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Sands modeling constrained by high-resolution seismic data

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Abstract: In the phase of field evaluation, the changing of interwell reservoir may be out of control if the geological model was built only on well data due to few existing wells. The uncertainty of the interwell reservoir interpolation based only on well data can be decreased by comprehensive utilization of geological, logging and seismic data, especially by using highly relative seismic properties from 3D seismic data adjusted by well point data to restrict interpolation of geological properties. A 3D-geological model which takes the sand body as the direct modeling object was built through stacking the structure, reservoir and water/oil/gas properties together in 3D space.

Key words: Reservoir geological modeling, Seismic inversion, Sand control modeling
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INTRODUCTION

The geological modeling technology has been widely applied in both domestic and overseas oil fields. However, for those fields with low degree of well control, the effects of its application are quite different (Waryan *et al*., 2001). In order to make the reservoir model more scientific and reasonable under the condition of few wells, how to increase the exactitude and decrease the uncertainty of these models has become the focus of the study for reservoir description and modeling nowadays (Yu, 2002). The geological modeling in this paper was developed to solve the problem mentioned above. The Oilfield W in the Bohai Bay Basin features its large area, low degree of well control, many types of reservoir, strong heterogeneity and high complexity of the relation between water and oil. For this kind of field, plenty of data are available, which include well logging, core data, test data, and high quality seismic data. Through the single well sedimentary facies analysis dependent on the high accuracy of the 3D-seismic data, good results of modeling were obtained based on the relationship between well and seismic data.

GENERAL IDEA ABOUT THE SAND CONTROL GEOLOGICAL MODELING

The deterministic result for the unknown area between wells is given by the deterministic geological modeling method, that is to say, beginning with the control point of the deterministic data (for example, well data), we can figure out the exact, unique and true reservoir parameters between wells (Yu, 2002). The conventional methods of construction graph such as interpolation, Kriging and geomathematics are deterministic modeling.

The main frequency of 3D seismic data acquired in Oilfield W has reached to 50~60 Hz. The distribution feature of the single sand body has been clearly exhibited by the 3D seismic data through the seismic inversion. So analyzing the seismic properties becomes the main work of modeling. The properties, which are suitable for this field and can truly reflect the changes of the underground rock from the multi-attribute analysis, are selected for the 3D seismic inversion. Based on the precise calibration, the correlation between well and seismic data is realized by using corresponding electrofacies.

Oilfield W is a structure-lithologic reservoir mainly controlled by the single sand object and subsidiarily by the structure. The key points of the reservoir study are the distribution of the single sand body and its 3D shape.

BUILDING 3D GEOLOGICAL MODEL

Basic data

The border of the study region from east to west is limited to the 3D seismic field, and from south to north is limited to the fault. The region of interest was totally loaded with twenty-three drilled wells within this field and its neighbor field. The region of interest was also loaded with log curves and the results of log interpretation including four curves of log interpretation such as shale content, porosity, permeability and water saturation, and also including four electric log such as self-potential, electric resistivity, combination gamma and well diameter, which offer the data to study the reservoir and stratigraphic correlation. The seismic data include the structural interpretation of the 3D seismic data, conventional 3D seismic data, shale content inverting data object and pre-stack Poisson inverting data object compose (Contreras *et al.*, 2005; Varela *et al.*, 2006)

Building the structural model

The structural model is based on the model of fault system which is expressed by the description of the single fault plane and the arrangement relationship among the faults. Bohai Bay basin is a depositional Basin with complex structure and well-developed faults. The fault plays an important role in the formation extension and the reservoir distribution. So, to ascertain the fault model is very crucial for the 3D geological model to exactly express the reservoir.

The basic fault model can be built according to the seismic interpretation result. The faults were built one by one and adjusted with the 3D seismic data, which worked as the foundation of the quality control. The extension of the 3D fault model and the whole 3D fault planes are more reasonable not only in a certain stratigraphic formation, but also in the 3D space (Figs.1 and 2).

Building shale content model—sand body model

For fluvial sand reservoirs, sand body is a storage place of oil and gas. Shale content, which can reflect the partition of the sand body and affect the change of the reservoir physical property, is an important parameter (Wu and Cao, 2006). Therefore, it is the first step to build a shale content model. Based on the pattern of well log analysis for shale content, the seismic shale content inversion is the analysis object. It aims to improve the accuracy of shale content estimation through adjusting the inversion parameter and analyzing drilling composite recording property. By combination of well logging and seismic data, we can identify the division criterion of the sand reservoir in the shale content model, and then identify the sand body model (Zhang *et al.*, 2006; Christensen *et al.*, 2006). In the shale content model (Fig.3), because we have adjusted the distribution of shale content through well log data, the river channel extends further to the north so that the runway shape can be adjusted effectively. The result illustrates that the 3D geological modeling can effectively combine seismic data and well log data so as to describe the sedarenite more accurately.

The main purpose of classifying and identifying the single sand body is to distinguish sediment units which have accumulation ability from those which do not have oil, so we can conveniently go in to reservoir research. The classified single sand body should essentially accord with the sandstone which is analyzed by well logging and with the extension of the deposition environment, and the continuance between the sand bodies should accord with reservoir relations which is disclosed with drilling (Stright, 2006).

Through research, it is the most reasonable that we use shale content as the classifying foundation and standard between accumulation sand body and non-accumulation ones. However, there are more packed beds in the lower member of the E_{s1} which do not possess accumulating ability but possess lower shale content. In the further research of reservoir distribution, we divide the low members of the E_{s1}

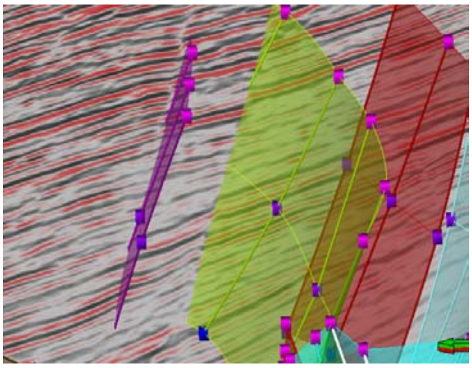


Fig.1 The correlation chart of 3D domain model and seismic cross section

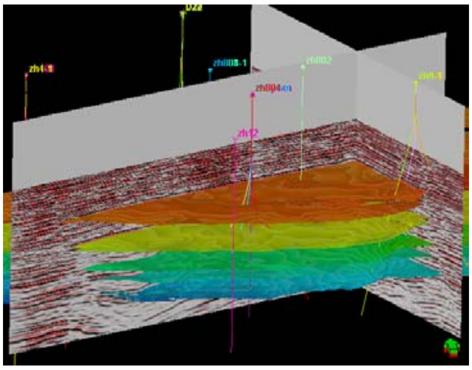
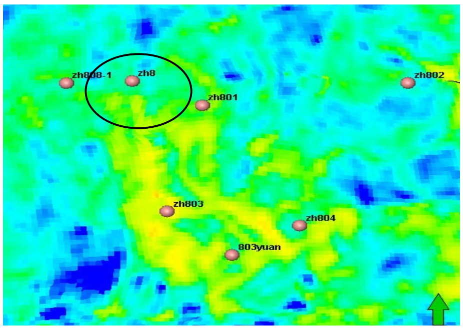
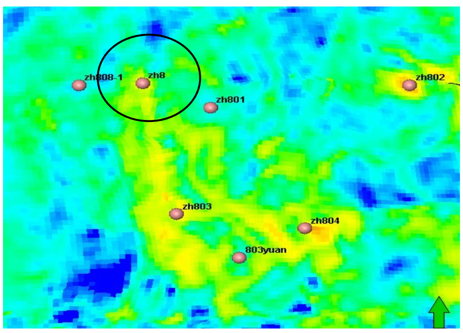


Fig.2 The correlation chart of time fault structure model and seismic cross section



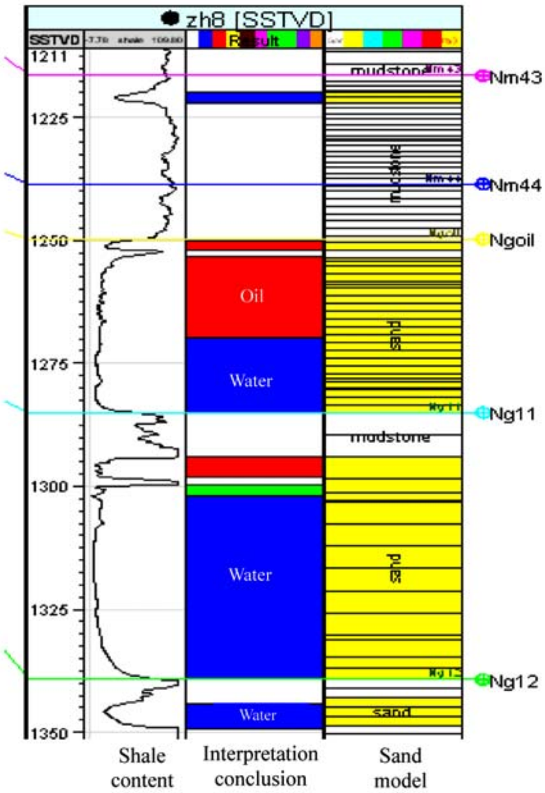
(a)



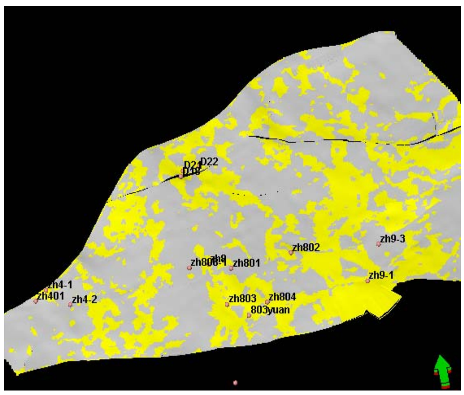
(b)

Fig.3 The correlation of NmIII2. (a) Seismic shale content inversion section; (b) Shale content model bedding section

with porosity. Meanwhile, we divided the sand body with shale content and got 3D sand model (King *et al*., 2006; Jiang *et al*., 2005). The analysis of the classified sand body model showed that the sand body which was divided according to this criterion confirmed with the reservoir which was interpreted with well logging (Fig.4).



(a)



(b)

Fig.4 Examining chart of the sand body classifying outcome. (a) The correlation of W8 well log interpretation and sand body model across well trace; (b) 3D display of NmIII2 sand body model bedding section

Oil sandstone model

We have done the trace interpretation of the oil sandstone according to the reservoir rule research, which was based on the sandstone model (Wu and Cao, 2006). On one hand, we need to distinguish oil sandstones from non-oil sandstones; on the other hand, we need to accurately identify the shape and the distribution of the oil sandstone. The technical methods and the standards of the tracing interpretation of the single oil sandstone with sandstone model are as follows:

(1) Just traced the oil sandstone which was met by drilling;

(2) Only traced the sandstone which completely communicated with the drilled reservoir, and did not consider the sandstone which was not connected;

(3) Be sure that the density of the traced sandstones would coincide with drilling data;

(4) The chased sandstone distribution and the connecting relation should accord with the reservoir feature disclosed with drilling;

(5) For the oil sandstone with the unanimous relation of the oil and water, we must distinguish the area and the border of each sand body.

Comparing the sandstone bodies which were traced in the geological model with the seismic attribute data (Fig.5), we found that they had good similarity of the total distribution tendency, especially with the pre-stack Poisson ratio inversion result. It is illustrated that the sandstone shape which is reflected by the geological modeling is more reliable. Also, we can get the differences between the geological model and the seismic property in details, which show that the sandstone shape in the geological modeling is more accurate after adjusted with drilling data.

The oil sand body distribution was determined from the depth of the oil-water interface by geological synthesis research after tracing the oil single sandstone (Fig.6) (Wu and Cao, 2006). The reservoir of the Oilfield W can be classified to three forms: (1) Some small sandstone bodies without borders of oil and water can be identified as be full of oil. (2) Though the sandstone communicates, the depths of the oil-water interface at different locations in the same sandstone are different because of the affection of lithologic and physical property. (3) For the majority of oil-bearing series, each sandstone body has united oil-water interface, and different single sandstone body has different oil-water interfaces.

Rock physical model

The building of the property model is based on the sandstone model. Its aim is to indicate the space change rule of reservoir characteristic parameters and to identify the geological features which affect the reservoir feature heavily (Wu and Cao, 2006; Fu, 2000). Based on the shale content model and the sand stone model, we can research reservoirs' parameters, for example, porosity, permeability and oil saturation with log information and build the rock physical model.

According to the electric log interpretation, permeability has intimate relations with porosity (Bracco Gartner *et al*., 2005; Qiu, 1991). The calculation of the permeability model adopted the Kriging method, and we used porosity model to restrict permeability model so that the two physical properties can maintain a similar distribution feature (Fig.7).

CONCLUSION

For instance as the Oilfield W geological model, it is proposed that, in the new field with high quality seismic data, we should well take the advantage of seismic data's high resolution, intuition, closely sampling rate and so on, to forecast the sandstone through intercalibration of seismic attribution, post stack inversion and pre-stack inversion, which can provide the definite object for the reservoir geological model.

In the process of the reservoir modeling, we use the seismic inversion data to demarcate the single well facies and analyze the seismic facies, which decline the uncertainty of the interwell forecast.

By using seismic information and high quality seismic property to describe sandstone, we directly build the 3D model of sand reservoir and avoid the uncertainty of the interwell interpolations, which is also an innovation of this paper and accords with the oilfield geological situation after the drilling verification.

The certainty model was built upon the unique results obtained from different raw data and information which geologists synthesized and searched, but it is one probability that confirms with present database and the geologists' knowledge level (Lv, 2001).

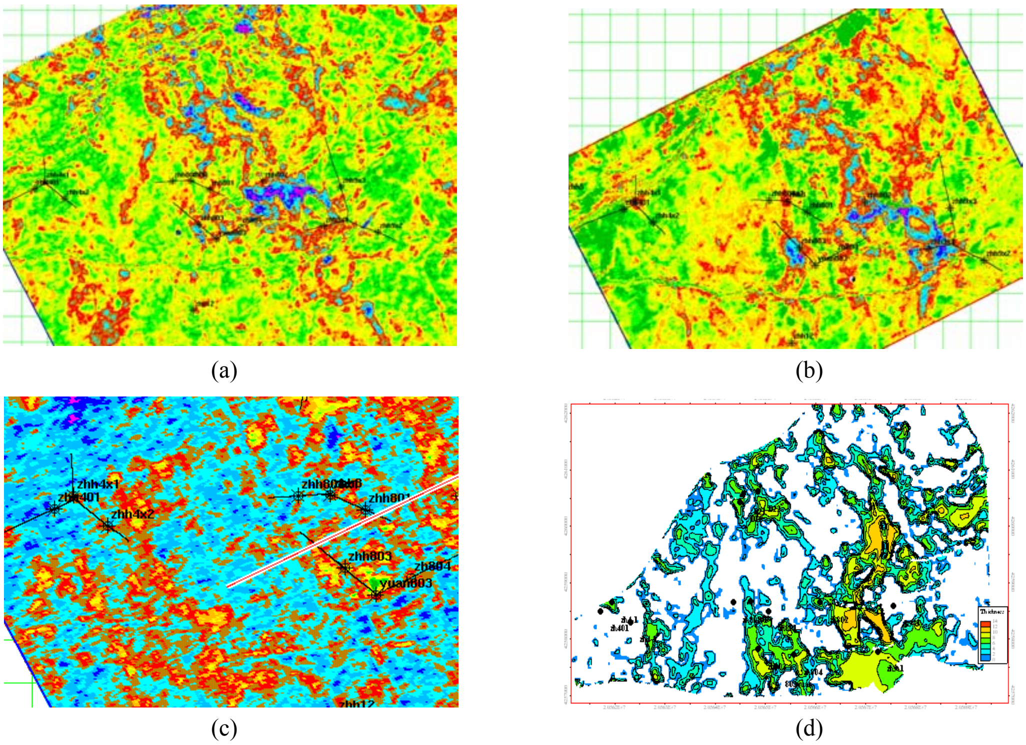


Fig.5 The correlation of geological model sand body NmIII2 isopach and seismic property parameter (NmIII2 is horizon name). (a) The mean-square-root amplitude; (b) Average shale content by seismic inversion; (c) Seismic pre-stack average Poisson ratio; (d) Geological model isopach chart of sand body

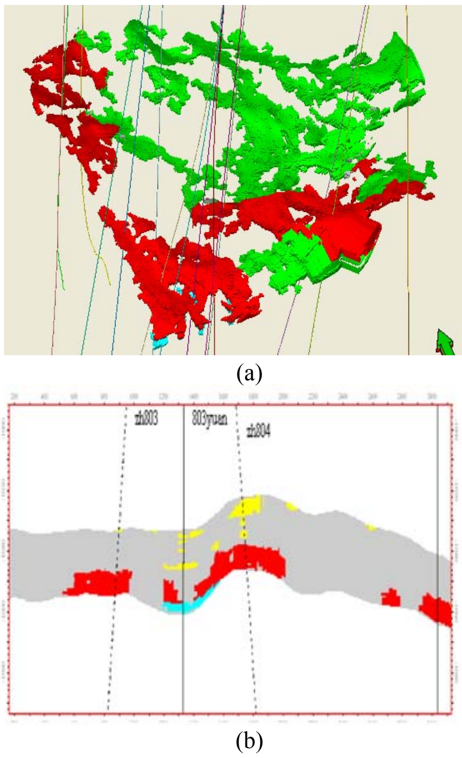


Fig.6 NmIII2 small oil layer interpretation fruit chart. (a) 3D display of oil layer distribution; (b) Oil layer distribution across well cross section

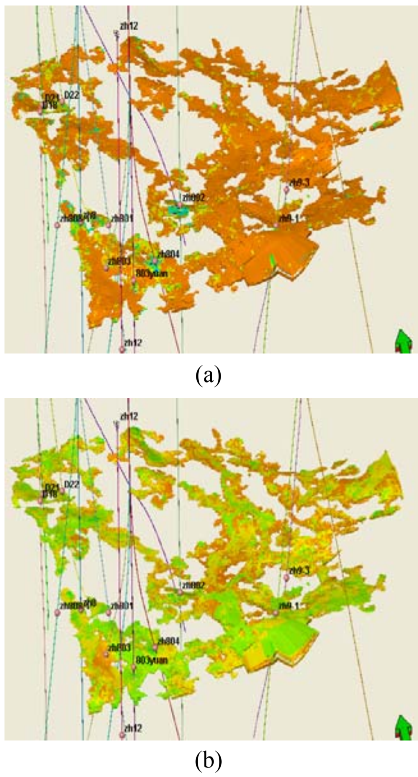


Fig.7 3D display of NmIII2 porosity model (a) and permeability model (b)

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