INTERNAL HEAT OF OIL- AND GAS-BEARING AREAS

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The thermal regime of oil- and gas-bearing areas is distinguished by great diversity. The geothermal step for different regions varies within very wide limits, from several meters to 100 m/deg and more. Often it undergoes changes even within individual areas.

The internal heat of the terrestrial globe creates the principal temperature background of the earth' s crust. Deviations from the normal temperature background are explained by lithological, tectonic, and hydrogeological factors, as well as by the character of the relief of the daytime surface. Explanations of differences in the magnitude of the geothermal step in terms of these factors are basically correct, but for the majority of oil- and gas-bearing areas they are insufficient. Until recently, the heating or cooling influence of gas on the surrounding medium, with changes in pressure, on fluids was not taken into account at all.

Changes in formation pressures in gas pools are an adiabatic process. Their increase leads to a rise in the temperature of free gas and to the transfer to the surrounding medium of the excess heat acquired. A decrease in formation pressures is accompanied by a lowering of the temperature of the gas in the pools and by cooling of the surrounding rocks, water, and oil. The adiabatic law may be expressed by the following formula:

$$\frac{T_c}{T_0} = \left(\frac{P_c}{P_0}\right)^{1-1/\gamma}, \qquad (1)$$

where T_c and T_0 are the final and initial absolute temperatures of the gas, P_c and P_0 are the pressures at the corresponding temperatures, and $\gamma = c_p/c_v$.

Thermal logging work to study the character of the thermal regime of gas-oil-bearing areas in the Central Fore-Caucasus has been carried out since 1948. At present, temperature curves are available for 60 exploratory and reference wells. The thermograms have varying degrees of reliability. The quality of the temperature curves was assessed according to two main criteria: the duration of the wells' shut-in period before thermal logging and the sequence of thermometric

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operations with operations to test gas-bearing and water-bearing objects. Testing of productive horizons led to significant cooling of the wells in accordance with the law of adiabatic change in the state of gas. Preliminary testing of water-bearing horizons with a large amount of dissolved gas also led to some cooling of the wells.

A clear example of the influence of oscillatory movements of the earth' s crust on the temperature regime of rocks in a section with gas pools is the Aleksandrovskaya area. Here the Eocene and Paleocene deposits are commercially gas-bearing. Geothermal studies were carried out in 6 exploratory wells. The thermogram of one of them (No. 2) is of good quality; three others (Nos. 5, 10, and 14) may be used after corrections are introduced for preliminary cooling, and two are rejected. On the basis of the materials from the first four wells, Table 1 was compiled with the temperature of rocks in the roof of the Khadum horizon, which lies 250–270 m above the Eocene gas pool.

The differences between the values of the actual and calculated temperatures of the cap rocks of the Khadum horizon are caused by the influence of the gas pools of the Aleksandrovskaya area on the thermal regime of the overlying deposits. Wells Nos. 5 and 14 were drilled within the gas-bearing contour of the Eocene gas pool (Fig. 1), and here this difference reaches values of +10.4 and 11°. In well No. 10, which penetrates the gas-bearing sandstones of the Cherkess Formation in the water-bearing part, the actual temperature is greater than the calculated one by only 0.7°. The greatest influence of the gas pool on the temperature of the overlying rocks is observed within the gas-bearing contour of the area and rapidly decreases toward the water-flooded flanks of the structure.

Fig. 1. Structural map (**a**) and isotherm diagram (**b**) of the Aleksandrovskaya area: **1**—isohypses of the roof of the sandstones of the Cherkess Formation (**a**) and isotherms of the roof of the Khadum (**b**), **2**—axis of the anticline, **3**—gas-bearing contour of the sandstones of the Cherkess Formation (outer and inner), **4**—oil rim, **5**—wells covered by geothermal investigations.

The structural forms of the exploratory areas of the Central Fore-Caucasus developed under conditions of a unified tectonic plan. In post-Sarmatian time they underwent predominant uplift. The uplift of the Aleksandrovskaya area may have begun as early as the end of Maikop time. The conclusion suggests itself that the positive influence of the gas pools of this

areas on the thermal regime of the overlying deposits was caused by ascending movements of the earth' s crust in the region of the monocline of the northern slope of the Caucasus, where the sandstones of the Circassian suite and the

Paleocene receive recharge from surface waters. Along with the predominant uplift of the Aleksandrovskaya area, uplift in the region of the monocline led to an increase in formation pressures in the gas-bearing beds and to a rise in the temperature of the gas deposits.

Another, no less important factor causing deviations from the normal thermal regime of deep horizons is the processes of gas and oil formation in rocks. In sandy rocks with open pores, liquid and gaseous substances are under hydrostatic pressure and do not take upon themselves the weight of the overlying deposits. In clays, the overwhelming majority of pores are closed, and the fluids contained in them experience pressures numerically equal to the weight of the overlying rocks, i.e., 2–3 times greater than hydrostatic pressures. Gaseous hydrocarbons formed from the organic matter of oil-source clay rocks dissolve in the liquid fluids filling the pores. The increase in the elasticity of the gas dissolved in them may continue even after it reaches the value of lithostatic pressure. The maximum elasticity of the dissolved gas C_m is determined by the sum of the lithostatic pressure and the limiting bending stress of the clay particles or the force of their cohesion

Table 1

Temperature at the top of the Khadum deposits (in °C)

No. of well	Measured by electrothermometer	Actual, corrected for cooling	Calculated in the absence of a gas deposit
2	72.4	72.4	72.4
5	74.7	77.4	67.0
10	66.4	77.1	70.4
14	75.4	78.1	67.1

$$C_m = 0.1H \cdot d_{\text{cp}} + 100\sigma \left(\frac{h}{2} - m\right),$$

where H is the depth of the volume of clayey rock for which the maximum possible elasticity of the dissolved gas is calculated (m), d_{cp} is the average volumetric weight of the overlying rocks, σ is the maximum bending stress of the sum of individual clay particles in 1 cm^3 of rock (kg/cm^2), h is the thickness of the gas-oil-source clay bed (m), and m is the distance in meters from the center of the gas-oil-source bed to the volume of rock for which the value of C_m is calculated.

Dissolved gas obeys the same laws as free gas. The dissolution of additional portions of gas in the pores of clayey rocks leads to an increase in internal pressures above lithostatic pressure and, consequently, to a rise in the temperature of the

Fig. 2. Thermolog cross sections of wells of the Central Pre-Caucasus: a —well No. 2 of Aleksandrovskaya area, b —well No. 3 of Sengileevskaya area, v —well No. 1 of Ipatovskaya area. 1 —electric thermolog curve, 2 —geothermal background, 3 —temperature curve Δt.

Figure 2: Fig. 2. Thermolog cross sections of wells of the Central Pre-Caucasus: a —well No. 2 of Aleksandrovskaya area, b —well No. 3 of Sengileevskaya area, v —well No. 1 of Ipatovskaya area. 1 —electric thermolog curve, 2 —geothermal background, 3 —temperature curve Δt.

gas and subsequent heat exchange with the surrounding medium. The temperature of gas from compression without transfer to the surrounding medium, t_c, can be found with the aid of the transformed formula of the adiabatic law (1)

$$t_c = T_0 \left[\left(\frac{P_c}{P_0} \right)^{1-1/\gamma} - 1 \right].$$

The increment in the temperature of the water and the rock skeleton in a unit volume of the bed as a result of heat exchange with the gas is determined with the aid of the formula

$$t = \frac{v_{\mathrm{g}} t_c}{\mu + v_{\mathrm{g}}},$$

where v_{g} is the volume of dissolved gas in a unit volume of oil-source rock, μ is the index of gas compaction in the rock

$$\mu = k \frac{N_{\mathrm{w}} - N_{\mathrm{p}}}{N_{\mathrm{g}}} + \frac{N_{\mathrm{p}}}{N_{\mathrm{g}}},$$

where k is the porosity of the bed in fractions of a unit, and N_{g}, N_{w}, N_{p} are the numbers of gram-molecules, respectively, of dissolved gas, water, and the rock skeleton in a unit volume of the bed under the existing pressure and temperature conditions.

Calculations show that in the center of a 10-meter clayey bed at a depth of 1000 m, with a porosity of 40% and a uniform distribution through the thickness of gas-oil-source matter, the temperature of the generated gas may rise by 12–13°C, if the absence of heat exchange with the surrounding medium is assumed. As a result of heat exchange, the temperature of the rock and water will increase by 2–2.5°.

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Across eight exploration areas of the Central Pre-Caucasus, within the lower 200–300 m of the Maykop clays, thermologging records a positive temperature anomaly. The average magnitude of its maximum values in the wells is $+3.1^\circ$, varying from $+1.9^\circ$ in the Ipatovskaya reference well to $+4.5^\circ$ in the Aleksandrovskaya area (Fig. 2). Analysis of geothermal and other geological materials accumulated in past years has shown that the detected positive temperature anomaly is caused by the generation of gaseous hydrocarbons in the clays of this stratum, whose bituminosity on average reaches 0.1%. The supposition that this anomaly is connected with the radioactivity of the Maykop rocks was not confirmed.

Migration of gaseous and liquid substances in rocks can occur only toward lower pressures. This process is also adiabatic and is accompanied by cooling of the gas and of the oil-source rock from which it migrates. Full-scale thermometric work in wells of oil-and-gas-bearing areas, together with more detailed comprehensive studies of sedimentary rocks, will help identify oil-source horizons in the sections of wells being drilled. In addition, they make it possible to explain the causes of qualitative differences among oils in deposits and to successfully solve a number of other practical and theoretical problems of general and petroleum geology.

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