

# HEAT FLOW AND GENERATION OF RADIOGENIC HEAT IN THE EPIGERCYNIAN STRUCTURES OF DAGESTAN

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**Abstract****Full Text**

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*GEOPHYSICS*

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**HEAT FLOW AND GENERATION OF RADIOGENIC HEAT IN THE EPIGERCYNIAN STRUCTURES OF DAGESTAN***(Presented by Academician V. V. Menner, 7 XII 1966)*

The terrestrial heat flow is the product of two jointly determined parameters: the temperature gradient and the thermal conductivity of rocks:  $q = (\partial T / \partial x) \lambda$ . However, estimating the true magnitudes of heat flow requires analysis of the artificial and natural factors that distort the thermal field. The former include distortion of the thermal field during the process of drilling wells; the latter include circulation of groundwater, changes in climatic conditions, the effect of tectonic movements, etc.

The most substantial distortions may be introduced by moving groundwaters, which sometimes completely disrupt the natural distribution of temperatures. Since sufficient methods for estimating these disturbances do not yet exist, where highly permeable rocks are present in the upper part of the section it is desirable to use sufficiently deep wells, whereas for homogeneous clayey sequences wells several hundred meters deep are acceptable.

To determine the heat flow, 5 fields were selected, located in the lowland part of Northern Dagestan. Tectonically, this area is a segment of the Epigercynian platform.

The platform cover is composed of deposits ranging from Jurassic to Recent inclusive, represented mainly by terrigenous rocks. The minimum thickness of the sedimentary cover is about 4 km.

The sedimentary cover has been penetrated by only three exploratory wells (Yuzhno-Sukhokumsk, well No. 15; Russkii Khutor, well No. 13; Bazhigan, well No. 2), which encountered marbled limestones conditionally assigned to rocks of the folded basement.

The relative tectonic stability of the area under consideration, as well as the lowland relief, make it possible to neglect many distorting natural influences, with the possible exception of disturbance of the thermal field by groundwater movement. Therefore, in the wells examined, sufficiently deep horizons were studied which, according to hydrogeological data, lie in a zone of very slow

water exchange. Only wells in which equilibrium values of the gradient had been established were studied; the criterion of equilibrium was the duration of well shut-in after drilling. In addition, the degree of equilibrium was checked by the method of two thermograms <sup>(1)</sup>.

The thermal conductivity of the rocks was studied by the method of a stationary thermal field, namely the plane-layer method, based on the solution of the equation

$$\lambda \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) = \rho c \frac{\partial T}{\partial t} \quad \text{for} \quad \frac{\partial T}{\partial t} = 0.$$

To check the reliability of the obtained thermal-conductivity values, many rock samples were reexamined by the regular-regime method, taking corrections for dimensions into account <sup>(2)</sup>.

Table 1 presents the results of determining the thermal conductivity of rocks sampled from various depths in the area under consideration. Comparison of the data obtained shows that sandstones have the highest thermal conductivity; for them  $\lambda_{av} = 6.92 \mu\text{cal}/\text{cm} \cdot \text{s} \cdot \text{deg}$ .

The considerable depths of the wells considered—on the order of 3-4 km—and the high temperatures recorded at the bottoms—about 160°—require the introduction of corrections for pressure and temperature. However, these corrections were not introduced, since for sedimentary rocks the increase in thermal conductivity with increasing pressure largely compensates for its decrease with increasing temperature.

**Table 1**

**Thermal conductivity of rocks of the sedimentary cover of the plain part of Northern Dagestan**  
( $\mu\text{cal}/\text{cm} \cdot \text{s} \cdot \text{deg}$ )

| Rocks      | Number of de-terminations | $\lambda_{\min}$ | $\lambda_{\max}$ | $\lambda_{av}$ |
|------------|---------------------------|------------------|------------------|----------------|
| Clay       | 8                         | 3.21             | 3.95             | 3.66           |
| Aleurolite | 9                         | 3.77             | 6.019            | 5.11           |
| Argillite  | 6                         | 3.48             | 4.36             | 4.13           |
| Limestone  | 8                         | 4.25             | 6.56             | 5.41           |
| Sandstone  | 17                        | 4.45             | 8.90             | 6.92           |
| Dolomite   | 5                         | 3.87             | 6.62             | 5.25           |

The heat-flow values calculated on the basis of measurements of the temperature gradient and thermal conductivity are given in Table 2. In Fig. 1, as an example, a graph is given of the change in geothermal parameters with depth for the

Russkii Khutor area. The greatest heat-flow value was obtained for the Bazhigan area ( $1.58 \mu\text{cal}/\text{cm}^2 \cdot \text{s}$ ), which may be explained by the nonuniform thermal conductivity of the rocks of the sedimentary cover and basement. The influence of a deep-seated fault assumed here is also not excluded.

The mean heat-flow value for the wells we investigated is  $1.277 \mu\text{cal}/\text{cm}^2 \cdot \text{s}$ , which is in good agreement with

**Table 2**

**Temperature gradient, thermal conductivity, and heat flow in the plain part of Northern Dagestan**

| Area of study            | Number of determinations | Investigation interval, m | Mean temperature gradient $g$ (deg/m) | Mean thermal conductivity $\lambda$ ( $\mu\text{cal}/\text{cm} \cdot \text{s} \cdot \text{deg}$ ) | Mean heat flow $q$ ( $\mu\text{cal}/\text{cm}^2 \cdot \text{s}$ ) |
|--------------------------|--------------------------|---------------------------|---------------------------------------|---|---|
| Russkii Khutor (central) | 9                        | 2435–3395                 | 0.026                                 | 4.64  | 1.21  |
| Yuzhno-Sukhokumsk        | 9                        | 1900–3730                 | 0.027                                 | 4.65  | 1.25  |
| Solonchakovaya           | 14                       | 3422–3622                 | 0.0175                                | 5.88  | 1.03  |
| Stepnaya                 | 2                        | 2600–2950                 | 0.025                                 | 5.27  | 1.32  |
| Bazhigan                 | 2                        | 3852–4000                 | 0.039                                 | 4.05  | 1.58  |

the most probable value characterizing regions of Paleozoic folding (3).

To obtain more accurate ideas about the thermal regime of the region, it is necessary to know the distribution of heat sources and possible heat losses at the depths studied. The latter is achieved by analyzing and comparing heat-flow values actually observed and those calculated taking into account the heat released during the decay of radioactive elements contained in the stratum under consideration. For this purpose, in wells where heat flows were measured, layer-by-layer determinations of the concentrations of long-lived isotopes U, Th, K were made by the method of four-component analysis. The method is based on differential  $\gamma$ -spectrometric measurements, whose accuracy is  $1 \cdot 10^{-4}\%$ .

Heat generation in the sedimentary sequence was calculated taking into account the different contents of radioactive elements in the specific lithological complexes, as

$$\Delta q = \sum_{i=x}^H (C_U \alpha + C_{Th} \beta + C_K \gamma) h_i,$$

where  $C$  is the concentration of radioactive elements in the rock;  $\alpha, \beta, \gamma$  are the heat-release coefficients for each element;  $h_i$  is the thickness of the lithologically homogeneous  $i$ -th layer;  $x, H$  are the top and bottom of the sequence under consideration.

Having calculated the amount of heat generated by radioactive decay in each interval, and taking into account the actual heat flow at the base of the layer under consideration, one can obtain the total value of the heat flow in the ideal case, i.e., in the absence of lateral leakage, energy-intensive processes proceeding with absorption of heat, and removal of heat by groundwater.

**Fig. 1.** Plot of the change in the temperature gradient ( $g$  (deg/m)), thermal conductivity of rocks ( $\lambda$  (mcal/cm · sec · deg)) and heat flow ( $q$  ( $\mu$ cal/cm<sup>2</sup> · sec)) with depth

**Table 3**

**Content of radioactive elements and generation of heat due to their decay in the sedimentary sequence of Northern Dagestan**

| Area of investigation | Interval of investigation, (m) | U · 10 <sup>-6</sup> | Th · 10 <sup>-6</sup> | K · 10 <sup>-2</sup> | Thermal effect $\Delta q$ ( $\mu$ cal/cm <sup>2</sup> · sec) |
|-----------------------|--------------------------------|----------------------|-----------------------|----------------------|--|
| Yuzhno-Sukhokumsk     | 2439–3452                      | 17,6                 | 5,12                  | 1,24                 | 0,072  |
| Russkii Khutor        | 2435–3395                      | 16                   | 10,59                 | 1,09                 | 0,058  |
| Solonchakovskaya      | 3422–3735                      | 15,45                | 12,75                 | 0,999                | 0,017  |
| Stepnaya              | 2600–2950                      | 17,5                 | 14,68                 | 1,965                | 0,041  |
| Bazhigan              | 3513–3852                      | 2,2                  | 9,2                   | 1,545                | 0,011  |
| Vostochno-Sukhokumsk  | 2725–2905                      | 15,43                | 4                     | –                    | 0,017  |

Table 3 gives the results of determinations of the content of radioactive elements and the magnitude of the thermal effect produced by them for the sequences under consideration. The data of Table 3 show that the generation of radiogenic heat in the sedimentary sequence of the area studied is very signifi-

...for example, the generation of radiogenic heat in the sedimentary sequence 1 km thick over the Russkii Khutor area gives approximately 5% of the total heat flux. Over the entire sedimentary sequence in this region, the generation of radiogenic heat will amount to  $\sim 20\%$  of the deep heat flow. Consequently, allowance for the generation of radiogenic heat in the sedimentary sequence is absolutely necessary when interpreting heat-flow measurements.

Comparison of the conductive heat flow with the value of the heat flow that

takes into account the interval radioactive increment makes it possible to speak of the magnitudes of heat losses at different depths.

Thus, by taking into account the heat produced in a particular sequence, one can come close to a quantitative assessment of thermal effects and of possible mechanisms of heat generation and absorption, with allowance for specific geological, physicommechanical, and hydrodynamic conditions.

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