Establishing the Formation Pressure Profile of Predrill Well Based on Adjacent Wells Data

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Abstract

The formation pressure plays a very important role in drilling engineering. So it is of great significance to predict formation pressure before drilling. In order to solve the problem, the concept of formation matrix and wellbore matrix were put forward. Also the method of epitaxial transplantation for the regional formation pressure was proposed. With the concept of wellbore pressure matrix, the target wellbore pressure matrix can be built by dealing with the adjacent wellbore pressure using the method of depth adjustment and weighted distance correction. Finally, we can obtain the formation pressure of the target well. Case study of Qinghai Oilfield was carried out to test the method. Through comparative analysis, the maximum relative error of the transplantation pressure and logging interpretation pressure is 4.2%. The result indicated that the accuracy and reliability of the method can meet the engineering requirement. This is conductive to designers to predict formation pressure which can provide the basis for the casing design and the selection of the drilling fluid density.

Key Words: Formation Pressure, Formation Matrix, Wellbore Matrix, Epitaxial Transplantation Method

1. Introduction

The formation pressure is the basic data of the exploration, development and construction. It is of great importance to predict the formation pressure accurately [1]. Currently, we normally predict the formation pressure according to the seismic or logging data [2]. The most commonly used method is Eatonlaw [3]. For a new development field, the seismic data is the only data that can be used. Pennebaker summed up a method of predicting the formation pressure based on the seismic data in 1968 [4]. Since then, many methods had been established, such as Eatonlaw [5], Dutta law [6] and Fillipponelaw [7]. The Fillippone law has been widely used because of the high accuracy and the wide applicability. Many experts improved the method of predicting the formation pressure on the basis of the Fillippone law. Martinez proposed the iterative simulation, which can predict the formation pressure more accurately [8].

Seismic data is one of the few materials which can be obtained before drilling. In most cases, there is no choice to predict the formation pressure according to the seismic data [9]. However we can get rich data of the drilled adjacent wells such as logging data and core data in the mature block. So we can use the adjacent well data to predict the target predrill well formation pressure. Then the formation pressure of any depth can be calculated by the epitaxial transplantation method [10]. In the absence of regional seismic data, this paper established the wellbore pressure matrix of the target well by using the drilled adjacent wellbore data. It includes the formation depth and formation pressure which are in the target formation.
group. It can provide important information and theoretical basis for the design of geological drilling, the casing program and the selection of the drilling fluid density. By comparing the transplantation pressure with logging interpretation pressure, we can reach the conclusion that the accuracy of this method can meet the engineering requirement. The method consists of the following steps: (1) Analyze the spatial distribution of the target formation; (2) Build the adjacent wellbore pressure matrix in this area; (3) Deal with the adjacent wellbore pressure matrix by the depth adjustment; (4) Build the target wellbore pressure matrix by using the weighted distance correction algorithm.

2. The Formation Matrix

The digital formation is a comprehensive research system which is gradually developed with the research of the 3D digital GIS [11], geological modeling [12] and 3D visualization in drilling operations [13]. The digital formation is a four-dimensional concept. For the formation of point I, it has two properties: the spatial position and geological parameters. So we can describe the feature of point I with the use of the array \((x_i, y_i, z_i, p_i)\). \(x_i, y_i, z_i\) is the spatial position of point \(i\), \(p_i\) is the geological parameter of point \(i\). In order to realize the scientific management and application of the digital formation, this paper put forward the concept of the formation matrix.

The formation matrix refers to the matrix of the spatial position of the formation and geological property parameters. Under the Cartesian coordinates, the formation matrix consists of four matrixes: \(X, Y, Z, P\), which represent the position matrix in the direction of \(x, y, z\) and the matrix of the attribute parameters. Each of them is a three-dimensional matrix and the numbers of their basis vectors are equal. When we build the formation matrix, we should firstly divide the formation by assuming the \(x\) direction being divided into \(m\) points, the \(y\) direction being divided into \(n\) points and the \(z\) direction being divided into \(k\) points. Figure 1 shows the formation matrix:

The formation pressure in the area changes greatly. It is influenced by the ups and downs and thickness of the formation group and extension trends of the fault. So when we use the data of the adjacent wells to predict the target well pressure, we need to take full account of the spatial distribution of the regional formation. Considering the above factors, this paper proposed the concept of wellbore matrix including the wellbore depth and wellbore data. The wellbore matrix is the application of the formation matrix in the direction of the well depth. The wellbore matrix is consisted of well depth and wellbore data. In case of formation pressure, the form of wellbore pressure matrix as formula 1:

\[
P_i^s = \begin{bmatrix} H_{i1}^x & p_{i1}^s \\
H_{i2}^x & p_{i2}^s \\
\vdots & \vdots \\
H_{im}^x & p_{im}^s 
\end{bmatrix}
\]

The wellbore pressure matrix includes the formation depth matrix \(H\) and the pressure matrix \(P\). The depth matrix \(H\) stands for the position matrix in the direction of well depth. The pressure matrix \(P\) indicates the corresponding formation pressure. The superscript \(x\) indicates the well number and the subscript \(i\) indicates one layer of the formation, the subscript \(m\) indicatesthe data point number in the \(i\)-th layer. The first column is the stratigraphic burial depth, and the second column is the corresponding formation pressure. \(p_{i-1}, p_i, p_{i+1}\), respectively denotes the wellbore pressure matrix of adjacent layers \((i-1), i, (i+1)\).

The target wellbore pressure matrix contains the depth of the target formation and its formation pressure, so the wellbore pressure matrix can accurately describe

![Figure 1. Formation matrix.](image)
the depth of the target formation and the formation pressure in the area.

3. Epitaxial Transplantation Method of Regional Formation Pressure

Assuming there are $N$ drilled and adjacent wells in the region, we can build the wellbore pressure matrix of the $N$ wells at the target formation according to the concept of the wellbore pressure matrix. Then by the following theoretical method and procedure the wellbore pressure matrix of the target well in the region can be established. The flow sheet of the algorithm is shown as Figure 2:

3.1 Division of the Target Well’s Stratigraphic Section

The terrain generation technology is one important research area of GIS. It mainly studies simplification, generation and display of the digital terrain model. In geology, formation is mostly given in the form of contour lines. Establishing the spatial distribution of the regional formation is the important basis for the description of the regional formation pressure.

By the comprehensive analysis of logging data, lithological data and geological information of the drilled wells, we will get the well deployment, geological stratification and graphic data. Then we can use the terrain generation technology to establish the three-dimensional spatial distribution of the regional formation. Depending on it, we can get the stratigraphic division of the adjacent and the target well in the area.

The top and bottom boundary of the $i$-th layer of the adjacent well and the target well are expressed as $F_{x} = (H_{x(i)}^{t}, H_{x(i)}^{t}) F_{o} = (H_{o(i)}^{t}, H_{o(i)}^{t})$ (Figure 3). If the formation has $M$ sections, the stratigraphic matrix of the adjacent well and the target well is as follows:

$$
F_{x} = \begin{bmatrix}
H_{x(i)}^{1} & H_{x(i)}^{2} \\
\vdots & \vdots \\
H_{x(i)}^{M} & H_{x(i)}^{M}
\end{bmatrix}, \quad F_{o} = \begin{bmatrix}
H_{o(i)}^{1} & H_{o(i)}^{2} \\
\vdots & \vdots \\
H_{o(i)}^{M} & H_{o(i)}^{M}
\end{bmatrix}
$$

We can build the stratigraphic matrix of the adjacent well according to the well report. Then the contour of the top and bottom boundary of the layers can be obtained based on the stratigraphic matrix of the adjacent well. At last, the division of geologic position of the target well can be gotten.

3.2 Calculation of the Target Wellbore Pressure Matrix

3.2.1 Depth Adjustment Method

The formation depth has a great impact on the formation pressure of the target well. However, the drilled wells and the target well have scarcely the save burial depth. It can be achieved by dealing with the adjacent wellbore pressure matrix. The $x$-th wellbore pressure matrix turns to $p_{i}^{t}$ by this method:

Figure 2. Algorithm diagram of extension and transplantation method.

Figure 3. Diagram of the regional stratigraphic spatial distribution.
3.2.2 Correction of the Weighted Distance

The distance between the adjacent wells and the target well has impact on formation pressure because the rock interior is continuous. Assuming that the coordinates of the adjacent wells is \((X_x, Y_x), x = 1, 2, \ldots, N\) and the coordinates of the target wells is \((X_0, Y_0)\). According to the inverse-weighted distance interpolation (Shepard method) [14], the \(x\)-th wellbore pressure matrix in the \(i\)-th lay of the target well is:

\[
\begin{align*}
\mathbf{d}_x &= \left( \frac{H_{0} - H_{0}^{*}(X_0 - X_0)}{H_{0} - H_{0}^{*}} \right) \\
&+ \frac{H_{0} - H_{0}^{*}}{H_{0} - H_{0}^{*}} \\
&= \left[ \begin{array}{c}
H_{0}^x \\
\vdots \\
H_{0}^{*}
\end{array} \right] \\
&+ \left[ \begin{array}{c}
1 \\
\vdots \\
1
\end{array} \right] \\
&= \left[ \begin{array}{c}
p_{1}^x \\
\vdots \\
p_{N}^x
\end{array} \right]
\end{align*}
\]

(3)

3.2.3 Building the Target Wellbore Pressure Matrix

The formation depth matrix of the adjacent wellbore pressure matrix has different distance after the depth adjustment and the correction of the weighted distance. It is because the depth and thickness of the adjacent wells and the target well are different. So the formation depth matrix of the adjacent wellbore pressure matrix needs to be converted to the target well formation depth matrix. While the column vectors of the pressure matrix should be interpolated. Finally we got the \(i\)-th lay wellbore pressure matrix of the target well:

\[
\begin{align*}
\mathbf{d}_x &= \left( \frac{H_{0} - H_{0}^{*}(X_0 - X_0)}{H_{0} - H_{0}^{*}} \right) \\
&+ \frac{H_{0} - H_{0}^{*}}{H_{0} - H_{0}^{*}} \\
&= \left[ \begin{array}{c}
H_{0}^x \\
\vdots \\
H_{0}^{*}
\end{array} \right] \\
&+ \left[ \begin{array}{c}
1 \\
\vdots \\
1
\end{array} \right] \\
&= \left[ \begin{array}{c}
p_{1}^x \\
\vdots \\
p_{N}^x
\end{array} \right]
\end{align*}
\]

(4)

4. Example

NiuDong Block has been the focal point of Qinghai oilfield in recent years. Because of the complex geological conditions, it is difficult to predict the formation pressure. The vague understanding of the formation pressure caused various drilling risks mainly including the lost circulation, kick, collapse and stick. So we regard the area of Qinghai Oilfield as the target area in this paper in order to verify the reliability of the method.

There are five vertical wells in this area. The coordinates of well location is shown in Figure 4. The top and bottom bounds of the target stratum are shown in Table 1. To verify the reliability of the method, we choose one of the five drilled wells as the target well and the restfour as the drilled adjacent wells.

Firstly, we calculated the formation pressure of the four drilled adjacent wells in the target formation based on the Eaton law by using the logging data. According to the calculation results, the wellbore pressure matrix of adjacent wells can be constructed. The left panel in Figure 5 shows the distribution of the adjacent wellbore
pressure in the target stratum. Secondly, we got the depth adjustment results of adjacent wellbore pressure based on the Equation (3). The results are shown on the right panel of Figure 5. Then the target wellbore pressure can be gotten by using the Equations (4) and (5). Finally, we got the transplantation pressure of the target well.

To verify the reliability of the method, we calculated the formation pressure of the target well based on the logging date. Then, we calculated the epitaxial transplantation pressure of the target well by using the method which was proposed in this paper. The dotted line in the Figure 6 represents the result of the transplantation pressure and the solid line stands for the result of logging interpretation pressure calculated by the Eaton law.

As is shown in Table 2, the maximum relative error of the transplantation pressure and logging interpretation pressure is 4.2%. Through the analysis, we can reach the conclusion that the accuracy of this method can meet the engineering requirement.

### 5. Conclusions

1. The concept of the formation matrix and the wellbore matrix were put forward. The matrix includes stratigraphic information and geological parameter information which can help us to grasp the distribution of the geological parameters accurately.
2. The epitaxial transplantation method was built. With

### Table 1. The bound of the target stratum

<table>
<thead>
<tr>
<th>Well</th>
<th>Top depth/m</th>
<th>Bottom depth/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>N102</td>
<td>1620</td>
<td>2160</td>
</tr>
<tr>
<td>N104</td>
<td>1600</td>
<td>2090</td>
</tr>
<tr>
<td>N1-2-10</td>
<td>1424</td>
<td>1928</td>
</tr>
<tr>
<td>N2</td>
<td>1340</td>
<td>2160</td>
</tr>
<tr>
<td>Target</td>
<td>1524</td>
<td>2050</td>
</tr>
</tbody>
</table>
the concept of wellbore pressure matrix, we can build
the target wellbore pressure matrix by dealing with
the adjacent wellbore pressure matrix by the method
of depth adjustment and weighted distance corre-
cction. The method regards the formation group as the
basic unit. So it can not only consider the impac-
tion of the adjacent wells but also reflect the spatial
characteristics of formation pressure. Results of the
case study indicated that the accuracy and reliability
of the method can meet the engineering requirement.

(3) The wellbore data, spatial location and spatial con-
tinuity of the adjacent wells are key factors for impact-
ing the calculation accuracy. For the area which has
faults or complex geological structures, utilizing the
3D seismic data to improve the calculation accuracy
of formation pressure is the research direction.

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