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DETERMINATION OF THE CALORIFIC VALUE OF SYSOLA OIL SHALE FROM GAMMA-GAMMA LOGGING DATA

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Abstract. *This historical review addresses one topic in well logging. In 1983–85 special geophysical work was carried out in the Poinga area of the Vychegda oil shale basin (OSB) in the northeastern part of the East-European Platform, to search for oil shale deposits [1]. The results of the study of Sysola oil shale by using the geophysical logging are presented. The density logging data was used to predict the calorific value of oil shale. It is shown that the elementary procedure of elimination of the regional component from the measured values of the gamma-gamma log provides an excellent correlation between the predicted and true calorific values of oil shale. The regional anomalies of gamma-gamma logging data were determined using the averaging method. The local anomalies of OS layers were calculated. In our calculations not the absolute values of the measured gamma-gamma logging parameter, but relative to average ones were used. So, the accuracy increased significantly and amounted to 87–91%.*

Keywords: *oil shale, gamma-gamma logging data, calorific value, Komi Republic of the Russian Federation.*

Annotation of the book. *A book "Oil Shale of The European North of The USSR", which was edited by Professor V. A. Dedeyev and published in Russian in 1989, was the first monograph to deal with oil shale (OS) found in the European north of the then USSR, today the Russian Federation. The publication presented the results of investigations carried out by a large group of specialists in the field. The book also contained a chapter titled "The results of the study of Sysola oil shale by using geophysical logging data". 25 years ago the main task of the research group was to clarify whether there was a correlation between the density logging data and oil shale calorific value, on an example of the oil shale of the Poinga area, Sysola region of Komi Republic, Russian Federation. It was a simple idea to calculate regional anomalies and eliminate them from measured values. It*

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was shown that the elementary procedure of elimination of the regional component from the measured values of the gamma-gamma log provided an excellent correlation between the predicted and true calorific values of oil shale. The accuracy amounted to 87–91%. It was a one-case history, i.e. application of logging. The procedure for gamma-gamma logging data processing was presented.

1. Introduction

Huge reserves of Jurassic oil shale are concentrated in the European north of the Russian Federation. Most of these OS deposits are located near the surface that will allow their open-cast development. The characterization of the deposits is presented in the Results of the experimental work carried out in the geologically thoroughly studied Poinga area in 1984–86 to identify potential OS sites by using the geophysical logging [1]. Until now, these deposits have not been exploited and huge reserves have not yet been claimed.

2. Geological background

Upper Jurassic-Lower Cretaceous deposits containing up to 20 OS bands are widely spread in the northeast of the East-European Platform; they particularly occur in the Timan-Pechora and Vychegda oil shale basins [1]. The deposits have been examined at a depth of from 50 to 300 m below ground and rare in exposures. Their thickness varies between 1 and 200 m. The OS formation is nonuniformly spread in the deposits of the Callovian-Kimmeridgian Stage (J_2k–J_3km) and is overlaid by Lower Cretaceous and/or Quaternary deposits. It is characterized by the fauna of foraminifers, ammonites, pelecypods and belemnites. The age of the OS formation has been established to be based on the ammonite fauna.

The oil shale deposits of the Timan-Pechora OSB are developed in two isolated areas, namely the Nar'yan-Mar and Izhma regions, and those of the Vychegda OSB are distributed in the Sysola and Yarenga regions (Fig. 1). In the Poinga area of Sysola region the commercial layers of oil shale are concentrated in the deposits of the Middle Volgian Stage (J_3v_2). All these rocks are rich in calcareous material (up to 27–35%). The Poinga OS deposits are subdivided into two lithological units.

The lower unit consists of intercalating grayish green clay, marl clay, kerogen-rich clay, oil shale ($Q_s^d > 6.3$ MJ/kg) and rare limestone. The layers of OS are only a few centimeters thick. The thickness of the lower unit ranges from 3 to 12 m.

The upper unit is composed of interbedded dark grey clay, kerogen-rich clay and oil shale. The fauna is represented by abundant mollusks and a few Lingulida brachiopods. The total thickness of the upper unit exceeds 10 m.

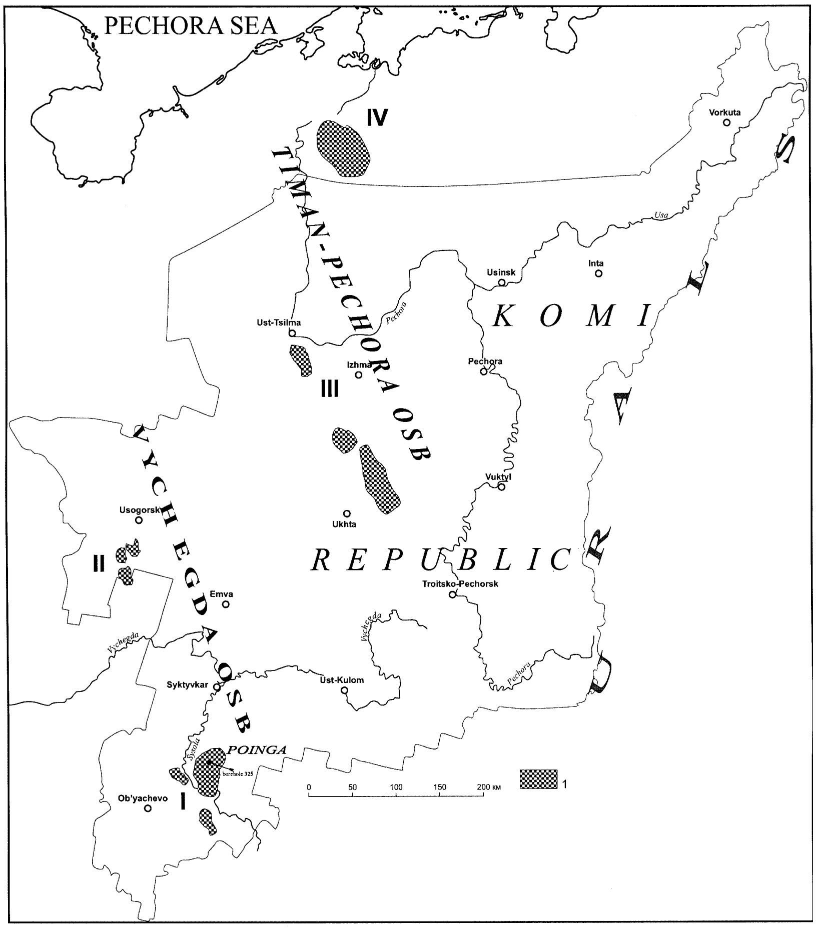

Fig. 1. Oil shale bearing basins in the northeast of the East-European Platform.

The unit contains three OS beds. Bed I consists of the layers of OS and kerogen-rich clay. The latter is divided into two lithotypes: kerogen containing clay ($Q_s^d < 5.04$ MJ/kg) and clayey oil shale ($Q_s^d = 5.04$–6.3 MJ/kg). Its layers differ in thickness. Bed I is of varying thickness which reaches 1.5 m.

The rocks between Bed I and the underlying Bed II are represented by kerogen-rich clay whose layer is about 2–3 m thick. Bed II consists of two to three layers of OS and kerogen-rich clay. The thickness of Bed II ranges from 0.8 to 2.5 m. Bed III is widely represented in the Sysola region. Its thickness is from 0.7 to 2.5 m with an average thickness of 1.5 m. Bed III consists of five to seven thin OS bands which are separated by the layers of kerogen-rich clay and whose thickness varies between 0.01 and 0.9 m.

The major constituents of oil shale are organic matter (OM), clay minerals, carbonates, framboidal pyrite, and other autogenous and allothigenous minerals, such as opal, chalcedony, feldspars, garnets, zircon. OM is represented by kerogen of sapropelic nature, which characteristically has a very high content of sulphur (above 3%, sometimes up to 10%), with its organic form dominating. The main micro-components of kerogen are kolloalginite and pseudovitrinite, while the former generally predominates. Oil shale is characterized by high concentrations of trace elements such as Ni, V, Mo. In the deposits under study the OM content of oil shale ranges from 20 to 30%, sometimes reaching 55%. The clay minerals are mostly represented by the interstratified layered silicates of illite-montmorillonite type with a variable amount of montmorillonite layers and, to a much lesser degree, by allothigenous kaolinite and chlorite. Calcite, which chiefly originates from coccolithophorids, is a major carbonate mineral.

3. Short essay on geophysical logging

The geophysical logging methods of research used for the lithological identification of rocks and determination of the correlation between borehole geologic sections included gamma-ray logging (γ), electrical apparent resistivity logging with gradient and potential probes, and the caliper-geometry measurement of boreholes. A detailed differentiation between OS layers was made only in case of the Volgian (J_3v) intervals of boreholes by using the methods of dual gamma-gamma logging in the density ($\gamma\gamma$-d) and selective ($\gamma\gamma$-s) versions, and the caliper-geometry measurement.

The isotope of cesium Cs^{137} with the energy of 3.05*108 Bq served as a source of gamma radiation by the dual gamma-gamma logging in the density modification ($\gamma\gamma$-d). Americium (Am^{241}) with the energy of 4.77*108 Bq was employed as a source of gamma radiation by the gamma-gamma logging in the selective modification ($\gamma\gamma$-s).

The rocks under study were characterized by the presence of three geophysical benchmarks. The geophysical benchmarks have been sustained over the entire area; therefore, they were applied to correlating boreholes logging data. The sequence boundaries were determined using correlations between the well log signatures and lithological characteristics of rocks (Table 1, Fig. 2). Benchmark 1 – the border between Lower Cretaceous (K_1) and Upper Jurassic (J_3) deposits is defined on the bottom of the marker layer represented by phosphorites containing glauconitic clay. The layer of phosphate nodules resulted as an anomalous spike (Fig. 2). Benchmark 2 is the border between the dark-coloured and gray Volgian (J_3v_2) deposits. The border between the gray and dark-coloured strata was determined from the diagrams of the scattered γ-radiation intensity. Benchmark 3 represents the bottom of Volgian deposits. An example of the logging data correlation is shown in Fig. 2.

There are three beds of oil shale which can be traced throughout the Poinga area. The OS calorific value was determined employing both laboratory and gamma-gamma logging data. [1]

To determine the radioactivity of Poinga rocks the core samples from more than 100 wells were analyzed and the diagrams of natural radioactivity for all types of rocks were constructed [1]. It is evident from Table 1 that the Valanginian and Ofxord-Kimmeridgian glauconitic clay of Lower Cretaceous (K_1v) and Jurassic (J_3ox-km) formations, respectively, had the highest natural radioactivity, up to 21 mc/h, while that of the sand from the sandy loam of Quaternary sediments was the lowest, 3 mc/h. The kerogen containing clay had a maximum natural radioactivity, 14 mc/h. For oil shale this value was much higher, 19 mc/h. The apparent electrical resistance of

Table 1. The geophysical characteristics of lithological differences

Age	Rock	γ, mR/h	r, Om×m	γγ-d, ×1000 imp/min	γγ-s, ×1000 imp/min
Q	Limestone	7.5–9.1	13–33		
	Clay	8–13	6–11	10.5–16.5	2–3
K_1	Glauconite containing clay	10.4–26	30–40	15–17	2.5–3.5
	Clay, kerogen containing clay	9.1–13	10–12	16.5–23	3.5–5.5
J_{3v2}	Oil shale, clayey oil shale	10.4–18,2	30–35	17–33	4–7.5
	Marl, limestone	4.5–9.1	15–30	10.5–15.5	1–2.5
J_2k-J_3km	Clay	7.2–16.5	8–12	10.5–16.5	2–3
	Glauconite containing clay	10.4–20.8	12–25	13.5–17	2–3.5
J_2	Sand	2.6–9.1	50–250		
	Clay	5.0–11.7	50–70		

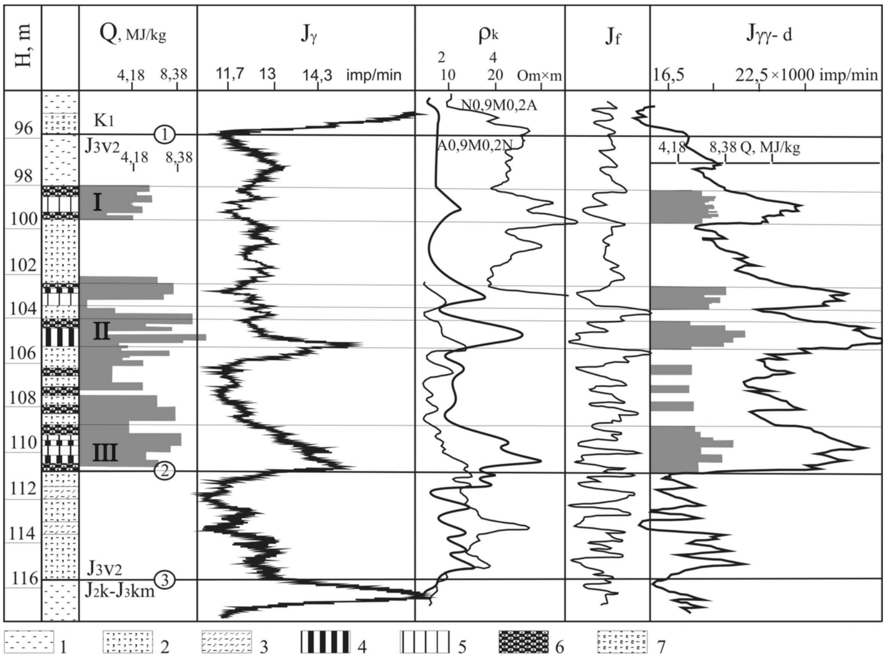

Fig. 2. The results of a complex interpretation of borehole 325. 1 – clay, 2 – kerogen containing clay (<5.04 MJ/kg), 3 – marl, 4 – oil shale (>7.5 MJ/kg), 5 – oil shale (6.3–7.5 MJ/kg), 6 – clayey oil shale (5.04–6.3 MJ/kg), 7 – glauconite containing clay.

the Volgian (J_3v) oil shale and clayey oil shale was the highest. The Lower Cretaceous clays were characterized by the presence of glauconitic clays with increased resistance in the lower part of the section.

4. Determination of the calorific value of oil shale

The most accurate method for determination of OS calorific value is to obtain core samples and determine the amount of oil which could be recovered from a given amount of shale in a retorting operation. This amount is typically referred to as "oil shale yield" [2–6]. Mostly the gamma-gamma density measurement is employed to make necessary predictions. There are several methods for determining the calorific value of oil shale from gamma-gamma logging data. It is well known that the latter correlate well with OS calorific value. Obviously, the proportionality is different for different places.

An attractive logging technique of gamma ray scattering called gamma-gamma density measurement was disclosed in US Patent 4529877 [2]. The formations were irradiated with the gamma radiation sourced from cesium (Cs^{137}) which emits gamma radiation and scatters gamma rays. The rays are detected by a pair of detectors. The signals are interpreted in terms of electron density or formation bulk density of the various strata of the earth. Density and resistivity log data were applied to predicting the amount of oil which could be produced from a specified volume of oil shale. A method for determination of oil shale yield from well log data was also disclosed in US Patent 4548071 [4]. The density, resistivity and sonic log data were employed to derive three variables: density variation, the logarithm of resistivity, and clay index. The accuracy was 72–89 %.

The method of fuzzy petrophysical compositions [7] enables predicting the permeability of oil shale on the basis of the fuzzy clustering algorithm [8]. Based on gamma-gamma logging data instead of the forecast parameter of oil shale permeability at every point the confidence intervals of values with an inverse reliability-quality dependency were obtained.

Our approach to the determination of OS calorific value from gamma-gamma logging data was based on using the increased intensity of the scattered gamma radiation (Table 1). The analysis of core samples was utilized to develop an equation for predicting the calorific value of oil shale. The authors also aimed at elucidating the relationship between the calorific value of oil shale and gamma-gamma logging data. The gamma-gamma logging diagrams were compared with the histograms of OS calorific value.

An elementary technique similar to gravity data interpretation methods was used to process gamma-gamma logging diagrams [1]. The absolute values of the measured parameter of gamma-gamma log data were employed to calculate regional and local variables. The calculated local variables of density log data were applied to predicting the calorific value of Sysola oil shale. For this purpose, the values of local variables calculated by regional anomalies, omitting the observed values of gamma-gamma logging, were used. As a result, the accuracy of prediction increased significantly and amounted to 87–91% (Fig. 3).

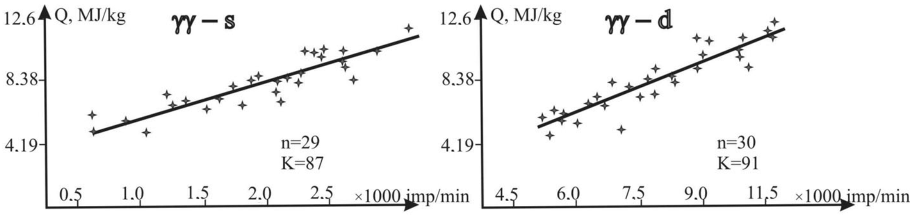

Fig. 3. Correlation between oil shale calorific value and geophysical logging data.

It was found that the elementary procedure of elimination of the regional component from the measured gamma-gamma log values provides an excellent correlation between the predicted and true caloric values of oil shale.

5. Conclusions

The obtained logging data enabled the layers of oil shale to be located and its calorific value determined. The regional background level of the gamma-gamma logging of the Jurassic section was established. The local anomalies of the gamma-gamma logging of individual lithological types of Jurassic rocks were calculated. It was established that only gamma-gamma logging data provided the desired accuracy of prediction of oil shale calorific value. The error of determination of OS calorific value from gamma-gamma logging data by using our elementary procedure did not exceed 9–13%.

In cases when resources necessary for obtaining core samples are limited, the elementary, yet highly effective procedure of gamma-gamma logging data processing can be applied to predicting the calorific value of oil shale.

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