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## **Paleotemperature research of coals in the Volga-Ural oil and gas province (Russian Federation) in connection with forecasting of non-traditional hydrocarbon sources**

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### **Abstract**

Using of thermal methods of influence on the formation allows engaging in the extraction unconventional sources of hydrocarbons. One of the most important unconventional oil and gas objects are highly carbonaceous deposits. On the territory of the Volga-Ural oil and gas province, such objects is the Domanik Formation, which are clayey-siliceous-carbonate shale rocks with a high content of organic matter (OM). To identify and clarify the mechanisms of formation of oil and gas fields, as well as forecast and search for promising areas in the area of distribution of shale strata, the method of measuring the reflectivity of vitrinite is used. However, the absence of residues of plant organic matter in the Domanikites creates difficulties in applying the method. To assess the prospects of individual sections of the Domanik Formation, it is possible to use the paleotemperatures of the field of adjacent and overlying sediments, where coal seams and inclusions of plant organic matter are present. The basis of this approach is the paragenetic association of oil, coal and shale sediments. The formation of shale and coal-bearing formations is due to the primary conditions of sedimentation, and the formation of oil and gas deposits is associated with deep thermal effects during periods of tectonic activation on the territory. The structure of modern thermal fields, due to changes in temperature values, is controlled by the location of zones of deep faults in the crystalline basement of the platforms. Paleotemperatures are determined quite accurately by the degree of catagenetic transformation of organic matter (OM), which can be used to reconstruct the structure of ancient thermal fields in sedimentary formations and identify areas of maximum warming. Regional patterns of change in the degree of coal metamorphism can be used as a basis for forecasting and identifying promising areas of oil and gas shale raw materials.

### **1. Introduction**

Using of thermal methods of influence on the reservoir allows engaging in the exploitation of unconventional sources of hydrocarbons, which include highly carbonaceous deposits. Within the Volga-Ural oil and gas province, the most promising as shale sources of hydrocarbon raw



materials are rocks of the Domanik Formation, confined to the Devonian sediments. The area of potentially oil-bearing deposits of the Devonian Domanik Formation covers an area of about 2 million km<sup>2</sup> [1, 2, 3]. The thickness of the Domanik Formation varies from 13 to 72 meters. In the section of the Devonian deposits of the Volga-Ural region, it covers the range from the Semilukian (Domanikovian) Horizon of the Frasnian Stage to the very tops of Famennian Stage [1, 2, 3]. Domanikites are dark clay-siliceous-carbonate shaly rocks with a high content of organic matter (OM) up to 1-5% and above. The rocks of the Semilukian (Domanikovian) and Rechitsian (Mendymian) Horizons of the Upper Devonian possess the greatest oil-bearing potential and perspective. In petroleum geology for forecasting and exploration, the degree of catagenetic transformation of organic matter is used as an indicator of the processes of oil and gas formation [4, 5]. Determining the degree of metamorphism of organic matter is produced by the coal-petrographic method, which is based on the determination of the vitrinite reflectivity index (Ro). However, in the pre-Carboniferous sediments, the application of the method is difficult due to the absence of microcomponents of plant organic matter. To assess the prospects of individual sections of the Domanik Formation can be used the variability of paleotemperature fields in adjacent or overlying rock complexes with inclusions of coal or coal seams. The temperature distribution of modern thermal fields is associated with zones of deep faults in the crystalline basement of the platform and clearly correlates with the degree of catagenetic transformation of organic matter (OM) in sedimentary formations. The basis of this approach is a paragenetic relationship of oil, coal and shale sediments [6]. The paragenesis of coal and oil deposits is global. At the planetary level is observed a distinct geochronological regularity in their location. Coal deposits of various sizes are contained within the post-Devonian oil and gas provinces around the world. This is due to the wide distribution of terrestrial vegetation on land, beginning with the Carboniferous period. The formation of shale and coal-bearing formations is due to the primary conditions of sedimentation, and the formation of oil and gas deposits is associated with deep thermal effects during periods of tectonic activation of the territories. On the territory of the Volga-Ural oil and gas province, early Carboniferous coal-bearing deposits are located directly on Devonian sediments. They are associated with the Visean deposits of the early Carboniferous, which are also oil-bearing. The Visean terrigenous stratum fills in erosion-karst incisions within the northern and southern domes of the Tatar arch and in the inter-domed depressions [7]. The number of coal seams in incisions is usually from 1 to 3, the middle of which is the thickest and reaches 10-30 meters with a depth of 900-1400 m. By their nature, coals are humus. Coals are mostly metamorphosed to the stone-coal stage, but the sections retain the properties of brown coal. Regional patterns of change in the degree of coal metamorphism can be used as the basis for forecasting and delineating promising areas of oil and gas shale HC raw materials.

## 2. Methodology

To clarify the structure of the ancient thermal field and clarify the sources of heat fluxes, paleotemperatures were determined by the degree of metamorphism of the Visean coal beds. The main method was the coal-petrographic method, based on the measurement of the reflectivity of vitrinite (% Ro). Vitrinite is one of the microcomponents (maceral) of coal, which has a high reflectivity. During the immersion of the coal-bearing strata to a depth, a consistent transformation of the organic part of the coal occurs as a result of an increase in pressure and temperature. At the same time, a gradual and regular increase in the reflectivity of vitrinite occurs, associated with a change in its chemical composition, physical properties

and intramolecular structure. The reflectivity of vitrinite in oil immersion ( $R_o$ ) consistently increases from 0.5–0.64% to 2–2.5%. In coal geology, this indicator is used as an optical criterion for the degree of coal metamorphism. It can also be used to determine the paleotemperatures of the formation of coal and coal-bearing strata. In petroleum geology, the vitrinite reflection index is also used to establish the stage of post-sedimentation transformation of a sedimentary complex containing organic matter [4, 5]. Comparison of reflectivity values with other indicators of the degree of maturity and distribution over the section of oil and gas accumulations allows setting the values of  $R_o$ , corresponding to the boundaries of oil and gas formation. Catagenesis of source rocks is analyzed by measurements of the reflectivity of vitrinite ( $R_o$ ). The lowest reflectivity value corresponding to the generation of oil is 0.45%, and  $R_o = 0.6\%$  is considered to correspond to the beginning of the formation of industrial oil deposits. The end of oil generation occurs approximately at  $R_o = 1.3\%$ , gas condensate - at  $R_o = 2\%$  and methane at  $R_o = 3.5\%$  [4, 5]. Coal-petrographic studies were conducted in reflected light using a Carl Zeiss Axio Imager A2m polarization microscope. Measurements of the reflectivity of vitrinite were made on an MSF-30U microscope-spectrophotometer, which is designed to record the reflection spectra of minerals and to measure the reflection coefficients of coal and dispersed organic substances.

### 3. Results and Discussions

Our studies of the metamorphism of coal in terms of the reflection of vitrinite showed an uneven distribution of this indicator within the coal-bearing area.  $R_o$  values within the territory under consideration vary in a fairly wide range from 0.44 to 0.73% [8]. They show a distinct tendency to increase in the direction from north to south. In the northern part of the territory, minimal values of the vitrinite reflectance are observed (0.44–0.51%, average 0.47%). The highest values of  $R_o$  are established in the southern part of Tatarstan, where the greatest depths of immersion of coal seams are noted up to 1300–1400 meters. In these areas of the earth's crust, the reflection index of vitrinite in coals reaches 0.73% in individual samples. Average values in various deposits vary from 0.58% to 0.66%. The maximum coal metamorphism is fixed in those parts of the coal basin where coal seams lie at maximum depths (1300–1400 meters). The  $R_o$  values in the coal in these areas, which coincide with the zones of deep faults in the crystalline basement, correspond to paleotemperatures of 50–70 °C. These areas are also characterized by elevated values of modern temperatures in the strata. According to field research [9], produced by oil wells, the maximum temperature difference at the absolute level of -1000 meters in the Volga region reaches 30 °C. Temperatures vary in the range of 14.25–48.2 °C. The structure of the modern thermal field is closely related with tectonic structure of the territory and location of deep faults. Thus, the reason for the increasing of the coalification degree of organic matter is the increasing in temperature in these areas of the earth's crust. However, the effect of the geothermal gradient, which consists in increasing the temperature by an average of 3 °C every hundred meters, is not sufficient to ensure the observed degree of coal metamorphism. The depth difference of the Visean coal seams does not exceed 300 meters. Devonian sediments (Domanik Formation) occur at a depth of 1.6–2 km. This indicates that the thermal regime in ancient geological epochs was characterized by higher temperatures than at present. The formation of oil should be associated with rocks of the Domanik Formation, where organic matter is about 1–3% or more. Apparently, in the past they have been subjected to higher thermal effects due to tectonic activation of the territory. This led to the generation of oil from the Domanik Formation. The possibility of heat and mass transfer is also confirmed by the results of deep

drilling. Within the Melekes Depression, where Domanik thick strata lie in the sedimentary cover, fractured rocks with traces of later hydrothermal activity are fixed in the crystalline basement.

An important applied direction may be the use of unconventional sources of hydrocarbons for additional energy supply for the development of high-viscosity oil and bitumen deposits [11], which are characterized by high energy consumption and require significant amounts of natural gas to generate steam. The problem of providing energy raw materials for steam generation plants can be solved through the use of local coal - raw materials. Depending on the technology chosen, coal seams can be used to produce combustible underground gasification gas or coal-based methane [12, 13] as independent fuels, which can be used for local needs.

#### 4. Conclusions

The results obtained clarify ideas about the nature of the lithification of early Carboniferous sediments and can be used for predictive researches. Based on the analysis of the tectonic structure of the crystalline basement, the structure of the modern temperature field and the patterns of changes in the degree of coal metamorphism, paleo-temperature zoning of the territory can be made, which will serve as the basis for forecasting and contouring prospective areas.

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