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# Superdeep Tests and Experiments at 9.1 km and 4 km

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**Abstract:** The Continental Deep Drilling Program of Germany (in German: Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland, abbreviated as KTB) was a scientific drilling project near the town of Windischeschenbach, Bavaria. The KTB Depth Laboratory comprises two 9.1 km and 4 km deep, water-filled boreholes in crystalline basement rocks just 200 meters apart from each other. Available equipment such as cables, winches, geophysical borehole tools as well as workshops and office infrastructure allows for in-situ tests and experiments at different pressure and temperature conditions. The two stable wells are large-diameter steel-cased and have been geophysically monitored in detail since 1996.

## 1 Introduction

In present day, earth system science geological and geophysical investigations on surface with support of modeling allow to chart out the underground of Earth. In certain cases however, a proof of concept can only be achieved by sampling and in situ observations at depth which requires drilling into the Earth´s crust. A drillhole opens not only the third dimension but through long-term observations also the critical fourth dimension. Time dependent properties in the deep underground comprise e.g. temperature, fluid composition and flow, stress, strain, among others. Deep and stable boreholes allow also technical test of tools for geophysical, deep marine, geotechnical or high temperature and high-pressure applications. As boreholes are fluid-filled, pressure and temperature stability of instruments can be checked as well as communication along umbilicals or cables.

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The deepest accessible test bed into the Earth´s crust is today the deep underground lab KTB of the Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences. In operation since 20 years, this lab comprises two adjacent deep boreholes of 4,000 and 9,100 m depth.

## 2 Field Conditions

During the KTB drilling project from 1987 to 1995 two deep boreholes were drilled in South-East Germany near the town of Windischeschenbach. The so-called pilot hole, KTB-VB, reached 4 km depth while the ultra-deep main hole, KTB-HB, reached 9.1 km depth. The boreholes truncated a stack of Paleozoic high-grade metamorphic rocks of leucocratic paragneisses and intercalated metabasic rocks (Fig. 1). This crystalline series forms the border between two major tectonic terranes which where amalgamated during Devonian to Carboniferous times in Central Europe. Brittle post-orogenic stacking deformed the rock pile during the Tertiary. The metamorphic rock pile is characterized by generally steeply dipping foliation of >60° and a few east-dipping fault zones (Emmermann et al., 1997).
However, both wells are almost completely cased with steel-pipes down to the total depth; the VB is accessible to nearly bottom hole while the HB is currently not accessible below 6,700 m. The two deep boreholes are very close to each other at a distance at surface of only 200 m. The KTB-HB shows very low deviation of the vertical (<2°) down to 7,400 m, below the deviation reaches higher values (>5°) as is in the entire VB. The platforms surrounding the two boreholes are completely concrete paved and therefore accessible also with heavy vehicles. High temperatures and pressures of T=190 °C at 6700 m depth, p >65 MPa in the HB below 6 km offer ideal test beds for high-tech developments and testing of new scientific and technical methods.

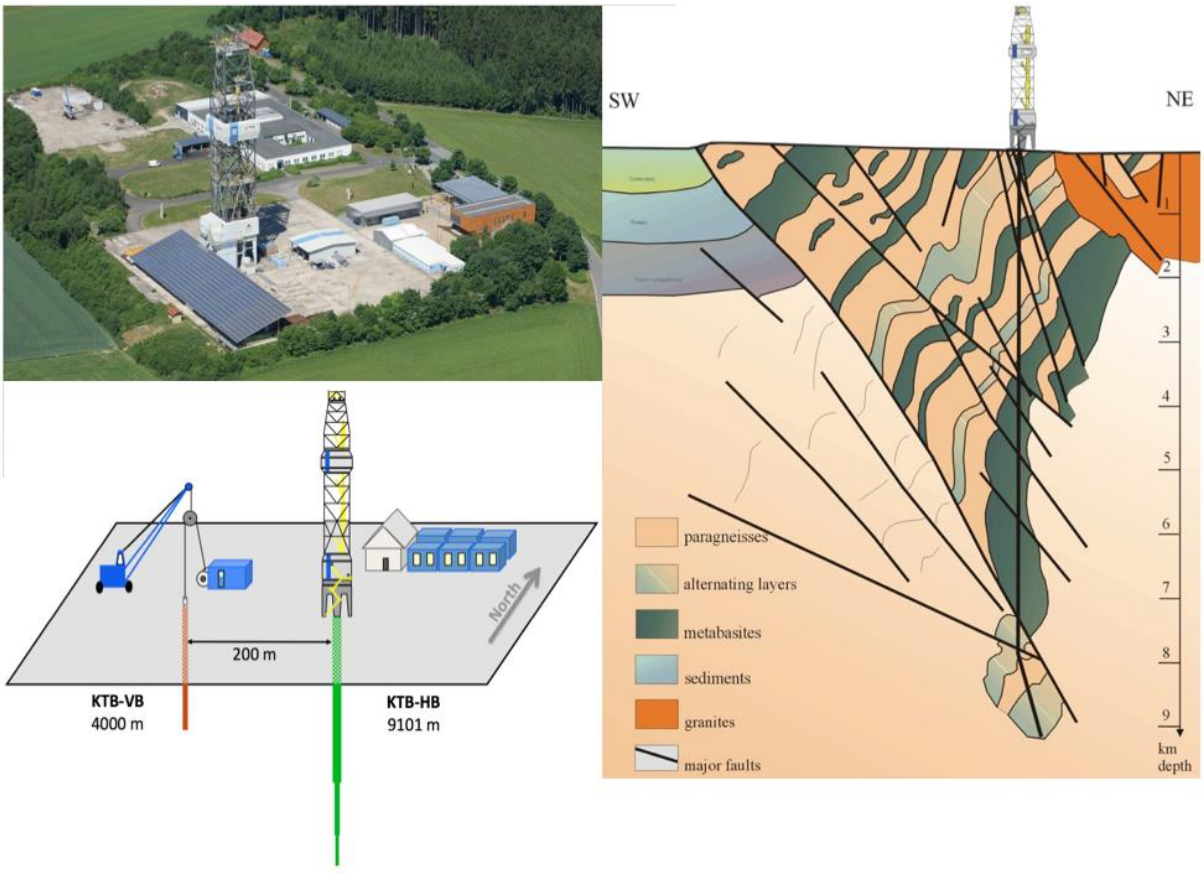


Figure 1: upper left: Aerial photo of KTB site, lower left: sketch of design of the two boreholes and geological profile to the right.

# 3 Technical Specifications

## 3.1 KTB-VB Pilot Borehole

- Depth = 4,000 m
- Maximum accessible depth = 3,970 m
- The borehole is cased to 3,850 m, below is open hole
- Casing diameter (inside) = 108 mm
- Diameter in open hole section = 152 mm (6")
- Hole deviation from vertical = strongly varying, maximum of 11.5° at 1,065 m
- Borehole fluid = rock fluid (saline formation water)
- Fluid density ≈ 1,020 kg/m$^3$
- pH ≈ 8, conductivity ≈ 86 mS/cm
- Pressure at 3970 m ≈ 40 MPa
- Temperature gradient ≈ 28 °C/km
- Temperature at 3,950 m = 115 °C (239 °F)
- Distance to KTB-HB wellhead: 200 m

## 3.2 KTB-HB main borehole

- Depth = 9,101 m
- Maximum accessible depth = 6,700 m
- The borehole is completely cased to 9,031 m
- Casing diameter (inside) 0 - 5,900 m: 312 mm, 5,900 - 7,785 m: 216 mm
- Hole deviation from vertical (<2° to 7,400 m)
- Borehole fluid = rock fluid below ≈ 3,000 m, above increasingly mixed with water
- Fluid density ≈ 1,020 kg/m$^3$ (average)
- pH ≈ 8 - 9.5, conductivity ≈ 47 - 86 mS/cm
- Pressure at 6,700 m ≈ 67 MPa
- Temperature gradient ≈ 28 °C/km
- Temperature at 6700 m ≈ 190 °C (374 °F)
- Distance to KTB-VB wellhead: 200 m

## 3.3 Available downhole tools and infrastructure on-site

Winches and truck:

- MW2000: 2000 m 4-conductor cable for slimhole sondes applications with 3 kN max. pulling force
- MW600: 600 m 4-conductor cable for slimhole sondes applications with 1.9 kN max. pulling force
- GFZ logging truck: 7200 m 7-conductor cable, 200 °C max.
- Winch Unit-2: 3600 m 7-conductor cable, 204 °C max.

A slimhole geophysical sonde set covers most typical geophysical logging parameters:

- Electrical resistivity (dual laterolog)
- Sonic velocity (two receiver, one transmitter)
- Natural gamma spectrum: U, Th, K (full spectrum SGR)
- Total natural gamma
- Oriented caliper & structures (4-arm dipmeter)
- Magnetic field (magnetometer inside dipmeter)
- Magnetic susceptibility

- Borehole images (acoustic televiewer)
- Mud parameters (T, p, resistivity)
- Fluid samples (PDS type)
- 3-component borehole geophone chain with 17 stations

Most tools are rated for 150°C/80 MPa and are operated with the lightweight data acquisition system Geobase (Antares) consisting of just a laptop and a hand portable tool interface panel. Logging data output is ASCII and LAS/LIS/DLIS. The SlimWave geophone chain is operated with WaveControl (Sercel).
The infrastructure comprises sheaves in the HB drill rig frame and on a crane at the VB allowing guided access to the wellheads via cables or steel ropes (Fig. 2). A fully equipped mechanical workshop and office space are available too.

Figure 2: a) sheaves cable guidance into the pilot well, b) photo of HB well head, c) drill rig of the HB

## 4 Data Resources

During the operational phase of the KTB drilling all technical and scientific digital data collected in the drill rigs and the field laboratory have been acquired in data bank systems. In the mid to late 1990 years they were opened to web access through the KTB Information System. Furthermore, all field lab reports published during the drilling were published later as open access reports and are available through web resources. Data available comprise:

- Data from Internal KTB Working Groups with geology, tectonics, geochemistry, petrophysics and rock mechanics on all core, cuttings and fluid samples
- Drilling engineering data with all daily reports from pilot and main well
- Large scale experiment data such hydrofrac/ seismic or fluid hydraulic experiments
- Borehole measurement data including all logs registered
- Measurements in the KTB with seismic and geoelectric tools
- Geology, geochemistry and petrophysics data from external KTB Working Groups

The data are available for download from the site: http://www-icdp.icdp-online.org/sites/ktb/. This site also provides combined background information on the KTB program.

A list of about 2000 published scientific papers is available at:
http://www-icdp.icdp-online.org/front_content.php?idcat=1090 references

The KTB field lab reports (1987-1995) with detailed data and method descriptions are available in printed versions in respective libraries. A full overview on all KTB Reports can be found via gfzpublic. In addition, all KTB Reports from 1987 – 1990 have recently been published as e-Reprints by the GFZ library (KTB Reports 87-1 to 90-8).

The strategy to migrate these data into a modern repository has been evaluated in a paper by Klump et al. (2015).

## 5 Typical Applications and Services Offered

The KTB deep laboratory of the GFZ is a primary site for deep borehole geophysical measurements, cross-hole experiments or surface to borehole trials for geoscientific or technical methods and equipment under in-situ borehole conditions. Other utilization comprise for example:

- Testing of deep water instruments or HP-HT (6,700 m, 190 °C, 67 MPa) tools
- True in-situ tests of sensors, housings, cables etc. at large depth with high temperature and high pressure (6,700 m, 190 °C, 67 MPa)
- Test of cables, umbilicals or wireless communication technologies
- Repeat measurements over several days, weeks and even months
- Test in just one well or in both wells simultaneously
- Cable seasoning up to a length of 6,700 m
- Check, verification and calibration of downhole and deep water instruments in boreholes that are thoroughly documented by many measurements

The KTB 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. The KTB-Deep Lab of the German Research Center for Geosciences Potsdam (GFZ) as a worldwide unique facility for a wide range of experiments under in-situ borehole conditions is available for science and research through requests to ktb-tl@gfz-potsdam.de.

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