Use of derivatives to assess preservation of hydrocarbon deposits

K A Koshkin¹, O A Melkishev²

¹. OOOUralOil, 15 Ordzhonikidze St., Perm, Perm Krai, Russia, 614990
². Perm National Research Polytechnic University, 29 Komsomolsky prospekt, Perm, Perm Krai, Russia, 614990

E-mail: melkishev@pstu.ru

Abstract. The paper considers the calculation of derivatives along the surface of a modern and paleostructure map of a Т₁₂₅₈ formation top used to forecast the preservation of oil and gas deposits in traps according to 3D seismic survey via statistical methods. It also suggests a method to evaluate morphological changes of the formation top by calculating the difference between derivatives. The proposed method allows analyzing structural changes of the formation top in time towards primary migration of hydrocarbons. The comprehensive use of calculated indicators allowed ranking the prepared structures in terms of preservation of hydrocarbon deposits.

1. Introduction

Features of oil and gas traps strongly impact both the accumulation of hydrocarbons (HC) and their preservation in-situ. Many research works are devoted to the influence of modern structural features on oil-and-gas content of structures [1-5,9]. At the same time, the preservation of oil deposits is mainly defined by historical background of local structure development and cap rock capacity.

The geological time may forster conditions for HC lateral migration from already formed deposit towards formation top uplift during structure opening. In case of undercapacity of a cap rock (or its bad quality due to high fracture intensity), the HC migration is possible further up the section (subvertical HC migration). Thus, the assessment of HC deposits preservation is an important phase to forecast local and zonal oil-and-gas content of structures, especially in areas characterized by considerable differences in their zonal tectonic structure.

The area of study is located within the territory of Perm Krai in the central part of the Visimsky monocline and belongs to the Kama-Kinel troughs flank, which is characterized by extensive development of reefal buildup and noncompensated sedimentation within interreef troughs [7].

There are 2 types of structures (Fig. 2) within the considered territory: 1st type – extended and narrow meridional uplifts with a small area located westwards of the considered territory and the 2nd type – more rounded uplifts with a bigger area and mainly placed along the latitude.

2. Materials and methods

The method of paleotectonic reconstructions by certain time [1], which makes it possible to define the trap confinement, is generally used to assess the HC lateral migration. Besides trap confinement as
such, it is also critical to consider the direction of HC primary migration [6], which is generally defined by regional inclination of formations and regional hydrodynamic processes in formation fluids.

The combined influence of these factors can be assessed by calculating the first derivative along the cap rock of the formation top. The obtained value of the first derivative equals to the slope in the contact point of a cap rock. Derivatives may be calculated along various azimuthal directions corresponding to directions of HC migration or they may be calculated as the maximum inclination angle in a contact point. The calculation of difference across derivative values between initial and paleosurface allows assessing the preservation of HC deposits towards their primary migration. In case of structure opening and loss of hydrocarbons, this difference takes great negative values (Fig. 1).

![Derivative calculation](image)

Figure 1. Calculation pattern

The implementation of this method to assess the conditions of HC deposits preservation is demonstrated within Tula terrigenous deposits in one of its 3D seismic survey regions in the territory of Perm Krai.

3. **Use of derivatives to assess the preservation of oil deposits**

   Maps of $T_{l2,b}$ formation top and the map of the top of Kungur deposits of the lower section of the Perm system were used for this purpose. These maps served as the basis for paleostructure map of the early Ufimian, which is described in various studies [7, 10] and corresponds to the termination of the main oil formation phase. Then, this paleostructure map and the modern structural map for $T_{l2,b}$ formation top are used to calculate the first derivatives north 0, 45, 90, 135, 180 degrees following the 25*25 m grid (Fig. 2). Further, the difference between derivative (Fig. 2, 3) was calculated as follows:

\[
d_{xxx} = \text{Der}_{T_{l2,b}}(\text{modern}) - \text{Der}_{T_{l2,b}}(\text{paleo}),
\]

where $\text{Der}_{T_{l2,b}}(\text{modern})$ – derivative in a point towards XXX degrees calculated via the modern map of $T_{l2,b}$ formation top, $\text{Der}_{T_{l2,b}}(\text{paleo})$ – derivative in a point towards XXX degrees calculated via paleostructure map of $T_{l2,b}$ formation top of the early Ufimian, XXX – direction of derivative calculation.
Besides the calculation of the first derivatives along the direction, the following values were additionally defined for modern and paleostructure maps: modern dip azimuths and inclination angles of Tl₂₄ formation top, as well as dip paleoazimuths and inclination paleoangles of Tl₂₄ formation top of the early Ufimian. To consider the regional inclination of formations (for modern and paleostructure maps), the regional trend maps were built using the moving average method in a window of 625 m radius, along which azimuths and dip angles were also defined.

The following parameters were additionally calculated: the difference module between a formation dip azimuth according to a paleostructure map and the initial map for Tl₂₄ formation top (\(d_{az\_dip}\), degrees), the difference between the inclination angles according to paleostructure map and the initial map for Tl₂₄ formation top (\(d_{ang\_incl}\), degrees), the difference between the formation dip according to paleotrend and paleostructure map of Tl₂₄ formation top (\(d_{paleo\_az\_trend}\)), formation capacity of the
Tula deposits \((h_{tl})\), formation capacity between reflecting boundary 2k and \(T_{l2-b}\) formation top (2k-tl2b).

Within the considered territory there are 2 oil deposits laying in \(T_{l2-b}\) formation and 12 drilled and tested wells. These data formed the basis for model sampling within the studied territory. The calculated values of derivatives within contours of C1 and C2 reserves belong to oil-bearing lands. Zones around discovered oil deposits and trough areas between them, as well as zones around wells without oil inflow belong to nonproducing sections.

The linear discriminant analysis is used for complex assessment of such differences obtained through multidimensional models. The details of this analysis applied for the solution of similar tasks is given in [8].

The linear discriminant function (LDF) is as follows. If \(X_{ij}\) is the value of indicators within oil zones, then the \(W_1\) matrix of \(m\) and \(n_1\) order may be received:

\[
W_1 = \begin{bmatrix}
X_{11} & X_{12} & \cdots & X_{1n_1} \\
X_{21} & X_{22} & \cdots & X_{2n_1} \\
\vdots & \vdots & \ddots & \vdots \\
X_{m1} & X_{m2} & \cdots & X_{mn_1}
\end{bmatrix}
\]

\(X_{ij}\) shall stand for values of indicators within nonproducing sections, and hence the \(W_2\) matrix of \(m \times n_2\) order shall be as follows:

\[
W_2 = \begin{bmatrix}
X_{11} & X_{12} & \cdots & X_{1n_2} \\
X_{21} & X_{22} & \cdots & X_{2n_2} \\
\vdots & \vdots & \ddots & \vdots \\
X_{m1} & X_{m2} & \cdots & X_{mn_2}
\end{bmatrix}
\]

where \(m\) – number of indicators; \(n_1, n_2\) – sample number.

Matrixes of centered sums of squares and mixed products are built for LDF followed by the calculation of a sample matrix. Then, sample inverse covariance matrix – \(C\) matrix – is calculated to determine the ratios of linear discriminant function. Then, boundary values of discriminant functions \((Z)\) are calculated. The quality of classification is calculated via the Pearson criterion - \(\chi^2\). Using the model sampling, the following canonical discriminant function was obtained via the stepwise linear discriminant analysis:

\[
Z = 8.4945 \times 171.6254 \times d_{180} + 0.0126 \times d_{paleo_az_trend} - 0.2791 \times h_{tl} - 0.5953 \times 2k_{H2tlb} - 0.4642 \times d_{angl_dip} + 8.1997 \times d_{90} - 0.0031 \times d_{az_incl}
\]

\(\lambda_{Wilks} = 0.880, \chi^2 = 2142.663,\) degree of freedom = 7, \(p < 10^{-5}\),

rate of correct recognition of the model sampling makes 66%

The greatest contribution to the division of areas is made by \(d_{180}\) parameter characterizing the difference of derivative values in a meridian direction since extended periclinal anticline terminals placed along the meridian are characterized by extremely flat inclination angles. Such small angles cause great sensitivity to the opening of structures, even at extremely insignificant inclination of the territory in the geological past. Increase in the capacity of Tula deposits \((h_{tl})\) and capacities of deposits between the reflecting horizon 2k and \(T_{l2-b}\) formation top (2k-tl2b) lead to the decrease in deposit preservation (which is likely caused by severe cracking of thick formations).

Figure 4 shows the dependence diagram of posterior probability \(P(Z)\) on values of discriminant function \(Z\).
Figure 4. $P(Z)$-$Z$ dependence diagram

Figure 5 shows the diagram of posterior probability $P(Z)$.

Figure 5. Diagram of posterior probability $P(Z)$ for $\text{TL}_{2,b}$
4. Conclusions

The conducted study made it possible to obtain the probabilistic scheme of HC deposits preservation based on changes of the formation top attitudes.

The majority of considered structures have high probability values with regard to deposit preservation; however, extended meridional structures in the east of the area have significantly lower probability values.

Thus, the designed probabilistic and statistical method to assess oil-and-gas content of structures can be used to rank structures according to their degree of HC preservation (using the example of 3D seismic study for Tl2-b formation top).

References

[1] Bakirov A A 1973 *Geological fundamentals of forecasting of oil-and-gas content*. (Moscow)
[2] Gabrielyants G A, Poroskun V I, Sorokin Yu V 1985 *Methods of search and investigation of oil and gas deposits*. (Moscow: Nedra)
[3] Putilov I S, Galkin V I 2014 Development of probabilistic and statistical method to forecast oil-and-gas content of localized structures (on the example of the southern part of Perm Krai). *Oil economy* 4 26-29
[4] Galkin S V 2002 Experience and results of applying probabilistic and statistical criteria to assess oil-and-gas content of anticlinal objects of the Perm region. *Geology, geophysics and oil field development* 3 4-9
[5] Galkin V I, Rastegayev A V, Galkin S V 2001 *Probabilistic and statistical assessment of oil-and-gas content of local structures*. (Yekaterinburg: Ural Branch RAS)
[6] Lyadova N A 1992 *The analysis of influence of regional and local geological conditions on placement of deposits in coal formations of the Kama region*. *Geology, geophysics and oil field development: express inform.* (Moscow)
[7] Lyadova N A, Yakovlev Yu A, Raspopov A V 2010 *Geology and development of oil fields in Perm Krai; JSC VNIIENG*. (Moscow)
[8] Galkin V I, Kozlova I A, Krivoshchekov S N, Melkishev O A 2015 Explanation for the design of zonal forecast models of oil-and-gas content for Lower and Middle ViseanComplex of Perm Krai. *Oil economy* 8 32-35
[9] Putilov I S, Galkin V I 2016 Features of using new criteria to forecast oil-and-gas content of structures of various tectonic elements of Perm Krai. *Geology, geophysics and oil and gas field development* 2 4-7
[10] Provorov V M 2003 *History of geological development of the Perm region. General and regional geology, marine geology and geological oceanography, geological mapping*. (Review of LLC Geoinformcentre. Moscow)