PROCEEDINGS, Eleventh Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 21-23, 1986
SGP-TR-93

THE COUPLING OF THE NUMERICAL HEAT TRANSFER MODEL OF THE PAUZHETKA HYDROTHERMAL SYSTEM (KAMCHATKA, USSR) WITH HYDROISOTOPIC DATA

A.V.Kiryukhin and V.M.Sugrobov

Institute of Volcanology,
Petropavlovsk-Kamchatsky,
683006, USSR

ABSTRACT

The application of the two-dimensional numerical heat-transfer model to the Pauzhetka hydrothermal system allowed us to establish that

1. A shallow magma body with the anomalous temperature of 700-1000°C and with a volume of 20-30 km^3 may be a heat source for the formation of the Pauzhetka hydrothermal system.
2. The water feeding source of the Pauzhetka hydrothermal system may be meteoric waters which are infiltrated at an average rate of 5-10 $kg/s{\cdot}km^2$.

The coupling of the numerical heat-transfer model with hydroisotopic data (D,T,^{18}O) obtained from the results of testing of exploitation wells, rivers and springs is the basis to understand more clearly the position of recharge areas and the structure of water flows in the hydrothermal system.

INTRODUCTION

The hydrothermal systems in Kamchatka occur in the volcanic zone of north-eastern trend 25 km wide and 1000 km long. The Pauzhetka hydrothermal system is the most studied among them (Fig.1). In the early sixtieth of our century a decision was taken to use the geothermal resources of Pauzhetka for the production of the electrical power and since 1966 the 5MW and later 11MW Power Plant has operated here.

Owing to exploration works we have obtained information on (1) temperature distribution in the interiors and natural heat discharge; (2) geological structure and magmatism; (3) geometry and permeability of reservoir; and (4) conditions of water recharge and discharge of the hydrothermal system. Of great importance were the studies made by V.V.Averiev, V.I.Belousov, S.I.Naboko and V.M.Sugrobov (Pauzhetka Hot Waters ..., 1965).

The surface discharge includes the discharge of hot springs (31 kg/s) with temperature of 98°C and steam vents with the whole heat capacity of $4.6{\cdot}10^3$ kcal/s (Fig.2). The temperature penetrated by wells is 150-200°C. The geothermal reservoir is composed of fractured psephitic tuffs. In this area acid extrusions (dacites and rhyolites), the intrusion of which took place in the Middle and Upper Pleistocene and Holocene (6000 yrs ago) were also found (Belousov et al., 1976).

The geometry of the reservoir is characterized by the distribution of thermal occurrences at the surface. This reservoir is located at the junction of the permeable zones of northwestern and meridional trends. The analysis of the results of well testing gives evidence that there is no correlation between the stratigraphic sequence and production zones that points to a deep enhancement of the geothermal reservoir (Fig.3).

The recharge areas of the Pauzhetka hydrothermal system include high parts of the Kambalny Ridge and the Kurile and Vitaminnoe Lakes which are situated at +104 - +273 m a.s.l. (see Fig.1). Data on well sampling for O^{18} and D support an idea on meteoric feeding of the hydrothermal system (Fig.4).

To explain the mechanism of hydrothermal activity in the region of the Pauzhetka structure a numerical heat transfer model was suggested. This model is 2-dimensional and is based on the laws of mass and heat conservation and on the equations of movement of water flows (Kiryukhin and Sugrobov,1985).

DISCUSSION

The results of numerical modelling made earlier (Kiryukhin and Sugrobov, 1985) yielded a somewhat higher value of temperature gradient (in comparison with actual data on geothermal wells) in the lower parts of the section. Besides, new hydroisotopic data (D,O^{18}) obtained recently, make us revise our model.

In particular, from these data, the hydroisotopic composition of thermal waters is intermediate between that of the Kurile lake and meteoric waters of the Kambalny Ridge. Meanwhile, within the framework of the previous model the source of heat feeding, namely a shallow magma chamber, did not differ in filtrational properties from ambient rocks and therefore the infiltrational waters could freely penetrate to this chamber. If it was really so, then the hydroisotopic composition in the discharge area should approach the hydroisotopic composition of "magmatogenic waters" which have $-71 < D < -40$, $0 < O^{18} < +6.6$ (Sakai and Matsubaya, 1976; Kononov and Polyak, 1982; Serezhnikov and Seletsky, 1982; Matsuo et al., 1985). Contrary to this, the water in the discharge area of the Pauzhetka hydrothermal system penetrated by wells has $-100 < D < -60$, $-11.5 < O^{18} < -6.5$ (see Fig.4).

Thus, it is necessary to use this model to find the mechanism owing to which the water penetration to the magma chamber decreases. This may be achieved by decreasing the permeability of magma body. In this connection, the sensitivity of the model to variations in filtrational properties of magma body was examined.

In order to regard the filtrational heterogeneity , it was necessary to improve the numerical model 1985 algorithm; to solve the hydrodynamic part of the model, the iteration method for finite-difference scheme which approximates the elliptic type equations with variable coefficients, was used.

For these reasons, a new model differs from the previous one (1985) in lower permeability of magma body, also in an increased by 1.5 times size of reservoir for considering the possible water recharge from the Kurile lake. The most important parameters for modelling are given below.

The size of reservoir L - 15 km
Heat conductivity λ-5.0·10^{-3}cal/cm°Cs
Volumetric heat capacity C-0.6cal/cm^3°C
Heat capacity of fluid C_0-1.0cal/gcm^3°C
Thermal expansion of fluid α -10^{-3}°C^{-1}
Average infiltration in recharge area
$\frac{\partial \Psi_0(x)}{\partial x}$ -3-13 kg/s km^2
The modelling time t_1 - 15000 yrs
The size of magma body S - 29 km^2
Initial magma body temperature T_2 - 700°C
Reservoir permeability K - 0.015 m/day
Magma body permeability K_u- 0.0015 m/day
Nondimensional parameters Ra= $\frac{K L \alpha T_2 C_0}{\lambda}$ =3000 Fo= $\frac{t_1 \lambda}{c L^2}$ =1.76·10^{-3}
Inf= $\frac{C_0}{\lambda}$ max $\Psi_0(x_1)-\Psi_0(x_2)$=50-200
Fe=S/L^2=0.13

The action of the hydrodynamic model is expressed, as in the 1985 model, as a succession of temperature and hydrodynamic fields (stream function) corresponding to different periods of time which have passed from the moment of the origin of magma body (Fig.5).

Before the emergence of magma body ($t<0$) the temperature increases linearly with depth in accordance with gradient G=0.02 °C/m. The ground water flow conditions in the considered permeable zone are defined by recharge in the right part of the model which imitates the eastern flank of the Kambalny Ridge and areas adjacent from the east, and by discharge in the left part of the model imitating the valley of the Pauzhetka river (see Figs.5.1, 5.2).

Then, when t=0, we consider that the intrusion of heat body occurs which imitates the impulse of magmatic activity in Holocene-Upper Pleistocene (see Figs. 5.3, 5.4).

However, the convective cells evolve with difficulty (as distinct from the variant considered earlier) because of the existence of a large impermeable zone, i.e. a hot magma body with low filtrational properties. Nevertheless, heat is extracted from this magma body rather intensively owing to washing of its surface by infiltrational flows. In addition, a small part (~10%) of meteoric waters penetrates to the magma body. As a result, a hot water flow forms; with time it approaches the surface (see Figs.5.5, 5.6, 5.7, 5.8).

To obtain the more reliable model parameters, data on temperature distribution in the interior of the Pauzhetka hydrothermal system and on its surface heat discharge were used. Values of the size of magma body, reservoir permeability and water feeding in the recharge areas were selected so as to reach the agreement between the observed and calculated thermohydrodynamic fields (see Fig.5.9).

Besides, in terms of this model we can find a more clear explanation to the fact that the isotopic composition of thermal waters in the discharge area becomes heavier. This is due to throughmagmatic filtration of meteoric waters.

It is worthy of note that if our conceptual model of the Pauzhetka hydrothermal system is true (see Fig.5.10), then some time later we must find the higher contents of tritium in the ascending high-temperature water flow (see Fig.4). If the water with the anomalous content of tritium penetrated to the system from the recharge area 25 years ago and if we take the average length of the way of filtration to be 15 km and the average rate of filtration $1.3 \cdot 10^{-8}$ m/s, then when the effective porosity is 0.01–0.001, the tritium water must emerge in the discharge area 400–40 years later, respectively. Anyhow, inasmuch as we cannot find tritium now, then the effective porosity of the reservoir is not less than 0.001.

CONCLUSION

As a result of hydroisotopic studies, the numerical thermohydrodynamic model-1985 of the Pauzhetka hydrothermal system was revised. In this connection, the mechanism of the final phase of evolution of the Pauzhetka hydrothermal system may be as follows.
I. The emergence of a hot magma body occurred 15000 yrs ago. II. The thermal interaction between the relatively impermeable magma (intrusive) body and permeable water saturated rocks is manifested in washing of the hot magma body by water flows with insignificant penetration of the latter into the magma body. III. The formation of the ascending hot water flow is caused by gradual cooling of the magma body.

In further investigations it is necessary to improve understanding of the interaction between the magma body and water saturated rocks since this mechanism determines the efficiency of heat extraction from high-temperature hydrothermal systems connected directly with the magma chambers.

REFERENCES

Belousov, V.I., Sugrobov,V.M. and Sugrobova,N.G., 1976. Geological structure and hydrogeological peculiarities of the Pauzhetka hydrothermal system. In: Hydrothermal Systems and Thermal Fields of Kamchatka. Vladivostok,p.23-57 (in Russian).

Kiryukhin,A.V. and Sugrobov,V.M.,1985. On the conditions of water and heat feeding of the Pauzhetka hydrothermal system (S.Kamchatka,USSR). Proc. 10th Geothermal Eng.Workshop, p.57-64.

Kononov,V.I. and Polyak,B.G., 1982. The problem of finding the juvenile component in recent hydrothermal systems.Geokhimiya, No.2, p.163-178 (in Russian).

Matsuo,S., Kusanabe,M., Niwano,M., Hirano,T. and Oki,Y., 1985. Origin of thermal waters from the Hakone geothermal system, Japan. Geochemical Journal, v.19, p.27-44.

Pauzhetka Hot Waters in Kamchatka, 1965, Moscow, 205 pp. (in Russian).

Sakai,H. and Matsubaya,O., 1976.Stable isotopic studies of Japanese geothermal systems. Geothermics, v.5, p.97-125.

Serezhnikov,A.I. and Seletsky,Yu.B., 1982. Deuterium, O^{18} and tritium in thermal waters of South Kamchatka. Geokhimiya, No.2, p.178-192 (in Russian).

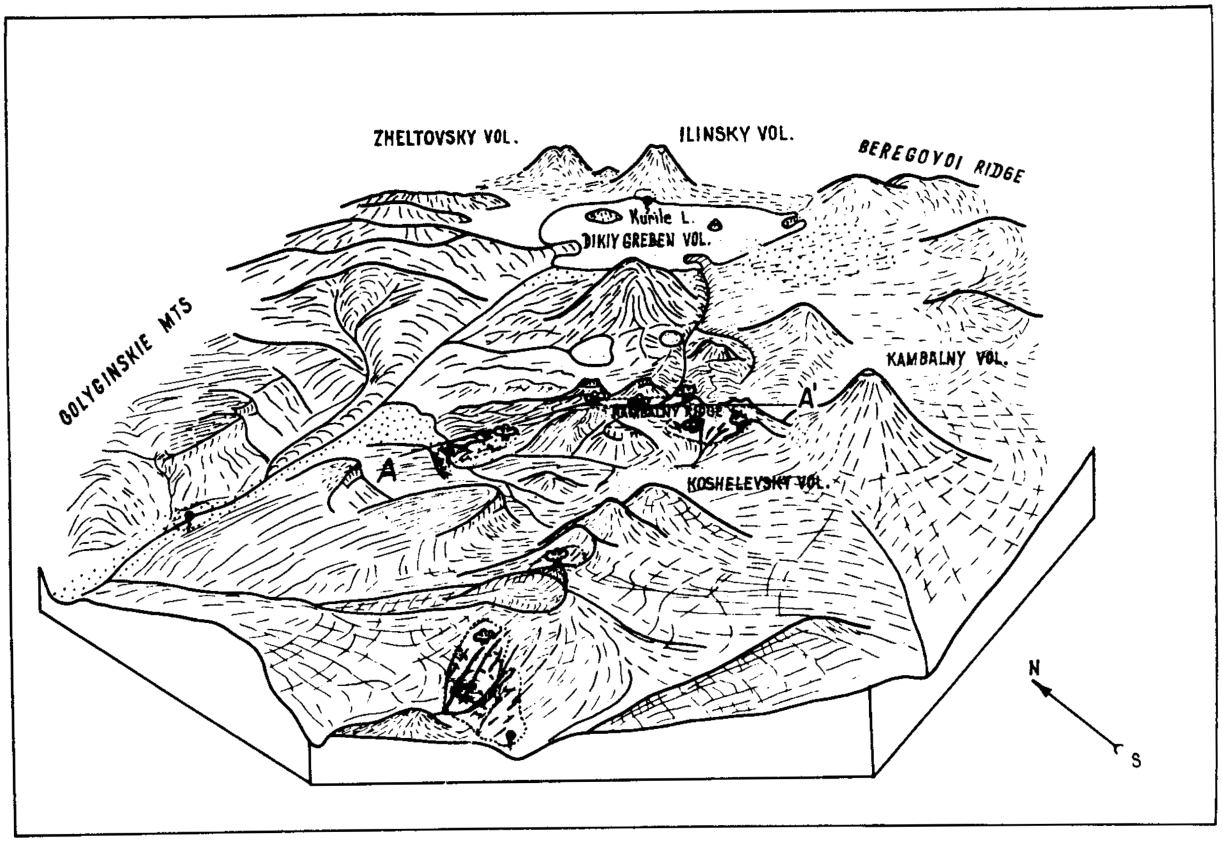


Fig.1. The block scheme of the Pauzhetka hydrothermal system.

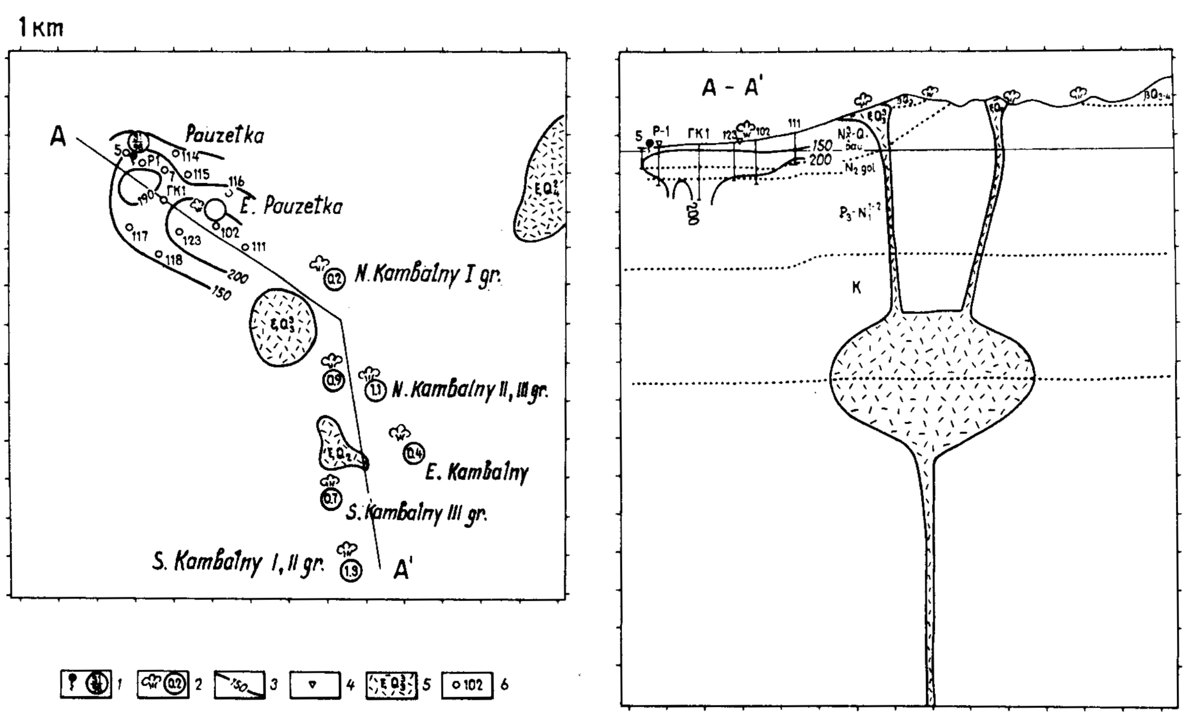


Fig.2. Thermal occurrences and magmatic activity within the Pauzhetka hydrothermal system: 1 - hot springs, the numerator denotes the discharge, kg/s, and the denominator denotes the temperature °C; 2 - steam grounds, heat capacity 10^3 kcal/s; 3 - geoisotherms; 4 - piezometric levels of thermal waters; 5 - acid extrusions; 6 - wells.

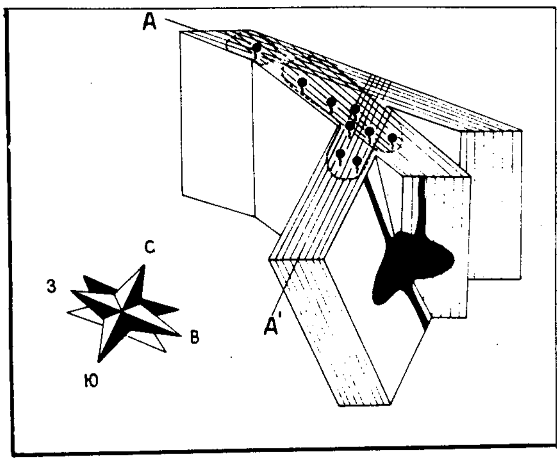


Fig.3. Geometry of the reservoir (cross section from Fig.1).

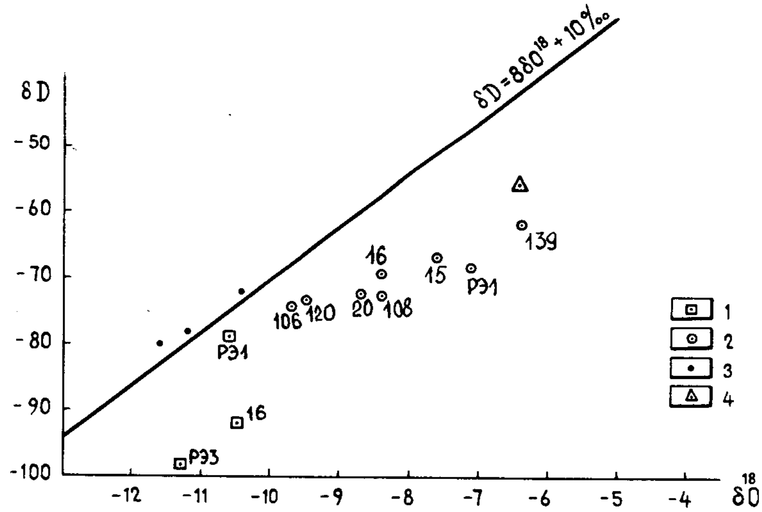
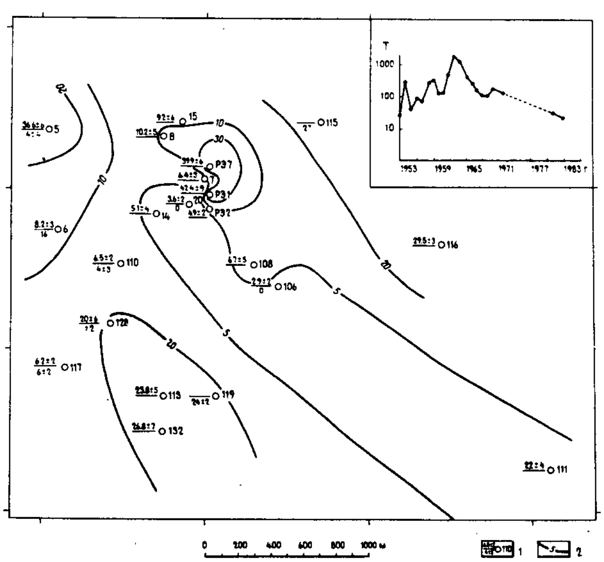


Fig.4. Hydroisotopic composition of thermal and meteoric waters within the Pauzhetka hydrothermal system (O^{18} and D were determined by V.A.Polyakov and T was determined by V.V.Romanov): a) deuterium and ^{18}O; 1 - data obtained by Serezhnikov and Seletsky (1982) from wells; 2 - data obtained by the authors from wells (sampling in 1983); 3 - cold waters from the Kambalny Ridge (sampling in 1983); 4 - water from the Kurile Lake, depth 300 m (sampling in 1983); b) the tritium concentration (in T.U.); 1 - well numbers are shown to the right of the circle, to the left- the numerator denotes the T concentration in 1981 and the denominator denotes the T.concentration in 1983; 2 - tritium isolines.



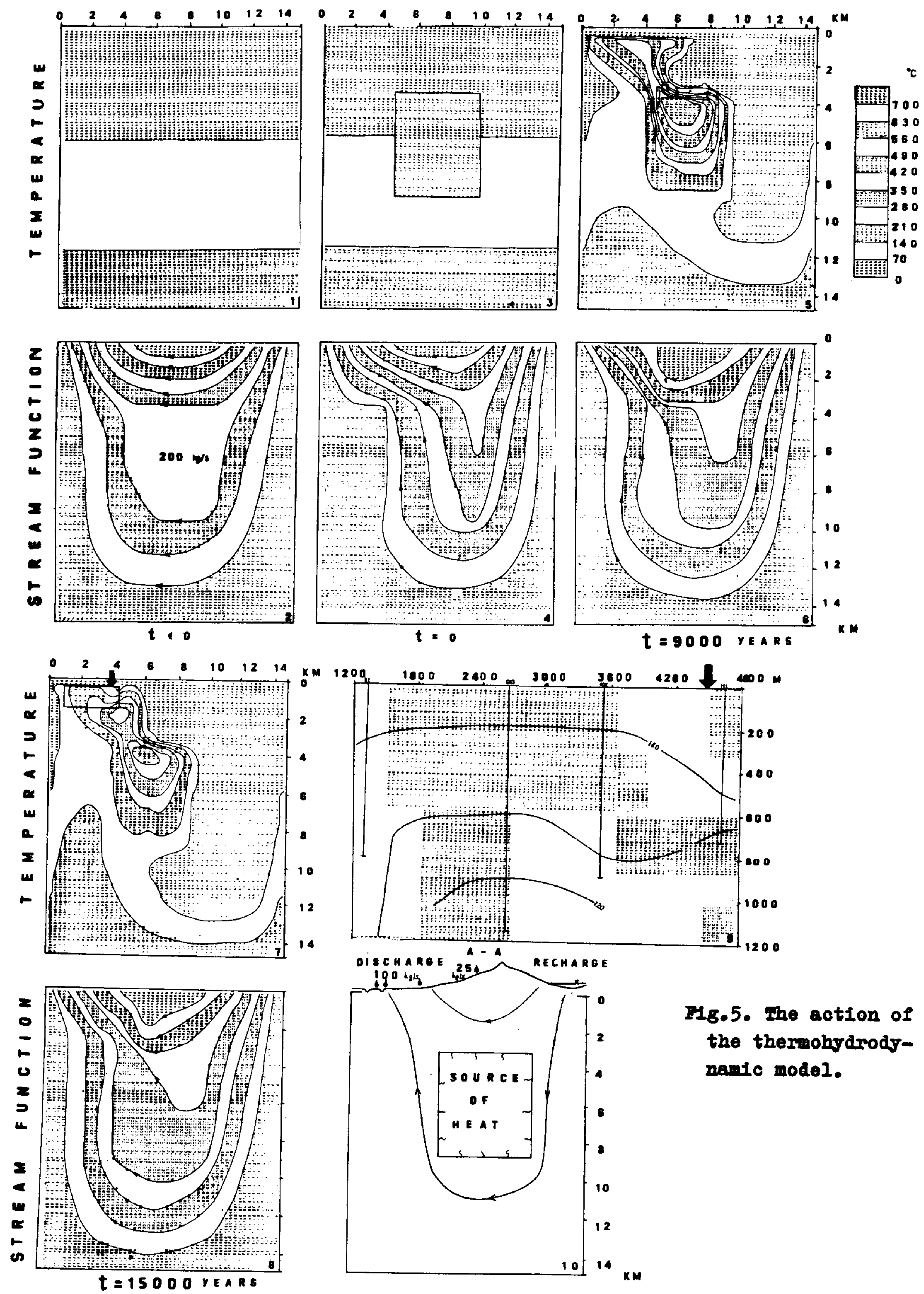


Fig.5. The action of the thermohydrodynamic model.