Seismic Reservoir Characterization of the Low Porosity and Permeability Reservoir
– A Case Study outside Daqing Oilfield, China

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Abstract
Seismic reservoir characterization is applied at a low porosity and permeability sandstone oil field, which has over 20 years of development and production history, located at the outside of Daqing Oilfield, China. This field was discovered in 1980s, developed and produced in 1993 by using an inverted nine spot method with 300 by 300m well network. The hydrocarbon reservoir is characterized to the fine-grained sandstone and silty sandstone which the porosity and permeability are 16.9% and 10.5mD, respectively. The reservoir thickness along wellbole is 0.5 – 15 m which the 90% of reservoir thickness is less than 5 meter in this field. There are very complicated distribution of the sand bodies and high heterogeneity of the reservoir in the field. Currently, the key challenge in this field is to find the residual and/or potential oil zones, so that it is necessary to carry out the fine reservoir characterization. This paper presents a case study of fine reservoir characterization in a low porosity and permeability sandstone reservoir by using geostatistical inversion outside of the Daqing oilfield. By using seismic reservoir characterization of geostatistical inversion with well constraint, the characterization result of the low porosity and permeability reservoir in the study area has been proved to be more reliable, and the spatial heterogeneity of the sand and/or reservoir is better described.

Key words
Reservoir Characterization; Case Study; Low Porosity and Permeability; Thin-Bedded Sandstone; Log Analysis; Seismic

Introduction
The case study is in a low porosity and permeability sandstone oil field, located outside Daqing Oilfield, China. The study area is a 40 km² block where located at a fault-block structure which is north-south direction. In the study block the high parts if structure is located at the northwest, and structure difference is 25-100m, and lot of faults was developed. The hydrocarbon reservoir is in the Q4 formation, Cretaceous, which is from a river delta depositional environment. The buried depth of the formation is between 700 and 1200m, and the thickness is approximate 250m. The block was developed and produced in 1993 by using an inverted nine spot method with 300 by 300m well network. The hydrocarbon reservoir is characterized to the fine-grained sandstone and silty sandstone which the porosity and permeability are 16.9% and 10.5mD, respectively. The reservoir thickness along wellbole is 0.5 – 15 m which the 90% of reservoir thickness is less than 5 meter in this field. The production practice indicate that the sand spatial distribution is very complicated, high heterogeneity of the reservoirs exist in this field. Figure 1 shows the correlation of the formation units and sand reservoir (yellow) distribution among 4 wells. In the figures the yellow area represents the reservoir penetrated by the wells, the color lines represent the boundary of the formation units, and blue number is the distance between wells. Under these conditions, it is impossible to effectively characterize such reservoir by using deterministic inversion of 3D post-stack seismic data due to the vertical resolution of the seismic data, and the lateral distribution of the reservoirs...
also can not be described effectively by the well data within such dense well network.

Many studies (Torres-Verdin et al., 1999, Grijalba-Guenca et al., 2000, Peter McCarthy et al., 2006 and Jason McCrank et al., 2009) have shown the geostatistical inversion can be used to increase the vertical resolution of reservoir characterization from 3D seismic data, especially in the vicinity of existing wells. A geostatistical inversion of 3D post-stack seismic data with well constraints is used to characterize the reservoir which is low porosity and permeability, thinly-bedded and highly heterogeneous in this study area.

The area for reservoir characterization is approximate 40 kilometers in this case study. There are 343 existing wells (305 vertical wells and 38 deviation wells) spaced approximately 300m and 300m apart. The 3D seismic data was acquired in 2003, with a time sampling interval of 1ms. The central frequency of the seismic data is approximately 40 Hz, with the range of 10 Hz to 70 Hz. This frequency bandwidth is an important constraint on the thickness of the reservoir that can be resolved in this study. The preliminary estimate indicates this post-stack seismic data can not resolve sand bodies thinner than 8m in the Q4 formation studied (depth between 700 and 1200m).

Log Analysis and Rock Physics

The log analysis and rock physics in the wells were used to establish the interpretation framework of seismic inversion, and to carry out the uncertainty analysis for the reservoir characterization. Well logs were measured by the conventional wireline logging tool. The log data available include Spontaneous Potential (SP), Gamma Ray (GR), P-sonic, Resistivity logs, and the Density log is only available in 57 of the 343 wells. Log analysis and rock physics play a very key role in seismic reservoir characterization in such low porosity and permeability as well as the thinly-bedded sandstone formation. In this study, log analysis and rock physics are carried out in each of the 343 wells. The works done include the follows,

1. Log data conditioning and quality control (QC);
2. Determination of shale content (Vcl) and porosity;
3. Density log synthetic in the wells where the density is not measured;
4. Determination of acoustic impedance log and vertical reservoir profile.
5. Lithology interpretation
6. Relationship between lithology and elastic log
7. Uncertainty analysis of the lithology identification from elastic logs

Log analysis and rock physics in the 343 wells indicate that the sandstone shows the higher acoustic impedance and shale shows the lower impedance in the study formation, and reservoir (sand) and non-reservoir (shale) can be distinguished by using an impedance cutoff for a certain formation unit. The impedance and GR crossplot in the figure 2 shows the relationship between the lithology and impedance log in a well. It clearly shows that sand and shale can be identified by the impedance log in study formation. As the structure difference of the formation in study block, the impedance cutoff used to identify the lithology is different for the different formation units. Figure

FIGURE 1. CROSS CORRELATION OF THE FORMATION UNITS AND SAND RESERVOIR (YELLOW) DISTRIBUTION AMONG 4 WELLS.
3 presents the impedance distribution and cutoff for sandstone and shale in the four formation units. The uncertainty of charactering reservoir with impedance is analyzed based on the well data. Figure 4 is one example of the impedance and porosity crossplot colored by shale content in one well. It is found that some high porosity sand (upper yellow triangle in figure 4) and some hard shale (lower green triangle in figure 4) will be incorrectly characterized by the impedance in the study formation.

![Figure 2. The impedance and GR crossplot colored by shale content in a well.](image1.png)

![Figure 3. Acoustic impedance characteristics between sand (brown) and shale in the different formation units.](image2.png)

![Figure 4. The impedance (x axis) and porosity (y axis) crossplot colored by shale content.](image3.png)

![Figure 5. The presentation of the conditioned log data and petrophysical results in a well.](image4.png)

Based on the petrophysical analysis the vertical reservoir distribution was identified in the vicinity of the existing 343 wells. Figure 3 shows an example of the conditioned log data, petrophysical analysis results and characterized reservoirs in a well. In Figure 5, the petrophysical analyses show (from left to right) gamma-ray, deeper and shallow resistivity, density (red) and sonic (blue), shale content (Vcl) and porosity, log resolution P-impedance (black) and seismic resolution P-impedance (red), and lithology profile.

The reservoirs in vicinity of the drilled borehole is finely characterized by using log analysis based on the well data available, and vertical lithology (sand/shale) profile as well as quality acoustic impedance curve can be obtained in each of the 343 wells. Based on the rock physics analysis in the 343 wells, the relationship between the lithology (sand and shale) and the acoustic impedance is determined in the study area. This provides a basic framework for following reservoir characterization from seismic inversion.
Seismic Reservoir Characterization

The integration, analysis and understanding of all available data (geology, well log and seismic data) are an exceptional way to characterize a reservoir. By using the geostatistical inversion with the well constraint, the seismic reservoir characterization has improved tremendously and has resulted in a more reliable result in a lower porosity and permeability reservoir. In the study block, the seismic reservoir characterization is carried out by the following technical methods, and each of them plays a very critical roles.

1. Quality control of seismic data
2. Fault and horizon interpretation integrating well and seismic data
3. Well seismic tie and wavelet estimate
4. Construction of the low frequency and/or formation frame model
5. Geostatistical inversion of seismic
6. Quality control (QC) of the seismic inversion
7. Reservoir characterization and quality control (QC)

The geostatistical inversion is based on statistically integrating core data, well logs, and geological constraints with the seismic data (Peter McCarthy et al., 2006). It provides a flexible and efficient formulation to populate the inter-well space with petrophysical parameters statistically linked to acoustic impedance (Grijalba-Cuenca et al., 2000). Geostatistical inversion provides a quantitative methodology to integrate the high resolution of well logs with wide and dense coverage of post-stack three-dimensional seismic data (Torres-Verdin et al., 2006). In this case study of a low porosity and permeability as well as the thinly-bedded sandstone reservoir, the reservoir characterization was improved by constraining geostatistical inversion of seismic data with the high vertical resolution acoustic impedance data from the well logs. The overall workflow of geostatistical inversion and reservoir characterization is illustrated in Figure 6. In the workflow, some wells, as the control wells, are successively selected to be the well constraints in the geostatistical inversion of the seismic data, and other wells are used to be test wells to verify the inverted results in the vicinity of the wells.

In this workflow, the low frequency and/or formation frame model based on the fault and horizon interpretation is a critical geological constraint for the seismic reservoir characterization. In this case study, the fault and horizon interpretation are effectively carried out by integrating the well and seismic data and using coherence cube techniques. Figure 7 presents the faults, horizons and formation frame model in the study block.

The practices of the geostatistical inversion and reservoir characterization in the study area show the increasing control well can increase the resolution of inverted elastic parameters (acoustic impedance), furthermore improve the reservoir characterization in the thinly-bedded formation. Figure 8 gives the comparison of the inversion results by using the 117, 179 and 240 control wells in this study. In the 40 km² area of this study, the thinly-bedded sandstone reservoir is finely characterized by using geostatistical inversion with 240 control well constraints.
Quality control of the seismic inversion was done by extracting the impedance logs and comparing them with the measured impedance log in the borehole. Figure 9 shows the comparison of the inverted and measured impedance log in six wells. The characterization results in the some test wells, which are not integrated in the inversion workflow, are used to carry out the quality control for the reservoir characterization. Figure 10 presents the QC results in the four wells.
Figure 11 shows an example of reservoir characterization for the thinly-bedded sandstone formation. This example shows the sand reservoir with a 1.0 meter thickness can be characterized by using geostatistical inversion with the 240 well constraints in the study area.

The hydrocarbon reservoirs in the 4 formation units of the Q4 formation are finely characterized in a block of 40km² located at the outside of the Daqing oilfield, China. Figure 12 shows the reservoir distribution along an inline and a crossline direction in the study area. Figure 13 presents the accumulative thickness distribution of the reservoir characterized of two formation units in the study area. This reservoir characterization has been proved to be more reliable and it is better to describe the reservoir distribution laterally. The relationship between injection and production in each of formation units is clearer and residual oil distribution can be effectively predicted based on results of this seismic reservoir characterization.

Conclusions

Geostatistical inversion constrained by well data and local geological model provides an approach to increase the vertical resolution of the inverted acoustic impedance. In the field which is produced by a dense well network, increasing a certain number of the constrained wells in a geostatistical inversion process can improve reservoir characterization in this low porosity and permeability reservoir. Log analysis and rock physics from well data in the existing wells play a key role in the workflow of the geostatistical inversion and reservoir characterization.

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References

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