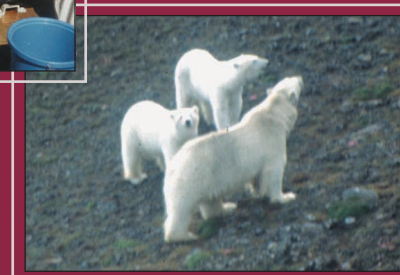
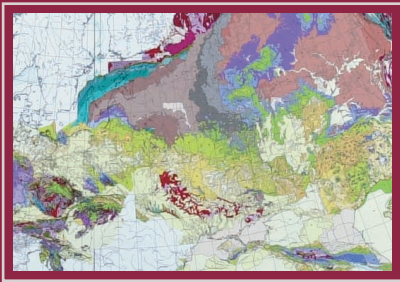


Biennial Report BGR



1999

2000





Federal Institute
for Geosciences and
Natural Resources

Biennial Report
BGR
1999/2000

Hannover, March 2001

Imprint

© Bundesanstalt für Geowissenschaften und Rohstoffe (2001)

Editorial Committee

Dr. FRITZ BARTHEL; JOACHIM BEHLAU; Dr. ULRICH BERNER; Dr. KLAUS BOSECKER;
Dr. KLAUS-PETER BURGATH; Dr. BERNHARD CRAMER; Dr. GUDRUN FRANKEN;
Dr. JÖRG HANISCH; Dr. VOLKER HENNINGS; BRIGITTE KOCH; Dr. KARL KOCH;
ROLF-RÜDIGER LUDWIG; GERHARD MINGERZAHN; Dr. SÖNKE NEBEN;
Dr. JÖRG REICHLING; KLAUS SCHELKES; Dr. THOMAS SCHUBERT; Dr. ULRICH SIEWERS;
LILY REIBOLD-SPRUTH; Dr. VOLKER STEINBACH; Dr. MICHAEL WIEDICKE-HOMBACH

Editorial Staff

Dr. THOMAS SCHUBERT, Editor in Chief,
BRIGITTE MESSNER, KAROLA OTREMBA,
KERSTIN RIQUELME, HANS-JOACHIM STURM and ANDREA WEITZE

Printed by

MedienService Gunkel & Creutzburg GmbH
Friedrichplatz 13, 99894 Friedrichroda

This Activity Report is free and can be obtained from
Publications Section,
Federal Institute for Geosciences and Natural Resources,
Stilleweg 2, 30655 Hannover, Germany
Phone: 49 (0511) 643 – 3470; e-mail: t.schubert@bgr.de

Press Officer/Public Relations: Dr. Jörg Reichling
Phone: 49 (0511) 643 – 2679; e-mail: info@bgr.de
mobile phone: 49 (0163) 2496591



Foreword

The 1999/2000 Activity Report of the Federal Institute for Geosciences and Natural Resources (BGR) appears here in a new form. The German and English versions are being printed separately. It has been reorganized according to the matrix of responsibilities of the BGR as laid out in the BGR 2000 strategic plan, the annual project budget, the biennial research plan, and the cost-efficiency calculations. Following the guiding principle "Improvement of living conditions by sustainable development of the geopotential", the work of the BGR is organized in a matrix of five interdisciplinary tasks and nine tasks in individual fields. The three special themes climate research, EXPO 2000, and Ocean Drilling Project (ODP) were high points of the past two years.

BGR works together with numerous partners within Germany and in other countries, especially with the two other institutions of the Hannover Geocenter: the Lower Saxony Geological Survey (NLfB) and the Institute for Joint Geoscientific Research, Hannover (GGA Institute).

The restructuring of the Hannover Geocenter was concluded on 26 January 2000 with the founding ceremony of the new GGA Institute, attended by Undersecretary Dr. Birgit Grote of the Lower Saxony Ministry for Economics. The GGA Institute is now an independent, non-university research institute of the Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL).

Since 1958, all three institutions of the Hannover Geocenter have a common administration infrastructure and utilize the library, archives, computer center and workshops of the Geocenter in common – a good example of "lean government" in practice.

The EXPO 2000 World's Fair was the high point of the year 2000 in Hannover. BGR was responsible for the scientific aspects of the "Environment" thematic area of the Expo. The three institutions of the Hannover Geocenter also participated in four other Expo projects:

- ◆ *the "One World Altar", which contained 6000 soil and rock samples from all over the world, in the One World Church in Schneverdingen;*
- ◆ *the "Steinberg Millennium View Point" in Schaumburg Land;*
- ◆ *the "Fascination with Soils" in the museum at Schölerberg near Osnabrück; and*
- ◆ *the "Experiencing Drinking Water Protection" in Göttingen.*

The Hannover Geocenter received two souvenirs of the Expo: From the Environment thematic area, a wood sculpture symbolizing a tree stands in the foyer; from the German pavilion, a bust of Ludwig Erhard, the founding father of the BGR, is on the gallery.

The bust of Ludwig Erhard is to become the core of a permanent exhibition of the history of the three institutions of the Hannover Geocenter. The "tree" symbolizes the guiding principal of sustainable development applied to our tasks in the fields of mineral resources, water, soils, and environmental protection: The concept of sustainable development was first formulated in 1713 by the head of the mining administration in Freiberg in Saxony, Germany, Oberberghauptmann von Carlowitz, who was also responsible for forestry in the Freiberg mining district.

Four of the developments that influenced our work in 1999 and 2000 are given here as examples:

- ◆ *Infrasound station IS26 at the GERESS site in the Bavarian Forest was officially dedicated on 4 October 2000. This station is part of Germany's obligations within the framework of the Comprehensive Nuclear Test Ban Treaty. It is the first infrasound station of a worldwide network to be certified.*
- ◆ *The Federal Soil Protection Act became effective on 1 March 1999. Owing to intensive consultations of the legislative by BGR and the state Geological Surveys, the new law takes important geoscientific aspects into consideration, especially with respect to geogenic (i.e., natural) background values. BGR maintains an information system that provides a uniform database of soil data for all of Germany.*
- ◆ *When the European Water Directive took effect, BGR, together with the Geological Surveys of the other EU member countries, became responsible for compiling and evaluating basic hydrogeological data independent of international or intra-national boundaries.*
- ◆ *During his visit to BGR on 20 August 1997, Undersecretary Dr. Lorenz Schomerus of the Federal Ministry for Economics and Technology emphasized that BGR should become more involved in the "climate discussion". A group of 41 scientists of BGR, NLFb, and GGA Institute was formed to evaluate experience and data on paleoclimate available within these three institutions. The result is the book "Climate Facts: The Past – A Key to the Future" in language understandable by the general public and with many illustrations.*

Special mention should be made of a few of the large number of visitors to BGR during this report period: Federal Minister for Economics and Technology, Dr. Werner Müller, on 7 April 2000; President of the Lower Saxony Parliament, Prof. Rolf Wernstedt, on 6 March 2000; and the Thai princess Maha Chakri Sirindhorn on 7 August 2000.

Dr. Müller was particularly interested in the geothermal pilot project GeneSys at the Hannover Geocenter. This project is meant to show how geothermal energy can be utilized for heating purposes at any site in Germany.

Thanks are due to the Hans-Joachim-Martini Foundation for its support of the three institutions BGR, NLFb, and GGA Institute. A research grant and two prizes were received:

- ◆ *The working group of Dr. Thomas Oberthür received a research grant supporting work on the platinum potential of the Chembadzi Hills in Zimbabwe.*
- ◆ *Günther Druivenga, Siegfried Grüneberg und Dr. Hermann Bunes received a prize for the development of a small vibrator for high-resolution seismic reflection surveys down to depths of 1000 m.*
- ◆ *Philipp Magiera of the Technical University of Braunschweig received a prize for his work on the protection of groundwater by overlying layers in Lower Saxony water protection zones.*

I wish to thank the members of the sixth and seventh BGR Advisory Boards for their advice and support, the Federal ministries, and our cooperation partners in Germany and other countries. And last, but not least, I wish to thank all of the BGR staff for their engagement in fulfilling our tasks.



Prof. Dr.-Ing. F.-W. Wellmer
President

CONTENTS

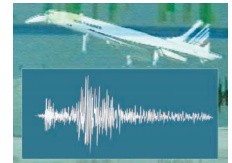
Interdisciplinary Tasks

Advising the Federal Ministries and the European Union	9
Construction Materials for Reconstruction in Southeastern Europe	10
Advising German Industry	12
Extension of the European Union to the East	12
Technical Cooperation with the Developing Countries	13
Are the Water Resources of the Near East Sufficient for Future Generations	15
International Cooperation in Research and Technology	18
Economic Cooperation with Countries of the former Soviet Union: Example Kazakhstan	19
Research and Development	21
openGEO4 – A New 3-D Software	23



Tasks in Individual Fields

1. Geotechnical Safety and Permanent Repositories for Radioactive Wastes	25
Status of the Investigations at Gorleben	27
The Search for Alternative Host Rocks	29
Microacoustic Monitoring of the Stability of the Repository	31
Closing of Solution-Mining Caverns	32
2. National Data Center – Nuclear Test Ban Treaty	35
Installation of Infrasound Station IS26	37
Modernization of the Regional Seismological Network ..	39
The Vogtland Earthquake Swarm Region	40
3. Water	41
Making Salt Water Intrusion Visible ..	44
Permafrost and the Advance of the Glacial Ice Sheet during the Last Ice Age Determined the Present Groundwater System	45
The Use of Isotopes to Detect Perpetrators of Water Pollution	45
Groundwater for the Cochabamba Region	47
Planning of Sustainable Development of Water Resources in Jordan	49
4. Energy Resources	51
The Potential for Oil and Gas on the Continental Margins of Argentina and Namibia	54
Deep-seated Source Rocks for Natural Gas in Northern Germany	55
Natural Gas Fingerprints	56
Geothermal Energy from Hot Dry Rocks	57
GeneSys – Utilization of Geothermal Energy in the Hannover Geocenter	58
Natural Gas Discoveries in Bangladesh	59





5. Soils **61**

BGR Contribution to the
New Hydrological Atlas of Germany **64**

Indicators of Loss of Soil on a European Scale **64**

Background Values of Heavy Metals in the Topsoil **65**

Leaching of Substances from the Soil
into the Groundwater **66**

Natural Degradation of
Petroleum Hydrocarbons in Soil **67**

Causes and Dynamics of the Salinification of Soils
in Western Paraguay **68**



6. Mineral Resources **69**

Material Flows and Energy
Requirements for Production **71**

Assessment Criteria for Industrial Minerals and Rocks . . . **72**

Nonmetallic Mineral Resources and
Gold Analysis in Mongolia **72**

Mapping and Advanced Training in Ghana,
Ivory Coast, and Guinea **73**

Principles of Sedimentology **74**

Platinum Deposits in Zimbabwe **74**

Platinum in the Mountains of Sabah **74**

Deposits of Metallic Ores with Short Reserves
Lifetimes in Southern Africa **75**

Allophane: a New Raw Material
for the Synthesis of Zeolite **76**

The Balkans and its Mineral Resources **77**



**7. Exploration of
the Marine and
Polar Regions** **81**

The History of the Opening of the South Atlantic and its
Significance for its Hydrocarbons Potential **83**

Submarine Gas Hydrates:
The Active Continental Margin of Costa Rica **84**

Methane-bearing Cold Seeps off Java **85**

Large Bacteria in the Upwelling Zone off Peru **86**

The Wegener Fault and the Nares Strait:
Slip Zones between Two Oceans **87**

Genesis of the Pockmarks in the Laptev Sea **88**

Seismic 3-D Tomography along the
Ninety East Ridge in the Indian Ocean **89**

The Antarctic as Key to the Continents
of the Southern Hemisphere **90**

**8. Protection of the
Geoenvironment and
Georesources** **91**

Sensors for Airborne Investigations
of Oil Contamination **93**

Degradation of Cyanide and
Biosorption of Heavy Metals in the
Production of Gold **94**

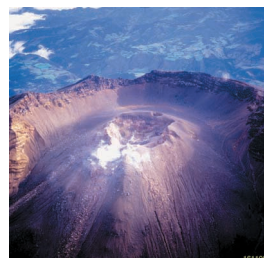
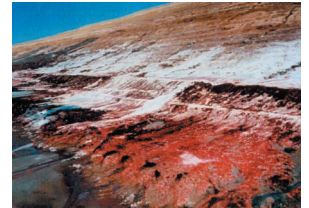
Microorganisms in Slag Heaps **95**

Old Mine Heaps and Water Quality **96**

The Potential of the Natural Environment in
Eastern Paraguay **97**

Namibia: Mining and Environment **98**

Colombia: Gold Mining and Environment **100**



**9. Geological
Hazards** **103**

The Multiparameter Station on the Galeras Volcano
in Colombia **105**

The Usoi Landslide Dam: Is the Largest Dam
in the World in Danger of Bursting? **107**

Long-term Monitoring of the Thulagi Glacial Lake **109**



Special Topics

10. Climate 111

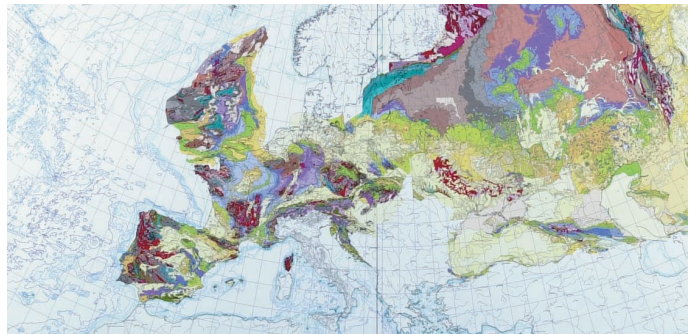
The Climate of the Past:
A Key to the Future 113

11. EXPO 2000 119

The Environment Thematic Area
of the EXPO 2000 World's Fair 121

12. The Geological Map 123

The Geological Map:
The Leap into the Digital Age 125



Advising the Federal Ministries and the European Union

The Federal Institute for Geosciences and Natural Resources (BGR) is the **central geoscientific institution of the German Federal Government**. It is subordinate to the Ministry for Economics and Technology (BMWi). Advising the Federal Government involves long-term responsibilities as well as current political aspects, e.g., involving sudden resource scarcities and ensuing price increases, crisis prevention, and protection from natural disasters.

Within the scope of the international engagement of the Federal Government:

International commitments of the BMWi, the Ministry for Economic Cooperation (BMZ), the Foreign Ministry, and the Ministry for Education and Research (BMBF) within the geoscientific sector are taken care of by BGR:

- BGR is commissioned directly by the BMZ to conduct Technical Cooperation projects in the geoscientific and mining sectors in developing countries.
- BGR operates the German National Data Center as the German contribution to the Comprehensive Nuclear Test Ban Treaty signed by Germany in 1996.
- Germany is signatory to the Antarctic Treaty. Within the framework of this treaty, BGR conducts research on the hard-rock geology of the Antarctic.

Advising the Federal Ministries and subordinate agencies:

- An important task of BGR involves geoscientific investigations for permanent repositories for radioactive waste, commissioned by the Ministry for the Environment, Nature Protection, and Reactor Safety (BMU) and the Ministry for Economics and Technology. The work includes investigations of the Gorleben, Morsleben, and the former Konrad mine sites, as well as alternative host rocks, such as clay and crystalline basement.
- BGR is the only institution of Germany that monitors global reserves, production, and availability of mineral and energy resources. This makes it possible to provide advice concerning sudden shortages of resources and the resulting price increases.
- The BMBF is advised within the scope of scientific and technical cooperation with industry and threshold countries, particularly Latin America and China. BGR conducts projects with Canadian, Romanian, and South American partner organizations. A current major project involves research on the prediction of volcano eruptions in Columbia. Within the scope of German-Chinese cooperation projects of the BMWi, the focus

is on the relationship between plate tectonics and the formation of ore deposits.

- BGR is responsible for collecting within Germany basic geoscientific data and geogenic (i.e., natural) background data within the scope of the Federal Soil Protection Law. This work is done in close cooperation with the Federal Environmental Protection Agency and the Ministry of the Environment. For the new EU Water Guidelines, BGR is preparing a special large-scale hydrogeological map. The Ministry of Defence is advised with respect to investigations of contamination in military training areas.
- The BMWi, the Foreign Ministry, and the BMU are advised with respect to their work with the International Seafloor Authority, the UN Commission on the Limits of the Continental Shelf, and the Antarctic Treaty on Environmental Protection. BGR also participates in marine, polar, and geotechnological projects within BMBF research programs.
- BGR is also commissioned by the BMWi, the Foreign Ministry, and the BMZ to carry out measures designed to contribute to the solution of conflicts in regions in crisis. For example, a Mineral Resources Symposium was held within the scope of the "South-east Europe Stability Pact".

Institutions of the European Union

- Institutions of the European Union are advised through EuroGeoSurveys, an association of Geological Surveys of the countries of the European Union, Norway, and Switzerland. The members of EuroGeoSurveys prepare joint papers on all georelevant aspects of the EU and conduct projects of the European Commission.

This project is contribution of the geosciences to the stabilization of the economic and political situation in southeastern Europe. After many years of conflict in the southeastern Europe and wars in Croatia, Bosnia and Herzegovina, and Kosovo, there is now a chance for a new beginning. One of the most important needs of the people living there, a roof over their heads, must be quickly fulfilled.

Reacting to this situation, BGR organized a mineral resources symposium for specialists in industrial minerals and rocks in southeastern Europe. This was done within the scope of the "Southeast Europe Partnership for Qualification", part of the "Southeast Europe Stability Pact". Twenty-two specialists and decision-makers from state institutions and the construction materials industry of Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Macedonia, and Romania participated in the symposium.

Construction materials, e.g., sand, gravel, clay and stone, are of decisive importance for reconstruction in the

Construction Materials for Reconstruction in Southeastern Europe

war-damaged regions, particularly for housing, repair of roads, railway lines, and bridges, and for the economic development of the region. Before these materials can be extracted, the occurrences must be assessed in terms of their geology, economic potential, and technical accessibility. This is necessary so that the most suitable materials can be made available for reconstruction at the least cost. Thus, the topics and activities of the symposium were as follows:

- geological, economic, and technological assessment of occurrences of construction raw materials;
- current situation with respect to construction raw materials in southeastern Europe;
- a presentation of the Association of Consulting Engineering Firms of Germany (VUBIC);
- visits to various construction raw materials operations in Lower Saxony, Westerwald in North Rhine-Westphalia, and Franconia in northern Bavaria.



Political background of the "Southeast Europe Stability Pact":

The "Southeast Europe Stability Pact" was brought into being in July 1999; the founding agreement was signed by 36 countries and international organizations, including Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Macedonia, and Romania. After the fall of the Milosovic government, Yugoslavia became a member of the stability pact on October 26, 2000.

The objectives of this Pact are

- promotion of economic cooperation with the countries of southeast Europe, stabilization of political conditions and reconstruction in the region;
- creation of sustainable conditions for democracy and economic development of the region;
- promotion of good-neighbor relationships between the Balkan countries.

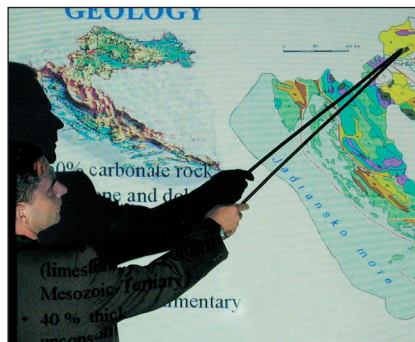
The presentation of the Association of Consulting Engineering Firms of Germany (VUBIC) and the excursions to the German excavation sites led to contacts between the representatives of the construction materials industry in southeastern Europe and German companies. This aspect of the symposium provided an important impulse for the economic development of the region, especially for small and medium-sized companies;

it also provided impulses for intensification of economic relationships between Germany and the countries of the stability pact.

Owing to the political significance of the positive experiences during the symposium, BGR will hold a workshop on "Environmental Geology for Regional Planning" in 2001, also within the scope of the "Southeast Europe Partnership for Qualification".

German contribution to the "Southeast Europe Stability Pact":

- German support of the Pact has three focal aspects:
 1. democracy and human rights,
 2. economic reconstruction and development,
 3. security and trust-building measures.
- Bilateral funds amounting to ca. DM 1.2 billion over a period of four years.
- The "Southeast Europe Partnership for Qualification" project of the BMWi, funded with ca. DM 800,000 annually.
- German businesses play a key role in the economic cooperation aspects of the Pact, since they are traditionally the most important trading partner of the countries in this region.



Advising German Industry

With its applied sciences orientation, BGR furthers economic development, advising German industry on georelevant aspects. An example is the map of the potential for natural gas in the deep formations of northern Germany.

Advice and information is provided by BGR especially for the supply of mineral and energy resources, geohazards, and georelevant aspects of environmental protection.

Mineral resources supply

Owing to changes in economic structures, there has been a decrease in BGR activities in the traditional fields of exploration and mining. Current requests for information deal with the properties of specific materials and the geographic distribution of mineral occurrences. There has been an increase in this kind of information over the last several years as a result of the increasingly rapidly changing requirements demanded of the materials used in manufacturing, not least due to environmental regulations.

Geohazards and geotechnical safety

Work in the field of engineering geology contributes to a minimization of hazards at specific installations, for example, during the construction and operation of underground gas storage facilities, repositories for hazardous wastes, and landfills, as well as to emissions reduction and the delineation, assessment, and rehabilitation of contaminated sites.

Georelevant aspects of environmental protection

Advice is provided on a wide range of protection and rehabilitation measures for groundwater and soils. The chemical industry is also advised with respect to their products; for example, agrochemicals are tested with respect to their ecological compatibility.

Neutrality with respect to individual companies is maintained by regular exchange meetings and working groups with German mining and exploration companies, business organizations, associations of consultants, and scientific societies.

Extension of the European Union to the East

Central and eastern European countries are expected to become members of the European Union in the next several years. The first group of new members is to include Poland, the Czech Republic, Hungary, Slovenia, Estonia, and Cyprus. Slovakia, Romania, Bulgaria, Lithuania, and Latvia are also candidates for EU membership. With the entry of these eleven countries, the present EU population of about 370 million will swell to about 475 million. This expanded market is expected to generate a substantial economic impulse.

BGR has published the results of analyses of the economic situation in the mineral resources and mining sector of eastern Europe in two reports: "Extension of the European Union to the East" and "The Czech Republic". These reports describe the results of the economic reforms that have taken place in the last ten years. Since the introduction of the market economy, many of the mineral deposits previously exploited are no longer competitive. Because the restructuring also offers opportunities for German companies, these reports have found considerable interest. These and further reports on the current mineral resources situation can be obtained from bookstores.

German Consulting Agencies

BGR works together especially with the Association of Consulting Engineering Firms of Germany (VUBIC) and the Association of Consulting Engineers (VBI). Consultants are involved in Technical Cooperation projects in developing countries. In this way, BGR fulfills an important function, that of "door opener" for the entry of German consultants into the international field.

Business Associations and Professional Organizations

Joint exploration and field decommissioning projects are conducted with companies of the Wirtschaftsverband Erdöl- und Erdgasgewinnung e.V. (WEG, an association of German oil and gas producers), for example, exploration of the natural gas potential of deep formations in northern Germany. BGR cooperates with the Wirtschaftsvereinigung Bergbau e.V. (WVB, an association of German mining companies), in which most producers of mineral resources are members. BGR also works closely with the Fachvereinigung Auslandsbergbau (FAB, an association of German mining companies with mines outside Germany), for example, on the mining of platinum group elements in Albanian chromitite deposits.

Scientific and Technical Societies

BGR works closely with the scientific and technical societies in which German industry, universities, and other research institutions are also members. For example, BGR is represented in a number of committees of the Society for Mining, Metallurgy, Mineral Resources and Environmental Technology (Gesellschaft für Bergbau, Metallurgie, Rohstoff- und Umwelttechnik e.V.; GDMB) and is engaged in the work of the Research Society for Applied Geophysics (Forschungsgemeinschaft Angewandte Geophysik e.V.). Close contact is also maintained with the German Association for Mineral Oil, Natural Gas and Coal (Deutschen Wissenschaftlichen Gesellschaft für Erdöl, Erdgas und Kohle e.V.; DGMK).

Technical Cooperation with the Developing Countries

The objective of German policy in developing countries is to improve the living conditions of the people, especially the poor. The focus is on fighting poverty, environmental and mineral resources protection, education and training.

The geosciences can contribute in the following ways:

- protection of the population from environmental pollution and natural disasters;
- provision of the basic needs: drinking water and construction materials for housing;
- sustainable development of natural resources.

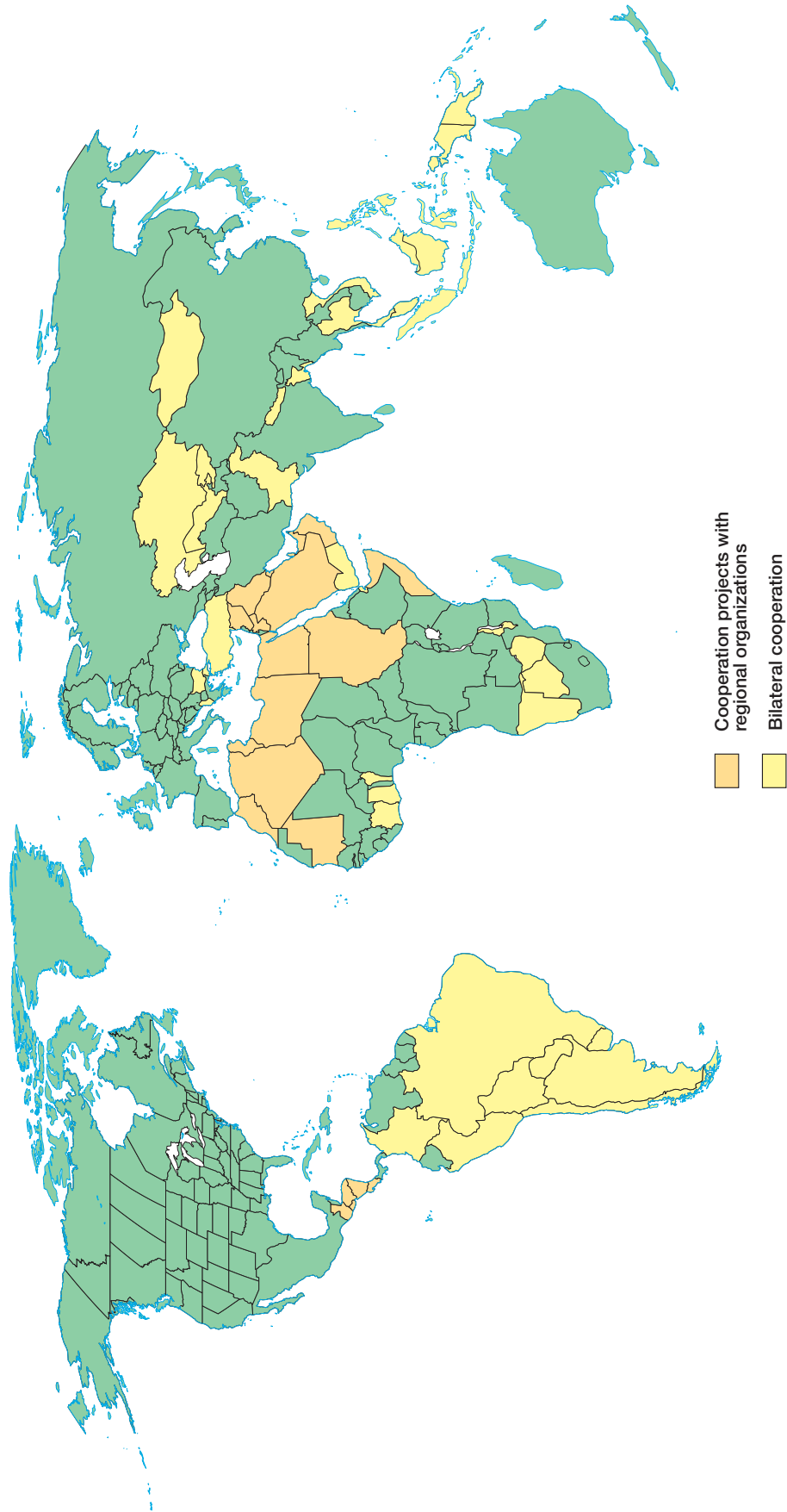
The German government supports development of partner countries in the form of Technical Cooperation projects. The main task is to help the people and organizations in the partner countries to be able to improve their situation on their own. This is done in Technical Cooperation projects by training in technical, economic, and organizational knowledge and abilities.

The Ministry for Economic Cooperation and Development (BMZ) commissions a number of government agencies to plan and execute Technical Cooperation projects. In the geology and mining sector, this is the BGR. Technical Cooperation projects in the geology and min-

ing sector provide support to state institutions, e.g., the Geological Survey, and other organizations in developing countries that have the following responsibilities:

- management of water, soil, and mineral resources,
- geological aspects of regional planning,
- assessment of mineral and energy resources,
- determining the mineral resources potential of the country,
- protection from natural disasters.

BGR was involved in more than 40 Technical Cooperation projects with more than 30 partner countries in 1999 and 2000. The focus was on advising counterpart organizations on their organizational structures and on on-the-job training of their personnel as well as in Germany or in another country. In this way BGR helps the developing countries improve the living conditions of the people, especially the poor, in these countries who are dependent on soils, water and mineral raw materials.



Countries and types of Technical Cooperation by BGR in 1999 and 2000.

BGR, the central geoscientific institution of the German Federal Government, has the knowledge and experience of many years in nearly all fields of applied geology, including aspects of mining. The following fields are of particular importance for Technical Cooperation projects:

- water;
- soils;
- mineral and energy resources (e.g., exploration and assessment of ore deposits and petroleum geology);
- mineral resources protection and environmental protection, especially with respect to mining;
- geohazards.

Besides German advisors, specialists from the respective counterpart countries are being involved in the Technical Cooperation projects.

As a rule, training is on-the-job. In addition, counterparts take part in special courses and seminars, receive further education at universities, and participate in other, similar Technical Cooperation projects in other countries.

Direct services are provided only in exceptional cases, e.g., in emergencies or to eliminate an acute problem. In such cases, German personnel is sent on short-term assignments.

Are the Water Resources of the Near East Sufficient for Future Generations?

The increasingly scarce water resources in the Near East is increasingly becoming a political challenge for the countries competing for these resources. For this reason, BGR continues to advise the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), the UN Economic and Social Commission for Western Asia (ESCWA), and the Jordanian Ministry for Water and Irrigation.

Most of the population of the Arab countries live in arid or semiarid regions, where water and arable land is limited.

conflict within the national boundaries as well as between the countries of the region.

Scarcity of water in the last several years has led to extreme problems in the supply of water to the large cities and agricultural areas. In many areas, the groundwater table has been rapidly lowered by the very high rates of abstraction (in many cases 1 – 2 m/a). This has caused many wells to become dry, a sure indicator of overuse of a groundwater occurrence. In some areas,



Water supplies in these regions are mostly from shallow, recharged aquifers and deep aquifers with no recharge. The water in perennial streams, e.g., the Nile, Euphrates, and Tigris, provide only regionally limited water supplies. The scarce resources are barely able to cover the present needs. The increasing population growth of the region, e.g., about 3.6 % in Jordan, will make the situation even more acute in the next several decades. The increasing water deficit is hindering the social and economic development of the region and represents a considerable potential for

e.g., the United Arab Emirates, the water supply can be provided only by “groundwater mining” of “fossil groundwater” and expensive and energy-intensive desalination of seawater. Fossil groundwater occurrences were formed thousands of years ago during a long period of humid climate and at present receive little or no recharge.

Sustainable development of water resources in the Near East requires conservation and protection of those resources.

Owing to this difficult situation, water management in the Arabian countries has concentrated on the development of new groundwater occurrences. Groundwater protection is often viewed as a luxury that only industrial countries can afford. Numerous cases of serious, irreversible groundwater contamination in the last several years has resulted in a rethinking of this view. Contaminated aquifers can no longer be used for the water supply. In the current critical situation, the countries of the region cannot afford to lose water resources to irreversible contamination. Therefore it is necessary to protect water on which human life depends from contamination so that future generations will have access to hygienically pure drinking water.

Within the framework of Technical Cooperation, BGR supports the Arabian countries by

- training in modern methods for determining, assessing, and protecting water and soil resources and their sustainable development;
- training of specialists in the respective organizations;
- jointly solving specific problems, e.g., groundwater vulnerability;
- developing maps etc. for planning pilot areas; and
- conveying the results in workshops on a national and regional basis.

Through this work, the people of the region become more conscious of the problem, resulting in a new view of the critical problems of water supply and the related environmental protection problems, thus fulfilling an important prerequisite for concrete measures for a sustainable water supply.

A further aim is the promotion of trust-building measures between the countries of the region via cooperation on cross-border aquifers.



Drinking water from the Euphrates River.

The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD)

The Arabian League founded the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) in 1971 as an autonomous international research institute with the objective to improve knowledge of the water, soil, and arable land in the region and to recommend measures for sustainable social and economic development of the member countries, which include almost all Arabian countries of the Arabian Peninsula and North Africa. ACSAD headquarters are in Damascus, Syria.

In a project with ACSAD and Syrian and Lebanese institutions, BGR provides advice on "Protection and sustainable

development of groundwater resources and minimization of soil degradation".

To maintain “living space” and quality of life, it is necessary to know where things are that can be used and that must be protected as well as where the contaminated sites are.

Practical experience is being obtained in projects in two pilot areas, one on the Ghouta Plain near Damascus and one in the Bekáa Valley in Lebanon. Both areas are important for agricultural production and the water supply of the Damascus region and Lebanon. The rapidly increasing water demand and several years of drought have led to a significant overuse of the aquifers. Irrigation with untreated domestic and industrial waste water, illegal waste disposal, and intensive application of pesticides and fertilizers are endangering the quality of the groundwater. The first sewage plant for Damascus was built several years ago. Most of the surface water occurrences are already considerably contaminated.

In both pilot areas, heavy metals (e.g., Cr, Cd, Pb, Zn, and Cu) and other contaminants have been analyzed in both water and soils. The degree of protection provided by the aquifer cover layers has also been determined. The results have been presented in thematic maps, providing an important basis for land-use planning.

Owing to the favorable properties of the soils, there is little contamination of the groundwater with heavy metals. The top soil, however, is locally highly contaminated. High nitrate concentrations, which locally exceed international standards, in the groundwater clearly shows that problems of groundwater quality will increase in the future.

In large parts of the Bekáa Valley, groundwater supplies are obtained from karstified limestone formations that provide little protection. If groundwater protection is not taken seriously, and the amounts pumped for irrigation are not limited and monitored, the water supply in many communities will be seriously endangered.

Recommendations are being developed for both areas for measures to limit contamination of water and soil resources. To convey the results of the project as wide as possible, the problems of sustainable development of water and soil resources, soil degradation, and groundwater protection has been discussed in workshops in Beirut and Damascus with specialists from all members of the Arabian League.

Economic and Social Commission for Western Asia (ESCWA)

BGR has advised ESCWA and its member countries for many years on solutions to groundwater problems and on the sustainable development of the available groundwater resources. Meeting of expert groups, publications, and reports convey the results of BGR-ESCWA projects to improve technical know-how for the management of groundwater resources in the member countries. Topics include

- joint sustainable utilization of trans-border aquifers and the legal aspects,
- groundwater protection and rehabilitation,
- new technologies for groundwater protection,
- application of remote-sensing method and isotope analyses for groundwater development and management.

Aquifers do not stop at national boundaries. This requires cooperation on the joint use of transborder aquifers.

Close cooperation on the joint utilization of cross-border aquifers was initiated between several member countries as a result of participation in the cross-border aquifer project.



International Cooperation in Research and Technology

Scientific and technical cooperation represents an important contribution to sustainable development worldwide. The objective is to establish networking among researchers and to involve small and medium-sized companies in application-oriented projects.

Commissioned by BMBF and BMWi, BGR works internationally with governmental institutions, universities, independent research organizations, and industry. Partner countries in such projects are the threshold countries of Latin America, the countries of eastern Europe and the former Soviet Union, China, Indonesia and Thailand, and Canada. During the report period 1999/2000, BGR cooperation projects were conducted with Albania, Poland, Ukraine, Russia, Kazakhstan, China, Nepal, Indonesia, Thailand, Brazil, Colombia, Chile, and Canada.

Information exchange

The exchange of knowledge and technology is becoming increasingly important. Close, bilateral cooperation of the BGR with governmental agencies of the countries of eastern Europe and the former Soviet Union have led to extensive removal of information barriers. Official access to data on mineral commodities is provided by regular exchange of information and joint projects, e.g., with Kazakhstan.

In southeastern Europe, old economic structures and relationships have broken down and globalization is requiring considerable adjustments. Development in this region has been promoted in the research and education sector since 1999 within the framework of the BMBF "Southeast Europe Stability Pact". BGR is supporting, for example, the Geological Survey and Polytechnical University of Albania with training programs, methods transfer, and by upgrading available instruments and equipment.

Discovering solutions

Protection of natural resources continues to increase in importance internationally.

BGR together with counterpart institutions investigates environmental problems and develops solutions.

For example, the German-Chinese Environmental Conference in 2000 in Beijing provided new impulses for sustainable, environmentally compatible development. Mining is an important part of the Chinese national economy. Environment damage associated with mining is being increasingly observed, however. BGR together with the Institute for Geology of the Chinese Academy of Sciences and the University of Wuhan is investigating the danger to the environment from the oil shale waste heaps in the area of the Fushun open-pit coal mines in northeastern China. After 8 – 9 months, the oil shale in the tips begin to smolder (spontaneous combustion), leading to atmospheric pollution, contamination of the soil, groundwater and surface water. The studies are providing a basis for evaluation of the environmental impact and recommendations for renovation of the damages. The expertise of German companies is also being utilized for finding solutions.

Utilization of synergies

Research on topics of global importance, e.g., climate development, can be reasonably carried out only in international cooperation. International joint use of research facilities optimizes the use of those facilities and promotes cooperation. One example is the research cruises off the coast of Indonesia in 1999.

Technological developments

BGR cooperates with industry on the development of geotechnologies. The focus of the last two years was in the field of geophysics, particularly in seismology and environmental technologies.

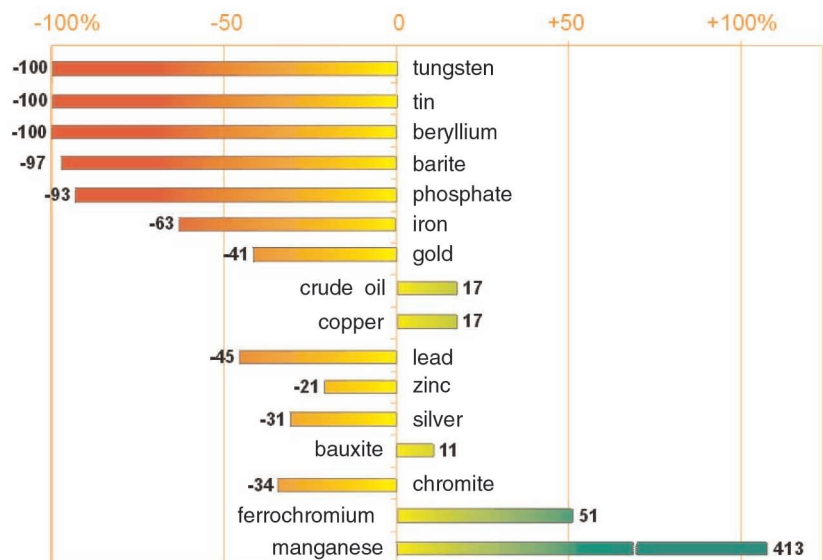
Avoidance of future contamination of surface water and groundwater is the objective of cooperation with the Department of Mineral Resources in Thailand. Within the scope of the project, guidelines for investigation of the ground below landfills and contaminated sites in the Chiang Mai and Lamphun areas. Technologies used in Germany are adapted to the conditions in Thailand. Participants in the project include a university and numerous German and Thailand companies.

Economic Cooperation with Countries of the former Soviet Union: Example Kazakhstan

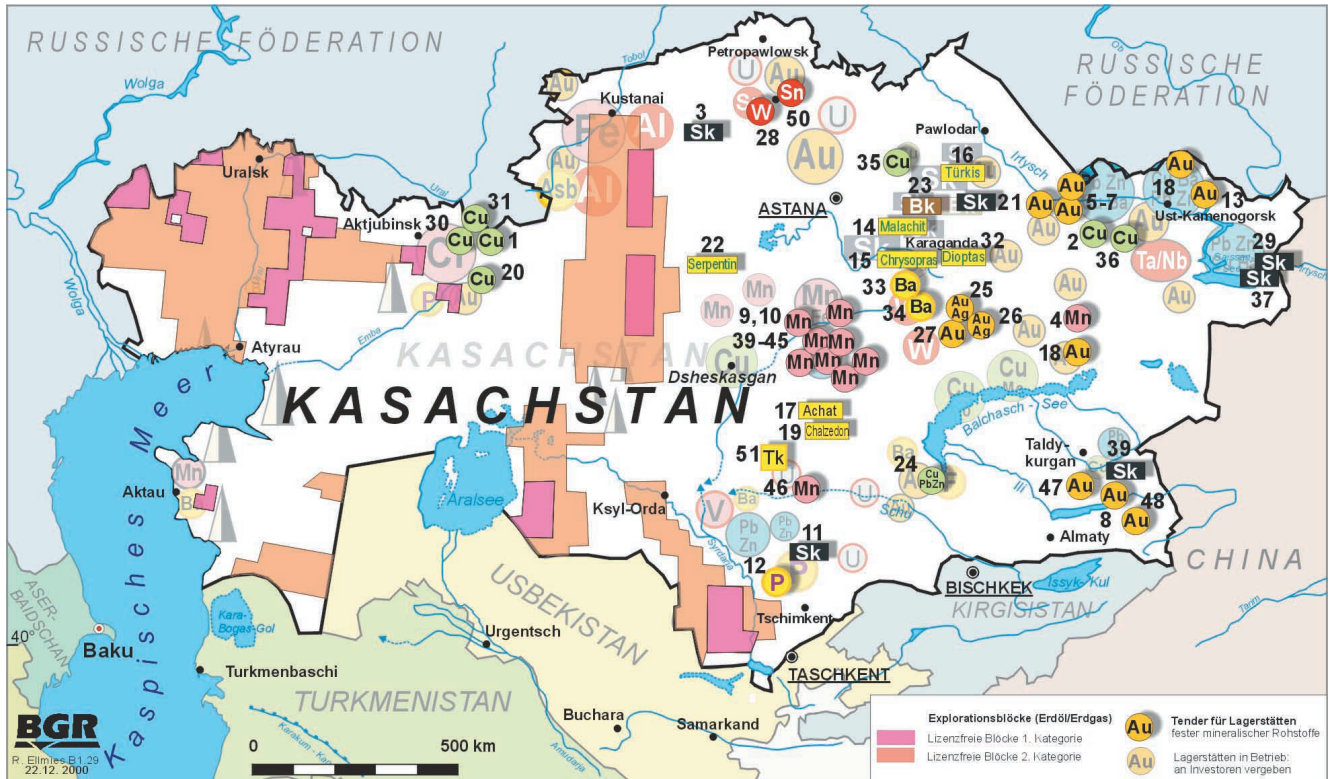
Kazakhstan has a wide assortment of mineral resources. It is a significant producer of chromite, non-ferrous metals, crude oil, uranium, and hard coal. About two-thirds of its industrial production is in the mineral commodities sector. The introduction of a market economy had far-reaching consequences for the Kazakh minerals industry. Production in 1999 is compared in the figure .1.1 below with that of the Kazakh Soviet Republic in 1990. Tin, tungsten phosphorite, and barite show a decline of 90 – 100 %; copper, manganese, and iron alloys show a considerable increase.

Why has there been such a large change in mining production in Kazakhstan?

For the Soviet Union, it was important to be independent of imports of mineral resources. For this reason, low-grade, labor-intensive deposits were also mined, e.g., phosphorite, tungsten, tin, and barite in Kazakhstan. In the conversion from a centralized planned economy to a market economy, the mining and processing operations were confronted with world market prices. Consequently, many inefficient mines were closed. In contrast, privatization of the state companies brought foreign investors for potentially profitable mining companies. After a phase of administration by a trustee, serious investors could buy stocks in Kazakh companies. After extensive modernization, some of the companies have realized significant increases in production



Change in mining production in Kazakhstan from 1990 to 1999 (in %).



Investors sought! Mineral resources projects in Kazakhstan in 2000.

and profitability. For example, the Korean company Samsung dominates copper mining, processing, and refining in Kazakhstan via its KazakhMys Holding with sales of more than US\$ 1 billion. More than three-quarters of direct foreign investment in Kazakhstan is in the mineral commodities sector.

German engagement in the mineral commodities sector of Kazakhstan is limited to plant construction and supply of equipment. The reasons are reservations about legal guarantees and bureaucracy and high transport costs. Other foreign companies have rapidly gained a foothold, however. The managers of these companies consider Kazakhstan to have the best investment and business climate of the countries of the former Soviet Union.

Information management by BGR for business and government

By its work in the forefield and making information available to German industry, scientific and technical cooperation projects promote know-how and technology transfer. Counterpart in Kazakhstan is the Committee for Geology and Protection of Mineral Resources in the Ministry for Ecology and Natural Resources. In an open, friendly way, cooperation over many years has been useful for both sides. Participants in the cooperation projects include scientific institutes, consulting firms, and the embassies of both countries.

The projects have provided

- information about the potential of ore deposits, mineral commodities, and economic conditions in Kazakhstan in the form of report;
- arrangements of contacts for business and scientific institutions;
- translation and joint publication of tenders;
- counseling of the Kazakh counterpart on repositories for radioactive and toxic wastes and underground storage of natural gas;
- advice to German companies, for example on roofing slate occurrences.

Research and Development

In order to competently advise the German government and industry, BGR conducts research and development projects, which make up about 40 % of its total activities. Focusing on applied research "in the forefield of industry", work is done on problems whose results can be transferred and applied in industrial applications within a short time. These projects are often conducted in close cooperation with industry.

Applied research in the forefront of industry

Interesting spin-off effects are often obtain by involvement of different geo-scientific sectors, e.g., mineral commodities, marine, and climate. Despite clear priorities for BGR research in the fields of mineral commodities, georelevant environmental problems, and geo-hazards, considerable importance is attached to sufficient flexibility to react quickly to problems.

Geotechnical safety and permanent repositories for radioactive waste

Within the scope of site investigations for a safe permanent repository for radioactive waste, BGR conducts geo-scientific R&D, especially in engineering geology, focusing on

- material properties of salt rock as the host rock,
- studies of alternative host rocks, e.g., clay and crystalline basement, and
- groundwater models and transport models. This will meet the requirements of the Federal government for the investigation of different host rocks for the permanent disposal of radioactive waste.

Monitoring of the Nuclear Test Ban Treaty: The National Data Center

BGR has been commissioned by the Foreign Office to monitor compliance with the nuclear test ban treaty and operate the associated national data center. BGR plays a leading role in R&D on methods for detection, localization, and identification of seismic events.

Water

Water is becoming increasingly important worldwide and has potential for conflicts in the 21st century, particularly in the arid regions. Accordingly, BGR has developed new methods for groundwater exploration and groundwater protection. The results of this continuing R&D work are used within a short time in Technical Cooperation projects.

Research is also being conducted in a demonstration project on the direct use of geothermal energy.

Fossil fuels

To secure the supply of energy for Germany, BGR conducts studies of the potential and generation of oil and gas in the "forefield" of industrial development. Since the continents of the Earth have been extensively explored for oil and gas accumulations, BGR research is focused on the little-explored continental margins. Further areas of research are gas hydrates and coal bed methane.

Gas hydrates are methane in "cages" of frozen water molecules at low temperatures and high pressures, e.g., below the seafloor or in permafrost regions. At the present time is not clear whether the enormous amount of methane in gas hydrates in the permafrost regions and continental margins can be tapped for future energy supplies. If the technology for this can be developed, these occurrences represent an immense potential.

Soils

As a consequence of the Federal Soil Protection and Contaminated Sites regulations of 1999, BGR is conducting research on the migration of substances in the soil, e.g., in seepage water. Studies are also being conducted on the natural attenuation of contaminants in the soil. Methods for harmonizing soil data from different sources are being developed to improve the soil databases needed for land-use and soil protection planning. These databases are also used for preparing EU guidelines.

Mineral resources studies

With the objective to optimally utilize mineral resources with respect to both economic and ecological aspects, research on mineral resources during the period of this report included

- development of interdisciplinary exploration strategies for metallic ore deposits with short reserves lifetimes, using the example of sulfidic Pb/Zn/Cu/Ge deposits in Namibia;
- study of the materials flow of the platinum group elements;
- modeling of deposit indicators;
- development of concepts for the use of alternative sources of materials, for reducing ecological damage from mining, and for rehabilitation of areas contaminated by mining.

Marine and polar research

BGR marine and polar research is conducted with the scope of the "Marine, Polar, and Geotechnology" research program of the Federal Government. The research is conducted with a view to future supplies of mineral resources, environmental aspects, and disaster prevention. Studies of the mineral resources potential of the seafloor are focused on the continental margins, mainly on the active continental margins (i.e., where oceanic crust is being subducted below continental crust) of the Indonesian archipelago, the Arabian Sea, and the East Pacific. Studies along passive continental margins (i.e., where there is no active plate tectonic movement) is being conducted in the South Atlantic and in the Laptev Sea (Arctic Ocean). BGR conducts research in the Antarctic to maintain German consultative status in the group of Antarctic treaty nations.

BGR marine research has had spin-off effects for geoscientific climate research in the last several years. For example, geochemical and isotope analyses of marine sediments have yielded evidence for short-term climate variations (alternation between warm and cold periods) during the last 80,000 years. These results are in very good agreement with studies on Greenland ice. Climate indicators are stored in sediments, and represent an archive for climate research.

Environmentally compatible resource development and protection of the geoenvironment

The continued functioning of the environment as a basis for human life is the objective of geoenvironment protection. Environmentally compatible resource development is focused on

- determining geochemical background values as a basis for evaluation of contaminant concentrations of natural and anthropogenic origin;
- development of groundwater vulnerability maps, using the aquifers in the military training area in the Colbitz-Letzinger Heath as an example;
- development of methods and instruments for long-term monitoring of areas of abandoned open-pit lignite mines and for investigating the environmental impacts of mine waste heaps;
- study of the ground below landfills and contaminated sites.

Geological hazards

Geohazards endanger life. Natural disasters cannot be prevented. Their effects, however, can be minimized by appropriate measures.

Geohazard research of the BGR is concentrated on earthquake activity, volcanic eruptions, subsidence, and mass movement. Investigations are being conducted in Vogtland and NW Bohemia on the potential for damage by earthquake swarms. BGR is developing methods for monitoring volcanoes and for predicting eruptions. Methods for avoiding subsidence due to collapse of mines, particularly potash mines.

Research on the causes, mechanisms, and structures of mud and debris flows and rock slides is providing a basis for developing precautionary measures and strategies for dealing with such events. These hazard management strategies are applied in Technical Cooperation projects. They strength the capabilities of these countries to minimize geohazards and protect themselves from georisks.

Climate development

After water vapor, carbon dioxide is the most important greenhouse gas in the Earth's atmosphere. The increase in the concentration of CO₂ in the atmosphere due to increasing use of fossil fuels is considered to be leading to a rise in the temperature of the atmosphere. BGR is conducting research on the carbon cycle and the part played by atmospheric CO₂. The circulation of fluids and gases at the continental margins is being studied and research is being conducted on the proportion of greenhouse gases derived from the burning of fossil fuels

Reconstruction of the climate in the past is a key to predicting future climate development. High-resolution studies of paleoclimate data – archived, for example, in marine sediments – are being conducted to reconstruct, for example, the development of monsoons in the past.

Development of new technologies

Work has been carried out in BGR research projects conducted in close cooperation with other research institutions and industry on the following new technologies:

- aerial and satellite sensor systems for recognition of impending collapse sinkholes;
- application nuclear magnetic resonance (NMR) methods to determine aquifer properties;
- a potentiometric method for monitoring waste heaps;
- an extraction method that does not use halogenated hydrocarbons for hydrocarbons analysis;
- software for visualizing complicated geological structures

Information about the geological structures is needed to predict groundwater flow and transport of contaminants. Boreholes provide information only about the vertical component at a single site. For a spatial picture, for example, of the groundwater flow in an aquifer, information about the three-dimensional structure of the aquifer is needed. It is difficult to derive the three-dimensional structure from the available information, particularly when the geology is complicated. If the complicated geology is not taken into consideration, however, the prediction will not be reliable.

To improve the practical application of 3-D models, the openGeo4 program was developed by BGR together with an engineering bureau. For complex conditions, results closer to reality can be obtained with this program than would otherwise be possible owing to the high cost of running more detailed programs.

The geology at depths of about 300 m is often quite complicated in northern Germany. The reasons for the complexity range from variation in glacial deposits (sand, marl, silt, clay) within short distances, compression of the sediments by overriding glaciers, and changes in salt structures due to uplift and dissolution.

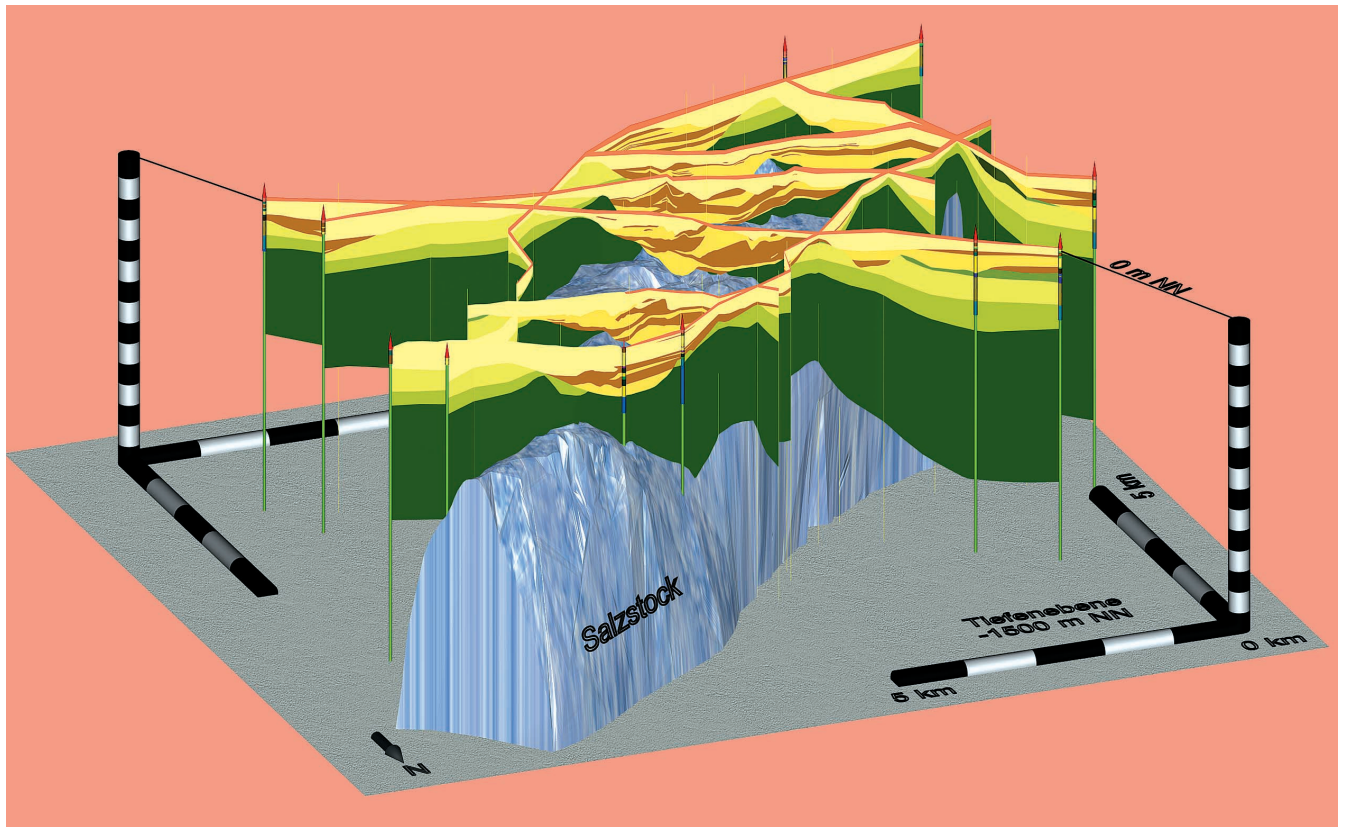
In order to model these complicated structures as close as possible to reality, the varioTriBox method was developed. This method permits three-dimensional modeling of complex structures using an arbitrary number of parameters. First, a borehole map is constructed

containing the vertical geological information of the boreholes. Cross sections are then constructed between the boreholes, yielding a triangular grid (see figure on the following page). From these cross sections, depth contour maps are then generated.

Under the control of openGEO4, the varioTriBox provides formally correct conditions at the grid nodes (i.e., borehole sites) and between the nodes (absence of crossovers and gaps). A further special feature is that an available model, e.g., of the spatial distribution of permeabilities, can be used to construct another model for another parameter, e.g., the spatial distribution of groundwater salinity. A borehole grid or the depth contours can be exported.

The varioTriBox method within openGEO4 has been used successfully for the area of a salt dome in the north German plain. The hydrogeological structures and distribution of saline and fresh water are complex in this area. The method was used to model the complex hydrogeological properties and the distribution of saline and fresh water as a basis for calculating groundwater movement. The hydrogeological model contains the spatial distribution of the aquifers; the saline/fresh water model describes the distribution of salt concentration in the groundwater.

The openGEO4 program can be purchased and is used in various BGR projects, e.g., cleaning up of contaminated sites, planning of landfills, and representation of underground structures.



Fence diagram of the cross sections constructed by the new openGeo4 software, together with the underlying salt diapir.

1



Geotechnical Safety and Permanent Repositories for Radioactive Wastes

Radioactive waste is produced not only by power plants but also by research institutes and hospitals.

BGR investigates geological structures and sites for their suitability as host rocks for permanent repositories for radioactive waste. The Asse salt dome is an example, whose long-term geotechnical safety must be demonstrated.



Geotechnical Safety and Permanent Repositories for Radioactive Wastes

The most important task of the Geotechnical Safety and Permanent Repositories for Radioactive Wastes division of BGR is the geoscientific investigations and research on underground repositories for the permanent deposition of radioactive wastes. BGR is commissioned by the German Government, represented by the Federal Office for Radiation Protection (BfS), to investigate geological formations with respect to their suitability for safe long-term deposition of radioactive wastes. BGR is the only institution in Germany with the know-how needed for this task.

Work is also conducted by BGR on geotechnical safety aspects, e.g., determination of the stability of open-pit and underground mines and other earthen construction, as well as geological hazards (e.g., earthquakes and landslides). Methods are developed in the field of technical safety and safety assessment. Projects include all aspects of engineering geology and geotechnology.

Many of the projects are interdisciplinary, involving other BGR divisions. An overview of the work in the Geotechnical Safety and Permanent Repositories for Radioactive Wastes division is given here:

- permanent repositories for radioactive waste: status of the investigations at Gorleben alternative host rocks.

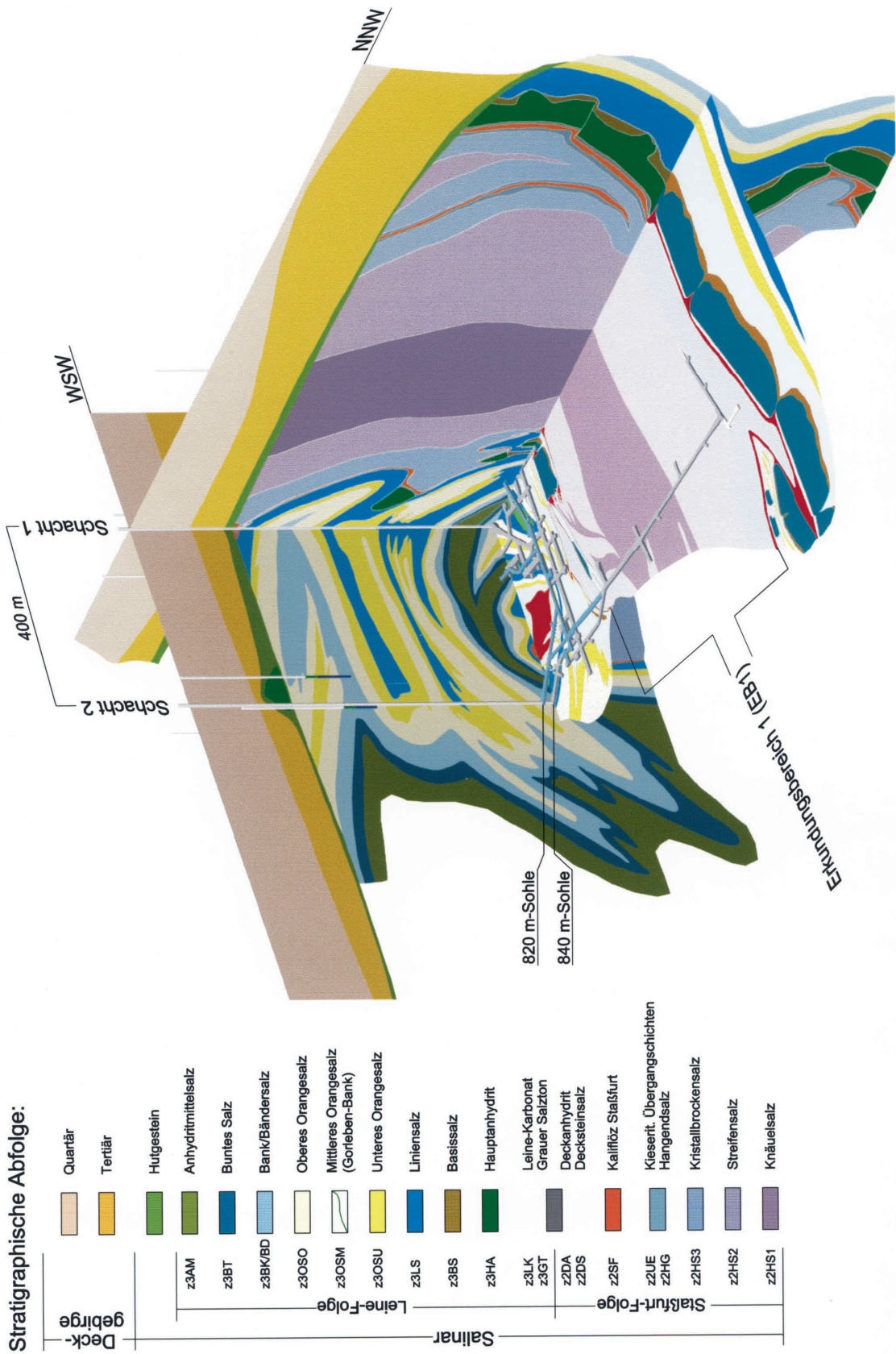
- geotechnical safety: microacoustic monitoring closing of brine caverns.

Status of the Investigations at Gorleben

The underground investigation of the Gorleben salt dome to determine its suitability as a permanent repository for radioactive waste was conducted until September 30, 2000. On October 1, the moratorium for the investigations in the exploration mine in the Gorleben salt dome went into effect, interrupting the June 14, 2000, agreement between the Federal government and the power companies to explore the salt dome over a period of three to ten years. Operation of the mine entered a phase of simply keeping the mine open. There have been no boreholes or drifts since October 1, 2000. Measurements in the drifts and boreholes are also not envisaged in the new operations plan. When the moratorium went into effect, all of the infrastructure drifts had been completed and all but about 120 m of the exploration drifts had been driven. For reasons of mine safety, these remaining drifts were excavated despite the moratorium, but with a smaller diameter.

Up to the time of the moratorium, the following results of the underground investigations had been obtained:

- It was found that the Hauptsalz beds, which are particularly suitable for the deposition of highly radioactive waste, have a larger volume than originally assumed. Ground-penetrating radar (GPR) measurements in the drifts and boreholes show that the fracture-free Hauptsalz is thicker than assumed. The predictions of the geological model are thus confirmed.
- No significant fluid inclusions were found in the Hauptsalz, as predicted. Minor amounts of hydrocarbons were found in parts of the Knäuelsalz, the oldest of the Hauptsalz beds. The safety assessment of this find is ongoing. The Knäuelsalz makes up about one-third of the area of the Hauptsalz in the exploration area EB1.



Geological model of one part (EB1) of the Gorleben exploration mine.

- The exploration boreholes and GPR measurements showed that Haupt Anhydrite in the center and the north margin of the salt structure is broken into separate blocks. The potential flow paths in the Haupt Anhydrite are thus isolated and have no connection with the groundwater in the cover rocks.
- On the basis of the convergence rates in the Hauptsalz, the rock salt would provide a good seal for the repository casks.
- The permeability measurements confirm the assumption that the rock salt is impermeable and would be an intact barrier. The extent of the excavation damage zone corresponds to the expectations and can be managed by technical measures.
- The findings to date indicate a rock salt barrier about 600 m thick from the repository level to the cover rock.

The results confirm the geological predictions for the exploration area EB1. Nothing was found that would speak against the suitability of the salt structure for a permanent repository for radioactive waste. Since the moratorium went into effect, BGR work on Gorleben has been concentrated on the evaluation of the data obtained up to that time.

The Search for Alternative Host Rocks

Applied research on permanent repositories for radioactive waste in Germany is concentrated on rock salt as the host rock. The German government now views other geological structures as potential host rocks.

With respect to granite as a potential host rock, the German government has supported the participation of German scientists since 1982 in international research projects in the Swiss Grimsel Rock Laboratory and since 1995 in the Swedish Äspö Hard Rock Laboratory.

With respect to clay and claystone, BGR has participated since 1996 in the international Mont-Terri project in Switzerland. Research on clay for the deposition of radioactive waste was intensified in 1999 in order to create a scientific basis for assessing the suitability of claystone as host rock.

The objective is to develop and apply methods for characterization of the geotechnical, hydrogeological and geochemical properties of claystones. Studies are also being conducted on the changes in these rocks caused by the excavation of drifts and tunnels. Such studies are being conducted in several underground laboratories, accompanied by laboratory experiments and modeling. The aim is to understand the processes involved and prepare models for the long-term safety assessment. Because Germany does not have a laboratory in a clay or claystone formation, the necessary studies are being conducted within the framework of international cooperation. In these projects, BGR is adapting procedures developed for salt for application to clay and is expanding its knowledge of clay formations as potential repository for radioactive waste.

Results

France, Belgium, Spain, and Switzerland are focussing their research on clay and claystone formations as potential host rock for permanent repositories for radioactive waste. This provides BGR with the possibility to participate in research in several underground laboratories:

The Hades/Mol Underground Research Facility in northeastern Belgium in the plastic Oligocene Rupelian Clay has been in operation since 1980. The operator is the Belgian Study Center for Nuclear Energy.

The Tournemire underground laboratory in the southeastern part of the Massif Central near Roquefort, France, is in a new gallery about 500 m above m.s.l. in a former railway tunnel that is about 100 years old. The gallery is in Liassic claystone. The laboratory has been operated since 1990 by the Institute for Nuclear Protection and Security (IPSN).

The Mont Terri Rock Laboratory in the Jura canton in Switzerland was set up in a tunnel excavated at an elevation of about 550 m above m.s.l. in 1989 for an Autobahn. Several alcoves and a parallel tunnel have been excavated since then. The underground laboratory, in operation since 1996, is in Dogger claystone (Opalinus Clay). Institutions in Switzerland, Belgium, France, Japan, Spain, and Germany are involved in the Mont Terri Project.

BGR has studied the excavation damage zone with high-resolution seismic methods in all three underground laboratories. The distribution of seismic velocities around the new Mont Terri tunnel is shown in the figure on the following page. The decrease in velocity in the vicinity of the tunnel, caused by the loosening of the rock in the excavation damage zone, can be seen in the Figure. The zone of low velocities corresponds to the zone of elevated permeability. The size of this zone must be taken into consideration when an engineered barrier is built to seal the repository. The excavation damage zone

extends about 1 m into the rock around the tunnel. Artifacts caused by the point-source measurements are observed at the margins.

Cooperation in the Mont Terri project was intensified during the period of this report and extended to other studies:

- geophysical characterization of the excavation damage zone,
- determination of the in situ stress field in overcoring experiments,
- laboratory studies of the long-term behavior of the Opalinus Clay at elevated temperature.

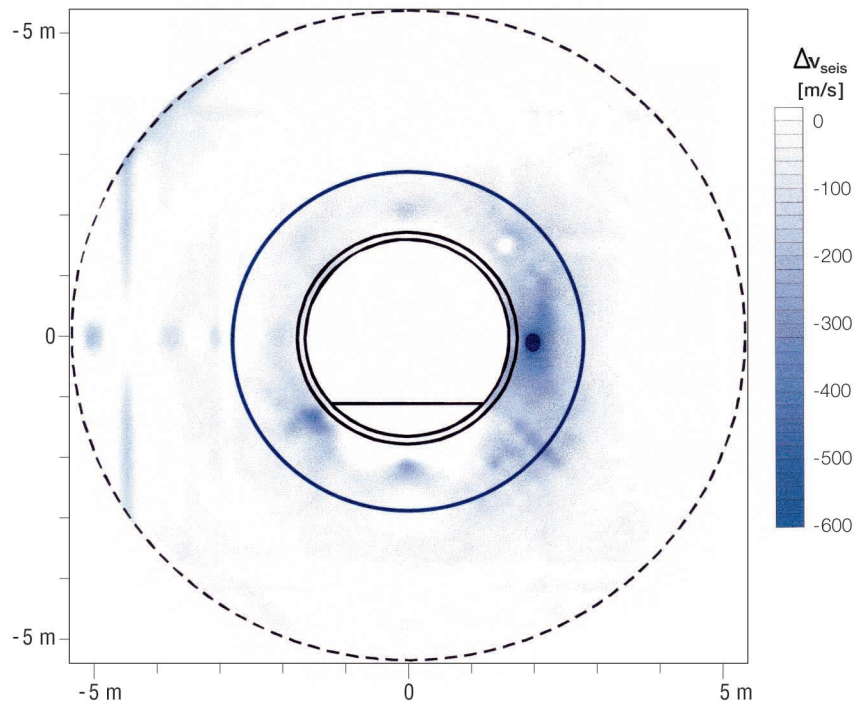
BGR is participating in three working groups on the evaluation of geochemical, hydraulic, and rock mechanics data for claystones. It is also participating in an EU project on the interaction of an engineered barrier with clay as the host rock (Engineered Barrier Emplacement Experiment). Coordinator of this project is the Spanish Empresa Nacional de Residuos Radioactivos (ENRESA).

BGR is integrated in international research on clay as potential host for radioactive waste repositories. It is transferring its experience in foreign underground laboratories to German applications. Even if the results of work in these laboratories can be quantitatively transferred only to a limited extent, due to the large variability in clayey rocks, the methods developed and tested in international cooperation provide a basis for further work.

A new underground laboratory is being excavated in claystone at a depth of about 450 m in northeastern France in the Meuse and Haute-Marne Departments. Work was begun in late summer of the year 2000. In situ experiments are planned to be begun in 2001 in the shaft and in 2003 in the underground laboratory.

BGR was invited to participate in this project already during the planning stage by the French Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA). The experience and methods developed in the Mont Terri project will be used for the first time to characterize a different clay formation. The objective of this new cooperation project is to determine the reliability of the methods and the transferability of the results, and to assess the suitability of clay formations as repository host rock. Work in this laboratory is certain to become a focus of clay research by BGR in underground laboratories in the next several years.

Participation will be continued in the Mont Terri project on the assessment of claystones and to further develop methods to characterize excavation damage zones, inhomogeneities, for long-term monitoring, and on laboratory studies of the behavior of materials. Participation will also be continued in studies on engineered barriers and the effectiveness of materials for sealing a repository.



Zone of low seismic velocity in the excavation damaged zone around a drift.

Microacoustic Monitoring of the Stability of the Repository

Microfissures are produced in the rock during mining. Microacoustic measurements are recorded of the high-frequency sound waves produced by the formation of these fissures. Formation of microfissures causes a loosening of the rock, increasing its permeability. Hence, microacoustic monitoring can be used to assess the stability and hydraulic integrity of a repository for radioactive waste. The location and intensity of fissure formation can be determined, as well as the mechanism of formation. Only a few short boreholes are needed for the sensors, making it possible to monitor large undisturbed volumes. Because the application of this method in mines is new, no commercial hardware or software is available. Several targeted boreholes were drilled to aid interpretation of the microacoustic measurements.

The measurements are being used to monitor operations in the Morsleben repository and to test the medium-term and long-term predictions on the stability and integrity of the repository derived from geomechanical modeling.

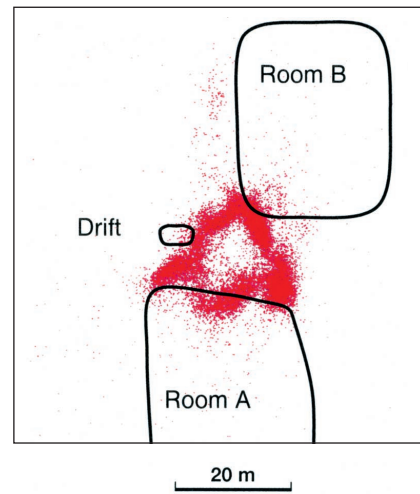
Two arrays with 24 microacoustic sensors were used for measurements in 1999 and 2000. The locations of the microfissures and the strength of the seismic waves were determined. New methods were tested for determining the mechanism of microfissure formation. A distinction can be made between shearing and fissure opening. A high proportion of fissure opening indicates a greater increase in permeability than a predominance of shearing.

Results

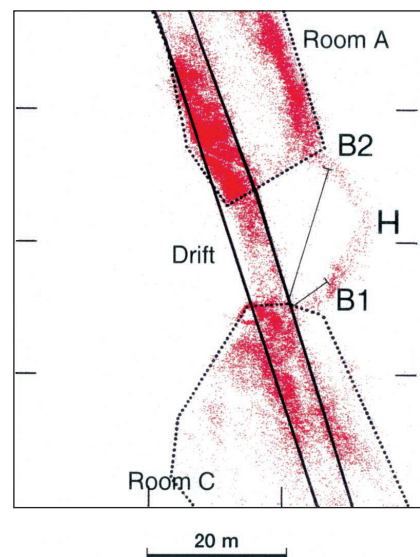
One of the microacoustic arrays is located in an area of large chambers in rock salt below thick anhydrite beds in the central part of the repository (location 1). Most of the microfissures in this area are located in the margin around the chambers. Boreholes drilled into the area of the strongest microseismic activity showed a distinctly higher permeability near the walls of the chambers. Clusters of microfissures are observed at some distance from the chambers. They occur in rings at irregular time intervals. Boreholes into one of these areas found that these clusters occur at the boundary of the rock salt to the anhydrite. The fissures have opening widths of several millimeters and lengths of several meters.

The second array was set up in the southern part of the repository where several large chambers are close to a drift (location 2). The event rate here is considerably higher than at location 1. The microfissures are concentrated in small bands between the cavities in the rock salt (figure above). These shear bands are predicted by geomechanical modeling of deformation and stress for such an arrangement of cavities. A curved band of microseismic activity was observed in area for which there are no cavities marked in the mine map (figure below). Two boreholes (B1 and B2) into this area penetrated an abandoned crosscut.

New methods for determining the mechanism of microfissuring were applied. This problem is more complicated than that of determining the location of the microfissures. Near the cavities, it was determined that both shearing and fissure opening occur.



Cross section showing microfissures between drifts in rock salt.



Cavity (H) detected via microseismic activity (dotted lines: repository chambers; solid lines: drift above the chambers).

Interpretation

In the case of location 1, the microfissures provide pathways for the migration of fluids along the anhydrite/rock salt boundary. They are caused by the convergence of the cavities in the rock salt below the rigid anhydrite. Local loosening of the rock salt is observed near the cavities. The more intense microseismic activity at location 2 is due to the higher mechanical stress in the roof of the repository chambers at this location. Changes in the geomechanical conditions can be monitored by microacoustic measurements at both locations. The measurements together with deformation measurements and geomechanical modeling show that the chambers can be stabilized by backfilling, guaranteeing long-term safety.

The method can also be applied in other fields of geotechnology, e.g., in mining, tunnel construction, and monitoring of bridges or dams. For this purpose, the experience gained to date must be used to develop hardware for commercial production. Further studies need to be carried out on the characterization of fissure formation on the basis of microacoustic signals. Together with other geotechnical studies, the extensive geomechanical studies of the BGR can be used for the interpretation of the data.

Closing of Solution-Mining Caverns

Solution mining is one of the methods for mining rock salt. Caverns with a diameter of about 60 m and heights of up to 500 m are created by the dissolving of the salt. When a cavern is no longer profitable, it is filled with saturated brine and sealed. After the cavern is sealed, convergence and thermal effects cause an increase in pressure. When a certain threshold pressure is reached at the top of the cavern, the rock salt becomes permeable and the brine penetrates the salt rock.

The hydraulic, chemical and thermo-mechanical processes involved have been studied in a joint project with AKZO Nobel and DOW Chemical. Experiments in the laboratory and in situ were conducted, as well as numerical modeling, taking into following aspects into consideration: solubility, creep, thermomechanical properties, and coupling of the hydraulic and mechanical processes.

The laboratory and in situ experiments were carried out by the Institute for Rock Mechanics (IfG) in Leipzig. Theoretical aspects of changes along grain boundaries resulting from diffusion, dissolution and precipitation were investigated by the Institute for Fluid Mechanics and Computer Applications in Civil Engineering (ISEB) of the University of Hannover and the results used for modeling. The Institute for Structural and Computational Mechanics (IBNM) of the University of Hannover implemented a BGR constitutive law in a finite-element (FE) program of the Institute to model the coupled hydraulic and mechanical aspects of the laboratory and in situ experiments. The increase in pressure in the sealed caverns was modeled with FE program by BGR and compared with the in situ measurements. Interpretation of the overall results of the project was carried out by BGR.

Results

If the pressure increases slowly, the brine can penetrate the salt rock without the formation of fractures. In this case, the penetration is governed solely by the hydraulic conditions.

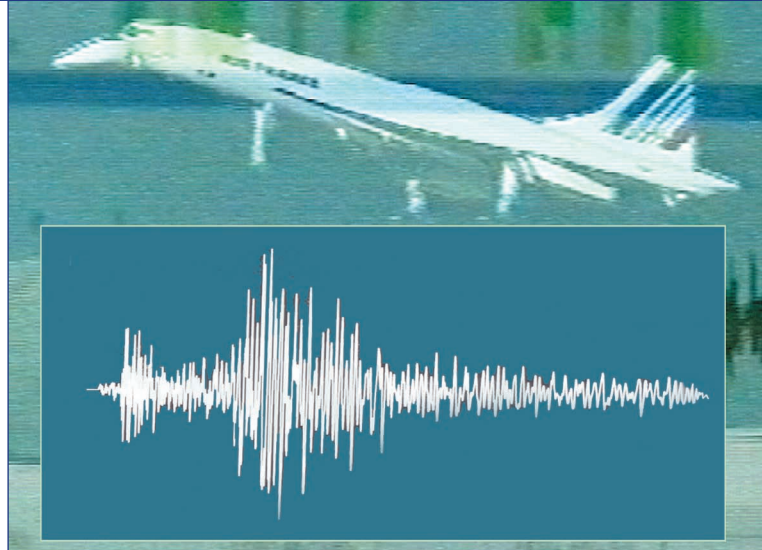
The results provide a basis for developing techniques that guarantee a long-term seal of a solution-mining cavern. They also provide a basis for the development of geotechnical safety concepts.

- ALHEID, H.-J., M. KNECHT, J.-Y. BOISSON, F. HOMAND-ETIENNE & PEPA, S. (1999): Comparison of in-situ hydraulic and seismic measurements in the excavation damaged zone of underground drifts.– In: VOUILLE, G. & BEREST, P. (Eds.): Proc. 9th Int. Congress on Rock Mechanics: 1263–1266; Paris.
- BÄUERLE, G., BORNEMANN, O., MAUTHE, F. & MICHALZIK, D. (2000): Origin of Stylolithes in Upper Permian Zechstein Anhydrite (Gorleben Salt Dome Germany).– *Journal of Sedimentary Research*, **70**, No. 3: 726–737, 19 Fig.; Lawrence, KS.
- BEHLAU, J. & MINGERZAHN, G. (2000): The use of CAD programs for the three-dimensional analysis of geological and geophysical data on the complex folded structures in salt diapirs.– Proc. 8th World Salt Symposium: 83–87, 3 Fig.; Amsterdam (Elsevier).
- BORNEMANN, O., FISCHBECK, R. & BÄUERLE, G. (2000): Investigation of Deformation Textures of Salt Rock from Various Zechstein Units and their Relationship to the Formation of the Salt Diapirs in NW Germany.– Proc. 8th World Salt Symposium: 89–94, 5 Fig.; Amsterdam (Elsevier).
- & BRÄUER, V. (1999): Results of Geological Investigations at the Gorleben Salt Dome, the Potential Repository Site for Radioactive Waste in Germany. – *Radioactive Waste Management and Environmental Remediation* – Proc. ICEM'99; Nagoya.
- DIEKMANN, N., SCHNIER, H. & SPIES, T. (2000): Geotechnical measurements for safety assessments in different development phases of radioactive waste repositories in salt.– Proc. of GeoEng2000; Melbourne.
- EICKEMEIER, R. & WALLNER, M. (1999): Numerical Calculations with Reference to the Increase of the Brine Pressure Concerning the Temperature Induced Stresses owing to the Varying Temperature Field around the Caverns – Presentation of In situ Measurements.– In: *Gekoppelte Probleme der Fluid- und Festkörpermechanik*.– ICCES Kolloquium '99; Hannover.
- EISENBLÄTTER, J. & SPIES, T. (2000): Ein Magnitudenmaß für Schallemission und Mikroakustik.– 12. Kolloquium Schallemission, Jena, **72**: 29–36; Berlin (dt. Ges. f. Zerstörungsfreie Prüfung e.V).
- KELLER, S. (1999): Scenario development and analysis for a repository in salt for high radioactive waste; proposal for a screening process (im Druck); Tagungsband des NEA Workshop on Scenario Development, 10–12 May 1999, Madrid.– 17 S., 2 Fig., 2 Tab., 1 Encl., OECD/NEA; Paris.
- KNECHT, M., ALHEID, H.J., VELASCO, M., MAYOR, J.C. & BAUER-PLAINDOUX, C. (1999): The excavation disturbed zone: Geotechnical and mechanical aspects.– In: Thury, M. & Bossart, P.: *Mont Terri Rock Laboratory. – Results of the Hydrogeological, Geochemical and Geotechnical Experiments in 1996 and 1997*.– *Geol. Ber. Landeshydrol. u. -geol.*, **23**: 171–182; Bern.
- MANTHEI, G., EISENBLÄTTER, J., SPIES, T. & EILERS, G. (2000): Bestimmung von Quellenparametern mikroakustischer Ereignisse im Salzgestein.– 12. Kolloquium Schallemission, Jena, **72**: 173–188; Berlin (dt. Ges. f. Zerstörungsfreie Prüfung e.V).
- SPIES, T. & EISENBLÄTTER, J. (1999): Micro- and macrofracturing at the boundary of rock salt und anhydrite. – In: Vouille, G. & Berest, P. (Eds.): Proc. 9th Int. Congr. on Rock Mechanics (ISRM): 1071 Eds. 1074; Paris, Balkema, Rotterdam.
- & – (2000): Monitoring of microcrack generation around closely spaced excavations in an underground repository.– *The 15th International Acoustic Emission Symp.*, Sept. 11–14, 2000: 275–280; Tokyo, Japan.
- & – (2000): Untersuchung von Clustern der akustischen Emission an geologischen Grenzflächen.– 12. Kolloquium Schallemission, Jena, **72**: 139–150; Berlin (dt. Ges. f. Zerstörungsfreie Prüfung e.V).
- , ALHEID, H.-J. & SCHULZE, O. (2000): Ultraschallseismische Verfahren zur Untersuchung der hydraulischen Integrität des Gebirges.– *Glückauf Forschungshefte*, **61**, 4: 156–163; Essen.

WALLNER, M., PAAR, W. A. & WERNER, M. (2001): New Results on Cavern Sealing and Permeation Processes. – Proc. Symp. on Cavern Sealing and Abandonment, Solution Mining Research Institute, Fall 2000 Technical Meeting, San Antonio, TX, USA, October 15–18, 2000: 127–135.

WEBER, R., BORNEMANN, O., MINGERZAHN, G. (1998): Lösung und Gase in Salzstrukturen – Beurteilung der Bedeutung für Untertagedeponien.– *Geotechnik*, **21**: 229–234, 5 Abb., 3 Tab.; Bochum.

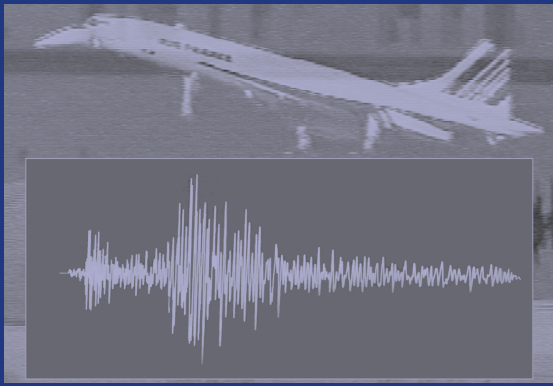
2



National Data Center – Nuclear Test Ban Treaty

BGR is the German National Data Center for the monitoring of the Nuclear Test Ban Treaty.

The IS26 infrasound array, the first within the scope of the Nuclear Test Ban Treaty, was certified in October 2000. As shown by the recorded signal, the array is so sensitive that even the breaking of the sound barrier by the Concorde over the English Channel is detected.



National Data Center – Nuclear Test Ban Treaty

As a signatory of the Comprehensive Nuclear Test Ban Treaty (1996) the Federal Republic of Germany is obligated to participate in the verification of this treaty. In addition to the development and cooperation of a data center and the integration of German stations in the International Monitoring System (IMS), the tasks include development of methods for identifying seismic events.

Installation of Infrasound Station IS26

Germany is participating in the International Monitoring System for the verification of the Comprehensive Nuclear Test Ban Treaty (CTBT) by providing data from five stations. BGR is responsible for the operation of two seismic and two infrasound stations, one each in Germany and one each in Antarctica. The fifth station, for measuring radionuclides in the southern part of the Black Forest, is operated by the Institute for Atmospheric Radioactivity of the Federal Agency for Radiation Protection. Of the seismic stations, the GERESS array (German Experimental Seismic System) in the Bavarian Forest is already in operation, transmitting data to the International Data Center (IDC) of the Comprehensive Nuclear Test-Ban Treaty Organization in Vienna. In cooperation with the Republic of South

Africa, BGR is making preparations to upgrade an existing seismic station in the Antarctic to IMS standards. The first infrasound station (IS26) has been set up in the area of the GERESS array. A site survey for an infrasound station is being conducted by BGR together with the Alfred Wegener Institute for Polar Research during the Antarctic summer 2000/2001.

The objective of the site survey for the IS26 infrasound station (official designation of the station in the technical annex of the CTBT) was to determine whether the Bavarian Forest was suitable for such a station. Together with the Provisional Technical Secretariat (PTS) of the CTBT Organization, measurements were made with four mobile stations at several sites. The results indicated that the conditions for recording infrasound signals were good. An array of five stations (array elements) was proposed, which would be better than the four-element array required as a minimum by the PTS. After approval by PTS, construction was begun in November 1998. At each station site, a 2 m deep concrete vault was buried, in which the microbarographs and data acquisition systems were installed, shielded from environmental influences. Underground cables for the power supply and data transfer were laid between the stations and the central control system of the array. A background noise filter (a wind-noise-reducing pipe array) was installed at the "sensor vault" at each station. One of these filters (18 m in diameter) is shown in the figure on top of page 38. The 96 filter openings are arranged in four groups on the circumference of

a circle. The filter improves the signal-to-noise ratio by an order of magnitude, independent of signal frequency. The frequency range monitored to identify nuclear explosions in the atmosphere are between several seconds and several Hertz.

Operation of the station IS26 was begun when construction was completed in the fall of 1999. Infrasound data has been transmitted to the IDC in Vienna by satellite since May 2000. The data are also transmitted to BGR in Hannover, archived, processed and evaluated together with the seismic data from the GERESS array. The directions of the infrasonic waves are determined in this process.

So that the IS26 infrasound station is recognized as an official IMS station, certain technical specifications had to be fulfilled. A PTS inspection team visited the array in August 2000 for a preliminary approval. In October 2000, the station was officially opened by the Executive Secretary of the CTBT Organization during a workshop organized by BGR and the PTS. It is expected that the IS26 array will be certified as the first station of the global infrasound monitoring system in early 2001.

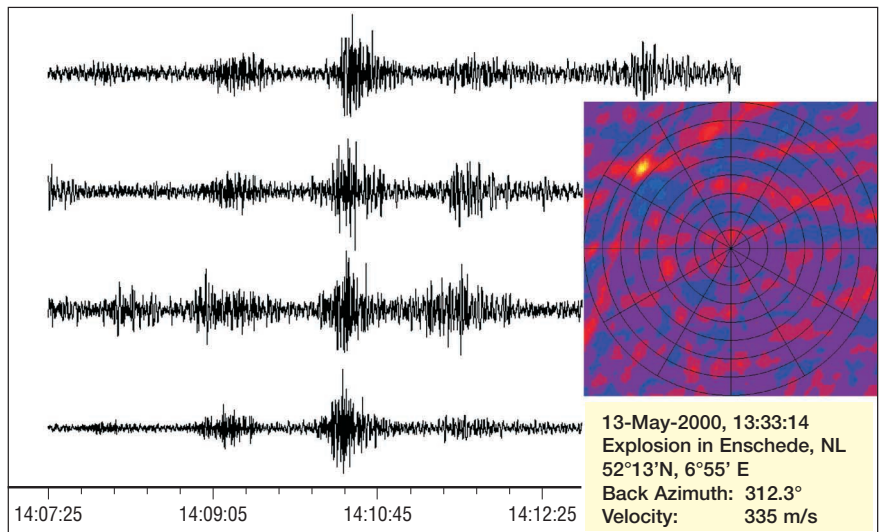
Signals from a number of different sources have been identified in the recordings since the initial operations were begun in October 1999: For example, the sonic boom of the Concorde was observed daily soon after the scheduled arrival in Paris. Explosions in the quarries around the station were also recorded; often these signals could not

be assigned to specific quarries, however, because most of them correlated only with extremely weak seismic signals recorded by the GERESS array. The sensitivity of the station is demonstrated by the recording of the acoustic signal from the explosion of the fireworks factory in Enschede, Netherlands, more than 600 km from the IS26 array.

To monitor seismic activity, BGR operates the Gräfenberg broadband seismological array (GRF) in the Franconian Jura region as well as a network of broadband seismological stations (GRSN) in all parts of Germany. These stations provide the basic data for seismological research at the universities in Germany. The data is collected at the Gräfenberg Central Seismological Observatory (SZGRF), a joint facility of BGR and the German Research Association (DFG), for scientific use.



Wind-noise-reducing pipe array, which functions as a filter to remove background noise from the infrasound signals.



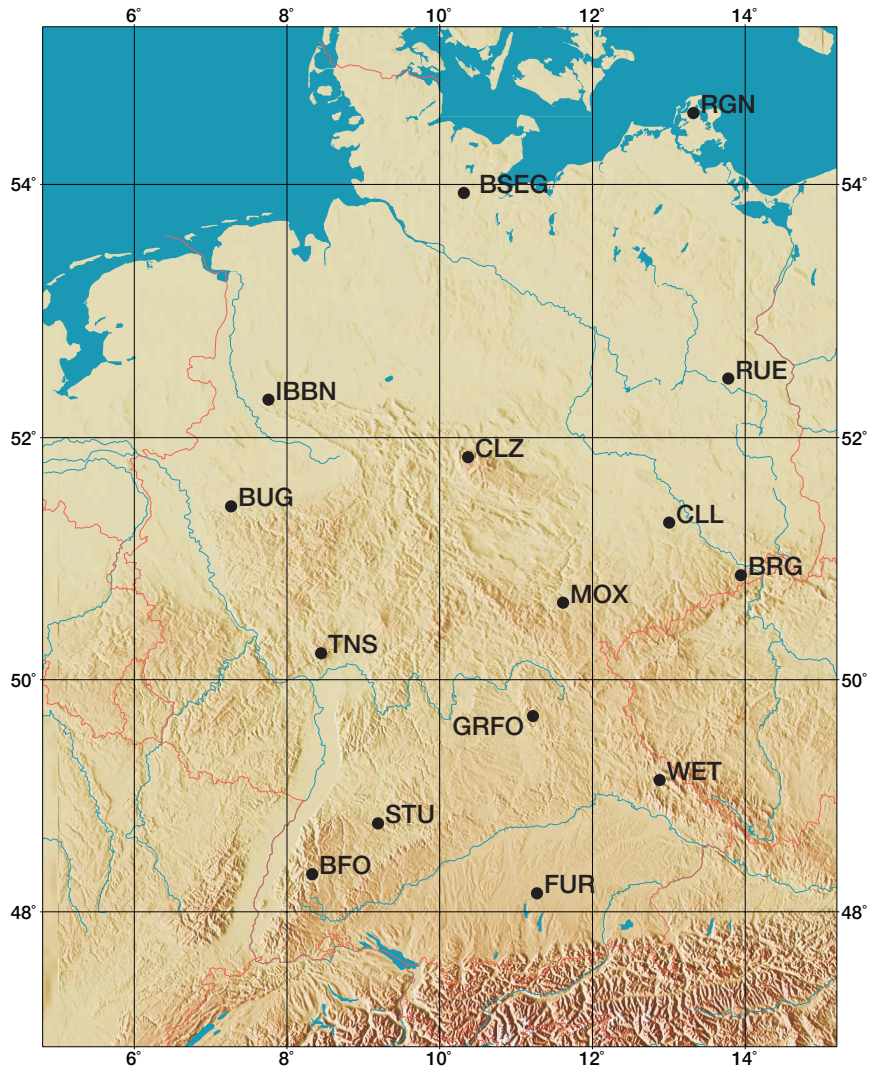
Infrasound signals from an explosion in the fireworks factory in Enschede, Netherlands, on May 13, 2000, 625 km from IS26. The results of a frequency–wavenumber analysis is also shown.

Modernization of the Regional Seismological Network

The stations of the German regional seismological network (GRSN) were set up in 1991–93, funded by the DFG. The sites are more or less uniformly distributed throughout Germany (see figure right). The stations are maintained by local institutions, usually university institutes. The data from these stations, together with the data from the Gräfenberg array, is archived in digital form by the Gräfenberg Central Seismological Observatory and made available at the internet address <http://www.szgrf.bgr.de>

When the Y2K problem had to be taken care of, the computers of the data acquisition system were nearly a decade old and are showing their “old age”: high repair costs and difficulties to obtain spare parts. The solution had to take into consideration uniformity of hardware and software at all stations with no interruption of data acquisition, and all functions of the old software had to be retained.

In 1999, BGR was commissioned by the Seismology Working Group of the Forschungskollegium Physik des Erdkörpers (FKPE) to upgrade the system so that it would be operational by the end of 1999. The system has operated without any problem since it was set up. When the new system became operational, BGR also became responsible for maintaining station operation and data quality. Software was developed at SZGRF to automatically monitor data acquisition and recognize errors.



Map of the stations of the German Regional Seismological Network.

The successful modernization of the seismological stations guarantees the continuing recording of the data with the same quality for the foreseeable future. By using only standard hardware parts, maintenance of the stations will be easier and less expensive. It will also be easier to integrate future technological developments into the system. The field of seismology in Germany will profit from the uniform, high data quality in the GRSN broadband archive, as well as numerous international projects.

Besides providing data for scientific studies by others, BGR conducts its own seismological research in order to be able to advise the German ministries and industry.

The Vogtland Earthquake Swarm Region

The Earth's crust and upper mantle in the Vogtland region and adjoining NW Bohemia are unusual with respect to continental crust in other parts of the world: periodic earthquake swarms occur that correlate with escape of CO₂ at a high flow rate from the Earth's surface throughout the region. The gas is assumed to come from an active magma reservoir in the upper mantle. Other processes associated with earthquakes are volcanism during the Quaternary and neotectonic crustal movement related to deep-seated fault zones (the marginal faults of the Eger graben and the Marienbad fault).

Seismologically, the region is distinguished by significant earthquake activity, mostly in six areas. Relatively strong earthquakes (ML > 2.5) occur frequently along the Marienbad fault, mostly in swarms. These earthquake swarms differ from "normal" earthquakes in that the energy is not released in a single, strong earthquake, but instead in thousands of small ones. These swarms usually occur within a few cubic kilometers at a depth of 8 – 10 km. Earthquake swarms have been recorded in the region since 1552. The last large swarm (>8000 earthquakes with local magnitudes ML up to 4.6) was registered in 1985/86 over a period of two months. Thus, the region is a major earthquake region besides the Rhine graben and the Swabian Jura not only due to the large number of quakes, but also to their strength. Since the last large swarm, there have been smaller swarms every two to three years, consisting of several hundred to a thousand events with a maximum magnitude ML of 3.

The largest swarm occurred between August 28 and November 10, 2000: Several thousand individual quakes with magnitudes ML of up to 3.7. The stronger quakes of this swarm were distinctly felt and heard as a deep growl in NW Bohemia and Vogtland, as well as in the Upper Palatinate. The locations of the epicenters of this swarm were determined by the Gräfenberg Central

Seismological Observatory (SZGRF) in Erlangen. In order to better study this swarm and its causes, additional seismometers were set up by the SZGRF, the Potsdam GeoResearch Center (GFZ), and the universities of Freiberg, Jena, Leipzig, and Munich. It has been assumed in the past that the earthquake swarms are caused by ascending fluids. A multidisciplinary geoscientific project was begun two years ago to answer this question. Scientists from BGR, GFZ, and ten German universities are working together with Czech colleagues from Prague and Brno in this project, financed by the German Science Foundation (DFG). Seismological studies are being carried out by BGR on the focal mechanisms of the swarm earthquakes and the regional stress field. The fault-plane solutions are very similar within a single episode and vary between the individual episodes. These fault-plane solutions together with precise determinations of the epicenters allow correlation of the earthquakes with specific fault planes. These are then compared with known faults and zones of ascending gases. A geochemical probe is being developed in the BGR. A database of all relevant seismological data from the region is being set up by SZGRF for use by all of the participants in the "Vogtland Project" and the interested public via the internet.

The general objective of the research on the swarm earthquakes in the Vogtland region is to explain the causes of these earthquakes and the relationships between the focal mechanisms, fault tectonics, the gravity field, neotectonic crustal movements, the paleostrain regime, fluid behavior, and deep-seated zones of ascending gases. This knowledge is to be used to be able to better recognize precursors of strong earthquakes in the more active seismic regions of the Earth.

Further reading on this topic

- GEISSLER, W., PLENEFISCH, T., KIND, R., KLINGE, K., KÄMPF, H., BOUSKOVA, A., NEHYBKA, V., SKÁČELOVA, Z. & JACOB, B. (2000): The Moho structure in the Western Eger Rift: A Receiver Function Experiment. – *Studia geophysica et geodaetica*, **2**, 44: 188–194.
- STAMMLER, K. (1999): The Regional Data Center at the Seismological Central Observatory Gräfenberg (GRF), Germany. – *CSEM/EMSC Newsletter*, **14**, 5. April 1999.
- WIRTH, W., PLENEFISCH, T., KLINGE, K., STAMMLER, K., SEIDL, D. (2000): Focal Mechanisms and Stress Field in the Region Vogtland/Western Bohemia. – *Studia geophysica et geodaetica*, **2**, 44: 126–141.

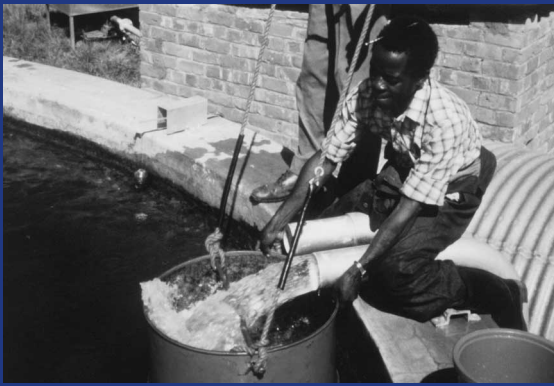
3



Water

The objective of many Technical Cooperation projects is to help the local people obtain a sustainable groundwater supply.

Besides its availability, particularly in arid regions, water quality is becoming increasingly important.



Water

Water as Essential Natural Resource is a Focus of the Work of BGR

One of the basic needs of people is a supply of drinking water; the availability of water of suitable quality is basic to the development of agriculture and industry. This can lead to regional and international conflicts in arid regions. Because it can be a medium for the dissemination of pollutants, water can also represent a hazard. For all of these reasons, water is a focus of the work of BGR.

In order to advise the Federal government in the water sector, the work of BGR extends from groundwater exploration and protection to qualitative and quantitative assessment of groundwater resources and to studies of surface water bodies and geothermal utilization. Counterpart institutions in the developing countries are aided in their work in this sector.

Development and application of geophysical, mathematical, and hydrochemical methods are basic for competent advice. BGR uses state-of-the-art geophysical methods for groundwater exploration. The BGR helicopter and its electronic systems is used to explore large areas, which are often to traverse on land, e.g., the tidal flats along the North Sea coast.

The BGR helicopter system consists of the following components:

- a Sikorsky S76-B helicopter in which a gamma-ray spectrometer and data acquisition and navigation instruments are installed and
- a cigar-shaped „bird“ about 9 m long containing the sensors of the 5-frequency electromagnetic system, a cesium magnetometer, a laser altimeter, and the GPS/GLONASS global positioning system.

- The „bird“ (40 m below the helicopter) is flown 30 – 40 m above ground level. Ten measurements are made per second at a flight speed of 150 km/h, yielding a sample spacing of about 4 m.



BGR helicopter and „bird“ preparing to start a survey flight.

Making Salt Water Intrusion Visible

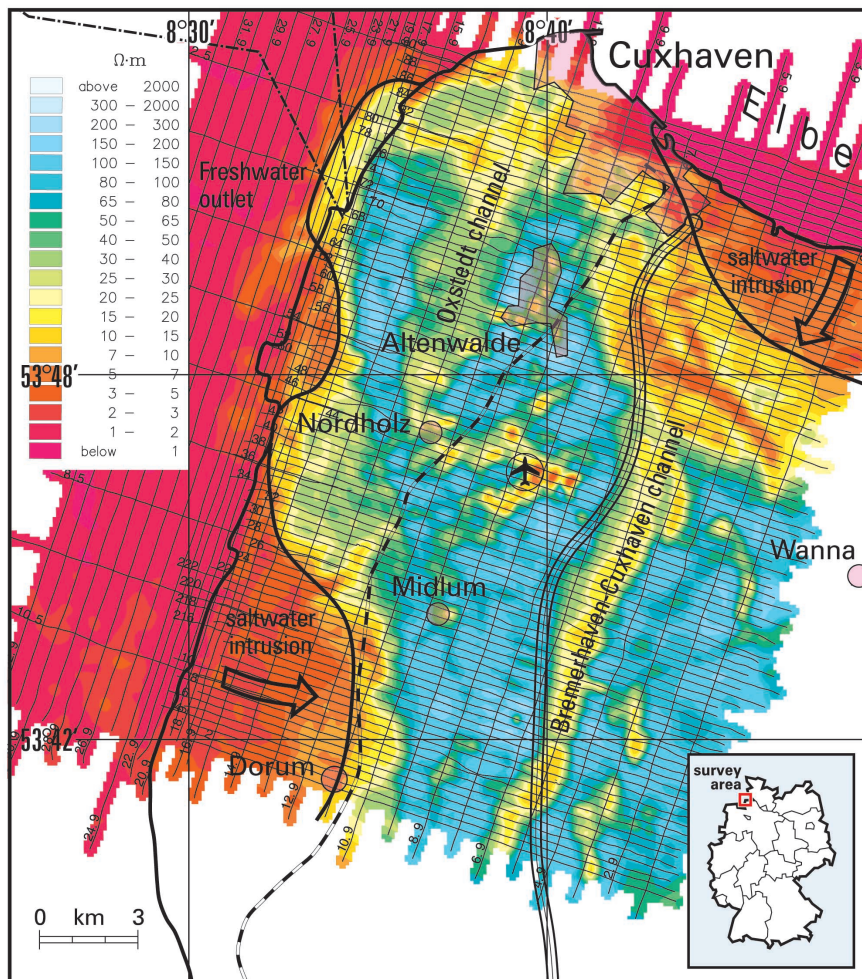
The BGR helicopter system was used to determine the location of the fresh water/salt water boundary and the distribution of salt concentration in an area of about 530 km² in the Cuxhaven region. This boundary can be recognized down to a depth of about 80 m. In some parts of the surveyed area, the salt water has intruded as much as 10 km inland. Fresh water was also observed in the tidal flats, however.

The survey data also give the depth of the groundwater table and provide information about the lithology. Glacial channels (in this case the Oxstedt and Bremerhaven-Cuxhaven channels) can

be identified because the electrical resistivity of the clay within the channels (in this case the Lauenburg Clay) is distinctly lower than that of the surrounding sediments.

The data have been used by the GGA Institute to model the flow of fresh water and salt water in this coastal region. Numerical models are also an important tool of BGR in the groundwater sector, e.g., for developing groundwater management strategies or for studying fresh water/salt water systems.

These models can be used to describe the present system, as well as its past development in order to analyze the effects of paleoclimate, e.g., the glacial periods. This analysis can be used to predict development in the future under changed climate conditions.



Salt water intrusion, fresh-water seeps, and channel structures in the Cuxhaven region.

Permafrost and the Advance of the Glacial Ice Sheet during the Last Ice Age Determined the Present Groundwater System

BGR has been known for some time on the basis of model simulations that the distribution of fresh water and saline water in the area of the Gorleben salt dome is still in the process of change since the last glacial. The factors governing the behavior of this groundwater system in the past can be better constrained with new regional models. These models were used to simulate the development of the groundwater system since the last interglacial 120 000 years ago.

Use of paleodata to validate hydrogeological models

Global objective:

Demonstration of the usability of complex groundwater models for long-term prediction.

Method:

Hydrogeological model simulating the development of a groundwater system during the last glacial from a defined initial state to the present state.

Study area:

Elbe valley between the Drenthe and Weichsel moraines and the area around the Gorleben salt dome.

Area boundaries:

Surface water divides, flow lines, and surface water bodies.

Simulated time:

120,000 years from the Eemian interglacial until today.

Events and processes:

Precipitation, permafrost, glacial advance, subsidence of salt domes, groundwater density as a function of salt concentration.

Groundwater flow changes with changes in climate, e.g., between stadials and interstadials, during the Weichselian from about 120,000 BP until today. Changes in the extent of permafrost cause changes in the main direction of groundwater flow, thus changing the distribution of saline water. The location of the glacier front at the north margin of the model at the

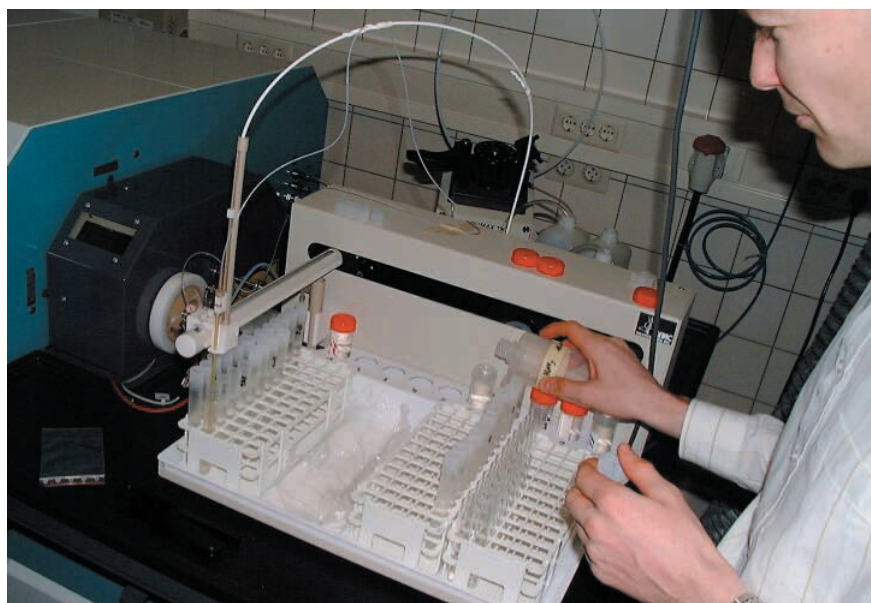
time of maximum glacial advance during the Weichselian about 20,000 years ago had a decisive influence on the groundwater conditions. A melt water stream at the base of the glacier determined the size and direction of flow in the regional groundwater system. The highly saline groundwater above the Gorleben salt dome is completely displaced in one of the simulation scenarios. The hydraulic conditions during the last 20,000 years have thus determined to a large extent the present groundwater flow system and the distribution of saline and fresh water.

Hydrochemical studies provide a particularly good basis for drinking water management. They are being increasingly used to determine water quality, to monitor the groundwater around landfills, to detect sources of contamination, and for hydrogeological studies.

The Use of Isotopes to Detect Perpetrators of Water Pollution

Water can become contaminated either naturally or as a result of human activities. Isotope ratios of certain elements, e.g., boron, can provide information about which of these sources is the cause in

the case of contamination. A method based on sector field ICP mass spectrometry has been developed by BGR for measurement of boron isotope ratios with a high throughput.



Work with the ICP-mass spectrometry method.

The input of river water into the groundwater was determined along a river containing water from a sewage plant. The boron isotope ratio of water from the river and from wells not far from the river (91 and 93 µg/L boron) was determined to be about 4.05, indicating boron from detergents. This water contains water from a sewage plant. In contrast, water from two wells further from the river (20 and 40 µg/L boron) showed ratios of about 4.12, indicating a natural source.

The results of hydrogeological studies are shown on hydrogeological maps and are used for planning purposes. BGR prepares the Hydrological Atlas of Germany and the 1 : 200,000 Hydrogeological Map of Germany. BGR is also coordinating work on the International Hydrogeological Map of Europe for UNESCO.

A new stimulus was given at the 29th IAH congress in Bratislava in September 1999, after a decade of stagnation due to the political reorientation of eastern Central Europe and Southeast Europe. Editors for map sheets D5-Budapest and E5-Bucuresti were appointed in Hungary and Romania. National editors were named in a total of fourteen countries. Editorial meetings were organized by BGR for each of these two map sheets, and for sheet A5-Lisboa. The naming of these editors and the holding of these meetings make it now possible to complete these three sheets and the accompanying Explanatory Notes.

Bolivian Project

Project title:

German-Bolivian Cooperation in the Groundwater Sector
Convenio Aleman-Boliviano de Aguas Subterráneas (CABAS)

Commissioned by the

Federal Ministry for Economic Cooperation and Development (BMZ)

Counterparts:

Federal Institute for Geosciences and Natural Resources (BGR) and
Servicio Nacional de Geología y Minería (SERGEOMIN)

Objective:

Strengthening of the hydrogeology division (Departamento de Hidrogeología) of SERGEOMIN for carrying out the assessment, exploration, and protection of groundwater in Bolivia.

Project measures:

- training of Bolivian hydrogeologists and geophysicists on-the-job, in seminars and courses, and graduate study in Europe;
- delivery of equipment for hydrogeological and geophysical field studies.

Activities:

- setting up of a hydrogeological database,
- setting up of a geophysics section,
- preparation of hydrogeological maps,
- hydrogeological and geophysical surveys in three areas of Bolivia: the central valley of the Cochabamba, the Pampas de Lequezana, and the Chaco of Tarija province.

International Hydrogeological Map of Europe

Umbrella organization:

International Association of Hydrogeologists (IAH)

Supported by the

Commission for the Geological Map of the World

Coordination and publishing:

BGR together with UNESCO

Scale:

1 : 1,500,000

26 map sheets and Explanatory Notes,
22 map sheets have been completed.

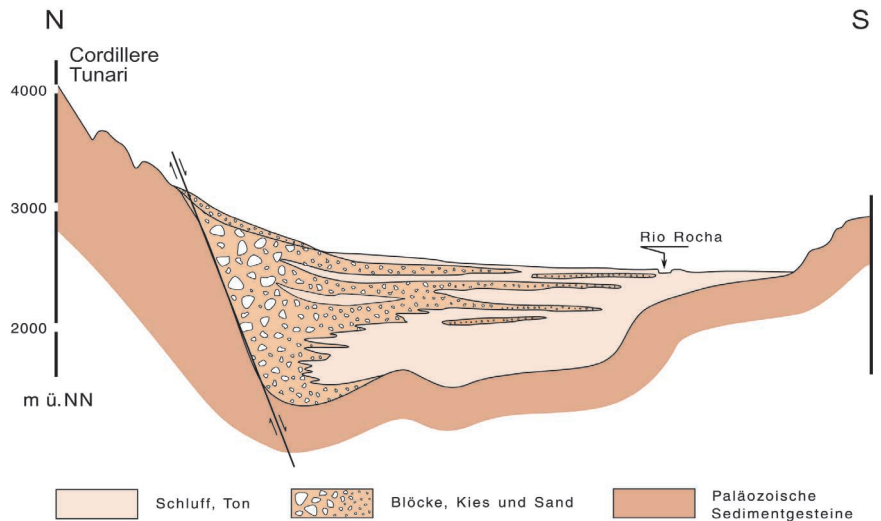
Technical Cooperation projects worldwide profit from the development of hydrogeological, geophysical, mathematical and hydrochemical methods and experience with the preparation of hydrogeological maps. BGR staff are involved in water sector projects on nearly all continents. Focus is on strengthening counterpart institutions, in part by training of their staffs. Such projects are illustrated by the following examples.

Groundwater for the Cochabamba Region

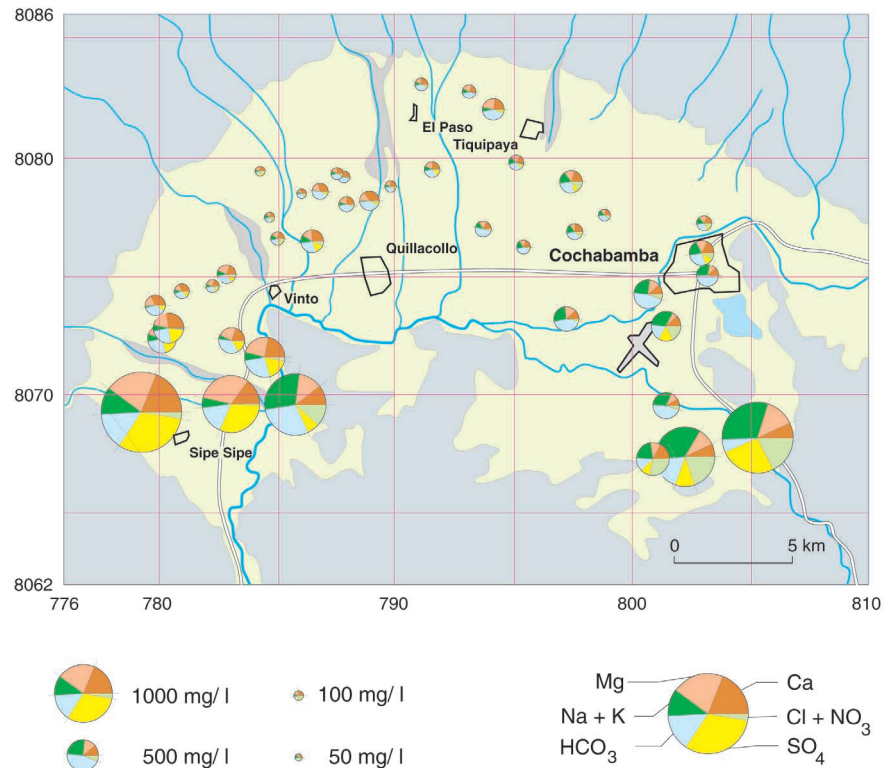
The Central Valley of Cochabamba is one of the largest valleys in the eastern cordillera of Bolivia. This 1150 km² valley has an elevation of about 2550 m. Extending more or less east-west, it is bounded on the north by a mountain range that reaches an elevation of 5035 m (the Pico Tunari). The groundwater in the valley is used for the drinking water supply of the Cochabamba, a city with a population of half a million. There are conflicts with the rural population over these groundwater occurrences. Emphasis in eight years of German-Bolivian cooperation has been exploration of the groundwater resources of the valley.

The sediments in the valley reach thicknesses of as much as 1500 m. In the north, at the foot of the mountains, fluvial deposits predominate; in the south, lacustrine clays predominate (see figure above). Groundwater recharge occurs mainly in the north, where perennial rivers enter the valley. To the south, the permeability of the sediments decreases, the aquifer increasingly contains clayey-silty layers. Wells as deep as 150 m provide drinking water with yield of up to 100 m³/h. Tests in deeper wells (more than 200 m) also have yielded good results. With increasing depth, however, the permeability of the sediments decreases and the quality of the water decreases to the point that it can no longer be used as drinking water.

In the northern and central part of the valley, weakly mineralized water provides most of the drinking and irrigation water. These resources are sufficient for the area around Cochabamba, but not the increasing needs of the city of Cochabamba itself. The city will have to increasingly tap more expensive surface water resources.



Schematic hydrogeological section across the Cochabamba Valley.



Map showing chemical sampling sites (the size of the circle indicates the total salinity).

Jordanian Project

Project title:
Advising the Water Authority of Jordan

Commissioned by the
Federal Ministry for Economic Cooperation and Development (BMZ)

Counterparts:
Federal Institute for Geosciences and Natural Resources (BGR),
the Ministry of Water and Irrigation (MWI) and
the Water Authority of Jordan (WAJ)

Objective:
Increasing the capabilities of the staff of the Water Resources Studies Division of
WAJ to prepare planning documents for the development of water resources for the
drinking water supply of Jordan.

Project measures:

- training of Jordanian hydrogeologists and specialists in geohydraulics, on-the-job, in project-intern seminars and in courses in Jordan and abroad;
- preparation of hydrogeological planning documents for northern Jordan,
- delivery of equipment for hydrogeological field studies and information technology.

Activities:

- setting up of a database on the hydrogeology of northern Jordan,
- preparation of hydrogeological maps and reports,
- groundwater modeling of the Suwaqa-Qatrana-Hasa and Muwaqqar areas,
- assessment of the prospective groundwater yield of the deep sandstone aquifer,
- introduction of groundwater protection procedures, e.g., determination of groundwater vulnerability and the setting up of groundwater protection areas.



Discussion at the site of a deep exploration well drilled near El Lajjun.

Jordan, with its high population density and low precipitation rate, has an extreme shortage of water. Most of the population is concentrated in a few large cities. Drinking water supplies depend almost exclusively on groundwater. Groundwater abstraction rates, however, are considerably higher than groundwater recharge rates. Hence, modern water management is absolutely necessary for the sustainable development of these groundwater resources. Prerequisites for this are being considerably improved in a project for increasing the qualifications of Jordanian personnel.

Planning of Sustainable Development of Water Resources in Jordan

Basic to any planning is the availability of an adequate data base. Data relevant for water management planning is now available for central and northern Jordan, from the Jordan Valley in the west to the Iraqi border in the east. GIS methods are used to process the data. Groundwater models based on this data are a decisive prerequisite for the planning and optimization of water management. A groundwater model has been prepared for all of northern Jordan as an aid to regional planning; models have been prepared for the supply of Amman and an industrial area near Amman; and models have been prepared, for example, for smaller well fields, for artificial recharge measures, and for the water supply of Petra.

Aspects of groundwater protection for planning purposes have included the determination of the natural protection

function of the groundwater cover layers and the corresponding groundwater vulnerability, as well as determination of potential sources of contamination. The results are expressed in an easy to understand form as the degree of groundwater vulnerability and in recommendations for the use of these areas. Modern land-use planning documents that take groundwater protection into consideration are now available for the Irbid and Amman regions.

In a pilot project in which recommendations were developed for a protection area for a spring used to supply the city of Pella in the Jordan Valley during the classical antiquity period, the counterpart was introduced to the methods used for determining drinking water protection areas. The results provide a prerequisite for the sustainable development of the water resources of the

greater Irbid area. Although the relevant laws are lacking in Jordan with which use restrictions can be enforced, the project results are already being put into effect. For example, a landfill in the catchment area of the spring has been closed.

The data collected by the project group, the thematic maps, simulation models, and reports prepared by the group are being used by governmental agencies, universities, and companies for their practical work. The maps prepared for the pilot areas for the delineation of groundwater protection areas and groundwater vulnerability have become an important basis for land-use planning. The Ministry for Water and Irrigation plans to continue the investigation in other parts of Jordan on its own.

Further reading on this topic

- GÄBLER, H.-E. & BAHR, A. (1999): Boron isotope ratio measurements with a double-focusing magnetic sector ICP mass spectrometer for tracing anthropogenic input into surface and ground water.– *Chemical Geology*, **156**: 323–330.
- KÖSTERS, E., VOGEL, P. & K. SCHELKES (2000): A Palaeohydrogeological Approach to Regional Density-Dependent Groundwater Modeling: A Case Study in Northern Germany.– In: BJERG, ENGESGAARD & KROM (Eds): *Groundwater*: 105–106; Balkema, Rotterdam.
- MARGANE, A., HOBLER, M. & SUBAH, A. (1999): Mapping of Groundwater Vulnerability and Hazards to Groundwater in the Irbid Area, North Jordan.– *Z. angew. Geol.*, **45** (4), 188–197; Hannover.
- NEUMANN-REDLIN, C., RENNER, S. & TORREZ, J. (2000): Hidrogeología del Valle Central de Cochabamba, Bolivia.– In: *Proc. 1º Congreso Mundial Integrado de Aguas Subterráneas*; Fortaleza, Brasil.
- PASIG, R., VILLENA, H. & NEUMANN-REDLIN, C. (2000): Hydrogeology of the Chaco Tarijeno (Bolivia).– *Z. angew. Geowiss., Sonderheft SH 1: Hydrogeology and Environmental Geology*: 201–206.

4



Energy Resources

The lifetimes of fossil fuel deposits are limited. BGR investigates newly discovered occurrences and develops new exploration methods within the scope of international projects.

Natural gas wells like the one in the Urengoy area in northwestern Siberia provide the local energy supply. One-third of Germany's natural gas consumption is from Siberia.

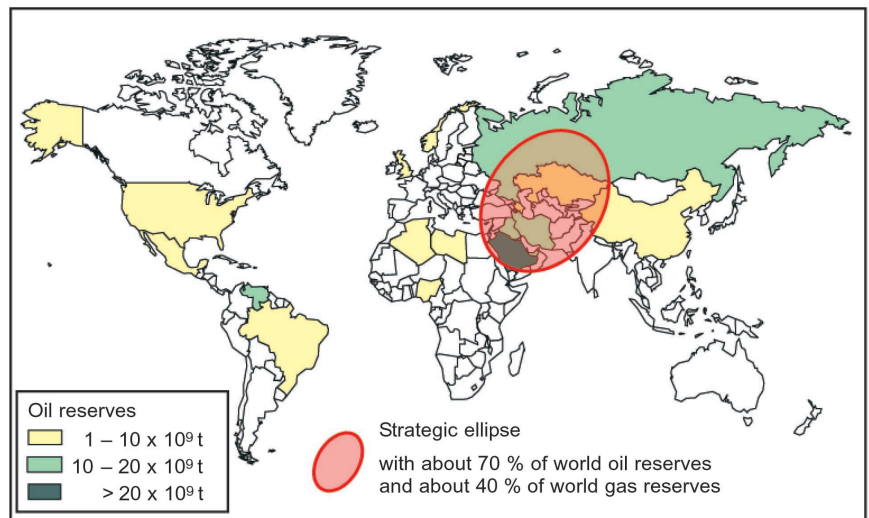


Energy Resources

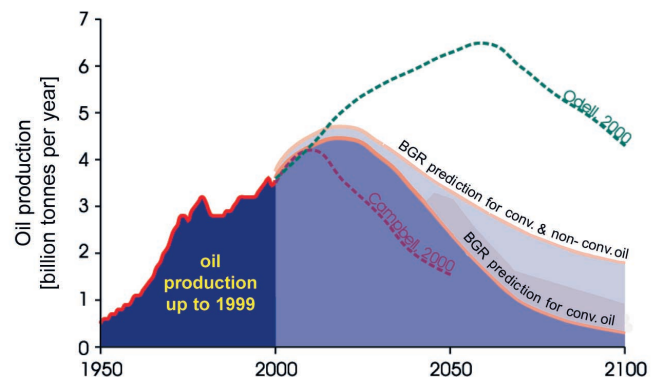
The End of the Petroleum Age and the Search for New Energy Sources

Energy drives our lives and societies. On the way to work, sitting in front of the TV, in the shower, we are consuming energy. Energy is such a natural part of our daily lives that we usually take it for granted. We seldom think about what it takes for us to have 10 liters of petrol to drive 100 km (23.5 miles/gal): That is 10 L of a valuable mixture of hydrocarbons formed at several kilometers depth from the remains of living organisms deposited together with inorganic material millions of years ago. This formation of crude oil, from which gasoline is made, was an exceptional occurrence, and the accumulations of oil and gas in the Earth's crust are limited.

The rapid developments of the 20th century were made possible by the apparently limitless availability of energy, mainly in the form of crude oil. Crude oil guaranteed economic growth, mobility, and prosperity. Oil has also led to political conflicts. About 40 % of the global energy demand is supplied by crude oil. The remaining oil reserves are not uniformly distributed among the countries of the world. Whereas most industrial countries, including Germany and the USA, have passed the apex of their crude oil production, the OPEC countries can increase production. OPEC has more than two-thirds of the known global oil reserves.



The "strategic ellipse": The map shows the countries that have more than a billion tonnes of oil reserves. The countries of the "strategic ellipse" have 70 % of the global oil reserves and 40 % of the natural gas reserves.



Global crude oil production until 1999. In contrast to the forecasts for conventional oil reserves, the predictions for unconventional oil occurrences include those that would be difficult to develop with today's technologies. The predictions given here are described by HILLER (1999). Two extremes are shown in the diagram: Whereas ODELL (2000) is optimistic, peak global oil production will be reached according to CAMPBELL (2000) within a few years.

Viewed globally, we are approaching the time when half of the conventional, i.e., the easily obtainable oil reserves have been used up. The estimates for this time range from a few years to 30 years. From this time on, oil production will decline and the price of oil will increase. This decline will coincide with a continually increasing global demand resulting from a twofold cause: global population growth and increased demand from the developing countries. Thus, it can be foreseen that there will be insufficient energy supplies in the near to medium-term future that could shake the foundations of our global economy.

If a situation in which supplies cannot meet demand is to be prevented, unconventional oil occurrences must be developed and other energy resources must be found and developed. Unconventional oil occurrences includes occurrences that would be difficult to develop with today's technologies. Advancing technological developments may be expected to make it possible to produce from such deposits. For example, it is becoming technologically possible to produce from continually increased water depths in the oceans. Whereas oil production was previously concentrated on the continents and shallow marine water depths, new target areas are

being developed on the continental margins. With this in mind, BGR has been conducting studies of the hydrocarbons potential in deep water areas, e.g., in the South Atlantic off Argentina, Namibia and South Africa. Such studies are conducted in the long-term "forefield" of industrial development. A major aspect of efforts to find a way to avoid the predicted scarcity of oil must always be environmental compatibility.

The Potential for Oil and Gas on the Continental Margins of Argentina and Namibia

Since the opening of the South Atlantic during the break-up of the continent Gondwana about 150 million years ago, South America and Africa have continually drifted further apart. Sediments, several kilometers thick, consisting of the debris eroded from the continents have been deposited at the continental margins – off the coast of Argentina and Namibia at water depths of up to 5 km. It is suspected that oil and gas have formed in these sediments. Owing to the considerable water depths, these areas have been little explored by the oil industry and little can be said about the hydrocarbons potential. The only commercial accumulation, the Kudu gas field off Namibia, has not been fully explored, but may be expected to contain more than 100 billion m³ of gas and condensate.

BGR explored the hydrocarbons potential in the South Atlantic off Namibia in 1995 and Argentina in 1998/99. The ongoing evaluation of the data from the two geoscientific cruises is being carried out together with the governmental agencies and companies on both sides of the Atlantic as well as with other research institutes. A knowledge of the geological structures in the region is the basis of an understanding of the petroleum geology of the area. Information about the sediment strata and structures is being provided by seismic reflection surveys in the two areas.

Since there is little or no detailed information from borehole data about the sediments in the study areas, methods that provide only indirect information about the generation and distribution of oil gas have to be used. Sediment samples were taken from near

the seafloor and analyzed for natural gas constituents and the isotopic "fingerprints" of these gases. The evaluation of this data showed that hydrocarbons are being produced from the same source rocks on both sides of the Atlantic. On the South American side, mainly oil is being generated, on the African side mainly gas is being generated.

The formation, migration, and distribution of oil and gas in complex geological structures over geological time periods are being simulated with computerized models based on all available information. The simulations are being carried out to provide a basis for assessment of the hydrocarbons potential of the continental margins off Argentina and Namibia. For example, the depth of hydrocarbons generation along a geological cross section off Argentina is estimated in such a simulation.

Deep-seated Source Rocks for Natural Gas in Northern Germany

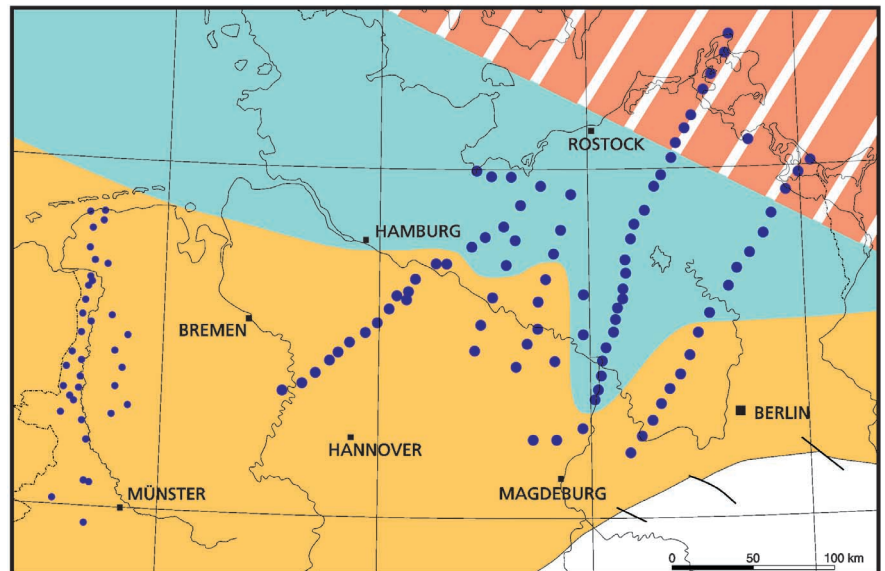
Methods that provide information about the distribution of certain physical properties of rocks at depth are often used for exploration of deep-seated structures from the ground surface. The magnetotelluric method is one of these geophysical methods; the natural electric and magnetic fields are measured to determine the distribution of electrical impedance in the ground. Deep-seated sediments are usually particularly good electrical conductors, i.e., they have very low resistivity. This is often due to their relatively high content of organic substances and/or iron sulfide. Natural gas is often generated in these black shales.

Magnetotelluric surveys in northern Germany in the 1960s and 70s demonstrated the presence of good conducting layers at depths of 6 – 11 km. At

first there was no definite information about what these layers were. In the 1980s it was determined that they are black shales. These rocks had not been taken into consideration by previous studies of the natural gas potential in northern Germany.

BGR has made magnetotelluric measurements at about 150 locations in northern Germany since 1993 to determine the regional distribution and depth of the black shales. The results (figure below) show that there are both areas with no black shales and those in which black shales are present at great depth. Especially the black shales identified in the southern part of the study area are possible natural gas source rocks. On the basis of its geochemical fingerprint, gas in the area around the

An alternative to crude oil exists already: natural gas. Since the use of natural gas began considerably later than that of oil, the proportion of gas reserves already consumed is much smaller than that of oil. Of the three fossil fuels, natural gas is the most environmentally friendly: With respect to energy yield, it emits the least CO₂. Transport cost is higher, however. For this reason, the market for natural gas is mainly regional, in contrast to the global crude oil market. Germany, as part of the European natural gas market, is in a rather favorable position. Large reserves are accessible in Norway, the Netherlands, Russia, the Middle East and North Africa. Conventional occurrences of natural gas in Germany are small and are considered to be all known. They would not be able to cover domestic energy demand of the next several years. BGR studies, however, indicate that natural gas may have been generated in deep, little studied sediments in northern Germany.



- Stationen magnetotellurischer Messungen
- Schwarzschiefer des Kambriums und Ordoviziums
- Schwarzschiefer des Dinant und Namur, potentielle Erdgasmuttergesteine
- Gebiet ohne Schwarzschiefervorkommen
- nicht erkundetes Gebiet

The distribution of black shale, a potential source rock for natural gas, in northern Germany as indicated by magnetotelluric surveys.

mouth of the River Ems was then shown to be from these black shales. This means there is an unconsidered potential for natural gas throughout the area of distribution of these black shales. This provides new incentives for exploration in Germany.

The more occurrences of natural gas and crude oil that are known, the more sophisticated the methods must be that are used to discover the few remaining occurrences. The high power computers available today make it possible to model geological structures three-dimensionally to depths of many kilometers. Greater demands are also being placed on our understanding of the mechanisms by which hydrocarbons are generated as well as their distribution at depth. BGR is working in this field on new concepts for improving the possibilities for hydrocarbons exploration.

Natural Gas Fingerprints

Natural gas is a mixture of gases, with methane as the main component; other components include ethane, nitrogen, and carbon dioxide. The proportions of the gases are determined by the kind of source rock, the conditions under which the gases were generated, and the formation history of the reservoir rocks. Besides the proportions of individual gases, the isotopic composition of the individual gases can provide information about the origin of a natural gas. BGR has been studying these isotopic "fingerprints" since 1997, together with the Jülich Research Center.

Natural gas source rocks are pyrolyzed in the laboratory and the amounts of methane, ethane, and propane and their isotopic compositions are measured. The results of these experiments now make it possible to predict the isotopic composition of natural gas in the reservoir rocks. This new method can be used to estimate the type of source and its depth on the basis of traces of natural gas at the ground surface. In turn, this can be used to develop strategies for exploration. In another application of this new method, the isotopic composition is used to reconstruct the evolution of a known gas accumulation in order to be able to target exploration for similar hydrocarbons prospects.

The amounts of gas in unconventional gas accumulations is suspected to be many times greater than that in conventional occurrences. Most of the

unconventional natural gas is in gas hydrate occurrences. Under certain pressure and temperature conditions, gas hydrates occur in the pores of rocks in a state similar to that of ice. These conditions occur in sediments in the oceans and in the polar regions. BGR is studying gas hydrate occurrences in all parts of the world and is developing methods for exploration for such deposits. Owing to the solid state of the gas hydrates in the rock, it is questionable whether the immense amounts of gas in these deposits can be made available for energy supplies. Many of the strategies for producing gas from gas hydrates would cause unacceptable environmental impacts.

At least in the first half of the 21st century, natural gas could replace crude oil as the most important source of energy for our societies. Like for crude oil, however, natural gas is available only in limited quantities. The Age of Petroleum was characterized by the rapid exploitation of a limited natural resource. Conversion to natural gas would be equally inconsistent with the concept of sustainable development. Besides the renewable energy sources, solar and wind energy, a promising alternative to fossil fuels is geothermal energy. In a pilot project conducted together with other research institutes and industry, BGR is developing new methods for the economic utilization of geothermal energy.

Geothermal Energy from Hot Dry Rocks

Geothermal energy is without a doubt the Cinderella of the renewable energy sources.

Available continuously, reliable, clean, day and night, summer and winter, for the most part out of sight it has provided electricity and heat for decades. It is a major factor for the energy supply in countries with recent volcanism, where hot water or steam is present at shallow depths. In countries like Germany, deep boreholes must be drilled to reach sufficiently high temperatures. In most areas the temperature increases by 30 °C for each kilometer increase in depth. Hence, every community has a supply of geothermal energy below it that could provide electricity and heat for the next thousand years. But this energy can be accessed only if the rocks at depth are permeable. Because optimal conditions are present at few sites, every geothermal borehole is a risk and its thermal capacity can be predicted only with considerable uncertainty. This is the main reason why the potential of geothermal energy has been little used.

If geothermal energy is to be used in Germany and other countries, a method must be available that permits production of heat from low permeability rocks in predictable amounts. A major step in this direction is frac technology (frac for hydraulic fracturing). This method from the petroleum industry has been successfully used in the last twenty years in hot-dry-rock (HDR) research to obtain heat from deep basement rocks (granite). Fractures are produced in the rock by high hydraulic pressure.

In the HDR project Soultz, this method was used to create a fracture system that when projected on a vertical plane has an area of 3 km². Two boreholes 500 m apart were connected via this fracture system. Water with a temperature of more than 140 °C has been produced in a circulation test from this heat exchange system. The heat produced over a period of four months corresponds to the annual electricity or heating needs of about 1000 households. To attain a higher efficiency for a power plant, one of the boreholes was deepened to 5080 m in 1998/99. The

201 °C temperature measured at the bottom of the borehole confirms optimistic predictions and is sufficient for efficient generation of electricity. A fracture system with an area of about 1.5 km² was produced at a depth of 4000 to 5500 m – one of the biggest and deepest frac operations in the world. The tectonic conditions in the Upper Rhine graben facilitate fracture generation and limit the required frac pressure to about 150 bar. The location and orientation of the fractures were determined with high precision on the basis of the acoustic seismic signals produced by the fracturing. The initial tests show that the new heat exchanger has favorable hydraulic properties in addition to the high temperature.

Two further deep boreholes are to be drilled in the next two years by a consortium of the power companies EDF and EDS (France), Pfalzwerke (Germany), and ENEL (Italy) and the oil company Shell. When the worldwide deepest HDR system is completed by further fracs, the new system can go on-line in about four years.



The geothermal plant at Soultz during a circulation test.

GeneSys – Utilization of Geothermal Energy in the Hannover Geocenter

The Renewable Energy Law went into effect on April 1, 2000. With this law it is planned to double the share of renewable energy in Germany by 2010.

Geothermal energy is one of the renewable energy sources. Heat pumps are already in common use to utilize the heat in near-surface ground layers. Geothermal energy in deep rocks is just beginning to be tapped. At present, only hot water sources are used. About 25 plants in Germany with a total installed capacity of 50 MW are powered by hot water up to 100 °C from depths of as much as 2500 m.

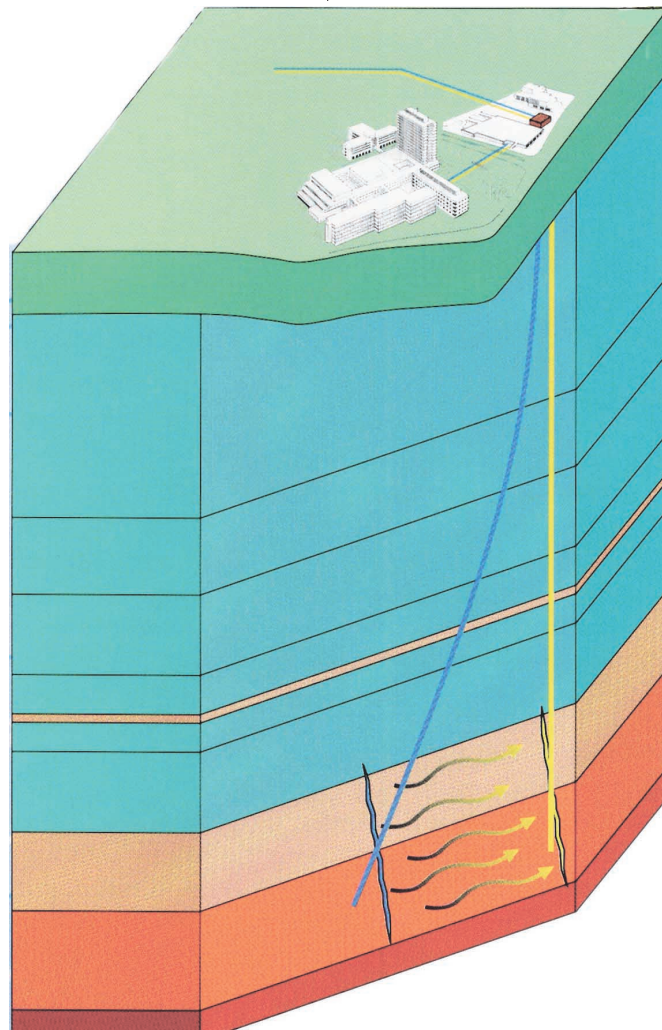
These hot water sources are used mainly for heating. Central heating plants have been shown to have the following advantages:

- They are highly reliable and are independent of the time of day or year.
- They use no fossil fuels.
- They have relatively low construction and maintenance costs, relative to other renewable energy systems.
- They are environmentally friendly and emit no environmental contaminants.

Whether conventional technology can be used to tap geothermal energy is dependent on the rock properties: A major requirement is high permeability. Boreholes must be drilled in order to determine these properties. Each of these boreholes is an economic risk. This risk can be minimized to a certain extent by geological and geophysical studies, but cannot be completely eliminated.

Studies by the Hannover Geocenter have led to concrete plans to utilize the geothermal potential at the Hannover site of the Geocenter. The preliminary studies have shown that the temperature at a depth of 3500 m is about 140 °C, which is sufficient for a heating plant.

Research on the hot dry rock method has been conducted by BGR, NLFb and GGA for twenty years. This method makes it possible to utilize the thermal



Three-dimensional sketch of the planned geothermal wells at the Hannover Geocenter.

energy in rocks with a low permeability. The proposal was made during the period of this report to investigate the Muschelkalk and Bunter horizons – at depths of 2800 to 3500 m at the Hannover site – with respect to the possibility of using them as a geothermal energy source. The expected temperatures lie between 120 and 140 °C.

Drilling of a 3500-m deep production well is to be begun in 2001 in a demonstration project "Generated Geothermal Energy Systems" (GeneSys). Preliminary work and permit applications were begun in 1999 and 2000.

In view of the limited amount of non-renewable energy resources, it is astonishing that so few limits are placed on energy consumption. The abrupt increases in the price of oil in the recent past have brought the question of the lifetimes and availability of energy resources to the attention of the public as well as the question of alternatives to fossil fuels. These are questions to which the geosciences can provide answers. These questions were dealt with by BGR in the study "Reserves, Resources and Availability of Energy Resources, 1998".

Natural Gas Discoveries in Bangladesh

Bangladesh has one of the highest population growth rates and lowest per capita energy consumption in the world. Energy demand has continually increased. Sufficient energy supplies are important for the development of the country and the living standards of its people.

Commissioned by the German government (BMZ), BGR has advised PETROBANGLA, the state oil company of Bangladesh, since 1977 and later its subsidiary BAPEX (Bangladesh Petroleum Exploration & Production Co. Ltd.). This work has focussed on the evaluation of the potential for oil and gas in northern Bangladesh. An extensive geophysical survey program was carried out together with Prakla Seismos GmbH. With the help of the BGR advisory group and a deep-drilling program financed by the German government, the Beani Bazar gas field was discovered. This field has more than three billion m³ gas reserves. In the following years three further fields (Fenchuganj, Jalalabad and Moulawi Bazar) were discovered. Together these fields have more than 50 billion m³ of natural gas reserves and more than two million tonnes condensate. BAPEX has also discovered the Shahbazpur gas field (more than 9 billion m³ reserves).

A new three-year phase of Technical Cooperation between BGR and BAPEX was begun at the beginning of the year 2000. The focus was on the training of

young geoscientists in petroleum geology and exploration geophysics. This included on-the-job training, as well as courses and seminars in Bangladesh and other countries. BAPEX management was also provided advice on improvements in organization structures and internal work flow. Support is also provided to BAPEX in the independent development of domestic gas fields as well as in their function as the Bangladesh partner for international oil companies operating in Bangladesh. Owing to the rapidly growing domestic demand for natural gas, the domestic reserves will be quickly exhausted if no new fields are developed. If the optimistic forecasts that new domestic fields will continue to be discovered as in the past since 1975 and the increase in production does not increase more than 3 – 6 % annually, Bangladesh will have sufficient domestic gas supplies for the next 25 years. Parallel to exploration and development of new fields, concepts for alternative energy sources have to be developed.

It is probable that in 20 years, petrol consumption of 10 km per liter (23.5 miles/gal) will be viewed as a waste of energy. The Petroleum Age will eventually end. What will replace it is only beginning to take form. BGR is making its contribution to securing the supply of energy resources for future generations.

The price for energy resources has been determined mainly by the market. The supply of energy resources is the responsibility of the private sector. The state provides the legal framework and the infrastructure, of which BGR is a part. A task of the BGR is to advise the German government, German industry, and partners in the threshold and developing countries. BGR has had considerable success in the energy resources sector within the scope of Technical Cooperation projects. For example, major natural gas deposits have been discovered during the many years of cooperation with PETROBANGLA, the state oil company of Bangladesh.

- BARTHEL, F. et al. (1999): Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen.– Bundesministerium für Wirtschaft und Technologie, BMWi-Dokumentation, 465: 62 S., ISSN 0342-9288; Bornheim (Chudeck Druck Service).
- CRAMER, B., FABER, E., GERLING, P. & KROOSS, B.M. (2000): Reaction kinetics of stable carbon isotopes in natural gas – new insights from laboratory pyrolysis experiments. – 19.04.00 subm. to *Energy & Fuels*, **15** (3): 16 p.
- , Gaschnitz, R., Krooss, B.M. & Gerling, P. (1999): Erdgas aus Kohle – Modelle zur Bildung und Isotopie. – DGMK Tagungsbericht, 9901: 43–53.
- EICKHOFF, G., HILLER, K. & REMPEL, H. (2000): Zukünftige Energieverfügbarkeit.– *Elektrizitätswirtschaft* **99**, 3: 47–51, 1 Abb., 1 Tab.; Frankfurt (Main).
- HILLER, K. (1999): Verfügbarkeit von Erdöl. – *Erdöl, Erdgas, Kohle*, **115**, 2: 50–54, 7 Abb.; Hamburg, Wien.
- (2000): Madagaskar Hydrocarbons. – BGR Rohstoffwirtschaftliche Länderstudien **XXII**: 23 S., 7 Abb., 1 Anl.; Stuttgart (E. Schweizerbart'sche Verlagsbuchhandlung)
- HOFFMANN, N., JÖDICKE, H., FLUCHE, B., JORDING, A. & MÜLLER, W. (1998): Modellvorstellungen zur Verbreitung potentieller präwestfälischer Erdgas-Muttergesteine in Norddeutschland – Ergebnisse neuer magnetotellurischer Messungen.– *Z. angew. Geol.*, **44** (3): 140–158.
- , – & GERLING, P. (2001): The distribution of Pre-Westphalian Source Rocks in the North German Basin – Evidence from Magnetotelluric and Geochemical Data. – *Geologie en Mijnbouw*; Dordrecht, The Netherlands. – (in press).
- KEHRER, P. & HILLER, K. (2000): Experience Curves in Exploration and Production of Petroleum.– In: WENE, C.O., VOSS, A. FRIED, D. (Hrsg.): Experience Curves for Policy Making – The Case of Energy Technologies.– Proc. IEA Internatl. Workshop, May 1999: 241–252; Stuttgart.
- & – (2000a): Erfahrungskurven bei der Suche nach und Förderung von Erdöl. – *Erdöl, Erdgas, Kohle*, **116**, 9: 427–430, 12 Abb.; Hamburg, Wien.
- REMPEL, H., KEHRER, P. & KRUSE, B. (2000): Der Kaspische Raum – Rohstoffwirtschaft im Schnittpunkt wirtschaftlicher und politischer Interessen. – *Z. angew. Geol.*, **46** (2000) 2: 110–118, 7 Abb., 3 Tab.; Hannover.
- SCHMIDT, S., GERLING, P., CRAMER, B. & NEBEN, S. (2001): Das Kohlenwasserstoff-Potenzial der konjugierenden Kontinentalränder von Argentinien und Namibia/Südafrika. – DGMK Tagungsbericht, Frühjahrstagung – Aufsuchung und Gewinnung –, 26.–27. April 2001; Celle.– (in press).
- WELLMER, F.-W. & BECKER-PLATEN, J.D. (Hrsg) (1999): Mit der Erde leben: Beiträge Geologischer Dienste zur Daseinsvorsorge und nachhaltigen Entwicklung. – XI + 273 S., 143 Abb., 40 Tab.; Springer Verlag Berlin, Heidelberg, New York.
- , BARTHEL, F. & HILLER, K. (2000): Fossil Energy Resources and Availability.– VDI Proc. World Engineers Convention EXPO Hannover: 245–267.

5



Soils

Soil is not renewable. This valuable resource must be protected so that a sustainable food supply can be guaranteed.

Salinization and erosion are problems that BGR investigates.



Soils

The significance of soils for sustainable economic development has increased during the last several years. Milestones have been the Rio conference in 1992, the UN convention for combating desertification, and – at the national level – the Federal soil protection law of March 1999. Reasons for increasing worries about the soil are, for example,

- the continuing sealing of the soil by building construction and roads,
- loss of valuable soil to erosion and compaction, and
- contamination of soils and groundwater.

Soils are acquiring further significance in connection with the climate discussion as source and sink of CO₂ and as an economic factor in connection with market globalization. The function of the soil as a filter is also becoming increasingly important, as expressed in the requirements of the European Water Directive, procedures for pesticide and fertilizer permits, and the amendments to the EU sewage sludge directive.

With all this in mind, BGR is continuing to evaluate information on soil use and protection in the FISBo BGR information system so that it can be used to advise the different levels of government. Emphasis in this work is

- the compilation of a 1 : 200,000 soil map of Germany in cooperation with the state Geological Surveys;
- further development of the 1 : 1,000,000 soil map of Germany by including land-use information and other soil-relevant parameters;
- development of thematic maps, e.g., in connection with the Hydrological Atlas of Germany;
- compilation of soil-relevant information and methods for the FISBo BGR information system; and
- improvement of the laboratory and soil profile databases used for these maps.

At the EU and international levels, BGR has been active in the development of indicators of soil degradation (especially erosion). Work on the establishment of the European soil information system EUSIS, coordinated by the European Soil Bureau in Ispra, Italy, was continued. This included work on the Georeferenced Soil Database for Europe 1 : 250,000. This database is being set up using a Manual of Procedures prepared by an international group of experts with BGR participation. This manual contains all work steps and methods for this digital atlas. One component of this manual is a 1 : 5,000,000 Soil Regions Map of Europe, which shows the most important soil regions in Europe.

The BGR focal field "Concentrations and Mobility in Soils and the Unsaturated Zone" has increased in importance with the recently issued Federal soil protection and contaminated sites regulations and expected European directives. These regulations require standardized databases at both the national and European levels and experience in the application of the required methods. Work on the determination of background values and migration of heavy metals in soils conducted within the scope of these measures requires a close networking of researchers in this field. Research on reactions in the soil concentrated on natural attenuation of contaminants and problems of salinization due to inappropriate land use.

BGR Contribution to the New Hydrological Atlas of Germany

BGR has contributed several maps at a scale of 1 : 2,000,000 to the Hydrological Atlas of Germany published by the Federal Ministry of the Environment coordinated by the Federal Institute for Hydrology and the Institute for Hydrology of the University of Freiburg. This new atlas provides up-to-date information, presenting basic and aggregated data, as well as giving an insight into the scientific methods used.

The first BGR contribution was the Soil Map, prepared from the existing 1 : 1,000,000 Soil Map of Germany (BÜK1000), showing the soil associations in Germany in 60 map units. The following thematic maps on soil water were also submitted in 2000: (a) Depth of the effective rooting zone; (b) Field capacity down to a depth of 1 m; (c) Available field capacity in the effective rooting zone; and (d) Air capacity in the effective rooting zone.

The CORINE Land Cover of the Federal Statistics Office, a digital land-use map derived from satellite data, from which mainly the areas of agricul-

tural and forestry land use were taken, was intersected with the 1 : 1 000 000 soil map to prepare the cartographic base map for the soil water maps. The values for the soil water parameters listed above were derived from soil texture, bulk density, and humus content and subdivided into five classes.

The soil-water parameters provide basic information about the capacity of the soil to retain water, the rate of drainage, and the plant-availability of the soil water. Together with climate data, conclusions can be drawn about the suitability of a site for a specific crop or the risk of lowered yield during dry periods.

The atlas makes it possible for the scientists, those involved in water management, politicians and lay persons interested in the environment to quickly recognize large-scale relationships and to access sources of further information. The maps can be used at the state, federal, and EU levels, providing valuable information in the fields of water and environmental protection.

Indicators of Loss of Soil on a European Scale

Soil degradation involves permanent, irreversible changes in the structure and functions of soils, eventually leading to soil loss. The European Environmental Agency (EEA) informs politicians and the public about the condition of the environment, including the extent of soil degradation. This was done in the past in cooperation with the European Topic Centre on Soil (ETC/S), in which BGR participates. ETC/S was established in 1996 for a period of three years.

The objective of the work coordinated by BGR was to develop indicators of soil degradation, i.e., parameters that can be measured simply and can be presented in tables, graphs, or maps. Within this project, the BGR contribution was indicators of soil degradation by erosion by water and of soil loss by the sealing of the surface by construction. Both processes lead to a nearly irreversible loss of soil and have increased to a threatening extent in Europe. The sealing problem is greatest in the countries of Central Europe; soil erosion by water is a particular problem in the Mediterranean region, and also some of the most fertile soils in Germany literally "go down the river" every year.



The badlands in the Jijona basin in the Valencia province of Spain are caused by erosion.

It must be possible to compare indicator parameter values. Comparability of data across Europe is inadequate for these soil problems at the present time. Indicators for Europe may be expected to be derived from satellite imagery. For the problem of sealing soil areas, the proportion of built-up areas and roads can be derived directly from remote sensing data. However, because such areas are not totally sealed, e.g., parks and yards, the remote sensing data must be supplemented by statistical surveys.

For the problem of erosion, a procedure has been developed in which soil cover is used as an indicator in areas vulnerable to erosion. Appropriate maps are being prepared by the European Soil Bureau. For the areas of these maps, the loss of soil to be expected is to be estimated by modeling and tested by monitoring selected observation sites.

The inclusion of the proposed indicators in monitoring programs opens the possibility to report on the extent of soil degradation and monitor the effectiveness of environmental protection measures. The indicators developed at the European level are also applicable at the national level for monitoring the environment.



Fertile soils are washed into the neighboring streams.

Background Values of Heavy Metals in the Topsoil

Threshold values are given in the Federal soil protection regulations for heavy metals. At concentrations above these values there is a danger of changes leading to impairment of the soil. The basis for these values is the natural background heavy metal concentrations. This information is stored in various databases of the federal and state governments and must be compiled and evaluated. BGR has developed a procedure for evaluating data from these different sources to derive background values for all of Germany. The point soil profile data are

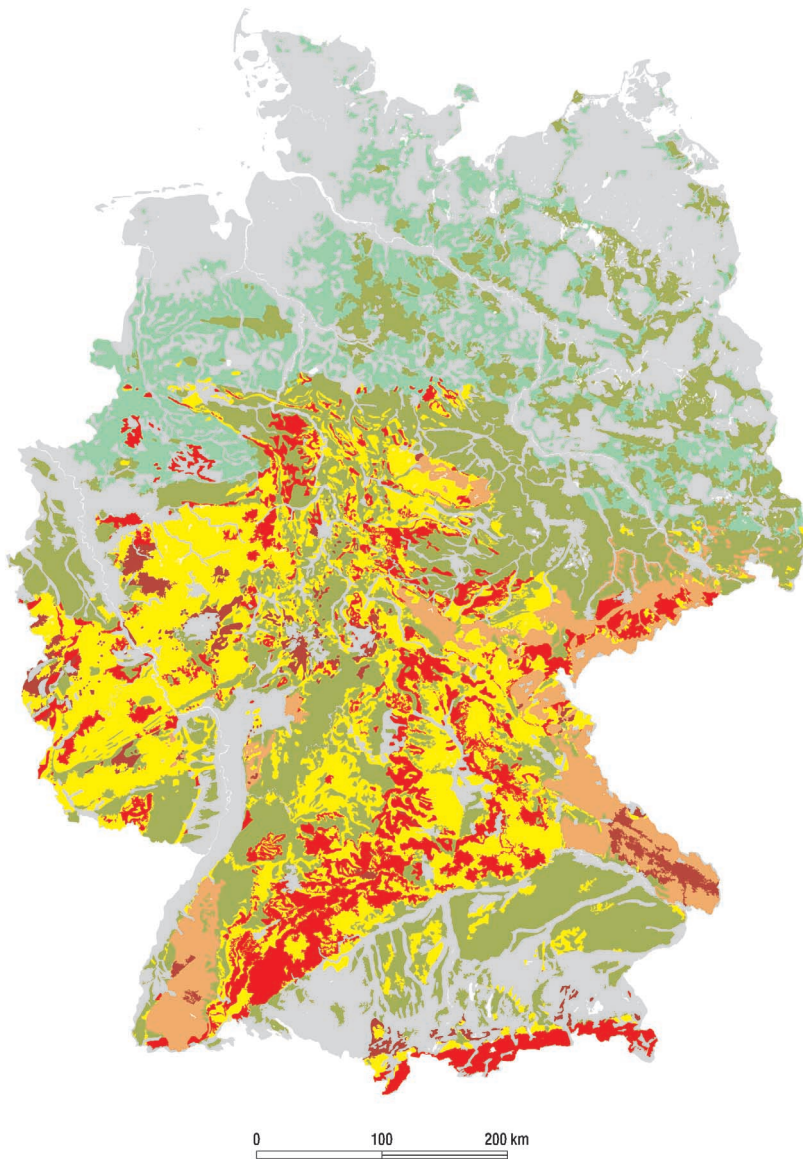
to be transformed into areal data for a 1 : 1,000,000 map.

This work has shown that background values can be derived for heavy metals in soils at intermediate and small scales using different sets of data from the federal and state governments. Prerequisite is a harmonization of the data, even if this involves a considerable reduction of the useable data. At the present time, background values can be derived from the harmonized data sets for about 67 % of the area of Germany.

Leaching of Substances from the Soil into the Groundwater

Contaminants can enter the groundwater from sandy soils in forests. Reliable predictions of the amount can be made only by taking the variation in soil properties and the atmospheric input into the soil. The extent and causes of variation have been objective of a BGR research project. To determine the physical and chemical properties of the soil at the study sites, soil samples were taken along a 10 m long, 1.5 m deep section and analyzed in the laboratory. The data were used for model simulations of soil leaching.

To determine the migration of substances under real conditions, measurements were made along two parallel 10 m profiles in a forest on sandy soil. pH and redox potential, as well as matric soil water potential and water content (vol. %), were monitored with a spacing of 50 cm down to a depth of



Hintergrundwerte Cadmium [mg/kg]

■ ≤0,4
 ■ >0,4 - 0,6
 ■ >0,6 - 0,8
 ■ >0,8 - 1,0
 ■ >1,0 - 1,2
 ■ >1,2
 ■ nicht bestimmt

Cadmium background values, taking land use and regional characteristics into consideration.

For further improvement with respect to soil protection, better data on the current soil conditions is needed. This is the case for Germany as well as Europe as a whole. Gaps in the data base that have been identified in the evaluations up to now at the national level are to be closed. Methods are to be developed

with which background values for subsoils can be derived from the available data. The amendments to the EU sewage sludge directive will necessitate similar work at the EU level, which will be coordinated by BGR in cooperation with the European Soil Bureau in Ispra, Italy.

140 cm. At the same places along the profile, soil solution samples were taken regularly and analyzed in the laboratory. To determine the complex interaction of the different parameters, a leaching experiment using bromide was carried out at the site. Bromide seldom occurs in the environment under natural conditions and is viewed as particularly suitable for this kind of experiment because it is not sorbed.

The data were used in a two-dimensional transport model to simulate the leaching experiment. The data from the leaching experiment and the analyses of the soil solutions showed that water does not flow through some parts of the soil, particularly below 0.5 m. This was not observed in the model simulations. Further studies are necessary to determine the causes of this behavior. The results of these studies can be used by water management authorities for well-based predictions and groundwater protection measures.



Study site in a pine forest on a sandy soil to study the flow of water and material transport.

Natural Degradation of Petroleum Hydrocarbons in Soil

Contamination of soil and groundwater with petroleum hydrocarbons is a common type of environmental contamination in Germany. Because it has also occurred on Federal property, BGR must acquire a knowledge of the long-term behavior of hydrocarbons in soils in order to be able to advise the ministries with respect to remediation measures.

Within the scope of scientific and technical cooperation with the Geological Institute of Hungary (MAFI), an accident with kerosene and diesel fuel in Hungary was investigated. A pipeline was damaged in 1995 near the village of Mikebuda (about 50 km SE of Budapest) and an unknown amount of diesel fuel and kerosene flowed over an area of about 1600 km² and percolated into the fine-grained Quaternary sand. At the spill site, soil cores have been taken at intervals of about six months since November 1997, the hydrocarbons

extracted and identified by gas chromatography.

The thickness of the hydrocarbons phase floating on the groundwater decreased as the groundwater table rose and increased as the water table fell. This means it is not possible to determine the amount of hydrocarbons underground via the thickness of the floating phase.

About three years after the accident, the maximum hydrocarbons concentration in the soil samples began to decrease: from 32,600 mg/kg in October 1998 to 7000 mg/kg in May 2000. This was probably due to pumping of the hydrocarbons phase several times each year.

Microbial degradation of the hydrocarbons is indicated by the decrease in n-alkanes (unbranched carbon chains, e.g., n-C₁₇H₃₆) relative to branched hydrocarbons (e.g., pristane), which are

more difficult to digest by aerobic microorganisms. At first (November 1997 to Mai 1998), this occurred mostly in the least contaminated parts of the soil. Later (October 1998 to May 2000), after the microorganisms had adapted, the situation was reversed.

A semi-log plot of the data shows that the hydrocarbons concentration decreases asymptotically. Natural attenuation by microbes without additional stimulation measures is a very slow process and does not lead to a complete disappearance of the hydrocarbons phase within several decades. In each case, whether the hydrocarbons can be tolerated over a long period of time must be weighed against the foreseen land use.

Causes and Dynamics of the Salinification of Soils in Western Paraguay

The groundwater in the western part of Paraguay (the Chaco), with a few local exceptions is highly mineralized. The groundwater table has risen in this region 2 – 2.5 m since the mid-1970s. The shallow fresh-water lakes have become salinized, vegetation has died due to salinization of the soil. The expanding salinization of the soil is endangering the existence of the farmers in the Chaco region.

The causes of the salinization of the soil associated with the rise in the groundwater table has been investigated in two Technical Cooperation projects since 1994. The influence of the extensive clearing of forests to make room for pastures was investigated. Measures to stop and reverse the expansion of salinized areas were an objective of the projects.

The salt dynamics in areas with similar soils with a depth to the water table of 1–3 m and with different land uses (natural thornbush and pasture) was studied. Observation stations were set up to monitor the weather, the groundwater table and the salt concentration at several depths in the soil and in the groundwater.

The data show that the groundwater table begins to rise only when the daily precipitation is more than 40 mm. This



Salinized lake in the central Chaco region.

is not unusual in the central part of the Chaco region. When saline water rises into the rooting zone via capillary action, the roots of the plants typical of pastures with a low-salt-tolerance are damaged. The clearing of large areas increases the problem, because groundwater recharge is higher in areas of pasture.

Measures to desalinate the soil that will rapidly take effect are not possible because there is very little lateral movement of the groundwater owing to the very low hydraulic gradient and the

clayey soil. One possible measure is to avoid clearing forests in areas where the groundwater table is less than 2 m deep.

Another measure is to increase the diameter of culverts of streams across which roads have been built so that salinized surface water can more rapidly drain from the area. More rapid drainage has the result that less water is available for recharge. When this is done over an expanded area, a further rise of the water table, and the further salinization of the soil, is avoided.

Further reading on this topic

- BUNDESMINISTERIUM FÜR UMWELT, NATURSCHUTZ UND REAKTORSICHERHEIT (BMU) (Hrsg.) (2000): Hydrologischer Atlas von Deutschland. – 1. Lieferung: 107 S.; Bonn.
- DEURER, M. (2000): The dynamics of water and solute flow in the unsaturated zone of a coniferous forest: measurement and numerical simulation.– *Horizonte* (Herrenhäuser Forschungsbeiträge zur Bodenkunde), **2**; Institut für Bodenkunde der Universität Hannover.
- , DUJINSVELD, W. H. M. & BÖTTCHER, J. (2000): Spatial analysis of water characteristic functions in a sandy Podsol under pine forest. – *Water Resources Research*, **36**: 2925–2935.
- UTERMANN, J. & DÜWEL, O. (2000): Räumliche und inhaltliche Harmonisierung von Datensätzen. – In: *Flächenhafte Darstellung punktbezogener Daten über Stoffgehalte in Böden*. – UBA-Texte 49/00: 65–74.
- & – (2000): Zur Ableitung von flächenrepräsentativen Hintergrundwerten für Schwermetalle im länderübergreifenden Maßstab. – *Bodenschutz* 3/00: 82–86.

6



Mineral Resources

Steel, sand and gravel are needed to construct buildings. Computers cannot be made without metals. Without sufficient raw materials, the diverse articles we use daily would not be available to the extent we are used to.

The basic needs of our society could not be satisfied without the geosciences.



Mineral Resources

Products for daily life are produced from a wide variety of mineral resources, e.g., metals from ores, cement from calcareous marl, and glass from sand and other materials. Agriculture also requires mineral resources: potash and phosphate are important fertilizers.

For most mineral resources, there is no danger of a scarcity in the short-term. Considering the population growth, however, and to supply essential resources for future generations, exploration for new deposits must be conducted or for deposits of alternative materials. This is a task of the geosciences and must take new technologies, product developments, and diversification of the mineral commodities supply into consideration. For our economy, it is necessary in order to guarantee the supply of strategic mineral resources whose deposits are concentrated in a few countries or those with short reserves lifetimes. The unavoidable environment impacts resulting from mining are a challenge for the geoscientist to find ways to minimize such impacts.

The challenges in the mineral resources sector are many-sided and varying in terms of the current demand situation, applications and availability, the medium-term development of demand, and the different quality requirements place on the mineral resources.

Material Flows and Energy Requirements for Production

In a study commissioned by the Volkswagen Foundation, the materials and energy balances were determined for the production of aluminium, chromium, iron, copper, manganese, nickel, phosphate, and hard coal. For this study, BGR investigated the amounts of backfill material, reagents, fresh water, additives, energy, and wastes (e.g., overburden, tailings, slag, sludge, and stack gases). The material balances for the metallurgical processing were determined by the Institute for Nonferrous Metallurgy of the University of Leoben.

The results of the study can lead to ideas for avoiding or reducing the amounts of materials and energy and how residues can be used. On the basis of the amounts of materials, the financial reserves required for restoration, renaturation, and safe deposition of toxic wastes can be estimated for the time when the mine is closed.

A second part of the study titled "Mineral Resources and Sustainable Development, conducted by the Environmental Protection Agency, deals with the economic aspects and international means for reasonable utilization of non-renewable resources.

Assessment Criteria for Industrial Minerals and Rocks

Industrial minerals and rocks are of great importance for the economic development of a country. Occurrences of these materials must be assessed with respect to the usability and workability of a deposit. This information is needed by the geologist, mining engineer, and regional planner. The most important criteria for the evaluation of an occurrence have been compiled by BGR in guidelines to aid decision-makers. Exact information of the chemical mineralogical and physical properties of a mineral resource is needed in order to determine which branch of industry can use it.

Guidelines have been prepared for clays, carbonate and sulfate rocks, quartz, and volcanic rocks. Guidelines for sand, gravel, crushed rock, dimension stone, and roofing slate are in press.

An adequate supply of mineral resources is also dealt with within the scope of Technical Cooperation with developing countries. The Geological Surveys in these countries are advised regarding geological mapping, exploration of occurrences, and development of the technological infrastructure needed to carry out their own investigations.

Nonmetallic Mineral Resources and Gold Analysis in Mongolia

The political and economic changes since 1989 have drastically affected the nonmetallic resources industry in Mongolia. The main reasons for the large decreases in production and for closing of pits are overcapacities, financial weakness of the companies, and the limited domestic market. On the other hand, nonmetallic mineral commodities and their products are imported in large quantities. Better information about the potential for mineral raw materials within Mongolia could make it possible to replace at least part of these imports by domestic products.

The objective of a project begun in 1999 is to make it possible for a Mongolian group to advise governmental agencies and the industry on the situation with respect to nonmetallic mineral resources. For this purpose, databases are being set up that are being continually updated. Advanced training is being

provided the project personnel, other staff of the Geological Survey, of the universities, the Academy of Science, and the private sector.

BGR has also set up a laboratory for the analysis of gold within the Central Geological Laboratory. The Mongolian personnel is now able to perform modern analytical procedures. The Central Geological Laboratory is thus able to work for private companies, providing an additional source of financing.

Modern thematic maps are important for an evaluation of the resource potential of a partner country in a Technical Cooperation project. Advising the counterpart on the preparation of such maps is a focal aspect of Technical Cooperation, e.g., in Ghana, Ivory Coast, and Guinea. The geology in these countries is favorable for the presence of mineral resource deposits.



Work-intensive production of bricks in a newly founded company.

Mapping and Advanced Training in Ghana, Ivory Coast, and Guinea

An area in southwestern Ghana that is considered prospective for nickel, platinum group metals, chromite, molybdenum, and kaolin has been mapped by the Ghanaian Geological Survey. Three geological maps have been edited and published together with BGR. Explanatory Notes for these maps were published, the first independently published volume of the GGS in the last twenty years.

The Geological Survey of the neighboring country Ivory Coast was advised on the mapping and collecting of geochemical samples in two areas totaling 6800 km². Three geological maps with Explanatory Notes have been published. The discovery of several areas with elevated gold concentrations led to the granting of five exploration licenses.

Staff of the Geological Survey in Guinea were provided advanced training within the scope of geological mapping. The most modern cartographic and computer methods were applied. Owing to a lack of a suitable topographic base map, a numerical terrain model was prepared using orthophotographs. Topographic contour lines and the stream network were entered in this model. Coordinates of infrastructure elements and geological sites were determined using GPS and entered in a field computer. The topographic maps were up-dated on a MS-NT server and printed. All of the data were stored in a database.

In these examples from West Africa, detailed geological maps were jointly prepared with BGR counseling. Such maps are indispensable for targeted exploration. Training in these modern methods make it possible for the counterpart experts to carry out such work in the future.

Supplementary courses in the respective country on basic aspects of modern geological mapping and resource utilization have been successfully carried out in several countries.



Entry of topographic and geological data into the field computer during geological mapping in Guinea.

Principles of Sedimentology

"Principles of Sedimentology" is a new course held in conjunction with Technical Cooperation projects. The course focuses on "Fundamentals of Sedimentology and Classification of Sedimentary Rocks", "Sedimentological Processes", and "Environmental Analysis". Laboratory practice in sedimentary petrography serve to strengthen the theoretical knowledge obtained in the course. Special courses, e.g., on carbonate rocks, claystones and siltstones, and excursions are held designed for the needs of the project in the respective counterpart country. Sedimentological studies are conducted to supplement the land-use planning and resource protection measures of the Technical Cooperation project.

Three courses in Nepal were held together with an analysis of the clay minerals in the Katmandu basin in support of the local ceramics industry. Two courses in Thailand were supplemented by a detailed analysis of carbonate rocks in terms of their use by the construction materials industry. A course was begun in Mongolia focusing on the possibilities for using clastic rocks. The course will be supplemented by a field seminar in 2001.

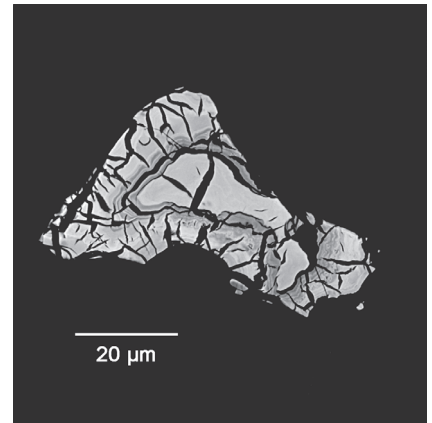
Work related to a diversification of the supply of mineral resources can be illustrated by projects being carried out on platinum group elements (PGE), strategic metals that with increasing demand show an oligopolistic supply structure (supply by only a few countries). The behavior of the PGE in endogenic and exogenic crustal processes, indicators of prospective areas, and deposit formation are inadequately known. Research is being conducted on these questions in several projects in several countries, illustrated by the following two examples.

Platinum Deposits in Zimbabwe

The PGE-rich "Main Sulfide Zone" (MSZ) in the Great Dyke region of Zimbabwe and the distribution of the PGE in exogenic processes are being studied. These studies are being supplemented by similar studies in South Africa and a study on the PGE distribution in chromite mineralizations in the Great Dyke.

The results for the MSZ show that platinum, palladium and nonferrous metals are stepwise enriched separately. Whereas palladium is present mainly in sulfides in the lower part of the MSZ, platinum occurs mainly in Pt minerals higher up in the MSZ. In the near-surface weathering zone, the PGE concentrations remain the same as below, but converted in part to the oxide and hydroxide. Thus, most of the platinum and palladium is not extractable by conventional methods. The PGE oxides are being characterized mineralogically to determine possible processing methods.

Characterization of the primary mineralizations in the MSZ will permit development of metallogenetic models for this and similar types of ores. For the first time, the behavior of the PGE in the migration from the endogenic to



Conversion of primary platinum minerals (light grey) to secondary platinum oxides and hydroxides (dark grey) in the oxidized Main Sulfide Zone.

the exogenic zones (from the sulfidic MSZ to the oxidized MSZ to the placer deposits) has been documented. The results of the study are of considerable significance for exploration for and exploration of PGE deposits, as well as for the production of the individual platinum group metals.

Platinum in the Mountains of Sabah

During exploration for platinum group minerals (PGM) in Sabah (northern Borneo) together with the Malaysian Geological Survey, two primary mineralizations and 19 enrichments were found in heavy mineral placers. All of the occurrences were in the area of the Palawan-Banggi-Darvel Bay ophiolite (accreted fossil oceanic crust).

The two primary occurrences are the palladium-rich PGM in the sulfides of the Mamut porphyry copper mine and an unusual enrichment of ruthenium-rich PGM (up to 5 ppm Ru) in chromium ores on the island Banggi. Most of the placers are dominated by osmium-iridium-ruthenium-rich PGM and similar to placers in Papua New Guinea. They

Deposits of Metallic Ores with Short Reserves Lifetimes in Southern Africa

A joint project of BGR and the Technical University of Berlin on the Sanyati polymetallic ore deposit in Zimbabwe and a project contracted to the Technical University Mining Academy in Freiberg led to the following results:

Structural studies and age determinations (Pb/Pb model ages of the ore of about 2100 Ma) show that the mineralization at Sanyati was formed before the folding of the deposit. The more than fifty secondary metal-bearing minerals in the oxidation zone document complex redistribution processes within the deposit. These processes were modeled.

New data on the relationship of deposits to the volcanic and sedimentary sequences was obtained in the Maranda mines in the Murchison Belt in South Africa. A new genetic model and concept for exploration of the deposit was developed and tested. Studies of the binding form of indium in the ores are expected to indicate possibilities for indium extraction.

These studies aid exploration for mineral resources by determining prospective areas and proximity indicators. They have been accompanied by environmental impact analyses, especially with respect to hazards resulting from mining.

were formed by erosion of various ophiolitic rocks. Three placers with a high enrichment of platinum-iron alloys – similar to occurrences in southeastern Borneo and the southern Philippines – were probably formed by erosion of an Alaska-Ural type intrusion.

The results of the investigations in Sabah and information on placers and the geology in the neighboring areas will be used to classify the PGM-bearing placers in Southeast Asia with their probable origins. This will provide important indications of the PGE potential throughout the region which can help target exploration for zones of platinum occurrences.

A further focus of BGR research is on deposits of metallic ores with short reserves lifetimes of about 25 years. Such ores include those of zinc, lead, and rare metals, such as indium and germanium.



Outcrop of the Sanyati deposit in Zimbabwe; Note the sparse vegetation, caused by the toxic concentrations of heavy metals.

Other BGR research involves experiments on the modification of a bulk raw material that has been overlooked up to now: hydrated unconsolidated volcanic rock. These experiments are expected to lead to the development of new products based on a raw material that may have worldwide distribution. They are part of a Technical Cooperation project with Ecuador.

Allophane: a New Raw Material for the Synthesis of Zeolite

In a Technical Cooperation project with Ecuador, allophane was discovered in an eluvial loam more than 5 m thick over an area of several 100 km². The parent rock of the loam is volcanic mud flow deposits. The loam contains more than 50 wt.% allophane, locally more than 80 wt.%.

Allophane is an amorphous clay mineral consisting of hydrous aluminium silicate with exceptional properties. The Al/Si ratio lies between 1 and 2;

the water content varies considerably. It contains no alkali or alkaline-earth ions, it dissolves readily, has a high specific surface, and can absorb large amounts of water.

To estimate the potential of the occurrence, eighty 15-m boreholes were drilled in Pichincha Province between February and June 2000. Allophane was identified on the basis of the loss-on-ignition between 40 and 700 °C.

A high-purity zeolite NaA was synthesized in BGR laboratories from the allophane, which has never been utilized before. Zeolite NaA is used, for example, in large amounts by the detergent industry as a ion exchanger. The new synthesis is being patented.



Drilling in allophane-bearing eluvial loam in Pichincha province in Ecuador.

Reports are published by BGR on the mineral commodities situation in selected countries in order to make our continually up-dated information more widely available. Work on these publications is concentrated on regions of special economic or political importance. In 1999 this was the Balkan region.

The political conflicts beginning in 1991 led to a disintegration of economic structures in the region. Reacting to this situation, BGR started Technical Cooperation projects with several of the Balkan countries.

The Balkans and its Mineral Resources

Reliable information on the mineral commodities situation in the Balkan countries is important for decisions about measures for the economic recovery in this region. Commissioned by the BMWi, BGR investigated the situation. The results are presented in of the publication series "Reports on the Mineral Commodities Situation in Selected Countries", Volume XVIII: The Balkan Region.

The political conflicts of the last ten years have led to a decline in the mineral commodities industry in the Balkan region. For economic development, an assured energy is of utmost importance. With the exception of Romania, which

has significant oil reserves, the region has a deficit of high-grade energy resources. They do have coal deposits, mostly low-quality lignite. Intensification of the coal industry with effective use of coal in thermal power plants is considered to be an important political task.

The metals industry in the Balkan countries has declined considerably since 1990, in part due to loss of markets. Possibilities for development, also for foreign investment, are seen only for chromite in Albania, copper in Yugoslavia and Albania, and lead-zinc in Bulgaria and Kosovo. The situation is viewed as relatively favorable for alumin-

um. The iron and steel industry is totally dependent on imports. For recovery and survival in the international marketplace, mining and processing operations must be modernized. For this, the economic policies of the respective countries must create conditions conducive for the engagement of foreign companies.

An important economic aspect in the Balkan countries – especially in the internationally supported reconstruction of the infrastructure in Bosnia-Herzegovina, Kosovo, and Yugoslavia – is the development of the construction materials industry, providing possibilities for the participation of German and other foreign companies



Centers of the mineral commodities industry in the Balkans.

- BURGATH, K.P. (1999): The Sanyati Ore Deposits in Zimbabwe: Petrography of ores and host Rocks. – In: OBERTHÜR, T. (Ed.): The Polymetallic Ore Deposits of Sanyati in Zimbabwe – Introducing a Recent BGR 2000 research project. – *Z. angew. Geol.*, **45**, 1: 9–11; Hannover.
- (1999): Der albanische Mirdita-Ophiolith und seine PGE-Anreicherungen. – *Mitt. Österr. Mineral. Ges.*, **144**: 23–44.
- & SALINAS, R. (2000): The Condoto Complex in Chocó, Colombia: A Pt-bearing Alaskan-type Intrusion. – *Z. angew. Geol.*, SH **1**: 163–170; Hannover.
- , STRIBRNY, B. & MOHR, M. (1999): Platingruppen-Element-Variation in Lamprophyren, ultrabasischen Vulkaniten und Erdmantel-Fragmenten des südlichen Oberrheingebietes (Deutschland). – *Beih. Europ. J. Min.*, **11**: 45.
- DILL, H.G. (1999): Chemical and mineralogical composition of fine-grained Palaeogene shelf deposits in northern Germany. A tool to identify key elements of sequence stratigraphy. – *Zeitschrift für geol. Wissenschaften*, **26**: 385–408; Berlin.
- (1999): Die Vorkommen oberflächennaher Rohstoffe im Kathmandu-Tal, Nepal – Ein Überblick über ihre Entstehung und ihre ungewöhnlichen Abbauformen. – *Steinbruch und Sandgrube*, **92**: 25–30; Hannover.
- , BOSSE, H.-R. & KASSBOHM, J. (2000): Mineralogical and chemical studies of volcanic-related argillaceous industrial minerals of the Central American Cordillera (western El Salvador). – *Economic Geology*, **95**: 517–538; Lancaster, USA.
- & PÖHLMANN, H. (1999): Phasenanalytische Untersuchungen des anorganischen Mineralbestandes von Kohlen verschiedener Inkohlungsgrade und Bildungsräume (Deutschland). – *Glückauf*, **60**: 92–98; Essen.
- & WEHNER, H. (1999): The depositional environment and mineralogical and chemical compositions of high ash brown coal resting on early Tertiary saprock (Schirmding Coal Basin, SE Germany). – *International Journal of Coal Geology*, **39**: 301–428; Amsterdam.
- , –, BOTZ, R. & DULTZ, S. (2000): Chemical logging of continental-marine depositional system. A tool to unravel the palaeogeography and diagenetic alteration of fine-grained clastic rocks in a transitional environment of deposition (Triassic-Liassic, Southeastern Germany). – *Chemie der Erde*, **60**: 129–171; Jena.
- MELCHER, F. (2000): Base metal – platinum group element sulfides from the Urals and the Eastern Alps: characterization and significance for mineral systematics. – *Mineralogy and Petrology*, **68**: 177–211.
- , GRUM, W., THALHAMMER, T.V. & THALHAMMER, O.A.R. (1999): The giant chromite deposits at Kemirsai, Urals: constraints from trace element (PGE, REE) and isotope data. – *Mineralium Deposita*, **34**: 250–272.
- , PUHL, J., MALI, H. & MEISEL, T. (1999): Chromite and platinum-group element mineralization in ultramafic rocks of the Speik Complex, Eastern Alps. – In: Stanley, C.J. et al. (Eds.): *Mineral Deposits: Processes to Processing*: 739–742; Rotterdam (A.A. Balkema).
- OBERTHÜR, T. (Ed.) (1999): The polymetallic ore deposits of Sanyati in Zimbabwe – introducing a recent BGR 2000 research project. – *Zeitschrift für Angewandte Geologie*, **45/1**: 2–21; Hannover.
- & KOCH, H.-P. (1999): Ore mineralogy of the Sanyati ores, and some geochemical considerations on supergene element redistribution. – *Zeitschrift für Angewandte Geologie*, **45/1**: 7–9; Hannover.
- , RAMMLMAIR, D. & KOJONEN, K. (2000): Comparison of automated particle search techniques for platinum group elements (PGE) and minerals (PGM): μ -XRF and electron-microprobe. – In: RAMMLMAIR, D. et al. (Eds.): *Applied Mineralogy*: 375–377; Rotterdam (A.A. Balkema).

- WEISER, T.W. & GAST, L. (1999): Mobility of PGE and PGM in the supergene environment at Hartley Mine, Great Dyke, Zimbabwe – a case study. – In: STANLEY et al. (Eds.): Mineral Deposits: Processes to Processing: 763–766; Rotterdam (A.A. Balkema).
- –, –, WITTICH, C. & KOJONEN, K. (2000): Mineralogy applied to the evaluation and processing of platinum ores of the Main Sulfide Zone, Great Dyke, Zimbabwe. – In: RAMMLMAIR, D. et al. (Eds): Applied Mineralogy: 379–382; Rotterdam (A.A. Balkema).
- STIBRNY, B., WELLMER, F.W., BURGATH, K.P., OBERTHÜR, T., TARKIAN, M. & PFEIFFER, T. (2000): Metallogenic and economic aspects of conventional and unconventional PGE Mineralizations. – Mineralium Deposita, **35**: 260–281.
- WELLMER, F.W., BERNER, U., HUFNAGEL, H. & WEHNER, H. (1999): Carbon Isotope Geochemistry of Archean Carbonaceous Horizons in the Timmins Area – Economic Geology. – Monograph, **10**: 441–456.
- & DALHEIMER, M. (1999): Trends und Perspektiven der Rohstoffversorgung Deutschlands im 21. Jahrhundert. – In: SLABY, D. & BREZINSKI, H. (Hrsg.): Rohstoffwirtschaft im Prozess der Transformation. – Freiburger Forschungshefte 05 (Wirtschaftswissenschaften): 11–52.
- & – (2000): Rohstoffe und Energie – Auswirkungen der Globalisierung auf die Versorgungssicherheit Deutschlands. – Erzmetall, **53**: 385–397.
- & NEUMANN, W. (1999): Bewertung und Akquisition von Lagerstätten. – Glückauf Forschungshefte: **60**, 4: 98–106.
- & WAGNER, M. (2000): Rohstofftrends am Beginn des 3. Jahrtausends. – Erzmetall, **53**, 10: 569–582.

7



Exploration of the Marine and Polar Regions

The marine and polar regions contain inestimable amounts of natural resources. During field work when exploring the geology of Spitsbergen, BGR participates in international research projects and contributes to maintaining the consultative status of Germany within the scope of the Antarctic treaty.



Exploration of the Marine and Polar Regions

The continental margins are of immense significance for the living habitats of the Earth. About 80 % of the world's population lives in the coastal zones. BGR conducts research on the natural resources and potential hazards along the continental margins. The objectives depend on the history of the evolution and the structures of the respective study area. The following examples show some of the scientific and application-oriented results.

As hydrocarbon accumulations on land become more scarce, production wells have been drilled in increasingly deeper water in the offshore areas of the passive continental margins. An extremely important target of future research will be the natural resources potential of the passive and active continental margins. Exploration of the continental margins will be a major contribution to future supplies of oil and gas. Industrial exploration extends at the present to water depths of about 2000 m. BGR research is meant to provide a basis for extending exploration to areas that are difficult to access and areas that have not yet been developed, improving estimates of global resources.

The History of the Opening of the South Atlantic and its Significance for its Hydrocarbons Potential

The passive continental margins of the volcanic type and the transitions to the nonvolcanic type provide information for scenarios for the generation of oil and gas in regions of deep water. Marine geophysical surveys and deep-sea boreholes in the last twenty years have shown that two very different kinds of passive continental margins are formed at the beginning of the spreading process when a continent breaks apart.

The nonvolcanic margins are characterized by a relatively thin crust with tilted blocks and sedimentary rift grabens. The crust of a volcanic continental margin is characterized by a thick sequence of lavas (seaward-dipping reflectors) underlain by several kilometers of lower crust with very high concentrations of mantle minerals. These magmatic units were emplaced shortly before the continental spreading. The lava sequences very often correlate with magnetic anomalies. It is not yet understood what parameters are important for

whether a volcanic or nonvolcanic passive margin is formed. It is of special interest how the hydrocarbons potential is influenced by these yet unknown parameters.

The research cruise BGR98 focussed on an area off the Argentinean coast in which the different types of continental margins could be studied within short distances. On the continental slope in the southern part of the study area, five sequences of lava were identified. Thus, the magmatic material was erupted in several phases and not in a single event like in the northern part of the study area. This form of volcanism in several phases is possibly a transition to the nonvolcanic margin further south, as indicated by the lack of correlation with the magnetic anomalies in that area.

These studies form the basis for basin analyses, which are used to test models and scenarios for the formation of hydrocarbon accumulations in deep-water regions.

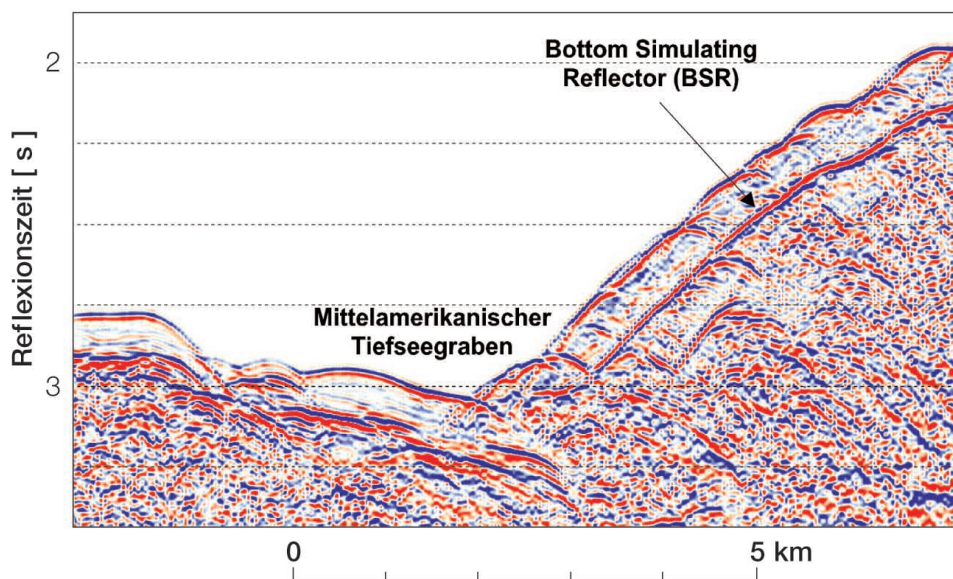
Submarine Gas Hydrates: The Active Continental Margin of Costa Rica

Gas hydrates are solid substances in which a gas, usually methane, is caged physically, not chemically bound, within the cavities of a crystal lattice of water molecules. These substances are stable under the high pressures and low temperatures of the deep sea, where they occur in a state similar to that of ice. The process by which they are formed and the regional distribution are not completely understood. It is conservatively estimated that the amount of hydrocarbons in gas hydrates is at least double that in conventional occurrences of fossil fuels. It is also not known what the effect on the Earth's climate would be if the methane (which is a major greenhouse gas) in these clathrates were suddenly released into the atmosphere. Sudden destabilization of a hydrate layer may initiate submarine slides and tsunamis.

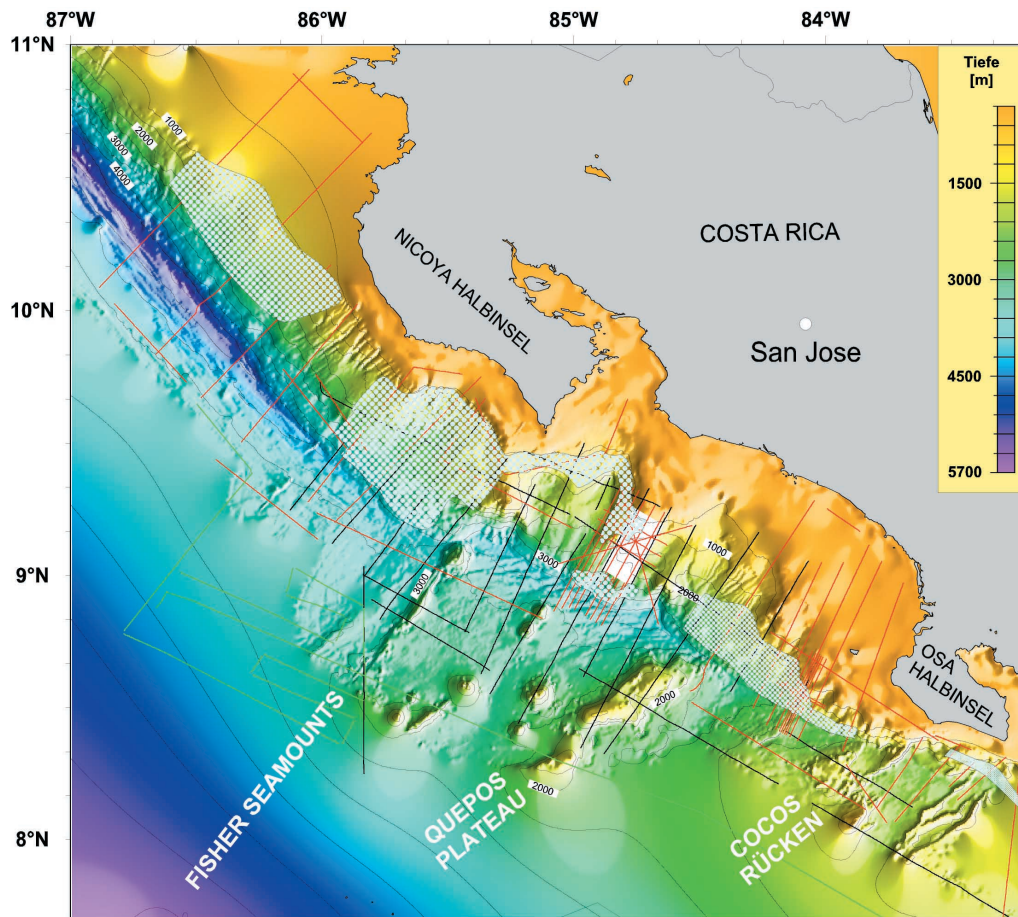
The presence of gas hydrates is often indicated in reflection seismic records by special reflections called bottom simulating reflectors (see figure below). The depth of these reflectors is determined by the gradient of the temperature-depth profile below the seafloor. They are produced by the transition from the solid gas hydrate phase to the underlying free gas, in which the seismic waves have a lower velocity. BGR has found bottom simulating reflectors indicating gas hydrates on many marine geophysical surveys of active and passive continental margins and in some cases taken samples.

On the active continental margin in the Pacific off Costa Rica, BGR has conducted three two-dimensional and three-dimensional seismic reflection surveys. The data from these surveys is

being specially studied with respect to gas hydrates. From the seismic signals, lithological parameters are to be determined, and a reservoir model of this kind of unconventional deposit is to be developed. The mapping showed that the bottom simulating reflectors cover an area of about 7700 km². The results of the international Ocean Drilling Program have shown that 1 m² of seafloor underlain by gas hydrates contains about 800 m³ of methane at standard temperature and pressure. Thus, the gas hydrates off Costa Rica could contain about 6.2x10¹² m³ of methane.



Seismic record of the lower continental margin off Costa Rica; a distinct bottom simulating reflector can be seen just landward of the deep-sea graben, its reflection polarity is the opposite of a seafloor reflection.



Bathymetric map of the active continental margin off Costa Rica. The distribution of bottom simulating reflectors (indicating gas hydrates) is indicated by dotted areas.

Methane-bearing Cold Seeps off Java

BGR conducted a joint German–Indonesian project in the marine area south of Sumatra and Java in 1999 to investigate the geological structures along this active plate boundary. Of interest are the potential for utilization of this marine region and the hazards for the densely populated Sunda Islands. A seismic reflection survey during research cruise SO137 of the research ship Sonne revealed sediments more than 5 km thick. An anticline is recognizable in the seismic data, forming a high at one place. It is hypothesized that the genesis of the structure is related to a transform fault with the same curvature as the Sunda Island archipelago.

During the SO139 cruise, concentrations of methane 150 times above normal concentrations were measured in the seawater along the anticline off Java. These high concentrations are made possible by the high pressures

under 3000 m of water. Using an underwater camera designed for use in deep water, seeps of cold water ascending through the sediments carrying high concentrations of dissolved gases and solids were observed. Local, high densities of highly specialized mussels and tube worms aided the localization of the seeps. These animals utilize hydrogen sulfide and methane as energy source in symbiosis with methane-feeding bacteria. Their nutrient cycle thus has a significantly different basis than that of the known plant and animal kingdom. They occur only at such seeps. Calcium carbonate is precipitated when the cold water emerges from the seeps, as demonstrated by isotope analysis of the precipitate.

The seeps were observed in a zone about 300 m in diameter. A highly disturbed zone is observed at the top of the anticline in the seismic records. It is

assumed that this disturbed zone represents the pathways for ascent of the cold water. Analysis of the dissolved methane in the BGR laboratories showed that it is of bacterial origin. Pore water in the sediment indicates that some of the gas is from decomposed gas hydrates. The seismic records show that the gas is widely distributed in the survey area. Gas supplies cannot be produced from this source today, but could be possible in the future.

Research on the numerous geological processes in marine regions are viewed as a key to understanding many mineral enrichments in deposits on land. Such research also reveals previously unknown influences on, for example, climate. In the following example, studies are being conducted in an area in which processes are occurring on the seafloor that are considered to be leading to the formation of a phosphorite deposit. The

results are being used for modeling deposit formation in shallow marine areas, which also aid exploration for deposits on land. Especially the role of the sulfur-metabolizing bacteria, which link the carbon, nitrogen and sulfur cycles, raises further questions: What part do they play in climate development?

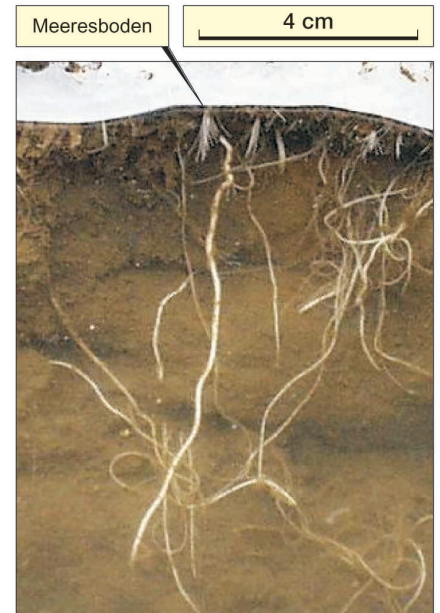
Large Bacteria in the Upwelling Zone off Peru

Bacteria are the governing factor in many geochemical processes. Bacterial participation is often postulated for chemical and mineralogical changes in marine sediments, but this is very difficult to demonstrate. Such participation by bacteria is hypothesized for the genesis of phosphorite, an important raw material for phosphate fertilizer. For this reason, the phosphorite widely distributed in the upwelling zone off Peru was studied during the SO147 cruise of the research ship Sonne in June 2000.

Seaward winds drive the warm surface water off Peru towards the West Pacific, causing upwelling of cold, nutrient-rich deep water, and increasing bio-production in the surface water. When the organisms die, the degradation of the organic material as it descends through the water uses up the dissolved oxygen in the deeper water. Below a depth of 50 m the water contains no oxygen and thus supports little or no life.

Certain bacteria have adapted to life under these conditions by utilizing sulfur as energy source. They form filaments up to 28 cm long extending several centimeters above the seafloor, forming dense mats of bacteria over hundreds of square kilometers. According to studies by the Max Planck Institute for Microbiology in Bremen, these bacterial mats consist mainly of *Thioploca* and *Beggiatoa* species. Their metabolism utilizes nitrate from the water and hydrogen sulfide from the sediment. The studies on board the Sonne show that these bacteria have a strong influence on the chemical reactions occurring at the sediment-seawater interface.

An ion chromatograph was used for the first time on board the Sonne to chemically characterize the sediment-seawater interface, making it possible to rapidly determine in unchanged form the substances in the seawater and sediment pore water that participate in the reactions. In the pore water several centimeters below the seafloor,



Sediment sample from the top 15 cm at a water depth of 100 m off Peru; the white filaments consist of large Thioploca and Beggiatoa bacteria.

phosphate concentrations three times normal concentrations were determined. Such elevated concentrations, probably derived from the bacteria, can lead to precipitation of the phosphate and the formation of phosphorite deposits.

Since the seventies, BGR has conducted land and sea expeditions to the Arctic. These expeditions are applied research in the forefield of industrial exploration. Within the scope of the Circum-Arctic Structural Events (CASE) program, BGR has investigated Tertiary deformation structures and volcanite provinces on the Arctic continental margins, a region that is of special interest due to its high potential for mineral deposits.

The Wegener Fault and the Nares Strait: Slip Zones between Two Oceans

The CASE campaigns in 1998 to 2000 in the Nares Strait were conducted together with the Canadian Geological Survey within the scope of Cooperation in Scientific Research and Technical Development.

During the Cretaceous, a large land mass, consisting of the present North America, Greenland and Eurasia, separated the developing Atlantic from the Canada Basin of the Arctic Ocean. At

the beginning of the Tertiary, two narrow basins (now the Labrador Sea and Baffin Bay) formed in this land mass connected by a system of transform faults. The largest of these faults created a connection between the Atlantic and the Arctic Oceans through the present Nares Strait. BGR seismic and magnetic surveys in the Labrador Sea indicate that this transform fault has an offset of more than 200 km. Field

studies on the Canadian side of the Nares Strait were then conducted to study the situation on land. The studied strike-slip faults are parallel to the Nares Strait and show sinistral movement, corresponding to the postulated transform fault. The individual faults are offset by a maximum of 20 km, the total offset of the fault system amounts to about 100 km. Whether the theoretically missing 100 km of offset in the Nares Strait is to be investigated with a marine seismic survey in 2001.

The opening of the Eurasian basin in the Arctic Ocean was preceded by volcanic activity on land during the Cretaceous. The volcanic rocks were analyzed by BGR and can be assigned to specific phases of development:

- From the Early Cretaceous until the earliest Late Cretaceous, oceanic-ridge basalts (lavas and dikes) were formed in several phases in the northernmost part of Canada. These basalts, together with similar volcanic rocks on the islands of Franz Joseph Land and Spitsbergen, probably belong to a large continental flood basalt province.
- Initial whole-rock age dating of alkali-volcanites on Ellesmere Island (Hansen Point Volcanites) and in northern Greenland (Cape Washington Group) indicate that there was active volcanism over several million years in both regions from the Late Cretaceous into the earliest Tertiary. This volcanism was probably associated with a branch of the large continental rift zone along which the seafloor spreading of the Eurasian basin of the Arctic Ocean began about 56 million years ago.

Other studies were conducted in areas of submarine and terrestrial permafrost. Among other things, questions about degassing and the effects on the climate during the recent past were investigated.



Field work on Ellesmere Island in the Canadian Arctic. In the foreground is a nappe of Paleozoic sediments thrust onto Cretaceous and Tertiary sediments.

Genesis of the Pockmarks in the Laptev Sea

Echo soundings of the Laptev seafloor off Siberia during BGR expeditions in 1994 and 1997 revealed circular rises several meters high and as much as several hundred meters in diameter. The origin of these "rings", called "pockmarks", is unknown. They could mark seeps of large amounts of gas or residual structures of old pingos or palsas or traces left by drifting ice. During the last glacial, the sea level dropped below the level of the Laptev shelf several times. During these times, deep permafrost formed. In warm times like today, the water depths were only a few decameters and the thickness of the permafrost layers decreased only slightly. Gases trapped in the permafrost during cold periods would have been released as the thickness of the submarine permafrost decreased during warm periods, migrating to the surface. This scenario supports the theory that the "pockmarks" were formed by gas breaking through the seafloor.



Borehole core from a frost mound; marine clay is fragmented by ice.



A fully developed frost mound and several others in various stages of collapse to a ring structure.

A further possible explanation for pockmarks is the special form of permafrost observed today on the east coast of Hudson Bay. In marine sediments on land newly formed by uplift, frost mounds form several meters high with diameters of several tens of meters. After several decades, at the end of their development, they collapse to ring structures. Such structures are being studied by BGR in cooperation with Laval University in Quebec, Canada. Seven boreholes were drilled in July 2000 in a mineralogenic palsa near Umiujaq, Nunavik, Quebec, on the east coast of Hudson Bay. The drill cores consist of a sequence of ice lenses with inclusions of clay fragments. The proportion of ice below the melted zone (about 1.5 m thick) is estimated to be about 80 %. A total of 45 temperature sensors and a pressure sensor were placed in six boreholes to monitor the temperature for at least twelve months and obtain indications of flow of water in the ice. This work should provide a better basis for deciding between the scenarios given above for the pockmarks in the Laptev Sea.

Geophysical studies of the oceanic crust are addressing increasingly complex questions. As a result, researchers are increasingly being confronted by the limits of two-dimensional interpretation methods. In seismic refraction studies, which are particularly suitable for investigation of deep-seated structures, large data sets cannot be processed by 3-D evaluation methods. The BGR seismics group has been able to develop a procedure enabling the three-dimensional analysis of extensive seismic refraction data sets. This is a prerequisite for seismic monitoring stations, for example, to better monitor global earthquake activity.

Seismic 3-D Tomography along the Ninety East Ridge in the Indian Ocean

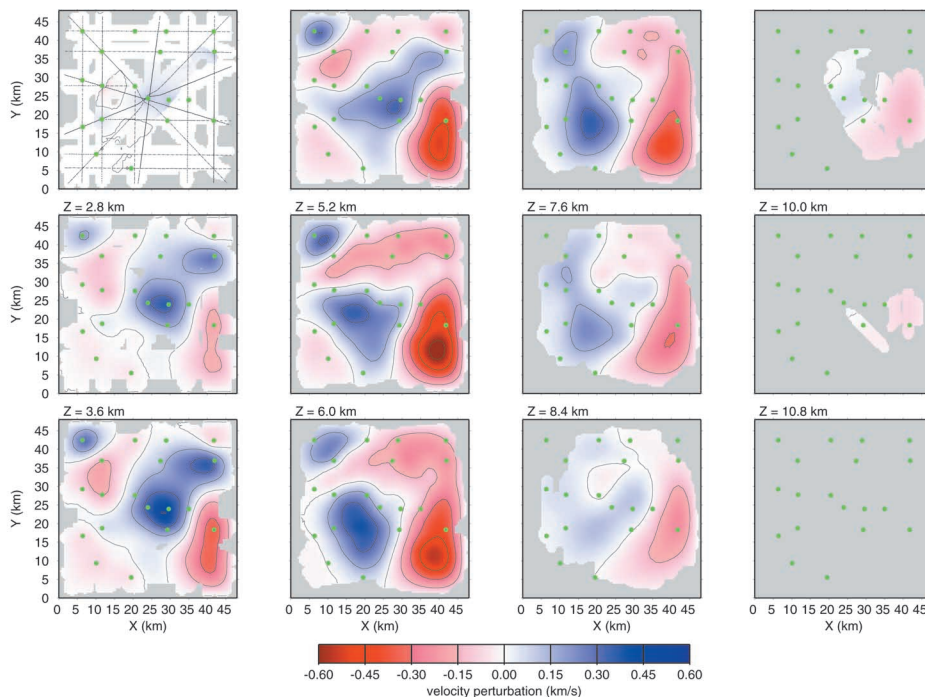
A mid-oceanic ridge extends for more than 5000 km along 90°E in the Indian Ocean, called the "Ninety East Ridge" due to its location. About 2000 km south of the equator, this ridge was the target of the SO-131 Sinus cruise of the research ship Sonne. An objective was the three-dimensional exploration of the area around a planned seismological station to be installed in a borehole on the seafloor.

In an experiment conducted by Geomar and BGR, the structures below the seafloor were surveyed in a manner similar to used for computer tomography in medicine: In a 50x50 km area, 24 ocean bottom hydrophones were placed on the seafloor. Seismic waves were produced by the BGR airgun array along closely spaced profile lines, producing more than 200,000 seismograms.

For the tomographic evaluation, the arrival time of the seismic waves had to

be determined in the seismograms. This is normally done manually on the computer screen. With the enormous amounts of data in this case, this is no longer practical. Therefore, a semiautomatic and fast procedure was developed by BGR using an appropriate filter to improve data quality. This made it possible to determine the first arrivals in the entire data set so that the data of the Sinus 3-D experiment could be used for three-dimensional tomography.

An example of the preliminary three-dimensional zoning of the seismic velocities is shown in the figure. The large variations in the structures below the seafloor can be seen even in this first model. These variations would cause large errors in the locating of earthquakes with data from the planning seismological station. Knowledge of these variations will considerably facilitate the determination of the station parameter values. The new procedure



Three-dimensional tomographic determination of the seismic velocities at different depths. The positions of the hydrophones on the ocean floor (green dots) and the airgun profiles (black lines) are shown at the top left.

will also make it possible to quickly and effectively process the increasingly huge data sets that are produced by the wide-angle seismic refraction method. This method, like reflection seismics, is being increasingly used in commercial exploration for three-dimensional surveys and tomographic analysis.

The activities of the BGR in the Antarctic are oriented to basic research and contribute to maintaining the consultative status of the Federal Republic of Germany in the group of Antarctic Treaty nations. Since this continent and its continental margins play a key role in the research of the formation and break-up of the Gondwana continent, important information is obtained about the other continents in the southern hemisphere (Africa, Australia, India, and South America), which were all part of Gondwana. In the austral summer of 1999/2000, BGR conducted its eighth GANOVEX expedition to the Transantarctic Mountains in northern Victoria Land and on the Oates Coast and George V Coast. Beginning in areas in which the rocks are exposed, the work was extended into areas nearly completely covered by ice and thus completely unexplored.

The Antarctic as Key to the Continents of the Southern Hemisphere

The Transantarctic Mountains, 3000 km long and 4000 m high, are the highest faulted-block mountains on the Earth. The causes of their formation and their relationship to the neighboring regions of the Ross Sea and the Antarctic Shield are largely unknown. Whereas BGR has extensive data for the Ross Sea area, there is little data for the Transantarctic Mountains and next to none for the East Antarctic side, the area of the transition to the Antarctic Shield.

To answer the questions about the structure of the mountains and that of the hinterland and transition to the shield area, a number of innovative applications of geoscientific methods were used during GANOVEX VIII:

- Numerous large strike-slip faults off Oates Coast offset the mid-oceanic ridge between Antarctica and Australia. These faults extend for more than 100 km in the direction of northern Victoria Land. Tectonic stress along old block (terrane) boundaries and the structural zones followed by the large glaciers were shown to be

effects of these faults on land. Earthquakes detected earlier in the areas of the Rennick and Matusевич glaciers demonstrate that these zones are still active. A relatively strong earthquake (magnitude 3) below the Rennick glacier was recorded during GANOVEX VIII.

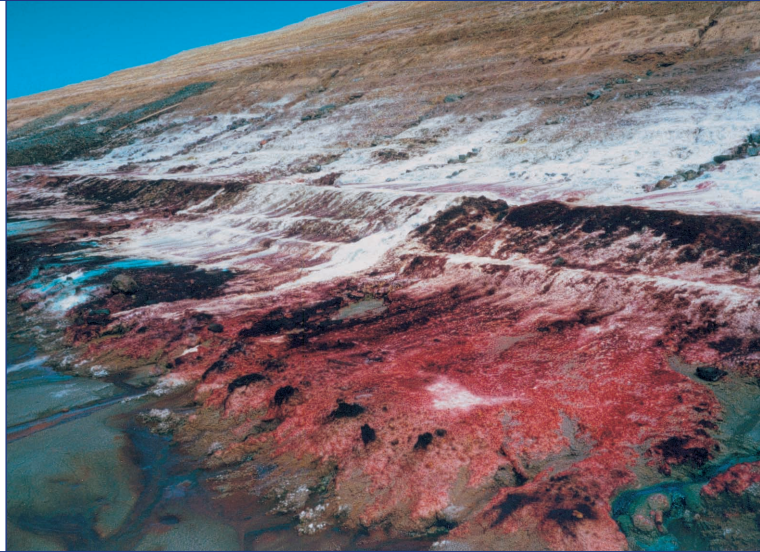
- Further to the west, rocks were found near Matusевич glacier that are interpreted as old ocean seafloor and which could mark an old active plate margin. This hypothesis is supported by an unusually strong magnetic anomaly extending 120 km along the glacier.

Analysis of the geological and paleomagnetic samples, the age dating, and the measurements of the gravity and magnet fields provide new information about the deep subsurface, about the transition between the old East Antarctic Shield and the younger mobile zones. The results permit conclusions to be drawn about the formation and break-up of large continents and the development of the continental margin off southern Australia.

Further reading on this topic

- BAUER, K., NEBEN, S., SCHRECKENBERGER, B., EMMERMANN, R., HINZ, K., FECHNER, N., GOHL, SCHULZE, A., TRUMBULL, R.B. & WEBER, K. (2000): Deep Structure of the Namibia Continental Margin as derived from integrated Geophysical Studies.– *J. Geophys. Res.*, **105**: 25.892–25.853.
- DAMASKE, D., BOZZO, E., MOELLER, D., FERRACCIOLLI, F. & CHIAPPINI, M. (2001): A new aeromagnetic survey along the Pennel, Oates and Georg V Coast (East Antarctica).– *Terra Antarctica Reports*, **5**: 1–11, Siena.
- HINZ, K., NEBEN, S., SCHRECKENBERGER, B., ROESER, H.A., BLOCK, M., GONZALVEZ DE SOUZA, K. & MEYER, H. (1999): The Argentine continental Margin north of 48°S: Sedimentary successions, volcanic activity during breakup.– *Mar. Petrol. Geol.*, **16**: 1–25.
- ROLAND, N.W., HENJES-KUNST, F., KLEINSCHMIDT, G. & TALARICO, F. (2001): Petrographical, geochemical, and radiometric investigations in northern Victoria Land, Oates Land and Georg V Coast: Towards a better understanding of plate boundary processes in Antarctica.– *Terra Antarctica Reports*, **5**: 23–45, Siena.

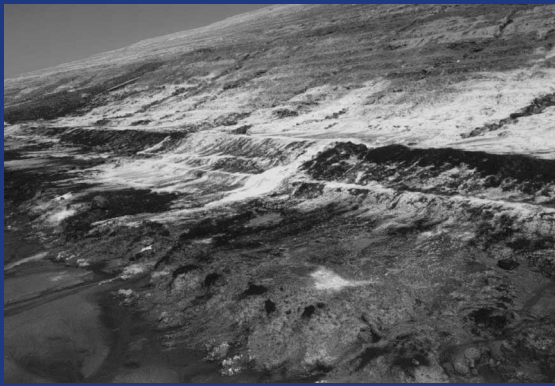
8



Protection of the Geoenvironment and Georesources

Resource and environmental protection are important considerations for the sustainable development of natural resources. Wastes from cyanide leaching, for example in Zimbabwe, must be avoided or disposed of in a nonhazardous form.

Strategies for avoiding pollution must take the dynamic behavior of the pollutant in different geological media into consideration.



Protection of the Geoenvironment and Georesources

Our environment can be affected by natural (geogenic) events and by human (anthropogenic) activities. In the quest for utilization of the geopotential for sustainable development and improvement of living standards, two questions arise: (i) What is the cause of an observed environmental impairment: geogenic or anthropogenic. (ii) What are the possibilities for investigating the problem and avoiding it. If the problem is to be correctly assessed, it is necessary to know the geogenic background values.

The following examples show the wide range of the work of BGR in this important field:

- Sensors for airborne investigations can be used to detect oil contamination.
- Bacteria and fungi can be used to remove heavy metals from waste water.
- Solutions to the problem of environmental contamination from mine waste heaps are being found.
- Simple measures can help reduce the hazards emanating from abandoned mines.
- Uses for residues from abandoned mines, waste heaps, and sludge ponds can be found.
- Recommendations for environmental protection and regional planning in developing countries contribute to the sustainable development of those countries.

Sensors for Airborne Investigations of Oil Contamination

Soil and groundwater are frequently contaminated with mineral oil products due to accidents. There has been a lack of suitable methods for monitoring areas of risk, for example, pipelines, transloading facilities, industrial plants, military exercise areas, and airports. Ground-based monitoring is expensive and often covers only part of the necessary area. Data from satellite or aircraft surveys has been ambiguous.

BGR has used the Australian 128-band HyMap scanner, one of the most modern sensors for aerial surveys, for research on methods to improve recognition of oil contamination. Whereas cameras for aerial surveys normally provide photographs in the visible light range (wavelengths between 400 and 650 nm), digital cameras (scanners) can provide images in non-visible ranges. Hyperspectral scanner divide the spectrum between 400 and 2500 nm into many narrow bands of about 10 nm. A complete hyperspectral recording consists of more than 100 congruent images. Certain combinations of images in different spectral ranges can be used to recognize certain types of rocks, soils and other materials, e.g., oil-contaminated soils.

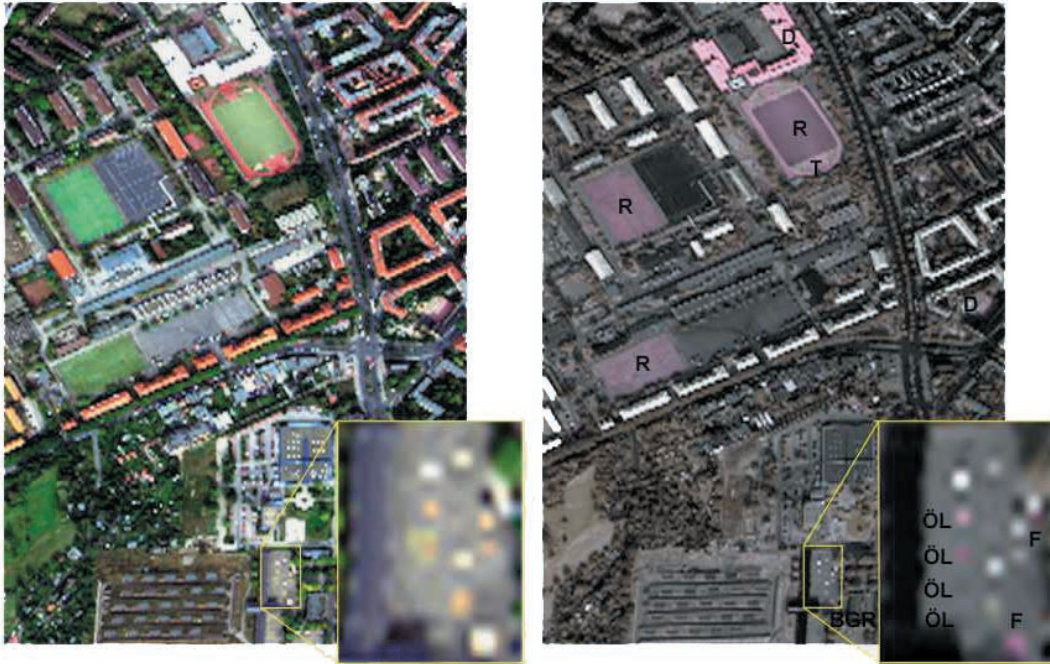
Test plots of 1 – 48 m² were set up on the BGR grounds in Berlin to obtain reference data. Some of the plots con-

tained materials mixed with mineral oil products. The objective was to determine the spectral signatures of the various materials in order to calibrate the method.

The flights with the HyMap scanner were made by the German Aerospace Center (DLR). The bands in the visible range were combined to composite images in nearly natural color (top, left).

The HyMap bands in the spectral range around 1710 nm were used to visualize oil-contaminated areas in false-color images (top, right). These bands contain the frequencies characteristic of the spectra of mineral oil products. Materials that contain hydrocarbons, e.g., oil-contaminated soils, all appear violet in the false-color images, other materials appear grey. Because mineral oil and plastics consists of hydrocarbons, they have identical spectral characteristics. A distinction between them can be made by comparing the spectral signatures in the visible range.

Hyperspectral scanners have made it possible for the first time to reliably recognize oil contamination of the ground in an aerial survey. The method permits rapid and unambiguous monitoring of vulnerable areas. The method can also be used in hydrocarbons exploration to find oil seeps.



left: HyMap color composite image in natural color made using three HyMap bands in the visible portion of the electromagnetic spectrum (VIS Bänder 16/R, 10/G, 3/B). The image shows an area in the Spandau district of Berlin that includes the Berlin Office of the BGR.

right: HyMap false-color image made using three HyMap bands in the non-visible portion of the electromagnetic spectrum between 1500 and 2500 nm. (ÖL) oil-contaminated soil, (F) plastic tarpaulin, (T) race tracks for light athletics, (R) artificial grass of sports fields.

Degradation of Cyanide and Biosorption of Heavy Metals in the Production of Gold

Bacteria and fungi include not only disease-causing germs, but also those that remove poisons from waste water from gold processing. The environmental disaster in Romania and neighboring countries in early 2000 drew attention to a problem associated with gold production worldwide: The cyanide in the waste water has to be removed before it is released into the environment. This is normally done using chemical processes, which have disadvantages due to the large amounts of chemicals required and the formation of toxic substances. Biotechnology is an alternative.

In a research project financed by the Federal Ministry for Education and Research (BMBF), BGR has done research in cooperation with the Institute for Mining Research (ICPM) in Baia Mare, Romania, on biological means of removing poisons from process wastes. Bac-

teria were isolated from waste water and sediments in the settling pond at Bozinta, Romania. Under suitable conditions (pH 8, 20–30 °C), these bacteria can decompose up to 520 mg cyanide per liter waste water within a few hours. The bacteria are fixed on zeolite columns for the purification process. Free cyanide can be used as a source of both nitrogen and carbon. To degrade thiocyanate, an organic source of carbon is needed. An organic source of carbon is also needed for the bacterial metabolism of the ammonia released during the metabolism of the cyanide and thiocyanate. Instead of expensive glucose, waste products from the soft drink and juice industries or molasses from the sugar industry can be used as the organic carbon source. If needed, inexpensive raw phosphate can be used as a source of phosphate.



Tailings pond for a gold processing plant.

Copper, iron, and zinc can be removed from the process water by sorption on fungal (*Aspergillus*) biomass. Decisive for the sorption of the metals is the substrate (apple juice, molasses, glucose) used as the organic source of carbon for the fungi.

The results up to now provide a good basis for the development of a biotechnological process. To convert the results of the experiments in shaking incubators, small-capacity fermenter, and glass columns, further studies will be necessary at larger scales in the laboratory and in the field.



Sample collecting

Microorganisms in Slag Heaps

Previously undescribed alkali-tolerant microorganisms were isolated from slag heaps. These organisms can mobilize metals from the materials they are contained in. Waste heaps often contain considerable amounts of residual metals that can be mobilized by natural chemical or microbiological processes, leading to contamination of soils and groundwater. It was previously assumed that mining spoil is populated by acidophilic, chemolithoautotrophic thiobacilla, which metabolize insoluble metal sulfides to soluble sulfates. Recent studies have shown that other groups of microorganisms can occur: aerobic and anaerobic bacteria and fungi, sometimes in high concentrations.

Microbiological studies of samples from a slag heap in Lower Saxony contained only heterotrophic bacteria and fungi. Most of them were previously undescribed alkali-tolerant strains, which were able to live in the slag heaps despite the very small amounts of organic carbon available (40 – 50 mg/kg dry material). Mainly sodium, calcium and magnesium, but also heavy metals, e.g., manganese, nickel, zinc, and cobalt, were mobilized by the isolated bacteria and fungi in the leaching tests. In contrast to chemical leaching, the bacterial experiments demonstrated selective mobilization. Electron microscope studies showed distinct erosion traces on the surfaces of the silicate particles, in contrast to the sterile controls. The microbially treated samples also showed a highly elevated proportion of fine-grained material on the surfaces, fissures, and pores of the particles.

Owing to the limited availability of dissolved organic nutrients in the slag heaps, the heaps do not represent a danger to the environment. The results of these studies, however, are significant for an understanding of the natural weathering processes at the surfaces of minerals as well as of crust formation and self-sealing of waste heaps.

These studies were conducted within the BGR Geomicrobiology Section by a guest scientist supported by the German Environmental Foundation.

Old Mine Heaps and Water Quality

The groundwater around mines and processing facilities is often contaminated by the seepage water from the associated waste heaps and dumps. For this reason, the Federal Ministry for Economic Cooperation and Development (BMZ) commissioned BGR to study the bacterial mobilization of metals in mine waste heaps and to find ways to minimize groundwater contamination in order to improve the water supplies of the local population.

Spoil and waste heaps are created by the mining and processing of metals. Some of the material in these heaps, which often have a size of several million cubic meters, contains low concentrations of the metallic ore. Seldom are remediation measures carried out on these waste heaps to integrate them into the landscape. As a rule, no measures are taken when the mine is shut down and the waste heaps are left to be affected by weathering. Rain water and residual water in the heaps dissolve metals and transport them into the surface water and groundwater. The metals in the waste are primarily mobilized by bacteria. The conditions under which bacteria mobilize the metals and other toxic substances and the extent to which this occurs is not very well known. The bacterial activity depends on the type of ore, the content of sulfides or oxides, the pH, the moisture content, and the availability of oxygen. The leaching processes are well known and are used at an industrial scale to recover metals from waste heaps. The same processes occur in old mine dumps, leading to contamination of the groundwater with toxic metals, lowering the groundwater quality downstream from the heaps.

BGR has studied mine waste heaps in a number of countries – with different metal contents and in different climate zones. Because bacterial leaching occurs mostly in sulfide ores, research has been concentrated on this kind of waste heap. Heaps in Zimbabwe, Namibia, Bolivia, Peru, and Kazakhstan have been studied. In all of the samples, bacteria were identified which mobilize metals from the material in the waste heap from which they were taken. The studies indicate that bacterial activity is influenced by climate and type of waste.

The samples were tested with respect to the presence of relevant microorganisms. The efficiency of the isolates and their significance for the mobilization of toxic substances from the waste heaps are being determined. Laboratory experiments will be carried out to determine the contamination potential of the different types of waste heaps with respect to climate, as well as to determine possibilities to inhibit or inactivate the leaching organisms.

The objective is to obtain enough information to predict the contaminant load on the basis of the type of ore and the climatic conditions and to determine the technological conditions needed to permanently minimize contamination of surface water and groundwater. The solutions will be adapted to the economic and social conditions in the developing countries. The developing countries are to be given the basis for treatment of their waste heaps.



1

2

3

Environmental pollution by acidic water

1: Waste dump at Caracota, Bolivia

2: Sampling of a waste dump at the Shamva Mine, Zimbabwe

3: Bolivar, Bolivia

The Potential of the Natural Environment in Eastern Paraguay

From 1997 to 2000, BGR worked together with the Department for Regional Environmental Planning (Dirección de Ordenamiento Ambiental) of Paraguay in a project on the potential of the natural environment in eastern Paraguay. Since July 2000, the new Ministry of the Environment (Secretaría del Ambiente) has been the counterpart.

The project objective is to document and evaluate the natural resources in three catchment areas in the eastern part of Paraguay. The results are to serve as a model for setting up an environment and resources oriented regional plan in order to promote an ordered development of the land use in the region.

Data on the geology, groundwater, surface water, vegetation, fauna, and soils, as well as the social and economic conditions in the pilot area have been obtained from reports and field work, evaluated, and presented on thematic maps at a scale of 1 : 100,000. All point and area data are being entered in an information system consisting of several modules. An analysis of satellite



Erosion and sedimentation.

images has been made to determine the remaining forested areas and compared with earlier studies.

This project is closely related to the completed project on the documentation, evaluation, and recommendations on the protection of the potential of the natural environment in western Paraguay (the Chaco region). In this region, supplementary studies were conducted on the causes of salinization of the soils and the consequences of extensive clearing of the land for the flora and fauna.

Namibia: Mining and Environment

Within the scope of a Technical Cooperation project with the Namibian Geological Survey and the Directorate of Mines, a study was conducted on the remediation of abandoned mines. Six of 23 mines that were visited in early 1999 were selected for the project. Geochemical, hydrochemical, and geotechnological methods were used for a study of five copper mines and one lead/zinc mine. Boreholes were drilled in the tailings impoundments and an aerial survey was made of the mine area to evaluate the remaining potential for mineral resources. The mine water was analyzed to determine its potential for the local drinking water supply.

The following measures were recommended to reduce the dangers emanating from the mines and to utilize the remaining resources:

Klein Aub and Oamites Mines:

- Construction of wind breakers at the tailings impoundments to reduce the blowing of dust in the village of Klein Aub and a military camp.

Fencing of sink holes.

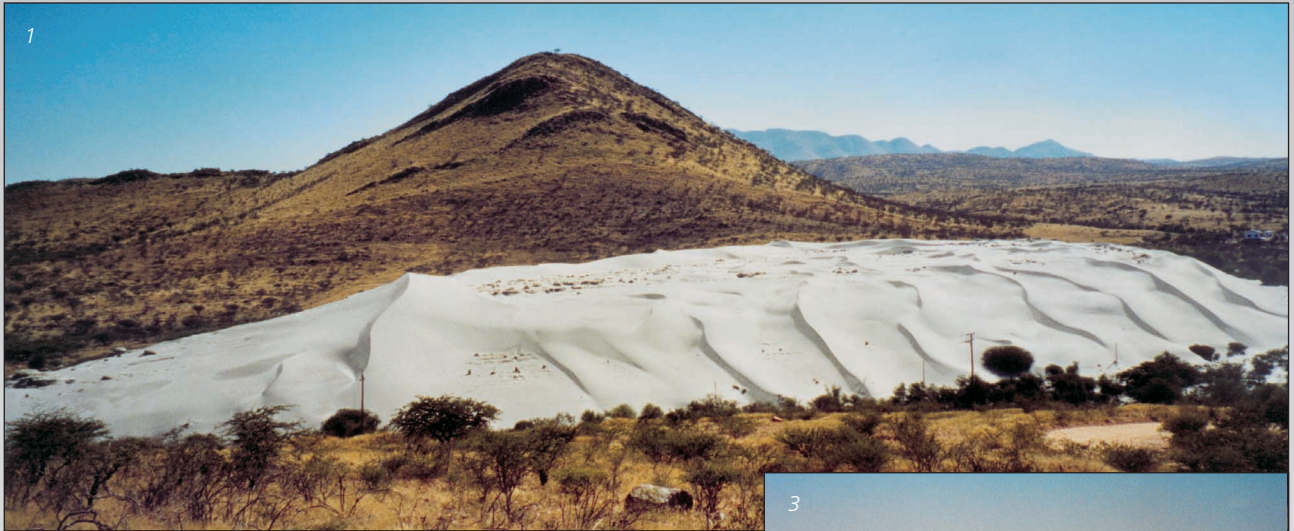
- Using the mine water (2.1 million m³) after appropriate processing.

Matchless Mine:

- Strengthening of existing earth dams and construction of a new dam to prevent water from escaping the tailings impoundment and the waste heap in order to prevent heavy metal contamination of the water in the Friedenau reservoir.

Namib Lead Mine:

- Tests to determine possibilities for utilization of the relatively high zinc and lead concentrations in the tailings impoundment.



- 1: Oamites Mine – Dunes and dust from tailings are a danger to the surrounding population
- 2: Matchless Mine – Insufficient retention of the metal-containing water
- 3: Namib Lead Mine – H residues
- 4: Khan Mine – Erosion of a tailings pond after heavy rains
- 5: Matchless Mine – Flow of heavy-metal-bearing water from a tailings pond

Colombia: Gold Mining and Environment

Gold has been mined in the Bucaramanga region since pre-Columbian times. There are about 25 active mines in the mining district today. Almost all of the processing facilities use simple, inadequate technology on a subsistence economy basis. In addition, more than 200 artisanal operations extract gold in the region. More than 3000 persons earn a livelihood from gold mining in the district, in which there are no other significant work possibilities.

The governmental agency responsible for the water supply has recognized the

dangers emanating from the mercury and cyanide used in the gold processing. The German government has been requested to help solve the problem.

BGR has worked with the Convenio Interadministrativo and the Ministry of Mines (MINERCOL) since 1997 to enable Colombian personnel to provide expert advice to the miners on the environmentally compatible processing of the gold. This has been done on-the-job training and advanced courses.

The project is directly affected by the security problems in Colombia. An

extension of the project to the end of 2000 was not sufficient to complete the work. The work is now concentrated on improving operations at two processing plants as examples for improving other plants. Two mine laboratories have been set up to monitor the processing plants and are to be managed by local personnel specially trained for this purpose. In the on-going project, sociologists will contribute to the success of the technological aspects.

Further reading on this topic

- BIRKE, M. & RAUCH, U. (2000): Urban Geochemistry: Investigations in the Berlin Metropolitan area, *Environmental Geochemistry and Health*.– Kluwer Academic Publ., **22**, No. 3: 233–248; Dordrecht.
- BITYUKOVA, L., SHOGENOVA, A. & BIRKE, M. (2000): Urban Geochemistry: A study of element distributions in the soils of Tallinn (Estonia), *Environmental Geochemistry and Health*.– Kluwer Academic Publ., **22**, No. 2, 173–193; Dordrecht.
- , SCHOLGER, R. & BIRKE, M. (1999): Magnetic Susceptibility as Indicator of Environmental Pollution of Soils in Tallinn.– *Phys. Chem. Earth (A)*, Elsevier Science Ltd., **24**, 9: 829–835.
- , BANKS, D., FRENGSTAD, B., SKREDE, A. K., KROG, J. R., STRAND, T., SIEWERS, U. & LIND, B. (2000): Grunnvann – ikke bare vann.– *Norges geologiske undersøkelse: Grasteinen 6*: 1–60; Trondheim.
- , FRENGSTAD, B., SKREDE, A. K. M., BANKS, D., KROG, J. R. & SIEWERS, U. (2000): The chemistry of Norwegian groundwaters: III. The distribution of trace elements in 476 crystalline bedrock groundwaters, as analysed by ICP-MS techniques.– *Sci. Total Environm.*, **246**: 21–40; Amsterdam.
- , HERRMANN, A. G., SIEWERS, U., HARAZIM, B., LODZIAK, J., WECK, H.-D. & STRASBURG, S. (2000): Die Herkunft von Haupt-, Neben- und Spurenelementen in Salzlösungen der Zechsteinevaporite Mittel- und Norddeutschlands. – *Glückauf*, **136**: 771–783; Essen.

- , REIMANN, C., SIEWERS, U., TARVAINEN, T., BITYUKOVA, L., ERIKSSON, J., GILUCIS, A., GREGORAUSKIENE, V., LUKASHEV, V., MATINIAN, N.N. & PASIECZNA, A. (2000) : Baltic soil survey: total concentrations of major and selected trace elements in arable soils from 10 countries around the Baltic Sea.– *Sci. Total Environm.*, **257**: 155–170; Amsterdam.
- , –, –, –, –, –, –, – & – (2000): The Baltic Soil Survey. – *Explore*, **107**: 1–7; Denver.
- , SIEWERS, U., HERPIN, U. & STRASSBURG, S. (2000): Schwermetalleinträge in Deutschland. Moos-Monitoring 1995/96. Teil 2.– *Geol. Jb., Sonderheft SD 3*: 1–121; Hannover.
- , BANKS, D., HALL, G., REIMANN, C. & SIEWERS, U. (1999): Distribution of rare earth elements in crystalline bedrock groundwaters: Oslo and Bergen regions, Norway.– *Applied Geochemistry*, **14**: 27–39; Oxford.
- , –, SIEWERS, U. SLETTEN, R.S., HALDORSEN, S., DALE, B., HEIM, M. & SWENSEN, B. (1999): The thermal springs of Bockfjorden, Svalbard: II : selected aspects of trace element hydro-chemistry. – *Geothermics*, **28**: 713–728; Amsterdam.–, MARKERT, B., WAPPELHORST, O., WECKERT, V., HERPIN, U., SIEWERS, U., FRIESE, K. & BREULMANN, G. (1999): The use of bioindicators for monitoring the heavy-metal status of the environment.– *J. Radioanalyt. and Nuclear Chem.*, **240**, 2: 425–429; Budapest.
- , MISUND, A., FRENGSTAD, B., SIEWERS, U. & REIMANN, C. (1999): Variation of 66 elements in European bottled mineral waters. – *Sci. Total Environm.*, **243/244**: 21–41; Amsterdam.
- , Reimann, C., Siewers, U., Skarphagen, H. & Banks, D. (1999): Does bottle type and acid-washing influence trace element analyses by ICP-MS on water samples? A test covering 62 elements and four bottle types: high density polyethylene (HDPE), polypropene (PP), fluorinated ethene propene copolymer (FEP) and perfluoralkoxy polymer (PFA). – *Sci. Total Environm.*, **239**: 111–130; Amsterdam.
- , –, –, – & – (1999): Influence of filtration on concentrations of 62 elements analysed on crystalline bedrock groundwater samples by ICP-MS. – *Sci. Total Environm.*, **234**: 155–173; Amsterdam.
- , THÖNI, L., KRIEG, F. & SIEWERS, U. (1999): Testing the Bergerhoff method to determine the bulk deposition loads of 49 elements. – *Atmospheric Environm.*, **33**: 337–344; Oxford.
- BLUMENROTH, P. & BOSECKER, K. (1999): Mikrobieller Abbau von Cyaniden in Prozesswässern der Goldgewinnung. – In: Wippermann, Th. (Hrsg.): *Bergbau und Umwelt*: 183–197; Berlin (Springer Verlag).
- BOSECKER, K. (1994): Mikrobielle Laugung (Leaching). – In: PRÄVE, P., FAUST, U., SITTIG, W., SUKATSCH, D.A. (Hrsg.): *Handbuch der Biotechnologie*, 4. Auflage: 835–858; München (Oldenbourg Verlag).
- (1997): Bioleaching: metal solubilisation by microorganisms. – *FEMS Microbiol. Rev.*, **20**, 591–604.
- & HAVELAND, C. (1999): The Sanyati ore deposit in Zimbabwe: Bioleaching of sulfide ore.– *Ztschr. Angew. Geol.*, **45/1**: 13–14.
- & RANKE, U. (1999): Verringerung der bakteriell bedingten Grundwasserbelastung von Bergbauhalden. – *Ztschr. Angew. Geologie*, **45/3**: 171.
- BUNDESMINISTERIUM FÜR UMWELT, NATURSCHUTZ UND REAKTORSICHERHEIT (BMU) (Hrsg.) (2000): *Hydrologischer Atlas von Deutschland*. – 1. Lieferung: 107 S.; Bonn.
- DEURER, M. (2000): The dynamics of water and solute flow in the unsaturated zone of a coniferous forest: measurement and numerical simulation.– *Horizonte (Herrenhäuser Forschungsbeiträge zur Bodenkunde)*, Bd. 2; Institut für Bodenkunde der Universität Hannover.
- , DUJINISVELD, W. H. M. & BÖTTCHER, J. (2000): Spatial analysis of water characteristic functions in a sandy Podsol under pine forest.– *Water Resources Research*, **36**: 2925–2935.
- GOMEZ, C. & BOSECKER, K. (1999): Leaching of heavy metals from contaminated soil by using *Thiobacillus ferrooxidans* or *Thiobacillus thiooxidans*.– *Geomicrobiol. J.*, **16**: 233–244.

- HERB, P., HAHN, L., BURGATH, K.-P., WITTICH, CH. & WOLFF, E. (2000): The gold mineralization of Bucaramanga, Colombia. – Implications to ore recovery.– In: RAMMLMAIR, D., MEDERER, J., OBERTHÜR, TH., HEIMANN, R.B. & PENTINGHAUS, H.: Applied mineralogy.– Proceed. Sixth Intern. Congr. Appl. Miner.: 345–348, ICAM 2000; Göttingen.
- HÖRIG, B. & KÜHN, F. (2000): HyMap Hyperspectral Remote Sensing to Detect Hydrocarbons. – Proceedings of the "Fourteenth International Conference on Applied Geologic Remote Sensing", 6–8 November 2000: 206–211; Las Vegas, Nevada.
- JUNG, H., TUFAR, W., RAMMLMAIR, D. & BOSECKER, K. (2000): Self-organization of a mining dump in the Freiberg mining district, Germany.– In: RAMMLMAIR, D., MEDERER, J., OBERTHÜR, TH., HEIMANN, R.B. & PENTINGHAUS, H. (Eds.): Applied Mineralogy in Research, Economy, Technology, Ecology and Culture, Proceedings of the 6th International Congress on Applied Mineralogy, ICAM 2000, Göttingen, Germany, 17–19. July 2000, **2**, 579–582; A.A.Balkema/Rotterdam/Brookfield (Publ.).
- NIEDERLEITHINGER, E., GRISEMANN, CH. & RAMMLMAIR, D. (2000): SIP geophysical measurements on slag heaps: A new way to get information about subsurface structures and petrophysical parameters.– In: RAMMLMAIR, D., MEDERER, J., OBERTHÜR, TH., HEIMANN, R.B. & PENTINGHAUS, H. (Eds.): Applied Mineralogy in Research, Economy, Technology, Ecology and Culture, Proceedings of the 6th International Congress on Applied Mineralogy, ICAM 2000, Göttingen, Germany, 17–19. July 2000, **2**, 607–610; A.A.Balkema/Rotterdam/Brookfield (Publ.).
- OBERTHÜR, TH., RAMMLMAIR, D. & KOJONEN, K. (2000): Comparison of automated particle search techniques for platinum group elements (PGE) and minerals (PGM): μ -XRF and electron-microprobe. – In: RAMMLMAIR, D., MEDERER, J., OBERTHÜR, TH., HEIMANN, R.B. & PENTINGHAUS, H. (Eds.): Applied Mineralogy in Research, Economy, Technology, Ecology and Culture, Proceedings of the 6th International Congress on Applied Mineralogy, ICAM 2000, Göttingen, Germany, 17–19. July 2000, **1**, 375–378; A.A.Balkema/Rotterdam/Brookfield (Publ.).
- RAMMLMAIR, D. & MEYER, L. (2000): Crust formation: Via column experiments to mathematical modelling.– In: RAMMLMAIR, D., MEDERER, J., OBERTHÜR, TH., HEIMANN, R.B. & PENTINGHAUS, H. (Eds.): Applied Mineralogy in Research, Economy, Technology, Ecology and Culture, Proceedings of the 6th International Congress on Applied Mineralogy, ICAM 2000, Göttingen, Germany, 17–19. July 2000, **2**, 641–644, A.A.Balkema/Rotterdam/Brookfield (Publ.).
- & Grisse mann, Ch. (2000): Natural Attenuation in slag heaps versus remediation.– In: RAMMLMAIR, D., MEDERER, J., OBERTHÜR, TH., HEIMANN, R.B. & PENTINGHAUS, H. (Eds.): Applied Mineralogy in Research, Economy, Technology, Ecology and Culture, Proceedings of the 6th International Congress on Applied Mineralogy, ICAM 2000, Göttingen, Germany, 17–19. July 2000, **2**, 645–648; A.A.Balkema/Rotterdam/Brookfield (Publ.).
- & – 2000: Natural Attenuation of slag heaps, less remediation. – In: SÁNCHEZ, M.A., VERGARA, F. & CASTRO, S.H. (Eds.): Waste treatment and environmental impact in the mining industry: 415–426; University of Concepción.
- , MEDERER, J., OBERTHÜR, TH., HEIMANN, R.B. & PENTINGHAUS, H. (Eds.) (2000): Applied Mineralogy in Research, Economy, Technology, Ecology and Culture, Proceedings of the 6th International Congress on Applied Mineralogy, ICAM 2000, Göttingen, Germany, 17–19. July 2000, **1**, 1–460 and **2**, 461–1048; A.A.Balkema/Rotterdam/Brookfield (Publ.).
- SMITH, A. & MUDDER, T. (1991): Chemistry and Treatment of Cyanidation Wastes.– Mining Journal Books Ltd.; London, England.
- UTERMANN, J. & DÜWEL, O. (2000): Räumliche und inhaltliche Harmonisierung von Datensätzen.– In: Flächenhafte Darstellung punktbezogener Daten über Stoffgehalte in Böden. UBA-Texte, **49/00**: 65–74.
- & – (2000): Zur Ableitung von flächenrepräsentativen Hintergrundwerten für Schwermetalle im länderübergreifenden Maßstab. – Bodenschutz, **3/00**: 82–86.

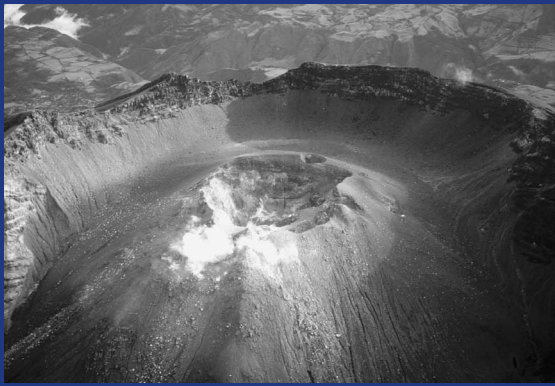
9



Geological Hazards

Natural disasters can be expected in all parts of the globe. Population density often increases the disastrous effects. The Galeras volcano in Colombia represents a considerable geohazard.

BGR researches geomechanisms in order to estimate the risks emanating from geohazards.



Geological Hazards

The basic natural resources necessary for human life are placed under the protection of the state by the constitution of the Federal Republic of Germany. Geohazards, such as landslides, earthquakes, volcanic eruptions, and floods, can endanger human life. Such natural disasters cannot be prevented, but measures can be taken to minimize their effects.

Research on geohazards by BGR contributes to a limiting of the damages caused by these natural disasters. Besides minimizing the effects on the people immediately affected, such research is of considerable economic importance.

Research on the complex relationships that lead to natural disasters involves a wide range of scientific disciplines. The examples given here are from BGR Technical Cooperation projects. They include research on prediction of volcanic eruptions in Colombia and estimation of the risk that a natural landslide dam in Tajikistan or a glacial lake dam in Nepal will burst.

The Multiparameter Station on the Galeras Volcano in Colombia

The monitoring of a volcano and predicting an eruption are comparable to the monitoring and predicting the weather. Volcanic "weather" is the turbulent flows of magma and hot gases in the chambers and channels within a volcano. In contrast to the weather in the atmosphere, "volcanic weather" is not directly visible. Conclusions must be made on the basis of measurements made from the ground surface. The most important signals that can be measured are

- seismic emissions from the flowing magma and gases,
- volcanic earthquakes,
- temperature and concentrations of gases emitted from fumaroles,
- acoustic emissions from the fumaroles,
- variation of surface temperature with time, and
- variation of the electric and magnetic fields.

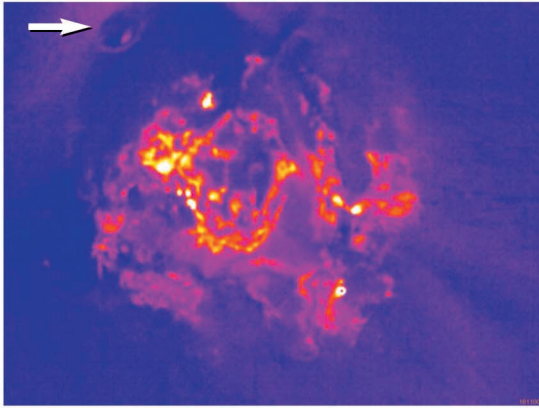
Together with the Geological Survey of Colombia (INGEOMINAS), BGR has developed a multiparameter station and installed it on the active Galeras volcano (elevation 4300 m). Analogous to a weather station, the various signals from the volcano can be measured simultaneously. The station uses sensors

installed in the crater (e.g., seismometers, gas probes, electric and magnetic field sensors, and infrasonic sensors). The data is radioed continually to the volcanic observatory in the city of Pasto, at the foot of Galeras, where it is analyzed. The temperature in the crater is measured at regular intervals with a sensitive thermal camera.

The distribution of surface temperatures within the crater is shown in the thermogram on page 108. It can be seen that at numerous places it is hotter than the surrounding background. This is due to the flow of hot gases or hot water in near-surface fissures. Especially the areas immediately around fumaroles are hotter due to the emitted vapors. An increase in temperatures is an important indicator of the ascent of magma and increasing degassing of the magma.

The turbulent flow of magma and gases in the near-surface chambers and channels generate various physical and chemical signals that are detected by the sensors of the multiparameter station. The values, patterns, and energies of these signals are important indicators of the state of activity of the volcano and the probability of an eruption.

Two examples are shown in the figure (right): the seismic *tornillo* signals and the recently discovered gas oscillations.



Thermogram of the Galeras crater and (bottom) an aerial photograph of gas emissions from fumaroles: The arrows mark the locations of the Pinta crater as reference. The colors red, yellow, and white indicate lower to higher temperatures. The thermogram was recorded on November 16, 2000, by a thermal camera installed on a helicopter.



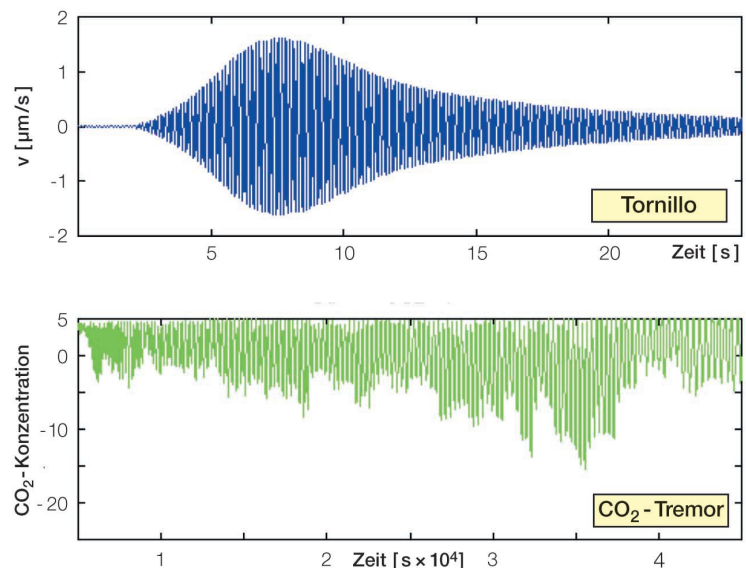
between the concentrations of radon and CO_2 . These measurements within short time intervals are important for interpretation of the dynamic processes within the volcano.

The most important results of the Galeras project are

- the installation and continuous operation of a multiparameter station on the 4300 m Galeras volcano under difficult conditions (e.g., thunderstorms, hurricane winds, extreme temperature fluctuations, highly corrosive atmosphere);
- development of a probe for measuring gases emitted from fumaroles at short intervals;
- observation of oscillations in the gas emissions;
- the use of thermal photography to map temperatures in the crater;
- interpretation of tornillo signals (important for prediction of eruptions) as resonance in gas flows.

tion signal. The tornillo signal is recorded by a wideband seismometer installed at the edge of the crater. A decrease in the frequencies of the tornillo signal are an important prelude to an eruption. The tornillos result from oscillations of gas-filled cavities caused by shock waves (an analogy is the sound produced by blowing across the mouth of an empty narrow-neck bottle).

Until recently it was a problem to continuously measure (e.g., at intervals of a few seconds) of the concentrations of various gases emitted by fumaroles, e.g., radon, CO_2 , and CO_2 . This is important because the gas emissions from fumaroles can be correlated with the seismic signals only if both are sampled at approximately the same intervals. A gas probe developed by BGR can measure at a sampling rate of several seconds. With this probe installed at an active fumarole on Galeras, new phenomena have been observed, such as oscillations in the concentration of CO_2 in the fumarole vapors and a correlation



Top: Seismogram of a tornillo signal.

Bottom: Oscillations with a frequency of 3–4 minutes in the concentration of CO_2 in the gas emissions of a fumarole, measured with the new BGR probe.

Expansion of the data base from the multiparameter station, correlation of the measured signals with the visually observed activity of the volcano, and interpretation of the signals by numerical modeling of the flow of magma and gases within the volcano – the Galeras project is opening new possibilities for monitoring volcanoes and predicting eruptions.

The Usoi Landslide Dam: Is the Largest Dam in the World in Danger of Bursting?

A strong earthquake in the Pamirs of Tajikistan in 1911 triggered a landslide containing about 2 km³ of rock that buried the village of Usoi in the Murghab valley, creating a dam across the river, backing up a lake about 60 km long and 500 m deep, containing about 17 km³ of water. If this natural dam were to break, the flood waters and debris flow would wipe out the villages in the immediate downstream valleys and endanger up to five million persons in four countries. For this reason, the UN/IDNDR Secretariat embarked on a new study in 1998.

To study the problem, an international team of nine experts was formed to study the following aspects:

- disaster risk assessment,
- monitoring and early warning systems,
- effect on the local people,
- effect on the floral and faunal diversity,
- geomorphological effects,
- possibilities for access roads to the dam.

An engineering geologist from BGR belonged to the international UN/IDNDR team as head of the “Disaster Risk Assessment” group. The task of this group was to estimate

- the stability of the dam with respect to the pressure of the lake water on the dam and the flow of water through the dam;
- the danger of a landslide into the north side of the lake, with the accompanying wave and rise in lake level;
- the stability of the dam with respect to a strong earthquake, which often occur in the region.

Nine experts,

It was found that the stability of the dam and mountain slopes around the lake are by far the most important aspect. Any measures taken to prevent or minimize a disaster depend on the stability assessment. The results of a one-week visit to the dam and lake area (elevations between 3000 and 4000 m) yielded the following results with respect to the engineering geology aspects:

Lake Sarez (elev. 3260 m) and the camp of the monitoring team; the landslide dam is seen in the background (marked by the dashed line); the source area of the landslide can be seen to the right of the dam.





South end of the Usoi dam, showing the mixture of fine-grained and very coarse-grained angular material.

- The dam itself is highly stable, even in the case of a strong earthquake. Failure of the dam due to water pressure is extremely improbable. A conclusive assessment can be made, however, only when the results of the investigation of the internal structure of the dam are available.
- The only realistic danger appears to be from a slope above the lake which is considered to be instable. If a landslide occurred at this location, a potential 2 km³ of rock could slide

into the lake, causing an enormous wave that would overflow the dam, which rises a minimum of 50 m above the lake. This could cause a breach in the dam that could be enlarged by erosion, leading to uncontrolled emptying of the lake.

- During the visit to the potential landslide slope, it was seen that there are at least three different kinds of mass movement. The observations indicate that the probability for a relatively shallow landslide is con-

siderably greater than that for a deep-reaching one. Thus, the future studies must be made in considerably more detail with modern engineering geology methods.

The results of the UN mission have been presented in Volume 1 of the new "ISDR Disaster Prevention Series". On the basis of the recommendations in this volume, new studies have been begun by a private consulting firm.



Lake Sarez from the mountain slope on the north side looking towards the dam; the landslide source area can be seen on the right side of the dam. The extensometers installed to monitor movement of the slope are visible in the foreground.

Long-term Monitoring of the Thulagi Glacial Lake

Owing to the high precipitation rate during the monsoon and the constant flow of melt water from the Himalayas, Nepal has a considerable potential for hydroelectric power. The development of this source of electricity is associated with a number of risks, however. Foremost among these risks are glacier lake outburst floods, which can develop into devastating debris flows. Such floods can reach as far as 100 km in the downstream valleys.

BGR has been studying the danger of a glacial lake outburst flood from Lake Thulagi since 1996, commissioned by the Nepal Electricity Authority (NEA) and the Kreditanstalt für Wiederaufbau (KfW). The outlet stream is the Dona Khola, which flows 12 km downstream into the Marsyangdi. There are three medium-sized hydroelectric power plants already built or in the planning stages on the Marsyangdi River.

The climate in the Himalayas has become distinctly warmer in the last several decades and the glaciers have retreated a considerable distance. The Thulagi glacier on the southwest slopes of Mt. Manaslu (elev. 8169 m) in central Nepal has retreated about 2.2 km since



The downstream end of Thulagi glacier lake and the natural dam, which has a slowly melting ice core. The dark areas are thermokarst features: ponds formed by collapse of the ground after local melting of permafrost.

1950. At the foot of the glacier (elev. 4000 m) a melt water lake has formed with a depth of 80 m and a water volume of 32 million m³.

The lake is dammed up by dead ice covered by up to 30 m of sediment, as demonstrated by BGR using ground-penetrating radar in 1996. Thus, the

dam does not consist of a wall of loose moraine material, as is usually the case for other glacier lakes. Such relatively unstable terminal moraines have often failed in the past. The usual failure mechanism can be excluded at Thulagi.

A detailed monitoring program was worked out and recommended to the Nepalese so that unpredictable developments that would increase the risk can be recognized. This program takes into consideration all the hydrological, glaciological and engineering geological aspects of the Thulagi glacier lake system.

Commissioned by the KfW and in cooperation with the NEA and the Department of Hydrology and Meteorology, BGR began monitoring in November 2000. The measurements are to be repeated every two years. The following measurements are made:



Thulagi glacier ends in Lake Thulagi at an elevation of 4000 m. It is assumed that 150 years ago the valley was filled with ice up to the top of the lateral moraines. The blank areas are the result of landslides caused by the rapid melting of the glacier.

- automatic recording of the lake level and rate of outflow;
- automatic recording of weather data;
- automatic recording of temperatures that affect the melting of the ice core of the dam;
- repeated tachymeter measurement of the ground level above the ice core;
- precision geotechnical measurements to determine the rates of movement of the slopes above the lake as the glacier recedes.

Comparison of field observations and topographic survey data from 1996 and 2000 shows that the melting of the ice core has accelerated. The bed of the outlet stream has become increasingly deeper and has probably eroded to near

the ice core: The water in the outlet stream was considerably warmer ($> 4\text{ }^{\circ}\text{C}$) in November 2000 than in 1996, acting as a linear heat source. The stream bed has lowered at a rate of about 50 cm per year during this four years, causing a lowering of the lake level by 2.2 m. In contrast, under the insulating sediment cover, the rate of melting of the ice core (10 – 20 cm/a) is considerably lower.

The measured data are being used for modeling future melting so that it can be predicted how slow Thulagi Lake will empty. This will permit measures to be taken, if necessary, to prevent a glacier lake outburst flood in the Marsyangdi Valley, on the east side of the famous Annapurna range.



Automatic gauging and meteorological stations, monitoring the rate of flow in the outlet stream and recording weather data.

Further reading on this topic

- FABER, E., GOMEZ, D.M., GREINWALD, S., HELLWEG, M., SEIDL, D. & TORRES, R. A. (2000): A new concept of volcano activity monitoring – the multi-parameter station at Galeras decade volcano, Colombia. – In: MILLER, H. (Ed.): Geoscientific cooperation with Latin America. – Z. angew. Geol., **SH 1**: 217–220; Hannover.
- HANISCH, J. & SÖDER, C.-O. (2000): Geotechnical assessment of the Usoi landslide dam and the lake Sarez area. – In: ALFORD, D. & SCHUSTER, R. L. (Herausgeb.): Usoi landslide dam and Lake Sarez: an assessment of hazard and risk in the Pamir Mountains, Tajikistan. – ISDR Prevention Ser., **1**: 115 S.; Genf.
- , POKHREL A. P., DELISLE, G., REYNOLDS, J. M., GRABS, W. E. & DIXIT, A. M. (1998): The Thulagi glacier lake (Manaslu Himal, Nepal) – Hazard assessment of a potential outburst. – In: MOORE, D. & HUNGR, O. (Eds.): Proc. 8. Congr. IAEG: 2209–2215; Rotterdam (Balkema).

10



SPECIAL TOPIC:

Climate

The Earth's climate has changed numerous times during the geological past. Ice landscapes like those of the Antarctic are an impressive example of the extremes.

Whether humans have an influence on short-term climate changes can be investigated by geoscientific methods.



Climate

The Climate of the Past: A Key to the Future

Politicians, business, and the public want to be informed about climate development. The questions about future climate can be answered objectively only if the climate of the past is understood. Atmospheric CO₂ concentrations, temperatures, or solar influences – BGR scientists are studying the various aspects of climate development and their relationships.

Plants: Carbon Storehouse of the Past

Carbon dioxide is not only one of the major greenhouse gases in the atmosphere, it is also the source of carbon for all plant life. This was the case in the distant geological past as well as the present. The large collection of plant fossils of the Hannover Geocenter is used by BGR researchers to reconstruct the carbon cycle over periods of millions of years. Land plants play a special role, because they have bound large amounts of carbon during the course of Earth history.

Carbon isotope values provided information about the relationships in the carbon cycle and thus also about changes in the concentration of carbon dioxide in the atmosphere. During the Carboniferous period, CO₂ concentrations in the atmosphere were higher

than today and at the same time there was a large ice cap at the south pole, a sign that the climate is not governed only by the CO₂ concentration.

Black Shales: Climate Indicator of the Cretaceous

When the Glomar Challenger drilled into Cretaceous black shales in the deeps of the field reacted with astonishment. This meant that large parts of this ocean had low oxygen concentrations. What could be the reason for this sudden appearance of low oxygen concentrations at the seafloor? And was it related to climate changes?

A borehole drilled in the Atlantic 400 km off the coast of Florida by the international Ocean Drill Program (ODP) provides an answer. An age of about 110 million years was determined for the black shale obtained from this borehole from studies of the fossil foraminifera in the shale. Conclusions could be drawn about the environmental conditions on the basis of the isotope ratios in the foraminiferal shells (called tests).

The oxygen isotope ratios indicate that the surface water began to warm up shortly before the black shales were formed. Somewhat later, the bottom

water also became warmer. The carbon isotope ratios indicate that there were plankton blooms during the warming of the water. This is supported by the benthic (bottom-dwelling) species of foraminifera: Just before the black shale was formed, there were large increases in the abundances of species that live where there are large amounts of organic material on the seafloor. At the time marked by the beginning of the carbon-rich layer, so much organic material was deposited on the seafloor that the organisms living there couldn't eat it all. The oxygen consumed by the bacteria eating the organic material caused oxygen concentrations to plummet, making the seafloor unlivable; few of the bottom-dwelling foraminifera survived. As the phase of high plankton production in the surface water ended, bottom-dwellers could resettle the seafloor and the considerably lower amounts of organic carbon descending could be removed. This is marked by the top of the black shale. After this, the oxygen isotope ratios of the foraminifera tests show a gradual cooling of the water.

But what was the reason for the plankton bloom? The following scenario can be reconstructed: Weathering of rock on land releases nutrients, which are transported to the sea by rivers. An oversupply of nutrients caused an explosion-like increase in certain alga species. At the same time, the temperature and salt concentration sank. This can be explained by the following

events: An increase in volcanic eruptions in the region of the present Kerguelen Islands in the southern Indian Ocean led to an increase in atmospheric carbon dioxide concentration. This volcanism raised the seafloor over a large area, causing a sea-level rise. The larger surface area of the seas led to increased evaporation, increasing the amount of water vapor in the atmosphere. The greenhouse effect of the increased levels of the CO₂ and, even more so, the water vapor in the atmosphere led to a warming of the Earth, accompanied by a increase in rainfall. The increase in the amount of fresh water reaching the seas created a layer of fresh water over the more saline seawater and decreased circulation of the seawater. This, in turn, led to increased stratification of the seawater, furthering a decrease in oxygen content and an associated decrease in degradation of organic material on the seafloor.

The plankton bloom and subsequent deposition of carbon on the seafloor removed enormous amounts of CO₂ from the atmosphere, decreasing the greenhouse effect. The Earth began to cool even before the end of the formation of black shale. There was less evaporation and less rain; the rivers transported less nutrient to the seas and the algae and plankton bloom come to an end. The freshwater layer in the seas disappeared and circulation between bottom water and surface water began anew.

From the reconstruction of events during the Cretaceous, we learn how quickly and thoroughly the climate system can be changed by external factors. The climate changes at that time were driven by forces in the interior of the Earth: tectonics and volcanism. The climate reacted, leading to counterbalancing processes.

A Roller Coaster of 70,000 Years of Monsoons

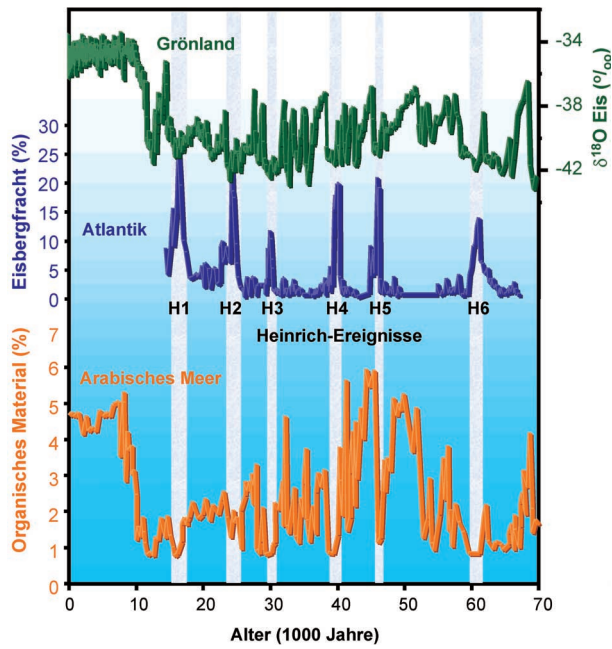
The monsoon is an important factor in the global climate system and water cycle. The extent and rate of variations in the monsoons over the last 70,000 years have been little researched. BGR researchers have now shed some light on the significance of the monsoons for the global climate system. Fossil dinoflagellates, calcareous algae, and foraminifera from the Arabian Sea and the Gulf of Bengal provide evidence for a changing climate in the region of the Indian subcontinent.

The change from an ice age to a warm period occurred extremely rapidly: within a few years to a few decades. The change from a warm period to an ice age occurred much more slowly: almost 100,000 years, interrupted by many short warming periods. These changes occurred too rapidly to have been caused by the slow changes in the Earth's orbit around the sun. Orbital changes cause climatic variations in cycles of many tens of thousands of years. Within these long-period cycles, there are many short-term abrupt changes caused by various climate feedback processes as the global temperature decreases until the culmination of the ice age.

The monsoon, which governs the climate of India and Southeast Asia, reacted to the glaciation in the northern hemisphere. This is documented in the marine deposits of the last 70,000 years in the Arabian Sea off Pakistan. Fine-grained, dark layers were deposited during periods on which the seawater contained little or no oxygen, resulting from a lack of circulation that would

mix the water at various depths; these layers mark warm periods. The light-colored, bioturbated layers mark cold periods with relatively high concentrations of oxygen in the bottom water permitted life on the seafloor. The changes between the two types of sediments occurred rapidly; even after the main glaciation 18,000 years ago can be recognized in this pattern. Evidence for the close relationship between the climate in the Arabian Sea region and that in the Bay of Bengal region was found by BGR 120 km south of the Ganges/Brahmaputra delta at a water depth of 1250 m. Salt content and temperature of the seawater, the sediment load of the rivers, and the climate conditions of the monsoon system could be reconstructed. The studies show that the developments in the Gulf of Bengal and in the Arabian Sea occurred simultaneously. The most important driving force in the climate development on both sides of the subcontinent is the rain-bringing southwest monsoon. The southwest winds of the summer monsoon transport warmth and moisture from the Arabian Sea across northern India to central Asia. Part of the water evaporated from the surface of the Arabian Sea is precipitated on the slopes of the Himalayas, and flows through the Ganges/Brahmaputra river system into the Gulf of Bengal.

Since the end of the last warm period 117,000 years ago, the ice sheets in Canada and Greenland have advanced rapidly at irregular intervals of 5000 – 15,000 years, releasing a "fleet" of icebergs into the North Atlantic. West winds and the Gulf Stream drive these icebergs across the Atlantic, where currents flowing southwards carry them as far as the marine areas off Portugal and even Morocco.



Sediments in the Arabian Sea and the Atlantic document the same climate development as cores taken from Greenland's ice sheet.

The changes in the monsoon climate on both sides of the Indian subcontinent correlate with the variations in the North Atlantic. The monsoons have changed in the last 70,000 years at the same times as the changes between warm and cold climate documented in the Greenland ice. The BGR researchers showed that the monsoon was not active at the height of the last Ice Age 18,000 years ago. The sediments in the Indian Ocean show evidence for six cli-

mate changes that occurred at the same time as the "fleets" of icebergs in the North Atlantic.

The observed climate variations are attributed to global causes. The northern Indian Ocean is largely cut off from the slow global oceanic circulation. Thus, only circulation in the atmosphere can rapidly connect the climate systems in the North Atlantic and northern Indian Ocean. The seasonal monsoon

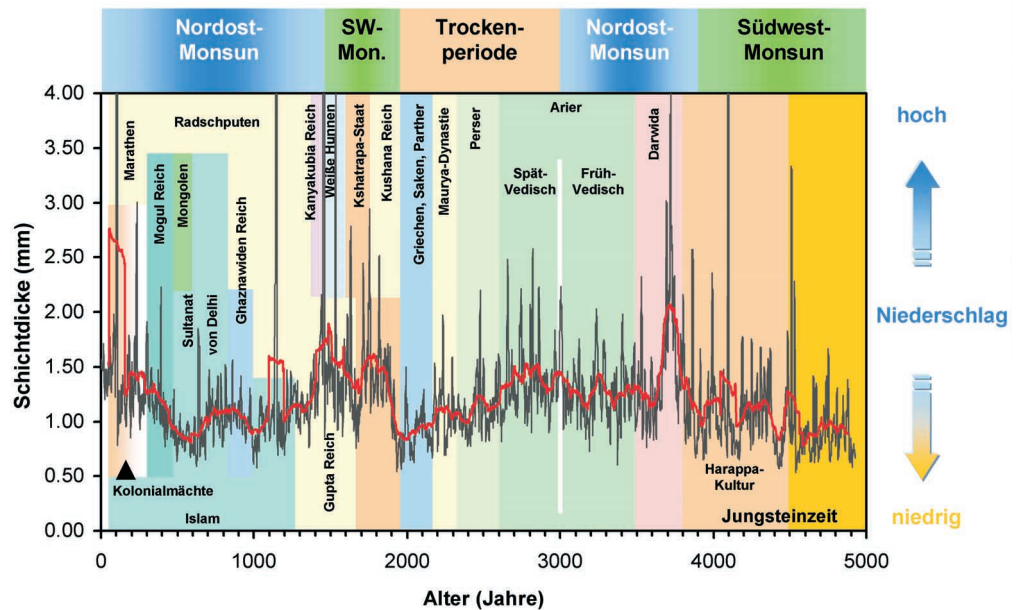
winds and the belt of west winds between 30°N and 60°N were apparently very closely linked during the last 70,000 years. The climate "kitchen" does not lie only in the Greenland "ice-house", as previously assumed, but is closely connected to the "steambath" of the tropics. That the changes in regions that lie very far apart occur at the same time clearly shows the global linkage of climatic processes.

The Oceans and Seas: A History Book

At depths between 150 and 1000 m, the water in the northern Arabian Sea has an oxygen minimum. Because no worms, sea urchins, crabs, or fish that stir up or burrow in the mud on the seafloor can live in this depth zone, the sediments are undisturbed and show the seasonal variations in millimeter-thick layers. Layers deposited in winter are light-colored and consist of river mud. The layers summer deposited in summer are dark-colored and contain considerable organic matter. These winter and summer layers are thick enough to be counted and measured. The "pages" of this climate chronicle covering the last 5000 years reveal time markers that are more exact than those available to historians for the time of the pharaohs. The BGR researchers have used this "archive" to reconstruct changes in precipitation over the last 5000 years.

The thickness of the individual annual layers is a measure of the amount of precipitation: the more rain, the more mud transported by the rivers into the Arabian Sea. The observed changes are related to changes between the northeast and southwest monsoons. Precipitation has had a decisive influence on human history in the region, the rise and descent of the different cultures. It is found that the large cities of the main phase of the Harappa culture on the Indus River more than 4000 years ago grew after a period of considerable rainfall. More than a hundred years later, in a period of heavy rainfall, began a period of scattered settlements and decay of the cities. A close relationship between climate development and cultural development in the Persian-Indian region can also be recognized after this time. The driving force of

these developments is always changes in the monsoon system. Whether it was too much water or too little, people were forced to react if they wanted to survive in this region. Peoples in other regions had to leave their homelands due to unfavorable climate and sought a new home in the Indopersian region. Thus, the present cultural diversity of the region has a climatic background.

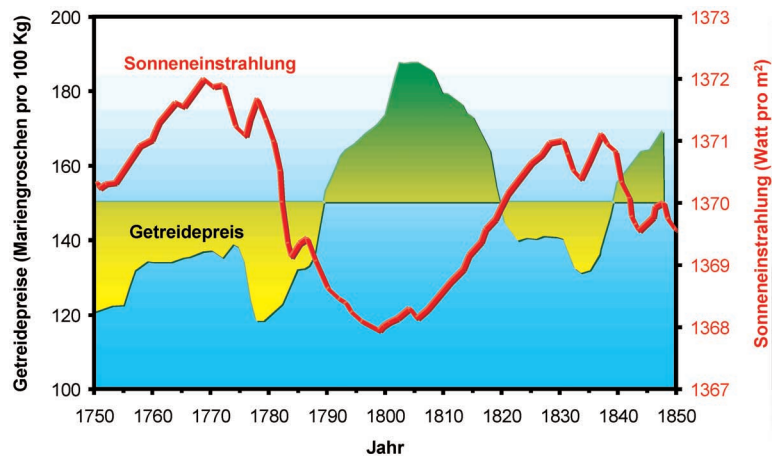


Changes in annual precipitation in the coastal region of Pakistan are documented in the thickness of the annual layers in the Arabian Sea. The climate has a large influence on the cultural development of the region.

Humans: Do They Influence Climate?

Wind and weather, sun and rain, all influence harvest yields. Climate factors determine win or loss for the farmer. The driving force of the climate system is the sun. For example: Between 1750 and 1850, good weather with much sun led to high yields and low grain prices in the Kingdom of Hannover; bad weather around 1800 caused an increase in prices. There is no question that natural climate variations have an effect on the economy.

Today, there is the general fear that humans are adding an artificial effect to the natural one, influencing the natural variation in climate by carbon dioxide emissions from the burning of the fossil fuels oil, gas, and coal. BGR scientists have begun researching this problem: The databases maintained by BGR on the production and consumption of coal, oil, and natural gas form a basis for calculating how much CO₂ is released to the atmosphere by civilization. Internationally, the data, however, has been rather inexact, and thus also the factors recommended by the Intergovernmental Panel on Climate Change (IPCC) for such calculations. Together with geo-ecologists at the Technical University of Braunschweig, BGR has developed an improved basis for calculation of more exact human CO₂ emissions, especially for the burning of coal.

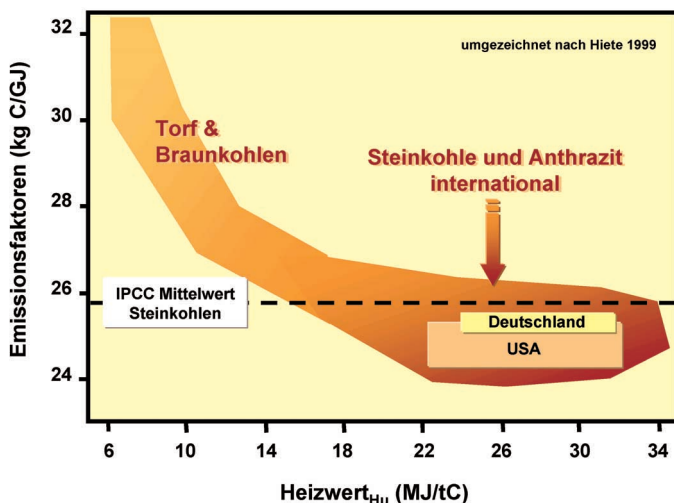


Grain prices in the Hannover region are inversely proportional to solar insolation.

However, it cannot be unambiguously said on the basis of the new calculations whether the current climate changes are being caused by humans or whether natural factors such as the sun still have the upper hand.

emissions would bring a decrease in atmospheric CO₂ concentrations only over a long period of time: In 2100 we would still have concentrations at the level of 1970!

Can we protect our climate by reducing carbon dioxide emissions? Model simulations give a pessimistic picture. Even if we had been able to keep emissions to the level of 1995, CO₂ levels in the atmosphere would continue to increase in the foreseeable future, because the carbon cycle cannot be stopped. Not even a complete, economically impossible termination of



The emissions factors for calculating the amounts of carbon dioxide from the burning of hard coal are for most countries below the values recommended by the Intergovernmental Panel on Climate Change.

A New Book on Climate Development

More information about the climate is given in the new book "Climate Facts: The Past – A Key to the Future". It provides a comprehensive overview of the climate problem, giving new background information in language understandable by the layman. This new information shows that CO₂ is not the only factor and that the sun is the driving force in processes affecting climate in the atmosphere, in the oceans, in the biosphere. Evidence for the climate roller coaster can be found in abundance in the "archives" in the rocks and polar ice. One must only be able to read them and decode them. In this book, BGR geoscientists have compiled facts from nature's archives.



References

- BERNER, U. & STREIF, H. (2001): KLIMAFAKTEN – DER RÜCKBLICK, EIN SCHLÜSSEL FÜR DIE ZUKUNFT.– BGR, NfB UND GGA (Hrsg.), 238 pp, STUTT GART (SCHWEIZERBART).
- ERBACHER, J., HUBER, B. T., NORRIS, R. D. & MARKEY, M. (2001): INCREASED THERMOHALINE STRATIFICATION AS A POSSIBLE CAUSE FOR CRETACEOUS OCEANIC ANOXIC EVENTS.– NATURE, **409**, 325–327.
- HIETE, M., BERNER, U. & RICHTER, O. (2001): CALCULATION OF GLOBAL CARBON DIOXIDE EMISSIONS: REVIEW AND COMPARISON OF EMISSION FACTORS AND A NEW APPROACH CONSIDERING FUEL QUALITY.– GLOBAL BIOGEOCHEM. CYCLES, **15**, (1): 169–182.
- KUDRAŠ, H., HOFMANN, A., DOOSE, H., EMEIS, K. & ERLKENUSER, H. (2001): MODULATION AND AMPLIFICATION OF CLIMATIC CHANGES IN THE NORTHERN HEMISPHERE BY THE INDIAN SUMMER MONSOON DURING THE PAST 80 000 YR.– GEOLOGY, **29**, (1): 63–66.
- LÜCKGE, A. (2001): MONSOONAL VARIABILITY IN THE NORTH-EASTERN ARABIAN SEA DURING THE PAST 5000 YEARS: GEOCHEMICAL EVIDENCE FROM LAMINATED SEDIMENTS.– PALAEOGEOGRAPHY, PALAEOCLIMATOLOGY, PALAEOECOLOGY, **167**, (3–4): 273–286.

11



SPECIAL TOPIC:

EXPO 2000

The principle of sustainability was expressed as early as 1713 in Saxony. The concept is as important today as it was then.

BGR was responsible for the subject matter presented in the Environment thematic area of EXPO 2000. Complex relationships were presented in a way to create associations in the minds of the viewers.



EXPO 2000

The Environment Thematic Area of the EXPO 2000 World's Fair

Exhibition

Didactics: A New Field for the BGR

BGR is well known in the geosciences, less well known to the general public. When the EXPO 2000 GmbH inquired at the end of 1996 whether BGR would take responsibility for the content of the "Environment: Landscape, Climate" part of the world's fair, the opportunity was welcomed. Being responsible for the content of such a large exhibition was a new field for BGR. The BGR Expo 2000 team worked on this project from 1997 to 2000. The theme, however, was not as much in the center of public interest in the year 2000 as it was at the end of the 1980s. Too often the admonishing finger had been waved, the public was tired of hearing about it. Thus, it was a challenge to create a presentation that was attractive and positive and which could inspire the public. An exciting process was begun, together with the Baden-Württemberg Film Academy in Ludwigsburg, the Brückner Atelier in Stuttgart, BIEGE, EXPO 2000 GmbH, and partners from industry, government, and NGOs

The Objective

BGR was to prepare the concept for the information in the exhibits and guarantee the correctness of the components. The exhibits were to be based on the Agenda 21 of the Rio de Janeiro conference in 1992, the content should be correct, and give a balance of opinions. The formulation "The exhibit should not be false" developed during the project; it was not possible for the exhibit to be scientifically highly demanding.

The Execution

The concept was prepared by a 40-member interdisciplinary and international work group of representatives from government, industry, and NGOs.

The exhibit was divided into five parts: climate, water, forest, and rural and urban environments. The main theme linking these aspects was the increasing use of the environment by humans. The different solutions to problems by different cultures under different climatic conditions were an important part of the presentation, for which 4000 m² were available. A particular challenge was to present the message "sustainable utilization of environmental resources" metaphorically in pictures with little text in an understandable and interesting way.



Climate

Fifteen partners from industry, government, and NGOs were involved in the exhibit. Between 5000 and 18,000 persons per day visited the exhibit. Special tours were provided to groups from industry, government, and NGOs, for example, members of parliaments, NGO delegations, and ministers of the environment and agriculture.

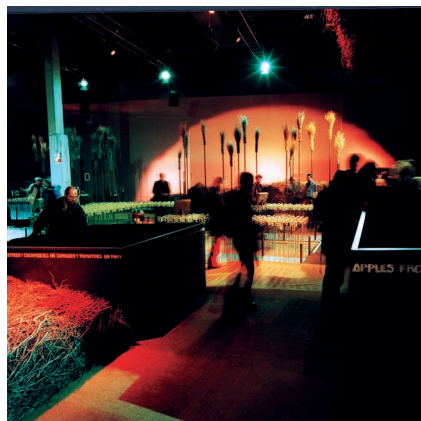
There are numerous opinions about the environment and many competing, or even conflicting interests. As moderator, BGR had to find solutions agreeable to everyone. This did not always proceed harmonically. As a neutral governmental agency, we were able to provide the necessary plurality in the exhibit and the views of all participants were presented in a balanced way.

Five television programs were prepared with ZDF and Pro7 in which environmental aspects were presented using as examples BGR projects in Namibia, Paraguay, Kazakhstan, and Colombia. Numerous newspaper and magazine articles on BGR's work on the thematic area of the EXPO were also published.

With its work on the EXPO 2000, BGR entered a new field, cooperating with other governmental agencies, industry, and NGOs as a competent and reliable partner. Contacts were made with television, radio and printed media that will be maintained in the future.



Water



Countryside



Forests



City

12



SPECIAL TOPIC:

The Geological Map

Geoscientific knowledge has always been represented on geological maps.

In the digital age, geoscientific information can be stored in geoinformation systems, where it can be processed according to the needs of the user. Preparation of the Geological Map of Europe is coordinated by BGR.



The Geological Map

The Geological Map: The Leap into the Digital Age

Geological maps are a means of visualizing geological conditions for the geologist, representing three-dimensional conditions in two dimensions in a readable and esthetic manner. They are always an interpretation of the available data, since the Earth has not been explored to the last detail. The geological data on a map provide a basis for planning any number of measures (e.g., exploration for ore deposits or groundwater of acceptable quality, determination of geohazards), and the maps illustrate geoscientific relationships in general.

The printed geological map has been increasingly replaced since the early 1990s by geoinformation systems (GIS). Geodata is stored in databases, edited, and analyzed; it can be printed as a map or processed on a computer. Maps are still printed by BGR, but they are almost always produced using a GIS.

The last map produced by BGR using analog methods is the 1 : 1,500,000 International Geological Map of Europe and the Mediterranean Region for which 48 map sheets and the legend have been completed. At the Interna-

tional Geological Congress in 2000 in Rio de Janeiro, BGR presented the GIS project for the 1 : 5,000,000 International Geological Map of Europe and Adjacent Regions (IGME 5000), continuing traditional cartography with modern methods and media.

Nearly 50 European and neighboring countries are participating in the new IGME 5000 project, which – like for the 1 : 1,500,000 map – is being coordinated by BGR under the auspices of the Commission of the Geological Map of the World (CGMW). Uniform definitions



The completed 1 : 1,500,000 International Geological Map of Europe and the Mediterranean Region at the BGR stand at the 31st International Geological Congress in Rio de Janeiro.

of terms and methods of representation in which existing standards are to be taken into consideration is an objective of the IGME project.

Good cooperation by all of the participating Geological Surveys and organizations has been achieved in the project, requiring intensive preparatory work. This work included preparation of a common topographic base map, development of standards, require-

ments, and guidelines for the draft maps and database entries of the participating countries.

The GIS will contain more information than a printed map. This will increase the flexibility for combining data for various purposes, e.g., ages, composition, degree of metamorphism, tectonic and genetic aspects. Information for the project is provided on the web (www.bgr.de/karten/IGME5000),

e.g., color chart, project news, the topographic base map.

The project results are not only for geoscientific organizations, but also for decision-makers, scientists in other disciplines, students, and other interested persons. The GIS for the IGME 5000 will provide a significant basis for future national and international geoprojects in Europe.

BGR *in numbers*

the budget

- 1999** DM 122 million
including DM 20 million in third-party
funds for external cooperation projects
and other projects
- 2000** DM 115 million
including DM 20 million in
third-party funds

staff

- 1999** 746, including 304 scientists
and 60 new staff
- 2000** 731, including 310 scientists
and 75 new staff

trainees

- 1999** 15
- 2000** 19

as follows:

- office organization,
- chemical technician,
- automobile mechanic,
- machinist,
- cartographer.



the BGR homepage

number of files on the web server: 8000

- 1999** 605,864 visitors
with an daily average of 1660
- 2000** 1,652,370 visitors
with an daily average of 4515

the library

The BGR library is one of the largest geoscientific
libraries in the world:

- 340,000 books and journals,
- 115,000 map sheets
- 6000 new additions annually
- more than 1000 exchange partners worldwide

the collections

BGR has one of the largest geoscientific collections
in Germany

- 30,000 type specimens
- more than 100,000 reference specimens
(fossils, rocks, minerals)
- 65 km of drill cores

geoathletics

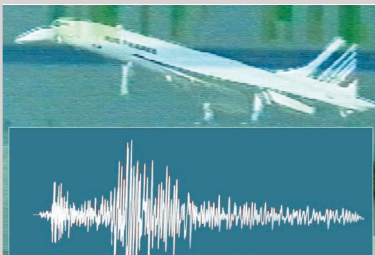
150 staff members in the BGR sports club
participate in the following sports:

- soccer,
- bowling,
- swimming,
- sailing,
- table tennis,
- volleyball,
- badminton,
- tae kwon do,
- yoga,
- and posture training

... you can find us here



BGR Federal Institute for Geosciences and Natural Resources



Federal Institute for Geosciences
and Natural Resources (BGR)
Stilleweg 2
30655 Hannover, Germany

Phone: 49 (05 11) 6 43 – 26 79
Fax: 49 (05 11) 6 43 – 26 81
Internet: <http://www.bgr.de>