was formed in 2004. It has EU funding for 5 years, but the intention is for the established network to remain active beyond that period.

The network comprises 13 institutes from 7 European countries. It could become a European competence centre that could answer technical questions about CO_2 storage. It could contribute to the development of technical standards, and conduct further joint research. The competence of the network is strengthened through dialogue with national and international organisations and stakeholders dealing with CO_2 storage.

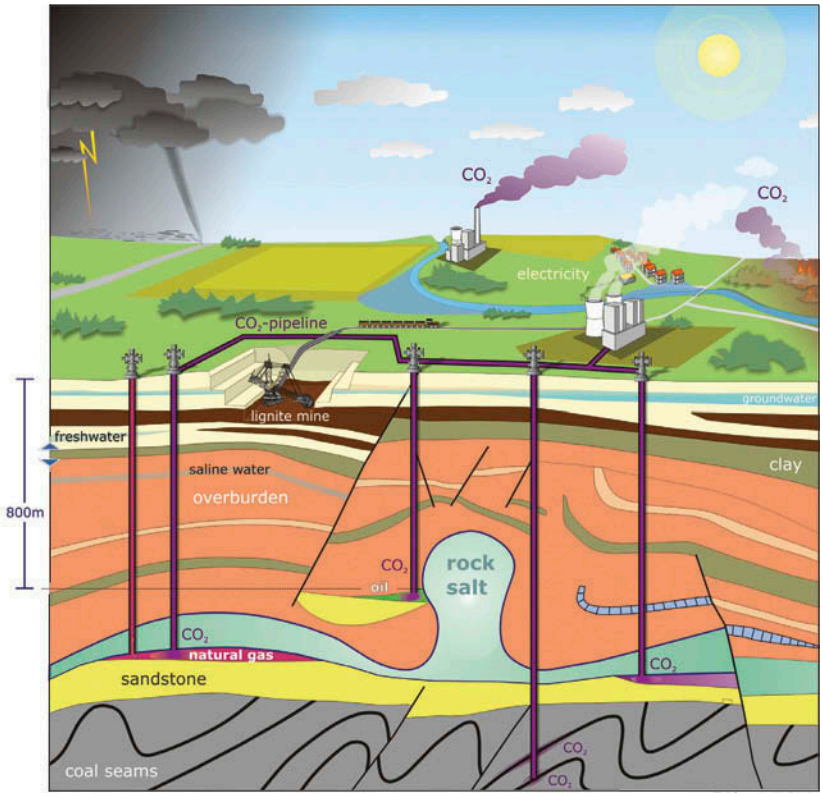
The network has defined six research areas. The network partners contribute according to their competence, use synergies with external projects, and conduct joint research activities. One research and development focus of the network is the optimisation of existing monitoring methods and the testing of new monitoring techniques at selected test sites. Test sites on land, in the North Sea and in the Mediterranean make use of natural CO_2 seeps for the comparison and calibration of methods. The investigation of ecological impacts in the vicinity of the CO_2 seeps is investigated to identify indicators for possible CO_2 leaks. BGR is involved in experiments in the Gulf of Trieste, in a Norwegian Fjord, and near Rome.
Further research topics looked at by the Network are: strategies for the application of numerical tools to predict the behaviour and expansion of CO_2 in storage reservoirs; laboratory experiments for the optimisation of such tools; injection of CO_2 into depleted reservoirs to enhance the recovery of hydrocarbons; and the generation of realistic geological models of complex underground structures and the internal heterogeneities of reservoir rocks.

The computer models for the assessment of reservoir properties make use of standard oil industry methods. Their application to CO_2 storage needs to take additional processes into account.

CO_2STORE

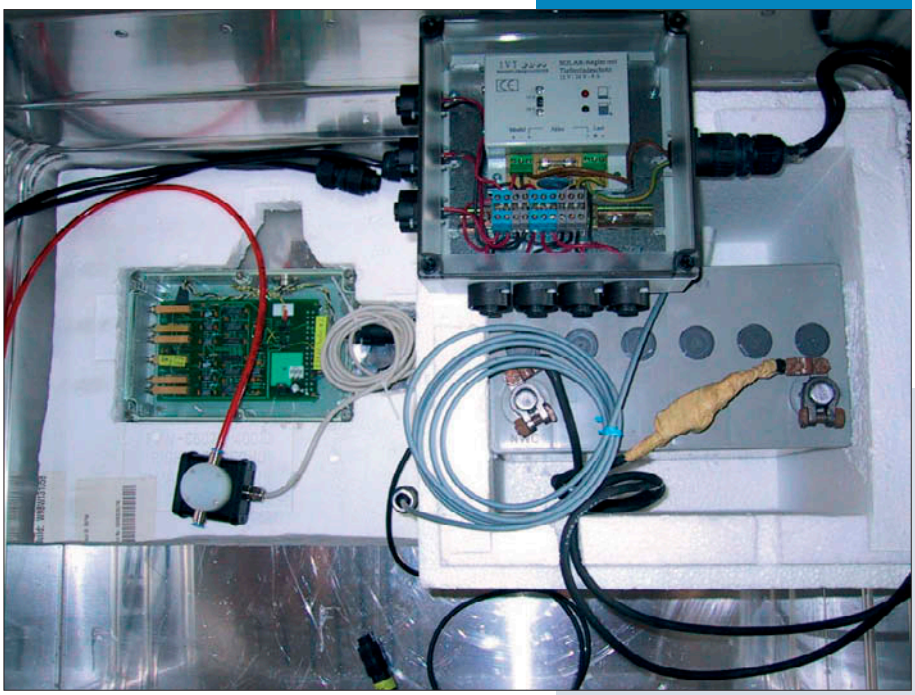
The EU project CO_2STORE builds upon the knowledge gained in the world's first climate mitigation CO_2 storage project in the Norwegian North Sea. This project explores the feasibility of transferring the offshore findings to aquifer storage on land and in different reservoir rocks. Four case studies have been selected for this purpose, one of them in Germany. BGR's task is finding a suitable geological structure in a deep saline aquifer large enough to take up the entire volume of CO_2 emitted during the operating life of a large lignite-fired power plant. This case study considers a novel type of power plant with CO_2 separation that is still under development. The power production of such a plant should be equivalent to that of modern power plants such as "Schwarze Pumpe" in Saxony.

The mapping of anticlinal structures in the northeast of Germany and a first estimate of their storage capacity were the first steps in the site identification exercise. Additional criteria such as depth of the structures, cap rock quality, and data availability were used to rank the identified structures. Accordingly, a structure underneath the village of Schweinrich, located in northern Brandenburg (North of Berlin) was selected for further site characterisation. Structural maps for different formations of the reservoir and overburden were elaborated on the basis of existing well logs and seismic lines. Petrophysical properties, and the mineral and chemical composition were determined form core samples obtained from reservoir and cap rocks.
This site-specific data was provided for the computer modelling of physical and chemical processes that could result from interaction with injected CO_2. The simulations were performed to predict the expansion of CO_2 in the reservoir and the chemical alteration of reservoir and cap rocks during the injection phase as well as in the long term storage period. These simulations were carried out together with partners from the Geological Surveys of France and The Netherlands.



Depleted natural gas reservoirs are regarded as the best storage options for CO_2 in Germany. Other options are provided by deep saline aquifers and un-minable coal seams.

CASTOR



Soil gas monitoring station.

The CASTOR Project (CO_2 from Capture to Storage) comprises 30 partners from European research institutes, universities and industry. The objective of this project is the development of innovative technologies for the capture of CO_2 produced by industrial combustion processes, and its safe underground storage. This 4 year project is financed by the EU Commission's 6th Framework Programme and an industrial consortium.

One essential part of the project is the selection of storage sites. The public acceptance of the underground storage of CO_2 will largely depend on storage safety. Site selection criteria have to be defined, and cost-effective monitoring strategies need to be developed. For this purpose, four natural gas and oil reservoirs have been selected as test cases. In addition to three offshore fields, the depleted natural gas field Atzbach-Schwanenstadt located between Salzburg and Linz in the Austrian Molasse Basin is also being investigated. A site selection catalogue will be created based on the experience gained from these case studies. It will be available to potential end-users of carbon capture and storage technologies.

Geological 3D models are being developed for all of the case study reservoirs. These models describe the geometry of the reservoirs as well as the physical and chemical properties of the reservoirs relevant for CO_2 storage. Injection tests and geomechanical modelling are used to investigate the tightness and strength of the cap rocks. Lab experiments are designed to study possible geochemical processes that can arise from CO_2 injection. Such processes could change the porosity and permeability of reservoir rocks and thus affect CO_2 migration within the reservoir. In addition, these experiments are used to test geochemical simulation programs that are used for the prediction of long-term processes in the reservoir.

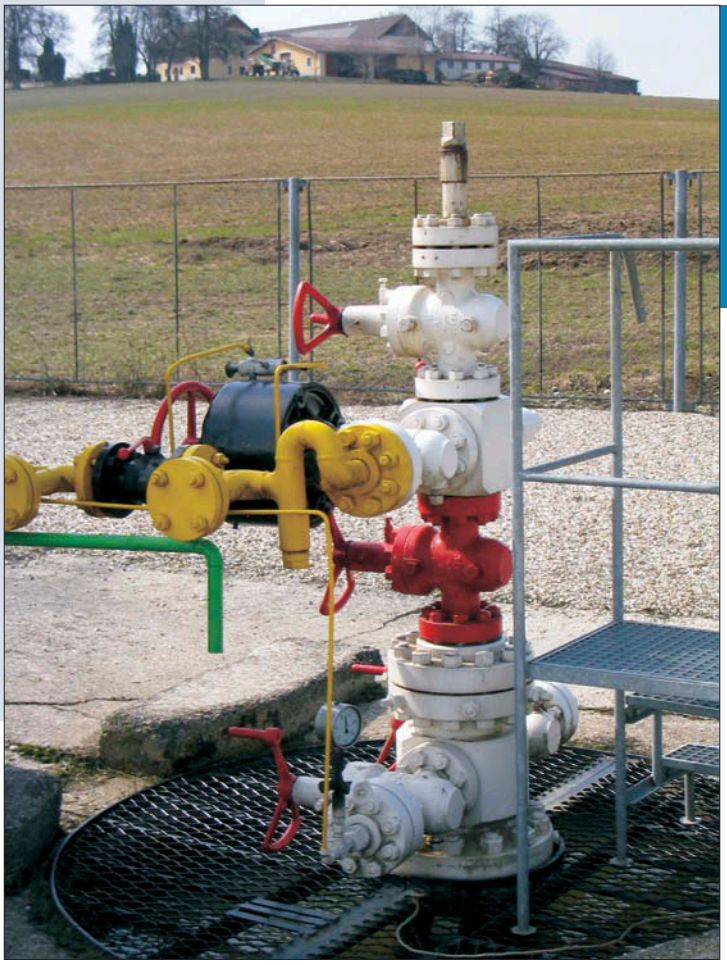
Baseline monitoring of soil gas fluxes will be required prior to the storage of CO_2. The comparison of measurements before, during and after CO_2 injection facilitates the detection of possible leaks and the assessments of possible ecological impacts. Therefore, different monitoring strategies are tested by this project. These tests shall contribute to the development of efficient and cost-effective monitoring tools and strategies.

The cap rocks of oil and natural gas reservoirs have been penetrated by many wells. Pipes and cement used in these wells can be altered by CO_2, and carbonic acid. Experiments are used to study the stability of these materials when they come into contact with CO_2. The detection of potential weak points will result in recommendations to future operators of CO_2 storages so that they can prepare appropriate preventive or corrective measures.

CSEGR

Can CO_2 storage in depleted gas reservoirs increase the recovery of natural gas?

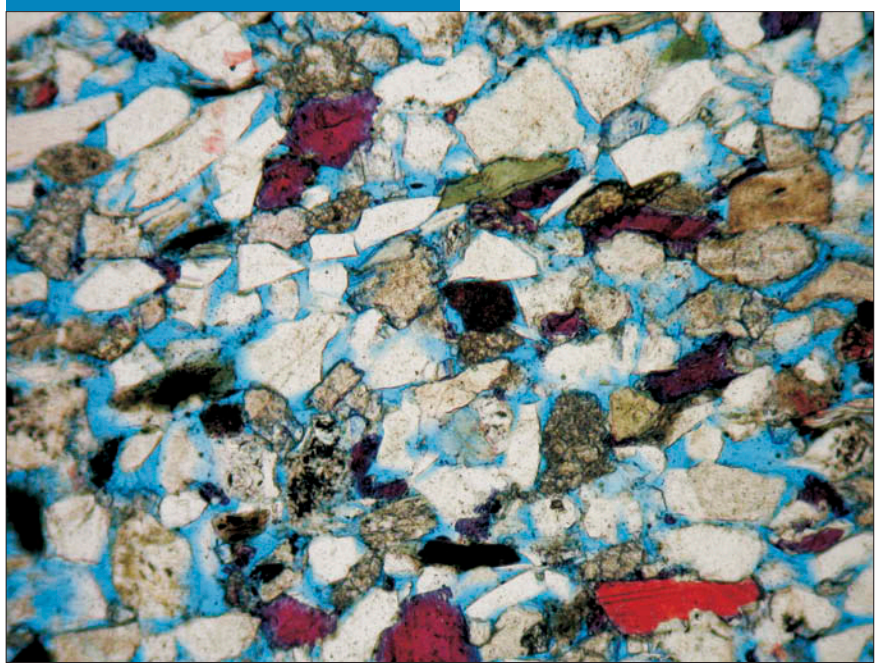
The injection of CO_2 into reservoirs for enhanced oil recovery (EOR) is established industrial practice. Thus, it is reasonable to also consider the application of this technology for gas reservoirs. The German Ministry for Research (BMBF) financed a three year study investigating the feasibility of CO_2 storage in depleted reservoirs and the potential for simultaneous enhancement of natural gas recovery (CSEGR).



Wellhead at a natural gas field in the Austrian Molasse. The stability of steel and cement used in the well completion is essential for long-term safe CO_2 storage, and therefore subject to ongoing testing.

More than half of the German natural gas fields are mature, relatively depleted fields that are potential candidates for CO_2 storage. CO_2 injection can raise low reservoir pressures so that some of the gas that would otherwise have remained in the reservoir can be produced. This could extend the production life of fields and increase their total recovery rate. After the breakthrough of CO_2 into wells producing natural gas, these can be shutdown, and the reservoir structures can then be used for CO_2 storage. The CSEGR option has not yet been tested on an industrial scale. The world's first pilot project, linked to the EU CASTOR programme, is currently being carried out in the Dutch sector of the North Sea.

This feasibility study investigates the concept to see if it can be applied to natural gas reservoirs in Germany. For this purpose, BGR analyses natural analogues of reservoirs, and simulates reactive transport processes. The Rotliegend gas fields of the Altmark in Sachsen-Anhalt, and Barrien Bunter gas field in Niedersachsen have been selected as representative study sites. The results of the investigations shall be relevant for practical questions concerning geochemical and mechanical reactions of the reservoir and cap rocks, or optimisation of recovery enhancement and CO_2 storage.



Thin section of a typical Austrian Molasse reservoir rock. The pore space filled by blue resin could take up CO_2; width of the photograph 0.3 mm.

Marine geophysical surveys to estimate the **hydrocarbon potential** of the **South Atlantic continental margin**

Ever since its establishment, BGR has been involved in marine geoscientific research in the forefront of industrial exploration to provide information and decision-making material to guide Germany's long-term energy strategy. The main regions for marine research for some time now have been the continental margins and adjacent abyssal plains, whose potential for exploitation and risks are still little understood.

The marine geoscientific investigations conducted by BGR along the coasts of Brazil, Uruguay, Argentina, Namibia and South Africa since 1978 reveal that large parts of the continental margins are of volcanic passive margin type. The opening of the South Atlantic over 130 million years ago was accompanied by extreme, albeit short-lived, volcanism – the scale of which exceeds anything experienced in the earth's recorded history. These volcanic rocks on the South Atlantic continental margins are now covered by thick layers of sediment. Very little is currently understood about the precise temporal and spatial conditions existing during the deposition of these vulcanites, and the impact of the geodynamic processes on sedimentary history, hydrocarbon genesis, and the hydrocarbon potential.

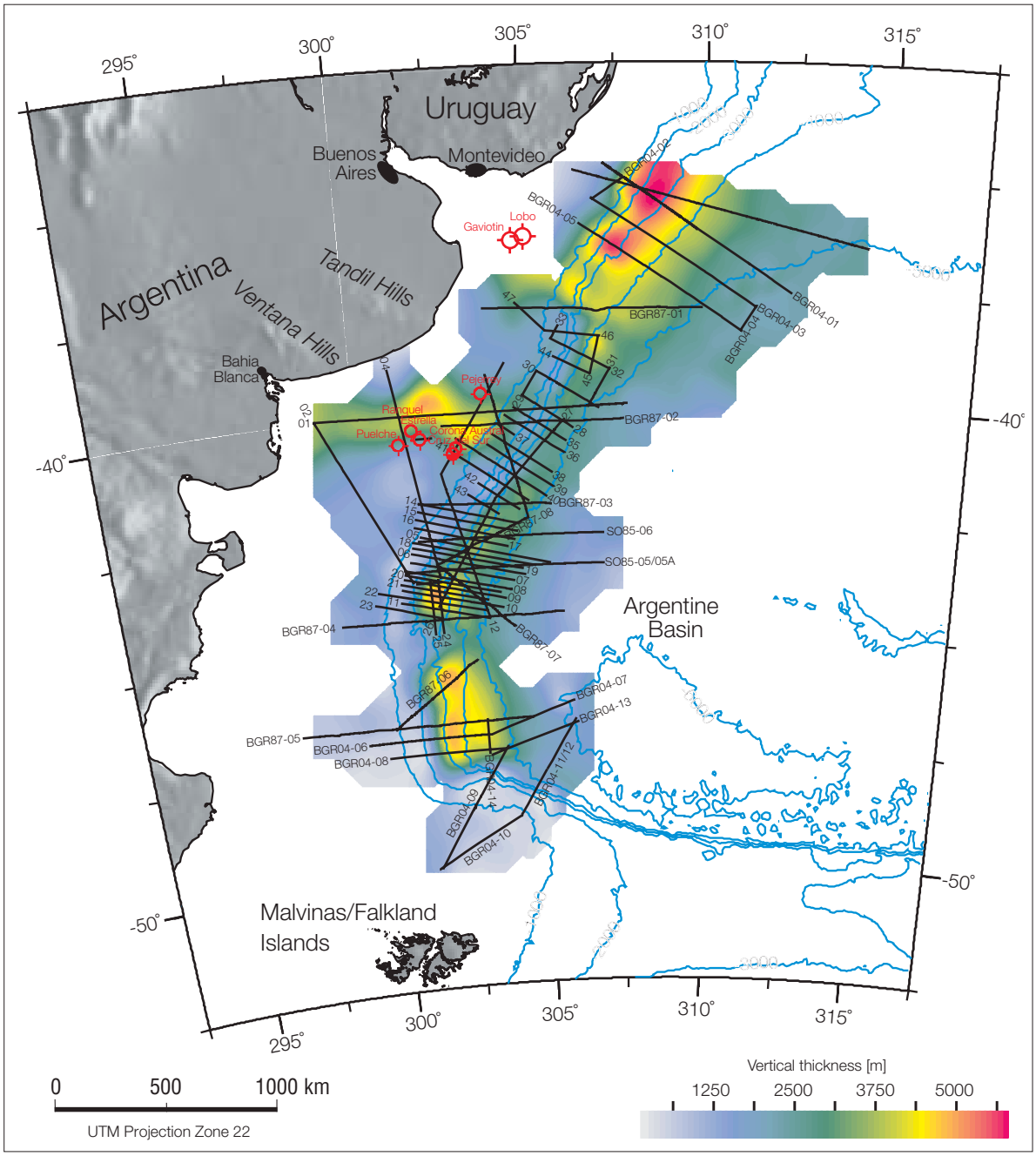
The previous investigations conducted by BGR were expanded and broadened in late autumn 2004 by marine geophysical surveys offshore Uruguay and southern Argentina. Multi-channel reflection seismic, magnetic and gravimetric surveys and swath bathymetry surveys were recorded in a survey grid. Ocean bottom hydrophones were used on one line. Investigations of adjacent sections of continental margin, i.e. on opposite sides of the South Atlantic ocean are of particular interest as the results can be used to provide significant new information

- On the geodynamic processes active during continental break-up.
- Initial estimates of resource potential.

Detailed analysis of the seismic lines revealed significant variations in the internal structures of the vulcanites (thickness and extent orthogonal to the continental margin): the volcanic units are broader in the northern part of the survey area than along the southern lines. This irregular distribution indicates the presence of a transform fault correlating with the Argentinean continental margin.

The hydrocarbon potential of this unprospected continental slope was interpreted from the sedimentary thicknesses derived from the seismic data and some exploratory wells drilled on the shelf. These revealed the presence of a south to north maturity gradient in the Cretaceous black shales along the continental margin.

In the south (approx. 48° S) modelling indicates medium (oil) maturity in most cases. In the central part (at approx. 40° S) maturity is estimated to be medium to high (oil and gas maturity respectively). In the northern part, offshore Uruguay, most of the black shale has already reached high (gas) maturity. The reasons for this maturity gradient are currently still the subject of discussion: it may be associated with the opening of the southern Atlantic which prograded from south to north. It could also be associated with the longer volcanic activity in the north – in the vicinity of the Rio-Grande-Rise/Whaleback hot spot, which forms an additional heat source. It may also be attributable to a combination of these two mechanisms.



Seismic line offshore Argentina and Uruguay showing the distribution of sedimentary thickness interpreted from the BGR seismic reflection data.

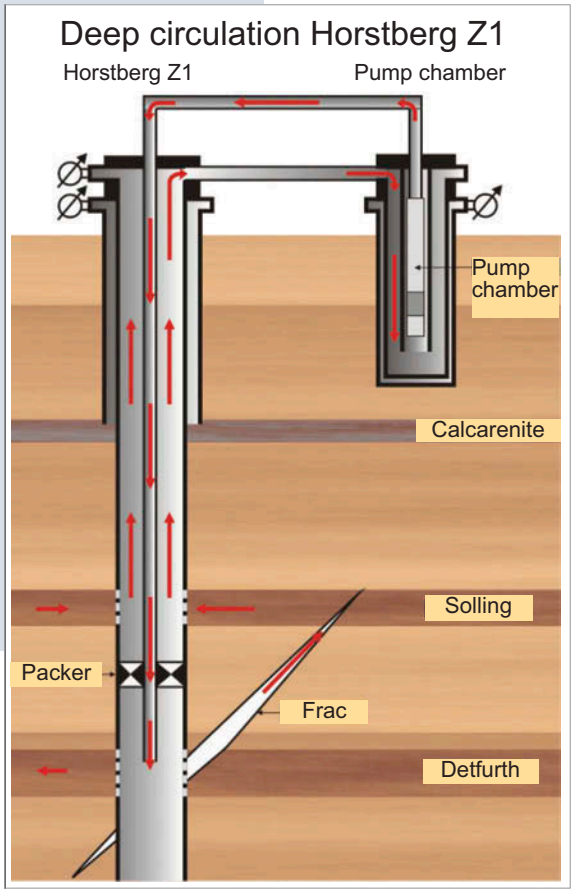
Oil and gas maturity

The state of a source rock with respect to its ability to generate oil or gas. When a source rock begins to mature, it generates gas. When an oil-prone source rock matures, the generation of heavy oils is succeeded by medium and light oils. Above a certain temperature, only dry gas is generated, and incipient metamorphism is imminent. The maturity of a source rock reflects the ambient pressure and temperature as well as the duration of conditions favourable for hydrocarbon generation.

GeneSys project
Planning and authorisation

The GeneSys project is concerned with the extraction of geothermal energy from tight sediments in the North German Basin. The concepts developed as part of the project aim to provide proof of concept that the GEOZENTRUM Hannover can be heated by direct thermal utilisation.

A series of hydraulic tests in the Horstberg Z 1 abandoned gas well were conducted in 2003 and 2004 as part of the GeneSys project (see previous biennial reports).



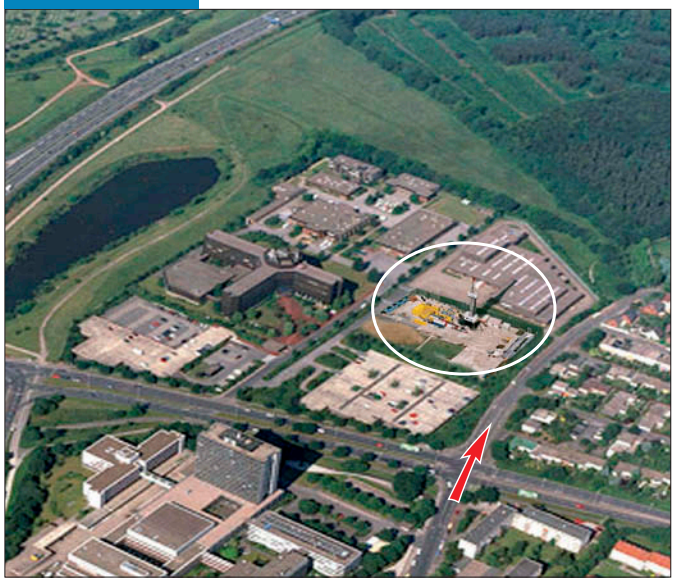
Long term test of the two-strata-concept using an electric submersible pump. Also scheduled: the stimulation of the Solling Sandstone

The concerns raised by industry in the run-up to the project were dispelled by the hydraulic tests conducted in the abandoned Horstberg Z 1 gas well during the GeneSys 1 research project. The tests confirmed that the waterfrac technique used in crystalline rocks to create fracture systems by injecting large volumes of water into the rock formation without the use of proppants, is also feasible in sedimentary rocks – and that the fractures created in this way remain open for long periods of time. Two additional innovative concepts were developed during the testing phase: the "huff-puff concept", and the "deep circulation concept".

The results of the tests carried out on the Horstberg Z 1 gas well were presented to a team of industry and scientific experts in February 2005, where the findings were given a largely positive response. This paved the way for implementing a demonstration project in Hannover. The new project was initiated in May 2005 and involved the project group in a great deal of planning and authorisation work. The first step involved passing the first stage of the mining authority approval process: the overall operation plan.

Overall operation

plans form the basis for involving all of the relevant authorities, i.e. all of the regulators involved in a project for which an obligatory operation plan is required are informed about the project and requested to submit their opinions.



Site of the Geozentrum Hannover as it could look in the near future. The planned drill site is marked by the white ellipse. The crossroads at the corner of the BGR complex is marked with an arrow as in the adjacent noise level map.

Noise level map of the GeneSys GT 1 well site in Hannover. The colour gradient illustrates the calculated noise levels: they vary from 30 dB(A) (boundary to dark green) to 70 dB(A) (dark red). The position of the 15 m high sound insulating wall is mark with a W.

The Overall operation plan form the basis for involving all of the relevant authorities, i.e. all of the regulators involved in a project for which an obligatory operation plan is required are informed about the project and requested to submit their opinions.

Another "problem" arose with respect to Section 48 German Mining Act (BBergG): because the planned drill site for the approx. 3 800 m deep well in Hannover lay adjacent to a housing district, the inhabitants had to be involved in the approval procedure. Here, the main concern was noise. The noise limit during the night for pure housing areas in Germany is 35 dB(A). Therefore the first task was to demonstrate that it was technically feasible to stay within this limit using an existing drilling rig and implementing major noise-reduction measures. A specialist company was engaged to conduct a noise study. This revealed that it would not be possible to keep below the 35 dB(A) limit even when using the best technical equipment available. However, the study also revealed that the base noise level in this housing district already exceeds 40 dB(A) because of the ambient noise. It is technically feasible to operate a drilling rig which keeps below a noise level of 40 dB(A).

The inhabitants were informed of the results of the study at a hearing organised by the responsible mining authority, and the overall operation plan was approved in December 2005. Work on the demonstration project in Hannover was therefore continued after receiving this authorisation. Another seismic line was recorded in May 2006 to provide additional information on the deeper basement and geology in the zone to be penetrated by the planned well.

Shooting a seismic line using big vibration trucks operated by DMT, Essen, Germany

In addition to this work, preparations were also made for the European-wide tendering of the drilling operations in Hannover. The current situation in the drilling contracting sector means that the well will probably not be drilled before the third quarter 2007. The booming oil and gas exploration and production market has lengthened delivery times for some equipment, e.g. steel casing, to 6 to 12 months. In addition, drilling rigs suitable for drilling a 3 800 m deep well are almost all tied up in long term contracts.

In parallel to the Hannover project, consent was given in May 2005 to an application to continue the project at the Horstberg well. The aim of the GeneSys 2 research project is to turn the well into a permanent proving ground to verify the previous findings by conducting additional tests, and to supply and extend them by conducting new tests.

This also involved the procurement of equipment such as two high pressure injection pumps including all of the high pressure and low pressure pipes; an extremely high quality electric submersible pump; a logging winch including pressure and temperature logging tools; a range of data logging systems and data collection systems. This equipment enables us to conduct tests with a great deal of flexibility. In addition, the procurement of this main technical equipment also means that long term tests can be conducted economically. All of the systems are designed for use in Hannover or other drilling sites too.

The equipment was delivered from July to October 2006 and installed for the first time in November to conduct a four-week hydraulic test. In the first step, the fracture created in 2004 was regenerated by injecting approx. 10.000 m^3 fresh water into the Detfurth Sandstone with the aim of examining the properties of the fracture after a long shut-down phase, and to observe the pressure behaviour in the Solling Sandstone connected to the Detfurth Sandstone by the frac system.

A production test was then carried out in the Solling Sandstone with simultaneous injection in the Detfurth Sandstone to simulate a deep circulation test. The test set-up and the hydraulic data are shown in the following diagrams. The test revealed that a skin had formed on the Solling Sandstone near to the well which prevents higher production rates. The main objective of ongoing research is to determine the cause and nature of the skin and to develop measures to remove and/or reduce this effect.

After stimulating the Solling Sandstone and "removing" the skin, another test will use the submersible pump to carry out a long term deep circulation test.

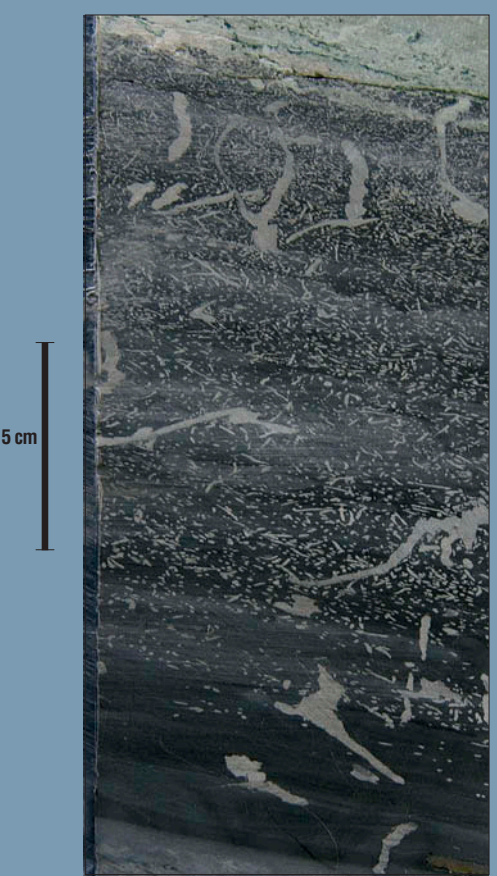
What is the **origin of the rocks producing oil?**

One of the main reasons for the constant increase in the costs of energy is the decrease in oil and gas from easily accessible reservoirs. Accordingly, the search for petroleum resources in settings which are not yet economically interesting for industry is one of the main tasks of the Federal Institute for Geosciences and Natural Resources. The reconstruction of environmental conditions leading to the sedimentation of source rocks (see box) is of growing interest in this context. At BGR, two projects focus on source rocks deposited approximately 90 Ma ago in the Atlantic Ocean. The oceanographic data generated by these projects can be used to model the environmental conditions leading to source rock formation, and can therefore help predict the presence of hydrocarbon resources.

One of the research areas lies off Surinam and Venezuela in an area rich in oil and gas. Boreholes drilled here during an international "Ocean Drilling Program" (ODP) expedition, cored thick successions of Cretaceous hydrocarbon source rocks. The chemistry of microfossils retrieved from these cores yielded important information on the temperature and salinity variations of the ocean surface and the seafloor when the source rocks were being formed. While the sea surface temperatures are an indicator of air temperatures, the gradients between the sea surface and the seafloor can be used to reconstruct the ocean currents existing 90 Ma years ago.

Hydrocarbon source rocks

are sedimentary rocks which produce oil and gas. They can be deposited on the seafloor under oxygen-poor conditions and in warm climates. The transport of nutrients to the sea surface, either from land or upwelling from deeper layers of the ocean, fertilise the ocean surface. This causes an increase in bioproductivity giving rise e.g. to algal blooms. The accompanying increased transport of organic matter to deeper layers of the sea gives rise to oxygen depletion and leads to the preservation of sapropels very rich in organic matter. After millions of years under the influence of increasing pressure, temperature and microbiological processes, these sapropels turn into source rocks.



Section of the Wunstorf drill core showing trace fossils.

Section of the Wunstorf drill core showing trace fossils

The results of these investigations are striking. The sea surface temperatures were up to 34°C. The related high air temperatures must have caused increased evaporation of seawater. As a consequence, very saline waters are believed to have dominated marginal seas, a situation very similar to the present Persian Gulf. Indeed, BGR scientists discovered evidence for such saline waters in the chemistry of microfossils living on the Cretaceous seafloor. The higher the salt content of water, the heavier the water. Therefore, it was concluded that saline waters created in marginal seas flowed down the slopes of the tropical Atlantic Ocean. Such saline waters are very oxygen poor, which is an important factor supporting the formation of sapropels or ooze.

At the same time, source rocks were formed offshore Surinam: Sediments with high concentrations of organic matter were also formed in a marginal sea covering the present day area known as Lower Saxony in Northern Germany. Scientists from BGR and the Leibniz Institute for Applied Geophysics working on a project funded by the German Science Foundation (DFG) drilled a core through these sediments close to the town of Wunstorf, 20 km NW of Hannover. The thickness of the recovered succession is very high. This enables the chronology to be studied in great detail – an important prerequisite for understanding source rock genesis

This is only a general scenario. But what were the environmental conditions leading to the formation of sapropels? Is it possible to reconstruct these environmental conditions? And if so, will such knowledge help industry discover new reserves of oil and gas?

Mineral resources – essential supplies for German industry

The global economy has received an enormous boost in recent years from the rapidly expanding economies of some emerging countries. The global economy has grown by around 3.5 per cent points since 2001. The German export industry is booming because of this global economic growth: Germany was the world's number one exporting country again in 2005 with exports totalling Euro 786 billion – around one third of gross domestic product.

More than half of German exports consist of goods requiring a significant input of metals and industrial minerals. These exports are mainly from metal processing companies as well as the mechanical engineering, car making and chemical sectors. However, commodity prices have risen for the fourth year in succession because of the global economic upswing, and there is no end in sight to the commodity price bull market. German industry is concerned about the more than doubling in commodity prices for some raw materials.

Regional provenance of commodities for the German market.

This development has again raised the question of how much longer our commodity reserves will last, and the price we will have to pay to satisfy the future demand for natural resources. One of the more important tasks for which BGR is responsible is providing policy makers and industry with advice on all natural resource supply issues, with the ultimate goal of safeguarding our prosperity.

Fears of shortages of metal resources and industrial minerals are unjustified from a purely geological point of view. However, the commodities business is associated with numerous risks involving technical availability and market access which jeopardise the maintenance of balanced commodity supplies at competitive prices. New ore and industrial mineral deposits have to be continuously explored for and developed. Success largely depends on the proper interaction of the capital expenditure, technology, expertise, and the creativity of exploration geologists. In addition to the geological risks, mining products are also subject to numerous production and supply risks.

The BGR's "Mineral Resources" department deals with a similarly broad range of tasks: at a national level and within the framework of technical co-operation agreements, its work includes the development of exploration concepts and prospecting methods, mineral analysis, the evaluation of deposits, market studies and market analysis. Other important tasks include environmental protection in the mining industry, mining law, mining safety, and studies on the sustainable use of mineral resources in developing countries.

Rohstoffwirtschaftliche Länderstudien XXXIV (2006): Annual commodities status report for the Federal Republic of Germany, 2005 (with a summary and captions in English). – 203 Pages, 21 Figures, 116 Tables, 1 CD. – E. Schweizerbart'sche Verlagsbuchhandlung, Johannesstr. 3A, 70176 Stuttgart

Natural resources are now a **top priority** at the **Federation of German Industries (BDI)**

The prices for many mineral commodities have risen dramatically because of changes in world market structures, world economic growth, and the rise in the demand for commodities. German industry is unable to pass on the increased commodity prices to its customers because it has entered into long-term contractual agreements. This led to competitive disadvantages which caused liquidity problems in some medium-sized subcontracting companies, and considerable problems in the industrial value chain.

The German Ministry for Economics and Technology (BMWi) worked together with BGR against this background at the "Natural Resource Policy Forum" in December 2004 to develop natural resource policy ideas. At the "Natural Resources Summit" organised by the Federation of German Industries (BDI), the former German chancellor Gerhard Schröder and the BDI President Jürgen Thumann agreed in March 2005 to develop a natural resource strategy for Germany backed up by industry and politics. BDI set up the "International Natural Resource Issues" executive committee for this precise purpose. The aim is to develop concepts to safeguard the availability of natural resources at competitive prices, and to develop recommendations for industry and politics. BMWi – using BGR data – was able to present a comprehensive report as early as July 2005 on the current economic implications of the natural resource situation, and to propose recommendations.

BGR works in the steering group of the executive committee as well as in the "Deposits, Availability, Geostrategic Risks" working group. This working group was set up to develop availability criteria to safeguard supplies and analyse important natural resources.

Work is carried out on several aspects including the following:

- Origin of the natural resources used in Germany
- Availability and regional distribution of deposits
- Technical availability including production and processing capacities
- Infrastructure and transport routes
- Commodity markets and market concentrations
- Legal conditions
- Changes in demand structures.

BGR makes a major contribution to understanding the many facets of the commodity markets and commodity industry relationships by maintaining comprehensive natural resource databases and conducting detailed market analyses.

German carmakers want **sustainable commodity supplies**

In the last two years, the automotive industry experienced unusually large hikes in the prices of its raw materials not seen for decades. The prices for aluminium and platinum rose by 75 % and 110 % respectively from 2002 to 2005. The carmakers and the automotive subcontractors even had to swallow price increases of up to 200 % for sheet steel and copper. At the same time, carmakers face increasing legislative pressure to optimise the use of materials and to recover materials in a renewable material cycle to enhance environmental sustainability.

Carmakers and automotive subcontractors only have limited options available to accommodate the rising commodity prices and more stringent environmental constraints. Designers strive to compensate for the higher material costs by incorporating product innovations and elaborating more streamlined production processes. Development work of this kind typically involves long lead times before being able to cash in on material savings and substitutes. Tomorrow's markets also demand innovative and environmentally-friendly fuel-saving motors – another major challenge facing the automotive industry and its engineers.

In addition to their pure negative effect on costs, high commodity prices and the high price volatility for natural resources can also depress business planning security. This was why Volkswagen AG asked BGR to elaborate indices to assess the supply risks of mineral resources. The analysis looks in particular at those natural resources used in new technologies, or raw materials used as substitutes for expensive raw materials with serious environmental impacts.

The commodity situation is evaluated on the basis of the commodity market analysis covering supply and demand, analysed using a numeric evaluation model. All the main parameters affecting supply security are investigated in time-series analyses based on the formulated indicator catalogue. In addition to an estimate of the market situation, the analysis of global exploration and mining projects is mainly used to provide forecasts for future developments in reserves and the supply situation for specific commodities.

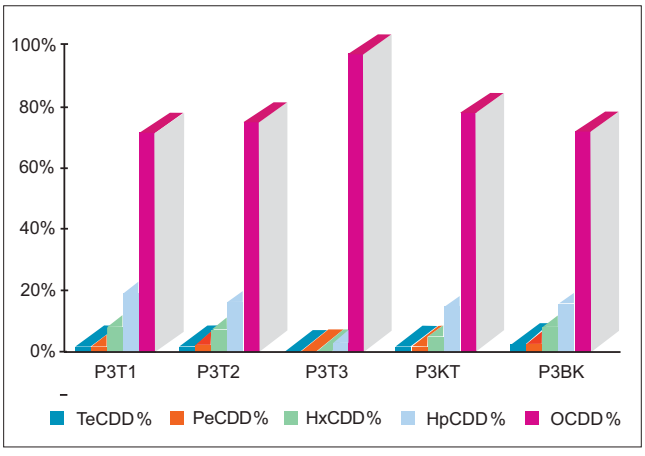
Evaluation criteria for the analysis of mineral resource supply risks

- Supply surpluses and deficits
- Changes in global stocks at the commodity exchanges and at producers depending on changes in prices and the occurrence of global events
- Changes in mine and refinery capacities utilisation
- Changes in mine development and production costs
- Opportunities for exercising market control through company mergers
- Geostrategic risks
- Development of global exploration and mining projects.

How did **dioxins** enter clay deposits way back in the **geological past?**

The animal feed scandals at the end of the 90s revealed that some clays contain increased concentrations of polychlorinated dioxins. The affected clays mostly have high kaolin contents. The dioxins are a group of toxic organic compounds belonging to the group of halogenated aromatic hydrocarbons. The pattern of different dioxin compounds found could not be correlated with any known source. Dioxins can reach dangerous concentrations in the human body via the food chain if clays rich in dioxins are used in animal feed. Raw materials known to be contaminated are therefore no longer used when they may come into contact with animal feed or food intended for human consumption.

Most people have heard of dioxins in the context of anthropogenic contaminants. They are generated as unwanted by-products mostly as a result of combustion processes, e.g. waste incineration. This always gives rise to a large number of different dioxins with different numbers of chlorine atoms. The often process-specific compositions are described as congener patterns. Information on the source of the dioxins is provided by the congener pattern identified in a sample.



Percentage distribution of dioxin congeners in clay (P3T1-3), coal (P3KT) and lignite (P3BK).

However, the immediate search for known anthropogenic sources of this kind to explain the dioxin contamination of the clays proved a dead end. A special feature of the congener patterns found in the clays was that they were dominated by the eight-fold chlorinated dioxin, OCDD. It was therefore concluded that the contamination was natural and had occurred way back in the geological past. No correlation has yet been found with the age or the mineral composition of the raw material. This stimulated the BGR to launch a study conducted in co-operation with the Technische Universität in Berlin (TU Berlin). The project was funded by the Hans-Joachim-Martini Foundation.

There are two main pathways for the creation of kaolinite-rich clays. The first involves the alteration of certain rocks to kaolinite and other accessory minerals without them coming into direct contact with the atmosphere and the ambient climatic effects: these are "primary" clays. The second pathway always involves a variably long and intense phase of weathering. In this phase, the minerals found in the raw material today were subjected to the climatic and vegetation conditions existing in the geological past: Minerals were eroded, transported and redeposited. Such deposits are known as "secondary" clays. The processes involved normally take several thousands of years.

The study revealed that no significant dioxin concentrations were present in the clay horizons typical for "primary" kaolin deposits. Dioxins are, however, found in clays today which were altered far back in geological history when they were exposed to the ambient climatic conditions and were exposed to immissions from the environment existing at the time. The secondary clay horizons investigated during the study all have slightly raised concentrations of dioxins and therefore differ fundamentally from the primary kaolins.

In addition to this clear finding, there are still unanswered questions concerning the precise genesis of the dioxins found in the clays. Analysis was carried out to determine whether the dioxins preferentially adhere to the very fine-grained clay minerals which form the actual resource, or to the extraneous material. Clay minerals have good water-adsorption properties, but because dioxins are hydrophobic, they can bind better to the sedimentary organic material which is also hydrophobic. This organic matter consists of residues of dead plants and animals (biogenic material) originally deposited in the sediment and found in secondary clays.

Detailed microscopic and geochemical analysis of the organic material from the secondary clays revealed a wide range of fluctuating compositions mainly consisting of preserved residues of the former vegetation cover. The comparative investigation of the grain size fractions revealed a trend in typical secondary clay horizons: no indication of any binding of dioxins to clay minerals, but rather, the binding of dioxins to organic matter. However, identification of the type of organic matter failed to provide any reliable indication of the possible origin of the natural dioxins in the dioxin-bearing clays.

There is still no answer to how these dioxins came to be enriched in the clays. It is certain, however, that the dioxins which formed naturally millions of years ago under different natural conditions were broken down and altered over time, and therefore aged quantitatively and qualitatively. This is shown in the following diagram. The more stable and less toxic OCDD congener – an eight-fold chlorinated single dioxin – is more strongly concentrated compared to the more toxic, less stable dioxins such as the four-fold chlorinated TeCDD. The clays therefore exhibit a typical preservation pattern. This suggests that although the dioxins did not originate in the clays, they were preserved in the clays.

The low hydraulic permeability of clays and their anaerobic burial are considered to explain how the dioxins were preserved until the present day. It is likely that the preservation processes also play a crucial role in the degree of dioxin contamination in the clay deposits. Nevertheless, a so far unknown generation mechanism or a special enrichment process has to be assumed to scientifically explain the size of the measured dioxin concentrations.

Further studies should be carried out to investigate the geological development of dioxin concentrations in different clay deposits related to the climate prevailing when the deposits were originally laid down. Investigations on the geohistory of the dioxins should also be conducted to identify any potential sources of the dioxins that account for their accumulation in the clays.

Gold from the floor of the ocean
Smoking vents on the floor of the southern oceans

Something is cooking on the ocean floor around the South Sea island of Tonga: the seafloor is being stirred up outside the arm-thick windows of the deep-sea diving capsule. Huge columns of crusty minerals tower above the sea bottom, boiling hot liquids pour out of holes and cracks, and bubbles of gas pirouette in sparkling chains up towards the surface. The spotlights of the PISCES submarine illuminate a subterranean world completely at odds with the holiday brochure images of palm-lined tropical beaches. Far away from the bathing and diving paradises, down at water depths of 200 to 1000 metres, ores form before your very eyes.

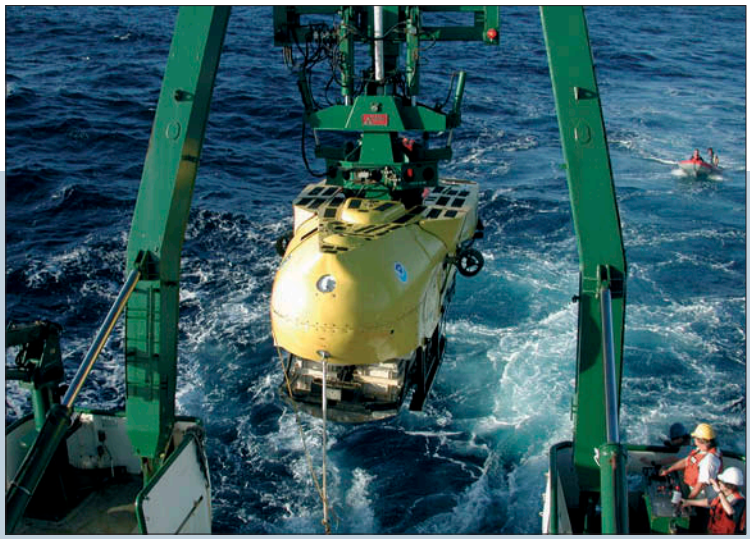
Scientists from BGR and the University of Kiel are running an international research expedition investigating the ore content of the submarine volcanoes in the south-western Pacific Ocean. The submarine volcanic chain was only discovered in 2002 by the German research ship SONNE during a research exhibition. It is part of the Tonga island arc, a chain of more than 20 deep-sea volcanoes – a place where hot, metal-rich solutions spew out on the sea floor, indicating ore deposits with high copper and gold concentrations. The release of magmatic solutions from the insides of the volcanoes plays a key role in the metal enrichment processes.

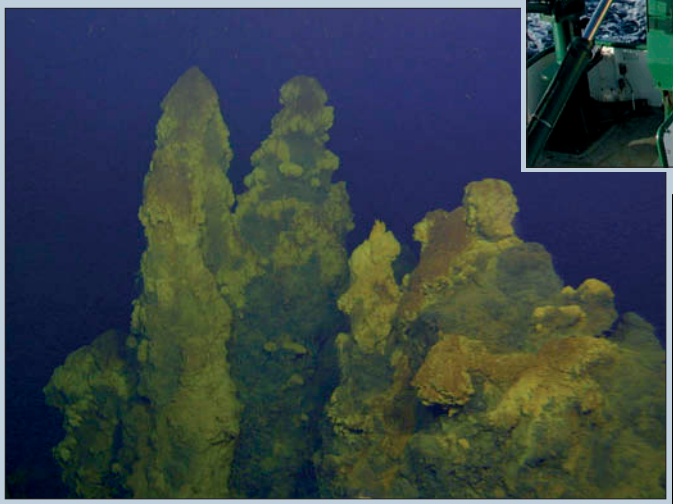
This latest international research expedition investigates and samples in detail the zones where the magmatic solutions gush out on the sea bed. Technical support is provided by the American research submarine PISCES and its mother ship the KA'IMIKAI-O-KANALOA. The research results provide important information to help interpret the processes involved in deposit formation in this region.

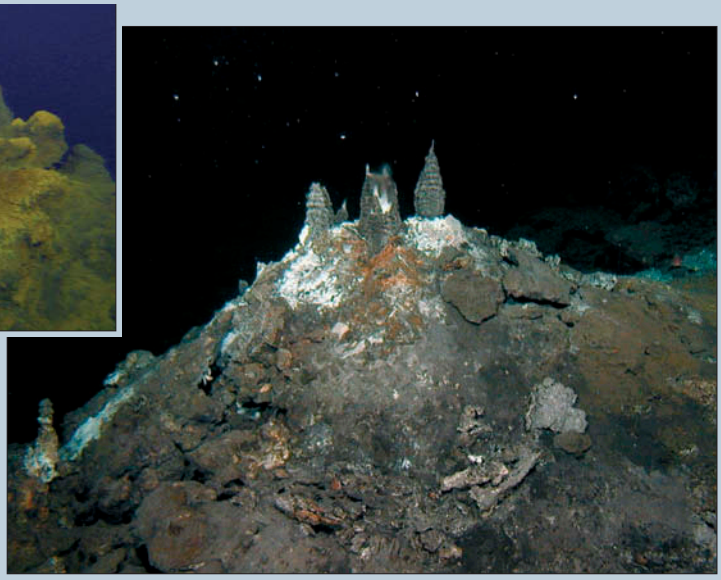
The economic importance of this study of the present day development of metal deposits around Tonga is not merely of value because of the local concentrations of copper and gold. The Tonga island arc is a geological model for the generation of major gold and non-ferrous metal deposits on land, such as those currently being exploited in Chile, Indonesia, Papua-New Guinea, and the Philippines. These deposits were also originally formed on the ocean floor by volcanic activity associated with island arcs – in these cases, many millions of years ago. Plate tectonic forces then folded and lifted the fossil island arcs and their ores out of the ocean and on to the land. They are now exposed to completely different temperature and pressure regimes to those which existed when they were originally formed, which complicates the study of the genetic processes involved.

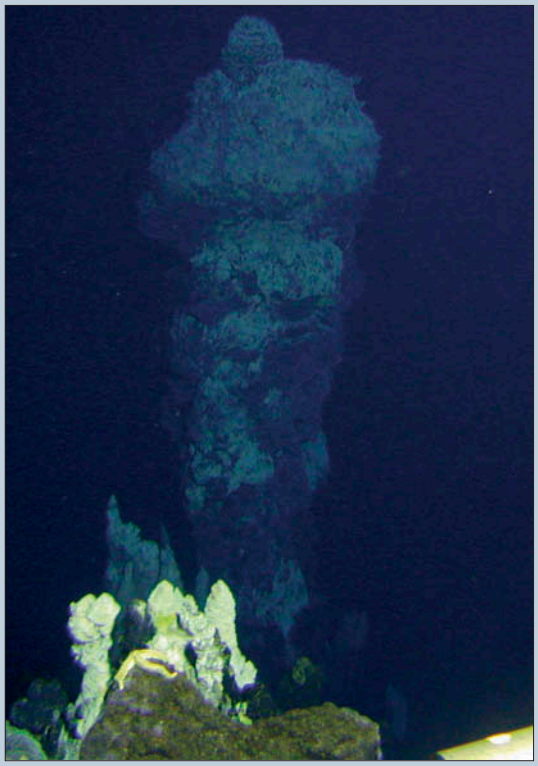
Unlike the fossil deposits on land, the formation of metal concentrations in their original geological setting can be observed "live" in the Tonga island arc. Tonga's submarine volcanoes are therefore a perfect natural laboratory for investigating the processes creating island arc metal deposits. Understanding the genetic processes improves the systematic prospecting of new deposits on land.

Photos of the research submarine PISCES and the seafloor around Tonga island.









The eighth continent and the kingdom: **Madagascar** and **Morocco** enhance their **metals production**

"Gold, silver and palladium!" cries Mustapha, the Moroccan PhD student, full of pride and enthusiasm every time he discovers macroscopically small inclusions of the sought-after precious metals during research work at the Federal Institute for Geosciences and Natural Resources. In doing so, he not only opens up additional options for the mining industry in his home country, but also helps diversify global supplies of palladium – a high-tech metal also in demand by Germany industry.

Morocco, which is favourably located at the gates of Europe, is rich in mineral resources: the North African kingdom generates a large portion of its income from the production of mineral resources. They range from iron, ferroalloys such as cobalt and nickel, silver and non-ferrous metals, and include a wide range of special clays, not to mention high quality barites and fluorspar. Morocco is also the world's third largest producer of phosphorite, used in the production of fertilisers.

Madagascan geologists training in the field.

Sampling the cobalt ore in diorite the Bou-Azzer mine.

Gold and silver have long been among the more important metals produced by Moroccan mines. And the recent major hikes in prices on the global markets make boosting production a promising venture. Unlike gold and silver, palladium previously only played a side role in the Moroccan mining industry. It was therefore all the more satisfying that the collaboration with the Moroccan colleague, and the major part played by BGR's analytical expertise and equipment, gave rise to the discovery of previously unknown gold – silver – palladium mineralisation in the deposits of the Anti-atlas mountains.

This successful co-operation with the BGR strengthened Morocco's status as a main focus of German development co-operation and an important partner for German commodity supplies.

Morocco and Madagascar – two major African countries whose contrasts could not be greater: Madagascar, the fourth largest island in the world, also known as the "eighth continent" because of its isolated geological development over the last 90 million years. Isolation also describes the most recent political situation in Madagascar: a situation which has suppressed the development of its economic infrastructure and throttled the geological exploration of the island for decades. Unlike Morocco with its 1000-year-mining tradition, Madagascar (one of the poorest countries in the world) still lacks a basic mining infrastructure and technical basis – including a modern geological map.

With financial support from the World Bank, BGR played an active role in mapping the geology of southern Madagascar – an area the size of Bavaria and Baden-Württemberg. In addition to the standard geological mapping of the rocks exposed at the earth's surface, special attention was also given to the precise localisation and classification of deposits of natural resources. The standard geological and the economic geological maps will be important planning tools for future investment in Madagascar's mining sector.

Advising the mining bureaux in **Vietnam** and **Mongolia**

The development of the mining sector and the rising commodity prices have increasingly opened up economic opportunities in Mongolia and Vietnam in the past few years, but also led to an increase in environmental and social risks. Up until very recently, the sole obligation of the industrial sector, including mining activities, was to fulfil economic targets – with no allowances made for occupational safety and environmental protection.

Hazardous: Unrestricted access to a working underground iron ore mine.

The establishment of a properly functioning state mining inspectorate capable of competently implementing all mining-related stipulations and responsible for safety and environmental protection was only possible with the creation of appropriate mining laws and standardised mining regulations.

However, the mining inspectorate is not yet capable of fulfilling its responsibilities efficiently and effectively despite the creation of the proper legal framework and the establishment of responsible agencies. This shortcoming is attributable to the shortage of equipment and properly qualified experts, and overlapping areas of accountability and competence.

This has the following consequences:

- The Health & Safety of third parties and employees are jeopardised
- The countryside, and the quality of soil, air and water are negatively affected
- Mining waste and tailings dumps cause environmental pollution,

As part of the project, Vietnamese surveyors received supplementary training from Australian Mining Authority personnel.

- There is no environmentally compatible renaturisation of abandoned mining sites
- There are serious losses of valuable resources during the extraction and beneficiation of commodities
- Illegal mining
- Lack of willingness on the part of some mining companies to forward production data to the responsible authorities.

Operational safety risks: Unrestricted access to iron ore mine heap. Hand-operated trolleys are not secured against tampering.

Hazardous and harmful hard coal tailings dump from open pit drainage.

Environmental degradation caused by active kaolin mining.

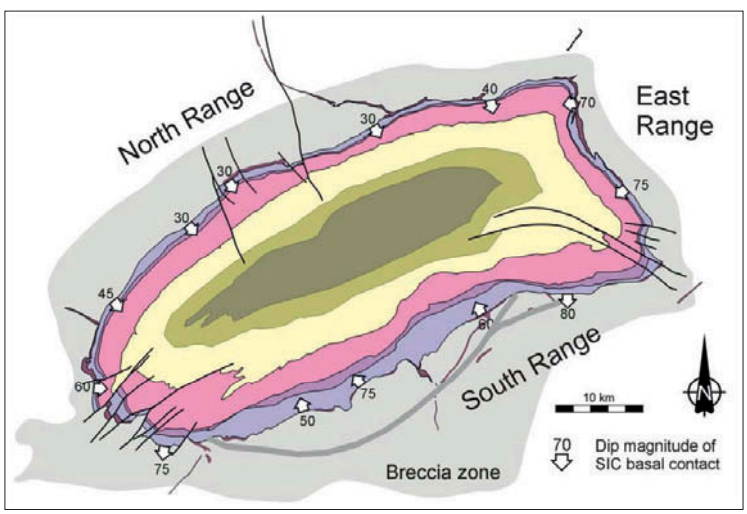
The technical co-operation projects "Mining inspectorate assistance" in Vietnam, and "Environmental protection in the mining sector" in Mongolia, support the mining inspectorates. The briefs of these projects include implementing mining legislation governing the regulated prospecting, extraction and beneficiation of mineral resources, the occupational safety of the mining workforce, and improving environmental protection in the mining sector – especially the recultivation of old mining sites. These goals are achieved by setting up and assisting mining inspectorates, providing technical support for the inspectors, and developing methods, regulations and capacities at the regulatory agencies responsible for mining and environmental protection in the mining sector.

By providing the mining inspectorate with assistance in the form of know-how transfer, counterpart training, the implementation and further development of modern mine recultivation methods, the elaboration and implementation of mining and environmental protection regulations, and the implementation of modern measuring technologies, the mining inspectorate will acquire the competence to properly fulfil its responsibilities for monitoring the safety of mining operations, controlling the occupational health and safety of the mining workforce, and upholding environmental protection in the mining sector. These projects are supported by BGR staff assigned to Vietnam and Mongolia.

Prospecting in a Canadian meteorite crater **The reality** is more exciting than **science fiction**

A massive chunk of cosmic rock whizzes through space, enters our solar system and hurtles towards the earth. Frictional heat vaporises the outer skin of the meteorite as it penetrates the earth's atmosphere. Trailing smoke as it burns up, the glowing fireball flashes down towards the surface of the earth. Despite shrinking as it falls, the meteorite still has a diameter of 12 kilometres as it hits the surface, excavating a 30-kilometre-deep crater, melting and vaporising the surrounding rock with its red-hot mass, and causing a major earthquake. Ten minutes after impact, the crater has a diameter of around 250 kilometres and is filled with an up to 2 500 m deep lake of boiling molten rock.

Long before Hollywood brought to our screens the dramatic consequences of a meteorite impact with "Deep Impact" and "Armageddon", geoscientists looked in detail at meteorites and the effect of their impact on the earth. Although our generation, and probably also our great grandchildren, will not experience a catastrophic meteorite impact, they have "regularly occured" almost everywhere around the world in the enormously long geological time periods looked at by geoscientists. The apocalyptic consequences are also not just dreamt up by the screen writers: meteorite impacts have laid waste whole regions over the course of geological history and wiped out significant proportions of the plant and animal world.



Geological map of the Sudbury meteorite crater. The offset dikes (black lines) radiate out from the centre of the crater.

Rusty weathered nickel sulphide ore in an offset dike in the Sudbury meteorite crater. This rock is being mined for nickel.

Is there anything positive to say about meteorite impacts? Major metal deposits form under the special temperature and pressure conditions created during such impacts, such as in northeastern Canada. Here in the Sudbury Crater carved out of the earth's crust in North America almost 2 billion years ago, nickel in particular has been mined for more than 100 years. The Sudbury complex accounts for 11 % of global nickel production and is therefore one of the largest nickel resources in the world.

In addition to nickel, the Sudbury complex also boasts economically interesting copper and platinum element deposits in mineralised expansion cracks radiating out from the crater. These ore veins, known as offset dikes, have also been mined since way back. Profitable mining has, however, been hindered in the past by their poorly predictable position and the sudden disappearance of the veins.

Scientists at the Humboldt University in Berlin studied the structure and formation of these ore veins on behalf of BGR and developed an offset dike structural model. The study turned over previous ideas by revealing that the ore veins originated several thousand years after the meteorite impact when expansion cracks formed in the surrounding rock during gradual cooling of the ground around the crater. Metalliferous molten rock from the overlying melt penetrated these expansion cracks and crystallised out. The practical applicability of this model is now being tested in the field to improve predictions of the prospectivity of the offset dikes.

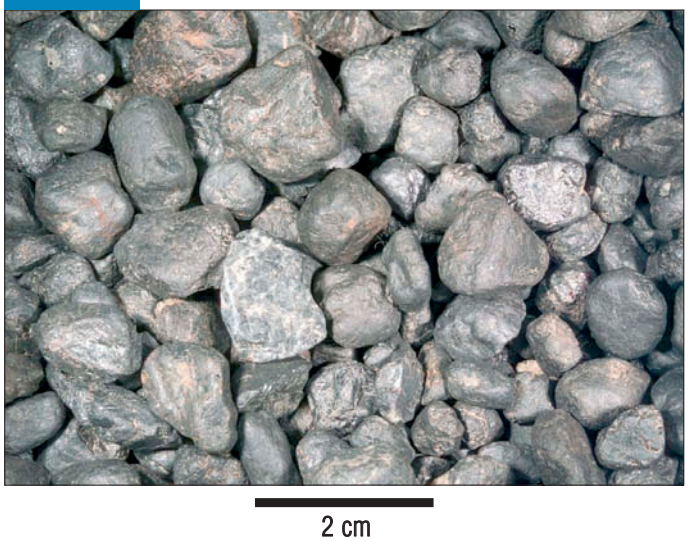
Nigrin – Black trail to light rocks

Black is a colour which plays a key role in a range of sciences. Astrophysicists hope that black holes will give them an insight into the creation of the universe, whilst marine geologists analyse black smokers to find out more about metallogenic processes operating on ocean floors. But when is your average economic geologist with a specialisation in sedimentology interested in the colour black? When he or she is looking for black sands – not saturated in bitumen – but made up of black minerals concentrated in rocks after winnowing in rivers and on beaches, and referred to in the technical jargon as placers.

As the name already suggests, nigrin (Latin niger = black) is in some ways a textbook example of black placer minerals. The experts still agree to disagree, however, whether nigrin is actually a mineral in the classical sense or an accumulation of minerals. Microscopic analysis has revealed that nigrin consists of the closely intergrown titanium minerals rutile (TiO_2) and ilmenite ($FeTiO_3$).

More detailed analysis identified that the rutile and ilmenite have a remarkably wide range of chemical compositions with respect to niobium, iron and wolfram. Additional microscopic analysis also revealed tiny inclusions of the minerals columbite, wolframite, betafite, pyrochlore, zircon, pyrrhotite, and sphalerite. The presence of cassiterite in these placers was also confirmed with the help of microprobe analysis and X-ray diffractrometry. The many different kinds of inclusions in nigrin would warm the heart of any mineral collector – but only if they had nice crystalline shapes and were at least the size of a pin head.

And although the diversity of the elements and the titanium concentrations might impress a beneficiation engineer or economic geologist, they would not like the closely intergrown fabric of the minerals because this increases the expense of the beneficiation and concentration of the economic minerals. In addition, the minerals in placer deposits should ideally also be close to the surface and present in the form of single grains in high enough concentrations. These parameters are rarely fulfilled by nigrin deposits. So why bother examining the economic potential of nigrin in the first place?



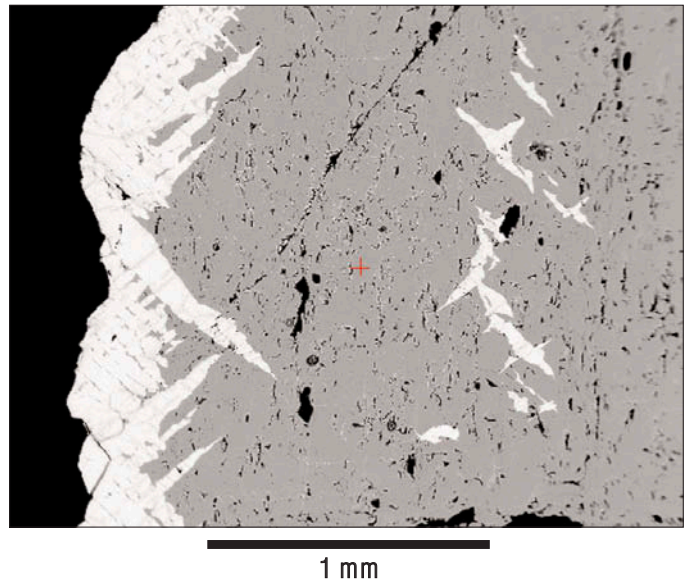
Nigrin particle from fluvial placer deposits near Pleystein (Bavaria).

Their economic significance – and thus the interest of economic geologists in these black mineral aggregates is linked to their pedigree and their high degree of resistance: nigrins are derived from pegmatitic rocks. The light-coloured alkali-feldspar-rich and micaceous pegmatites – close relatives of granites – often contain a wide range of economically interesting minerals.

Special metals (niobium, lithium, uranium) and phosphate-bearing pegmatites in particular pass through the nigrin stage. The black minerals – the nigrins – highlight their special composition. They reflect a crucial development phase in the creation of these pegmatites. Pegmatites with simple compositions on the other hand do not have any of these indicator or pathfinder minerals.

Although rugged looking, pegmatites do not stand up well to the effects of weathering on crystalline basement rocks. It is therefore very useful that the closely intergrown rutile and ilmenite wrap around and protect their mineral inclusions. The main titanium mineral in nigrin, rutile, is very resistant to weathering and the transport processes rocks are exposed to in rivers. Nigrins are therefore the "armoured relicts" of their parent rocks and their associated economic minerals.

Whether or not an exploration geologist recognises the importance of the nigrins as an economic collection of black mineral grains depends on the geologist's specialisation and experience. Those in the know will follow the black trail to the light pegmatites. The payoff is the higher chance of finding those highly sought after special metals.

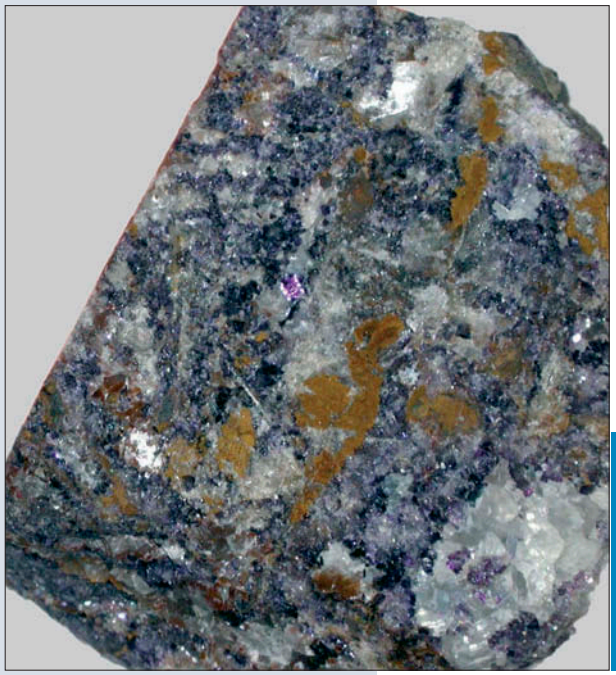


Nigrin under the electron microprobe. The light, spindle-shaped parts in the centre of the mineral aggregate and near its margin are ilmenite, an iron-titanium oxide. The dark matrix consists of rutile, a titanium dioxide mineral.

Fights fires and melts ores: **fluorspar**

Stunning violet, yellow and green colours – but also transparent cubic crystals? That is fluorspar, or fluorite as the mineralogists call it. The name of this sought after industrial mineral is derived from its use as a flux. Fist-sized lumps of fluorspar have been added to the melt in blast furnaces for hundreds of years to lower temperatures and save fuel. Fluorspar is also added to glass and ceramic melts, again with the aim of saving valuable energy.

Aerial view of the Okorusu fluorspar mine in the highlands of northern Namibia.



Colourful fluorspar ore.

But fluorspar has other attributes: German industrial companies are amongst the leading producers of hydrogen fluoride, and derive the fluorine from fluorspar. Hydrogen fluoride is used to make the catalysts required to produce super petrol, efficient etching and polishing products for the glass industry, and flame-retardant plastics.

German demand is largely supplied by deposits in southern Africa which have to satisfy the stringent quality specifications laid down by the chemical industry for its raw materials. Accessory minerals are therefore undesirable in the interests of cost-effective and environmentally-friendly production.

BGR analysed the fluorite ores and the concentrates produced from these ores at two mines in Namibia and South Africa producing a large proportion of the fluorite exported to Germany. The study showed that the ores from both mines were purer than previously assumed.

Electron microprobe analysis revealed that the strontium concentration previously used as an indicator for unwanted carbonate is largely actually bound to the fluorite itself – and not to carbonate as previously assumed. The good news is that the strontium incorporated in fluorite does not present any problems during beneficiation and further processing. This is a big advantage to the mines in southern Africa because fluorite concentrates containing low levels of carbonate contamination command a better price. Moreover, businesses in Germany processing the concentrate further can dispense with unnecessary beneficiation steps and use the savings to their competitive advantage.

Allophane –
Bricks are not everything

Allophane is a common mineral, particularly in soils. However, it is difficult to detect because it does not have a well formed crystalline structure and has very small particle sizes. Geoscientists can only confirm its presence unequivocally if allophane is present in the soil in large quantities. A special feature of this mineral is that it is formed out of tiny hollow spheres. This means it has an enormous total surface area of approx. 1000 square metres per one gram of allophane. Under a scanning electron microscope, the countless hollow spheres are piled up on one another to look like clouds.

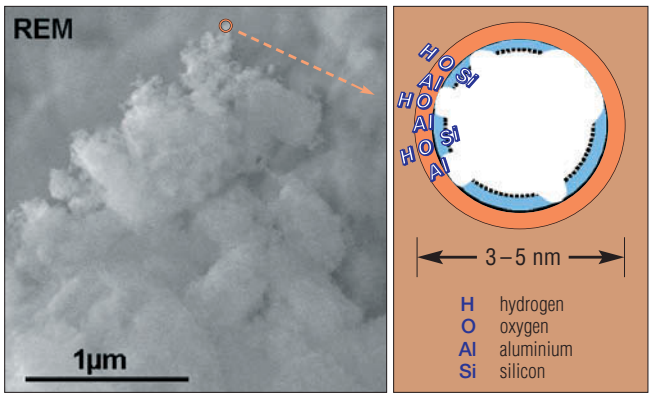
A fifteen-metre-thick allophane layer in Ecuador.

The very high specific surface area means that allophane can determine the properties of a soil – even if it is only present in small concentrations. Allophane-bearing soil has good water retention properties and can bind contaminants so strongly (e.g. organic contaminants, arsenic and chrome compounds) that they cannot enter plants or the groundwater.

Making economic use of this fascinating technical property is only possible if the allophane is present in the soil in strong concentrations, e.g. forming an allophane deposit. Such concentrations are known in young volcanic areas fringing the Pacific Ocean where soils up to several metres thick can occur containing 40 to 60 % allophane.

BGR studied brick clays in Ecuador back in the 1980s: it sampled various clays because clays can almost always be used to make hard bricks with a range of strengths. However, some of the clay samples investigated were unusual because they were completely unsuitable for brick manufacture. This was due to their composition: the samples contained very high concentrations of allophane.

So if the clays are not suitable for the production of bricks because they are so rich in allophane, why not make use of the special properties of allophane instead? What opportunities and what problems are associated with its production (purification, grinding, drying)? What market and product advantages are there by using allophane in what sectors? These were the questions which stimulated the study conducted at the Federal Institute for Geosciences and Natural Resources as part of a doctoral thesis carried out in co-operation with the University of Halle.



Scanning electron microscope image and a sketch of the crystal lattice of allophane.

Exploration work in Ecuador discovered up to 15-metre-thick allophane deposits with low concentrations of organic matter. Although the field work failed to reveal that the earthy material below a depth of 9 m no longer consisted of allophane but the related mineral halloysite, allophane concentrations of this kind were previously completely unknown. A highly valuable deposit of this type is worthy of further investigation.

Because of its capacity for retaining organic and inorganic contaminants, the main area of application of allophane is considered to be environmental engineering. A method was developed for producing stable allophane aggregates (in sizes 1 – 5 mm diameter) to use allophane in flue-gas filtration plants. Allophane powder can be used to treat slightly acid to basic wastewater (pH > 5). A particular advantage is that allophane settles out independently even under these conditions – unlike many other clay minerals.

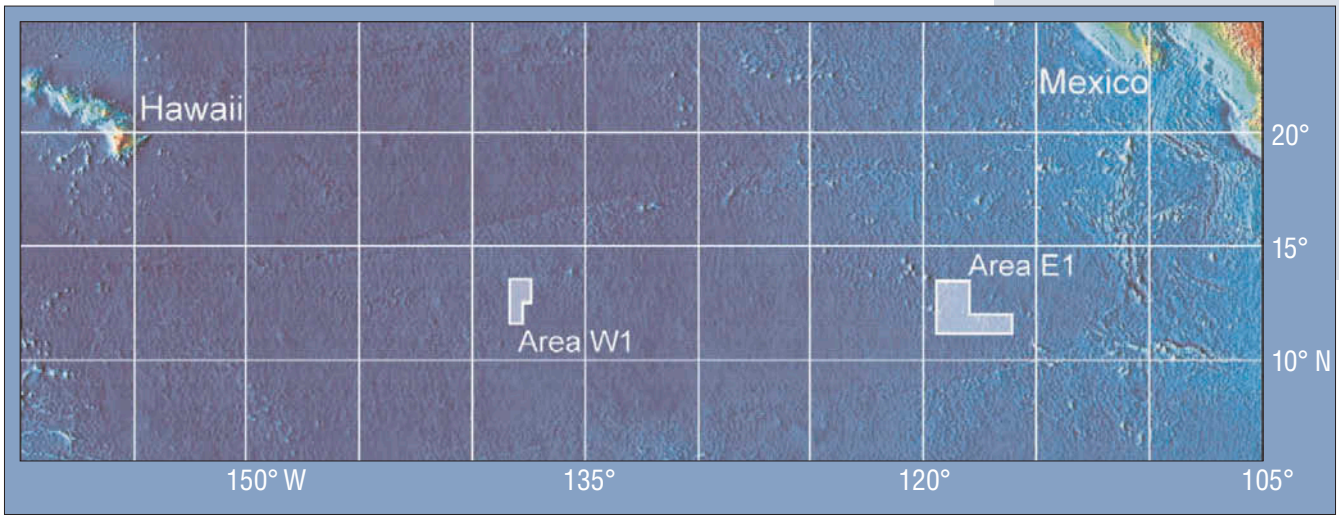
Our research has also revealed other interesting technical and scientific niche applications – although they usually only require small amounts of natural resources. The potential main applications of allophane are currently being enthusiastically tested by industry.

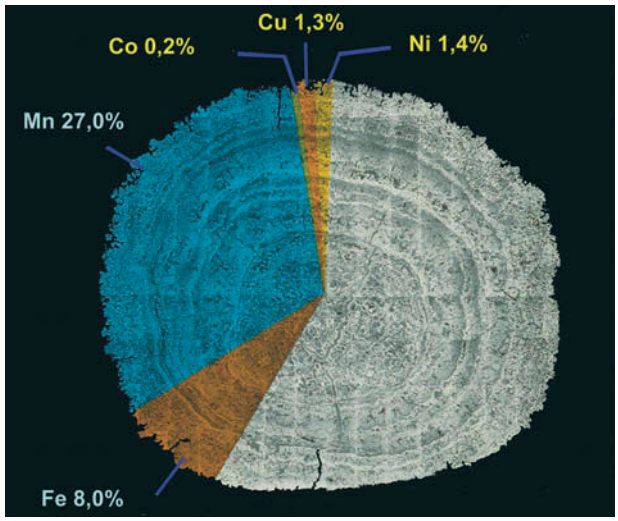
Manganese nodules – Mineral resources of the future

Manganese nodules seen as natural resources have been an important topic in the 1970ies through 1980ies. During the days of the Cold War, new approaches were sought to reduce Germanys worrying dependence on mineral resources. Manganese nodules, widespread in the deep sea, were discovered as a new and so far not utilized resource for different metals such as copper, cobalt, and nickel. Because of their complex chemical composition, the nodules are frequently also termed "polymetallic nodules". After years of intensive research by the Federal Institute for Geosciences and Natural Resources (BGR) along with universities and after the development of nodule recovery techniques by German companies, submarine mining seemed to be within reach. A consortium with participation of German companies acquired a concession for the exploitation of manganese nodules in the central Pacific Ocean and only the subsequent price decline prevented the beginning of commercial extraction.

Within a world of global economic growth now facing noticeably increasing commodity prices, manganese nodules gain new attractiveness. Recently, BGR initiated another advance on the exploration of manganese nodules in the Pacific, based on an archive of previously elaborated scientific results and voluminous data sets inherited from the Preussag Company. In June 2005, BGR submitted an application for the exploration of manganese nodules in the Pacific Ocean to the International Seabed Authority (ISA) of the United Nations (UN). According to the UN Convention on the Law of the Sea, the ISA is responsible for the mining of natural resources in the open ocean outside the national exclusive economic zones. The German application was received positive by the ISA and the Contract on Exploration between the BGR and the ISA was signed in Berlin on July 19, 2006.

Map of the central Pacific Ocean indicating the position of BGR's licence areas. In total, areas W1 and E1 cover about 75 000 km²





Average metal contents of a manganese nodule from the central Pacific Ocean.

Key parameters of the BGR licence area in the central Pacific Ocean (current state of knowledge)		
Total area size [km²]		75 000
Average water depth [m]		4 500
Range of water depth [m]		3 700 – 5 100
Nodule coverage [kg/m²]		usually 8 – 13
Calculated nodule resources [pieces]		920
proportional contents of metals [%]	Mn	27 – 29
	Fe	6,2 – 7
	Ni	1,3
	Cu	1,0 – 1,1
	Co	0,17 – 0,22
Ni + Cu + Co (106 t)		24

In this contract, Germany was assigned exclusive rights on exploration for an ocean area of 75.000 km² and a period of 15 years. Prearrangements and realization of detailed investigations in this area by the BGR are now underway. The intended research project is multi-disciplinary: it covers a survey of the geographical distribution and regional abundance of the manganese nodules as well as its chemical composition with state-of-the-art equipment and methods with lowest possible detection limits. BGR plans to survey the topography of the licence area in high resolution with multi-beam echosounders to compile a precise three-dimensional digital terrain model. Benthic life in the deep sea, which is only little known so far, will be studied and classified to estimate and predict possible environmental disturbances by future manganese nodule mining.

Research on manganese nodules carried out by the BGR at this early stage is a strategic measure contributing to maintain sufficient supplies of mineral resources for our country in the future.

Georesource Soil

Soils Soils

Soils – essential

In classic economics, soil is one essential factor of production, in addition to labour and capital. In this connection, the term "soil" is mainly used as a location or as a cultivation and mining area.

Soil: *The second original factor of production next to human labour. Soil is a factor of production involving a) agricultural production, b) initial production, i.e. mining the raw materials in the soil such as coal, ore, crude oil, etc., c) any other production (as support)*

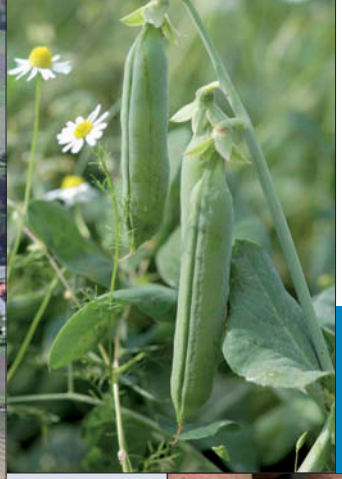
(Source: Dr. Gablers Wirtschaftslexikon, Kurzausgabe; 1969)

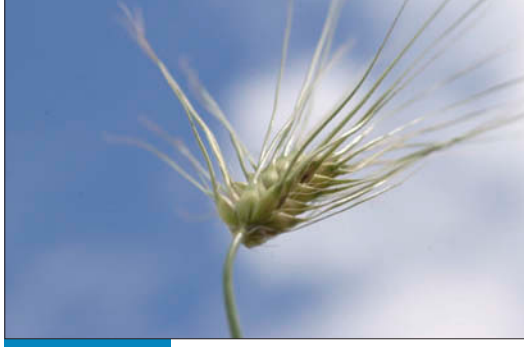
This economic point of view found its way into the German soil protection legislation by explicitly calling the use of soils one of three soil functions defined in the Federal Soil Protection Act in 1998. The other functions are described as "natural functions" and "functions as archives of natural and cultural history". Among the natural functions, it is emphasised that soil is essential for the life of humankind, animals, plants, and soil organisms.

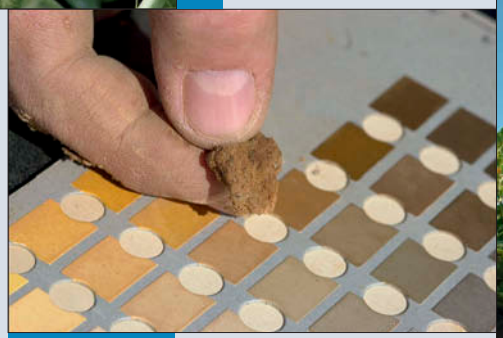
Though the soil functions do not coincide in all cases – soil protectionists call them competitive claims – economists and ecologists agree that soil is a limited and non-renewable resource, which deserves respect and should be treated sustainably.

Within the meaning of this Act, the soil performs natural functions as a basis for life and a habitat for people, animals, plants and soil organisms …

(Excerpt from Section 2 Federal Soil Protection Act, BBodSchG; 1998)







Aspects of use and protection require sound scientific as well as standardised basic information on the properties and distribution of soils (with their understanding of the multiplicity of different soil types and their properties, soil scientists use the term in plural).

At BGR, soil scientists work on the elaboration, further development and provision of geoscientific basics. The soil map (1:1.000.000) already compiled in 1995 from the soil maps of East and West Germany was recently revised and considerably upgraded by using information on land use and climate. The revised map – the soil map stratified according to land use – is part of the Soil Information System (FIS Bo BGR) and is available to users at BGR and research institutions. The map presents information that is needed for example for the interpretation of the spatial distribution of trace element background values. A concomitant project looked at the question of how the properties of soils have to be assessed at a national level with respect to their soil texture distribution. Both topics – background values for trace elements and soil texture distributions – play an important role in the revision of the federal soil protection legislation and are of fundamental importance in providing advice to government departments.

Advice to the departments is also given within the framework of methodological development. Among other things, the answer to the question "What kinds of clay minerals and how many are present in soils – and how can they be quantified?" is used to advise the German Ministry of Nutrition, Agriculture and Consumer Protection for the technical steering of the survey project conditions of forest soils.

When working on basic geoscientific issues, BGR cooperates with the State Geological Surveys in Germany within the framework of the Ad-hoc-Soil Working Group, set up by the Federation/Federal States Committee on Soil Research of the Conference of the Ministers of Economic Affairs. In 2005, BGR took the chair of the Ad-hoc-Soil Working Group, revising and upgrading the fifth edition of the guidelines for soil mapping.

"Soil is precious"

This idea is aimed at boosting the awareness of various stakeholders (for example citizens, entrepreneurs, consumers, legislators, public providers) and raising the status of soils as valuable environmental resources…

(Excerpt from expertise of the Scientific Council to the German Ministry for the Environment, Nature Conservation and Nuclear Safety, 2000)

Another essential factor supporting sustainable and careful soil management in addition to scientific information is the creation of awareness among the general public.

Soil scientists at BGR make contributions at important public occasions (e. g. festivals of science) or in publications aimed at politicians as well as interested members of the public. A good example is the European Soil Atlas published in 2005, produced with the participation of BGR soil scientists.

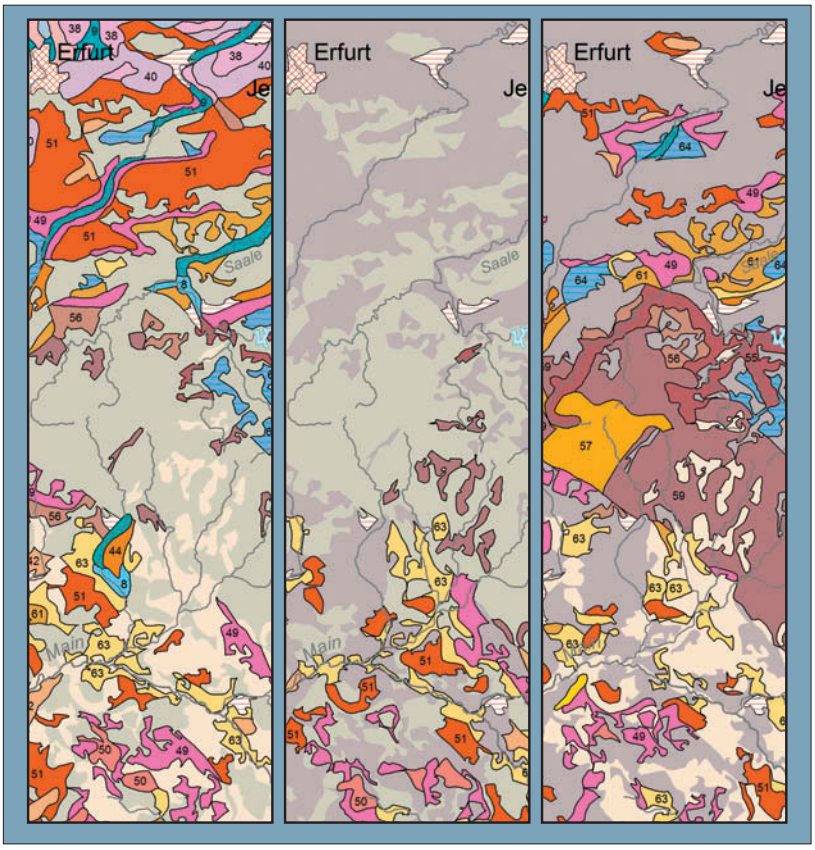
These efforts are bearing fruit: according to an internet enquiry in 2005 on the topic of soil protection, more than 90 % of EU citizens considered the mitigation and reduction of soil losses, as well as the losses of soil functions, to be "very important" or "important". Furthermore, more than 70 % of EU citizens agree that standardised framework regulations should be created at an EU level, but that individual actions should be implemented at a national or local level.

The work of BGR in this context ensures that Germany has the basic geoscientific data required for this purpose.

Land-use and **soil** in Germany

In 1995, the first post-reunification national small-scale soil map at a scale of 1:1 000 000 was produced by the Federal Institute for Geosciences and Natural Resources (BGR) for the new and old federal states of Germany (BÜK 1000). This involved harmonising the content and nomenclature of the previously existing soil maps. Since then, the BÜK 1000 has served as the main data source not only for the map database of BGR's Soil Information System (FISBo BGR), but also for numerous national-level research and policy-support actions.

The demand for nationally comparable and quality-checked soil information has strongly increased since the Federal Soil Protection Act (BBodSchG, 1998) came into force. In addition, regional soil data became increasingly available as a result of soil mapping work and the digitisation of older data by the German federal states. After accurately evaluating the specific user requirements for soil maps, it was shown that the specific soils under different land uses are crucial for the interpretation of soil evaluations. Thus, it became necessary to closely investigate the soil communities for the main land cover types: forest, grassland and cropland. It was therefore decided to utilise land-use specific soil data to further specify the legend information of the BÜK 1000 according to the main land uses (land cover types: forest, grassland and cropland).



Land-use stratified soil map of Germany at a scale of 1:1.000.000. Map extracts for cropland soils (left), grassland soils (centre) and forest soils (right)

Definition and delineation of land use within the soil map

The database for land use is the CORINE land cover (1990). The data was generated roughly at a scale of 1:100.000. For this project, the original 44 land cover classes were combined within 14 composite classes. The resulting forest, grassland and cropland areas cover 90 % of the German land surface.

Because the map units of the BÜK 1000 describe the heterogeneous and spatially structured inventory of soils at the overview scale of 1:1.000.000, it is not possible to directly infer soil data from this database for land-use stratified sub-polygons. This limitation, and because the land cover and soil databases have substantially different resolutions, resulted in the introduction of the soil/land-use cartographic framework concept. It contains the generalisation of the 100 m CORINE land cover databases into map polygons of at least 4 km2. Even though the number of land use patches in the resulting map was greatly reduced, such generalisation is essential for further database development. A simple overlay with the soil map provides the final geometric soil/land-use maps. For each of the main land cover types (forest, grassland, cropland), the graphics of the BÜK 1000 became stratified into land-cover specific sub-polygons.

Climatic stratification

Different climatic regimes clearly affect soil formation and soil properties. This may be especially valid for base map scales covering large land areas. Soil mapping units, which extend beyond climatic regions, require further regional stratification. This was accomplished with the four macro-climatic areas from the Georeferenced Soil Data Base for Europe.

Land-use stratified soil inventory and reference soil profiles

At this stage, the soil map is stratified on a purely graphical basis (cartographic basic framework). It is now important to describe the soil properties for the area under forest, cropland and grassland. However, the general BÜK 1000 legend descriptions are not sufficient to describe the soil inventories of the land-use stratified soil (sub-)polygons. In order to retrieve more detailed information on the distribution of the dominant and associated soils under specific land uses, larger-scale soil maps are needed. The specific soil properties for land-use stratified and quality-checked soil properties were derived from National Forest Soil Monitoring data and from BGR's soil analytical and profile database (FISBo BGR). However, this step was only realised for the dominant soils.
66, 55 and 63 mapping units are found under cropland, grassland and forest respectively. If the effect of larger mapping units and climate regions are also considered, the total number of mapping units with separate descriptions for land use increases to 205.

Map development
The results are presented in three individual map sheets, forest, cropland and grassland soils. The hue of the basic colours for the main land cover types (green: forest; grey: cropland; yellow: grassland), not presented in each of the maps, is reduced to background intensity to make the maps more readable. The colours for the presented soil mapping units correspond to those suggested by the German Soil Mapping Guideline (4th edition).

The topographic basis for the map is the digital landscape model 1:1.000.000 provided by the Federal Agency for Cartography and Geodesics (BKG). It contains data on hydrography, settlement and mining areas, the geodetic system, and the administrative boundaries. The delineation of the soil mapping units was harmonised with the topographic data, which greatly improved the spatial accuracy of the mapping units.

Explanatory notes were produced, which contain accurate descriptions of the input data, methodologies (e.g. selection of the soil profiles), and resulting profile descriptions.

Map legend
The legend in each of the three maps contains short descriptions of the dominant and associated soils as well as the parent material. Mapping units which do not contain one of the main land cover types are combined into one legend entry as "area of other use", for example, settlements, mining areas, aquatic areas. Supplementing each map, a separate and more extensive description of the map legend is available in digital form. It contains the general legend information from the original BÜK1000, such as information on parent material and depth of the soil, as well as data on the land-use specific soil profiles and properties.

Map database
The thematic information of the map together with the geometric data are part of an ArcInfo geo database. The entries are sorted by mapping unit, land use, climatic area, soil region, and dominant soil type. The characteristic association of soils is also provided. The map database fulfils specific user needs by extracting the chosen soil parameters available for the dominant soils in each of the three maps.

Summary

The evaluations and interpretations of thematic maps in the context of soil protection and sustainable soil management can be greatly improved with the land-use stratified soil map of Germany. For example, the data has already proven useful to identify potential hazards to soils, such as soil erosion, which can then be used in support of national and EU-related environmental policies and reporting. Furthermore, the user receives a more exact image of the soils associated with a specific land-use regime.
Universities and other research institutions, as well as agro-industrial research organisations, are already working with database extracts, which specifically address the respective data needs.

Soil texture –
a key parameter of **soil assessment**

The Federal Institute for Geosciences and Natural Resources (BGR) is compiling basic geoscientific information at a national scale to give advice to the German Government and German industry. This includes information on soil because pedological reference parameters are needed when looking at preventative soil protection for instance. Thus, the composition of the mineral constituents (grain size distribution, soil texture) is an important assessment criteria for soils when dealing with many ecological questions (e. g. groundwater recharge, retention of pollutants) and economic questions (e. g. agricultural production).With this in mind, it is intended to give as precise as possible information on the typical distribution of the texture of topsoils and their spatial variability. By this it should be possible to complete and characterise existing information based entirely on expert knowledge.

Soil texture is an expression of the size and composition of the mineral particles that, together with the organic particles, account for the solid substance of soils. Type, size and properties of mineral particles depend on the parent material of the soil and weathering, and consequently on the intensity of soil development. According to the size of the mineral particles, one can distinguish the grain fraction sand (Ø = 2.0 – 0.063 mm), silt (Ø = 0.063 – 0.002 mm), and clay (Ø < 0.002 mm).

The grain fractions have very different properties: sand grains retain very little water, the same applies to plant nutrients and pollutants. Clay particles can adsorb and retain these substances. Due to their high water retention, soils with very high clay contents are subject to water logging, and it is very difficult to cultivate these soils. In the table on the right, the properties of sandy and clayey soils are shown in their extremes. Mixtures of more or less equal proportions of sand, silt, and clay are called loam.

Properties of soils of different composition

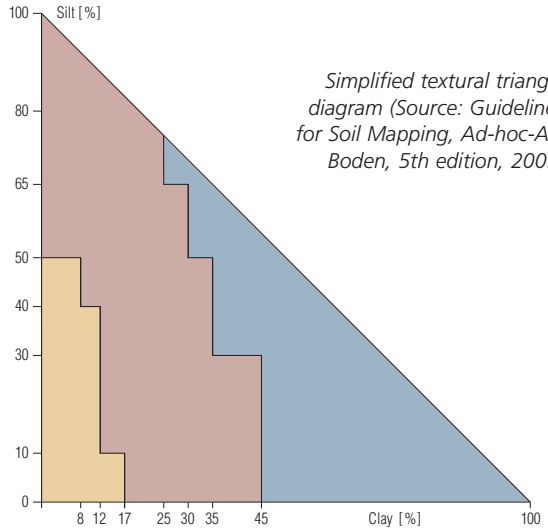
Property	Sandy Soil*)	Clayey soil*)
Grain size	coarse (>0,063 mm)	small (<0,002 mm)
Pore size	wide	small
Aeration	good	bad
Water percolation	good	bad
Retention for plant nutrients and pollutants	bad	good
Warming	rapid	slow
Management	good	bad

*) Loamy soils are between sandy and clayey soils

The properties of loamy soils lie between sandy and clayey soils, and due to their good physical and chemical properties, these soils are of major economic importance. In spring time, the different properties of the grain size compositions become apparent, when recently ploughed fields dry in different patterns reflecting the varying soil textures.

In soil texture classification, the ratio of sand : silt : clay is decisive. The respective soil texture is determined in the chart showing percentages of sand, silt, and clay (triangular texture diagram).

Differences in grain size composition in soils cause different patterns when drying.



Simplified textural triangle diagram (Source: Guidelines for Soil Mapping, Ad-hoc-AG Boden, 5th edition, 2005)

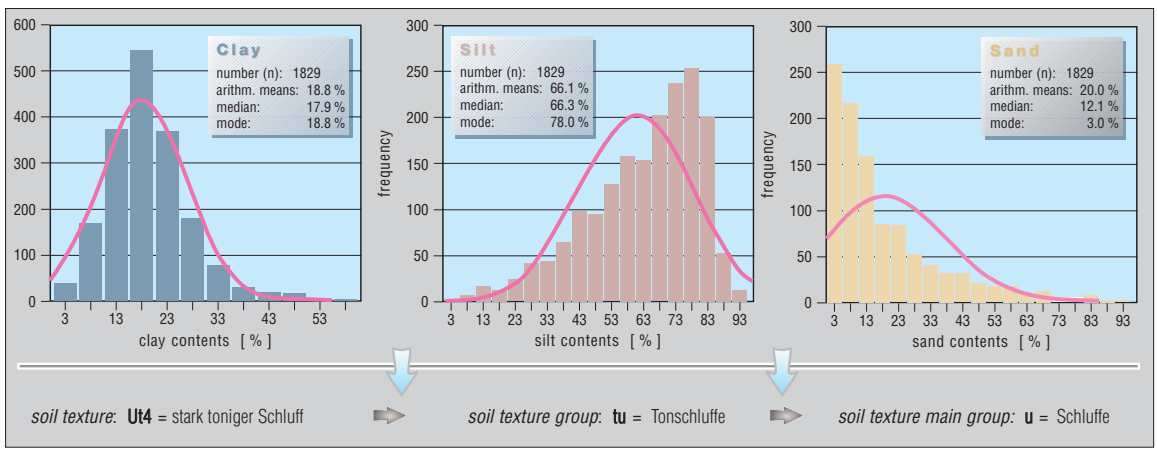
Soil basic information in map form

The importance of soil texture makes it a basic parameter for all pedological infor-mation. The BGR provides a map showing texture classes in topsoils, which high-lights the predominant textural classes of topsoils in Germany. The map is based on information of some 16 000 topsoil horizons compiled at BGR and other Geological Surveys. The soil profiles were allocated to the mapping units of the 1 : 1.000.000 soil map and statistically evaluated. The soil map (1:1.000.000) is stratified according to land use, and provides a base map for the territory of Germany. In the descriptions of the soil associations there is also information on parent materials (substrates) which are important for the development of the textural classes.

The statistical distribution of sand, silt, and clay contents was determined based on the sum of all representative profiles of each legend unit. The soil texture was identified in the triangular texture diagram using the medians of the clay and silt fractions. In. The map presentation is restricted to the level of soil textural classes to guarantee the level of clarity appropriate to the scale. More detailed statistical results are available to work on the questions mentioned above. As result, typical grain size distributions and soil textures are presented for all soil associations in Germany.

What is done with the information?

The provision of basic geoscientific information is one of BGR's core tasks. On the scientific side, the information on soil textures and their distributions can serve as input parameter for models to calculate soil functions, potentials and risks (e. g. nitrate retention, erosion hazard). They can also increase the precision of soil-related evaluations by rendering the uncertainty and variability in space. Knowledge of the typical distributions of the soil textural classes also plays a major role in consulting services because soil textural classes are reference values for the classification of the precautionary values stipulated by the current Soil Protection Act in combination with the Federal Soil Protection and Contaminated Sites Ordinance.

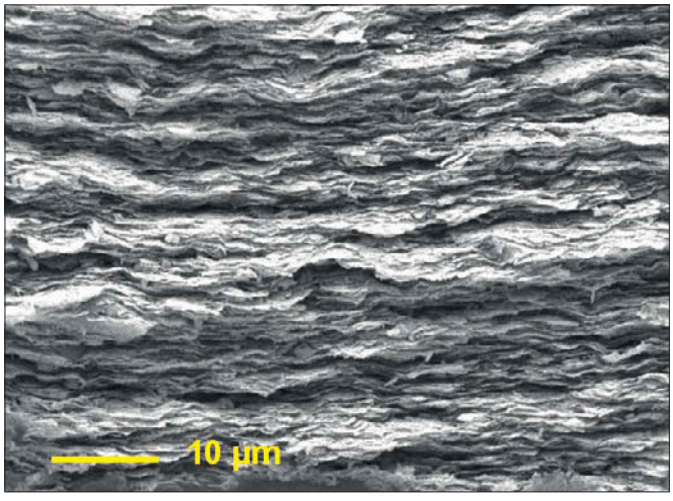


Distribution of clay, silt and sand contents of the soil association "Medium to deep layered brown silty clays with clay-rich subsoils consisting of loess or elocated loess clay…"

What kinds of **clay minerals** and how many are present in soils – and how can they be **quantified**?

Soils on the mainland develop from rocks near the surface affected by climatically driven processes. Soils have important ecosphere functions: regulation of air, water, and material cycles; habitats for microorganisms; agricultural use and forestry operations. They consist of minerals and organic matter. Clay minerals in particular have a major influence on soil functions.

Understanding the relevant soil processes is essential for understanding soil functions. Here it is important to know the quantity of the minerals and their properties. Approx. 5–15 minerals are usually present in soils. The problem is that qualitative analysis (which minerals?) and quantitative analysis (how many minerals?) is complicated, error prone, and laborious. To overcome these problems, scientists at the Federal Institute for Geosciences and Natural Resources (BGR) and the State Authority for Mining, Energy and Geology (LBEG) develop and standardise procedures for the quantification of soil clay minerals.



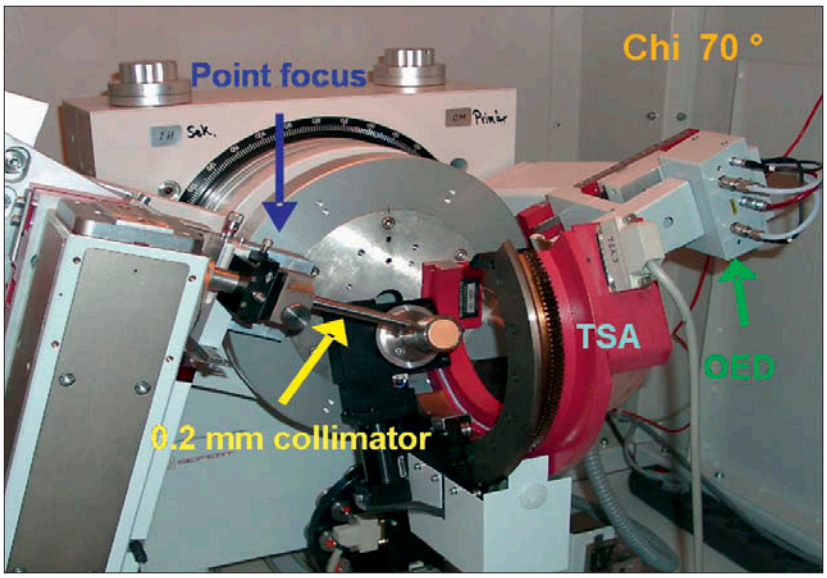
Scanning electron micrograph answering the question: How high is the degree of orientation?

Two projects were finished successfully. These projects were performed in cooperation with the Freiberg/ Sachsen Technical University and Aachen Technical University, and Halle/Saale University.

In the first project we succeeded in developing models suitable for the quantification of swelling clay minerals. This involves grinding these sheet-like minerals as fine as flour and preparing them for analysis in a suitable measuring device without creating too much preferred orientation. The challenge of the project was that the extremely fine crystallites, a millionth of a millimetre in size, are not exactly parallel to each other in three dimensions. This natural condition resembles a deck of cards that is pushed sideways. This results in an arrangement of planes that are parallel in two dimensions. For the third dimension, an exact projection is impossible because each card can be distorted by a random angle compared to the underlying one. The technical term for this is turbostratic disorder. This makes physical measurement very tricky.

However, the problem was soluble. A "real structure" model was developed for minerals of the smectite group, representing the most frequent swelling clay minerals. This model allows the arrangement to be described in a physically meaningful way. The resulting PhD thesis of Dr. K. Ufer was honoured in 2005 by the German Clay Group (Deutsche Ton- und Tonmineralgruppe, DTTG) with the scientific Karl-Jasmund award. The figure at the following page is taken from the presentation of the results at the conference.

A different approach to soil clay mineral quantification was looked at by a joint research project with Halle University. Here, the exact parallelism of the sheet-like clay minerals was studied because these oriented aggregates can also be quantified. For many years scientists have debated the physical meaning of the results. All clay mineral sheets are of different size with typical diameters ranging from millionths to thousandths of a millimetre. Some minerals are frayed by weathering and some are lath shaped.



Developing a measuring method.

The project proved for the first time that the texture of swelling clay minerals could be quantified. Very small minerals are usually poorly oriented and so flexible that they are oriented more or less non-parallel to the surface of a specimen that is used for analysis. It could be shown that minerals in mixtures influence each other so that the resulting degrees of textural ordering differ from one sample to another. The mechanism involves large minerals forcing the smaller minerals to be become better oriented. The results of the project clearly show that traditional methods based on the assumption that all soil clay minerals have the same degree of orientation, even in different samples, cannot work.

Both studies are important because they allow us to evaluate the limits and possibilities of the methods used. The advantage of these methodological developments is that the quality of the quantification results of these important minerals in terms of soil properties is now more comprehensible. In addition, more soil samples can be quantified. The results of the studies can be regarded as an important milestone in better understanding the processes involved.

BGR will use the knowledge from both projects to monitor a research project aimed at classifying the parent rocks of forest soils. This is part of the Survey of the Condition of Forest Soils (BZE II) implemented in cooperation with the German Ministry of Nutrition, Agriculture and Consumer Protection (BMELV).

Legislation needs basic scientific facts: **heavy metals in soils**

In 1998, the 'Act on Protection against Harmful Changes to Soil and on Rehabilitation of Contaminated Sites' (briefly: Federal Soil Protection Act (BBodSchG)) came into force. In combination with the act, regulations (Federal Soil Protection and Contaminated Sites Ordinance) were also adopted to implement the Act. For example, it defines the criteria for the investigation and assessment of areas with suspected soil contamination, and it defines the demands preventing the use of harmful substances.

After the ordinance was adopted, the Upper House of the German Parliament (Bundesrat) decided to review and, if necessary, to change the established safe limits based on expert advice and advanced scientific knowledge.

Against this background, BGR carried out substantial geoscientific research to define background values representative for areas of selected trace elements (cadmium, chromium, copper, mercury, nickel, lead, zinc) in topsoils and subsoils.

Background values

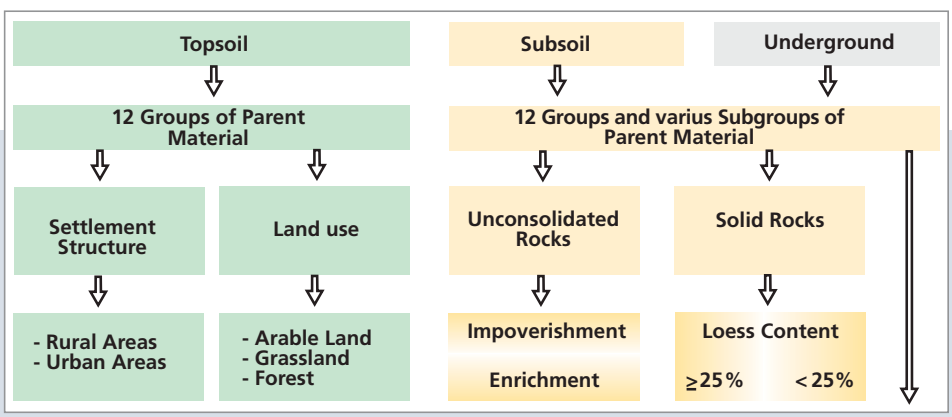
Background values are representative values of generally widespread background concentrations of a substance or a group of substances.

(German National/Federal States Committee on Soil Protection (LABO) 2003)

Precautionary values

soil values which, if exceeded, shall normally mean there is reason that concern for a harmful soil change exists, taking geogenic or wide-spread, settlement-related pollutant concentrations into account.

For this, concepts were developed clarifying workable criteria for differentiating the amounts of trace elements in soils. Subsequently, the developed concepts were implemented using some 5.000 to 8.000 soil profile descriptions archived by the Federal States and BGR. The identified background values were shown on the revised soil map 1:1.000.000 indicating the land use (see article on soil base map differentiated according to land use). The following presents the results for lead (Pb) and nickel (Ni) using the base maps for typical concentrations of trace elements in



Concept of stratification for the definition of background values in topsoils and subsoils, as well as in the substrata.

topsoils and subsoils. Lead serves as a typical element introduced into our environment as a result of human activities (anthropogenic main element). Nickel is considered to be an element whose presence in our environment is mainly due to the local geology (geogenic main element).

The scientific concept

The factors that affect the concentrations of trace elements in soils are adequately known from various investigations. As soils develop by weathering from rocks, background values for trace elements are primarily differentiated according to the parent material; in the case of subsoils, additionally according to subgroups of parent material. Information is available from the soil base map on the distribution of 15 groups of soil parent material. At a subordinate level, the topsoils are classified according to settlement patterns (urban/rural areas) and according to main land use types or land cover (cropland, grassland, forest, others). Subsoils are classified according to parent material from unconsolidated or solid rocks. When defining the background values in subsoils, consideration is also given to the fact that large parts of Germany (primarily regions with solid rocks) were covered by a more or less thick layer of loess during the ice ages. That is why when dealing with soils from solid rock, we also subdivide sub-soils according to the amount of added loess. In soils derived from unconsolidated rocks, we differentiate between soil horizons affected by accumulation or depletion – which play a role in various soil forming processes (pedogenetic processes). The figure on the opposite page summarises how the units (soil scientists talk of "stratification") are built up (concept of stratification).

On the basis of the map mentioned above, the stratified profile information was superimposed with the soil parent material map and the main land cover units. To create a map representation appropriate to the scale, the superimposition was carried out with the provision that point and area information coincide with the soil parent material and land cover. In addition, the frequency distributions of soil texture and soil types of the respective random samples should coincide with the distributions characteristic for the relevant legend units as a measure for the representativeness as regards content. Random samples with a number of at least $n \geq 20$ were statistically evaluated.

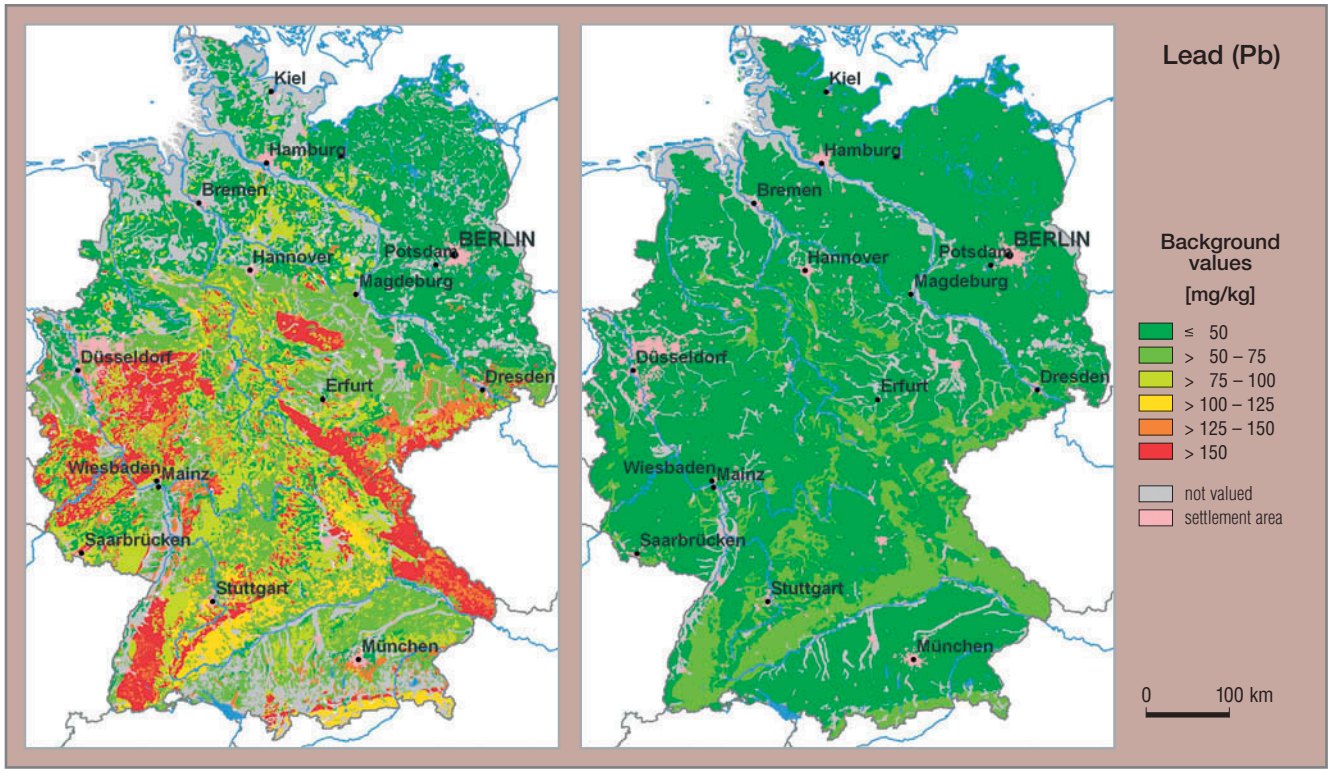
Results

As a result, background values for topsoils, subsoils and substrata can be presented at a national level for those trace elements whose precautionary values are regulated in the Soil Protection Act. For the characterisation of the defined background values, the number of profiles used, the median and the 90 percentile values are given as recommended by the Federal-States Working Group on Soil Protection. The evaluations refer to the total concentrations of the listed elements.

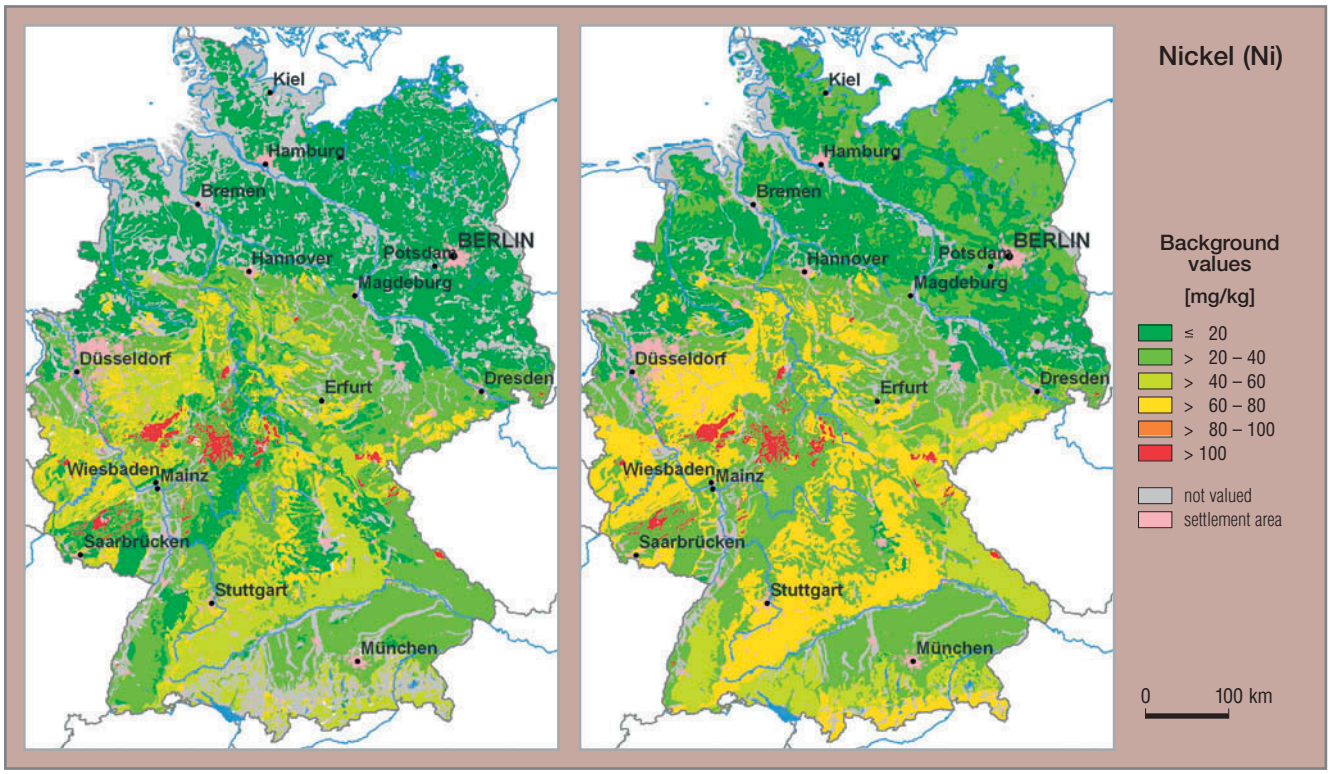
Soil profile descriptions from the German States significantly increased the number of random samples. It was thus possible to verify the background values of the trace elements mentioned above for almost all relevant legend units nationwide. The two figures at the following page show the 90 percentile values of the distribution of the lead and nickel concentrations. The typical distribution patterns of elements which are strongly influenced by either anthropogenic (created by humans) or geogenic (originated from parent material) factors become apparent.

The Pb concentrations in topsoils are with few exceptions (e. g. Lias claystone) significantly higher than in subsoils. The highest concentrations are found in topsoils under forest land cover in hilly areas due to the "comb-out" effect of forests on wind-borne trace elements. In subsoils, the lead concentrations are very similar (exception: Lias claystone), soils above solid rocks tend to have double the Pb concentrations of lowland soils derived from unconsolidated rocks.

The reverse holds true for nickel as a leading geogenic element: the subsoils have significantly higher concentrations than the topsoils, in particular in the solid rock areas. The highest Ni concentrations are found in the group of alkaline igneous rocks and metamorphic rocks. In this soil parent material group, the dilution effect of loess becomes apparent: the highest concentrations of Ni are found in substrata with no loess, followed by subsoils with low levels of loess, subsoils (close to surface) rich in loess, and topsoils. Despite the dilution by loess, the geogenically higher concentrations of Ni can still be traced in the topsoils. Different concentrations in topsoils due to different land uses are minor and inhomogeneous. The soils derived from unconsolidated lowland rocks do not reveal much differentiation, neither between groups of soil parent material nor within topsoils and subsoils within each group.



Percentile values (classified) of lead concentrations in topsoils and subsoils.

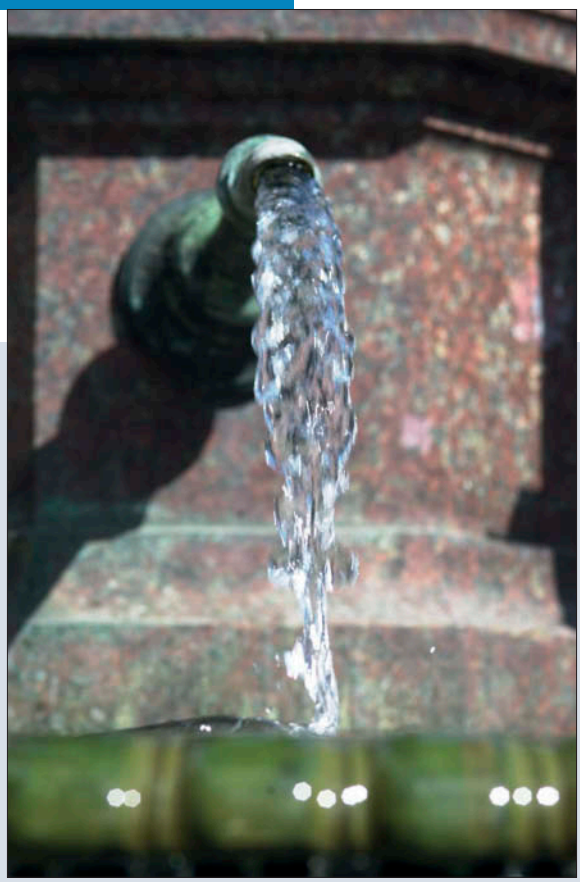


Percentile values (classified) of nickel concentrations in topsoils and subsoils.

Conclusions

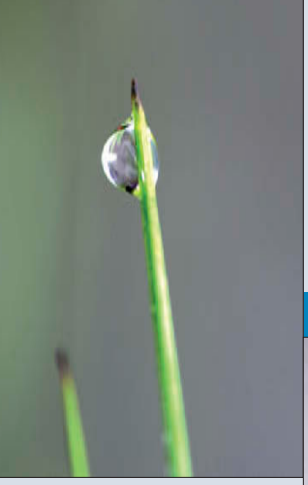
The development of the stratification concept makes it possible to define plausible background values for Germany thanks to the great improvement in the information. The results are used to describe the general trace element related condition of the soil required to provide technical advice for legislation matters. The relevance to soil protection legislation is the highest priority. Background values are used for plausibility checks when defining precautionary values, and are a fundamental basis for the justification, recording, and harmonisation of regulations to limit immissions. BGR experts are involved in consultation on various topics to prepare the amendment to the Federal Soil Protection and Contaminated Sites Ordinance. Furthermore, background values are applied for regulations concerning the deposition and incorporation of substances on or into the soil, a topic which directly affects the business sector.

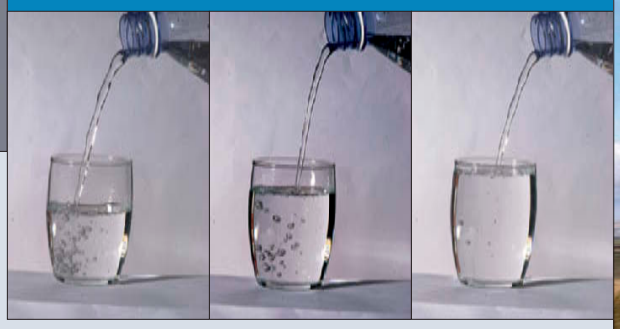
It is planned to augment the information on typical elements in soils (e. g. in connection with the second assessment of forest soil conditions) and to account for more elements (e.g. As, Se, Mo, Sb, U).

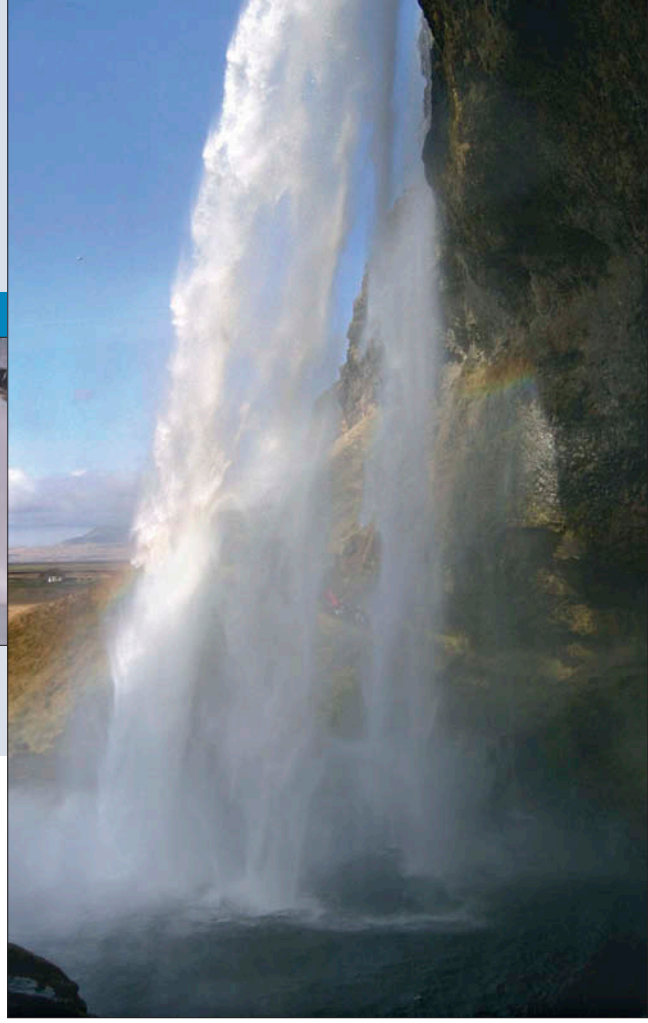


Georesource Water

Water Water







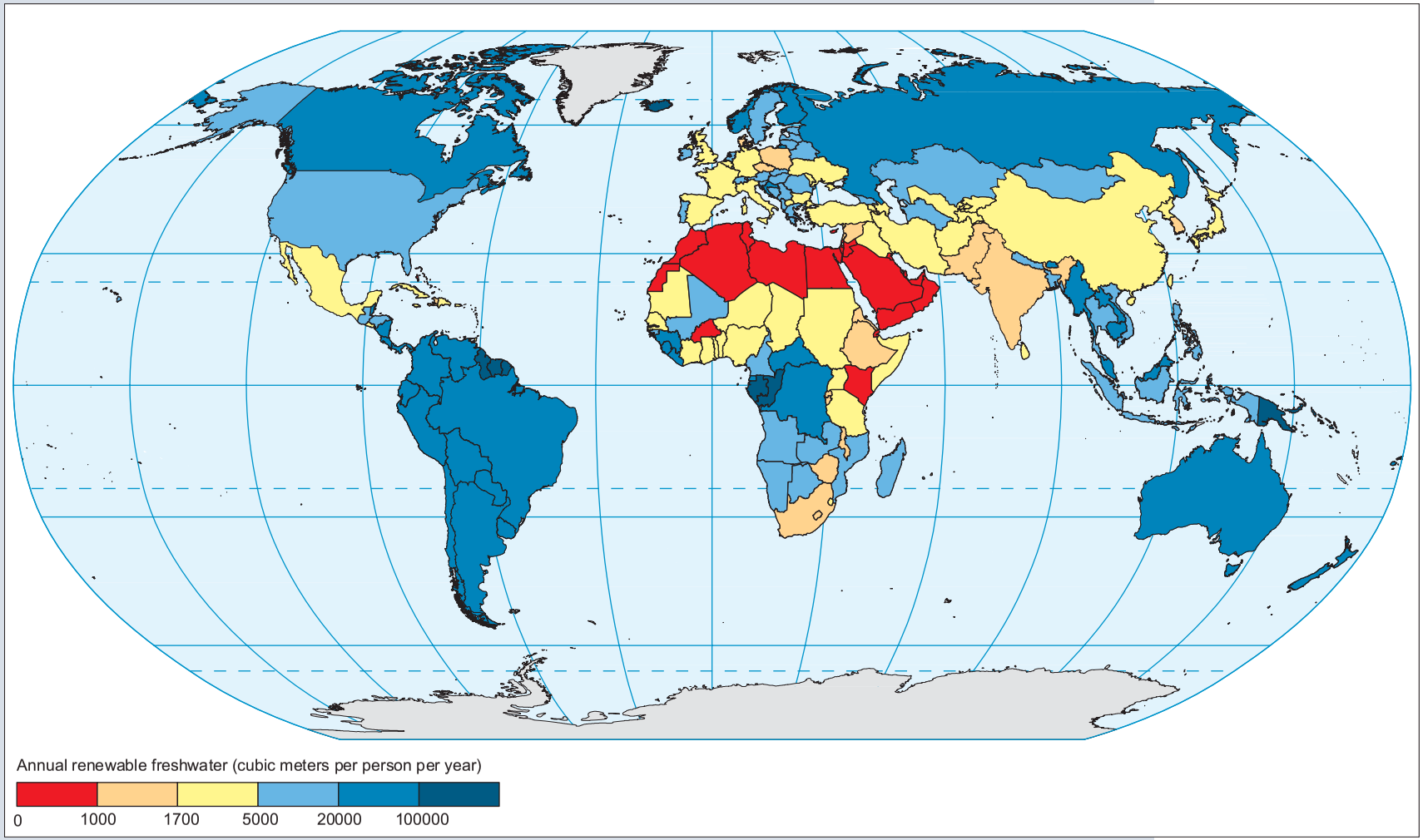
Are we running out of **drinking water?**

The media have recently been full of reports that the world is facing an imminent water shortage. Similar statements are also included in the first World Water Development Report. Are the drinking water resources really drying up?

The earth is called a blue planet with good reason: around 71 % of the earth's surface is covered with water. The calculated amount of water on the earth is an incredible 1.4 billion km^3. However, most of this is salt water, and only around 2.5 % of global water resources are fresh water (approx. 35 million km^3).

Only a small part of these freshwater resources can be used because approximately 69 % are locked up in ice and snow, primarily in the polar or mountainous regions. The rest is present in the form of groundwater and surface water. The proportion of surface water in wetlands, rivers and lakes is less than 0.5 % of the global freshwater resources, whilst water beneath the surface, i.e. groundwater, accounts for the remaining reserves of available freshwater with a proportion of 30 % (approx. 10.5 million km^3).

But how much water is sustainably available around the world, i.e. without overexploiting the resource? Global freshwater resources of about 43.000 km^3 are flowing into the oceans annually and can be considered as renewable. If we compare this with the global population in 2006, approx. 6.6 billion people, then there are theoretically 6.500 m^3 fresh water available per year per person. This theoretical figure would still be 5.400 m^3 fresh water per person per year for the forecast global population of 7.9 billion in 2025.



The annual renewable water supply per person varies greatly across the world (source: WRI 2006)

This average figure of over 5.000 m^3 fresh water per person per year is, however, totally unrealistic because it does not take into account the regional distribution of freshwater resources. People in almost 30 countries are already suffering from water shortages because there is less than 1.000 m^3 water available per person per year. Most of these countries are situated in North Africa and on the Arabian Peninsula. This unequal distribution will get worse in the coming decades as a consequence of population growth, economic development and climate change. According to UNESCO, around 1.8 billion people will live in countries or regions with absolute water shortages in 2025.

This still does not justify the alarmist cries of a global water crisis. There is enormous potential for saving water even in the driest parts of the world. The situation in these regions can be significantly improved by using water more efficiently and protecting groundwater resources more effectively. The biggest problems today are not so much physical shortages of water but bad or non-existing water management in the form of unregulated usage, lack of expertise on water-saving irrigation methods and resource protection measures, as well as inadequate financial resources and infrastructure deficiencies.

There are numerous approaches and methods for improving water management and thus counteracting water shortages: these range from quantifying the amount of possible groundwater resources, the development and implementation of sustainable management strategies, and the initiation of legislation governing protection and usage. In this context the Federal Institute for Geosciences and Natural Resources advises the German government on water sector issues, provides groundwater-related input to integrated water resources management programmes in developing countries, and supports national and international measures to protect water resources.

An example of BGR's activities in Germany is the installation of a long-term groundwater monitoring system at the former Altmark military training area in Colbitz-Letzlinger Heide. BGR therefore plays an important role in the sustainable maintenance of water supplies to the city of Magdeburg and the adjacent rural districts to the north.

BGR also supports the German government via technical cooperation projects in the groundwater sector to achieve its millennium development goal of halving the number of people who have no access to clean drinking water by 2015.

- BGR conducted a groundwater exploration project in Namibia to locate previously unknown resources in the north-east of the country which can now be used to supply water sustainably to the rural inhabitants.
- A national groundwater model was formulated in Jordan which is used as the basis for sustainable water management, and which can therefore make a significant contribution to the water resources vital to the country's survival.
- The containment of uranium-bearing mining dumps near Mailuu-Suu in Kirgizstan improves groundwater protection in one of the most seriously polluted regions in the world.

And finally, the WHYMAP project conducted in collaboration with UNESCO and other institutions globally active in the water sector, maps and evaluates global groundwater resources for the first time in a form comprehensible to non-water experts.

Groundwater resources management in Jordan

The nationwide groundwater simulation model is the foundation for the "National Water Master Plan"

The Haschemite Kingdom of Jordan is divided up into three physiographic regions – highland, the Jordan Rift Valley and the desert – and is exposed to a combined Mediterranean and arid desert climate.

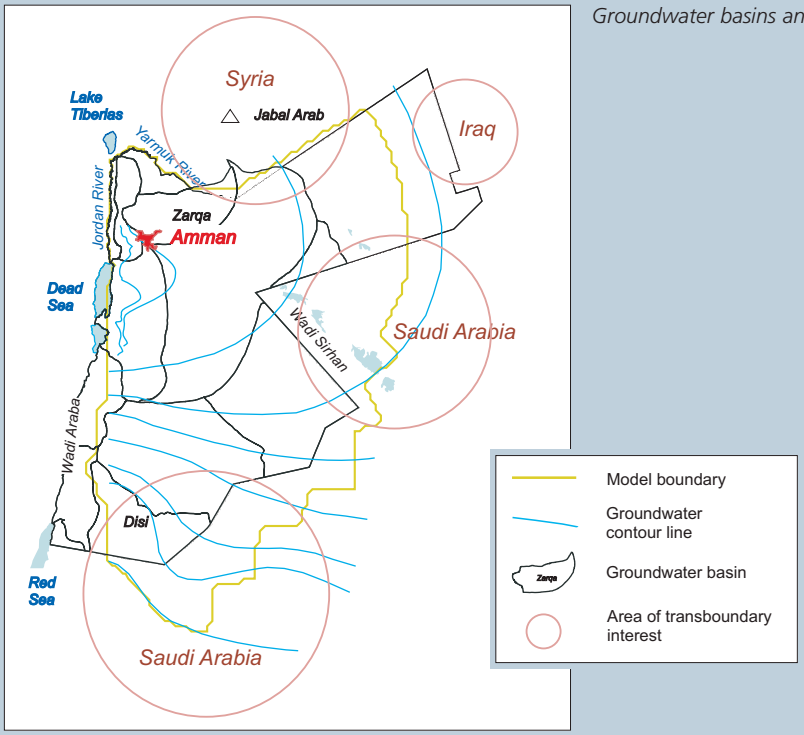
The country has a total area of 89.206 km^2 and a population of 5.8 million (2005). The different climatic zones, and thus water-relevant living conditions, mean that most of the population are concentrated in a few conurbations, and particularly in the Amman-Zarqa region. 1.9 million people alone live in the greater Amman area. Because Jordan has one of the fastest growing populations in the world (approx. 3 %), the provision of adequate water supplies will continue to be a critical issue in future.

A global comparison identifies Jordan as one of the ten countries with the lowest volumes of available renewable water resources per capita. It has been suffering from a water crisis for many years. Although Jordan has the lowest water consumption per capita in the Near East – approx. 90 litres per capita per day – the country still uses more water than is naturally replenished by precipitation (groundwater recharge) and river water (the Jordan and Yarmuk). The non-renewable fossil groundwater reserves are now also being exploited to an increasing extent.

Because water demand is largely covered by extracting water from the renewable groundwater, this overexploitation causes considerable drops in the water table resulting in the drying out of wells and wetlands. The conflicting demands of the inhabitants, agriculture and industry are jeopardising the secure provision of water supplies nationwide, and also putting water quality at risk: this is because overexploitation causes salty water to encroach on the freshwater aquifers. In addition, the use of agricultural fertilisers and pesticides, and the partially uncontrolled disposal of waste and wastewater, also expose the groundwater to considerable pollution risks.

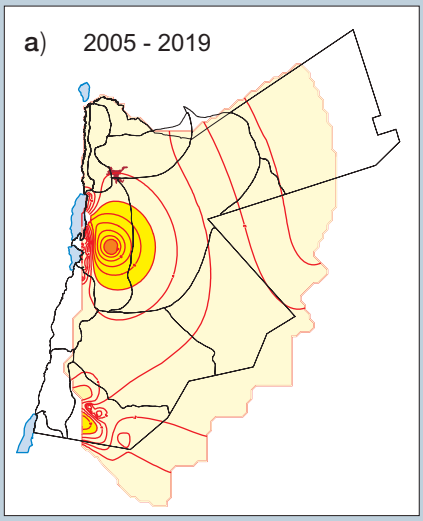
BGR's co-operation projects with the Jordanian water authorities focus on the protection of water resources against contamination and overexploitation. BGR has contributed for approximately 30 years to the expansion of the relevant expertise, including the exploration and evaluation of groundwater resources throughout Jordan. The National Water Master Plan (NWMP) is the main planning instrument in Jordan for the sustainable use and protection of groundwater resources. BGR provides assistance in formulating the NWMP in the form of basic hydrogeological data and water balances. The water balances are calculated on an up-to-date basis from the nationwide groundwater simulation model jointly developed by BGR and the Ministry of Water and Irrigation.

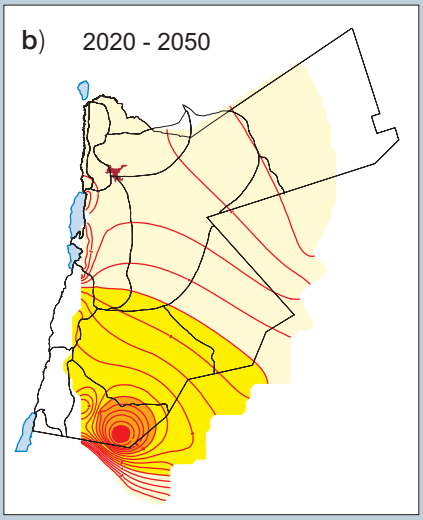
Jordan's groundwater system is part of a regional complex extending into the neighbouring countries of Syria, Iraq and Saudi Arabia. The groundwater system consists of a complex sequence of basalts, limestones and sandstones, which can be separated from one another by less permeable to almost impermeable rock formations consisting of marl, clay and schist. The groundwater system can be divided roughly into two flow systems. The upper system consisting of basalts and limestones is recharged by annual precipitation on the topographically high parts of the country, and develops a shallow dynamic groundwater system with natural local discharges and spring flow. Groundwater flow in this system is generally in the direction of the Wadi Sirhan topographical depression in the east of the country.

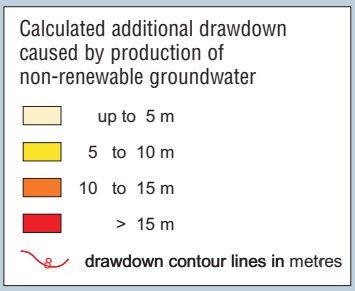


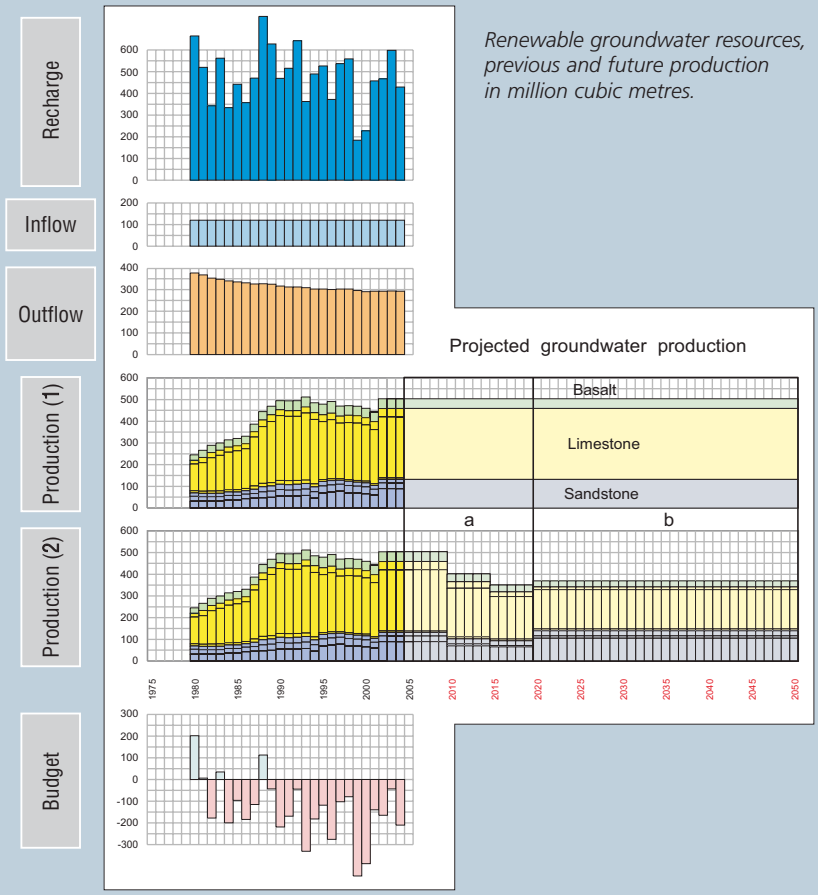
Groundwater basins and transboundary aspects.

Model results on the effects of production scenario 2 in the sandstone aquifer.









Renewable groundwater resources, previous and future production in million cubic metres.

The deeper system consisting of sandstone formations is filled with fossil groundwater which mainly accumulated several thousand years ago under the more favourable climatic conditions prevailing at the time (pluvial period). This groundwater generally flows in the direction of the depressions in the Jordan Valley and ultimately discharges into the Dead Sea, whose water level is approx. 400 m below global sea level. The local outcrops of the sandstone complex are only recharged in the northern part of the country: the large sandstone outcrops in the south of the country cover an area currently dominated by an arid climate where the aquifer is not recharged.

The three-dimensional groundwater flow model covers an area of approx. 100.000 km^2, encompassing ten hydrogeological units (rock formations) dipping down to depths of approx. 2.000 m. Parts of Saudi Arabia (Wadi Sirhan and areas south of the border of Jordan) were incorporated in the model for geohydraulic reasons – water knows no political boundaries.

Based on a groundwater situation calculated from the model assuming almost natural conditions, ideally not affected by abstraction activities, the model simulates the development of the groundwater system in Jordan over the last three decades making allowance for precipitation and volumes of groundwater abstraction.

The calibrated model developed on the basis of water level observations and discharge records is therefore the main instrument for modelling the current groundwater situation, and forecasting the effect of planned groundwater abstraction strategies. The potential effects are shown in the form of water level drawdowns and groundwater budgets (also for selected subzones, e.g. administrative regions and catchment areas). Two strategy scenarios have already been simulated with this model. These examples reflect the future planning of the NWMP and extrapolate the potential effects until 2050.

All of the water management measures change the groundwater system and can therefore have transboundary consequences. Large-scale activities therefore require pan-regional agreements and the exchange of information at an international level in order to avoid conflicts. The Wadi Sirhan area, the southern region of Jordan, and the basalt complex in the north around Jabal Arab in particular are all of high bilateral interest for joint management in this context.

Within the context of renewable groundwater reserves, there is a dramatic deficit between natural reserves and water consumption in the Jordanian water budget. Based on an average precipitation of 7.400 million m^3 (MCM) for the period 1980 to 2004, annual average groundwater recharge has been 470 MCM. The extreme events of 700 and 185 MCM in 1988 and 1999 respectively clearly highlight Jordan's dependence on annual precipitation.

The potential yield is supplemented in the northeast of the country by the transboundary groundwater inflow from the Syrian part of the basalt formation on the flanks of the Jabal Arab (68 MCM/year), and nationwide by an additional 42 MCM/year estimated in the model area from the return flow from agricultural irrigation.

From this total potential yield of 580 MCM/year (average), the groundwater system loses water naturally over the course of the year by way of e.g. spring flow. The natural groundwater discharge has reduced continuously from almost 400 MCM in 1980 to less than 300 MCM/year as a result of the general drawdown of the water table.

The remaining yield is much less than the annual groundwater abstraction from the renewable resources reservoir averaging 410 MCM. The overall balance therefore reveals an average annual deficit of 135 MCM (peaking at 400 MCM in the dry years 1999 and 2000). The annual deficit in the Amman-Zarqa conurbation alone is 50 to 70 MCM.

The future development of the groundwater system in Jordan was estimated from models inputted with different development scenarios. If overexploitation of the renewable groundwater continues, it is estimated that the additional regional drawdown of the groundwater level by 2019 will be around 5 to 10 m – with inevitable consequences for the environment.

The National Water Master Plan (NWMP) foresees changes in groundwater abstraction with the aim of avoiding these consequences. Further groundwater drawdown is to be slowed down and stopped in the long term by the step-wise modified reduction in abstraction rates of the renewable resources. This must be compensated for by harnessing other resources or possibilities: e.g. water savings in general (also in the agricultural sector by using improved irrigation techniques) and by increasing the abstraction of fossil groundwater which already accounts for 90 MCM per year.

Every year, approx. 200 MCM of fossil groundwater currently flows unused out of the sandstone complex into the Dead Sea in the form of natural depletion. Greater use of this water is planned and will give rise to regional drawdown of approx. 10 metres by 2019. The reduced inflow to the Dead Sea will also result in a lowering of its sea level which is already dropping continuously as a result of lower inflow from the Jordan River. Additional drawdown of the fossil groundwater by approx. 20 metres by 2050 will result from the planned intensive abstraction in the Disi area.

Wadi-Wala Dam: this dam is used for artificial groundwater recharge; groundwater is withdrawn a few kilometres downstream in the Hidan well field and pumped to Amman for drinking water.

With **helicopter** and **4x4 – groundwater investigation** in the northeast of Namibia

River bordering the Namib Desert.

Covering a land surface of approx. 825.000 km², Namibia is 2.5 times bigger than Germany and lies in one of the driest regions of southern Africa. With only 2 million inhabitants, the country is one of the least populated on the African continent. Half of Namibia is considered arid, and because the scarce precipitation falls unpredictably in time and space, periods of water shortage are commonplace.

At the request of the Namibian government, a German-Namibian cooperation project was carried out between 2002 and 2005 in Northeast Namibia. Its aim was to investigate the potential of the groundwater resources in Oshivelo, Caprivi and Omaheke, in the eastern Namibian Kalahari. The Department of Water Affairs (DWA) within the Ministry of Agriculture, Water and Rural Development (MAWRD) of Namibia, and the German Federal Institute for Geosciences and Natural Resources (BGR) were partners in the exploration project. Urgent needs for water, and a realistic chance of a successful exploration campaign, were the criteria for the pre-selection of target zones.

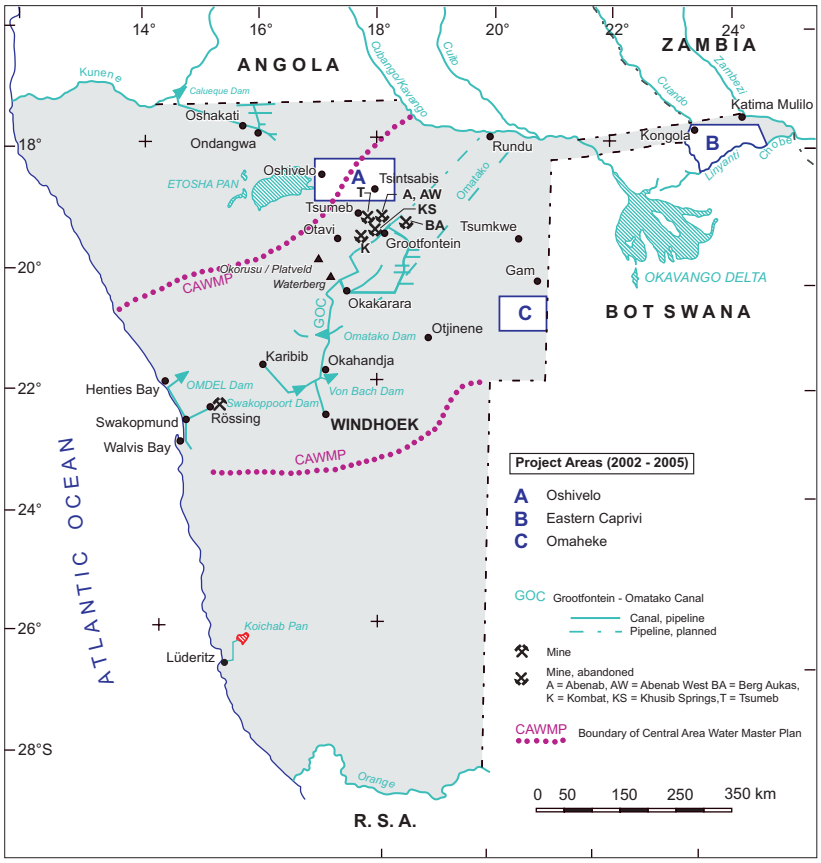
The final definition of prospective areas was largely based on regional hydrogeological knowledge and the experience of the project partners' experts, and included the delineation of regional tectonics and geological structures from satellite image analysis. During the investigations, the main research tools were electromagnetic methods for the detection of potential freshwater aquifers by means of their characteristic electrical resistivities. The electromagnetic surveys were either flown using BGR's own helicopter, or recorded on the ground.

While the airborne measurements produced an areally dense survey grid with detailed information down to depths of approx. 80 m, the ground-based survey contributed resistivity values at selected points down to a depth of approx. 400 m. A service company was contracted to do the ground-based resistivity surveys. The airborne measurements were carried out from October 2002 until March 2003 by the BGR working group for airborne geophysics.

View from Vogelfederberg into the Namib Desert.

The results of the measurements and their interpretation were controlled and confirmed with test drillings. Pumping tests provided information on the productivity of the confirmed groundwater resources. Isotope analyses investigated the origin and age of the water. Finally, the information was combined in a hydrogeological conceptual model. These concepts on the genesis and hydraulics of the water resources provide the framework for responsible and sustainable groundwater management.

The careful selection of the project areas proved fortuitous, and the investigations turned out to be rather successful. In Caprivi and Omaheke, highly promising, formerly unknown freshwater aquifers were detected. On the other hand, the measurements in the Oshivelo region revealed that the extent of the already known Oshivelo Artesian Aquifer had previously been overestimated: the new findings are inconsistent with the optimistic expectations of the Namibian hydrogeologists.



Map of Namibia with location of the project areas.

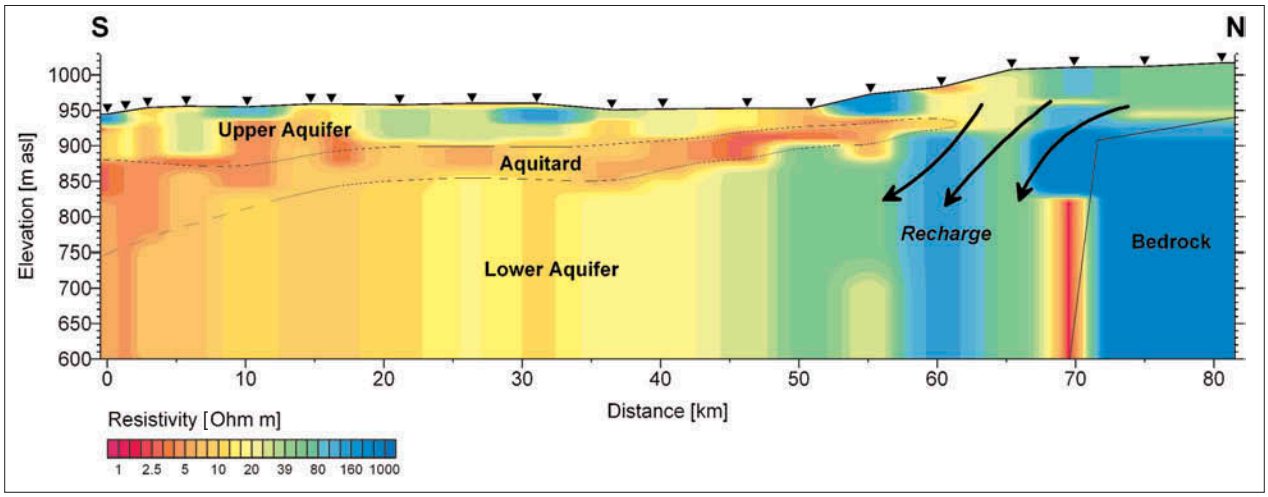
Results of the Caprivi research:

Away from the three border rivers, the population of Caprivi traditionally depends on freshwater lenses, embedded in a shallow regional aquifer containing mostly brackish to saline water. These small freshwater deposits are directly recharged by strong rains that fall during the three-month rainy season. Their small volumes are insufficient to supply the people and stock for a whole year. This fact is again reflected in the distribution of the population in Caprivi: mainly because of the precarious water supply situation, only two narrow stretches of land are settled along the main traffic routes between Kongola and Katima Mulilo. These are the only places where essential water supplies for people and cattle can be guaranteed even in times of severe drought, if necessary by the use of water tankers.

The survey project was initially scheduled to delineate the sizes and positions of the small scale freshwater lenses. The BGR helicopter with its ability to quickly record a dense survey grid over large areas was considered the ideal tool for this purpose. Because of the particularly critical water supply situation, a stretch of land in the southeast of Caprivi along the border to Botswana was selected for the aerial survey. The exploration was technically successful: freshwater bearing channels and isolated lenses were detected and delineated, but their extent and supply potential proved to be rather limited. Because of this moderate success, some experimental, ground-based deep resistivity soundings were made outside the helicopter survey area. They revealed clear hints of a completely unknown deep seated and highly promising freshwater resource.

After a series of soundings confirmed the initial indications of a potentially new freshwater resource, the project concentrated on this new aquifer. It turned out that large parts of Caprivi are underlain by a second freshwater aquifer lying below the well known shallow brackish aquifer. This new aquifer is separated from the regional shallow brackish water body by a low-permeability layer, and has higher hydrostatic pressure. The existence of this important resource was confirmed in the northern part of the investigation area by 6 boreholes. The extent of the deep aquifer towards the south needs to be determined by further drilling, but the results of geophysical soundings suggest a gradual increase in the salinity of the groundwater toward the southeast.

The newly discovered aquifer opens up new development possibilities in Caprivi. Provided that sufficient recharge can be confirmed, this aquifer opens the possibility of broad agricultural land use with an appropriate water supply for the first time, even far from the main roads. Costly alternatives, like the planned pipeline along the Golden Highway, can now be shelved, at least partly.



Cross-section showing the resistivity distribution along a transient electromagnetic profile in eastern Caprivi.

Results of the Omaheke research:

In Omaheke, a tectonic graben, the "Eiseb Graben", was chosen for detailed research because this structure presents the only realistic chance for successful water exploration in the whole area. The key problem for the detection of groundwater in Omaheke is the great depth to the water table typical of this region. Around the Eiseb-Graben, boreholes hit water at depths of about 150 m. That means that, outside the sediment filled graben, groundwater can only be encountered in solid rock formations, and is therefore dependent on fractures. Unfortunately, and in spite of advances in modern geophysics, no geophysical ground based techniques currently exist capable of detecting water-filled fractures at such great depths.

Under these conditions, selecting a drilling location for a productive well is something of a lottery. In the past, only 1 in 10 wells drilled in this area have encountered any water, and the productivity of these "successful" wells varied from 1 m³/h to 3 m³/h. Within the graben, on the other hand, thick sediment fill is likely, and because the sediments forming the graben fill were thought to be deposited under fluviatile conditions, it was hoped that zones with particularly coarse sediments deposited under fast flowing water conditions might exist. Old channels might have formed which may now contain particularly fresh water and have especially high permeabilities. These coarse sediment structures within the Eiseb Graben were the main exploration target in the Omaheke area.

The area of the supposed graben was systematically examined with ground-based resistivity surveys. The measurements confirmed the interpretation results of the satellite pictures. The graben shoulder, already delineated from the satellite pictures, was accurately displayed by the distribution of resistivities of the subsurface formations. Furthermore, a linear structure with elevated resistivities was detected inside the graben along its northern rim, reaching far below the water table. It was interpreted as a former river bed or "paleochannel", and its groundwater potential was tested by three test drillings. These three wells turned out to be the most productive wells by far ever drilled in the whole area. The most productive one yielded about 120 m³/h, and even the two less productive wells exceeded by a factor of 10 and 20 the best formerly known well with 3 m³/h. Furthermore, the pumped water is of excellent quality and corresponds in all aspects to the criteria defined in the Namibian drinking water regulation.

The groundwater found in the Eiseb Graben can be used to improve the water supply of the local population whose life is mainly based on cattle farming. Because the groundwater recharge and the cattle carrying capacity of the Kalahari veldt are very low, careful management of the aquifer is of utmost importance. The number of stock which could now be supplied with water by far exceeds the pasture capacity of the area; hence there exists very high risk of desertification by overgrazing. A series of information road shows were implemented to explain the complex interrelationships and to raise awareness of the problem amongst the local authorities and stakeholders.

DWA drilling crew at work in Caprivi.

Results of the Oshivelo research:

The area of investigation in Oshivelo was located at the southern edge of the Cuvelai-Basin, east of the settlement of Oshivelo and near the rural area with the highest population density in Namibia. The intention of the survey was to delimit the horizontal and vertical extent of the "Oshivelo Artesian Aquifer", to assess its potential and to characterize its water quality. The Oshivelo Artesian Aquifer was detected during an earlier survey run by the project partner DWA, and it was supposed to be fed through the Otavi-Dolomite-Aquifer with water from the Otavi Mountain Land area. There was hope of finding an extensive highly productive aquifer, and the most optimistic forecasts were that enough groundwater would be present to transport it by pipeline to the densely populated areas in northern Namibia.

Groundwater exploration with helicopter D-HBGR in northeastern Namibia.

Electromagnetic sensor of the BGR helicopter.

As before in Caprivi, the BGR helicopter was used for the exploration of the upper formations, while ground-based resistivity soundings looked at deeper levels. Unfortunately the results were rather disappointing. The horizontal extent of the Oshivelo Artesian Aquifer turned out to be considerably smaller than hoped, and good productivity was only encountered in test wells drilled on a small stretch of land along the Ovambo river. In addition, another sandstone aquifer was detected, but unfortunately its water rapidly becomes increasingly saline towards north.

Groundwater monitoring in Kyrgyzstan

To protect its people, it is essential for Kyrgyzstan to remediate the radioactive waste which accumulated during the soviet era. In Mailuusuu, a small town in southern Kyrgyzstan, uranium mining waste has a high risk potential extending far beyond the region due to geotechnical mistakes and georisks from earthquakes and landslides.

BGR expert Dr. Hagen Gunther Jung (2nd on the right), the director of the local sanitary station Nemad Mambetov (left) and inhabitants of Mailuusuu.

To conduct the measures, the World Bank and the Kyrgyz government reached agreement in April 2003 on the "Natural Disaster Mitigation Project" costing several million US $. The overall goal is to reduce the impact of natural hazards on uranium mining wastes to an acceptable risk.

The Federal Institute for Geosciences and Natural Resources (BGR) has supported the World Bank project since the beginning of 2006 with its project "Reduction of Dangers from Uranium-Mining Waste Sites in Mailuusuu, Kyrgyz Republic", which is financed by the German Ministry for Economic Cooperation and Development (BMZ). A BGR expert working in cooperation with the Kyrgyz Ministry of Emergency Situations in Bishkek and the metropolitan authority in Mailuusuu is establishing a groundwater monitoring system. A BGR project team was formed to implement the measures, which are scientifically supported by the Centre for Radiation Protection (ZSR) of the Leibnitz University of Hannover.

Mailuusuu is supplied by a central waterworks using river water coming from the mountains unaffected by the former uranium mining activities. This water is of good drinking water quality according to the World Health Organization (WHO) standard, but not all the inhabitants in the valley have access to it. To overcome this shortage, water from artesian wells and dug wells is also used, especially in the villages south of Mailuusuu. It is not known if this water is already contaminated, or suitable for drinking.

Water sampling and monitoring at an artesian well in Mailuusuu with mobile analytical equipment.

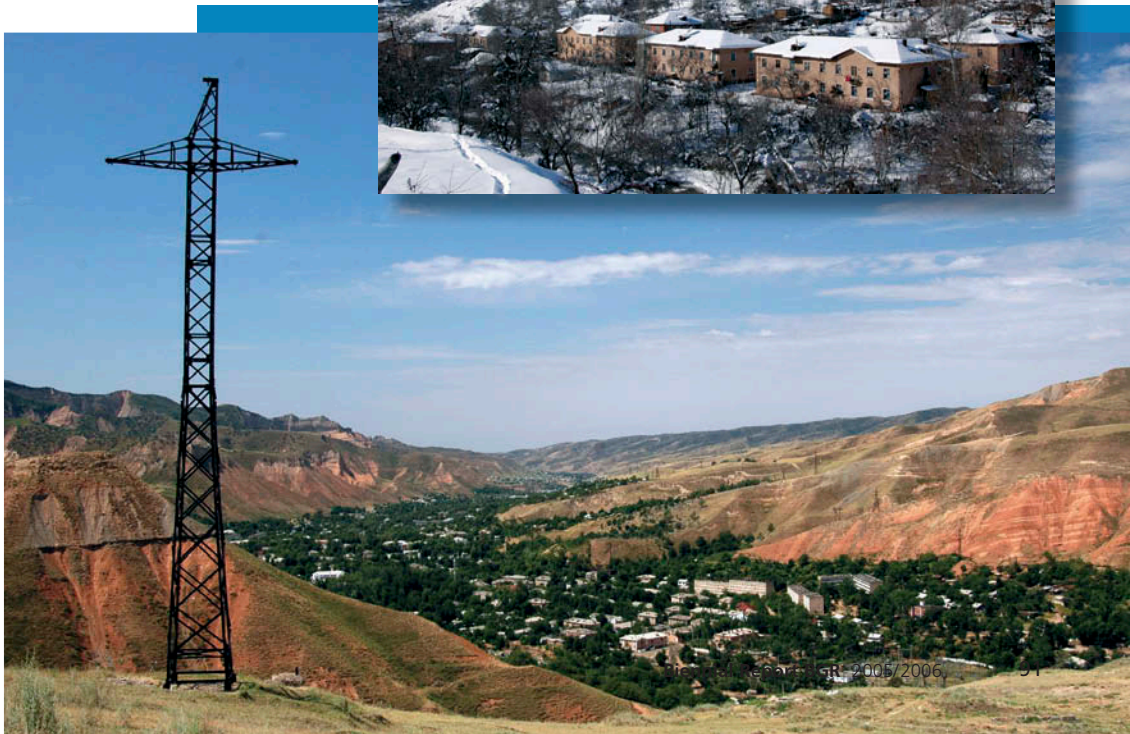
Analysing seepage water of a tailings pond near Mailuusuu using a mobile field laboratory.

These measures are aimed at establishing a local team with the expertise to carry out the water quality monitoring activities themselves. Together with the Kyrgyz counterparts, BGR constructed additional state-of-the-art groundwater observation wells to improve monitoring.

By improving scientific understanding, and training the Kyrgyz counterparts, the inhabitants of Mailuusuu gain skills and the will to improve the situation in their city. Most important here is technical cooperation, because in Central Asia there is seldom a lack of commitment, but often a shortage of equipment and finances.

To support the metropolitan authority of Mailuusuu, BGR is involved in:

- hydrogeological research as part of the remediation of waste rock dumps and tailings ponds, as well as evaluating the potential hazards
- sampling campaigns to evaluate the water quality of groundwater and surface water
- designing a concept for a long term groundwater monitoring system
- training local experts in water sampling and monitoring



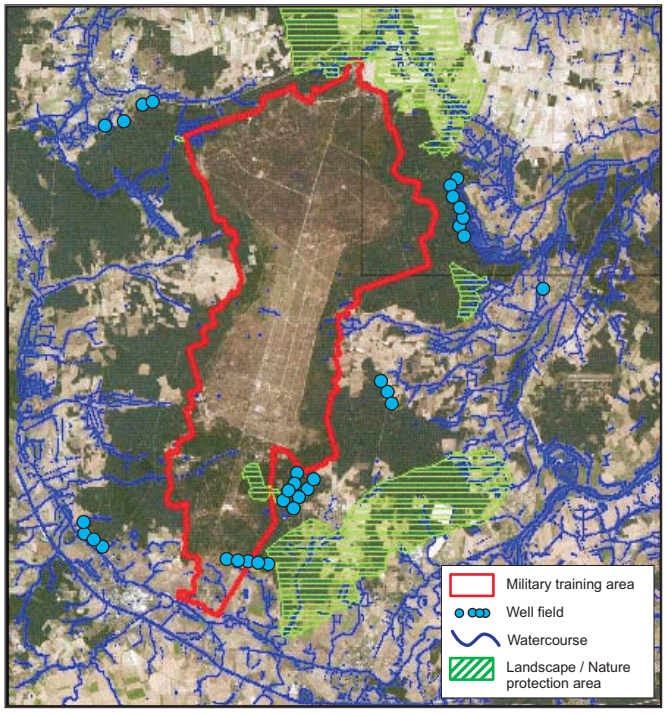
Mailuusuu, located in southwestern Kyrgyzstan.

Conflicts in the **Colbitz-Letzlinger Heide** between **military use** and **drinking water protection**

Background

The groundwater resources in the Colbitz-Letzlinger Heide are used to supply drinking water to the city of Magdeburg and the adjacent districts to the north in the Magdeburger Börde and the Altmark. The groundwater in the approx. 980 km^2 area between Uchte, Tanger, Ohre, Milde and Secantsgraben, are exploited by the waterworks in Colbitz (drinking water for Magdeburg), Haldensleben, Gardelegen and Schernebeck. The central part of the Colbitz-Letzlinger Heide has been used as a military training ground since 1934 (up to 1945 as an artillery test firing range used by the company Krupp, then by the Wehrmacht, and subsequently by the Soviet army until 1993).

Investigation area with the Altmark military training area.



The German Armed Forces are now in charge of the area and are building a battle training centre for the army in the Altmark military training area. The military use of the area in the past caused soil contamination in areas including explosion and firing ranges, washing facilities, barracks, fuel depots and test facilities. Immissions involved a range of contaminants (e.g. heavy metals, explosive residues, mineral oils) and are therefore suspected to be present in the groundwater given the presence of interconnected wells at the edge of the military training area.

The Colbitz-Letzlinger Heide is not only used for the abstraction of drinking water and as a military training area: some parts are designated nature protection areas or have the status of "temporarily protected". There is therefore a general conflict of interest between the military, the water industry and environmental protection. A long-term groundwater monitoring programme is a fundamental requirement for the amicable resolution and regulation of the various interests.

The use of large parts of the old military training area as a battle training zone in a way which complies with the current environmental protection regulations was tied to the results of detailed hydrogeological investigations and reports. The Federal Institute for Geosciences and Natural Resources (BGR) was engaged by the German Federal Ministry of Defence (BMVg) to assess, implement and evaluate hydrogeological investigations concerning various aspects including geology, hydrogeology, hydrochemistry, remote sensing, surface geophysics, borehole geophysics, drill sites, the construction of observation wells, and land surveys. The investigations are carried out in close collaboration with the Ministry for Agriculture and the Environment of the State of Saxony-Anhalt, the State Geological Survey and Mining Inspectorate, the Countryside Commission and the State Construction Authority.

Work phases

The whole military training area and its surroundings have been investigated in detail since 1992 in various work phases. 176 groundwater observation wells were installed at 56 sites in the military training area to investigate the hydrogeological structures, measure groundwater levels, and extract water samples. Pumping tests were conducted at 11 observation wells to determine the hydraulic parameters. Surface geophysical surveys were conducted to document the geological information. The monitoring network includes the new observation wells as well as those belonging to the water resources management and the State of Saxony-Anhalt in the vicinity of the military training area.

Water samples were collected simultaneously on five sampling days at around 650 observation wells between 1993 and 1998. Water samples were analysed to determine standardised inorganic and organic parameters and use-related organic parameters (including chemicals used in explosives).

Groundwater monitoring was continued in 1998 in the form of long-term monitoring realised in various measuring and sampling campaigns. The first phase of the long-term groundwater monitoring was concluded in 2006 with a summary report covering the four previous campaigns.

Results

All of the important hydrogeological data in the area was compiled within a central database as part of the investigation programme. 20 hydrogeological sections were drawn up using the results of the new data points and the older data.

The base of the freshwater-bearing multiaquifer formation is the Mid-Oligocene Rupel Clay. This lies directly beneath thick Quaternary, primarily sandy formations of Elsterian and Saalian glacial deposits in the southern part of the Colbitz-Letzlinger Heide. The Elsterian glacial till in this multiaquifer formation forms a discontinuous aquitard between the lower and upper aquifers. These aquifers are further subdivided

Protected monitoring well with destroyed protecting frame, and landscape with devastated soil cover.

BGR staff sampling an observation well

by other sealing interbeds. The upper multiaquifer formation is used intensively for drinking water abstraction. The oldest known aquifers in this sequence are the fine and medium-grained sands of Upper Oligocene to Lower Miocene age. These are the deepest aquifers in the freshwater-saturated overburden which is only present to the north of the Gardelegen Fault. A locally significant perched aquifer, with perched groundwater in part, is present in the southern part of the military training area.

The periodically produced water table contour maps define in detail the groundwater flow from large parts of the military training area to the abstraction plants at the Colbitz, Haldensleben, Schernebeck and Gardelegen waterworks. The depth of the water table in the terminal moraines is over 60 metres. The groundwater level measurements show local differences in pressure between the Saalian glacial aquifers and the Elsterian aquifers.

Chemical analysis carried out to date indicates that the groundwater is only slightly and locally contaminated as a result of military activities. Most of the military facilities and activities were in the area covered by the perched aquifer. This is where the German Armed Forces Contaminated Sites Remediation Programme is looking in detail at the contaminant immissions. The results of this programme will be taken into consideration when evaluating the groundwater monitoring data. Because the water table is deep in most cases, any contaminated percolating water spends high residence times within the formations overlying the aquifers. In addition, the flow times of potential contaminated groundwater to the interconnected abstraction wells is relatively high, at a few decades to a few hundred years.

A regional computer model for groundwater flow and mass transport was elaborated for the whole of the area of investigation covering the Altmark military training area to simulate water management measures and generate forecasts.

WHYMAP – Looking at **groundwater** from a **global point of view**

During the past decades, the interest in groundwater has increased considerably due to water shortage problems at a local, regional and even global level. The use of groundwater is considered an appropriate way out of regional water crises caused by population growth, economic growth and the associated water shortage problems. But information on these hidden resources is still week in many places. The World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP) was launched in 1999 to contribute to the world-wide efforts to better understand, manage and protect aquifer resources.

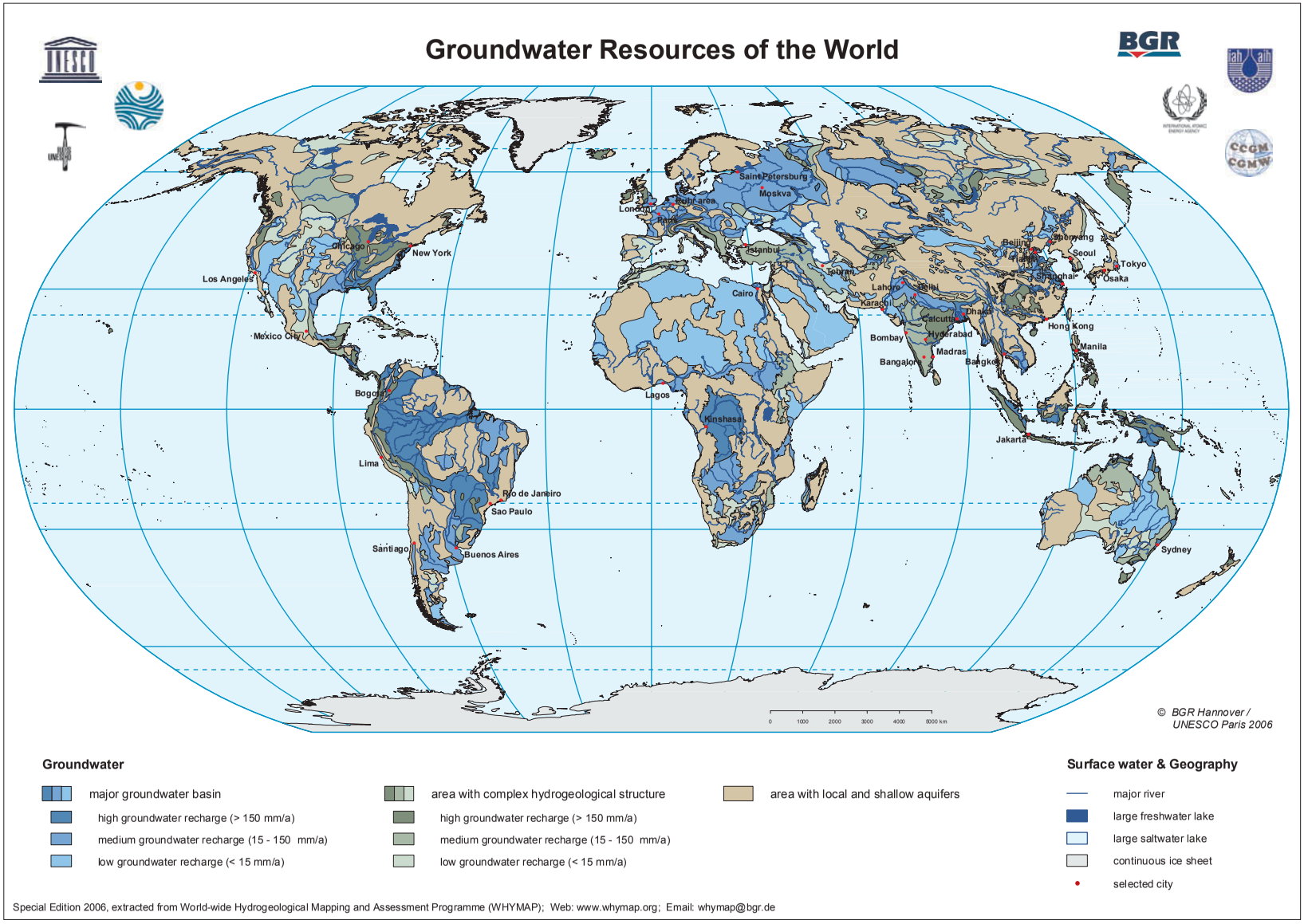
The programme aims at collecting, collating and visualising hydrogeological information at a global scale in a geographic information system (GIS). Maps are convenient tools to convey groundwater related information in an appropriate way to groundwater experts as well as to non-experts and politicians, e.g. they are used for international publications like the World Water Assessment Programme (WWAP) issued by the United Nations. WHYMAP thus brings together the huge hydrogeological mapping efforts at regional, national and continental levels. Close cooperation with the International Groundwater Resources Assessment Centre (IGRAC) in Utrecht is assured through UNESCO to clarify the role of groundwater in the discussion on Millennium Development Goals declared by the international community.

The WHYMAP structure

WHYMAP is the joint programme of a consortium consisting of the UNESCO, the Commission for the Geological Map of the World (CGMW), the International Association of Hydrogeologists (IAH), the International Atomic Energy Agency (IAEA) and the German Federal Institute for Geosciences and Natural Resources (BGR). The consortium is responsible for the general thematic outline and management of the programme. BGR as the executing unit provides important resources in terms of manpower, mapping capabilities and data.

In 2002, a committee of eminent international experts was established under the supervision of the consortium. This WHYMAP-Steering-Committee is supported by the continental Vice Presidents of the IAH and CGMW, the UNESCO regional offices and the National Committees of UNESCO's International Hydrological Programme IHP.

The WHYMAP Programme has already produced a number of maps presenting the Groundwater Resources of the World. As a first step of the realisation, continental drafts at the working scale of 1 : 10.000.000 were compiled based on existing hydrogeological maps of continents, regions and countries. Because the available maps were very inhomogeneous, specialised interpretation and translation was necessary to make this information compatible with the designated legend of the global map. Coping with the different, often unknown projections of these maps was also a special challenge.



The basic version of the global groundwater resources map shows the main hydrogeological units of the world.

The continental drafts are revised and completed by the members of the WHYMAP-Steering-Committee as well as other hydrogeological mapping experts from all parts of the world, making use of their regional knowledge. Finally, a new consistent global groundwater map is compiled by adjusting and merging the continental drafts.

Step by step, different thematic layers are prepared for the global groundwater map. In some cases, a single organisation or a group of institutions is taking care of the compilation of one specific thematic layer, e.g. the information on groundwater recharge is developed under the auspices of IAEA, while the layer on transboundary aquifer systems is mainly realised by IGRAC and the Internationally Shared Aquifer Resources Management (ISARM)-group of UNESCO. Different IAH commissions are working on global maps of karst aquifers, groundwater vulnerability, coastal aquifers and the hydrogeology of hard rocks.

The main focus of the WHYMAP Programme is the establishment of a modern digital Geo-Information System (GIS) in which all global data relevant to groundwater is stored together with its geographic reference. Hydrogeological information published in national and regional maps is converted into a digital version, and will be available in a GIS compatible format in the future. Scanned maps are integrated as graphics, and metadata is collected for each map. These activities will lead to a world-wide information system on hydrogeological maps.

From the WHYMAP-GIS database, a variety of high quality thematic map products at different scales and complexity can be derived. In addition, the information is visualised via an internet-based map server application. A prototype of this application is available at www.whymap.org.

First results and products

A first overview at a scale of 1 : 100.000.000 was compiled as a contribution to the 3rd World Water Forum in Kyoto in March 2003 and published in the first World Water Development Report (WWDR) of the United Nations. The preliminary draft of an educational wall map at a scale of 1 : 25.000.000 is currently being corrected and revised and will finally be published by spring 2008.

In August 2004, a first special edition of the global groundwater resources map at a scale of 1 : 50.000.000 was released at the International Geological Congress in Florence. A second special edition at the same scale focussing on the transboundary aquifer systems of the world was compiled for the 4th World Water Forum in Mexico City in March 2006. The corresponding explanatory text on the back of each map gives background information on the project and a description of the map itself. On the one hand, this is intended to inform the scientific community about the WHYMAP Programme and asks for contributions. On the other hand, WHYMAP aims at raising awareness amongst politicians and the general public of groundwater as an important natural resource. Several thousand copies of the map have been sold and distributed at important conferences and symposia. Single copies are available on request from BGR.

The basic version of the global groundwater resources map shows the main hydrogeological units of the world:

- the groundwater basins (blue),
- hydrogeologically complex areas with important aquifers (green), and
- areas with local and shallow aquifers (brown).

In addition, the groundwater basins and complex areas are divided into three classes according to their groundwater recharge. Orange hatching has been applied in areas where the salinity of the groundwater regionally exceeds 5 g/l. Topographic and administrative information is shown along with areas of polar and continental ice sheets, as well as the permafrost boundary in North America and Asia.

The following conclusions can so far be derived from the maps and the corresponding data:

- Groundwater is found almost everywhere, but is not always sufficient for drinking water supply or irrigated food production. The quantity and quality of groundwater as well as the portion of groundwater annually recharged has to be studied in detail before using this valuable natural resource.
- Most of the large groundwater units form shared transboundary aquifers. Cooperation between all countries participating in such shared aquifer resources is essential to manage the resources sustainably and avoid environmental, economic and social damage. The ISARM group of UNESCO and IAH is working on this issue.
- The quantification and reservoir modelling of non-renewed, fossil groundwater resources in the arid and semiarid regions of the world is particularly important prior to their use.
- Mainly in low rainfall areas river basins and groundwater units rarely coincide geographically. Therefore, the delineation of integrated water resources management areas must be carefully selected, i.e. groundwater features must be adequately considered to avoid misconceptions for water management.

With the first WHYMAP results, the essential groundwater resources have already been given an improved profile on the global water agenda. This is particularly necessary because groundwater is a hidden, invisible asset for mankind and nature, and more awareness needs to be created to manage it properly and protect it from degradation.

The publication of the educational wall map at a scale of 1 : 25.000.000 accompanied by an explanatory booklet in 2008 is considered an important milestone in the WHYMAP Programme. The development und maintenance of the WHYMAP-GIS will continue far beyond 2008, to support German development policies in developing water management strategies and to improve the availability of groundwater related information to support international water strategies.

Geosafety

Geosafet

Reposit

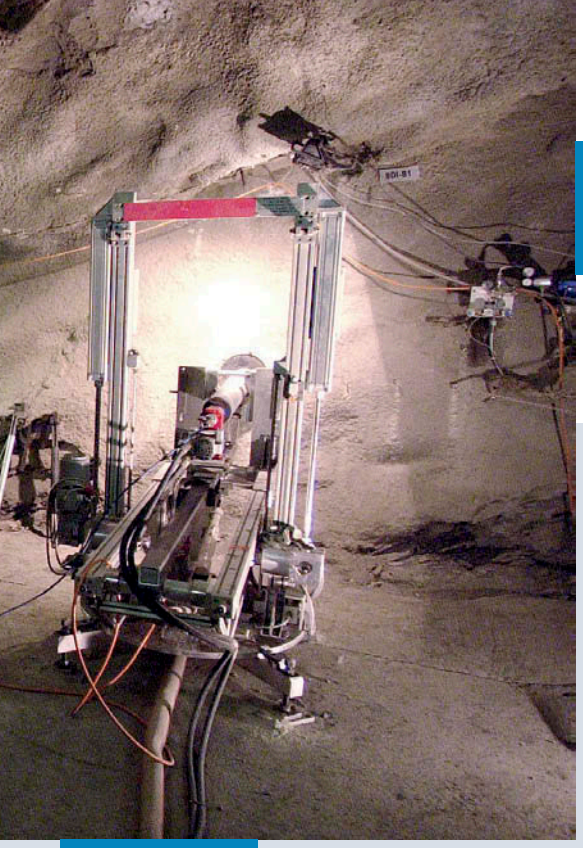
Experts around the world are all in agreement: **deep geological formations** are the most suitable locations for the **disposal** of **high-level radioactive waste**

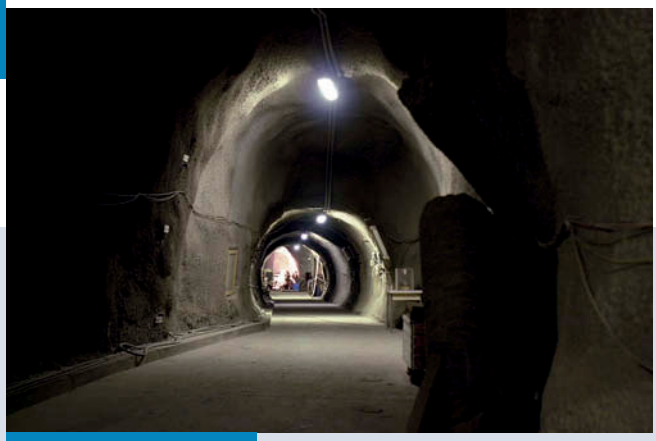
Radioactive waste is not only produced by nuclear power stations, but also by the use of radioactive substances in the health and research sectors, not to mention industrial applications. All of this waste must be disposed of safely.

The most important safety priority for a nuclear repository is protecting people and the environment from the damaging effects of ionising radiation. Because of the long half-lives of some of the components in high-level radioactive waste, it has to be safely isolated from the biosphere for very long periods of time. Experts around the world unanimously agree that deep geological formations are the best places to dispose of such waste.

The Federal Government in Germany is responsible for the safe disposal of radioactive waste, as defined in the Nuclear Act. The Federal Institute for Geosciences and Natural Resources (BGR) handles the associated geoscientific aspects as the government's central advisory agency on geoscientific matters.

BGR actively tackles the geoscientific challenges faced by the state in the context of energy supplies by working on projects involving the use of geothermal energy, CO_2 reduction (see chapter Energy Resources), and the permanent disposal of radioactive waste.





The figures show the Mont Terri underground laboratory in Switzerland.

Long-term safety analysis: Predicting the **future of a geologic repository** in salt

With their knowledge of the earth's past history, geoscientists are also able to predict future geological processes. In long-term safety analysis, they investigate the various processes taking place in a geologic repository over the next million years, paying special attention to all of the mutual interactions.

The geological barrier in a repository for radioactive waste plays a particularly important role: combined with the technical barriers designed for each site, the geological barrier must guarantee the isolation of the waste disposed of in the repository over very long periods of time. BGR carries out long-term safety analysis to confirm whether the geological barrier can fulfil this stipulation.

The reason why geological barriers are particularly suitable as a means of isolation becomes clear when considering the time periods involved for the safe isolation of waste: the international stipulation is that a repository must prevent any damaging consequences over periods exceeding one million years.

Such a long period is unimaginably long compared to recorded human history. In the same way that early humans one million years ago – long before Cro-Magnon Man and Neanderthal Man existed – could have little inkling of how we live today, we also cannot really look ahead with any certainty to predict how mankind will develop over the next 1 million years.

However, one million years is very short when compared to geological processes. At locations where we can analyse and deduce the geological history going back many millions of years, we can also reliably predict what will take place geologically in the next million years.

This naturally presupposes that in addition to identifying the changes that have taken place in the past, we are also capable of understanding why they took place. This means we have to understand all of the different processes which have had an effect, and elucidate their interactions. The mutual interaction and interdependence of all the processes taking place in a geologic repository in the future are then looked at as part of the long-term safety analysis, primarily using computer simulations.

BGR has already begun a safety analysis of a repository for high-level radioactive waste constructed in salt. This starts with an FEP list (features, events, processes) which is prepared by incorporating all of the aspects which could influence a geologic repository in future. The safety analysis would be fatally flawed if the FEP list missed out any important aspect. To prevent this from happening, reference was made to the international FEP database of the NEA (Nuclear Energy Agency of the OECD). This comprehensive database was elaborated on the basis of safety analyses conducted by various countries. Its use guarantees that even those FEP which are less obvious for repositories constructed in salt are also taken into consideration.

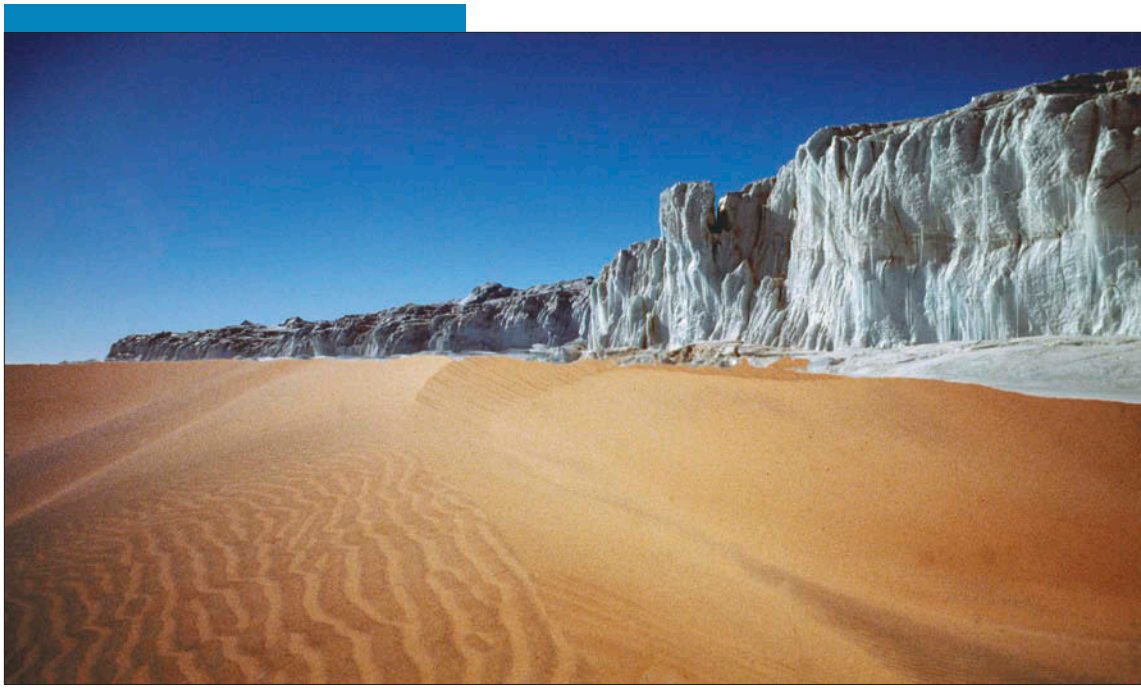
Deriving a location and host-rock specific FEP list from the NEA FEP database involved a screening process looking at each individual FEP to assess its relevance for a geologic repository constructed in salt, as well as the interactions of each individual FEP with the other FEPs. It is useful to do this analysis by dividing up the overall repository system into subsystems, such as the cover rock and the approximate zone around the waste, to avoid looking at illogical interactions between FEPs, such as the corrosion rate of the waste packaging and erosion at the ground surface. Even by streamlining the analysis in this way, the interactions between over 1000 potential FEP combinations had to be reported and justified to ensure that the process remains completely transparent. The result was the elaboration of a site-specific FEP list which will be used in the next phase to derive scenarios of the future development. These include any significant scenarios which describe the changes to the surface caused by the next ice ages, as well as scenarios describing the thermo-mechanical processes taking place in the host rock caused by the heat given off by the waste.

Climate scenarios

One of the scenarios looked at was the ice age scenario: when the surface above the repository is affected by a periglacial or glacial climate. A range of processes have to be taken into consideration here associated with the presence of permafrost, e.g. changes in the groundwater flow, and all of the major changes associated with the presence of a glacier in the vicinity of the repository location or even if a glacier slides over the surface above the repository itself.

A "super warm period" scenario could also give rise to processes which influence the isolation properties of the geological barrier. This scenario assumes that the climate cycles which would soon lead us into the next ice age are actually shifted by several hundred thousand years so that we initially experience more warming, e.g. from the increased emissions of greenhouse gases. The processes (FEP) associated with this scenario include reduced groundwater recharge, and groundwater salinification.

When elaborating the site-specific FEP list for a repository in salt, BGR was able to refer to its comprehensive understanding and in-depth findings gained through its previous investigations in the Asse research mine, the Morsleben repository, and the Gorleben research mine. Experts from a range of scientific disciplines were involved in preparing all of these separate findings within the location-specific FEP list. The efficiency with which this was achieved was attributable to the favourable circumstances that specialists from a whole range of geoscientific disciplines all worked together under one roof at the Federal Institute for Geosciences and Natural Resources.



Climate scenario: Glacier in the desert.

How **modern computer-supported equipment** helps researchers describe the extremely slow and complex processes taking place in a **repository for radioactive waste**

High-level radioactive waste is to be isolated for extremely long periods in deep geological formations. The German repository concept also specifies that the repository should be capable of maintenance-free operation after emplacement and isolation of the waste. This means that the potential thermal, hydraulic, mechanical and chemical processes (THMC) processes) relevant for the long-term safety of a repository would not be subject to direct monitoring. These processes may also be so complex that they cannot always be analysed beforehand in experiments, and they can be affected by varying degrees of strong mutual interaction. These are referred to by experts as "coupled" processes. To be able to describe and evaluate the effects of these complex "coupled" processes and their mutual interactions, scientists make use of computer models. The finite element method (FEM) is used for the two and three-dimensional simulation of geological structures with a range of different rock layers and any form of cavity configuration. The overall model is based on the model of the geological structure. This gives rise to a THMC model describing a specific rock mass cross-section and in which the relevant rock mass layers are divided up into homogenous zones each with their own uniform material properties. The next stage is the discretisation of the FE model, in other words, subdividing the model structure into finite elements.

The finite element model produced in this way is then used to compute the sought after physical parameters, and their spatial and temporal changes, e.g. to look at mechanical aspects, rock stresses and deformation, cavity convergence, and dilatant rock zones. These are computed by the BGR using FE software such as RockFlow and Jife.

RockFlow program

Scientists at the Federal Institute for Geosciences and Natural Resources have been developing the finite element code "RockFlow" since 1984 in collaboration with the Institute of Fluid Mechanics and Computer Applications in Civil Engineering (ISEB) at the University of Hannover and the Centre for Applied Geosciences (ZAG) at the University of Tübingen.

The software written in FORTRAN-77 programming language was originally used to describe flow and material transport in granite (a fractured porous medium). This was one of BGR's main research topics investigated at the Grimsel Rock Laboratory (Switzerland). As part of the expansion of the BGR's international activities in other areas of research, e.g. bentonite as a geotechnical barrier, and clay formations as alternative host rocks for nuclear repositories, RockFlow was further developed in recent years into a software system for coupled thermal, hydraulic, mechanical and chemical processes (THMC).

This enables the relevant process and the associated influencing processes to be simulated simultaneously. Unlike other software focusing on thermo-mechanics, the development of RockFlow concentrates on hydraulics (multi-phase flow) and chemistry (transport and reactions). The growing complexity of the physical processes in geosystems could be incorporated in the model. The associated need to have access to dynamic data structures, meant that the software system had to be redeveloped in a different programming language: first ANSI-C, and then in C++ (object-oriented programming) since 2004.

Scientists at the Federal Institute for Geosciences and Natural Resources have already successfully used RockFlow to complete numerous research projects, including EU programmes.

One of their current research projects is characterising the disturbed zone in cavities constructed in claystone.

Mont Terri Rock Laboratory in Switzerland

Claystones as potential geologic host rocks for nuclear repositories are being studied in Switzerland in the Mont Terri Rock Laboratory, and in the Meuse/Haute Marne underground research laboratory (Bure) and Tournemire in France. BGR has actively participated for many years in these international research programmes.

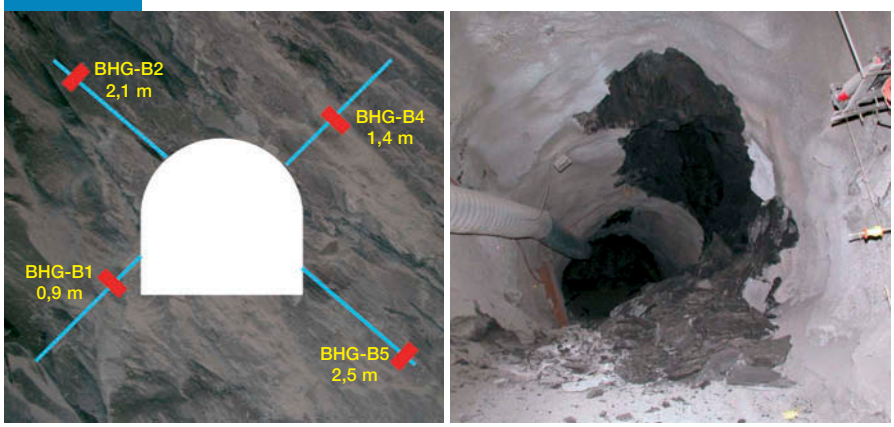
The long-term effectiveness of claystones as geological barriers has been confirmed in their function as impermeable seals above, e.g. oil and gas fields. The favourable properties of clay-rich (argillaceous) rocks enabling them to form such tight barriers are their very low permeability and their ability to bind toxic substances. Claystones primarily consist of clay minerals with grain sizes less than 0.002 mm. By virtue of their layered structure, claystones have direction-dependent hydraulic and mechanical properties (anisotropy). For instance, permeability is lower normal to the layers than parallel to the layers. The disturbed zone around cavities constructed in claystone also develops inhomogenously around the cavity. Disturbed zones are created when new drifts are cut under ground. The material properties of the rocks are altered in the disturbed zones giving them e.g. higher permeabilities to liquids or gases. These zones are therefore particularly interesting to repository scientists.

The mineral compositions and fabrics of claystones vary depending on the conditions existing when they were formed. There are therefore a wide range of natural claystone types with a spectrum from plastic clays to strongly consolidated and, in some cases, fractured claystones. This can give rise to enormous differences in deformation behaviour, temperature sensitivity and rock strength. Clay minerals such as montmorillonite also have the special property of swelling when they absorb water, and shrinking when they dry out.

To improve the assessment of the influence of swelling clays on geologic repository systems, a coupled hydraulic-mechanical approach was incorporated in the RockFlow software which also takes into consideration the swelling properties of argillaceous rocks.

A typical example for a model calculation was the modelling of the creation of the disturbed zone in the Opalinus Clay in the Mont Terri Rock Laboratory (Switzerland). The results of this simulation were compared with in situ measurements of the permeability of the rock in the disturbed zone after constructing the cavity. The formation strength is twice as high parallel to the bedding as normal to the bedding in the undisturbed zone (before cutting the cavity). In its original condition, the formation permeability is five times higher parallel to the bedding than orthogonal to the bedding.

The formation permeability after construction of the cavity was determined by injecting nitrogen into four boreholes, and comparing the results with the original formation permeability. This revealed that a zone with increased permeability (10^{-16} m²) extends parallel to the bedding up to around 2.5 metres from the tunnel wall, whilst the zone of raised permeability normal to the bedding only extends for half this distance.

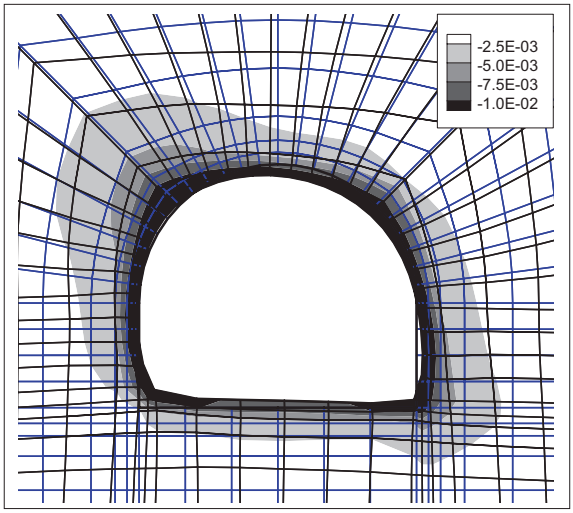


Measured permeability distribution around drifts (left) and recorded cavings during the construction phase (right).

Caving during tunnelling was observed attributable to the low modulus of elasticity (Young's modulus) and therefore lower formation strength normal to the bedding. The ellipsoidal deformation zone caused by the hydraulic and mechanical anisotropy can be realistically simulated with an HM-coupled model.

The results of the calculations show that the observed deformation is largely caused by shrinking processes: low humidity levels of only 40 % exist in the tunnels because of the fans used to ventilate the roadways. This causes the claystones around the tunnels to dry out which then leads to higher permeabilities.

The experts are pursuing the objective of completely describing the material behaviour of claystones. Future plans in this context are to implement the material laws for claystones developed from laboratory tests, take into consideration creep and fracture formation, and then to test its applicability. They are currently coupling RockFlow to another program (PhreeqC) to also be able to accommodate chemical processes within their simulations. Coupling with other chemical programs is also being worked on to create models simulating conditions with temperatures well over 100 °C and high salt concentrations.



Calculated total volumetric deformation around the drift using a coupled.

JIFE program

BGR has worked very closely together with SRD, Berlin, for many years to develop the finite element program JIFE (Java Interactive Finite Element code) for the computer simulation of coupled thermo-hydraulic-mechanical-chemical (THMC) processes. This software is intended to replace the ANSALT code (Analysis of Nonlinear Thermomechanical Response of Rocksalt) previously used by BGR to analyse thermo-mechanical problems, but whose obsolete program structure now restricts its applicability to today's requirements, particularly with respect to complex three-dimensional computations. JIFE is based on the JAVA programming language which supports a modular program structure, the rapid implementation of new program options, as well as interactive operation and graphic visualisation techniques. Because of the application of special solution algorithms, JIFE boasts very short computation times and can therefore also be used to analyse very large three-dimensional structures.

Program development initially focused on elaborating and implementing computation algorithms for thermo-mechanical problems, and to enable the program options incorporated within ANSALT to also be used for JIFE simulations in current projects. Algorithms to compute hydromechanically coupled processes were also implemented.

At its current stage of development, JIFE for instance comprises various element types for one, two and three-dimensional computation models, a large number of material laws to take into consideration a range of geological materials, and special options for the interactive display and animation of computation results.

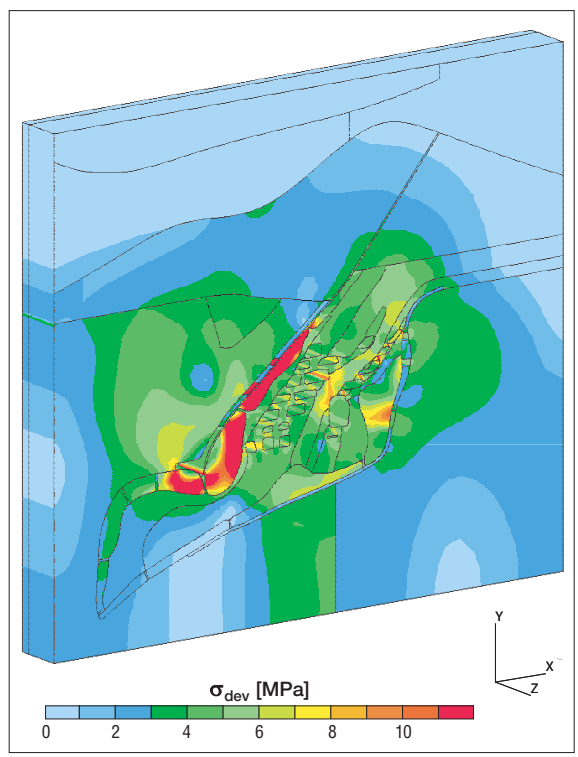
Because JIFE will be used as a priority in geologic repository projects, it also incorporates different material laws on the thermo-mechanical behaviour of salt and claystones reflecting the current state of the art. This makes it possible for instance to model the time-dependent properties of salt such as creep and dilatancy, or the anisotropic inelastic behaviour of argillaceous rocks.

The JIFE code has been used in a range of projects for the following numerical confirmation and analysis:

- Calculating the stability and operational suitability of brine caverns in salt domes and bedded deposits under operating conditions,
- Confirming the stability of old underground workings in the Repository for Radioactive Waste (ERA) in Morsleben, as well as the integrity of the salt barriers above these underground workings,
- Investigating the load-bearing behaviour and confirming the effectiveness of drift sealing structures in ERA Morsleben,
- Computer simulation of the construction of a mine drift in claystone in the Meuse/Haute Marne underground research laboratory (Bure), France,
- Modelling the emplacement of waste containers in drifts in a repository for radioactive waste in salt formations.

The diagram shows a typical example of the results of three-dimensional modelling with JIFE. This shows the stress state of the salt body at the present day in the southern part of the central zone in the Bartensleben mine in the Waste Repository (ERA) Morsleben. The stresses shown in the diagram, which reach particularly high levels in the roofs between the old mining rooms and the neighbouring anhydrite beds, are used to asses the mechanical stresses acting on the load-bearing elements in the mine such as pillars and roofs, as well as to evaluate the geomechanical integrity of the salt barrier

With its JIFE and RockFlow program systems, BGR now has access to high performance tools specialised in handling the unusual features of salt behaviour such as dilatant creep (JIFE), as well as special mechanisms in flow processes such as claystone swelling or chemical interactions (RockFlow).



Three-dimensional modelling of the southern central section of the Bartensleben mine at ERA Morsleben with a superimposed display of the JIFE-calculated rock stresses.

Real 3D models of salt caverns
taller than 50-storey skyscrapers?

This can now be done with more detail than ever with the BGR's salt expertise and the further developed version of the OpenGeo code.

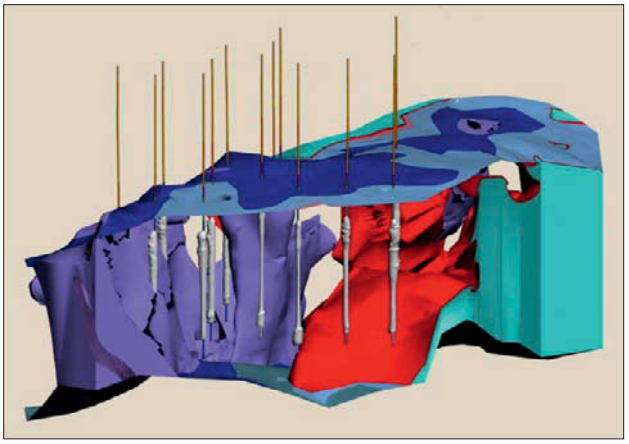
Salt caverns have been constructed using solution mining techniques since the middle of the 1960s in Germany using boreholes up to 2000 m deep in horizontally bedded salt layers, as well as in salt pillows and salt domes. Large caverns have been constructed in this way with an average height of 300 m, diameters of approx. 60 m, and volumes of approx. 500.000 cubic metres and more. This approximately corresponds to the space enclosed by a 50-storey skyscraper.

Salt caverns are divided up into production and storage caverns. The former are used to extract brine for the production of halite or as a raw material for chemical factories. The latter are used to store gaseous and liquid hydrocarbons, not to mention compressed air and carbon dioxide (CO_2). There is also an ongoing debate on the potential use of abandoned salt caverns for the underground disposal of residuals and waste.

The salt geologists at the Federal Institute for Geosciences and Natural Resources boast many years of experience in the exploration and investigation of salt structures for the safe long-term disposal of radioactive waste in geologic repositories. This in-depth knowledge is made available to salt cavern operators for the exploration, construction and operation of their underground storages. The storage of this natural resource in Germany is increasingly gaining in importance in the face of the growing demand for crude oil around the world, and rising prices. BGR is therefore currently a very highly sought after consultant to the cavern industry.

The stability of these huge underground caverns is crucially dependent on the shape of the cavity. The creation of a favourably shaped cavern can be controlled during the solution mining process by regulating the injection of fresh water and pumping out the brine during the underground dissolution of the salt. Proper control of the solution mining process is only possible based on a proper understanding of the sequence of variably soluble salt types within the salt deposit.

The Federal Institute for Geosciences and Natural Resources uses the OpenGeo code for the three-dimensional geological modelling of salt structures. The special feature of this system compared to other software packages is that the geological units are modelled as real three-dimensional bodies and not defined in space by two-dimensional boundary surfaces. This makes volume calculations very easy, and the cross-sections important for solution mining planning can be generated at every possible angle. Complete series of cross-sections in any position can be automatically generated to interpret the structure and for reconnaissance. Virtual boreholes with the relevant stratigraphy can also be created at any position within the model.



Cross-section of the 3D geological model of the Etzel cavern field. The caverns shown in light grey are approx. 600 m high and have a diameter of approx. 35 m.

Another important advantage of the real three-dimensional models is the ability to superimpose them directly on echometric survey results. This means that the actual solution mining progress during cavern leaching can be directly compared online with the original planning to control the leaching process even more effectively.

The BGR salt geologists are continually further developing their OpenGeo software: in the latest upgrade, they changed the design core of the program so that it can now more easily model even highly complicated salt structures. Because of the creep properties of halite, salt domes typically contain a mixture of small-scale and large-scale folds, in some cases also very disharmonic folds. OpenGeo even allows the small-scale folds to be very precisely modelled. The program also now boasts special tools for geophysical evaluation, e.g. using radar surveys.

Reliable 3D models can only be generated in combination with precise geological petrographic identification and classification, and 3D evaluations. The Federal Institute for Geosciences and Natural Resources boasts a unique level of experience in this field unprecedented in Germany and world-wide.

The BGR's experts successfully completed their modelling of the Krümmhörn, Lesum and Etzel (Niedersachsen) salt structures in 2005 and 2006. Ongoing projects are looking at salt structures in Gorleben, Rüstringen (both in Niedersachsen) and Mökow (Mecklenburg-Vorpommern).

OpenGeo is also currently being used by BGR in the co-operation project "Consequential Mining Damage in Staßfurt" to model deliberately and accidentally flooded salt mines and their cover rocks. This project was begun in 2006 with eleven project partners from industry and universities. The aim of the project is to forecast changes to the surface topography in the Staßfurt region which is exposed to a very high risk of surface subsidence because of the many decades of industrial salt mining. A sustainable planning concept for the region is to be elaborated on the basis of these investigations.

3D deposit model for the Etzel cavern field

The Etzel cavern field in northwest Germany currently contains 40 salt caverns. BGR produced a three-dimensional geological deposit model of the cavern field with its OpenGeo program for the cavern field operator, IVG Logistik GmbH.

3D presentation in the media room of the Geozentrum Hannover.

The field model encompasses the relevant layers in the salt body cut by the caverns, the caverns themselves, and the associated boreholes. The BGR salt geologists modelled the cavern field by using improved methods to classify the beds making up the Staßfurt Series in detail (including a new interpretation of well logs, and bromide analysis). This enabled the complex folding within the salt dome to be mapped much more accurately than previously possible.

The evaporite sequences encountered in the salt dome form a complete stratigraphic sequence from the Staßfurt Series (z2) to the Leine Series (z3). It even proved possible in this case to subdivide the Kristallbrockensalz (z3HS3) into upper and lower Kristallbrockensalz. This improves the estimation of the thicknesses of the evaporite beds. This means that the safety margins between the caverns and easily soluble beds such as the Staßfurt Potash Seam (z2SF) can be much more precisely calculated. In general, this means that new cavern locations can be selected with greater margins of safety.

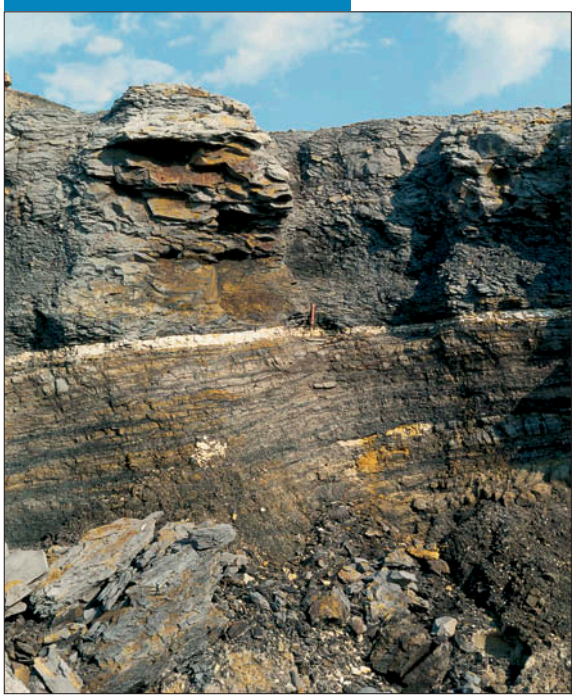
OpenGeo provides the Etzel field operators with a more efficient planning tool which breaks new ground in the analysis and visualisation of complex geological data.

Investigation and evaluation of regions with argillaceous rock formations

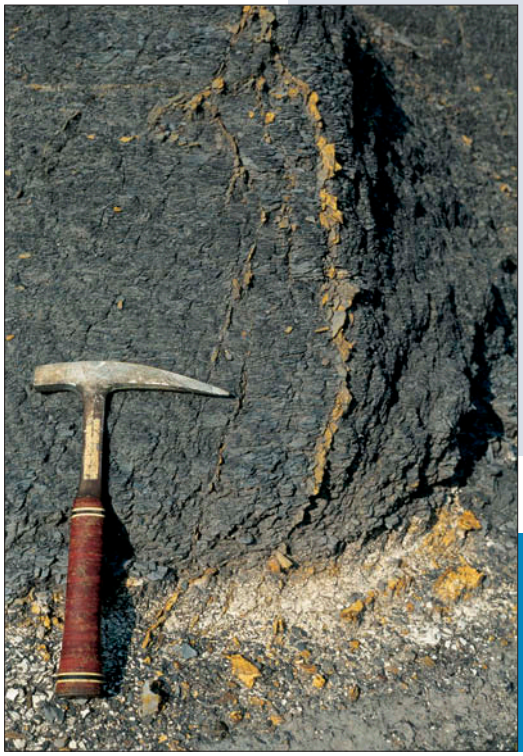
The German Ministry of Economics and Technology (BMWi) assigned the Federal Institute for Geosciences and Natural Resources in 2003 with the responsibility to prepare a study on the distribution of argillaceous rocks in Germany with the potential for acting as host rocks for a geologic repository for high-level radioactive waste. The study was to complement the two studies on halite and crystalline rocks published by the BGR back in 1995, and thus round off the understanding of the distribution of potential host rocks in Germany suitable for the construction of a nuclear repository.

The investigation of the claystones made use of the internationally recognised exclusion and evaluation criteria formulated by BGR for the host rocks salt and crystalline rocks. These criteria were supplemented by the host rock independent exclusion criteria and minimum requirements defined in 2002 by the Committee on a Site Selection Procedure for Repositoiry Sites (AkEnd). The BGR also made use of additional evaluation criteria considered significant from a geoscientific point of view for the selection of regions. Preparation of the study was based on all available data from maps, archive material and wells. No field work was carried out.

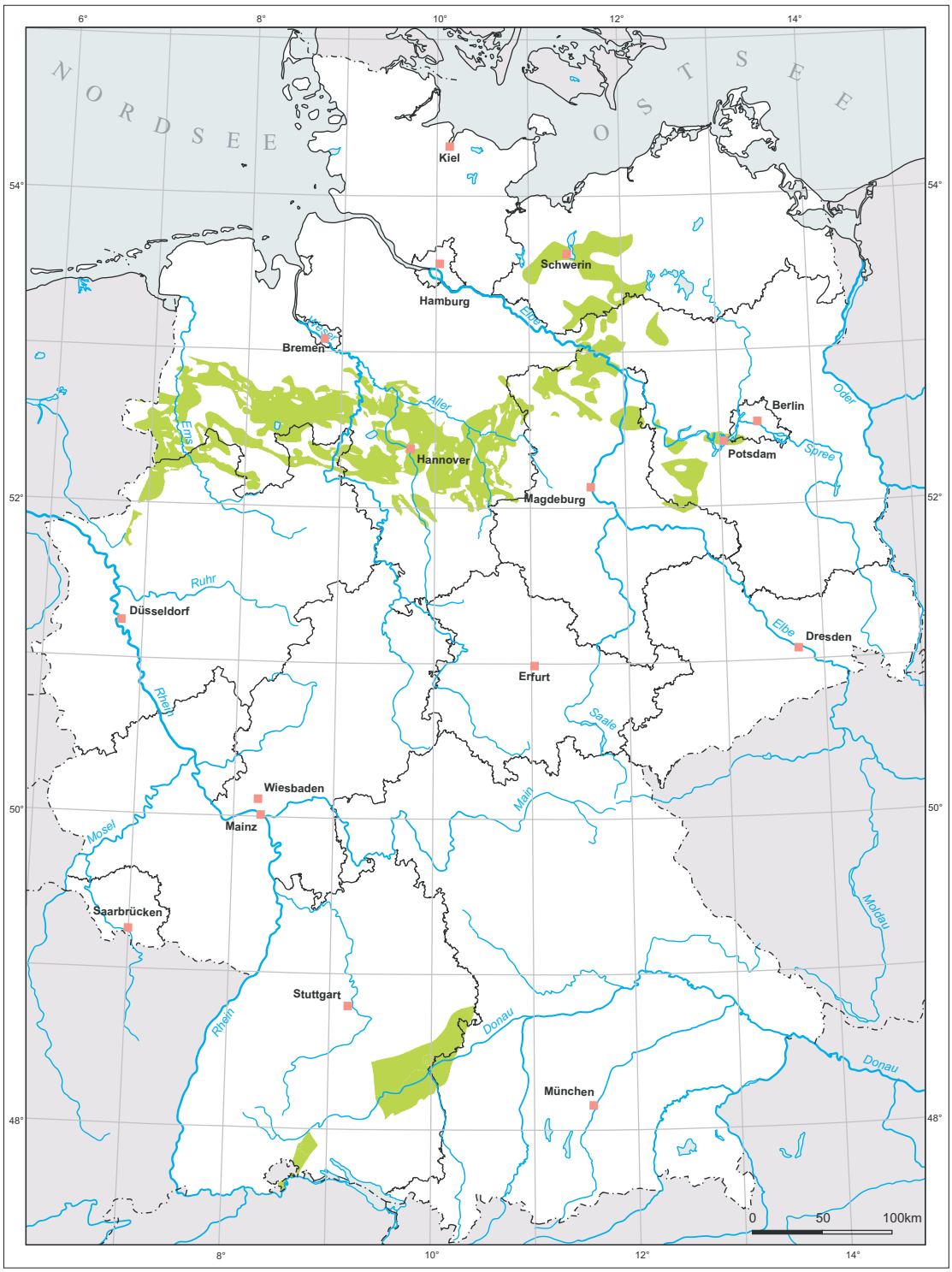
Publication of a volume containing all of the detailed results was made at an event organised by the BMWi.



Example of an argillaceous rock formation – shown here in a surface outcrop.



Argillaceous rocks vary widely from plastic clays, through transitional forms, to strongly consolidated and, in some cases, fractured clays (as shown here).



argillaceous rock formations worthy of further investigation

Partial areas with argillaceous rock formations in Germany worthy of further investigation.

Geological Hazards

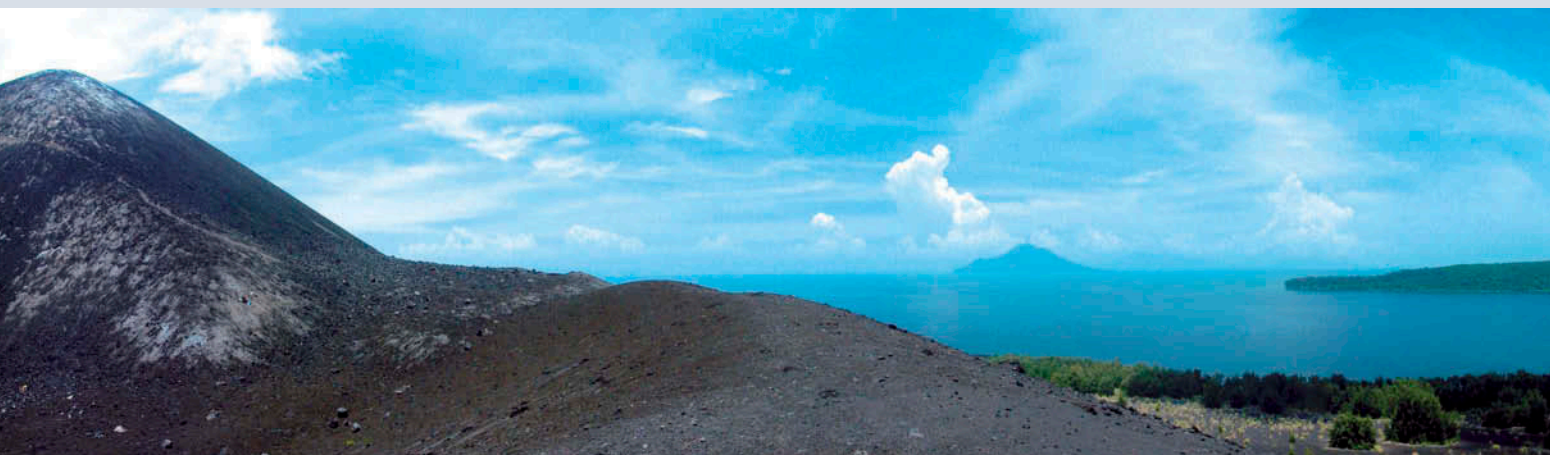
eological Hazards

Geological hazards – Georisks

In a world with a continually expanding human population, natural disasters – and environmental deterioration caused by human impact – increasingly threaten human life and vital high-tech infrastructure. Natural disasters cannot usually be prevented. However, they can be predicted within limits e. g. for regions with known risks of earthquakes or volcanic eruptions.

Impressions of Anak Krakatau, a volcanic island located in the Sunda Strait between Java and Sumatra.

BGR is engaged in the development of a monitoring system on Krakatau volcano in Indonesia. We want to improve our understanding of its volcanic activity to provide a scientific basis for establishing a future early warning system. Similarly, BGR is engaged in support work to fight coal fires in China – an environmental disaster which not only destroys valuable energy resources every day, but also emits significant volumes of CO_2 affecting the global climate.



Geoscientific monitoring of the **Krakatau volcano** – KrakMon

The island volcano of Krakatau in the Sunda Strait between Java and Sumatra gained a tragic reputation in 1883 when it exploded and triggered devastating tsunamis along the coasts of southern Sumatra and western Java that caused the loss of 35.000 souls. At the location of the nearly completely destroyed former volcanic island, a new volcano grew out of the sea in 1927: Anak Krakatau, the child of Krakatau. This young volcanic island grows at a rate of about four metres per year, and the pile of ash and rock today reaches a height of about 300 metres above sea level. As recently as 2005, the volcano sent out a characteristic tremor that forced the Indonesian administration to close the island to visitors.

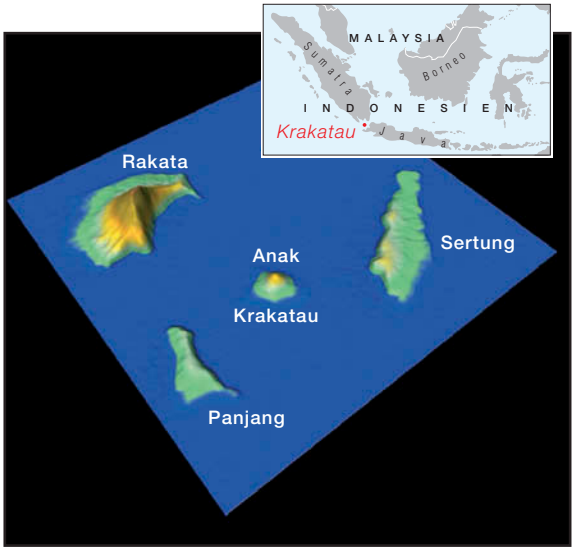
The Sunda Strait is one of the most important transport routes in south-east Asia. It lies close to highly populated parts of Indonesia and is itself a centre of strong seismic and volcanic risk. This background led to the decision in early 2004 by BGR (Federal Institute for Geosciences and Natural Resources) to establish a research project named KRAKMON to evaluate the volcanic risk in the Sunda Strait. The project is part of the BMBF (German Ministry of Education and Research) financed programme SUNDAARC.
The scientific need for a realistic appraisal of the georisks in this region was highlighted by the deadly aftermath of the earthquake west of Sumatra on 26 December 2004. As a direct consequence, the KRAKMON system will be part of the German-Indonesian Tsunami Early Warning System for the Indian Ocean.

Anak Krakatau in June 2004. Caldera island Rakata in the background.

Instruments for volcano monitoring.

It is also envisaged coupling the KRAKMON system to a global multi-hazard early warning system at some time in the future.

The outbreak of a volcano is the result of a complex interaction of internal and external processes. The precursors of an eruption can best be detected by the simultaneous monitoring and interpretation of different physical parameters. A multi-parameter system, such as KRAKMON, includes numerous geophysical, meteorological and geochemical instruments. The individual sensors detect seismic signals from the interior of the volcano as well as anomalies in the electric and magnetic field around it. The deformation of the volcano's surface is monitored by high precision GPS measurements. Geochemical sensing systems detect various gases set free by volcanic activity in fumaroles near the top of the volcano. To determine the external factors, a weather station monitors



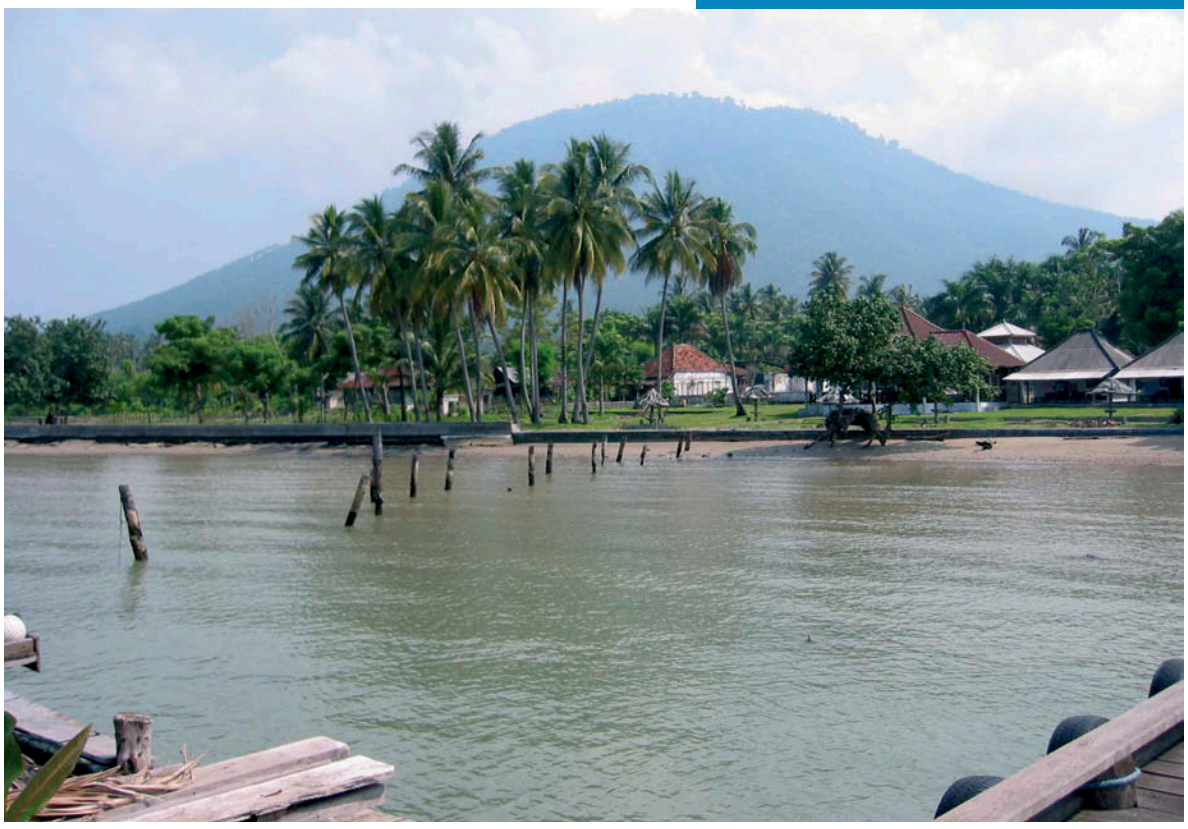
Location of Anak Krakatau.

On the crater rim of Anak Krakatau.

rainfall, wind speed and direction, air temperature and air pressure, and a tide gauge measures sea level variations. Additionally, the crater is observed by a video camera system. All data is transmitted to an observatory on Java about 50 km east of the volcano. Here, the data is stored and processed. All of the data and its variation in time is used to reveal changes in the volcano's status and thus its present risk. A comparable multi-parameter system has been operated by BGR since 1997 at the Galeras volcano in Colombia.

Transporting measuring equipment in the field at Krakatau.

Indonesia has the largest number of active volcanoes in the world. The volcanic activity is caused by the same geological processes responsible for the earthquakes in this region: the dense oceanic crust of the Indian plate is forced under the lighter continental Eurasian plate. This process is called subduction. Stresses build up when movement between the plates is blocked, the sudden release of the stress by movement causes the subduction earthquakes. Subduction volcanism is caused by the rise of molten material from the subducted oceanic crust, i.e. magma production. The magma rises at typical distances from the collision zone of both plates, feeding the Indonesian ring of fire.

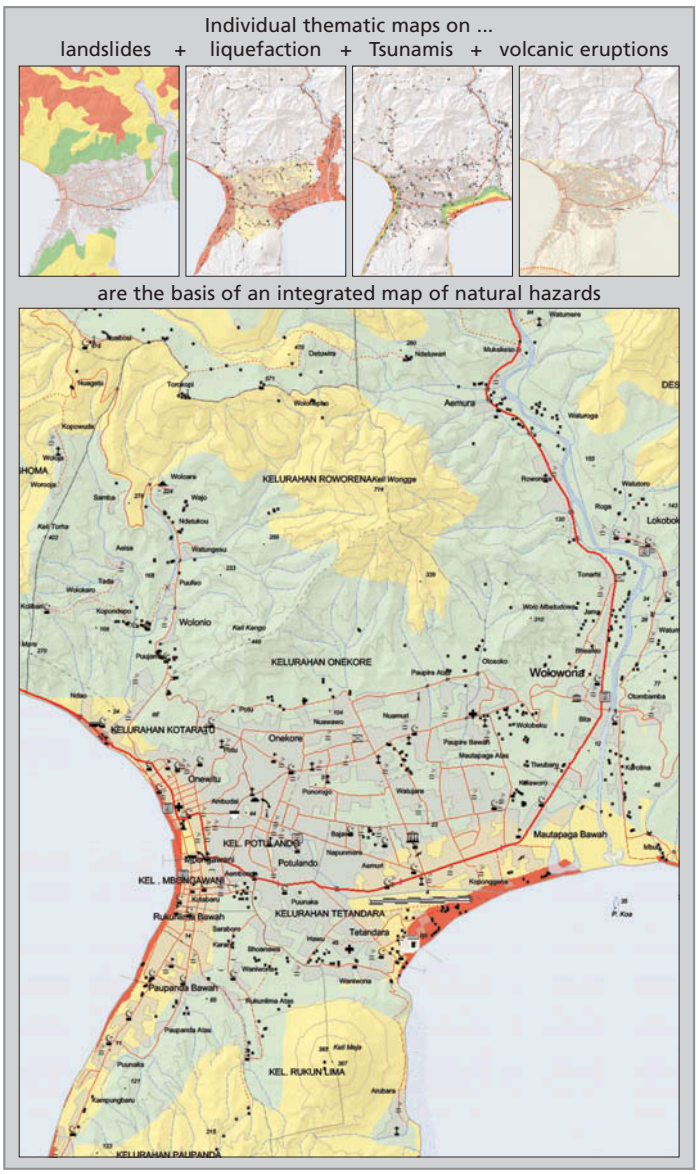


The coast of Sebesi island north of the volcano in the Sunda Strait. In the Krakmon project, BGR established a seismological station on the island.

Mitigation of georisks
in Indonesia

Indonesia did not come to a rest after the devastating tsunami of 26 December 2004. The country was affected by other natural disasters, such as the May 2006 earthquake in Central Java with a magnitude of 6.3 on the Richter scale. The tremor came at the same time as the status of the Merapi volcano was also worrying the Indonesian Geological Agency: the volcano, bordering the city of Yogyakarta, had been spewing ash and lava for several months. Local authorities started to evacuate the population at risk. Even though people and authorities were on the alert, the sudden earthquake caused more than 5.700 casualties within a few minutes in the towns of Yogyakarta, Bantul, Sleman and Klaten.

In Bantul, 80% of the buildings were destroyed. This highlights how georisk-management at a local and national level has to be capable of implementing prevention measures and reacting to very different natural dangers. The Indonesian Geological Agency in Bandung is therefore supported in conceiving and implementing a multi-hazard georisk management system through a technical cooperation project: 'Mitigation of Georisks'.



Overall risk map of an area around the town of Ende (Flores, Indonesia) taking into consideration the risks associated with landslides, Tsunamis, volcanic eruptions and soil liquefaction following an earthquake.

Following the earthquake, the German Ministry for Economic Cooperation and Development commissioned the project to analyse georisks affecting the greater Yogyakarta area. To ensure that the reconstruction of the destroyed towns of Bantul and Klaten involves the erection of buildings and infrastructure less prone to earthquake damage, hazardous areas were identified using engineering geological and seismic methods. Good experience using this approach was gathered by BGR and the Indonesian partners during the reconstruction work in Banda Aceh on Sumatra. It involves the drilling of boreholes and mapping of soil conditions using geotechnical parameters.

The acquired engineering-geological data is combined within a regional 3D model from which information on the building ground stability can be generated for any point of interest. These investigations are jointly conducted by BGR and GGA, as well as the Indonesian Geological Agency and the Universities of Bandung and Yogyakarta.

In July 2006, another earthquake triggered a tsunami causing the death of more than 700 people along the southern coast of Java. Natural disasters of such scale are covered in the media, however, unreported landslides or floods for example, which happen almost everyday in Indonesia, not only take lives but also cause significant socio-economic damage.

Therefore, the project is building and administering a database that is fed with all such natural disasters – focussing on the last 12 years. To date, this database comprises 11.000 events and forms the most comprehensive database of its kind in the country. The National Coordination Board for Implementation of Disaster Management BAKORNAS PB is going to adopt this database and plans to extend it into an intra-institutional data-network.

Sino-German
Coal Fire Research Initiative

Spontaneous fires in near surface coal seams and coal heaps can occur at any place worldwide. Coal fires represent major problems for two reasons: firstly, valuable energy resources are destroyed in large quantities, and secondly, many toxic gases and greenhouse gases are released into the atmosphere. In northern China, such coal fires ravage a broad east-west swathe of land stretching about 2000 km. In this area, hundreds of coal fires are burning and consuming an estimated 10 to 20 million tonnes of coal per year. To put this into perspective: the annual coal production in Germany is about 25 millions tonnes per year. In addition, the fires damage ten times the amount of coal that is burnt so that it cannot be used or mined in the future.

Against the background of China's growing energy demand, the problem is growing by the minute. The fumes from the toxic gases and dust generated by the fires affect large parts of China, causing serious health problems. The amount of greenhouse gases released by the coal fires is considerable, even at a global scale.

Mineral encrustations formed by gas seeps.

About three years ago, a Sino-German initiative was established to carry out research and implement measures to combat coal fires. The project is financed by the BMBF (German Ministry for Education and Research) and is carried out in close co-operation with the BMZ (German Ministry for Economic Co-operation and Development) and the BMWi (German Ministry for Economics and Technology). So far, project partners are DLR (German Aerospace Centre, Oberpfaffenhofen), HarbourDom (Cologne), DMT (Deutsche Montan Technologie GmbH, Essen), Technical University Bergakademie Freiberg, BAM (Federal Institute for Materials Research and Testing, Berlin), GGA (Leibniz Institute for Applied Geosciences, Hannover) and BGR (Federal Institute for Geosciences and Natural Resources, Hannover).

The overall aim of the project is to find ways to avoid, prevent, control and extinguish coal fires by applying multi-disciplinary approaches. BGR's contribution involves three different geoscientific methods. Petrography contributes important insights into the physical and chemical structure and the ignitibility of coal; geochemistry provides qualitative and in some cases quantitative gas measurements; geophysics yields important data for mapping the extent and depth of coal fires. Petrography and geochemistry in conjunction are able to distinguish different fire processes such as open fires, carbonisation and smouldering fires. The type of fire determines the gases that are set free. Many coal fire areas are not accessible on the ground. Therefore, a local helicopter survey was performed to map the electromagnetic and magnetic anomalies above coal fires. The work was complemented by ground-based geophysics to map certain fire locations in greater detail.

"Hellfire"
Photo of the Wuda coalfield, North China.

A planned second phase of this project will change the focus from fire research to fire extinguishing using innovative methods. Another new focal point will be the quantification of gases produced by coal fires and the verification of extinction measures. This work is necessary to resolve conditions for extinction and emission reduction certificates. Representatives from German industry accompanying the project will be informed about the results and provide advice on possible follow up work. The final aim is to get German industry involved in fire extinguishing programmes and to provide access to the trading in CO_2 emission certificates.

In the Wuda area, North China.

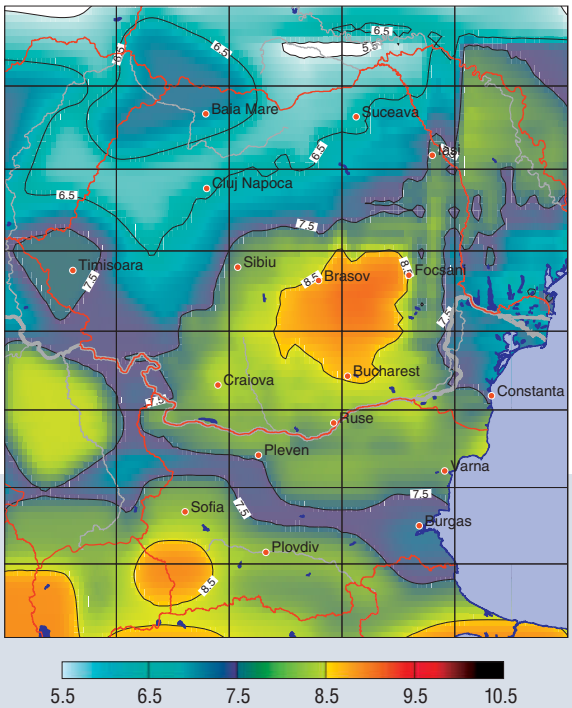
Coal fires in Wuda, North China.

Earthquake hazard maps
of Bulgaria and Romania

A new European earthquake design code – EUROCODE 8 – obligatory for all member states will be introduced in the near future. Application of this standard in Bulgaria and Romania, future members of the EU, presuppose new seismic hazard maps to determine the seismic loads affecting buildings. EUROCODE 8 requires a unique hazard parameter, e.g. the macroseismic intensity as used here. Two different design cases are intended, each requiring an earthquake hazard map. For the ultimate limit state design the building has to withstand an earthquake with an average recurrence period of 475 years without collapse. The main priority is the protection of human life. The second design case (damage limitation) against smaller earthquakes which reoccur on average every 95 years is required to demonstrate that the building does not suffer any serious damage from small earthquakes, and therefore restricts the level of financial losses.

Large earthquakes are rarer than small earthquakes. This means that the longer the stipulated time period for which an assessment shall be done the bigger the earthquake can be which occurs at some time over this period. This is referred to as the average recurrence period of an earthquake of a certain strength.

The Federal Institute for Geosciences and Natural Resources worked together with Bulgarian and Romanian scientists on the calculation of the seismic hazard maps. The data input was from the earthquake catalogues for Central and Southeastern Europe, as well as for Bulgaria and Greece, which in some cases stretch back to ancient world. The most time consuming task was preparing a compiled earthquake catalogue.



Earthquake risk probability map of Bulgaria and Rumania. The risk parameters are shown in different colours corresponding to the 12-unit macroseismic intensity scale for earthquake strength expected during an average recurrence period of 475 years. Buildings become damaged above an intensity of 6.5.

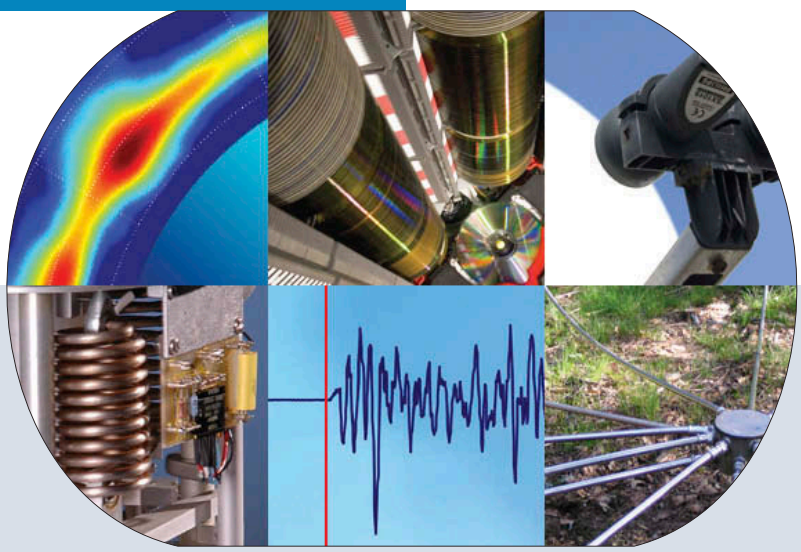
Earthquake hazard is calculated using seismic source regions defined on the basis of seismicity, neotectonics and geological development. The seismicity within each of these source regions is assumed to be homogenous. Pre-shocks and aftershocks were removed from the catalogue to leave statistically independent earthquake events. An intensity frequency distribution of the earthquakes was calculated for each seismic source region. The shaking effect at a site was calculated using an intensity attenuation function. The statistical parameters for each of the regions and the intensity attenuation function were then used to calculate the earthquake hazard for each map point on a dense grid.

Earthquake hazard in Romania is mostly affected by the Vrancea region north of Bucharest. In this region besides crustal earthquakes which occur at depths down to 60 km, also strong intermediate-depth earthquakes occur at depths from 60 – 180 km. Such type of an earthquake occurred in 1977 (magnitude 7.4, focal depth 95 km) and seriously affected Bucharest: 1,560 dead, more than 11,000 injured; serious damage to or destruction of 32 high-rise buildings, 32.000 homes and 763 industrial buildings.

Unlike the intermediate-depth earthquakes in the Vrancea region which cause very irregularly tremors at the surface, the crustal quakes show quite circular areas with the same shaking strength (isoseismals). A new approach was developed to realistically cover the unusual spread of tremors of Vrancea earthquakes. Detailed macroseismic maps of three strong intermediate-depth quakes were used to modify the intensity attenuation function in such a way that the attenuation of shaking for every analysed grid point corresponded to the average values of the observations. Separate hazard maps were calculated for the intermediate-depth earthquakes of the Vrancea region and for the crustal quakes of all regions. Subsequently the two maps were compiled within one.

The combined earthquake hazard map for an average recurrence period of 475 years is shown in the figure. The area of highest hazard in Romania is that around the Vrancea region (intensity 9). The earthquake hazard is also high in Bucharest where there is actually a high earthquake risk due to partially bad soil conditions and poor built constructions. The area with the strongest earthquakes, and also with the highest seismic hazard in Bulgaria is the Kresna region south of the capital Sofia.

Seismic hazard maps are the basis for evaluating earthquake loads. Buildings have to be designed and constructed to withstand these loads, in order to minimize the grade of damage of future earthquakes.



Central Seismological Observatory and CTBT Verification

Central Seismological Observatory and CTBT Verification

Ten years of CTBT

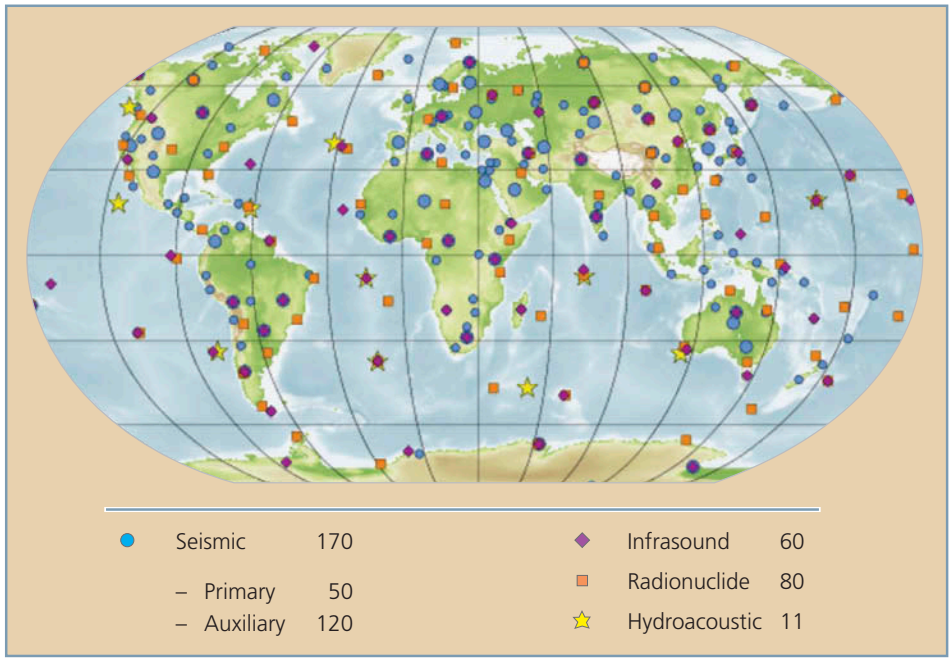
The tenth anniversary of the Comprehensive Nuclear Test Ban Treaty's (CTBT) opening for signature at the UN General Assembly was celebrated on 24 September 2006. Germany was one of the first state signatories of this treaty which has now been signed by 179 states. Although the CTBT has not yet entered into force for various political reasons, all state signatories have complied with this treaty to date, which can be rated as a success.

As a consequence of its signing the CTBT, the German Government assigned BGR new responsibilities including the operation of the German National Data Center (NDC). This function is of decisive importance because NDCs are responsible for monitoring compliance with the CTBT. An additional main task is the build up, operation and maintenance of seismic and infrasound stations as Germany's contribution to the International Monitoring System (IMS). The most challenging station operation task is to ensure data availability of at least 98%.

Taking the specific technical requirements for IMS stations into account, the past decade was devoted to the build up of the stations. BGR succeeded in completing and commissioning IS26 in 2001, the first IMS infrasound station. In the following years, more stations became operational: the GERES seismic array was completed in 2002, and finally in the Antarctic in 2004, the I27DE infrasound array and the SANAE seismic station were completed. BGR is responsible for all these stations, whereas the Federal Institute for Radiation Protection has been responsible for the RN33 radionuclide station on the Schauinsland mountain near Freiburg, which was certified as the last German IMS station in December 2004. Since then, Germany has fulfilled its obligations within the IMS. An overview on the current stage of development of the IMS network with a total of 321 monitoring stations, including the participating German stations, is given in the figure at the following page.

The installation of the new infrasound stations in the Bavarian Forest and in the Antarctic opened up new technical and scientific fields for BGR. As a first step it was necessary to develop and operate the appropriate infrastructure for processing, analysing and interpreting the data acquired by the new infrasound stations. Afterwards, the focus of work moved gradually to scientific areas relevant for CTBT verification. A prominent example in this context is the investigation of the low-frequency noise generated by wind turbines, which is significant with respect to the site selection of highly-sensitive infrasound sensor arrays.

For the German NDC, a new chapter for CTBT verification was opened by its participation in the European Research Project GMOSS (Global Monitoring for Security and Stability), which was launched within the EU's sixth Framework Programme. As a member of the "Network of Excellence", the German NDC investigates on a case-by-case basis various possibilities for combining conventional and INSAR (INterferometric Synthetic Aperture Radar) satellite images with seismic detection and localisation methods for the verification of underground nuclear explosions.



Overview of the current status of the IMS network consisting of 321 stations in total.

Less spectacular but no less important are seismological investigations related to the improvement of seismic event location in Germany by determining valid 3D velocity models. To achieve this objective, earthquake data from the German Earthquake Data Catalogue going back 20 years has been used with tomographic methods to derive a three-dimensional model of the velocity and anisotropic structure of the mantle-crust transition zone below Germany. This model is a prerequisite for more accurately locating the sources of seismic events in future.

This work is also relevant in the CTBT context if an on-site inspection is requested by a state. In this case, National Data Centres are obliged to provide accurate information on the location and nature of a suspicious event on its territory to avoid an on-site inspection.

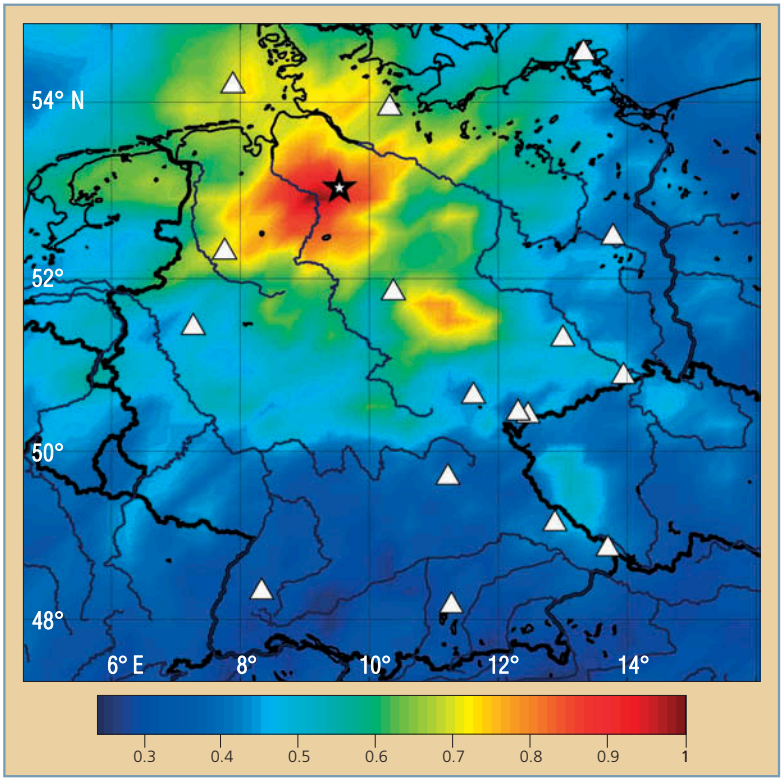
To fulfil this task with minimum effort it was logical to develop a reliable system for the automatic location and identification of seismic events. Starting with the CTBT requirement it was only a small step to develop ALISE, a new Alert and Information System for Earthquakes in Germany. It is particularly aimed at events with a minimum magnitude of 3.0, which represents a subset of the observed seismicity in Germany.

ALISE, the Alert and Information System for **Earthquakes in Germany**

Since the devastating Sumatran earthquake on 26 December 2004, there has been increasing public interest in the establishment of earthquake alert and information systems. Although Germany is not a region with high seismic risks, damaging earthquakes have occurred occasionally in the past. A demand exists for fast, reliable and comprehensive information after such events as well as for small but perceptible earthquakes. This information can be used by emergency services or disaster relief organisations as well as by the coordination centres of the Ministry of the Interior to estimate the impact of an earthquake and to perform appropriate actions. This includes calming down alarmed citizens after small but perceptible events with no expected damage.

ALISE, the Alert and Information System for Earthquakes in Germany was developed to provide this information. ALISE is capable of informing responsible facilities quickly, comprehensively and reliably after an earthquake in Germany and adjacent areas.

The system consists of three components: (1) the seismic network, (2) the processing software, and (3) the user interface for visualisation of the results. The seismic network consists of the digital broadband stations of the German Regional Seismic Network (GRSN), stations maintained by BGR such as the GERES array in the Bavarian Forest and additional stations in adjacent countries. The waveform data of all stations is transmitted in near real-time to BGR ensuring a timely analysis of the events.



Results of the BGR-developed multiphase grid search localisation method for the Rotenburg event of 20 October 2004. The location probability is shown colour coded for each point of the map. The computed epicentre (most probable location) is marked by a star.

The processing software scans the continuously received waveform data for signals which are caused by an earthquake. If an earthquake is detected, its event parameters and the estimated impact, e.g. in terms of vulnerability and potential damage, are automatically calculated. BGR developed a new method to ensure the high reliability of the computed epicentre location. This method not only takes into account the first arrivals but also later arriving signals. This leads to much higher reliability and robustness of the calculated epicentre coordinates. Additionally, consistency checks are applied to evaluate the quality of the results enabling further refinement of the event parameters. All event parameters and the estimated impact are determined and made available within 5–10 minutes.

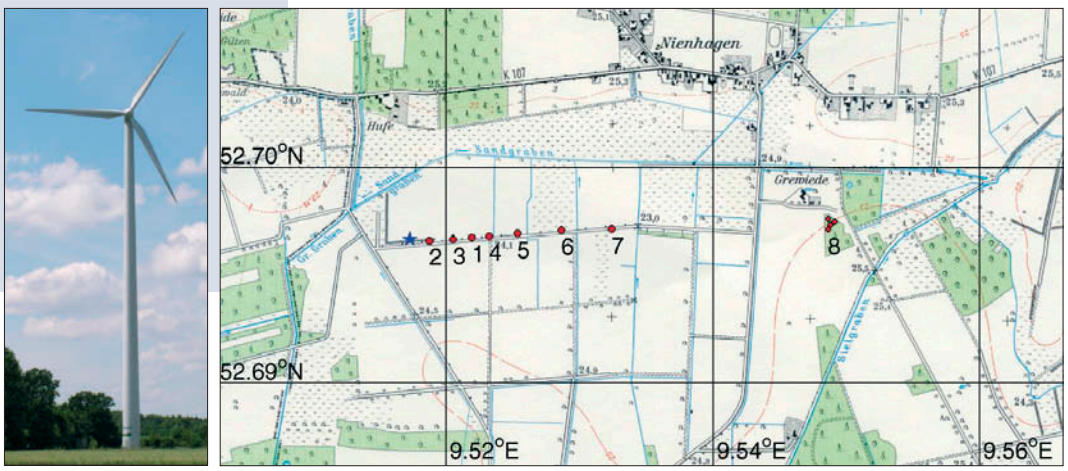
The results of the data analysis are displayed by a web based user interface which just requires a web browser and access to the internet. With this interface the user can for example display maps showing the estimated impact of an earthquake in terms of vulnerability or estimated damage, together with topographical and geological maps or satellite images. Additional information such as historical earthquakes, mining activity, quarries, power plants, gas and oil fields and fracture zones can be superimposed. The required information is prepared on demand by mapserver software which has access to a comprehensive database located at BGR. The accessibility using a standard web browser and the intuitive visualisation of the generated information also enables non-experts to interpret and use the results.

The automatically computed epicentre location (star) found by the ALISE system, together with the error ellipse (red) can be displayed on top of different maps. From left to right: topographic map 1:25.000; satellite image (25 m resolution); geological map 1:200.000. It can be superimposed with additional information like the area of potential damage (far right).

The **inaudible noise** of **wind turbines**

There is an ongoing public discussion on the possible negative influence on the environment of large electric power generating wind turbines. The debate focuses in particular on the increased number and size of such installations, especially their construction near inhabited areas. Therefore, most of the scientific publications look at the perception of and annoyance associated with wind turbines. Generally, the operation of wind turbines leads to a local increase in acoustic background noise, whereas the increase is determined by the prevailing wind conditions with respect to duration and strength. This means that for continuous winds, the corresponding noise level persists over a long period and may cause negative exposure in the immediate vicinity of a wind turbine. However, at larger distances, noise immissions are below the background noise level caused by traffic, industry, local winds and turbulence.

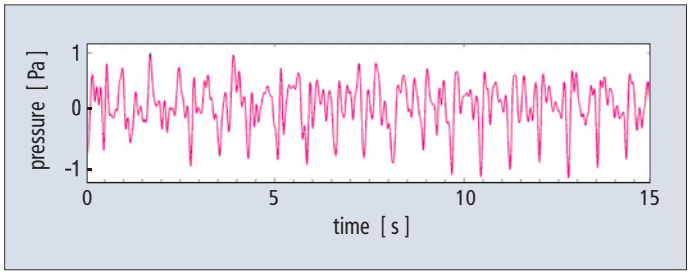
Most of the aerodynamic noise emitted by wind turbines is generated by the revolution of the blades. As the blades pass the tower, a vortex is created by compressing air between the tower and the blades. The noise signals consist of a composition of pure tones which are integer multiples of the fundamental blade-passing harmonic – the product of rotational speed and number of blades. Moreover, the huge size of the blades and their low rotational speed means that the noise is not limited to the audible frequency range. A large amount is emitted as infrasound below 20 Hz. These observations are valid for all turbines with generation capacities exceeding 100 kW irrespective of their design parameters.



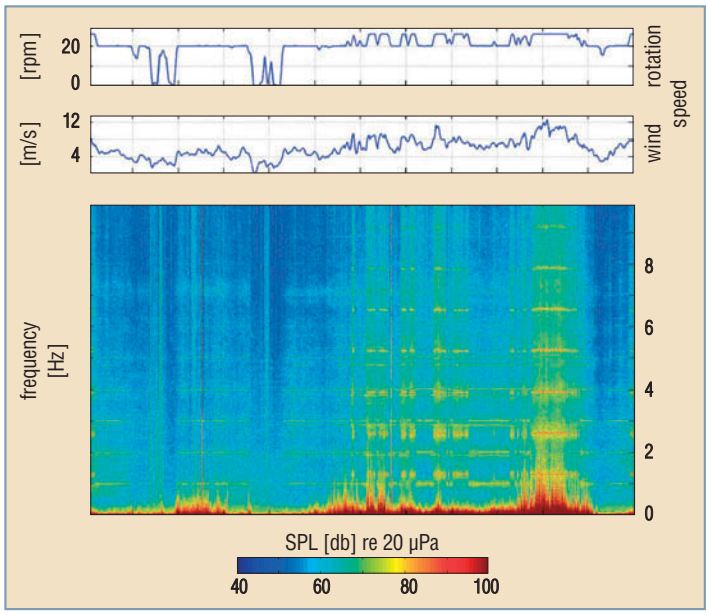
Infrasound measurement at a 200 kW Vestas V47 wind turbine, located north of Hannover (blue star). The recordings using MB2000 microbarometers were obtained along a 2 km line (red dots).

As the operator of highly sensitive infrasound stations, BGR is particularly interested in estimating the aerodynamic infrasonic noise signals generated by large wind turbines.

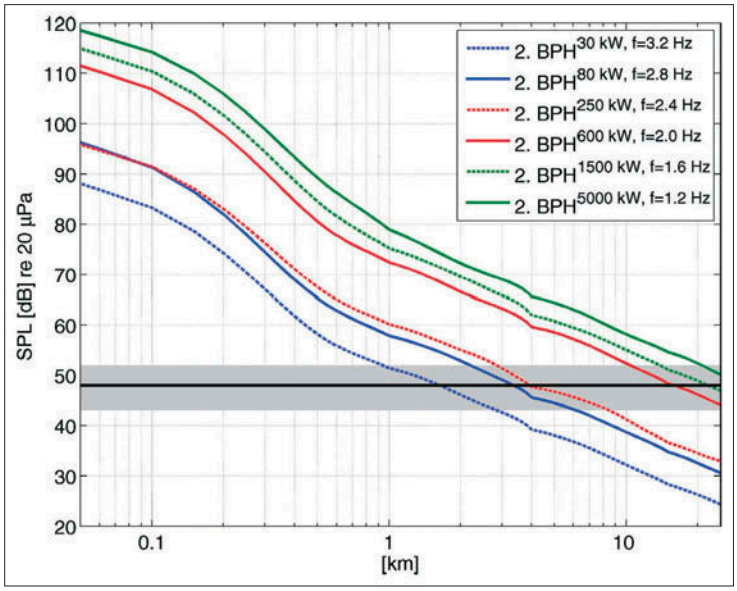
For this purpose a field campaign was carried out north of Hannover measuring the low frequency noise emitted by a single 200 kW wind turbine. Using microbarometers, the acoustic signals were recorded at eight sites along a 2 km east-west line. Altogether, a clear relation was obtained between the measured (infra-)sound pressure level and the wind speed, ranging from calm conditions to high wind speeds. Because the sound pressure level emitted by a wind turbine strongly depends on the rotational speed, most wind turbines are stall controlled. The angle of attack on the blades varies with prevailing wind speeds resulting in two distinct revolution numbers. In the studied case, these are 20 revolutions per minute for weak and intermediate winds, and 26 for stronger winds respectively. This leads to a difference in the generated sound pressure level by a factor of three for the blade-passing harmonics.



Sound pressure recorded about 200 m from the wind turbine. Impulsive signals generated by the blades passing the tower are clearly visible.



Time frequency analysis for a period of 72 hours showing the correlation between wind and rotational speed, and the occurrence of the blade-passing harmonics with the fundamental frequency of 1.0 and 1.3 Hz respectively. At lower frequencies below 1 Hz, the increase and decrease of the background noise is related to the prevailing wind speeds.



A minimum distance for undisturbed recording at station I26DE in the Bavarian Forest can be calculated from the theoretical model for estimating the sound pressure level emitted by different types of wind turbines with electric power outputs of 30 to 5 000 kW, and taking into account the average noise level in the frequency range from 1 to 3 Hz.

Depending on the design parameters and the generated electric power, it is possible to calculate the radiated sound as a function of distance to the wind turbine. The theoretical values could be validated considering the measurements in the infrasonic frequency range. These results provide an opportunity to define a minimum distance between a wind turbine and an infrasound station in order to guarantee unhindered recording conditions. This is of great interest to BGR as the operator of the infrasound station I26DE in the Bavarian Forest, which is part of the International Monitoring System for compliance with the Comprehensive Nuclear Test Ban Treaty (CTBT). According to the theoretical estimation, a minimum distance between a wind turbine and an infrasound station should be in the order of 10 km considering a state-of-the-art 600 kW plant. This value should be doubled in the case of a wind farm.

In contrast to the high sensitivity of microbarometers which therefore require large distances between infrasound stations and wind turbines, the human perception of infrasound is very much lower. The generated sound pressure level of wind turbines drops below the human perception threshold at distances of about 300 to 500 m.

Monitoring compliance
with the CTBT using satellite and seismic data

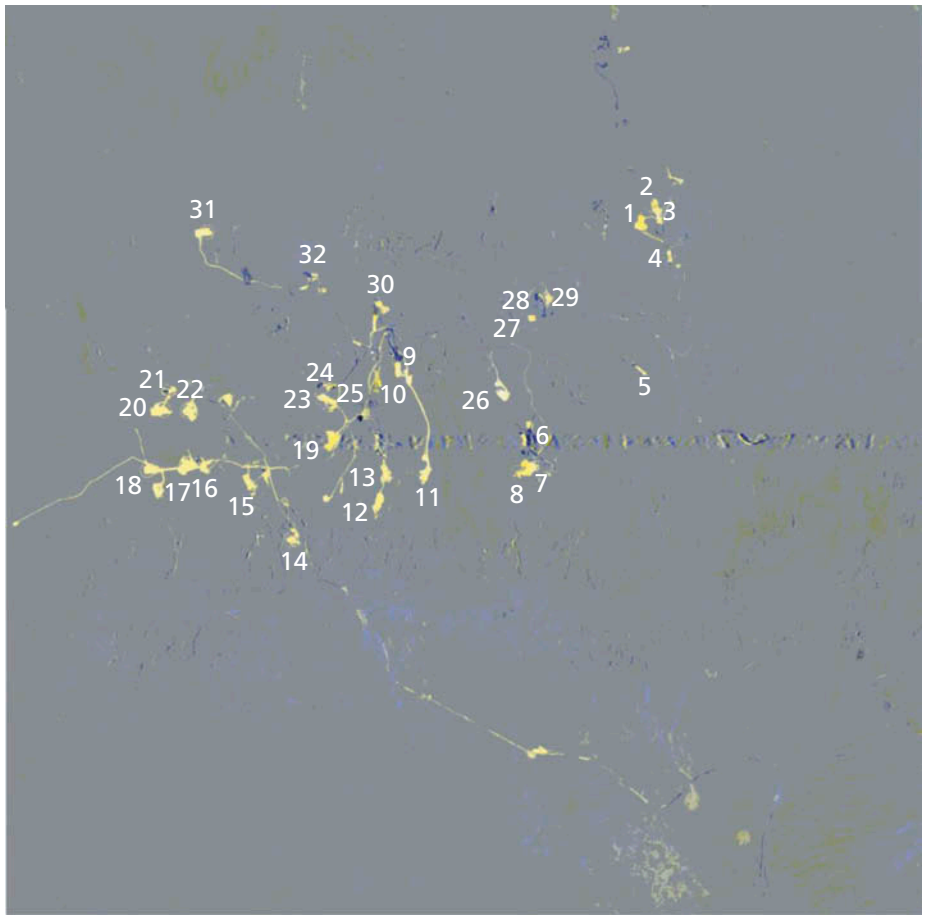
BGR's activities in the EU Network of Excellence GMOSS

Monitoring compliance with the Comprehensive Nuclear Test Ban Treaty by accurately locating underground nuclear explosions is one of the main tasks of applied seismology. In order to supplement the seismic methods, the National Seismological Data Center at BGR uses satellite image analysis techniques for the identification and localisation of dubious seismic events. This research work has been integrated with the Network of Excellence GMOSS initiated by the European Commission since March 2004 (see http://www.bgr.bund.de, → Seismologie/ Kernwaffenteststopp, → Projekte). GMOSS (Global Monitoring for Security and Stability) is part of the Thematic Priority Aeronautics and Space of the Sixth EU Framework Programme for Research and Technical Development.

In the past, mainly multispectral data of underground nuclear weapons tests in India and the nuclear test site in Nevada (USA) were investigated using a statistical change detection method. The method numerically determines the changes between two satellite images of the same area taken at different times. Validation of the technique was carried out using a number of available satellite images taken over the "Nevada Test Site" (NTS). The calculated change detections of the historical underground nuclear explosions were compared with seismic data (origin time, location, magnitude) and associated phenomenological data of the explosions (e. g. crater diameter). The ground resolution of the Landsat satellite images from the 1980s is only 30 m. Detection of changes corresponding to subsidence crater formation at the NTS "Pahute Mesa" site was possible for all investigated tests with one exception. The results prove that changes associated with test site preparations can easily be discriminated and well correlated with the seismic reference data.

Therefore, the observation of suspicious preparatory activity can provide information on possible future tests, and in conjunction with a recorded seismic explosion signal can help identification and improved localisation. This result underlines the synergy of combined satellite and seismic analysis techniques for well-guided on-site inspections and further investigations at the test site. Precise information about the location of potential nuclear explosions is an essential prerequisite for effective on-site inspection by the international CTBT Organisation in Vienna.

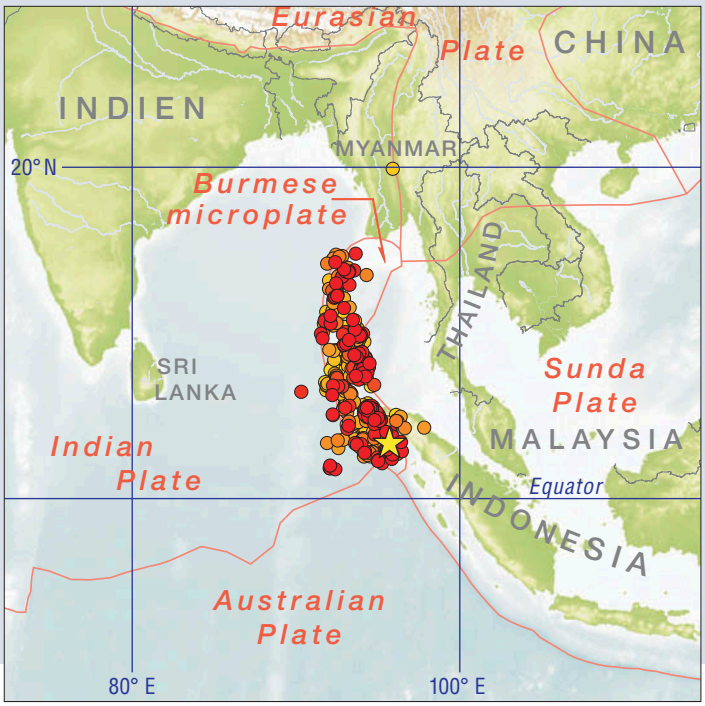
Change detections (bright and dark areas, coloured spots) for the "Pahute Mesa" test site based on two Landsat satellite images from 6 May 1984 and 26 May 1991 resp. Between the two exposures, 32 underground nuclear tests were carried out (the code names of the tests are given). They all clearly show visible change signals which originate from preparative activities at the surface.



1	Bexar	11	Bamwell	21	Egmont
2	Labquark	12	Hoya	22	Hornitos
3	Kearsarge	13	Hardin	23	Cornstock
4	Tiena	14	Belmont	24	Jefferson
5	Towanda	15	Goldstone	25	Bullion
6	Galveston	16	Salut	26	Alamo
7	Houston	17	Tenabo	27	Junction
8	Lockney	18	Delamar	28	Cybar
9	Kappeli	19	Montello	29	Amarillo
10	Bodie	20	Darwin	30	Contact
				31	Kernville
				32	Serena

Tsunami-Help

Tsunami Help



Tectonic map showing the plate boundaries in red (from Coffin et al., 1998, and USGS). The most powerful aftershocks with a magnitude greater than 5.0 (more than 100) are shown as circles together with the main shock (star). The colour code indicates the time sequence from 26 Dec. 2004 (yellow) through 4 Jan. 2005 (red).

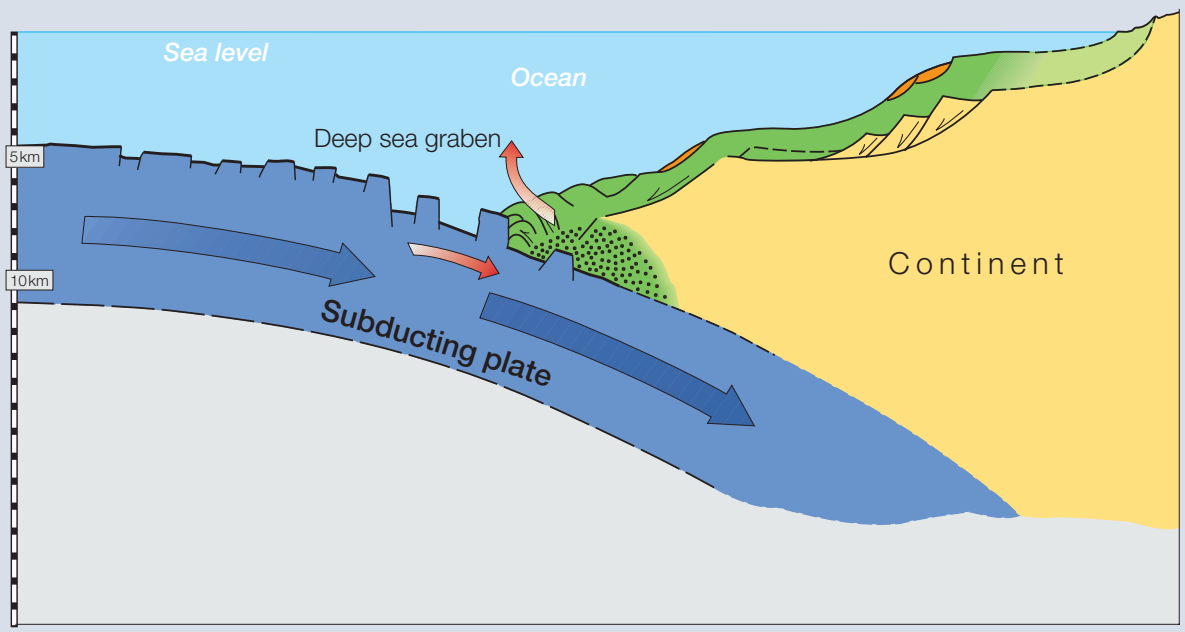
The magnitude 9 **Sumatran earthquake** of 26 December 2004

The magnitude 9 Sumatran earthquake of 26 December 2004 was the third strongest earthquake in the 20th and 21st centuries after the Chile earthquake (1960) and the Alaska earthquake (1964). The tsunami generated by the earthquake flooded many coastal regions of Indonesia, India, Thailand, Sri Lanka and other countries. The earthquake and the generated tsunami caused severe devastation resulting in more than 230.000 deaths and loss of property worth several billion US Dollars. The event attracted massive public attention, not least because a large number of European tourists died or were injured.

Geocientists have long known that the Sunda Arc, covering Sumatra and Java, is a tectonic unit with high georisks. In addition to the numerous volcanoes in Indonesia, the earthquakes occurring along the Sunda Arc subduction zone are the other main risk in the region. Already in the 19th century, two large earthquakes with tsunamis (1833 and 1861) occurred offshore NW Sumatra and caused severe flooding. The devastating earthquake of 26 December 2004 occurred at the NW tip of Sumatra in the area where the Indo-Australian plate is being subducted to the NNE beneath the Eurasian plate at a subduction rate of approx. 7 cm/year. The earthquake was recorded by seismic networks including the Gräfenberg-Array (GRF) and German Regional Seismic Network (GRSN), and investigated by the Seismological Central Observatory (SZGRF) belonging to BGR. According to the localisation by the SZGRF, the main shock occurred at 00:58:48 UT and started at a latitude of 2.76°N and a longitude of 96.92°E.

The daily routine analysis carried out at SZGRF of the recordings made by BGR's seismic networks not only located the main shock but also nearly one thousand aftershocks. The magnitudes of the investigated aftershocks range from 4.2 to 7.1. The spatial distribution of the aftershocks not only traces the plate boundary between the Indo-Australian and Eurasian plate, but also the more than 1000 km long rupture which propagated S-N. The data from the German Regional Seismic Network was also used for a detailed analysis of the main shock rupture propagation as published in Nature (Krüger and Ohrnberger, Tracking the rupture of the Mw=9.3 Sumatra earthquake over 1150 km at teleseismic distance, Nature, doi: 10.1038/ nature 03696, 2005).

The seismological networks operated by BGR, and the national broadband waveform data centre at SZGRF in Erlangen form the basis for internationally acclaimed seismological research. They are relevant not only in the case of mega events like the Sumatran earthquake, but also in the case of local and regional earthquakes in Germany and Europe. In order to guarantee this, a profound knowledge of the principles of seismology as well as high quality seismic data are essential for the evaluation of earthquakes and seismic hazards, and the pursuit of geoscientific research.



Schematic sketch of a subduction zone. The dense oceanic plate plunges under the more buoyant continental plate. The two plates get entangled at the interface. This leads to a build up of tectonic stress which is abruptly released during an earthquake. The red arrows indicate the movement of the plates. The continental plate snapped upward lifting up the water column which triggered the devastating tsunami.

HELicopter **Project Aceh –** HELP ACEH

The earthquake of magnitude 9.3 on 26 December 2004 and the resulting tsunami destroyed about 80% of the private housing, infrastructure and public services in the coastal region of the province of Aceh. The waves of the tsunami caused widespread coastal flooding with salt water and thus ruined thousands of shallow drinking water wells. The deeper fresh water aquifers in the coastal plains were largely protected by shallow clay layers from the salt water swept in by the tsunami , but natural salt water intrusion also occurs. Emergency wells quickly established at many places only produced small amounts of useable fresh water.

In the Indonesian-German project HELP ACEH, the Federal Institute for Geosciences and Natural Resources (BGR) supported its Indonesian counterpart DGGMR (Directorate General for Geology and Mineral Resources, since renamed the Geological Agency), BRR (Executive Agency for Rehabilitation and Reconstruction in Aceh and Nias) and BAPPENAS (National Development Planning Agency) with the sustainable reconstruction of public and private as well as communal water supplies, by providing geophysical, geological, hydro-geological and topographical information as basic data for future planning. The project was financed by BGR's internal budget, by BMZ (German Ministry for Economic Cooperation and Development) and the Indonesian government.

Before take off.

BGR sent its helicopter and associated measuring equipment into the province of Aceh, northern Sumatra, to perform aerogeophysical reconnaissance of the groundwater situation after the tsunami. The helicopter survey flights were carried out from August to October, 2005 around Banda Aceh and between Calang and Meulaboh. Experienced BGR hydrogeologists as well as mostly young hydrogeologists and geophysicists from the project partner DGGMR accompanied the BGR helicopter team. Their task was to help with the interpretation of the helicopter-borne electromagnetic (HEM) data and to produce a hydrogeological reconnaissance map in the areas of interest. Right after the finish of HELP ACEH flights, a second airborne and ground based survey was performed around Sigli on the northern coast of Sumatra (financed by CCFI Coca Cola Foundation Indonesia).

BGR's helicopter survey system includes electromagnetic, magnetic, and radiometry tools. The HEM system with five different frequencies was used to determine the distribution of electrical conductivity down to a depth of up to 150 m. The detection depths of the EM fields are not only dependent on the frequency used but also on the electrical conductivity of the shallow subsurface. High conductivities and high frequencies result in shallower penetration than high resistivities and low frequencies. The subsurface conductivity distribution is controlled by the rock matrix and the fluid content in the pore volume. Therefore, clayey sediments can be distinguished from sandy layers, and salt water from fresh water.

The HEM data provided vital information for the production of urgently needed reconnaissance maps and vertical sections, giving important information on shallow salt water contamination, salt water intrusions, fresh water sources, aquifers and groundwater barriers for organisations helping in the reconstruction process. Shallow salt water contamination and salt water intrusions were detected several kilometres inland in some localities. Nevertheless, fresh water resources could be mapped along the coast that promise the successful installation of new freshwater wells.

Above the roofs of Aceh.

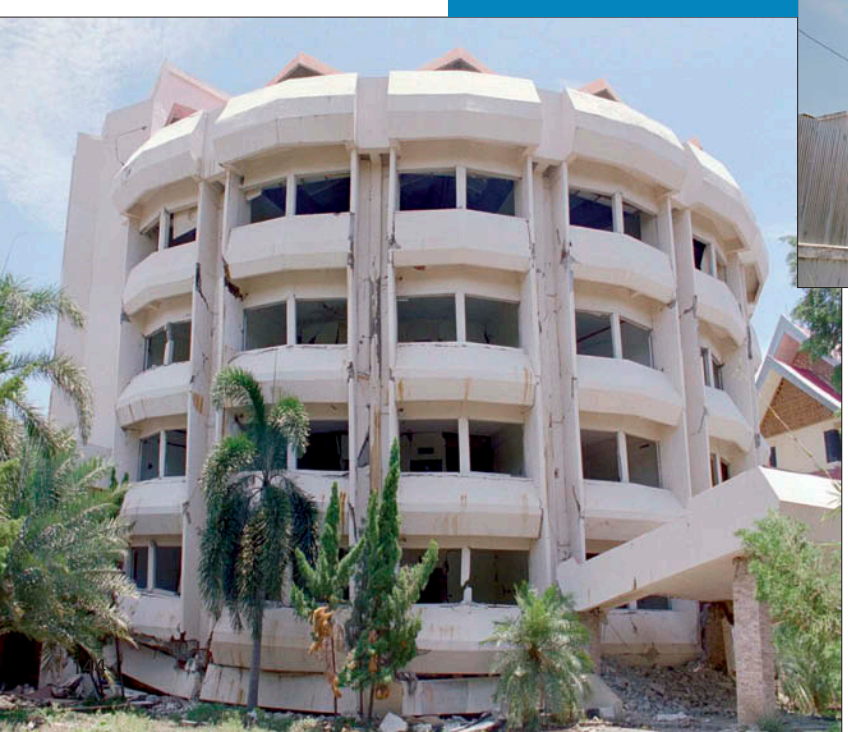
Supporting the **reconstruction** of Banda Aceh in Indonesia – the **ManGeoNAD project**

The province of Aceh in northern Sumatra was severely devastated by the 26 December 2004 earthquake and the subsequent tsunami. The overall death toll totals 170.000, of which 60.000 were killed in the provincial capital of Banda Aceh alone. Every fourth resident of the city fell victim to the destructive force of nature.

Following the disaster, an unprecedented national and international campaign came into effect, to help reconstruct the tsunami-hit region. The German Development Aid for Indonesia focuses on the northern and north-eastern parts of the province.

Work in the first months after the disaster concentrated on immediate aid and clean up operations. This was followed by the challenge of sustainable reconstruction of the destroyed villages and towns. It is necessary to consider the natural conditions at an early stage in the reconstruction planning phase and to focus on the area's susceptibility to the impact of all kinds of natural disasters in order to better safeguard the living conditions of the local population. In August 2005, the Federal Institute for Geosciences and Natural Resources (BGR) was commissioned by the German Ministry for Economic Cooperation and Development (BMZ) to support local authorities in this task. The joint German-Indonesian technical cooperation project was called "Management of Georisks, Province Nanggroe Aceh Darussalam", or ManGeoNAD.

The 'Geological Agency of Indonesia', the 'Authority for Mining, Energy and Geology of the Province of Aceh' (Distamben) and BGR evaluated the georisk-potential and the hazards for humans and infrastructure in selected regions following an interdisciplinary approach. Geoscientific data, forming the basis for a more natural-disaster-proof reconstruction, is acquired and used by institutions responsible for regional planning. The project profits from the georisk management concepts developed in the context of BGR's technical cooperation project 'Mitigation of Georisks' in Bandung.



Banda Aceh:
government building (above)
and hotel building (left) destroyed by the
earthquake on 26.12.2004 (August 2005).

The main tasks and aims of ManGeoNAD can be summarised under five headings:

Subsoil stability

Owing to its plate tectonic location, the northern tip of Sumatra is very prone to earthquakes. The way houses collapsed and infrastructure was destroyed demonstrates that sustainable reconstruction has to take into account how a specific patch of soil behaves during an earthquake. To this end, Indonesian and German engineering geologists study subsoil using shallow boreholes and cone penetration tests. The subsurface is additionally examined with the help of artificial earthquake waves, using a geophysical apparatus constructed by the GGA Institute in Hannover. Combining all this data in an "Engineering Geology Information System" produces an area-wide characterisation of the subsoil stability, allowing the specification of soil settlement, bearing capacity and the potential to undergo liquefaction in the event of a strong earthquake.

All of this information is invaluable for Indonesian civil engineers, who can adjust the architecture and foundations to construct more resilient buildings. Urban planning and development planning authorities fall back on such data, as in the case of the reconstruction of a vocational training centre financed by the KfW development bank: the new subsoil analysis led to changes in the original plans for the location of the building.

Liquefaction

Soil liquefaction is a phenomenon which can occur during earthquakes by the vibration of sandy water-saturated soils. Under normal conditions, the sand grains within a soil layer support one another to form a stable framework. The spaces between the grains are filled with pore water at low pressure. Earthquakes can increase the water pressure and therefore reduce the contact forces between the sand grains. This causes them to slide past one another and form a very low-strength sand-water mixture (liquefaction) which can no longer support the load of buildings or structures. Buildings can then literally sink into the ground.

BGR/Counterpart geologists during engineering geological fieldwork in December 2005 (from left to right: Dr. Andreas Günther, Dr. Dirk Kuhn, Pak Joni, Dr. Dirk Balzer).

Groundwater

The exploration of new hygienic drinking water resources is one of the prime measures to be taken in the Aceh province. The coastal population traditionally supplied themselves with groundwater from shallow groundwater, extracted from shaft wells. This resource was largely ruined by salt water intrusions caused by the tsunami, and many wells were buried by mud and debris. Hydrogeologists are therefore looking for fresh water from deeper beds at more inland locations. Around 40 drilling sites for new wells were identified based on the results of a helicopter-borne electromagnetic survey to map 'salty groundwater', and the hydrogeological fieldwork conducted along the west-coast of the province.

Furthermore, the quality of the drinking water of many wells and springs has to be tested. The Deutsche Welthungerhilfe (German Agro Action) asked the BGR laboratory to analyse the quality of 300 samples from reinstalled shaft wells along the east coast. All such collected hydrogeological data and information on well locations are fed into a database maintained by Distamben and made available to local authorities and NGOs. The tsunami almost completely destroyed similar data archives, the new database therefore forms a much-needed foundation for the development of the region. Its importance is underpinned by the enormous demand for hydrogeological information from organisations such as UNESCO, UNICEF, Red Cross, GTZ, German Agro Action, USAID, Swiss Caritas, etc.

Construction material

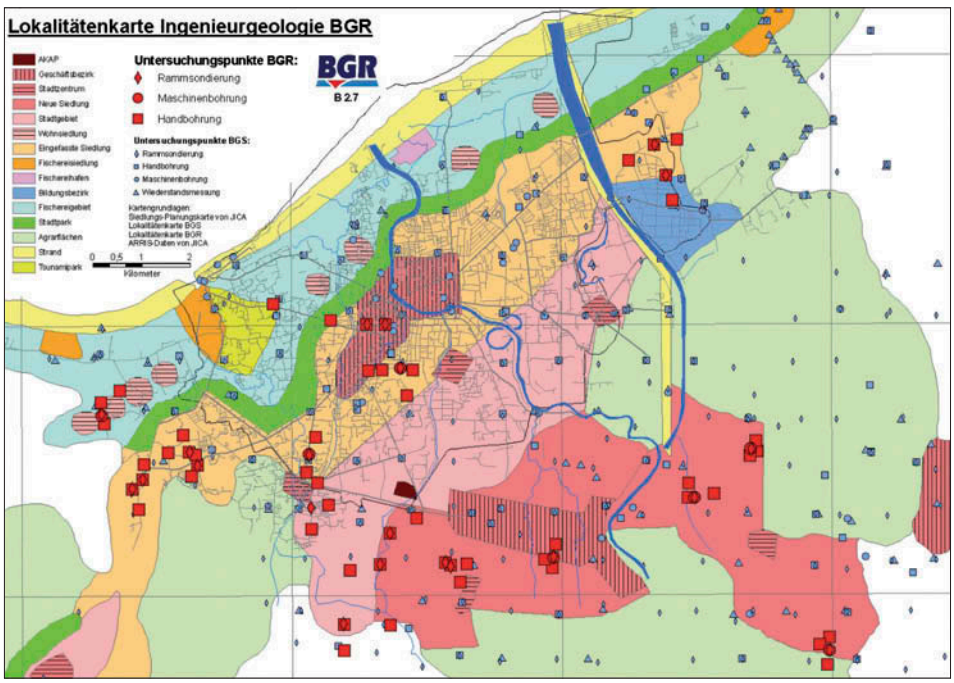
The reconstruction of such a large area affected by the earthquake and the tsunami requires a considerable amount of building material. Sand, gravel and bricks quickly run out and prices rise accordingly. The project supports the partners in evaluating the demand for building material and exploring for new deposits. This also helps local authorities thwart illegal mining that becomes more and more profitable as prices rise.

Management of georisks

All collected data are managed in a central Geo Information System run by Distamben. This helps the institutional strengthening of the authority, which suffered severe losses in personnel and tangible assets. The personnel participate in on-the-job training with new and modern equipment. The authority can thus resume its consultancy work with regional development institutions, and consolidate georisk-related recommendations and aspects in the planning and implementation process for the reconstruction of Banda Aceh. As an initiator of a 'Round table for the mitigation of georisks' Distamben can promote the elaboration of a local body of regulations for preventative natural disaster management.

Raising Awareness

The more the local population is informed about the georisks of their environment and about the measures to take in the event of a natural disaster, the smaller the losses of life and property. Awareness building not only takes into account the consequences of earthquakes and tsunamis but also the hazards caused by landslides, floods, surface subsidence and volcanic eruptions. ManGeoNAD therefore supports open workshops in villages organised by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) that precede the reconstruction of settlements. Local exposure to georisks is discussed with the villagers, and measures for their mitigation are agreed.



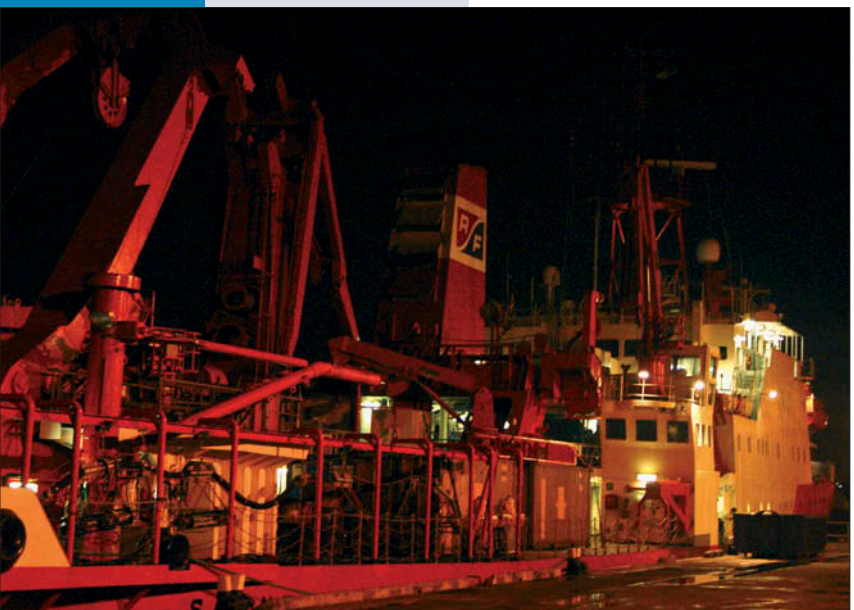
The strongly reduced locality map of Banda Aceh shows the activities of BGR experts in three geological disciplines: building foundations, groundwater, and construction raw materials. This planning map is an indispensable tool for future urban planning.

SeaCause

The Federal Institute for Geosciences and Natural Resources carried out several scientific expeditions off Sumatra with the research vessel SONNE to investigate the cause of the magnitude 9.3 earthquake on 26 December 2004, and its associated tsunami. These studies provide an essential contribution to the installation of a tsunami early warning system as agreed between the Federal Republic of Germany and Indonesia. In addition to mapping the surface of the seafloor (bathymetry) which is indispensable for the installation of the early warning system buoys, the tectonic setting for the large earthquakes was also studied. These results are to be incorporated into improved models of earthquake origin and tsunami propagation in the area achieving the fastest possible warnings for the coastal population.

Scientific equipment on the afterdeck.

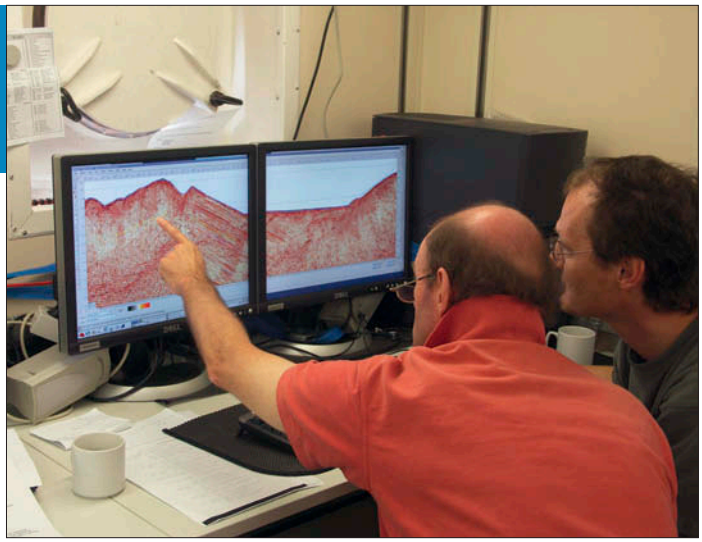
The seafloor displays elevation differences of several thousand metres. These submarine rises may limit the propagation of tsunami waves. BGR is in charge of compiling a comprehensive map of the seafloor in this area, integrating the data from other international expeditions. Cooperation with European and international partners makes an important contribution to this work.



Evening scene at the pier: RV Sonne moored.

Geoscientists developing models onboard immediately after data acquisition.

Onboard interpretation of new data.



In the scientific lab: seismic line interpretation.

During the devastating tsunami earthquake of December 2004, the rupture plane propagated along a total length of 1300 km. The rupture initiated immediately off the coast of northern Sumatra (Aceh Province) at a depth of about 30 – 40 km, and extended to the northwest and north into Indian waters along the Nicobar and Andaman Islands. Three months after the December 2004 earthquake, another large earthquake with a magnitude of 8.7 occurred about 200 km southeast of the first earthquake on 28 March 2005. The rupture plane of this earthquake was a mere 400 km long and caused only a small and regionally limited tsunami. The length of the fault plane depends on the magnitude of an earthquake and is a crucial parameter for its risk potential.

Off Sumatra, the continuity and propagation of earthquake rupture planes on the subducting oceanic Indo-Australian plate is abruptly terminated along relatively sharp segment boundaries. The position and orientation of the segment boundary between the December 2004 and the March 2005 earthquakes are well defined by their after-shock distributions. To understand the structure and the cause of this clear-cut segment boundary, the subsurface below the seafloor was investigated to a depth of about 15 km. The reflection seismic method uses sound wave signals that penetrate the seafloor and deeper rock layers, the reflected portion being recorded at the ocean surface. The analysis of these data by BGR scientists using modern processing and interpretation systems led to the conclusion that the boundary between the rupture planes of the two large earthquakes consists of a hitherto unknown fracture zone in the oceanic Indo-Australian plate subducting beneath Sumatra.

RV Sonne trailing seismic equipment.

Deploying the air gun system.

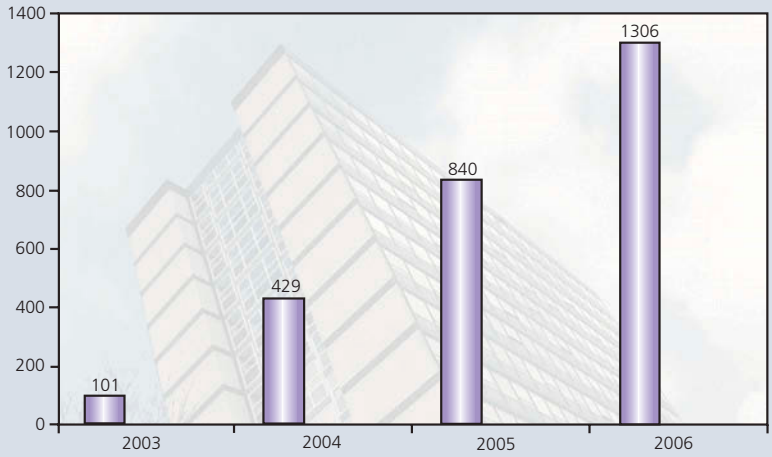
In addition, mapping of the seafloor reveals numerous additional fracture zones in the oceanic plate, which are likewise already partially subducted beneath Sumatra. They could limit the propagation of earthquake ruptures in a similar way. These findings now have to be included in new models for risk estimation. The subsurface structure of the submarine continental margin off Sumatra is very complicated.

Our investigations reveal several possible causes for the formation of a tsunami. Large slumps from slope failures actuated during a large earthquake have to be considered as well as fault zones on the continental slope, which reach up from great depth either to the seafloor or just below.

Air-gun shot generating seismic waves.



Special Topics



Development of media coverage of BGR from 2003 to 2006 (number of times mentioned).

Public relations at BGR:
"Hunting the truffles of the deep sea"

On 31 June 2006, this was the title given by the Hamburger Abendblatt to BGR's activities involving manganese nodule exploration in the Pacific Ocean. It is also a fairly good description of the daily work of the press officer – to find the gems of knowledge that BGR scientists hold in their everyday activities, and to make them accessible to a broader public. The "truffles of the deep sea" is certainly not the most scientifically exact term for manganese nodules, but it certainly raises interest in a subject that would otherwise not be easily understood by the normal newspaper reader.

Over the last two years, BGR has put a lot of effort into establishing a broad media presence. Not only since the Indian Ocean tsunami on 26 December 2004, BGR has become known to an ever increasing number of journalists as a reliable information partner concerning all geoscientific aspects. This is mirrored in the press statistics: the presence of BGR in the media has increased by more than twelve times since 2003.

The media echo follows an interesting, not always foreseeable dynamic process. Often interest is dictated by external events such as natural disasters or energy crises. On the other hand, BGR is successful in setting its own themes as the example of the manganese nodules shows. Some unforeseen oddity or polemics are also part of the game. For example, in June 2005 there was extensive media coverage about the "water hunters in Namibia" (a project that had actually been completed two years earlier) – while the BGR helicopter was actually flying at the time over Indonesia's Aceh province to examine the groundwater that had been oversalted and polluted by the Indian Ocean tsunami.

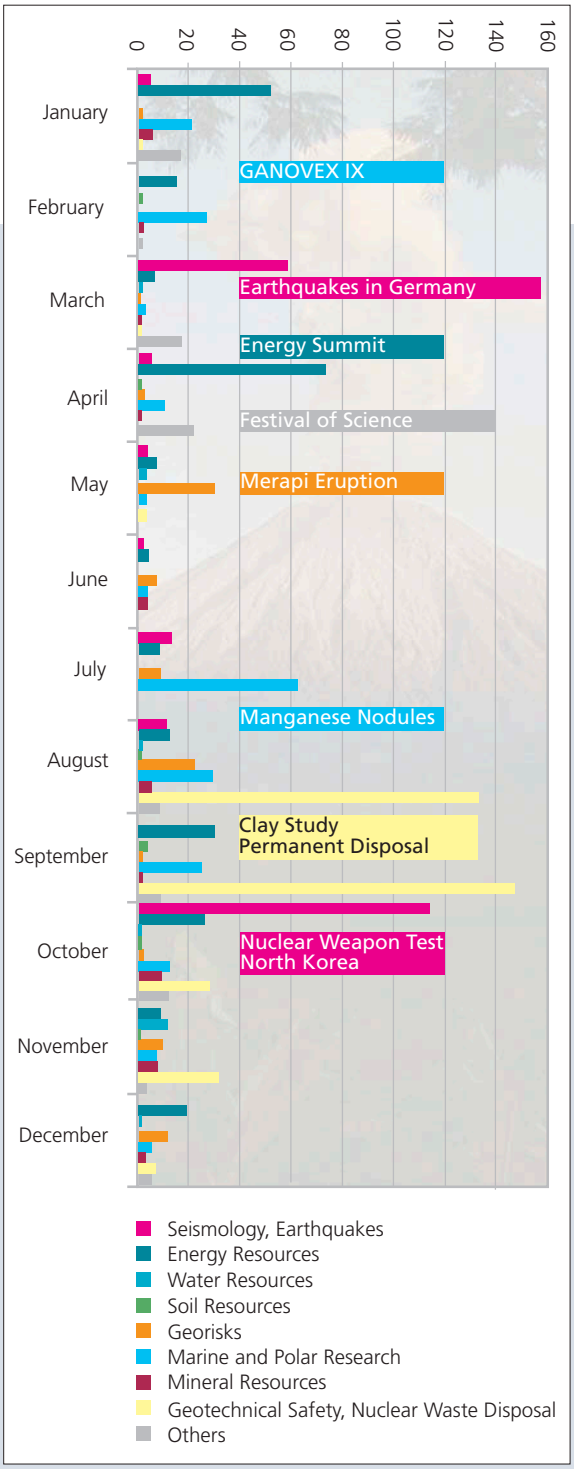
In August 2006, a BGR study on German claystone formations fulfilling the geological criteria for potential radioactive waste repositories was extensively discussed in many newspapers throughout Germany.

The timing of this interest was rather arbitrary. The study had been made available on the internet server several months before, and went unnoticed until one journalist discovered the theme and triggered a discussion that reached the highest political levels. Shortly after, the nuclear weapon test in North Korea attracted worldwide public attention. In accordance with its mandate, BGR immediately informed the government and the public about the location, strength and character of the explosion.

There is always a great deal of public interest in the availability of natural resources. In addition to energy resources, mineral resources are also attracting more and more interest – as the "truffles of the deep sea" shows. Another hot spot of BGR information requests concerns earthquakes in Germany and worldwide. They were discussed extensively, and in some part controversially, in TV, radio and newspapers.

The polar and marine research expeditions have also become something of a classic among BGR's media favourites. For the first time ever, an Antarctic expedition named "GANOVEX IX" could be followed in weekly features of the daily TV show "Hallo Niedersachsen". This premiere in media coverage from icy and remote Antarctica was made possible by modern satellite communications and a film team that accompanied the scientists throughout their expedition.

This short outline of media feedback reflects the importance of BGR's activities for society as a whole. Many of its projects and daily work are still carried out quietly and unnoticed by the media or a wider public. But there are still lots of "truffles" to be discovered in the sea of BGR's activities.



Subjects of media coverage 2006.

Technical cooperation with developping countries

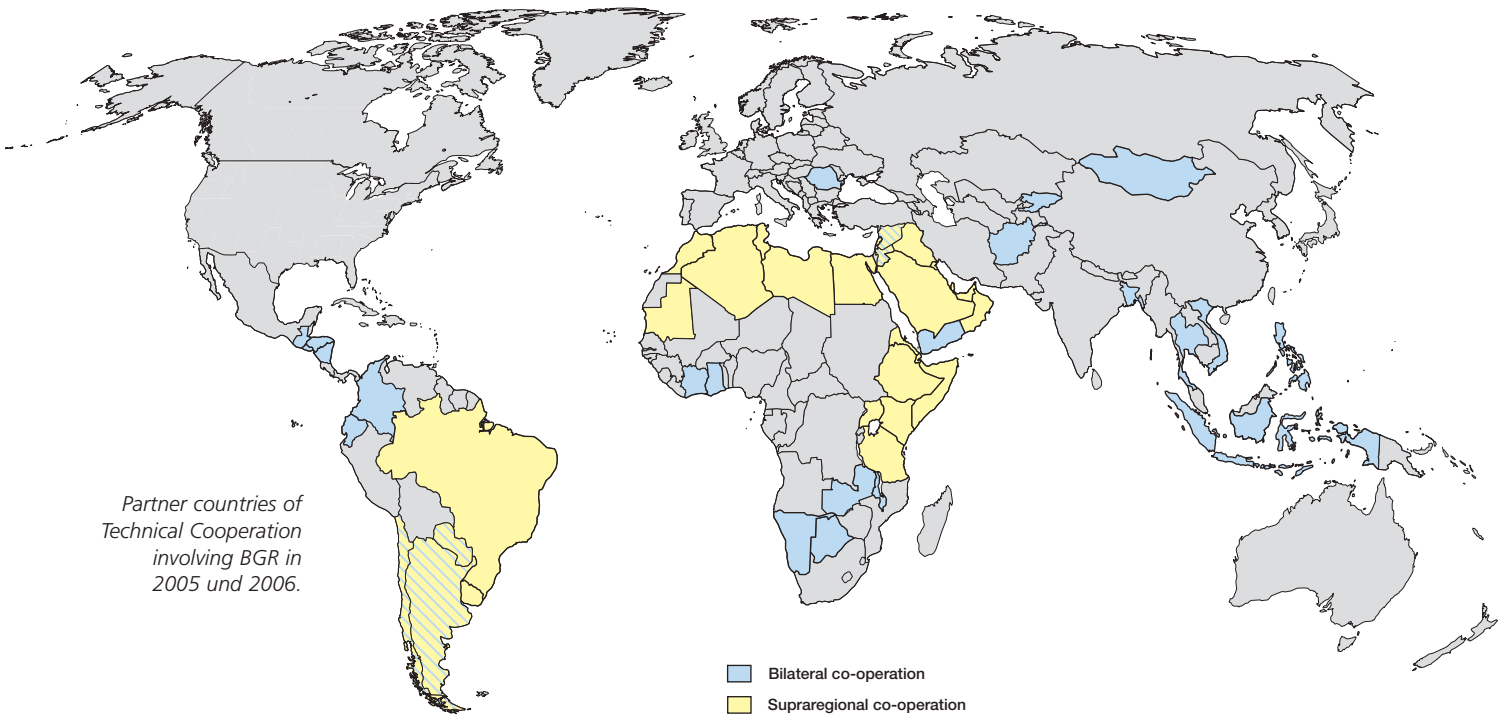
The development policy of the Federal Republic of Germany aims at improving the living conditions of people, particularly the poor in partner countries. Four main objectives are:

- Reducing poverty worldwide
- Building peace and bringing about democracy
- Promoting equitable forms of globalisation
- Protecting the natural environment

The German government supports development processes in partner countries through development cooperation to enable people to improve their living conditions.

The German Ministry for Economic Cooperation and Development (BMZ) commissions a number of organisations to plan and implement development projects and programmes. These include the Federal Institute for Geosciences and Natural Resources (BGR) for projects regarding geology, mineral and energy resources and mining, including soil and groundwater.

BGR supports partner in developing countries in establishing an adequate framework for their development. This comprises institution building and development, and the improvement of their capacity for qualified and good governance. In general, BGR experts support partner institutions through advisory services and know-how transfer, but increasingly, domestic experts are integrated to foster the "South-South exchange of know-how". Regional co-operation projects and organisations are also supported as a platform for the development of cross-boundary solutions. The cooperation with the private sector in the field of mineral and energy resources is seen as an element that can contribute to the development of local economies.



Partner countries of Technical Cooperation involving BGR in 2005 und 2006.

The know-how of BGR experts comprises long term geoscientific expertise in all aspects from applied geology to mine inspection. Partner institutions are mainly governmental institutions such as geological surveys, water ministries, mining authorities and other public authorities.

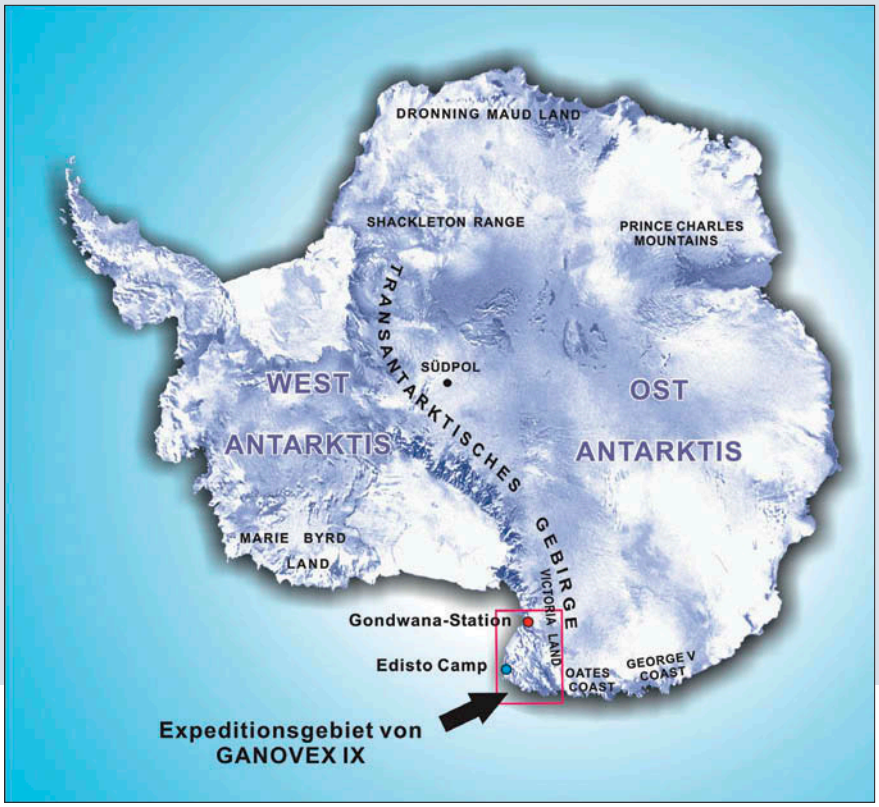
Focal areas of support are:

- Assessment and sustainable use of mineral and energy resources, including geothermal energy
- Sustainable management of groundwater and soil
- Mining and environmental protection in mining
- Protection of natural resources and the environment, geological basis for spatial and regional planning (e.g. for the location of waste disposal sites),

BGR's contribution therefore helps to satisfy technical baseline requirements to improve economic and social efficiency in developing and emerging countries and to protect and manage natural resources in a sustainable way.

In 2005 and 2006, BGR implemented more than thirty technical cooperation projects in more than twenty partner countries. The following articles from technical cooperation projects are included in this report:

- With helicopter and 4 x 4 – groundwater investigation in the northeast of Namibia
- Advising the mining bureaux in Vietnam and Mongolia
- Supporting the reconstruction of Banda Aceh in Indonesia – the ManGeoNAD project
- Mitigation of georisks in Indonesia
- Groundwater monitoring in Kyrgyzstan



Location of the target area of GANOVEX IX

GANOVEX IX – Expedition to the perpetual ice of the Antarctic

Since 1979, geoscientists at the Federal Institute for Geosciences and Natural Resources have collaborated with German universities and foreign institutions to study the structure and geological evolution of northern Victoria Land and the Ross Sea sector of West Antarctica within the framework of the GANOVEX programme (German Antarctic North Victoria Land Expedition). The common target of these activities is the investigation of continental masses and their margins in order to gain a better understanding of the early history of the Earth, and particularly the formation of the supercontinent Gondwana and its precursor Rodinia, but also their fragmentation and the formation of the modern Antarctic continent and its shelf margins. BGR's activities are a major contribution to the key targets of German Antarctic research.

The BGR's research activities in polar regions are tied up in some cases to long-term international co-operation agreements and treaties. Working together with the Alfred-Wegener Institute for Polar and Marine Research (AWI), BGR helps to maintain Germany's consultative status within the Antarctic Treaty – and does this by conducting regular research expeditions in the Antarctic. The work involved is delegated between AWI and BGR: BGR being responsible for terrestrial (or "hard-rock") geoscientific aspects of the Antarctic research. In addition, numerous geoscientific programmes conducted by university groups and funded by the German Research Foundation as part of its "Antarctic Research" priority programme, are only possible because of the support they are given by the BGR logistics infrastructure.

In early Gondwana history, i.e. 500 million years ago, a high-elevation mountain range existed in northern Victoria Land, which is geologically comparable to the modern Andes in many ways. Like the Andes, this mountain range formed because the Pacific plate was

In its geological past, Antarctica was not always an isolated continent, but was part of larger land masses. It was the central part of the supercontinent Gondwana that formed as a result of the collision of several continental fragments approximately 500 million years ago and included all modern continents of the southern hemisphere. Gondwana existed until ca. 180 million years before present, when it began to break-up, indicated by voluminous basaltic eruptions. Africa, India, Australia and finally South America drifted away from Antarctica, eventually leading to todayís isolated position of the continent in the South Polar Region and the establishment of the modern global ocean circulation system and todayís climatic conditions.

continuously dragged down under the much lighter continental plate of Gondwana. This ancient, ca. 500-million-year-old high-elevation mountain range is generally referred to as the Ross Orogen. It was subsequently levelled to an extensive peneplain by intense erosion within a geologically relatively short time. The common landscape of Gondwana was then characterised by wide basins with braided river systems for a period of almost 300 million years. Smaller and larger freshwater lakes repeatedly formed within these basins. The sediments that were deposited in the basins are generally referred to as the Beacon Supergroup in northern Victoria Land. Deposition terminated when huge volumes of flood basalts of the Ferrar volcanic event started to erupt around 180 million years ago marking the initial break-up of the Gondwana supercontinent.

After eight GANOVEX campaigns and further expeditions to the Shackleton Range, central Dronning Maud Land, the southern Prince Charles Mountains, and the central Transantarctic Mountains, geological and geophysical research on the crustal structure and tectonic evolution of northern Victoria Land, the Ross Sea, and the Pennell Coast was performed within the framework of GANOVEX IX in the austral summer 2005/06. The main target of this expedition was to reconstruct the initial break-up history of Gondwana in this sector of Antarctica, and the subsequent opening of oceanic gateways between Australia and Antarctica which led to the final isolation of the modern continent of Antarctica. This target required the close cooperation and coordination of different research programmes developed by scientists at BGR, the universities of Bremen, Jena and Münster, and the Technical University of Freiberg. The scientists involved covered a wide spectrum of different specialisations from geophysics, structural geology, geochronology and thermochronology, geochemistry, sedimentology, stratigraphy, palaeontology and palynology. Because the expedition was accompanied by a media team and the subject of a great deal of reportage, GANOVEX IX has been continuously present in television, radio, print media, and the World Wide Web during the

Collection of fossils in sandstones of the Transantarctic Mountains.

expedition and beyond. This offered the unique opportunity of continuously raising awareness of the activities and knowledge gained from polar research amoungst the general public and in schools and universities.

The close interdisciplinary application of many different geoscientific methods is absolutely essential to understand the processes involved in the Cretaceous and Cenozoic reorganisation of northern Victoria Land and the formation of the West Antarctic Rift System, which eventually led to the modern plate configuration between Australia, Antarctica and New Zealand. Particularly, geophysics and structural geology play a key role in these reconstructions. Structural geology is an important tool to outline differences or similarities in the geodynamic evolution of continental fragments that are located several thousand kilometres apart today. While structural geology is largely dependent on rocks exposed at the surface, geophysical methods (and particularly aeromagnetics used during GANOVEX IX) can provide important information on the crustal structure hidden under the ice or in offshore regions. With the aid of geochronological and thermochronological methods, the evolutionary steps of the geodynamic evolution of the region identified by structural geology can be related to absolute ages.

During GANOVEX IX, an approximately 200 km long section of Beacon sedimentary and Ferrar volcanic rocks within a roughly 25 km² large area was studied by volcanologists, sedimentologists and palaeontologists during a three-week fieldwork campaign from a base camp at Mt. Carson – on foot and with the aid of a helicopter. A large number of stratigraphic

Field camp at Cape Hallett.

Helicopters at Archambault Ridge in the Deep Freeze Range.

Tents at Gondwana Station.

sections were analysed in great detail at a centimetre and decimetre scale, including several sections of ancient lakes. Among many other results, it was demonstrated for the first time that sandstones interspersed with numerous volcanic fragments occur at the base of chaotically brecciated rocks that formed from explosive eruptions before the onset of the actual Ferrar lava flows. Intercalations of slack water horizons contain a rich flora and fauna that will yield an age for this succession. The results will surely lead to fundamental changes in the known stratigraphy and thus to a totally new view of the geological evolution of the region at the end of Triassic and in early Jurassic times.

The results of the expedition show that northern Victoria Land and southern Australia shared a very similar geological evolution after the eruption of the Ferrar volcanic rocks, at least since the Late Jurassic and through the whole Cretaceous. In Cretaceous times, i. e. the period between 146 and 65 million years before present, increased subsidence led to the formation of a relatively wide, extensive basin that received several kilometres of sediments. These sediments are up to 10 km thick in southern Australia, but are not preserved in northern Victoria Land. They were completely eroded away in Cenozoic times (presumably since approx. 55-50 million years before present) from the high-elevation areas outcropping today and were deposited in the rift basins (i.e. tectonic depressions bounded by parallel faults) of the Ross Sea. The Cretaceous basins formed within a network of extensional faults and NW-SE oriented left-lateral faults. The basin-forming processes eventually led to the formation of the Antarctic passive continental margin in Late Cretaceous and earliest Cenozoic times, and the separation of Tasmania and southern Australia from northern Victoria Land within a generally left-lateral tectonic regime.

The Early Cretaceous fault pattern is mirrored today in the oceanic ridge systems and the transform systems oriented roughly perpendicular to ridges between Australia and Antarctica.

Once the two continents were separated, and Antarctica assumed its isolated position in the South Polar Region, a new tectonic setting involving large-scale crustal extension and dominantly right-lateral fault movements established itself in Cenozoic times about 55-50 million years ago due to the now independent evolution of northern Victoria Land and the formation of the West Antarctic Rift System in the Ross Sea. This geodynamic setting is still active today and shows the continuing destruction of the Gondwana fragment Antarctica. With these studies in the Antarctic, BGR makes a major contribution to understanding the key role of the Polar Regions with regard to global changes in the Earth's system from the past to the future and its influence on the conditions supporting human life.

Geology without (political) limits:

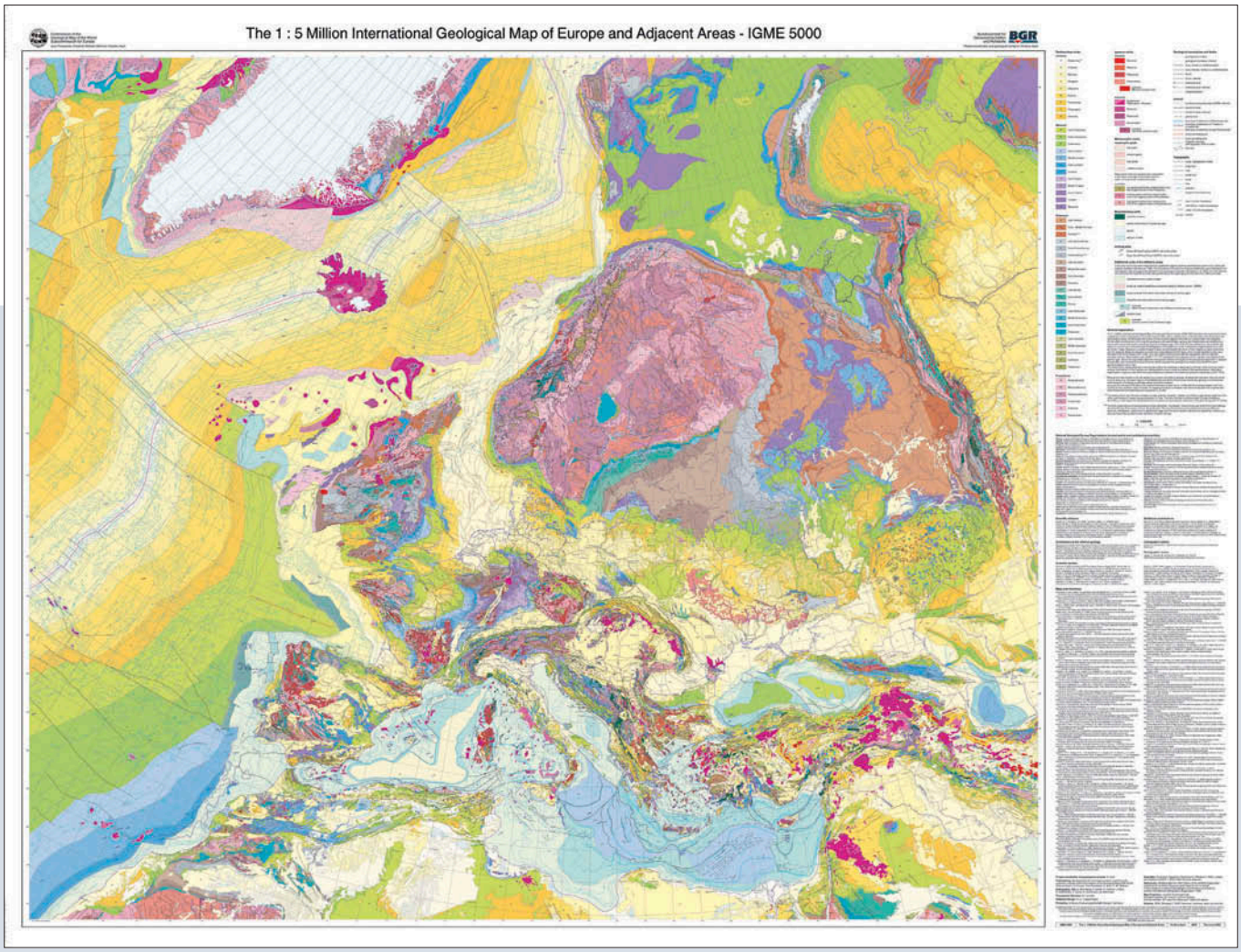
The new International Geological Map of Europe and Adjacent Areas 1 : 5.000.000 (IGME5000)

The new International Geological Map of Europe and Adjacent Areas was printed in November 2005 and published in spring 2006. The map is a result/product of the IGME5000-GIS-Project of the BGR (under the auspices of the Commission of the Geological Map of the World – CGMW). Its aims were:

- to build up a Geographic Information System (GIS) on the pre-Quaternary geology onshore and offshore Europe,
- to print a map according to high standards and with respect to scientific and cartographic aspects,
- to implement a web mapping application.

48 active (not only) European Geological Surveys have been involved in this project. It was supported by a network of academic advisors from European and northern American universities and scientific institutes.

Because a large scale international project decisively depends on the quality of the contributions from the numerous countries (or Geological Surveys) meticulous preparation was required. Procedures, workflows and input templates were developed to gather and integrate the necessary spatial and attribute information from the participating organisations, while at the same time attempting to standardise and constrain their input, e.g. by developing the 'term dictionary' which defines all the terms used in the GIS. Its development took place in cooperation with – and with the agreement of – the participating scientific advisors. As a minimum, the system should be stable and user friendly to simplify the acquisition of basic data spread throughout Europe (and beyond).



The map print of the 1 : 5 Million International Geological Map of Europe and Adjacent Areas (strongly reduced in scale) is available either in one map sheet, folded, or in two sheets, rolled. Total size: approx. 130 x 170 cm.
The map includes a map key, reference list and explanations.

Special scientific research was undertaken, especially on the offshore areas, to acquire confirmed and provable data and information, and to review the information's plausibility and age.

On the geo-informatics side, a data model and a hierarchically built-up data structure were developed to reproduce Europe's geology in a practical computer-based concept. It was an outstanding challenge to integrate not only the onshore but also the offshore geology of Europe into a GIS and a map because the data on the offshore geology mostly derives from geophysical research (seismic, magnetometry, gravimetry) and/or drilling programmes (ODP and DSDP). The conversion and interpretation of this data to describe the rocks geologically, at least their age and lithology, were an outstanding challenge for traditional cartographic work as well as modern GIS development.
The result of 12 years research and compilation was a GIS of the geology of a whole continent, containing information such as lithology, age (geochronology) and regional names, metamorphism, and tectonic and genetic elements.

There are approximately 2.300 different descriptions of geological units in the map and the GIS, covering 32.591 areas. In order to make this mine of information usable for the public, a web mapping application based on the UMN MapServer is nearing completion. The beta-version runs from August 2006. The harmonised geological information of the whole of Europe is stored in an SQL-Server database; spatial data are provided as ArcGIS Shape files.

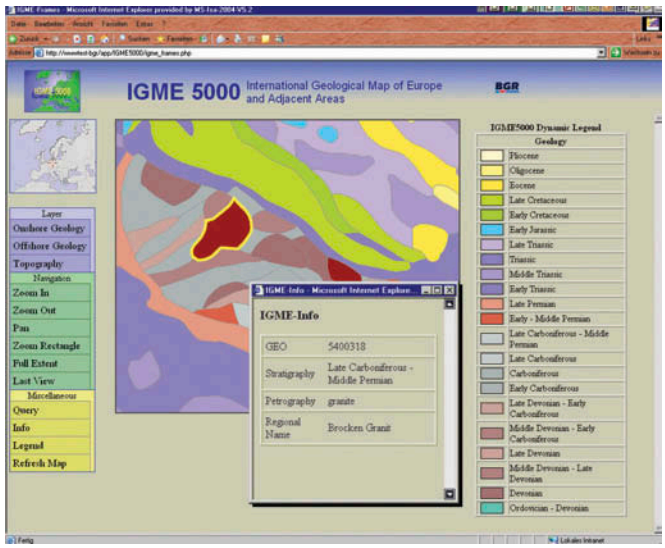
The GIS IGME 5000 also has a web map application allowing a wide range of international queries for the whole of Europe. For example, one may select the 'Harzer Brockengranit' either via its regional name or its specific geological attributes. With the 'info'-function, individual properties of an area are shown on screen. In the case of 'Harzer Brockengranit' it is geochronological: Late Carboniferous to Mid Permian; and lithological: Granite. The query function offers a vast range of properties to select geological units which can be shown on screen, e.g. Variscan granitic rocks or ophiolite complexes.

Further Information

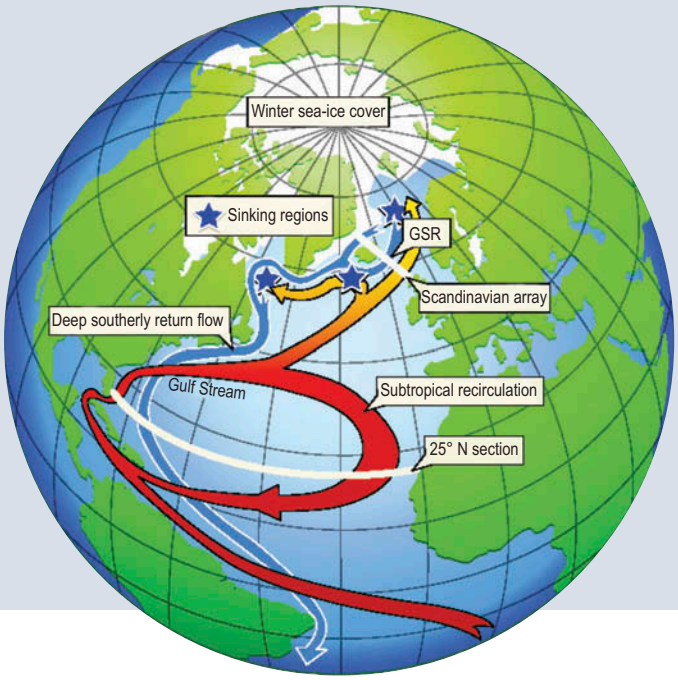
Bundesanstalt für Geowissenschaften und Rohstoffe (BGR):
http://www.bgr.bund.de

Commission for the Geological Map of the World (CGMW):
http://ccgm.free.fr/

Web Map Application:
https://www.bgr.de/app/_IGME5000/igme_frames.php



The IGME 5000 web mapping application: demonstration of the "info" function showing the Brocken Granite of the Harz Mountains.



The North Atlantic heat conveyor: the Gulf Stream (red arrow) carries heat northward. Part of the warm surface water moves clockwise in a giant horizontal gyre in the subtropics. Water masses reaching the North Atlantic (yellow arrow) release heat to the atmosphere and form a dense (cold, salty) water mass that predominantly sinks in the regions indicated by the blue stars, and flows back southwards at depths between 1 and 6 km (blue arrow). Figure after Quadfasel 2005.

Atlantic climate seesaw:

Tropical Atlantic warming indicates North Atlantic climate shifts

Currently, there is much public debate about whether the Gulf Stream may weaken in response to climate change, which would probably be associated with regional cooling in northern Europe despite continued global greenhouse warming. Reconstruction of past natural climate variability is crucial for improving our understanding of how the climate system works and for estimating possible future climate change. The ocean plays a critical role in the climate system through the transport of heat from the tropics to temperate and polar latitudes. Therefore, abrupt changes in ocean circulation (on time-scales of decades), possibly triggered by global warming of the oceans and the atmosphere, are of major importance to central and northern Europe. To advance our understanding of these processes, the Federal Institute for Geosciences and Natural Resources (BGR) investigates changes in the Atlantic's environment and the underlying causes during the recent geological past.

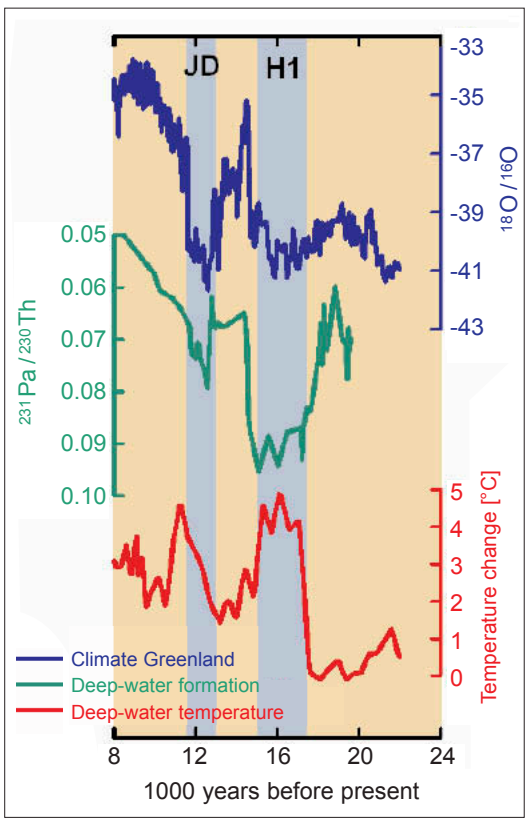
Temperature reconstructions of surface and deep waters of the Atlantic Ocean indicate that past changes in Gulf Stream intensity were governed by an interplay between the northern Atlantic and the tropical Atlantic. During the terminal stage of the last ice age, the tropical Atlantic warmed each time the Gulf Stream slowed down and temperatures around the North Atlantic drastically decreased within a couple of years. While global temperatures increased slowly but persistently over a period of about 10.000 years at the end of the last cold stage, the North Atlantic region repeatedly returned to near-glacial conditions. Such a climate collapse occurred about 16.000 years ago when temperatures across North America, Europe and Western Asia suddenly reverted to bitterly freezing conditions while surface temperatures in the tropical Atlantic increased by about 1.5°C and even 5°C at medium depths. A similar event, the Younger Dryas cold spell, occurred 12.000

years ago, immediately before the beginning of our present interglacial. Between these two cold periods, the North Atlantic passed through a warmer climate period and the seesaw operated in reverse mode. Reconstructions of this period show that the tropical ocean cooled by up to two degrees Celsius.

These insights come from investigations of two sediment cores: one recovered southeast of the Caribbean island of Grenada at 1.300 m water depth, and one offshore Angola at a depth of 430 m. The climate history of the tropical Atlantic Ocean since the last ice age is preserved in the seafloor sediments. The evolution of sea surface temperatures for the two regions was reconstructed from alkenones, long-chain unsaturated hydrocarbon molecules, whose relative proportions provide information on ocean temperatures. Changes in deep ocean temperatures were reconstructed from the remains of benthic foraminifera (carbonate tests of animalcule unicellular organisms thriving on the seafloor).

The underlying mechanism for the climate seesaw lies within the dynamics of the Gulf Stream system. Presently, dense (cold and salty) surface waters sink in the subpolar North Atlantic, and flow southwards at depth. In return, warm upper ocean waters move northwards with the Gulf Stream. This heat transport, sometimes compared with a conveyor belt, makes a substantial contribution to the moderate climate of maritime and continental Europe. During the last ice age, the conveyor operated at a lower level. At the glacial termination, enormous glaciers repeatedly burst off the disintegrating North American ice cap, and large volumes of meltwater discharged into the North Atlantic through the St. Lawrence River. This huge freshwater input reduced the salinity and hence the density of the water in the North Atlantic, preventing surface waters from sinking. Accordingly, the northward transport of warm Gulf Stream water decreased and the circulation system slowed down and was possibly shifted to the south. The consequence: amplified cooling in the north and warming in the tropical Atlantic. Simulations with a climate model show that this characteristic pattern of temperature change in the Atlantic Ocean is a common feature for abrupt shifts in ocean circulation under both glacial and interglacial climate conditions. Therefore, continuous temperature measurements in the deeper layers of the tropical Atlantic may aid in the early detection of a possible future slowdown in Atlantic circulation.

Currently, we measure magnesium/calcium ratios of benthic foraminifera for selected periods of weakened ocean circulation during the past 15.000 years. We employ this relatively new method for the reconstruction of ancient water temperatures to more accurately determine the rate of temperature change during periods of abrupt climate change at the terminal stage of the last ice age.



Comparison between changes in water temperature at 1.300 m depth off Grenada (red) during the termination of the last ice age, with the climate in Greenland (blue) and the rate of deep water formation in the North Atlantic (green). Deep-water formation was drastically reduced and the deep tropical Atlantic warmed by up to 5°C concurrent with the short-term climate shifts associated with the Heinrich event H1 and the Younger Dryas (YD), associated with low temperatures in Greenland.

Facts and Figures

Budget (planned expenditure)

2005 € 60.2 million budget,
including € 11.8 million from third-party funding

2006 € 61.5 million
including € 10.1 million from third-party funding

Staff

2005 752 of which 305 scientists.

New staff:
24 female and 38 male staff and
4 female and 6 male trainees

2006 739 of which 300 scientists.

New staff:
22 female and 25 male staff and
7 female and 4 male trainees.

Trainees

2005 34 trainees
17 female and 17 male

2006 33 trainees
20 female and 13 male

Training areas:

- *Chemical laboratory assistant*
- *Electrician*
- *Office communications assistant*
- *Vehicle mechatronic technician*
- *Precision mechanic*
- *Cartographer*
- *Media and information services assistant*
- *IT specialist*

The BGR website

2005 12.533.158 page impressions,
of which 3.331.166 page-impressions
Average 9.127 per day.
Visitors 451.732,
average 1.238 per day

2006 10.572.865 page impressions
Average 28.967 per day.
Visitors 690.524,
average 1.070 per day.

Reference library

One of the largest geoscientific reference libraries in the world with more than 360,000 books and journals and 100,000 map sheets. 3500 new editions per year; more than 1000 exchange partners world-wide.

The collections in Hannover and Berlin

One of the largest geoscientific collections in Germany;
50,000 type specimens;
more than 1,000,000 reference specimens (fossils, rocks, minerals)
65 km core samples

GeoAthletics

250 staff members regularly use the organised sporting arrangements.The SBL Sports Association at BGR organises:

- *Badminton,*
- *Football,*
- *Posture training,*
- *Running,*
- *Swimming,*
- *Sailing,*
- *Table tennis,*
- *Volleyball,*
- *Walking,*
- *Yoga,*
- *Fitness-Arena (Fitness-Studio)*

Imprint

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Picture references

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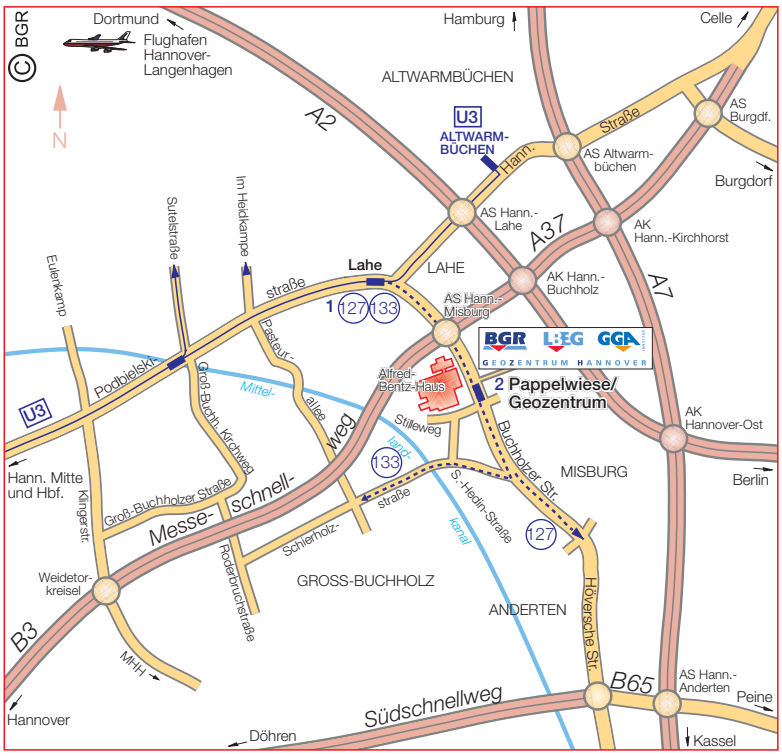

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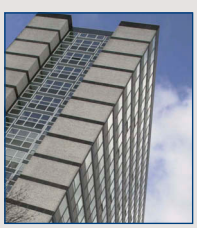

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