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Energy and fluid transport in continental fault systems 1st phase: fluid production test in the KTB pilot hole

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The "Kontinentale Tiefbohrprogramm der Bundesrepublik Deutschland (KTB)" was enormously successful. It has revealed a wealth of geoscientific data and brought up new results of unrivalled quality and broadness. However, several of the main objectives have only been marginally investigated, and the scientific potential of the two KTB boreholes, the 4.0 km deep pilot hole (KTB-VB) and the 9.1 km deep main hole (KTB-HB), has by no means been fully exploited. The general aim of a new series of projects is to study transport processes of energy and fluids in continental fault systems at the KTB drill site - on the kilometer scale. The whole section of the drilled formations comprise crystalline rocks, namely paragneisses, amphibolites and metabasites. Two dominant fault systems are encountered at 4.0 and 7.2 km depths, respectively.

The first major experiment is a fluid production test over a period of 12 months in the KTB-VB. The test started on 10 June 2002 with the installation of an electrical submersible pump at 1283 m below surface. The motor of the pump has a performance of 21.3 H.P. at 650 volts and 24.5 amps; it is operated with a frequency controller. A LEUTERT pressure gauge (0–350 bars) is mounted below the motor at 1285 m depth. The crustal fluids produced from the open hole section (3850 m – 4000 m, approx. 120°C) are led through a 2 3/8″ tubing to the surface. The installation was finished on 18 June.

Fluid outlet temperature, variation in water pressure above the pump, fluid yield as well as pH and redox values, electrical conductivity and the amount of dissolved gases are monitored and recorded in real-time. The separated gas phase is analyzed in real-time with a quadrupole gas mass spectrometer for N_2, CH_4, He, H_2, O_2, Ar, and CO_2. ^{222}Radon is measured by alpha-spectrometry using a Lucas cell detector (see also Fig. 1). Several working groups are taking water and gas samples on a regular basis for further detailed investigations.

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In addition to this, the KTB main hole is equipped with (1) a borehole seismometer (BG 250 from Createch S.A., Paris) which is permanently installed at 3900 m depth and (2) with two water level sensors at shallow depths. These tools monitor seismic and hydraulic signals that might be caused by the draw down in the KTB-VB, 200 m away from KTB-HB (distance at surface).

On 24 June, the long-term fluid production test started with the pump operating at approx. 60% of its maximum power. This resulted in an average yield of crustal fluids of 29 liters per minute (surface water temperature 25°C). The draw down was some 280 m, only, or about 8 times less than was estimated on the basis of an earlier pump test in 1991 – one year after drilling of the KTB-VB was completed. On 2 October, the pump speed was increased to its maximum performance, which resulted in a fluid yield of 54 l/min at a draw down of some 620 m and 42,3°C outlet temperature, close to the end of the production test on 26 June 2003.

Since the beginning of the test, the volume ratio of gas to water (surface conditions) was varying between 0.95 and 1.05. Electrical conductivity of the fluid was rather constant at 86 mS/cm, as were the values for pH (7.4) and Eh (−430 mV). 99% of the gas phase was composed of nitrogen and methane (including other HC); He (0.5%), H_2, Ar and CO_2 were present in trace quantities, only. ^{222}Rn activity varied between 5000 and 6000 Bq/m^3. Data reports on the regularly monitored parameters are available to the Science Team through the KTB web page (http://www.icdp-online.de/html/sites/ktbhydraulic/news/news.html).

Major, though preliminary findings from to test can be summarized as follows:

– Analyses of two interim recovery tests in October and December 2002 appear to indicate that the probed reservoir at 4 km depth is infinite; hydraulic transmissivity is around 3×10^{-13} m^2

– Hitherto, we did not observe any significant changes in the concentrations of dissolved fluid constituents including gases. Furthermore, isotope ratios of Helium

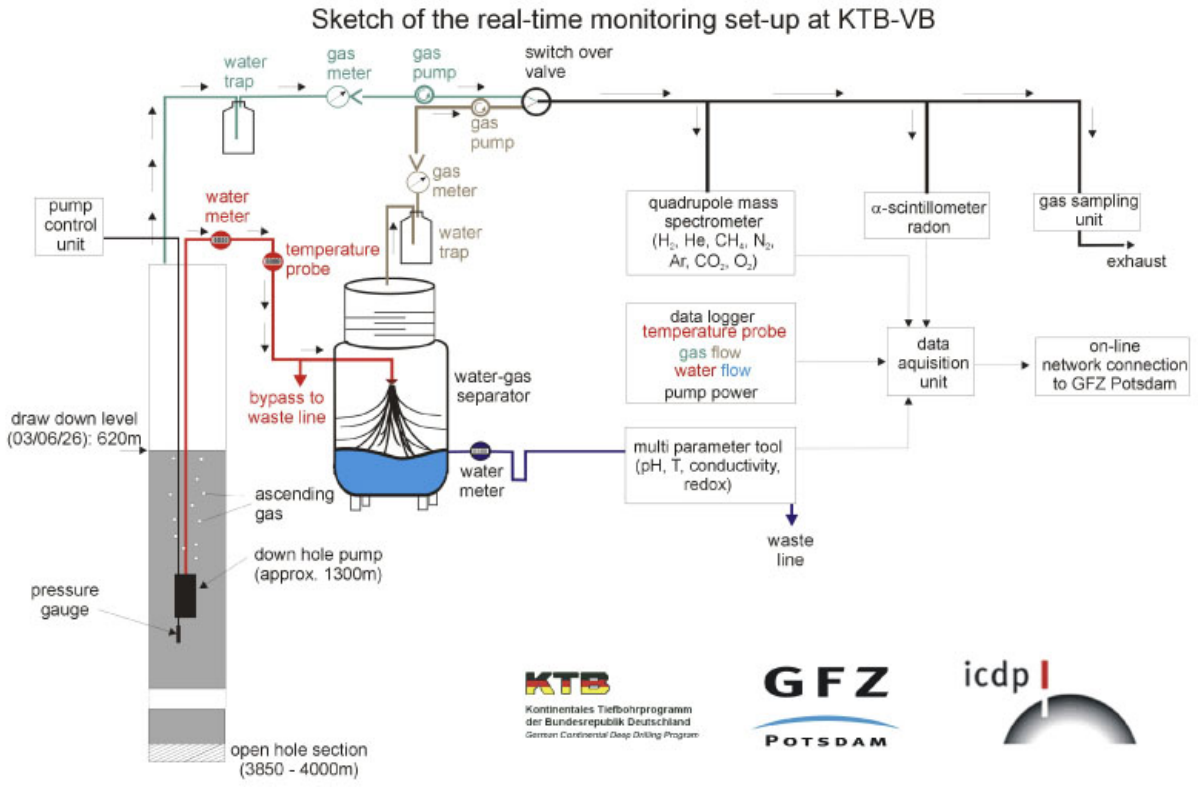

Fig. 1. Real time monitoring set-up of KTB-VB.

($He^3/^4He = 5.7 \pm 0.2 \times 10^{-7}$; $R/R_A = 0.41$), Neon ($^{21}Ne/^{20}Ne = 0.0035$), Argon ($^{40}Ar/^{36}Ar = 900$), CH_4 ($\delta^{13}C = -52‰$) and Sr were more or less constant throughout the production period.

– Rare earth element (REE) concentrations of the produced fluids are extremely low. Such low REE concentrations have rarely been reported before, neither for natural surface waters nor for crustal fluids.

– Surprisingly, up to now Radium and Radon are the only elements the concentrations of which depended on the production rate. Concentrations were 30% higher at 58 l/min yield than at 29 l/min. However, Ra and Rn are in radio-chemical equilibrium.

– The down-hole seismometer in the KTB-HB worked fine and has detected small seismic events in the near vicinity of the borehole, indicating that the events might be released by the production activities.

– Neither thermophile nor hyperthermophile organisms were detected unequivocally until present, possibly because the inlet-temperature at the bottom of the pilot hole is too high (approx. 120°C).

In accordance with the original schedule, the active fluid production in KTB-VB was finished on 27 June 2003. A water level recovery test lasting four weeks has already been started. The submersible pump and the tubing will be pulled out in August. Thereafter, DC resistivity and alternating temperature and conductivity logging is scheduled until the end of 2003.

The second phase of this new series of KTB experiments is planned to start in April 2004 and will include a massive fluid injection test in the KTB-VB, lasting again 12 months. Monitoring and analysis of induced seismicity and some other geophysical and hydraulic parameters will be the key issues. International partners who are interested in the coming or future experiments are most welcome to participate.