ON THE PREDICTION OF TEMPERATURE IN THE EARTH' S INTERIOR

GEOPHYSICS

1967

SovietRxiv

Abstract

Full Text

UDC 550.836(479.24)

GEOPHYSICS

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ON THE PREDICTION OF TEMPERATURE IN THE EARTH' S INTERIOR

(Presented by Academician A. L. Yanshin on 26 III 1966)

For an approximate estimate of the temperature at a depth of 15 km in the Saatly region (southeastern Caucasus), where the drilling of an ultradeep borehole is being planned, we used the expression for the geothermal gradient:

$$\Gamma = \left[Q - H_n x - \sum_{i=2}^{n} (H_{i-1} - H_i) l_{i-1} \right] / \lambda, \tag{1}$$

derived in work ([6]), where H_n is heat generation in a layer of the earth' s crust; l_i is the distance from the surface to the base of the layer; Q is the magnitude of the heat flow near the surface; n is the number of layers and λ is the thermal conductivity of the rocks in them; x is depth.

In works ([3],[6]), when this equation is used, it is allowed—because measurements of the quantity Q are lacking in most regions—to take its value as the planetary average at the surface of the continents, 1.2 μcal/cm^2·s. In the region considered by us the quantity Q was not measured, but in the nearest adjacent area—Iran ([10])—it proved to be 0.87 μcal/cm^2 · s. This value of Q was used by us for the calculations.

According to work ([1]), we compiled Table 1, showing the percentage of the various rock types in each interval characterizing a definite stratigraphic complex. This table gives interval values of H_n, λ, and Γ.

The interval values of H_n were obtained as weighted averages of these quantities for the individual rocks. For sedimentary rocks, H_n was calculated from the data of work ([8]) on uranium content along a section of the Prikura and Kobystan regions of Azerbaijan. For metamorphic rocks, H_n was calculated according to works ([8],[9]) on the amount of uranium in the corresponding rock-forming minerals (quartz, feldspar, limestone). The values of H_n for granites, gabbro, and basalts were not taken as those usually used ($5.3 \cdot 10^{-13}$ and $1.5 \cdot 10^{-13}$ cal/cm^3·s, respectively), since their samples, as is known, were taken mainly from the upper parts of the corresponding layers, and the content of radioactive elements in these samples can only in certain cases be equal to their average content over the thickness of the layers. According to present concepts, the content of radioactive elements in the indicated layers may sometimes decrease from the roof to the base. In addition, it is known that, for example, under shield conditions (in which the thermal field may be regarded as stationary), the use of these values of H_n in calculations gives a value of Q approximately twice as large as the actually measured values. Thus, the indicated values of H_n for acidic and basic rocks are overestimated by approximately a factor of 2. Therefore, for our calculations we took values of H_n twice as small as those indicated, namely, for granite we adopted $H_n = 2.65 \cdot 10^{-13}$ cal/cm$^3 \cdot$ s, and for gabbro and basalt $H_n = 0.75 \cdot 10^{-13}$ cal/cm$^3 \cdot$ s.

Using measurements of λ for sands at different moisture contents and depths of occurrence ([7]); for clays, sandstones, limestones, and marls at different depths ([3,5]); and for shales, gneisses, marbles, acidic and basic rocks at different temperatures ([2]), we constructed curves of the dependence of the rocks' λ on

depth and temperature (Figs. 1 and 2). In doing so, for sands and clays, owing to the absence of exact information on the degree of their water saturation, we assumed, in accordance with statistical data for the southeastern Caucasus, that 60% of them are water-saturated, and 40% are practically dry. On the basis

Table 1

Intervals and stratigraphic units	Sands	Clays	Sandstones	Limestones	Marls	Shales	Gneisses	Marbles	Acid rocks (granites)	Basic rocks (gabbro and basalts)	$\lambda \cdot 10^5$, cal/cm · sec · deg	$H_m \cdot 10^3$, cal/cm^2 · sec	T, °C/km
0.01 – 0.75 km (Upper Quaternary deposits)	29	27	12	32	–	–	–	–	–	–	490	1.8	17.5

Intervals and stratigraphic units	Sands	Clays	Sandstones	Limestones	Marls	Shales	Gneisses	Marbles	Acid rocks (granites)	Basic rocks (gabbro and basalts)	$\lambda \cdot 10^5$, cal/cm·sec·deg	$H_m \cdot 10^3$, cal/cm^3·sec	T, °C/km
0.75 – 1.55 km (Absheron stage)	30	46	15	9	–	–	–	–	–	–	441	2.3	19.5
1.55 – 2 km (Akchagyl stage)	29	67	4	–	–	–	–	–	–	–	379	2.7	23.1
2 – 3.6 km (Productive unit)	35	47	14	4	–	–	–	–	–	–	520	2.4	16.1
3.6 – 4 km (Sarmatian stage)	19	44	–	21	16	–	–	–	–	–	545	2.3	15.8
4 – 5.3 km (Cretaceous deposits)	10	8	12	41	29	–	–	–	–	–	679	1.3	11.8

Intervals and stratigraphic units	Sands	Clays	Sandstones	Limestones	Marls	Shales	Gneisses	Marbles	Acid rocks (granites)	Basic rocks (gabbro and basalts)	$\lambda \cdot 10^5$, cal/cm·sec·deg	$H_m \cdot 10^3$, cal/cm^3·sec	T, °C/km
5.3 – 8.8 km ("Granite" layer)	–	–	–	–	–	35	45	10	10	–	550	2.65	15.3
8.8 – 10 km ("Basalt" layer)	–	–	–	–	–	–	–	–	–	100	390	0.75	18.9
10 – 11 km ("Basalt" layer)	–	–	–	–	–	–	–	–	–	100	355	0.75	20.9
11 – 12 km ("Basalt" layer)	–	–	–	–	–	–	–	–	–	100	320	0.75	23.1
12 – 13 km ("Basalt" layer)	–	–	–	–	–	–	–	–	–	100	298	0.75	24.9

Intervals and stratigraphic units	Sands	Clays	Sandstones	Limestones	Marls	Shales	Gneisses	Marbles	Acid rocks (granites)	Basic rocks (gabbro and basalts)	$\lambda \cdot 10^5$, cal/cm·sec·deg	$H_m \cdot 10^3$, cal/cm^3·sec	Γ, °C/km
13 – 14 km ("Basalt" layer)	–	–	–	–	–	–	–	–	–	100	292	0.75	25.3
14 – 15 km ("Basalt" layer)	–	–	–	–	–	–	–	–	–	100	280	0.75	26.5

From Table 1 and the curves, weighted-average values of λ were calculated for each interval. In doing so, the values of λ were assigned to the corresponding depths by the method of successive approximations.

From works ([3],[5],[7]) and from our curves it is evident that the λ of some rocks increases with increasing depth, whereas for others, with increasing depth—or, more precisely, with increasing temperature—it decreases. This is explained by the fact that in the first case the magnitude of the increase in λ of the rocks due to a decrease in their porosity and an increase in density prevails over the magnitude of the decrease in λ caused by the property of a number of minerals to lower λ with increasing temperature, while in the second case the opposite effect is obtained. The influence of the indicated property of certain minerals (quartz, sylvite, corundum, etc.)

is manifested more strongly at high temperatures [4], and, consequently, at great depths.

Substituting into equation (1) the adopted value of Q and the interval mean-weighted values of H_n, λ, we obtained the values of Γ for each interval, given in Table 1. For the uppermost interval the calculation was made not from the surface, but from the neutral layer, whose depth and temperature were taken by us as identical to these quantities for the Apsheron Peninsula, where they are 10 m and 16.5°, respectively.

Fig. 1. Dependence of λ of rocks on depth.

1 —sands, 2 —clays, 3 —sandstones, 4 —limestones, 5 —marls

Fig. 2. Dependence of λ of rocks on temperature.
1 —shales, 2 —gneisses, 3 —marbles, 4 —acidic rocks, 5 —basic rocks

Fig. 3. Dependence of temperature on depth

Then the temperature values were calculated and a graph of its change with depth was constructed (Fig. 3). As is seen from the curve, the expected temperature at the bottom of a 15-km-deep borehole in the Saatly area is about 265°.

The author expresses gratitude to B. G. Polyak and Ya. B. Smirnov for valuable comments in reviewing the manuscript.

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Received
22 III 1966

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Note: Figure translations are in progress. See original paper for figures.