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The geothermal potential in the **Upper** Rhine Graben valley

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ABSTRACT

The geothermal energy potential in the Upper Rhine Graben and the adjacent areas was estimated using a 3D model. The total length of the graben area, which lies mainly on German and French territory and to a small part on Swiss territory in the Basel area, is about 300 km and the average width is 40 km. The data base for the creation of the 3D model consists of temperature values measured in intervals of 100 m in 928 boreholes with a maximum depth of 3600 m. The data sets were provided by the NLfB - GGA, Hannover.

The energy which can be obtained by cooling down the model volume enclosing the first 6 km of the underground of the Upper Rhine Graben to 30 "C lies is in the range of 2.7 10+22 [J]. This huge theoretical energy potential could cover the momentary primary energy demand of Germany for more than thousand years. Roughly 15% of this theoretical heat potential are stored in areas exceeding temperatures over 150 "C. This technically usable potential of terrestrial heat of approximately 3.7 10+21 [J] is suitable for the production of electricity. It resembles more than 1000 times the energy consumption during one year in Germany and more than 500 times the energy consumption of Germany and France together.

The conversion of this technically usable heat into electrical power could be assessed using geothermal power plants, considering the results of the European Hot-Dry-Rock project in Soultz-sous-Forêts. A successful installation of a HDR power plant with an electrical power net production of 26 MW(e), the conditions will be discussed later, is necessary to finance the construction and maintenance of the plant by the sale of electrical power.

KEYWORDS

Upper Rhine Graben, geothermal potential, 3D-Model, temperature distribution.

1. Introduction

The valuation of the geothermal potential of the Upper Rhine Graben was realized using a 3-dimensional model of the temperature distribution. The data base consists of temperature values measured in intervals of 100 m in 928 boreholes with a maximum depth of 3600 m. The temperature values of 38 boreholes were extrapolated to a depth of 6000 m, assuming a geothermal gradient of 30°/km. Calculating 3-dimensional model rock volumes of defined temperatures intervals allows the estimation of the geothermal energy potential of the entire rock volume. Therefore additional parameters as density and specific heat capacity must be defined.

2. Location of the investigation area

The investigation area encloses the whole Upper Rhine Graben between Frankfurt in the North and Basel in the South and adjacent areas of the Vosges, the Pfalzerwald, the basin of Mainz and the Odenwald. The total length of the graben structure is about 300 km , the average width is 40 km and it has a strike of about 20° SSW-NNE. The research area within the graben structure is shown in figure 1.

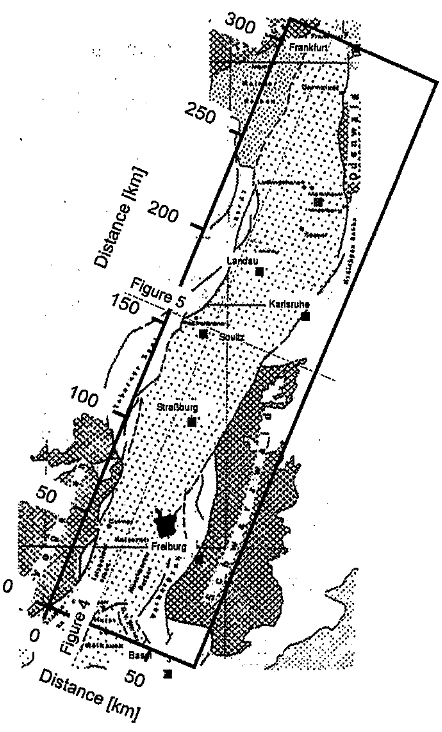


Figure 1: Location of the studied area

Within the Upper Rhine Graben several positive geothermal anomalies are known, mostly located at the eastern and western boundaries of the graben structure. Due to investigations at several oil fields the geology and the terrestrial temperature field are well know. The location of these temperature-highs are:

Landau / Pfalz: The geothermal gradient in the sediment (1,5 to 2 km thickness) is 10°C per 100 m depth.

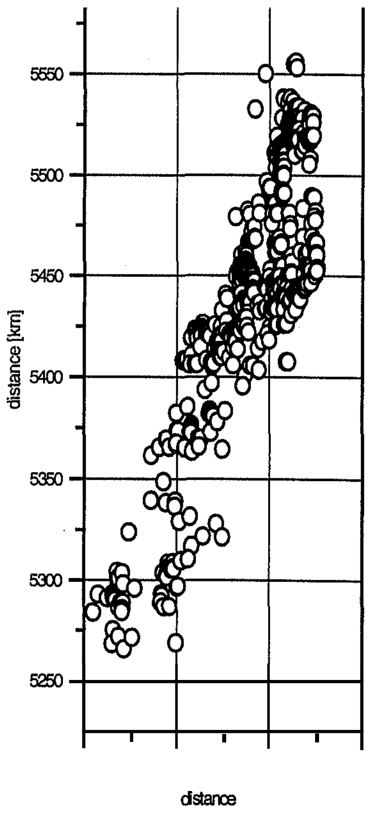
Soultz-sous-Forêts: This anomaly is also well documented by temperature measurements in oil wells. Additional fundamental experience in HDR-technology was gained at this location in the last decades. The basement was reached in 1.5 km. The Landau and the Soultz anomaly are most probably connected. They represent the best known and most favourable locations for high temperatures in relatively moderate depths.

Deidesheim/ Pfalz: This anomaly might be connected with the anomalies in Soultz-sous-Forêts and Landau.

Bruchsal/ Baden-Württemberg: From depths of 1,9 km and 2,5 km hot groundwater with 116°C and 129°C can be produced with flow rates of 20 – 40 l/s. The aquifers lies in geological layers of the Bundsandstein and the Permian.

It should be pointed out that in the whole area of the Upper Rhine Graben between Frankfurt and Basel the rock temperatures below 5km depth are above 150°C. Thus all locations within the graben area offers the natural conditions for geothermal electricity production.

3.3-D-Model



The data base for the potential evaluation was provided by the Niedersachsische Landesamt für Bodenforschung (NLfB) - Geowissenschaftliche Gemeinschaftsaufgaben (GGA) in Hannover. It consists of temperature data points recorded in 928 boreholes in intervals of 100 m up to 3600 m depth. The distribution of investigated boreholes is displayed in figure 2. Most of the data are concentrated within regions with former oil fields and some deep boreholes for potassium and thermal water exploration. Other areas provides only scarce indications, especially below 3600 m depth where no reliable measuring data exists.

The depth distribution of the used boreholes are shown in the histogram Figure 3. It is obvious that the most obtained depths lies in the interval between 500 and 1800 m. For the extrapolation below 3600 m depth a geothermal gradient of 30°C per km was assumed.

With the present data set a 3-dimensional model of the temperature distribution was evaluated. The model has an extension of 310 km in length and **70** km in width and reaches up to *6* km in depth. The horizontal nodal distance is 5 km and the vertical nodal distance is 100 m. The model has a .volume of 130 200 km^3 and an area of 21 700 km^2. In respect of the geometry of the Upper Rhine Graben the area of the model has a greater extension than the graben itself. In the following discussion of the modeled temperature distribution this fact was taken into account.

The modelling was performed with the program Spyglass® Dicer®. **A** quadratic interpolation and a 3-dimensional smoothing were applied. In the figure **4** isotherms of a vertical 2-dimensional N-S section are shown. The figure 5 displays them at a horizontal 2-dimensional section in 6000 m depth. The positive temperature anomalies of Landau and Soultz-sous-Forêts and the negative temperature anomaly of Freiburg are recognisable.

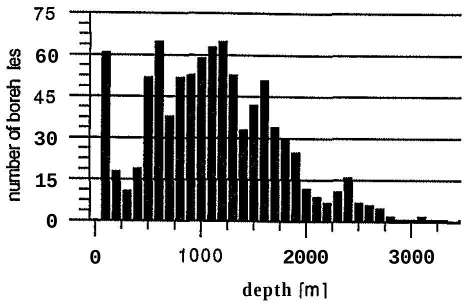


Figure **3:** *Distribution of boreholes as a function of depth*

Fig. ***4:*** *Isotherms of a vertical 2-dimensional section in N-S- direction*

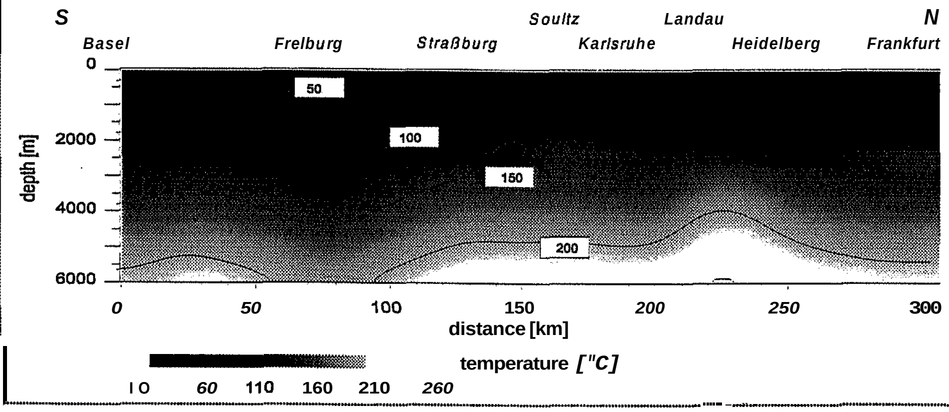
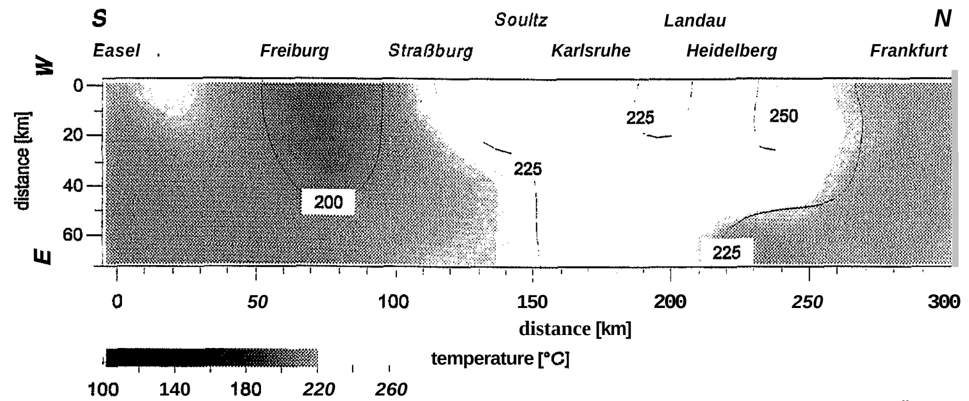


Fig. **5:** *Isotherms of a horizontal 2-dimensional section in 6000 m depth*



4. Theoretical geothermal energy potential

The evaluation of the geothermal energy potential was done by calculating rock volume with selected temperature intervals fiom the modelled temperature distribution. The following equation was used to calculate the potential thermal energy in the selected rock volume:

$E_{th} = c \cdot \rho \cdot V \cdot \Delta T$

Representative values for the specific heat capacity c and the rock density ρ were assumed, taking into account the variation of these parameters within space. For each of the selected rock volumes specific values were assigned. Rock volumes possessing temperatures less than 90°C got typical parameters for wet sediments, for volumes greater than 90°C parameters for typical granites were chosen. The calculated rock volumes and the corresponding evaluated geothermal energy potential are listed in table 1, considering a cooling down of the volume to 30°C. The table 1 displays the differentiation of the geothermal energy in low; middle- and high-temperature potentials. Assuming a total model surface of 21700 km^2 yields a potential geothermal energy per area of $1{,}29\ 10^{+18}$ J/km^2 is calculated.

5. Technical geothermal energy potential

It is obvious, that the theoretical terrestrial heat potential suitable for electricity production increases tremendously if we consider depths below *6* km. How far this is meaningful is a question of drilling technology and costs of drilling in great depth. At present it seems to be reasonable to restrict to *6* km depth. Technically possible are at present maximum borehole depths of 8 - 10 km; the KTB (Continental Depth Drilling) reached 9 km depth in the crystalline rocks of the Bohemian Massive.

Temperature interval [°C]	Volume [km³]	Thermal energy potential E_{th}	%
30 – 60	19997	1,2 10^{+21}	4
60 – 90	20329	3,7 10^{+21}	13
90	80642	10,8 10^{+21}	39
Low temperature potential (temp. decrease to 30°C)		**15,7 10^{+21}**	**56**
90 – 120	16777	0,5 10^{+21}	2
120 – 150	17943	1,8 10^{+21}	6
150	45922	6,2 10^{+21}	22
Middle temperature potential (temp. decrease **to 90°C**)		**8,5 10^{+21}**	**30**
150 – 180	20908	0,7 10+21	3
180 – 210	19639	2,0 10^{+21}	7
210 – 230	3375	0,6 10^{+21}	2
230 – 250	2001	0,4 10^{+21}	2
High temperature potential (temp. decrease to **150°C**)		**3,7 10^{+21}**	**14**
	Total	**27,9 10^{+21}**	100

The importance of an extension of the technically and economically acceptable resource to greater depths, shows the following example. If 1 km^3 of rock mass is cooled down to 150°C, it provides the following thermal power over a period of 20 years:

- 200 MW(th) if the rock is at 200°C
- **300** MW(th) if the rock is at 225°C
- 400 MW(th) if the rock is at 250°C

This model indicates also, that the terrestrial heat has an economic value like other natural resources or deposits.

After the demonstration of the availability of the terrestrial energy resource, it is now necessary, to evaluate the feasibility of an economic geothermal energy production. For this purpose the costs for the production of heat and electricity in conceptual HDR-power plants are treated.

The transformation of heat into electricity is governed by the Carnot efficiency, which increases with temperature. At production temperatures between 140°C and 240°C, and reinjection temperatures between 60°C and 100°C, this Camot efficiency lies between 0.21 and 0.33. This relation between the produced electricity and the heat used for its production, can be technically approached, but never be reached. Power stations, which are in use today, have efficiencies of about 50% of this Camot factor; thus the factor for the transformation of the available terrestrial heat (at 140°C to 240°C) into electricity is in the range 0.1 to 0.16 (10% to 16%). Only this portion of the theoretically available terrestrial heat above 150°C can be transformed into electricity.

For a cost evaluation of electricity production in a HDR power plant, some assumptions were made, based on the results of the European HDR Soultz project:

- a total production rate of 400 kgls (9 boreholes, 5 production wells each 80 kg/s, 4 injection wells);
- production temperature 200°C (reached at 5.5 km depth);
- re-injection temperature of 70°C to 110°C (high injection temperature is for combined use of electricity and heat);
- the temperature draw-down in the geothermal reservoir should be small (less than 20%) during a period of 20 years or more;
- electricity production in the power station 8000 h/a;
- heat production 1800 h/a for district heating and 7000 h/a for process heat;
- selling price for electricity per kWh 0.15 DM (0,075 ECU);
- selling price for heat per kWh is 0.09 DM (0,045 ECU);
- energy demand for pumps, for the production and for the injection in the geothermal heat exchanger (circulation pumps) 10 kW per kg/s;
- cost for 1 borehole 5.5 km depth: 8 Mio DM (4.5 Mio ECU), 9 holes: 72 Mio DM (36 Mio ECU);
- cost for power station 2 Mio DM (1 Mio ECU) per MW;
- reservoir monitoring 12 Mio DM *(6* Mio ECU);
- buildings, etc 1 Mio (0.5 Mio ECU);
- pipelines within the geothermal plant 3 Mio DM (1.5 Mio ECU);
- adjustment to the existing electricity net 20 Mio DM (10 Mio ECU).

If a power station with a net-output of 26 MW(e) can be build (9 boreholes of 5.5 km depth), the necessary capital for construction and the expenses for maintenance can be paid from the income for the electricity (26 MW*8000 h*150 DM/MWh = 31 Mio DM per year). The available capital for the investment would be in the order of 200 Mio DM (100 Mio ECU). The interest rate is assumed to be 10% and the annuity 11.75%; operation time 20 years.

An extension of this model to a combined usage of electricity and heat shows, that the expenses for the distribution of heat to small consumers are prohibitive expensive for an economic operation; a consumer of process heat with a great demand for heat during a long period of the year would be attractive (but individual circumstances have to be considered). Further the input of geothermal heat into an existing district heating distribution system would be favourable.

The possibility of a HDR power station providing energy at moderate production cost, in the order of present market prices, has not been proven in reality until now. This statement is not in contradiction to the results obtained from the European HDR-project at Soultz. The present results regarding flow rate per production wells (in Soultz 30 kg/s but 80 kg/s in the model) and power demand for the circulation in the geothermal system are encouraging. A big step forward is also the decrease of drilling costs during the last drilling operations at Soultz. The greatest success is the stimulation of a very extended heat exchanger in about 3.8 km depth in Soultz, with an extension (some km2), which is necessary for operation periods of 20 years or more.

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