Enhanced Geothermal Systems: The Soultz-sous-Forêts Project

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1 Introduction

The utilization of geothermal power from natural hot water or steam deposits is not rare, nor new. Today the installed capacity add up to more than 11 GW (electricity) and the first geothermal power production started in Italy at the beginning of the twentieth century. Unfortunately, geothermal sites with adequate geological conditions are limited. Contrariwise there is a high potential linked to low permeable, but deep and therefore hot rocks, which can be utilized by the so-called enhanced geothermal systems (EGS).

Since more than 20 years, scientists from universities and industry spent their effort at Soultz-sous-Forêts to build the first EGS power plant, which came into operation in 2009. During a first phase, a certain number of wells have been drilled down to more than 5000 m depth and hydraulic and chemical stimulation techniques have been used to reopen existing joints and tectonic faults with the aim to create an artificial heat exchanger in the crystalline basement rocks [1–3]. In a second phase, a binary power plant has been installed on site. The recent third phase of R&D activities is related to the operation of power plant and reservoir and their interaction. Major topics are for example corrosion, scaling and the testing of the whole equipment.

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2 Geology and Natural Reservoir

The Soultz site has a long lasting history of gas and oil exploration. In fact, the region is one of the oldest oilfields worldwide. Because of several thousand boreholes drilled for hydrocarbons, the geology and especially the temperature distribution in the depth was known quite well. A comparison to typical Central European conditions, anomalously high geothermal gradient—up to 11 K per 100 m—was the reason, why Soultz-sous-Forêts was chosen for the utilization of geothermal power.

The local caprock is formed by a suite of tertiary sedimentary rocks (light yellow in Fig. 1). Below a sequence of Mesozoic layers (Jurassic to Buntsandstein, blue and purple in Fig. 1) covers the crystalline basement (red in Fig. 1).

The crystalline basement at Soultz-sous-Forêts consists of Paleozoic granites. Microfissures at grain scale and cataclastic shear zones present various mineral alterations and are occasionally filled with highly mineralized brine with salt content up to 100 g/l.

Samples of the natural formation fluids in the crystalline basement from various wells and from different depths present a similar geochemical fluid composition (NaCl-dominated brine, pH 5). Isotope studies indicate that the whole brine volume has the same sedimentary origin and history. From gas analyses, carbon dioxide is the predominantly free-gas fraction. Geothermometry information derived from geochemical fluid data gave hints that the brine was once heated up to 220–240 °C temporarily [4–6].

Tectonic faults and joints are preferred flow paths. According to hydraulic tests the transmissibility of shear zones inside the granitic basement rocks can be determined

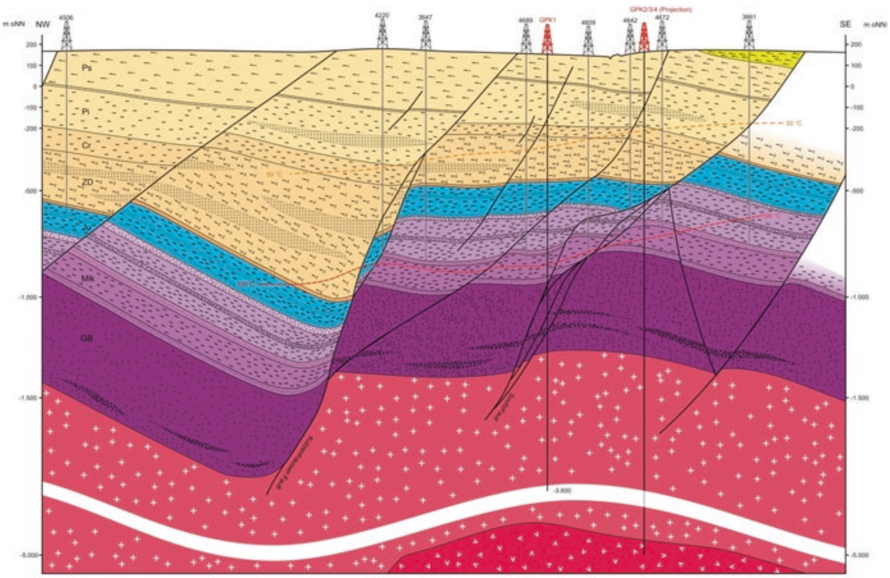

Fig. 1 Geological profile section (according to Cautru, 1989)

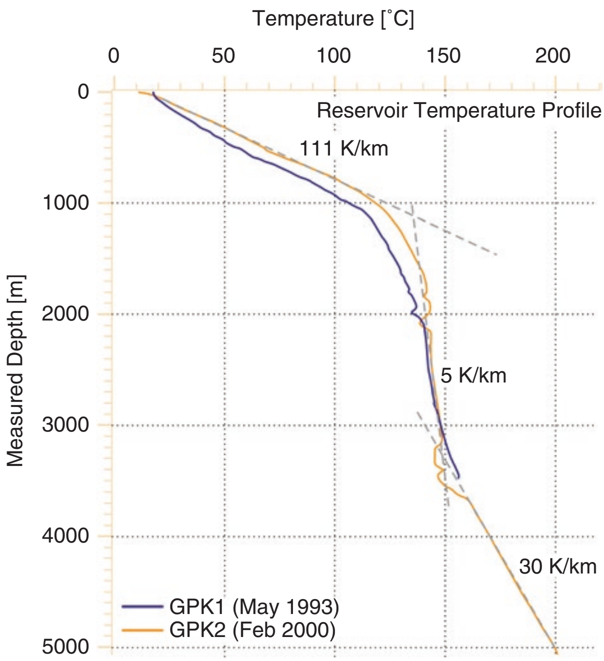

Fig. 2 Geothermal gradient in the Soultz wells (data from LIAG, Hannover)

to 10^{-11} m^2, while the non-sheared or alterated rock suites present a transmissibility of 10^{-16}–10^{-17} m^2 [7].

The average temperature gradient in Central Europe increases with 3 K per 100 m depth. As mentioned above, the temperature increase at Soultz-sous-Forêts amounts up to 11 K per 100 m in the sedimentary cover (Fig. 2). This leads to a geothermal heat flow which is in a range from 100 to 120 W/m^2. This is twice times higher than the average heat flow measured in Central Europe.

As presented in Fig. 2, the geothermal gradient drops significantly in a depth between 1000 and 3500 m (0.5 K per 100 m). The reason is a convection cell of natural brine which occurs at the interface of the sedimentary caprock and the underlying crystalline basement. Below this convection cell and therefore deeper than 3500 m the geothermal gradient at Soultz-sous-Forêts is equivalent to the average geothermal gradient in Central Europe.

3 Stimulation and Microseismicity

The main goal at Soultz-sous-Forêts was to enhance the natural permeability of the crystalline basement rocks. Therefore, several hydraulic and chemical stimulation tests have been performed. In Fig. 3 the principal of both stimulation techniques is

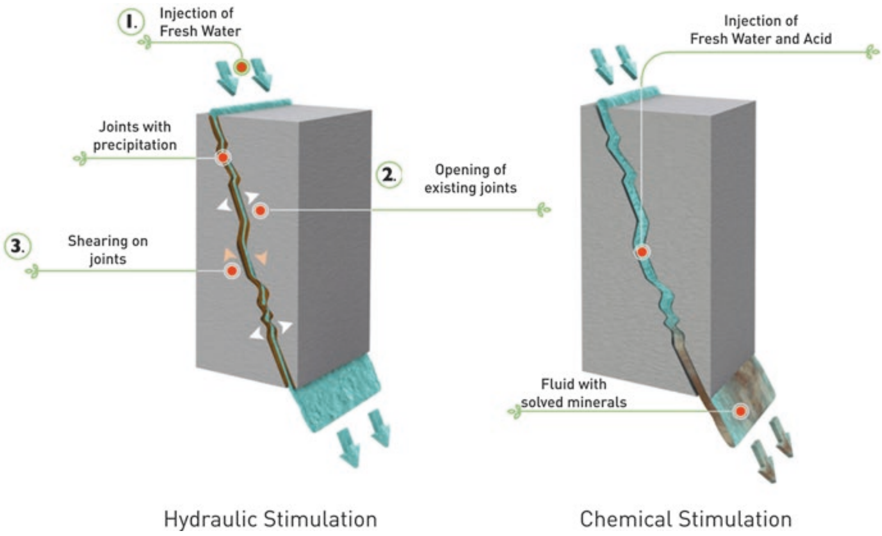

Fig. 3 Principal of hydraulic and chemical stimulation

presented. To open existing joints and tectonic faults, fresh water is injected under high pressure in deep wells (maximum 180 bar). As a consequence the joints is reopened and then sheared. After pressure reduction at the end of the hydraulic injection phase, the reopened joints and faults might tend to close again, but their uneven surface counteracts. For chemical stimulation, different additives can be used (alkaline or acidic). The target is to clean by mineral dissolution, joints, faults, and pore volume in the vicinity from precipitations or matrix cement.

After stimulation, the productivity/injectivity of the Soultz wells was improved 20 times and an artificial heat exchanger with a volume of 3 km^3 has been developed. While the chemical stimulation was nearly aseismic, the hydraulic fracturing caused ten thousand of microseismic events. They have been measured by an extending seismic monitoring network and located 3D in real time (Fig. 4). The highest magnitudes recorded while hydraulic stimulation were up to 2.9, but by far the largest proportion was below a certain level, which can be felt by the public [8, 9].

4 Recent R&D Activities

Since 2009, the geothermal power plant is in operation (Fig. 5). Today it is supported by the industrial consortium G.E.I.E. with its members EnBW and ES. After years of intensive R&D work the power plant unit together with the major part of the surface installation was retrofitted in springtime 2016 and will be used for commercial power production in future.

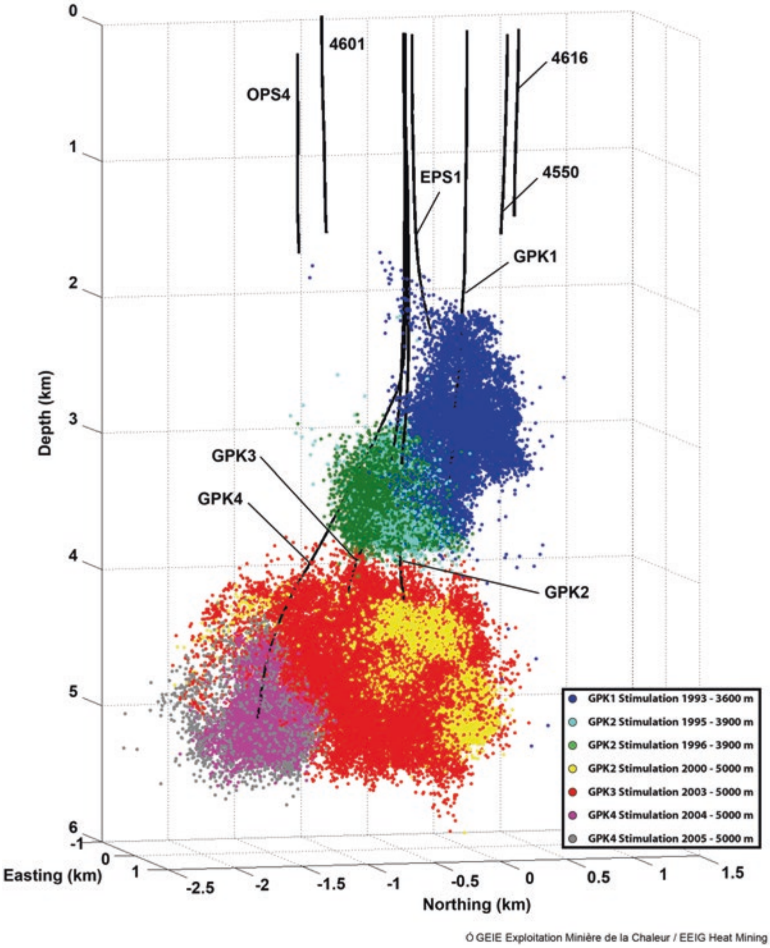

Fig. 4 Microseismic events at Soultz during hydraulic stimulation (©GEIE, 2011)

5 Conclusion

The Soultz-sous-Forêts project indicates clearly that geothermal power production is possible from an area without any active volcano within a low natural permeable reservoir (naturally fractured granite). This opens the opportunity to install geothermal power plants independent from sites with preferable geological conditions and—similarly important, because heat can only be transported for high cost—the utilization of geothermal power close to the client. Today the levelized cost of energy from an EGS plant is not low. But it can be compared with other renewable energy options like photovoltaic and it has a high cost reduction potential.

Fig. 5 Geothermal power plant at Soultz-sous-Forêts (©GEIE, 2009)

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