Predicting Fractured Carbonate Reservoirs at the Early Stage of Exploration of Oil and Gas Deposits

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Abstract—The paper considers a possibility of using complex information on morphological parameters of structures, unconnected porosity and reservoir pressure gradient for previously explored deposits for developing a multidimensional equation to estimate the secondary porosity on an example of reservoirs with secondary (fracturing) porosity of Upper Cretaceous deposits in the Terek-Sunzha oil and gas bearing region of Pre-Caucasus. This equation allows predicting the secondary porosity value in new anticlinal structures revealed with seismic survey at later stages of exploration in the respective oil and gas bearing region and using it as a quantitative criterion to predict existence of an entrainment trap.

Keywords—fractured reservoir, oil and gas deposit, porosity, prediction, carbonate sediments, Terek-Sunzha oil and gas bearing region

I. INTRODUCTION

More than 60% of all the oil produced globally is confined to carbonate reservoirs, predominantly those of fractured type. The global initial recoverable reserves of oil linked to this group of reservoirs are estimated at over 6 billion tons of commercial oil, the global proven reserves are estimated at approximately 63 trillion m$^3$ [14].

In the territory of the Russian Federation, oil and gas deposits in fractured reservoirs are found in various tectonic conditions and in sediment sheaths of various age. Fractured reservoirs have the paramount importance in determining the prospects of oil and gas presence, for example in the oil and gas bearing region of East Siberia. Thus, importance and topicality of any developments related to the issues of fractured reservoirs are obvious, as many related issues are understudied. First of all, it is true of exploration attributes of reservoirs in low porosity rock, which are impossible to identify without considering the formation factors of fractured reservoir rocks. The problem of fractured reservoirs gets special topicality and complexity when considering the prospects of the carbonate reservoirs located in extreme conditions at deep depths.
II. ANALYSIS OF EXPLORATION DEGREE OF THE FRACTURING
FORMATION MECHANISM IN ROCKS AND METHODS FOR ITS
IDENTIFICATION

One of major factors in oil and gas reservoir formation in
carbonate rocks is development of fractures. As for genesis and
mechanism of rock fracturing, there are several points of view,
often mutually exclusive [3, 4 and others].

Studies of fracturing develop along several lines of research.
Continuum mechanics and solid state physics develop a general
understanding of the laws governing formation and
development of hard rock fracturing. Rock mechanics pays
major attention to the problems of plasticity and strength of
rocks, that is, to determination of conditions of attaining
limiting strain states. Currently, there is a quite definitive and
experimentally confirmed understanding of the atomic
mechanism of plastic deformation and solid body breakdown
related to developments in the dislocation theory.

The most complete summary of this line of research may be
found in proceedings of two international conferences that were
held in the US in 1959-1962. There, the main attention was paid
to appearance of cracks in various solid bodies, at that, all the
main types of solid body destruction (brittle, viscous, fatigue-
related) were considered in the context of a unified paradigm of
dislocation mechanism during the deformation. Kinetics of the
fracture process linked to dislocation development is
schematically represented as a consecutive transition from glide
and merging of dislocations, leading to local concentration of
stress and formation of proto-fractures, their development and
joining, up to formation of the main destructive fracture.

Formation of oil and gas deposits in carbonate rock massifs is
usually possible on condition of presence of fracture porosity
therein. Due to this, it is very important to reveal presence of
fractured reservoirs in carbonate section throughout the stages
of oil and gas deposit exploration, including:

1) preliminary prediction of possible presence of fractured
reservoirs from the results of field seismic [9,10,14],
geomorphological [3,5] and aerospace [1, 2, 4, 7] surveys.
Thanks to aerospace methods’ inherent ability of obtaining
information on the same natural features, retrospective analysis
becomes easy. It allows studying the dynamics of the geological
processes [3,4,14];

2) identification of reservoirs while drilling from the results
of geological and engineering survey (GES) data;

3) complex study of oil-bearing of the carbonate sediments
and detailed identification of fracture reservoirs ranges in
carbonate massifs with well surveys after completion [3, 9, 10].

As well drilling is associated with large financial and
material costs, it is very important to produce the preliminary
prediction for the presence of reservoir in the carbonate massif
at the first stage, that is, from the results of seismic surveying
of anticlinal structures. According to modern theoretical
understanding of fracture reservoir formation mechanism [5],
the amount of fracture porosity in carbonate massif is largely
influenced by the strength of rocks, fault morphology and
reservoir pressure. In [6, 11], influence of various
morphological parameters has been revealed, including the
angle at the knee of a fold leading to strain loads arising that
form fracturing. According to modern understanding [11, 12],
reservoir formation proceeds simultaneously with formation of
the structural layout. Tectonic movements cause redistribution
of stress field, leading to intensive formation of a system of
fractures. It is related to tectogenesis phases and has cyclic
nature. At that, formation of a fractured reservoir is largely
influenced by the presence of tectonic faults [15].

One of informative methods to identify the fault zones is a
method of paleotectonic studies by means of analyzing
thickness distribution [14]. The fractured discontinuous faults
that were active in contemporary history appear on the daylight
surface especially vivid. This notion is supported by a large
number of foreign [3, 13] and Russian [8 and others] research
works. The most impressive results were obtained by Blanchet
and Hodgson [13]. The researchers reported, that the systematic
layout of dislocations found in more ancient rock was almost
completely repeated in all the later sedimentary systems.

III. PREDICTION OF FRACTURED RESERVOIRS

The problem of formation of reservoirs with fracture
porosity on the example of Upper Cretaceous sediments of
Terek-Sunzha region was considered in a number of previous
works [8 and others].

For example, the authors of [10] proposed combined use of
information on morphological structural features and proved an
empiric multidimensional equation (1), that allows calculating
the value of secondary (fractured) porosity (K_{sfp}, %) from such
parameters as depth of the fold hinge (H, km), maximum
bending of strata (i, m), area (S, km²), intensity of fault
formation (J=i/S, m/km²), predicted value of unconnected
porosity (K_{up}, %) and reservoir pressure gradient (P, mPa/m),
and then, considering 0.2% as a critical value, draw conclusions
on practicality of drilling the first well in the crest of the
structure, as well as on the order of well drilling.

\[
K_{sfp}=3\cdot10^{-4}i + 0.895\grad P + 2.5\cdot10^{-2}J - \\
2.58\cdot10^{-2}K_{up} - 6.67\cdot10^{-3}H - 0.945
\]

Under some conditions, the information is incomplete, and
it become problematic to use the equation (1) to calculate the
value of K_{up}. Due to this, to increase the efficiency of
exploration of territories prospective for oil and gas that are
related to the zones of maximum dislocation tectonics, and as a
result, those of maximum fracturing, the authors conducted the
following research.

From the material of seismic exploration survey conducted in
the Terek-Sunzha oil and gas bearing region, outlines of the
structures were identified for the reflective Upper Cretaceous
sediments of interest (Fig.1).
Fig. 1. A diagram of location of oil and gas deposits within the Terek-Sunzha zone, with elements of tectonic zoning of the Terek-Caspian depression

I - Monocline of the northern margin, II - Pre-Terek depression, III - Near-Terek anticlinal zone, IV - Terek anticlinal zone, V - Sunzha anticlinal zone, VI - Chernogorsk monocline, VII - Chechen basin, VIII - Alkhanchurt syncline, IX - Petropavlovsk syncline, X - Sulak basin.

Then, spacial positions of disruptive faults were established throughout the studied territory along this reflective horizon (Fig. 2).

Fig. 2. Structural map along the overburden of Upper Cretaceous sediments with disruptive faults in the territory of Terek-Caspian depression

The studied territory was divided into equal squares with 5km sides and for each square the number of disruptive faults was determined. After that, these values were put into centers of respective squares and a map was plotted to reflect the height contours of along the same values of the disruptive faults (Fig 3).

Fig. 3. A map of height contours of disruptive faults for Upper Cretaceous sediments in the territory of Terek-Caspian depression Capacity and filtration properties of Upper Cretaceous rocks with breakdown per deposit (According to data from North Caucasus branch of NIPIneft)

As it is evident from analysis of this map, a zone of maximum values of the disruptive faults is revealed that includes the largest deposits in the Upper Cretaceous sediments (Malgobek-Voznesenskoye, Bragunskoye, Eldarovskoye on Terek mountain range; Starogroznenskoye and Zamankulskoye on Sunzha mountain range); reservoirs of these deposits are characterized with the highest fractured (secondary) porosity from both hydrodynamics and field geophysical data (Tables 1, 2, 3).

Thus, this method may be employed to predict the fractured reservoir development zones in sedimentary sheath in new unstudied territory. Drilling of the first wells is practical in the crest of the structures, which pertain to the zone of maximum disruptive faults.

Thus, the results of the conducted research have not only theoretical, but also important practical value, mainly for targeting of exploratory works.

TABLE 1. CAPACITY AND FILTRATION PROPERTIES OF UPPER CRETACEOUS ROCKS WITH BREAKDOWN FOR DEPOSITS (ACCORDING TO DATA FROM NORTH CAUCASUS BRANCH OF NIPINEFT)

<table>
<thead>
<tr>
<th>Deposits</th>
<th>Laboratory Core Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Porosity of saturation, %</td>
</tr>
<tr>
<td>Malgobek-Voznesenskoye</td>
<td>0.1-16.4</td>
</tr>
<tr>
<td>Khayan-Kortovskoye</td>
<td>0.3 - 6.4</td>
</tr>
<tr>
<td>Eldarovskoye</td>
<td>2.16</td>
</tr>
<tr>
<td>Bragunskoye</td>
<td>1.6 – 9.4</td>
</tr>
<tr>
<td>Goryacheistochenskoye</td>
<td>0.2 - 4.5</td>
</tr>
<tr>
<td>Gudermes</td>
<td>0.3 - 4.9</td>
</tr>
<tr>
<td>Mineralenskoye</td>
<td>0.7-6.5</td>
</tr>
<tr>
<td>Zamankulskoye</td>
<td>2.4</td>
</tr>
<tr>
<td>Karabulak-Achalakskoye</td>
<td>1.3-19.4</td>
</tr>
<tr>
<td>Starogroznenskoye</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>0.7 - 14.1</td>
</tr>
<tr>
<td></td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
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TABLE II. HYDRO_DYNAMIC STUDIES INTO CAPACITY AND FILTRATION PROPERTIES OF UPPER CRETACEOUS ROCKS (FROM THE DATA OF NORTH CAUCASUS BRANCH OF NIPINEF)

<table>
<thead>
<tr>
<th>Deposits</th>
<th>Hydrodynamic studies</th>
<th>Average depth, m</th>
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<tbody>
<tr>
<td></td>
<td>Fracture porosity, %</td>
<td>Permeability, MD</td>
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<tr>
<td>Malgobek-Voznesenskoye</td>
<td>0.35</td>
<td>245</td>
</tr>
<tr>
<td>Khayan-Kortovskoye</td>
<td>0.16</td>
<td>34</td>
</tr>
<tr>
<td>Eldarovskoye</td>
<td>0.28</td>
<td>500</td>
</tr>
<tr>
<td>Bragunskoye</td>
<td>0.29</td>
<td>476</td>
</tr>
<tr>
<td>Goryacheistochnenskoye</td>
<td>0.2</td>
<td>84</td>
</tr>
<tr>
<td>Gudermesskoye</td>
<td>0.16</td>
<td>70</td>
</tr>
<tr>
<td>Mineralnenskoye</td>
<td>0.06</td>
<td>17</td>
</tr>
<tr>
<td>Zamankulskoye</td>
<td>0.25</td>
<td>205</td>
</tr>
<tr>
<td>Karabulak-Achaluhskoye</td>
<td>0.25</td>
<td>256</td>
</tr>
<tr>
<td>Starogrozenskoye</td>
<td>0.32</td>
<td>398</td>
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TABLE III. CAPACITY AND FILTRATION PROPERTIES OBTAINED BY FIELD GEOPHYSICAL TESTS (FROM THE DATA OF NORTH CAUCASUS BRANCH OF NIPINEF)

<table>
<thead>
<tr>
<th>Deposits</th>
<th>Field geophysical tests</th>
<th>Average depth, m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total porosity, %</td>
<td>Unconnected porosity, %</td>
</tr>
<tr>
<td>Malgobek-Voznesenskoye</td>
<td>5.4</td>
<td>4.6</td>
</tr>
<tr>
<td>Khayan-Kortovskoye</td>
<td>3.57</td>
<td>2.6</td>
</tr>
<tr>
<td>Eldarovskoye</td>
<td>3.06</td>
<td>2.54</td>
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<tr>
<td>Bragunskoye</td>
<td>2.83</td>
<td>2.25</td>
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<tr>
<td>Goryacheistochnenskoye</td>
<td>5.62</td>
<td>5.0</td>
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<tr>
<td>Gudermesskoye</td>
<td>1.47</td>
<td>0.97</td>
</tr>
<tr>
<td>Mineralnenskoye</td>
<td>1.38</td>
<td>1.0</td>
</tr>
<tr>
<td>Zamankulskoye</td>
<td>4.65</td>
<td>2.6</td>
</tr>
<tr>
<td>Karabulak-Achaluhskoye</td>
<td>3.16</td>
<td>2.6</td>
</tr>
<tr>
<td>Starogrozenskoye</td>
<td>6.03</td>
<td>5.3</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

1. The results of the conducted research have not only theoretical, but also important practical value, mainly for targeting of exploratory works.

2. The proposed method for prediction of fractured (secondary) porosity in anticlinal structures may be employed for search of deep reservoirs with secondary porosity in terrigenic massifs, which are not prospective for search of granular reservoirs.

3. Economic efficiency of the proposed method lays in reduction of expenses for exploration of oil and gas deposits in deep reservoirs with secondary porosity by means of proving the practicality of drilling on the anticlinal structures revealed by seismic surveying.

References


