GEOTHERMAL STUDIES IN SIBERIA AND MONGOLIA

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SUMMARY — The paper presents summarized heat flow data obtained from more than 217 heat flow stations over East Siberia and Mongolia. On the most of the area the heat flow varies from 30 to 50 mW/m^2. The highest flux is observed in the Baikal rift zone. Heat production of rocks varies from about 0.59 to 5.7 mW/m^3. Heat flow /heat production correlation relationships established for the Baikal rift zone and south-eastern Trans-Baikal area did not prove valid for Mongolia. The lithospheric,thickness from geothermal data is 200 km beneath the Siberian platform thinning to 150-170 km beneath the Trans-Baikal area, and to 55-75 km under the Baikal rift zone.

1. INTRODUCTION

During last two decades, the geothermal regime in East Siberia and Mongolia has been studied in the southern Siberian platform, Baikal rift zone, Trans Baikal fold area, and Mongolia four provinces differing by their geology and tectonics. The continental crust is highly heterogeneous within the provinces ranging in age from the Early Riphean to the Late Cenozoic.

Data on deep temperatures and geothermal parameters were obtained through geothermal logging in deep boreholes in the southern Siberian platform (Lysak, 1984). First precise heat flow determinations were *carried* out in Baikal Lake and adjacent regions. By now geothermics of the Baikal basin is one of the best studied in Asia with more than 300 heat flow stations over its territory. More than 80% of the data were obtained in course of the last decade due to sounding bottom sediments by non- autonomous thermistor probes (Golubev, 1982, 1987).

The reported data are from 93 heat flow stations in the south of the Siberian platform, 35-on land stations in the Baikal rift zone, 57 stations in the Trans-Baikal fold area, and 32 ones in Mongolia.

2. METHODS AND INSTRUMENTS OF GEOTHERMAL MEASUREMENTS

The heat flow was calculated based on thermogram segments not affected by seasonal temperature variations or on those from beneath permafrost layers in the cases of studies in cryogenic areas. Temperatures in the holes were taken at points spaced according to specific objectives of the study and hole depths so that temperature difference for a couple of neighbouring points exceeded the possible error. Most of the sampling was taken each 10 m.

The temperature sensors were highly sensitive thermistors calibrated using special techniques and instruments according to 5 temperature values (-37, -12, 0, +12, +37 "C). Three of them (-37, 0, +37) were used in processing tabled parameters of the thermistors, and two other were reference ones. If the difference between calculated and empirical values in the reference points (+12 and -12) exceeded 0.1 °C the thermistors were rejected. The measurement error was 0.03-0.05 "C.

Thermal conductivity of core samples from boreholes was determined in laboratory through the comparative method by means of a thermal comparator designed by Siberian engineers. The thermal comparator operates based on two-point probing of the surface of specimens by two thermoprobes. It is calibrated against standard thermal conductivities within the range of 0.2 to 14.7 W m^{-1}K^{-1}. The instrument is remarkable due to its high speed of measurement (2-3 min), its ability to examine specimens of arbitrary size and shape, as well as to its high accuracy with 3-7% error for the whole temperature range.

3. RESULTS AND DISCUSSION

3.1 General characteristics of heat flow

In the southern *Siberian platform* the mean of heat flow is 39 mW/m^2 rising to 25-50 in the centre of the area and decreasing to 35 mW/m^2 in marginal uplifts (Dorofeeva and Lysak, 1989).

Low heat flow here is due to a rather small geothermal gradient of about 13+-1 mK/m and high thermal conductivity of about 3.0+-0.1 W/mK in the carbonate-halmeic and terrigeneous sediment cover (Fig. 1). The southern Siberian platform displays the steady-state thermal regime that is associated with rather smooth topography and low seismicity.

In the *Baikal* rift *zone* the flux is more variable, especially in Lake Baikal itself. A positive thermal anomaly in its southern and central parts parallels its south-eastern edge whilst in the northern part, local highs are recognized both near the eastern and the western edges of the basin.

Maximum heat flow values coincide with a local increase in the bottom water temperatures, well pronounced against the background of a broad regional bottom water temperature

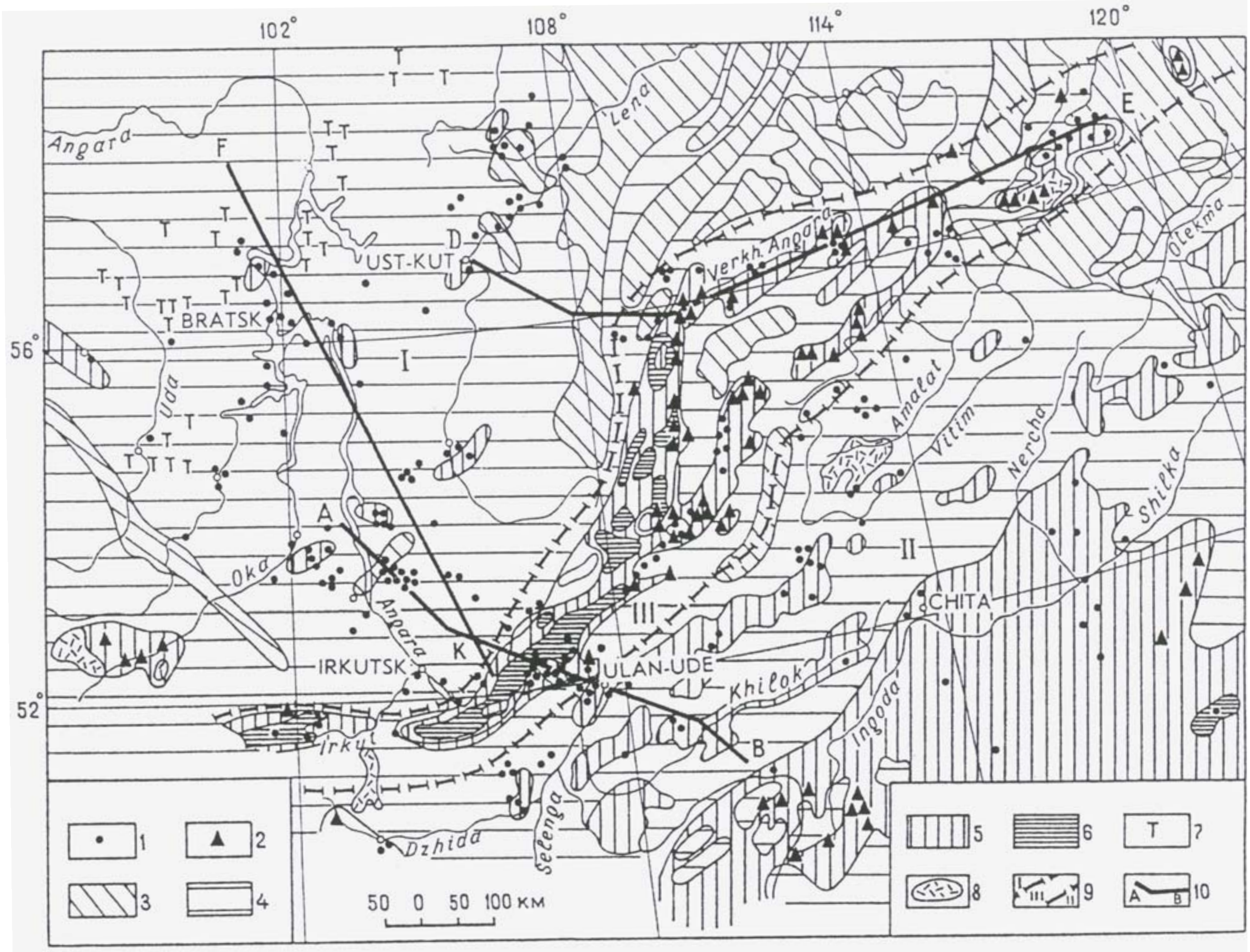

Figure 1- Heat flow distribution in the southern East Siberia. (Dorofeeva and Lysak, 1989)
1 = heat flow stations on land; 2 = hot springs; 3-6 = regional heat flows (in mW/m^2): lower than 25 (3), from 25 to 50 (4), from 50 to 75 (5), higher than 75 (6); 7 = Siberian traps (Permian-Triassic); 8 = flood basalts (Cenozoic); 9 = major tectonic zones: southern Siberian platform (I), Trans-Baikal fold area (II), Baikal rift zone (III); 10 = profile lines.

anomaly. Heat flow distribution in the northern and central basin is related to the thermal field in the adjacent mountains. That may be due to the groundwater which penetrates into *great* depths along faults in the ridges, heats up, migrates toward the Lake and outflows on its coast and in the bottom through hot springs. This phenomenon must be responsible for low temperatures and the respective flux in the mountains bordering Baikal (Golubev, 1982; 1987). A broad high in the southern part of the Lake may be associated with a recent mantle injection. In other rift basins, the heat flow is about 60 mW/m^2 (Fig.1), i.e. higher than that in the mountains.

Thus, the crust in the Baikal rift zone is the hottest beneath the rift basins where asthenospheric and upper mantle diapirs come closer to the crustal base, and in the zones of active faulting which involve intense hydrothermal heat and mass transfer. The uneven heat flow field may be also related to different permeability of the upper crust for the convective deep heat flow or to some other geological and geodynamical factors.

Until recently the heat flow in the Trans-Boikal area was supposed to be 51+-14 mW/m^2, ranging from 47 mW/m^2 in the features affected by the Caledonian orogeny to 70-80 mW/m^2 in those subjected to the Hercynian movements. High thermal activity of the area is evident in hot springs associated with Cenozoic faults, and in Mesozoic and Late Cenozoic volcanism (Fig. 1). Newly obtained geothermal data (Dorofeeva and Sintsov, 1990) yield higher mean flux of 77+-17 mW/m^2 in the south- eastern Trans-Baikal area. The thermal anomaly in the region may be related either to crustal inhomogeneities or to violated steady-state behaviour of the thermal regime. Over most of the Trans-Baikal area, the thermal field is close to the steady-state one whilst in its south-eastern part, the stationary behaviour is disturbed by Cenozoic tectonics (Fig.1).

The thermal regime in *Mongolia* was studied from 32 heat flow stations. The South Mongolia Hercynian belt and Mongolia-Altai province are still poorly studied (Fig.2). The data here obtained are less reliable as they come from shallow boreholes (no deeper than 150-200 m) drilled through sediments. On average, some features show a general westward decrease in heat flow from 62+-9 to 40+-7 mW/m^2 (Table 1).

The observed scatter in heat flow values in southern East Siberia and in Mongolia testifies to variable thermal conductivity due to crustal structures. Beside the local (crustal) anomaly, there is a large regional (mantle) anomaly indicated also by gravity, seismic and electric data (Zorin et

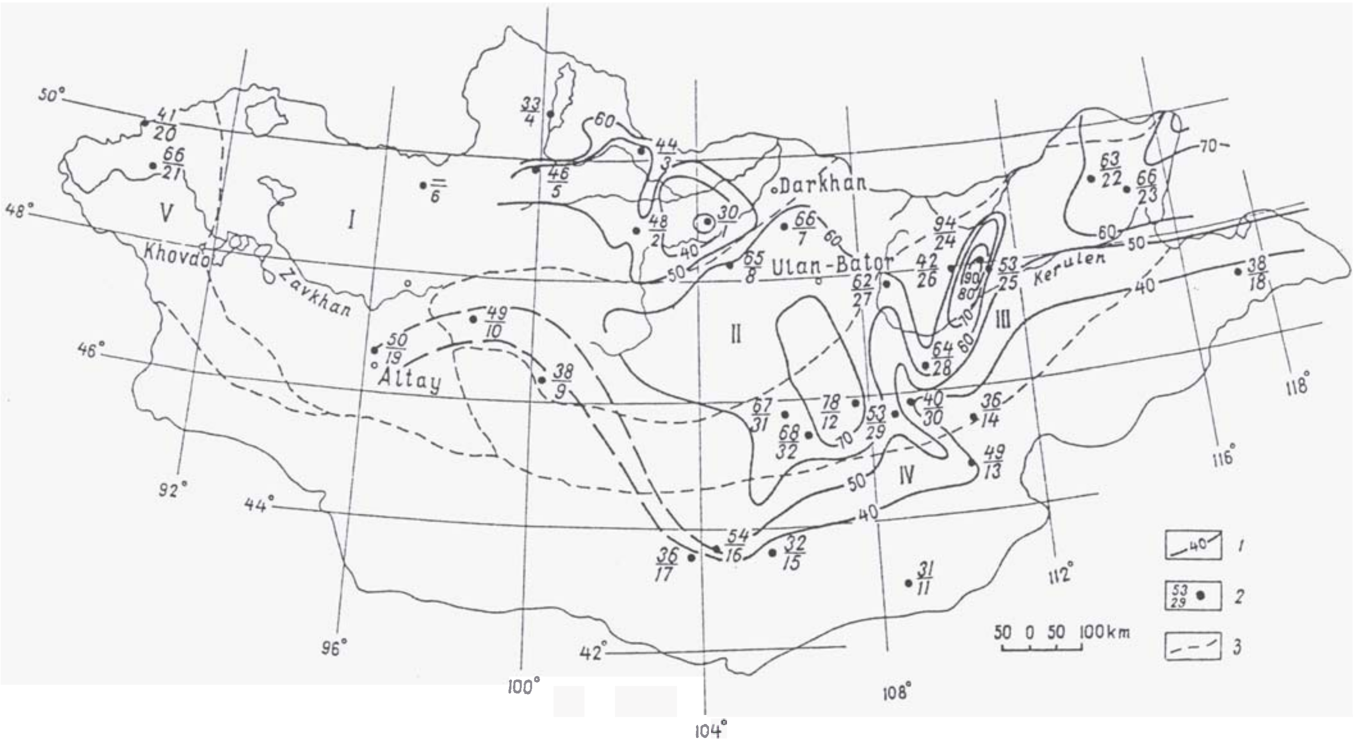

Figure 2 - Heat flow distribution in Mongolia (Dorofeeva and Sintsov, 1990)
1 = heat flow contour lines in mW/m^2; 2 = heat flow stations: heat flow values (numerators) and numbers of the stations (denominators); 3 = contours of fold areas: I - Selenga-Yablonevy (points 1-6), II - Mongolia-Trans-Baikal area (points 7-10), III - Kerulen-Argun (points 12, 22-32), IV - South Mongolia (points 11, 13-19), V - Mongolia-Altai (points 20, 21).

al., 1990). These data show that the Mongolia-Siberia mountainous province is underlain by anomalous mantle the top of which is marked by low seismic velocities of 7.7-7.8 km/s beneath the Baikal rift. According to these data, the lithosphere under the Siberian platform is as thick as 200 km thinning to 55-75 km below the Baikal rift zone and thickening again beneath the Trans-Baikal fold area till 120-170 km. The thinned crust beneath the Baikal rift zone is supposed to be due to the asthenospheric diapir injected into the lithosphere 30-35 m.y. ago.

3.2 Heat production and radiogenic beat flow

Contribution of radiogenic heat flow to the total flux was evaluated based on a broad investigation of heat production of igneous, metamorphic and sedimentary rocks. Heat production was estimated from U, Th and K contents measured by gamma-spectrometry.

An obtained relationship between heat production and composition of rocks for the standard rocks shows an exponential decrease in heat production with increase in alkali content (from 5.7 to 0.2 mW/m^3), that agrees well with earlier data (Dorofeeva, 1990).

Reduced heat flow and D parameter were estimated proceeding from the known heat flow versus heat production relationship of $q = qr + AD$. The reduced heat flow turned out to be 32 and 45 km in the Baikal rift zone and Trans-Baikal area, respectively, at the same D of 5+-3 km and a correlation coefficient of 0.5. Such kind of relationships for Mongolia were impossible to get though we had data from

Table 1- Mean values of geothermal parameters for fold system in Mongolia

No. (Fig. 2)	Fold Systems	n	Geothermal Gradient (mK/m)	Heat Flow (mW/m^2)
III	Kerulen — Argun	11	27	62 ± 9
II	Mongolia — Trans-Baikal	4	22	54f 13
I	Selenga — Yablonovy	5	17	40 ± 7
V	Mongolia — Altay	2	16	54 +25
IV	South Mongolia	8	20	40k 7

more than 500 samples. Heat production of granites, for example, varied from 0.88 to 4.34 mW/m^3, that is indicative of radiogeochemical heterogeneity of the upper crust (Dorofeeva and Sintsov, in press).

Deep lithospheric temperatures were calculated based on a heat production versus depth exponential function at D = 5+-3 km. Temperatures of sites where heat production was not determined were inferred from seismic velocities using the respective correlation relationship (Dorofeeva, 1990). Based on temperatures calculated from the thermal conductivity equation, depths of the 1200°C geotherm were mapped provisionally, where the 1200°C value is conventionally assumed to be the lower temperature limit of the lithospheric base. According to this preliminary map, the lithospheric thickness beneath the Siberian platform, being fairly variable, approaches 200 km; in the Trans-Baikal fold area it ranges from 120 to 180 km, thinning to 90 km in the south-east; in Mongolia its variation range is from 90 to 170 km. Therefore, the lithospheric thickness estimated from geothermal data agrees with that from gravity, seismological and magnetotelluric data (Zorin et al.,1990). At the same time, any final conclusion seems premature because of uneven distribution of heat flow stations and hence different reliability of data from poorly studied areas.

4. CONCLUSION

In the most territory of East Siberia and Mongolia the heat flow varies within the range of 30 to 50 mW/m^2. Low flux (lower than 20 mW/m^2) is typical of some localities in the Siberian platform. Thermal highs (above 60-90 mW/m^2) are observed in the Baikal rift zone.

The younger is the stable continental crust and tectono-magmatic activity, the higher is the regional heat flow. Geo- thermal parameters vary in different tectonic features being a function of composition of the crystalline basement, deep structure and mode of heat transfer (convection dominates anomalous sites).

In the areas reactivated in the Mesozoic and Cenozoic (the Baikal rift zone, the southern Trans-Baikal fold area) the thermal field is highly uneven that is evident in alternation of relatively narrow and long thermal highs, associated with active faulting, with wider zones where the flux never exceeds 30-50 mW/m^2. The thermal regime in the anomalous areas is controlled mainly by deep heat transfer through the upper mantle or the asthenosphere.Local thermal anomalies are produced by additional heat sources in the crust. In tectonically active areas, there are mostly fracture mantle intrusions (including the deep-seated ones) and faults. Depth, frequency and permeability of these faults controls destruction of the lithosphere which, together with surface factors (climate, erosion, sedimentation, topography) and radioactivity significantly affects the heat flow pattern.

The *area* is abundant in hot springs which are of great medical and industrial importance. The hottest areas show good prospects for extraction of the thermal energy in Siberia.

5. ACKNOWLEDGEMENTS

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