Geophysics

1957

SovietRxiv

Abstract

Full Text

Geophysics

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On the Question of Geothermal Anomalies of the Donbass

(Presented by Academician N. M. Strakhov, 29 IV 1957)

A change in the geothermal regime within the thickness of Carboniferous deposits in the exposed part of the Donets Basin is due chiefly to the features of its tectonic structure.

Numerous geothermal measurements carried out in boreholes over the area of the Central, Chistyakovo, Stalino-Makeevka, Shakhty, and other geological-industrial districts of the basin have established that in the crest parts of anticlinal structures, as compared with the central parts of synclines, geothermal conditions are higher ([1,3,4]).

In recent years, as a result of geothermal investigations within the western sector of the greater Donbass, elevated values of the geothermal gradient and of the altitude marks of geoisothermal surfaces have been found in individual areas. We shall consider one of these anomalies, established by geothermal investigations within the Petropavlovsk-Mezhevaya district.

The geological structure of the district under consideration includes Lower Carboniferous deposits, overlain in its northwestern part by Meso-Cenozoic sediments represented by loose, vari-grained sandstones and sandy clays of the Triassic, a clayey-aleuritic Jurassic sequence, and Paleogene sands and clays.

At the base of the Lower Carboniferous deposits lies a sequence of massive limestones. The overlying Lower Carboniferous sequence consists of clayey and sandy shales, fine-grained sandstones, limestones, and coals, the percentage content of which is given in Table 1.

Table 1

Suite index	Suites	Sandstones	Sandy-clayey shales	Limestones	Coals	Γ (deg/km)	λ (kcal/m · h · deg)
E_1, D_1	Coal-barren (D+E)	25.4	73.4	1.0	0.2	26.9	1.33

Fig. 1. Geoisothermal profile of the Petropavlovsk thermal anomaly. a—Paleogene, b—Triassic-Cretaceous, c—Carboniferous, d—coal seams, e—limestones of suites

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Suite index	Suites	Sandstones	Sandy-clayey shales	Limestones	Coals	Γ (deg/km)	λ (kcal/m·h·deg)
C_1	Coal-bearing (C)	18.0	80.0	0.2	1.8	36.9	1.29
B_1	Under-coal (B)	18.3	78.3	3.0	0.4	24.2	1.35
A_1	Limestone (A)	—	—	100	—	19.0	1.9

In tectonic terms, the area of investigation represents a monoclinal fold forming the southern limb of the extensive Kalmius–Toretsk depression, with gentle dipping of the strata at an angle of 2–5°.

Geothermal measurements in boreholes located in the central part of the area (the village of Petropavlovka) recorded a more intense increase in temperature than in boreholes located on its periphery. Over the area, this anomaly of the geothermal regime is traced quite clearly both along the strike and across the strike of the Carboniferous coal-bearing deposits—the values of the geothermal gradient here decrease from the central part of the anomaly in all directions.

In the central part of the Petropavlovsk anomaly, according to measurement data, the geothermal gradient ranges within 36.2–37.1 deg/km; in the northern part, 26.0–28.0 deg/km; in the southern part, 23.0–25.5 deg/km; in the western part, 27.2–29.2 deg/km; and in the eastern part, 24.2–28.6 deg/km.

Fig. 1. Geoisothermal profile of the Petropavlovsk thermal anomaly. *a*—Paleogene, *b*—Triassic-Cretaceous, *c*—Carboniferous, *d*—coal seams, *e*—limestones of suites.

The increased value of the heat-flow density within the area over which the thermal anomaly under consideration extends is determined by the general rise of the geoisothermal surfaces in its central part, which is illustrated quite clearly by Fig. 1.

Turning to the possible causes responsible for the thermal anomaly of the Petropavlovsk–Mezhevaya area, it is necessary first of all to note that in the present case the elevated geothermal regime cannot be due to the influence of the relief of the earth' s surface, since within the area where the anomaly appears the variation in elevations does not exceed 40 m. Moreover, the difference between temperatures measured at the same depths in boreholes in the central and peripheral parts of the anomaly does not decrease with depth but, on the contrary, increases on average from 1.2° at a depth of 100 m to 4.6° at a depth of 500 m.

The gentle monoclinal occurrence of the Carboniferous deposits within the area naturally also excludes the possibility of linking this phenomenon with a geostructural factor.

As is evident from Fig. 1, increased values of the geothermal gradient and, correspondingly, the higher hypsometric position of the geoisothermal surfaces have been established from boreholes that penetrated the coal-bearing suite, which is distinguished by the maximum coal content in the region. It should be noted here that along the strike of the deposits of this suite, the values of the geothermal gradient decrease together with a sharp decrease in its coal content.

The association of the thermal anomaly with areas of greatest coal content gives grounds to suppose that one of the possible causes determining its nature may be the difference in the thermophysical properties of coal and of the sandstones and shales enclosing it.

The magnitude of the geothermal gradient in different rocks under one and the same heat flow, as is known, is inversely proportional to their thermal conductivity.

If it is assumed that the normal geothermal gradient for crystalline rocks having a thermal conductivity of 3 kcal/m · hour · degree is equal to 12 deg/km (5), then, knowing the thermal conductivity of the individual lithological varieties of the Carboniferous deposits of the Donbass and assuming that the heat flow is constant, one can calculate for them the corresponding magnitudes of the geothermal gradients from the relation

$$\Gamma_{\mathrm{p}} = \Gamma_{\mathrm{k}} \frac{\lambda_{\mathrm{k}}}{\lambda_{\mathrm{p}}},$$

where Γ_{p} and Γ_{k} are the geothermal gradients of the given rock and of crystalline rocks, and λ_{p} and λ_{k}, respectively, are their thermal conductivities.

According to A. N. Shcherban' (6), the thermal conductivity* of the sandstones of the Donbass is 1.84, of sandy-clayey shales 1.18, and of coals 0.17 kcal/m · hour · degree.

Using these values, we obtain the following values of the geothermal gradient: for sandstones 19.2 deg/km, for sandy-clayey shales 30.6 deg/km, for limestones 19.0 deg/km**, and for coals 212.0 deg/km.

Under the condition of constancy of the heat flow over the entire area of investigation and taking into account the percentage content of the individual lithological varieties composing the thickness of the Lower Carboniferous deposits, the mean values of the geothermal gradient will be: in the interval of the section of the coal-barren suite, 25.9 deg/km; in the interval of the coal-bearing suite, 31.9 deg/km; and in the interval of the subcoal-bearing suite, 28.6 deg/km. The difference between the geothermal gradients calculated for the coal-bearing and coal-barren suites is 6 deg/km, and between their values for the coal-bearing and subcoal-bearing suites, 3.3 deg/km. If it is assumed that coal seams are absent from the thickness of the deposits, then this difference (conditioned chiefly by the greater content of sandy-clayey shales in the coal-bearing suite and the smaller percentage content of sandstones) will amount, respectively, to 2.6 and 0.3 deg/km.

It should be noted that the increase in the geothermal gradient due to the presence of coal seams in the coal-barren suite is 0.4 deg/km, in the coal-bearing suite 3.8 deg/km, and in the subcoal-bearing suite 0.8 deg/km.

Thus, it may be considered that the presence of coal seams in the section of the Lower Carboniferous deposits explains to a significant extent the observed more rapid increase of temperature with depth in the areas of greatest coal saturation.

The distribution of temperatures in the investigated section of the Lower Carboniferous deposits is also additionally influenced by the different values of the density of heat flow in the thicknesses of the underlying deposits.

Analysis of the geothermal data obtained for the Central and Krasnoarmeisk districts of the Donbass shows that here, together with folding, the degree of metamorphism of the rocks also influences the change in the geothermal regime.

Within the Central district, along the southern limb of the Main Anticline, where the features of geological structure are the same, a regular decrease in the values of the geothermal gradient is observed from 32.3–32.6 deg/km in the western part of the district to 19.6–20.9 deg/km in its extreme eastern part. In the same direction within the district, a regular increase in the density of the rocks from 2.4 to 2.7 (7) has been established.

In the area of the Krasnoarmeisk geological-industrial district, a similar (although less clearly expressed) dependence is observed between the geother—

* With heat flow directed perpendicular to the bedding.
** Thermal conductivity of limestones from (2).

thermal regime and rock density. Here there is a slight, but regular, decrease in the averaged values of the geothermal gradient from 25.7 deg/km in the northwestern part of the region to 23.6 deg/km in its southeastern part. The average density of the rocks in the indicated direction correspondingly increases from 2.5 to 2.6.

Thus, under the conditions of the Donets Basin, the degree of metamorphism of the rocks appears as one of the factors responsible for changes in the density of heat flow in the Carboniferous coal-bearing deposits.

The examples cited indicate that the geostructural factor is far from the only cause responsible for the entire diversity of thermal manifestations within the Donets Carboniferous strata.

The dependence of the geothermal regime on folding is clearly manifested only in those areas where it is expressed most sharply. Moreover, even in these areas the established general dependence is affected by other factors as well, in particular by the degree of metamorphism of the rocks.

As for areas with gently dipping monoclinal occurrence of Carboniferous deposits, the nature of the observed geothermal anomalies is explained by the action of other causes, among which a notable place is occupied by the difference in thermal conductivity between coal and the enclosing rocks.

Trust "Artemuglegeologiya" Donbass

Received30 III 1957

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