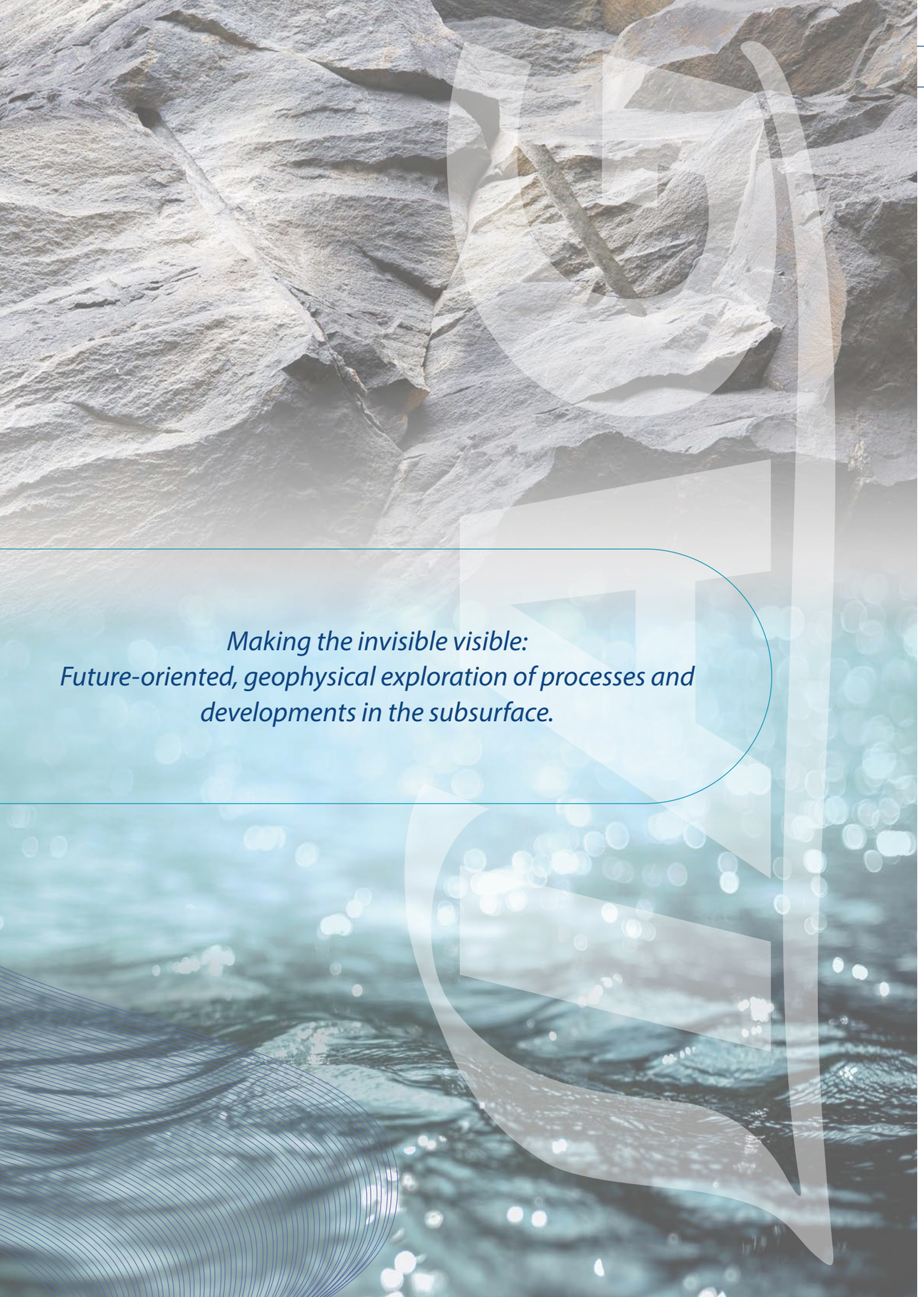
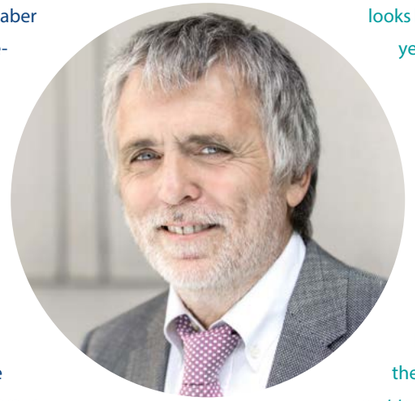
Research Report 2020

Leibniz Institute for Applied Geophysics



VORWORT

Liebe Leserinnen und Leser,



Das Leibniz-Institut für Angewandte Geophysik blickt auf ein aufregendes, aber erfolgreiches Jahr 2020 zurück. Bereits im Januar schuf die Zusage der Niedersächsischen Landesregierung zur Weiterfinanzierung des Institutes über das Jahr 2022 hinaus die notwendige Basis für den Fortbestand des LIAG, mit dem Ziel einer schnellstmöglichen Wiederaufnahme in die Leibniz-Gemeinschaft. Die Corona-Pandemie brachte bald darauf aber große Herausforderungen mit sich, da die Einschränkungen teilweise zu Verzögerungen von Projekt- und Geländeaktivitäten im In- und Ausland führten. Mit einem frühzeitig ausgearbeiteten Hygienekonzept im Geozentrum konnte jedoch schnell aktiv weitergeforscht und die wissenschaftliche Ausrichtung des LIAG weiterentwickelt werden. Im ersten Jahr nach Beendigung der Mitgliedschaft in der Leibniz-Gemeinschaft haben wir auf diese Weise wichtige Meilensteine im Rahmen der Institutsentwicklung erreicht. In zahlreichen internen und externen, nationalen und internationalen Workshops erarbeiteten wir Konzepte für ein zukünftiges Institut für Umweltgeophysik, welche derzeit zusammengefasst und präzisiert werden. Im Fokus stehen hierbei die Forschungsbereiche Grundwasser-Geophysik und Geogefahren. Der in den beiden vergangenen Evaluierungen mit Nachdruck vertretene Aufbau einer Kernverwaltung ist zudem in vollem Gange. Des Weiteren haben wir das Wissenschaftsmanagement weiter ausgebaut und den Forschungsbericht 2020 neu aufgelegt. Dieser erscheint erstmals in ansprechendem modernen Format mit vielen interessanten Beiträgen der Mitarbeitenden über intern und extern finanzierte Projekte aus diesem Jahr.

Wir wünschen viel Lesefreude und sind neugierig auf die Resonanz.

PREFACE

Dear Readers,

The Leibniz Institute for Applied Geophysics looks back on an exciting, but successful year 2020. Back in January, the commitment of the Lower Saxony state government to continue funding the institute beyond 2022 created the necessary basis for LIAG's ongoing existence, with the aim of rejoining the Leibniz Association as soon as possible. However, the Corona pandemic brought major challenges soon thereafter, as the restrictions led in part to delays in project and field activities at a national and international level. However, with a hygiene concept developed at an early stage at the Geocentre, it was possible to continue quickly active research and further develop LIAG's scientific orientation. In the first year after the end of our membership in the Leibniz Association, we thus achieved important milestones in the institute's development. In numerous internal and external, national and international workshops, we developed concepts for a future Institute of Environmental Geophysics, and are currently summarizing them to one and specifying it. The focus here lies on the research areas of groundwater geophysics and geohazards. In addition, the establishment of a core administration, which was emphatically required in the past two evaluations, is in full swing. Furthermore, we have further expanded science management and relaunched the Research Report 2020. Now it has an appealing modern format, with many interesting contributions from staff about internally and externally funded projects in this year.

We hope you enjoy reading it and we are looking forward to your response.

Prof. Dr. Manfred Frechen
Kommissarischer Direktor
Acting Director

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Our expertise and mission

The Leibniz Institute for Applied Geophysics is an independent, non-university research institute, based in Hanover, Germany. We use applied geophysical methods to explore future-oriented issues that are of importance to society. The focus of our research is the exploration of the usable subsurface and the development of measuring techniques and evaluation methods. The institute has over 50 years of geophysical research experience.

Unique specialist expertise and facilities

Our research activities are centred on the Earth's upper crust and the depths that can be influenced by humans. This zone is relevant for immediate commercial exploitation and the provision of services. Our aim is to understand, preserve and protect geopotential resources, such as groundwater, soil, energy sources and raw materials, and to develop them for vital and sustainable use. It is also essential to understand geohazards caused, for example, by land movements, sinkholes or other environmental changes. Due to the increasing vulnerability of populated areas, it is vital to promptly identify, evaluate and potentially minimise the resulting damage.

Against this backdrop, the institute focusses on the overarching topics of groundwater geophysics, geohazards, sediments through the ages (paleoclimate/climate dynamics) and geothermal energy. We address issues that have great societal relevance and that aim to generate added value for stakeholders. No other facility has a comparable range of services in the area of applied geophysics connected to the key topics of groundwater systems, geoenergy systems, terrestrial sediment systems and targeted methodological development. No other institute dedicates their entire range of services to application-oriented questions in this scientific sector. LIAG is able to address socially relevant topics nationally and internationally. We handle basic research, process research and applied research and, in this way, cover an indispensable proportion of the necessary research. Our many years of specialisation in near-surface geophysical applications, our equipment and data infrastructure, and our resulting scope for combining diverse, interdisciplinary geophysical methods within the institute make LIAG unique in Germany.

LIAG's principle fields of work

- Geophysical investigation of structures in the subsurface to determine and record the geological morphology and as a basis for understanding process sequences and the physical parameters that control them.
- The exploration of processes in the geosphere, i.e. their origins, their temporal and spatial sequences and correlations and their impact on the geosphere and the environment.
- Devising new measurement methods and further improving them, interpretation techniques and systems of equipment for solving the aforementioned tasks.

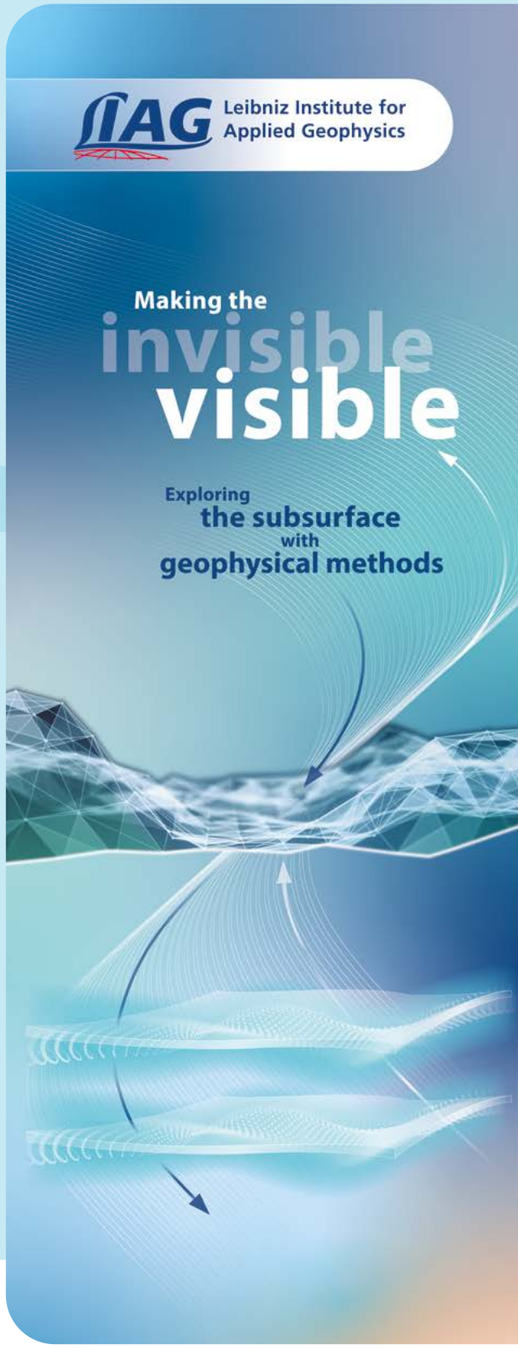
LIAG is also involved in political consultancy, public relations, support for young researchers, and the transfer of knowledge. Internally, LIAG also actively supports equality standards and is dedicated to meeting employees' needs, such as promoting advanced training. Researchers at LIAG actively participate in academic teaching and delivered lectures at five universities in 2020. Furthermore, LIAG employees provide extensive services for the scientific community as reviewers and committee members.

Exclusively research-related services

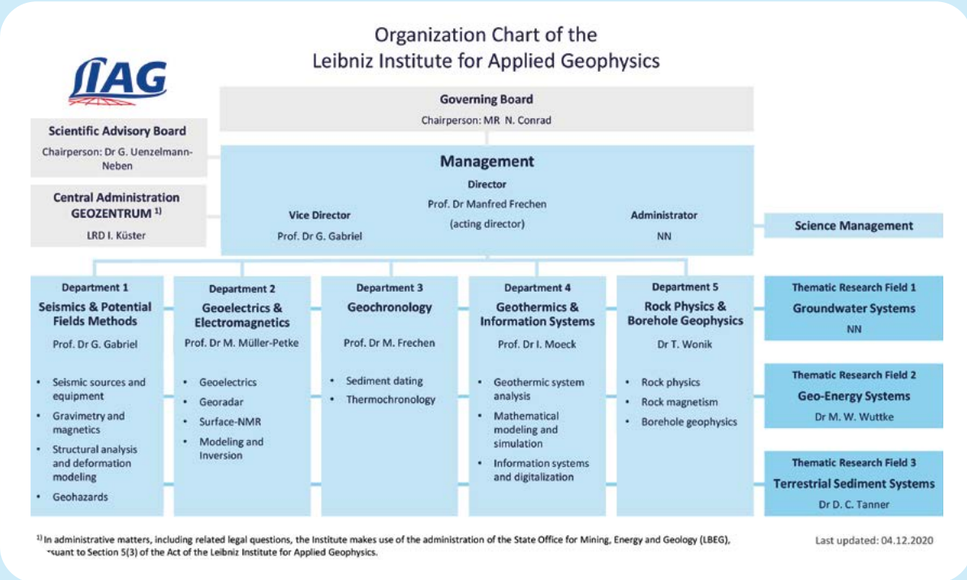
We also conduct autonomous and independent research in national and international contexts in close collaboration with university institutes, other research facilities, the state geological services and industrial partners. As a research institute, LIAG only conducts contract work or provides services in exceptional cases. This applies if the projects are research-related and cannot be conducted in any other way, if the issue on hand has research potential worthy of publication that fits the institute's profile, or if industrial companies lack the particular expert knowledge.

Integration into the Geozentrum

One special aspect of LIAG is that we are integrated into the Geozentrum Hanover. Along with the Federal Institute for Geosciences and Natural Resources (BGR) and the State Office for Mining, Energy and Geology (LBEG), LIAG benefits from a shared infrastructure for administration, buildings, IT, vehicles, workshops and laboratories and one of the most extensive specialised geoscientific libraries in the world. Large-scale devices, measuring systems, research sites and project locations are frequently shared.
The particular benefit of being integrated into the Geozentrum is that we can communicate directly with the applied geosciences and have immediate access to a breadth of specialist knowledge that is unique within Germany and, in some cases even internationally. This also gives rise to synergetic and cooperative research campaigns.



Organisation and committees



LIAG structure

The institute's constitution is based on two bodies: the advisory board and the director. The advisory board is the decision-making body for all significant institute matters and exercises the employer's duty of care. The board has eleven members: The federal state of Lower Saxony and the federal government each nominate two members, each university supplies one person, the German national/regional committee for soil research supplies two members, and the state geological service (SGD) nominates one person. The areas of industry and geosciences are represented by one person each and the scientific advisory committee is represented by the current chair. By statute, the director is nominated by means of a joint appointment process with a German university.

The institute is advised by a scientific advisory committee (WB) on questions of scientific relevance. The scientific advisory committee is responsible for the continuous evaluation of the Institute's research activities and, to this end, conducts internal assessments that are submitted to the advisory board. It consists of nine respected figures from different fields: four from the higher education sector, two from the state geological service, two from the non-university research facility sector and one from the industrial sector. Two members must be from outside Germany and one member must belong to the Leibniz University Hanover. The members of the advisory committee are proposed by the institute's directors and appointed by the advisory board. The term of office is four years. The current advisory committee was reconstituted in 2020.

The institute also has an internal research committee, whose members are selected from within LIAG. This committee provides advice on issues of scientific orientation and research planning.

Advisory board

MR Norbert Conrad *(Chair)*
Lower Saxony Ministry of Industry, Labour, Transport and Digitalisation,
Hanover (DE)

Dr Peer Hoth *(Deputy chair)*
Federal Ministry for Economic Affairs and Energy,
Berlin (DE)

Prof. Hans-Jürgen Götze
Christian-Albrecht University of Kiel,
Institute of Geosciences,
Kiel (DE)

Dr Birgit Fritz-Taute
Senate Department for Enviroment, Transport and Climate Protection,
Berlin (DE)

Claudia Mitsch-Werthwein
Ministry of the Environment, Climate Protection and the Energy Sector,
Stuttgart (DE)

Dr Birgit Nolte
Lower Saxony Ministry for Science and Culture, Hanover (DE)

Dr Gabriele Uenzelmann-Neben
Alfred Wegener Institute for Polar and Marine Research,
Bremerhaven (DE)

Dr Wolf Junker
Federal Ministry of Education and Research,
Bonn (DE)

Dr Michael Neubert
Baker Hughes INTEQ GmbH,
Celle (DE)

Ltd. GD Sabine Rosenbaum
State Office for Agriculture, Environment and Rural Areas, Schleswig-Holstein,
Flintbek (DE)

Prof. Brigitte Urban
Leuphana University of Lüneburg,
Institute of Ecology,
Lüneburg (DE)

Scientific advisory committee

Dr Gabriele Uenzelmann-Neben *(Chair)*
Alfred Wegener Institute for Polar and Marine Research,
Bremerhaven (DE)

Prof. Thomas Bohlen (*Deputy Chair*)
Karlsruhe Institute of Technology (KIT),
Geophysical Institute (GPI),
Karlsruhe (DE)

Dr Oliver Kuras
Environmental Science Centre,
Keyworth, Nottingham (UK)

Prof. Gudrun Massmann
Carl von Ossietzky University of Oldenburg,
Working Group for Hydrogeology and Landscape Hydrology,
Oldenburg (DE)

Prof. Insa Neuweiler
Leibniz University Hanover,
Institute of Fluid Mechanics and Environmental Physics in Civil Engineering, Hanover (DE)

Prof. Jörg-Detlef Eckhardt
State Office for Geology, Raw Materials and Mining,
Freiburg Regional Council,
Freiburg (DE)

Prof. Andreas Lang
University of Salzburg,
Department of Geography and Geology,
Salzburg (AT)

Prof. Hansruedi Maurer
Swiss Federal Institute of Technology (ETH) Zurich,
Institute of Geophysics,
Zurich (CH)

Dr Dirk Orlowsky
DMT GmbH Explorationsseismik & Geosurvey,
Essen (DE)

Internal research committee

Dr Christian Zeeden *(Spokesperson)*
Dr Manfred W. Wuttke *(Deputy spokesperson)*
Dr Jan Igel
Dr Sumiko Tsukamoto
Dr Thomas Burschil

Institute development – Reviewing our progress

On 21/01/2020, a cabinet decision created the necessary conditions for continued financial support from the state of Lower Saxony. This secured the future of the institute after the termination of its membership in the Leibniz Association. The state of Lower Saxony views LIAG as a vital component of the national research community. It considers the methodical and scientific expertise and the advisory services of the institute to be indispensable in connection with the current societal, economical and environmental issues related to the exploration and utilisation of the subsurface. For this reason, the state of Lower Saxony will provide funding once joint funding from the federal and state governments is discontinued at the end of 2022. Every effort will be made to ensure the readmission of LIAG into the Leibniz Association as soon as possible by implementing the recommendations from the last evaluation. A central issue is the modification of internal structures and the development of an own internal administration management, which will systematically and efficiently support the future scientific development of LIAG. In addition, there must be a change of ministry from the Lower Saxony Ministry of Economics, Labor, Transport and Digitalization (MW) to the Lower Saxony Ministry of Science and Culture (MWK). A further crucial point is the continued development of our research strategy on the basis of overarching key issues concerning the use and exploration of the upper geosphere.

Strengthening the line of research with an external commission of experts

Hence, LIAG continues to drive forward its reorientation this year. The institute has initiated its own two-day future workshop to strengthen the scientific strategy: Eleven external national and international researchers with recognised expertise in geoscientific topics and geophysics discussed potential lines of research on the 7th and 8th of September. The event was launched by Dr Berend Lindner, state secretary of the Lower Saxony Ministry of Industry, Labour, Transport and Digitalisation. Guests included the president of the German Geophysical Society, Prof. Heidrun Kopp, and Prof. Hildegard Westphal of the Leibniz Centre for Tropical Marine Research, the former scientific vice president of the Leibniz Association. They held discussions along with further figures from the Federal Ministry for Economic Affairs and Energy, from Lower Saxony ministries (MW and MWK), from institutes in the Helmholtz Association, and from universities. Discussions were focused on future concepts prepared by LIAG (on the topics of groundwater, georisks and climate dynamics) and by the external guest experts based on the evaluation report from the senate of the Leibniz Association. Further topics under debate included current methodological expertise, available equipment and the entire infrastructure of LIAG.

Dr Berend Lindner, state secretary of the Lower Saxony Ministry of Industry, Labour, Transport and Digitalisation, launched the future workshop together with Prof. Manfred Frechen, acting director of LIAG.

"With the assistance of external scientific experts, we planned a reorientation of the institute while retaining our unique selling point in the research landscape", explains Prof. Manfred Frechen, acting director of LIAG.

> *» We must utilise and strategically develop LIAG's indisputable existing wealth of professional and methodological expertise. «*

"The workshop provides the committees with an important basis for making further decisions concerning research strategies".

State secretary Dr Lindner also considered the future workshop to be a significant step: "The state government wants LIAG to be readmitted to the Leibniz Association. This will require a reorientation of both subject matter and strategy within the institute. The subject areas addressed must be adapted to cover key scientific and sociopolitical issues of the present and the future. To this end, we must utilise and strategically develop LIAG's indisputable existing wealth of professional and methodological expertise".

Scientific advisory committee at their twice-yearly meeting: The committee counsels the advisory board with regard to LIAG's research orientation. In October, they proposed the springboard topics of groundwater geophysics and geohazards.

Concept formulation: Groundwater Geophysics and Geohazards as springboard topics

The scientific advisory committee reconstituted on 8th October 2020 with Dr Gabriele Uenzelmann-Neben (AWI Helmholtz Centre for Polar and Marine Research) as chair and Prof. Thomas Bohlen (Geophysical Institute of KIT) as her deputy. The committee rated the topics of geohazards and groundwater geophysics that were identified by LIAG and the commission of experts as being suitable. These topics represent the initial basis for developing an institute of environmental geophysics and must be further substantiated and elaborated by investigations of key scientific importance. For instance, how the effects of climate change or aspects of the impending energy revolution can be incorporated into investigations of these two topics. It was also emphasised that LIAG is renowned for a wide range of methodological expertise in applied geophysics, making us unique in Germany, if not globally.

On 4th November 2020, the advisory board met as the supreme body of LIAG to discuss these recommendations. They agreed that LIAG management will expand the concept in detail in consultation with the scientific advisory committee. They will further refine the subject matter and structure of the concept with regard to the springboard topics of groundwater geophysics and geohazards.

LIAG management (left to right): Prof. Gerald Gabriel, Dr Thomas Wonik, Prof. Manfred Frechen, Prof. Inga Moeck, Prof. Mike Müller-Petke; far right: Dr Sumiko Tsukamoto.

Acting director of the institute

Prof. Manfred Frechen and Prof. Gerald Gabriel after inauguration to their new positions.

» At LIAG, we are highly motivated to develop a strategy for orienting our work towards forming an institute of environmental geophysics in collaboration with and building on the strengths and geophysical expertise of our researchers. «

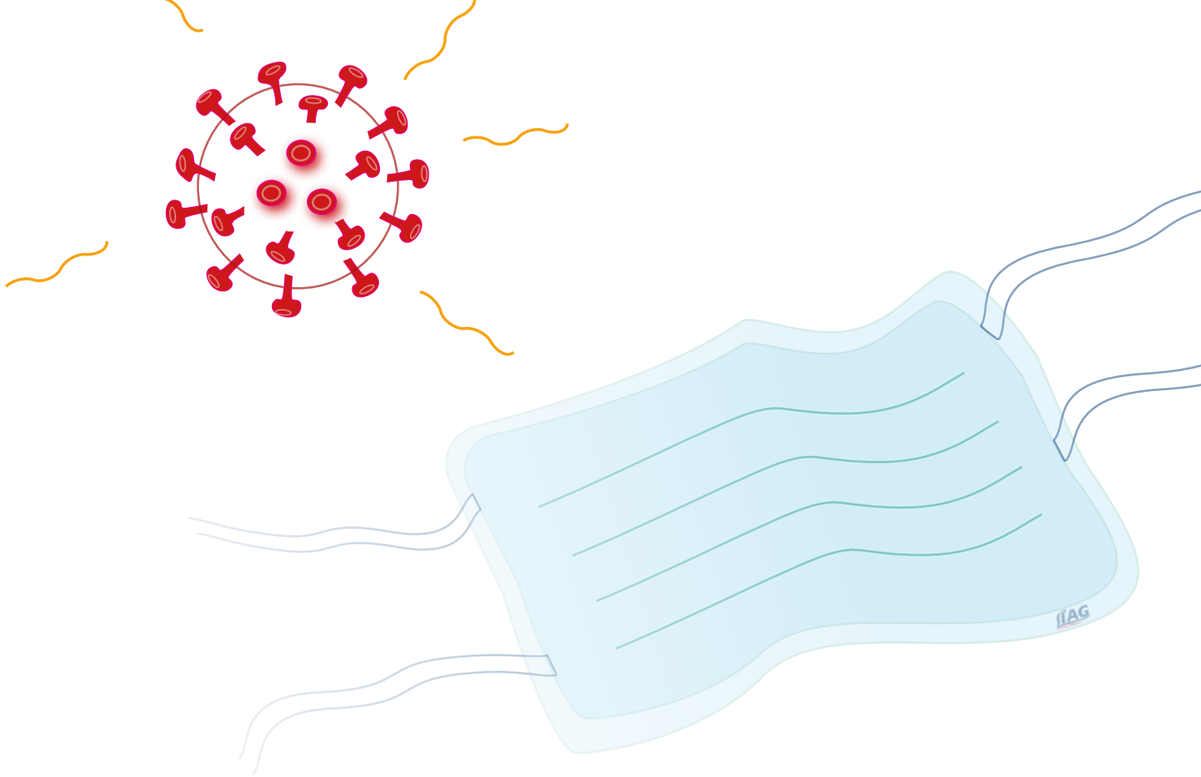
Prof. Manfred Frechen

Following the decision of the advisory board, LIAG also officially appointed Prof. Manfred Frechen as the acting director. Prof. Gerald Gabriel took up the office Prof. Frechen previously held as deputy director. The two currently head the research fields of Geochronology and Seismic, Gravimetry, and Magnetics at the institute, respectively. The highest executive positions in LIAG are formally and entirely filled based on the decision of the advisory board as the supreme body of the institute. Prof. Manfred Frechen has been the section head of Geochronology at LIAG since 2001; he managed the institute as deputy director for two years. Prof. Gerald Gabriel has worked in the Seismic, Gravimetry, and Magnetics department at LIAG since 1998 and also worked in LIAG's predecessor organisation. He has been the head of the department since 2016.

The challenge of a pandemic

Ongoing research under the threat of COVID-19

Masks are mandatory during daily collaborations: Dr Thomas Günther, LIAG (left) and Dr Olaf Josafat Cortés Arroyo, BGR, installing a ground station for the joint DESMEX II project investigating ore deposits in the Harz mountains.



The year 2020 was dominated by the COVID-19 pandemic. It had a massive impact on development and research at LIAG as well as on national and, in particular, international research projects. All employees had to make major changes to their working methods. However, the three establishments within the Geozentrum (BGR, LBEG and LIAG) established a joint hygiene protocol that allowed the institute to continue operating.

Right at the beginning of the pandemic, LIAG shifted almost all regular operations to mobile working arrangements. The laboratories and surveying assignments were initially shut down in line with COVID-19 directives. In-house laboratory operations resumed in mid-May under a provision stipulating that only 30 percent of employees were permitted to be present in the offices, subject to strict hygienic measures. In this manner, the institute ensured that those scientists who required advanced technology for their work could continue their research projects. However, mobile working from home was always deemed to be a vital method of protection during the entire period given the overall situation in Germany. This helped to keep working capacity and efficiency at a very high level while keeping the infection incidence in the offices thankfully low.

A combination of patience and digital solutions

Organising necessary business trips and fieldwork for ongoing projects was a further complication. Here too, the implementation options available to partner organisations and external participants were determined by the hygiene protocol of the three establishments. We even had to postpone some investigations and project launches, especially in high-risk regions and more distant countries. The majority of conferences, meetings and trade fairs in which LIAG usually participates were cancelled or held as digital events. Likewise, lectures, teaching assignments and policy consultations were mainly conducted online.

LIAG is well-prepared to continue our research during the pandemic thanks to continuous monitoring of the infection incidence by the Geozentrum crisis team, adherence to the joint hygiene protocols, and the use of mobile working alternatives.

RESEARCH TOPIC PROFILES

Groundwater Geophysics
Geothermics
Sediments through the Ages
Geohazards

Groundwater Geophysics

Observing and understanding the elixir of life

Drought, salinisation, contamination: Problems that threaten our groundwater and, therefore, our foundation of life. The first comprehensive, global water-related objective has been determined in the United Nations' 2030 Agenda for Sustainable Development. In particular, the secondary goal of ensuring availability and sustainable management of water and sanitation for all requires a deeper understanding of the structures and effective processes that take place in groundwater systems. Natural groundwater systems are the most important resources of drinking water. However, to use these sustainably, a great deal of research is required to investigate aquifers and the protective function of the layers above them. The necessary integration of geophysical, hydrological, geological and geochemical findings is a challenge that science has only just begun to tackle. This applies to measuring technologies used in the field and in laboratories, where observations and measurement results are on a variety of different spatial and temporal scales. It also applies to modelling linked processes, a task that can only be achieved using numerical simulations.

Making processes and structures in the soil and groundwater visible

Aerial photograph of Borkum.

In the field of groundwater research, LIAG focuses on the application, development and optimal use of state-of-the-art geophysical technologies for the detailed investigation of the shallow subsurface. We conduct investigations for the sustainable management of drinking water resources, working with partners from the fields of scientific research and practical application. Our research is conducted within the framework of medium- and long-term forecasts of the dynamic development and the protection of our drinking water resources.

LIAG makes geophysical observations of the (partially saturated) soil, the (fully saturated) aquifer and the transition zone as a whole and as a part of the critical zone. The critical zone is the dynamic range of interaction between the atmosphere, hydrosphere, biosphere and upper lithosphere and extends from the treetops to the base of the aquifers. Investigating the temporal dynamic changes and highly variable spatial structures forms the basis for understanding the transport processes that occur there. These include the ingress of nutrients and contaminants into groundwater, exchange with the atmosphere and, consequently, interaction with climatic changes. Processes in the coastal regions, such as groundwater salinisation, the impact of rising sea levels or freshwater discharge into the ocean are also extremely important. To this end, we are developing long-term recording systems, high-resolution, ground-based methods and drone-based measurement systems that are capable of closing the gap between large-scale remote sensing methods with low depth penetration and measurements on the ground.

The current changes in climate and environmental conditions remind us of the complex interdependencies that necessitate a wide-ranging approach and comprehensive view of the natural systems. For this reason, LIAG contributes its geophysical expertise to this area of research and focuses on understanding coastal aquifers and soils.

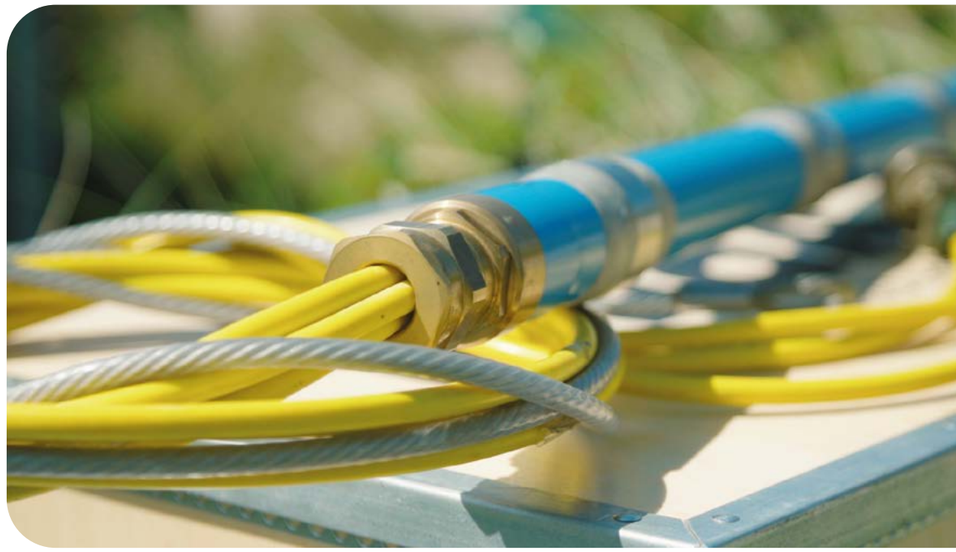
Coastal aquifers – The basis of life for millions of humans

According to the 2010 Eurostat regional yearbook survey, 43 percent of Europeans (around 196 million persons at that time) were living in coastal regions in 2007, with 50 percent living less than 50 kilometres from the sea. Around the world, the number was approximately over one billion citizens, according to the World Ocean Review. What is more, the foundation of the lives of these people is not only threatened by global warming and the associated rising sea levels. The availability of drinking water from groundwater resources is closely connected to the ocean, and consequently linked to saltwater. The freshwater/saltwater transition does not follow the coastline in subsurface layers that carry groundwater. On the contrary, it is a dynamic system of geological circumstances, precipitation, changing sea levels and the effects of aquifer utilisation. We must describe and understand this dynamic system in order to be able to detect future changes at an early stage, facilitate sustainable and needs-based use, and prevent conflict. Coastal aquifer research is therefore also an integral part of societal processes. Tourism and agriculture, infrastructure expansion and conservation of nature are just a few key words that are of constant relevance to coastal aquifer research.

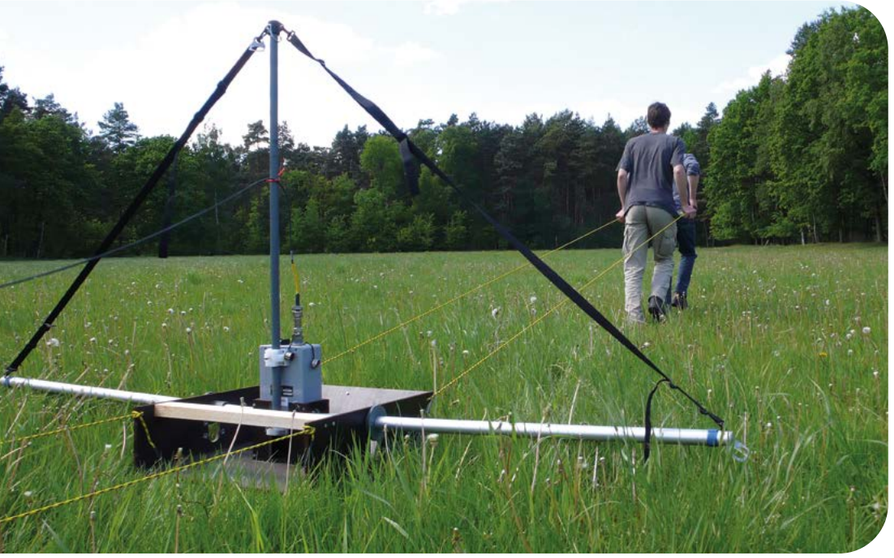
The institute contributes to numerous international projects – currently mainly in northern European coastal regions. However, the methodology developed and applied by LIAG is not generally restricted to coastal areas and can be applied to other research contexts.

Localising and monitoring salinisation for more efficient groundwater management

Data that allows us to draw conclusions concerning the structure of the lithosphere, its condition and variations forms the basis for effective groundwater management and is indispensable for predicting future changes to the aquifers. During national and international projects such as TOPSOIL (page 56) and goCAM (page 58), LIAG collects data that demonstrates the salinisation of aquifers or records even the most minute changes in subsurface salinisation over long periods



The SAMOS electrode system measures the entire saltwater/freshwater transition zone over several metres.



Georadar records high-precision structural information in the lithosphere. This is combined with nuclear magnetic resonance measurements and with geoelectric data to determine porosity, hydraulic conductivity and salinity. The transmitting and receiving antennas of the georadar are connected by cables to the recording unit carried by the operator.

using permanently installed measuring instruments. To do so, we perform electromagnetic measurements from helicopters, on the ground and in boreholes. Some measurements are evaluated using newly developed algorithms and we even develop new measuring instruments specifically for this purpose. The future clearly points in two directions: (1) Fast, cost-effective and large-scale investigations for visualising the lithosphere using drone-based technology, and (2) Monitoring changes with high temporal resolution.

Describing subsurface hydrogeology with precision

Visualising salinisation zones is an important tool for analysing coastal aquifers, but not the only one. Clayey layers protect the aquifers from contamination and their low permeability isolates the saturated lithosphere. But the permeability and porosity of aquifers also varies. We need to know their orientation, depth and hydraulic parameters within the subsurface to be able to visualise the hydraulic system in numerical models and analyse future changes in scenarios. LIAG develops innovative methods and combinations of methods to explore structures and parameters in greater detail. For instance, high-precision structural information from georadar can be combined with nuclear magnetic resonance (NMR) measurements and geoelectric data acquisition to determine porosity, hydraulic conductivity and salinity. In this way, we can obtain an ever more precise view of the subsurface.

Soil – Our daily bread

Soils are the interfaces between the atmosphere, lithosphere, biosphere and hydrosphere. As such, they are not only generated by weathering processes, but are directly subjected to (changing) environmental conditions. Soils perform a multitude of services within the ecosystem, including carbon sequestration and supporting biodiversity, and also serve as foundations for buildings. Last but not least, they are also one of the foundations of human nutrition as a component of the water cycle and nutrient cycle.

New horizons: Drone-based surveys for large-scale explorations

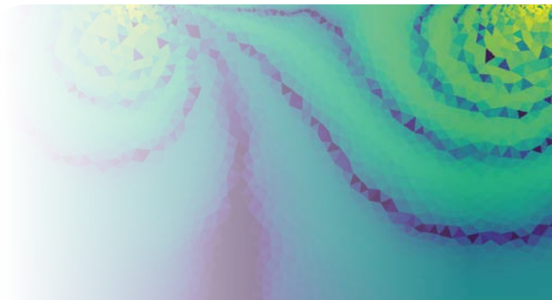
Large-scale investigations of the three-dimensional subsurface are of extreme interest to many fields of research. But extensive survey flights in helicopters or planes are often too expensive. As a product of the joint project Deep Electromagnetic Sounding for Mineral EXploration (DESMEX, funded by the BMBF (German Federal Ministry of Education and Research), LIAG has opened up a new field of research by measuring electromagnetic fields from the air using modern drone technology. Supplemented by methodological developments, this looks to be a very promising field for future research and application.

Using drones simplifies the investigation of structures in the subsurface and supports large-scale data acquisition.

Determining soil moisture and structures non-destructively and on a large scale

A multitude of soil processes are directly influenced by soil moisture, its spatial distribution and changes over time. Modern geophysical procedures, including those based on NMR (the basis of medical magnetic resonance imaging), enable subsurface water to be detected directly using non-destructive methods. In the MoreSpin project (page 60), LIAG expanded this method to obtain precise information about soil moisture in the soil zone. Other techniques include georadar, which enables soil structures to be visualised in great detail, and geoelectric methods that provide fascinating insights into the dynamic dispersal and transport of water and nutrients into the soil.

As when attempting to understand groundwater systems, large-scale data sets are also essential for understanding processes and structures in the soil. Drones can be a valuable source of direct and detailed data, including depth information. Models can be used to link this data with information from satellite measurements (with low depth ranges and a coarse measurement grids), soil science and meteorology data. In this way, complementary methodological principles are combined for use in drone-based measurements of groundwater and soil.



Geothermics

Renewable energy from the deep

One of the greatest challenges of this century is the abandonment of fossil energy sources in favour of renewable energy. In Germany, the energy revolution is determined by political, societal and financial factors. But questions remain concerning how this sweeping transformation of the energy sector can be accomplished. One of the fundamental questions is the energy source. Back in 2016, LIAG, working in collaboration with the German Geothermal Association (BVG), pointed out that the urgently needed heating transition (from fossil to renewable energy) can only be managed by using geothermal energy. As a result, LIAG published the much-noted brochure Wärmewende mit Geothermie (heating transition using geothermal energy) in 2018, based on LIAG's scientific publications and the Geothermal Information System GeotIS. In this brochure, LIAG called for the use of medium-depth geothermal energy. Only now is this method economically viable, thanks to new technological developments on the heat pump market. LIAG resumed researching medium-depth geothermal energy in 2020. The following chapter introduces the specific research topics and information systems used in the field of geothermal energy.

Discovering and understanding geothermal reservoirs

Geothermal district heating plant run by Munich city utilities in Riem, Munich, Germany.

Since its foundation, LIAG has been involved in applied geothermal research, based on over 50 years of research experience in earlier departments. The dataset from which the well-known and widely used German geothermal information system, GeotIS, has been developed through over more than 15 years of research from third-party projects, is correspondingly extensive. GeotIS is the foundation and starting point for all research activities in the field of geothermics. Within the field of geothermics, the institute specialises particularly in geological and geophysical reservoir characterisation, reservoir modelling in the area of reservoir engineering and, in collaboration with our partner university Georg August University of Göttingen (GAUG),in reservoir genesis. Research conducted by LIAG is more involved in practical projects than any other research institution.

Current research topics in 2020

Our current research topics deal with reservoir predictions and the sustainable use of reservoirs. Uniquely, LIAG's research activities include the validation of thermally coupled reservoir simulations using operating data from practical projects. Our specific research activities are focussed on carbonates and currently encompass the verification of new methods of analysis for seismic velocity data and attributes for improved reservoir diagnosis. The institute also performs petrophysical reservoir characterisation by evaluating and interpreting cross-correlated borehole logs. In this way, we can determine the integrity of specific reservoirs. We generate thermally/hydraulically/mechanically coupled simulations from a geosystem scale down to the reservoir and borehole scale. We also develop new, validated temperature models and lithosphere models in GeotIS. To cope with these now considerable quantities of data and in the run-up to the new German Geological Data Act (GeolDG), LIAG has recently been looking at artificial intelligence methods for processing seismic data. By adding these new areas, the institute joined the field of medium-depth geothermal energy and siliciclastic geothermal reservoirs in 2020. In the medium term, our aim is to use data mining, deep learning and machine learning to inspect, analyse and interpret geophysical and geological exploration data. To this end, LIAG is working in close collaboration with the Heisenberg Chair of Computational Geosciences at GAUG. LIAG also played a leading role in submitting an NFDI4Earth application to the German Research Foundation (DFG).

Transfer of knowledge and networking

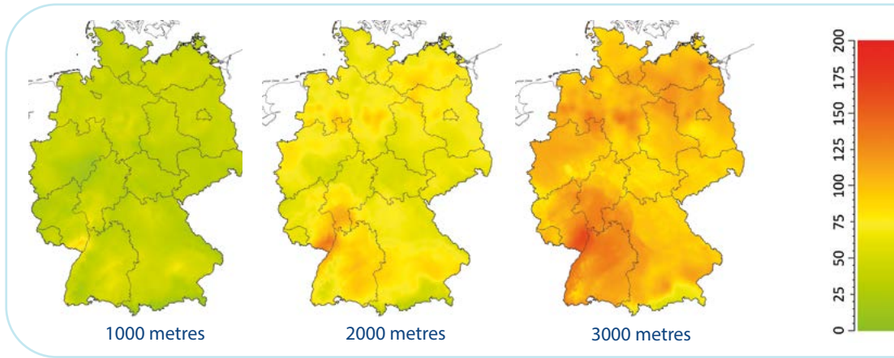
One of our noteworthy accomplishments is the development of the first deep geothermal energy e-learning modules in the LIAG GeoFaces project. These modules are provided free of charge on the GeotIS website. Our applied geothermal research is conducted in collaboration with GAUG, the home of the shared Chair of Applied Geothermics and Geohydraulics (Jülich Model). We work in close cooperation with the Fraunhofer Institute IEG through an honorary professorship for the exploration and geology of geothermal reservoirs at the Bochum University of Applied Sciences.

In addition, LIAG is involved in organising the two most important geothermal energy conferences in Germany: (1) the German Geothermal Conference (DGK) in cooperation with the German Geothermal Association (on whose board LIAG is represented) and (2) the North German Geothermal Conference in Hanover in cooperation with the LBEG and the BGR. The institute also holds a leading scientific role as editor-in-chief of the journal Geothermal Energy (Springer Nature). LIAG covers the increasing demand for geothermal prospecting studies in projects that are in the institute's area of interest. Due to our experience in planning and conducting research drilling and our in-house Borehole Geophysics Department, the institute is an important point of contact for the field of geothermal drilling.

Our present research activities and co-operations are strongly oriented towards the unanswered questions posed by ongoing geothermal projects currently being developed or conducted in the German states of Bavaria and Mecklenburg-Western Pomerania. Our third-party-funded projects cover corresponding topics and are presented with examples in the descriptions of our services.

Geothermics across Germany: Between temperature distribution models and reservoir simulations

LIAG provides the one-of-a-kind GeotIS platform and FIS geophysics information system for geothermal research across Germany. Understanding the process of thermal transport in Earth's upper crust and the resulting temperature distribution is of huge scientific and economic interest.



Temperature distribution in Germany at 1000, 2000, and 3000 metres under the surface.

Challenges in modelling temperature distribution

In 2020, LIAG calculated a new 3D temperature model for all of Germany, Upper Austria and other neighbouring regions using modern geostatistical methods. Calculating a temperature model of this size was a scientific challenge as it required more than 12,000 boreholes to be factored in and weighted differently. For this reason, we are continuing our research into temperature distribution modelling and expanding it to include uncertainty analysis. The present 3D temperature model can be viewed at no charge in either GeotIS or FIS geophysics and raster datasets of any desired sections can be downloaded.

Simulating reservoir processes

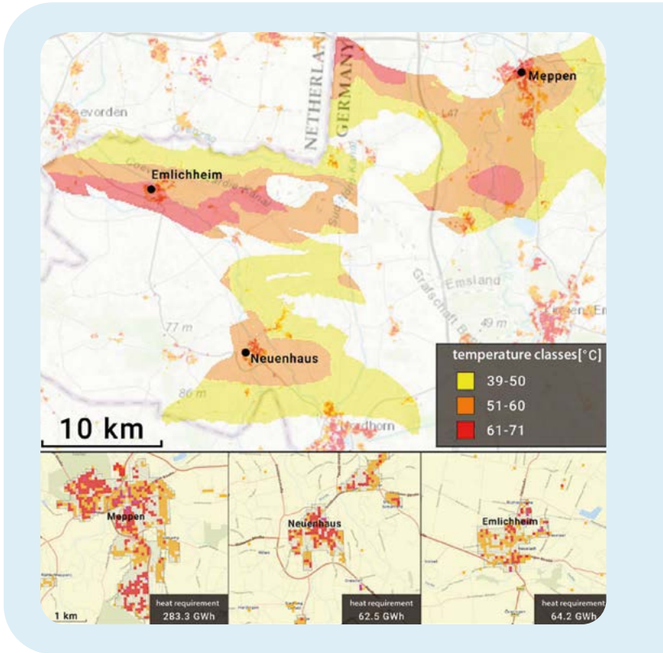
LIAG is involved in the REgine research project in collaboration with Munich city utilities (SWM) and the Technical University of Munich (TU Munich). This project studies the validated characterisation and simulation of carbonate reservoirs. Amongst other things, we are attempting to trace a supposed thermal infiltration to the south of Munich using a thermal-hydraulic reservoir simulation that includes the adjacent fields (page 52). A further thermal-hydraulic simulation that we generated during the PlayType project is a comprehensive basin model. This model is intended to clarify the influence of global climate change (ice ages) on temperature development in the lithosphere and, ultimately, to explain the thermal anomaly in the Molasse basin in eastern Bavaria (page 54).

Research in the area surrounding nine geothermal deep boreholes

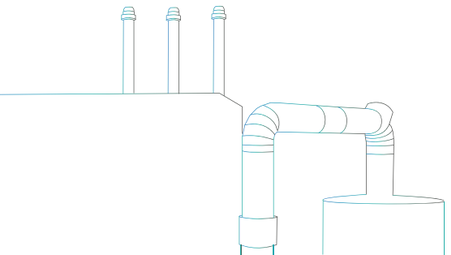
LIAG is also involved in the ZokrateS project in collaboration with Ruhr University Bochum (RUB). This project is investigating an innovative reservoir treatment to increase productivity and as well as thermally/hydraulically/mechanically coupled reservoir simulations for the development of the first petrothermal heating project in Germany. LIAG is collaborating with GAUG on the mesoTherm project. This project researches the characterisation and validation of medium-depth geothermal energy in northern Germany with the first application of machine learning to process seismic data and drilling success forecasts. Both projects involve deep drilling, hydraulic tests and borehole geophysics, which illustrates and underlines LIAG's outstanding expertise in the field of deep boreholes (down to 6000 metres).

Regional geothermics: Potential uses of Lower Cretaceous strata for the heating transition in Lower Saxony

Further progress has also been made with regional research; for example, the potential uses of medium-depth geothermal energy in Lower Saxony. The thermal potential of medium-depth geothermal energy (depth range of 400 metres to around 2000 metres) is currently underutilised in Germany.



Temperature distribution of Valanginian rocks and heating requirements of the towns of Meppen, Neuenhaus and Emlichheim in the Emsland region and the county of Bentheim based on GeotIS and the Pan-European Thermal Atlas 4.3 (2018).



Sandstones in focus for medium-depth geothermal energy

Lower Cretaceous sandstones in Lower Saxony are a potential reservoir of medium-depth geothermal energy. The map of Valanginian deposits newly issued by the LBEG provides data that allows simulations of a geothermal doublet system to be generated. For this reason, LIAG systematically investigated Lower Cretaceous rocks in Lower Saxony in collaboration with the Leibniz University Hanover (LUH) and in consultation with the LBEG. The research was conducted within the framework of a master's thesis using thermal-hydraulic reservoir simulations with the latest reservoir parameters regarding geothermal potential. Previously, it was not known whether sustainable geothermal energy management was possible using Lower Cretaceous rocks.

Model of a geothermal doublet system

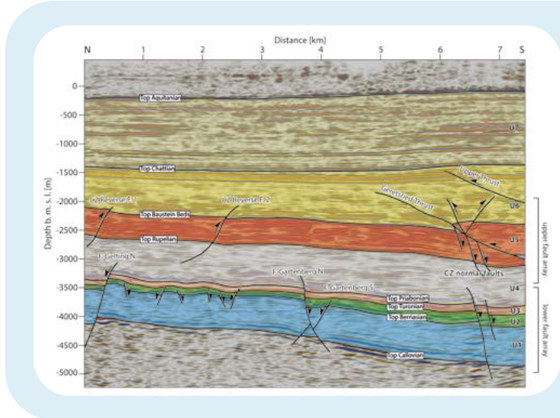
The results show that it would be possible to operate hydrothermal doublet systems in Lower Cretaceous sandstones at many sites in Lower Saxony over a period of more than 35 years while maintaining reservoir integrity. Each doublet system could produce over 8 MW of thermal output. For instance, three doublet systems could already cover 50 percent of the heating requirements of the town of Emlichheim. But it is not only Lower Cretaceous rocks that have geothermal potential. In future, other reservoirs are to be investigated using similar methods to assess their potential with greater detail.

Determining the geothermal potential of faults for drilling targets

The origins of faults in the deep lithosphere and their relation to geodynamic processes in the upper crust are also of geoscientific interest. Furthermore, detailed seismic interpretations and systematic structural analyses of fractured geothermal reservoirs can streamline geothermal exploration and field development strategies. The PlayType project was conducted in collaboration with GAUG and SWM. The example of the German Molasse basin was used to examine the local geodynamical development of faults using detailed seismic data processing and interpretation. This allowed the lithosphere to be classified using an innovative mechanical stratigraphy.

Analysis and interpretation of seismic attributes

The Molasse basin is the only foreland basin in the world where hydrothermal heat and energy is successfully produced. LIAG contributed considerably to this success with their research activities in geophysical reservoir characterisation. Geothermal resources are mainly located in the fractured, karstified carbonates of the Upper Jurassic at a depth of 2000 to 5000 metres. The 3D seismic reflection data that was collected 30 kilometres to the south of Munich near Geretsried helped us to understand the tectonic development of complex structures at the Alpine deformation front.



Interpretation results of seismic attributes shows the fault populations separated by Rupelian clay.

Fault development hypothesis

The results clearly show that the phases of fault activity correlate with the development of stress fields as the Alpine Orogeny advanced. One key observation resulting from this study is that fault populations in the Mesozoic and Cenozoic deposits are separated by the thick Tertiary Rupelian clay formation and consequently developed independently from one another both temporally and spatially.

Sediments through the Ages

Learning from the past

Understanding past climate and environmental changes is an essential requirement when generating detailed scenarios of future climate developments. Continental sediments give us the option of investigating terrestrial climate systems, as opposed to marine sediments. Sediments of this kind react more quickly to local climate changes, such as transitions between interglacial and glacial periods, variations in monsoon circulation, local tectonic changes and landform development. At LIAG, we can apply a wide range of geophysical methods to terrestrial sediments to draw robust conclusions on the development of the climate and derive a cross-regional and internally consistent picture of landscape and climate evolution. This also includes reconstructing climate changes and environmental changes that affected the lifetimes of early hominids.

Following the trail of the past

Taking sediment samples in Zambia.

LIAG uses geophysical methods to obtain evidence of the structural and climatic development of selected sediment systems by working in collaboration with national and international partners. The research is also characterised by multidisciplinary approaches. For instance, we use various luminescence dating methods to determine the age of sediments. LIAG has an in-house geochronology laboratory that the institute uses to conduct research at the forefront of global science. For instance, we can reconstruct the chronology of past changes in precipitation by dating lake and fluvial sediment patterns and loess-palaeosol sequences. When combined, the methods provide us with information concerning wind conditions in the past. Innovative applications in thermochronology allow us to reveal the history of erosion in mountain valleys that are affected by glaciation and changing precipitation.

We also use palaeomagnetic and geomagnetic dating methods. In this way, researchers at LIAG investigate changes in sedimentation conditions using petromagnetic proxies. We also employ geophysical borehole measurements to make statements concerning the lithological properties of the sedimentary sequences drilled. Seismic investigations are the basis for generating structural models of the lithosphere and enable us to create 3D visualisations of sedimentary bodies. We also investigate climate-sensitive parameters using cyclostratigraphic analysis to generate, for example, age-depth models from the geophysical properties of the sediment alone.

The combination of all these methods allows us to draw reliable conclusions concerning the age and natural sedimentation dynamics of terrestrial geological archives. The overarching objective is to derive a cross-regional and internally consistent image of landscape evolution and climate evolution from the local and regional findings. This work is being conducted in national and international projects.

Drilling platform on barge on Lake Towuti (Indonesia), where an international team of researchers have drilled various boreholes and taken measurements.

Unexplored climate archive: The secrets of old sediment basins

LIAG is particularly interested in studying sediment basins, such as old lakes or overdeepened Alpine valleys resulting from glacigenic influences. In such places such as these, extremely thick layers of sediment can be deposited in a relatively short time and are largely undisturbed by other influences. Continental sedimentary basins have a much better chronological resolution than most marine climate archives.

Climate reconstructions using lake sediments

Some LIAG research activities have been conducted under the umbrella of the International Continental Scientific Drilling Program (ICDP) for many years. In 2020, we conducted research at the following sites and lakes: Towuti (Indonesia), Ohrid (North Macedonia), Bosumtwi (Ghana) and Junin (Peru). The boreholes are several hundred metres deep and have been drilled from floating platforms in recent years. These are joined by drilling projects in several now dry lakes, such as Lake Chalco (Mexico) and the Lake Fucino (Italy). These latter projects are also exploring the information archived in the sediments concerning the climate conditions and environmental conditions from 1.3 million years ago to the present day in a wide range of climate zones from the tropical Pacific to the Mediterranean. We will present the results and potential of LIAG's research using the example of Lake Ohrid (page 70). The institute is also involved in a drilling project investigating climate dynamics during the Lower Jurassic period (around 200-174 million years ago) in England.

Insights into ice ages in overdeepened Alpine valleys

As we have insufficient knowledge of how continental environmental systems in Central Europe responded to past climate fluctuations, the institute is also involved in the exploration of glacially overdeepened Alpine valleys and basins. The multidisciplinary analysis of Quaternary sediments enables us to deduce information about the spatial distribution and temporality of the various ice ages in the Alpine region. These issues will be tackled by the ICDP project Drilling Overdeepened Alpine Valleys (DOVE), in which the institute plays a leading role. LIAG is currently preparing to drill a research borehole to investigate this same topic in the Tannwald basin in Baden-Wuerttemberg (page 48). We are also sinking a 500-metre-deep borehole in the section of the northern Upper Rhine Graben located in the state of Hesse. This will access the fluvial-aeolian and fluvial-lacustrine archive and enable us to explore the glacial and interglacial periods of the Quaternary, ideally going back to approximately 2.6 million years before the present.

Grey/yellow loess layers and dark brown palaeosols near Neka-Abelou in northern Iran: Dating results show that some of the sediments are more than 200,000 years old.

What loess tells us about the past

Loess is a valuable environmental and climatic archive: this type of sedimentary geoarchive is widespread in the middle latitudes and has huge potential for enabling us to understand global climate dynamics through research projects. This is because loess is formed by the solidification of aeolian dust. The dust can be blown out of, for example, dry riverbeds or lakes in large quantities and fine components can be transported through the air over great distances. In a some places (lower Danube basin, Tajikistan, China), dust deposits are several hundred metres thick. Determining physical properties is vital for understanding climatic evolution. For this reason, LIAG conducts research at various sites (in Iran, in India, Croatia, Romania and Serbia in addition to those already mentioned) investigating loess and palaeosol sequences (see pages 64 and 68 for examples).

Combining methods opens up new reconstruction options

In addition to utilising established methods, such as rock magnetism and grain size analysis, we develop new techniques, and test and improve them until they are ready for application. Reconstructing wind directions and directions of flow from the orientation of particles is usually a labour-intensive and challenging exercise. The way that LIAG meets this challenge sets us apart from other institutions in the world. One key method is determining the anisotropy of magnetic susceptibility. X-ray microtomography (µ-CT) allows sample material to be characterised in high spatial resolution with regard to mineralogical, structural and geometric material properties. We can formulate more robust conclusions concerning wind and flow fields by combining the results of volume integral magnetic anisotropy with µ-CT datasets.

Dating sedimentary deposits using optically stimulated luminescence (OSL) and related methods is an essential tool for the chronological classification of climate data archived in the sediment (going back to approximately 300,000 years before present). NMR enables us to make deductions concerning the bonding force of water in the pore volume. From this we can derive the spectrum of potential natural variation in soil moisture. For instance, we used NMR to considerably reduce the number of implausible OSL age estimations from the Toshan loess plateau in Iran.

Reconstructing the climatic living conditions of our human ancestors

Where, how and under what conditions did our human ancestors live and what were the effects of climatic changes? Investigating sediments at a wide variety of sites helps us to reconstruct climatic conditions. At the same time, it helps us to understand the lifestyles and behaviours of our human ancestors as well as their development of tools. Researchers at LIAG use OSL and electron spin resonance (ESR) dating methods to narrow down the time at which various types of sediments were deposited. For example, we dated sediments found in the vicinity of Stone-Age tools in Zambia to ascertain the progress of the technological and functional revolution that took place in the Middle Stone Age and Early Stone Age (page 62) among our human ancestors. Similar investigations are being conducted in the Sudan and in Germany.

LIAG and other partners involved in the Lichtenberg project are questioning why Neanderthals settled in northern Lower Saxony (Wendland) although the Ice Age presented inhospitable conditions. The Lichtenberg basin was a shallow lake approximately 120,000–80,000 years ago, i.e. from the Eemian interglacial period to the Early Weichselian glacial period. New investigations making use of LIAG methodological expertise show that the local climate and, therefore, also the vegetation at this site varied widely. This was due to the lake being connected to the river Elbe at different periods in the past (page 50).

Consequently, it is possible to reconstruct the past environmental and climatic conditions from the changing sediments by taking advantage of combined geophysical expertise and diverse methods. For instance, we can draw fundamental conclusions regarding climatic history, evolutionary history and their dynamics. At the same time, this potentially allows us to make statements regarding future developments.

Fieldwork: Taking samples and describing sections.

Geohazards

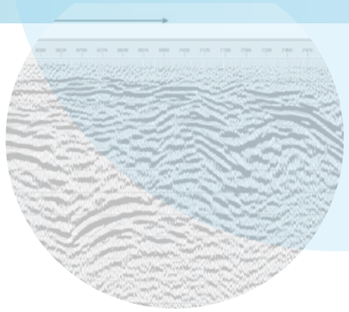
When the earth surface moves

Geological structures are the result of geological developments that often lasted many millions of years. Most of the associated changes are barely noticeable or entirely imperceptible to humans. This is due to the speed with which they happen or the great depth at which they take place. However, some geological processes pose a potential risk to infrastructure or even human life that should not be underestimated. Changes connected to geohazards of this type often happen slowly at first, and we frequently have scant knowledge of their location in the subsurface. LIAG addresses the further development and the use of geophysical methods to improve the identification of suspected sites, visualise structures with more precision and record processes better. Many projects are being conducted in cooperation with university partners and local specialist institutions. The chapter entitled Geohazards provides a brief overview of current LIAG research in the areas of neotectonics and faults, Eifel volcanism and subrosion.

Pivotal topics at LIAG

Earthquakes, volcanic eruptions, tsunamis – geoscientific topics are frequently only noticed by the public when they cause lasting, often catastrophic changes near to or on the Earth's surface. Because geohazards of this kind can significantly affect or alter our environment, they deserve particular consideration in geoscientific research. They also pose a substantial risk of economic loss. The 2011 Tōhoku earthquake (Japan) resulted in a tsunami and consequently the Fukushima nuclear catastrophe. The Munich Reinsurance Company have estimated the total damage caused at 210 billion dollars for this one event alone. This shows that geohazards can have far-reaching consequences.

Germany is not known for large geological catastrophes of this kind. Nevertheless, from a scientific point of view, the Eifel is still an active volcanic area, for example. The most recent eruptions in the area around Lake Laach only date back 13,000 years. In Germany, the responsible services regularly record tectonic earthquakes, but these are often below the perception threshold. However, as recently as 1612, a severe earthquake destroyed large parts of Bielefeld, which is far removed from any tectonic boundary. Other types of geohazards can be relevant depending on the geological or morphological conditions; landslides caused by climate change or sinkholes resulting from dissolution processes in the subsurface are familiar examples.



Very recent active fault in the grounds of a kindergarten in Corona Heights, San Francisco, USA. It could move again at any time.

Neotectonics – The search for recent tectonic activity

Movements within the Earth's crust that took place in the recent past or that are currently taking place are referred to as neotectonic processes. Faults are the particular focus of geoscientific investigations. At faults, geological units are shifted vertically and horizontally. This means that they provide us with information concerning geological development and also define areas where movements could currently occur.

Postglacial uplift and salt intrusion

In previously glaciated regions, such as northern Germany, post-glacial rise of land masses caused by the melting ice sheets also play a role. This is known as the Glacial Isostatic Adjustment (GIA). If GIA and faults coincide, this can lead to movements at faults and hence induce earthquakes. LIAG is also investigating interactions of this kind in Lower Saxony, for example. Salt intrusion is a further possible trigger for changes in the stress field, particularly in northern Germany.

Understanding neotectonic processes and the associated hazards is a challenge. Faults are often overlaid by sediments, meaning that the outcrops are sparse. This is where we need geophysical methods to image the faults spatially and obtain indirect information about the temporality of fault activities. At LIAG, we respond to these challenges by using reflection seismic, dating and modelling, amongst other methods. Geophysical investigations are yielding ever more data that substantiates previously unknown tectonic movements in the distant past.

Localising faults

High-resolution reflection seismic measurements using the measurement technology developed at LIAG return detailed images of fault geometry and strata structures that have been shifted by the faults. The use of shear waves also allows us to deduce the elastic moduli, in particular the shear modulus. This parameter describes the elastic deformation behaviour of the subsurface and is of great importance for its characterisation.

The institute is involved in projects investigating concealed near-surface faults around the world (page 66). In New Zealand, we are working with the Institute for Geological and Nuclear Science to explore concealed faults in the Whakatāne district, around 30 kilometres away from the Edgecumbe Fault that was reactivated by a severe earthquake in 1987. Structures in the subsurface show the traces of a concealed fault line that has offset younger sediments by more than 10 metres and runs through the entire district in a previously unsuspected area.

We are investigating a section of the Sorgenfrei-Tornquist fault zone in collaboration with LUH and the Geological Survey of Denmark and Greenland. In addition to more precisely identifying the location, we were also able to show that the fault exhibits considerable displacement and was still active during the Holocene period. We also documented neotectonic activities triggered by halotectonics in the Wunstorf-Bokeloh area using modern reflection seismic measurements.

Dating palaeo-earthquakes

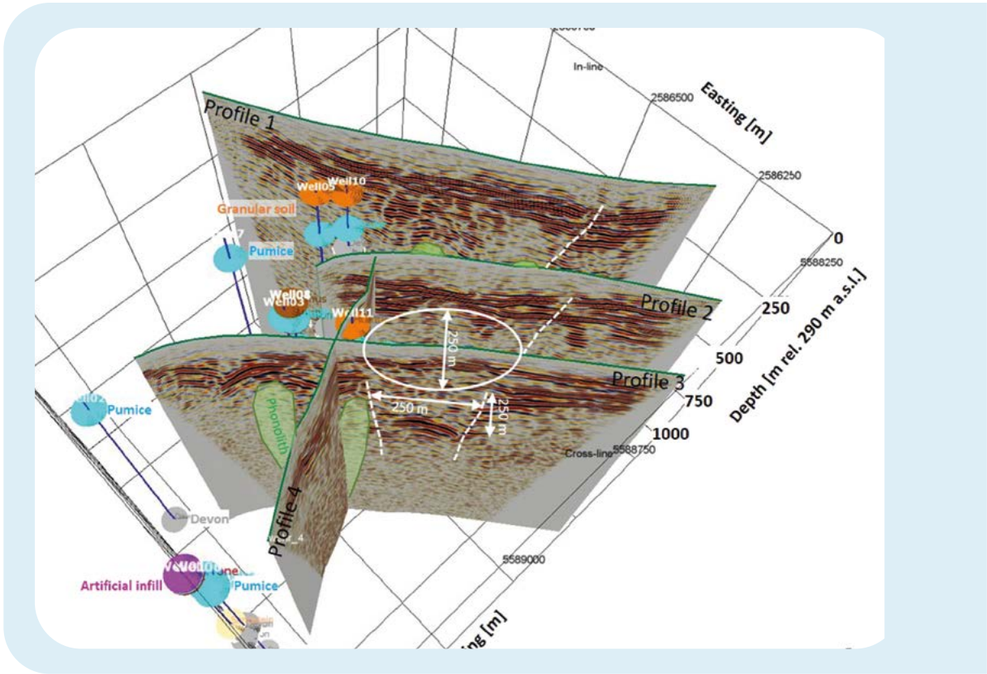
Seismic images show the current state of faults. Dating provides us with important information about the chronology of past earthquakes that triggered movements at faults. LIAG develops luminescence and ESR dating methods to be able to directly date earthquakes for the last 2.6 million years using fault gouges. This is important information that promotes the understanding of geological evolution and provides qualitative indications of future movements.

For example, LIAG performed luminescence dating for the Northern Harz Boundary Fault in Lower Saxony. At the Atotsugawa fault in Japan, we showed that the methods are useful for comparing the relative activity of faults. LIAG researchers are currently dating a wide range of faults in Pakistan, Austria, Slovenia and other countries. The European Alps are a new area of focus: We successfully acquired two projects to date main faults in the Alps as part of the DFG priority programme Mountain Building Process in Four Dimensions (4D-MB).

Eifel volcanism – Movements from the deep to the surface

Volcanic structures also exist in Germany. Recently, particular attention has been focused on the Eifel region due to the first ever observations of deep low-frequency earthquakes that occur in the lower crust. Researchers interpret these as indications of ongoing magma movements. For this reason, the question of whether volcanism in the Eifel poses a medium-term to long-term hazard, and to what extent, is being intensively discussed.

Regional, integrative approaches are needed to allow us to understand the processes taking place at a crustal scale. The information concerning gravimetric and magnetic anomalies collected by LIAG was incorporated into a review paper on the Eifel as a world-renowned region of intraplate volcanism. Near-surface investigations are vital for exploring the paths taken by rising magma. Until now, reflection seismic investigations did not have the desired imaging quality due to methodological limitations and difficult conditions caused by the volcanic structures. Some significant progress has been made in this regard. The seismic profiles recorded by LIAG in the area of the Wehrer Kessel volcanic complex have enabled us to generate the first seismic interpretation of this structure; furthermore, they also provide insights into the array of faults present in the surroundings. The latter is of great interest because both fault-related tectonic earthquakes and earthquake swarms occur in this region.



Seismic 3D view of the volcanic structures and late sedimentary infill in the Wehrer Kessel (East Eifel). The vertical blue lines indicate deep boreholes, surrounding discs show the tops of the drilled lithology, dashed white lines indicate faults. A slump structure approximately 250 metres in diameter and depth can be seen in the foreground (in section 3).

Subrosion – From slow subsidence to sudden sinkholes

Subrosion is a serious risk, particularly in urban areas. The term subrosion describes water-soluble components (salt, for example) leaching out of rocks. The resulting loss of mass can lead to instabilities or even cavities in the subsurface. On the surface, these processes are manifested by the ground slowly subsiding or suddenly slumping, creating what is referred to as a sinkhole. Subrosion can be expedited by faults in the subsurface and disruptions in the sequence of strata that can become pathways for water.

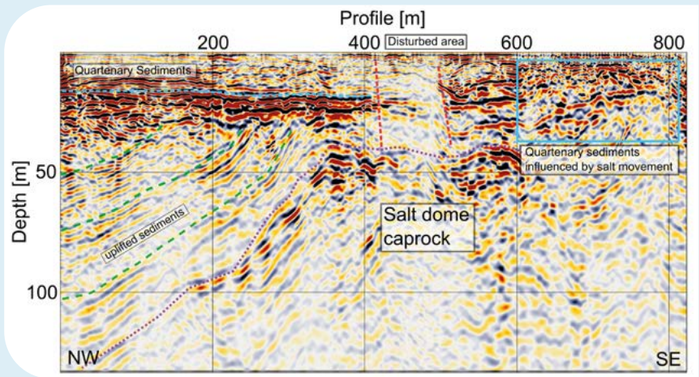
Determining the shape of salt structures using seismic methods

Regions in northern and central Germany where salt structures occur are especially prone to subrosion. The region of Quickborn in Schleswig-Holstein is characterised by a vertically intrusive salt dome that has caused subsidence and sinkholes in the town over the last twenty years. We surveyed a growing number of seismic shear wave profiles in Quickborn, Elmshorn and the surrounding area using the measurement system developed at LIAG. The system consists of a miniature vibration source (ELVIS VII) and a landstreamer. The grid of measured seismic profiles and the excellent resolution of the data enabled us to determine the shape of the intrusive salt structure with more precision; the results can also be used to distinguish between regions that are more or less affected by salt intrusion. When identifying areas prone to sinkhole formation, sections in which the salt structure occurs in the near-surface area in connection with disrupted or shifted strata are of particular interest, as water pathways can develop at these areas. Borehole logs are employed to support the interpretation of the geological situation.

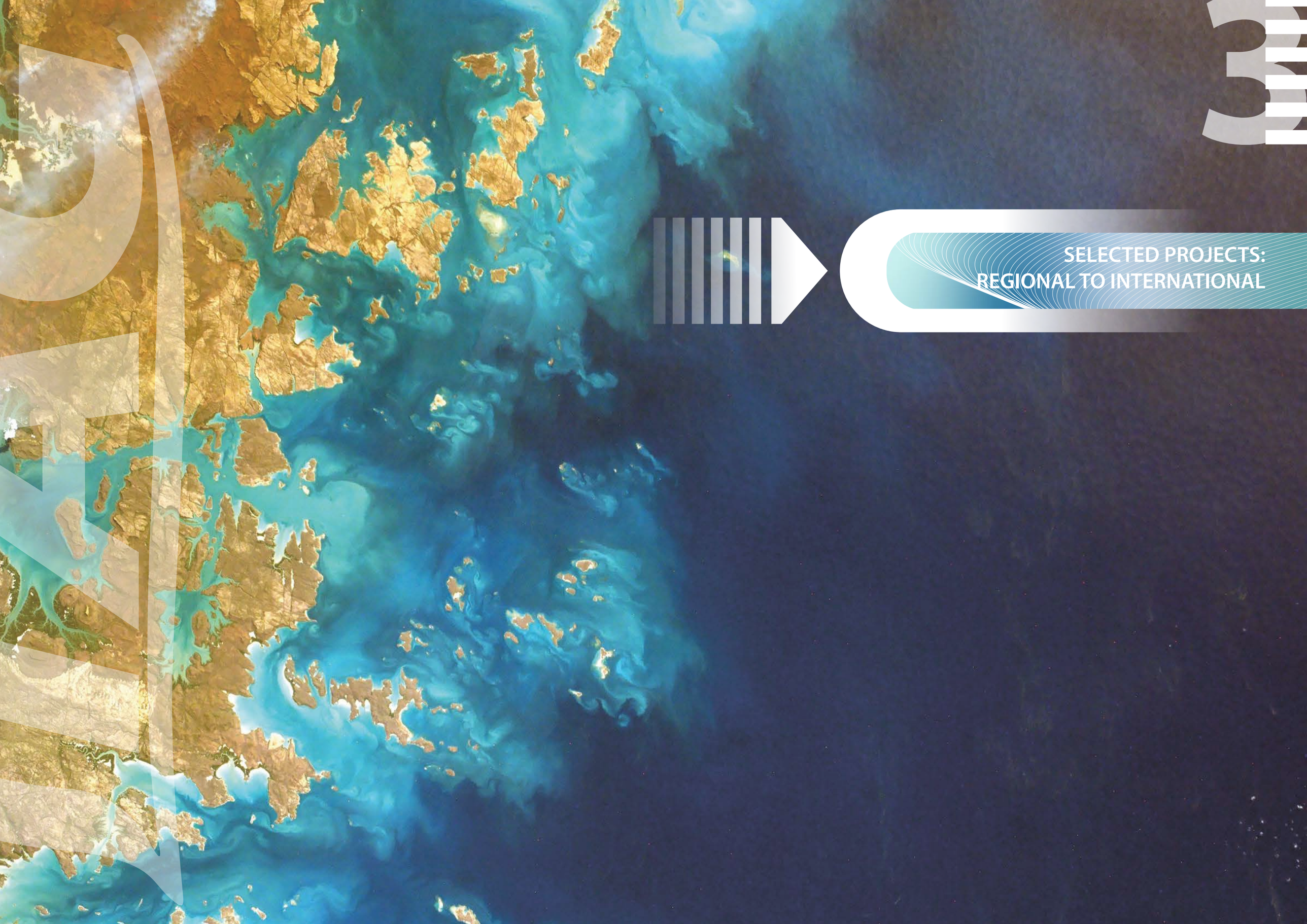
Gravimetric monitoring network

For several years now, LIAG has operated a gravimetric monitoring network in two regions of Germany – Hamburg Flottbek and Bad Frankenhausen (Thuringia). As the processes are slow and the changes small, the time series must be accordingly long. For the first time, we succeeded in detecting the loss of mass caused by subrosion based on oberservations of temporal changes in Earth's gravitational field. The monitoring activities have been continued, motivated by these positive results.

The examples mentioned above show the focus of our current research in the field of geohazards: improving the imaging of present conditions of the various research objects and establishing new methodological approaches and time series.



Seismic section through the western part of the salt domes under Quickborn. The intrusive salt dome (pink) causes the overlying strata (green) to bulge upwards. The reduced seismic amplitude above the visible salt structure (red) and the disturbed Quaternary sediment (blue) to the south-east indicate ongoing movement of the salt.



3

SELECTED PROJECTS: REGIONAL TO INTERNATIONAL

Overview: Where we conduct research

Our regional to international activities

LIAG researchers are active both nationally and internationally in worldwide joint projects and in-house projects funded by third parties. They make a crucial contribution to solving scientific questions with their geophysical expertise and our outstanding internal infrastructure and methods. This map of the world visualises the locations of our project activities. We take measurements and samples related to our areas of priority in numerous countries; for instance in Zambia, Mexico, Mongolia, India, Iran, New Zealand, Denmark and Japan. The institute's activities in multiple ICDP projects is particularly noteworthy. ICDP is a multinational programme that funds continental scientific drilling to further the understanding of geological processes and structures in England, Indonesia and Germany, amongst others. LIAG is also involved in multiple research projects of the priority programme 4D-MB - Mountain Building Processes in Four Dimensions run by the German Research Foundation within the international AlpArray mission.

But regional and local research in Germany is just as important: for example, we are involved in the European Interreg TOPSOIL project in the North Sea region and the joint goCAM project in Lower Saxony. On top of all this work, we are currently running investigations in the North German Basin, in the Eifel region, in the Tannwald basin and in the Molasse basin, amongst others.

The acquired data is analysed and the findings are summarised within the institute itself. Methods and required technological systems are also improved by conducting basic research, process research and applied research.

3D visualisation of glacial structures in the Tannwald basin

LIAG conducted two small-scale 3D survey campaigns using reflection seismology for a detailed preliminary site investigation before drilling in the Tannwald basin.

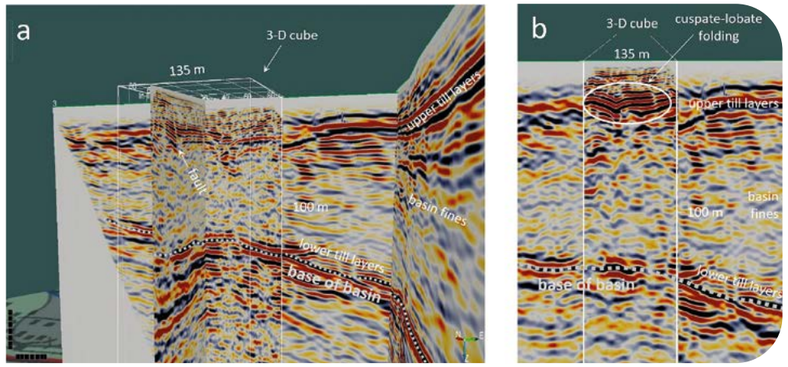
For the first time, 3D seismology enabled us to create a detailed visualisation of geological structures in the Tannwald basin and identify previously undetected structures in the area. LIAG conducted two small-scale 3D survey campaigns using reflection seismology for a detailed preliminary site investigation before drilling in this formerly glacial area. They were the first to be conducted in a region of this kind and on this scale. The seismic measurements are associated with the project Drilling Overdeepened Alpine Valleys (DOVE) of the International Continental Scientific Drilling Program (ICDP). This project is investigating sediment traps in seven glacially overdeepened valleys across the Alps with the aim of drawing conclusions concerning spatial and temporal changes in the Alps over the last 2.6 million years – a time that was governed by highly dynamic cycles of glaciation. Visualising the subsurface also provides important information for the ICDP project and the drilling campaigns planned within the project.

Since 2014, LIAG has been exploring the Tannwald basin in Baden-Wuerttemberg using 2D sections. It is a pilot region that is used to study overdeepened valleys and transfer the results to other, more populous regions. The additional reflection measurements had the goal of identifying geological structures more precisely within an area of approx. 120 metres by 120 metres in advance of the ICDP drilling campaign near Winterstettenstadt. LIAG's measurements started in early 2018 and were partly funded by the German Research Foundation.

LIAG has completed two measurement campaigns: (1) Multicomponent shear-wave seismics and (2) compression wave seismics (with a single component). We first generated a shear wave multicomponent dataset with 6 components: We recorded vertical ground movements and movements in both horizontal directions using 3-component geophones. The horizontal source signal was generated by a small electrodynamic vibrator (ELVIS) in two perpendicular directions. The weather conditions caused varying and challenging situations on the surface that had to be factored in during data analysis. A few months later, we also recorded a compression wave dataset using vertical geophones and a vertical ELVIS source.

Visualising previously undetected geological structures

3D visualisations revealed previously undetected structures, especially in the near-surface area. These structures were probably formed by glacial compression during the last ice age. The presence of deposits of differing hardnesses created a structure referred to as cuspate-lobate folding that has not been previously



Model: 3D view of the seismic P wave datacubes compared to 2D P wave seismology: (a) Perspetive view of the 3D volume, (b) Orthographic view. The detailed part of the 3D volume is located 60 metres in front of the 2D section and shows the glacial compression at 20-40 metres down.

detected in glacial sediments. The imaging quality of the structures in the 3D section is much better than the parallel 2D section. Furthermore, 3D seismology allows these structures to be spatially orientated. Despite using a small seismic source (due to the strength of the generated signals and, therefore, the depth of penetration) and conducting the measurements on loose soil, the base of the basin was visualised very clearly at a depth of approx. 135 metres.

High resolution and simple measurement

This shows that 3D seismology significantly improves the identification of previously undetected geological structures and spatial orientation using a straightforward measuring method.

On this basis, we intend to generate a systematic comparison of the shear wave and compression wave reflection behaviour. This combination will yield more in-depth information about sedimentation processes in the Tannwald basin. The planned drilling campaign is intended to clarify the processes that occurred during and after the period in which the Tannwald basin was filled. In future, the investigations will be supplemented by seismic measurements from borehole to borehole (crosshole seismic testing). An application has been submitted to the DFG priority programme ICDP to this end.

Changes in the weather resulted in fluctuating, challenging surface conditions.

FACTS & DETAILS

LIAG project head: *Dr Hermann Buness & Prof. Dr Gerald Gabriel.* ***LIAG project processing:*** *Dr Thomas Burschil & Dr David C. Tanner.* ***Duration:*** *01/12/2015-31/12/2020.* ***Funding:*** *DFG, LIAG.* ***Partners:*** *ETH Zürich, LGRB.*

Published by LIAG during the project:

BURSCHIL, T. *&* ***BUNESS, H.*** *(2020): S-wave seismic imaging of near-surface sediments using tailored processing strategies. - Journal of Applied Geophysics, 173: Article 103927.*

BURSCHIL, T., TANNER, D.C.*, REITNER, J.M.,* ***BUNESS, H.*** *&* ***GABRIEL, G.*** *(2019): Unravelling the shape and stratigraphy of a glacially overdeepened valley with reflection seismic: The Lienz Basin (Austria). - Swiss Journal of Geosciences, 112: 341–355.*

BURSCHIL, T., BUNESS, H., TANNER, D.C.*, WIELANDT-SCHUSTER, U., ELLWANGER, D.* *&* ***GABRIEL, G.*** *(2018): High-resolution reflection seismics reveal the structure and the evolution of the Quaternary glacial Tannwald Basin. - Near Surface Geophysics, 16(6): 593–610.*

Climate reconstruction: Neanderthal survival through the ice ages in Lower Saxony

Archaeological excavation near Lichtenberg, Germany in early 2019.

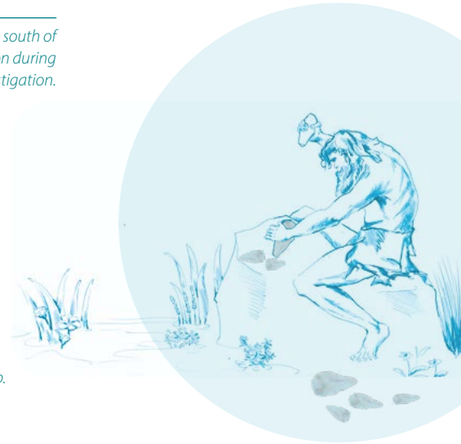
In the 1990s, archaeologists made a surprising discovery on the outskirts of the village of Lichtenberg in the Hanoverian Wendland region of Germany. At a depth of only 2-4 metres, they found artefacts that clearly conformed to Neanderthal design. Previously, it was assumed that this very northerly area, at that time partially surrounded by ice masses, would have been practically uninhabitable. Why and when exactly did the Neanderthals settle so far in the North? What drew our human predecessors to this place? The Lichtenberg project seeks to answer these questions. To this end, a group of researchers from the sectors of archaeology, geology and geophysics are determining the environmental and climatic conditions that prevailed when Neanderthals colonised the area.

Scientists from the Max Planck Institute for Evolutionary Anthropology and LIAG worked in close collaboration to conduct these investigations. LIAG began a comprehensive investigation of the region two years ago. This involved a drilling campaign around the archaeological trench using the LBEG drill. LIAG concentrated on generating multiple seismic profiles that link these drill sites and thus converted the 1D borehole geological data into 2D geological profiles. The cores are stored in the Geozentrum in Hanover.

Stone-Age Lichtenberg – A lake, marsh wildlife and a tool production site

Even the preliminary results are very enlightening. The researchers determined that the site is located on the northern shore of what at the time was an enormous (more than 10 x 20 square kilometres in size), shallow and ancient lake. The preliminary borehole information showed that the Neanderthals occupied the area multiple times in the period from 120,000 to 80,000 years before present, i.e. from the Eemian interglacial to the cold period of the Weichsel Early Glacial. The landscape reconstruction showed that the River Elbe regularly filled the lake with water. Furthermore, the reconstruction of the flora from the peat layers conducted by Leiden University indicated that the area was characterised by low-growing marsh plants. During further excavations, archaeologists found so many flint artefacts (such as hand axes) that they surmised that the site was a type of toolmaking workshop. A small channel ran through the shore and presumably revealed the many high-quality flints from older glacial till. Analyses of the cores showed a very extensive profile, particularly through the Eem strata. This is rare in Lower Saxony. Currently, sediments from the core are being processed using a combination of OSL dating, pollen markers, geochemical markers, geophysical markers (borehole measurements, palaeomagnetics) and biomarkers. These can then be used to reconstruct the climatic environment at the time of occupation.

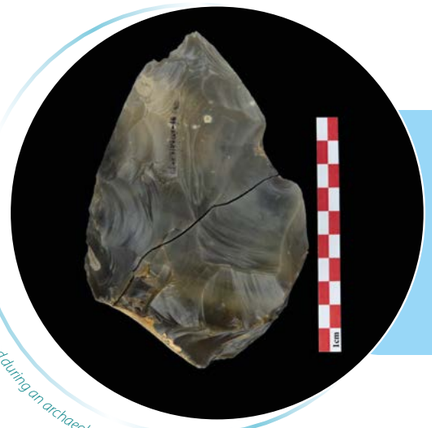
The LBEG drill around 15 metres south of the archaeological excavation during the geological investigation.



Mass production of tools: Neanderthal hand axe workshop.

Deeper understanding of northern Neanderthal settlements

In this way, we gained a better understanding of why and when the Neanderthals ventured so far north. The climate reconstructions generated during the project also revealed the effects of climate change in Lower Saxony caused by the advance and retreat of ice sheets. This information is critical for predicting future changes to the climate.



Hand axe – found during an archaeological excavation near Lichtenberg.

FACTS & DETAILS

Project lead and processing at LIAG: *Dr. David C. Tanner.* ***Duration:*** *01/01/2018-31/12/2020.* ***Funding:*** *LIAG.* ***Partners:*** *Max Planck Institute for Evolutionary Anthropology, Technical University of Braunschweig, Lower Saxony Heritage Authority, Leuphana University Lüneburg, Friedrich Schiller University of Jena.*

Sustainable exploitation of the Malm geothermal reservoir in the Munich Metropolitan Region

Drilling site of the Schäftlarnstrasse geothermal project.

Sustainable thermal energy production is vital for geothermal projects if they are to be economically viable. Therefore, the objective of the subproject REgine, funded by BMWi within the GEOmaRe joint project, is the improved and more sustainable exploitation of the Malm reservoir in the South German Molasse basin in the Munich metropolitan area. The Molasse basin is the most important area for geothermal energy utilisation in Germany and has high geothermal potential. LIAG is collaborating with Munich municipal utilities and the TU Munich to produce a precise reservoir characterisation and to model operational scenarios for a comprehensive reservoir model.

At the Schäftlarnstrasse geothermal site, geophysical borehole measurements will be combined with seismic attribute analysis, drill core sample tests and analogue sample tests to determine parameter correlations for promising zones in terms of carbonates. Optimum operating parameters will also be determined using numerical simulations. LIAG's tasks are divided into three subject areas.
1) Basic petrophysical, hydraulic and geomechanical investigations, 2) Understanding processes and reservoir engineering 3) Calibrating and expanding the development models. The following section discusses investigations that aim to expand the development model.

Improved understanding of the structures for sustainable reservoir development

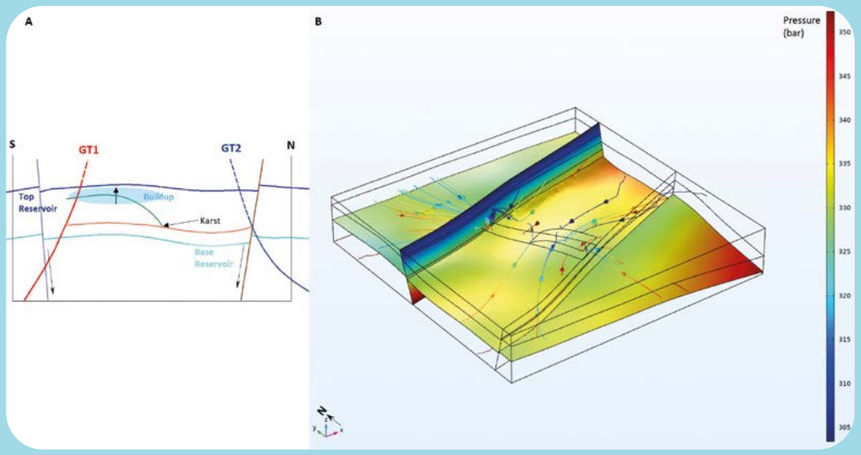
A better understanding of thermal infiltrations with regard to their influencing factors (geological and geomechanical properties of the reservoir) and process cycle times is critically important for ensuring sustainable thermal energy production.

This is being examined at a geothermal site to the south of Munich, as an unforeseen drop in temperature has occurred in the production borehole. The reservoir model factors in the matrix porosity of the carbonates, the fracture porosity of faults and local karst porosities. It is based on the structural analysis and facies analysis of seismic lines. The petrophysical parameters were obtained from the geothermal boreholes. Thermohydraulic simulations on the basis of this reservoir model were used to investigate the temperature profile in the production borehole and compare it with the measured temporal temperature profile.

The hydraulic parameters were determined by adapting the analytical calculations of temperature profiles to the measured data.

Karstification is the dominant parameter

Part A of the visualisation above shows a sketch of the structural and facial conditions in the reservoir. The area is defined by two normal faults that can be verified by local increases in fracture porosities in both boreholes. One borehole has been sunk through a bioherm facies, i.e. a fossilised sponge reef structure, whose extents have been mapped using seismology. One significant element is a karst aquifer that splits in the middle of the area and can be detected in both of the boreholes.



Part A shows an N-S sketch of the reservoir model with the positions of the geothermal boreholes GT1 and GT2. Part B shows the area with the hydraulic pressures taken from a reservoir simulation within the reservoir and along a fault zone. The arrows show the direction of flow. The borders of the Karst aquifer are shown in the middle of the model.

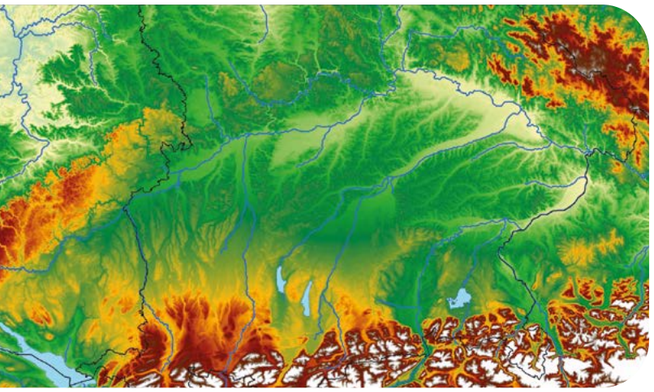
Part B shows a result of the hydraulic simulation as a pressure field with directions of flow: The strong influence of karstification on the flow patterns is clearly visible. The calculations have confirmed that the previous models are generally suitable for generating reservoir simulations.
Further investigations are necessary to factor in the correlation between fracture porosity and matrix porosity and to further adjust the model. To this end, a new seismic 3D dataset will be integrated into the analysis.

Munich city utilities plan to exploit the high geothermal potential of the region. By 2040, the district heating system of the Munich metropolitan area will be supplied entirely from renewable energy sources, a large part of which will come from deep geothermal energy. The research activities within this project help to reduce the exploration risk by evaluating the exploration and simulation methods for geothermal energy. This work is revealing fundamental new findings concerning the structural and facial conditions in the lithosphere and how these can be used for modelling processes in reservoirs.

FACTS & DETAILS

LIAG project head: *Prof. Dr Inga Moeck.* ***LIAG project processing:*** *Mohamed Fadel, Dr Johanna Bauer, Dr Sonja Wadas.* ***Duration:*** *01/10/2018 - 30/09/2021.* ***Funding:*** *BMWi within the joint project GEOmaRe.* ***Partners:*** *Munich city utilities, TU Munich.*

The influence of groundwater flow on heat transport and temperature distribution in the play type *foreland basins*



Terrain model of the Molasse basin.

The Molasse basin in southern Germany is the most geothermally exploited sediment basin in the country. It is classified to the play type *foreland basins*. The joint PlayType project is being conducted in collaboration with the International Geothermal Centre in Bochum (now Fraunhofer IEG) and our associate partner Storengy. It is concerned with cataloguing geothermal provinces according to the concept of play types for economic development and in the interest of internationalising the German geothermal industry. The Upper Jurassic carbonate aquifer (Malm) fulfils the requirements for sustainable use of geothermal energy. For this reason and for the first time, LIAG used a thermal-hydraulic model to examine the influence of the Würm glaciation in the northern Alpine foreland and rock permeability in the Molasse basin to gain an understanding of the pronounced negative temperature anomaly to the east of Munich.

The Molasse basin has been investigated for mineral oil and natural gas deposits for decades. However, current attention is also focussed on thermal water for various types of geothermal uses, such as thermal spas, heating energy for local and district heating systems and electricity production. Geostatistical evaluation of measured borehole temperature data currently offers the most reliable predictions of subsurface temperatures in the Molasse basin. Positive temperature anomalies are much in demand. In contrast, negative temperature anomalies are a great risk for geothermal investigation and development because they significantly lower expectations or restrict the useful volumes of thermal water.

First study on the consequences of the Würm glaciation

The negative anomaly to the east of Munich is a noteworthy example of as yet unexplained processes in a region used intensively for geothermal energy extraction (Fig. 1). For the first time ever, LIAG examined the impact of the Würm glaciation in the northern foreland of the Alps as well as the highly diverse levels of rock permeability along the Molasse basin. Using numerical modelling, we simulated the periglacial and glacial conditions that resulted in the formation of low-permeability permafrost on the one hand and also controlled the periodic advance of massive Alpine glaciers into the foreland on the other. The Molasse basin served as a reference for comparing and understanding the interaction between the palaeoclimate and forced convection in other foreland basins around the world.

In the South German Molasse basin, the groundwater in the western area of the geothermally developed Malm in Baden-Wuerttemberg is generally recharged by the Danube, which cuts through the carbonate platform. The infiltration of Tertiary molasse sediments into the generally unkarstified carbonate aquifers is low, as is shown by Pleistocene waters in the deeper areas of the Molasse basin. The model demonstrates that thermal conduction predominates in this area.

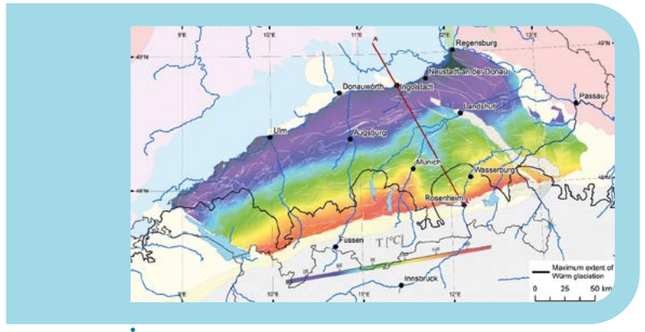


Fig. 1: Temperatures in the top Malm from LIAG's 3D temperature model.

It is a different story in the Bavarian part of the Molasse basin to the east. The pressure level of the Malm, karstified to great depths in this area, is directly coupled to the river Danube by the outflow between Neustadt and Regensburg. As shown in the thermal-hydraulic model, thermal convection is caused by the karstification of the Malm, which leads to high rock permeability throughout the entire system. Over lengthy geological time scales (more than 10,000 years), the superimposition of highly permeable carbonate rock and relatively permeable Tertiary and Quaternary layers above them caused thermally effective infiltration of the Molasse basin (Fig. 2).

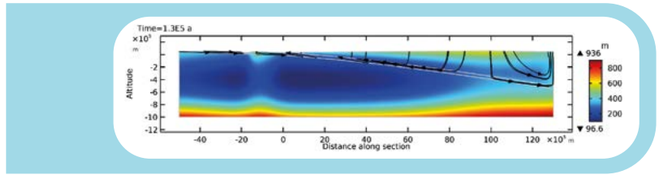


Fig. 2: Hydraulic head and molasse infiltration with higher permeability of the karstified Malm carbonates.

Sufficient rock permeability leads to significant negative anomalies

If the complete molasse/carbonate karst system has sufficient rock permeability, the high throughput of cold surface water can result in the formation of a considerable negative anomaly (Fig. 3). Astonishingly, it is irrelevant whether we use a palaeoclimate with the formation of permafrost and foreland glaciation as the upper temperature boundary condition or simply a consistent temperature of 9°C. The deciding factor in all scenarios is the permeability of the Malm and the resulting magnitude of the convective flows of groundwater and heat. Remarkably, in simulations without a palaeoclimate, the anomaly is even 16°C colder at -50°C even though the average palaeotemperature is 3.2°C and the median palaeotemperature is 2.3°C. The formation of permafrost actually reduces hydraulic conductivity and so blocks the convective flow of groundwater and heat and protects the Malm from cooling down. The greater hydraulic head caused by the formation of the Inn Glacier had a negligible effect on further cooling of the lithosphere. The effects of the palaeoclimate have only been retained to a depth of 2 kilometres up to the present interglacial period due to the slightly lower temperatures in areas of low permeability. This remaining cold is a remnant of the former permafrost that delayed heating by thawing.

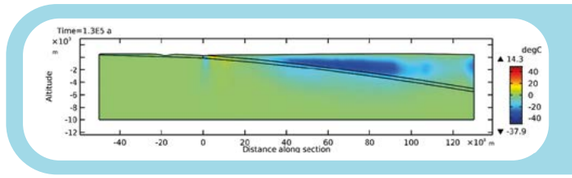


Fig. 3: Temperature differences of the palaeoclimate scenarios with higher and lower Malm permeabilities.

Consequently, the formation of the negative anomaly to the East of Munich is largely determined by rock permeability and, in particular, by the permeability of the Malm. The potential hydrogeothermal uses in the Munich are more favourable than in the western part of the Molasse basin due to the higher recharge rate.

FACTS & DETAILS

LIAG project head: *Prof. Dr Inga Moeck.* ***LIAG project processing:*** *Dr Tom Schintgen.* ***Duration:*** *01/08/2017 - 31/05/2021.* ***Funding:*** *BMWi within the joint project PlayType.* ***Partners:*** *International Geothermal Centre in Bochum (now: the Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems IEG), Storengy (associate).*

LIAG publications during the project:

DREWS, M.C., HOFSTETTER, P., ZOSSEDER, K., ***SHIPILIN, V.*** *& STOLLHOFEN, H. (2020): Predictability and controlling factors of overpressure in the North Alpine Foreland Basin, SE Germany: an interdisciplinary post drill analysis of the Geretsried GEN 1 deep geothermal well. - Geothermal Energy: Article 20.*

SHIPILIN, V., TANNER, D.C., VON HARTMANN, H. *&* ***MOECK, I.*** *(2020): Multiphase, decoupled faulting in the southern German Molasse Basin – evidence from 3D seismic data. - EGU Solid Earth, 11: 2097-2117.*

TOPSOIL: Understanding the water under our feet

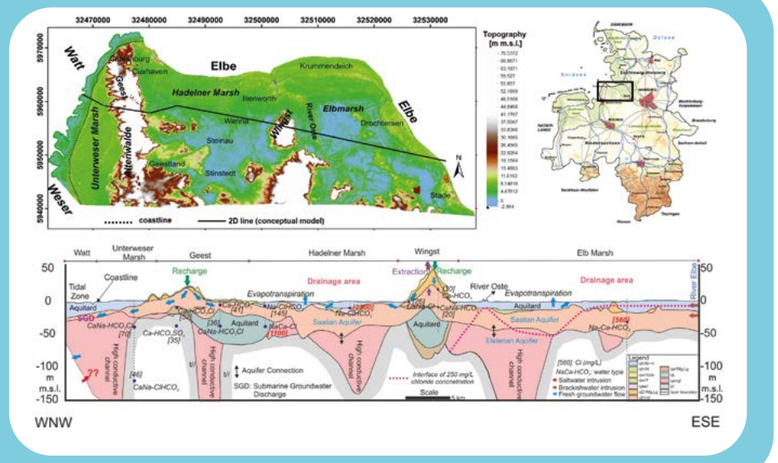


Fig. 1: Elbe-Weser triangle project region and concept model for flow and transport modelling (groundwater is recharged in the geest regions and drainage occurs in marshy areas).

The effects of climate change are not only limited to our weather. Heavy rainfall and storm surges also affect the groundwater and consequently the quality and quantity of our water resources. The objective of the EU Interreg TOPSOIL project is to enhance the adaptability of the North Sea region in response to climate change. The main focus is the joint development of methods to investigate and manage the upper 30 metres of our soil in order to predict risks to our water supply and agriculture and develop solutions and adaptive strategies.

LIAG contributes to the topic of impaired groundwater quality caused by saltwater intrusion or seawater intrusion. Working in collaboration with the State Office for Mining, Energy and Geology, we developed a groundwater model for the Elbe-Weser triangle (Lower Saxony) project region (Fig. 1). It enables us to draw conclusions concerning the future development of groundwater reserves and groundwater salinisation, flood risks and the freshwater lenses in the marsh that are vital for agriculture. The model consists of an 8-layer flow model (grid size 200 metres x 200 metres, diverse aquifer properties, calibrated and validated groundwater levels) and a transport model based on this. The transport model presents a refined layer model and calibrated chloride concentrations. The simulation was based on the assumption that sea levels will rise by almost one metre and that groundwater extraction will increase by up to 15 percent by the year 2100. The groundwater recharging rates used were based on RCP scenario 8.5. The model gives us an initial impression of the changes in chloride concentration caused by climate change (Fig. 2). However, the changes are minimal; saltwater intrusion turns out to be a very slow process.

Developing methods for entering parameters into groundwater models

LIAG is also developing methods for deducing porosities using geophysical methods, for instance, or revealing structures in the subsurface. These parameters and structures will be integrated into groundwater models as input parameters. Within this project, LIAG is working in close collaboration with the LBEG and the State Office for Agriculture, Environment and Rural Areas (LLUR). We are also involved in a vital sharing of experience with project partners from Germany, Great Britain, Denmark, the Netherlands and Belgium. The monitoring of subsurface processes also plays a crucial role.

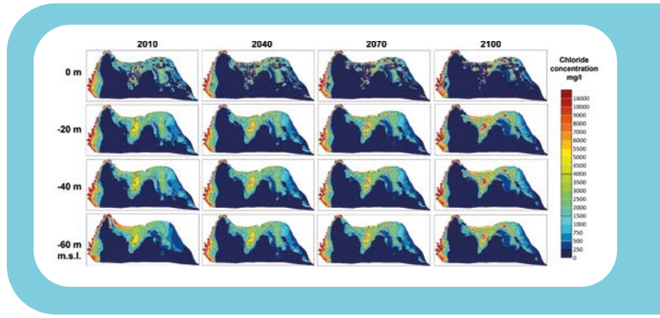


Fig. 2: Simulation calculation results: development of chloride concentration in groundwater in the area between the Weser and Elbe by 2100. Generally, there are no great changes in salinisation. However, the chloride concentrations change the deeper we go. The chloride concentration is generally rising in the Weser marsh area, particularly in the south of the region. But the high water level in the geest functions as a barrier against the intrusion of saltwater. In the future, the concentrations will rise downstream of the Elbe in the shore area of the Hadeln marsh. Further inland, the near-surface zones will be desalinated while the concentrations simultaneously increase at greater depths.

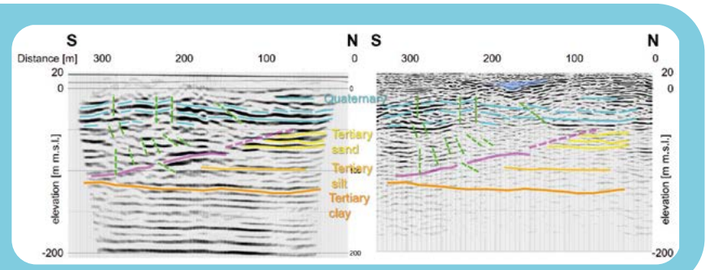


Fig. 3: Seismic sections with P waves (left) and S waves (right). Structures in the subsurface are visualised with different levels of detail. The P waves reveal the undisturbed Neogene deposits (yellow) and the boundary of the Quaternary deposits (red); the S waves reveal details at depths of up to 50 metres in higher resolution, for example an internal channel (blue).

Hamburg-Sülldorf: Undetected ice-age channel discovered

One major concern of the Interreg programme is stakeholder involvement. Against this backdrop, the Hamburg water utilities became aware of the potential of seismic exploration methods in advance of water prospecting and the first project initiation and initiative discussions were held. This year, we conducted S wave comparison measurements to supplement the P wave test measurements recorded in 2019 in the water prospecting area of Hamburg-Sülldorf. We discovered an ice-age channel that was previously unknown in this area. Our results also show the very different imaging behaviour of the two wave types (Fig. 3).

FACTS & DETAILS

LIAG project head: *Dr Helga Wiederhold.* ***LIAG project processing:*** *Dr Mohammad Azizur Rahman (2017-2019).* ***Duration:*** *01/12/2015-31/12/2021.* ***Funding:*** *EU (EFRE) im Rahmen des Interreg North Sea Region Programme.* ***Partners:*** *24 partners from five countries; lead partner: region of Midtjylland, 8 partners from Germany including LBEG and LLUR.*

LIAG publications during the project:

GONZÁLEZ, E., DEUS, N., ELBRACHT, J., RAHMAN, M.A. & ***WIEDERHOLD, H.*** *(2020): Current and future state of the groundwater salinization in the northern Elbe-Weser Region. - Grundwasser: submitted, GRUN-D-20-00034.*

GONZÁLEZ, E., DEUS, N., ELBRACHT, J., RAHMAN, M.A., SIEMON, B., STEUER, A. & ***WIEDERHOLD, H.*** *(2021): Modellierung der küstennahen Grundwasserversalzung in Niedersachsen abgeleitet aus aeroelektromagnetischen Daten. [Coastal groundwater salinisation models in Lower Saxony derived from aerial electromagnetic data]. - Grundwasser - Zeitschrift der Fachsektion Hydrogeologie 26:73–85.*

RAHMAN, M.A., ZHAO, Q., ***WIEDERHOLD, H.***, ***SKIBBE, N.***, *GONZÁLEZ, E., DEUS, N., SIEMON, B., KIRSCH, R. & ELBRACHT, J. (2021): Coastal groundwater systems: Mapping chloride distribution from borehole and geophysical data. - Grundwasser - Zeitschrift der Fachsektion Hydrogeologie 26:191–206.*

go-CAM: Protecting groundwater using a planning tool and saltwater early warning system

With the saltwater monitoring system on Spiekeroog (left to right): Michael Grinat, geophysicist at LIAG, Dr Konstantin Scheihing, go-CAM project manager at OOWV, Robert Meyer, electrical engineer at LIAG.

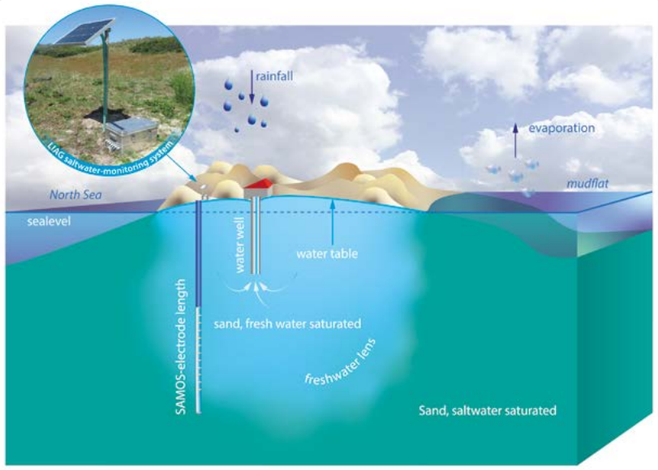
The sustainable use of water resources in coastal regions is a great challenge around the world. Climate change, changing sea levels, low topographies, potential salinisation, high nutrient input from agriculture, high population densities and water-intensive industries all endanger our natural freshwater reserves. Overexploitation of water resources inevitably leads to conflict. Hence, our water supply must be managed comprehensively and sustainably.

The objective of the joint project go-CAM is to develop a multi-criteria optimisation system for water supply management. It can then be implemented and applied for the sustainable use of water in various coastal regions around the world. This planning tool will become part of an online dialogue platform (Coastal Aquifer Management - CAM). This platform will unite the results of hydrosystem modelling with modern decision-making and support methods. The result will be an integrated, coastal zone management system. Modern hydrological, hydrogeological and geological models form the basis for assessing water resources and water requirements in coastal regions.

Installing the measurement station.

Early-warning system with comprehensive monitoring of the freshwater/seawater transition zone

One important factor that affects sustainable water supplies is the risk of salinisation caused by overexploitation of resources. The observation of real-world conditions is just as relevant to research as the simulation of future developments based on numerical models. The SAMOS saltwater monitoring system developed at LIAG is unique. It is capable of measuring electrical resistance over a distance of 25 metres and can therefore monitor the entire freshwater/seawater transition zone. As a rule, observations are only made at separate groundwater measurement points and specific depths. LIAG scientists installed two monitoring systems in northern Germany as part of this project, working in close collaboration with the water supply company Oldenburgisch-Ostfriesischer Wasserverband (OOWV) and the Technical University of Braunschweig (initiator and coordinator).



Monitoring the freshwater/saltwater boundary on Spiekeroog.

Evaluating measured data via remote transmission

The project region of Sandelermöns extends for approximately 15 kilometres around the city of Jever.It was here that a monitoring system was installed in the village of Abickhafe in December of 2018. The North Sea island of Spiekeroog, just off the coast, proved to be the ideal location for installing a second system. On Spiekeroog, the dry summer of 2018 had pushed the water supply system to its limits. The conditions here are ideal: the freshwater/seawater transition zone can be identified relatively clearly. Also, the confined freshwater lenses on islands greatly simplify the task of monitoring for the purposes of sustainable groundwater management. All components have now been installed at both sites. The measurement program and registration process run automatically once a day. The measurement data is sent to LIAG via remote transmission.

Saltwater intrusion is a slow process. This makes it even more vital to observe the process over a long period. This will enable us to detect potential risks in good time using SAMOS and notify the water supplier in advance. LIAG will continue to take measurements and collaborate with OOWV for a long time after the go-CAM project has been concluded. Seamless monitoring of groundwater, the elixir of life, promotes sustainable water management and is extremely relevant to society and the economy.

SAMOS monitoring station in Abickhafe with Dr Helga Wiederhold and Robert Meyer.

FACTS & DETAILS

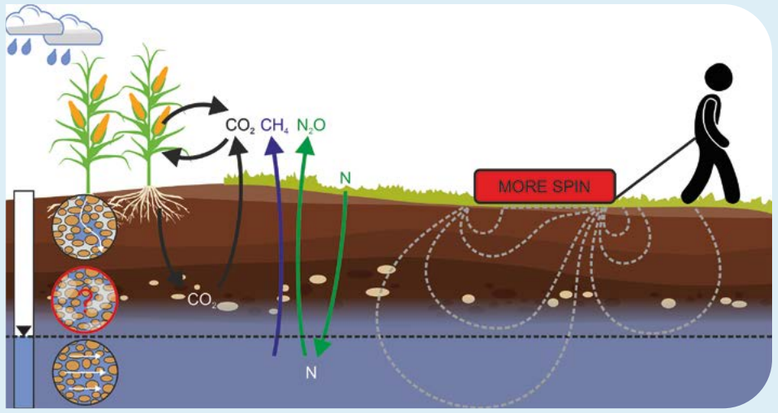
LIAG project head: *Dr Helga Wiederhold.* ***LIAG project processing:*** *Dr Mathias Ronczka.* ***Duration:*** *01/06/2017-31/12/2020.* ***Funding:*** *BMBF iMBF within the joint GRoW project.* ***Partners:*** *GISCON Geoinformatik GmbH, GRS, INSIGHT Geologische Softwaresysteme GmbH, NLWKN, OOWV, Technical University of Braunschweig (coordination).*

LIAG publications during the project:

RONCZKA, M., GRINAT, M., MEYER, R., EPPING, D., GRELLE, T. & WIEDERHOLD, H. *(2020): Geoelektrische Vorerkundung und Installation des Monitoringsystems SAMOS auf Spiekeroog. - Kurzbericht vom LIAG: 1-9. [Geoelectrical preliminary investigation and installation of the SAMOS monitoring system on Spiekeroog. - short report by LIAG]: 1-9.*

RONCZKA, M., GÜNTHER, T., GRINAT, M. & WIEDERHOLD, H. *(2020): Monitoring freshwater-saltwater interfaces with SAMOS - installation effects on data and inversion. - Near Surface Geophysics, 18(4): 369-383.*

MoreSpin: Innovative, mobile soil moisture sensor for high-resolution water content measurements



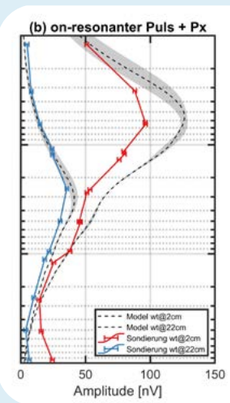
MoreSpin project: target depth, application focus and mobility of the newly-developed sensor.

Soil is not only the interface between the atmosphere and lithosphere, it is also the essential basis for supplying everyone in the world with food. The soil and the moisture it contains is becoming ever more important as climate change progresses. Nearly all physical soil exchange processes are linked directly or indirectly to the water content of the soil. The MoreSpin project intends to determine this water content quantitatively and with high spatial resolution.

The goal of the project is to develop an innovative mobile soil moisture sensor based on nuclear magnetic resonance (NMR) technology. This sensor will allow us to detect, and in future also to map, the soil moisture non-destructively, over a wide area and with high resolution down to a maximum depth of two metres. The distinguishing feature of this sensor is that we are using a superconducting prepolarisation coil to amplify the Earth's magnetic field. Based on our numerical simulations, LIAG is developing this coil in close collaboration with the Leibniz Institute of Photonic Technology (IPHT) in Jena. Due to the compact sensor design and the accordingly small sample volume, it is necessary to amplify the Earth's magnatetic field. Otherwise it would be impossible to detect a response signal from the water molecules with conventional methods.

First successful field tests and numerical simulations

This development is being funded by the DFG and is divided into two project phases. The first project phase was completed by the end of 2020. Its objective was to examine the basic feasibility of the sensor using numerical simulations and initial field trials. Based on these results, a sensor prototype will be developed in the subsequent second phase.

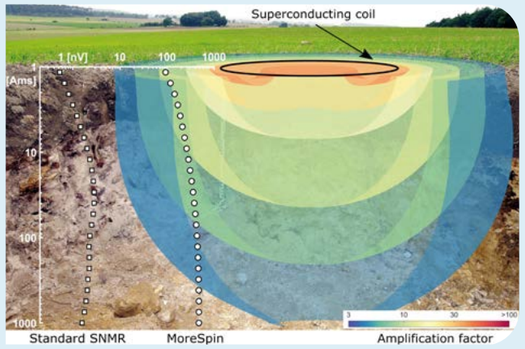


Results of a field experiment using the first conceptual sensor installed above a water basin. The data indicates that the sensor measures the response signal as required, is sensitive to the distance between the water surface and the coil (red and blue curves) and corresponds well with the numerical simulations.

The first project phase has already been completed with categorical success. LIAG has developed a comprehensive numerical simulation tool that allows the complete and coupled simulation of all essential physical processes. The simulation results show that the conceptual sensor provides the neccessary signal amplification together with the corresponding receiver sensitivity. Therefore, the sensor will be able to rapidly detect soil moisture with the desired depth resolution. Furthermore, initial field trials have been conducted in cooperation with the BGR and have impressively confirmed both the numerical simulations and the general electronic feasibility of the concept.

Application submitted for the second project phase: Developing the first usable prototype

We have applied for the second project phase based on these positive results. This phase will mainly focus on the development of a usable first prototype for real-world investigations on the field scale. The BGR will become more actively engaged as a project partner by integrating the MoreSpin sensor into field studies within the ReCharBo project (project aiming to characterise regional soil properties using remote sensing, geophysics and soil science).



Superconducting coil generates a spatially inhomogenous magnetisation as an amplification factor of the normal equilibrium magnetisation. The NMR signal is amplified by up to a factor of 100.

FACTS & DETAILS

LIAG project head: *Prof. Dr Mike Müller-Petke.* ***LIAG project processing:*** *Dr Thomas Hiller.* ***Duration of 1st phase:*** *01/01/2018-31/12/2020.* ***Funding:*** *DFG under the "New Instrumentation for Research" funding programme.* ***Partners:*** *IPHT Jena, BGR (assoziiert).*

LIAG publications during the project:

HILLER, T., DLUGOSCH, R. *&* ***MÜLLER-PETKE, M.*** *(2020): Utilizing pre-polarization to enhance SNMR signals - effect of imperfect switch-off. - Geophysical Journal International, 222(2): 815-826.*

LIN, T., YANG, Y., TENG, F. & ***MÜLLER-PETKE, M.*** *(2018): Enabling surface nuclear magnetic resonance at high noise environments using a pre-polarization pulse. - Geophysical Journal International, 212(2): 1463-1467.*

Dating stone age tools in Zambia

Victoria Falls in Zambia.

Investigating the deep roots of human behaviour: When did our ancestors begin to behave like modern humans? Where and how did this development take place? It is probable that our direct ancestor Homo heidelbergensis exhibited modern behaviour patterns and produced complex stone tools as far back as 600,000 – 200,000 years ago. Archaeological finds provide us with evidence of stone tool development. LIAG collaborated with an interdisciplinary, international research team on the project Investigating the deep roots of human behaviour funded by the Arts and Humanities Research Council (AHRC). The aim was to improve the hitherto scarce and geographically unequally distributed available data. The project involved field work at three archaeological sites in Zambia (Victoria Falls, Kalambo Falls and the Luangwa Valley). LIAG examined sediment samples using ESR. Sediment dating performed in this way and examination of the artefacts is expected to provide information on the chronological sequence of the technological and functional revolution that took place in the Middle Stone Age and Early Stone Age.

In the summer of 2018, LIAG researchers took a total of 19 aeolian sediment samples from four different sites around Victoria Falls. The stone tools found on site have characteristics that point to having been made in the Early Stone Age, Middle Stone Age and Later Stone Age. In early August 2019, a further 16 sediment samples were collected from Northeast Zambia near the Kalambo Falls. The fluvial deposits there are several metres thick and contain stone tools and worked, charred wood.

Dating sediment samples in the LIAG laboratory

The light-sensitive sediment samples were prepared for ESR measurement using the standard coarse grain method in the LIAG dark laboratory. This method consists of separating the mixture of mineral grains into various grain size fractions. The sieved target fractions were then chemically etched and rinsed. Next, the quartz grain fraction was removed by heavy liquid separation for the purpose of ESR dating. Gamma spectrometry measurements and grain size analysis were performed at the same time. Gamma spectrometry mainly returns the annual dose rate of ionising radiation in the sediment, which is an important factor for calculating age. Grain size analysis generates information on the shape and size of the sediment grains. This can be used to deduce the environmental processes that occurred when the sediment was formed from the original material, the transport mechanisms and the subsequent accumulation process.

Early stone age hand axes found in the region of Victoria Falls in 2018.

Preliminary results in discussion

The gamma spectrometry results enabled us to draw initial conclusions concerning the rough composition of the Kalahari sands: They exhibit a low concentration of radioactive potassium-40. This was reflected by a relatively low total dose rate of 0.53 to 1.2 Gy/ka in all our samples. This indicates that all minerals other than the resistant quartz have mostly weathered away. Grain size analysis revealed bimodal distribution, the cause of which is currently under discussion.
Each of the ESR samples was examined using SAAD (single aliquot additive dose) and SAR (single aliquot regenerative dose) protocols. Using this method, we generated growth curves up to 5000 Gy, fitted the curves using a saturating exponential function and determined the equivalent dose. The dates determined using the SAAD protocol were in the range of ~200 ka to ~1700 ka for the titanium signal and ~400 ka to 2600 ka for the aluminium signal. The measurements recorded using the SAR protocol were between ~300 ka and 2100 ka for the aluminium centre and between 94 ka and 870 ka for the titanium centre. The differences in dating returned by the respective protocols and centres are a result of the methods employed. The project partners are currently discussing the results. The youngest samples were tested using OSL dating to correct the ESR residual signals. The samples were also subjected to dose recovery tests. These tests helped to highlight a possible change in sensitivity to ionising radiation caused by the annealing step of the measurement process. The results were satisfactory, particularly for the titanium centre.

The research results from Victoria Falls are currently being compiled and written up as a publication. Due to the COVID-19 pandemic, the 2020 fieldwork season has been postponed to 2021. The fieldwork will involve further sampling in the Luangwa Valley. We will also be studying the samples taken from the banks of the Kalambo River and complete the fieldwork season.

Taking samples on the shores of the Kalambo River.

FACTS & DETAILS

LIAG project head: *Dr Sumiko Tsukamoto.* ***LIAG project processing:*** *Marcus Richter.* ***Duration:*** *01/01/2017-31/12/2022.* ***Funding:*** *LIAG.* ***Partners:*** *Aberystwyth University, Leiden University, Moto Moto Museum, University of Edinburgh, University of Liège, University of Liverpool (Projektleitung), University of Oxford, University of Zambia.*

Loess-palaeosol sequences in northern Iran and their palaeoclimatic significance

Loess plateau, northern Iran.

LIAG, the universities of Cologne and Bayreuth and the Gorgan University in Iran collaborated on the joint DFG project Loess "palaeosol sequences in northern Iran and their palaeoclimatic significance". This project examined the very finely structured Middle Pleistocene to Upper Pleistocene sedimentary sequences of the Caspian Depression that are of great significance to palaeoclimate research. The focus of LIAG's activities was to develop age models and to create a better understanding of past environmental conditions.

Northern Iran lies within the Eurasian loess belt that stretches from Northwest France to China. The Caspian Depression is characterised by thick and highly differentiated loess-palaeosol sequences and is positioned in a key location between regions of loess in Central Asia and in South-West and North-West Europe. Geographically speaking, the area in question is situated in the zone of influence of various atmospheric circulation patterns of the northern hemisphere. These include the Atlantic westerlies, the polar front and the Asian monsoon. Loess-palaeosol sequences are the most important geological archive of the climate change in the region. They can be used to reconstruct the changes and variations in atmospheric circulation patterns for a period of at least 200,000 years.

Investigations of the climate events archived in loess

The area under investigation is extremely interesting for questions concerning the palaeoclimate. Geochronology, magnetostratigraphy and pedostratigraphy show very clearly that loess deposits accumulated more or less synchronously in the northern hemisphere during the Pleistocene and so must have been triggered by the global climate changes of the glacial and interglacial periods. High-resolution proxy investigations show that even brief climate events documented in ice cores from Greenland and in deep-sea sediment archives are also recorded in loess. This allows us to synchronise the archives and compare them systematically. To this end, LIAG researchers and the universities concentrated on taking proxy samples and on dating numerous loess samples.

Improved findings on climate variability

Investigations in the Caspian Depression of the northern foothills of the Alborz mountains, northern Iran and in the Persepolis Basin in Central Iran have considerably improved upon previous findings concerning spatial and temporal climate variability in this transitional region between the Atlantic climate to the West and the continental climate to the East. The project team provided new and precise data on age development, geomorphodynamics (including sedimentation rates as a proxy of dust content in the atmosphere in the past), palaeoenvironment and palaeosol development.

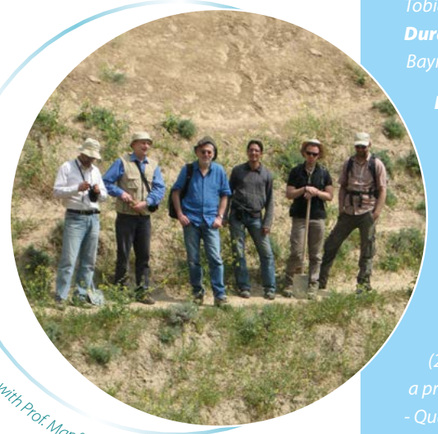
First evidence of volcanic activity in the Caspian Depression

At least 11 palaeosols are intercalated in the Upper Pleistocene loess-palaeosol sequence of Neka-Abelou. Three clayey, strongly weathered palaeosols were assigned to MIS 5. Therefore, the situation has a similar quality to that found in Central Europe or Central Asia. Furthermore, we found the first evidence of volcanic activity in MIS in the Caspian Depression. This was shown by the presence of trachytic volcanic ashes from Mount Damavand, a volcano in the Alborz mountain range that is more than 90 kilometres away and more than 5000 metres high.

Far-reaching investigations in an impressive loess landscape: The stepped sections are approximately 60 metres long in total.

The interesting lower section of the loess-palaeosol sequence in Neka-Abelou consists of at least four thick, reddish brown palaeosols that are separated by thin, superimposed layers of pedogenic loess. This sequence indicates more humid climate conditions and low dust accumulation rates during the Middle Pleistocene and is significantly different to what was previously known from the last glacial/interglacial cycle.

A total of eight young scientists acquired additional qualifications during this project.



The research team in Iran with Prof. Manfred Frechen (3rd from the left).

FACTS & DETAILS

LIAG project head: *Prof. Dr Manfred Frechen.* ***LIAG project processing:*** *Dr Tobias Lauer (prev.), Neda Rahimzadeh, Dr Christian Rolf, Dr Christian Zeeden.* ***Duration:*** *01/01/2015-31/12/2020.* ***Funding:*** *DFG.* ***Partners:*** *University of Bayreuth, Gorgan University, University of Cologne.*

LIAG publications during the project:

KEHL, M., KHORMALI, F. & ***FRECHEN, M.*** *(2020): Editorial: Loess records of environmental change. - Quaternary International, 552: 1-3.*

KHORMALI, F., SHAHRIARI, A., GHAFARPOUR, A., KEHL, M., LEHNDORFF, E. & ***FRECHEN, M.*** *(2020): Pedogenic carbonates archive modern and past precipitation change – A transect study from soils and loess-paleosol sequences from northern Iran. - Quaternary International, 552: 79-90.*

SHARIFIGARMDAREH, J., KHORMALI, F., ***ROLF, C.****, KEHL, M. &* ***FRECHEN, M.*** *(2020): Investigating soil magnetic properties with pedogenic variation along a precipitation gradient in loess-derived soils of Golestan province, northern Iran. - Quaternary International, 552: 100-110.*

… and 11 other publications since the beginning of the project.

Identifying and analysing near-surface concealed fault structures and weak zones

Measurements in New Zealand.

This research topic was initiated by the 2011 Christchurch earthquake in New Zealand. The earthquake had serious direct consequences, and not only for the city and its inhabitants. Ultimately, approximately 10,000 buildings in the city centre had to be demolished due to the unexpected instability of the ground. Studies carried out by the New Zealand Institute of Geological and Nuclear Sciences (GNS Science) revealed a previously unknown fault zone concealed by young sediments. The fault zone was reactivated by the earthquake and was responsible for the huge extent of damage. It had not been taken into account during the historical development of the urban infrastructure due to a lack of knowledge. It was recognised that this situation could apply to many other historic towns, including the capital city of Wellington. For this reason, a bilateral project was launched in 2013 between LIAG and GNS Science. Its objective was to optimise the 2D or 2.5D shear-wave seismic reflection methods developed by LIAG for finding concealed fault zones and, in particular, for finding them in built-up urban areas. Since 2017, LIAG has continued this optimisation at prominent tectonic faults zone in collaboration with national partners, including activities in Germany and neighbouring states. An overview.

After intensive logistical preparations, a joint pilot project between GNS Science and LIAG was implemented in 2015 in the town of Whakatāne, New Zealand. The project was funded by the New Zealand Earthquake Commission (EQC NZ). The aim of the project was to localise the fault with more precision, suspected to be a normal fault with lateral displacement, below the built-up area of the town. As a result of this pilot application in New Zealand, the location of the fault was accurately defined in an area that was significantly different from the suspected position. The project also demonstrated that studying the effect of the fault on the deformation of young sediment layers enables us to deduce the period (approx. 10-15 ka) and the strength of the last reactivation of the fault (more than 10 metres of vertical throw). A subsequent project in 2016-2017 (funded by the New Zealand Royal Society) favourably evaluated the extension of the methodology to other New Zealand cities (Napier, Auckland, Wellington) and the establishment of the method within GNS Science. There are definite prospects for future funding.

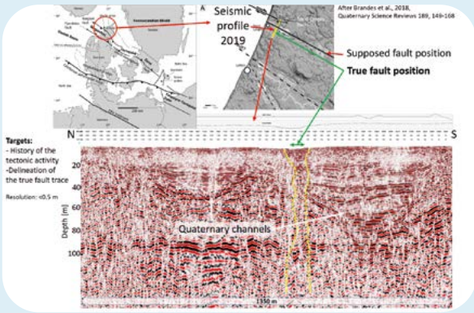
Identifying and analysing faults in Germany

The method was applied for the first time in Germany in 2017 in cooperation with the LUH and the BGR during a multi-methodological investigation of the Northern Harz Boundary Fault. The project examined a postulated younger reactivation caused by preglaciogenic and postglaciogenic processes. The task posed much greater challenges than the situation in New Zealand. The area is characterised by extremely steep horizontal strata caused by the upthrust fault in the Harz mountains, multiple superimposed glacial strata and by many centuries of continuous extraction of limestone, gypsum and sandstone from the area. As a consequence, the methodologies employed had to be upgraded. In this way, we generated the first, very detailed, near-surface structural visualisation of the Northern Harz Boundary Fault using shear wave reflection seismology. It is only possible to analyse the location and age of a fault reactivation in such difficult conditions by employing a multi-methodological combination of structural geology, geochronology and geophysics.

In 2018, the investigations of glaciogenic fault reactivations were expanded to include the area of the Bokeloh salt dome in cooperation with the LUH. The aim of this case study was to classify the causes of an unexpected cluster of fault signatures that had been mapped in outcrops of Quaternary deposits. The data gives us reason to postulate a reactivation of halotectonic faults through glaciogenic overload processes. However, the lack of boreholes mean that further investigations would be required to make a final conclusive assessment.

Expansion into neighbouring European areas

The latest research object is the Bøklund fault in North Jutland (Denmark), a primarily transversal fault in the Sorgenfrei-Tornquist collision zone. Previous investigations conducted by the Danish geological services Denmark and Greenland (GEUS) and mapping of outcrops on the west coast conducted by LUH indicated its approximate location and pointed to recent activity. Its inland extension and inland structural position are still unknown due to a thick covering of young sediments. There are further questions concerning the ongoing activity of the fault over its inland extension that could serve as an indicator for the activity of the entire Sorgenfrei-Tornquist zone. During the initial pilot survey campaign in 2019, we accurately localised the fault along one of two profiles and mapped it in high-resolution to a depth of approx. 100 metres. It cuts through the space between two parallel, Quaternary channels of different ages at depths of 60 metres and 80 metres and deforms the stratigrapy of the northern channel. The overlying Holocene sediments also exhibit deformation signatures up to the surface, which indicates very recent activity. Identifying and analysing the stratigraphy of the fault's inland extension will require further investigation, and this would seem appropriate due to the favourable geological situation determined during the pilot studies.



Visualisation of the Bøklund fault in North Jutland (Denmark). The transverse fault penetrates and deforms the stratigraphic signature of two Quaternary channels of different ages at 60 metres and 80 metres down, respectively. The overlying Holocene sediments also exhibit deformation signatures up to the surface, which indicates very recent activity.

FACTS & DETAILS

Project lead and processing at LIAG: *Dr Ulrich Polom.* ***Duration:*** *01/06/2013-31/12/2021.* ***Funding:*** *EQC NZ, LIAG, Royal Society NZ, BGR.* ***Partners:*** *BGR, GEUS, GNS Science, LUH, University of Canterbury.*

LIAG publications during the project:

MÜLLER, K., ***POLOM, U.****, WINSEMANN, J., STEFFEN, H.,* ***TSUKAMOTO, S., GÜNTHER, T., IGEL, J.****, SPIES, T., LEGE, T.,* ***FRECHEN, M.****, FRANZKE, H.-J. & BRANDES, C. (2020): Structural style and neotectonic activity along the Harz Boundary Fault, northern Germany: A multimethod approach integrating geophysics, outcrop data and numerical simulations. - International Journal of Earth Sciences, 109: 1811-1835.*

POLOM, U.*, MUELLER, C., NICOL, A., VILLAMOR, P., LANGRIDGE, R.M. & BEGG, J.G. (2016): Finding the concealed section of the Whakatane Fault in the Whakatane Township by a shear wave land streamer system: A seismic surveying report. - GNS Science Open File Report 2016, 41: 1-41.*

REGROUP: Reconstructing precipitation patterns in Europe using soil properties

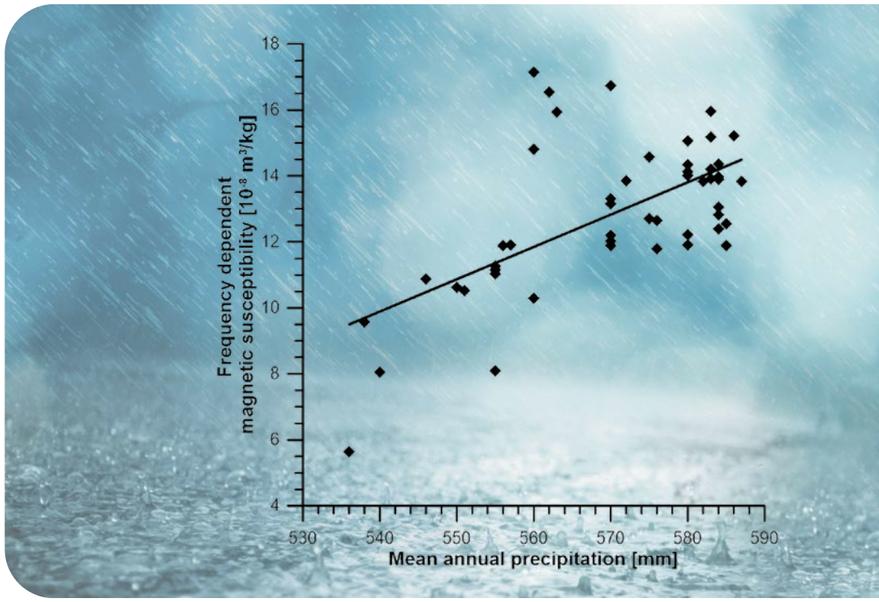
Agricultural soils in Serbia.

The necessity of generating regional climate models that can predict spatial patterns of temperature and precipitation for defined areas was recognised early on in the scientific climate change debate. However, models of this kind require valid input data that can be used for large-scale calibration and evaluation. Promising preliminary study results have already verified a direct correlation between rock magnetic parameters in soils and precipitation. The aim of the DFG funded REGROUP project is to better understand the link between climate and soil properties. The objective is to quantify the link between climate variables and soil properties over large areas based on a multi-proxy approach that includes data on rock magnetic parameters, sediment colour, geochemical data and soil texture.

Within this project, LIAG is investigating how precipitation is reflected in soil properties, geophysical parameters, geochemical proxies and the colour of soils. Calibrating the data collected using meteorological measurements will enable us to develop transfer functions that are primarily used to generate temporal and large-scale insights into precipitation patterns of the past.

Gaining a better understanding of the link between precipitation and geophysical soil properties

The REGROUP project is based on the quantitative analysis of a sample set from the middle Danube basin in Serbia. It includes samples of a uniform soil type that were taken along gradients of temperature and precipitation. We have reliable precipitation and temperature data and an aridity index provided by the Serbian meteorological monitoring network for every site at which a sample was taken. The soil samples were provided for analysis by partners at the University of Novi Sad (Serbia). We used them to answer the question of how a multi-proxy dataset of topsoil samples can better describe rainfall distribution than using magnetic susceptibility and rock magnetic properties alone. To this end, we collected a suitable dataset and evaluated the multivariate statistics using established methods.



Link between precipitation and the frequency dependence of magnetic susceptibility.

Soil properties appear to be influenced by climate

Preliminary results show that both rock magnetic data and soil colour are influenced by climate. In particular, the link between climate and rock magnetic parameters is more sensitive that the link between climate and soil colour. However, some colourimetric datasets seem to exhibit clear dependency on temperature, which can be used to separate the climatic influencing factors.

Loess deposits in Serbia.

FACTS & DETAILS

LIAG project head: *Dr Christian Zeeden, Dr Sumiko Tsukamoto, Dr Christian Rolf.* ***LIAG project processing:*** *Dr Christian Zeeden, Dr Sumiko Tsukamoto, Dr Christian Rolf, Mathias Vinnepand.* ***Duration:*** *01/09/2020-30/09/2021.* ***Funding:*** *DFG.* ***Partner:*** *University of Novi Sad.*

Mysteries of Lake Ohrid – Researching the oldest lake in Europe

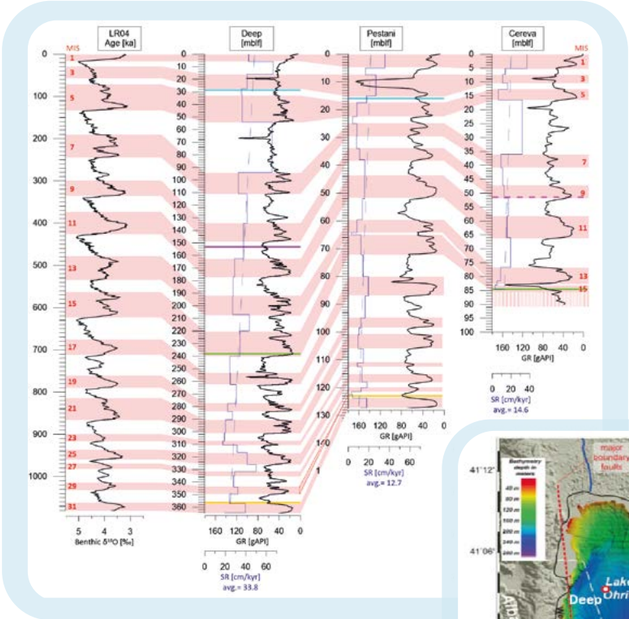
Floating drilling platform on Lake Ohrid.

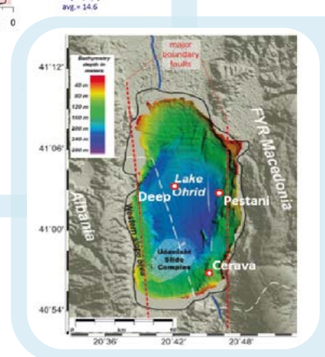
Lake Ohrid is the oldest lake in Europe and has fascinated scientists since the beginning of the 2000s. Its location between North Macedonia and Albania make it an outstanding climate change archive: its sediments reflect information concerning the changes in climatic conditions in the Mediterranean area for almost the last 1.4 million years. Although the lake has experienced multiple interglacial and glacial periods, it has hardly been disturbed by external influences and so allows us to view the past. LIAG has previously explored the lake sediments due to these special circumstances and did so again in 2020. The institute's studies were previously published in the renowned science journal Nature in 2019.

On the basis of multiple preliminary investigations, four locations were selected for a 2013 drilling campaign. The campaign was conducted by the International Continental Scientific Drilling Program (ICDP) in collaboration with LIAG. During this nationally and internationally funded project, scientists from various European countries drilled down 584 metres into the sedimentary layers under the lake, which is 293 metres deep at its deepest point. LIAG took geophysical borehole measurements and evaluated the data during this drilling campaign. Results to date concern a section of the main borehole and were published in 2015 as part of a doctoral thesis.

Improved understanding of sedimentological processes

This year, LIAG researchers resumed their evaluations of the deep areas of the main borehole and at other locations. These geophysical borehole measurements are improving our understanding of sedimentological processes. These include temporal changes in sedimentation rates and the description of the sediment types typical for this system. When combined, this enables us to make initial statements concerning the various drilling locations.





Correlation of reference data (LR04) with natural gamma radiation (GR), measured at the various sites in Lake Ohrid: Deep, Pestani and Cerava. The coloured lines represent marker horizons from preliminary seismic exploration. Sedimentation rates (SR) are shown in blue for the respective interglacial/glacial periods (marine isotope stages, MIS). All sites shown a linear upward SR trend (dashed blue line). Below, a bathymetric map of the Lake Ohrid showing the drilling sites.

Faster and more independent dating using new methods

The team of researchers also explored the potential of geophysical measurements for calculating age-depth models using the example of Lake Ohrid. They used seismic data from preliminary investigations and identified distinctive boundaries between interglacial and glacial periods. The geophysical borehole data is being compared to global reference curves and analysed using cyclostratigraphic methods to improve the precision of the developed models still further.

The aim is to develop a method of determining the age of lake sediments based on seismic investigations and geophysical borehole data. This will accelerate the task and enable researchers to work largely independently of sediment cores. In this way, initial age-depth models will be available relatively quickly after completion of a drilling campaign and not only once the cores have been opened and analysed some months or even years later.

Connecting the SGR70 tool. Measuring the natural radioactivity spectrum of sediments.

FACTS & DETAILS

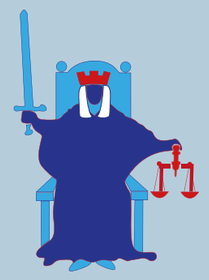
LIAG project head: *Dr Thomas Wonik.* ***LIAG project processing:*** *Arne Ulfers.* ***Duration:*** *01/10/2018-14/01/2021.* ***Funding:*** *DFG, LIAG.* ***Partners:*** *Christian Albrechts-University of Kiel, University of Cologne.*

LIAG publication during the project:

WAGNER, B. et al. & ***WONIK, T.*** *(2019): Mediterranean winter rainfall in phase with African monsoons during the past 1.36 million years. - Nature, 573: 256–260.*

LIAG AT A GLANCE

Facts and figures



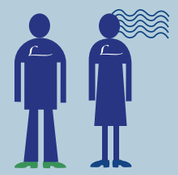
37 departments and functions of 15 employees

29 third-party-funded projects

~ 50 presentations

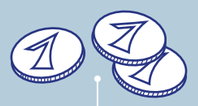
9 university lectures

15 doctoral candidates at LIAG, 6 of them are external candidates with temporary research residences



76 employees

64 publications in specialist journals and one book edited by LIAG



€1.38 million from third-party funding

> 150 international and national cooperations

Finances

+ €13.67 m.

– €9.26 m.

Total budget 2020	€13.67 m.
Institutional funding from the federal government	€4.35 m.
Institutional funding from the congress of regional authorities	€3.49 m.
Own revenue	€0.04 m.
Remaining institutional funding from previous years	€3.94 m.
Third-party revenue + remaining funding from previous years	€1.85 m.

2020 expenditure	€9.26 m.
Staff	€5.32 m.
Material expenses	€1.17 m.
Administrative expenses*	€1.60 m.
Investments	€1.17 m.

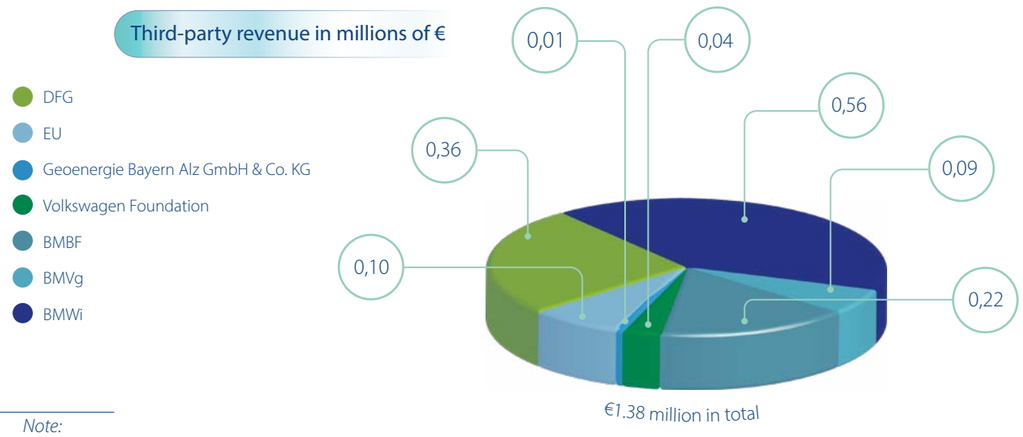
** Reimbursement of administrative costs, benefits, membership fees and others.*

In the 2020 financial year, LIAG received institutional funding of 7.84 million euros from the federal government and states to cover ongoing measures. Around 57 percent of the institutional funding was spent on staff, around 30 percent on material expenses and administration and around 13 percent was used to make investments. In 2020, we raised 1.38 million euros via third-party-funded projects.

LIAG has been in financial resolution since 01/01/2020, due to the termination of our membership in the Leibniz Association. In the first and in the second financial year after the end of the joint funding period, the amount of this joint financial resolution is 100 percent of the reference value. In the third year, the amount is 100 percent of the reference value, if the committee does not decide otherwise in this particular case. The reference value is the amount of the last-paid donation to the core budget. Accordingly, LIAG will receive institutional funding (financial resolution) of 7.84 million euros in each of the first two years (2020 and 2021). In 2022, LIAG will be provided with a financial resolution of 7.63 million euros following the decision of the Joint Science Conference committee.

The state of Lower Saxony continues to view LIAG as an important and indispensable element of the national research landscape. It will provide funding from 2023 when joint federal and state government funding ends.

Third-party revenue in millions of €



Note:
Rounded up to two decimal places from €0.005 million.

Employees

The LIAG staffing plan lists 55 full-time equivalent positions (FTE). The distribution of these positions is one of LIAG's special features: 29 are in the technical field and 26 in the scientific field. This high proportion of technical employees is a critical factor for conducting applied research at LIAG. Of the 55 FTEs, 6.8 positions were not occupied on 31/12/2020 (4.0 have already been advertised). 21 researchers and one person in administration were funded by third-party-funded research projects or by LIAG's own resources for temporary employment. Thirty percent of all employees were female. Sixteen percent of all employees were of foreign nationalities.

Human resource development is an essential activity at LIAG. Sixteen training courses were held in 2020. Four women (25 percent of attendees) and 12 men (75 percent) participated in the seminars. Our employees participated in training activities on a total of 24 days. Promoting gender equality is also of great importance to the institute and therefore is an integral component of our human resources development programme. LIAG is subject to the provisions of the Lower Saxony equality act (NGG). This act aims to provide women and men with equal status and to promote the reconcilability of gainful employment and family duties. LIAG has explicitly followed this objective by formulating our own equality plan from 2018 to 2020. Beyond the year 2020, additional efforts will be adopted, particularly to rectify the under-representation of women at higher pay grades.

New and ongoing projects

Third-party-funded projects

Funding		Project title	Duration	LIAG associates	Project partners
BMBF	€220,154	go-CAM: Protecting groundwater using a planning tool and saltwater early warning system (implementing strategic development objectives in coastal zone management) ** p. 58	01/06/2017 - 31/12/2020	Head: Dr Helga Wiederhold Processing: Dr Mathias Ronczka	GISCON Geoinformatik GmbH, GRS, INSIGHT Geologische Softwaresysteme GmbH, NLWKN, OOWV, Technical University of Braunschweig (coordination)
BMBF	€348,619	DESMEX II: Investigation of deep mineral deposits using innovative electromagnetic inversion methods **	01/07/2019 - 31/07/2022	Head: Dr Thomas Günther Processing: Dr Raphael Rochlitz	BGR, Deutsche Montan Technologie GmbH, iMAR Navigation, IPHT Jena, Supracon AG, Terratec, University of Cologne, University of Münster
BMVg	€414,812	CounterIED 3: Numerical simulation to generate synthetic sample data for analysing the influencing factors of georadar sensors to optimise ordinance localisation	01/02/2020 - 31/12/2021	Head: Dr Jan Igel Processing: Stephan Schennen, Sam Stadler	Material research and testing institute at the Bauhaus University Weimar
BMWi	€839,000	PlayType: Cataloguing geothermal provinces according to the concept of play types for economic development and the internationalisation of the German geothermal industry **/*** p. 54	01/08/2017 - 31/05/2021	Head: Prof. Inga Moeck Processing: Dr Tom Schintgen	International Geothermal Energy Centre Bochum (GZB) (now: Fraunhofer IEG), Storengy (associate)
BMWi	€833,300	REgine: Geophysics/geology-based reservoir engineering for deep carbonates *** p. 52	01/10/2018 - 30/09/2021	Head: Prof. Inga Moeck Processing: Mohamed Fadel, Dr Johanna Bauer, Dr Sonja Wadas	Munich City Utilities, TU Munich
BMWi	€614,900	ZoKrateS: Sequential reservoir treatment at natural fracture zones in deep-seated carbonate rock to develop a petrothermal site in Germany **	01/10/2018 - 30/09/2021	Head: Prof. Inga Moeck	ENEX Power Germany, G.E.O.S. Ingenieurgesellschaft mbH, Geothermie Neubrandenburg GmbH, Ruhr University Bochum
DAAD	Grant	Structural interpretation in the Dahomey Basin, Nigeria, using gravimetric/magnetic modelling	01/10/2019 - 31/03/2020	Project lead and processing: Prof. Gerald Gabriel, Dr Matthias Halisch, Dr Christian Rolf Processing fellow: Michael Falufosi	University of Ibadan
Sino-German Center for Research Promotion (SGC)	€30,000	kobra.19-21: Detecting, monitoring and early warning of coal fires – Monitoring surface changes using LIDAR and determining fossil temperature distribution using the ESR method **	01/01/2019 - 31/12/2021	Project lead and processing: Dr Manfred W. Wuttke	Xinjiang University, Urumqi

* Additional partial funding from the own budget ** Joint project *** Coordination at LIAG

Funding		Project title	Duration	LIAG associates	Project partners
DFG	€39,000 *	Investigation of loess-palaeosol sequences (Neka-Abelou) in northern Iran p. 64	01/01/2015 - 31/12/2020	Head: Prof. Manfred Frechen Processing: Dr Tobias Lauer (formerly), Neda Rahimzadeh, Dr Christian Rolf, Dr Christian Zeeden	University of Bayreuth, Gorgan University, University of Cologne
DFG	€312,000 *	3D visualisation of glacial structures in the Tannwald basin p. 48	01/12/2015 -31/12/2020	Head: Dr Hermann Buness, Prof. Gerald Gabriel Processing: Dr Thomas Burschil, Dr David C. Tanner	ETH Zurich, LGRB
DFG	€30,000	Holocene climatic changes in the forest steppes of Central Mongolia	01/08/2017 - 31/07/2020	Head: Prof. Manfred Frechen, Dr Sumiko Tsukamoto	Georg August University of Göttingen
DFG	€210,000	Lake Towuti: Paleoenvironmental indications and cyclostratigraphic studies of sediments from tropical Lake Towuti obtained from geophysical downhole logging DFG **	15/10/2017 - 14/01/2021	Head: Dr Thomas Wonik Processing: Arne Ulfers	Australian National University, Brown University, Berlin Museum of Natural History, University of Bern, University of Cologne, University of British Columbia, University of Kansas, University of London, University of Minnesota, University of Rhode Island, University of Windsor
DFG	€264,600	MoreSpin: new mobile soil moisture sensor for high-resolution determination of moisture content *** p. 60	01/01/2018 - 31/12/2020	Head: Prof. Mike Müller-Petke Processing: Dr Thomas Hiller	IPHT Jena, BGR (associate)
DFG	€215,000 *	Lake Ohrid – research at the oldest lake in Europe to reconstruct earlier climatic conditions p. 70	01/10/2018 - 14/01/2021	Head: Dr Thomas Wonik Processing: Arne Ulfers	British Geological Survey, Christian-Albrecht University of Kiel, Hydrobiological Institute in Ohrid, Justus Liebig University Giessen, Polytechnic University of Tirana, RWTH Aachen University, University of Pisa, University of Cologne
DFG	€21,000	Cenozoic fossil deposits in the Atbara Valley, Sudan	01/01/2019 - 31/12/2021	Project lead and processing: Dr Sumiko Tsukamoto	Berlin Museum of Natural History, Technical University of Braunschweig
DFG	€15,589	LION: High-resolution proxy data for loess in Kashmir	01/05/2019 - 31/05/2021	Project lead and processing: Dr Christian Zeeden, Dr Christian Rolf, Dr Sumiko Tsukamoto	University of Srinagar
DFG	€2671	KiSNeT: Königshafen submarine groundwater discharge network - for intensifying the collaboration and exchange of knowledge across regional boundaries and disciplinary boundaries in the field of SDG research as a joint experiment in Königsberg bay, Sylt, Germany **	01/02/2020 - 28/02/2023	Head: Prof. Mike Müller-Petke Processing: Dr Thomas Günther, Dr Jan Igel, Dr Mathias Ronczka	AWI, BGR, Carl von Ossietzky University Oldenburg, Leibniz Institute for Baltic Sea Research Warnemünde, UFZ, University of Bayreuth, University of Kiel, ZMT
DFG	€9325	CYCLES: Cooperation with the University of Geosciences in Peking related to cyclic deposits during ice ages	01/07/2020 - 31/07/2021	Project lead and processing: Dr Christian Zeeden	Chinese University of Geosciences
DFG	€172,000	BBT-LAB – The Brenner Base Tunnel natural laboratory: from cross-section construction and fabric and elastic anisotropy analysis to 4D structural modelling (4D-MB focus)	01/08/2020 - 31/07/2023	Project lead and processing: Dr David C. Tanner	Leibniz University Hanover, Martin Luther University Halle-Wittenberg

* Additional partial funding from the own budget ** Joint project *** Coordination at LIAG

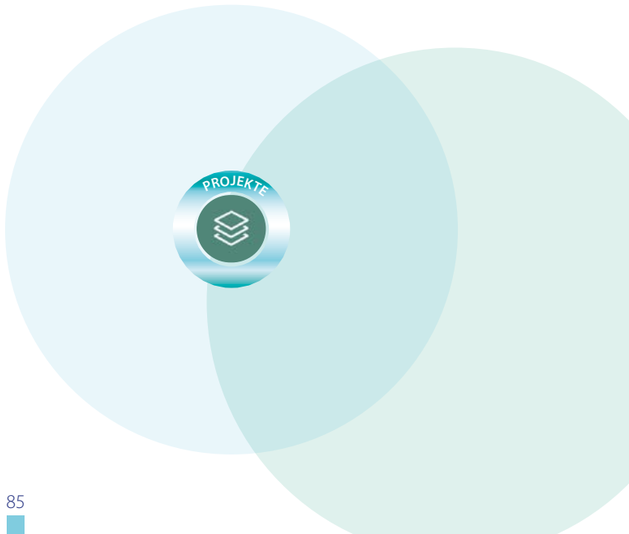
Funding		Project title	Duration	LIAG associates	Project partners
DFG	€195,000	The last impulse – dating the most recent deformation in the Alps using ESR thermochronology (LUNAR, 4D-MB focus) **/***	01/08/2020 - 31/07/2023	Project lead and processing: Dr Sumiko Tsukamoto, Dr David C. Tanner	Leibniz University Hanover, University of Salzburg
DFG	€21,000	Identifying past disruption activities along the eastern Periadriatic fault zone using combined OSL and ESR dating at fault gouges in IT, AUT, SVN (4D-MB focus)	01/08/2020 - 31/07/2023	Project lead and processing: Dr Sumiko Tsukamoto	Friedrich Schiller University of Jena
DFG	€12,000	REGROUP: Multi-proxy dataset of soil samples from Serbia p. 68	01/09/2020 - 30/09/2021	Project lead and processing: Dr Christian Zeeden, Dr Christian Rolf, Dr Sumiko Tsukamoto. Additional processing: Mathias Vinnepand	University of Novi Sad
DFG	€337,000 *	JET: physical properties, in-situ structures and cycles of Lower Jurassic mudrocks, derived from geophysical measurements in the ICDP borehole in Prees, England **	01/10/2020 - 30/09/2023	Head: Dr Thomas Wonik Processing: Katharina Leu	26 universities and institutions from 13 countries
DFG	€8740	MONICA: The East Asian monsoon and its cyclone activity: information from the Pliocene for an assessment of future developments	01/11/2020 - 31/11/2021	Project lead and processing: Dr Christian Zeeden, Dr Thomas Wonik	Simon Fraser University
EFRE	€220,000	TOPSOIL: Understanding the water under our feet ** p. 56	01/12/2015 - 31/12/2021	Head: Dr Helga Wiederhold Processing: Dr Mohammad Azizur Rahman (former)	Four partners from five countries; Lead partner: Region of Midtjylland, eight partners eight partners from Germany, including LBEG and LLUR
EQC NZ, BGR, Royal Society NZ	€50,000 *	Identification and stratigraphic analysis of concealed near-surface fault structures and weakness zones p. 66	01/06/2013 - 31/12/2021	Project lead and processing: Dr Ulrich Polom. Additional processing: Dr Jan Igel, Dr Thomas Günther, Prof. Manfred Frechen, Dr Sumiko Tsukamoto	BGR, Geological services Denmark and Greenland, GNS Science, Leibniz University Hanover, University of Canterbury
ICDP, LGRB	€250,000	Drilling Overdeepened Alpine Valleys (DOVE): core drilling at three locations (DE, CH, AUT), including in the Tannwald basin **	01/06/2017 - 31/12/2021	Project lead and processing: Prof. Gerald Gabriel, Dr David C. Tanner. Additional processing: Dr Thomas Wonik, Dr Christian Zeeden, Dr Thomas Burschil	Geological services of Slovenia, LGRB, National Research Council Milan, University of Bern, University of Freiburg, University of Natural Resources and Life Sciences, Vienna, Savoie Mont Blanc University and other ICDP partners
My Energie G.I.E.	€93,730	GeothermLUX: Identifying and optimising the use of geothermal potential in Luxembourg	01/06/2020 - 31/05/2021	Head: Prof. Inga Moeck. Processing: Dr Tom Schintgen	Georg August University of Göttingen
Volkswagen Foundation	€108,600	SIRIUS-B: Redesigning magnetic resonance to visualise Earth's underground water distribution usingsimpler, more robust and faster technology	01/05/2020 - 31/10/2021	Head: Prof. Mike Müller-Petke Processing: Nico Skibbe	No partners

* Additional partial funding from the own budget ** Joint project *** Coordination at LIAG

Budget projects

Duration	Project title	LIAG associates	Project partners
01/01/2014 - 31/12/2021	Gravimetric monitoring Bad Frankenhausen	Head and Processing: Prof. Gerald Gabriel	Thuringian State Authority for the Environment, Mining and Conservation of Nature, Leibniz University Hanover
01/01/2017 - 31/12/2022	Investigating the deep roots of human behaviour – dating stone age tools in Zambia p. 62	Head: Dr Sumiko Tsukamoto Processing: Marcus Richter	Aberystwyth University, Leiden University, Moto Moto Museum, University of Edinburgh, University of Liège, University of Liverpool (Project lead), University of Oxford, University of Zambia
01/01/2018 - 31/12/2020	Climate reconstruction in Lichtenberg: Neanderthal survival through the ice ages in Lower Saxony p. 50	Head and Processing: Dr David C. Tanner	Max Planck Institute for Evolutionary Anthropology, Technical University of Braunschweig, Lower Saxony Heritage Authority, Leuphana University of Lüneburg, Friedrich Schiller University of Jena
01/01/2018 - 31/12/2020	Seismic investigations of the Wehrer Kessel volcano crater	Head and Processing: Dr Ulrich Polom Additional Processing: Dr Rüdiger Thomas	Rhineland-Palatinate State Authority for Geology and Mining
01/01/2018 - 31/12/2022	Research drilling in Rodderberg to study lake sediments and loess from the last 300,000 years to reconstruct climate conditions and environmental conditions	Head and Processing: Dr David C. Tanner, Franz Binot (formerly)	Geological services of NRW, University of Bayreuth, University of Bonn, University of Braunschweig, University of Bremen, University of Freiburg
01/01/2018 - 31/12/2024	Participation in the international Fucino Basi drilling project Central Italy	Head: Dr Thomas Wonik Processing: Dr Christian Zeeden	National Research Council (CNR, Rome), University of Cologne

Duration	Project title	LIAG associates	Project partners
01/01/2019 - 31/12/2021	Surveying campaigns near the copper-mining town of Outokumpu for a better understanding of the inflow of saline and gaseous formation waters and the spatial distribution of mechanical stresses in the rock (stress zone)	Head: Dr Thomas Wonik Processing: Katja Hesse	Geological services, Finland
01/01/2020 - 31/12/2022	Drilling campaign as part of the ICDP MexiDrill project on Lake Chalco in Mexico City – detailed measurements of the physical properties	Head: Dr Thomas Wonik Processing: Dr Mehrdad Sardar Abadi	University of Minnesota, University of Pittsburgh
01/04/2020 - 31/03/2024	mesoTherm: Investigation and development of hydrothermal reservoirs in medium-depth geothermal energy – an article on the heating transition in northern Germany; partner project on the energy revolution in the German federal government's real-world laboratories: Integrated heating transition, Hamburg Wilhelmsburg	Head: Prof. Inga Moeck	Georg August University of Göttingen, Geothermie Neubrandenburg GmbH



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PFEIFER, L.S., HINNOV, L., **ZEEDEN, C.**, **ROLF, C.**, **LAAG, C.** & SOREGHAN, G.S. (2020): Rock magnetic cyclostratigraphy of Permian loess in eastern equatorial Pangea (Salagou Formation, south-central France). - Frontiers in Earth Science, 8: Article 241.

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RAHIMZADEH, N., SPRAFKE, T., THIEL, C., TERHORST, B. & **FRECHEN, M.** (2020): A comparison of polymineral and K-feldspar post-IR IRSL ages of loess from Fraconia (Bavaria, Germany). - E&G Quaternary Science Journal: in press.

RAHMAN, M.A., ZHAO, Q., **WIEDERHOLD, H.**, **SKIBBE, N.**, GONZÁLEZ, E., DEUS, N., SIEMON, B., KIRSCH, R. & ELBRACHT, J. (2020): Coastal groundwater systems: Mapping chloride distribution from borehole and geophysical data. - Grundwasser: in press.

RICHTER, M., **TSUKAMOTO, S.** & LONG, H. (2020): ESR dating of Chinese loess using the quartz Ti centre: A comparison with independent age control. - Quaternary International, 556: 159-164.

RONCZKA, M., **GÜNTHER, T.**, **GRINAT, M.** & **WIEDERHOLD, H.** (2020): Monitoring freshwater-saltwater interfaces with SAMOS – installation effects on data and inversion. - Near Surface Geophysics, 18(4): 369-383.

RUSSELL, J.M., BARKER, P., COHEN, A., IVORY, S., KIMIREI, I., LANE, C., LENG, M., MAGANZA, N., MCGLUE, M., MSAKY, E., NOREN, A., PARK BOUSH, L., SALZBURGER, W., SCHOLZ, C., TIEDEMANN, R., NURU, S. & THE LAKE TANGANYIKA SCIENTIFIC DRILLING PROJECT (TSDP) CONSORTIUM [**C. ZEEDEN** AS PART OF LAKE TANGANYIKA SCIENTIFIC DRILLING PROJECT (TSDP) CONSORTIUM] (2020): ICDP Workshop on the Lake Tanganyika Scientific Drilling Project: A late Miocene-present record of climate, rifting, and ecosystem evolution from the world's oldest tropical lake. - Scientific Drilling, 27: 53-60.

SCHEIDT, S., HAMBACH, U., HAO, Q., **ROLF, C.** & WENNRICH, V. (2020): Environmental signals of Pliocene-Pleistocene climatic changes in Central Europe: Insights from the mineral magnetic record of the Heidelberg Basin sedimentary infill (Germany). - Global and Planetary Change, 187: Article 103112.

SCHNEPP, E., THALLNER, D., ARNEITZ, P., MAURITSCH, H., SCHOLGER, R., **ROLF, C.** & LEONHARDT, L. (2020): New Archaeomagnetic Secular Variation Data From Central Europe, I: Directions. - Geophysical Journal International: Article ggz492.

SCHNITTGER, J., MCCUTCHEON, J., HOYER, T., WEYD, M., FISCHER, G., PUHLFUERSS, P., **HALISCH, M.**, VOIGT, I. & LERCH, A. (2020): Hydrophobic Ceramic Membranes in MD Processes – Impact of Material Selection and Layer Characteristics. - Journal of Membrane Science, 618: Article 118678.

SCHUMACHER, S. & **MOECK, I.** (2020): A new method for correcting temperature log profiles in low-enthalpy plays. - Geothermal Energy, 8: Article 27.

SHARIFIGARMDAREH, J., KHORMALI, F., SCHEIDT, S., **ROLF, C.**, KEHL, M. & **FRECHEN, M.** (2020): Investigating soil magnetic properties with pedogenic variation along a precipitation gradient in loess-derived soils of the Golestan province, northern Iran. - Quaternary International, 552: 100-110.

SHIPILIN, V., **TANNER, D.C.**, **VON HARTMANN, H.** & **MOECK, I.** (2020): Multiphase, decoupled faulting in the southern German Molasse Basin – evidence from 3D seismic data. - EGU Solid Earth, 11: 2097-2117.

SHU, Q., ZHAO, Y., **FRECHEN, M.**, **ZHANG, J.**, CHEN, Y., LIU, Y. & **YANG, P.** (2020): Chronology of a sedimentary sequence from the land-ocean interaction zone in the North Jiangsu Basin. - Quaternary International: in press.

SIEMON, B., IBS-VON SEHT, M., STEUER, A., DEUS, N. & **WIEDERHOLD, H.** (2020): Airborne electromagnetic, magnetic and radiometric surveys at the German North Sea coast applied to groundwater and soil investigations. - Remote Sensing, 12(10): Article 1629.

SKIBBE, N., **ROCHLITZ, R.**, **GÜNTHER, T.** & **MÜLLER-PETKE, M.** (2020): Coupled magnetic resonance and electrical resistivity tomography: An open-source toolbox for surface nuclear-magnetic resonance. - Geophysics, 85(3): 53-64.

SPISKE, M., GARCIA GARCIA, A.M., **TSUKAMOTO, S.** & SCHMIDT, V. (2020): High energy inundation events versus long term coastal processes – room for misinterpretation. - Sedimentology, 67: 1460-1480.

STEUER, S., SMIRNOVA, M., BECKEN, M., SCHIFFLER, M., **GÜNTHER, T.**, **ROCHLITZ, R.**, YOGESHWAR, P., MÖRBE, W., SIEMON, B., COSTABEL, S., PREUGSCHAT, B., IBS-VON SEHT, M., ZAMPA, L.S. & MÜLLER, F. (2020): Comparison of novel semi-airborne electromagnetic data with multi-scale geophysical, petrophysical and geological data from Schleiz, Germany. - Journal of Applied Geophysics, 182: Article 104172.

SYCHEVA, S., **FRECHEN, M.**, TERHORST, B., SEDOV, S. & KHOKHLOVA, O. (2020): Pedostratigraphy and chronology of the Late Pleistocene for the extra glacial area in the Central Russian Upland (reference section Aleksandrov Quarry). - Catena, 194: Article 104689.

TAFT, L., WIECHERT, U., ALBRECHT, C., LEIPE, C., **TSUKAMOTO, S.**, WILKE, T., ZHANG, H., & RIEDEL, F. (2020): Intra-seasonal hydrological processes on the western Tibetan Plateau: Monsoonal and convective rainfall events at ~7.5 ka. - Quaternary International, 537: 9-23.

TAMIRU, G. & **WIEDERHOLD, H.** (2020): P- and S-wave reflection profiling for near-surface investigation of glacial sediments. - Journal of Applied Geophysics, 183: Article 104216.

TSUKAMOTO, S. (2020): Electron spin resonance (ESR) dating of quartz for sediment dating and ultralow temperature thermochronometry. - The Quaternary Research (Daiyonki Kenkyu): in press.

TSUKAMOTO, S., TAKEUCHI, T., TANI, A., MIYAIRI, Y. & YOKOYAMA, Y. (2020): ESR and Radiocarbon Dating of Gut Strings from Early Plucked Instruments. - Methods and Protocols, 3(1): Article 13.

ULFERS, A., **HESSE, K.**, **ZEEDEN, C.**, RUSSELL, J.M., VOGEL, H., BIJAKSANA, S. & **WONIK**, **T.** (2020): Cyclostratigraphic and paleoenvironmental results from downhole logging of sediments from tropical Lake Towuti, Indonesia. - Journal of Paleolimnology: in press.

WADAS, S.H., TSCHACHE, S., **POLOM, U.** & KRAWCZYK, C.M. (2020): Ground instability of sinkhole areas indicated by elastic moduli and seismic attributes. - Geophysical Journal International, 222: 289-304.

WAROSZEWSKI, J., SPRAFKE, T., KABALA, C., MUSZTYFAGA, E., KOT, A., **TSUKAMOTO, S.** & **FRECHEN, M.** (2020): Chronostratigraphy of silt-dominated Pleistocene periglacial slope deposits on Mt. Sleza (SW, Poland): Palaeoenvironmental and pedogenic significance. - Catena, 190: Article 104549.

WEI, H., WANG, L., AZARMDEL, H., KHORMALI, F., **FRECHEN, M.**, LI, G. & CHEN, F. (2020): Quartz OSL dating of loess deposits since the late glacial in the Southeast of the Caspian Sea. - Quaternary International: in press.

WEISE, A., TIMMEN, L., DENG, Z., **GABRIEL, G.**, ROTHLEITNER, C., SCHILLING, M. & VOIGT, C. (2020): Observing Ocean Mass Variability with Spring Gravimeters – Storm Surge Induced Signals on the North Sea Island Helgoland. - AVN Allgemeine Vermessungsnachrichten; 2020(4): 163-173.

ZEEDEN, C., OBREHT, I., VERES, D., KABOTH, S., HOSEK, J., MARKOVIC, S.B., BÖSKEN, J., LEHMKUHL, F. & HAMBACH, U. (2020): Smoothed millennial-scale paleoclimatic reference data as unconventional comparison and correlation targets: Application to last glacial cycle European terrestrial records. - Scientific Reports, 10: Article 5455.

ZHANG, Y., OGG, J.G., FRANZ, M., BACHMANN, G.H., SZURLIES, M., RÖHLING, H.-G., LI, M., **ROLF, C.** & OBST, K. (2020): Carnian (Late Triassic) magnetostratigraphy from the Germanic Basin allowing global correlation of the Mid-Carnian Episode. - Earth and Planetary Science Letters, 541: Article 116275.

All LIAG Publications 2020 available at:

Understanding Faults: Detecting, Dating, and Modeling

BOOK

TANNER, D.C. & BRANDES, C. (2020): Understanding Faults: Detecting, Dating, and Modeling. - Elsevier: 1-366. ISBN: 9780128159859.
DOI: 10.1016/B978-0-12-815985-9.00001-1.

For many years, one special focus of LIAG's geological/geophysical work has been the investigation of faults. Edited by Dr David Colin Tanner (LIAG) and Dr Christian Brandes (Leibniz University Hanover), this book is a unique source of information on fault analysis for a multitude of applications, from hazard identification to earthquake processes and geophysical investigation. Many specialists from Germany and other countries contributed to this comprehensive work, as did other LIAG researchers.

Lectures

BARCKHAUSEN, U., **BURSCHIL, T.**, **GRINAT, M.** & **IGEL, J.** (2020): Geophysics. - lecture and tutorial, WS 2019/2020 and WS 2020/2021. Leibniz University Hanover.

FRECHEN, M. (2020): Theory and practice of physical-geographic methodology: Physical dating methods. - lecture, SS 2020. Free University of Berlin.

GÜNTHER, T. (2020): Inverse problems in geophysics. - lecture and tutorial, SS 2020. Freiberg Mining Academy and University of Technology.

MOECK, I. (2020): Borehole geophysics. - lecture, SS 2020. Georg August University of Göttingen.

MÜLLER-PETKE, M. & **GABRIEL, G.** (2020): Geophysics I. - lecture, WS 2019/2020 and WS 2020/2021. Leibniz University Hanover.

MÜLLER-PETKE, M. & **GABRIEL, G.** (2020): Geophysics II. - lecture, SS 2020. Leibniz University Hanover.

POLOM, U. (2020): Applied seismic data interpretation. - lecture and tutorial, SS 2020. Clausthal University of Technology.

Presentations (Selection)

AGEMAR, T. (2020): The geothermal information system GeotIS. - Workshop / talk, Digital Geothermal Conference 2020. 09/11/2020; digital. *Invited talk.*

AGEMAR, T. (2020): Using knowledge from German mineral oil and natural gas exploration for the heating transition. LIAG as a guest at the Leibniz im Landtag event, 10/11/2020 and Leibniz in der Bremischen Bürgerschaft event 10/12/2020; digital.

AGEMAR, T., BÄR, K. & WAGNER, B. (2020): Geology & geophysics interest group. - talk, 1st NFDI4Earth Conference. Online event, 11/11/2020; digital. *Invited talk.*

BAUER, J.F. (2020): Presentation on the status of the subproject REgine: determining basic petrophysical, geomechanical and hydraulic principles. - 2nd GEOmaRe group meeting, 15-16/1/2020; Munich.

BAUER, J.F. (2020): Presentation on the status of the subproject REgine: determining basic petrophysical, geomechanical and hydraulic principles. - 3rd GEOmaRe group meeting, 16-17/9/2020; digital.

BAUER, J.F., KRUMBHOLZ, M. & PFRANG, D. (2020): Characterisation and predictability of important reservoir parameters for geothermal energy in the Molasse basin. - short lecture, German Geothermal Conference, 11/11/2020; digital.

BUDACH, I., **MOECK, I.**, WUNSCH, M., KARAFOTIS, N., **AGEMAR, T.** & FRANZ, M. (2020): Drilling success forecasts for the sandstones of the North German Basin. - Digital Geothermal Conference 2020. 12/11/2020; digital.

BUNESS, H., **BURSCHIL, T.** & **TANNER, D.C.** (2020): Imaging glacial sediments and tectonics with a small-scale 3D reflection seismic survey. - EAGE Near Surface Geoscience, 7-8/12/2020; digital.

BURSCHIL, T. (2020): Lienz seismology. - AGAQ 2020. 01/12/2020; digital.

BURSCHIL, T., **BUNESS, H.**, **BRANDT, A.-C.**, **TANNER, D.C.** & **GABRIEL, G.** (2020): Seismic imaging of glacial overdeepened valleys using P waves and S waves. - Seminar of the DGG Seismics working group, Camp Reinsehlen, 10-12/2/2020; Schneverdingen, Germany.

BURSCHIL, T., **BUNESS, H.** & Schmelzbach, C. (2020): 3D multicomponent S wave survey in the Tannwald Basin: data processing and component rotation. - EAGE Near Surface Geoscience, 07-08/12/2020; digital.

COSTABEL, S. & **HILLER, T.** (2020): Estimating soil hydraulic parameters using nuclear magnetic resonance measurements (NMR) based on triangular capillary models. - 80th annual conference of the German Geophysical Society, 23-26/03/2020; digital.

FADEL, M. (2020): Presentation on the status of the subproject REgine: reservoir engineering. - 2nd GEOmaRe group meeting, 15-16/01/2020; Munich.

FADEL, M. (2020): Presentation on the status of the subproject
REgine: updates on the KST geothermal project: results of analytical solutions, formation evaluation, structural adjustments, and process of hydraulic calibration. - 3rd GEOmaRe group meeting, 16-17/9/2020; digital.

FADEL, M., BRUSS, D. & **MOECK, I.** (2020): Thermal breakthrough history matching of a deep geothermal doublet using geophysical analysis and TH modelling. - short lecture, German Geothermal Conference, 11/11/2020; digital.

FRECHEN, M. (2020): LIAG's range of services for surface exploration of siting regions: LIAG laboratory analysis and structure. Colloquium series on methods and innovations for surface exploration of siting regions in line with StandAG, Federal Company for Radioactive Waste Disposal (BGE), 19/11/2020; digital. *Invited talk.*

GABRIEL, G. (2020): LIAG's range of services for surface exploration of siting regions: seismics, gravimetry, magnetometry @ LIAG: An overview. - Colloquium series on methods and innovations for surface exploration of siting regions according to StandAG, Federal Company for Radioactive Waste Disposal (BGE), 19/11/2020; digital. *Invited talk.*

GRINAT, M. & **RONCZKA, M.** (2020): Geoelectrical long-term monitoring with vertical electrode arrays – three case studies. - Hydrogeophysics and geophysical engineering seminar, Camp Reinsehlen, 12/-14/2/2020; Schneverdingen, Germany.

GRÜTZNER, C., DIERCKS, M., **TSUKAMOTO, S.** & USTASZEWSKI, K. (2020): Active faulting in SW Slovenia - the Selce Fault. - GeoUtrecht, 24-26/08/2020; digital.

GÜNTHER, T. (2020): Recent developments in DC/IP inversion using pyGIMLI/BERT. - Research seminar, University of Aarhus, 13/02/2020; digital. *Invited talk.*

GÜNTHER, T., GRÜNENBAUM, N. & GRESKOWIAK, J. (2020): ERT at the saltwater-freshwater interface – Experience from North Sea islands Borkum and Spiekeroog. - KISNET seminar, 08/07/2020; digital.

GÜNTHER, T. & **MÜLLER-PETKE, M.** (2020): Aridity, drought, salinisation – advancing towards condition assessments of groundwater using innovative drone-based geophysics. - Leibniz im Landtag event, 10/12/2020; digital.

HAMBACH, U., VERES, D., CONSTANTIN, D., **ZEEDEN, C.**, PÖTTER, S., OBREHT, I., **LAAG, C.**, BÖSKEN, J., SCHULTE, P., MARKOVIĆ, S., LEHMKUHL, F. & TIMAR-GABOR, A. (2020): Evidence for uninterrupted glacial and interglacial dust accumulation in Eurasian dry steppe regions. - Quaternaire12, 03-05/02/2020; Paris, France.

HILLER, T. & COSTABEL, S. (2020): Prepolarized surface Nuclear magnetic resonance - First experiences and preliminary results. - open geophysical seminar, RWTH Aachen University, 09/01/2020; Aachen, Germany. *Invited talk.*

LAAG, C., **ZEEDEN, C.**, HAMBACH, U., JOVANOVIC, M. & MARKOVIC, S.B. (2020): Advantages in integrating rock-magnetic and colorimetric measurements for palaeoenvironmental reconstructions on loess-palaeosol sequences: A case study from northern Serbia for the last 430 ka. - GeoUtrecht, 24-26/08/2020; digital.

LAAG, C., HAMBACH, U., VERES, D., **ZEEDEN, C.**, **WORM, K.** & **ROLF, C.** (2020): High-resolution palaeomagnetic and environmental magnetic data from the last interglacial to glacial transition in a loess-palaeosol sequence (LPS) from the Lower Danube (Romania) – Implications for the chronology of the S1 pedocomplex in Eurasian LPSs. - Quaternaire12, 03-05/02/2020; Paris, France.

LAAG, C., **ZEEDEN, C.**, HAMBACH, U., LAGROIX, F., JOVANOVIC, M. & MARKOVIC, S.B. (2020): Integrating magnetic susceptibility and colorimetric parameters for palaeoenvironmental reconstructions from loess-palaeosol sequences: A case study from northern Serbia for the last 430 ka. - AGU Fall Meeting, 01-17/12/2020; digital.

MOECK, I. (2020): Medium-depth geothermal energy as a component of the heating transition. - Webinar on geothermal insights, 23/10/2020; digital.

MOECK, I. (2020): Versatile geothermal energy for renewable heating and cooling. - Geothermal sector in dialogue with the Bundestag, parliamentary evening meeting, 21/09/2020; Berlin, Germany.

POLOM, U., OMLIN, A. & LEINEWEBER, P. (2020): Seismic reflection investigations of near-surface salt structures using the example of the sinkhole-prone area of Quickborn. - Seminar of the DGG seismology working group, Camp Reinsehlen, 10-12/2/2020; Schneverdingen, Germany.

RICHTER, M. & **TSUKAMOTO, S.** (2020): Investigation of quartz ESR residual signals in the last glacial and early Holocene fluvial deposits from the Lower Rhine. - German Luminescence and ESR Dating Online Meeting (DLED2020), 27-29/11/2020; digital.

TANNER, D.C. & **WADAS, S.H.** (2020): Georisks: sinkholes and earthquakes move Lower Saxony (as well). - Leibniz im Landtag event, 10/12/2020; digital.

TSUKAMOTO, S. (2020): Luminescence and ESR dating of active faults. - geoscientific colloquium, University of Jena, 17/12/2020; digital. *Invited talk.*

TSUKAMOTO, S., GURALNIK, B., OOHASHI, K., OTSUBO, M., **TANNER, D.C.**, BRANDES, C. & VON HAGKE, C. (2020): Direct dating of faults by luminescence and ESR: Case studies from Japan and Switzerland. - Japanese Geosciences Union, 12-16/07/2020; digital. *Invited talk.*

ULFERS, A., **ZEEDEN, C.**, **HESSE, K.** & **WONIK, T.** (2020): Paleoenvironmental indications and cyclostratigraphic studies on lacustrine sediments obtained from geophysical downhole logging data – Lake Towuti (Indonesia), Lake Ohrid (Macedonia/Albania). - geoscientific colloquium, WS 2019-2020. 29/01/2020; Goethe University Frankfurt am Main, Germany.

VON HARTMANN, H. (2020): Analysis of seismic structures to differentiate areas of carbonate facies. - REgine project meeting, 16-17/9/2020; digital.

VON HARTMANN, H. (2020): Seismological interpretation and machine learning. - MesoTherm project meeting, 04-05/08/2020; digital.

VON HARTMANN, H. (2020): Presentation on the status of the subproject REgine: analysis of seismic structures to differentiate areas of carbonate facies. - 3rd GEOmaRe group meeting, 16-17/90/20; digital.

WADAS, S.H. (2020): Reservoir characterisation of Malm carbonates in the Munich region using seismic inversion and attribute analysis. - Short lecture, German Geothermal Conference, 11/11/2020. Digital.

WADAS, S.H. (2020): Presentation on the status of the subproject REgine: calibrating and expanding the development model. - 2nd GEOmaRe group meeting, 15-16/01/2020; Munich, Germany.

WADAS, S.H. (2020): Presentation on the status of the subproject REgine: development models / reservoir characterisation. - 3rd GEOmaRe group meeting, 16-17/09/2020; digital.

WAGNER, F., RÜCKER, C., **GÜNTHER, T.**, DINSEL, F., **SKIBBE, N.**, WEIGAND, M. & HAASE, J. (2020): Open-source hydrogeophysical modelling and inversion with pyGIMLi 1.1 – Recent advances and examples in research and education. - EGU General Assembly, 07/05/2020; digital.

WIEDERHOLD, H. (2020): Project TOPSOIL – the contribution of geophysics to hydrogeological modelling in the lower Elbe region. - Hydrogeophysics and geophysical engineering seminar, Camp Reinsehlen, 12-14/02/2020; Schneverdingen, Germany.

WONIK, T. (2020): LIAG's range of services for surface exploration of siting regions: Potential of borehole geophysics and rock physics at LIAG. - Colloquium series on methods and innovations for surface exploration of siting regions according to StandAG, Federal Company for Radioactive Waste Disposal (BGE), 19/11/2020; digital. *Invited talk.*

ZEEDEN, C. (2020): Cyclostratigraphy applied to outcrop, core, and logging data. - Waikato School of Science Seminar, 18/2/2020; Hamilton, New Zealand. *Invited talk.*

ZEEDEN, C. (2020): Reconstructing the European climate over the last 1 million years – a comparison of European loess archives. - Geographic colloquium, Dresden University of Technology, 22/1/2020; Dresden, Germany. *Invited talk.*

ZEEDEN, C. (2020): European Quaternary climate inferred from loess-paleosol sequences: knows, unknows and future perspectives. - SFB806 seminar series, 29/06/2020; digital. *Invited talk.*

ZEEDEN, C. (2020): Orbital forcing of sedimentary systems through Earth history. - ARISE group seminar, Simon Fraser University, 04/06/2020; digital. *Invited talk.*

ZEEDEN, C. (2020): Orbital forcing of sedimentary systems through Earth history. - colloquium of the Institute for Geosciences, University of Potsdam, 20/11/2020; Potsdam, Germany. *Invited talk.*

All LIAG presentations 2020 available at:

Departments and functions

Agemar, Thorsten, Dr

- Research network for including geothermal technologies into decarbonised heating and cooling (Cost Action 18219) – member of the steering committee
- WG information systems (formerly BIS steering group) of the state geological services (SGD) – permanent member
- 3D structural models/3D models, working group of the state geological services (SGD) – permanent member

Burschil, Thomas, Dr

- Near Surface Geophysics (EAGE) – Associate Editor

Frechen, Manfred, Prof.

- Federal/state committee for soil research (BLA-GEO) – permanent guest status
- Directorship of the state geological services (DK) – permanent guest status
- German Stratigraphic Commission (Quaternary) – member
- Editorial Board Geologia Croatia – member
- Scientific board of the international magazine Geochronometria – member
- Scientific board of the international magazine Palaeohistoria – member
- Editorial board of the international magazine Proceedings of the Geologists Association – member

Gabriel, Gerald, Prof.

- Near Surface Geophysics (EAGE) – Associate Editor
- Leibniz research centre magazine GEO – member of the board

Grinat, Michael

- German Geophysical Society – advisor to the board
- Geoscientific newsletter GMIT – member of the editorial department
- Newsletter of the German Geophysical Society – member of the editorial department
- GMIT working group – deputy leader

Günther, Thomas, Dr

- German Geophysical Society – member of the Internet committee
- Journal of Applied Geophysics, Elsevier – associate editor

Halisch, Matthias, Dr

- German Geophysical Society – Permanent member in the IP working group
- Society of Core Analysts (SCA) – member of the Technical Committee

Von Hartmann, Hartwig, Dr

- Geothermics working group of the German Geophysical Society – member

Moeck, Inga, Prof. Dr

- German Geothermal Association – director
- Resources and Reserves Committee of the International Geothermal Association – member
- Geothermal Energy (international journal in the Springer Verlag publishing group) – editor-in-chief
- Advisory board for the Geothermal Alliance Bavaria (GAB) – councillor

Müller-Petke, Mike, Prof.

- Near Surface Geophysics (EAGE) – Associate Editor
- Applied geophysics working group of the German Geophysical Society – member

Polom, Ulrich, Dr

- DIN/VDI Standards Committee for Acoustics, Noise Reduction and Vibration Technology – permanent staff member

Wadas, Sonja, Dr

- German Geophysical Society – member of the Editorial department for the DGG newsletter
- German Geophysical Society – member of the Public Relations & Outreach committee

Wiederhold, Helga, Dr

- Technical Committee Salt Water Intrusion Meeting 26th SWIM – member

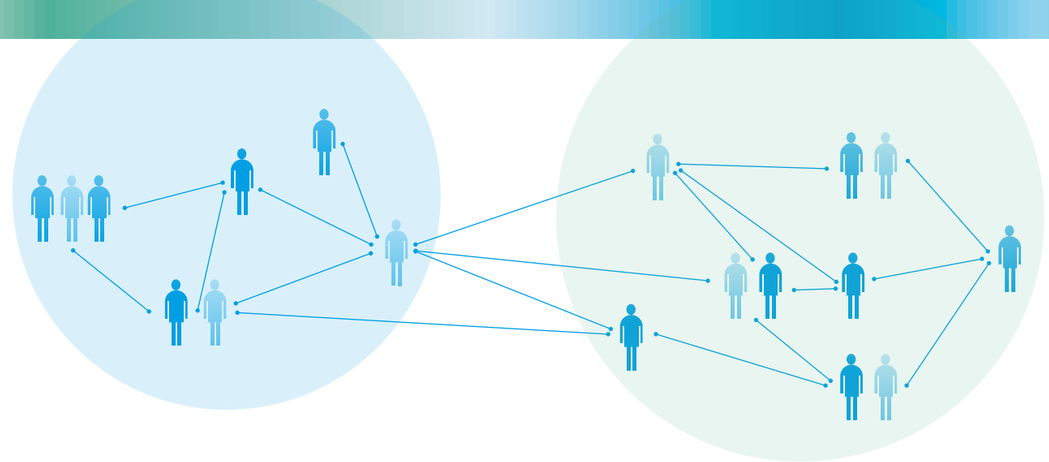
Wonik, Thomas, Dr

- D-ANDRILL working group in the SCAR state commission – member
- FKPE borehole geophysics and rock physics working group – member
- German Scientific Earth Probing Consortium (GESEP) – member

Zeeden, Christian, Dr

- Editorial board of the international magazine Quaternary Geochronology – member
- Editorial board of the E&G Quaternary Science Journal – member

Collaborations (Selection)



NATIONAL

Universities

Bauhaus University, Weimar, Material Research and Testing Institute
Christian-Albrecht University of Kiel
Free University of Berlin
Friedrich Schiller University of Jena
Georg August University of Göttingen
Bochum University, International Geothermal Centre GZB
Leibniz University Hanover
Leuphana University of Lüneburg
RWTH Aachen University
Freiberg Mining Academy and University of Technology
Technical University of Braunschweig
Clausthal University of Technology
Johannes Gutenberg University of Mainz
University of Mainz
University of Potsdam
University of Cologne

Non-university research facilities

AWI Bremerhaven, Geophysics and Glaciology departments
Dresdner Grundwasserforschungszentrum e. V.
Helmholtz Centre Potsdam – German Research Centre for Geosciences
Potsdam Institute for Climate Impact Research
Karlsruhe Institute of Technology
Leibniz Centre for Agricultural Landscape Research
MPI for Evolutionary Anthropology
MPI for Geochemistry

Further cooperations (governmental and non-governmental)

Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
Bundesamt für Kartographie und Geodäsie (Federal Agency for Cartography and Geodesy)
ESWE Versorgungs AG, state capital of Wiesbaden, environmental agency
GeoEnergy Celle e. V.
Geothermie Neubrandenburg GmbH
Hentschel Systems GmbH
State Office for Mining, Energy and Geology
State Office for Geology, Raw Materials and Mining of the Freiburg regional council
State Office for Agriculture, Environment and Rural Areas (Schleswig-Holstein)
Math2Market GmbH
Saxon State Office for the Environment, Agriculture, and Geology
Technical Information Library Hanover (TIB)
WEG-Wirtschaftsverband Erdöl- und Erdgasgewinnung e. V.

INTERNATIONAL

Universities

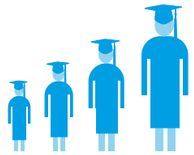
Aberystwyth University, United Kingdom
Brown University, USA
China University of Geosciences, Peking, China
Durham University, United Kingdom
ETH Zurich, Swiss Federal Institute of Technology, Switzerland
Gorgan University of Agricultural Sciences and Natural Resources, Iran
Kumamoto University, Japan
International Centre for Geohazards, Norway
Jilin University, College of Instrumentation & Electrical Engineering, China
Kyoto University, Japan
Liège University, Belgium
National Taiwan University, Department of Geosciences, Taipeh, Taiwan
Szeged University, Hungary
The Interuniversity Institute for Marine Sciences, Israel
Tohoku University, Japan
UCD School of Earth Sciences Dublin, Ireland
University of Bern, Switzerland
University of Gorgan, Iran
University of Kashmir, India
University of Lausanne, Institute of Earth Surface Dynamics, Switzerland
University of Liverpool, United Kingdom
University of Vienna, Institute of Meteorology and Geophysics, Austria
University of Novi Sad, Department of Geography and Tourism, Serbia
University of Oklahoma, Norman, USA
University of Tehran, Iran
University of Waikato, New Zealand
Utrecht University, Netherlands
Xinjiang University, Joint Centre on Coal Fire Research, China

Further cooperations

Andean Geothermal Center of Excellence (CEGA): Scientific and Technical Cooperation in Applied Geothermics, Chile
Czech Academy of Sciences, Czech Republic
Geological Survey of the Czech Republic, Czech Republic
Geophysical Institute of Israel, Israel
Institute for Geological and Nuclear Science, New Zealand
Instituto Costarricence de Electricidad, Costa Rica
Lantmäteriet, Sweden
Observatoire de Paris, France

… and with 81 other universities and research organisations within joint international projects (including the AlpArray Research Group, three ICDP projects, TOPSOIL)

Support of young scientists



Doctoral candidates at LIAG

Buchanan, Gwynlyn
Infrared radiofluorescence of sediments: a methodological investigation (working title)
Free University of Berlin
Advisor at LIAG: Dr Sumiko Tsukamoto

Fadel, Mohamed
Highly fractured carbonate reservoir characterization and simulation for geothermal exploitation (working title)
Georg August University of Göttingen
Advisor at LIAG: Prof. Inga Moeck

Leu, Katharina
Interpretation of borehole measurements in the Lower Jurassic in England (working title)
University not yet decided
Advisor at LIAG: Dr Thomas Wonik, Dr Christian Zeeden

Rahimzadeh, Neda
Violet stimulation luminescence (VSL) dating on sediments (working title)
Free University of Berlin
Advisor at LIAG: Dr Sumiko Tsukamoto

Richter, Marcus
Electron spin resonance dating of sediments (working title)
Free University of Berlin
Advisor at LIAG: Dr Sumiko Tsukamoto

Rochlitz, Raphael (concluded)
Analysis and open-source implementation of finite element modelling techniques for controlled-source electromagnetics
University of Münster
Advisor at LIAG: Dr Thomas Günther

Shipilin, Vladimir
Seismic characterization of geothermal plays in the Bavarian Molasse basin under structural geological constraints (working title)
Georg August University of Göttingen
Advisor at LIAG: Prof. Inga Moeck

Skibbe, Nico
Modelling of magnetic resonance data in 1D and 2D with special emphasis on smooth resistivity distributions and structural coupled inversion (working title)
Leibniz University Hanover
Advisor at LIAG: Dr Thomas Günther, Prof. Mike Müller-Petke

Ulfers, Arne
Interpretation of borehole measurements in Quaternary lakes in North Macedonia and Indonesia (working title)
Goethe University Frankfurt am Main
Advisor at LIAG: Dr Thomas Wonik, Dr Christian Zeeden

External doctoral candidates with temporary research residences at LIAG

Abbas, Wahid
Paleoseismology and neotectonics of the Sub-Himalayas in Pakistan (working title)
RWTH Aachen University
Period: 01/07/2020-31/12/2020
Advisor at LIAG: Dr Junjie Zhang

Carillo de la Cruz, Juan Luis
Curie point depth and heat flow estimations in Mexico (working title)
National Autonomous University of Mexico
Period: 01/11/2019-31/05/2020
Advisor at LIAG: Prof. Gerald Gabriel

Falufosi, Michael
Geologically constrained 3D gravity and magnetic inversion for modelling the Nigerian sector of Dahomey Basin (working title)
University of Ibadan
Period: 01/10/2019-31/03/2020
Advisor at LIAG: Prof. Gerald Gabriel, Dr Matthias Halisch, Dr Christian Rolf

Hou, Yandong
Lake evolutions in Asian monsoon since Late Quaternary - A case study of Selin Co and Daihai Lake (working title)
Chinese Academy of Sciences
Period: 11/12/2019-28/11/2020
Advisor at LIAG: Prof. Manfred Frechen, Dr Sumiko Tsukamoto

Loba, Aleksandra
Erosion rates and soil formation in loess landscape based on isotopic procedures (10Be, 239+240Pu) and OSL datings, Trzebnickie Hills (SW, Poland) (working title)
Wroclaw University of Environmental and Life Sciences
Period: 15/07/2020-12/08/2020
Advisor at LIAG: Dr Sumiko Tsukamoto

Yang, Pu
Geomorphological characterization and luminescence dating of coastal terraces in central and northern Portugal (working title)
University of Coimbra
Period: 18/03/2019-04/08/2020
Advisor at LIAG: Prof. Manfred Frechen

Degree theses

Brandt, Anna-Catharina
Investigation of the Alpine, glacially overdeepened Basadingen Basin using P wave seismology
Bachelor thesis
Leibniz University Hanover
Advisor at LIAG: Dr Hermann Buness, Prof. Gerald Gabriel, Dr David Tanner, Dr Thomas Burschil

Wolpmann, Lars
The use of medium-depth geothermal energy in Lower Saxony using the example of Valanginian deposits (Lower Cretaceous) – reservoir simulation of doublet boreholes under various geological conditions
Master's thesis
Leibniz University Hanover
Advisor at LIAG: Prof. Inga Moeck

Honours

Wolfgang-Helms Foundation prize awarded to Dr Sara Hupfer

In 2020, Dr Sarah Hupfer, a former doctoral candidate at LIAG, was awarded the Clausthal University of Technology's
Wolfgang-Helms Foundation prize for the best doctoral thesis in the field of geosciences for her dissertation on carbonate dissolution. For her dissertation entitled "Spectral induced polarisation for an enhanced pore-space characterisation and analysis of dissolution processes of carbonate rocks" she conducted important basic research on the enhanced characterisation and analysis of pore volumes in carbonate dissolution processes using spectral induced polarisation (SIP). Hupfer employed SIP methods to systematically determine the complex electrical properties of various types of carbonates for the first time. Her study contributed to a better understanding of subrosion-related processes, such as sinkholes.
Advisor at LIAG: Dr Matthias Halisch.

Young scientists group at LIAG

Middle Pleistocene surface processes
Coordinator: Dr Sumiko Tsukamoto
The goal of the young scientists group is to further develop the range of luminescence and radiofluorescence methods and to apply them in high resolution to Middle Pleistocene sediments to gain a better understanding of this still largely unresearched era.

Members: Dr Junjie Zhang, Neda Rahimzadeh, Gwynlyn Buchanan

Software development, specialist information services and research data infrastructure

Open-source software developments

pyGIMLi – Geophysical Inversion and Modelling Library in Python

A Python library for the modelling and inversion of geophysical data.

Developed by: Dr Thomas Günther (LIAG),
Dr Florian M. Wagner (RWTH Aachen University),
Dr Carsten Rücker (TU Berlin)
www.pygimli.org

BERT – Boundless Electrical Resistivity Tomography

Electrical resistivity tomography of arbitrary geometries.

Developed by: Dr Thomas Günther (LIAG),
Dr Carsten Rücker (TU Berlin)
www.gitlab.com/resistivity-net/bert

MRSmatlab

MRSmatlab is a MATLAB-based toolbox for processing and modelling surface NMR data.

Developed by: Prof. Mike Müller-Petke (LIAG)
www.github.com/mmpetke/MRSmatlab

custEM

The Python toolbox custEM is an open-source development for the 3D finite element modelling of any controlled-source, transient, and magnetotelluric data.

Developed by: Dr Raphael Rochlitz (LIAG)
www.gitlab.com/Rochlitz.R/custEM

COMET – COupled Magnetic resonance and Electrical resistivity Tomography

The software developed in the COMET project is used for modelling surface magnetic resonance data in 2D, taking arbitrary conductivity structures into account, and for the coupled inversion of this data with 2D ERT measurements.

Developed by: Nico Skibbe (LIAG)
www.gitlab.com/Skibbe/comet/

BLOCHUS

BLOCHUS can be used to model the NMR spin dynamics or the underlying Bloch equation for surface NMR cases in which no analytical solution is available. The software was developed during the MoreSpin project.

Developed by: Dr Thomas Hiller (LIAG)
www.github.com/ThoHiller/nmr-blochus

NUCLEUS

The software NUCLEUS is a graphic user interface for modelling and, above all, for the inversion of NMR laboratory data. In this way, it attempts to draw conclusions concerning the pore geometry or the pore volume of a sample on the basis of NMR laboratory measurements.

Developed by: Dr Thomas Hiller (LIAG),
Dr Stephan Costabel (BGR)
www.github.com/ThoHiller/nmr-nucleus

Specialist information services and research data infrastructure

GeotIS – German Geothermal Information System

GeotIS is LIAG's freely available information system. It supplies an overview of geothermal plants in Germany including annually updated heat and electricity production statistics. It also provides comprehensive data concerning the geological requirements for the use of geothermal resources. Other specialist data can also be called up, such as maps of deep-seated faults, rock permeability or sandstone thickness. Of particular importance are the 3D models of geological structures that can be called up via interactive maps and sections. GeotIS provides high-quality data that contributes to optimising site selection for new projects and minimising the exploration risks.

Responsible parties: Dr Thorsten Agemar (scientific contact),
Jens Gramenz (technical administration/implementation)
www.geotis.de

Geophysics Information System

The Geophysics Information System (FIS GP) is used to store and provide geophysical metadata, measurements and evaluations for LIAG and its partner organisations. The IT architecture of the overall system consists of an import program, an online GIS and a database. These are subdivided into a general part (superstructure), containing the metadata of all methods, and multiple subsystems. The temperatures subsystem is particularly noteworthy. It contains a unique collection of measured and corrected subsurface temperatures from Germany. Anyone can log in as guest user and retrieve metadata, free measurements and data evaluations. Some of the datasets are confidential and can only be accessed by registered users with the permission of the data owners.

Responsible parties: Dr Thorsten Agemar (scientific contact),
Jörn Brunken (technical administration/implementation)
www.fis-geophysik.de

SIP-Archive

The SIP Archive is a web application that can be used by participating institutions to manage petrophysical measurement data recorded using the spectral induced polarisation (SIP) measurement method in a shared repository. Metadata is used to simplify searching for samples and measurement data. The institutions administer their data autonomously and release it under their own responsibility for other institutions to download. The participating institutions mainly belong to the Induced Polarisation working group of the German Geophysical Society. The SIP Archive is also used by international working groups (USA, Russia, France). The repository is listed in re3data.org (Registry of Research Data Repositories) under the DOI http://doi.org/10.17616/R38Q0H.

Responsible parties: Dr Matthias Halisch (scientific contact),
Jens Gramenz and Klaus Krause (technical administration/implementation)
www.sip-archiv.de

LIAG PROSPECTS

2021 objectives and research

This section is intended to give you an impression of our work and research programme for 2021 and also the long-term objectives of the institute. LIAG is currently undergoing successive restructuring. We are currently considering the Groundwater Geophysics and Geohazards departments. LIAG management is fleshing out a general concept that will specify scientific key issues more precisely and rethink areas of overlap and integration potential with other LIAG departments. At the same time, projects are currently under way in all areas of research. These projects will still be important to LIAG in the coming years and especially in 2021.

Groundwater Geophysics

Future research on coastal aquifer systems will concentrate on the application and development of geophysical methodologies for detecting changes, e.g. in the intertidal saltwater/freshwater mixing zone of barrier islands or submarine groundwater discharge. The combination of temporally and spatially diverse scales that have been recorded using geophysical datasets plays a particularly significant role, as does the amalgamation of these datasets to create hydrological, geochemical and biological models (and systems).

Our most relevant planned methodological goal is the development and application of drone-based measurements and their evaluation both in coastal aquifer research and to determine physical soil parameters of the vadose zone. We intend to develop and apply drone-based measurements as a rapid and cost-effective alternative to helicopter surveying flights for large-scale mapping of subsurface properties. Further areas of focus include methodological developments for large-scale recording of the temporal and spatial variability of soil moisture as a significant factor of geochemical and biological processes.

In the future, we wish to use geophysical investigations closely linked with hydrogeological modelling to gain a fundamentally better understanding of processes, their respective dynamics and changes within the overall system of the critical zone (for example caused by mass transport or groundwater recharging). The critical zone consists of the vadose zone, the capillary fringe and the saturated zone.

Geohazards

The field of geohazards requires a deeper understanding of geological structures and their physical properties and an investigation of the processes on different spatial and temporal scales. With regard to areas at risk of subrosion (as well as the Eifel volcanic field as a secondary subject), we will explore relevant structures and parameters using geophysical methods and develop, apply and evaluate innovative monitoring concepts.

We have submitted multiple third-party-funding applications to pursue a better understanding of (neo)tectonic processes. One of the particular areas of interest is northern Germany. Regarding the use of subsurface areas and seismic risks, we must improve our understanding of the potential reactivation of large fault zones and their connection to postglacial isostatic adjustments. One initial key focus will be on the Osning lineament. We aim to better understand its formation using an integrative approach.

Three funded projects will study the geological development of the Alps as part of the DFG's priority programme "4D-MB - Mountain Building Process in Four Dimensions". We will be studying the activity of large faults in the Alps during the Quaternary period using advanced dating methods. This methodological approach will also be evaluated on faults outside the Alps. In addition, we aim to derive detailed 3D tectonic models on the basis of geological information from the area around the Brenner Base Tunnel. Using new dating results, this will enable us to reconstruct the region in 4D.

We will conduct tomographical experiments using reflection seismology in crystalline rocks (Odenwald) and in sediment (Tannwald basin) to quantify seismic anisotropy and its interpretation with regard to structures and processes. Methodological expertise gained during this task will be of further use in the future.

The methodological goal of one proposed project is to develop a measurement system for acquiring seismic shear wave reflection profiles from the bottom of bodies of water. In future, this could be used to explore faults very near to the surface even if they are located beneath lakes.

Sediments through the Ages (climate dynamics)

The overarching objective is to derive a cross-regional and internally consistent image of landscape evolution and climate evolution from the local and regional geophysical findings.

To this end, LIAG will be participating in multidisciplinary ICDP projects throughout 2021: Lake Ohrid (North Macedonia), Lake Bosumtwi (Ghana), Lake Chalco (Mexico), JET (England), DOVE (countries of the Alps), Lake Nam Co (China), Lake Tanganjika (Tanzania), Deep Dust (USA/France), Weihe Basin (China), Colonia Deep (Brazil), Lake Junin (Peru), Lake Izabal (Guatemala) and "Sensitivity of the West Antarctic Ice Sheet to 2 Degrees Celsius" (Antarctic). This will allow us to examine overarching questions in various geological surroundings and periods of time and to further develop statistical analysis methods to resolve these issues. Collaborations in large international working groups and the resulting network of contacts will be invaluable for future projects.

In addition, we will be examining palaeoclimate landscape development in a midcontinent region based on the interaction of fluvial, lacustrine and aeolian processes in Western Mongolia. We will also be researching the extent to which humans were influenced by vegetation patterns in the ecosystem and changes in geomorphological processes since the Neolithic. We will be conducting further investigations into the complexity of climate changes and environmental changes in northern Iran. This will provide more clarification concerning short-term and long-term climate changes subject to natural climate variations and the influence of fluctuating sea levels in the Caspian Sea. LIAG will also be working on dust deposits in northern India. The laboratories will have varied tasks, including collecting petromagnetic data that will allow conclusions to be drawn concerning precipitation dynamics. The age of the sequences will be determined using luminescence dating methods. Furthermore, LIAG is currently establishing a cooperation with the University Mardan in Pakistan.

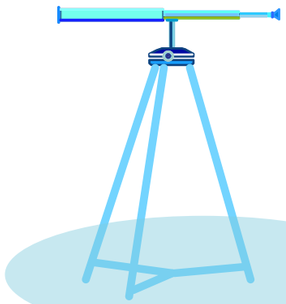
On the methodological front, we aim to improve luminescence dating of quartz and feldspar minerals using fluvial sediments from the upper Atbara valley (Sudan). This will contribute to a more precise reconstruction of the climate-related extinction of Pleistocene megafauna and the development of the Homo (Hominini) genus in Africa during the transition from the Old Stone Age to the Middle Stone Age as a consequence of paleoclimatic and ecological changes.

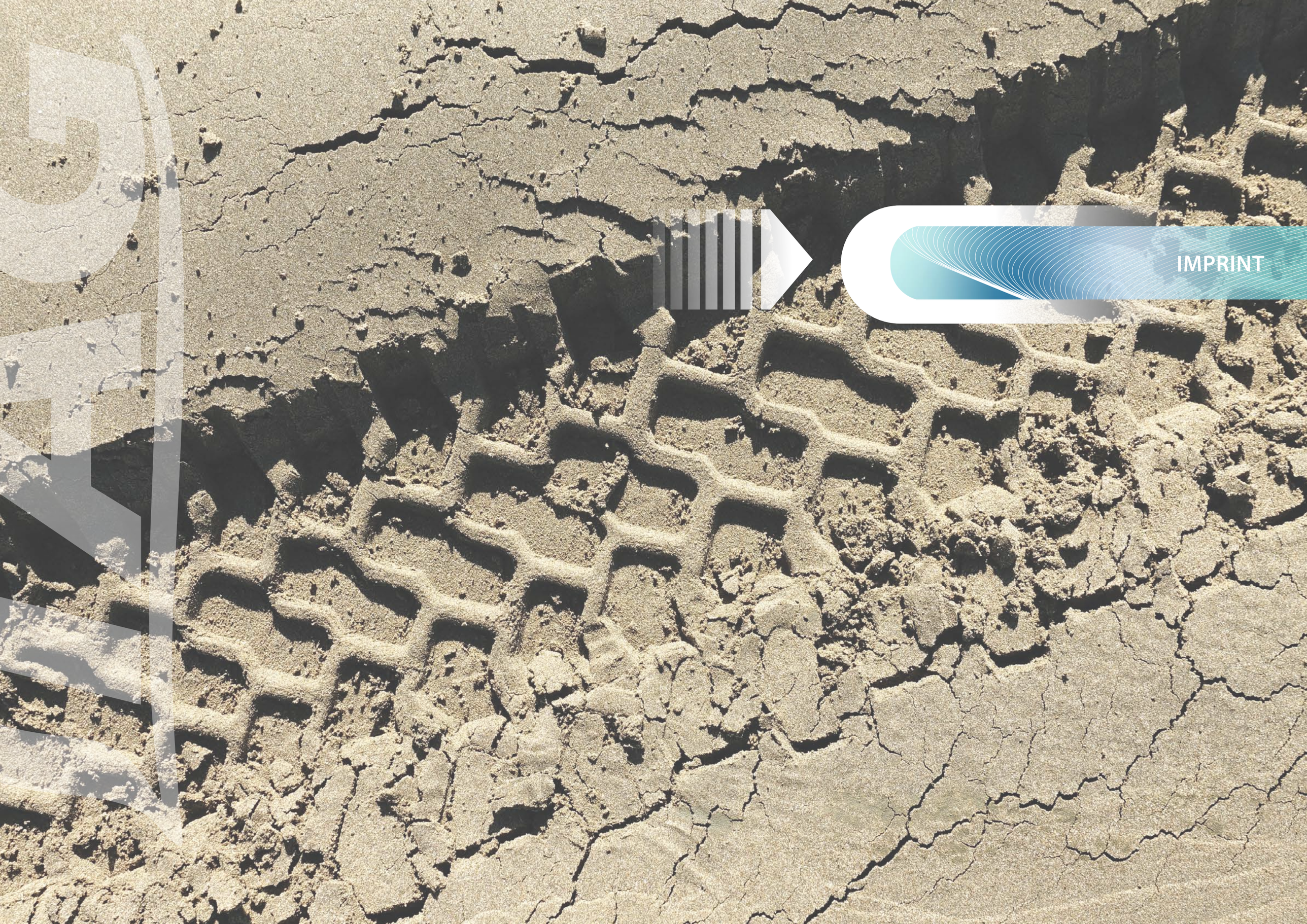
Research for the heating transition

Geological reservoirs for medium-depth geothermal energy in northern Germany are at the centre of our current research activities. In addition, we are testing an innovative stimulation concept in an in-situ laboratory to the south of Munich in the only petrothermal research project in Germany.

The methodological research approach uses the concept of play types, developed by Moeck (2014) and specified in the PlayType project. In line with this concept, we must first understand temperature distribution and its anomalies at a geosystem scale by employing large-scale thermal-hydraulic models. We can then characterise large-scale geological structures that influence local fluid flow and heat. Only then can we evaluate the resource on the prospect scale. The activities within the project ultimately serve to verify and validate the play-based exploration concept.

In 2021, the following topics will be examined in current, third-party-funded projects: (1) The development of an innovative seismo-facial exploration methodology for the play type fluvio-deltaic channel systems, (2) The first integration of artificial intelligence into the seismic exploration of geothermal reservoirs, (3) The development of a transferable methodology for innovative drilling success forecasts that integrates statistical and geological data from the Upper Keuper in the North German Basin, (4) The verification of decoupled fault patterns in connection with the thickness of the Rupelian clays in the Munich area and (5) The beginning of the implementation phase for medium-depth geothermal energy in the geothermal information system GeotIS.





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List of abbreviations

Only includes abbreviations related to organisations, projects and research

AHRC:	Arts and Humanities Research Council
AWI:	Alfred Wegener Institute
BBT:	Brenner base tunnel
BGR:	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BMBF:	Bundesministerium für Bildung und Forschung (federal ministry for education and research)
BMWi:	Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
CAM:	Coastal aquifer management
DAAD:	Deutscher Akademischer Austauschdienst (German academic exchange service)
DESMEX:	Deep electromagnetic sounding for mineral exploration
DFG:	German Research Foundation
DOVE:	Drilling Overdeepened Alpine Valleys
ELVIS:	Name of the LIAG shear wave vibrator
ERDF:	European Regional Development Fund
ESR:	Electron spin resonance
EQC NZ:	Earthquake Commission New Zealand
GAUG:	Georg August University of Göttingen
GEUS:	The Geological Survey of Denmark and Greenland
GNS Science:	Institute of Geological and Nuclear Sciences (New Zealand)
GPI:	Geophysical institute (KIT)
GR:	Gamma radiation
GRS:	Gesellschaft für Anlagen- und Reaktorsicherheit (Global Research for Safety)
GZB:	International Geothermal Centre, Bochum
ICDP:	International Continental Scientific Drilling Program
IPHT:	Leibniz Institute of Photonic Technology
ka BP:	Kiloannum before present
KIT:	Karlsruhe Institute of Technology
LBEG:	Landesamt für Bergbau, Energie und Geologie (State Office for Mining, Energy and Geology)
LIDAR:	Light detection and ranging (opt. method for determining ranges)
LGRB:	Landesamt für Geologie, Rohstoffe und Bergbau (State Office for Geology, Raw Materials and Mining) of the Freiburg regional council
LLUR:	Landesamt für Landwirtschaft, Umwelt und ländliche Räume (State Office for Agriculture, Environment and Rural Areas) Schleswig-Holstein
LUH:	Leibniz University Hanover
MIS:	Marine isotope stage
MW:	Niedersächsisches Ministerium für Wirtschaft, Arbeit, Verkehr und Digitalisierung (Lower Saxony Ministry of Industry, Labour, Transport and Digitalisation)
MWK:	Niedersächsisches Ministerium für Wissenschaft und Kultur (Lower Saxony Ministry for Science and Culture)
NFDI4Earth:	National Research Data Infrastructure for Earth System Sciences
NLWKN:	Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (Lower Saxon State Department for Waterways, Coastal and Nature Conservation)
NMR:	Nuclear magnetic resonance
RUB:	Ruhr University Bochum
OOWV:	Oldenburgisch-Ostfriesischer Wasserverband (Oldenburg-East Frisian Water Association)
OSL:	Optically stimulated luminescence
P waves:	Seismic primary waves
S waves:	Secondary waves (seismology)
SAAD:	Single aliquot additive dose
SAR:	Single aliquot regenerative dose
SDG:	Sustainable development goals
SGD:	State geological services
SR:	Sedimentation rates
SWM:	Munich City Utilities
TU:	Technical university
µ-CT:	X-ray microtomography
WB:	Scientific advisory committee (Wissenschaftlicher Beirat)
UFZ	Helmholtz Centre for Environmental Research GmbH
ZMT	Leibniz Centre for Tropical Marine Research

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The Leibniz Institute for Applied Geophysics is an independent, non-university research facility based in Hanover, Germany. We use applied geophysical methods to explore future-oriented issues that are of importance to society. The focus of our research is the exploration of the usable lithosphere and the development of measuring techniques and evaluation methods. The institute has over 50 years of experience in geophysical research. Our many years of specialisation in near-surface geophysical applications, our equipment and data infrastructure, and our resulting scope for combining diverse, interdisciplinary geophysical methods within the institute make LIAG unique in Germany.

LIAG Leibniz Institute for Applied Geophysics