The technology of effective reservoir prediction in fault development zone

Zhenhai Jiang
Daqing Oil Field Co No.3 Production Plant, Daqing, Heilongjiang, 163113, China
913111@sina.com

Abstract. Reservoir prediction in the middle and late stages of development is not only to predict the sandstone, but also to define the specific location of Petroleum-bearing sandstone. The post-stack seismic data is superimposed on a multi-channel seismic data level, although the signal-to-noise ratio is improved to a certain extent, the average amplitude value is obtained in the superposition process, so that only the effective prediction of the sand body can be realized. However, the pre-stack seismic data can obtain the information of shear wave by the longitudinal wave. The characteristics of the shear wave that cannot propagate in the fluid can effectively predict the reservoir and fluid distribution. In order to further quantify the remaining oil potential in fault area, prestack seismic inversion technology and petrophysical analysis are used to determine the favorable oil-bearing area. On this basis, prestack geostatistical inversion is completed to further clarify sand body with high oil saturation. Combined with numerical simulation, it effectively predicts the residual oil distribution at the edge of fault and the precision of the remaining oil quantitative characterization results is high. The recognition rate of thick layer saturation is more than 90%, and the recognition rate of thin interlayer saturation is more than 70%, which can meet the demand of fine reservoir prediction.

1. Introduction
With the requirement of oil and gas development and remaining oil tapping near fault, there is an urgent need to strengthen the application research of pre-stack seismic data and information. The practice of, reservoir prediction and development shows that the pre-stack AVO/AVA inversion based on pre-stack CRP gathers can improve the accuracy of reservoir prediction and reservoir identification[1], and then improve the accuracy of remaining oil prediction, which can determine the key areas of remaining oil potential tapping.

2. Pre-stack inversion of multiple elastic parameters

2.1. Shear wave prediction
In the pre-stack seismic inversion, the S-wave information is required. Nevertheless, the seismic data of the original work area only acquires the high-resolution longitudinal wave data, and the s-wave is not collected. In the past year, the research area has measured six multi-level sub-array acoustic XMAC logging data, including the measured information of S and P waves. Using this data, choosing Greenberg-Castagana method to predict the shear wave velocity which based on the empirical relationship of saturated rocks that using P-wave velocity, lithology, porosity and pore fluid data. The relative error between measured shear wave and predicted value is less than 3.2%, which meets the requirement of prestack inversion for shear wave prediction[2].
2.2. prestack simultaneous inversion
The pre-stack simultaneous inversion includes four steps: horizon calibration interpretation, establishing low frequency model, offset wavelet extraction and pre-stack simultaneous inversion[3]. The parameters are set to complete the pre-stack simultaneous inversion work. The forward results from different angles show that the inversion parameters are reasonable, the inversion effect is good and the reliability is high. The elastic parameters such as P-wave impedance, S-wave impedance, P-wave velocity ratio and density can be obtained by prestack inversion at the same time, which can describe reservoir fluid characteristics more accurately.

3. Establishment of multi-parameter intersection rock physical model

3.1. The analysis of fluid displacement
Rock is a complex two-phase medium composed of rock skeleton and pore fluid. The change of seismic response of rock is not only the change of lithology and structure, but also the change of fluid properties. In order to determine the sensitive parameters of oil-bearing reservoir in the work area, the original reservoir section is analyzed for fluid displacement under water-saturated and oil-saturated conditions, and fluid replacement was performed by Gassmann's (1951) equation. The results of fluid replacement show that the velocity of P-wave, density, VP/VS, Poisson's ratio and P-wave impedance is decreased, while the S-wave impedance keeps unchanged from water-saturated to oil-saturated reservoir fluids.

3.2. Reservoir Sensitive Parameters Analysis
The sensitive elastic parameter analysis process includes three steps: reservoir sensitive parameter analysis, single sensitivity elastic parameter optimization, and elastic parameter optimization.

Reservoir sensitive parameter analysis: Firstly, the characteristics of reservoir log in target interval can be determined. It can be judged that gamma curve and deep lateral curve can distinguish reservoirs well, density curve can distinguish reservoirs better, but single P-wave impedance curve can distinguish reservoirs poorly. The gamma curve is selected as one of the coordinate axes in the sensitive parameter test template.

The optimum selection of single sensitive elastic parameters: rock elastic parameters mainly include P-S wave velocity, rock density, Poisson's ratio, elastic modulus, Lame's coefficient and so on. Making templates with various parameters and gamma curve, oil saturation of well sample points is taken as distinguishing attribute. By comparison, the intersection of P-S wave velocity ratio and gamma curve, P-S wave velocity ratio is less than 1.95, which can distinguish most oil-bearing reservoirs, but also some low oil-bearing reservoirs are classified.

The optimum selection of double sensitive elastic parameters: single parameter division often can not precisely divide the oil and gas area. Through the sensitivity of reservoir fluid to different elastic parameters and considering the feasibility of practical operation, the intersection analysis results of longitudinal and transverse wave velocity ratio and P-wave impedance are selected to divide the oil region.

3.3. Establishment of Rock Physical Plate
Based on the analysis of the relationship between the elastic parameters of the well point and the oil and physical properties, a rock physical model based on P-wave impedance and P-S wave velocity ratio is optimized and established, which provides a standard for quantitative interpretation of pre-stack inversion results.

The template indicates the relationship between reservoir elastic parameters and physical properties and oil-bearing parameters (Figure. 1). The selected oil saturation is more than 49.6% and porosity more than 20%. The pre-stack simultaneous inversion results are quantitatively interpreted to determine the remaining oil saturation distribution in fault areas.
4. Fine Recognition of Potential Sand Bodies by Geostatistics Inversion

4.1. Pre-stack Geostatistical Inversion

Because prestack simultaneous inversion is still a deterministic attribute inversion method, based on the elastic parameters obtained by this method, the vertical resolution is equivalent to seismic vertical resolution, which can only reach 7-10m, so it is difficult to characterize thin reservoir fluids[4]. On the basis of prestack simultaneous inversion and ensuring the consistency of elastic parameters and spatial distribution, prestack geostatistical inversion with well point participation is needed to achieve fine characterization of thin reservoir fluids.

Finally, the inversion results of geostatistics are obtained, and the vertical resolution is 2-3m, which realizes the fine characterization of interwell sand distribution. Combining the correlation analysis results of density with sandstone content and water saturation, the location of high oil saturation sand body is further clarified.

4.2. Prestack-Digital-Analog Integration

In order to push the saturation parameters obtained by prestack inversion from seismic acquisition time to the present state, the prestack inversion-numerical simulation integrated research technology is applied to analyze the discrete data of single well prestack saturation under the constraints of the prestack inversion saturation field of sedimentary units, and a three-dimensional saturation model is established to realize seamless transformation from inversion data volume to numerical simulation data volume, which improves the model. Accuracy, and greatly shorten the time span, reduce the error caused by the long time of digital and analog history fitting[5].

4.3. Accuracy Verification of Quantitative Characterization of 4.3 Remaining Oil

According to the measured saturation data of B2-322-JP43 in the work area, the measured oil value of coring samples up to 50% is selected as the criterion to classify effective reservoirs that compared with the effective reservoirs classified by prestack inversion on the right side, in which the white area is based on rock physical plate. Through comparison, the recognition rate of thick layer saturation is
over 90% and the recognition rate of thin interbed saturation is over 70%, which can meet the needs of reservoir anatomy.

According to the remaining oil enrichment rule of structure and reservoir control near the foregoing faults, the analysis result of imperfect injection-production area of well pattern, the favorable area of fault edge in the study area is reconfirmed by combining well seismic with reservoir characterization and pre-stack inversion prediction results, and the potential of fault edge in the study area is investigated. A total of 21 directional wells with large deviation are deployed.

5. Conclusion
Pre-stack simultaneous inversion can obtain elastic parameters such as P-wave impedance, S-wave impedance, P-wave velocity ratio and density. Compared with post-stack inversion, only P-wave impedance elastic parameters can be obtained, which can describe reservoir fluid characteristics more accurately, but its longitudinal resolution is comparable to seismic longitudinal resolution, so that it is difficult to characterize thin reservoir fluid.

Geostatistical inversion effectively integrates high-frequency logging information, greatly improves the vertical identification ability, respects actual drilling data at well points, and reflects reservoir sedimentary characteristics more objectively and truly.

According to the analysis results of remaining oil, the inversion prediction accuracy is high, and the favorable areas at the edge of faults in the study area are effectively reconfirmed, and 21 directional wells with high deviation are deployed.

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