Studying the Structural and Thickness Characteristics of the Sedimentary Mantle of the Northern Part of the Surgut Arch

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Abstract. The paper is devoted to the analysis of the structural and thickness characteristics of the sedimentary mantle of the northern part of the Surgut arch (Western Siberia, Russia). Based on the results of generalization of the structural surfaces of the Meso-Cenozoic sedimentary mantle reflecting horizons, the specifics of the surface relations have been determined. It was found that the relationship between the reflecting sedimentary horizons controls the oil and gas content of the YUS1 formation in the area studied. To determine the prospective oil and gas content of the area, the relationship between the reflecting horizons has been analyzed in detail. The resulting specifics have been analyzed, and the identification of zones has been justified. Zoning of the study area has been performed. The identified zones are characterized by different structural surface relation patterns and correspond to areas with similar sedimentation conditions and tectonic regimes manifested during the sedimentation period.

1. Introduction

The achieved level of oil exploration in Western Siberia is characterized by a high degree of drilling and seismic investigation of the area. In this regard, the search for new promising objects for replenishing the mineral resource base and arranging exploration is relevant [1].

To improve the efficiency of replenishing the resource base and determine the prospects for increasing oil reserves, the authors perform comprehensive generalizing research aimed at forecasting the oil-bearing capacity of the Upper and Middle Jurassic deposits within the northern part of the Surgut arch.

Many researchers have previously devoted their studies to regional forecasting of oil and gas content [2-6]. The works [7-8] are devoted to the applicability of probabilistic-statistical techniques to forecast oil and gas content in a given area. The issues of the impact of structural-tectonic factors on the distribution of oil-producing zones have been considered in [2, 9, 10].

In [11], a team of authors covered the general features of the geological structure and the history of the geological development of the region. The issues of tectonic division of the territory have been studied and the boundaries of tectonic zones clarified. Also, the main views of researchers on the crystalline basement and sedimentary mantle evolution stages in the area have been listed.

Studies [12-15] are devoted to the issue of the impact of disjunctive tectonics on the oil and gas content of the Jurassic and Cretaceous deposits within the Kogalym region. The author investigates the impact of tectonic activity and post-sedimentary events on the migration and accumulation of oil, as well as the destruction of already formed paleo-deposits.
Foreign researchers [16-18] discovered in detail the role of the tectonic regime, disjunctive tectonics, crustal stresses, and other tectonic factors on the oil and gas content of formations. The authors of [19-21] postulate many details of the geological structure and regional regularities of the Vasyugan horizon and the productive strata YU1 in the study area, which have been used during the study.

One of the study objectives is zoning the territory and identifying areas characterized by a relatively homogeneous geological structure and the deposit formation conditions and, consequently, uniform patterns of distribution of hydrocarbon deposits.

2. Materials and techniques

Tectonically, the territory under study is confined to the northern end of the Surgut arch, which is located in the northern part of the West Siberian plate. The territory is bordered by the North-Surgut monocline in the north and the Yarsom trough in the east. Within the study area, the second-order structures have been identified: Tevlinsky, Vassalukhinsko-Kochevsky, and Yagunsky swells, Imilor dome uplift, Druzhno-Gribnoy plunging anticline, and Yuzhno-Gribnoy and Vostochno-Venglinsky troughs [22]. The total area of the territory is 9,230 km².

The stratigraphic section is represented by the pre-Jurassic and Meso-Cenozoic deposits. The section is terrigenous; there are interlayers of carbonate rocks and coals. The section contains many regionally persistent reflective horizons (RH). Some of the main reflecting horizons have been used herein: A – the roof of the pre-Jurassic complex; T3 – the roof of Togur clays; T – the roof of the Tyumen suite; YU1 – the roof of the Vasyugan suite; B – the roof of the Bazhenov suite; CH – bottom of Cheuska clays; M – bottom of the Koshaisk suite; D – the roof of the Berezovskaya suite.

In terms of oil and gas geological zoning, the territory belongs to the Surgut oil and gas region. The main productive oil and gas bearing complexes within the study area are Middle Jurassic, Upper Jurassic, including the anomalous section of the Bazhenov suite, Upper Berriass-Lower Valanginian, and Upper Valanginian.

As part of forecasting the oil and gas content of the Upper Jurassic deposits in the northern part of the Surgut arch, the structural factors controlling the oil and gas content of the YUS1 formation have been studied. Generalizing structural maps have been built for the main reflecting horizons.

3. Results

Using the training sample consisting of 207 oil and 208 water wells, a correlation matrix of the absolute marks of the reflecting horizons was built (Table 1).

|     | T3  | T   | YU1 | B   | CH  | M   | G   |
|-----|-----|-----|-----|-----|-----|-----|-----|
| A   | 0.786 | 0.716 | 0.667 | 0.703 | 0.311 | 0.434 | 0.613 |
| T3  | 1   | 0.971 | 0.958 | 0.927 | 0.790 | 0.854 | 0.876 |
| T   | 1   | 0.956 | 0.936 | 0.889 | 0.682 | 0.821 | 0.828 |
| YU1 | 1   | 0.993 | 0.948 | 0.848 | 0.896 | 0.909 |
| B   | 1   | 0.984 | 0.920 | 0.774 | 0.871 | 0.841 |
| CH  | 1   | 0.949 | 0.884 | 0.923 | 0.917 |
| M   | 1   | 0.915 | 0.830 | 0.903 | 0.833 |

*the numerator and the denominator show the correlation values for oil and water wells, respectively.
In the given correlation matrix, cells with different values for oil and water wells are highlighted in red. There is a statistically significant difference in the inheritance of structural features for oil and non-oil zones of the formation. It can be noted that for oil and water wells, large and small values prevail, respectively. It is noteworthy that significant differences in correlations for oil and water wells are observed between horizons stratigraphically distant from the roof of the YUS1 formation, the oil-bearing capacity of which is forecasted.

The relationships between structural plans have been studied by building cross-plots of the marks of the reflecting horizons (Figure 1); the regression and group characteristics are given in Table 2.

![Cross-Plots of the Reflecting Horizon Marks](image)

**Figure 1.** Cross-Plots of the Reflecting Horizon Marks: a) T3 from A; b) T from A; c) YU1 from A; d) T from T3; e) YU1 from T3; f) YU1 from T.

When studying the relationship between the reflecting horizons in the study area, a division of the common point cloud into different groups is observed. These groups are strictly laterally separated, which indicates different sedimentation regimes in different parts of the area. The authors believe that such a difference is determined by different tectonic activity, which has led to the different preservation of structures in different areas of the northern part of the Surgut arch.

Figure 1a shows two groups of points; the trend lines have different slopes and intercepts. The points show an areal zonal distribution without tectonic referencing. In the south, the border of zones runs submeridionally along the axial line of the Tevlinsky Swell, then changes its direction and continues to the north-east, adjoining the Imilor trough. Groups of points are scattered similarly relative to the trend (Table 2). The difference in the functions describing the trend line is noted: the northwest trend slope is 0.65, and the southeast trend slope is 0.4. The slope characterizes the degree of preservation of the structural plan amplitude in the areas described by trends. Thus, e.g., in the western part, where the slope is 0.65, the RH A surface amplitude of 100 m will correspond to the RH T3 surface amplitude of 65 m. Similarly, for the southeastern part of the study area with a slope of 0.4, the RH A surface amplitude of 100 m will correspond to the RH T3 surface amplitude of 40 m. The correlation on the entire area of the two reflecting horizons is 0.7 at the determination coefficient $R^2=0.5$, which can be characterized as a direct relationship with a significant scattering degree relative to the trend curve. In this case, when dividing into two zones, both indicators $r=0.93/0.9$ and $R^2=0.86/0.81$ increase for the western and eastern parts, respectively. The high correlation coefficient of the two areas indicates that the structural surface A is inherited by the T3 horizon. The inheritance
of the structural plan is a consequence of postsedimentary changes – the surface downwarping and upwarping. The slope is a metric of the reflecting horizon surface inheritance degree. Differences in the slope indicate different preservation of the structural plan intensities; a larger slope in the west compared to the east indicates a greater intensity of the tectonic regime in the eastern part in the Early Jurassic period. This conclusion assumes that the currently observed T3 structure amplitudes have been formed in the post-Early Jurassic period, and part of the amplitude has been smoothed away by the Early Jurassic tectonic rearrangements.

Table 2. Characteristics of Relationship between the Reflecting Horizons.

| Group          | Equation       | r    | R²   | St. Dev. | \(\chi^2\) - numerator | \(t\) - numerator |
|----------------|----------------|------|------|----------|------------------------|------------------|
| a              | T3=1.586+0.48·A| 0.7  | 0.48 | 56.1     | -                      | -                |
| West West      | T3=1.083+0.65·A| 0.93 | 0.86 | 27.12    | 499.45                | -28.0434         |
| Common East    | T3=1.802+0.4·A | 0.9  | 0.81 | 23.08    | 0                      | 0                |
| b              | T3=1.459+0.43·A| 0.64 | 0.41 | 58.54    | -                      | -                |
| West East      | T3=747.24+0.66·A| 0.95 | 0.9  | 24.91    | 498.27                | -30.8351         |
| Common East    | T3=1.739+0.33·A| 0.87 | 0.75 | 21.99    | 0                      | 0                |
| c              | YU1=-1.410+0.43·A| 0.59 | 0.35 | 65.44    | -                      | -                |
| West East      | YU1=-651+0.68·A| 0.95 | 0.89 | 25.12    | 364.8                 | -32.9531         |
| Common East    | YU1=-1.719+0.32·A| 0.84 | 0.7  | 24.23    | 0                      | 0                |
| d              | T=94.91+0.94·T3 | 0.97 | 0.94 | 19.34    | -                      | -                |
| North-West     | T=253.4+0.84·T3 | 0.91 | 0.82 | 18.62    | 6.14                   | 8.08             |
| South-East     | T=338.8+0.8·T3  | 0.95 | 0.9  | 15.59    | 0                      | 0                |
| e              | YU1=-326.4+T3    | 0.96 | 0.92 | 23.59    | -                      | -                |
| North-West     | YU1=-324.2+0.8·T3| 0.9  | 0.81 | 18.65    | 169.78                | 14.632           |
| South-East     | YU1=-169.3+0.84·T3| 0.92 | 0.85 | 20.04    | 0                      | 0                |
| f              | YU1=226.4+T      | 0.99 | 0.98 | 11.76    | -                      | -                |
| North-West     | YU1=-79.63+0.96·T| 0.98 | 0.96 | 8.323    | 218.34                | 14               |
| South-East     | YU1=185.9+T      | 0.97 | 0.94 | 12.23    | 0                      | 0                |

When analyzing the A and T reflecting horizons in Figure 1b (Table 2b), an increase in contrast between the two selected groups can be noted. The division boundary almost repeats that in the description of A and T3 horizons with minor changes. The correlation on the entire area of the two reflecting horizons is 0.64 with the determination coefficient \(R^2=0.4\) and is characterized as weaker, as compared to A/T3, with a large scattering relative to the common trend. The slopes for the western and eastern parts are 0.66 and 0.33, respectively. It is noteworthy that in the western part, an increase in the slope and the correlation and determination coefficients and a decrease in the standard deviation are observed. In the eastern part, on the contrary, there is a slight decrease in the indicators listed. The decrease in the values characterizing the relationship between the reflecting horizons up the section is typical – the structure amplitudes decrease due to erosion and tectonic fluctuations. An increase in values up the section, albeit minimal, on the contrary, is abnormal: the structural surface intensity increases again and becomes closer to that traced along the A surface. According to the authors, a probable reason for this is that as of the end of the formation of the Lower Jurassic deposits, not a complete peneplanation but a small inversion of the day and the basement surfaces is observed, in other words, in the upwarped sections of the basement, we observe downwarp of the day surface, which may be a consequence of denudation. Therefore, it follows that in the Lower Jurassic deposits, in the areas upwarped along the basement, we observe traces of erosion and continental conditions of sedimentation, and in the downwarped ones – alimentation areas and increased deposit thickness.
Up the section (Figure 1c, Table 2c), the emerging trend continues – the contrast between the western and eastern parts of the area increases, which is confirmed by the slopes of the trend lines and the correlation and determination coefficients. It is worth noting that the division into groups here is the same as for the RH A and T ratio, but in this case, an increase in the slope in the west is also observed. An increase in the contrast between the groups indicates the continuation of the processes that have formed a specific section of the Lower Jurassic deposits.

On the plot of the relationship between the reflecting horizons T and T3 (Figure 1d, Table 2d), a common direct dependence with the coefficients \( r=0.97 \) and \( R^2=0.94 \) is observed, which indicates a subconformal relationship between the reflecting horizons. The plot shows that a set is isolated from the common cloud in the region of lower values. A separate set, like the entire sample, is characterized by a strong straight-line correlation of reflecting horizons. The plot shows that the isolated set characterizes the area where the thickness of the Middle Jurassic deposits is less. Geographically, it belongs to the northwestern part. In faci terms, this area is attributed to the facies of the lacustrine-alluvial plain, which are characterized by a reduced deposit thickness. In tectonic terms, the area belongs to the Imilor trough and the junction zone of the Kogalym peak with the Konitlorskaya terrace.

When considering the relationship between the reflecting horizons T3 and YU1 (Figure 1e, Table 2e), similar isolation of a set with reduced thickness is observed. The correlation coefficients for the two subsets decrease relative to those characterizing the T3 and T trends. This suggests that the reasons for this isolation are confined within the section of the Middle Jurassic deposits and do not spread to the Vasyugan suite; this is also illustrated by the plot.

On the cross-plot of the reflecting horizons T and YU1 (Figure 1f, Table 2f), a monolithic group of points with a very strong straight-line correlation \( r=0.99 \) and a low scattering relative to the trend \( \sigma=11.76 \) is observed. Such a strong relationship between the surfaces of the Vasyugan and Tyumen suites is the result of the relatively uniform sedimentation conditions for the entire area and the absence of sharp tectonic shocks in the Callovian-Oxfordian period, both local and regional. However, the isolation of a set of points in the north of the study area is also observed and confirmed by the t and \( \chi^2 \) criteria, which indicates a single tectonic activity regime throughout the entire period of formation of the Tyumen and Vasyugan suites.

On the plots of the relationship between the reflecting horizons of the Cretaceous deposits, from three to five separate sets of points are isolated. Each set has a spread area elongated in the meridional direction. The isolation of zones is primarily determined by avalanche-like, high-intensity, overcompensated sedimentation; any features of tectonic regimes in the Cretaceous interval cannot be identified.

Based on the analysis performed, the schemes of zoning the Jurassic deposits have been built (Figure 2).

**Figure 2.** Zoning Schemes: a) by A dependences; b) by T3 dependences.
Schemes 2a and 2b illustrate zoning with respect to the reflecting horizons identified with the roof of the pre-Jurassic complex and the roof of the Togur clays, respectively. These two trends are most clearly traced in the section of the Jurassic deposits of the northern part of the Surgut arch; the zones into which the area is divided are characterized by a greater similarity of the geological structure and sedimentation conditions.

4. Conclusion
Clustering in the cross-plots of the sedimentary reflecting horizons in the northern part of the Surgut arch is characterized by spatial separateness. The area division is determined by the difference in tectonic regimes prevailing in its different parts. During the Jurassic strata sedimentation, a difference in tectonic regimes was observed in the western and eastern parts of the area. Zoning is valid and true, which is illustrated by the plots of the relationship between the reflecting horizons, as well as Student’s and Pearson’s tests. The authors’ zoning with the identification of areas characterizing by similar tectonic-sedimentation features is required for further creating more accurate models for the zonal forecasting oil and gas content. Ranking areas by the tectonic activity degree will improve understanding the nature of sedimentation in a specific part of the section and will be used in building models to forecast the oil and gas content of the area.

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