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THE HEAT FIELD OF THE WEST SIBERIAN PLATFORM[1]

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In the present article, which is based on work done by the Laboratory of Crustal Physics of our Institute, we shall analyze data on the first determinations of heat flow in the West Siberian Plain and of the temperatures at the upper (top of folded basement) and lower (Mohorovičić surface) boundaries of the consolidated crust. In the last case we have also used deep seismic probing (DSP) data on crustal layering along profiles crossing the plain in several directions.

Tectonically, the West Siberian Plain coincides for the most part with the young platform (plate) of the same name. The sedimentary cover of the plate, that is, its third structural stage, consists of terrigenous formations (sandstone, siltstone, clay and mudstone of the Mesozoic and Cenozoic), which thicken toward the middle and northern part of the plain. Lying below, but not in a continuous sheet, are largely terrigenous sediments of different origin and metamorphic grade, which belong to the intermediate (second) structural stage. The first structural stage consists of folded complexes of different age, forming the heterogeneous basement of the platform [9].

A considerable number of temperature measurements has now been made in the sedimentary cover of the platform, in holes drilled in many of the areas explored for oil and gas. There are publications in which the results of these measurements are summarized, described and also interpreted in terms of different aspects, including the metamorphism of organic matter in the sedimentary cover ([2], etc.). In general, the temperatures of the cover decrease from west to east in the West Siberian platform. The behavior of the geothermal gradient reflects broadly the behavior of the temperature field.

In order to ascertain the terrestrial heat flow in the platform, the thermal conductivities of rocks of the sedimentary cover were determined in the laboratory on cores from deep holes, drilled in 11 areas in the middle, south and southeast of the platform. More than 250 specimens were investigated. Measurements were made by the method of steady-state heat flow. The thermal conductivity values obtained range from $2.5 \cdot 10^{-3}$ to $4.3 \cdot 10^{-3}$ cal/cm·sec·deg. The sandstones exhibit values that lie over the entire range; the thermal conductivities of siltstones range from $2.9 \cdot 10^{-3}$ to $3.8 \cdot 10^{-3}$ cal/cm·sec·deg, but those of mudstones equal $3.1 \cdot 10^{-3}$ cal/cm·sec·deg. Most sedimentary rocks have a thermal conductivity of 2.8 to $3.8 \cdot 10^{-3}$ cal/cm·sec·deg (Fig. 1).

Using data on the geothermal gradient and thermal conductivity obtained in the same drillholes, we have determined the heat flow from the earth's interior for the 11 areas of the above platform and for three areas in the Minusinsk basin, in the nearby Altai-Sayan fold zone [8] (Table 1). The heat flow in the West Siberian platform ranges from $1.23 \cdot 10^{-6}$ to $0.87 \cdot 10^{-6}$ cal/cm^2·sec, i.e., it is somewhat lower than the normal value for continents [5, 11]. The heat flow is maximal in the Aleksandrovskaya area and minimal in the Beloyarskaya area. There is a very general tendency for the heat flow to decrease outward from the middle of the platform (at any rate, southward and southeastward). There is also a smaller-scale localization of the heat-flow field in the interior of the platform (Fig. 2).

The above data on heat flow in various areas of the West Siberian platform have been used, with allowance for the temperature dependence of thermal conductivity [6, 7], to estimate, of course very roughly, the temperature at the lower crustal boundary, that is, at the Mohorovičić surface. One of the principal factors accounting for the approximate nature of the estimate is that the information about the concentration of radioactive elements in the crust in the areas under consideration is rather tentative. Ideas about crustal composition and layering are based, to some extent, on interpretations of gravity and magnetic anomalies ([10], etc.) and on the data of deep seismic probing [3, 4]. The sections used show that the mode of deep crustal layering also differs in different intervals of the deep seismic probing profiles. The boundaries of the "granite" and "basalt" layers and the Mohorovičić surface are revealed clearly by cutoff velocities in some

[1] Translated from: O teplovom pole Zapadno-Sibirskoy plity. Doklady Akademii Nauk SSSR, 1969, Vol. 189, No. 2, pp. 385-388.

Table 1

Heat Flow and Temperatures at the Basement Surface and Mohorovičić Boundary for Some West Siberian Districts

Number	Area	Depth, km		T_b, °C	T_M tentative (calculated), °C			Heat flow, 10^{-6} cal/cm²·sec
		Basement (b)	Mohorovičić boundary from DSP data		T_{min}, assumption 1	T_{max}, assumption 2	T_{B-J}, assumption 3	
				West Siberian platform				
1	Aleksandrovskaya	3.0	44.0	110	870	1480	870	1.23±1.18
2	Beloyarskaya	2.0	44.0	56	200	1000	600	0.87±0.13
3	Zav'yalovo	3.6	37.4	93	310	1080	540	0.94±0.14
4	Ust' Balyk	3.0	35.0	100	470	1020	630	1.12±0.17
5	Novologinovskaya	2.6	34.8	67	270	1040	480	0.88±0.13
6	Tobol'sk	2.4	34.5	87	360	1070	530	0.94±0.14
7	Omsk	2.7	32.0	70	360	850	460	0.94±0.14
8	Mikhaylovskaya	2.0	38.5*	84	600	1400	700	1.22±0.18
9	Chelnokovskaya	2.5	39.0*	86	530	1200	670	1.12±0.17
10	Tuy	2.5	38.0*	80	420	1300	650	1.13±0.17
11	Bochkarevskaya	3.5	38.5*	110	460	1360	630	1.09±0.16
				Altai-Sayan zone. Minusinsk depression				
12	Bystrya[illegible]kaya							1.06±0.16
13	Altayskaya							1.48±0.22
14	Sol'zavodskaya							1.63±0.24

*Data of [11]

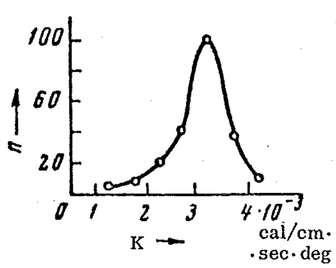


Fig. 1. Variations in thermal conductivity (K) of terrigenous rocks of the West Siberian platform.

cases, as is the smaller-scale layering of the crust. In other cases, one sees no such differentiation in the crustal layering. However, the Mohorovičić surface can be reliably traced everywhere.

Given the above explanations, the temperature at the Mohorovičić surface was estimated by the approach often used in such cases ([12, 13], etc.). We employed the formula

$$T_M = T_b + \sum_i T_i, \quad \text{where } T_i = 1/K_i\,(q_i - 1/2 H_i d)\, d.$$

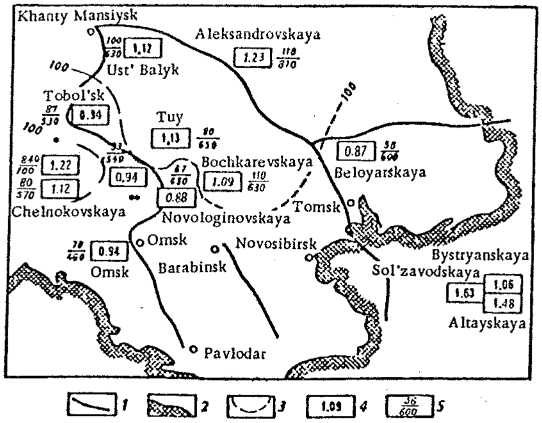
Here: K_i is the thermal conductivity of the i-th layer (within which K is assumed to be constant); q_i is the heat flow through the lower boundary of the i-th layer; H_i is the quantity of heat liberated in the i-th layer by decay of radioactive elements; d is the thickness of the i-th layer, taken as equal to 2 km on the average; and T_b is the temperature at the basement surface.

The estimates of possible temperatures at the Mohorovičić boundary are given in several versions (see Table 1).

1. On the assumption of maximum concentrations of radioactive elements in the crust, assuming further that its layering is that given by DSP data, and estimating the heat due to radioactive decay in accordance with the data of Birch (granite $7.0 \cdot 10^{-13}$ cal/cm³·sec) [1]. In this mediate rock $4.0 \cdot 10^{-13}$ cal/cm³·sec, basalt and gabbro $1.1 \cdot 10^{-13}$ cal/cm³·sec) [1]. In this case the temperature at the Mohorovičić boundary will be at a minimum (T_{min}).

2. On the assumption that no heat is liberated in the crust by radioactive decay, that is, that all heat comes in from the mantle. In this case the temperature at the Mohorovičić boundary will be at a maximum (T_{max}).

3. On the assumption that the mantle provides roughly a quarter of the observed heat flow, in accordance with the ideas of Birch and Jeffreys (T_{B-J}). Temperature estimates 1 and 3 for the Mohorovičić surface can be assumed compatible, although they are in need of further and considerable improvement. Also, estimate 1 is consistent with data of Lyubimova [5]. As for estimate 2, it is interesting that the so



*Mikhaylovskaya, **Zav'yalovo

Fig. 2. Heat flow and temperatures at the basement surface and Mohorovičić boundary within the West Siberian platform. 1) DSP profile, 2) Paleozoic fringe, 3) line of heat flow, 4) heat flow (μcal/cm²·sec), 5) temperatures (°C); nominator) at basement surface; denominator) at Mohorovičić boundary.

derived temperatures at the Mohorovičić boundary are similar to those of Toser's theoretical model for steady-state temperature distribution beneath Precambrian shields [5].

This is the basic information on the heat field of the West Siberian platform. The extremely small number of determinations of the heat flow permits no serious conclusions about its correlation with geologic structure, recent movements and other parameters. However, some suggestions can be made in this respect. For example, the observed differentiation of heat flow over this area could reflect the nonuniform age of its folded basement. The higher heat flow in the Aleksandrovskaya area is certainly related to its overlying the zone of the deep Koltogorskiy faults [9] and also to the fact that DSP data indicate that the crust here has no "granite" layer. This last fact could also account for the high temperature at the basement surface and especially at the Mohorovičić boundary (Table 1). Moreover, elsewhere in this region, there seems to be some correlation between the heat flow and, for example, the elements of the geomagnetic anomaly field, the structure and morphology of the folded basement, the Mohorovičić and other surfaces.

Received April 1, 1969

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