

# GFZ Underground Laboratory in the Research and Education Mine “Reiche Zeche” Freiberg

GFZ German Research Centre for Geoscience \*

Instrument Scientists:

- Rüdiger Giese, GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany, phone: +49 331 288 1575, email: [ruediger.giese@gfz-potsdam.de](mailto:ruediger.giese@gfz-potsdam.de)
- Katrin Jaksch, GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany, phone: +49 331 288 1518, email: [katrin.jaksch@gfz-potsdam.de](mailto:katrin.jaksch@gfz-potsdam.de)

**Abstract:** The GFZ Underground Laboratory is operated by the Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences. It is located in the research and education mine “Reiche Zeche” in Freiberg, Germany allows testing of geophysical and geotechnical tools and methods in boreholes and galleries. The lab is ideally suited for seismic system components such as receivers and sources for three-dimensional high resolution seismic imaging and tomography surveying. The lab layout of a basement rock block surrounded by galleries around a vertical as well as two horizontal boreholes enables the realization of various underground survey geometries e.g. well-to-well and well-to-gallery. The galleries are equipped with thirty 3-component geophone anchors installed in 1 m and 2 m depths for tomographic measurements or the recording of radiation pattern of seismic borehole sources.

## 1 Introduction

The GFZ Underground Laboratory of the Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences is utilized for continuous measurements since 1998. It is situated 150 m below surface on the first floor in the research and education mine “Reiche Zeche” of the Technical University of Freiberg (<http://tu-freiberg.de/lfbw>). Surrounded by three galleries, the site comprises a block of homogeneous high-grade gneiss of almost 50 m width and 100 m length ensuring constant environmental conditions. Along the galleries thirty 3-component geophone anchors with a length of one or two meters are installed in a distance of 4–9 m from each other. Two horizontal 8 ½” wide boreholes of 20 and 30 m length were drilled at the test site.

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In 2011 the lab has been extended with a 5 m wide borehole chamber (BC) situated 10 m above the galleries from which a 70 m  $8\frac{1}{2}$ " wide vertical borehole has been drilled (Fig. 1). The boreholes are open, not cased or cemented and are completely cored.

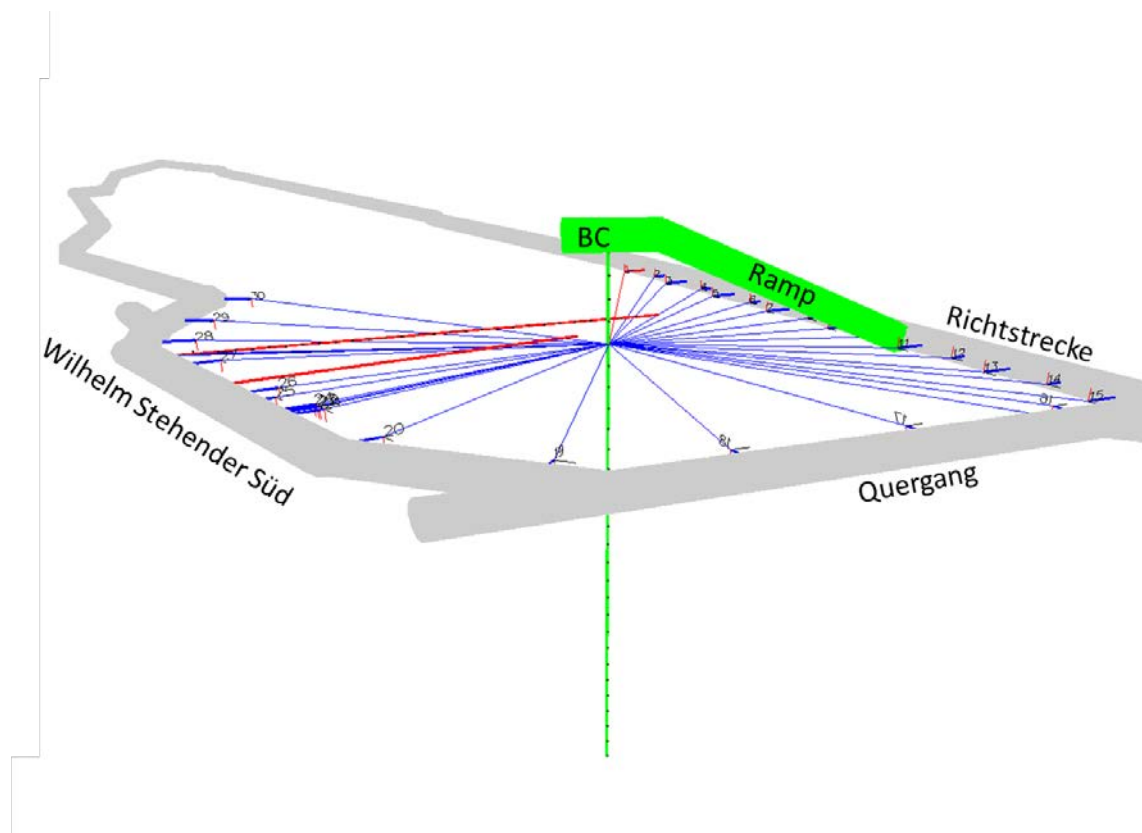


Figure 1: Perspective view of the GFZ Underground Laboratory. The horizontal boreholes BH1 and BH2 are 30 m and 20 m long (red lines). A 70 m deep vertical borehole BH3 (blue) is located in the center and accessible via a ramp (Ramp) and a chamber (BC). Thin blue lines mark the rays between a borehole source point at 10 m depth and the thirty 3-component geophones.

## 2 Technical Developments

High resolution surface seismic sources and different seismic receivers for application in underground constructions works have been tested Borm & Giese (2003). In-house developed and pneumatically-driven impact hammers and magnetostrictive vibrators (Fig. 2) have been used as sources. The signals of these surface sources are comparable to those from small charges of explosives fired in boreholes. Different geophone, piezoelectric and optical receivers have been compared with respect to their signal amplitude, signal phase characteristics and signal to noise ratio. The objective of other experiments was to study the influence of near surface conditions, different glues for geophone rock anchors as well as mechanically coupling techniques on the signal quality at the galleries surface and in boreholes. A removable mechanical coupling system for 3-component receivers in boreholes was developed and successfully tested at the GFZ Underground Laboratory. Geophone rock anchors were mounted along all galleries to gain sufficiently high resolution for experiments on seismic tomographic and imaging techniques Krauß et al. (2014) (Krauß et al., 2014). Major progress during the development of the control technique for magnetostrictive actuators has allowed the simultaneous steering of signal amplitudes and phases of multiple vibrators. Based on this technique two prototypes of phased array borehole sources, SPWD -laboratory and SPWD-wireline prototype, have been developed and tested in the two

horizontal and the vertical boreholes of the GFZ Underground Laboratory (Jaksch et al., 2010). The measurement results demonstrate the possibility of focusing seismic wave energy in the desired directions.



Figure 2: Pneumatic impulse hammer source pre-stressed against the Richtstrecke gallery wall (see Fig. 1).

### 3 Scientific Objectives

The development of high resolution 3D seismic imaging techniques for the structural exploration around tunnels and boreholes is currently the main objective of the research activities at the GFZ Underground Laboratory. Other geophysical or geotechnical tests like borehole magnetic and electric experiments can be performed in the lab as well. Different imaging techniques such as 3-component Kirchhoff-Migration or Fresnel-Volume-Migration (Lüth et al., 2005) are tested and modified with respect to their capability to resolve small-scale structures within the gneiss block (Fig. 3). The galleries also act as potential seismic reflectors for seismic imaging. The major challenge of seismic imaging in the underground is the spatial ambiguity of the recorded wave field due to limited aperture of seismic source and receiver survey geometry. New imaging techniques are developed to improve the spatial resolution of structural objects. Therefore, the measured polarization direction of the three-component data is used to determine points of reflection and to restrict the migration operator to the region that physically contributes to a reflection event (Fresnel Volume limit). Thus migration artefacts and crosstalk effects from converted waves can be reduced compared with standard migration schemes. The application of a phased array source for directional enhancement of seismic wave energy allows a further restriction of the migration operator and therefore leads to a further improvement of resolution. For the exploitation of the full potential of phased array sources for imaging it is important to study the process of wave generation and wave propagation in space. The configuration of receivers at the GFZ Underground Laboratory offers the possibility to study the radiation pattern of seismic waves around boreholes in the near and far field area. Recently, experiments to quantify the spectral energy of P- and S-waves have been carried out.

A further focus of investigation is tomographic inversion techniques. Experiments to analyze the application of full waveform inversion methods have been performed to detect and locate changes in rock

conditions while drill and construction works within the lab Krauß et al. (2014) (Krauß et al., 2014). An alternative approach to identify changes in rock condition is the application of coda wave interferometry Lüth et al. (2014) (Lueth et al., 2014). Meanwhile several thousands of measurements with permanently fixed magnetostrictive actuators were used to transmit seismic waves through the gneiss block. Various seismic chirp and sweep signals in the frequency range from 100 Hz to 6000 Hz have been applied. The experiments conducted so far have provided a high-resolution geophysical image of a defined crustal block that allows conducting further tests in an extremely well-characterized setting.

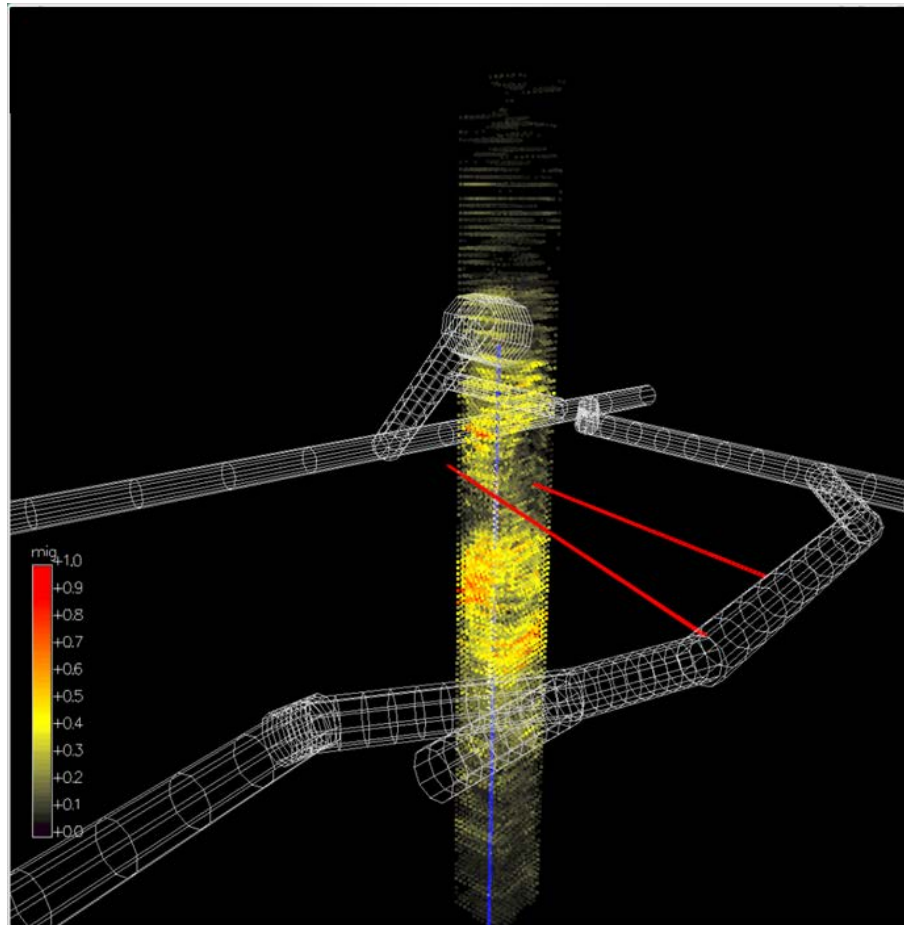


Figure 3: Example of a Fresnel-Volume-Migration for shear waves to image the surrounding area of the vertical borehole BH 3. High reflective areas caused by fracture zones are marked by yellowish and reddish colors.

## 4 Technical Specifications

### 4.1 Boreholes

- two horizontal open hole boreholes BH1 and BH2, diameter= 8 ½" (216 mm), BH1 length = 30.6 m, BH2 length = 20.4 m
- vertical open hole borehole BH3, diameter = 8 ½" (216 mm), BH3 length = 70 m
- 30 1-m and 2-m deep monitoring boreholes, diameter = 44 mm, distributed along the galleries with 4 m –9 m distance from each other

#### 4.2 Available downhole tools and infrastructure on-site

- SPWD - laboratory prototype equipped with four magnetostrictive actuators and four three-component geophones (GS 14L9, 28 Hz) for the application in horizontal dry boreholes
- SPWD - wireline prototype equipped with four magnetostrictive actuators and four three-component geophones for the application in vertical fluid-filled boreholes
- Two pneumatic impulse hammer sources for the application at tunnel surface
- Magnetostrictive actuator sources for the application at tunnel surface
- Seismic borehole receiver tool equipped with four three-component geophone receivers (GS 14L9, 28 Hz) and 1 m spacing for the application in horizontal dry boreholes
- 30 three-component geophone (GS 14L3, 28 Hz) anchors installed in 1 m and 2 m deep steel ropes
- winch with 100 m cable for downhole tool application in the vertical BH3
- two carriages equipped with hoisting cranes to transport and apply seismic surface sources on rails installed along the galleries
- workshop including tools for mechanical and electrical services
- two compressors
- internet connection

#### 4.3 Typical Applications and Services Offered

The GFZ Underground Laboratory is a test site for geophysical measurements, single- and cross-hole experiments or tunnel surface to borehole trials. With its combination of galleries and horizontal and vertical boreholes the GFZ Underground Laboratory enables the execution of three-dimensional geophysical experiments e.g. for tool validation and calibration under in-situ rock conditions. In this way it is a complementary test site to other deep crustal lab facilities which allow tool testing under high-pressure and high-temperature conditions.

The GFZ Underground Laboratory boreholes and the infrastructure are available for external scientific (and commercial) utilization. Due to complex, heavy-duty operations and because of safety regulations all operations will be conducted under the supervision of GFZ personnel. Tools and instruments of the GFZ as described above can be made available according to needs. For scientific purposes only the net costs have to be borne by the external user.

Various seismic datasets, logs and core scanner data are available from surveys in the GFZ Underground Laboratory for further investigations. The seismic tomography data to Krauß et al. (2014) Krauß et al., 2014 are published and available as supplementary datasets Krauß et al. (2013) (Krauß et al., 2013).

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