Adaptive Geological Modelling and Its Application for Petroleum Reservoir Conditions

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Abstract. The article discusses the difference between the adaptive geological model and the traditional deterministic one, which is based on the manual work of geologists in the pre-computer era. Today, the deterministic approach to modelling has outlived its usefulness. Computer simulations use other methods. Therefore, it is necessary to break away from the deterministic tradition in order to move on. The adaptive geological model is a mathematical function, the purpose of which is not at all to display actual information about the structure of a petroleum reservoir as accurately as possible, but to predict its structure in undrilled zones. The adaptive approach proves that it is not necessary to obey the facts for a successful forecast. This is often even harmful, since the geological structure of the petroleum reservoir at the points where the wells are drilled is known without modelling. Just as in the regression analysis, it is not at all necessary that the function passes exactly through all the actual points, it is not necessary for the geological model of the petroleum reservoir to fully reproduce the actual data. This is the fundamental feature of the adaptive geological model.

1. Introduction

A digital geological model of any petroleum reservoir is a set of two-dimensional maps and three-dimensional grids that represent the geometry, distribution of petrophysical parameters, and the oil original in place in the studied object. In this regard, it may seem that there should not be large differences between the deterministic and adaptive versions of the geological model. However, these differences exist and, above all, in the gross thickness and number of vertical layers of the model as well as the model’s reproduction of actual data.

2. Main differences between deterministic and adaptive geological model options

The deterministic models are being developed extensively towards thinning vertical layers up to 0.4 m and, in connection with this, increasing the total number of models’ cells to hundreds of millions [1]. However, to build such a cumbersome model, there is no required amount of initial information, so the deterministic model only seems detailed. Certainly, in addition to well data, seismic data can be used to build a model, but the vertical resolution of these data is much coarser than 0.4 m.
Slicing thin vertical layers is the weakest point of the deterministic model. Each layer of the model extends over its entire area, and from this, it should be understood that it is correlated everywhere. That is why, thin layers set a false structure of the petroleum reservoir space, since it is known from practice that it is impossible to perform a detailed correlation of layers with a step of 0.4 m. After all, any layer usually has a lenticular structure and even between adjacent wells some lenses can pinch out, and some - appear.

A significant difference between the deterministic geological model and the adaptive one is also the fact that the adaptive model generally has fewer vertical layers [2-3]. As a rule, the number of such layers does not exceed 6 - 8. In this case, the average gross thickness of a vertical layer is 5 - 10 m. If the layer thickness in the deterministic model tends to 0.4 m, then the cell area still remains large and does not correspond to this thickness. When the layer thickness is 5 - 10 m, then it corresponds to the horizontal cell size. In the adaptive model, even for large petroleum reservoirs, its grid is set with a step of no more than 25 m.

When a petroleum reservoir is divided into layers, it is assumed that each layer is a genetically single cycle of sedimentation, with its inherent patterns. The point of the detailed correlation used in the adaptive model is the correlation of the permeable sublayers. We would like the layer to be characterized by coherent permeable sublayers, but separated from the adjacent layers by fluid seals. Thus, each layer would represent a quasi-single isolated reservoir. Therefore, an arbitrary number of vertical layers cannot be specified in the adaptive model, but exactly as many - how many of them can be identified from actual data.

An even more controversial stage in the construction of the deterministic model is its upscaling. There is no reasonable explanation as to why it is impossible to immediately build a grid of a hydrodynamic model from well data, but it is necessary to enlarge it from the geological model grid. The detail of any model is determined not by the size of its grid, but by the amount of input information of wells and seismic surveys. Another way, justified by practice, looks more reasonable - to go from the general to the particular, i.e. first to build a coarse hydrodynamic grid and then grind it down to geological. There is no upscaling in the adaptive model, since it is not built for visualization, but for the needs of the computing system itself, as the basis of the hydrodynamic model.

Another difference between the deterministic model and the adaptive one is that the adaptive model in some cases does not coincide with the actual well data. It seems unacceptable, but the model is needed not so that it coincides with the wells, but to predict the geological structure of the petroleum reservoir in its undrilled zones. Consider, for example, some regression function, for example, a polynomial of the first or second degree. Its calculated values also do not coincide with the original points and this is normal. If we take a polynomial of a higher degree, then it is possible to achieve that its calculated values completely coincide with the actual ones, but such a polynomial cannot be used for forecasting.

Now let us look at the adaptive geological model. It does not coincide with wells in cases where closely spaced wells have significantly different values of the interpolated parameter. Suppose the well passes through some cell and the well parameter is assigned to this cell, for example, the absolute depth of the reservoir top. This cell has an area of 2500 m² and its edge zones are affected by data from the adjacent well. Let the influence of the offset well be only 20 %, but this may be significant for the weighted average parameter assigned to the cell to differ from the value of the parameter in the well intersecting this cell. One can discard some of the wells in which the greatest differences from the model are noted, which is often done, or one can correct the parameters of these wells to make them closer to the model. But in both cases, the initial information will simply be lost and nothing will be obtained in return, except for the smoothness of the surface. If we approach the model as a function, then variations in the actual parameters in the wells do not interfere with anything. The adaptive model averages and smooths the well data.
3. Reproduction of parameters of an oil field in its adaptive geological model

The geological space of the petroleum reservoir is highly anisotropic, because it is formed layer by layer over millions of years. The adaptive model is created for each selected layer of the reservoir, and then these models are summarized into a general multi-layer model of the reservoir. This logic of creating and calculating models of individual layers is justified by the fact that the layers were distinguished as single genetic formations, with their own internal laws, which can be traced in the change in the gross thickness or the proportion of permeable layers (the net to gross ratio).

When calculating the adaptive models of individual layers, seismic data are used as much as possible, which are defined for all cells. The calculation requires at least three structural surfaces constructed from seismic data. It does not matter on what reflective horizons the structural surfaces are built. It is desirable that they be as close to the studied reservoir as possible. The set of structural surfaces reflects the history of the reservoir formation. The distances between them show the rates of sedimentation. By themselves, they show tectonic activity at different periods of time. It is known from practice that the foundation surface is always most informative.

If there are three structural surfaces, then three fields of dispersion of these surfaces can be obtained from them. They reflect the curvature and possible activity of post-depositional processes that affect the formation of fracturing and reservoir properties. Further, there are two thickness fields between these three surfaces. Thus, there are already eight parameters. To them are added two fields of the total derivatives along the X and Y axes, as well as a relief surface that displays new tectonic movements. This is how a vector of eleven parameters is formed for each cell of the model. If there are more than three texture surfaces available, let us say six, then we can form a vector of twenty parameters.

Next, a training sample is compiled from those cells through which the wells pass and on this sample a cascade of fuzzy-logic matrices is trained [5]. At the same time, the system has some freedom of choice. It does not take all the components of the vector, but selects from them only nine parameters that have the greatest correlation with the target and the least among themselves. Nine parameters allow to compose a matrix cascade of 36 paired layers (mean and variance). It is a powerful system with an average of 180,000 coefficients and is capable of displaying the complexity of the parameter distribution within the model. Such matrices are compiled for five main parameters of the geological model: gross thickness, net pay thickness, porosity, permeability, and oil saturation. The base fields of these parameters are calculated from them. From Figure 1, it follows that the matrix quite adequately reflects the distribution patterns of the gross thickness, revealing details that are not directly related to wells.

In principle, one could simply use the base fields for geological modeling, but they are refined with well data. To do this, the data of these wells is entered into the cells through which the wells passed, and further along the additional grid, the nodes of which are located at distances of at least 150 m from the wells, the data of the base field are entered. After that, interpolation is performed in a manner reminiscent of cellular automata (Figure 2). It uses a trend that guides the movement of cells. It can be obtained from seismic parameters or calculated from well data. In addition, grids are created along which weights move. At the first stage, the cells through which the wells pass are initiated. They are given the values of the interpolated parameter that is assigned to the well. These cells are given an initial weight of one. Active cells, in which the parameters are initiated, transfer it to the adjacent six cells and thus activate them. At the same time, they also transmit weight parameters, the values of which are already less than one.

Moreover, the weight parameter decreases nonlinearly and its value is influenced by the trend. More weight is transferred when the trend values in the transmitting and receiving cells are close. If the difference is large, then the transferred weight is reduced. It directs the flow. Preferably, it goes where conditions are close. For example, if a structural surface is taken as a trend, then the flow is preferable to where the absolute depths of the receiving and transmitting cells are close. If a map of the gross thickness is interpolated, then it can be assumed that the depositional conditions on the flank
and in the dome of the structure were different. Therefore, the original active cells located on the flank will propagate along the flank and not move towards the structure's dome.

A cell that has passed its parameter to an adjacent cell loses its activity. But the cell to which the parameter and weight were transferred becomes active. The process continues until all the cells of the model receive their parameter and weight. Note that the initially activated well cells do not change further in the course of one calculation. This is too harsh a condition. In order to reduce this rigidity, the sample of wells is sorted by parameter value and divided into three or four parts. Further interpolation is performed separately for each part of the sample. At the same time, interpolated values are entered to the places of the missing wells, which will differ from the parameters of these wells. In this case, interpolation does not take place over the entire area of the model, but only for the first 15-20 steps, so that only the cells of adjacent wells are influenced. As a result, the adaptive model never exactly coincides with the wells, but more objectively reflects the distribution patterns of geological parameters.

![Figure 1. Base map of a gross layer thickness.](image1)

![Figure 2. Diagram of the cellular automata interpolation.](image2)
Having the base maps, it is possible to calculate the fields of parameters necessary for the hydrodynamic model: pore volume per square meter, hydraulic conductivity and density of the original oil in place per square meter. The parameter of hydraulic conductivity is normalized in the range from 0 to 1, since there is no need for its absolute value, but only for its relative value. However, the conductivity calculated from petrophysical data alone is not sufficient. Therefore, it is refined by two additional fields built according to well parameters - production wells liquid rates and injection wells liquid rates, which are more informative than petrophysical parameters. The first of them is the field of wells interaction coefficients, which are calculated from the time series data of liquid rates of the production and injection wells. Further, in a similar way, the field of the coefficients of wells interaction among the production wells are calculated.

The next step is related to the construction of the logarithm field of the maximum liquid rates of the production wells. This is done using a cascade of fuzzy-logic matrices with nine input parameters, which has already been built up to this point in the geological model. For this, a part of the liquid rate of the well related to a specific layer is taken. This proportion is calculated in the main multilayer model at the moment when all geological models of the layers are already available according to the petrophysical parameters of these layers. Having received the field of maximum liquid production rates, the field of hydraulic conductivity is modified once again and in the end it turns out to be more meaningful than if it had been calculated only from petrophysical data. Here, as it were, the geological model is tuned to history, which, when using the deterministic approach, is done only at the stage of hydrodynamic modeling. The adaptive approach immediately takes into account the liquid rates when calculating the hydraulic conductivity field.

4. General scheme and results of calculating the adaptive geological model

The adaptive geological model is calculated in five stages. The first stage prepares the data, corrects stratigraphic markers if necessary, and splits the petroleum reservoir into layers. On the second, auxiliary submodels are calculated according to the main five parameters. On the third, these models are summed up into multilayer ones, geological sections of auxiliary nodes are calculated, oil and fluid production, and injection is divided into layers and all this is distributed according to submodels. At the fourth stage, the submodels calculate the fields of wells interactions and maximum liquid rates. At the fifth stage, these fields are summed up into a multilayer model, the hydraulic conductivity field is corrected and the oil-water and gas-oil contacts are calculated, as well as the density field of the original oil in place. This completes the calculation of the adaptive geological model of any studied reservoir.

The summation of submodels in itself does not present any difficulties, but at this stage there is also the task of forming geological sections of auxiliary nodes. Although there are few layers in the adaptive geological model, this is compensated by auxiliary nodes [5-7]. They are located on a grid of 150 meters and cover the entire area of the model, while they are located no closer than 150 meters from the actual or new wells for drilling. At the third stage of the calculation, when the main parameters of the multilayer model are already obtained, geological sections of auxiliary nodes (including new wells for drilling) are calculated. For this, the sections of these nodes are divided into intervals with an average thickness of 0.4 m. The division is done separately for each layer of the model, and the number of intervals is the same for all auxiliary nodes. In essence, it resembles the division into layers of the deterministic geological model, but with a relatively large grid spacing. And at the same time, there is no general bulky thin-layered grid. Node data is stored in binary files, from where it is uploaded if necessary. Such a need arises when the geological section is drawn through the reservoir, which can be obtained in real time simply by drawing a line of this section on the map (Figure 3).

The cuts of the auxiliary nodes are calculated by the interpolation method using the cellular automata mechanism. To do this, first the same sections are created for the actual wells, and then interpolation is done. The most difficult moment here is associated with the identification of intervals of permeable and impermeable sublayers. Interpolation is done over layers of the model with a
thickness of 0.4 m. For each such sublayer, the probability that it is a permeable sublayer is calculated. Further, according to the known layer net pay thickness at the point of any auxiliary node, this thickness can be compiled from sublayers with the highest probability that this is a permeable sublayer. The sections of the auxiliary nodes are subsequently transferred to the submodels and are used to calculate the coefficients of well interactions.

Figure 3. Geological cross-section.

The adaptive geologic model grid is directly used without any upscaling for the hydrodynamic simulation. All impermeable cells are removed only from the grid of the hydrodynamic model in order to reduce the consumption of random access memory, which, as a rule, is very significant in hydrodynamic simulation.

5. Conclusion
It cannot be argued that the proposed methodology is fully developed and there is nothing to add to it. On the contrary, it is most likely just an idea of how to create the adaptive geological model. However, such idea has been implemented in a workable software package. And although, it can be further strengthened, the idea already shows that there are no complexity limits for the novel geological modeling approach, therefore it is suitable for almost any petroleum reservoir including ones with unconventional reserves, which are characterized by serious deficit of geological information not allowed using any deterministic options for their geological and hydrodynamic calculations.

6. References
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