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3D Geological Modeling and Its Application under Complex Geological Conditions

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Abstract

3D modeling technique has become a favorable tool for people to observe and analyze the world, and has been used widely in various trades. Geological body enrich mineral resources, and the spatial shape and petrophysical distributions of geological body are controlled by geological conditions. So 3D geological modeling under the control of complex geological conditions becomes the research emphasis. This article analyzes the uncertainty, complexity and diversity of geological body, and lists complex geological conditions controlling spatial shape and petrophysical distributions of geological body. And then 3D geological modeling method under the control of complex geological conditions is proposed, and corresponding modeling workflow is set up. Finally, taking 3D geological modeling of petroleum exploration and development for example, 3D geological model of Yulou oil formation, Jin-16 block, Liaohe oil-field, is built and some applications like 3D visualization of geological body are realized.

Keywords: geological body; complex geological conditions; 3D geological modeling; modeling workflow

1. Introduction

The 3D visualization can give people an intuitive feel. The virtual reality technology can create a virtual environment. The common influence of visual sense, auditory sense and tactile sense can make users feel in virtual environment like that they are experiencing in reality. The 3D visualization technology and virtual reality technology provide a favorable tool for people to observe and analyze the

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world. The 3D modeling is the foundation of the 3D visualization technology and the virtual reality technology. In the 1970s, I.E. Sutherland at the Massachusetts Institute of Technology's Lincoln Laboratory issued a doctoral dissertation about a graphics system of man-machine communication. Since then, the 3D modeling theories and methods were continuously innovated. And 3D modeling softwares were also rapidly developed. Softwares supporting 3D modeling include AutoCAD, 3DS Marks, SolidWorks, Pro/Engineer, MDT, SketchUp, SkyLine, and so on [1]. The 3D modeling technology has been widely used in military, land and resources, urban construction, road traffic, architectural design, machine design, medical treatment and some other industries.

In 1994, Simon W Houlding from Canada proposed a method of computer assisted 3D geological modeling. This method introduced 3D modeling technology into the expression of geology research results, so the 3D geological modeling technology was widely used [2]. In traditional geological work, geological researches and results are showed by 2D maps such as well sections, geologic profiles and plans. The essence is to project geological phenomena in 3D space, such as stratum, structure and landform, onto a plane, and thus will cause the loss and distortion of spatial information [3-4]. Using technologies of 3D modeling and 3D visualizing, geological body and geological environment can be understood and expressed directly in terms of 3D space. So this technology is characterized by vividness, directness, precision, dynamic, abundance [5]. The technology of 3D geological modeling will bring great changes in the methods of geological data acquiring, storing, processing and displaying [6].

2. Geological body & geological conditions

For the different genesis and geological age, geological body has the features of uncertainty, complexity and diversity [6]. Hydrocarbon bearing geological body is located in underground 1000 to 3500 meters, so it can’t be directly observed. Analysis and research on the geological body are carried out only through outcrop data, seismic data and drilling data. For the accuracy and limitation of these data, there are many uncertain factors in understanding geological body. Stratum is often affected by faults, and multi-period faults dislocate each other. Spatial topological relations between geological bodies are extremely complex. The generation of geological body is controlled by sedimentary environment. The advents of folds and faults make geological body diverse in geometric shapes. So establishing high precision geological body model must consider the following influences of three geological conditions [7-8].

- Tectonic condition: In the forming process or after forming, geological bodies are often influenced by tectonic conditions such as faulting and folding, especially faulting which will cause geological body dislocated in 3D space. Tectonic condition must be considered in building high precision model.
- Sedimentary environment: Geological bodies have various forms and physical properties, for their forming are controlled by sedimentary environment. Building 3D model of geological body should fully take the effects of sedimentary environment into consideration.
- Anisotropy in geological body: Geological body show quite strong heterogeneity both in mineral content and physical properties such as density, porosity and permeability. During the process of building 3D model, appropriate mathematical model representing anisotropy of geological body in 3D space must be built to improve precision of the model.

3. Modeling Method

The difficulties of 3D geological body modeling technology focus on how discrete geological data can be used to accurately rebuild complex geological structures [5]. At present 3D geological modeling has gradually formed two modeling methods respectively based on facial model and volumetric model [2][9].

Modeling methods based on facial model generates surface models by selecting a 3D space interpolation to interpolate 3D sampling points. This modeling method can carry texture mapping on generated surfaces, and nicely reflect external features and 3D spatial shape of geological body, but can't reflect its internal petrophysical changes. Familiar 3D space interpolations in modeling methods based on facial model include inverse distance, minimum curvature, moving average and Kriging. Minimum curvature interpolation can effectively generate smooth surface model, and Kriging interpolation can use mathematical model to reflect changing tendency of sample data in space.

Modeling method based on volumetric model uses 3D spatial grids to describe forms of geological body. Sample data of some physical property in geological body is interpolated to assign values to 3D spatial grids, thus 3D entity model reflecting this physical property is generated. The modeling method can nicely reflect internal changes of geological body. Because built model is heaped up by 3D grids, the description of external features and spatial forms of geological body is relatively weak under the control of grid splitting precision. The modeling method can be further divided into determinable modeling and stochastic modeling. The understanding of geological body has been increasingly deepened, so there are uncertain factors existing in built determinable model. Stochastic modeling method can evaluate model's uncertainty.

4. Modeling Workflow

This paper presents one fundamental workflow to build 3D geological model. Firstly, the modeling method based on facial model, which can reflect the impact of structural factors on geological body, is used to build structural model. And under the control of structural model, 3D grids of geological body are built. Then 3D model of sedimentary facies is built to reflect the impact of sedimentary environment. On the basis of sample data and under the control of structure frameworks and sedimentary facies, variogram models of every stratum's sedimentary facies belt is established to describing anisotropy in geological body. Lastly, 3D spatial sample data is interpolated by the modeling method based on volumetric model. For the interpolating process is affected by variogram model, built petrophysical model can reflect anisotropy of geological body [10]. Basic workflow of 3D geological modeling is shown in Figure 1.

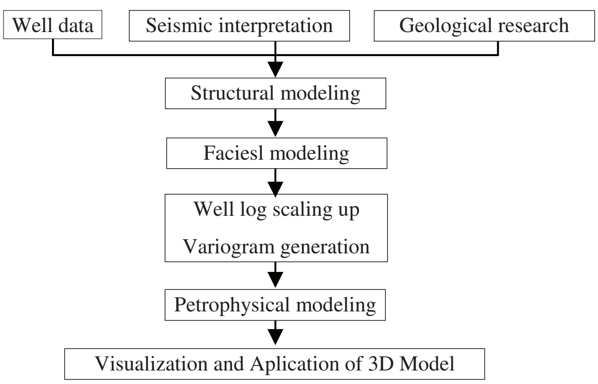

Figure1. Workflow of 3D geological modeling

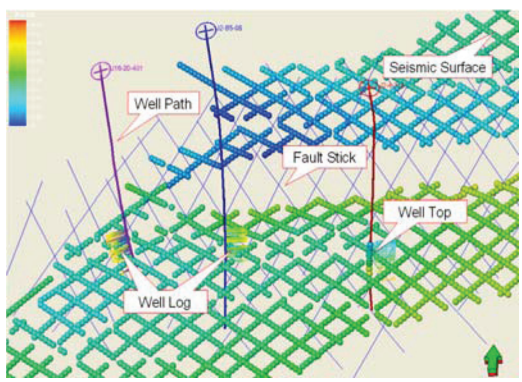

Figure2. Loading effect of basic data for modeling

5. Example

Yulou oil formation in Jin-16 block lies in Liaohe fault-depression. There are 4.5 million tones of explored reserves. This reservoir was put into production in 1992, and now already came into the middlelater period of the development. Building fine 3D geological model is of great importance for oilfield reasonable development, development well patter arrangement, reserves potential tapping.

5.1. Basic data for modeling

Collected data information in this project is shown as following. Figure 2 shows the loading effect of basic data.

- Well drilling data: These include well location, well path, oil-water contact and well log.
- Seismic interpretation data: These results include seismic surfaces and fault sticks.
- Geological research data: These results include well top, sedimentation model, planar distribution map of sedimentary facies, analysis information of petrophysical property, etc.

5.2. Structural Modeling

Modeling method based on facial model builds structural model, which includes bedding planes and fault surfaces, and generates 3D basic grids of geological body. Figure 3 shows structural modeling workflows. And Figure 4 displays Structural model of geological body

Step1. Building bedding planes

On the basis of seismic surfaces and geological layers, 3D model of four geological horizons, named Top, Y1bottom, Y2bottom and Bottom, is built by selecting Minimum Curvature interpolation.

Step2. Building fault surfaces

On the basis of fault data from seismic interpretation and fault-point data from geological analysis, 3D model of faults is built by selecting Minimum Curvature interpolation.

Step3. Generating 3D basic grids

On the basis of 3D models of bedding planes and fault surfaces, 3D grids of geological body in the target zone are built. This model can reflect 3D entity forms of geological body.

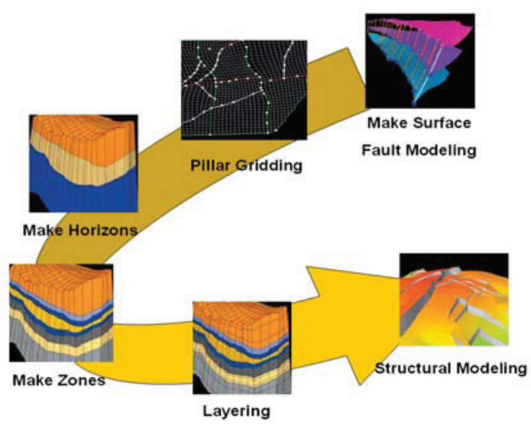

Figure 3. Structural modeling workflows

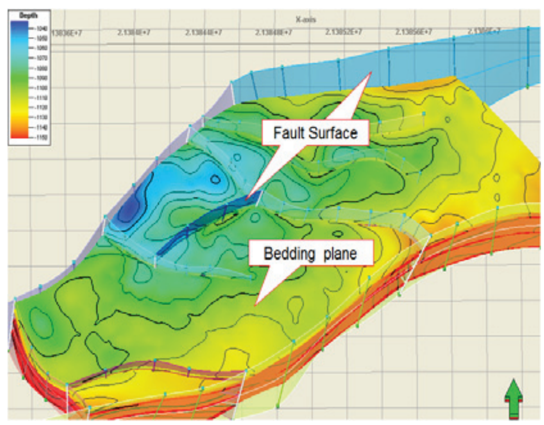

Figure 4. Structural model of geological body

5.3. Facies Modeling

Modeling method based on volumetric model is used to build facies model. Firstly, scaling up sedimentary facies data is assigned to 3D spatial grids crossed by well trajectories. Then assigned grids are converted and analyzed. Finally, sequential Indicator, one 3D spatial interpolation method, is used to build 3D model of sedimentary facies.

5.4. Petrophysical Modeling

Petrophysical modeling takes place in following three steps.

Step1. Data analysis

Scaling up logging curves are assigned 3D spatial grids crossed by well trajectories. And these grids are carried out data conversion and analysis like Output Truncation, Input Truncation, Logarithmic transformation, Scale Shift and Normal Score Transformation.

Step2. Variogram Generation

A typical variogram is a plot of variability in terms of semi-variance against separation distance. It is generated by finding pairs of data with similar separation distances and then calculating the degree of dissimilarity between these pairs. Figure 5 is a diagram of typical variogram. Aiming at assigned 3D-grid sample points, variogram model is built to reflect anisotropy of sample data by geostatistics method. Variogram model is used to restrain interpolating of 3D spatial interpolation. The concrete procedure is to build variogram model in X, Y and Z direction aiming at built every sedimentary facies belt of every formation, which is on the basis of structural frame model and sedimentary facies model.

Step3. Petrophysical 3D modeling

Petrophysical 3D model is built by the modeling method based on volumetric model. On the basis of data analysis and variogram modeling, the 3D spatial interpolation of Sequential Gaussian Simulation is selected to generate 3D model of geological body to display the distribution of physical properties such as porosity, permeability, oil saturation, etc.

5.5. Applications of Model

After building the 3D model of geological body, we can realize the applications of 3D visualization like well drilling trajectories, geological sections and fence diagrams, and process oil-gas development aided decision-making like well design. The applications of 3D visualizations are shown in Figure 6.

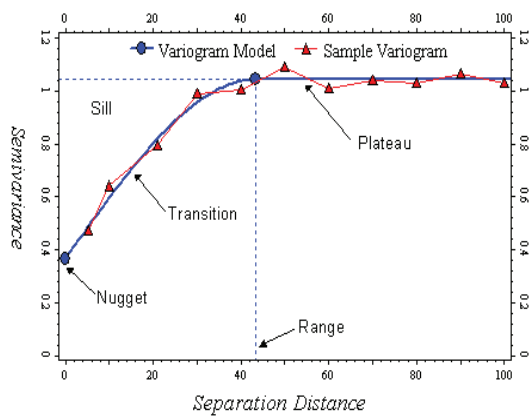

Figure 5. Diagram of variogram

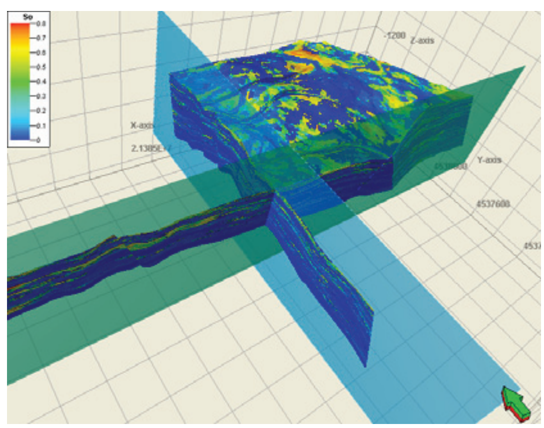

Figure 6. Visualization of geological Section

6. Conclusion

Hydrocarbon bearing geological body is the main study object of petroleum exploration and development. Building high-precision 3D geological model can offer basic information platform for oil-gas exploration and development and realize 3D visualization of geological body, so it is very important to improve work efficiency and reduce risk of oil-gas exploration and development. On the basis of 3D geological modeling method studying, this article built 3D geological model of Yulou oil formation, Jin-16 block, Liaohe oil-field, which includes 3D models of geological frame, sedimentary facies and Petrophysical distribution. With the continuous development of 3D geological modeling technology, 3D geological modeling certainly will become one of core works of petroleum exploration and development, and supply strong guarantee for the scientific and reasonable development of oil and gas.

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