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REINJECTION: A FRENCH APPROACH

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ABSTRACT

This paper gives a brief introduction to the geothermal resources of France. These are all of the low temperature (T < 100°C) type, initially identified in the sedimentary basins by petroleum exploration.

The geothermal "doublet" reinjection technique is described. More than 40 doublets have been drilled and are exploited in the Paris Basin. These geothermal developments have taken place only during the past *6* years, and *so* far no major problems have occurred. Mathematical modelling has been carried out, and computer programs developed.

Introduction

In 1973 France was importing 80% of its energy. Among major occidental countries only Japan and Italy were more dependent on energy imports. By 1985 this dependency has been lowered in France to 55%. This evolution has occurred for several reasons, among them increase in the use of nuclear energy, geothermal energy and energy savings. Even though its contribution is still marginal, the use of geothermal energy in France is of interest because:

- the temperature in French reservoirs is produced by normal terrestrial heat flow;
- the doublet technique is used widely;
- development of geothermal energy has occurred very quickly.

Geothermal resources in France

Geothermal resources in metropolitan France are nearly all of the low temperature (T < 100°C) type. They have been identified in sedimentary basins such as the Paris Basin, the Aquitaine Basin and basins in the Alsace.

These deep aquifer formations were essentially identified by petroleum exploration. The data obtained were used for geothermal developments, thanks to favourable legislation and close collaboration between oil companies and those involved in geothermal energy.

Figure 1 shows the extension of known aquifer formations where the temperature exceeds 30°C.

The'Paris Basin

This large sedimentary basin, 3 km deep under the Brie, extends a5 far as England. It is distinguished by calm tectonics, with the geological beds arranged regularly like a stack of plates, and by the considerable development of porous formations. Hence the resource displays a "continuous" character.

The main aquifers appearing in the section (Fig. 2) are designated by their standard geological name.

A well drilled at the centre of the basin will encounter the following sequence:

Albian and Neocomian sands: the water is fresh and the temperature about 30°C under the Paris urban area. These aquifers are tapped for air-conditioning of buildings (the Albian for the National Radio Agency in 1956 and the Neocomian at Bruyères-le-Châtel, south of Paris, in 1980). Very stringent legislation now protects the Albian aquifer, which was over-used at the turn of the century. Nevertheless, operations tapping these aquifers do not (yet) need reinjection wells.

The Dogger: this is Europe's most important geothermal resource base. The high-productivity area, where more than 300 m^3/h of water at a temperature exceeding 70°C can be obtained, covers about 15,000 km^2 including the Paris urban area. *An* artesian flowrate of *400* m^3/h was measured at Bonneuil. The temperature is as high as 85°C at Coulommiers at the centre of the Brie region. The saline pore water of the Dogger aquifers (20 to 35 g/ℓ) must be reinjected.

Trias sandstones: These are well known in Lorraine, where they supply swimming pools and breweries. Water composition is non-saline and does not require reinjection. However, in other areas Triassic sandstones are not tapped because of reinjection problems.

The Aquitaine Basin

This basin contains several continuous aquifer formations. Inframolassic sands are tapped at Blngnac near Toulouse and at Lamazere (Gers); the Cenomanian of the Bordeaux region is intensely tapped for geothermal energy (Bordeaux), and, to the north, the Trias sandstones are tapped at Jonzac and at Rochefort (Charente-Maritime).

However, most of the fields encountered are discontinuous. These include the very thick Jurassic and Cretaceous limestones tapped at Mont-de-Marsan and at Dax (Landes).

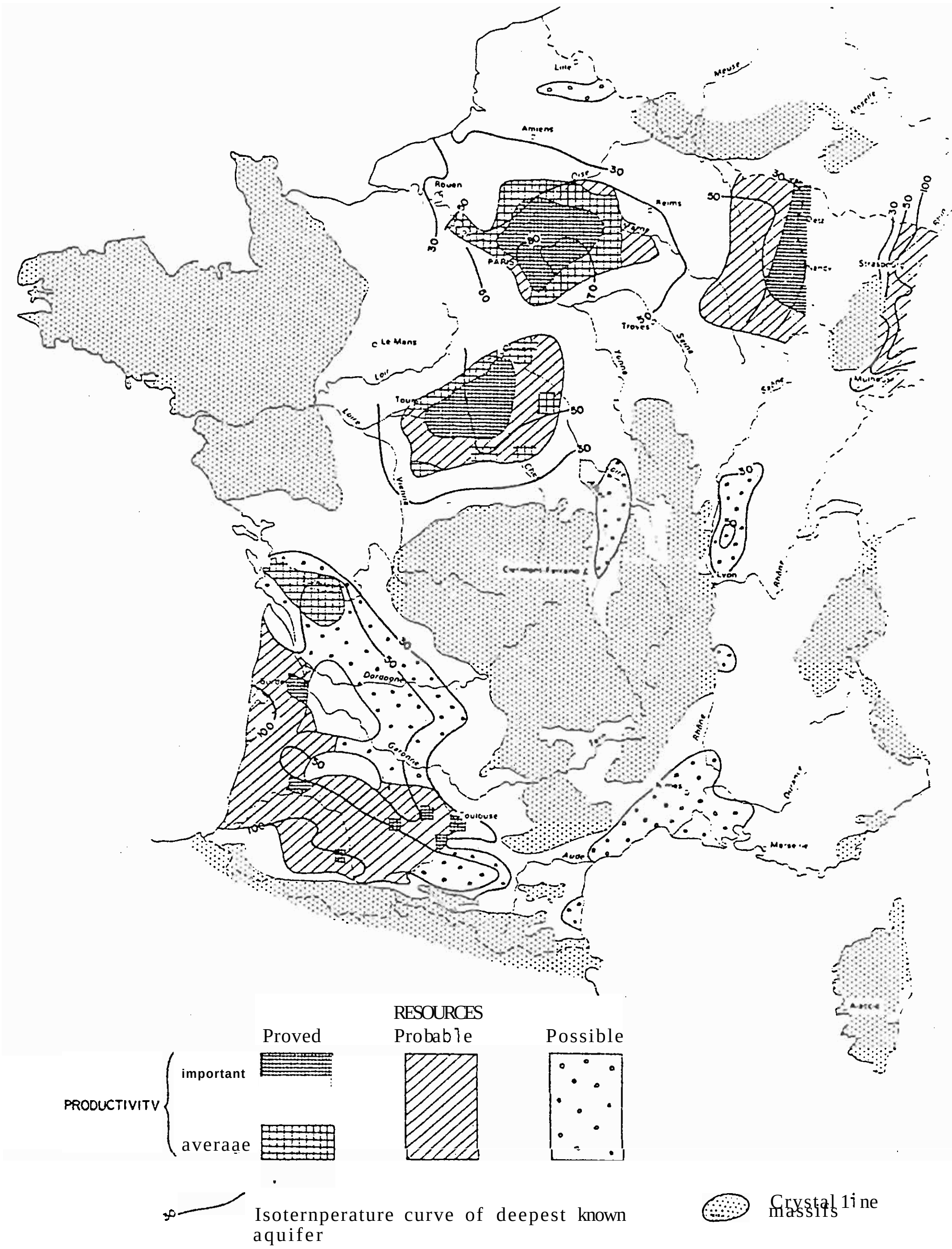

Fig. 1: Extension of known aquifer formations in France where temperature exceeds 30°C within the deepest known aquifer.

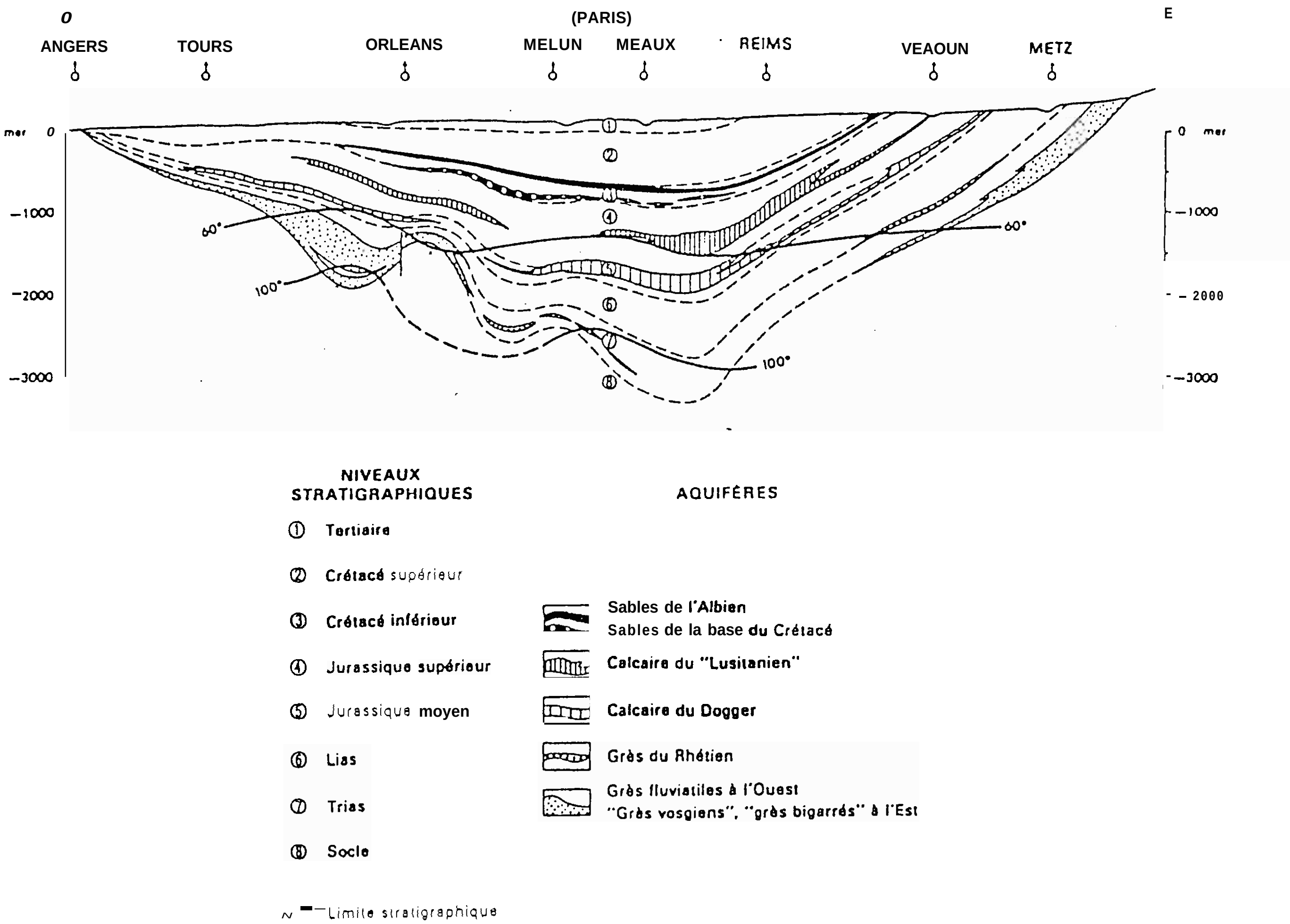

Fig. 2: Diagrammatic cross-section (W–E) of Paris Basin.

Geothermal water in the Aquitaine Basin is normally fresh, making it possible to drill single wells and to discharge the water at the surface for all operations. At very great depths, the Aquitaine also has aquifers in which very salty water is at over 100°C.

Several other areas also present interesting features, but up to now have not been exploited (Alsace, North Basin, Languedoc).

Geothermal doublet technique

In France, the distinguishing feature of tapping systems in comparison with other' countries where' low enthalpy applications are highly developed (Iceland and Hungary, particularly) is the large number of operations using the geothermal "doublet" technique.

The term "doublet" applies to systems which include two boreholes, one for production and the second one to reinject the water after extracting its heat. The first realization of such a doublet scheme took place in 1969 at Melun, a town of 50,000 inhabitants 50 km south east of Paris.

Figs. 3 and 4 present schematically the geothermal doublet principle and a geothermal low enthalpy operation.

This technique meets two objectives:

- to maintain the pressure of the field throughout the production period in order to maintain the initial yield;

- to dispose of saline water which cannot be discharged into the surface environment.

Around the reinjection well a colder zone will be created which will spread gradually, and ultimately will reach the production well. The distance between these two wells must therefore be calculated beforehand, at the level of the aquifer, so that the decrease in temperature does not affect the production well for a period at least as long as the amortization period of the installation (generally it is much longer). This period must be compatible with the accepted service life of a borehole.

This interval is normally taken as about 30 years. Rut it does not mean that when the cold zone arrives at the production well the operation must be closed down. In fact the geothermal doublet can continue to operate beyond this deadline as long as the production temperature remains high enough for the installation concerned and the state of the boreholes is satisfactory. The decrease in temperature is estimated in normal exploitation conditions as 2°C each five years.

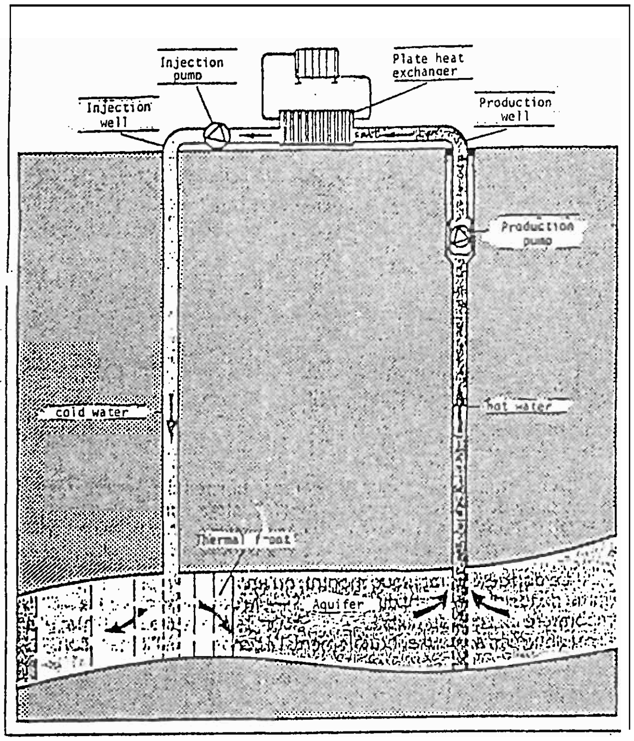

Fig. 3: Principle of a geothermal doublet scheme.

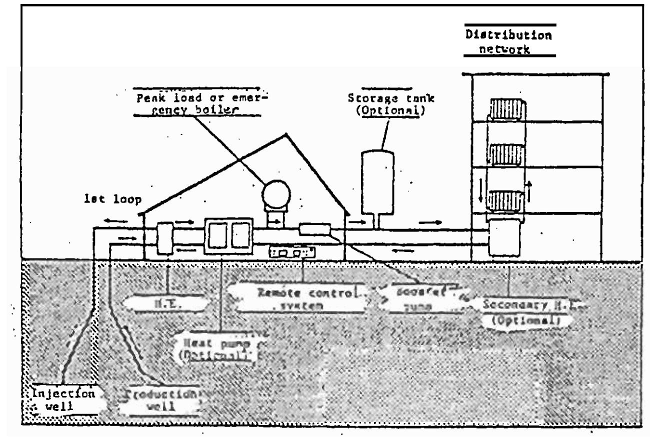

Fig. *4:* Diagram of a geothermal doublet scheme.

Région sud-ouest

Région parisienne

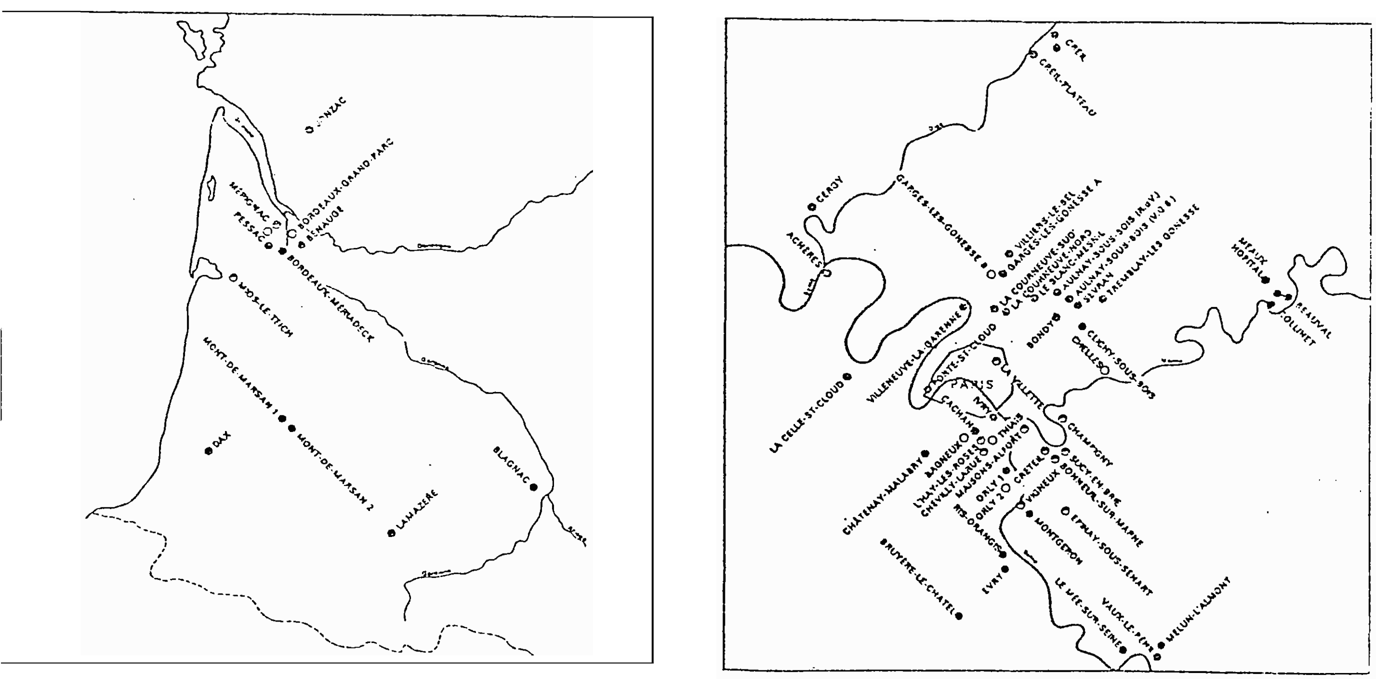

Fig. 5: Geothermal exploitation in the Aquitaine and Paris Basins.

O)
◐) Being developed
◕)

● Operational

During the last ten years more than 40 doublets have been drilled in the Paris Basin. All of them have been exploited (Fig. 5).

Up to 1985, about 200,000 TOE (tonnes of oil equivalent) were saved with geothermal energy. The target of the French Government is to save 800,000 TOE per year by 1990, and more than one million per year by the year 2000.

Reinjection in Dogger limestones

It is said in France: "Happy people do not have a history", and we could also say that happy reinjection does not have a history. No major problem has occurred with reinjection wells in the Dogger limestones. There are two main reasons for this:

- the high porosity of the aquifer;
- the fact that, in the geothermal loop, a pressure (in general about 5 bars) higher than the "bubble point" pressure is maintained, thus preventing a lot of scaling. It has therefore been possible to reinject at flow-rates of 300 m^3/h (83 ℓ/s) without any problem.

Reinjection in the same aquifer means that sooner or later some cold water will arrive at the production well. The elapsed time between the beginning of the operation and the declining of temperature is a very important parameter both on technical and economic grounds. Mathematical models allow us to predict when it will happen, and how. These models are particularly helpful in selecting the azimuth of the wells in the suburbs of Paris, where the density of doublets is very high and where every square km of the reservoir can be used.

Mathematical modelling

For predicting the regional effects of reinjection of waters at a different temperature from the initial aquifer temperature, we developed a computer program called METERNIQ for calculating temperature distributions in aquifers with a uniform regional flow.

The conceptual framework assumes that it is a one-layered aquifer of infinite lateral extent, with an impermeable cap and bed rock of infinite vertical extent.

The aquifer is assumed to be homogeneous and isotropic, with a uniform thickness and infinite lateral extent. Replenishment occurs through artificial recharge supplied by wells; the outlets are production wells. The fluid phase is supposed to be incompressible, and variation of density and viscosity with temperature are neglected. The flow is assumed to be steady.

Input parameters are:

- aquifer thickness and porosity;
- direction and magnitude of natural flow;
- heat capacity of rock in aquifer and in bed and cap rocks;
- initial temperature in aquifer, cap and bed rocks;
- radius, coordinates and flow rate of each production or injection well, injection temperature at each injection well.

Output parameters:

- transient temperature at each production well (printed on the listing and plotted);
- streamlines and thermal fronts.

Fig. 6 shows the streamlines and thermal fronts for a system of five doublets in the Paris Basin.

Other programmes have been developed based on METERNIQ which allow prediction of the same outputs but with multiple-layered aquifer, and with aquifers limited by faults.

Other examples

Triassic sandstones

Reinjection in this aquifer has not yet been successful. A lot of work on this subject is at present being done by the French Geothermal Institute, IMRG (Institut Mixte de Recherche Geothermique). The main results of their work will be published soon.

Aquitaine Basin

In this part of France the very good quality of the tapped water has allowed it to be used with single wells. But all the operations which have been realized in the past few years include in their price a special cost for drilling reinjection wells as soon as this will be necessary.

Shallow aquifers

Reinjection in shallow aquifers is too complex a problem to be discussed here; however, it is practised in France because heat pumps using shallow aquifers are increasingly being used. Reinjection problems are different in this case for several reasons:

- the natural flow speed in the aquifer is not zero or as low as in deep aquifers;
- the water is often used for several purposes (e.g. industrial, agricultural);
- the reinjected water can also be hot water if the heat pump is used for cooling;
- bacteriological problems are more acute than in deep aquifers;
- reinjection rates in general are low.

Conclusion

The object of this paper was not to give an extensive and scientific presentation of reinjection problems in France, but only to present, in brief, what has been done in the low enthalpy field over the last few years in a region antipodal to New Zealand. More technical and scientific data on this subject can be obtained from BRGM.

Brief bibliography on French geothermal energy

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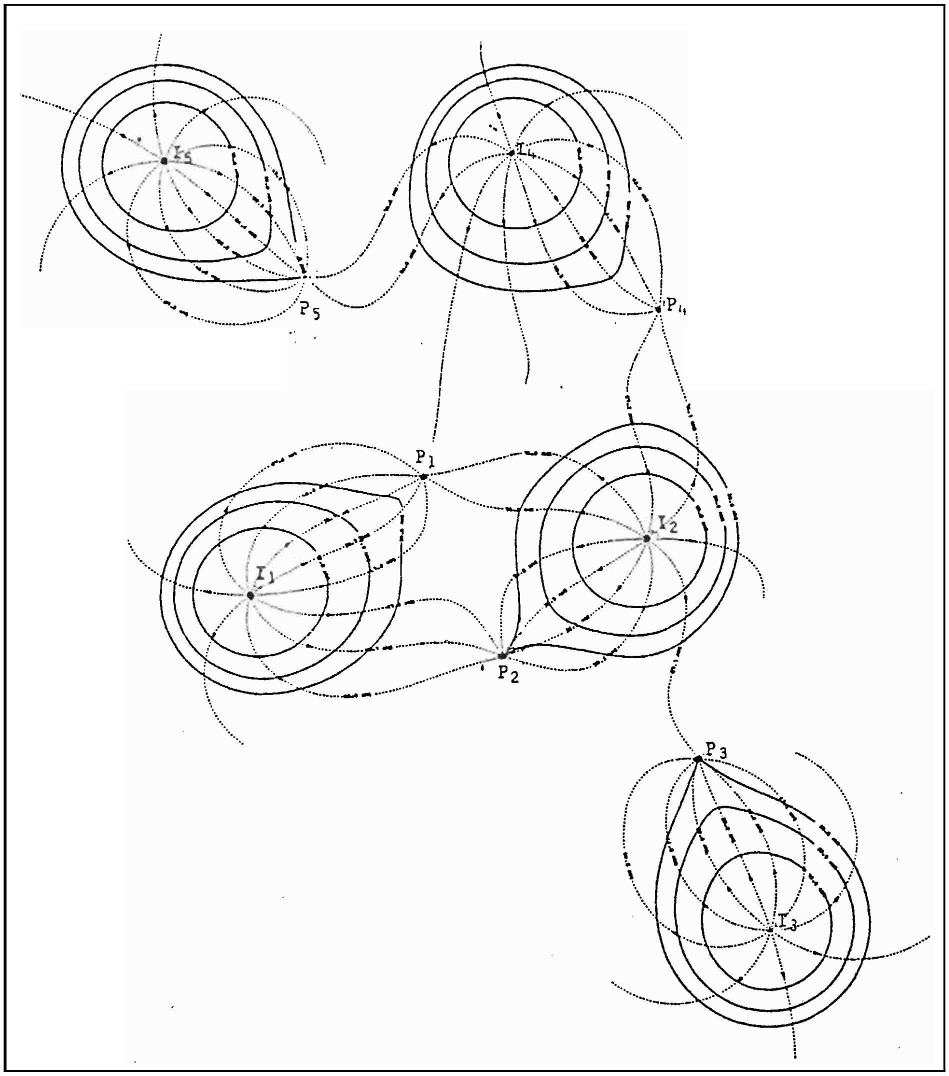

Fig. 6: Streamlines and thermal fronts for a system of five doublets in the Paris Basin.

Porosity: 11%

Thickness of productive aquifer: 39m

Calorific capacity of fluid: 1.00 cal/cm^3/°C

Calorific capacity of rock: 0.50 "

Calorific capacity of bed and cap rocks: '0.50 cal/cm^3/°C

Thermal conductivity of bed and cap rocks: 0.60 x 10^{-2} cal/cm/s/°C

P = production well

I = injection well

Average flowrate: 110 m^3/h