SÚRAO | RADIOACTIVE WASTE REPOSITORY AUTHORITY

Experimental programme **2015–2020**

Bukov Underground Research Facility

URF Bukov

Czech Radioactive Waste Repository Authority (SÚRAO)

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Introduction

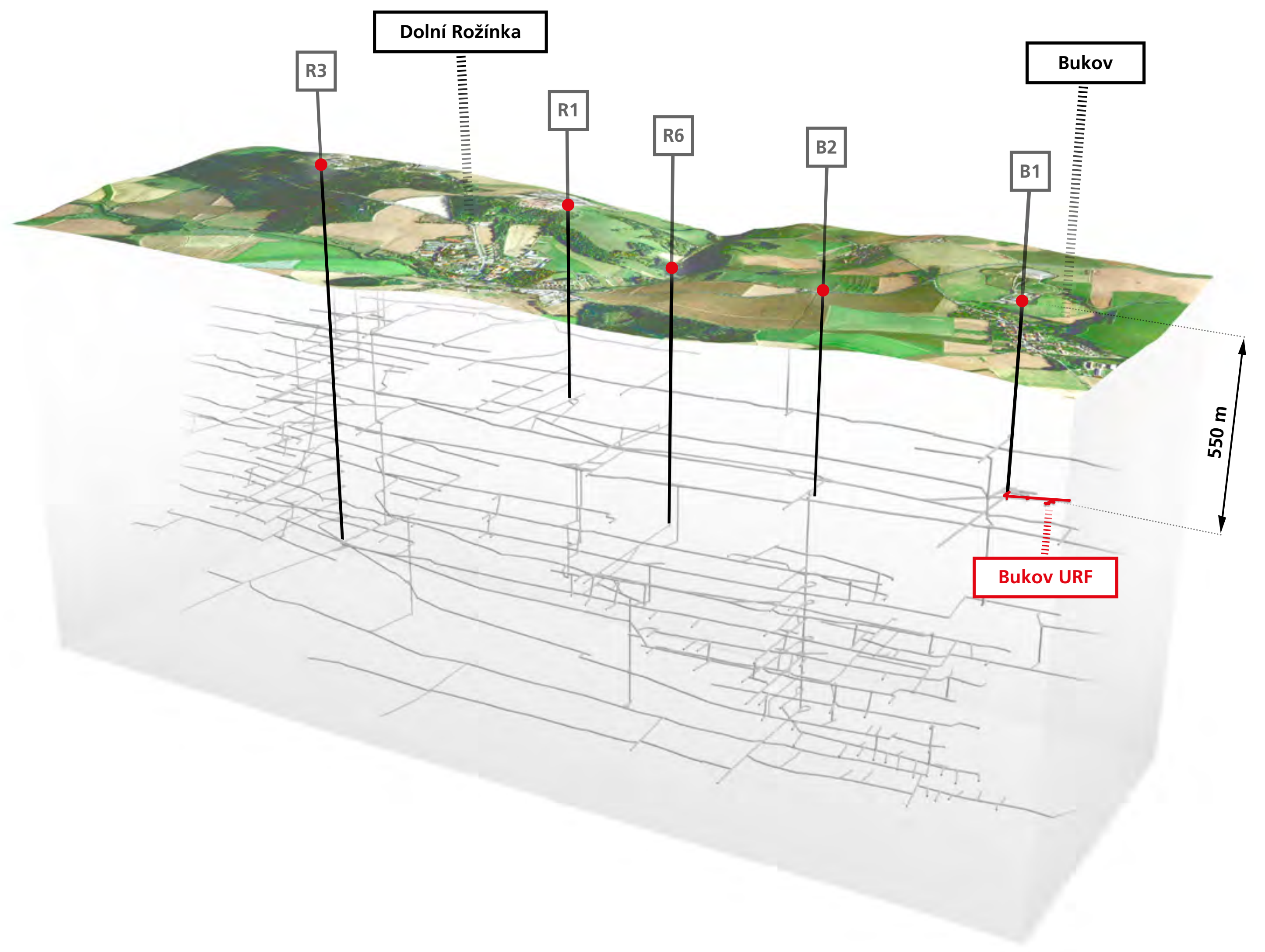
The Radioactive Waste Repository Authority (SÚRAO), in accordance with the Government-approved Radioactive Waste and Spent Nuclear Fuel Management Concept and valid legislation, is responsible for the development of the Czech deep geological repository (DGR) for high-level waste and spent nuclear fuel project. Globally, a number of underground laboratories have been constructed in connection with the development of deep geological repositories concerning which they play an essential role in terms of research and development and the conducting of demonstration experiments.

Underground laboratories are used for the testing of the robustness of engineered barriers and for the gathering of descriptive multidisciplinary geoscientific and safety analysis data. An equally important part of the research conducted at such facilities concerns the determination of the appropriate methodologies for describing and assessing the rock massif, the measurement and modelling of the various processes at work within the rock environment and the training of highly-qualified experts. The data and experience obtained subsequently play an important role in the various processes applied for the assessment of potential DGR sites with respect to the optimisation of the engineering and construction techniques, enhancing the professional level of national programmes and the potential for engaging in international research cooperation.

Currently, the greater part of SÚRAO's research activities involving in-situ experimentation related to the planning of the Czech DGR is conducted at the Bukov Underground Research Facility (URF) consisting of 470 m of specially-excavated tunnels and chambers on the 12th level of the Rožná I mine (at a depth of 550 m below the surface) and selected former mine workings in other parts of the mine, up to a depth of 1,200 m. The Bukov URF is a so-called generic underground laboratory, the construction and characterisation of which took place from 2013 to 2017, in which year the experimental phase commenced.

The laboratory is located near the B-1 working north of the village of Bukov in the Vysočina (Czech Highlands) region. The Bukov URF is located in crystalline rocks, i.e. in an environment characterised by high strength and fracture permeability properties, typical of the rock environment in which the Czech DGR is planned to be constructed. The laboratory consists of a system of underground spaces that feature a variety of geological conditions that allow for the conducting of a wide range of tests and experiments.

This article aims to provide an overview of both already completed and ongoing research projects.



Scheme showing the principal mine workings of the Rožná I mine and indicating the location of the Bukov URF

History of the Bukov URF

2013–2017: Construction

The construction of the Bukov URF commenced in 2013 and was completed in 2017. The exploratory phase included the excavation of the 320 metre-long BZ-XIIJ access crosscut which was followed by a drilling campaign aimed at specifying the geological structure and the selection of the rock blocks. The third phase consisted of the excavation of the experimental chambers. The construction of the laboratory areas involved the application of the contour blasting method that allowed for high-quality excavation without the need for reinforcement. The underground complex consists of the BZ-XIIJ access crosscut, three borehole chambers, the BZ_1-XII laboratory crosscut and four chambers for the conducting of long-term experiments.

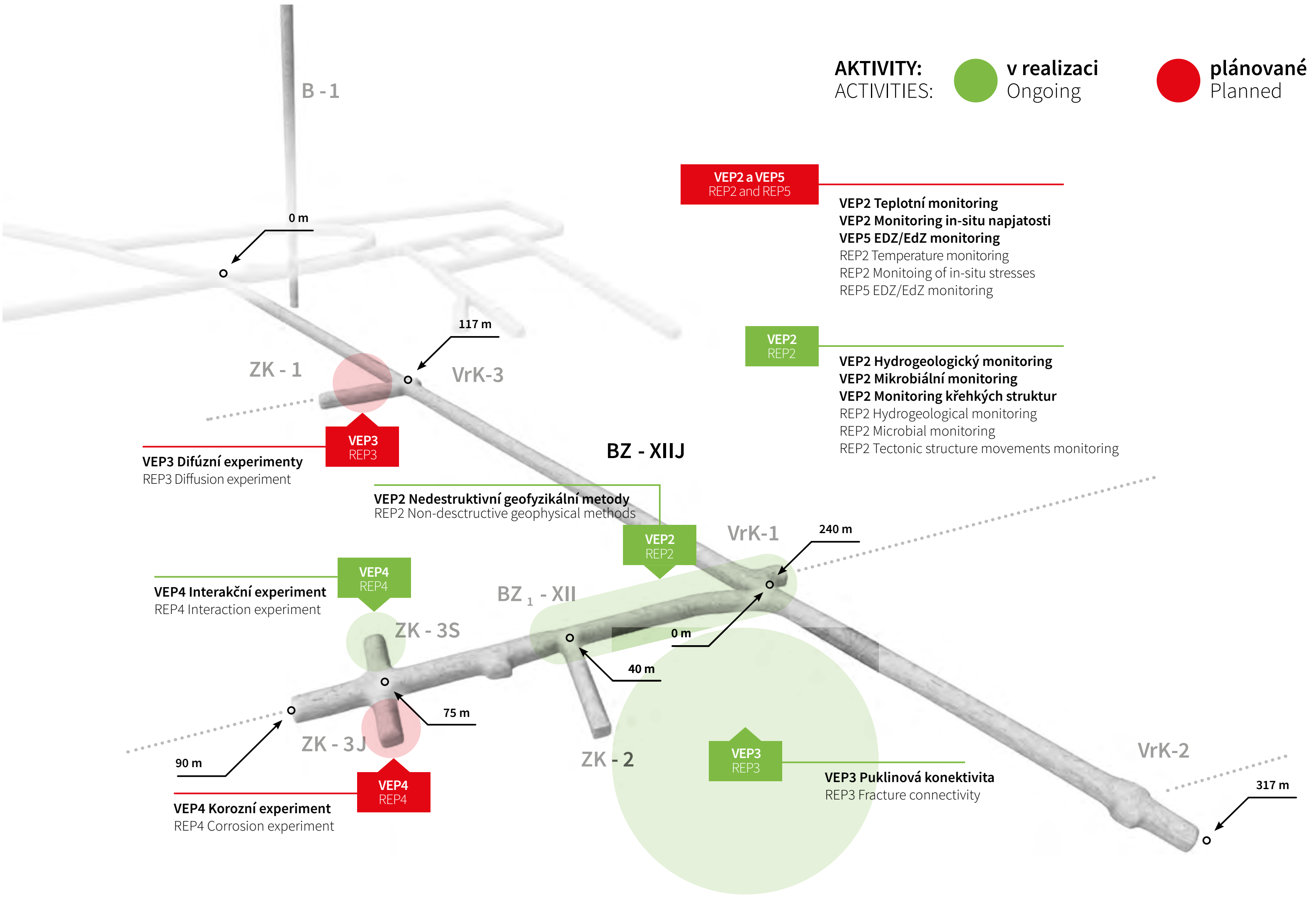
2015–2017: Characterisation stage

The aim of this stage was to compile a description of the rock environment for the emplacement of individual experiments and to obtain unique data concerning the opening of the rock massif as a result of excavation activities. The following areas were subjected to research: the geological structure, geotechnical properties, hydrogeological properties, seismicity and the transport properties of rock. The various outputs of this stage included the creation of a geological and geomechanical model of the Bukov facility. This stage also included the compilation of a description of the development of selected parameters of the rock environment with depth such as the composition and age of the groundwater and the quality of the rock massif.

Since 2017: Experimental stage

The experimental programme commenced following the conclusion of the characterisation stage and includes a broad range of activities related to the design and development of the future DGR.

Map of the facility



Experimental programme

The Research and Experimental Programme (REP) was defined according to the actual state of the rock environment while taking into account SÚRAO's research requirements and the opportunities offered by the Bukov URF rock environment. Experimentation concerned the following areas:

REP 1 – Characterisation and compilation of geoscientific models of the rock environment

This research area includes activities focusing on the collection of descriptive geological data, its database storage and subsequent interpretation in the form of 3D models and the development of general methods for the compilation of descriptions of the rock environment. This research commenced during the construction stage as part of the extensive Complex Geological Characterisation of the Bukov URF project. Currently, the Data Acquisition from the Deep Horizons of the Rožná Mine project is underway. The Rožná I mine provides a unique opportunity for obtaining data from various depths to a maximum depth of 1,200 m below the surface. The research includes the gathering of data via the conducting of geological surveys both on the surface of the site and various levels of the mine, which is then unified and applied to the compilation of 3D geological, hydrogeological and geomechanical models of the whole of the Bukov complex.

REP 2 – Long-term monitoring of the rock environment

This research area includes the testing and development of methods for the long-term monitoring of various processes that will occur in the rock environment at depths corresponding to that of the future DGR. The benefit of this research lies in the potential for the estimation of the extent of the process parameters, which will be important in terms of compiling a description of the DGR site and the evaluation of its long-term stability.

The following projects are currently underway:

- Microbiological screening of the Bukov URF and the Rožná I mine.
- Hydrogeological and hydrochemical monitoring of the groundwater and mine water in the Bukov URF.
- Monitoring of the brittle structure activity of the Bukov URF and the Rožná I mine.
- Long-term monitoring of the rock massif of the Bukov URF via non-destructive geophysical methods.

A number of projects focusing for example on the monitoring of temperature at various depths below the surface and seismic and in-situ stress conditions are in the preparatory phase.

REP 3 – Groundwater flow and the transport of radionuclides

This experimental cycle concerns the research of groundwater flow and radionuclide transport in the fractured DGR rock environment including the testing and verification of modelling tools. A number of projects are in the preparatory stage concerned with forming an understanding of the advective transport of substances in the fracture systems of crystalline rocks and the research of diffusion transport processes from fractures into the intact rock matrix. The research will include the establishment of a network of test boreholes equipped with multi-packers for the conducting of hydraulic and tracer tests in a selected rock block within the Bukov URF. All the tests will be accompanied by the compilation of models that will allow for the refinement of the geological and hydrogeological model of the block of interest, which will then be used for the development of modelling tools and the simulation of the tests performed.

REP 4 – DGR engineered barriers

Research in this area concerns the verification of the characteristics of the materials used in the disposal system and waste disposal package (WDP) technologies. The aim is to determine the rate of their degradation and mutual interactions under real DGR conditions. The In-situ interaction physical models in the Bukov URF project is currently underway concerning the study of interactions between the various DGR engineered barrier materials, and a project concerning the research of the corrosion resistance of candidate WDP materials in a rock environment and the effect of the corrosion of these materials on the properties of bentonite is in the preparatory stage.

REP 5 - Influence of the construction of the DGR underground workings on the rock environment

This experimental cycle concerns principally the compilation of a description of the extent and character of excavation damage zones (EDZ) and excavation disturbed zones (EdZ) created via the construction of the DGR underground complex. A pilot project on this theme was conducted during the construction of the Bukov URF (The Creation and Monitoring of EDZ during the Construction of the Bukov URF project), the aim of which was to obtain the data necessary in terms of the creation and development of EDZs and the rock vault in connection with the construction of the underground complex. Knowledge of the behaviour of EDZs and rock vaults at depth is important in that it enables the accurate prediction of the impact of mining techniques on the creation and development of EDZs and the optimisation of the technical approach. A more extensive project concerning this issue is currently in the preparatory stage.

REP 6 - Technological procedures concerning DGR construction

The construction of the future DGR will require the application of certain technological procedures which require special methodologies that are not applied to standard commercial excavation activities, i.e. special drill and blast and drilling procedures. Research in this area will, therefore, focus on the development of new construction methods for the construction of underground workings in terms of the optimisation of both time and financial considerations.

REP 7 – Demonstration experiments

The research will concern the conducting of complex experiments aimed at the testing of the behaviour of various elements of the disposal system at the real scale and under conditions corresponding to those of the future DGR. Experimentation will prioritise the testing of waste handling technologies, the construction of experimental models and the monitoring of processes.

Research projects

Complex geological characterisation of the Bukov URF

2013–2017

Research institutions:
Czech Geological Survey;
Institute of Geonics, Czech Academy of Sciences;
ÚJV Řež, a. s.;
SG Geotechnika, a. s.

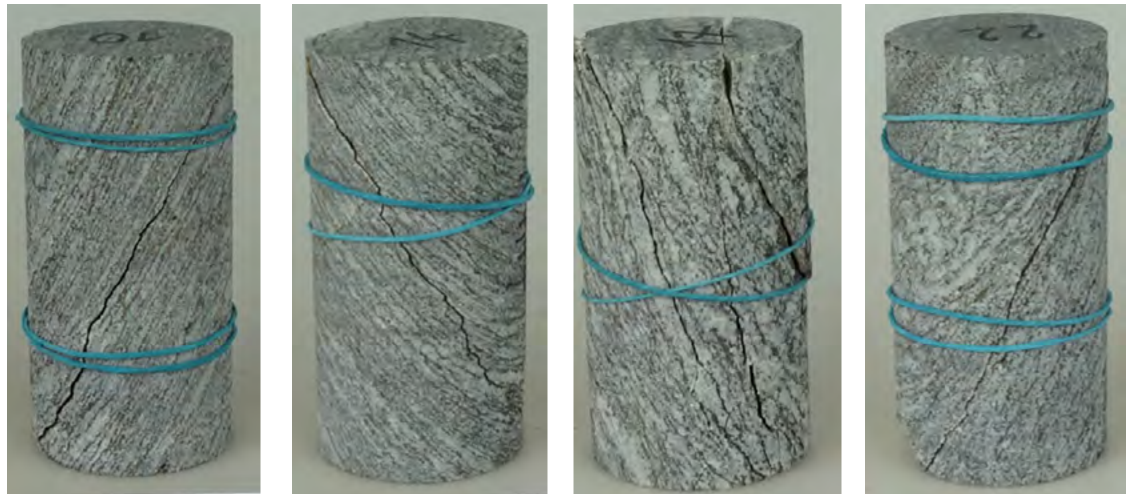
The research took the form of a subproject that formed part of the Research Support for the Safety Assessment of the Deep Geological Repository programme. The aim of the project was to compile a multidisciplinary assessment of the rock environment of the Bukov URF and the Rožná I mine. The research was conducted by four institutions and included the determination of the complex geological, petrological and petrophysical characteristics, the basic hydrogeological parameters of the groundwater, spectral analysis of borehole cores and seismic monitoring, the determination of the rock transport characteristics and the analysis of the geomechanical and geotechnical parameters of the rock massif. A 3D structural-geological and geomechanical model of the Bukov URF was subsequently created on the basis of the integration of the resulting complex set of geological data.

The research provided the comprehensive data necessary for the subsequent conducting of experiments concerning the long-term safety and technical feasibility of the future DGR. Moreover, the research also allowed for the gathering of valuable data which is only available shortly after the opening of the rock massif.

Goodman Jack device for the measurement of rock deformation properties

Selected results:

- Geological structure – metamorphic rocks with discontinuities and internal anisotropy (migmatitised biotite gneisses to stromatitic migmatites, amphibolite-biotite to biotite-amphibolite gneisses and amphibolites).
- Geotechnical properties
  - – high to very high strength according to the Bieniawski (1989) and Hoek and Brown (1997) classifications
  - – hydraulic conductivity of 10^{-11}–10^{-13} $m.s^{-1}$; gas permeability: 10^{-18}–10^{-22} m^2
  - – RQD index: high variability, 70-80% on average, in tectonic zone areas <50%; areas without tectonic zones 90-100%
  - – Goodman Jack deformation modulus: 15–20 GPa
  - – in-situ stress determined by means of hydraulic fracturing methods and conical strain gauge probe measurements in boreholes (values verified by means of the reverse analysis of convergence measurements): max. horizontal stress 16.5 - 31 MPa, min. horizontal stress 10 - 17 MPa
  - – convergence measurements: workings with a profile (area) of 9.2 m2, average values of convergence of -1.5 mm (with maxima of approx. -2.5 mm); profile of 14.5 m2, average values of convergence of -3.0 mm (with maxima of approx. -6.0 mm).
- Hydrogeological properties
  - – the $CaHCO_3$-type water in the Bukov URF shows signs of deep circulation
  - – mixture of waters aged 200–7000 years.
- Seismicity – the Bukov URF is located in a seismically stable environment with no indications of technical or other seismicity.
- Transport properties of the rocks – the diffusion and sorption of radionuclides revealed the low level of radionuclide mobility in the rock.



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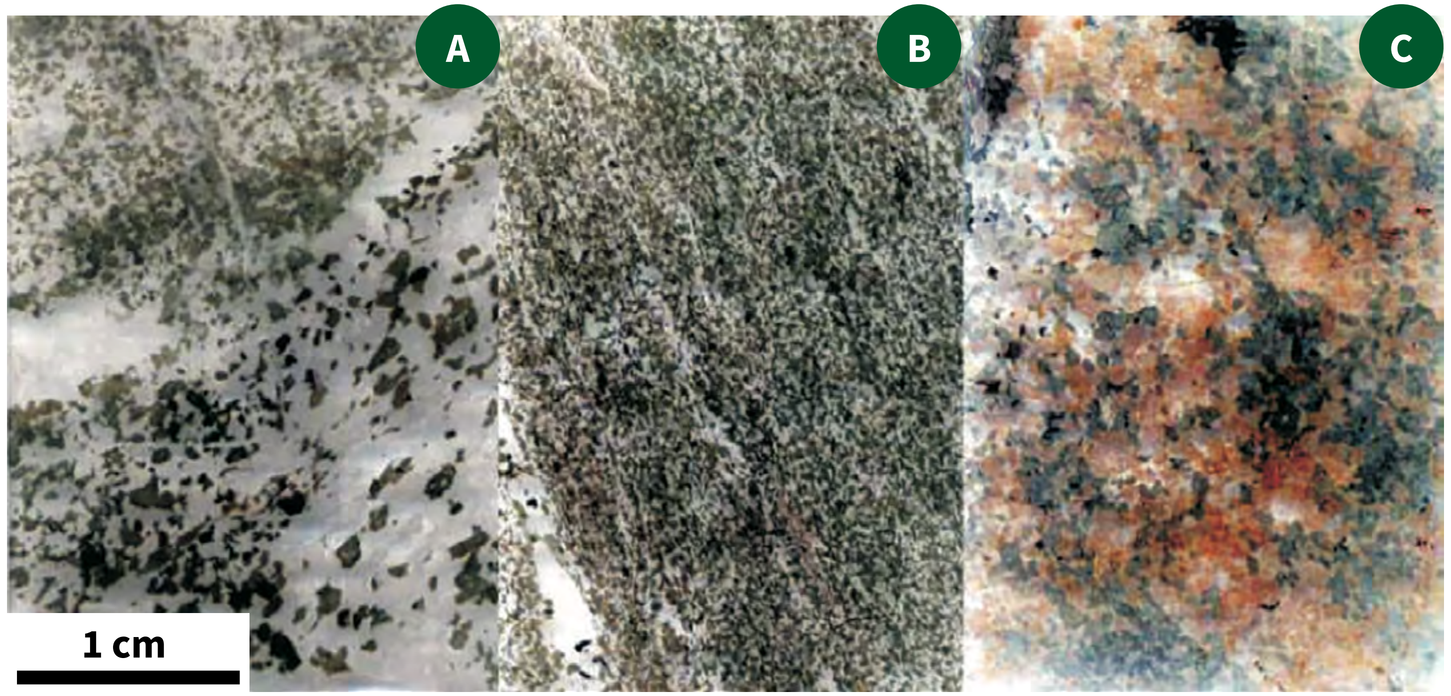
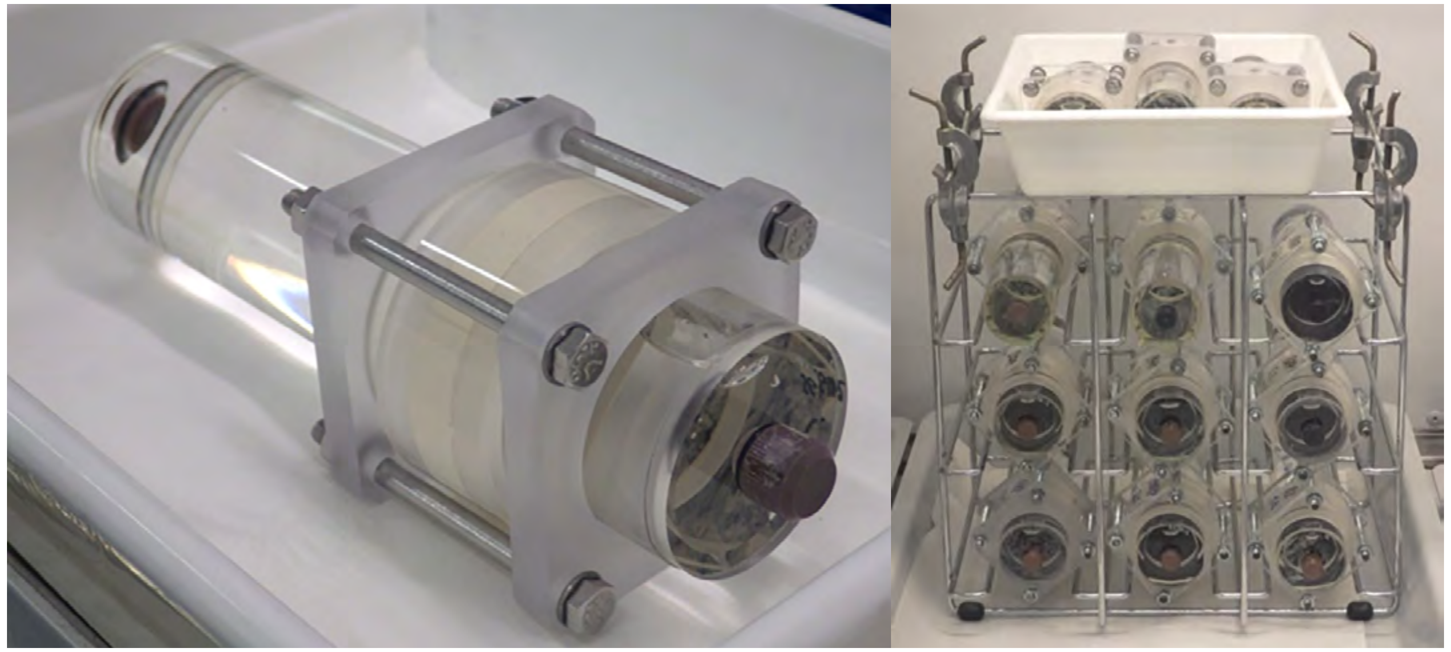
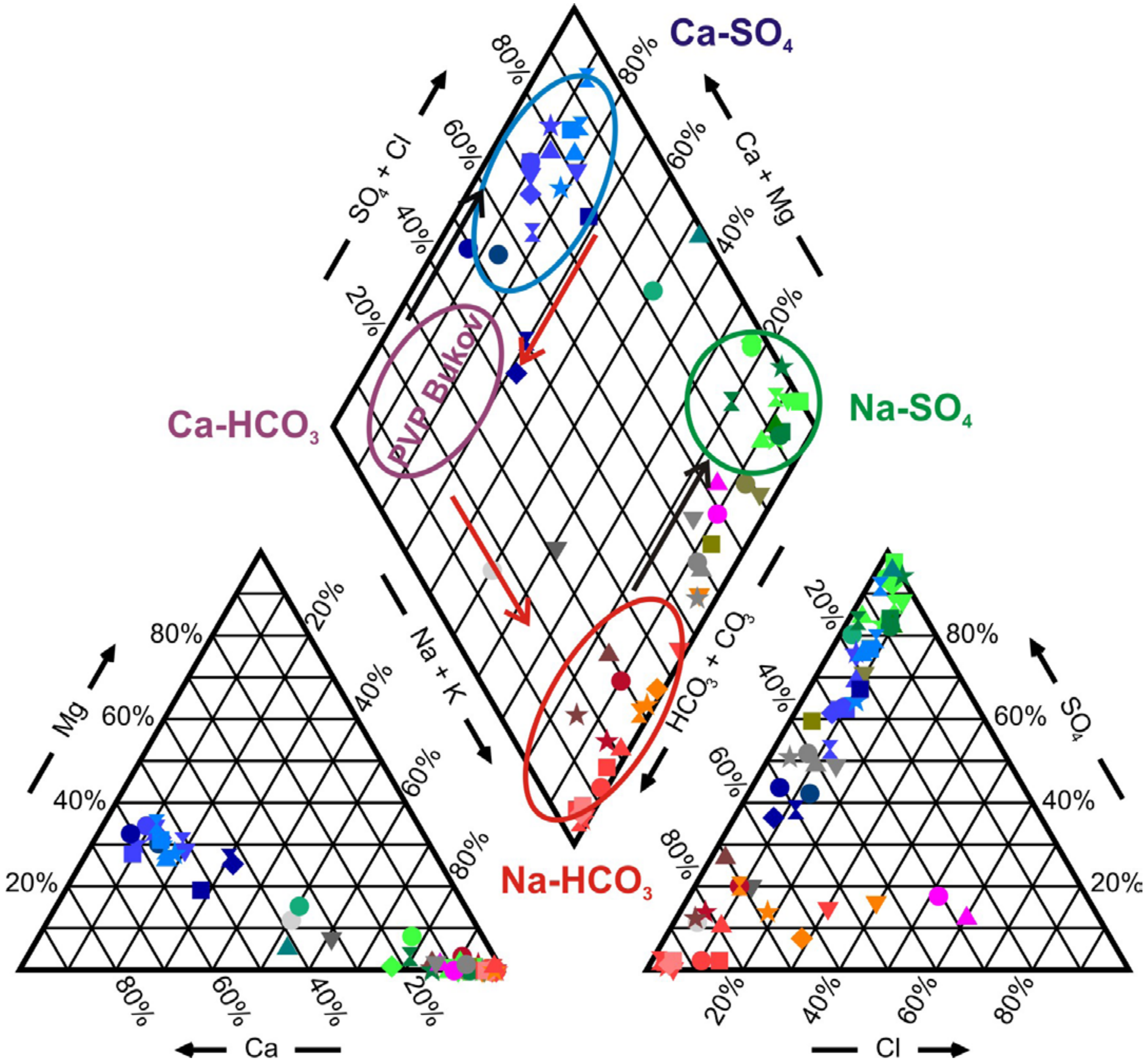
Demonstration of the failure of migmatite samples following strength testing



Examples of rock profiles from the Bukov URF. Textural differences between the dominant types of amphibolites: A – migmatised amphibolite, B – amphibolite, C – hydro-thermally altered amphibolite



Diffusion cell at ÚJV Řež for penetration diffusion experiments and the placement of diffusion cells during an experiment



Piper diagram of the composition of groundwater in the Rožná I mine showing the basic water types and development trends. Red arrows – natural changes in the groundwater composition with increasing depth, black arrows – changes in the chemical composition due to oxidation processes at work in the mine

Creation and monitoring of EDZs during the construction of the Bukov URF

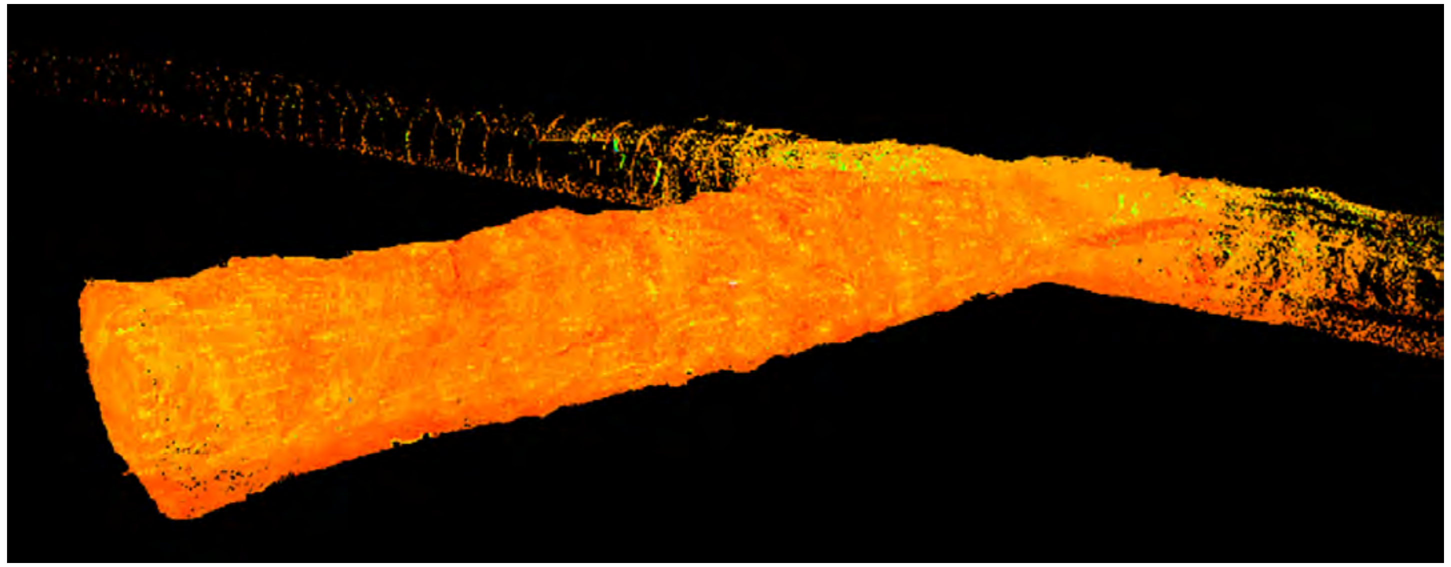
2015–2018

Research institutions:
Institute of Geonics, Czech Academy of Sciences;
Geotest, a. s.

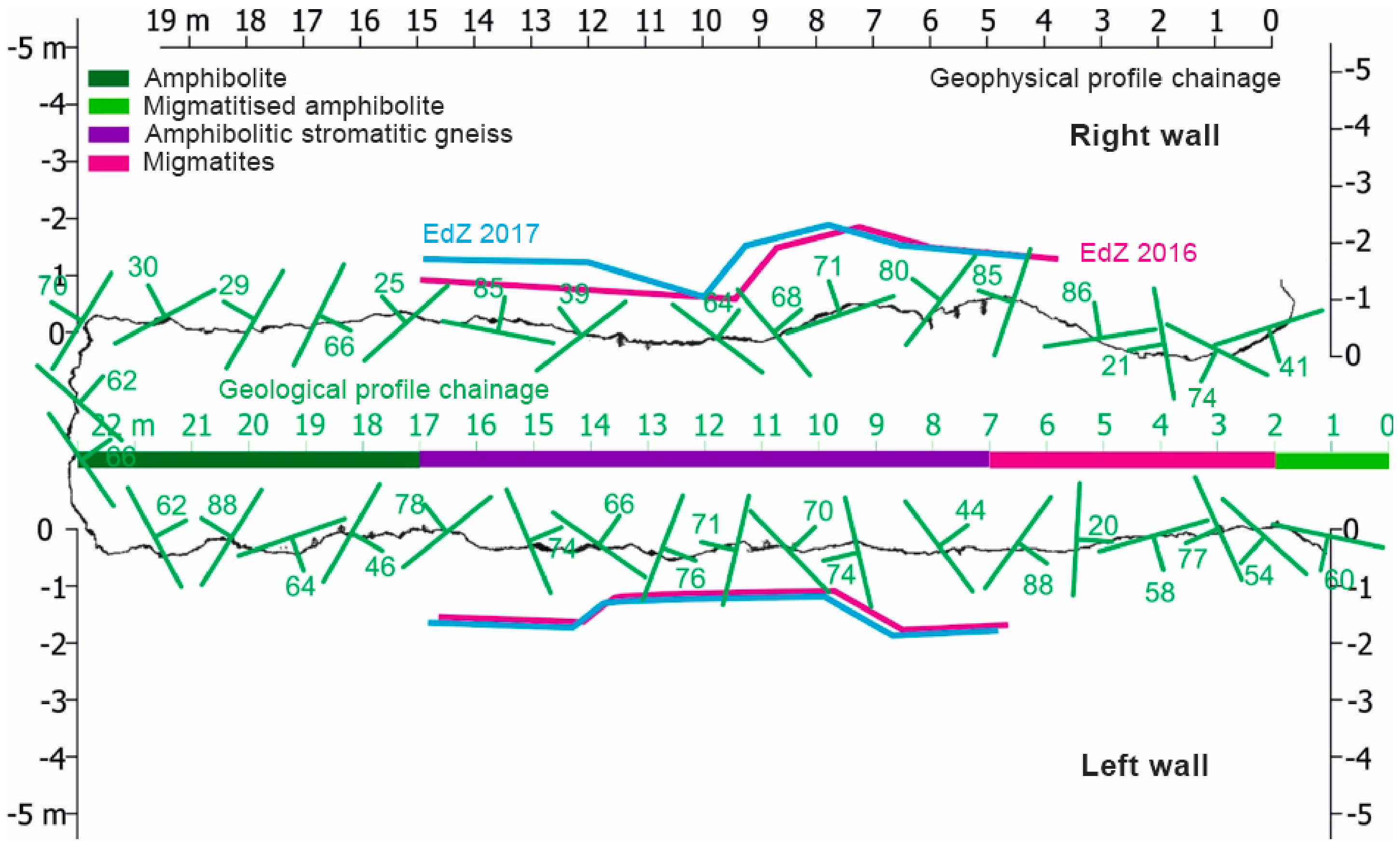
The aim of the project was to obtain the data necessary from the viewpoint of the origin and development of the excavation damaged zones (EDZ) and excavation disturbed zones (EdZ) of the underground workings and the rock vault. Such zones were described via the recording of both geophysical and in-situ stress measurements. The project provided valuable information on the development of such zones in various rock environments when employing a range of underground construction technologies. The project included the compilation of a 3D model of the Bukov URF using laser scanning data and the creation of a mathematical model of the stress field.

Conical strain gauge probes installed in boreholes drilled in the BZ_1-XII tunnel and other parts of the Bukov URF were used to monitor stress changes during the excavation phase. The results confirmed the expected reactions to the excavation process; the most significant changes in stress were recorded by those probes nearest to the excavation zones. Long-term monitoring revealed that a gradual redistribution of stress continues long after the conclusion of active intervention in the rock massif (even with consideration to one-year intervals).

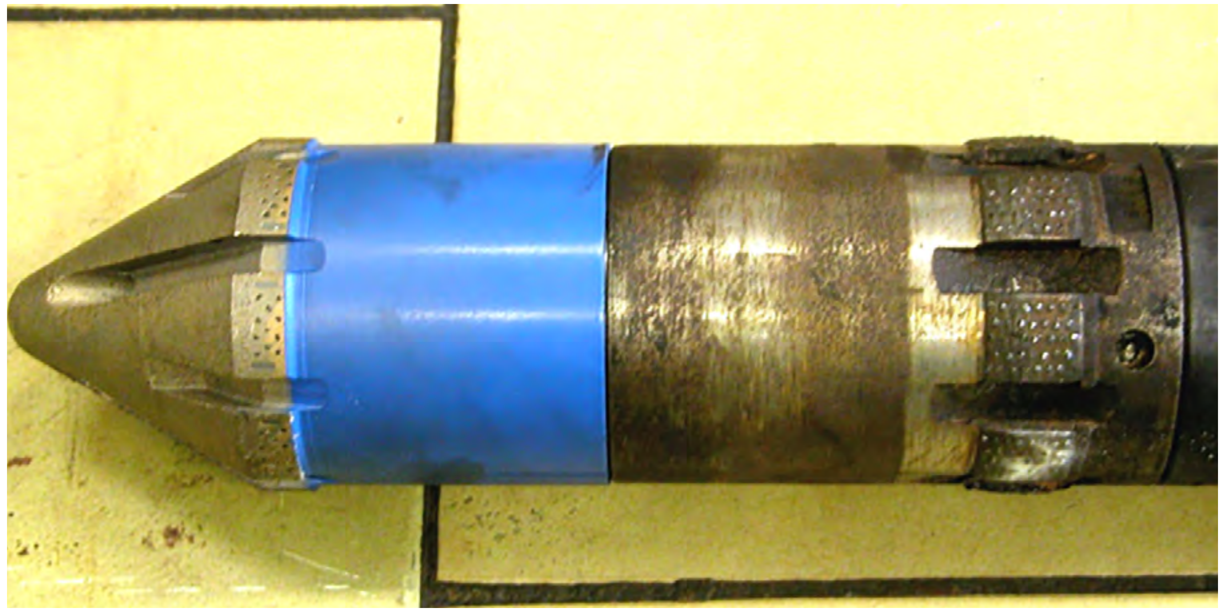
Electrical resistivity tomography (ERT) and seismic tomography methods were applied repeatedly in selected areas aimed at the detection of EDZs and EdZs. Based on seismic measurements taken in the main access crosscut, which was excavated using the conventional method, the EDZ range was estimated to be up to 1.5 m and the EdZ from 3 to 5 m. By applying the ERT method in the main crosscut, measured resistance changes indicated a boundary at depths of 4 to 6 m from the gallery surface, i.e. the stress redistribution region. Conversely, with respect to the ZK-1 experimental chamber at a location where the smooth excavation method was applied, the boundary was determined at depths of just 0.75 to 1.5 m.



Laser scanning image – ZK-1 chamber



ERT measurement results – interpretation of the development of the EdZ in the ZK-1 chamber



Drill bit for the adjustment of the bottom of the borehole for the installation of conical strain gauge probes


0m

Microbial screening of the Bukov URF and the Rožná mine

2017–2019

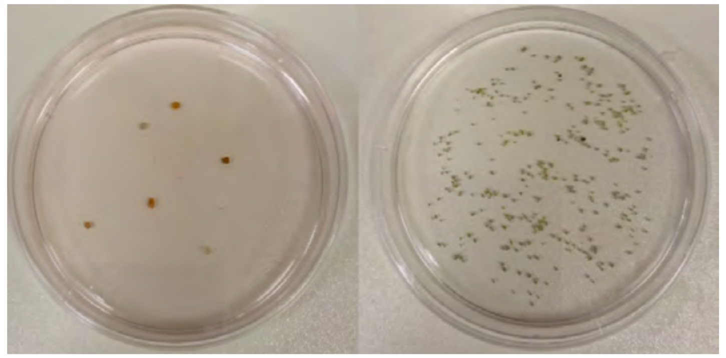
Research institution:
Technical University of Liberec, Institute for Nano-materials, Advanced Technologies and Innovation

One of the most important requirements concerning the materials used for the DGR engineered barriers is long-term durability, which may be affected by the presence of microorganisms that evolve as the result of human activity. In order to assess gradual colonisation or, conversely, reductions in microbial settlements it is necessary to monitor this phenomenon over the long term. In addition to long-term trends, which can only be observed over a period of several years, seasonal fluctuations may also exert a developmental impact. Fluctuations in temperature, chemical composition and the local water regime may result in changes in terms of microbial settlement.

The project included the analysis of water and microbial growth samples taken from the 12th level (the Bukov URF and other parts of the mine) and the 24th level of the mine. A passive sampling system was developed for the extraction of microbial biomass from flooded horizontal boreholes. The system included a device for the sealing of the boreholes and a chamber equipped with a filter for capturing the water that exited from the boreholes.

Molecular biological methods (principally the amplicon sequencing of the 16S rRNA and qPCR regions) were employed for the determination of microbial diversity supplemented by cultivation procedures for some of the samples. Emphasis was placed particularly on capturing the functional diversity of the various microbial communities. The most abundant functional groups included microorganisms capable of oxidising organic substances and iron and sulphur compounds.

The project focused on the identification of taxa that were present in the rock environment prior to human intervention and the identification of taxa that were introduced via anthropogenic activity. The project included the identification of those critical species capable of influencing the corrosion of the materials that will make up the waste disposal package. The project served for obtaining initial data on microbial settlement, based on which recommendations were presented concerning future research including the long-term monitoring of the site.



Examples of cultivated microorganisms

The collection of microbial mats and placement in a sterile test tube

Monitoring of the activity of brittle structures in the Bukov URF and the Rožná mine

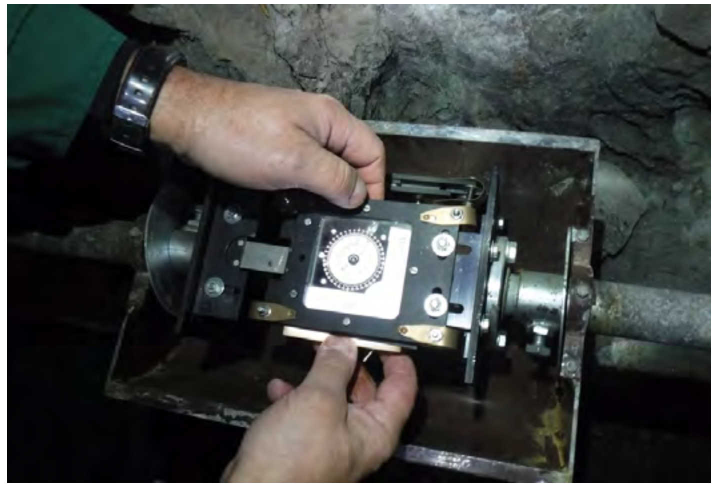
2018–2022

Research institution:
Institute of Rock Structures and Mechanics (IRSM), Czech Academy of Sciences

The aim of the project is to acquire knowledge on the movements of brittle structures in crystalline rocks at DGR depth. The research involves the construction of a monitoring network that will provide time series data on the behaviour of various generations of fragile tectonic structures including representative structure generations at the fault zone-fault-fracture zone-fracture scales.

A 3D TM-71 optical-mechanical extensometer is being used to measure the movements of brittle structures. The TM-71 device, developed by the IRSM, features a very high resolution compared to other slow-motion monitoring techniques and is capable of measuring displacements in all three directions while rotating and boasts a degree of accuracy of up to 0.001 mm. The measuring device utilises the optical interference phenomenon involving the observation and interpretation of the mutual displacements of spirals on a pair of overlapping slides.

Suitable structures of various scales with differing orientations to the main stress directions were selected for the installation of the extensometers in the Bukov URF itself. In addition, the movements will be monitored of two structures on the 24th level and one structure located on the 20th level near the so-called “first zone”. The extensometers are mounted on steel brackets fixed into the rock massif, and bridge the rock structures under observation. The meters located in the Bukov URF are connected to the data network, while the others are connected to automatic data loggers.



Detail of an extensometer on the 24th level of the mine

Installation of extensometer mounting brackets in the BZ-XIIJ crosscut

Hydrogeological and hydrochemical monitoring of the groundwater and mine water in the Bukov URF

2018–2023

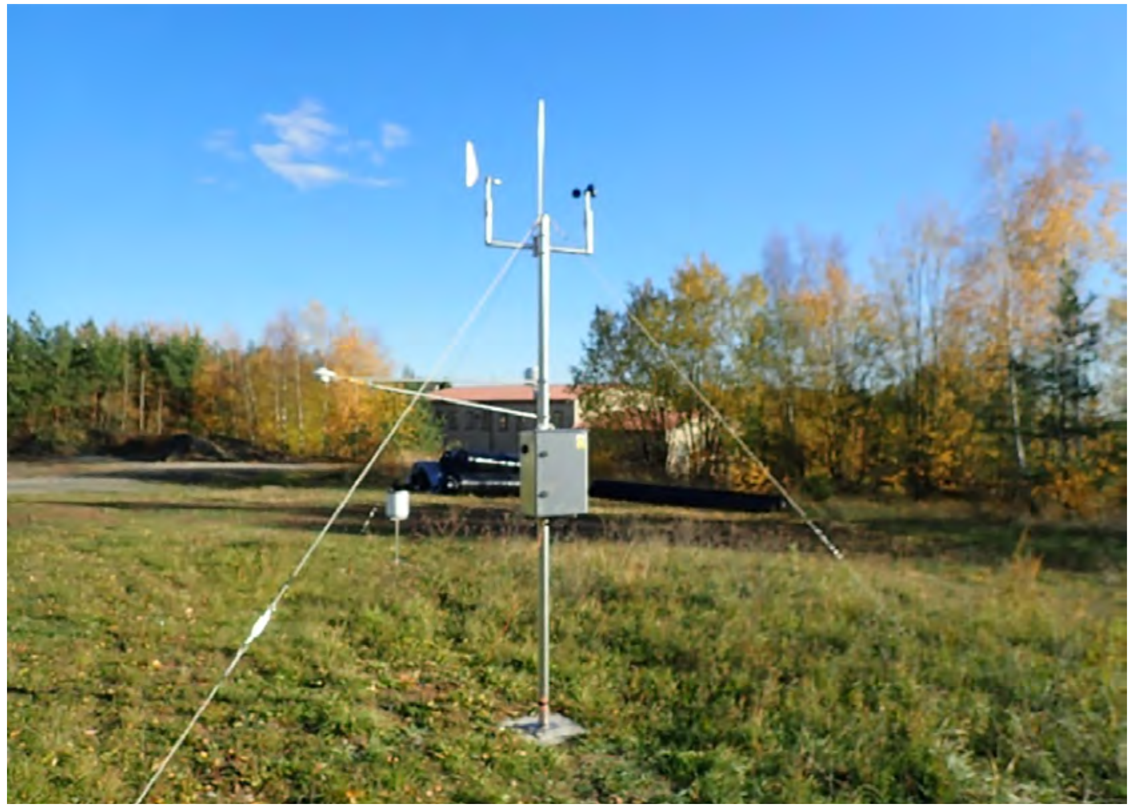
Research institutions:
Geotest, a. s.;
KOCMAN Envimonitoring, s. r. o.

The aim of the hydrogeological research underway in the Bukov URF and its wider surroundings is to obtain information on the character of both shallow and deep circulation groundwater and the qualitative and quantitative parameters thereof in terms of time and spatial characteristics. The research also concerns the assessment of the interrelationships between various water types and the characterisation of the environments in which they formed, flow patterns and accumulation.

Hydrogeological research has been underway at the Bukov URF since 2015, when hydrogeological research and mapping commenced in connection with the characterisation of the site during the construction phase. Research is also underway of levels other than that of the Bukov URF, i.e. to a depth of 1,200 m (24th level). The data obtained from the underground complex is being supplemented with data obtained from surface measurements.

The project included the detailed description of the hydrogeological monitoring network installed during the construction phase, the installation of new observation points and the automation of the operation of the network so as to allow for the long-term monitoring of all the flows of water into the laboratory and on the surface in the vicinity of the Bukov URF including the observation of meteorological phenomena.

Further work will include the conducting of hydrodynamic tests in boreholes in order to determine the hydraulic parameters of the rock massif. In summary, the research is aimed at gaining a thorough understanding of groundwater flow patterns in the area under investigation.



Meteorological station above the B-1 shaft

Original and new water collection points on the surface of the site

System for the measurement of water inflows to the Bukov URF employing tilting vessels

Obtaining data from the deep horizons of the Rožná mine

2017–2020

Research institutions:
Czech Geological Survey (project coordinator);
ÚJV Řež, a. s.;
Institute of Geonics, Czech Academy of Sciences;
Masaryk University;
SG Geotechnika, a. s.;
INSET, s. r. o.;
DIAMO, s. p.

The aim of the project is to obtain information on the spatial distribution of the geological and geotechnical properties of the rock environment at various depths of the Rožná I mine. The research includes the assessment and reinterpretation of existing archived geological and tectonic information on the site, including the specific geological documentation of selected parts of the mine and the characterisation of selected geological structures that may be important from the point of view of the safety of the future DGR.

The R1 tectonic zone (the so-called "first zone") which is well developed at a depth of between 600 and 1,200 m was selected for the research, the aim of which is to determine the structural, geomechanical and geochemical parameters of the rock at various distances from this zone. Data is being obtained from monitoring stations located on levels 12, 18, 20, 21, 22 and 24 of the mine. Particular emphasis is being accorded to the documentation of elements of the fracture network, the results of which will be used to compile a DFN (Discrete Fracture Network) model. The range of the structural documentation is related to the realisation of in-situ geotechnical research and a laboratory research programme aimed at obtaining data and results that can be interpreted with respect to both the depth profile of the mine and localisation with concern to the structure of the R1 zone.

In total, more than 500 m of boreholes with a diameter of 76 mm were drilled for the determination of the geotechnical parameters of the rock and the taking of geophysical measurements. The research includes the determination of the deformation properties of the rock applying the Goodman Jack method and the determination of the stress state of the massif by means of the rock hydraulic fracturing method. Seismic tomography is also being applied for the determination of both the structural characteristics of the rock and the extent of rock failure in the vicinity of the fault structure. The project consists of an extensive laboratory research programme that includes the study of, for example, the rock petrography, the mineralogical research of the filling materials of significant faults, the geochemical characteristics of the rock, the physico-mechanical and geotechnical properties of the rock and the transport characteristics of the rock massif (diffusion and sorption experiments). In addition, large-scale samples (borehole cores with a diameter of 300 mm) are being extracted from the underground environment, from which intact samples are taken in the laboratory environment for analysis purposes.

The information obtained from this project will assist in expanding both the existing knowledge database and the scientific potential of the Bukov URF and will allow for the more reliable interpretation of the at-depth development of the geological parameters of the crystalline rocks of the Bohemian Massif.

Storage of core samples in the materials documentation archive

Rock samples extracted from fault zones on level 21 of the mine for the determination of mineralisation


1205

In-situ interaction physical models in the Bukov URF

2017–2022

Research institutions:
Faculty of Civil Engineering, Czech Technical University, Prague;
Czech Geological Survey;
ÚJV Řež, a. s.

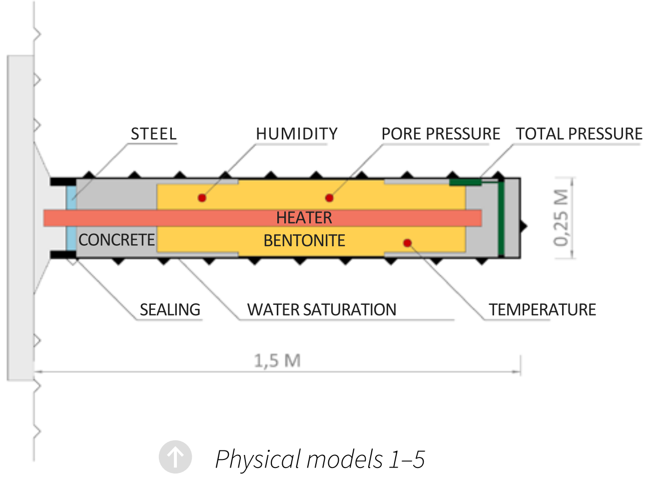
When designing the engineered barriers of DGRs, it is essential to form an understanding of the interaction of materials under real rock environment conditions. This project, known as the Interaction Experiment, concerns the study of interactions between various candidate DGR engineered barrier materials and their interaction with the rock environment and groundwater.

The project involves the emplacement of ten physical models in horizontal boreholes. Five of the models were designed for the study of interactions at ambient temperatures and the other five models for the study of interactions at elevated temperatures (4 heated to 100°C; 1 to 200°C). The heated models are cylindrical in shape with a diameter of 240 mm and a length of 1450 mm and have been fitted with a heater in their centres which are surrounded by a bentonite filling material. The models also include concrete components, a system for the artificial saturation of the models with local groundwater and instrumentation for monitoring the development of the saturation of the bentonite barrier and heat transfer. In order to allow for the investigation of various types of interactions, different combinations of materials were selected for each model, i.e. bentonite blocks with two different bulk densities, a pellet mix, standard concrete and low pH concrete, all of which, as well as the rock environment, were characterised in detail so as to allow for the study of changes that occur during experimentation.

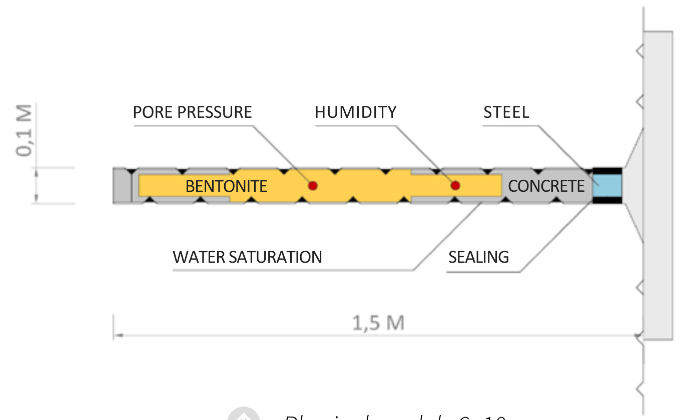
The physical models were installed at the beginning of 2019 and the loading procedure, which will continue for at least 3 years, has been underway since March. The experiment includes the monitoring of the development of temperature within the models and in the surrounding rock as well as of the saturation and bentonite swelling processes. While the results of the monitoring will provide basic information on the development of processes underway within the physical models, the analysis of samples extracted from the experiments following the long-term "disposal" of the models under in-situ conditions will be crucial in terms of the assessment of bentonite-concrete-rock interactions. Following the conclusion of the loading phase, the physical models will be removed from the boreholes and subjected to detailed analysis. The main outcome of the research will consist of a detailed description of the geochemical and mineralogical changes that have occurred with respect to the various materials.

Installation of a junction box and cabling

Physical model ready for emplacement in a borehole



Physical models 1–5



Physical models 6–10

Development of geotechnical and geophysical methods for obtaining 2D and 3D geological structure images
2017–2021

Research institutions:
GEOtest, a. s.;
Institute of Geonics, Czech Academy of Sciences; Technical University of Liberec, Institute for Nanomaterials, Advanced Technologies and Innovation

Commissioned by:
Ministry of Industry and Trade, FV - TRIOFV20294 programme, project FV20294

The aim of this external project concerns the testing and development of geotechnical and geophysical methods for obtaining information on the geological structure in directions perpendicular and longitudinal to the underground workings.

The project includes the testing of a wide range of geotechnical and physical measurement methods that are applied at the Bukov URF and other parts of the Rožná I mine. The main principle concerns the development of methods that can "see" inside the rock mass, including procedures where measurements taken on the surface of underground workings are sufficient, as well as methods that provide information on the properties of the rock between boreholes or between boreholes and the surface of underground workings. The research also includes an investigation of dependencies between individual physical and geotechnical properties and the development of software tools for the interpretation of the experimental data.

The geophysical methods being subjected to testing include terrestrial and borehole radar, seismic tomography and electrical resistivity tomography. Repeat measurements are taken at the Bukov URF with respect mainly to a rock block that is accessible from three sides, i.e. from the BZ-XIIJ, BZ_1-XII and ZK-2 corridors as well as in exploration boreholes that were drilled during the construction phase of the facility. A series of geotechnical measurements are also being taken in parallel with the geophysical measurements, the aim of which is to verify and interpret the results provided by the geophysical methods via the application of other established exploratory methods including, for example, stress state measurement methods using conical strain gauge probes and the oriented optical and acoustic inspection of the walls of boreholes.

Seismic measurement

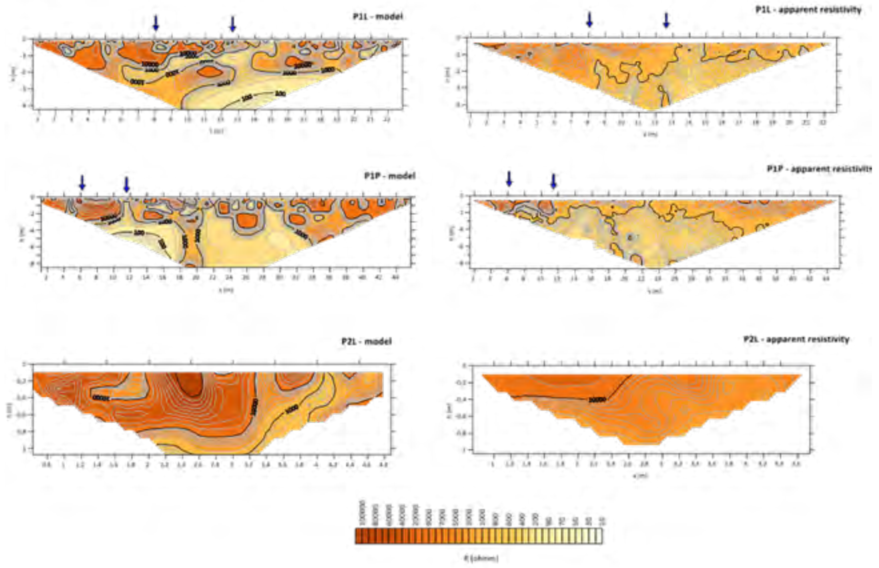
Long-term monitoring of the rock massif of the Bukov URF via non-destructive geophysical methods
2018–2022

Research institutions:
Faculty of Sciences, Charles University;
Technical University of Liberec, Institute for Nanomaterials, Advanced Technologies and Innovation

Geophysical research methods provide valuable information on the geological structure, properties and behaviour of the rock mass, including information on excavation damaged zones. The research concerns the development and optimisation of various geophysical methodologies and the characterisation of significant geological interfaces that are accessible only via indirect observation and the changes that occur over time.

The project concerns the installation and operation of the SGI1 system for the long-term monitoring of the rock massif via non-destructive geophysical methods. The SGI1 system makes use of the geoelectric and seismic properties of the massif and is intended for the long-term monitoring of changes in these properties in the immediate vicinity of mine workings. The system includes Electrical resistivity tomography (ERT) and seismic measurement equipment. The main BZ_1-XII laboratory crosscut was chosen for the installation of the equipment including the fixing of a series of ERT measurement electrodes on the walls of the crosscut and geophones for the measurement of seismicity. The electrodes on the left side of the crosscut were spaced at 1-metre intervals for the monitoring of the resistivity of the rock to depths in the order of decimetres and, on the opposite side of the crosscut, a system was installed with larger intervals between the electrodes for the monitoring of more deeply situated structures to depths of 10 to 15 m.

The installation of the system was completed in September 2019. The aim of the monitoring phase consists of the long-term monitoring of changes in the properties of the rock block of interest through the repeated application of radiation via seismic ultrasonic waves and the repeated measurement of apparent resistivity. Changes in the properties of the rock are expected, for example, as a result of other experiments that are planned in this area of the URF. The capacity of the SGI1 monitoring system also allows for the expansion of the measurement methodology to include the detection of nearby seismic sources created in the stress change phase via the identification of micro-cracks, which may subsequently lead to the formation of fracture structures.



Interpretation of the ERT measurement method results

Testing of seismic measurement equipment at the Bukov URF

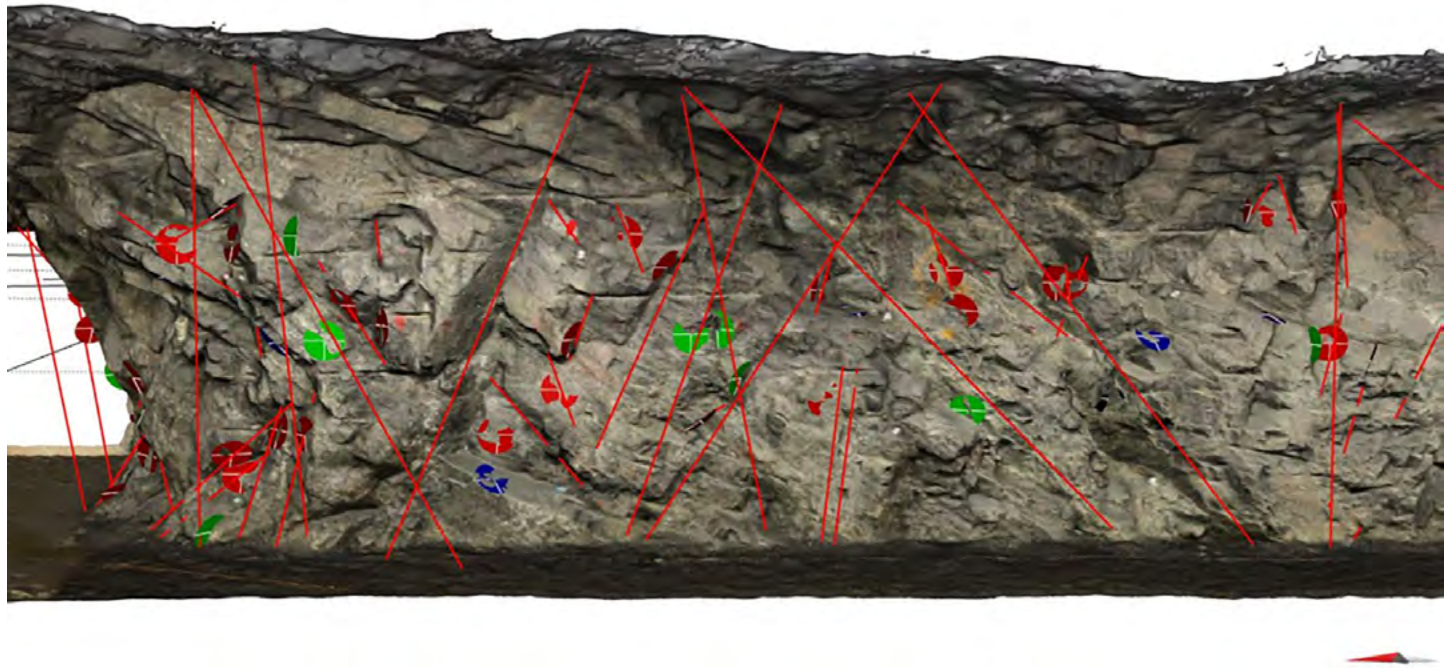
The research of fracture connectivity at the Bukov URF
2019–2024

Research institutions:
ÚJV Řež, a. s.;
Czech Geological Survey;
SG Geotechnika, a. s.;
PROGEO s.r.o.

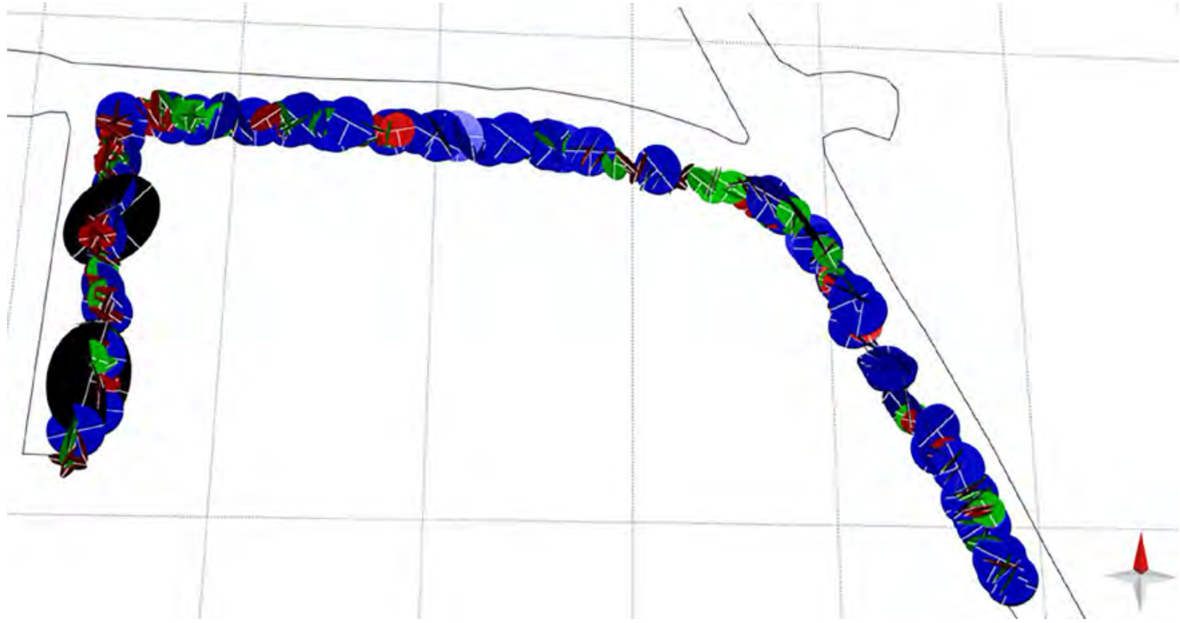
The main motivation for this project concerns the lack of information on the hydraulic properties of the rock mass from depths corresponding to those of the future Czech DGR – crystalline rocks of the Bohemian massif. The detailed description of the connectivity of fracture systems constitutes one of the most important contributions to forming an understanding of radionuclide transport processes.

The objectives of the project include acquisition of real data for the development of hydrogeological models for the modelling of water transport and the associated migration of radionuclides. The programme involves the geological/hydrogeological characterisation of a crystalline rock volume (including discrete water conducting features) at the metre to decametre scale with an emphasis on the description of the fracture connectivity of water conductive fractures. The main tool of the study is conducting of borehole hydraulic testing (single hole, cross-hole) and tracer tests and the subsequent mathematical simulation of the tests.

The in-situ activities involve the progressive drilling and testing of several boreholes that traverse the target rock mass block which is bordered by the BZ-XIIJ, BZ_1-XII and ZK-2 workings. One of the advantages of the experimental site consists of its accessibility from three sides which facilitated the compilation of a complete initial discrete fracture network model of the target block. The project is now in the characterization phase of the pilot 58m-long pilot borehole (S-27). All the boreholes will be characterised employing a number of methods (Optical and Acoustic Borehole Imaging, fluid logging, basic hydro-testing, etc.). The test boreholes will be subsequently equipped with multi-packer systems. The in-situ work will be accompanied by modelling, including the creation of a hydro-structural model of the studied rock block and the ongoing improvement of the model via the use of newly-acquired data from the boreholes. The final phase will involve the simulation of the tracer tests performed by means of the developed model.



Example of a photogrammetric model of the rock block of interest with marked orientations of measured structures



Representation of all measured and plotted structures in the studied block

Geochemical measurements in the pilot borehole S-27


10 m

URF Bukov

Conclusion

The first projects conducted in the context of the Bukov URF experimental programme concerned primarily the description and verification of the properties of, and the monitoring of processes underway within, the rock environment. These projects will provide the information necessary for the conducting of further research and the design of in-situ experiments that will reflect the specific needs of the DGR development programme.

Further information on the Bukov URF is available at: www.bukovurf.com

Information centres:
SÚRAO, Prague
Richard repository, Litoměřice
Bratrství repository, Jáchymov
Dukovany repository, Rouchovany

Project personnel – our team

Mgr. Lukáš Vondrovic, Ph.D.

He graduated from the Faculty of Sciences, Charles University in Prague with a master's degree in Structural Geology. He continued his doctoral studies in the same field, obtaining his PhD. in 2015.

He has been working at SÚRAO since 2014 firstly as head of the Geological Barrier Department and, since 2018, as head of the DGR Development Section. He was responsible for the design and construction and, subsequently, the characterisation stage of the Bukov URF. He is currently involved in the operational organisation and development of the URF and is responsible for the management of a number of research projects underway at the facility.

Ing. Jan Smutek, Ph.D.

He completed his master's degree in Environmental Engineering at the Faculty of Civil Engineering of the Czech Technical University in Prague, where he continued his doctoral studies in Physical and Materials Engineering, obtaining his PhD. in 2017.

He has been working at SÚRAO since 2017 as a specialist in the implementation of experiments. He is involved in the operational organisation of the Bukov URF and the preparation of the experimental plan and is also responsible for the overall coordination of research activities and the management of a number of projects underway at the facility.

Ing. Jaromír Augusta, Ph.D.

He completed his studies at the Faculty of Civil Engineering, Czech Technical University in Prague in the field of Construction and Transport Structures (specialising in Geotechnics) in 1994. In 2004 he obtained certification in geotechnics and in 2005 certification in the testing and diagnostics of buildings. In 2013 he defended his dissertation and was employed as an expert at the Czech Mining Office. He was subsequently appointed as an expert legal witness.

He has been involved for many years in issues surrounding underground constructions, project design and the assessment of geotechnical and blasting activities. He has been working for SÚRAO since 2015 as head of the Project and Engineering Department. He is responsible for activities related to the operation and development of the Bukov URF.

Ing. Marek Vencl

He graduated from the Technical University of Ostrava, Faculty of Mining and Geology in the field of Geological Engineering in 2012. He has been involved for several years in both Czech and international projects concerning hydrogeology and the modelling of THMC processes.

He has been working at SÚRAO since 2012 in the Geological Barrier Department. He is the manager of the hydrogeological monitoring project underway at the Bukov URF.

Mgr. Jozef Urík

He graduated from Charles University, Faculty of Sciences in the field of Applied Geophysics in 2005. He holds certification of professional competence in the field of geophysics (Ministry of the Environment) and he is also certified to work with closed sources of ionising radiation in the Czech Republic and Slovakia.

Prior to joining SÚRAO, he was involved primarily in geophysical projects focusing on the remediation of environmental burdens, hydrogeology and construction and engineering geology. At SÚRAO, where he has been working in the Geological Barrier Department since 2015, his main responsibility is the preparation and management of geophysical projects. He is also currently managing a number of projects involving the application of geophysical methods at the Bukov URF.

Ing. Markéta Dohnálková

She graduated from the Mining School of the Technical University of Ostrava, Faculty of Civil Engineering, in Geotechnics focusing on underground construction in 2009. She is involved primarily in technical projects concerning the design of the future DGR, in-situ experiments and international scientific projects.

She has worked for SÚRAO since 2009 as a senior technical development specialist in the DGR Development Section. She was involved in the preparation of the project for the construction of the Bukov URF and is currently working on the preparation of new research projects to be conducted at the facility.

Ing. Lucie Hausmannová, Ph.D.

She graduated from the Czech Technical University in Prague, Faculty of Civil Engineering in Environmental Engineering focusing on geotechnics in 2011, where she continued her doctorate studies in Physical and Materials Engineering, obtaining her PhD. in 2017. She has been involved for many years in the laboratory testing of clay materials (mainly bentonite) and has participated in a number of prestigious Czech and international scientific projects.

She has worked for SÚRAO since 2017 in the Engineered Barrier System Development Department, which she has led since early 2019. As a specialist in engineered barrier materials, she is closely involved in the management of the Interaction Experiment project at the Bukov URF.

Ing. Lucie Gorčica

She graduated from the Mining School of the Technical University of Ostrava, Faculty of Mining and Geology in Geological Engineering.

She has worked for SÚRAO in the Project and Engineering Department since 2014 and focuses principally on DGR design-related projects. She is responsible for the management of the materials documentation archive at the Bukov URF.

Mgr. Lucie Mareda

Ms. Mareda graduated with a master's degree in environmental geochemistry at the Faculty of Science of the Charles University in 2007.

Prior to joining SÚRAO, she worked for a private company where she focused on issues concerning geology and project management. She has worked at SÚRAO since 2020 as a technical specialist in the Geological Barriers Department. With respect to her work involving the Bukov URF, she participates in projects related to geological and geochemical issues and the documentation of geological research work.

Mgr. Ondrej Mikláš

Mr. Mikláš completed his studies in geology at the Faculty of Science of the Masaryk University in 2017.

Prior to joining SÚRAO, he worked on the creation of hydrogeological and transport mathematical models as part of a number of land reclamation projects. At SÚRAO, he has worked in the Repository Safety Department since 2018 as a safety analysis specialist addressing issues principally concerning hydrogeology, radionuclide transport and mathematical modelling.

www.bukovurf.com

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