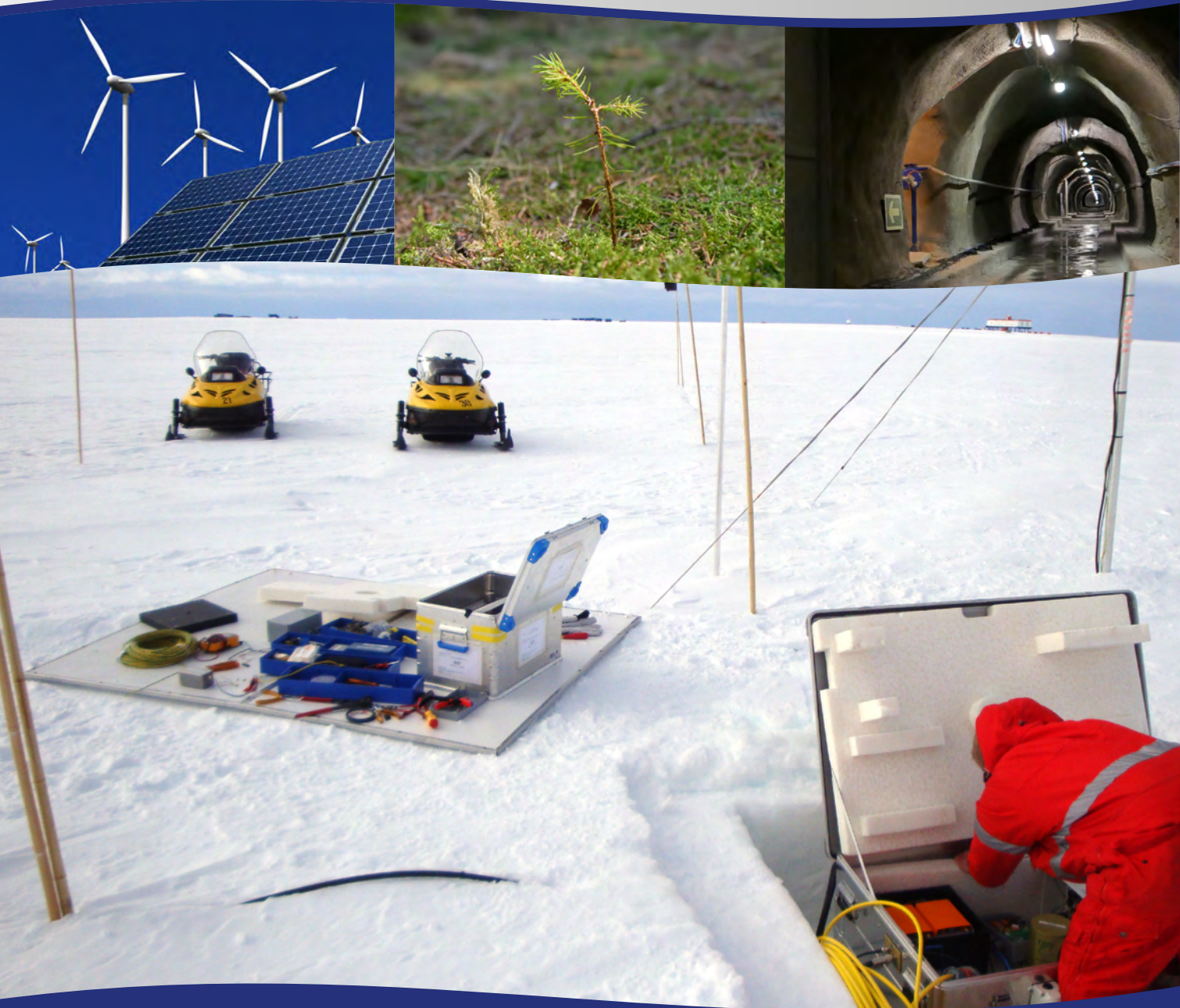


BGR Report

FEDERAL INSTITUTE FOR GEOSCIENCES AND NATURAL RESOURCES AUGUST 2018



Cover Feature:

Listening Out for Peace

Nuclear Test Ban: Improved monitoring using seismoacoustics

Planet Earth represents
the basis for all our lives,
its resources are limited.

This is why BGR is committed to protecting the human habitat
and promoting the sustainable use of natural resources.

Imprint

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**This BGR report presents BGR projects from the years 2016
and 2017. It also provides an outlook to future projects.**

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Editorial



Prof. Dr. Ralph Watzel,
President of the Federal Institute for
Geosciences and Natural Resources

Dear Readers,

BGR supports the monitoring of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) on behalf of the German Federal Government. For this purpose, BGR operates monitoring stations in the Bavarian Forest and in the Antarctic, in addition to the national data centre in Hannover. The seismic and infrasound stations form part of the Vienna-based CTBT Organization's global monitoring system.

In the course of a research project, BGR scientists have now been able to show that explosions or earthquakes can be localised more precisely if, in addition to seismic waves, infrasound signals from the event are simultaneously recorded. Thus, 'seismoacoustics', i.e. a combination of seismology and infrasound analysis, provides an opportunity to better characterise future nuclear tests and their effects. You can find out more about the new investigation method in our cover feature 'Listening Out for Peace' on page 60.

Electromobility is becoming increasingly significant, which leads to a rising demand for specialty metals such as lithium or neodymium. Today it is still unclear, how the demand for specialty metals required for other upcoming technologies can be covered. A new study by BGR's German Mineral Resources Agency (DERA) has investigated how commodity demand is developing in important future technologies. Read the article on the results of the study on page 6.

The condition of forest soils in Germany has improved since the 1990s. This is confirmed by BGR analyses. For example, they reveal that the heavy metal content of the soil is largely harmless. Find out more about the investigations on page 26.

I hope you enjoy a good read!

PREPARED FOR THE FUTURE

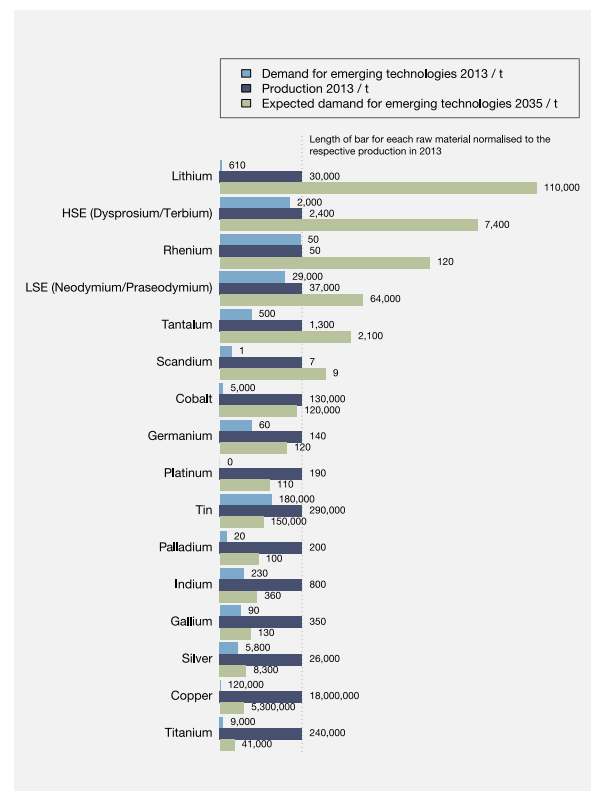
Emerging technologies can drastically increase demand for several specialty and accessory metals by 2035

With increasing demand for electric cars, the demand for specialty metals such as lithium, cobalt, or neodymium also increases. Other new technologies also require metals that are currently only produced in small quantities. The German Mineral Resources Agency (DERA) at BGR has commissioned a study with the Fraunhofer Institute for Systems and Innovation Research to determine future demand.

“The markets for specialty and accessory metals will see strong movement in the coming years”, said Dr. Torsten Brandenburg, head of the resource management section at DERA. Electromobility is likely to drive not only demand for lithium in high performance batteries, but also for the rare earths neodymium, praseodymium, terbium, and dysprosium that are needed in electric motors. Other technologies that are currently still in their infancy also rely on special raw materials. For example, innovative high-performance magnets also contain rare earth metals. Rhenium, tantalum, niobium, or hafnium are constituents of heat-resistant superalloys used in aircraft turbines. The corrosion-resistant materials of desalination plants contain palladium, titanium, and molybdenum, while fuel cells contain yttrium, zirconium, or scandium.

The DERA study examines how commodity demand evolves in terms of emerging technologies when used on an industrial scale. To that end, the team at the Karlsruhe Fraunhofer Institute for Systems and Innovation Research first determined the market maturity, best available technology, demand for raw materials, and recycling potential for more than 160 technologies. Afterwards, 42 emerging technologies were selected for a detailed analysis with the aim of determining the possible demand for raw materials in 2035 in different scenarios.

The findings of the investigation: Demand for the metals lithium and rhenium in particular, as well as for the heavy rare earths dysprosium and terbium, is expected to rise sharply over the next two decades. According to the study, the investigated technologies will consume



Demand for various raw materials for selected emerging technologies (2013 and 2035) compared to primary production of the respective commodities in 2013.

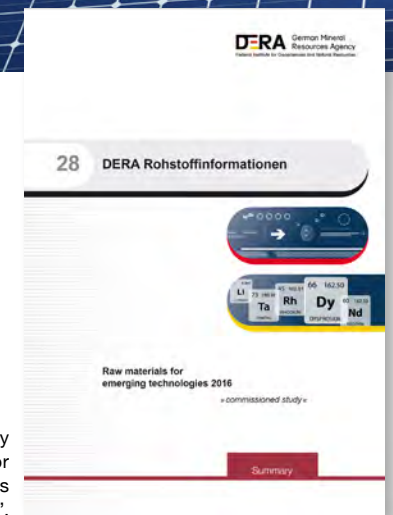
more than double the present global production of these metals by 2035. In addition, the demand for germanium, cobalt, scandium, tantalum, and the light rare earths neodymium and praseodymium will likely be higher in 2035 than today's total production as a result of the investigated emerging technologies alone.



Two of 42 investigated emerging technologies: thin film photovoltaics and wind turbines.

Whether bottlenecks and price increases actually do occur in the future, however, also depends on a number of volatile factors. That said, the study results help commodity companies and the manufacturing industry to recognize critical developments at an early stage. Ulrike Dorner, Project Manager at DERA, emphasised: “Our study will make an important contribution to assessing future commodity demand.” Companies can respond to potential shifts in demand, such as by gaining new suppliers, using less commodities, replacing critical commodities, or increasing recycling.

A look at the first study from 2009 on commodity demand for emerging technologies reveals just how dynamic the interplay between technological change and the demand for commodities is: Metals still scarce at that time, such as gallium and scandium, are now produced in larger quantities; meanwhile, some technologies, such as LEDs and fuel cells, are achievable using fewer metals, while some materials may even be replaced completely. For this reason, DERA regularly examines developments in supply and demand in the commodities markets as part of commodities monitoring. In the future, a study entitled ‘Raw materials for emerging technologies’ will be published every five years.



Title page of the study ‘Raw materials for emerging technologies 2016’.

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Project:
Study: ‘Raw materials for emerging technologies 2016’

INVESTMENT OPPORTUNITIES IN AUSTRALIA

Possibilities to secure future supply of raw materials

Only around two percent of the raw materials imported by Germany in 2015 came from Australia. However, the southern hemisphere continent is one of the most resource-rich countries in the world. In 2016, to support German companies in their activities, the German Mineral Resources Agency (DERA) at BGR published the manual 'Mineral Resources in Australia – Investment and Supply Potentials'.

The study focused on 15 metals, twelve industrial minerals and a number of gemstones relevant to German industry. "Australia offers interesting investment opportunities for German buyers", concludes DERA co-author Siyamend Al Barazi, who visited numerous mines and processing facilities on the fifth continent for the study, together with colleagues. In the manual, the DERA experts describe the most important deposits and advanced exploration projects to identify the most economic ones.

Among the commodities studied, for example, is lithium, for which Australia is the world's most important producer. Forty-two percent of the world's lithium production currently comes from the Greenbushes deposit in Western Australia. Another interesting commodity is antimony, an important constituent of flame retardants and lead batteries. Here, too, Australia is one of the most important producers. In addition, bismuth, lead, manganese, nickel, rare earths, silver, tantalum, tungsten, zinc and tin are mined on a larger scale in Australia. Here, DERA can see numerous opportunities for German investors. "Numerous new commodity projects are currently under development. We therefore expect that new producers for these metals will establish themselves on the market", reports Al Barazi.

Promising exploration projects include nickel, which could deliver cobalt as a by-product, as well as graphite. These commodities are used in electric car batteries, in addition to lithium. The DERA experts can also see potential for the metal scandium. While scandium is currently not mined in Australia, investment may become interesting as prices rise. Increasing demand for scandium seems possible: "For example, this metal is used in fuel cells, which could generate electricity in residential housing in the future. Scandium is also important in hybrid power plants and lightweight construction", says Al Barazi.

The study also deals with industrial minerals such as bentonite, gypsum, kaolin and magnesite. Here, the authors currently see only limited new investment opportunities.

However, existing suppliers for these industrial minerals offer a wide range of specified products in Australia. "The new manual contributes to securing Germany's commodity supply", Al Barazi emphasises. Companies purchasing commodities are offered support and receive comprehensive information on possible investments.

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Project: DERA Manual 'Mineral Resources in Australia – Investment and Supply Potentials'



Antimony concentrate in Big Bags from the Costerfield deposit, Victoria.



Shipping lead ingots from Port Pirie, South Australia.

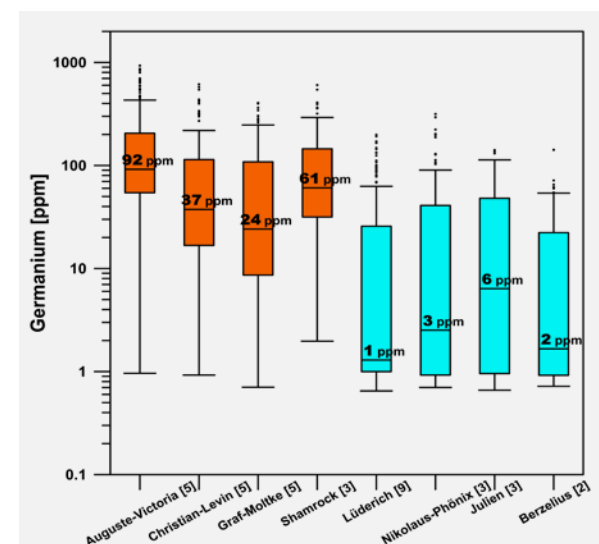


Cores from the Woodlawn deposit, New South Wales.

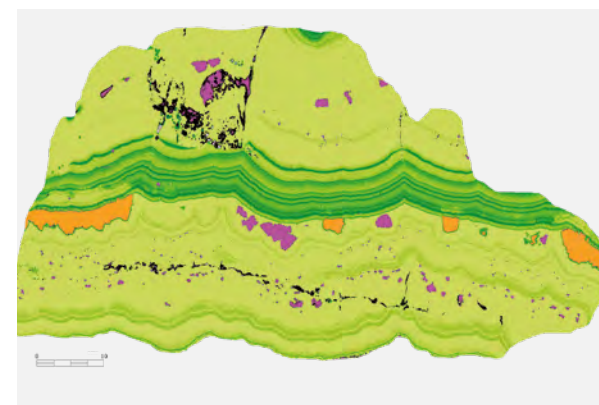
FORMER MINING REGION TREASURES

BGR compiles a nationwide data base for high-tech resources

German ore deposits hide trace elements that are in demand for innovative technologies. However, in the 1990s, mining for base metals was abandoned completely in this country. To find out whether resources of by-products such as indium, germanium or gallium could contribute to the economic success of mining, BGR is currently assembling a data base, together with universities, business and state geological surveys. In it, they collect data on the potential of various historic mining regions for the respective high-tech resources.



Comparison of the concentrations of the trace element germanium in sphalerite from the Ruhr region (orange) and the Bergische Land (blue).

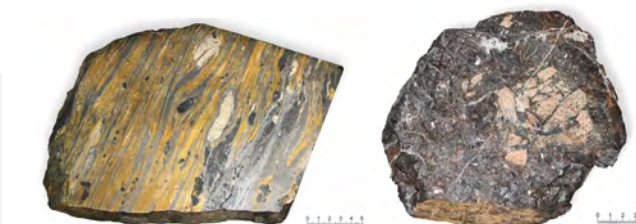


Mineral distribution in a zinc ore from the Aachen ore mining district. The micro-X-ray fluorescence data show sphalerite with different iron levels in green shades, while violet represents galena and orange stands for grains of pyrite.

Once meaningless trace elements have transformed into sought-after high-tech resources: the metal indium, for example, is in every smartphone screen in the form of indium tin oxide (ITO). Solar cells and blue LEDs use gallium compounds. Germanium can be found in semiconductors and thermal imaging cameras, for example. Germany is heavily dependent on imports for these rare metals – compounded by the fact that there has been practically no domestic metal mining for the last two decades. Overall German high-tech resource potentials have therefore not been systematically analysed.

However, these trace metals also occur in German deposits. The three elements indium, gallium and germanium often occur together with lead, copper, zinc and tin in what are known as base metal ores. However, their content is usually only a few grams of each element per tonne of ore. “Trace element-rich ores reach concentrations that are a more than ten times higher”, reports Dr. Torsten Graupner, who heads the r⁴ HTMET joint research project funded by the German Federal Ministry of Education and Research (BMBF) at BGR.

He and his colleagues are currently in the process of analysing ore samples from various mining regions. To date, they have investigated around 350 samples from the Upper Harz Mountains, Erzgebirge (Ore mountains), Bergische Land, the Aachen-Stolberg region, the Ruhr region and the Schwarzwald (Black Forest). “The samples partly originate from historical BGR collections and our project partners, in part we also collected new samples in former mines”, says Graupner.



Left: Generalised map of Germany showing the historical mining regions investigated in the HTMET project. The dots represent selected individual deposits (base map source: GeoBasis – DE/BKG 2018).

Top: Samples of sulphurous lead-zinc-copper ores from historical German deposits.

Bottom: Hand specimens and cores in the BGR collection from historic ore mines and exploration work.

The investigations show that the three investigated trace elements mainly occur in the minerals sphalerite and chalcopyrite. Their actual ore content not only depends on the type of deposit, but also on the region, the researchers found. “In certain areas of the Black Forest, the sphalerite is rich in germanium, in the Harz Mountains it is enriched in gallium”, explains Graupner.

In the Ruhr region, too, researchers discovered elevated gallium and germanium concentrations in lead-zinc ores. They determined that the ore minerals in some deposits in the Ruhr region and in the Black Forest contained more than 100 grams of germanium per tonne on average. In contrast, samples from ore veins in the Upper Harz Mountains only had a moderate level of trace elements, with gallium dominating. The team found the lowest trace element levels in the Bergische Land region.

In this project, which will run until October 2018, the researchers aim to examine samples from other mining regions, including from neighbouring countries. The data base will not only contain data on high-tech metal resources, but also on site characteristics, such as infor-

mation on infrastructure and nature conservation requirements, as well as additional insights from mineral processing tests. The researchers are also developing an evaluation tool to allow interested users from industry to draw meaningful conclusions from the data.

The geological surveys of the federal states can also use the data base to assess domestic raw material potentials. “Whether the domestic ores can actually be economically produced in the future depends primarily on developments in world market prices”, says Graupner.

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Project:
High-Technology-Relevant Metals in German Sulphidic Base Metal Ores – Resource Potential Estimation (HTMET)

NO ENERGY RESOURCE SCARCITY

Relaxed global supply situation

The energy revolution is not complete by far: currently coal, crude oil and natural gas still deliver around 80 percent of Germany's primary energy demand. Although the proportion of renewables is growing rapidly, the share of fossil fuels in energy production has barely dropped, due to the phasing out of nuclear energy. Because domestic oil, gas and coal production is in decline, Germany remains heavily dependent on imports for fossil fuels, according to the BGR energy study published in December 2017.

Crude oil production in the German Emlichheim field.

Since 1976, the publication, which is highly respected both in Germany and internationally, provides information on the availability of all energy sources, from crude oil, natural gas and coal to uranium and renewable energies, including deep geothermal energy. The authors pay special attention to the situation in Germany. The study has appeared annually since 2004. "With the energy study, BGR aims to support the gradual transformation of energy supplies towards a renewable energy-based system", explains Dr. Harald Andruleit, head of the BGR 'Availability of Energy Resources' section.

The most important result of the study: from a geological perspective, the known reserves of natural gas, coal and nuclear fuels can meet long term demand, even if consumption continues to rise. Together with the renewable energies, long term energy supplies can be guaranteed. Considerable fossil energy reserves, much greater than the quantities produced so far, remain on all continents. Particularly in North America, the states of the former Soviet Union and in Australia, huge quantities of coal and natural gas remain in the subsurface. Limitations can only be seen for crude oil. "Generally, however, the supply situation is currently relaxed", says Andruleit.

In their analysis, BGR differentiate between reserves and resources. Reserves are classified as deposits, with proven volumes which can be economically

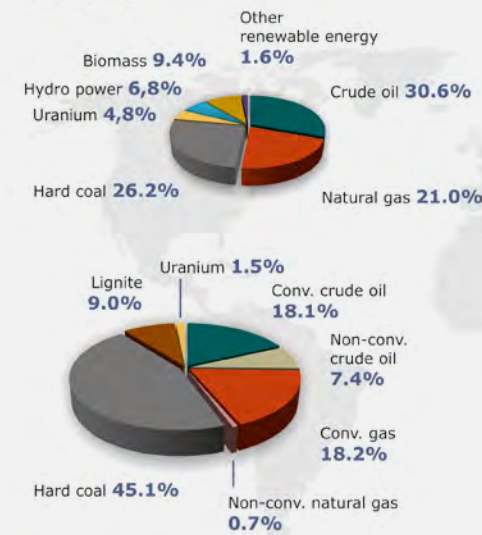
extracted using today's technology. Resources include less well-known deposits and deposits that are currently not economically viable. In 2016, energy resources with a total energy of 515 exajoules (1018 joules) were produced worldwide. According to the study, the known fossil reserves contain about 75 times as much energy, with resources of around 551,000 exajoules even amounting to one thousand times the energy of current annual production.

The world's most important energy supplier is still crude oil, accounting for 30 percent of the global energy supply in 2016. The fact that crude oil could become scarce in the future is mainly due to the comparatively low price: producers are currently investing less than previously in the development of new fields. Natural gas and coal, on the other hand, are abundant. Both natural gas and uranium production continued to increase over the period covered by the study, while coal production declined again year-on-year. The proportion of renewable energy forms in power generation increased particularly rapidly to a record high in 2016. Overall, renewable energy sources covered around 18 percent of global energy demand in 2016.

The 2017 energy study focussed on three topics: lithium as a key energy revolution commodity, worldwide underground coal gasification and utilisation options for associated petroleum gas.

Energy consumption

600 EJ

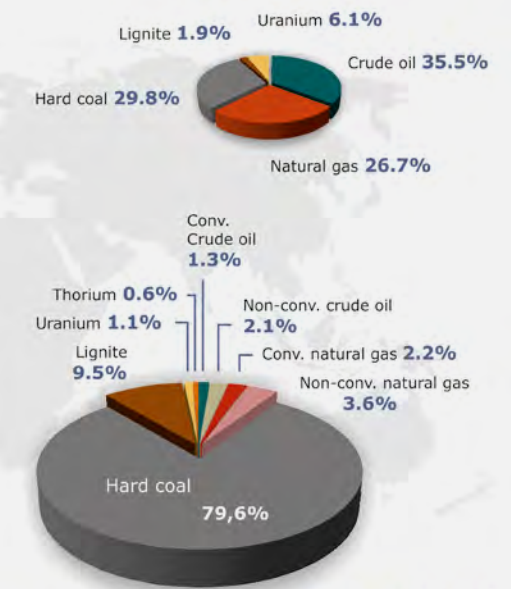


Reserves

39,530 EJ

Production

515 EJ



Resources

550,690 EJ

Worldwide share of energy sources in consumption, production, reserves and resources.



Icelandic geothermal power station.

Thanks to its specific properties, lithium is considered one of the key commodities in the energy and mobility revolutions. In particular, the field of energy storage with the help of lithium-ion based batteries is particularly important here. Alternative uses of coal have been discussed worldwide for many decades. One option here is underground coal gasification. However, the technical challenges remain great. Associated petroleum gas is a by-product of crude oil production, which in practice is often flared or discharged unburned into the atmosphere. The case studies in Algeria and Cameroon demonstrate the challenges and opportunities available for the use of associated petroleum gas. "The utilisation of associated petroleum gas can contribute both to climate protection and to the economic development of developing countries", says Andruleit.



Current BGR Energy Study 2017.

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Project: Energy Study 2017

SEISMIC WAVES IN THE INDIAN OCEAN

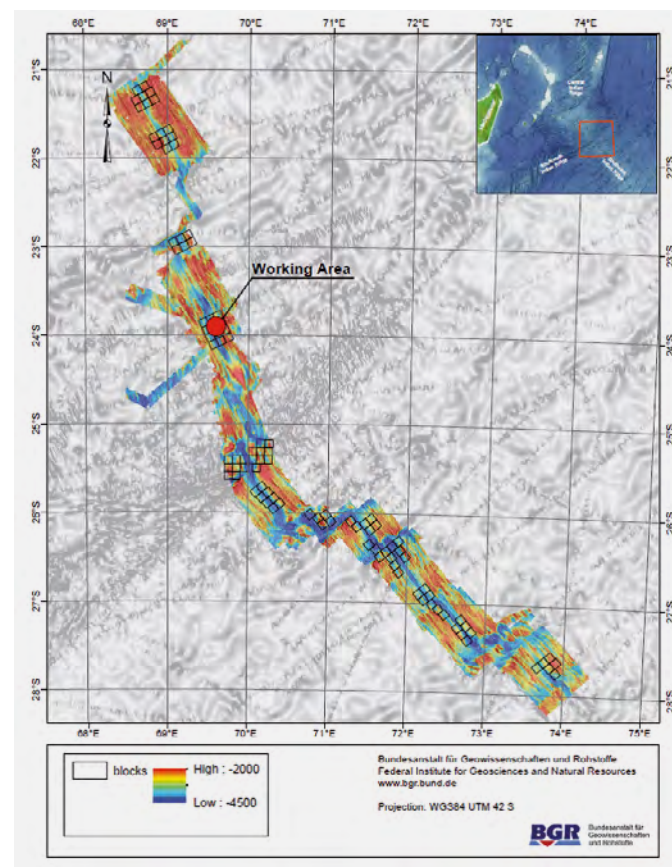
BGR explores massive sulphide deposits in the German license area

At the end of 2016, BGR researchers used the research vessel MARIA S. MERIAN in their search for massive sulphides on the seafloor of the Indian Ocean. The team conducted extensive exploration work not far from the intersection of three underwater spreading zones. In the first leg, the innovative 3D seismic method was used.

BGR's INDEX 2016 expedition scientists were enthusiastic about their work on the modern MARIA S. MERIAN research vessel. "The equipment is extremely good, the ship's command and crew work very professionally and there is a friendly tone on board", Ulrich Schwarz-Schampera, leader of the second leg of the expedition, was very impressed. The team, which also included researchers from the GEOMAR Helmholtz Centre for Ocean Research Kiel, the German Centre for Marine Biodiversity Research – Senckenberg am Meer Wilhelmshaven, and the University of Hamburg, returned home with a wealth of data.

The destination was a region south-east of the island of Mauritius. BGR holds a license for this region from the International Seabed Authority for the seabed exploration of so-called polymetallic sulphides, i.e. metal-rich sulphur ores. The license agreement, signed in 2015, obliges BGR to explore the 10,000 square kilometre area in the Indian Ocean in detail within 15 years. Companies can then apply for licenses to mine the ores there. "Our exploration area consists of one hundred squares with edge lengths of ten kilometres each. They are divided into twelve blocks along the Central Indian and South-east Indian Ridges", reports Dr. Volkmar Damm, leader of the first leg of the journey.

Under his leadership, in October and November 2016, the team explored a block where massive sulphide deposits had been detected on previous expeditions. "The ores are located beneath now dormant hot springs on the seabed, known as black smokers", says Damm. On the one hand, the research team aimed to determine the



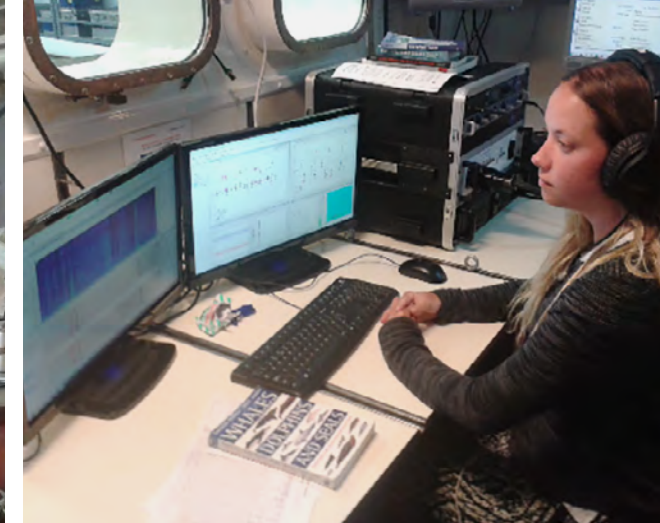
Locations of the individual license blocks along the central and south-eastern Indian Ridge and the research area in 2017 (colour coding: water depths).

extent of the ore field more precisely, and on the other, they intended to visualise the rise of hydrothermal fluids from below.

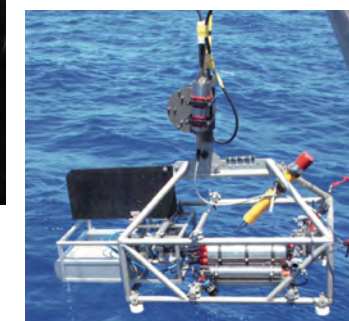
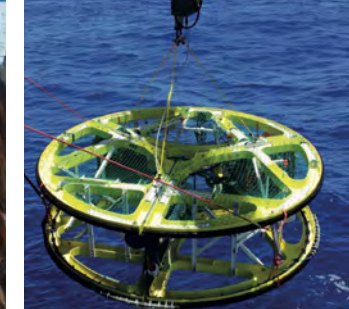
BGR's mobile 3D seismic technology was employed for this purpose. "Similar to computer tomography in me-



Ocean floor seismometers are prepared for use.



Using hydroacoustic sensors, biologists make sure that the marine environment is not compromised during the survey.



Some of the equipment used by BGR to explore the seabed for sulphide ores (top: Golden Eye. Centre: HOMESIDE. Bottom: TV grab).

dicine, we can use this innovative method to create a three-dimensional image of the ocean floor", explains Damm. "However, we do not use X-rays to penetrate the ground, but seismic waves." Two so-called air pulsers generate the underwater sound waves behind the ship. These sound waves penetrate several hundred metres deep into the seabed. Their echoes are captured by numerous underwater microphones, which are also towed behind the ship in two 1,500 metre long hoses. In addition, the researchers deployed nine ocean floor seismometers on the 3,100 metre deep seabed to capture signals from even deeper layers. All in all, they scanned a 25 square kilometre area of the license area in this way.

On the second leg, MARIA S. MERIAN visited the three northernmost blocks of the license area. They were previously unexplored. "We surveyed at a total of 70 stations", reports the responsible Chief of Operations Schwarz-Schampera. The team deployed the autonomous underwater ABYSS robot 15 times, with the researchers covering 14 lines with the deep underwater sonar HOMESIDE.

BGR found no active black smokers there, but promising evidence of dormant fields, especially in the northernmost block of the license area. Resource exploration was accompanied by environmental studies. The INDEX team investigated biodiversity and levels of dissolved nutrients and metals in the water column.

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Project: Expedition INDEX2016_2

APPETITE FOR COPPER SHALE

BGR geomicrobiologists improve bioleaching processes



Chuquicamata copper mine in Chile.

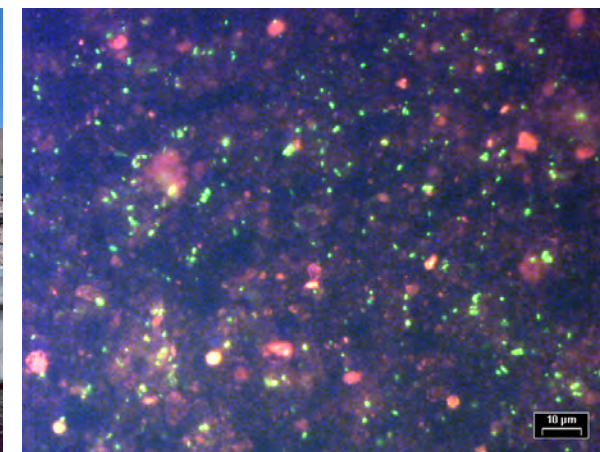
Copper is increasingly being produced with the aid of minute workers: certain microorganisms can liberate the metal from ores in an environmentally friendly and cost-effective manner. As part of the EcoMetals collaborative project, BGR scientists are testing which microbial cultures are best suited for biomining copper shale and mining residues.

During the Permian, a shallow sea covered large expanses of Central Europe. A special legacy of this Zechstein Sea is a rock known as copper shale. It is found, for example, on the south-eastern edge of the Harz Mountains in the region around the towns of Mansfeld and Eisleben. The dark, fine-grained marine mudstones were deposited in oxygen-poor areas of the sea. “Copper shale is an important Central European deposit”, reports Dr. Sabrina Hedrich, geomicrobiologist at BGR. The rock was mined as early as the 12th century in the Mansfelder Land. It contains not only copper ores, but also other metals such as cobalt, nickel, zinc or silver.

In Mansfeld, copper shale mining became unprofitable as early as the 1930s, and mining was discontinued in 1990. However, this dark, sedimentary rock has now moved back into focus. “In the German-French EcoMetals research project, we have developed a biological treatment process for copper shale”, says Hedrich. Instead of heat and chemicals, they and the research team rely on bacteria to extract the metals from the ore. “Biotechnological processes are energy-efficient, environmentally friendly and cost-effective”, emphasises Prof. Dr. Axel Schippers, head of the BGR geomicrobiology section. In biomining, not only bacteria but also other



Top: Use of copper heap bioleaching in Chile.



Top right: Bacteria (green) in a sample under the fluorescence microscope.

microbes and biomolecules are used to liberate metals from the ore and separate different metals. “Bioleaching is the biological transformation of an insoluble metal compound into a water-soluble form”, explains Schippers.

A significant proportion of world copper production is already delivered with biological assistance, mainly coming from sulfide ores deposited as heaps. The aim of the EcoMetals project is to further optimise bioleaching. The project network consists of 17 partners, including industrial companies and research institutes in Germany, France and Poland. The BGR Geomicrobiology Laboratory deals, among other things, with the process of tank bioleaching. The so-called ore concentrates and mining residues are processed in bioreactors. “We investigate the conditions under which different bacterial cultures leach the ores most effectively”, says Hedrich.

In their laboratory experiments, BGR researchers use state-of-the-art molecular biology techniques, for example, to find out which of the microbes dumped most effectively operated under given conditions. In addition, the team is developing procedures to subsequently separate the bioleached metals.

The research team examined copper shale from various sources, for example dumped material from Mansfelder Land or copper concentrate from Lubin in Poland. The scientists primarily aim to improve leaching of the



Bioleaching copper in stirred reactors in the BGR geomicrobiology laboratory.

mineral chalcopyrite, a compound of copper, iron and sulfur, contained in the copper shale. “We specialise in bioleaching at low pH levels with microorganisms that feel comfortable at temperatures around 50 degrees Celsius”, says Hedrich.

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Project: EcoMetals Collaborative Project

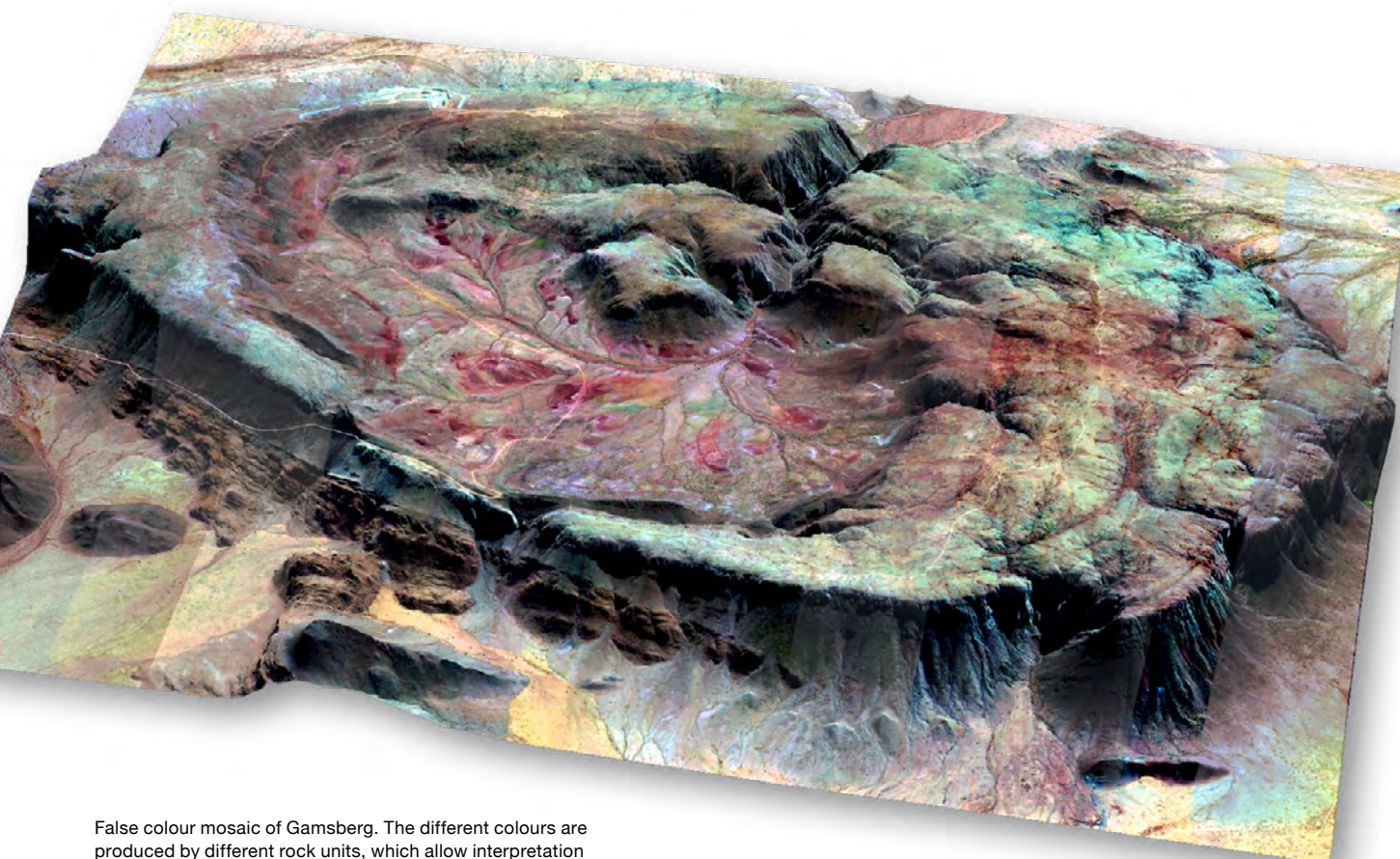
THE SECRET OF COLOURS

Hyperspectral analysis delivers information on mineral deposits

Iron formations, lead-zinc ores or rare earths: hyperspectral data allow fast and precise mineral mapping. BGR has now developed a method whereby rock formations can be characterised based on the spectrum of their reflected light.

The Gamsberg in the north of South Africa is an ancient rock formation with an interesting inner life. The shales, quartzites and gneisses of this solitary desert mountain are 1.5 billion years old. They harbour some recoverable lead-zinc mineral assemblages. Which minerals can be found where was determined by a BGR team during an aerial surveying campaign in northern South Africa.

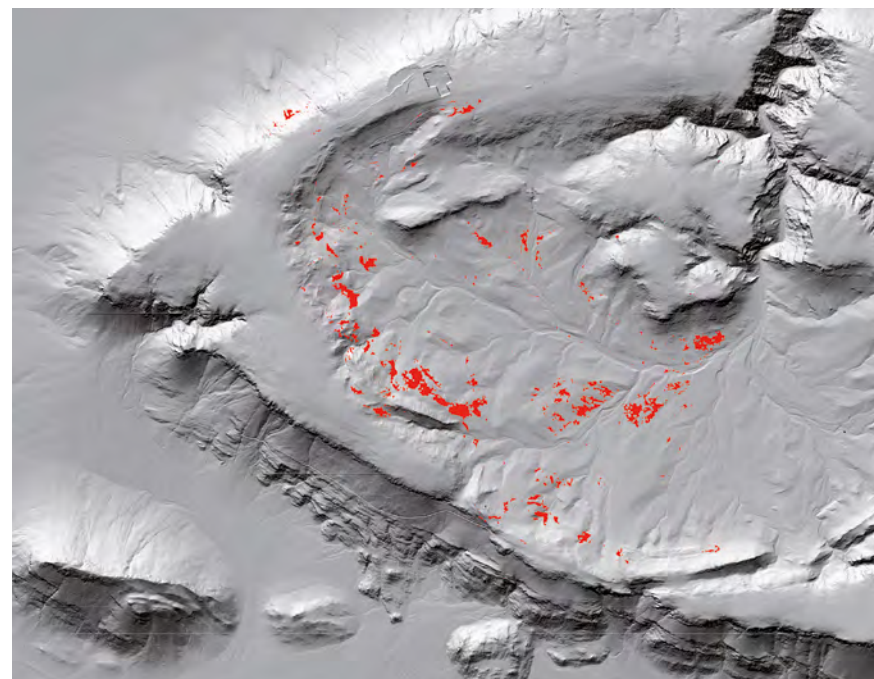
Here, the researchers employed what is referred to as hyperspectral remote sensing. "Sensors in an aircraft recorded both the reflected sunlight and the infrared radiation emitted by the earth's surface", explains BGR remote sensing expert Dr. Martin Schodlok. The spectrometers split the light into its different wavelengths. In this way, minerals and rocks on the earth's surface can



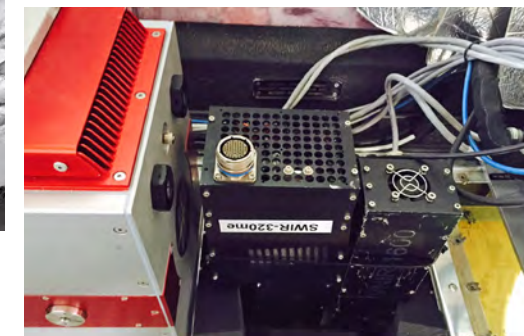
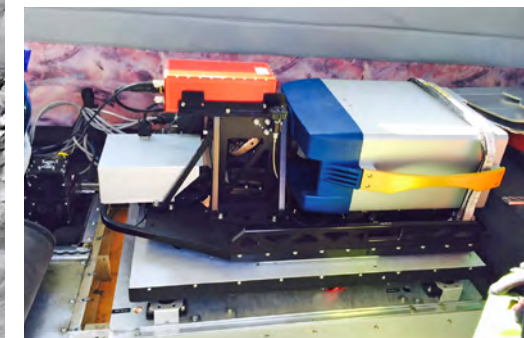
False colour mosaic of Gamsberg. The different colours are produced by different rock units, which allow interpretation of the distribution of geology and mineralogy.



The hyperspectral aerial reconnaissance was carried out using a small Cessna 404 aircraft. Four remote sensing sensors were installed in the aircraft.



Gray scale representation of the terrain model with detection of an increased iron enrichment superimposed in red for spatial geoscientific interpretation.



Sensors used during airborne hyperspectral survey in South Africa. In addition to the hyperspectral cameras, a LIDAR system was also used to generate a high-resolution terrain model.

be identified by their spectral features, their colour patterns, so to speak. "In some cases, even the finest mineralisation, invisible to the human eye, can be demonstrated", says Schodlok.

For the first time, he and his colleague, Dr. Michaela Frei, used sensors that register not only short-wave but also thermal infrared radiation. "We were able to demonstrate that mineral classification could be improved by combining the different wavelengths", reports Frei.

In a second campaign in South Africa's Transvaal Super-group, the BGR team characterised further iron-bearing formations, known as Banded Iron Formations (BIF). In addition, the researchers tested new hyperspectral sensor systems in Norway, Sweden, Namibia and South Africa to see if they could further optimise the search for deposits of the coveted rare earths.

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Projects: Hyperspectral Remote Sensing, Hyperspectral mapping of Rare Earth Elements (REEMAP)

FOSSILISED FOREST IN ETERNAL ICE

BGR expeditions to the Antarctic decipher the history of the supercontinent Gondwana

200 million year old fossilised wood from a newly discovered rock sequence in Helliwell Hills.



North Victoria Land was twice the destination of BGR Antarctic research over the last two years and Dronning Maud Land once. The programme included extensive refurbishment work in the Gondwana station.

BGR polar researchers know well enough that expeditions into the Antarctic are not a walk in the park. But what the team around expedition leader Andreas Läufer experienced during the eleventh German Antarctic North Victoria Land Expedition (GANOVEX XI), surprised even experienced participants: “We’re stuck in our base camp in the Helliwell Hills”, Läufer noted in his expedition diary on 26 January 2016. “The snow is so dense that we can’t even see five metres to the next tent. Our toilet tent was even completely snowed under for a while.” The team were forced to interrupt field work several times due to the severe snow storms.

In the end, all participants in the international team were nevertheless satisfied with the results of the expedition. On foot and by helicopter, the scientists explored the more than 4000 metre high Transantarctic Mountains in North Victoria Land, which lies on the western edge of the Ross Sea. The following season, a small research team continued the work from the Italian ‘Mario Zucchelli’ station.

Since 1979, the GANOVEX programme has been studying the history of the supercontinent Gondwana, at the centre of which was Antarctica, until some 180 million years ago. Over the past two years, the participants have explored the entire history of Gondwana – from its origins to its disintegration. In North Victoria Land, for example, they examined the remains of a high mountain range that existed about 500 million years ago. “Initial results from the two expeditions suggest that the formation of this ancient mountain range began earlier than previously assumed”, reports Läufer. It may now be necessary to revise models of Gondwana’s convergence.

In addition, the team discovered the remains of a 200 million year old fossilised forest, including fossilised wood, where the remains of maggot bores and insect excrement were preserved. The fossils come from a previously unknown series of rocks from a time when branched rivers and extensive lakes covered the largely flat continent of Gondwana. Even early dinosaurs



Geologists from BGR and the Italian Antarctic Programme in joint field work in the more than 4000 m high Transantarctic Mountains in North Victoria Land.

roamed the forests and river landscapes of what was then North Victoria Land, as evidenced by the first find of a footprint of one of these animals.

The end of Gondwana also left its traces in North Victoria Land. The researchers discovered a system of older, previously unknown, faults that originate from the time when Australia broke away from the Antarctic. “We can now more plausibly understand the details of how the two continents separated”, says Läufer.

At the same time as the two expeditions, BGR modernised the Gondwana summer station at Terra Nova Bay. It was built in 1983 and was technically outdated. Now, solar panels, a seawater desalination plant, new sanitation facilities and modern generators have been installed.

The BGR research team was active on the other side of the southern continent at the end of 2016, together with colleagues from the Alfred Wegener Institute (AWI). They explored central Dronning Maud Land in the Polar-6 surveying aircraft from Kohnen Station, which is operated by the AWI and located on the Polar Plateau.



Top: The Polar-6 research aircraft served as a surveying platform for aerogeophysical investigations in central Dronning Maud Land.

Bottom: Snow drift in the GANOVEX XI expedition base camp in the Helliwell Hills in North Victoria Land.

There, they studied a magnetic anomaly hidden beneath the ice sheet – possibly the relic of an approximately 700 to 500 million year old ocean that was trapped during the formation of Gondwana. “The new data should help to better understand this magnetic structure and refine the models for the geodynamic development of East Antarctica”, says Läufer.

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Projects:

- GANOVEX (German Antarctic North Victoria Land Expedition)
- MOGS (Modernization of Gondwana Station)
- GEA (Geodynamic Evolution of East Antarctica)



ENDANGERED GROUNDWATER

BGR investigates salinisation in the Dutch province of Zeeland

BGR helicopter taking off from Midden Zeeland airport.

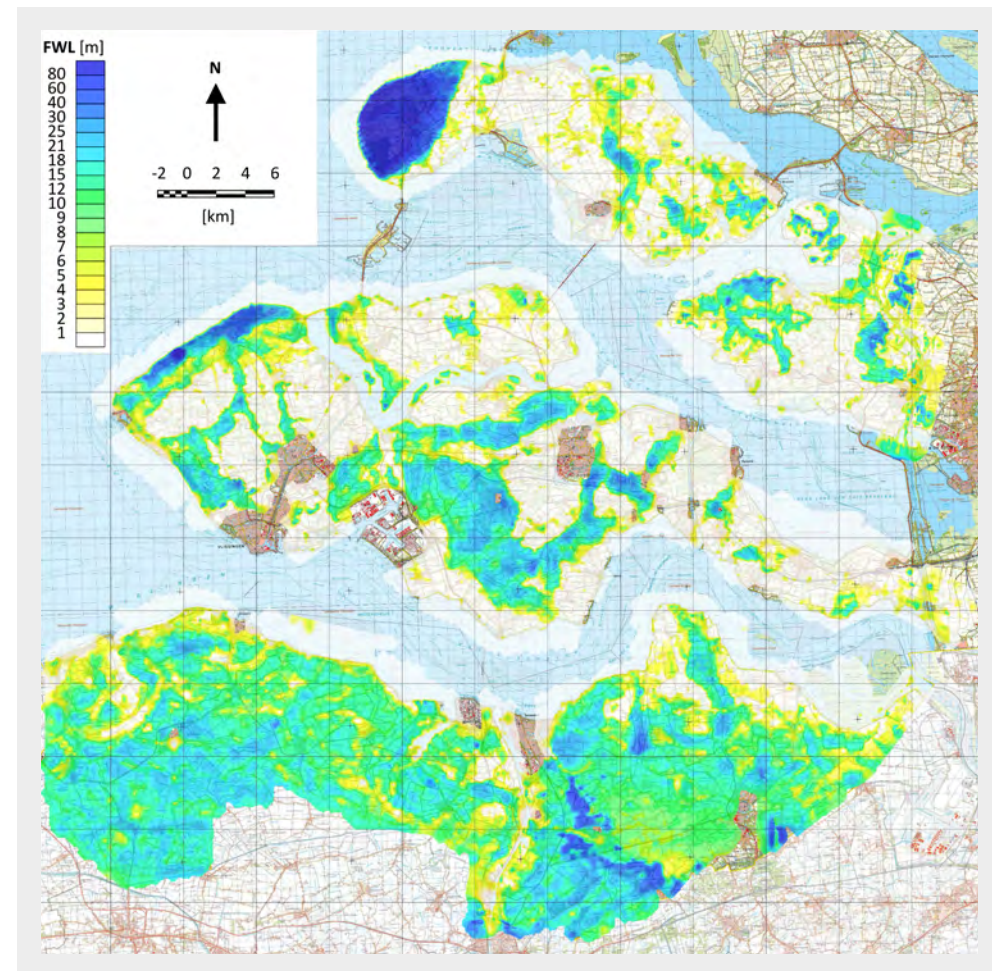
Almost all of the south-west of the Netherlands is as flat as a postage stamp. Large areas of Zeeland province are even located below sea level. Groundwater in the region is therefore particularly impacted by salinisation: storm surges, rising sea levels and groundwater pumping mean that saline water can propagate in the subsurface. To facilitate better groundwater management, BGR mapped the distribution of fresh- and saltwater in Zeeland using their own survey helicopter on behalf of their Dutch partners.

“We traversed around 10,000 profile kilometres in three surveying campaigns of two weeks each”, reports BGR project manager Dr. Bernhard Siemon. BGR collaborates with its Dutch partners Stichting Deltares and TNO, as well as Zeeland province. Siemon and his Dutch colleagues subsequently developed models and interpretations based on the survey data.

The BGR helicopter and a cigar-shaped airborne probe were used for the survey. “The signals, transmitted at six different frequencies, penetrate down to different depths in the subsurface and are then reflected as a function of subsurface electrical conductivity. Relatively low conduc-

tivity is typical for fresh water or a sandy soil, while salt water and clayey sediments indicate high conductivity”, explains Siemon.

Based on the survey data, he and his colleagues were able to delineate the boundaries between freshwater and saltwater resources, among other things. Moreover, they were able to differentiate between aquifers and aquicludes. With the aid of in-house software, the BGR researchers produced conductivity models as the basis for a three-dimensional model of the chloride concentrations across the entire province.



Thickness of freshwater lenses in Zeeland province (NL).

Because Zeeland consists to a large extent of islands and polders enclosed by dykes, freshwater reservoirs are rare here. They generally exist as isolated 'lenses' above salt water. Although there is abundant average annual rainfall, there can also be extended periods of dryness, especially in the summer. It is then difficult for farmers to find freshwater for their fields.

With the aid of the new data, farmers now have access to information on where the groundwater is excessively saline. They can then decide on which fields irrigation is promising and where they should cultivate more salt-tolerant crops. In addition, the BGR survey also revealed where large volumes of freshwater are still located beneath the saline groundwater. These reservoirs flow from Belgium to Zeeland beneath impermeable sediments.

The data obtained in the project can also be used to investigate not only the salinity of the groundwater but also the effects of sea-level rise on groundwater resources and thus on drinking water.

All of the resulting maps have been published by the Dutch partners on the internet. They are available at: <https://www.zeeland.nl/water/zoet-water/zoet-zout-verdeling-zeeuwse-ondergrond>.

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Projects:

AEM-Zeeland – Airborne electromagnetic mapping Zeeland (NL)
FRESHM Zeeland (FRESH Salt groundwater distribution by Helicopter ElectroMagnetic survey in the Province of Zeeland)

THE SALTY HERITAGE OF THE STORM SURGE

BGR models sea water propagation in Baltrum's subsurface in 1962



Geophysical measurements on Langeoog.

The East Frisian islands get their potable water from what are referred to as freshwater lenses: here, the groundwater consists of lighter rainwater that floats on top of the surrounding saltwater. However, the reservoirs are threatened by rising sea levels, and especially storm surges. In order to improve crisis management, two BGR researchers have now used previously unpublished data to understand how the catastrophic storm surge of 1962 affected the groundwater of Baltrum Island.

In the night from 16 to 17 February 1962, hurricane 'Vincinette' makes landfall on the German North Sea coast. The storm brings with it a devastating flood that hits the city of Hamburg completely unprepared. The district of Wilhelmsburg and other regions close to the Elbe are under metres of water, hundreds die.

The storm surge also causes devastation on the East Frisian islands: it destroys dykes, damages dunes and smashes the revetments on the western ends of Baltrum, Norderney,

Spiekeroog and Wangerooge. However, the saltwater also leaves behind an invisible heritage, reports BGR hydrogeologist Dr. Georg Houben: "On Baltrum, seawater penetrated the dune valleys and seeped into the groundwater." Years later, Houben says, some of Baltrum's wells were still salinised.

Rising sea levels increase the danger that such salinisation will be repeated along coastlines in the future. Here, past experience can help to prepare for such scenarios. Houben



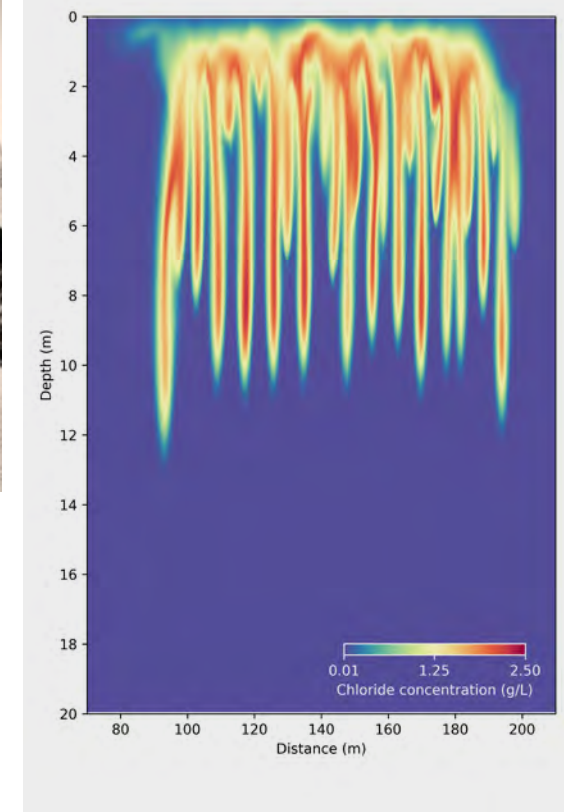
Flooding in Baltrum, 1962.

and his colleague Dr. Vincent Post have now analysed data from the 1960s, collected by the Niedersächsisches Landesamt für Bodenforschung following the storm surge on Baltrum.

"For the first time, the measurements reveal the effects of seawater penetration on a freshwater lens in a sandy aquifer", says Post. They show that in those areas where the land surface was flooded, 180 litres of saltwater per square metre seeped into the ground. This volume of seawater contains around six kilograms of salt.

"Within a few months, the saltwater contaminated a large proportion of the shallow freshwater", says Post. According to the study, which he published together with Houben in the Journal of Hydrology in August 2017, it was six to eight years before the groundwater could be utilised again. It was only then that fresh rainwater had completely displaced the brackish water.

The researchers are now developing new models to analyse the consequences of similar events in the future. 'We can now better predict how much freshwater will remain after such a disaster and what immediate action needs to be taken', says Post. This information is important, for example, to ensure that freshwater is not pumped from wells excessively. Excessive pumping can lead to a well being permanently salinised, explains Houben. If too much freshwater is removed from the ground, saltwater that was previously below the freshwater lens may penetrate the well and lead to long-term salinisation.



Modelled salt distribution in groundwater one year after flooding.

The study delivers tools for improving crisis management in other threatened coastal zones around the world. Similar catastrophic floods as that in 1962 in Hamburg were caused by the 2004 tsunami in Indonesia, typhoon Haiyan in the Philippines in 2013 or hurricane Harvey in Houston in 2017.

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Project:
FLIN Project – Freshwater Lens Investigations

LESS LEAD IN HUMUS

BGR analyses heavy metals in forest soils

The condition of forest soils in Germany has improved since the 1990s. This was revealed by the second National Forest Soil Inventory (NFSI II), published in late 2016. For example, BGR analyses show that the majority of heavy metal concentrations are below what is known as the precautionary limit. In the case of lead and arsenic, in particular, these values are exceeded at some locations – for example in the Harz Mountains, Erzgebirge and the Rhenish Slate Mountains.



In the 1980s, the fear of forest dieback was rampant in Germany. The infamous acid rain, research at the time feared, could mobilise heavy metals such as lead or cadmium in the forest soil, and thus damage the trees. Meanwhile, sulphurous compounds – the cause of acid rain – are being removed from power station emissions and fuels using special processes, and lead in petrol is banned throughout Europe.

This had a positive effect on forest soils. “The condition of forest soils has begun to recover slowly”, states a report by the Thünen Institute in Eberswalde in 2016. Not only exhaust gas cleaning, but also the conversion of coniferous to deciduous forests and the distribution of lime have improved the condition of many forest soils, as NFSI II shows.

For the purpose of the investigation, researchers from various institutions took samples of forest soils at 1,900 points around the country. In addition, they determined the state of vegetation, treetops and forest nutrition. “The aim of the NFSI was to provide reliable, representative and comparable nationwide statements on the condition of the forest, but also on how the forest soil changes or how climate change can affect the soil condition”, reports BGR pedologist Dr. Florian Stange.

Together with his colleague Dr. Daniel Rückamp, Stange has taken over the task of analysing the heavy metal concentrations in samples from several federal states. BGR research concentrated on the elements arsenic, lead, cadmium, chromium, copper, nickel, mercury and zinc. “Heavy metals are naturally present in all soils, they come from the rock from which the soil forms”, explains Rückamp. However, inputs from industry and transport can increase the natural background. “In forests, these pollutants come mainly from the atmosphere and primarily accumulate in litter layers and topsoils”, says Rückamp. Lead, cadmium, copper and mercury, in particular, enter forest soils through the atmosphere.

The NFSI investigations showed that the heavy metal reserves in the humus layer covering the forest floor have declined almost everywhere since the first forest soil inventory. “This decline may be due to the fact that heavy

metal emissions have decreased over the last 30 years”, says Stange, “but one must also keep in mind the fact that the heavy metals are slowly migrating from the humus to the mineral soil.”

Heavy metals are normally adsorbed onto soil particles, but become more mobile at low pH levels. In acid forest soils, in particular, there is therefore a risk that they can enter the groundwater. In the first forest soil inventory, many forest soils were acidified, but their condition has now improved in many places.

The BGR research team noted that what are referred to as the precautionary limits are barely exceeded. These limits are specified in the Federal Soil Protection Act. Concentrations beneath the precautionary limit are regarded as harmless. Nor does a violation necessarily mean that there is any danger, but primarily only that further inputs should be limited. “For arsenic, the precautionary limit is exceeded at 13 percent of the inventory points, and lead at 22 percent”, reports Stange. Primarily, mining regions such as the Erzgebirge and the Harz Mountains, as well as regions on the lee side of large industrial zones, are polluted.

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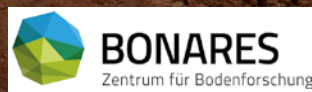


Project:
Second National Forest Soil Inventory (NFSI II)

SOIL DATA STANDARDS

BGR involved in establishing a soil data centre

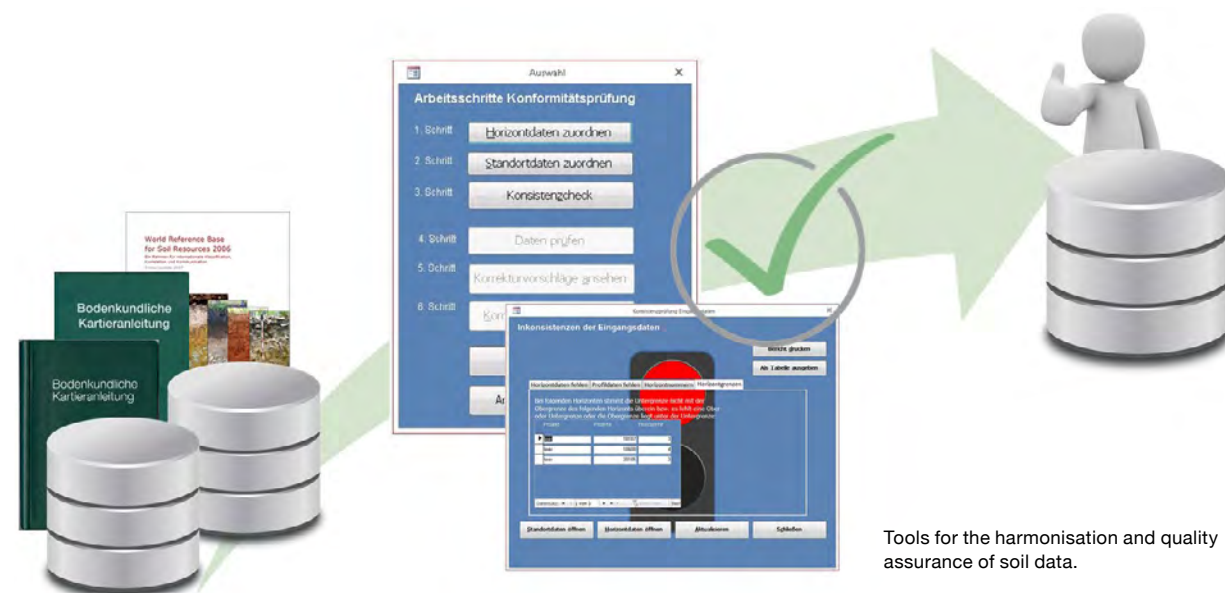
How do different soils react to new cultivation methods? What consequences does climate change have for soil? Ten research groups and the BonaRes Centre for Soil Research deal with questions such as these in the BonaRes project, which is funded by the Federal Ministry of Education and Research (BMBF). BGR is involved in compiling an exhaustive database to house the project results and other soil data. To date, there has not been a centralised repository for soil research data in Germany.



One could regard BonaRes as a gargantuan project: the funding programme, which is part of the 'National BioEconomy 2030 Research Strategy', includes ten joint projects with up to ten project partners. As part of BonaRes, scientists from across Germany investigate how the productivity of soil as a resource can be safeguarded in the long term. The project teams are involved in almost 30 long-term field experiments, in which they develop methods for sustainable soil use. "For example, they deal with reducing our dependency on phosphate-containing fertilisers or developing strategies against soil compaction by heavy agricultural machinery", BGR scientist Sina Schulz reports.

Together with her colleague Dr. Einar Eberhardt, Schulz forms part of the BonaRes Centre team. In this higher-level project module, BGR works with four other research institutes to collect the soil data in a central database. "Such a data pool is extremely useful for complex scientific problems, for example for uncovering unidentified relationships", says Schulz. "It is a valuable basis that provides data for modelling purposes."

BGR has extensive experience in data harmonisation. For example, BGR experts are working on developing standards for exchanging digital soil data for the International Organization for Standardization (ISO), among other things. At the national level, BGR cooperates



Tools for the harmonisation and quality assurance of soil data.

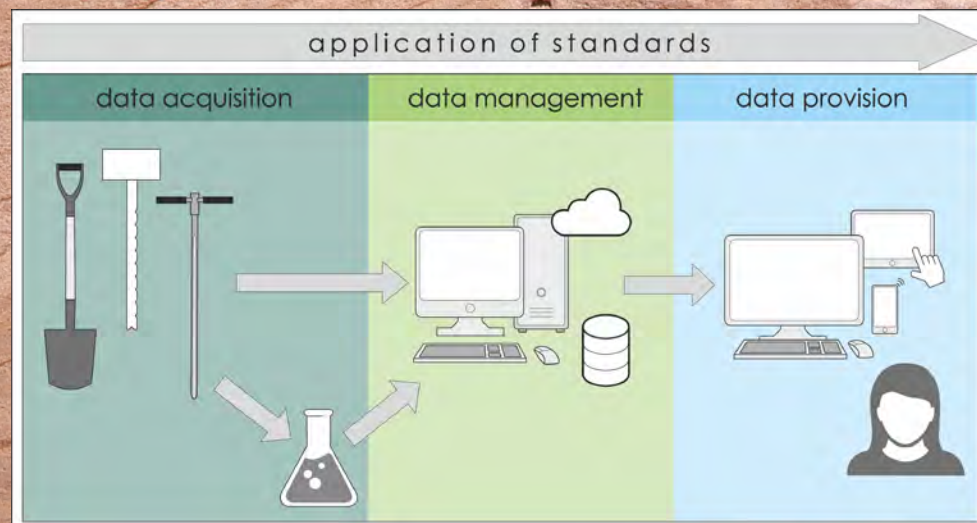
closely with the federal state geological surveys to compile national soil survey standards. "We have therefore also contributed, within BonaRes, to develop the data infrastructure standards", reports Eberhardt. In data acquisition and data management, in particular, BGR expertise was in demand.

Here, the team faced challenges typical for harmonisation processes. "The data come from a variety of sources and are available in different formats", reports Schulz. "In addition, standards for all stages of data life are required – from acquisition to processing to publishing and reuse." During the initial funding phase, the BonaRes Centre team described the content of all key standards, identified conflicts between competing standards and identified uncovered areas. "We then developed recommendations for application of relevant standards, such as in the fields of data acquisition, data management and data provision", says Schulz.

For example, BGR has developed tools to transform data between different standards or to ensure compliance with the prescribed standards. "For example, one of our applications can check the soil data entered to see if it complies with the national 'Soil Survey Guidelines' (Bodenkundliche Kartieranleitung)", Eberhardt explains. Another BGR tool converts the soil data recorded compliant with German standards to internationally understandable soil designations. Schulz emphasises: "With this, we make our data usable in an international context."



Soil data standardisation activities with BGR participation.



Use of standards from data acquisition to data provision.

CONTACT:

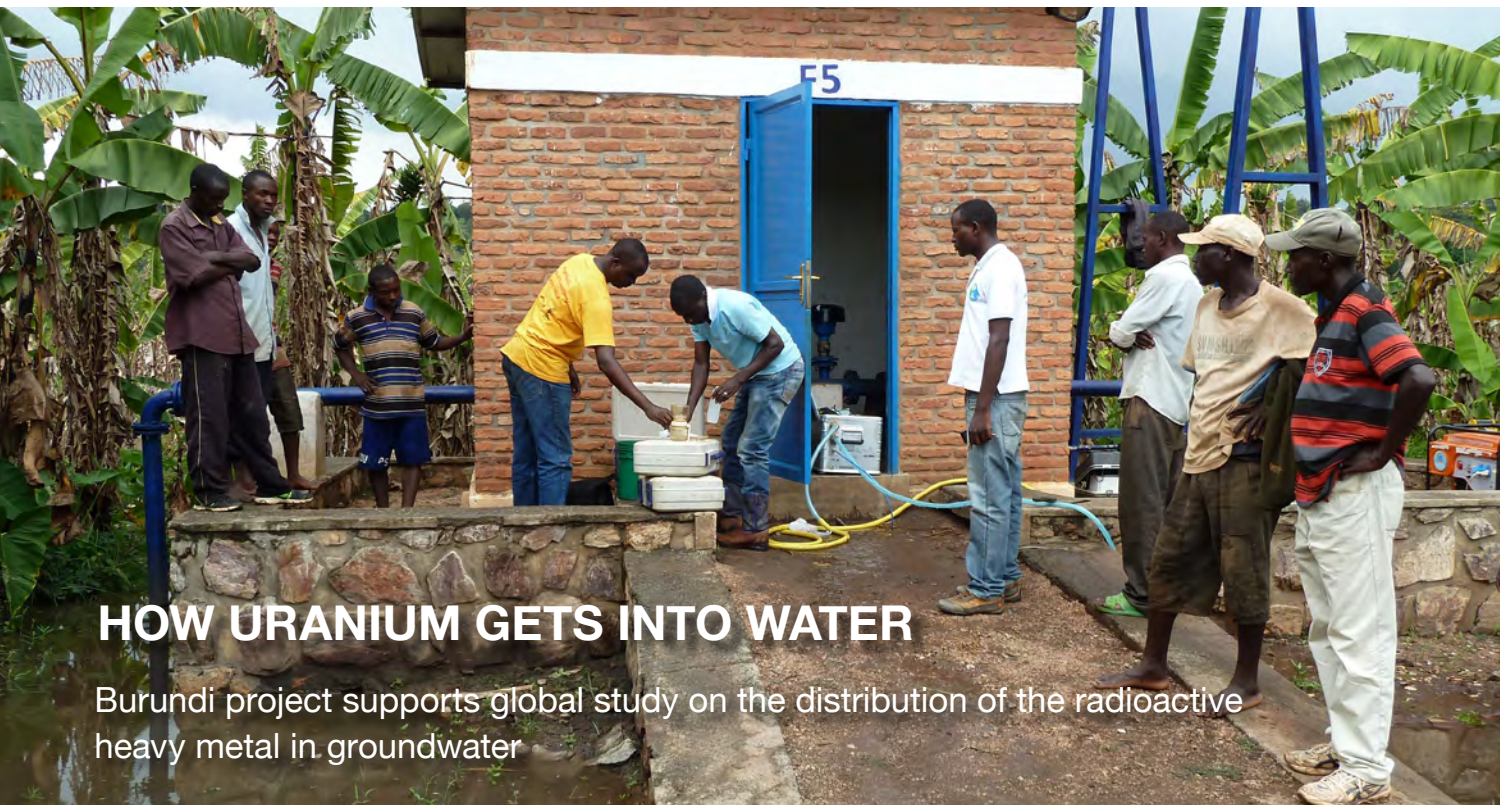
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Project: BMBF BonaRes funding programme (Soil as a Sustainable Resource for the Bioeconomy)



HOW URANIUM GETS INTO WATER

Burundi project supports global study on the distribution of the radioactive heavy metal in groundwater

Employees of the Institut Géographique du Burundi (IGEBU) take water samples from a pump well in Kirundo.

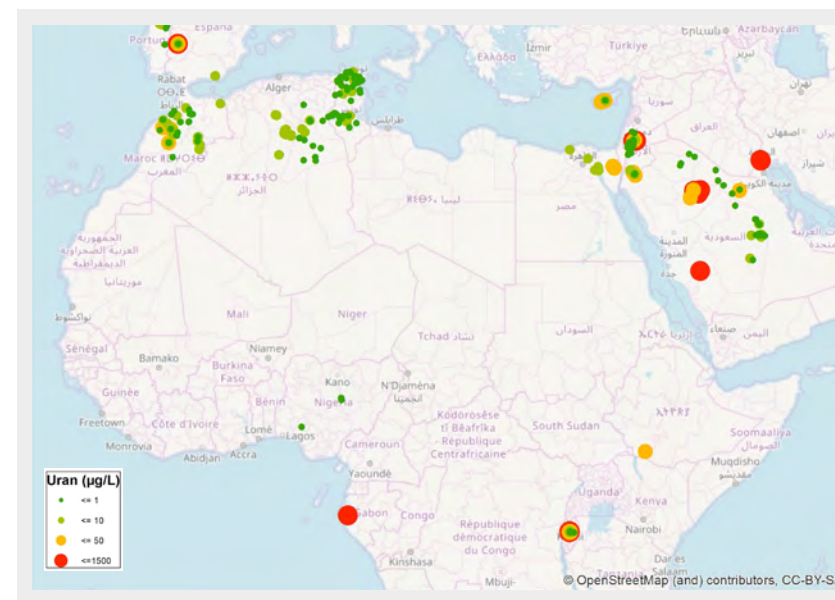
Uranium is a natural constituent of groundwater in many regions of the world. In some places, however, the concentration is much higher than the value recommended by the World Health Organization (WHO). The central African country of Burundi is one of the countries impacted by high uranium concentrations. BGR hydrogeologists are compiling published cases of enhanced global uranium levels in groundwater in order to derive the most important factors for uranium mobility.

In the province of Kirundo northern of Burundi, the earth is fertile: beans, sweet potatoes, corn, sugar cane, bananas and millet thrive on the green hills south of Lake Cohoha. With almost 1300 millimeters of precipitation annually, Burundi is a rain-rich country. “However, the population grows enormously at a rate of around three percent annually. This means that natural springs are approaching their limits”, reports Dr. Sara Vassolo, BGR hydrogeologist. As a result, Burundi will increasingly have to resort to groundwater in the future. Yet, its volume and quality are only poorly known.

In a joint project with the Burundian Ministry of Water, BGR has been working to investigate groundwater resources more closely since 2011. This brought some unpleasant surprises to light.

“In the province of Kirundo, we found such high concentrations of uranium in groundwater that some wells had to be shut down”, says BGR hydrogeologist Dr. Vincent Post. Together with colleagues from BGR and the Institut Géographique du Burundi, he searched for the cause. The team analysed the local geology, took numerous water samples and finally set up models. “We discovered that a combination of rock weathering and high evaporation is responsible for the high concentrations”, says Post.

The uranium comes from ancient and heavily weathered granite rocks in the subsurface of the Burundian highlands. “Rainwater infiltrates the subsurface, moves through the ground and finally evaporates again”, explains Post. Uranium, which is dissolved from the wea-



Compilation of internationally published data on the distribution of dissolved uranium in groundwater in North and Central Africa and the Middle East.

thered rock, is concentrated by this process. As the BGR researchers discovered, dissolved carbonate and calcium may enhance uranium enrichment.

Similar to the situation in Burundi, other regions around the world also have high uranium concentrations of more than 1000 micrograms per liter. The limit considered harmless by WHO is only 30 micrograms per liter. “It is always very difficult to predict the activity of radioactive nuclides in a given groundwater resource”, says BGR expert Dr. Frank Wagner. “The local geology and the geochemical frame conditions play a major role.”

Together with the Institute of Radioecology and Radiation Protection at Leibnitz University of Hannover, a BGR team has therefore implemented a bibliography research to establish a worldwide data collection on uranium distribution in groundwater. High uranium levels often occur in regions with deposits of natural uranium ores. Such ores can occur in either sedimentary rocks, in granite or in volcanic host rocks. “For example, in regions of North Africa and the Middle East, uranium-enriched sediments occur in conjunction with a layer of marine phosphorites deposited in the Cretaceous and subsequently in the Neogene”, reports Wagner. Besides regions with large ore deposits, groundwater can also be enriched with natural uranium nuclides – in addition to Burundi, cases have also been documented in the USA, Portugal, Scandinavia, Jordan, India and Germany.

According to BGR findings, the release of natural uranium into the groundwater depends, among other things, on how

much oxygen and carbonate the water contains: “Under reducing conditions, uranium is poorly soluble in leachate. Moreover, carbonates can lead to the formation of stable and mobile uranium compounds”, explains Wagner.

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Projects: R&D Project on the Mobility of Radionuclides (U, Ra) in Groundwater Bilateral TC Project ‘Management and Protection of Groundwater Resources’ in Burundi

WINDOW TO THE SUBSURFACE

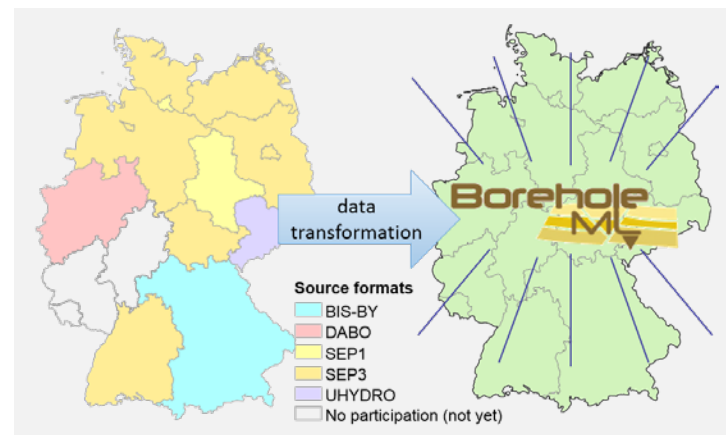
Data from two million boreholes available online

Foundation ground examinations, geothermal energy or well construction – information on the subsurface is essential for many projects. The completely revised version of the German Borehole Map as a browser application significantly improves access to geological information: in this way, the data from two million individual boreholes across Germany can now be retrieved for the first time online, in a uniform format, at a central location.

“Essentially, we have created a window to the subsurface”, says BGR geodata manager Gerhard Arns-Krogmann about the new database. Here, users find a wealth of geological information – from drillings for the purpose of foundation ground examinations that extend only a few metres down, to research boreholes that can penetrate the ground to depths of more than 6000 metres. “If one adds all the borehole depths, the borehole database results in a total length of about 80,000 kilometres”, says Arns-Krogmann.

Together with the state geological survey organisations of the federal states, the BGR expert has developed a data exchange format to allow all German borehole data to be displayed uniformly in German or English. “Historically, the data formats of the individual geological surveys were very heterogeneous. This diversity hindered the exchange of data and made it difficult for engineering consultants to use the data”, says Tanja Wodtke, Head of geodata and stratigraphy at BGR.

The state geological survey organisations now provide their data via standardised database interfaces as so-called geodata services. It all comes together at BGR. For example, the new, freely available German Borehole Map contains information on the borehole density in smaller scales, on well casings or on groundwater measurements. In addition, the valuable information on geological strata is also visualised, if permitted. All data can be searched and exported to other applications. Professional users integrate the underlying geodata services in their own geodata. “The advantage of this is that users can import and visualise the borehole data together with their own geodata in their own software”, Wodtke emphasises. This marks a milestone in the software-independent provision of complex, thematic geoscientific data.



The borehole data formats of the federal states are transformed to a single exchange format.

More information at: <https://boreholemap.bgr.de/>

KONTAKT:

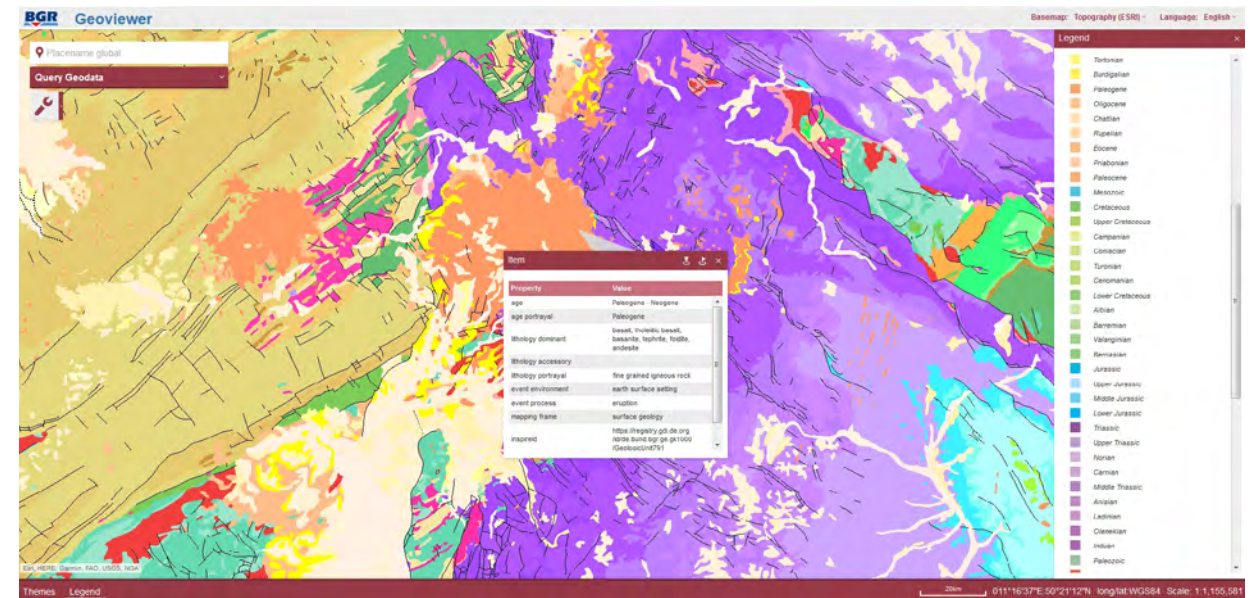
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Projekt: Modernisation of the German Borehole Map



BGR Geoviewer: visualisation based on the INSPIRE-compliant GK1000 dataset.

GEOLOGY FOR EVERYBODY

First INSPIRE-compliant geodata product is online



The surface geology of Germany has been available either as a digital map or as a GML file (a data format for exchanging spatial data) since the end of 2016 in INSPIRE-compliant format and free of charge. BGR is thus fulfilling its obligation to implement the INSPIRE Directive. The objective of this European initiative is to process and prepare existing spatial data, in this case geoscientific data, uniformly throughout Europe and to make it available in a common infrastructure.

The deadline is 21 October 2020. “By this date, BGR must, by law, have transformed its relevant geodata sets to comply with the INSPIRE Directive”, explains Dr. Marc Filip Wiechmann of BGR. INSPIRE is the acronym for Infrastructure for Spatial Information in Europe. The EU-wide initiative envisages that geodata on 34 environment-related topics will be presented and described in a uniform way throughout Europe and will also be available free of charge via web services. “This allows the data to be used across borders”, says Wiechmann.

BGR has numerous geodata sets that are affected by INSPIRE, for example the Soil Map of Germany 1:200,000 (BÜK200) or the German Earthquake Catalogue. “The geodata sets have been undergoing transformation by BGR for a year, step by step”, reports BGR expert Dr. Andreas-Alexander Maul. As the first product, he and Wiechmann have adapted Germany’s surface geology geodata set to the new requirements on a scale of 1:1,000,000 (GK1000).

Since December 2016, users have been able to access and view information on the age, genesis and composition

of rocks in Germany in the INSPIRE geoportal, in the BGR product centre and in the Geoviewer. Faults and the glacier fronts, known as ice marginal positions, are also INSPIRE compliant.

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Projekt: INSPIRE Implementation at BGR, GK1000

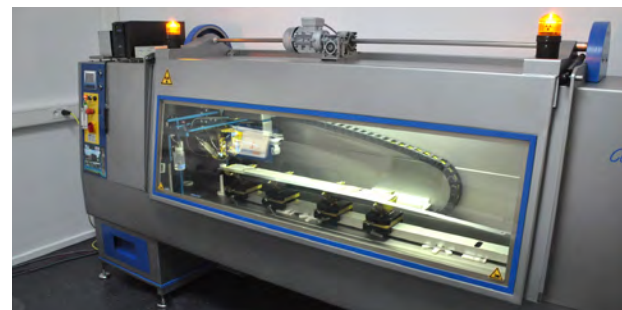
EXCURSION TO THE CRETACEOUS

Sea level fluctuations control sediment distribution

Over the last five years, BGR drilled a series of research boreholes in eastern Lower Saxony. The goal was to better understand the Lower Cretaceous, which began about 140 million years ago and ended one hundred million years ago.



Scharrel 10 borehole site (approx. 20 km north-west of Hannover).



BGR X-ray fluorescence core scanner in the core storage facility in Berlin-Spandau.

the sedimentology and stratigraphy of five existing boreholes, including employing state-of-the-art analytical techniques such as automated X-ray fluorescence spectroscopy on cores.

The sequence of sandy and clayey strata is mainly due to fluctuations in sea level, the interpretation shows. At low sea levels, sandy coastal deposits shifted more towards the centre of the basin and at higher sea levels, fine, clayey sediments could also settle out in the shallower regions. A deposition model will now determine which factors controlled the distribution of reservoir and barrier rocks throughout the Lower Saxony basin.

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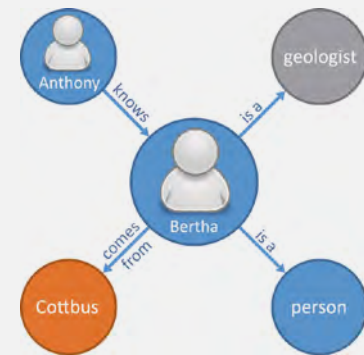


Projects:

Lower Cretaceous Research Boreholes – Potentials of the Underground Storage and Economic Area in the North German Basin (TUNB)

On the surface, the region north-east of Hanover is characterised by glacial deposits. However, much older sediments hide beneath the ground, being predominantly early Cretaceous marine deposits. The rocks reflect variable environmental conditions. “Permeable rocks such as sandstone alternate with impermeable clay and marl stones”, the BGR geologist Dr. Jochen Erbacher reports.

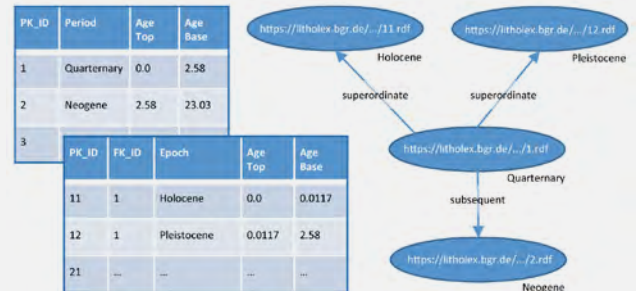
Today, the legacy of the Cretaceous ocean is interesting as reservoir and barrier rocks. In the TUNB project, BGR, together with the state geological surveys of the north German federal states, is investigating the potential of the North German Basin as an economic space. For this purpose, BGR, together with Landesamt für Bergbau, Energie und Geologie (LBEG) in Hannover, have drilled six new research boreholes up to 250 metres deep in the Lower Cretaceous. The team has also studied



Top left: Simple RDF model using the example of a social network.
Top right: From relational database model to RDF model.
Bottom right: Mapping the database contents to the RDF interface.

PK_ID	Period	Age Top	Age Base
1	Quaternary	0.0	2.58
2	Neogene	2.58	23.03
3

PK_ID	FK_ID	Epoch	Age Top	Age Base
11	1	Holocene	0.0	0.0117
12	1	Pleistocene	0.0117	2.58
21



FOUR STARS FOR BGR

IT experts adapt information systems to new web standards

The World Wide Web is evolving. At BGR, therefore, several databases are being restructured so that computers can better understand them.

The originally largely unstructured World Wide Web is growing larger, but also more and more intelligent. The World Wide Web Consortium (W3C) centred around the inventor of the Internet, Tim Berners-Lee, proposed making the information available on the Web linkable as early as the late 1990s, allowing machines to evaluate these relationships better. This extension of the Internet, through which the content relationships of the distributed information become visible to one another, is referred to as the Semantic Web.

BGR also continues to evolve their information systems. At present, the German Lithostratigraphic Encyclopaedia (Litholex), the GeWiS geological collection database and the BGR's Central Bibliographical Reference System (ZSN) are being revised in terms of data technology in accordance with the new requirements. “The databases for these systems are being restructured to this end”, explains BGR scientist Dr. Andreas-Alexander Maul.

Another important point: all database entries will be allocated a fixed address. When a new version is developed, the old data may not simply be deleted, but receive a reference

to a successor object. “In this way, the links to existing information are preserved and are still available to the semantic network”, explains Maul.

Data records such as the German Lithostratigraphic Encyclopaedia thus satisfy Tim Berners-Lee's 4-star status, the Semantic Web's second highest quality level for networked information. “To achieve the 5-star status, the information contained in the databases would have to be linked with other distributed resources”, says Maul. For now, BGR has not taken this step, as further organisational preparations are necessary, in consultation with other federal state geological surveys and within Europe. This is planned for one of the following project phases.

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Project: Semantic Web



The inactive Los Frailes (Aznalcóllar) mine in the Iberian Pyrite Belt in southern Spain.

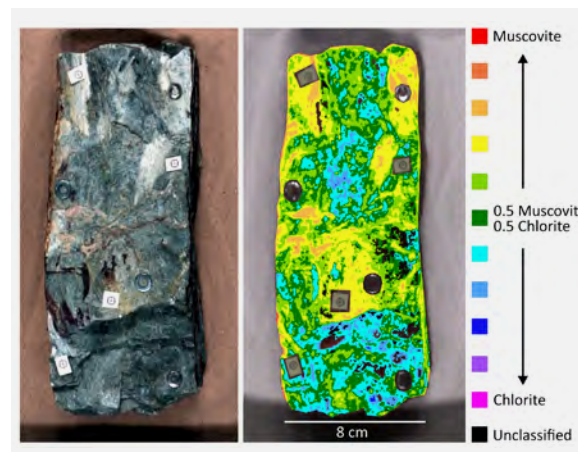
3D MAPPING ON A REGIONAL SCALE

BGR combines remote sensing and geophysics

Enormous ore deposits can be found in the south of the Iberian Peninsula. In a test area in Spain, BGR researchers combine a number of state-of-the-art methods to explore the earth's surface and subsurface over a large area.

Around 2,000 years ago, the Romans were already mining gold, silver and copper in today's southern Spain. The ores in the Iberian Pyrite Belt remain economically interesting to this day. "Only recently have cores been removed for exploration in the eastern part of the region", says Anne Blumberg of BGR. The researcher belongs to an interdisciplinary team that is testing new, efficient exploration methods in Spain.

The group relies on hyperspectral remote sensing and geophysical exploration techniques such as gamma spectrometry and gradient magnetics to detect what are known as massive sulphides. These ores were formed many millions of years ago by hydrothermal activity on the sea floor. The BGR helicopter conducted two aerial surveys on the Aznalcóllar and Tharsis open-pit mining areas in southern Spain.



Hyperspectral analysis of the mineral distribution in a rock sample.

field measurements using a SQUID sensor (acronym for Superconducting Quantum Interference Device) allow magnetic anomalies to be traced into the subsurface.

"Our concept consists of surveying known ore bodies in the open-pit mining areas and tracing them through the local region", says Blumberg. By combining the three processes, the team aims to make mineral resource exploration more efficient and accurate.

"Using hyperspectral remote sensing techniques, we can identify rocks and minerals on the surface of the earth and draw conclusions about resource deposits", explains Blumberg. Gamma-ray spectrometry measures natural radioactivity at the surface, allowing rocks to be characterised in terms of their mineralogy, structure and weathering patterns. Highly sensitive magnetic

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Project:
HYPGEO – New Methods for the Exploration of Mineral Resources

FINAL DISPOSAL IN CRYSTALLINE ROCK IS POSSIBLE IN PRINCIPLE

CHRISTA feasibility study considers different options



Native crystalline rock.

A final repository for the disposal of highly radioactive waste must meet numerous safety requirements. In Germany, concepts are already in place to prove the safety of a rock formation in terms of saline and clay rocks, but not for crystalline rocks. Forming part of the CHRISTA project, experts from BGR and the companies DBE Technology and GRS have now investigated what such a safety concept for crystalline rocks might look like.

‘Containment Providing Rock Zone (CRZ)’ is a bit of a mouthful. “This refers to a rock formation which ensures that radioactive substances in a final repository remain contained in the long term”, explains BGR expert Axel Weitkamp. The German final repository concept stipulates that nuclear waste is stored in a deep geological formation and isolated from the environment for at least a million years. The BGR researcher explains Containment Providing Rock Zone (CRZ), in conjunction with geotechnical closures, will guarantee that no radioactive substances can escape from a final repository and come into contact with the biosphere.

In a potential final repository in salt or clay, the host rocks themselves represent such an impermeable barrier. In the Federal Ministry for the Environment's safety requirements, precise criteria are defined primarily for these two types of rock, with which the long-term integrity of the CRZ can be demonstrated. For example, the high temperature response of the rock would have to be examined as a component of potential repository planning. Complex physical variables such as the ‘dilatancy strength’ or ‘fluid pressure resistance’ would need to be determined.

“However, such criteria are not available for crystalline host rocks”, Weitkamp reports. Crystalline formations must be considered equally with salt and clay formations in the search for a final repository. This is stipulated by the Site Selection Act, which came into force

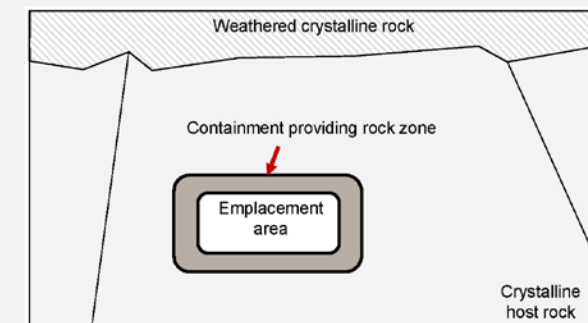
on 15 May 2017. In the CHRISTA research project, the BGR experts, together with colleagues from the companies Gesellschaft für Anlage- und Reaktorsicherheit gGmbH (GRS) and DBE TECHNOLOGY GmbH, therefore examined whether the German final repository concept can be applied to crystalline rocks – and in particular, whether Containment Providing Rock Zones can also be found in crystalline rocks. For the study, BGR has published an overview of the state of research on crystalline host rocks in Germany, among other things. In addition, the BGR team dealt with site investigation methods and with rock parameters.

The second problem addressed by the project was whether the Scandinavian concept for final disposal in crystalline rocks can be transferred to the German situation. In Sweden and Finland, it is proposed to package exhausted fuel rods in copper vessels with a steel insert. The wastes are then stored underground in boreholes, which in turn are backfilled with bentonite, in a final repository mine.

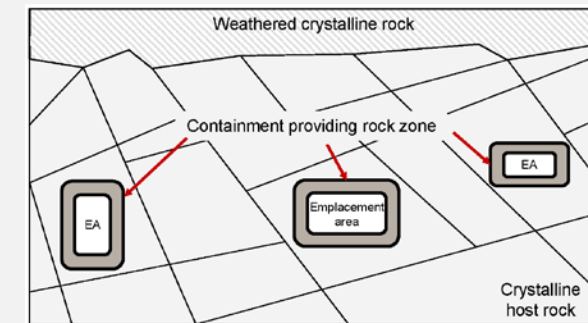
However, the Scandinavian concept cannot be applied to Germany one-to-one, according to the study. Because, unlike in Scandinavia, so-called mixed oxide fuel rods, which emit a lot of heat, also form part of Germany's nuclear waste. In addition to this, the proofing period in Scandinavia is only 100,000 years whereas in Germany, one million years are used.



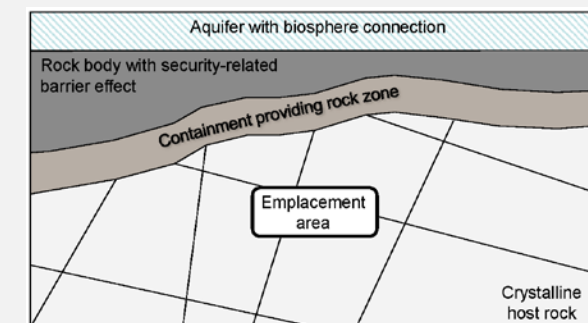
Underground laboratory in crystalline rock.



Surrounding CRZ in a weakly jointed, barrier host rock.



CRZ distribution over several enclosed components in weakly jointed, barrier zones in the host rock.



CRZ as a component of a barrier host rock overlies a jointed, non-barrier host rock.

This results in different demands on the safety concept. The team concluded that, in principle, three types of crystalline rock formation may meet the requirements. Weitkamp: “The options would either be larger homogeneous formations, containing barely any jointing and thus having a high containment capacity, or those containing at least smaller, separate areas with few joints.” The third option: strata with a high containment capacity, for example clay rocks, overlying a crystalline formation.

“Which of the three options would actually be possible in Germany can only be evaluated with difficulty with the information now available”, says Weitkamp. What is clear is: there are barely any unjointed crystalline formations in Germany, making the first option appear

unrealistic. In general, however, the researchers arrive at the conclusion that there are also CRZs in crystalline rocks. Weitkamp: “Furnishing proof is difficult, but it is possible in principle.” Further research is needed to develop concrete disposal concepts and safety proofs.

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Project: CHRISTA (Feasibility Study on the Development of a Safety and Analysis Methodology for Final Repositories for Heat-generating Nuclear Wastes in Crystalline Rock in Germany)



Edge position of a glacier in front of a mountain ridge.

THE POWER OF GLACIERS

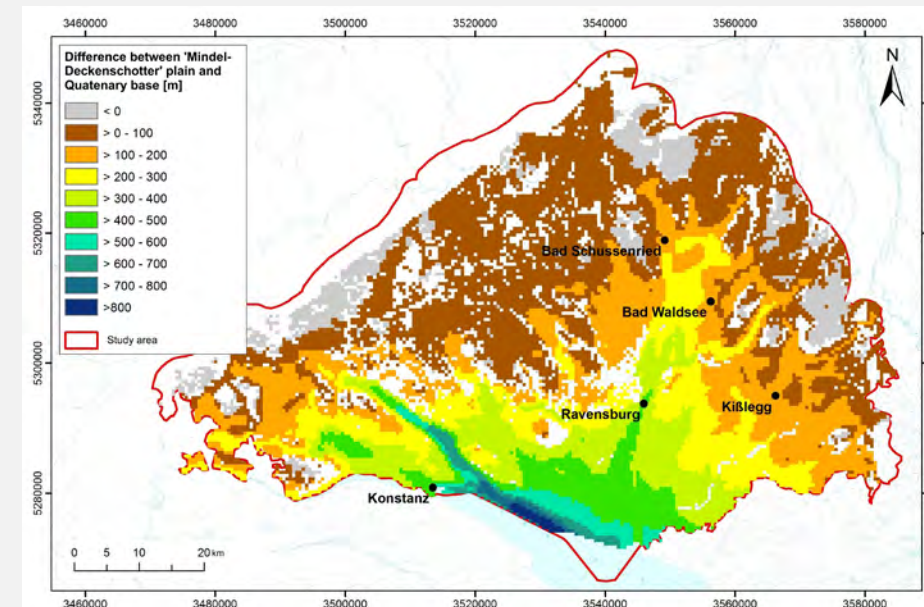
Deep glacial erosion must be taken into consideration when searching for final repositories

Nuclear wastes are to be safely stored for a period of one million years in a final repository in Germany. During this time, glaciers could once again spread across Germany and erode deep tunnel valleys in the subsurface in the foothills of the Alps, for example. A team led by the BGR scientist Anke Bebiolka has compiled a study of current knowledge on deep glacial erosion in southern Germany.

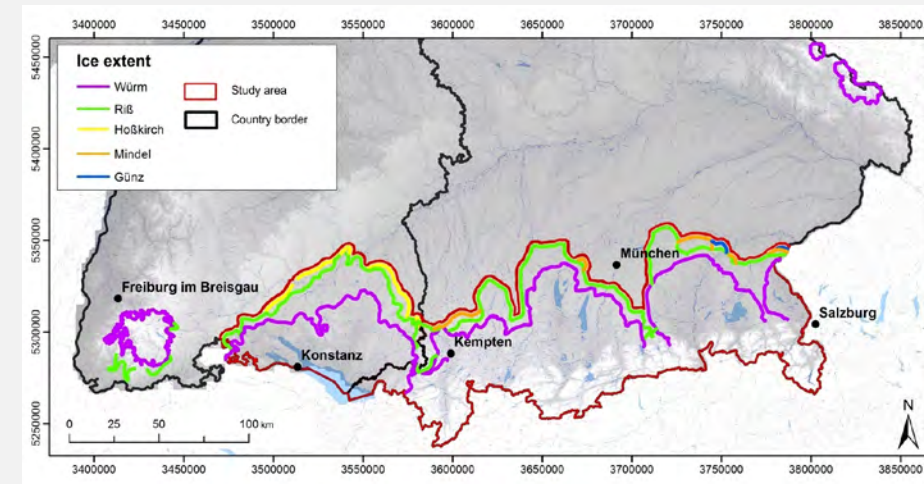
Nuclear wastes are to be stored in Germany in a deep geological formation – and in such a way that they do not come into contact with the environment for at least a million years. But how does one find a site where geological forces only have minor impact for such a long period of time? “One must consider the geological evolution of the respective host rock and the geosphere in the vicinity of the final repository site”, says Bebiolka.

The study addressed a specific problem that any future final repository would need to be prepared for: erosion by glaciers. Because even though the Earth's climate is currently warming up rapidly, it is not impossible for ice ages to occur again in the future. BGR research team assumes that, similar to the recent past, glacials will continue to recur in a one hundred thousand year rhythm. This means that another ten ice ages should be expected over the next million years.

Glaciers would once again also spread across southern Germany. The ice cover could once again be as widespread as during the Pleistocene (2.6 million to 12,000 years ago). Back then, mountain glaciers sometimes advanced several times into the foothills of the Alps, occasionally carry away rocks beneath the glacier base and unloading their material freight elsewhere. The BGR research team also anticipates significant future deep glacial erosion in southern Germany, especially at the boundary to the Alps. No significant deep glacial erosion is anticipated with regard to glaciations in the Black Forest and the Bavarian Forest. For their study, the BGR scientists therefore selected a working area that corresponded to the maximum extent of the northern Alpine glaciation. The aim of their project was to identify all deep erosional structures formed during past ice ages and to calculate the maximum depth of erosion.



Distribution of differential elevations [m] between the preglacial reference surface and the base of the Quaternary (GeoMoI/LGRB project). Gaps in the raster data represent regions without Quaternary Background: DTK200 (BKG) water bodies.



Selected outermost extensions of inland ice sheets according to different authors. Background: DGM50 and DTK200 (BKG) water bodies.

“Glacial erosion can leave behind elongated channels, but also, occasionally, wider and shorter structures”, reports Bebiolka. Thus, the entire spectrum of possible forms was included in the investigation. Because the depressions fill up with sediment when the glaciers melt, they are often not immediately discernible on the surface. Based on data from the State Geological Surveys of Baden-Württemberg and Bavaria, the BGR team was also able to locate such hidden structures. To then estimate how deeply the glaciers had eroded the rocks regionally, they needed to reconstruct the land surface elevation prior to the oldest glaciation. The result of the study: In the Baden-Württemberg section of the area investigated, erosion amounted to at least 830 meters over three glaciations. During a single glaciation, the glaciers locally eroded up to 435 meters of rock.

In the opinion of the BGR, greater heights cannot be ruled out. Channel-forming erosion processes may

influence the long-term safety of a potential final repository in southern Germany and should therefore be taken into consideration in the search for a final repository compliant with the site selection act.

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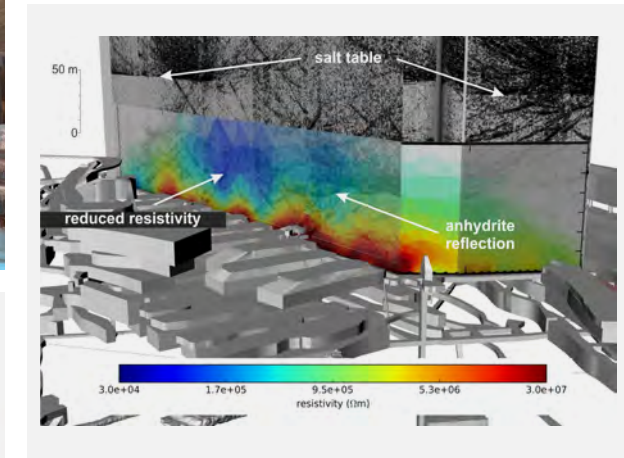
Project: 'Overdeepened Pleistocene Structures and their Relevance to the Long-term Safety of Possible Final Repository Sites in Southern Germany'



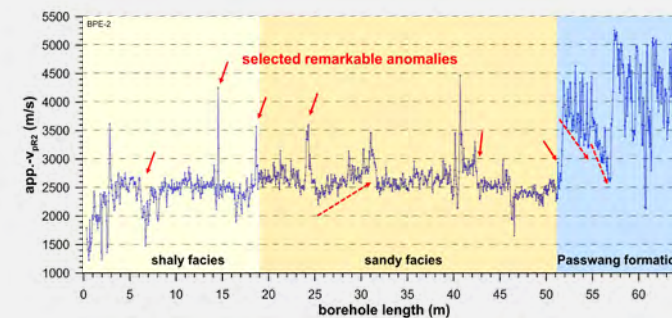
Geophysical surveys in Mont Terri rock laboratory, Switzerland.



BGR's electromagnetic reflection method for investigating a salt structure.



Combined interpretation of electromagnetic reflection and geoelectric survey results in ERA Morsleben.



The apparent P-wave velocity distribution in a bore produced as part of the extension of the Mont Terri rock laboratory shows a clear differentiation of the Opalinus Clay.

SCANNING ROCKS USING GEOPHYSICS

BGR research work makes underground structures visible

Whether you are looking at hydrogeology, rock mechanics or exploration for a final repository for nuclear waste: BGR has the correct method for scanning the subsurface at hand. The researchers employ several different geophysical methods. This allows them to characterise rock properties in situ.

It's dark in front of the hoe, as miners like to say. By that they mean that when drilling or digging down into the depths, surprises come to light again and again. Of course, this old wisdom is no longer entirely correct. For some time now, geophysical methods have existed with which the ground can be scanned from the outside, as it were. BGR's Geophysical Site Investigation Section has been developing the methods continuously for decades.

“We essentially employ four methods and are world leaders in some areas”, reports Dr. Kristof Schuster. Among other methods, the geophysicist and his colleagues employ electromagnetic reflection (abbreviated EMR). “Here, we transmit electromagnetic pulses into the rock and detect their reflections”, explains Schuster. The

signals are reflected where the dielectric properties of the rock alter, for example at strata boundaries within a salt dome. In this way, hidden internal structures can be made visible.

BGR also specialises in mini-seismics, geoelectrics and temperature measurements. “We can carry out borehole surveys, but also perform completely non-destructive investigations, for example from tunnel walls”, reports Schuster. The BGR team is active in several national and international underground research laboratories.

In the Morsleben final nuclear waste repository (ERA), Schuster's team combined EMR measurements with geoelectric methods. “The penetration depth of the EMR

signals is highly dependent on the electrical resistivity of the rock. This parameter, in turn, can be determined using geoelectrics”, explains Schuster. In Morsleben, the BGR examined a section in which the EMR signals, in places, could barely penetrate the rock. The geoelectric survey revealed that material with reduced electrical resistivity is located here.

The BGR team discovered unusually low temperatures in the Gorleben salt dome, which was investigated for several decades – with interruptions – for its suitability as a final repository for nuclear waste. “We developed special probes for dry and fluid-filled boreholes to facilitate high-resolution temperature surveys”, says Schuster. On the one hand, the measurements can document the original status of a potential final repository, and on the other, they can provide data for models, for example to analyse long-term stability. In Gorleben, the team measured temperatures of around 33 degrees Celsius about halfway along a 160 metre horizontal borehole. The researchers had anticipated 37 degrees

there. Modelling confirmed the team's suspicions: lower-lying tunnel sections connected to a fresh air supply cool the rock.

In the spring of 2017, BGR carried out geophysical surveys in three boreholes at the Mont Terri rock laboratory, which is soon to be extended. “With our 8-channel ultrasonic probe, developed in-house, we were able to measure important rock parameters at a very high-resolution”, says Schuster. For example, the results allowed us to distinguish between two types of Opalinus Clay and a neighbouring rock formation. The surveys also revealed several anomalous regions, in which the material properties fluctuated greatly. “These regions need to be investigated in more detail before the new tunnels are bored”, says Schuster.

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Project: Geophysical Site Investigation Section

THE ROLE OF ORGANIC MATERIAL IN THE HOST ROCK OF A FINAL REPOSITORY

How hydrocarbons in clay or salt react to heat and radiation

Clay stones or shales and salt rocks are regarded as possible host rocks for a final repository for nuclear waste. Because the rocks contain small quantities of organic material, chemical reactions of these carbonaceous substances may influence the processes in a final repository. BGR investigations are aimed at clarifying the consequences.



A high-pressure reactor system with online-analysis equipment connected for investigating the conversion of organic matter within rock cores.

Organic compounds are not especially heat-resistant. At temperatures above 100 degrees Celsius, some bonds within the carbonaceous molecules break down and the substances decompose. Ionising radiation can also destroy organic substances. As a result, gases such as hydrogen, methane, carbon monoxide or dioxide and liquid compounds, some soluble in water, are formed.

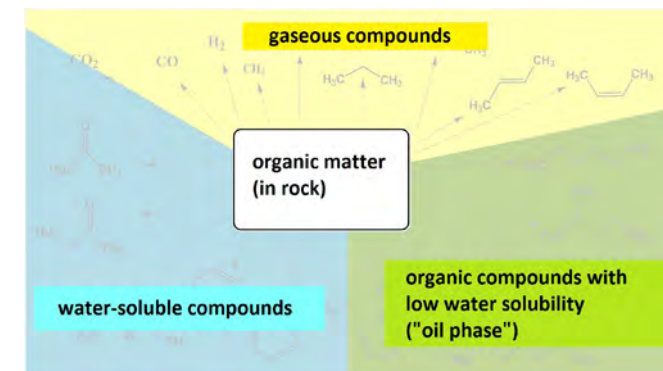
“We are currently investigating how organic material behaves in the host rock when exposed to heat or ionising radiation”, reports the BGR geochemist Dr. Christian Ostertag-Henning.

These experiments are important for assessing individual processes in a future final repository. For example, the decomposition of organic material could increase the pressure in the pore space. It is also possible that the reaction products will dissolve minerals in the host rock or form new minerals. On the other hand, radionuclides could bond to the altered organic material.

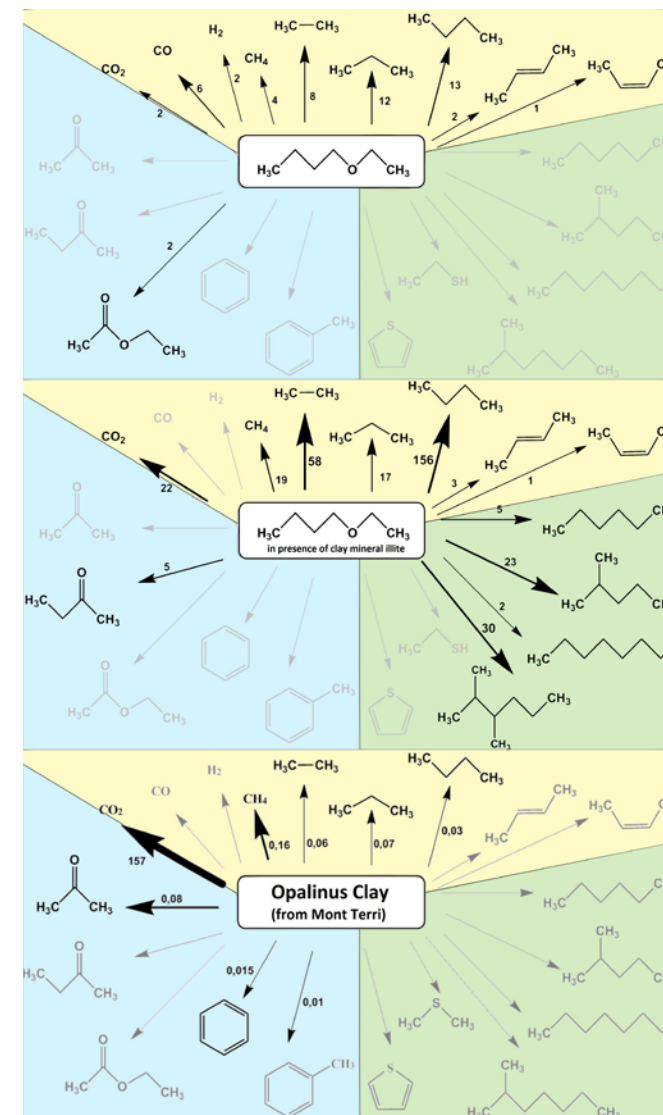
“We carry out our experiments in the laboratory in Hannover and supplement them with analyses of experiments performed in the Swiss rock laboratory at Mont Terri”, says Ostertag-Henning. Here, the BGR team collaborates closely with international partners. The researchers heat their samples in high-pressure reactors and then analyse the reaction products.

“Because there is very little organic material in most rocks, we additionally carry out experiments with isolated organic compounds”, explains the BGR researcher. These so-called model compounds represent important components of the complex organic material within the host rocks. Based on these experiments, the scientists can describe individual chemical reactions in detail.

In a study, the research team compared three different cases: they heated an isolated organic model compound and, in addition, a mixture of this model compound with the clay mineral illite. Finally, the Opalinus Clay from the Swiss underground laboratory in Mont Terri,



The products formed from organic materials are divided into three groups, the gaseous (yellow), the soluble (blue) and the poorly soluble (green) compounds.



Exemplary representation of selected compounds released in the thermal transformation of organic model compounds (above), also mixed with the clay mineral illite (centre) or from a natural claystone (Opalinus Clay from the Mont Terri underground laboratory). The numbers indicate relative quantities.

emphasises Ostertag-Henning. Carbon dioxide is less critical to a final repository than, say, highly reactive hydrogen because, under certain conditions, it can gradually transform into solid carbonate minerals in the rock.

The experiments also demonstrated that organic matter not only decomposes in the presence of minerals, but also partially converts into larger, tarry molecules. These substances may bond with radionuclides and thus prevent them from being further transported in the rock.

In the future, the BGR team also wants to experiment on rocks from underground laboratories in Belgium and France. In addition, it is planned to investigate the influence of ionising radiation on organic material in more detail. Ostertag-Henning: “The initial results reveal that gas formation is amplified by radiation, but remains very low overall.”

which also contains organic material, was heated. The result: the experiments with the isolated compounds typically gave rise to reaction products such as hydrogen or carbon monoxide. In the presence of clay minerals or within the rock itself, mainly carbon dioxide was formed instead. “The comparison makes it clear that one should not only consider isolated organic model compounds”,

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Project: The Stability of Organic Materials Near Radioactive Material

3D GEOLOGICAL PUZZLE

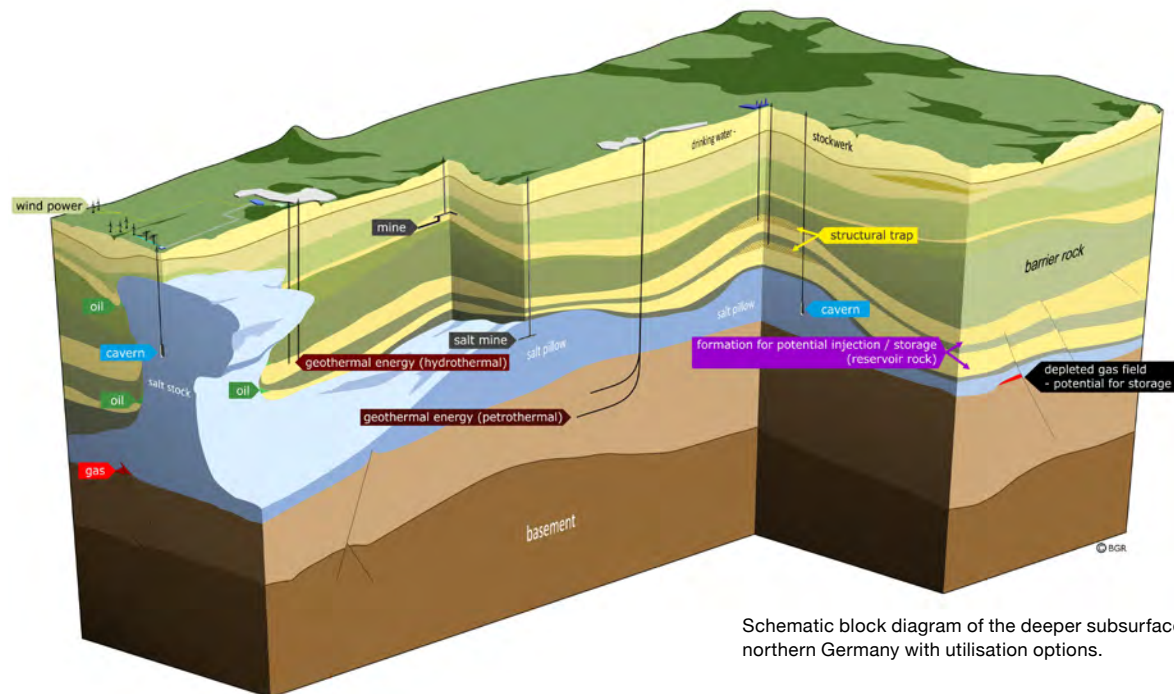
Digital Model of the North German Basin is in Progress

Authorities need a three-dimensional, structural geological model of the subsurface in northern Germany. In the future, the rocks of the North German Basin will increasingly be used for energy storage and as an energy source. BGR is currently working on creating such a digital model, together with the geological surveys of five federal states.

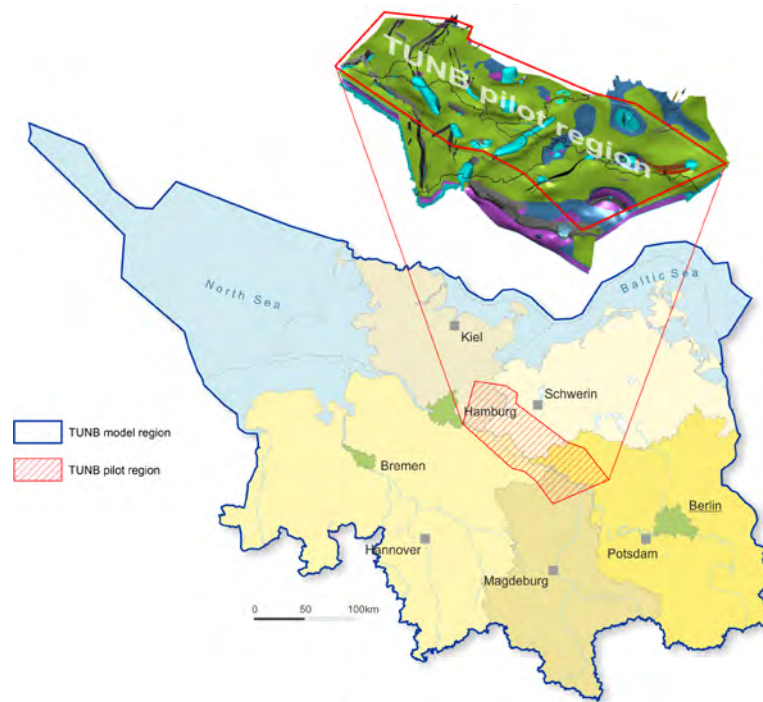
During the geological periods from the Permian to the Oligocene (296 million to 24 million years ago), today's northern Germany was subject to a turbulent history, including phases in which the Earth's surface was submerged for many millions of years. Thousands of metres of sedimentary strata, which today characterise the North German Basin, represent the result of this long development history. Of course, all of these layers of rock are not simply stacked on top of each other horizontally just like in a layer cake, but are often folded and permeated by faults. Countless salt structures bulge upwards and sometimes penetrate the overlying layers. Rock layers deposited during the same periods of time are more like a crumpled piece of paper than a smooth surface.

Northern Germany's deep geological subsurface is very important in terms of energy supply. It already supplies crude oil, natural gas and coal, and is used for temporary storage of natural gas. "Other utilisation options may be added in the course of Germany's 'Energiewende' (energy transition)", says Dr. Gabriela von Goerne, Head of the Unit 'Subsurface Models and Potentials' at BGR. For example, the North German Basin has a large geothermal energy potential. In addition, underground storage systems can store excess energy, produced by wind power and solar power installations.

The responsible State Geological Surveys (SGD) have to deal with numerous new questions. One of the challenges is that the different usage options compete



Schematic block diagram of the deeper subsurface in northern Germany with utilisation options.



Five federal states are harmonising their subsurface data in the pilot region for the digital model of the TUNB project.

with each other. Energy can be stored in salt caverns, for example in the form of natural gas or compressed air, and pore reservoirs – usually extensive sandstone formations – can also store natural gas, but also CO₂ from industrial facilities or provide geothermal energy. "In order to make the best possible use of all options, the underground space must be systematically explored", explains von Goerne.

She and her colleagues are therefore collaborating with the geological surveys of Schleswig Holstein, Lower Saxony, Mecklenburg-Western Pomerania, Brandenburg and Saxony-Anhalt to create a transregional, 3D geological model. "The geological surveys of the federal states each develop a sub-model for their state territory, BGR deals with the German North Sea sector and combines the sub-models into an overall model", explains von Goerne.

The researchers evaluate all the known structural geology data for the model and collate information from deep wells, seismic surveys and maps. Sometimes, new data is also collected, for example from the Baltic Sea. "Data base, data density and data quality are highly heterogeneous. It is therefore extremely important to coordinate and harmonise the modelling steps between all partners", emphasises Stefan Knopf, BGR geoscientist. To test harmonisation, the team has selected a 7800 square kilometre pilot region along the former inner-German border, which covers all participating federal states.

"The model of the pilot region includes 16 different horizons, 24 salt structures and more than 200 faults", Knopf describes the complex material. The pilot region forms the first piece of the model puzzle. Based on it, the team aims to model further tiles and adapt them to each other. Overall, the model will contain 13 model horizons, (related to lithostratigraphic units), that is, it will model rock units that were deposited between the Permian and Oligocene geological periods in the North German Basin. Salt structures and faults are also modelled. The aim is to make the finished 3D model available in a web application to anyone interested.

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Project: Subsurface Potentials for Storage and Economic Use in the North German Basin (TUNB)

HIGH-PRESSURE REACTIONS

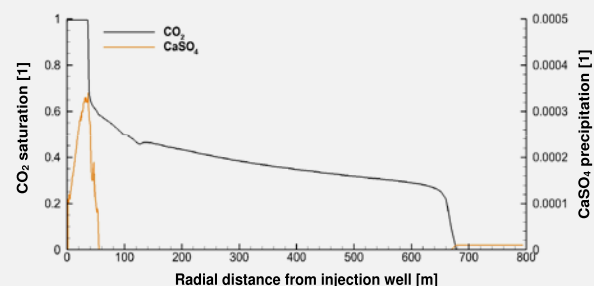
How do impure CO₂ streams distribute in geological storage systems

Carbon dioxide (CO₂), which is separated from flue gases of power stations or industrial facilities, usually contains small quantities of so-called impurities, such as sulphur oxides or nitrogen oxides. Researchers at BGR are investigating how these substances influence the properties of underground CO₂ storage formations in the joint project CLUSTER.

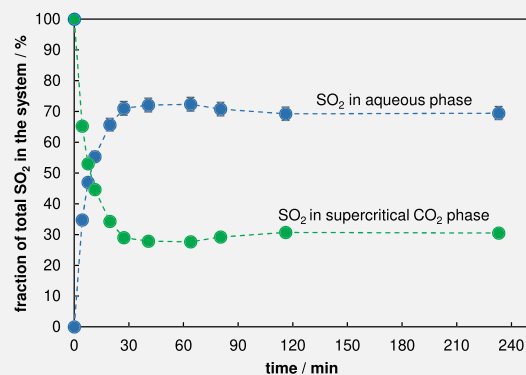
The German Federal Government aims to cut greenhouse gas emissions by at least 80 percent by 2050. In order to achieve this goal, they are considering separating CO₂ from flue gases of fossil-fuelled power stations, steel or cement works and storing it in deep geological formations. One concept involves combining CO₂ streams of neighbouring industrial facilities for transport and then injecting them into the subsurface. In particular, depleted natural gas fields and deep, salt-water-bearing rock strata are being considered as potential reservoirs.

The separated CO₂ is generally not pure, but contains different impurities depending on the industry source. To date, it is unclear under what conditions the different CO₂ streams can be combined for transport and storage. Currently, a BGR team is investigating how different impurities influence geochemical reactions in the reservoir and how this alters rock properties. “To be able to predict these changes, we need to understand how impurities propagate within the reservoir”, says geochemist Dr. Sebastian Fischer.

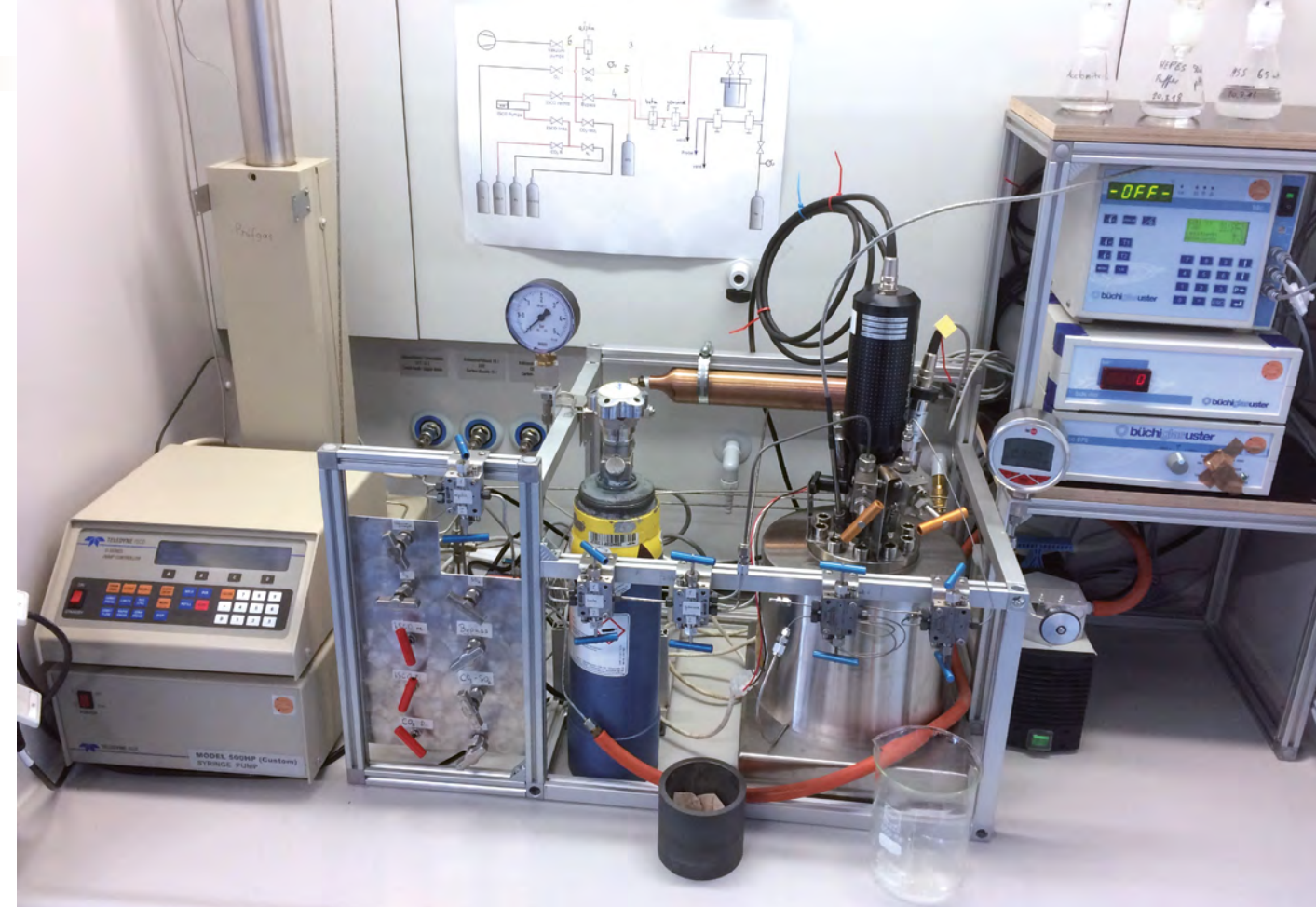
In the CLUSTER project, the BGR team is working on interactions between saline formation water and reservoir rock as a function of the composition of the CO₂ stream. “We are especially interested in how the rock properties porosity and permeability alter. Both rock properties determine how well the CO₂ is distributed in the subsurface”, says BGR researcher Dr. Christian Ostertag-Henning. The scientists investigate, in experiments and model simulations, which processes occur at different distances from the injection well.



Spatial distribution of CO₂ (approx. 680 m) compared to precipitation of CaSO₄ (approx. 60 m) as a measure of SO₂ propagation in a saline aquifer after a simulation period of one year.



Dissolution of SO₂ from a CO₂ phase into an aqueous phase under pressure and temperature conditions that are typical for a geological reservoir (160 bar, 60 °C).



Experimental setup for investigating dissolution reactions and mass transfer of gases (e.g. SO₂ or O₂) out of the liquid CO₂ phase into water at in situ temperatures and pressures of a storage formation. On the left the high pressure syringe pump is apparent. It delivers the CO₂ – and through the valve system accessory gases SO₂ or O₂ – to the titanium high pressure reactor in the middle. To the titanium high pressure reactor a stirrer as well as pressure and temperature controllers are attached (on the right).

“One of the central questions is how much of which impurity species can be found, at which time, and where in the storage formation”, Ostertag-Henning emphasises. To clarify this, the team examines how fast the CO₂ spreads underground, for example, and how the impurity species behave within the CO₂ phase. In addition, the researchers must understand how the impurity species enter the formation water and influence geochemical reactions there.

In detail, for example, the team has investigated how quickly sulphur dioxide from the CO₂ stream dissolves in aqueous solutions and which sulphur compounds are formed. For this purpose, the researchers conducted experiments in special titanium reactors, for example at 60 degrees Celsius and 160 bar. “These are pressure and temperature conditions that can occur in a geological reservoir”, says Ostertag-Henning.

Geochemical modelling shows that the impurity species in the scenario considered only subordinately react with the minerals in the storage system, says Fischer

and explains: “Given the low concentrations of impurity species anticipated in the flue gas of power stations or industrial facilities, the porosities of the reservoir rock do not alter to a geo-technically relevant extent in the scenarios considered so far.”

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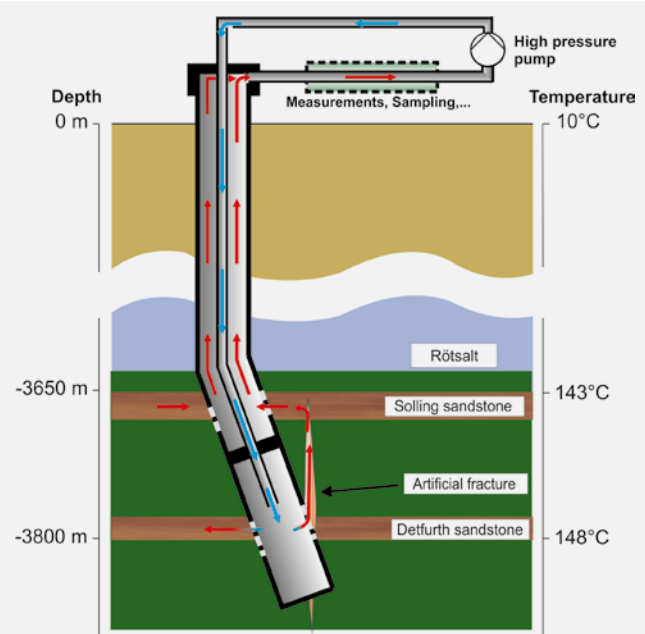
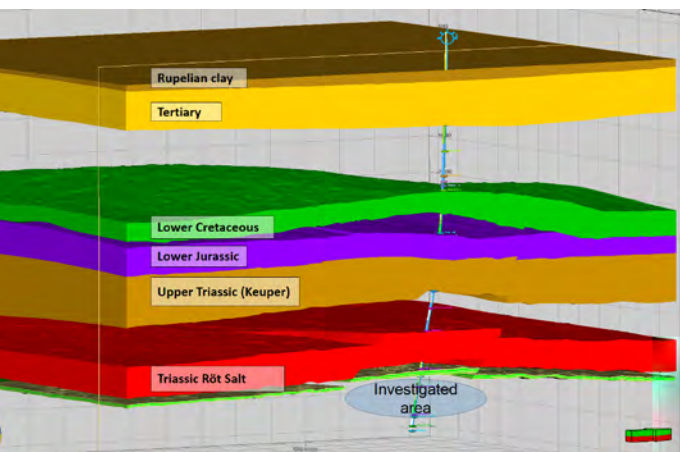


Project: Impacts of impurities in CO₂ streams captured from different emitters of a regional cluster on transport, injection and storage

TESTS IN THE MIDDLE BUNTSANDSTEIN

Horstberg well is back in operation

For six years, the Horstberg Z1 geothermal well, located near the village of Dreilingen (Uelzen district), in Lower Saxony, stood idle. In 2016, BGR rehabilitated the well site and recommissioned the well. Now the artificially created fracture zone in the subsurface is to be precisely characterised.



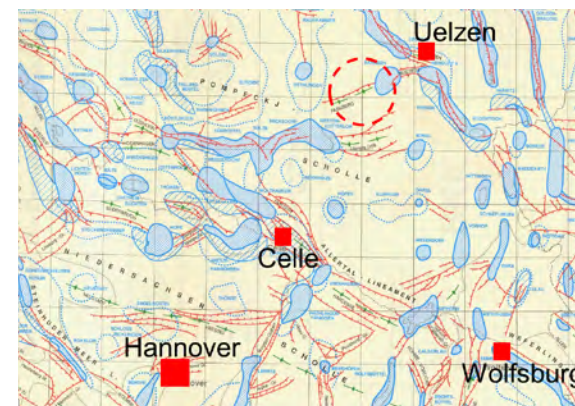
Top: Visualisation of the investigated area and overlying barrier strata (dominated by claystone and salt).

Bottom: Schematic of planned monobore circulation via an artificial fracture between two sandstones.

BGR submitted the appropriate licence application in April 2017 to Landesamt für Bergbau, Energie und Geologie (LBEG) in Hannover. “We aim to conduct long-term circulation tests at a number of different flow rates and pressure levels”, explains Dr. Torsten Tischner. He and his colleagues aim to demonstrate that it is also possible to extract geothermal energy from the low-permeability sandstone strata typical of northern Germany.

BGR has been utilising the former Horstberg Z1 natural gas well for this purpose since 2003. It is located about 80 kilometres north-east of Hannover and serves as a research platform for testing various geothermal utilisation concepts. Suitable temperatures for geothermal energy production can be found at depths of around 3800 metres. However, the Triassic Middle Bunter Sandstone strata there have very low permeability. In 2003, therefore, BGR carried out a hydraulic simulation. In order to create an artificial fracture zone, about 20,000 cubic metres of fresh water, without additives, were injected into the Detfurth Sandstone, a 14 metre thick sandstone layer 3,800 metres below the surface. This resulted in a several hundred metre long, artificial fracture zone, connecting the Detfurth Sandstone with the Solling Sandstone, more than one hundred metres higher up.

“Subsequent hydraulic testing demonstrated that the fracture zone has very good hydraulic conductivity over a large area”, reports Tischner. BGR tested two different utilisation concepts by 2009: on the one hand, the cyclical process, in which water is alternately injected and removed again, and monobore circulation, in which continuous injection and pumping takes place. “In both cases, the thermal water flows through the artificially created frac-



Borehole site (top left) and view from above the borehole site (top right).

Bore location (red circle) on a geotectonic map.

ture zone, which also serves as a heat exchanger”, says Tischner. The good results returned by the first tests formed the basis for the GeneSys project in Hannover, which began in 2009.

The BGR has been active in Horstberg again since 2016. First, the well site was rehabilitated to accommodate new legislation. Following licensing by LBEG, the first pumping tests were performed in December 2016. BGR is now planning circulation tests using the monobore method. It is planned to inject the cold water into the Detfurth Sandstone and pump the heated water from the Solling Sandstone. The researchers are aiming at a pumping rate of between one and ten litres per second. “In order to be able to better estimate the possible energy yield, we must first characterise the fracture zone in more detail”, says Tischner. For example, the planned investigations include what are known as tracer experiments, in which water propagation is tracked using trace substances. In addition, the research team aims to deter-

mine the stress field in the rock mass and determine how stable the fractures are. Numerical modelling completes the research programme.

BGR monitors both groundwater and seismic vibrations over the complete project phase. BGR also provides regular information about the project at public events. The research team were forced to disappoint the hopes of local residents that the geothermal energy produced may be used for heating: because this is a research project, it is not possible to do this.

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Project: Horstberg Z1 Geothermal Well

NO RESERVES, BUT RESOURCES

Study commissioned by BGR shows hydrocarbon potential at a similar magnitude to that of Kuwait in countries in the Horn of Africa

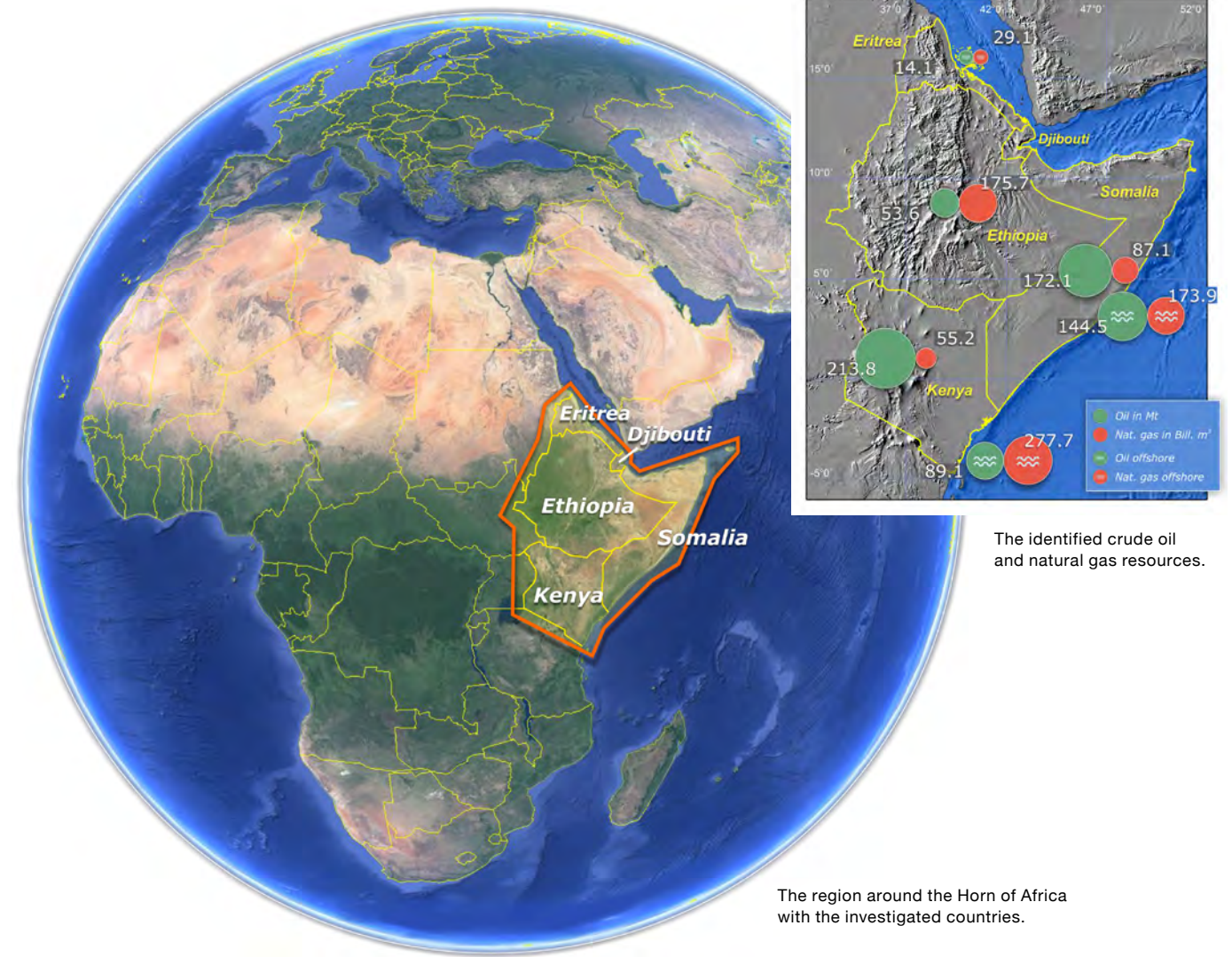
A poor prospect in terms of crude oil and natural gas – that was the opinion of commodity experts for a long time with regard to East Africa. However, around ten years ago, larger deposits were discovered in Uganda, Mozambique and Tanzania. Since then, interest in the countries in the Horn of Africa has also increased. On behalf of BGR, Falcon-Geoconsulting has identified hydrocarbon potentials in Ethiopia, Djibouti, Eritrea, Somalia and Kenya.

“The region is one of the poorest in the world and has a lot of catching up to do in terms of energy infrastructure”, says Dr. Harald Andrulleit of BGR. Theoretically, the five countries could tap into the large geothermal reserves of the East African Rift Valley to generate electricity. But crude oil and natural gas could also drive their development. “Economic growth in the region is high, leading to rapidly increasing primary energy demand”, explains Andrulleit.

To find out what potential for oil and gas exists in the region, Falcon-Geoconsulting experts analysed geological maps, scientific papers, geological survey reports and information from other companies. They recorded about

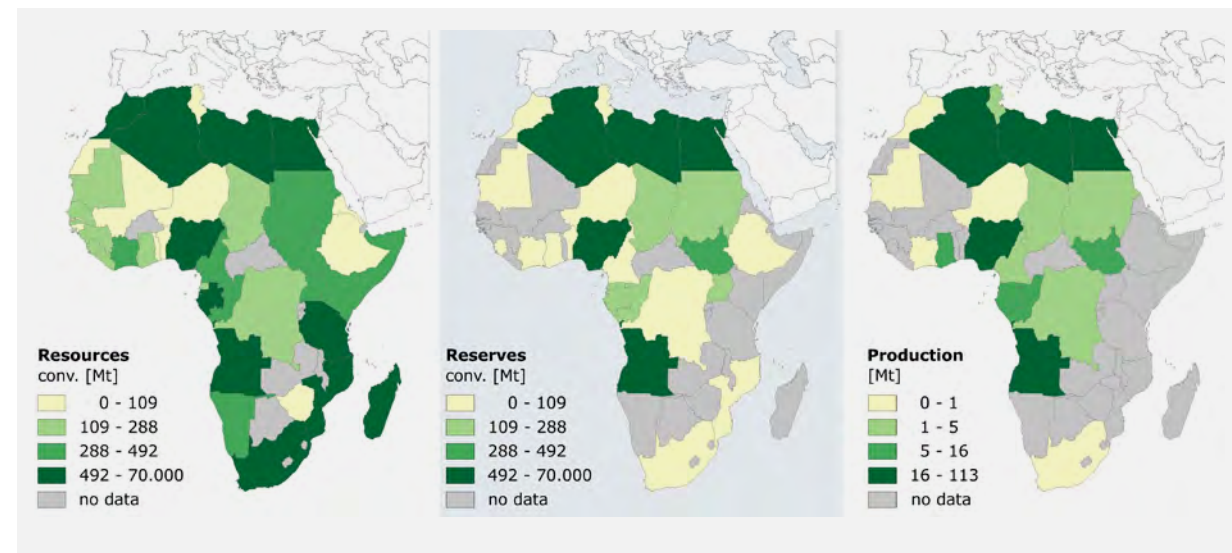
350 boreholes and 750 possible deposits. They then analysed 45 sedimentary basins on land and off the East African coast.

At the moment, none of the five countries are producing, nor are there reserves in the Horn of Africa – i.e. deposits proven to be economically viable using current technology. Resources – deposits that currently are not economically recoverable – however, are present: according to the study, there is a total potential for around 687 million tons of crude oil resources, the majority in Kenya and Somalia. By comparison: Kuwait's crude oil resources are around 700 million tonnes. “This volume could cover the coun-



The identified crude oil and natural gas resources.

The region around the Horn of Africa with the investigated countries.



The most important crude oil producers in Africa by resources, reserves and production (data status 2015).

tries' current oil needs for well over a hundred years”, says Andrulleit. The natural gas resources of the region are around 800 billion cubic metres and are comparable to the deposits in Tunisia. The greatest deposits are anticipated off the coast of Somalia and Kenya. Another region with potential is the Ogaden Basin in south-eastern Ethiopia.

Only in Djibouti does the study see no potential for hydrocarbons whatsoever: the subsurface temperatures in the tectonically highly active Afar Triangle are so high that any previously existing crude oil and natural gas are likely to have already decomposed. Neighbouring Eritrea also displays little potential, according to the study. The possible resources are all off the coast. However, the geology of the Red Sea is complex and there is a lack of infrastructure to transport any crude oil or natural gas produced.

With regard to the other countries in the Horn of Africa, it is not anticipated that the possible onshore deposits will be

tapped soon. “The lack of infrastructure and smouldering political conflicts deter potential investors”, says Andrulleit. The situation off the coast is different: the offshore basins off Kenya and Somalia in the Indian Ocean are easier to reach and may harbour rich treasures. According to the study, there is a potential for enormous individual fields – known as giants.

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Project:

Study: Crude Oil and Natural Gas Potential of the Countries in the Horn of Africa

TARGETING DEEP GROUNDWATER LEVELS

Literature study forms the basis for exploration of semi-fossil aquifers

Fresh groundwater can be found beneath saline layers in southern Africa's Kalahari Basin. Researchers have reconstructed how this unusual constellation may have been formed. There is evidence that one of the ancient water resources is gradually being renewed.

When the supercontinent Gondwana fragmented around one hundred million years ago, the southern part of Africa also changed. The crust stretched, creating a vast, endorheic depression extending from South Africa to northern Angola today: the Kalahari Basin. It is filled with thick layers of sediment deposited by rivers, lakes and the wind.

BGR researchers have been studying the complex geology of the huge basin for about 15 years. They are looking for groundwater in the northern part of the Kalahari, which could supply people in the arid border region of Namibia, Angola, Zambia and Botswana.

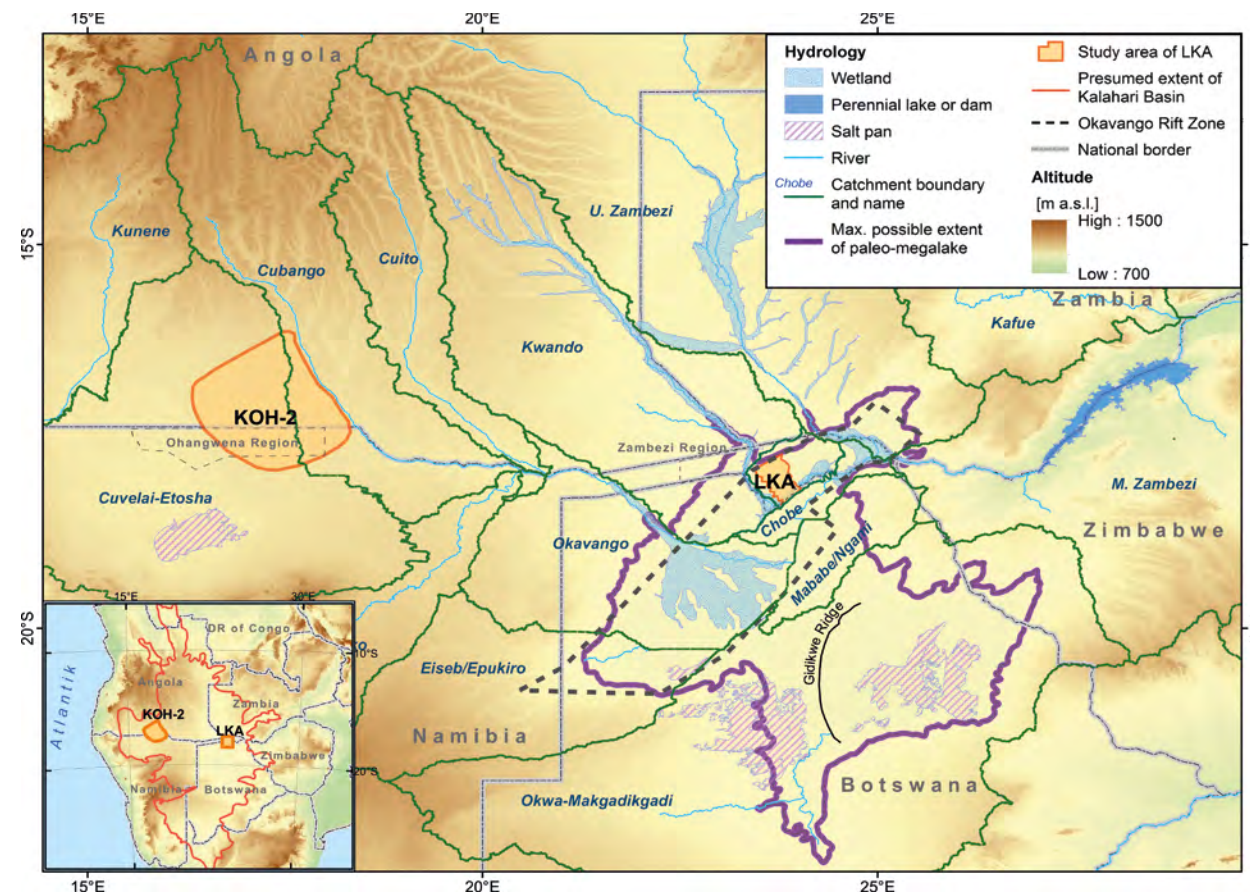
“Two deep aquifers have recently been discovered within the northern Kalahari”, reports BGR expert Dr. Roland Bäuml. One of the aquifers (Ohangwena II aquifer, abbreviated to KOH-2) is about 200 to 300 metres deep and

is located in the Angola/Namibia border region. The other (Lower Kalahari Aquifer, abbreviated to LKA) is smaller and 120 to 250 metres deep in the Zambezi region in north-eastern Namibia. “These two aquifers have a low mineral content, but lie beneath saline, shallow aquifers, which can hardly be used as drinking water”, explains Bäuml's colleague Prof. Dr. Thomas Himmelsbach. More recent BGR geophysical surveys indicate that similar hydrogeological levels may lie beneath parts of the famous Okavango delta.

Bäuml and Himmelsbach have analysed more than 200 scientific reports, among other things on previous climatic conditions in Africa and on the geology of the northern Kalahari Basin. “We want to demonstrate that the exploration of deep aquifers can be improved by combining different methodological approaches”, says Himmelsbach.



Many people in the region are dependent on shallow aquifers.



The investigation areas in the Kalahari Basin.

He and Bäuml, for example, included BGR geophysical surveys in the study, carried out on the ground and by helicopter in recent years. In addition, they analysed remote sensing data, geochemical investigations and isotope measurements to understand the formation of aquifers.

They found that the KOH-2 aquifer is particularly pronounced in the area of a former river delta. “The future development of this aquifer should be correlated to the proven structures of this palaeodelta”, says Bäuml. In the opinion of the two researchers, the LKA aquifer in north-eastern Namibia, on the other hand, is controlled by tectonic activities that continue to this day: due to crustal extension, a graben structure formed millions of years ago. In the central part of the region, the water-bearing sediment stratum was lowered, whereupon a salt pan formed in the depression, in which new sediments were deposited. The aquifer was therefore initially filled with saltwater. “This originally salty groundwater body, however, has been gradually freshening since the end of the Ice Age”, reports Bäuml. The researchers see evidence that fresh water is still entering the deep aquifer at the graben boundary – albeit very slowly.

Although such semi-fossil aquifers originated in wetter climatic periods, they are not completely cut off from

recharge and could therefore be used sustainably. Himmelsbach emphasises: “Our study underpins the assumption that additional, deep, semi-fossil aquifers can be found in southern Africa.”

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Project:
Study: Exploration of Deep, Previously Unknown, Semi-fossil Aquifers in the Kalahari Basin (Southern Africa)

SUSTAINABLE USE OF SOIL RESOURCES USING BIOCHAR

Biochar fertiliser could improve Ethiopia's soils

The Ethiopian highlands have comparatively fertile soils. However, arable land loses nutrients through erosion, overgrazing and inadequate fertilising. Biochar systems may help to contribute to a remedy. A BGR project has now investigated the possible applications of sustainably produced biochar.



Erosion – a common problem in Ethiopia.



Technical discussion on the use of a biochar stove by a smallholder in Jimma/Ethiopia.

further processed with compost and other components to produce high-quality organic fertilisers. The scenarios look at the entire value-added chain including acceptance issues within the population.

The result of the study: in Ethiopia, it is conceivable to produce biochar at different scales from harvest residues such as corn cobs or coffee husks and at the same time to use the process energy. The use of small cooking stoves at the local level appears most promising. The researchers identified three regions in north-western Ethiopia that provide good conditions for biochar systems.

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Project: Ethiopia – Biochar Systems for Improving Soil and Nutrient Management

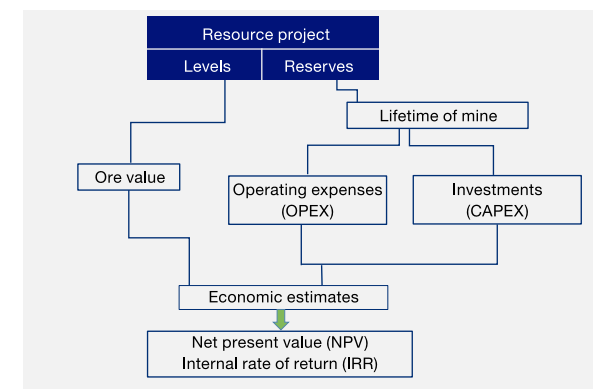
Soil resources are heavily exploited in Ethiopia. The high population growth leads to an increased demand for food and wood as a fuel and building material. However, firewood is scarce, as only 12.5 percent of Ethiopia's area is forested. If resources were used more efficiently and agricultural production significantly increased, Ethiopia could escape this dilemma.

“Biochar systems could make a meaningful contribution to solve these problems”, says BGR soil scientist Dr. Andreas Möller. Together with technical cooperation experts, the Ethiopian Ministry of Agriculture and international universities, he is developing holistic scenarios to demonstrate how biochar systems can be implemented in Ethiopia. The idea is to utilise plant residues in special pyrolysis ovens for cooking, for example. The by-product biochar, i.e. the charred plant residue, is then

TOOLBOX FOR MINING AUTHORITIES

BGR trains partners in evaluating resources projects

The economic feasibility of mining projects depends on numerous factors: for example, on the ore content of the rock, the ore reserves or on economic indicators such as operating and investment costs. BGR has now developed a simple process with which partner countries can roughly estimate the profitability of resource projects.



Top: Training in Maputo in October 2017, for employees of the National Directorate of Geology and Mining of Mozambique.

Bottom: Calculation flowchart.

“In terms of technical cooperation, we collaborate with numerous countries in which the mining sector is regarded as an important economic engine”, reports Dr. Klaus Steinmüller, responsible at BGR for the Extractives and Development sector programme. In many cases, however, the mining authorities lack the knowledge necessary to test feasibility studies or to assess whether submitted economic feasibility analyses are plausible.

Steinmüller and colleagues have therefore developed a toolkit, a kind of toolbox with which the profitability of resources projects can be easily tested. In 2016, the BGR experts trained employees of the Main Department for Geology of Tajikistan. “In the meantime, the project partners are successfully using the toolkit to re-evaluate known resource deposits based on archive data”, says Steinmüller. The toolkit was also introduced in Mozambique in 2017. There, the National Directorate of Geology and Mining now works with this instrument.

“For mining nations, the toolkit is an important aid in determining the value of discovered or suspected resource deposits early on in a project or for assumed possible tax revenues”, explains BGR expert Dr. Thekla Abel.

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Project: Toolkit for the Economic Assessment of Mineral Resources Projects

THE HUMAN FACTOR

German-Sino team supports urban development in Lanzhou

The fertile loess plateau in northern China gives the Yellow River, in Chinese Huang He, its name. But the surrounding hills, made up of the soft, yellow sediment, keep slipping. BGR researchers and their Chinese colleagues in the provincial capital of Lanzhou have now conducted slope stability investigations and compiled regional landslide susceptibility maps.

The city of Lanzhou, with a population of three million, is spreading rapidly into the surrounding loess mountains. “To facilitate the growth of the city, which was once a Silk Road hub, mountains are being excavated and valleys filled up over a large area”, reports Dr. Jewgenij Torizin of BGR. The researcher is involved in a German-Sino cooperation in which the potential threat posed by mass movements in the Lanzhou region, such as collapses and landslides, was investigated. “We aim to develop special methods for regions that are subject to rapid urban development”, says Torizin.

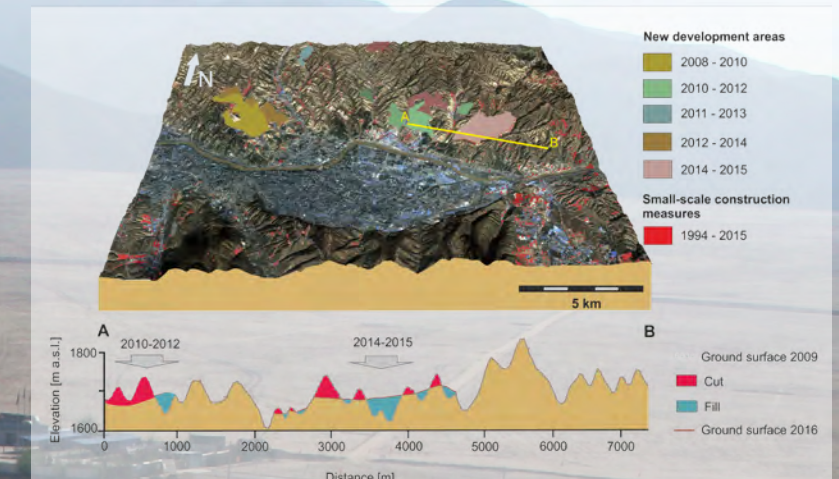
Historical records, aerial photographs or maps of past landslides are typically studied to create so-called susceptibility maps using statistical techniques. “Because landslides are comparatively rare events, one must look at long periods of time to get statistically representative results”, says Torizin. Here, it is important that the control factors remain as constant as possible during these periods. However, in rapidly growing urban areas such as Lanzhou, this approach does

not work because the landscape is changing too fast as a result of massive geomorphological transformation.

The German-Sino team is therefore trying to account for the influence of human construction activity when estimating hazard potentials. In the first phase of the project, the team investigated the extent to which the hazard potential for landslides has changed since the year 2000 as a result of the human factor. The project results will be directly incorporated into urban development planning for the years 2020 to 2025.



View of Lanzhou on the Yellow River.



Visualisation of surface modification by human activity for different time periods. The elevation section A-B illustrates the intensity of relief modification between 2009 and 2016.

The development area north of Lanzhou artificially shaped between 2014 and 2015. The loess mountains in the background suggest the original landscape form. Relief differences of up to 140 m were compensated over an area of approx. 5 km².

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Project: LHARA (Landslide Hazard and Risk Assessment Lanzhou, Province Gansu)

LISTENING OUT FOR PEACE

Comprehensive Nuclear-Test-Ban Treaty: Improved monitoring using seismoacoustics

With its seismometer and infrasound stations, BGR forms part of a global monitoring network to monitor compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT). BGR can now track nuclear tests even more reliably. With the help of a combined seismoacoustic method, explosions near the surface are detected more precisely.

“Our aim is to improve the detection capability of seismometers and infrasound stations as a whole”, describes Seismologist Dr. Lars Ceranna the intention of the current BGR project CTBT seismoacoustics. This not only concerns the obligation under international law resulting from the Comprehensive Nuclear-Test-Ban Treaty, but also all other tasks of BGR as the national earthquake service. In the latter function, BGR registers all seismic events in Germany and neighbouring European regions around the clock.

The BGR seismometers record signals from a variety of natural sources. These include earthquakes, volcanic eruptions, meteorite impacts or even ocean waves. However, the seismometer stations also frequently record explosions caused by quarry blasting and mining operations, the detonation of ammunition, military exercises or underground nuclear weapons tests. All of these shallow events, whether of natural or artificial origin, set >>

One of the Antarctic infrasound station array elements.

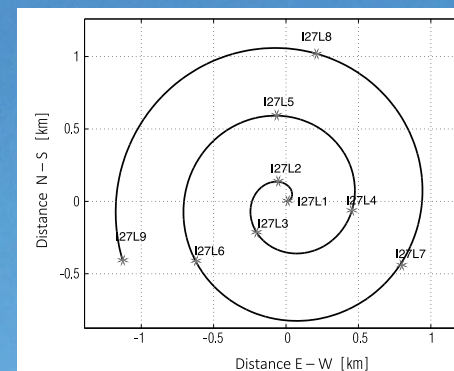
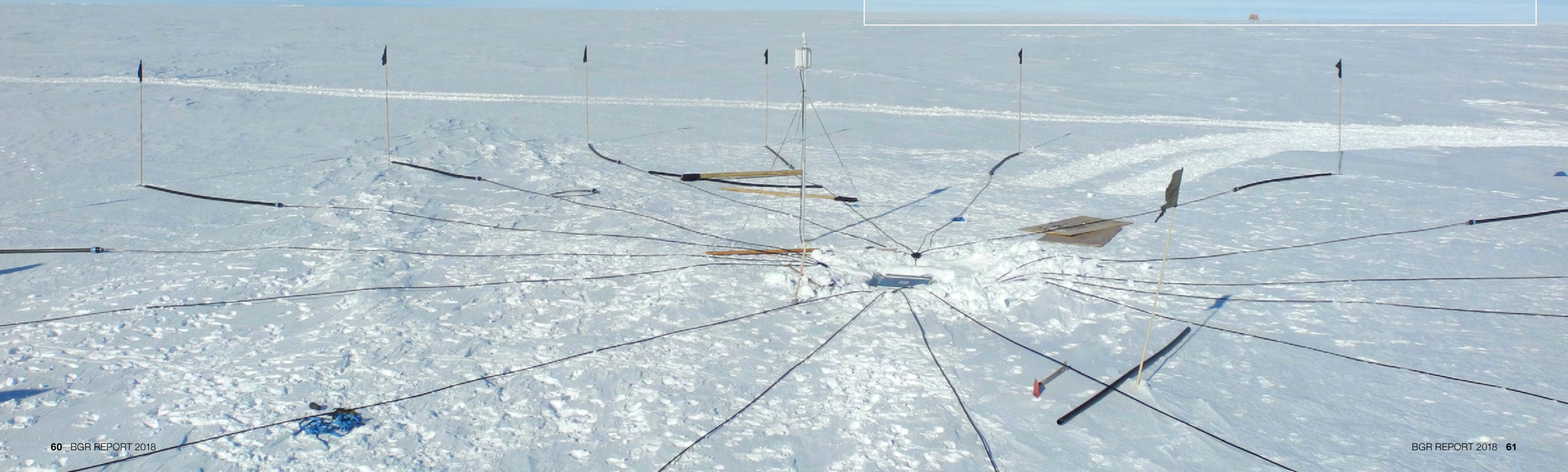


Fig. 1a

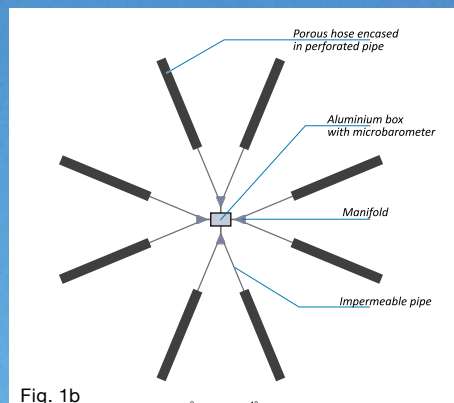


Fig. 1b



Fig. 1c

INFRA SOUND STATION DESIGN

BGR is responsible for the operation of a total of two of the 60 infrasound stations in the global CTBT compliance monitoring network. The stations are located in the Bavarian Forest and Antarctica.

The BGR infrasound station in the Antarctic consists of nine interconnected, identical monitoring points. This so-called array allows a directional bearing of the sound waves to be taken. At least four array elements are required for the directional bearing and identification of even small signals. The geometric, spiral arrangement (Fig. 1a) of the nine array elements ensures optimal recording of the infrasound signals.

Each array element (Fig. 1b) is equipped with a high-sensitivity microbarometer (Fig. 1c) and a digital data recording unit. To reduce wind noise, a pipe system is connected to each microbarometer. It consists of eight 25 m long arms. The outer 15 m consist of porous hoses,

which allow the necessary air intake. Infrasound waves are detected across a wide area by this arrangement and arrive at the sensor through the pipe system. The data is transmitted via WLAN. In Antarctica, the position of the devices is marked by flags so that they can always be rediscovered under a meter-thick layer of ice.



Fig. 2a



Fig. 2b

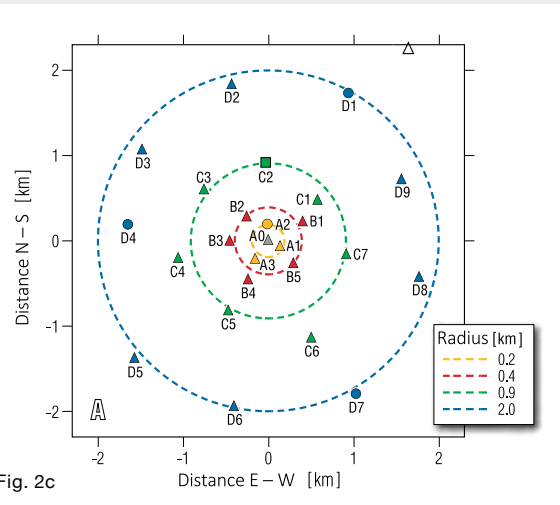


Fig. 2c

SEISMOLOGICAL STATION DESIGN

The seismological station network of the international CTBT monitoring system is specifically designed to detect, locate and identify underground nuclear explosions. This includes BGR's GERES seismometer station (see p. 64) in the Bavarian Forest. At this station, seismic waves caused by earthquakes or explosions and propagated through the Earth's interior are monitored. The station is formed by 25 individual array elements arranged on concentric circles (Fig. 2c) with radii of 200 m, 430 m, 925 m and 1988 m. The maximum extent of this seismic array is around 4 km.

GERES is one of the most sensitive seismic monitoring stations in central Europe. The reason for this is the location of the seismometers (Fig. 2a) directly on the solid native rock (gneiss and granite) of the Bohemian Massif in shafts several metres deep (Fig. 2b). In addition, the site enjoys a low noise level.

>> the earth's crust in motion. At the same time they also emit sound waves that propagate through air. Infrasound in particular, which at low frequencies below 20 Hz is imperceptible to people, propagates almost without loss up to several hundred kilometres due to the long wavelength.

method. By combining both waveform technologies, the depth and direction of signal sources can be better localised and their properties more accurately determined. For example, shallow blasting in a quarry emits significantly more energy as infrasound than deeper events, such as natural earthquakes. Ceranna and his colleague Dr. Christoph Pilger exploited this relationship to their advantage in their BGR research project in action for peace. Together, they succeeded in developing a more precise investigation method for detecting anthropogenic events.

In past nuclear weapons tests in North Korea, the BGR researchers were able to measure and analyse significant infrasound signals in addition to the seismic waves. "Subsequently, we were able to make the explosions triggered by the nuclear tests almost audible again", says Ceranna. During these events, the originally seismic signals of the blasts, which propagate as waves in the earth, were strong enough to also produce an acoustic signal in the atmosphere.

The task of the BGR scientists is to reliably differentiate the signals recorded from conventional explosions from possible nuclear explosions as part of nuclear weapons test ban monitoring and from earthquakes in the context of earthquake monitoring. To allow this, the scientists are currently developing a new method. Early in the project, seismic and acoustic sources in Germany were selected. The signals generated by them and received at German seismometer and infrasound stations were carefully examined and characterised. Subsequently, the seismic and acoustic signals from these events were jointly analysed and the results developed into a new seismoacoustic

THE PRINCIPLE BEHIND SEISMOACOUSTICS

The acoustic infrasound waves propagate as pressure fluctuations in the atmosphere and are refracted back to the ground by layers with strong increases in temperature and wind.

In contrast, seismic waves propagate at substantially higher speeds through the earth. Combining to form a seismoacoustic method delivers great advantages.

For example, the direction of origin and distance of an event can be calculated from the difference between seismic-to-acoustic travel times.

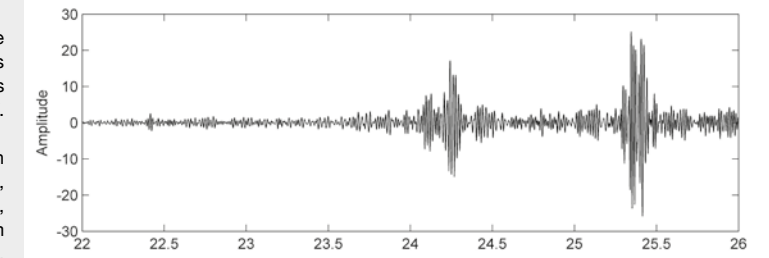
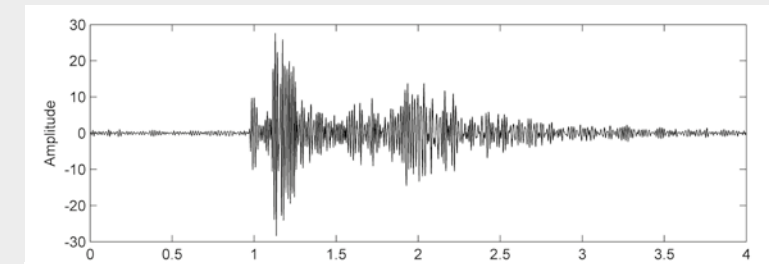
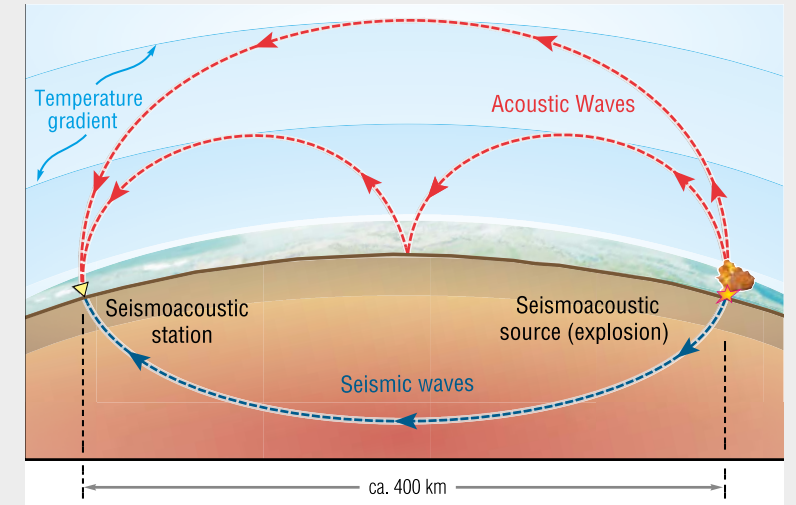


Fig. 3a (top): Schematic representation of the propagation of seismic and infrasound waves following the North Korean nuclear weapons test in 2017.

Fig. 3b: Seismic waves from the North Korean nuclear test in 2017 after 1–3 minutes (top), acoustic waves after 24–26 minutes (bottom), both at the Russian I45RU station 400 km away in Ussuriysk Bay.

From this the two BGR experts came to the conclusion that the sources must have been close to the surface – as was the case with the underground nuclear tests. Background: As the depth of the explosion increases, the associated surface seismic signal becomes weaker and thus less likely to propagate in the air as a measurable infrasound signal.

can be explained using numeric sound propagation modelling. The strong, magnitude 6.2, explosion generated acoustic waves on the surface in the source region, which could still be measured clearly at a great distance (Fig. 3a).

In a detailed study on the North Korean nuclear weapons test on 3 September 2017, BGR scientists are currently investigating how the infrasound recorded in this way

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Project: CTBT Seismoacoustics

Additional references:

Pilger, Ceranna & Bönnemann (eds.) (2017): Monitoring Compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) – Contributions by the German National Data Center, Geol. Jb., B 105, ISBN 978-3-510-96858-9



Cable installation on the main route; 97 wiring harnesses converge here and are mounted on the cable chutes.

CONSTRUCTION WORKS IN THE BAVARIAN FOREST

Cabling of the GERES array is being renewed

For 25 years BGR has been operating a seismic monitoring station on the 1147 metre high Sulzberg in the Bavarian Forest near the Czech border. The facility, which consists of 25 monitoring points and forms part of the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), has increasingly experienced electronic malfunctions and failures. BGR is now investing eight million euros in the renewal of the wiring network, together with the United Nations Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO).

In the summer of 2017, hikers and cyclists had to circle around the popular Haidel recreation area near the village of Bischofsreut, where the GERES array (the name stands for GERman Experimental Seismic system) is located. BGR geophysicist Gernot Hartmann: “Cable ducts are being dug along a length of 22 kilometres in order to modernise this monitoring facility. Approximately 56 kilometres of power, glass fibre and control cables will be installed.” For safety reasons, this area of the forest was temporarily closed to the public during construction works.

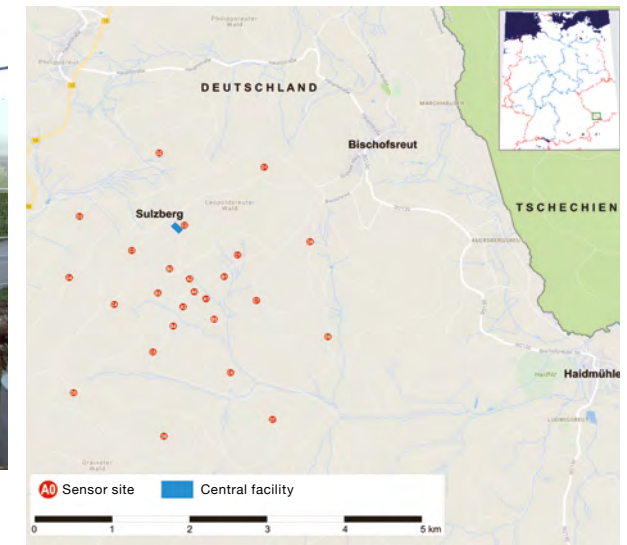
The new wiring had become necessary because the system needed to be repaired ever more frequently in recent years, despite regular servicing. “The underground cables

were repeatedly damaged by lightning strikes during thunderstorms. There were repeated power failures, water penetrated into some monitoring shafts. Occasionally, the cable trays were also affected by heavy forestry vehicles”, Hartmann describes the situation at Sulzberg. Because the damage had become so extensive, BGR decided to replace the cables completely. In addition, the lightning and surge protection was also updated. Moreover, the building on the Sulzberg, which houses the central data acquisition and communications systems, among other things, was also given a new operating room.

The GERES array consists of 25 seismic monitoring points, each installed in an approximately five metre deep shaft. They are located in four concentric circles with radii



GERES facility on Sulzberg: All the GERES array seismometer monitoring points are connected via cable to the central power supply and data acquisition in this building.



between 200 and 2000 metres around the central point. “Because of the spatial distribution of the individual monitoring points, an array has the properties of a seismic receiving antenna”, explains the BGR geophysicist. Hartmann: “Because the seismometers are installed on crystalline gneiss and granite and the area is also remote from industry and traffic, GERES is the most sensitive seismic station in Central Europe.”

This means the array is not only suitable for registering natural earthquakes around the world, but also artificial explosions such as nuclear weapons tests. Under the name PS19, GERES is one of the 50 seismic primary stations to monitor compliance with the CTBT. The data is sent to the data centre of the CTBTO, the organization supervising the treaty at the United Nations in Vienna, with only a few seconds delay. “As the operator of such a station, BGR is obliged to ensure an annual average of 98 percent data availability”, says Hartmann.

To prevent GERES being completely shut down during the construction work, ten of the monitoring points have been temporarily equipped with fuel cells for independent power supply. The measured data are transmitted via the mobile phone network. BGR engineers ensure reliable functioning. Uninterrupted operations must also be guaranteed for the eight monitoring points of the IS26 infrasound array, which is also located on the Sulzberg and forms part of the CTBT monitoring network.

“The aim is to complete construction works within a year. This demands extensive planning and coordination”, Hartmann reports. In addition to two engineering



Top: Location of GERES monitoring points in Leopoldsreuter Wald.

Bottom: Cable routing from the GERES central facility to the 25 seismic monitoring stations.

consultants and the two civil engineering and electrical engineering contractors, the interests of the community, forestry operations, water management and nature conservation needed to be taken into account.

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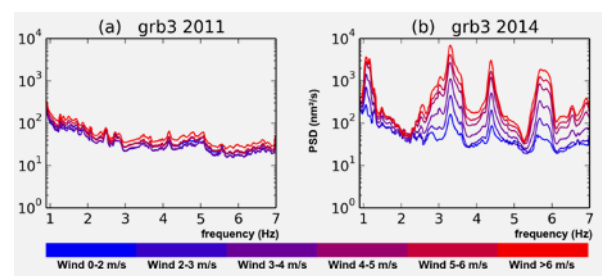


Project: Modernisation of Seismic Station PS19

WIND TURBINES DISRUPT SEISMIC MONITORING

In strong winds, the Gräfenberg Array can no longer detect small quakes

The 13 stations of the Gräfenberg Array on the Franconian Alb have registered seismic waves for more than 40 years. However, the data quality has worsened considerably since 2011. The cause are wind turbines set up at a short distance from the stations, a BGR study shows.



The wind turbines amplify Earth's background noise, which Stammler, together with his colleague Dr. Lars Ceranna demonstrated in a study. Wind turbines reduce the number of earthquakes that the seismic network can detect, the two recently reported in the journal *Seismological Research Letters*.

The two scientists compared measurements made in 2011 and 2014 and found that the wind turbine towers transmit disruptive vibrations into the earth even in light wind conditions. According to their calculations, one fifth of the earthquakes – generally the weakest – are no longer recorded, even at wind force 3. “In terms of earthquake statistics, however, the small earthquakes are particularly relevant, because there are so many more than larger earthquakes”, explains Ceranna. BGR therefore demands a minimum distance of several kilometres from wind turbines to seismic monitoring station sites.

CONTACT:

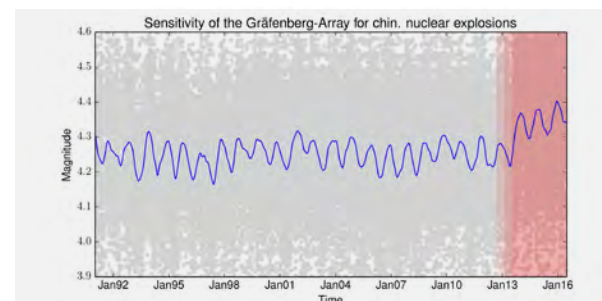
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Project: The Influence of Wind Turbines on the Seismic Monitoring of the Gräfenberg Array



Top: Wind-dependent disturbance spectra of a monitoring station (a) before and (b) after construction of three wind turbines in the vicinity.

Bottom: Seasonal fluctuations in the detection threshold of the Gräfenberg array over 25 years relative to a reference event and the influence of the wind turbines (red areas since 2012).

The 13 recording stations are all equipped with broadband seismometers, which can measure seismic waves with frequencies between 0.01 and 50 hertz. Due to the station configuration – in the north-south direction, the field spans a distance of about 100 kilometres, and 40 kilometres in the east-west direction – the Gräfenberg Array is an extremely sensitive seismological antenna.

However, in recent years the network has lost some of its capability. “Since 2011, numerous new wind turbines have been erected in the area of the Gräfenberg Array, some of them as little as 1.4 kilometres away from the stations”, reports the BGR physicist Dr. Klaus Stammler.

SEISMICITY UNDER CONTROL

BGR project investigates micro-earthquakes in geothermal fields

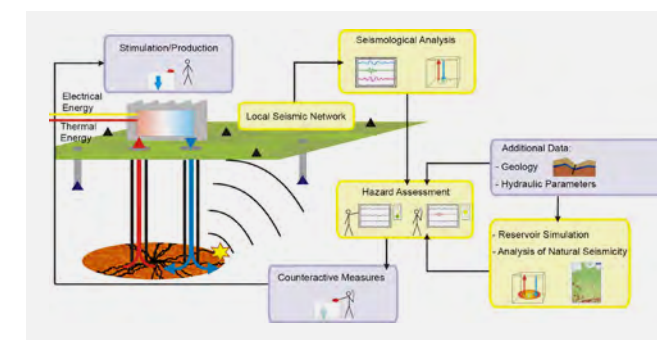
Prototype of a seismic monitoring system for efficiently determining the amplification of seismic waves in the subsurface.

In August 2009, operations at the geothermal power station in Landau in the Palatinate, Germany, triggered a magnitude 2.7 earthquake. Many people felt the vibrations and even buildings were slightly damaged. From 2010 to 2017, the MAGS collaborative project, with participants from German universities, federal and state geological surveys, as well as industry partners, addressed the causes of this induced seismicity and developed avoidance strategies.

“In the first project phase, we developed the concept of controlled circulation based on induced seismicity”, explains BGR geophysicist Dr. Thomas Plenefisch. The aim was to limit the seismicity caused by the use of geothermal energy and avoid perceptible earthquakes. “We estimate the probability of undesirable, perceptible earthquakes from the occurrence of small earthquakes and other parameters”, explains Plenefisch.

The operators of the geothermal power stations in Landau, Insheim and Unterhaching can now reduce the volume of water or the pressure in good time if seismicity threatens to increase. “In Landau and Insheim, we have greatly expanded the seismic monitoring network and developed a method to fully record even weak seismicity”, reports Prof. Dr. Thomas Spies.

In the second project phase, the team expanded the concept of controlled circulation to larger geothermal fields with multiple power stations. “However, power stations becoming uneconomical as a result must be avoided”, says Spies. The team therefore developed strategies to assess the occurrence of induced seismicity prior to drilling. BGR also developed a method for calculating the probabilities of perceptible or even harmful ground movements occurring. “We have taken into account that seismic waves are amplified differently depending on the nature of the local subsurface conditions”, explains Spies. The results are incorporated in local hazard assessments.



Reaction scheme developed in the MAGS project: The operation of deep geothermal power stations is controlled using local seismic surveys in such a way that as few seismic events as possible occur.

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Project: : MAGS – Microseismic Activity in Geothermal Fields

Cooperation Agreement between BGR and the Geological Survey of Brazil

OPTIMISED PROCESSING OF TIN AND TANTALUM ORES

In the context of a cooperation agreed with the Brazilian Geological Survey (CPRM) in 2016, which is initially scheduled to run for five years, the first joint project aims to optimise processing of tin ores from the Brazilian state of Rondônia. Ore samples are currently being analysed for this purpose at BGR. BGR sampled several mines and deposits in Rondônia during two field campaigns. Tin is mined there mainly from secondary deposits such as placer deposits and tailings, and subordinately from primary hard rocks. Tantalum minerals are produced as a by-product.

The aim of the processing tests, which are carried out on an industrial scale in Germany, is a more efficient and environmentally friendly concentration of valuable ore minerals. In addition, methods for an optimized separation of economically interesting by-products such as niobium-tantalum minerals are being investigated. BGR investigates the mineralogy of placer



Ore processing plant with spiral separators in the Estanho de Rondônia SA Santa Bárbara tin mine (ERSA).

deposits, processing residues and ore concentrates using the scanning electron microscope and electron probe microanalysis.

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BMBF r4 SEEsand Collaborative Project

RESOURCES AS COMMON AS SAND ON THE BEACH

On the beaches of the island of Usedom and from Darß to Kühlungsborn, the Baltic Sea is sweeping a valuable cargo ashore: together with ordinary quartz sand, zircon and garnet grains from Scandinavia reach the shore. These heavy minerals are a previously unused resource for high-tech raw materials. In the SEEsand collaborative project, in which BGR is involved, methods are being tested to separate the minerals from the Baltic Sea sand.



Valuable resources are gained from washed up sand in the project SEEsand (source: LUNG MV/Andreas Börner).

Baltic zircon contains heavy rare earths, such as the metal dysprosium, which is used in permanent magnets. Among other things, garnet is used as an abrasive. To separate the minerals from the sand, the researchers combine a variety of technologies, such as mechanical, biological and chemical treatment processes. Because hundreds of thousands of tons of Baltic Sea sand are already mined each year for the construction industry and coastal protection, the valuable

minerals could, so to speak, be obtained as a by-product. This would not only be sustainable, but would also significantly increase the sand's value.

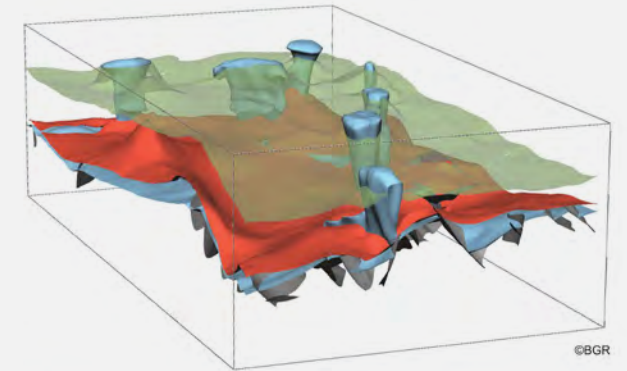
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Extension of the TUNB 3D Subsurface Model to Cover the Region of the German Baltic Sea

CRUISE WITH DRAUGHT

The German research vessel MARIA S. MERIAN covered more than 3000 kilometres in the Baltic Sea during February and March 2016. The purpose of the journey was to collect seismic data for a 3D geological model of the North German Basin that BGR is working on as part of the TUNB project (Potentials of Underground Storage and the Economic Space in the North German Basin).

The seismic profiles reflected the sediment layers of the Baltic Sea down to depths of several kilometres. Here, the Zechstein salts were made visible for the first time over a large area. The rocks from the seabed down to the base of the Zechstein salt are of particular interest to the TUNB project. The new data will now be processed together with older measurements in such a way that the geological model of the Baltic Sea can be connected to the land-based 3D model, which is also under construction.



The 3D model from the German North Sea (duckbill) exemplifies the complex three-dimensional character of the deep underground with horizon surfaces, salt structures and faults.

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Deep, Semi-Fossil Aquifers in Southern Africa

GROUNDWATER RESOURCES FOR AFRICA'S FUTURE

BGR recommends repositioning prospecting for groundwater in southern Africa. "We need an exploration strategy similar to that for crude oil or natural gas", says Prof. Dr. Thomas Himmelsbach, head of the BGR Groundwater and Soil department. BGR has long been involved in technical cooperation, especially in northern Namibia.

Previously, new groundwater resources have been identified more by chance. "But we need to move away from erratic drilling and towards an interdisciplinary exploration strategy", demands Himmelsbach. He and his colleagues aim to detect large, as yet undeveloped, so-called semi-fossil aquifers in new research projects in sub-Saharan Africa. "The water in such strata is very old, but the groundwater systems and especially their recharge areas are still active", explains Himmelsbach. The BGR team plans to employ remote sensing and geophysical methods to identify geological structures such as former deltas and horst-graben systems. "Such sediment troughs are the water reservoirs of the future", says Himmelsbach.



To what extent does groundwater recharge occur?

Subsequently, BGR researchers aim to determine the groundwater age using a variety of dating methods. Here, they utilise measurements of the distribution of stable and radioactive isotopes. In this way, they can find out where and to what extent groundwater recharge still takes place and how much water can be used sustainably without exhausting the aquifers.

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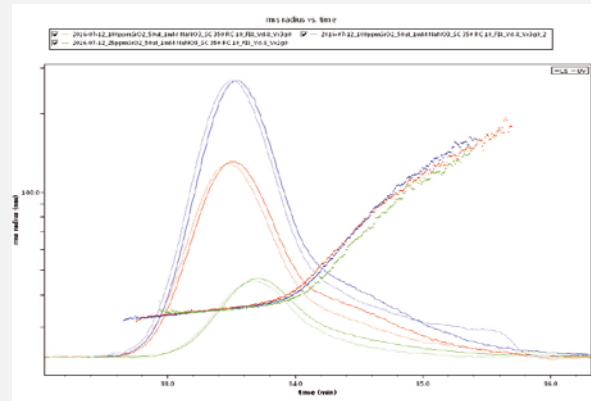
New AF4 Method (Asymmetric Flow Field-Flow Fractionation)

SEPARATION IN THE NANOWORLD

How mobile are artificial nanoparticles in soil and groundwater? BGR researchers clarify this question in a number of projects inter alia funded by the Federal Ministry of Education and Research (BMBF). Previously, however, it has been difficult to even detect nanoparticles in soils at all. Now, the BGR experts are applying a new method with the cumbersome name of asymmetric flow field-flow fractionation, abbreviated to AF4.

Using this method, particles in soil samples can be separated according to their size. "AF4 enables fast, gentle and high-resolution separation of samples with particles ranging from one nanometre to a maximum of ten micrometres", explains Dr. Daniel Rückamp of BGR. The subsamples thus obtained can then be analysed more accurately using a multi-angle light scattering detector or by chemical methods.

In this way, the researchers will be able to better detect and characterise artificial and natural nanoparticles in environmental samples in the future.



Measurement signals from various sensors for determining silica nanoparticles after separation using AF4.

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International Conference on the Mechanical Behavior of Salt 2018 at BGR

ROCK SALT IN FOCUS

BGR will host the 9th International Conference on the Mechanical Behaviour of Rock Salt, abbreviated SaltMechIX, between 12 and 14 September 2018. "The conference provides a forum for exchanging the latest research results on the behaviour of rock salt in mining, cavern storage and the final disposal of radioactive waste", reports Dr. Sandra Fahland of BGR, who is responsible for organising the event together with her colleague Dr. Annika Schäfers.

The conference delegates will discuss the results of laboratory studies on salt mechanics, salt geology or the microstructure of rock salt, for example. In addition,

they will also discuss modelling and simulation processes related to the storage of conventional or renewable energies in salt caverns.



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Project BEACON – Bentonite Mechanical Evolution

BARRIER BENTONITE

Final repositories for highly radioactive wastes are being planned in several European countries. Concepts involving mudstones and crystalline host rocks usually include what is known as a geotechnical barrier produced from the swelling clay bentonite, which is also intended to safely encapsulate the waste.

With the aim of understanding the mechanical behaviour of bentonite better, the European Commission has been funding the BEACON project within the Horizon2020 programme since June 2017 to an amount of €3.8 million. The BGR is among the 25 research partners involved in the project. Research in the long-term behaviour of bentonite as a seal or backfill material is done both experimentally and with numerical simulations. The focus of the project lies on the anomalies such as a spatially heterogeneous density distribution which

may arise, for example, due to the usage of bentonite both in the form of solid blocks and as smaller pellets. These anomalies are reduced when the minerals in the bentonite swell with the uptake of water. The anomalies of the geotechnical barrier are thus homogenised.

The results of the project will later be incorporated into training courses and facilitate the evaluation of different repository concepts.



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Planned Extension to the Mont Terri Rock Laboratory

START FOR GALLERY 18

The Swiss Mont Terri rock laboratory is being extended. Another 600 metres will be added to the existing tunnels, which are around 600 metres long. The new section will be given the name Galerie 18. "BGR has been researching for over twenty years as a consortium partner in the Mont Terri project", reports Dr. Kristof Schuster.

The rock laboratory offers international research teams the opportunity to conduct experiments in the Opalinus Clay, a Jurassic rock stratum that is being discussed as a possible host rock for a final repository for radioactive waste. The topics of geothermal energy and CO₂ storage have also recently been added to the agenda.

The extension began in spring 2017 with three exploratory bores. BGR carried out surveys, with the aid of which the route was then determined (see Page 42). During tunnel construction, Schuster and his colleagues aim to observe in an experiment how the Opalinus Clay responds to the



Site map of the Mont Terri rock laboratory with planned 2018 extension (green).

altered loading. "Of a total of 55 experiments planned in the extended laboratory, BGR is involved in 15", the geophysicist reports. "We oversee eight further experiments."

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Somalia - Crude Oil Sector Cooperation

BGR SUPPORTS SOMALIA MINISTRY OF PETROLEUM

BGR will soon be receiving a visitor from Somalia: an employee of the Ministry of Petroleum and Mineral Resources (MPMR) will be trained for one year in Hannover in the interpretation of seismic data. In addition, BGR also implements continued professional development measures for Somali ministry staff in Nairobi, Kenya, and helps to recover lost geological data.

Following twenty years of civil war, state institutions in Somalia are currently being rebuilt. One of the tasks of the MPMR is to grant exploration and mining licenses for crude oil and natural gas reservoirs, which are suspected offshore. Collaboration with BGR aims to enable the ministry to examine geophysical data itself and to assess resource potentials.



Collaboration agreement with the Somali Ministry of Petroleum and Mineral Resources, represented by Minister Abdirashid Mohamed Ahmed (2nd from left).

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Technical Cooperation with Indonesia in the Geothermal Sector

REDUCING THE RISK OF BARREN WELLS

Barely any other country in the world has as many volcanoes as the island state of Indonesia. The geothermal energy potential is correspondingly high: an electrical output of 27 gigawatts may be possible using deep geothermal energy. This corresponds to the capacity of all German anthracite-fired power stations.

According to Indonesian government plans, a geothermal output of 9.5 gigawatts will be installed by 2025. However, power station capacity was recently only 1.6 gigawatts. The reason for the slow development is mainly that geothermal projects are a high-risk venture for private investors: exploration wells are expensive, and many produce no yield due to limited knowledge of the subsurface. In order to reduce the risk of barren wells, the Federal Ministry for Economic Cooperation and Development (BMZ) has commissioned BGR to support the Geological Survey of Indonesia in the future with geological pre-exploration. Among other things, BGR hosts training in new exploration methods. The aim here is to reduce costs for power station developers – for



Pipelines at the 200 MW Kamojang Geothermal Power Station, West Java.

example, by incorporating additional data into site prospect forecasts.

The collaboration focuses on smaller geothermal resources in eastern Indonesia, where the power grid is still patchy.

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Interview

Great challenges – BGR is well on track

Talk with BGR President Prof. Dr. Ralph Watzel

BGR performs duties of great societal relevance. The German Council of Science and Humanities recently confirmed this in its evaluation of BGR and acknowledged the very good quality of BGR's work. What really distinguishes BGR?

One of our major tasks is to advise policy makers and business. The basis – and here I am happy to quote the Council – for the very good consulting and services provided by BGR is qualified, demand-oriented research. In addition to a high degree of continuity in the research work, it is also important that relevant research fields are identified and staffed at an early stage and forward-looking initiatives driven ahead. Furthermore BGR specifically obtains third party funding to supplement its departmental research. We contribute our technical expertise to social discourse and political decisions – above all in the areas of sustainable resource supplies and the responsible use of natural resources.

However, the German Council of Science and Humanities also sees room for improvement...

The Council points out that further efforts are needed in some areas to achieve a top international position. For example, it recommended the expansion of scientific collaboration with universities and non-university research institutions at national and international level. It is also important to communicate the research results obtained in a more targeted and recipient-specific manner. The Council's recommendations and suggestions help to further reinforce BGR's scientific capacity.



"The need for consultation on geoscientific topics has increased in recent years, both in politics and in business."

What challenges do geosciences face in future?

The future has already begun. The need for consultation on geoscientific topics, for example in the fields of resource supply security, groundwater supplies and protection, and the sustainable use of soil and the subsurface, has increased in recent years, both in politics and business. In a world of steady population growth, rising standards of living, and changing lifestyles in emerging and developing economies, the pressure to use ge-resources grows continuously. Sustainable management of these resources is a prerequisite for a secure livelihood and economic base, especially in rapidly developing countries and in regions with sensitive natural conditions such as arid regions and coastal zones. As a federal research institute, BGR supports this goal with research and consulting as well as with its involvement in numerous international development cooperation projects. Challenges are huge.

POSITIVE EVALUATION

BGR fulfils its research tasks in predominantly very good quality. This is the result of an evaluation by the German Council of Science and Humanities on behalf of the Federal Ministry for Economic Affairs and Energy (BMWi). Federal Minister Brigitte Zypries praised BGR expertise in the fields of sustainable resource supplies and the responsible use of natural resources. She was pleased, the Minister said, that the Council had praised BGR's excellent consulting and services to politics and business on the basis of its research.

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BGR COLLABORATES WITH IRAN

Water management, energy resources and mineral resources are the fields in which BGR intends to cooperate with the Geological Survey of Iran in the future. The agreement is the result of a visit by the Federal Minister for Economic Affairs and Energy, Sigmar Gabriel, in January 2016. The cooperation is flanked by the new short study 'Iran – a resource management status', in which BGR has summarised the key facts and most important investment projects in the resources sector.

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Economic Affairs Minister Brigitte Zypries (left) and Premier Stephan Weil (2nd from right) received a manganese nodule from the Pacific as a gift from BGR Vice-President Dr. Ing. Volker Steinbach (right).

MINISTER ZYPRIES FASCINATED BY BLACK SMOKERS

Massive sulphides and manganese nodules were the topics presented by BGR Vice-President Dr. Volker Steinbach at IdeenExpo 2017 to the Federal Minister for Economic Affairs and Energy, Brigitte Zypries, and Lower Saxony's Premier Stephan Weil. Both politicians visited the BGR booth at the technology fair for young people in Hannover. The attraction was a black smoker chimney from BGR's exploration claim in the Indian Ocean, and the dazzling surface of gold, copper and zinc ores especially fascinated the Minister.

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SISUROCK ANALYSES CORES

BGR can now characterise rock samples mineralogically using the SisuRock hyperspectral scanner. The scanner consists of three cameras that record light reflected from samples in different wavelengths. It can closely examine samples from the smallest thin sections to large cores, or even the chimneys of black smokers. The spectral range analysed ranges from visible light to long-wave infrared.

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Hyperspectral laboratory scanner SisuROCK for reflection spectroscopy characterisation of rock samples.

CONSISTENT ENVIRONMENTAL PROTECTION DEMANDED IN DEEP-SEA MINING

At a workshop in Berlin in March 2017, BGR and the German Environment Agency (UBA) advocated consistent environmental protection for mining in the deep sea. Both government agencies jointly called for a long-term Environmental Management Strategy to be established to protect the biodiversity of the deep sea. At the event, around one hundred participants from around the world discussed draft environmental regulations for deep-sea mining, submitted by the International Seabed Authority (ISA).

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Holothurian (sea cucumber) at a water depth of 4000 m above a manganese nodule field in the German license area in the Pacific.

GLOBAL RESOURCE SITUATION PORTAL

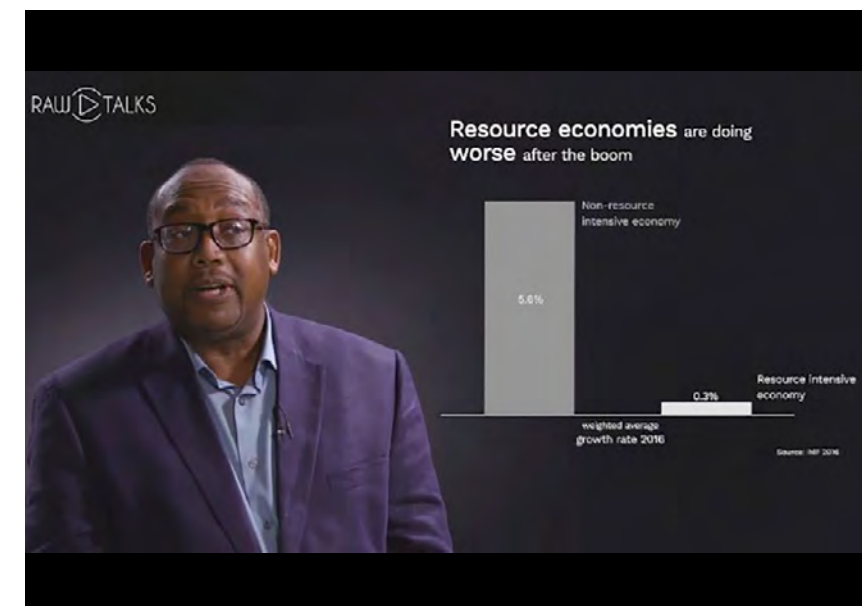
Since October 2017, the German Mineral Resources Agency (DERA) has been providing information on current developments on the commodities markets in its ROSYS information system at BGR. By going to the link <https://rosys.dera.bgr.de/>, companies and other interested parties can retrieve interactive maps and diagrams of 80 important commodities, identify trading partners and track developments. The information aims to increase transparency in the commodity markets.

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RAW TALKS

Resource wealth can promote but also hinder a country's economic development. In a new video format entitled RAW Talks, www.rawtalks.org, international experts deliver insights into resource management and resource policy to a broad audience. BGR is a cofounder of RAW Talks, supports the content of the series and contributes to the financing of the interviews. Previous speakers include, among others, Kojo Busia, director of the African Minerals Development Centre, who reports on the burden of African wealth in an Internet video.

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Kojo Busia, Director of the African Minerals Development Centre, in a RAW Talks interview.

SPITZBERGEN'S VANISHED PRIMORDIAL OCEAN

The geological remnants of a 400 million year old ocean have been discovered by an international research team led by BGR in July and August 2017 on Ellesmere Island, Canada. The CASE 19 expedition was the BGR's largest arctic expedition to date. The north of Ellesmere Island was once connected to Spitzbergen. Based on rock sampling and field findings, the team demonstrated that this landmass collided with North America 400 million years ago, with the intervening tectonic plate hosting the primordial ocean disappearing almost entirely into the Earth's mantle.

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In the coastal mountains of Ellesmere Island, the researchers found evidence of the primordial ocean.

BACKGROUND LEVELS FOR POLLUTANTS IN THE GROUND UPDATED

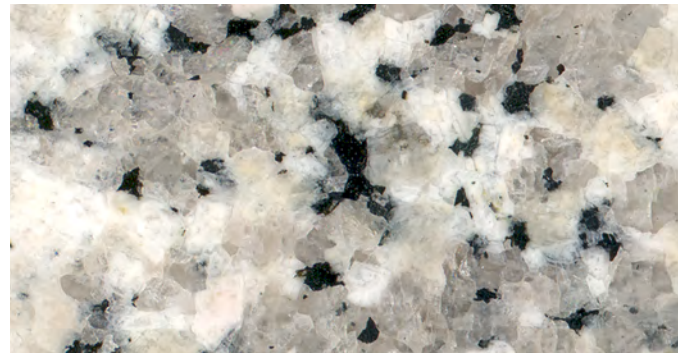
In 2017, the Federal/State Working Group for Soil Conservation (LABO) published the fourth edition of its Background levels for inorganic and organic substances in soils report. For this purpose, BGR has calculated the background values of 16 inorganic trace substances nationwide. The analysis for the current issue is much more detailed than in the 2003 3rd edition of the report. In addition, statistical uncertainties were determined for the background values for the first time.

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WELCOME TO THE CRYSTALLINE CLUB

To bundle international research on crystalline host rocks, the Nuclear Energy Agency (NEA) has set up a group of experts in which BGR is also involved. The newly formed Crystalline Club also includes representatives from the Czech Republic, the USA, Russia, Japan, Canada and Spain. The experts plan to promote the exchange of scientific insights on final repositories in crystalline rocks. Their first objective is to write a report on the international status of final repository research in crystalline rocks.

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Granites are relatively coarse crystalline magmatic rocks, which in principle may be considered as host rock for the final disposal of radioactive wastes.

RELIABLE WATER SUPPLIES FOR THE COAST

Sustainable management of coastal groundwater is the topic of a new BGR manual. It addresses current problems and challenges resulting from population growth, urbanisation and sea level rise as a result of climate change, in terms of sustainable potable water supplies in coastal regions. Under the title 'Groundwater Management in Coastal Zones', the manual demonstrates innovative management solutions intended to guarantee sustainable water supplies.

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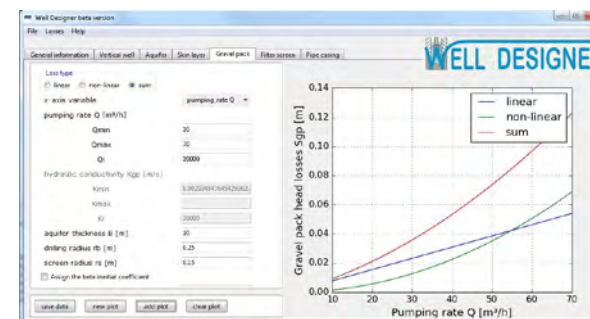
EXPERTS DISCUSS WATER SCARCITY IN THE MIDDLE EAST

Addressing the water scarcity in the Middle East requires structural reforms in the water sector. 30 experts from the Gesellschaft für Internationale Zusammenarbeit (GIZ), the development bank KfW and BGR came to this conclusion at a meeting in the Bonn office of the Federal Ministry for Economic Cooperation and Development (BMZ). In particular, according to the researchers, groundwater abstraction for irrigation should be heavily regulated and efficiency increased in many places, for example by drip irrigation or the use of recycled wastewater.

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Irrigated agriculture in Jordan using fossil groundwater.



Well Designer modelling software user interface for analysing and optimising intake losses in vertical wells.

OPTIMISED WELL HYDRAULICS

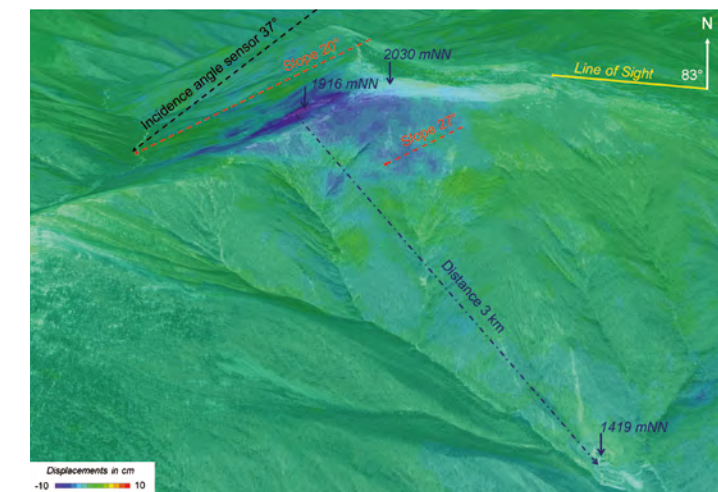
The WellDesigner software application, developed at BGR, is intended to reduce energy consumption at groundwater pumping wells. The software tool, which is based on model analyses, experiments and field tests serves to design more efficient wells and enhance utilisation of existing wells. With the aid of WellDesigner, users can adapt well geometry to specifically optimise their hydraulics.

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RADAR SATELLITES MONITOR NUCLEAR TESTS

As a result of the North Korean nuclear bomb test on September 9, 2016, the earth's surface in the test area was lowered in places by 12 centimetres. This is revealed by radar satellite Sentinel-1 measurements taken as part of the Copernicus mission. A team around the BGR scientist Dr. Michaela Frei was also able to pinpoint the location of the blast for the first time with the help of these satellite data. Satellite images, in addition to seismic methods, are helping to pinpoint nuclear tests under the auspices of the CTBT international Nuclear Test Ban Treaty.

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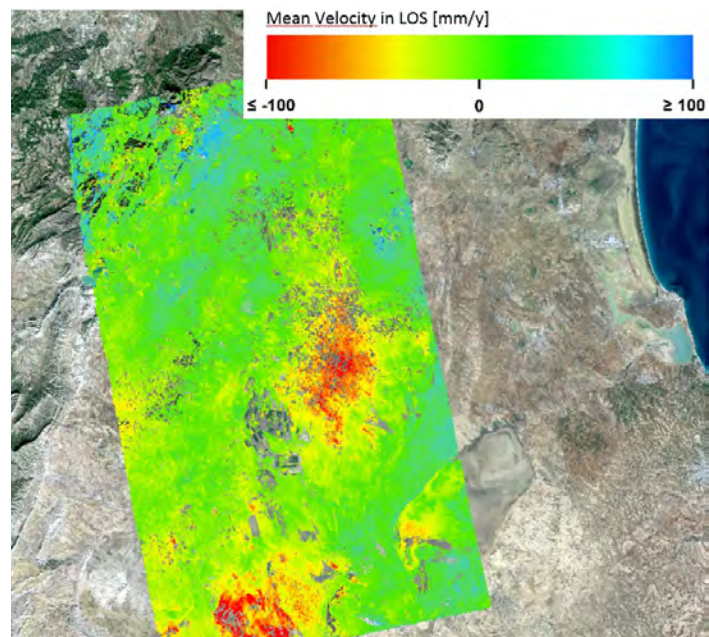


The resulting ground motion map shows the subsiding area at a distance of 3 km from the tunnel entrance.

REMOTE SENSING AIDS GROUNDWATER MANAGEMENT

BGR supports Tunisia and other Maghreb countries in monitoring falling groundwater tables by remote sensing. The project uses radar interferometry, which detects ground motion via satellite. This can determine where the groundwater is being too heavily exploited. On the other hand, multi-spectral optical data can be used to determine how much water is required by agriculture. The authorities can then improve water management using this combined knowledge.

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Investigation area and ground movements determined using radar interferometry. Red areas represent regions with greater subsidence due to agricultural groundwater exploitation.

LEGALLY SECURE STORAGE OF FINAL REPOSITORY DATA

In future, all underground data recorded in-situ by BGR in national and international final repository projects will be stored to preserve their evidential value and will thus be legally secure. To this end, the German Federal Archives (Bundesarchiv) provides the Federal Intermediate Digital Archive (Digitale Zwischenarchiv des Bundes (DZAB)). BGR must ensure that the data is safeguarded in the long term and available for examination.

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ANDRA AGREEMENT EXTENDED



Seismic surveys in clay rocks in an underground research laboratory (France).

BGR and ANDRA (Agence nationale pour la gestion des déchets radioactifs) have been researching jointly in the field of final radioactive waste disposal since 2001. Collaboration has been extended by a further five years until 2021 in a cooperation agreement. Through this exchange, BGR is expanding its knowledge of mudstone as a host rock with regard to selection of a final repository site in Germany. ANDRA is currently compiling the planning documents for the Cigéo (Centre industriel de stockage géologique). The French high-level radioactive waste repository is to be built north of the Meuse/Haute-Marne underground laboratory.

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GEOHERMAL ENERGY USE AT MOUNT MERU



Crater of Mount Meru with central cinder cone.

Remote sensing can help identify regions of interest to geothermal energy utilisation. This is demonstrated by a BGR project in Tanzania. A research team around the BGR scientist Kai Hahne mapped geological faults on the Mount Meru volcano using multispectral data and elevation models. With the aid of satellite radar interferometry, it was also possible to identify linear subsidence zones probably associated with active faults. Geophysical and hydrochemical investigations on the ground will now specifically clarify where the geothermally utilisable potential is located.

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MILLIMETRE-ACCURATE MEASUREMENT FROM SPACE

The Satellite-Based Ground Movement Map for Germany is a winner in the Excellent Places in the Land of Ideas 2016 competition. The map and the German Ground Movement Service (BBD), which is currently built up by BGR, are based on Sentinel-1 satellite mission radar data. It is part of the EU's Copernicus Earth observation programme and regularly scans Earth's surface. Movements of Earth's surface can be identified with millimetre accuracy based on the data.

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ESA satellite Sentinel-1.

NEW BOOK ON MONITORING NUCLEAR WEAPONS TESTS

BGR scientists Christoph Pilger, Lars Ceranna and Christian Bönnemann have now published a book on the status of scientific work by BGR and other partners on monitoring the international Comprehensive Nuclear-Test-Ban Treaty. Under the title Monitoring Compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) – Contributions by the German National Data Center, the BGR authors present the history of the treaty, the four monitoring technologies employed and the German monitoring stations. They also describe key cases in application, such as the recent nuclear tests in North Korea.

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BGR

The Federal Institute for Geosciences and Natural Resources (BGR) advises and informs the Federal Government and German business on all issues relating to geosciences and natural resources. As the German Centre of Excellence for geoscience, BGR's work focuses on ensuring that natural resources are used in a way that is economically and environmentally sound and thus in the interest of humankind. BGR is a higher federal authority. It is subordinate to the Federal Ministry for Economic Affairs and Energy (BMWi) and is part of Germany's scientific and technical infrastructure. As Germany's Geological Survey, BGR undertakes a large number of international duties. In Germany, its main task is to act as a co-ordinator. Together with the State Authority for Mining, Energy and Geology (LBEG) and Leibniz Institute for Applied Geophysics (LIAG), BGR forms the GEOZENTRUM Hannover.

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