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Choosing the Most Correct Method to Predict the Distribution of Fractured Zones in Carbonate Reservoirs

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SUMMARY

Today there are several methods which are considered effective for the prediction of fractured zones, but the practice demonstrates that they give very different results thus automatically guiding us to the question on how to choose the most applicable. Obviously it's highly desirable to create an algorithm which then can be applied not only for one field, but for at least some others. In particular in this project the unified methodology has been created which proved its validity for two fields in Timano-Pechorskaya province – Varandeyskoye and Yuzhno-Toraveyskoye.

The authors of this paper suggest the comparison between the field history data and the results of reservoir modelling as a way to verify the quality of the prediction. While the reservoir models used for running the scenarios included different cubes of fractured zones (and the permeability subsequently) obtained from different prediction methods.

The duplex waves migration method provided for the prediction of the fractured zones in Varandeyskoye and Yuzhno-Toraveyskoye fields which were confirmed using the historical well data. Consequently, including fractured zones within dynamic model allowed us to choose the better scenarios accounting for specific production dynamics of wells situated in fractured zones thus decreasing the risk for the investor.

Introduction

Planning of development of fields with naturally fractured reservoirs is quite risky due to the possible contingencies while drilling (intensive or total circulation loss) as well as the development phase (low oil rates and high water cut rate). Accounting for this it's evident to conclude that having a reliable methodology for prediction of fractured zones at the early planning phase is crucial for such fields. This is fully true for the fields in Timano-Pechorskaya oil and gas province of Russia, where the majority of fields are carbonate reservoirs with fractures due to the tectonic forces which are very active here.

Today there are several methods which are considered effective for the prediction of fractured zones, but the practice demonstrates that they give very different results thus automatically guiding us to the question on how to choose the most applicable. Obviously it's highly desirable to create an algorithm which then can be applied not only for one field, but for at least some others. In particular in this project the unified methodology has been created which proved its validity for two fields in Timano-Pechorskaya province – Varandeyskoye and Yuzhno-Toraveyskoye.

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The task

Initially the task was to build 3D models of Early Permian carbonate deposits of Varandeyskoye filed. The field is green, at very early development phase, with only about a dozen of production wells drilled so far. Thus collecting as much reservoir characterization data as possible is crucial to choose the best development scenario. That's why a 3D seismic survey was run in the field and all the wells are drilled with extensive logging program.

The seismic data allowed distinguishing of some faults within the oil bearing area which were accounted in the static model. But we've had a simultaneous task to analyze the reason of rapid water cut increase in some wells drilled in different areas of the field and provide recommendations on how to overcome this problem in the existing wells and prevent it in future.

Initially it was presumed that the problem with the water cut is related not to the geology but to the poor completion quality. But later, after the analysis of the wells production dynamics was done, the conclusion was made that the character of the water cut increase is similar in almost all wells under consideration and much corresponds to the picture we usually observe in fractured reservoirs. At the same time we saw that this behaviour is typical only for some wells around the field, while the other wells don't demonstrate any signs of fractured reservoir presence. This allowed us to conclude that the reservoir is not fully fractured but only at some zones which we needed to map. Our guess was supported with the data from the neighbour field Yuzhno-Toraveyskoye where similar picture of the wells dynamics was observed and the presence of fractures in the problematic wells had been confirmed with FMI logs.

The theory behind fractured zones mapping

There are several methods which are able to predict fractured zones. They are: (1) the method of the duplex waves migration (DWM); (2) the method of coherency interpretation; and (3) the method of the second derivative of the structural surface. The main feature of these methods is that they are based on seismic data, i.e. they are synthetic methods.

Second derivative of the structural surface amplitude is a common method for mapping tectonic faults and, as a subcase, for associated fractures. By visual analysis the zones of maximum curvature of second derivative map can be recognized and identified as fractured zones. However increased gradient values can be resulted from not a real structure change but a horizon surface distortion during seismic data processing. A key question here is what values of the second derivative should be attributed to fractured zones, i.e. this method is highly subjective.

Another seismic attribute, which can be used for fractured zones recognizing, is coherency. Algorithms of coherency cube calculation are much different in modern software packages, but main point of the operation is the same and consists of comparing of the characteristics of the neighbour seismic traces. The more similar the traces are – the higher the coherency is. Sharp incoherency is a possible sign of a fault and also can be an indirect sign of fractures associated with the fault. Apparently this method is quite inaccurate, includes a lot of admissions and assumptions. Also it's necessary to remember that not only faults zones may be incoherented, but also sharp lithological changes and unfiltered noises of different kind, even technogenic.

Method of duplex waves migration is based on properties of twice reflected waves. It's based on the statement that before reaching acquisition surface waves are first reflected from subhorizontal surface and then from subvertical surface (or vice versa).

Duplex waves data interpretation is based on Kirchhoff transformation, in which Green's function is changed according to kinematics of duplex waves. Migration of duplex waves also may be performed using any other types of migration transformations - finite-difference, spectral, etc. For realization of Kirchhoff's duplex waves transformation the same velocity model of that for common migration operation and additionally reference subhorizontal boundary is established.

Resolution capability of usual migration operations along lateral direction is several times lower than vertical resolution capability. Rotation of the operator by 90 degrees relatively to usual operators provide increasing resolution capability of duplex waves in lateral direction. It means that the localization of tight subvertical boundaries in area is performed which is indeed the way to recognize the fractures in the reservoir. However this method often overestimates vertical length of subvertical boundaries (fractures), this is a specific feature of the method and should be considered while using its results.

This method also leaves an area for creativity, because there are no predefined parameters of transformation and criteria for recognizing these subvertical boundaries - they should be selected based on experience and additional data analysis.

Verifying the quality of the fractured zones prediction

During the preliminary analysis we approached the conclusion that the method of coherency cube interpretation was very unreliable and couldn't be considered as a tool for an accurate prediction. Therefore only the method of duplex waves migration and the method of the second derivative were approved for further use. Based on these methods two fractures distribution cubes (similar to lithology cubes) were created in 3D geological modelling package in addition to standard set of cubes (lithology, porosity, saturation and permeability). Consequently we've got 3 variants of the static model (3 sets of cubes):

- without fractures (no fractures distribution cube)
- with fractured zones mapped using DWM method (Figure 1, left)
- with fractured zones mapped using method of the second derivative (Figure 1, right)

Easy to notice that, as it was initially stated, the zones mapped using different methods are not the same. So the next step of the analysis is the choice of the method which more corresponds to the actual data. For this purpose the 3 dynamic models were compiled and equally initialized based on the different static models.

At this stage the fractures distribution cube was merged with the permeability cube and the latter, both vertical and horizontal, was significantly increased in the predicted fractured zones. Besides the impermeable layers which are continuous and serve as natural barriers to the bottom water have got vertical permeability in the fractured zones thus corresponding to the situation when the fractures are induced by tectonic forces.

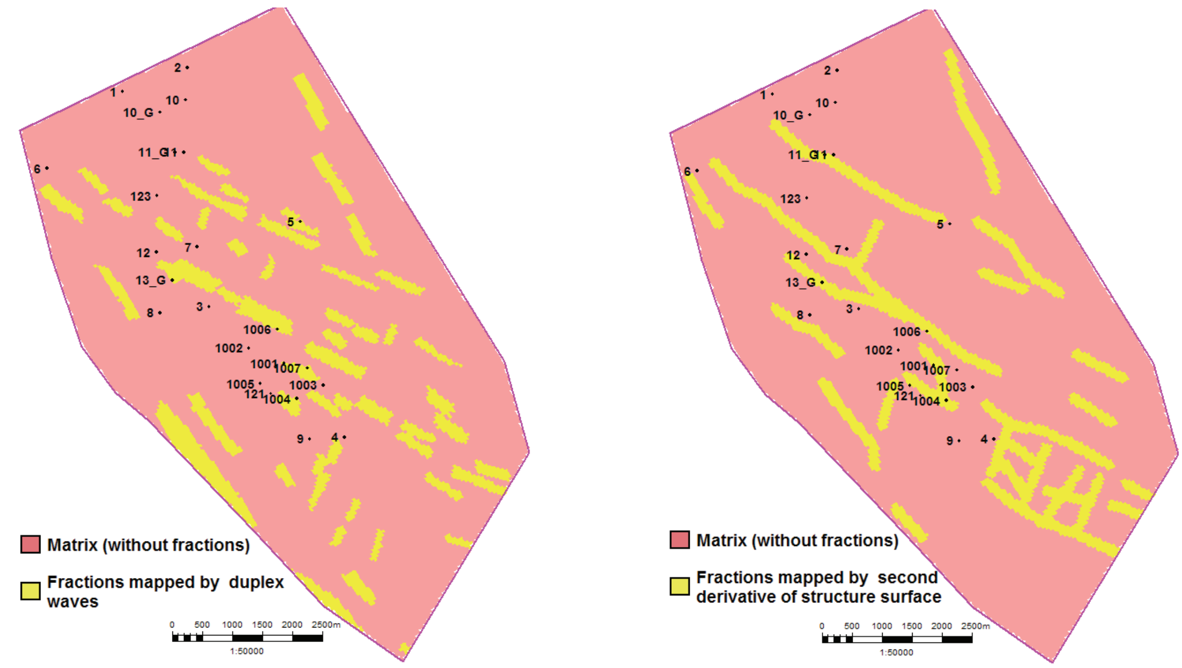

Figure 1. *Maps of the fractured zones in the static model. Left) Using DWM method. Right) Using method of the second derivative.*

Then we ran the field history on the 3 models without any changes to the parameters of the models and the results of the run on the model without fractures were compared to the results of the runs of the two remaining models. An example of such comparison for the DWM method is presented in Figure 2.

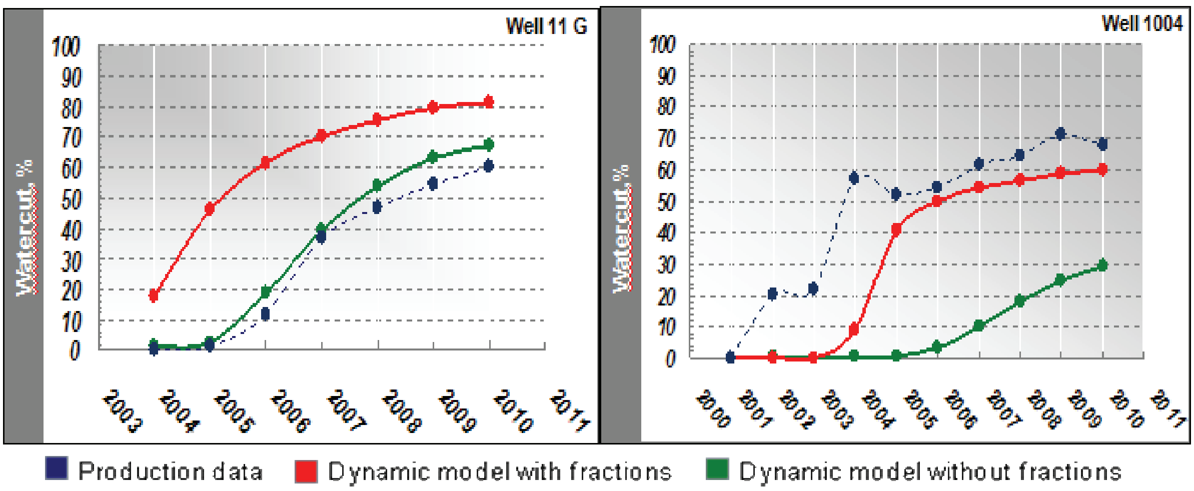

Figure 2. *Observed (blue) water cut in selected wells vs. water cut in the same wells on model without fractures (green) and with fractures predicted with DWM method (red)*

Having run a detailed analysis for each well individually we concluded that the model with the fractures predicted by the DWM method only is much better corresponding to the field data. The method of the second derivative predicted fractures where their presence was not confirmed by the well data. Therefore the model with the fractured zones predicted using the DWM method only was chosen for further history matching and scenarios evaluation. Besides this approach was later tested in the neighbour Yuzhno-Toraveyskoye field where the results of fracture prediction matched the well data without any changes to the method parameters proposed within Varandeyskoye study.

Conclusions

The duplex waves migration method provided for the prediction of the fractured zones in Varandeyskoye and Yuzhno-Toraveyskoye fields which were confirmed using the historical well data. Consequently, including fractured zones within dynamic model allowed us to choose the better scenarios accounting for specific production dynamics of wells situated in fractured zones thus decreasing the risk for the investor.

The analysis performed and the calculations run allow assuming that the methodology created and the results of the analysis can be spread out to the other fields of Timano-Pechorskaya oil and gas province and other regions with similar geological conditions.

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