Geophysical characterization (A2.1)

Baltic Sea Underground Innovation Network (BSUIN)

Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
BSUIN

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REPORT

A2.1 Geophysical characterization

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Content

1. BSUIN project introduction

The aim of the Baltic Sea Underground Innovation Network (hereinafter BSUIN) project is to make the underground laboratories (hereinafter ULs) in the Baltic Sea Region (BSR) more accessible for innovation, business development and science by improving available information about the ULs and their operation principles and opportunities therein. In addition, the BSUIN project aims to collect the safety protocols of each UL as well as experiences of their respective users to aid further development.

BSUIN is a collaboration project between 13 partners from eight BSR countries. Besides project partners 17 associated partners contribute for achieving the project goals. The BSUIN project is participated by six ULs from the BSR area. Each of the ULs will be characterized and presented to potential customers in order to attract developing innovative activities and effectively activate use of those laboratories. These six underground laboratories by name are:

1. Callio Lab, Pyhäsalmi mine, Finland
2. Äspö Hard Rock Laboratory, Oskarshamn, Sweden
3. Reiche Zeche, TU Freiberg Research and Education mine, Germany
4. Lab development by KGHM Cuprum R&D centre, Poland
5. Khlopin Radium Institute Underground Laboratory, Russia
6. Ruskeala Mountain Park[1], Russia

The main outcome of the project is a sustainable network organization, which will disseminate technical, marketing, operational quality, training and other information about the BSR ULs.

The BSUIN project is funded by Interreg Baltic Sea funding cooperation. Its duration is 36 months with a total budget of 3.4 M€.

[1] The name Ruskeala Mining Park is used in some texts. Herein we will adopt the term "Ruskeala Mountain Park".

2. Content of present document

2.1 Document justification

This document is part of the Work Package (hereinafter WP) 2.1 output. The objective of WP2.1 is to characterize the ULs with geophysical methods. Aim is to give a geophysical description of each UL for the following reasons:

1. Make data of geophysical surveys visible in underground
2. Allow an access to geophysical data
3. Show possibilities for scientific underground measurements

2.2 Content description

For characterizing the underground laboratories a 2 stage questionnaire was sent to representatives of six ULs, namely to Callio Lab (Finland), Äspö Hard Rock Laboratory (Sweden), Reiche Zeche (Germany), KGHM Cuprum R&D centre (Poland), Khlopin Radium Institute Underground Laboratory (Russia), and Ruskeala Mountain Park (Russia).

At the first stage was mainly asked for geophysical surveys in or around the underground labs. Collected were the metadata of each known geophysical survey. So, the aim is not to make visible the results of the geophysics. Here were collected the metadata as survey methods, conditions and parameters.

At the second stage was asked additionally for geological, petrophysical and petrothermal conditions of the underground labs. Collected were known data of geological, petrophysical and petrothermal parameters. This data is mainly characterizing the rock conditions in each underground lab.

From these six ULs the answers differ from expanded information to no given information. For simplicity, the following short names are used when referring to them:

- Callio = Callio Lab (Finland)
- Äspö = Äspö Hard Rock Laboratory (Sweden)
- Reiche Zeche = Reiche Zeche Freiberg (Germany)
- Ruskeala = Ruskeala Mountain Park (Russia)
- Khlopin = Khlopin Radium Institute Underground Laboratory (Russia)

- Cuprum = Polkowice-Sieroszowice, Lab development by KGHM Cuprum R&D centre (Poland)

Table 1: Database given by BSUIN underground labs

Underground Lab	Geophysical data	Geological, petrophysical, geothermal data
Callio	yes	yes
Äspö	yes	yes
Reiche Zeche	yes	yes
Ruskeala	yes	no
Khlopin	no	no
Cuprum	yes	no

2.3 Conclusion of geophysical characterization

To collect information about the underground laboratories leads to new knowledge and understanding about the underground environment. This report will also give hints, opportunities and conclusions for the underground labs. Aim of the BSUIN network is to broaden the knowledge and learn form each other for own apllications.

3. Results of the questionnaires for ULs

3.1 Callio Lab Pyhäsalmi

The Pyhäsalmi Mine is the deepest base metal mine in Europe. Mainly zinc and copper but also pyrite are excavated from the volcanogenic massive sulphide ore deposit. Pyhäsalmi Mine is the oldest perating mine in Finland and also the deepest active hard rock mine in Europe with a depth of 1444 metres. The mining will end in 2021.

The Callio Lab was established for using the underground environment after completion of mining activities. The underground environment was opened for business and scientific usage within the Callio Lab. This lab is part of the Callio Pyhäjärvi concept, a multidisciplinary operating environment.

There are several underground labs. The Deep laboratory facility Lab 2 at a depth of 1.44 km is especially suited for particle physics experiments requiring low cosmic ray background. The vast tunnel network is very suitable for testing of mining and tunnelling equipment, especially at the levels 75 m in Lab 1, at 660 m In Lab 4 and at 990 m in Lab 3. Old maintenance levels at 400 metres provide also extensive space for research.

Geophysics

The geophysical mainly seismic investigations can be parted in two groups: geophysical surveys at the surface and surveys in underground.

Methods within seismics:

- Passive microseismics (surface and underground)
- Reflection seismics (surface)
- High resolution Seismics (surface)

The geophysical surveys measured in the underground are passive microseismic observations within the Microseismic monitoring network. From 2002 ongoing the active mining area is covered and also some key feature points.

At the surface seismic surveys of passive seismic monitoring, reflection seismics for FIRE (Finnish reflection experiment) and high resolution reflection seismics for ore exploration were realized.

Also various data from surface surveys for magnetic, topographic and geological maps and rock mechanic mapping reports were obtained.

Geology

The dominating main rocks are 3 different igneous rocks: Mafic and felsic volcanic rock, pegmatite. These rocks are briefly characterized:

- Mafic volcanic rock – fine grained dark rocks with minerals plagioclase and pyroxene
- Felsic volcanic rock - fine-grained, sodium-rich rhyolites with high SiO_2 content with minerals quartz and alkaline feldspar
- Pegmatite – coarse-grained pink-grey and white rocks (as veins) with minerals quartz and alkaline feldspar

Both volcanic rocks have a high RQD value from 90 up to 100, the pegmatite has also 90. Joints are mostly unaltered. Only in the mafic volcanic rock were 7 % of altered joints with fillings as chlorite, pyrrhotite and pyrite. (Reference 1)

Petrophysics

Densities of mafic volcanic rock is 2.97 g/cm^3, of felsic volcanic rock 2.66 g/cm^3 and of pegmatite 2.6 g/cm^3. The elastic moduli lies in the range from 64 to 81 GPa for all rocks, which assigns very stable rocks.

The Pegmatite shows no magnetic susceptibility. The volcanic rocks have low magnetic susceptibilities of 0.61 and 0.8 because quantities of paramagnetic minerals are small.

Felsic volcanic rocks have higher heat conductivity than mafic volcanic rocks as seen here in Pyhäsalmi (Reference 2) with 2.65 $Wm^{-1}K^{-1}$ for felsic and 1.85 $Wm^{-1}K^{-1}$ for mafic volcanic rock. Pegmatite has a higher heat conductivity with 2.87 $Wm^{-1}K^{-1}$ than the volcanic rocks.

The heat capacity shows a similar trend. (Reference 2)

A rock mechanical study of the deep part of the mine (deeper than 1 km) was the LAGUNA proposal. (Reference 3)

References

1. LAGUNA-LBNO, extended site investigations at Pyhäsalmi, Finland, Deliverable 7: Geological modelling

2. Clauser & Huenges, 1995: Thermal Conductivity of Rocks and Minerals. Rock Physics and Phase Relations, A Handbook of Physical Constants. AGU Reference Shelf 3: 105-126, American Geophysical Union, Washington.
3. LAGUNA-LBNO, extended site investigations at Pyhäsalmi, Finland, Deliverable 8: Rock mechanical modelling and analysis http://laguna.ethz.ch:8080/Plone/deliverables/laguna-lbno-site-investigations-deliverables/d7-geologicalmodelling/d7-geological-modelling/at_download/file

3.2 Äspö Hard Rock Laboratory

The Äspö Hard Rock Laboratory was established for the purpose of necessary underground investigations for the final repository for nuclear waste in Sweden. At the island Äspö an underground lab was built up for scientific experiment in the hard rock and also above for experiments of necessary materials and technics. The current use is for different methodological and technical development for final disposal of spent nuclear fuel in combination with the new use for projects such as environmental, geotechnics, geo-energy, material science and various technical development projects.

The depth of the Äspö Hard Rock Laboratory is from surface down to 460 metres. Most of the experiments are placed at the levels 420 and 450 metres depth. The owner is the Swedish Nuclear Fuel and Waste Management Co (SKB).

At Äspö Hard Rock Laboratory is established a broad range of specialised knowledge in geology, hydrogeology, geochemistry, groundwater chemistry, geophysics, rock mechanics, rock engineering and clay materials within scientific and technical experts at the Äspö Hard Rock Laboratory and in networks.

Additionaly, all data from SKB investigations and research activities are stored in SICADA (Site Characterization Database), which are available for researchers in active or future research acitivities.

Geophysics

A wide spectrum of geophysical surveys have been measured in the underground laboratory. These geophysical were mainly surveyed for the purpose of characterizing the hard rock but also for the suitability for the exploration of structures in the underground.

The mainly geophysical methods are seismics, electromagnetics and geoelectrics. In detail there a several kind of methods which has been examined for underground research experiments at Äspö Hard Rock Laboratory:

Methods within seismics:

- Cross-hole seismic tomography
- Cross-tunnel seismic tomography
- Reflection seismics
- VSP (Vertical Seismic Profile)
- Seismic monitoring after hydraulic fracturing

Methods within electromagnetics:

- RMT (Radiomagnetotelluric)
- CSMAT (Controlled-source audio-frequency magnetotellurics)
- VRP (Vertical radar profile)

Methods within geoelectrics:

- Cross-tunnel resistivity
- Cross-hole Mise-á-la-Masse
- Geoelectrical tomography

Geology

The rocks at Äspö HRL are classified as magmatic and plutonic rocks with two dominant crystalline rock types Äspö diorite and Ävrö granodiorite. These rocks are briefly characterized as:

- Äspö diorite (65 %) – is the most common rock with grey to reddish grey colour which is medium grained with large phenocrysts of K-feldspar. Diorite is a quartz monzodiorite to granodiorite, porphyritic.
- Ävro granodiorite (20 %) – is more bright and sometimes with more reddish colour than the Äspö diorite and also inferred to be younger as the diorite. The rock is more equigranular with a lower content of K-feldspar. Granodiorite is a granite to quartz monzodiorite, generally porphyritic.

- Granite (10 %) – is fine-grained and occurs typically as dikes. The granite is more fractured with many small, closely spaced fractures.
- Gabbroid-dioritoid (5 %) – is a mafic rock, equigranular and very dark, greenish or greyish black. This rock occurs as irregular, elongated bodies within the Äspö diorite and the Ävrö granodiorite.

The age of these quartz monzodiorites, granodiorites, granites, are in the order of 1.8 G years. Important subordinate rock types are dykes, veins, patches and minor bodies of fine-grained granite, pegmatite and composite intrusions.

The rocks at Äspö HRL have generally high RQD values from 75 up to 90 outside deformation zones and slightly lower in the fine-grained granites, but below 25 in parts of brittle deformation zones. Predominant fracture filling minerals are calcite, chlorite, epidote, prehnite and quartz. Frequently occurs reddening caused by oxidation along fracture walls. In the Simpevarp-Ävrö-Äspö area the regional structural framework is dominated by NE- to ENE-trending deformation zones, minor in NW-SE direction. (Reference 4)

Petrophysics

The densities of the Äspö diorite with 2.74 g/cm³ and of Ävrö granodiorite with 2.72 g/cm³ are very similar, the granite has a lower density of 2.66 g/cm³ and the gabbroid-dioritid a higher density of 2.9 g/cm³. The porosities of the hard rocks are small in the range of about 0.47 %, the gabbroid-dioritid has a very small porosity of 0.19 %. The elastic moduli lies in the range from 73 to 78 GPa for all rocks, which assigns very stable rocks. The compressional wave velocities of the rocks are around 6 km/s.

The rocks have high magnetic susceptibility anisotropies of $217 \cdot 10^{-6}$ up to $1290 \cdot 10^{-6}$ because of high quantities of paramagnetic minerals. So, all types of rock show a permanent magnetism measured as magnetic remanence. (Reference 4)

Granite has a higher heat conductivity with 3.69 $Wm^{-1}K^{-1}$ than the Äspö diorite and the Ävrö granodiorite with 2.88 $Wm^{-1}K^{-1}$. Gabbroid-dioritoid has in comparison a lower heat conductivity with 2.64 $Wm^{-1}K^{-1}$. The heat capacity shows a reverse similar trend. (Reference 5)

The formation water shows a temperature range from 9.7 °C to 17.8 °C with an average of 13.6 °C. In field measurements the pH is neutral to alkalescent and lies between 7 and 8.1. The electrical conductivity shows in the field high values up to 3.87 S/m. The Redox potential shows a reducing environment. (Reference 6)

References

4. Äspö HRL - Geoscientific evaluation 1997/5. Models based on site characterization 1965-1995. SKB TR-97-06
5. Thermal properties Laxemar SDM site Laxemar. SKB R-08-61
6. SICADA database

3.3 Reiche Zeche

The nowadays called Reiche Zeche Mine was founded as “Himmelfahrt Fundgrube” and was a consortium of multiple individual shafts in 1839 to enhance the production of silver in Freiberg. It was first closed in 1913 and handed over to Bergakademie Freiberg in 1919 for teaching purposes. In 1937 the mine was reactivated and once again in operation until 1969. In the year 1976 the shafts “Reiche Zeche” and “Alte Elisabeth” were finally handed over back to the University for research and teaching purposes.

Today many research institutions and partners from industry use the mine for the development of new technologies, production methods, new materials or to gain reference materials for their databases. In addition, universities use the mine in order to train their students practically in mining and surveying operations.

For the future the mine is intended to develop an European platform for enhancing mining techniques and education. Therefor it is planned to build up an access over a ramp and also to develop new underground rooms.

Geophysics

The mainly geophysical methods are seismic methods. In detail there a several kind of methods which has been examined for underground research experiments at several underground places:

Methods within seismics:

- High-resolution seismics

- Seismics
- Seismic tomography
- Seismology
- Microseismic monitoring after hydraulic fracturing

Methods within electromagnetics:

- TEM (Transient electromagnetics)
- GPR (Ground penetrating radar)

Other methods:

- Geoelectrics
- Borehole geoelectrics
- Gravimetry
- Magnetics
- Geothermal

Geology

In the Reiche Zeche mine the rock is gneiss named mainly as the Freiberg grey gneiss with ore veins. The Freiberg mine lies in a lead-zinc deposit.

In carboniferous to Permian and late Jurassic to tertiary periods ore veins have been created within the already existing gneiss in connection with the variscan and alpine orogeny. This gneiss is briefly characterized as:

- A biotite-plagioclase-gneiss and metagranite
- Veins have contents of the main minerals: Galena, Sphalerite, Pyrite, Arsenopyrite, Chalcopyrite, former silver ore and Quartz.

The gneiss has generally high RQD values from 90 to 100. Fault fillings are mineralized. In Reiche Zeche two fault systems existing. From the variscan orogenese a strike NNE-SSW with steep dip of 70° to 90° and ruffle faults with N-S strike and 25° to 30° W dip. From the alpine orogenese a strike WNW-ESE with steep dip and ruffle faults E-W. (Reference 7, 8)

Petrophysics

The density of the Freiberg gneiss is 2.68 g/cm³ and of the ores nearly 4.57 g/cm³. The porosity of the gneiss is very small in the range of about 0.01 to 0.02. The elastic moduli is about 83.9 GPa in parallel and 57.1 GPa perpendicular, which assigns a very stable rock. The compressional wave velocities of the gneiss are in the range from 4 to 6.3 km/s. Because of anisotropy of 0.81 (from perpendicular to parallel) due to foliation the compressional wave velocities are around 5.94 km/s in parallel and around 4.83 in perpendicular direction. In ore veins the compressional wave velocities are at 6.5 km/s. (Reference 8, 9)

The Freiberg gneiss has a heat conductivity of 2 $Wm^{-1}K^{-1}$ perpendicular to foliation and of 3.6 $Wm^{-1}K^{-1}$ parallel to foliation. The heat capacity shows values from 700 to 770 $J/kg^{-1}K^{-1}$ with an increase of 60 $J/kg^{-1}K^{-1}$ for water filled pores. The permeability is parallel to foliation higher with $0.11 – 0.16 \cdot 10^{-18}$ m².

The formation water shows a temperature range from 10.2 °C. In field measurements the pH is measured as neutral with values of 7. The electrical conductivity shows in the field low values up to 0.09 S/m. The formation water has low iron and manganese content. (Reference 10, 11)

References

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11. LfULG: http://www.geologie.sachsen.de/geothermische-karte-13914.html, geological service for Saxony

3.4 Ruskeala

Ruskeala is located in the Ruskeala area in the municipality of Sortavala in Russian Karelia. The Ruskeala Mining Park is located 25 km north of Sortavala and based around an old marble quarry with underground space. This quarry was developed first by former Finnish responsibilities. In this quarry facing stone and lime were mined. Since 2005, the quarry was revalued with a touristic context.

The underground part of Ruskeala consists of several galleries from a quarry lake to the underground area with cellars. The underground part, which is in operation today, includes the above-water part of two galleries and one hall with supporting pillars. The underwater part with several galleries is not in operation.The depth of Ruskeala mine is from surface at 0 down to 36 m. Most of experiments and full-scale demonstration tests are carried out at the first level in order to study the features and the stability of the massif around these galleries.

The Ruskeala UL was established for test, design and construction of touristic destinations in old lost quarries and mines. The current use is for different methodological and technical developments of the roof control, investigations of weak zones in order to risk management for visitors and environment and to conduct e.g. geotechnological and photogrammetry investigations of the underground space. The aim is to transfer the experience to other historic mines and quarries in the territory of Russian Federation.

In the future is planned to conduct microseismic studies of this massif and a monitoring of movements of the roof in the galleries and the hall with laser devices. In addition, tectonic and physical observations of the behavior of the array are planned to conduct. In addition to these studies, Ruskeala is planning a more detailed study of the microcracking of rocks in this area and the physical and mechanical characteristics of these rock.

No information about the geology and petropyhsical questionnaire was given. According to Ruskeala studies of the deposit was limited only to the accounting of geological reserves and the quality of ores while mining acitvities.

Geophysics

Within the BSUIN project Ruskeala has performed in the underground lab a geophysical survey including the following geophysical methods:

- Electrotomography
- Magnetic prospecting
- Natural electric field

These surveys were executed in combination of surface and underground galleries in order to explore the rock massif around the Ruskeala underground lab.

Geology

The dominant crystalline rock type in Ruskeala is marble, another known rock is lime. The age of these rocks is approximately 1.6 – 2.0 G years.

Petrophysics

The known rocks are marble as dominant crystalline rock type and also lime. Petrophysically parameters are not known.

References

12. Geophysical study of galleries Marble mine Ruskeala park (in russian)

3.5 Khlopin

The underground lab of Khlopin is located in St. Petersburg in an underground cellar in the near of two metro stations. This room in the underground lies in a depth from around 60 m. The cellar is encased by concrete and is laying in a sediment soil.

Measurements of Khlopin show that the laboratory is at a depth of 120 meters of a water equivalent which can vary because of of buildings aroundthe undergrpund lab.

In the Khlopin underground laboratory constantly measurements of tritium were taken. Additionaly three gamma-spectrometer complexes are installed with powerful protection against external background radiation.

No information about the geology and petropyhsical questionnaire was given.

Geophysics

The experiments in the underground lab are for research of tritium and gamma radiation.

Geology and Petrophysics

The sediment around the underground lab is called Cambrian clay.

3.6 KGHM Cuprum

The mines of KGHM Cuprum excavate copper and salt at different depth levels. KGHM Cuprum makes therefore scientific and technical investigations depending to mining activities. For the future KGHM Cuprum plans to establish an own underground lab. The data given is from geophysical monitoring which are standard methods in underground exploration for mining issues. Information about the geology and petrophysics were not given to the asked questionnaires.

In west-southern Poland near Polkowice and Lubin KGHM has three copper mines located in the copper belt. In two different depths are copper and salt deposits. These deposits lie from 650 down to 1300 metres depth with a lot of existing excavations. These excavations are accessible for underground investigations and technical purposes.

Geophysics

KGHM Cuprum has reported seismic methods for own underground investigations. The used methods within seismics are:

- High-resolution seismics
- Seismics

These surveys are placed in the tunnel or at the chamber walls. Both methods - seismics and high-resolution seismics - deploy an impulse for seismic investigation in the underground. The source for the impulses are aseismic tremors in the underground or blasting work for mining. There is a permanent seismic monitoring in underground for locating active structure zones in the underground.

Geology

The major rock types in the productive copper mine are: Below the copper-bearing ore a thin layer of quartzite sandstones precedes some 300 m thick layer of hard Rotliegendes sandstones. The productive level with copper-bearing ore is located at the depth from 900 to 1200 m. The ore is overlain by a thick dolomite layer with good quality. Upwards follows a rigid anhydrite strata of around 150 m thickness. Above them, salt rock and more than 300 m of Motley fine grain sandstone are deposited.

Petrophysics

The average rock mass compressive strength is about 140 MPa for the strata above the copper ore deposit, 50 MPa for the deposit layer and 30 MPa for the floor layer.

By the depth of the ore body the ability to accumulate strain energy by both the upper layer of anhydrites and the lower sandstone layer as well as highly variable tectonic conditions constitute grounds for generating violent seismicity and rockbursts.

3.7 Metadata

In this chapter a list for metadata keyword will be given separated by the topics geophysics, geology and petrophysics. All these metadata keywords were asked to the BSUIN underground labs in the questionnaires. For the surpose of sharing data it is necessary to know the data which are accessible at each underground lab.

Table 2: Metadata of geoscientific datasets at underground labs

Metadata Geophysics	**Metadata Geology**	**Metadata Geothermics**
Underground Lab	Rock	Heat conductivity
Owner	Rock type description	Heat capacity
Survey identification number	Minerals	
Geophysical method	Anisotropy	
Dataformat	Fault orientation	
Survey coordinates	Fault filling	
Source	RQD-value	
Source parameters	Rock Mass Rating	
Acquisition parameters		
Geometry of measurement		
Permanent installation		
Metadata Petrophysics	**Metadata Petrophysics**	**Metadata Petrophysics**
for rocks	**for rocks**	**for fluids**
Density	Porosity	Temperature
Permeability	Poisson's ratio	pH
Compressional wave velocity	Shear wave velocity	Electrical conductivity
Compressional wave attenuation	Shear wave attenuation	Isotops
Elastic modulus	Unconfined compressive strength	Redox potential
Young's modulus	Uniaxial compressive strength	Qualitative inorganic analysis
Dynamic E-modulus	Splitting tensile strength	
Modulus of deformation	Fracture toughness	
Magnetic susceptibility	Magnetic remanence	
Magnetic susceptibility anisotropy		

3.8 Implementation in scientific databases

Formerly the geophysical data should be implemented into scientific databases like EPOS, EGDI or ICDP. While project time of BSUIN we had contact and meetings with the EPOS project.

EPOS is the European Plate Observing System and has a long-term plan to facilitate integrated use of data, data products and facilities from distributed research infrastructures for solid Earth Sience in Europe (Reference 13). The aim is to increase the access and use of multidisciplinary data recorded by solid Earth monitoring networks, acquired in laboratory experiments and/or produced by computational simulations.

The formerly aim to include BSUIN data into EPOS database is not realizable. Reasons for a not possible implementation are:

- Inheterogenity of BSUIN data: The geophysical data contains different kind of geophysical surveys, mainly surface measurements and measurements in the underground. Also, the geophysical methods differ from one BSUIN underground lab to each other.
- BSUIN geophysical data have mainly the context of an exploration of the underground environment or a monitoring of the underground buildings in a sense of stability.
- The BSUIN geophysical data was collected as a metadata database. The raw data or the processed data was not collected. This data will only be available via the contact of the BSUIN underground labs.

4. Conclusions and recommendations

The questionnaires of WP2.1 was sent to six ULs operating in the framework of the BSUIN project. The report and the summary is based on the given answers of **Callio** Lab, **Äspö** Hard Rock Laboratory, **Reiche Zeche**, **Cuprum**, **Khlopin** Radium Institute Underground Laboratory and **Ruskeala** Mountain Park.

4.1 Database

The answers from the BSUIN underground labs are the database for this work package 2.1 Geophysical characterization. The amount of data differs between all six underground labs: from very good and broad dataset to not known or not much existing datasets. There are different reasons for that:

1. For the purpose of underground usage geoscientific research was not necessary.
2. Only for the purpose of the specific underground lab was done geoscientific research e.g. exploration for mining activities.
3. The underground lab was also open for geoscientific collaboration with external partners.

The amount of datasets and therefore the metadata gives an impression which grade of geophysical usage the BSUIN underground labs have. Related to the former history as mine this underground labs have usually a higher grade of geoscientific investigations. Other underground labs know only relevant parameters which are necessary for access and usage of the underground lab.

4.2 Content summary

The given data shows the geoscientific knowledge of the owner of his own underground lab. In some cases it was the first time to collect the existing data from the past.

- **Callio** Lab (Finland) – very good knowledge and very good database
  Through exploration for mine activities exits a good understanding of the underground environment and the rock specifications.
- **Äspö** Hard Rock Laboratory (Sweden) – very good knowledge and very good database

Through exploration for mine activities exits a good understanding of the underground environment and the rock specifications.

- **Reiche Zeche** (Germany) – very good knowledge and very good database
  Through exploration for mine activities and also long-time documentation exists a good understanding of the underground environment and the rock specifications.
- **Ruskeala** Mountain Park (Russia) – good knowledge and good database
- **Khlopin** Radium Institute Underground Laboratory (Russia) – basic knowledge and basic database
- **Cuprum** (Poland) – good knowledge and good database
  Through exploration for mine activities exits a good understanding of the underground environment and the rock specifications.

4.3 Recommendations and aspects for future

To collect and summarize data is an advantage for an underground lab: To know all relevant information about geoscientific surveys and to know the responsible person induces a network of information and data. Nevertheless there are always possibilities to improve like data management. For each underground lab are given some examples:

- **Callio** Lab (Finland) – Callio Lab has made a broad business concept for an underground use after termination of mine activities. An example for that is Äspö with his SICADA database. A transfer from knowledge of underground investigations in the past but also future activities should be get together in a database. This database should be permanently maintained.
- **Äspö** Hard Rock Laboratory (Sweden) – After termination Äspö seeks for business concept. Nevertheless, Äspö has built a very good database SICADA which offers oppurtinities.
- **Reiche Zeche** (Germany) – Knowledge from different user groups should documentated at one central point. This central contact person brings together all information about underground acitivities, responsible persons and documentates results of underground research. An example for that is Äspö with his SICADA database. A transfer from knowledge of underground investigations in the past but also future activities should be get together in a database. This database should be permanently maintained.

- **Ruskeala** Mountain Park (Russia) – Rsukeala has initiated own geophysical measurement for a better understanding of the massif environment in the underground lab. If Ruskeala can made possible their planned investiations, Ruskeala can built up an own database. Additionally some more geological investigations are also preferable.
- **Khlopin** Radium Institute Underground Laboratory (Russia) – For the given issue of the used underground lab seems to be more exploration not necessary. A scientific concept for underground use will be helpul for a broader use of the underground lab.
- **Cuprum** (Poland) –A scientific concept for underground use will be helpful for the concepted and planned underground lab.

It is important for the underground labs to have one place for collecting information about scientific activities fromt the past, present and in the future. The knowledge of scientific activities in an underground lab allows to iterate existing business concepts or to create new business concepts.

Also, in a sense of technology transfer it is important to know own geoscientific methods and it´s applications. For a technology transfer different ways are possible:

1. Technology transfer of own exploration techniques
2. Technology transfer of geoscientific data
3. Services or knowledge transfer for external and internal scientists or companies
4. Utilize technology transfer for themselves

At last, the underground lab should use the existing BSUIN network to learn about possibilities in their own underground labs.

Appendix - References

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Appendix - Overview of data given by underground labs

Database from geophysical questionnaire

The next pages show the collected geophysical metadata implemented with the answers given by each BSUIN underground lab.

Äspö Hard Rock Laboratory Underground Lab

Owner	Nr. ID	Geophysical method	Data format	Source type	Device specification	Source parameters	Acquisition parameters	Kind of measurement (point, linear, tomography,...)	Permanent installation yes / no	Interval of measurement	Date	Location in UL Level	Exact coordinates			Place in tunnel or chamber (roof, bottom, side)	Miscellaneous
													Northing	Easting	Elevation		
SKB	101	Cross-tunnel seismic reflection and tomography	seg-2 or seg-y	Vibrator	VIBSIST-500	Signals were produced along tunnels TASA, TASU and TASP by the VIBSIST-500 seismic source on the tunnel wall.	3C geophones equipped with Oyo Geospace SMC1850/30Hz	Tomography measurements of P-waves and S-waves between the gallery tunnels TASU, TASP and the access tunnel TASA.	Partly, the short drilled boreholes drilled into the tunnel surface remains.	Single	03.2013 - 04.2013	TASA, TASU, TASP at -400 m level	Äspö 96 7980 8020 7980 7938	Äspö 96 1630 1670 1700 1660	RHB70	Two galleries: TASU, TASP, main tunnel TASA	The seismograms were recorded on a Summit II Plus 24-bit seismic data recording system with up to 235 channels, and subsequently decoded to produce 0.30 s seismic traces. The interpretation consists mainly of computing the 3D locations and orientations of the main reflectors using a 3D Image Point migration algoritm (Cosma et al., 2010).
SKB	102	Cross-tunnel and cross-hole seismic reflection and tomography	seg-2 or seg-y	Piezo source, Hydraulic hammer, Vibrator	SPH-64c piezo source, Borehole hammer source (MH-70c), Hydraulic hammer (VIBSIST-150)	Signals were produced along tunnels TASA, TASU and TAS08 by the VIBSIST-150 seismic source and in borehole K08028F01 by the MH70c mechanical hammer and SPH-64 piezoelectric source.	A TC-25 hydrophone receiver chain was put into the borehole KA03009F01 and equipped with 25 cylindrical-sensitivity velocity/pressure sensors.	Tomography measurements between the boreholes as well as seismic recording along three tunnel lines, TASA, TASU and the tunnel TAS08.	Partly, the short drilled boreholes drilled into the tunnel surface remains.	Single. The setup for such measurements is common for mise-á-la-masse surveys.	11.2014 - 12.2014	TASA, TASU, TAS08 at -400 m level	Äspö 96 8010 8090 8015 7982	Äspö 96 1490 1560 1650 1620	RHB70 -380 -392 -398 -400	Three galleries: TASU, TAS08, TASP, main tunnel TASA, two boreholes: K08028F01, K03009F01	The interpretation consisted mainly of computing the 3D locations and orientations of the main reflectors using a 3D Image Point migration algorithm (Cosma et al., 2010).
SKB	103	1. Cross-tunnel resistivity 2. Mise-à-la Masse	csv	Injection of current (transmitter/source) and recording of resulting electric potentials (receiver) at a large number of points at the tunnel walls.	Multi-channel IP receivers with separate high-power transmitter units (e.g. Scintrex IPR-12, Iris Elrec Pro, GDD GRx8-32, Zonge GDP).	A high-power, high-voltage transmitter (GDD TxII-3600W-2400V was selected as a source tool. The output current would be limited by the electrode contact resistance, but high resistance would be balanced by the high maximum output voltage (2400V) of the transmitter	A GDD GRx8-32 receiver measured up to 32 channels simultaneously which enabled efficient data collection. The receiver was also capable of quickly changing between single-pole (relative common reference) and dipole configuration through software setting.	Borehole-borehole and borehole-tunnel resistivity measurements (cross-hole inversion and Mise-à-la-masse techniques) as a tool for identifying and physically characterize critical structures.	Partly, the short drilled boreholes drilled into the tunnel surface as well as metallic bolts remains.	Single. The setup for such measurements is common for mise-á-la-masse surveys.	04.2014 - 09.2014	TASA, TASU, TASP at -400 m level	Äspö 96 7980 8020 7980 7938	Äspö 96 1630 1670 1700 1660	RHB70	Two galleries: TASU, TASP, main tunnel TASA	The program DCIP3D from UBC-GIF (University of British Columbia, Vancouver) was used for the inversion of data. The program uses a 3D finite difference mesh with rectangular cells for the calculation of electric potentials. The program can find a resistivity model whose calculated measurement response fits measured data to within a certain error limit by an iterative process.
SKB	104	1. Cross-tunnel resistivity 2. Cross-hole Mise-à-la-Masse	csv	Injection of current (transmitter/source) and recording of resulting electric potentials (receiver) at a large number of points at the tunnel walls.	ABEM Terrameter SAS1000 The measurement equipment was improved by using a relay card to multiplex the two ports in the ABEM Terrameter. With a relay card the two ports can be directed to 7 different locations.	Source signal: Several 0.3 s long positive and negative square pulses of current with 0.2 s zero current interval fed into current electrodes.	The measurement electrode bolts and current feed bolts were attached prior to the survey.	Tomography measurements between the boreholes as well as resistivity and Mise-à-la-Masse measurements along three tunnel lines, TASA, TASU and the tunnel TAS08.	Partly, the short drilled boreholes drilled into the tunnel surface as well as metallic bolts remains.	Single. The setup for such measurements is common for mise-á-la-masse surveys.	02.2015 - 03.2015	TASA, TASU, TAS08 at -400 m level	Äspö 96 8010 8090 8015 7982	Äspö 96 1490 1560 1650 1620	RHB70 -380 -392 -398 -400	Three galleries: TASU, TAS08, TASP, main tunnel TASA, two boreholes: K08028F01, K03009F01	The program DCIP3D from UBC-GIF (University of British Columbia, Vancouver) was used for the inversion of data. The program uses a 3D finite difference mesh with rectangular cells for the calculation of electric potentials. The program can find a resistivity model whose calculated measurement response fits measured data to within a certain error limit by an iterative process.
TRUST	105	1. Geoelectrical 2. Seismic tomography measurements	1. Raw data in mV 2. seg-2/seg-y	Electrodes	The geoelectrical surveying is done as DCIP tomography.	A continuous survey across land and water with land-based and underwater sensors linked together was made with a continuous layout in order to create a continuous uninterrupted data profile along the access tunnel	The sensor positions for the resistivity-IP electrodes and the hydrophones used in the seismic survey were co-located in order to provide optimal conditions for joint inversion. A tailor made underwater electrode cable with 5 m take-out separation was used in combination with hydrophone strings with the same sensor interval.	Linear and tomography measurements	No	5 m separation between electrodes as well as between hydrophone sensors.	02.2015 - 04.2017	From surface down to c. -10 - -100 m	SWEREF99 TF 6366500 6366500 6365700 6365700	SWEREF99 TF 599700 600100 600100 599700	RHB70 0 0 0 0	At surface, c. 60 to 100 m above tunnel	The resistivity and seismics refraction data were first evaluated separately using the Res2dinv and Rayfract and later with coupled inversion using the BERT/GIMLi inversion software package. Investigation of possible correlations between geophysical and engineering/environmental key parameters were performed as well as development of algorithms for 3D inversion of DCIP data.
TRUST	106	Electromagnetic measurements 1. RMT 2. CSMT 3. Seismic reflection data	1.&2. Raw data in mV 3. seg-2 or segy	1. Double horizontal magnetic dipole transmitter 3. 9C seismic landstreamer holding 3C geophones and 3C vibrators (sources)	1. RMT data for modelling the electrical resistivity of the ground below the measurement stations. 3. Landstreamer (GPS time stamped) with 100 DSU3 sensors	1. Selected transmitter frequencies are 1.25, 2, 4, 6.25, 8, 10, 12.5 kHz 3. 9C seismic landstreamer holding 3C geophones and 3C vibrators (sources) were developed in close cooperation with the industry. The existing RMT system was modified for collection of data also on (fresh) water, where traditional land based geoelectrical methods are inefficient.	For seismic investigations: Landstreamer (GPS time stamped) with 100 DSU3 sensors • 4x20 units 2 m geophone offset • 1x20 units 4 m geophone offset P-waves and S-waves were collected with a 3C broadband landstreamer.	Linear measurements	No	1.&2. 40 stations were observed both for CSRMT and RMT data on the water. The longest distance between the source and the stations is 430 m. 3. For seismics a separation of 2 to 4 m along a 240 m layout.	02.2015 - 09.2016	In tunnel ramp section 0/000 to 1/600 m, from surface down to c. -10 - -100 m	SWEREF99 TM 6366500 6366500 6365700 6365700	SWEREF99 TM 599700 600100 600100 599700	0 0 0 0	At surface, c. 60 to 100 m above tunnel. Along the tunnel from 0/000 m to 1/600 m.	RMT 2D inversion code was used to carry out 2D inversion, the controlled source electromagnetic signals can be treated as planar waves. For the seismics a 3C sensors enable recording and definition of the full seismic wave field. Both P- and S-waves could be used, hence better resolution images can be obtained.
SKB	107	Cross-hole seismic tomography	seg-2 or seg-y	Stack of piezoelectrical crystals	The receiver chain consists of eight orthogonal 3C accelerometers spaced at 5.0 m intervals. The receivers were clamped against the borehole wall using a motor driven side arm.	Piezoelectric transducers are perpendicular to the borehole axis.	P-waves and S-waves sampled in a 8 receiver chain.	A CMP stack and move-out correction were onto the midline located in the rock volume between the boreholes.	No	The receiver chain consists of eight orthogonal 3C accelerometers spaced at 5.0 m intervals.	10.1996 - 03.1997	Target area is between boreholes KA2511A and KA2563A west of the tunnel spiral of TASA, at a depth of -330 to -530 m below ground surface.	Äspö 96 7140 7280 7220 7080	Äspö 96 1800 2020 2030 1810	RHB70 -520 -320 -320 -580	In two boreholes	The interpretation consisted mainly of computing the locations and orientations of the main reflectors using a the combined CMP-stack, a ρτ-transform and migration for different azimuths (in 10-15° steps), (Heikkinen and Cosma, 1996).
SKB	108	Cross-hole seismic tomography	seg-2 or seg-y	Piezoelectrical crystals and two hydraulic pistons	The piezoelectric transducers are perpendicular to the borehole axis. The hydraulic clamping system is similar to the one used for the source module.	Piezoelectric transducers are perpendicular to the borehole axis.	P-waves and S-waves sampled in a 8 receiver chain.	Tomography performed in pair of boreholes.	No	The receiver chain consists of eight piezoelectric transducers with an interval of 0.15 m	05.1994 - 10.1994 11.1994 - 05.1995	Target area is between boreholes KXZA4 (A4) & KXZA5 (A5), KXZA6 (A6) & KXZA7 (A7); KXZC4 (C4) & KXZC5 (C5), KXZC6 (C6) & KXZC7 (C7); KXZB2 (B2) & KXZB4 (B4) at a depth of -415 m below ground surface.	Äspö96 7310 7320 7280 7270	Äspö96 2250 2290 2290 2250	RHB70 -415 -415 -415 -415	In 8 boreholes	An analysis of the seismic tomography data in the pair of boreholes (A4-A5, B2-B4, C4-C5) were presented in SKB report, SKB TN HRL -96-11z (Heikkinen P, Cosma C, 1996)
SKB	109	Hydraulic fracturing in borehole KN0033B01 (F1) and monitoring of seismic events and acoustic emissions in boreholes	seg-2 or seg-y	1. Conventional HF test with linear increase of pressure versus time 2. Dynamic FHF test with stepwise increase of pressure and for each step the pressure was varied.	1. HF test with linear increase of pressure versus time. 2. Dynamic FHF test	Hydraulic pulse	Hydraulic pulse. Registration of P-wave and S-wave velocity, frequency and tomography, monitoring of acoustic emissions and the Self Potential in mV. For MT measurements a large frequency band of 512 to 4,096 Hz was used.	Tomography performed in between tunnels TASN, TASP, TAS04 and TASD and the ramp section 2/059 to 2/206 on the level above (-289 m). The source borehole is KN0033B01 (F1). Receiver boreholes in near vicinity were KN0021B01 (M1), KN0047B01 (M2) and KN0048B01 (M3) are located at a depth of -410 m below ground surface.	No	Sensor interval varied.	04.2015 - 06.2015	Between boreholes KXZA4 (A4) & KXZA5 (A5), KXZA6 (A6) & KXZA7 (A7); KXZC4 (C4) & KXZC5 (C5), KXZC6 (C6) & KXZC7 (C7); KXZB2 (B2) & KXZB4 (B4) at a depth of -415 m below ground surface.	Åspö 96 7320 7335 7310 7290	Äspö96 2390 2410 2425 2400	RHB70 -410 -408 -408 -410	Source borehole KN0033B01 (F1). Receiver boreholes in near vicinity KN0021B01 (M1), KN0047B01 (M2), KN0048B01 (M3) are located at a depth of -410 m below ground surface.	The geothermic Fatigue Hydraulic Fracturing (FHF) in situ experiment at Äspö Hard Rock Laboratory (HRL were jointly performed by GFZ, GmuG, MeSy Solexperts, ISATech and KIT supported by Nova in the Nova Project 54-14-1: The geothermic Fatigue Hydraulic Fracturing (FHF) in situ experiment at Äspö Hard Rock Laboratory (HRL).
SKB	110	1. Seismic and radar reflection and VSP 2. VRP	seg-2 or seg-y	1. VSP: detonation cap in boreholes; seismic reflection survey: sledge hammer on tunnel walls 2. VRP source is a RAMAC transmitter antenna in the borehole and a transmitter on the tunnel wall	Seimic cap and sledge hammer, radar transmitter. Receivers were clamped against the borehole wall using a motor driven side arm.	Seimic cap and sledge hammer, radar transmitter. Receivers were clamped against the borehole wall using a motor driven side arm.	8 channel receiver. A number of stacking and CDP, band-pass filtering.	A combined CMP-stack, a ρτ-transform and migration were performed for different azimuths (in 10-15° steps),	No	The receiver chain consists of eight orthogonal 3C accelerometers spaced at 5.0 m intervals.	07.1991 - 09.1991	In tunnel ramp section 0/640 to 0/950 m, - 90 to - 130 m below ground surface	Äspö 96 6600 6600 6300 6300	Äspö 96 2120 2160 2160 2120	RHB70 -90 -90 -130 -130	On tunnel walls, both sides, and in short boreholes.	The interpretation consisted mainly of computing the locations and orientations of the main reflectors using a the combined CMP-stack, a ρτ-transform and migration for different azimuths (in 10-15° steps), (Heikkinen and Cosma, 1996).

Abbreviations:

TRUST - Transparent Underground Structures, http://trust-geoinfra.se/
MT - MagnetoTelluric
RMT - Radio magnetotelluric
CSMT - controled source magnetotelluric
VSP - Vertical Seismic Profiling
VRP - Vertical Radar Profiling
HF - Hydraulic fracturing
FHF - Fatigue Hydraulic Fracturing
csv-files (comma separated values), sorted with reference to the current electrode position.
9C - 9 component
3C - 3 component
SIST - Swept Impact Seismic Technique
DCIP - combined Direct Current resistivity and time-domain Induced Polarisation
CDP - Common depth point
CMP - Common midpoint

Reiche Zeche Underground Lab

Owner	Nr. ID	Geophysical method	Data format	Date	Location in UL Level	Exact coordinates		Place in tunnel or chamber	Source type	Device specification	Source parameters	Acquisition parameters	Kind of measure-ment	Permanent installation yes / no	Interval of measurement	Miscellaneous
						Northing	Easting									
GFZ		High-resolution seismics			GFZ UndergroundLab 1. level			2 galleries, 3 chambers, 3 boreholes				25 pre-installed geophone anchors		yes, partly		pre-installation of geophone anchors (1 & 2m length)
GFZ	1	Seismics	segy	09.1998 - 12.2004	GFZ UndergroundLab 1. level			side	impulse	Hammer or impact source	several hammer, mechanical and pneumatically hammer	up to 10 channels	point	no	single	several source and geophone tests
GFZ	2	Seismics	segy	11.1998 - 04.2001	GFZ UndergroundLab 1. level			side	impulse	Explosive source	20 - 500 g	up to 10 channels	point	no	single	several source tests
GFZ	3	High-resolution seismics	segy	07.2005	GFZ UndergroundLab 1. level			side	vibrator, impulse	Vibrator, 5 kg hammer	Sweep 0.1-3 kHz, Impulse	3 receivers 460 source points	point	no	single	vibrator: magnetostrictive actuator
GFZ	4	High-resolution seismics	segy	11.2005	GFZ UndergroundLab 1. level			side	vibrator	Vibrator	Sweep	5 3-C geophones 84 source points	point	no	single	vibrator: magnetostrictive actuator
GFZ	5	High-resolution seismics	segy	05.2006	GFZ UndergroundLab 1. level			side	vibrator	Vibrator	Sweep 0.1-3 kHz, Impulse	5 3-C geophones 139 source points	point	no	single	vibrator: magnetostrictive actuator
GFZ	6	High-resolution seismics	segy	11.2006	GFZ UndergroundLab 1. level	4595070 4595170 4595130 4595034	5644370 5644340 5644190 5644204	side	vibrator	Vibrator, double source	Sweep	10 3-C geophones 219 source points	point	yes, partly	single	vibrator: magnetostrictive actuator, source distances from 0.75 m - 15.9 m
GFZ	7	High-resolution seismics	segy	12.2009	GFZ UndergroundLab 1. level			side	vibrator	Vibrator, double source, GFZ development	Sweep 0.5 - 5 kHz Length 2.9 s	34 3-C geophones, spacing 4-9 m 76 source points, 2-4 m spacing	tomography	yes, partly	single	vibrator: magnetostrictive actuator Krauß et al. (2014): Seismic travel-time and attenuation tomography to characterize the excavation damaged zone and the surrounding rock mass of a newly excavated ramp and chamber, Rock Mechanics and Mining Sciences
GFZ	8	High-resolution seismics	segy	02.2009 - 06.2011	GFZ UndergroundLab 1. level			borehole	vibrator	Vibrator, quadruple borehole source, GFZ development	Sweeps	34 3-C geophones 36 source points	Point, linear	yes, partly	single	several source parameter tests, in 20 m and 30 m boreholes (BH1, BH2), 8,5" diameter, vibrator: magnetostrictive actuator
GFZ	9	High-resolution seismics	segy	01.2010	GFZ UndergroundLab 1. level			borehole	vibrator	Vibrator, quadruple borehole source, GFZ development	Sweep 0.5 - 5 kHz Length 3 s	30 3-C geophones 19 source points	linear, tomography	yes, partly	single	in 20 m borehole (BH2), 8,5" diameter, vibrator: magnetostrictive actuator
GFZ	10	High-resolution seismics	segy	04.2010	GFZ UndergroundLab 1. level			borehole	vibrator	Vibrator, quadruple borehole source, GFZ development	Sweep 0.5 - 5 kHz Length 3 s phased array	31 & 35 3-C geophones 29 source points	linear, tomography	yes, partly	single	in 30 m borehole (BH1), 8,5" diameter, vibrator: magnetostrictive actuator
GFZ	11	High-resolution seismics	segy	05.2010	GFZ UndergroundLab 1. level			borehole	vibrator	Vibrator, quadruple borehole source, GFZ development	Sweep 0.5 - 5 kHz Length 3 s phased array	35 3-C geophones 36 source points	linear, tomography	yes, partly	single	in 20 m borehole (BH2), 8,5" diameter, vibrator: magnetostrictive actuator Contact: TU Bergakademie Freiberg,Institute of Geophysics and Geoinformatics
GFZ	12	High-resolution seismics	segy	01.2011	GFZ UndergroundLab 1. level			borehole	vibrator	Vibrator, quadruple borehole source, GFZ development	Sweep phased array	35 3-C geophones 36 source points	linear	yes, partly	single	in 30 m borehole (BH1), 8,5" diameter, vibrator: improved magnetostrictive actuators Contact: TU Bergakademie Freiberg,Institute of Geophysics and Geoinformatics
Stefan Lüth (GFZ)	13	Seismic tomography Stefan Lüth		01.2011 - 07.2012	GFZ Underground Lab 1. level			borehole, side	vibrator	magnetostrictive actuator (developped at GFZ)	Sweep	6 different source signal types 76 source locations 2-4 m spacing, 30 3-C geophones, spacing 4-9 m	tomography	yes, partly	14 single measurements in total, three week interval	Lüth S. et al. (2014) Seismic Tomography and Monitoring in Underground Structures: Developments in the Freiberg Reiche Zeche Underground Lab (Freiberg, Germany) and Their Application in Underground Construction (SOUND). In: Weber M., Münch U. (eds) Tomography of the Earth's Crust: From Geophysical Sounding to Real-Time Monitoring. Advanced Technologies in Earth Sciences. Springer, Cham, doi: https://doi.org/10.1007/978-3-319-04205-3_7
TUBAF	14	Borehole geoelectrics		02.2018	1. level, horizontal borehole close to shaft; besides server room			borehole (10 m deep, horizontal)		Terrameter electric borehole sensor		4 different sensor configurations (potential (pole-pole), Schlumberger , 2 x gradient (pole-dipole))	linear (along bh)	no	single (but yearly repetitions from ~90s-2008 and 2018-now)	in the frame of underground geophysical practical course @ TUBAF, student reports Contact: TU Bergakademie Freiberg,Institute of Geophysics and Geoinformatics
TUBAF	15	Gravimetry		02.2018	along the shaft			bottom		AutoGrav CG-5 (Scintrex), resolution 0.01 mGal		4 different depth levels	loop	no	single (but yearly repetitions from ~90s-2008 and 2018-now)	in the frame of underground geophysical practical course @ TUBAF, student reports
TUBAF	16	High-resolution seismics	segy	02.2018	BHMZ test site 1. level, Wilhelm Stehender Nord, block between Überhauen 166/2 and 166/3	5644580.734 5644546.300	4595074.644 4595075.156	side	Hammer (4 kg)	horizontal geophones attached to fixed angle brackets	stack of 3	1 m source and receiver spacing; 32 geophones at different locations; 35 hammer	tomography	yes, partly	single (but yearly repetitions from ~90s-2008 and 2018-now)	in the frame of underground geophysical practical course @ TUBAF, student reports
TUBAF, Se-bastian Winter	17	High-resolution seismics	segy	07.2015 - 01.2016	BHMZ test site 1. level, Wilhelm Stehender Nord, block between Überhauen 166/2 and 166/3	5644580.734 5644546.300	4595074.644 4595075.156	side	Powder-actuated tool And hammer (5kg)	3-C geophones attached to fixed angle brackets	stack of 3-5, 80 source locations, distance ca. 1 m	80 3-C geophones, Geode geometrics recording (sampling 0.125 ms, 0.1 s recording)	tomography	yes, partly	single	Winter, Sebastian (2016): Seismic Tomography at the BHMZ test facility of the teaching and research mine Reiche Zeche; Msc-Thesis TU Bergakademie Freiberg, in German
TUBAF	18	Seismology	e.g. mini-SEED	Since 09.2004	4. Gezeugstrecke Alte Elisabeth	50,9212°	13,3542°	bottom	passive	Lennartz seismometer, 5 s eigenperiod	earthquakes, mining acitivy...	continuous recording	point	yes	permanent	F. Donner (07/2005): Seismologische Station Freiberg (FBE), Internal report TUBAF, data (from 09/2004-now) download: https://www.bgr.bund.de/EN/Themen/Seismologie/__Content_alt/Wellenformdaten_en/waveform_data_node.html Older data available at TUBAF (Falk Hänel)
TUBAF, Lukas Römhild	19	Geoelectrics		06.2016	BHMZ test site 1. level, area between seismic tomography points S64 and S63	ca. 5644580.734	ca. 4595064.644	side		Terrameter SAS 300C (ABEM Instruments)	Wenner-configuration	measurements of an area of ~ 1m², point distance 5-10 cm	2D area	no	single (with two repetitions)	Römhild, Lukas (2016), Small-scale geoelectrics at an ore vein in the Reiche Zeche mine (Freiberg, Germany); Bsc-Thesis, TU Bergakademie Freiberg, in German
TUBAF, Daniel Pötschke	20	Geoelectrics		07.2016	BHMZ test site 1. level, Wilhelm Stehender Nord, block between Überhauen 166/2 and 166/3	5644580.734 5644546.300	4595074.644 4595075.156	side		Multielectrode-equipment, constructed at TUBAF	Wenner(α)-configuration	80 electrode locations with 1 m spacing	tomography	no	single (with two repetitions)	Pötschke, Daniel (2017), Imaging of an Ore Vein in the Reiche Zeche Mine (Freiberg, Germany) using Electrical Resistivity Tomography; Msc-Thesis, TU Bergakademie Freiberg, in German
TUBAF	21	Seismics		Before 2008	1. level, close to „Ziegenstall" block between „Wilhelm Stehender Süd", Quergang and Richtstrecke	see coordinates of GFZ-underground lab		side	hammer	Bison seismic equipment					single (but yearly repetitions from ~90s-2008)	in the frame of underground geophysical practical course @ TUBAF, student reports
TUBAF	22	GPR		Before 2008	1. level, prolongation of „Querschlag West", two horizontal boreholes			borehole	100 MHz Antenna	PulseEkko-100-GPR-equipment		transmission between two boreholes, distance ca. 4 m	tomography	no	single (but yearly repetitions from ~90s-2008)	in the frame of underground geophysical practical course @ TUBAF, student reports
TUBAF	23	Geothermal		Before 2008	at the shaft (different levels)			borehole		PT100 temperature sensor		sensors every 4 m within horizontal borehole	point	no	single (but yearly repetitions from ~90s-2008)	in the frame of underground geophysical practical course @ TUBAF, student reports
TUBAF	24	Seismics	segy	Before 2008	1. level			borehole	hammer			measurement every 1 m along horizontal borehole	linear	no	single (but yearly repetitions from ~90s-2008)	in the frame of underground geophysical practical course @ TUBAF, student reports Aim is to determine crevasse formation/ mechanical defects
TUBAF	25	Gravimetry		2011-2012	surface, parking place before the main entrance	5644400 5644620	45954000 4595600	bottom		AutoGrav CG-5 (Scintrex), resolution 0.01 mGal			area	no	single	Bouguer anomaly of the mine dump
TUBAF	26	GPR		03.2019	1. level, prolongation of „Querschlag West", two horizontal boreholes			borehole	100 MHz Antenna	GSSI-20 GPR equipment 2 x 100 MHz antenna		Transmission between two boreholes, distance ca. 4 m, Reflection recorded by transmitter and receiver in the same borehole	tomography Linear (along bh)	no	single	in the frame of underground geophysical practical course @ TUBAF, student reports Contact: TU Bergakademie Freiberg,Institute of Geophysics and Geoinformatics
STIMTEC project	27	Ultrasonic		2017	1. level, GFZ underground lab			borehole/side	hammer	Broadband ultrasonic sensor GmuG MA Blw-7-70-75 Accelerometer Wilcoxon 736T		25 source points (Wilhelm Stehender) 4 ultrasonic receiver points (Richtstrecke)	tomography			in the frame of the STIMTEC project, overview e.g.: http://stimtec.rub.de/downloads/STIMTEC-2017-11-21.pdf Derivation of detailed stress model
TUBAF, Malecki	28	TEM		2013-2016	1. level				vertical magnetic dipols as transmitter at the surface			vertical magnetic dipols as receivers underground	point, tomography	no	single	Aim: absolute underground positioning with the help of transient electromagnetic fields (Malecki, S., Börner, R. U., & Spitzer, K. (2016): Absolute Positionierung unter Tage mittels transientelektromagnetischer Felder. Conference abstract)
LfULG	29	Gravimetry		1954-1989	from surface, overview map of geological service											Collection of various gravimetric data sets, map compiled with 500 m grid: http://www.geologie.sachsen.de/gravimetrische-uebersichtskarte-14147.html
LfULG	30	Magnetics		1953, 1956, 1980ies	from surface, overview map of geological service											Collection of various magnetic data sets, map compiled with 500 m grid: http://www.geologie.sachsen.de/geomagnetische-uebersichtskarte-14162.html
LfULG	31	diverse														A variety of other helpful data and maps provided by the Saxonian geological service, e.g. geothermal maps: http://www.geologie.sachsen.de/geothermische-karte-13914.html

Ruskeala Underground Lab

Owner	Nr. ID	Geophysical method	Data format	Date	Location in UL Level	Place in tunnel or chamber	Source type	Device specification	Source parameters	Acquisition parameters	Kind of measurement	Permanent installation yes / no	Interval of measure-ment	Miscellaneous
KarRC RAS		Geophysical research		07.2018	Ruskeala UL 1 level-ground profile (projections adits to the surface), 0 level - underground galleries	surface of the earth, walls, floor						no		
KarRC RAS	1	Method of electrotomography	segy	07.2018	Ruskeala UL 1 level-ground profile (projection of the gallery 1 on the surface)	surface of the earth	Generator of the SKALA-48 device	Electro-prospecting station SKALA-48 "KB Electrometry"	resistance	48 channels, electrodes spacing - 1 m, installation - slumberberg	electro-tomography	no	single & roll	On the section of marbles, confident measurements at currents of 10-80 mA
KarRC RAS	2	Magnetic prospecting method	segy	07.2018	Ruskeala UL 1 level-ground profile (projection of the gallery 1 on the surface)	surface of the earth	Earth's magnetic field	Magnetic storage station "Minimag-M" and "Minimag"	magnetic field strength	Vector T, step - 1 m, the variation period - 10 s	point	no	single	There were technogenic hindrances (remains of metal structures, scrap metal).
KarRC RAS	3	Natural electric field method	segy	07.2018	Ruskeala UL 1 level-ground profile (projection of the gallery 1 on the surface)	surface of the earth	Natural electric Field of the Earth	Multimeter Mastech 7032	used limits - 200 mV	Installation of potential measurement using non-polarizable electrodes, measurement step - 1 m	point	no	single	The plot of the potential of the natural electric field reflects the ground relief, with separate cracks and fracture zones in the form of relative positive anomalies from 15 to 30-35 mV.
KarRC RAS	4	Method of electrotomography	segy	07.2018	Ruskeala UL 1 level-ground profile (projection of gallery 2 on the surface)	surface of the earth	Generator of the SKALA-48 device	Electro-prospecting station SKALA-48 "KB Electrometry"	resistance	48 channels, electrodes spacing - 1 m, installation - slumberberg	electro-tomography	no	single & roll	On the section of marbles, confident measurements at currents of 10-120 mA
KarRC RAS	5	Magnetic prospecting method	segy	07.2018	Ruskeala UL 1 level-ground profile (projection of gallery 2 on the surface)	surface of the earth	Earth's magnetic field	Magnetic storage station "Minimag-M" and "Minimag"	magnetic field strength	Vector T, step - 1 m, the variation period - 10 s	point	no	single	There were technogenic hindrances (remains of metal structures, scrap metal).
KarRC RAS	6	Natural electric field method	segy	07.2018	Ruskeala UL 1 level-ground profile (projection of gallery 2 on the surface)	surface of the earth	Natural electric Field of the Earth	Multimeter Mastech 7032	used limits - 200 mV	Installation of potential measurement using non-polarizable electrodes, measurement step - 1 m	point	no	single	The plot of the potential of the natural electric field reflects numerous individual cracks and fracture zones up to 40 mV, the potential plot is interfered with by electrical installations (cabinets, cables, branching boxes), from the gallery floor (reinforced concrete).
KarRC RAS	7	Method of electrotomography	segy	07.2018	Ruskeala UL 1 level - the land profile (projection of gallery 3 on the surface)	surface of the earth	Generator of the SKALA-48 device	Electro-prospecting station SKALA-48 "KB Electrometry"	resistance	48 channels, electrodes spacing - 1 m, installation - slumberberg	electro-tomography	no	single & roll	On a section of marbles, confident measurements at currents of 10-52 mA. The array in the region of this gallery is less waterlogged.
KarRC RAS	8	Magnetic prospecting method	segy	07.2018	Ruskeala UL 1 level - the land profile (projection of gallery 3 on the surface)	surface of the earth	Earth's magnetic field	Magnetic storage station "Minimag-M" and "Minimag"	magnetic field strength	Vector T, step - 1 m, the variation period - 10 s	point	no	single	There were technogenic hindrances (remains of metal structures, scrap metal).
KarRC RAS	9	Natural electric field method	segy	07.2018	Ruskeala UL 1 level - the land profile (projection of gallery 3 on the surface)	surface of the earth	Natural electric Field of the Earth	Multimeter Mastech 7032	used limits - 200 mV	Installation of potential measurement using non-polarizable electrodes, measurement step - 1 m	point	no	single	The tunnel crosses the mine, when approaching the location of the mine, a positive anomaly of the natural field, presumably of a filtration origin.
KarRC RAS	10	Method of electrotomography	segy	07.2018	Ruskeala UL 0 level-underground tunnel 1	wall	Generator of the SKALA-48 device	Electro-prospecting station SKALA-48 "KB Electrometry"	resistance	48 channels, electrodes spacing - 1 m, installation - slumberberg	electro-tomography	no	single & roll	On a section of marbles, confident measurements at currents of 11-120 mA, The electrodes were on the walls. There are crushing zones and man-made noise (an iron bridge).
KarRC RAS	11	Magnetic prospecting method	segy	07.2018	Ruskeala UL 0 level-underground tunnel 1	wall	Earth's magnetic field	Magnetic storage station "Minimag-M" and "Minimag"	magnetic field strength	Vector T, step - 1 m, the variation period - 10 s	point	no	single	Failed to comply due to man-made interference from communications.
KarRC RAS	12	Natural electric field method	segy	07.2018	Ruskeala UL 0 level-underground tunnel 1	wall	Natural electric Field of the Earth	Multimeter Mastech 7032	used limits - 200 mV	Installation of potential measurement using non-polarizable electrodes, measurement step - 1 m	point	no	single	The plot of the potential of the natural electric field reflects numerous individual cracks and low-power zones of fragmentation of rocks up to 1 m, the graph is complicated by an anthropogenic anomaly - an iron bridge with an intensity of 300 mV.
KarRC RAS	13	Method of electrotomography	segy	07.2018	Ruskeala UL 0 level-underground tunnel 2	wall	Generator of the SKALA-48 device	Electro-prospecting station SKALA-48 "KB Electrometry"	resistance	48 channels, electrodes spacing - 1 m, installation - slumberberg	electro-tomography	no	single	On the section of marbles, confident measurements at currents of 40-140 mA, The electrodes were on the walls.
KarRC RAS	14	Magnetic prospecting method	segy	07.2018	Ruskeala UL 0 level-underground tunnel 2	wall	Earth's magnetic field	Magnetic storage station "Minimag-M" and "Minimag"	magnetic field strength	Vector T, step - 1 m, the variation period - 10 s	point	no	single	Failed to comply due to man-made interference from communications.
KarRC RAS	15	Natural electric field method	segy	07.2018	Ruskeala UL 0 level-underground tunnel 2	wall	Natural electirc Field of the Earth	Multimeter Mastech 7032	used limits - 200 mV	Installation of potential measurement using non-polarizable electrodes, measurement step - 1 m	point	no	single	Individual zones of increased fracturing are marked with relatively positive anomalies of the potential of the natural electric field from 15 to 40 mV.
KarRC RAS	16	Method of electrotomography	segy	07.2018	Ruskeala UL 0 level-underground tunnel 3	floor	Generator of the SKALA-48 device	Electro-prospecting station SKALA-48 "KB Electrometry"	resistance	48 channels, electrodes spacing - 1 m, installation - slumberberg	electro-tomography	no	single & roll	On the section of marbles, confident measurements at currents of 3-120 mA, The electrodes were on the floor. Not reinforced concrete, there is a technogenic soil (iron bridge).
KarRC RAS	17	Magnetic prospecting method	segy	07.2018	Ruskeala UL 0 level-underground tunnel 3	floor	Earth's magnetic field	Magnetic storage station "Minimag-M" and "Minimag"	magnetic field strength	Vector T, step - 1 m, the variation period - 10 s	point	no	single	There were technogenic hindrances (remains of metal structures, scrap metal). The tunnel is not equipped with lighting. It does not have a pedestrian path (reinforced concrete floor).
KarRC RAS	18	Natural electric field method	segy	07.2018	Ruskeala UL 0 level-underground tunnel 3	floor	Natural Electric Field of the Earth	Multimeter Mastech 7032	used limits - 200 mV	Installation of potential measurement using non-polarizable electrodes, measurement step - 1 m	point	no	single	The tunnel crosses the mine, when approaching the location of the mine, a positive anomaly of the natural field, presumably of a filtration origin.

Under-ground Lab	Owner	Nr. ID	Geophysical method	Data-format	Date	Location in UL Level	Exact coordinates		Place in tunnel or chamber	Source type	Device specification	Source parameters	Acquisition parameters	Kind of measurement	Permanent installation yes / no	Interval of measurement	Miscellaneous
							Northing	Easting									
Khlopin			no geophysical research														
Cuprum/ Polkowice-Sieroszowice	N/A	N/A	High-resolution seismics	depend on sensor type-always convertable into .csv or .txt	N/A	Not within projected UL	N/A	N/A	side	impulse	Geophones, accelerometers, seismometers (ARP-2000 ; ELOGOR)	seismic tremors	triaxial measurement with 500 Hz frequency	point	yes	pernament	
Cuprum/ Polkowice-Sieroszowice	N/A	N/A	Seismics	depend on sensor type-always convertable into .csv or .txt	N/A	Not within projected UL	N/A	N/A	side	impulse	Geophones,	blasting works	triaxial measurement with 500 Hz frequency or higher	point	yes, partly	irregural	
Callio Lab	University of Oulu	1	Passive seismic observations	mseed	17.8.2013 – 25.8.2013	Surface	7056089.43 to 7056344.328 (ETRSTM35-FIN)	457574 to 449562 (ETRSTM35-FIN)	-	Passive sources	Passive vibration from Pyhäsalmi mine		6 stations with Nanopmetrics Trillium compact seismometer (samplerate 500 Hz)	line	no	single	10 km line with 6 trilliumcompact
Callio Lab	University of Oulu	2	Passive seismic observations	SEGD / (mseed)	1.11.2013, 12:10 pm to 5.11.2013, 7:19 am total: 91.2 h (local time)	Surface	7056089.43 to 7056344.328 (ETRSTM35-FIN)	456012.8968 to 456043.883 (ETRSTM35-FIN)	-	Passive source	Passive vibration from Pyhäsalmi mine		Sercel UNITE, DSU3-SA accelomters, samplerate 500 Hz	line	no	single	10 km line with 24 SERCEL UNITE 3compponent accelometers (DSU3-SA)
Callio Lab	GTK (Geological survey of Finland)	3	High Resolution Reflection Seismics for Ore Exploration 2007-2010, Pyhäsalmi mine part.	SEGY	November, 2007	Surface, on roads & offroad	Approx cornerpoints of studyarea: 7063040.5950, 7055043.8575	Approx cornerpoints of studyarea: 450847.9619, 456845.5639	-	Vibration	2-3 Geosvip (13.5 ton) were used as group.	Sweep 30-165 Hz	max spread length: 5025m (asymmetric end of line), 2502 m in case of symmetrical geometry. Sweep length: 16s linear upsweep, Active channels: 402, Channel interval 12.5 m, shot point interval 25-50 m	line	no	single	4 vibroseismic lines (25.1 km) and 2 explosion seismic lines (12.5 km).
Callio Lab	GTK	4	Reflection seismics (Finnish reflection experiment, FIRE)	SEGY	September - December, 2001 and March 2002	Surface, on roads & offroad	Approx cornerpoints of studyarea: 7062488.360 to 7056248.360	Approx corners of studyarea: 460560.895 to 439360.895	-	Vibration	Truck vibrator	Sweep 12 - 80 Hz	Spread length 18050 meter, Sweep lenght 30 s, Active channels 362, geophones / channel: 12, geophone interval 10 meters, shot point interval 100 m.	line	no	single	Pyhäsalmi mine is located along of FIRE 1. Part of The FIRE data is already freely available and the remaining is being under way as release platform is develophed (OPENFIRE).
Callio Lab	Pyhäsalmi Mine Ltd	5	Microseismic observations via Microseismic monitoring network	IMS format (can be converted to ASCII,mseed etc)	10/2002 - presents	Covers active mining area and some keyfeature points	7061857.2 m to 7062205.6 m	3452439.3 m to 3452816 m	roof	passive observations	-	-	Hardware sampling rate 6000 / 3000 Hz	Covers volume	yes	constant	Hardware and software is from Institute of mine seismology (IMS). System consists microseismic network with trigger. Passive measurements to locate induced seismic events. The system owner is Pyhäsalmi mine Ltd.
Callio Lab	GTK, National land survey of Finland, Pyhäsalmi mine	6	Various data: magnetic, topographic, geological maps, rock mechanic mapping reports (related to geophysical parameters) etc.	Arcgis shape, TIFF	Latest official	Surface			-	-	-					single	Most of these data is freely available, (magnetic, laserscans on topography, bedrock map)

Database from geological, petrophysical and geothermal questionnaire

The next pages show the collected geological, petrophysical and geothermal metadata implemented with the answers given by each BSUIN underground lab.

Callio Lab Pyhäsalmi

Geology

Rock	Rock type description	Minerals	Fault filling (dry, mineralized or fluid)	RQD-value
Mafic volcanic rock	Fine grained dark rocks	Plagioclase and pyroxene	Most of joints are unaltered (25 %) or just slightly altered (68 %). When altered, joints have fillings such as chlorite, pyrrhotite, and pyrite.	90-100
Felsic volcanic rock	Fine-grained, sodium-rich rhyolites with high SiO_2 content	Quartz and alkaline feldspar	Joint roughness is similar to mafic volcanic with the difference that felsic rock has slightly more rough joints and less smooth joints. Joints in felsic volcanic are mostly unaltered or slightly altered.	90-100
Pegmatite	Coarse-grained pink/pinkish-grey and white rocks, which occur usually as dikes and lenses of variable thickness. Usually veins are 0.1-2 m wide and might be very long.	Quartz and alkaline feldspar	Joint set number value is similar to the other major rock types. Pegmatite has mostly one plus random or two joint sets. Joints are mainly rough (69 %) and unaltered (66 %).	90

Literature, reference
LAGUNA-LBNO extended site investigation at Pyhäsalmi, Finland
Deliverable 7: Geological modelling

Petrophysical parameters

Rock	**Mafic volcanic rock**	**Felsic volcanic rock**	**Pegmatite**	
Density	2,97	2,66	2,6	g/cm³
Magnetic susceptibility	0,61	0,8	0	cgs unit or SI unit 10^{-6}
Elastic modulus	81,1	73,1	63,9	Gpa
Geothermal parameters				
Heat conductivity	1,85	2,65	2,87	(λm) [W m-1 K-1]
Heat capacity	735	741	758	(cp) [J kg-1 K-1]

Literature, reference
LAGUNA-LBNO extended site investigation at Pyhäsalmi, Finland
Deliverable 8: Rock mechanical modelling and analysis

Äspö Hard Rock Laboratory

Geology

Rock	Rock type description	Details or specifics, minerals	Anisotropy	Fault orientation	Fault filling	RQD-value	Rock Mass Rating	RMR (mean±stddev)	Literature, reference
Äspö diorite	65%, quartz monzodiorite to granodiorite, porphyritic	The far most common rock within the Äspö HRL. Grey to reddish grey, medium-grainde with large phenocrysts of K-feldspar.	Most rocks in the area exhibit tectonic foliation. These foliations are predominantly protomylonitic or mylonitic. Axial planar foliations due to folding also occur. The vast majority of (proto-) mylonitic foliations have a moderately to steep dip towards WNW or ESE and strike ENE-WSW regardless of their kinematic character.	The regional structural framework in the Simpevarp-Ävrö-Äspö area is dominated by NE- to ENE-trending deformation zones. The minor deformation zones are oriented in a NW-SE direction.	**Predominant fracture filling minerals:** Calcite, chlorite, epidote, prehnite and quartz **Less frequent fracture filling minerals:** Laumontite, adularia, clay minerals and pyrite Reddening (oxidation) along fracture walls occurs frequently.	Generally 75-90% outside deformation zones and slightly lower in fine-grained granites. Below 25% in parts of brittle deformation zones.	RMR distribution along Äspö main tunnel with very good: 28% RMR>72 good: 39% RMR 60-72 fair: 28% RMR 40-60 poor: 4% RMR<40	69 ±10	Äspö HRL - Geoscientific evaluation 1997/5. Models based on site characterization 1965-1995. SKB TR-97-06
Ävrö granodiorite	20%, granite to granodiorite, sparsely porphyritic to porphyritic	Differs from the Äspö diorite in their brighter, sometimes distinctly more reddish colour. The rock is more equigranular with a lower content of K-feldspar phenocrysts. The Ävrö granodiorite is inferred to be younger than the Äspö diorite.						65 ±11	
Fine-grained granite	10%, granite, fine- to medium-grained	Occurs typically as dikes, but there are also examples of occurrences with diffuse contacts to the wall rock. The fine-grained granite is generally more fractured that the other rock types with many small, closely spaced fractures, which result in a blockiness.						48 ±13	
Gabbroid-dioritoid	5% Mafic rock, undifferentiated In addition, there are subordinate amounts of Fine-grained dioritoid (Intermediate rock, fine-grained) and Pegmatite.	Equigranular and very dark, greenish or greyish black. Occurs typically as irregular, elongated bodies within the Äspö diorit and Ävrö granodiorite.						64 ±6	

Petrophysical parameters

Rock	Wet density (kg/m3) - mean [range]	Dry density (kg/m3) - mean [range]	Porosity (%) - mean [range]	Compressional wave velocity (m/s) - mean [range]	Magnetic susceptibility anisotropy (SI) - mean [range]	Magnetic remanence (A/m) - mean [range]	Young's modulus (GPa) - mean [range]	Unconfined compressive strength (MPa) - mean [range]	Poisson's ratio - mean [range]	Literature, reference
Äspö diorite	$2.72585 \cdot 10^{3}$ [$2.62676 \cdot 10^{3}$ - $2.82156 \cdot 10^{3}$]	$2.74212 \cdot 10^{3}$ [$2.63300 \cdot 10^{3}$ - $3.11900 \cdot 10^{3}$]	0.46 [0.16 - 1.00]	6006 [5805 - 6756]	$1.20 \cdot 10^{-2}$ [$5.70 \cdot 10^{-5}$ - $3.23 \cdot 10^{-2}$]	0.06824 [0.03000 - 0.17000]	73 [65 - 85]	171 [103 - 210]	0.24 [0.22 - 0.29]	Äspö HRL - Geoscientific evaluation 1997/5. Models based on site characterization 1965-1995. SKB TR-97-05
Ävrö granodiorite	$2.71335 \cdot 10^{3}$ [$2.64890 \cdot 10^{3}$ - $2.79000 \cdot 10^{3}$]	$2.72406 \cdot 10^{3}$ [$2.61800 \cdot 10^{3}$ - $2.89300 \cdot 10^{3}$]	0.48 [0.24 - 0.92]	5905 [5666 - 6115]	$1.29 \cdot 10^{-2}$ [$3.16 \cdot 10^{-4}$ - $4.54 \cdot 10^{-2}$]	0.23339 [0.00102 - 3.11000]	74 [63 - 79]	225 [197 - 275]	0.23 [0.20 - 0.26]	
Fine-grained granite	$2.63049 \cdot 10^{3}$ [$2.60902 \cdot 10^{3}$ - $2.65459 \cdot 10^{3}$]	$2.66044 \cdot 10^{3}$ [$2.62300 \cdot 10^{3}$ - $2.83900 \cdot 10^{3}$]	0.47 [0.25 - 0.78]	5977 [5775 - 6278]	$5.45 \cdot 10^{-3}$ [$1.00 \cdot 10^{-5}$ - $2.06 \cdot 10^{-2}$]	0.07774 [0.00784 - 0.20000]	77 [72 - 80]	258 [103 - 329]	0.23 [0.21 - 0.25]	
Gabbroid-dioritoid	$2.91680 \cdot 10^{3}$ [$2.73446 \cdot 10^{3}$ - $3.10689 \cdot 10^{3}$]	$2.90489 \cdot 10^{3}$ [$2.81018 \cdot 10^{3}$ - $2.93634 \cdot 10^{3}$]	0.19 [0.14 - 0.36]	6133 [5386 - 6447]	$2.17 \cdot 10^{-3}$ [$3.00 \cdot 10^{-4}$ - $1.10 \cdot 10^{-2}$]	0.08741 [0.00049 - 0.25026]	78 [71 - 96]	207 [121 - 274]	0.24 [0.18 - 0.31]	

Fluids	Temperature °C	pH	Electrical conductivity mS/m	Isotops	Isotops	Redox potential	Qualitative inorganic analysis: Anions	mg/L	Kations	mg/L	Other ions	Literature, reference
	Minimum 9.7 Maximum 17.8 Average 13.6	Field measurements: 7.0-8.1 Laboratory measurements: 7.10-8.23	Field measurements: 162.1-3870.0 Laboratory measurements: 143.0-4360	^{14}C: 16.8 to 97.0 pmc ^{13}C: -4.0 to -20.3 dev PDB $^{34}S(SO_4)$: 4.2 to 31.2 dev CDT $^{34}S(HS)$: 11.5 to 12.0 dev CDT	^{87}Sr: 0.715815 to 0.719481 ^{2}H: -46.3 to -110.8 dev SMOW ^{18}O: -6.5 to -14.9 dev SMOW ^{3}H: 0.8 to 22.8 TU	Reducing environment	Cl SO4 Br F HNO3 I HS	220-16220 44-770 1.1-171.0 1.0-3.0 4.81-401.0 0.0214-1.61 0.01-3.93	Na K Ca Mg Fe Mn	227-4140 2.4-42.3 68.3-5690 11-179 0.008-2.2 0.119-1.22	Si, Li, Sr, S, Al, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, P, Pb, Vi, Zn, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, La, Sc, Rb, Y, Zr, Sb, Cs, Hf, Tl, U, Th	SICADA database

Geothermal parameters	Heat conductivity (W/(mK)) - mean [range]	Heat capacity (MJ/m^{3}K) - mean [range]	Critical mineral contents	Other notes	Literature, reference
Äspö diorite **Ävrö granodiorite**	2.88 [2.01 - 3.76]	2.23 [1.73 - 2.60]	For the gabrroid - dioritoid the low conductivity samples are plagioclas rich, whereas the high-conductivity samples are rich in mafic minerals, such as amphibole (hornblende) and pyroxene.	The mean thermal conductivity of the fresh samples is about 5% higher than for altered samples.	Thermal propities Laxemar SDM site Laxemar. SKB R-08-62
Fine-grained granite	3.69 [3.58 - 3.76]	2.04 [1.93 - 2.12]			
Gabbroid-dioritoid	2.64 [2.06 - 3.65]	2.34 [1.91 - 2.65]			
Notes	Measured by the TPS (Transient Plane Source) method	Calculation from TPS measurements			

Reiche Zeche

Geology

Rock type description	Minerals	Fault filling	Fault orientation	Anisotropy	RQD-value
Gneiss mainly Freiberg grey gneiss with ore veins	Freiberg grey gneiss: biotite-plaioclase-gneiss and metagranite Veins: galena, sphalerite, arsenpyrite, pyrite, chalcopyrit, former silver ore, quartz	Mineralized	Fault systems variscan orogenese: strike NNE-SSW, steep dip of 70-90°; ruffle faults with N-S strike and 25-30° W dip Fault system alpine orogenese: strike WNW-ESE, steep dip; ruffle faults E-W	Due to foliation or associated to mica orientation P-wave anisotropy Freiberger gneiss: 0.08 - 0.51 (1,6); 0.81 (7)	90-100%

Petrophysical parameters

Rock	Density	Porosity	Permeability	P-wave velocity	P-wave attenuation	S-wave velocity	Specific electrical resistivity	Magnetic susceptibility	Other notes
Gneiss	2.68 g/cm³ (mean gross density, 7)	0.01 - 0.02 (1)	0.05 - 0.19·10^{-18} m² (1)	4 - 6.3 km/s; mean 5.4 km/s (2,5,6)	Q ca. 26 - 30 (1)	1.5 - 3 km/s (literature 4)	1000 - 2000 Ohm m	0 - 25000·10^{-6} SI (4)	Stress field model of Reiche Zeche available from (9, 10)
Ore	4.57 +/-0.11 g/cm³ (6)			ca. 6.5 km/s (6)			17 - 125 Ohm m (3, 5)		

Rock	Poisson's ratio	Dynamic Poisson's ratio	Permeability	P-wave velocity	Dynamic E-modulus	Modulus of deformation	Uniaxial compressive strength	Splitting tensile strength	Fracture toughness
Parallel to foliation	0.16	0.21	10^{-20} m²	5940 m/s	83.9 Gpa	77.6 Gpa	160 Mpa	6.2 Mpa	0.8 MPa·$m^{0.5}$
Perpendicular to foliation	0.13	0.19	<10^{-20} m²	4830 m/s	57.1 Gpa	56.7 GPa	120 Mpa	16.8 Mpa	1.7 MPa·$m^{0.5}$
Literature, reference	All from 7 (Frühwirt et al., TUBAF)		(8, laboratory analysis)	All from 7 (Frühwirt et al., TUBAF)					

Fluids	Temperature	pH	Electrical conductivity	Special minerals	Other notes
	10.2 °C	7 (neutral)	0.9 ms/cm	Low iron and manganese content	Depth mean water equivalent: 400 m w.e. (1. level)

Geothermal parameters	Permeability	Heat conductivity	Heat capacity	Other notes
Parallel to foliation	0.11 - 0.16·10^{-18} m²	ca. 3.6 W/(m K)	770 J/(kg K)	Geothermal potential from general overview maps: 50 - >60 W/m (LfULG)
Perpendicular to foliation	0.05 - 0.19·10^{-18} m²	ca. 2.0 W/(m K)	700 J/(kg K)	
Others			For waterfilled pores increase by 60 J/(kg K)	

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Geology

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