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Exploration of thermal groundwater from metamorphic rock aquifers in Austria

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ABSTRACT

During the past **15** years more than twenty geothermal wells were drilled in Austria. In most cases the targets of thermal water exploration were tertiary sediments and above that, Palaeozoic and Mesozoic carbonatic rocks.

Three of the geothermal wells drilled in Austria (Gabelhofen Thermal 1, Längenfeld Thermal **2** and Sauerbrunn Thermal 1) were planned to explore thermal ground water in Aquifers of metamorphic rocks. Although most metamorphic rocks have to be regarded to be hydraulically low conductive, depending on the geological settings these formations may play the role of **aquifers** featured by weathering and brittle deformation. A number of hydrogeological features of metamorphic rocks **are** presented by these three geothermal wells. They represent examples **of** successful thermal water exploration in metamorphic rocks.

KEYWORDS

Fractured metamorphic rocks, thermal water exploration, Austria

Methods of exploration

Features of metamorphic rock aquifers

Most metamorphic rocks **are** regarded not to be sufficiently hydraulically conductive in terms of water exploitation, and if they are, their transmissivities **are** generally low compared to coarse clastic sediments and to fractured carbonatic rocks. The porosities of metamorphic rocks are caused by weathering and by brittle deformation (STOBER 1995).

Sensing

Existing hydrocarbon exploration wells and/or geothermal exploration wells including geophysical borehole measurement programs provide information in order to explore deep groundwater aquifers. As these data are rare especially regarding metamorphic rocks, on site measures are generally necessary. In depths between 700 m and 3.000 m reflection seismic including geological interpretation proved to be a **useful** tool of modelling basins. Additional Information can be obtained by remote sensing and tectonic analysis. *After* performance of the on site measures and interpretation of the results, the consultant has to define the target and the technical program.

Drilling and wireline jobs

The well is drilled by a contractor, using a Petroleum rig. After drilling the sections, wireline measurements are performed to obtain data about the section drilled. Besides Gamma Ray, Resistivity, Temperature and other standard measurements, wireline service companies developed special tools for hardrock geophysical measurements e.g. Formation Micro Scanner (S E W 1989). High quality detection **of** fabric and imaging the borehole wall in terms **of** Resistivity gradients in high resolution can **be** performed. The dip of tectonic elements are made visible and among others the following mathematical processing can be performed mean orientation, fracture density, fracture trace length, mean fracture aperture and the apparent fracture porosity (SERRA 1989). **These** wireline measurements and the interpretation of the data **are** relatively expensive, but they can provide clarity regarding the hydraulically conductive sections and support the consultant deciding the upcoming technical program. Especially if in brittle rock aquifers a production liner has to be installed, it makes sense to judge the productive sections of the bore ahead and save **wire** wrapped liner meters. Furthermore the data derived from these geophysical measurements feed back the consultant's model of the tectonic features, that the project was scientifically based on.

Completion

Open hole completion or liner completion is performed. Generally carbonatic aquifers **are** open hole completed, while wells producing out of aquifers of clastic sediments generally are completed by **wire** wrapped liner and gravelpack. Metamorphic rocks can be open hole completed if the rocks **are** mechanically stable, however according to experiences regarding the well Sauerbrunn Thermal 1 in Burgenland, Austria, it can be necessary to perform liner completion and open hole gravelpack, due to mechanically unstable conditions of metamorphic rocks (BOCHZELT & GOLDBRUNNER 1997).

Testing

Short term hydraulic tests provide information about whether or not the well is successful, and information about temperature, hydrochemical conditions and an idea about the productivity of the well. A round trip after an open hole test can help to fmd out whether or not the borehole is stable and can be open hole completed or liner completion is necessary. Reliable data about the aquifer can usually not be obtained by a short term test. ***An*** aquifer test over a period of at least six weeks including observation of recovery and hydraulic interpretation turned out to be a representative measure to obtain hydraulic information of the aquifer. These tests are run with several production rates. Rates are not increased before a stationary production is performed. These stationary flow conditions supply the consultant with data, that can be processed to calculate skin effects. Furthermore from these information the consultant is able to design the long term production device. Data out of recovery after a long term test (aquifer test) are **some** of the most valuable information for the hydrogeologist. He can process the data and also calculate the transmissivities of different sections of the aquifer, e.g. barriers with lower hydraulic conductivities (LANGGUT & VOIGTH 1980).

Examples of thermal water exploration in metamorphic rock aquifers

Gabelhofen Thermal 1

The well Gabelhofen Thermal 1 was drilled 1995 in an alpine basin in Styria, Eastem Austria (figure 1) to a total depth of 2.000 m. The well was successful in carbonate micaceous schist in the section between 1.050 m and 2.000 m below ground level. Due to intense and regionally developed brittle deformation these rocks work as an aquifer of a deep groundwater system. The system is artesian with a closing pressure of 8 bars, however the artesian production rate was only 0,15 l/s during the fust test (KRIEGL & GOLDBRUNNER 1996).

An acid well stimulation was performed to improve the hydraulic conductivities in the well near section of the aquifer. Although this measure is usually performed in carbonatic rocks, it was done in order to stimulate carbonatic fractures of the metamorphic rocks. The artesian flow rate increased to 0,4 l/s after the stimulation. The expected yield by pumping is 1,5 l/s at 600 m drawdown and roughly 2,5 l/s at 1.000 m drawdown (KRIEGL & GOLDBRUNNER 1996).

Langenfeld Thermal 2

Längenfeld is situated in a valley called Ötztal in Tirol, Western Austria (figure 1). From 46 m below ground level to the final depth, metamorphic rocks (amphibolite, micaschist and eclogite) were drilled (KRIEGL & GOLDBRUNNER 1998). Tectonically they are part of the Middle Austroalpine Nappe pile (TOLLMANN 1977).

According to H. MOSTLER (1995) these metamorphic rocks are featured by several zones of intense brittle deformation, that are called cataclastic **zones.** Two of them (cataclastic zones 5 and 6) represented the targets of the project Längenfeld Thermal 2. The borehole was drilled in 1997 to a depth of 1.318 m vertically and from 1.318 m to 1.870 m [Measured Depth (= 1.804,8 m True Vertical Depth)] by directional drilling. The section below the casing shoe 9.5/8" from 811 m to 1.804,8 m TVD was completed open hole due to mechanic stability of the rocks.

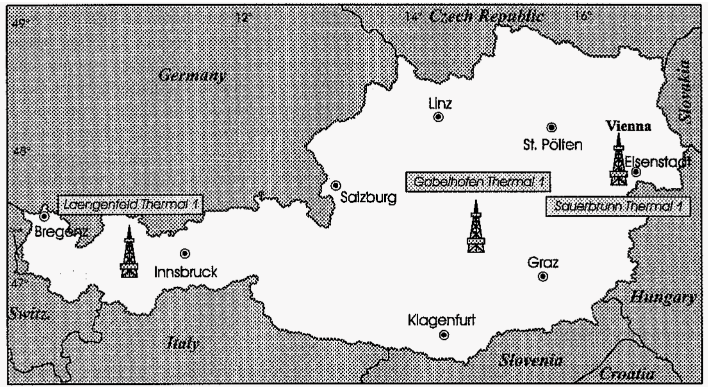

Figure 1: Map of Austria including the drilling sites Langenfeld Thermal 2, Gabelhofen Thermal I and Sauerbrunn Thermal 1.

The following intervals were proved to be productive by flowmeter wireline measurements (KRIEGL & GOLDBRUNNER 1998): 980 m - 1.000 m, 1.490 m - 1.540 m (MD) and 1.800 m - 1.835 m (MD).

The water was produced by a flowrate of maximum 5 l/s with a wellhead temperature of up to 41 "C. The corresponding drawdown was 185,8 m, which is 576 m below closing pressure (KRIEGL & GOLDBRUNNER 1998).

The transmissivities of the aquifer system calculated from a recovery test according to LANGGUT, H. & VOIGTH, R. (1980) range from 2,1 x 10^{-5} m^2/s to 3,7 x 10^{-6} m^2/s, decreasing with distance from the production well (KRIEGL & GOLDBRUNNER 1998).

Sauerhrunn Thermal 1

The Mattersburg Basin is a basin, which represents a marginal development of the Vienna Basin (TOLLMANN 1985). It is 24 km x 18 km wide and the thickness of the tertiary sediments is up to 2.500 m (WESSELY et al. 1993). The Basement are metamorphic rocks of the Lower Austroalpine nappe pile (FUCHS 1962; BOCHZELT & GOLDBRUNNER 1997).

Sauerbrunn is situated at the western margin of the Mattersburg Basin (figure 1). The transition zone of the metamorphic rocks and the tertiary sediments was found out to be a groundwater discharge area, where mineral water and CO_2 are gained out of metamorphic rocks in the section between 78 m and 110 m below ground level (GOLDBRUNNER 1995). According to wireline measurements 80 m below ground level temperatures of up to 24 "C were observed (BOCHZELT & GOLDBRUNNER 1995).

The margin of the basin is featured by steep faults with drop rates of several hundred meters (WESSELY et al. **1993).** By reflection seismic, remote sensing and tectonic interpretation of the results (BOCHZELT & GOLDBRUNNER **1995)** the top of the metamorphic rocks, featured by interval velocities **of 6.000 m/s,** was modelled in a depth off **850** m below ground level at a location only **1.750** m from the mineral water well.

The borehole Sauerbrunn Thermal **1** was drilled at the location mentioned above to a final depth of **1.100** m and hit the basement of the tertiary sediments at **892** m. From **892** m to the **final** depth the borehole tapped gneiss from **892** m to **1.055** m and marble from **1.055** m to **1.100** m (figure **2).**

After drilling Formation Micro Scanner wireline measurement was performed, the data were processed and interpreted (BRISTOW **1997).** Certain fractured sections were connected to brittle deformation as observed by remote sensing prior to **the** drilling phase. They were interpreted to be hydraulically conductive over the sections listed in table **1.** This table demonstrates as well results of flowmeter wireline measurement after completion (see also figure **3).**

Table 1: List of sections judged as being hydraulically conductive by FMS and results of Flowmeter wireline measurement afer completion (FMS = Formation Micro Scanner, WWL = Wire Wrapped Liner).

Section from - to	**FMS classification**	**Flowmeter classification**
	productive	productive
910 m - **920** m	productive	no WWL
931 m - **946** m	productive	productive
965 m - **966** 5 m	productive	productive
	productive	productive
976 m - **980** m	productive	no WWL
980 m - 1.012 m	not productive	not productive, no WWL 976 m - 1012 m
1.012m - 1.100 m	productive ?	not productive, no WWL from 1.055 m

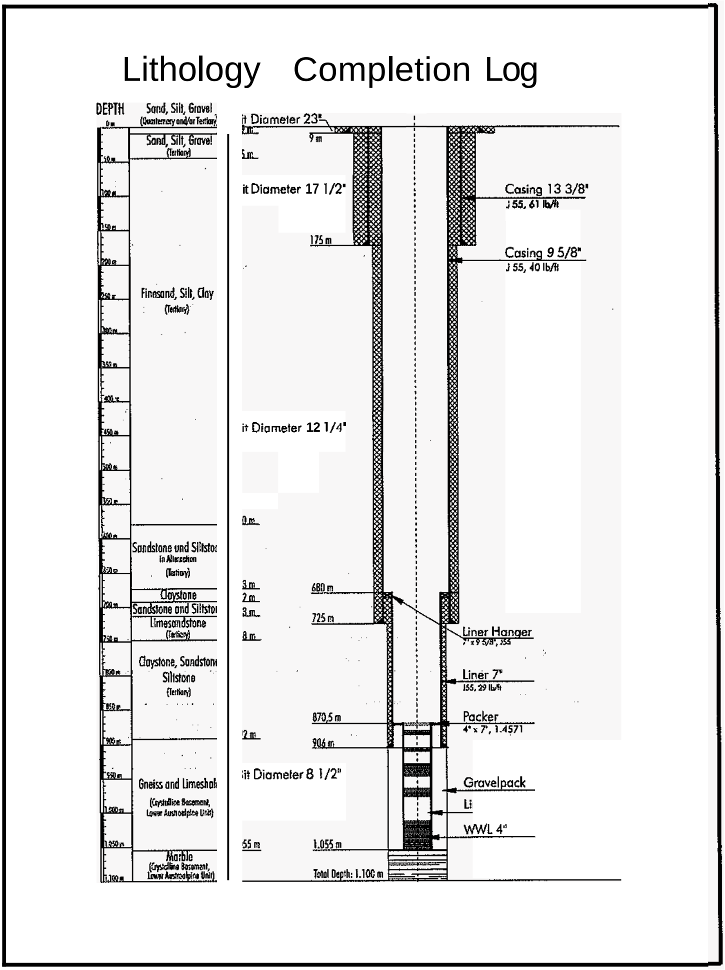

Figure 2: Completion of the well Sauerbrunn Thermal 1.

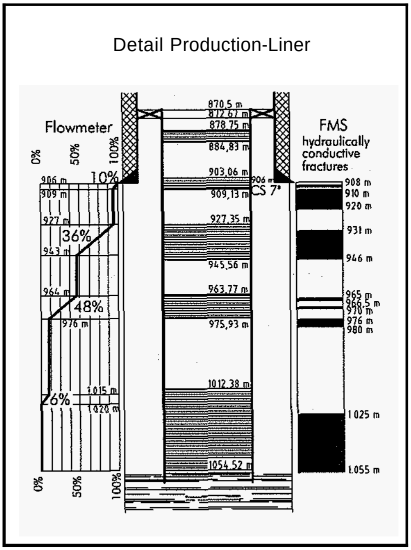

Figure 3: Formation Micro Scanner (FMS) and flowmeter wireline results

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