ENHANCED GEOTHERMAL SYSTEMS: NEW PERSPECTIVES FOR LARGE SCALE EXPLOITATION OF GEOTHERMAL ENERGY RESOURCES IN SOUTH AMERICA

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Abstract. The European Hot-Dry-Rock (HDR) project in Soultz, France, is located at the western flank of the Rhine Graben to explore the use of geothermal resources for producing electric power. The HDR concept is based on creating an artificial underground heat exchanger by hydro-fracturing deep crustal rocks between two or more boreholes. Such a system was realized in Soultz at a depth of 3.0 to 3.5 km by injecting and producing more than 700,000 m^3 of fluids from 1993 to 1997, resulting in a vertical slab of stimulated rock with a surface area of 3 km^2 and a horizontal extension of about 400 m. During a four-month experiment in 1997, more than 240,000 m^3 of fluids were injected and produced at flow rates between 20 and 25 l/s. The outflow temperature was 142 °C. The heat exchanger is thus functional.
However, there are indications that the hydraulic fracturing also created a connection to the natural fault system, which is part of a flow field across the Rhine Graben (80-100 km). The artficial underground heat exchanger is thus connected to a very large natural reservoir, and the original HDR concept evolved to an Enhanced Geothermal System (EGS). This 'Soultz-Concept' for energy production can be transfered to any location with large-scale fault systems, e.g. rift systems associated with opening of the Atlantic (Potiguar, Barreirinhas and Tacutu, Brazil), and areas of large scale deformation in the northern parts of the continent (El Pilar-Casanay, Venezuela).

1. Introduction

An artificial underground heat exchanger at a depth of 3.0 to 3.5 km was created in the granitic basement of the Rhine Graben, close to the town of Soultz in France, by hydraulically connecting two deep boreholes with the hydrofrac-technique (Baumgärtner et al., 1998). The success of this artificial underground heat exchanger was proven by producing more than 10 MW thermal energy for four months in 1997. The concept developed in Soultz is an improvement of the conventional Hot-Dry-Rock (HDR) method for conditions found at flanks of continental rift systems and can thus be transferred to other locations as well.

2. The Regional Flow- and Temperature- Field

Soultz-sous-Forêts is the center of the largest anomaly of surface heat flow in central Europe. With a background value of 80 mW m^{-2} for the Rhine Graben, heat flow exceeds 140 mW m^{-2} at the European HDR project site (Schellschmidt and Clauser, 1996). This anomaly is located about 70 km north of the Kaiserstuhl volcano which is associated with a minimum in crustal thickness and a maximum of mantle He-isotope concentrations in the upper Rhine Graben. The surface heat flow density anomaly at Soultz is not a signal associated with processes at great depth (e.g., rifting) but the result of a redistribution of heat by advection due to fluid flow across the Rhine Graben, which in turn is focussed on the rift faults.
The temperature field across the Rhine Graben is shown in Figure 1 together with the simplified geological cross section. High temperatures characterize the area of Soultz, the HDR site (X=20 km). The general trend, showing lower temperatures in the center of the graben (X=40 km), is in part a result of the high radiogenic heat production of the granite in combination with the topography of the basement. The large near-surface gradient is the result of convective heat transport partly in the Buntsandstein aquifer but mainly from deep parts of the granitic basement (Pribnow and Clauser, 1998).

3. The Soultz Concept

Numerous hydraulic experiments in Soultz indicate that the fracturing of the granitic basement on the one hand produced a volume of enhanced permeability between the two boreholes (Fig 2), and on the other hand hydraulically connected this stimulated volume to the regional fault system (Jung et al., 1995). The conceptual Model of the underground heat exchanger is thus based on two flow mechanisms: flow in the artificially stimulated volume and channeled flow along natural fault zones.
Figure 3 shows the geometry of typical fault systems observed at the western flank of the Rhine Graben: parallel and transverse to the graben flank, and parallel to the present-day stress field. The volume of artificially enhanced permeability connects the boreholes to this extensive flow system. Considering the two flow regimes in equivalently porous media and in faults zones is important for the understanding of the heat exchange process in the underground. The stimulated zones provide the pathways and the large internal surface for an efficient heat exchange between rock and fluid. This heat exchanger may change in time by effects of over-pressure, reduced permeability or cooling during long-term heat-mining (several decades). However, the observed connection of the system to the regional fault zones will have a significant influence on this development. Figure 4 illustrated results of a 4-month circulation test in 1997 producing 11 MW thermal power.

4. Other Potential Locations for the Soultz Concept

The Soultz concept can be transferred to other locations with smilar conditions, i.e. a flow system on a regional scale linked to deep faults found at the flanks of continental rift systems. Examination of the tectonic setting of the South American continent indicates that potential areas with such flow systems may exist, associated with rift basins on the eastern border (Potiguar, Barreirinhas, Tacutu and Taubaté in Brazil), regions of large scale deformation in the north (El Pilar-Casanay, Venezuela) and Pre-cordilleran basins in the south (Copahue area, Argentina). Adoption of the Soultz Concept in these cases may open up economically attractive alternatives for exploitation of local geothermal resources.

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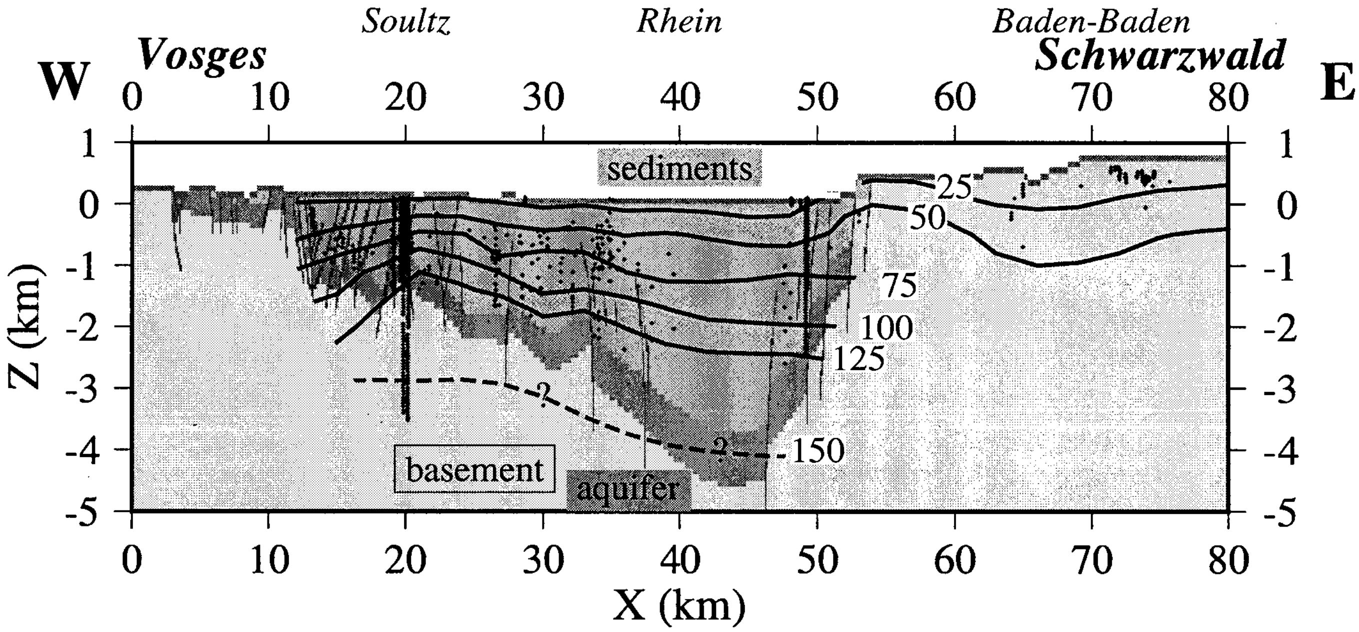

Fig. 1. Model of the geological structures across the Rhine Graben based on seismic profiles together with temperature contours from borehole measurements. Subvertical structures are fault zones. The projected temperature data positions are marked with dots (746 values from 174 boreholes). Temperature contours are labeled in °C. The 150 °C contour is dashed because temperatures this high have only been measured at Soultz (X=20 km).

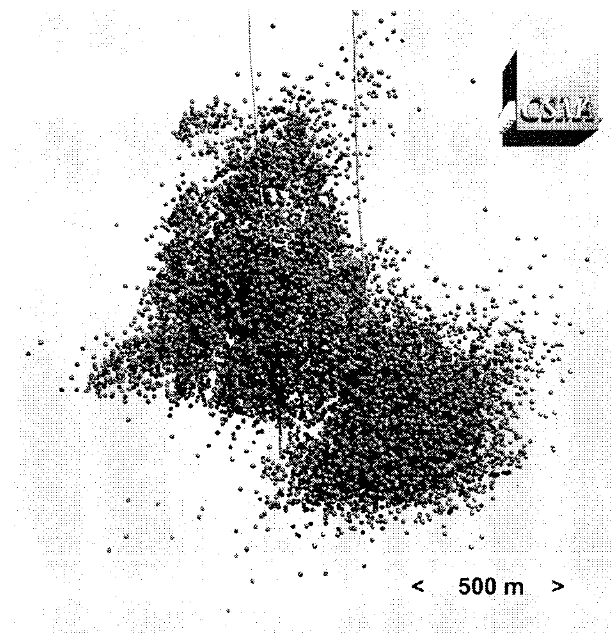

Fig. 2. Location of micro-seismic events between 2 and 4 km depth created by injection of water through two boreholes (thin lines) at high pressures (hydraulic stimulation). The volumes of increased permeability overlap and create a hydraulic connection between production and injection well.

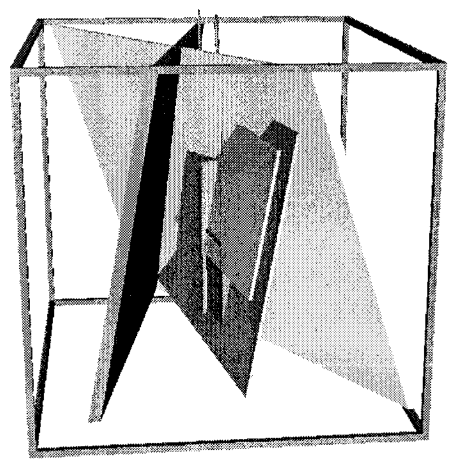

Fig. 3. Modell for coupled simulation of fluid flow in fractures (planes) and stimulated areas (center boxes) with heat flow density (large box).

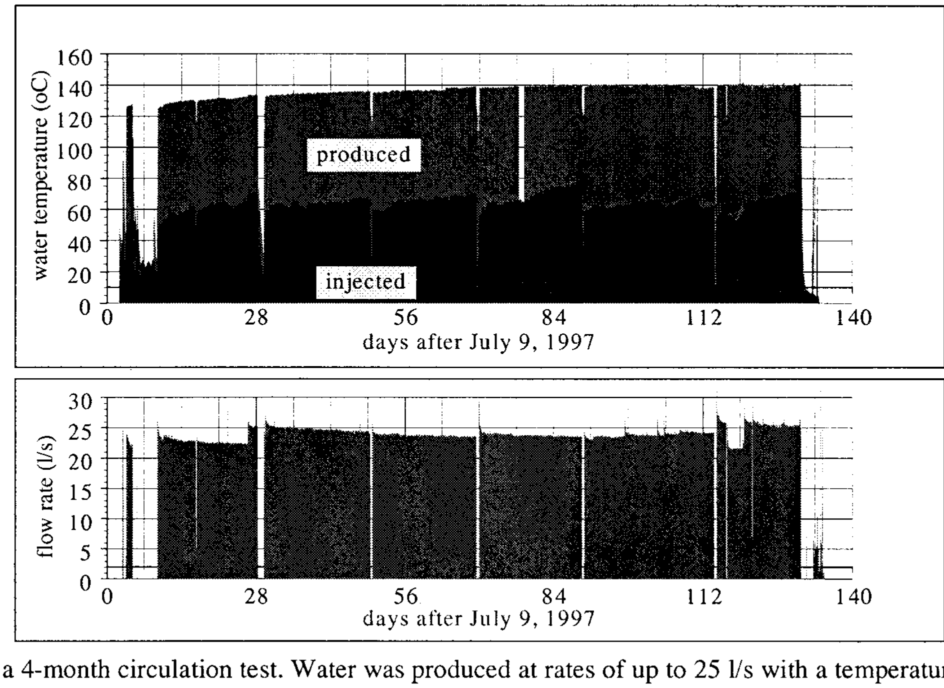

Fig. 4. Results of a 4-month circulation test. Water was produced at rates of up to 25 l/s with a temperature of up to 142 °C, cooled, and injected at identical rate at temperatures between 60 and 80 °C. The net thermal power production was 11 MW.