GEOTHERMAL EXPLORATION IN THE RHINE GRABEN
(West Germany and France)

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The Rhine graben (Fig. A-17), situated in southwestern Germany and northeastern France, has been and is the main target for geothermal exploration in Germany. This is mainly due to the fact that some wells being drilled for oil exploration encountered anomalous high temperatures (up to 160°C in 1800-m depth). Prior to these observations, high geothermal gradients were known in the oil mining region of Pechelbronn. Numerous hot springs in the surroundings of the graben indicate active hydrothermal convection. In 1975, the commission of the European Communities started a research and development program for geothermal energy. This program concentrated on exploration in special regions, assessment of geothermal potential of the states of the European Communities, data gathering and feasibility studies. The research work in the Rhine graben was performed in cooperation with universities, regional geological surveys and other institutions.

In order to have a better view of this exploration campaign, it is necessary to summarize some facts on geology and geophysics of the Rhine graben. The hercynian basement consists of gneisses and metamorphic schists intruded by granites of carboniferous age. The Permian is developed in some regions as a thick sequence of conglomerates, arkoses and siltstones. The Lower Triassic formed by the Buntsandstein, a sandstone with its thickness increasing from south (30 m) to north (500 m). The Middle and Upper Triassic plus the Jurassic is a series of marls, limestones, and sandstones, up to 500-m thickness. In the Uppermost Jurassic sedimentation stopped, and began again in a bigger scale only in the Rhine graben since Middle Eocene. A 2,000-3,000-m-thick sequence of mostly marls, clays and evaporites was deposited in the period ending with the Upper Miocene. In the Pliocene, the tectonic style changed froom an extensional rift valley with mainly vertical movements to left-lateral strike slip tectonics continuing till today, as can be concluded from fault plane solutions of earthquakes.

The most prominent geophysical feature of the Rhine graben is the updoming of the mantle under its southern part up to 25-km depth. The absence of a

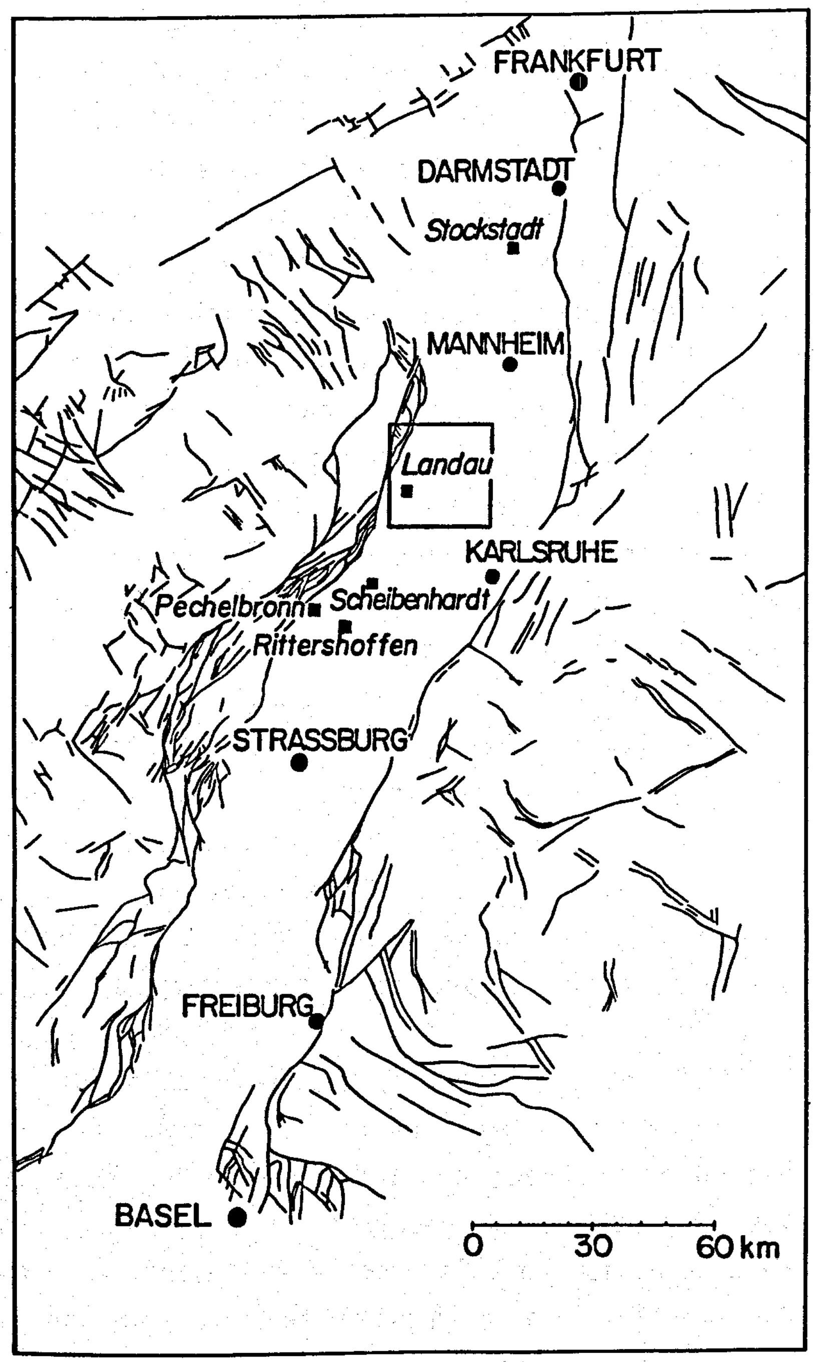

Fig. A-17.
Sketch map of the Rhine graben with locations mentioned in text.

corresponding positive Bouguer anomaly is believed to indicate hot low-density material under the graben. However, the surface heat flow is quite normal; 70 mw m^{-2} has been measured in potash mines of the southern Rhine graben. Values twice as much as this one have been obtained from some oil wells in the oil fields of Pechelbronn and Landau, but exploratory wells drilled only a few kilometers away from such "hot spots" encountered normal and low temperatures. This is in good agreement with observations on the degree of coalification of organic matter, which is dependent on the temperature history of that material in cores from many boreholes and clearly shows that almost no connection exists between the recent temperature field and the coalification. In now "cool" boreholes the degree of coalification may be high indicating high temperatures in the past, or in some "hot" boreholes there is no corresponding coalification. Thus, the temperature field, varying considerably in space and time, may be best explained by convective heat transfer, i.e., deep ground-water circulation. Two-dimensional numerical modeling of the temperature effect of hydrothermal convection yields a minimum age of the geothermal anomalies of about 80,000 years, under the assumption that water rises from 6-km depth with an initial, undisturbed temperature gradient of 30°C/km. It is assumed in this model that the water rises vertically in the basement and flows horizontally in the strata of the Buntsandstein (Fig. A-18). The permeability in the basement that is necessary for the required flow (1.2 Mg cm^{-1} $year^{-1}$) is due to the regional shearing parallel to the graben axis, opening up second-order shear planes or Riedel shears, which can be seen in quarries on the shoulders of the graben and even in the sedimentary graben fill. The geothermal anomalies are bound to tectonic horse structures within the graben, which is probably caused by the hydraulics of the convection system.

Geophysical field experiments and measurements giving information about the underground temperatures were performed extensively in the sixties and seventies, including refraction and reflection seismics, gravimetry, magnetotellurics, magnetics, and geoelectrics. The main result of all this work, of interest here, is the existence of a temperature anomaly in the lower crust and upper mantle associated with the diapiric uprise of the mantle mentioned above. The northern part of the graben with its near-surface anomalies was not investigated in detail in its deep structure. However, some exploration work has been done successfully on the known geothermal anomalies, mainly for testing the methods (magnetotellurics, magnetic deep sounding and microseismic noise). Special exploration for exploitation projects has been carried out by reflection seismics (Vibroseis), looking for deep hot aquifers in the Triassic and Jurassic formations of the graben.

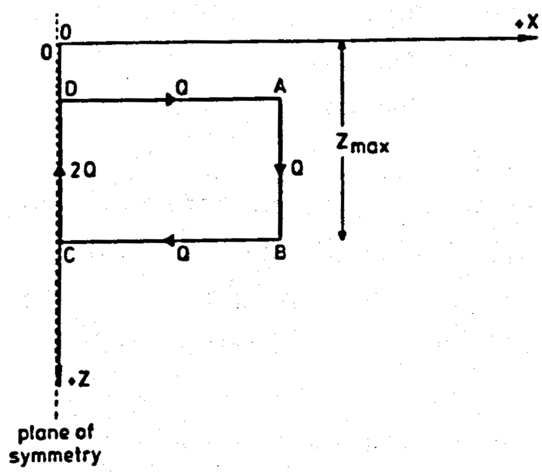

Fig. A-18.
Vertical section used for calculation of temperature effects of hydrothermal convection. Water is entering the system at Point A and is then flowing according to lines with arrows.