The identity of oil deposits in Western Siberia depending on their stratigraphic confinement

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Abstract. A procedure was carried out for grouping oil deposits in terrigenous reservoirs of the West Siberian petroleum basin using various methods of factor analysis. A physical interpretation of the results obtained from the point of view of the emergence of stratigraphic systems is given. In the absence of a sufficient amount of data on deposits, it is proposed to search for identical objects based on the stratigraphic confinement of development objects. The necessity of using the tectonic confinement of objects to reduce risks during identification and selection of analogous objects is shown.

1. Introduction

Oilfield development management is based on the availability of a sufficient amount of data to make informed decisions aimed at improving technical and economic indicators.

The peculiarity of the oil industry is both low density of information about the objects of exploitation, and its excessive volume. Very often, the information obtained is very heterogeneous and creates uncertainties when making certain decisions [1–6].

In these conditions, the analogy method acquires great importance, which allows both increasing and rejecting current information about deposits. However, it is important, for example, to determine the strategy for the effective development of oil fields already at the stage of exploratory drilling and drawing up the first project documents, when there is no deep knowledge about the deposits and the processes in them [7–10].

This is the very stage where it is necessary to use the results of object identification, taking into account their stratigraphic confinement.

2. Materials and methods

To solve the problem of assessing the impact of stratigraphic confinement on the identity of deposits, more than 500 development objects were selected, confined to the West Siberian petroleum basin (WSPB). The province is characterized by significant:

- geological reserves of oil;
- residual recoverable reserves for deposits that have been in development for a long time and that are becoming difficult to recover;
- reserves classified as non-recoverable;
- oil reserves in satellite deposits of large oil fields not being developed, but penetrated by the wells of the transit fund;

as well as the presence of:
- high probability of discovering new small and medium-sized deposits;
- highly developed transport and industrial infrastructure;
- many years of experience in field development in various geological and field conditions using a variety of technologies;
- highly qualified human resources [11–14].

We selected objects that have been in development for a long time; drilled quite tightly by wells for various purposes; sufficiently fully studied based on the results of geophysical, laboratory, hydrodynamic and field studies of wells; not put into active development. However, their geological structure has been studied quite fully on the basis of data obtained from wells drilled to other productive horizons [15–16].

Commercial oil and gas content is confined to the Jurassic (J) and Cretaceous (C) deposits.

When carrying out the procedures for identifying and grouping the selected objects, the principal component analysis (PCA) and canonical discriminant analysis (CDA) were used.

The following parameters that have a prevailing effect on the production of reserves were used as identification parameters:
- $H_{form}$, formation depth, m;
- $H_{tot}$, total thickness of the formation, m;
- $H_{e}$, effective oil-saturated formation thickness, m;
- $m_{p}$, coefficient of porosity, unit fraction;
- $K_{sat}$, oil saturation coefficient, unit fraction;
- $K_{perm}$, permeability coefficient, $10^{-3} \mu m^2$;
- $K_{ntg}$, net-to-gross ratio, unit fraction;
- $K_{c}$, coefficient of compartmentalization;
- $t_{res}$, initial reservoir temperature, °C;
- $P_{res}$, initial reservoir pressure, MPa;
- $\mu_{o}$, oil viscosity in reservoir conditions, mPa·s;
- $p_{o}$, oil density in reservoir conditions, kg/m³;
- $\beta$, volumetric coefficient of oil;
- $S$, hydrogen sulfide content in oil, %;
- $P_{w}$, wax content in oil, %;
- $P_{sat}$, pressure of oil saturation with gas, MPa;
- $G$, gas content in reservoir oil, m³/t;
- $\mu_{w}$, viscosity of water in reservoir conditions, mPa·s;
- $\mu_{rel}$, relative viscosity of oil, unit fraction.

The values of these parameters for the objects of study of the WSPB are presented in Table 1.
# Table 1. Values of geological and physical parameters of objects of study of the WSPB

| Parameter | Values | minimum  | average | maximum  | mean-square deviation |
|-----------|--------|----------|---------|----------|-----------------------|
| $H_{\text{form}}$ [m] | 1432.9 | 2348.7 | 3343.5 | 393.8 |
| $H_{\text{tot}}$ [m] | 2.0 | 21.8 | 99.2 | 13.1 |
| $H_{\text{e}}$ [m] | 0.5 | 4.1 | 18.0 | 2.6 |
| $m_g$ [unit fraction] | 0.12 | 0.18 | 0.26 | 0.02 |
| $K_s$ [unit fraction] | 0.30 | 0.54 | 0.85 | 0.08 |
| $K_{\text{perm}}$ [$10^{-3}$ µm$^2$] | 0.03 | 54.9 | 693.0 | 87.2 |
| $K_{\text{ntg}}$ [unit fraction] | 0.03 | 0.37 | 1.00 | 0.19 |
| $K_c$ | 1.0 | 4.5 | 24.0 | 2.8 |
| $t_{\text{res}}$ [°C] | 53.6 | 83.7 | 110.0 | 9.6 |
| $P_{\text{res}}$ [MPa] | 14.6 | 23.5 | 39.0 | 4.4 |
| $\mu_o$ [mPa·s] | 0.9 | 1.2 | 8.2 | 0.80 |
| $\rho_o$ [kg/m$^3$] | 470 | 766 | 920 | 47.0 |
| $\beta$ | 1.05 | 1.20 | 1.59 | 0.14 |
| $S$ [%] | 0.03 | 0.61 | 1.96 | 0.30 |
| $P$ [%] | 0.2 | 3.5 | 14.0 | 2.21 |
| $P_{\text{sat}}$ [MPa] | 3.6 | 10.2 | 31.3 | 3.47 |
| G [m$^3$/t] | 20 | 82 | 523 | 50.0 |
| $\mu_{\text{sw}}$ [mPa·s] | 0.3 | 0.4 | 0.7 | 0.07 |
| $\mu_{\text{rel}}$ [unit fraction] | 0.3 | 3.0 | 21.6 | 1.93 |

## 3. Results and Discussion

The results of PCA calculations (see Figure 1) showed that the first four principal components ($Z_1$–$Z_4$) account for about 65% of the total variance of the parameters. This allows the multidimensional space to be reduced to four dimensions.

![Figure 1](image-url)
Each of the first four main components is meaningful. The first characterizes the conditions of occurrence and viscous properties of formation fluids. The second reflects the composition of the reservoir oil, including: the density of the reservoir oil. The third to the greatest extent reflects the thickness properties of oil-and-gas-water-saturated reservoir rocks. The fourth characterizes the heterogeneity of the oil-saturated volume of deposits. A clear picture of the contribution of parameters to the first two components is shown in Figure 2. It can be seen that the lowest contribution to these main components is made by the net-to-gross ratio and compartmentalization, as well as the total and effective oil-saturated thickness, which form the basis of the third and fourth main components.

It should be noted that the parameters included in the main components, by certain connections and relationships, are united into an inseparable whole and determine the integrity of the system, which is described by emergent properties. The study of these connections is not only of theoretical interest, but also practical in solving various problems of geology and the development of oil fields.

The graph of significant relationships (Figure 3) between the parameters characterizing the geological-physical and physicochemical properties of the formations and the fluids saturating them shows that within the study objects, the initial formation pressure and temperature naturally increase with an increase in the depth of the deposits, and as a result of the compaction of reservoir rocks, their porosity and permeability decrease, viscosity and relative viscosity decrease, saturation pressure and gas content of reservoir oil increase. An increase in the total and effective oil-saturated thickness, as can be seen, is accompanied by an increase in the compartmentalization coefficient. In other words, objects, on the one hand, characterized by better reservoir properties, due to significant thicknesses can be exploited worse due to significant layer-by-layer heterogeneity. Interestingly, the wax content in oil decreases with an increase in the depth of the formation and the initial formation pressure.

The decrease in the porosity and permeability of the reservoirs as a result of the increase in the initial reservoir pressure and temperature is explained by the close correlation between pressure and temperature and the depth of the reservoir, which indirectly determines this relationship between the parameters. Similar explanations apply to the negative relationship between the initial temperature and
viscosity of reservoir oil and water, initial reservoir pressure and oil saturation pressure. The functional dependence of the volumetric coefficient with the density of reservoir oil and its gas content explains the presence of a close relationship between them in Figure 3. And, finally, an important point is the presence of a significant correlation between the porosity and permeability of objects, which makes it possible to successfully solve important problems of analysis, design, control and regulation of the development process of the analyzed deposits and those similar to them in terms of geological and physical parameters.

The positive relationship between the depth, initial reservoir pressure and temperature indicates the absence of reservoir pressure and temperature anomalies in this region.

Analysis of the distribution of objects in the axes of the first four main components, depending on their stratigraphic confinement, shows the following (see Figures 4–5):

- a stable tendency towards separation of objects based on stratigraphic confinement, despite the fact that the average values of the parameters for the systems differ insignificantly, with the exception of the coefficients of permeability, net-to-gross content and compartmentalization, sulfur and wax content in oil (see Table 2).

Significant differentiation of objects on the factorial plane is explained by a specific set of parameters in the conditions of various systems, as well as by the influence of tectonic confinement;

- the presence of zones of unambiguous presence of objects of a particular system (zones I and III in Figures 3 and 4), which allows, in the conditions of objects confined to these zones, using with a high degree of reliability the principles of development formed for the corresponding objects that have been in development;

- the presence of areas of uncertainty.
Figure 4. Distribution of objects in the axes of the main components Z\textsubscript{1}–Z\textsubscript{2}: □ are the objects of the Jurassic and Paleozoic; ○ are the objects of the Lower Cretaceous; I) zone of concentration of objects of the Jurassic and Paleozoic; III) zone of concentration of objects of the Lower Cretaceous; II and IV) zone of joint concentration of objects of the Lower Cretaceous, Jurassic and Paleozoic

Figure 5. Distribution of objects in the axes of the main components Z\textsubscript{1}–Z\textsubscript{4}: □ are the objects of the Jurassic and Paleozoic; ○ are the objects of the Lower Cretaceous; I) zone of concentration of objects of the Jurassic and Paleozoic; II) zone of joint concentration of objects of the Lower Cretaceous, Jurassic and Paleozoic; III) zone of concentration of objects of the Lower Cretaceous

Table 2. Difference in the average values of geological and physical parameters of objects of the Cretaceous (C), Jurassic (J) systems and Paleozoic (PZ)

| Difference parameter | Parameters |
|----------------------|------------|
| \(\frac{X^{J+PZ} - X^K}{(X^{J+PZ} + X^K)/2}\) \cdot 100 | \(H_{\text{form}}\) | \(H_{\text{tot}}\) | \(H_e\) | \(m_g\) | \(K_e\) | \(K_{\text{perm}}\) | \(K_{\text{ng}}\) | \(K_c\) | \(t_{\text{res}}\) | \(P_{\text{res}}\) |
| -8 | -1 | -10 | -11 | 9 | -40 | 51 | -32 | 2 | -10 |

| Difference parameter | Parameters |
|----------------------|------------|
| \(\frac{X^{J+PZ} - X^K}{(X^{J+PZ} + X^K)/2}\) \cdot 100 | \(\mu_o\) | \(\rho_o\) | \(\beta\) | \(S\) | \(P\) | \(P_{\text{sat}}\) | \(G\) | \(\mu_w\) | \(\mu_{\text{rel}}\) |
| -23 | -4 | 3 | -30 | -55 | -3 | 15,9 | 0 | -22 |

\(X^{J+PZ}\), \(X^K\) are the average values of parameters for objects of the Jurassic system and Paleozoic and Cretaceous systems, respectively.
The reason for this is the proximity of objects of different systems in terms of geological and physical properties of layers, especially near the border of separation of these systems. To a greater extent, this concerns the deposits of the Achimov strata of the Cretaceous system and deposits of the Upper and Middle Jurassic; or, for example, individual deposits of the Valanginian age of the North-Vartovskaya and North-Surgut monoclines are similar in terms of the considered parameters to the deposits of the Jurassic system, and individual objects of the Middle Jurassic age of the Sherkala trough are very close to the objects of the Cretaceous system.

The principal component equations for the search for analog objects are as follows:

\[ Z_1 = 0.14H_{form} + 0.02H_{tot} + 0.03H_e - 0.13m_g - 0.02K_e - 0.10K_{perm} - 0.01K_{ntg} + 0.03K_c + 0.12t_{res} + 0.14P_{res} - 0.13\mu_o - 0.09\rho_o + 0.11\beta - 0.02S - 0.08P + 0.13P_{sat} + 0.13G - 0.08\mu_w - 0.11\mu_{rel}; \]

\[ Z_2 = 0.18H_{form} - 0.01H_{tot} - 0.07H_e - 0.06m_g - 0.17K_e - 0.06K_{perm} - 0.02K_{ntg} + 0.06K_c + 0.11t_{res} + 0.17P_{res} + 0.06\mu_o + 0.17\rho_o - 0.23\beta + 0.26S - 0.18P - 0.11P_{sat} - 0.19G - 0.08\mu_w + 0.09\mu_{rel}; \]

\[ Z_3 = -0.02H_{form} - 0.29H_{tot} - 0.37H_e - 0.12m_g - 0.16K_e - 0.16K_{perm} - 0.22K_{ntg} - 0.35K_c - 0.04t_{res} - 0.03P_{res} - 0.02\mu_o - 0.01\rho_o + 0.02\beta - 0.06S + 0.06P + 0.01P_{sat} + 0.001G + 0.03\mu_w - 0.03\mu_{rel}; \]

\[ Z_4 = 0.12H_{form} - 0.32H_{tot} - 0.02H_e + 0.15m_g + 0.03K_e + 0.21K_{perm} + 0.34K_{ntg} - 0.16K_c - 0.09t_{res} + 0.13P_{res} + 0.19\mu_o - 0.02\rho_o + 0.15\beta + 0.08S - 0.23P + 0.18P_{sat} + 0.15G - 0.004\mu_w + 0.20\mu_{rel}. \]

To reduce the size of the zone of uncertainty, a discriminant analysis was carried out. The canonical discriminant function was obtained in the following form:

\[ y_1 = -740.6 + 0.16H_{form} + 0.24H_{tot} + 1.19H_e + 835.2m_g - 3.92K_s - 0.03K_{perm} - 24.1K_{ntg} + 0.66K_e + 1.84t_{res} - 9.7P_{res} - 27.7\mu_o + 746.0\rho_o + 242.3\beta + 9.02S + 4.12P + 3.37P_{sat} - 0.20G + 299.2\mu_w + 15.5\mu_{rel}. \]

![Figure 6. Distribution of the number of objects (N) by intervals of changes in the values of the canonical discriminant function (y): □ is the distribution by objects of the Lower Cretaceous; ▢ is the distribution by objects of the Jurassic and Paleozoic; \(y'\) is the centroid of the Lower Cretaceous objects; \(y''\) is the centroid of Jurassic and Paleozoic objects.](image)

The distribution of the values of this function and the values of the centroids are shown in Figure 6. It can be seen that the number of objects that fell into the zone of uncertainty has significantly
decreased (up to 14% of the total number, while in the PCA there is more than 70% in the zone of uncertainty).

4. Conclusion
Based on the conducted studies of the fields in Western Siberia:
– the possibility of searching for analogous objects based on the stratigraphic confinement of oil deposits was established;
– a physical interpretation of the results obtained from the point of view of the emergence of stratigraphic complexes is given;
– it is proposed to use sequential application of various methods of pattern recognition to reduce risks in determining the identity of objects.

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