Introduction and Application of the Key Technology of Subsalt Reservoir Prediction in Jingbian Area

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Abstract. Jingbian area located in the middle and east of Ordos basin, where the dolomite gas reservoir develops in $Ma_5{}^7$, the seventh subsection of Ordovician Majiagou Formation, and gypsum and salt rock develop above it, forming good sealing conditions for the dolomite gas reservoir. Well T74 gained a high yield of millions of parties in $Ma_5{}^7$ recently, revealing it has a good natural gas resource. However, the drilling rate of industrial airflow well is low, and gas accumulation law in gas reservoir is complex, which can be characterized by tight dolomite reservoir, poor porosity, strong heterogeneity, rapidly lateral changes of the reservoir, and little difference from the geophysics of the surrounding rock, which leads to more difficulties in seismic prediction. In view of the difficulties above, forward modeling of elastic wave equation was carried out, typical wells of different types were chosen, and the logging curves were normalized to establish impedance model, and field seismic data acquisition was simulated to get model seismic data. Lastly, the characteristics of the favorable seismic waveform of reservoir were clearly defined. Then, binding study was performed by pre-stack inversion based on physical analysis, analysis on attributes of frequency domain, and the results of the study had the better performance in well location selection of $Ma_5{}^7$. The results of forward modeling of elastic wave equation show that a medium strong peak appears owing to gypsum and salt rocks of Ma_5^6 richly developed, and a weak complex peak in Ma_5^7

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indicates good reservoir and high yield. Petrophysical analysis indicates that the gas ratio of Lambda to Mu (λ/μ) is below 0.8 and the high-frequency seismic attenuation and negative anomaly of fluid mobility. In the study, elastic wave equation forward modeling was applied in Jingbian area firstly and the waveform reflection mode of reservoir was identified, and the sensitive fluid mobility attribute was selected to detect the gas bearing property. Lastly, the gas reservoir was effectively identified, and the compliance rate of reservoir prediction was increased to 78%.

Keywords: Subsalt · Dolomite reservoir · Seismic forward · Petrophysics · Pre-stack inversion · Fluid mobility

1 Introduction

The dolomite gas reservoir of Ma_5^{7-9} in the Ordovician of Jingbian area was currently focused, the upper gypsum-salt rocks of Ma_5^6 are well developed, forming a good sealing, and furthermore, it is beneficial to form gypsum underneath rock trap. Recently, the carbonate reservoir exploration of Ordos basin followed the guidance of "targeting another Jingbian gas field under Jingbian gas field," the exploration gradually concentrated on the Ma_5^{7-9} layers, lots of drilling wells such as T38, T74, and T75 got industrial gas flow, especially T74, got a high production flow of millions of parties, indicating that gas reserve of Ordovician is potential. However, according to the statistical data, the ratio of industrial gas flow wells is less than 14%, which suggested a complicated gas reservoir condition of Ma_5^{7-9}, In addition, the dolomite reservoir was characterized by dense lithology, lack of pore development, and little geophysical difference between reservoir and non-reservoir, which could result in more difficulties in seismic reservoir prediction. In order to spot the abundant gas zone and good well location, the seismic wave forward modeling was performed to build the seismic reflection mode of both Ma_5^6 gypsum-salt and Ma_5^{7-9} dolomite reservoir rocks, and then, combining the pre-stack inversion under the basis of rock physics analysis with the post-stack attribute prediction in the frequency domain, the gas content was estimated. Moreover, a good application effect was observed in well deployment of Ma_5^{7-9}.

2 Establishment of Prediction Model for Gypsum-salt Layer and Dolomite Reservoirs

The geological model was firstly built under the strata sequence constraint with six representative wells and interpolation and extrapolation of wave impedance data, and then, the elastic wave equation simulation was performed [1], as shown in the example Fig. 1. The acquisition system is basically followed the parameters setup in the actual seismic data acquisition, the exploration source is placed in the middle point, and the receiver traces are set on both sides, the trace interval is 10 m, the shot interval is 50 m, the length of receiver array is 3000 m, and the excited wavelet is 35 Hz Ricker wavelet.

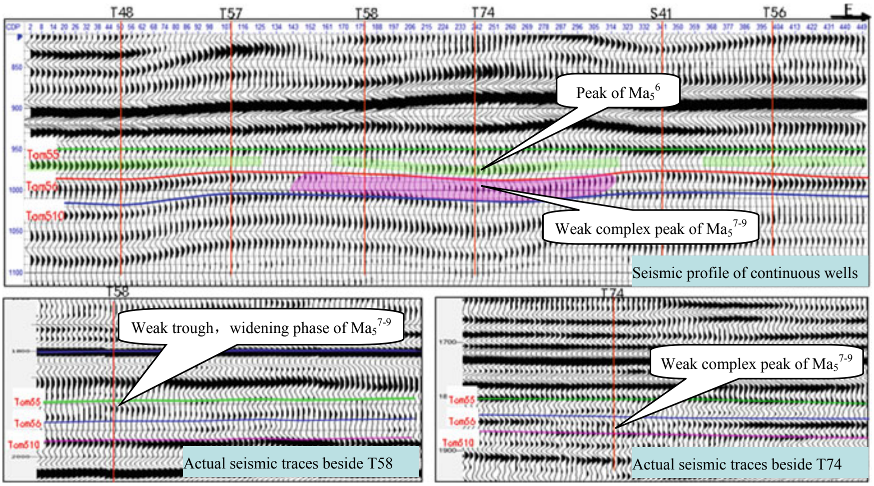

Fig. 1. Seismic profile of reservoirs forward simulation of Ma_5^{7-9}

The gas layer of well T74 and T58 is 4.3 and 5.5 m, and the gas productivity is 127 million m^3/day and 50 thousand and 900 m^3/day, respectively. Other wells are either a dry hole or non-reservoir, namely the gas content is poor. The following laws can be observed from the actual seismic trace around the well spot: The upper Ma_5^{7-10} of both well T74 and T58 appears widen reflection phase or complex wave feature; meanwhile, the peak wave reflection is observed between the Ma_5^5 and Ma_5^6, while Ma_5^{7-10} of other non-reservoir well appears intense trough or peak, or it has no reflection between the Ma_5^5 and Ma_5^6. Comparing the geological model with seismic wave forward modeling analysis, we could conclude when the dolomite reservoir of Ma_5^{7-10} is gas-saturated, the velocity reduces, and complex reflections are observed due to the different impedance between the reservoir and surrounding rocks. Therefore, the complex wave reflection of Ma_5^{7-10} can characterize a gas layer. The wave peak between the Ma_5^5 and Ma_5^6 due to low velocity gypsum can reflect the properties of overlying rock. The reservoir of both well T74 and T58 is relatively developed, and however, the wave peak reflection between the Ma_5^5 and Ma_5^6 of well T74 is more intense than that of well T58, which suggests the sealing of overlying rock of well T74 is superior.

From above comprehensive analysis, the seismic reflection mode of dolomite reservoir of Ma_5^{7-10} was built as follows, the wave peak reflection (overlying rock) is observed between the Ma_5^5 and Ma_5^6, while the reflection phase with complex wave features (favorable reservoir) of Ma_5^{7-10} was observed.

3 Dolomite Reservoir and Gas Prediction

3.1 Pre-stack Elasticity Inversion

According to the full sonic wave data from three wells, the independent elasticity parameters and combined parameters could be calculated. Then, the crossplots as shown in the example Figs. 2 and 3 suggested that both the Poisson's ratio and λ/μ have certain separability for rock lithology, even the lithology boundary is overlapped at a certain extent. Especially, the λ/μ with eliminating the mudstone case can definitely identify the gas reservoir. In consideration of the mudstone in the target zone is not developed, the λ/μ can be applied to predict the gas dolomite reservoir. λ/μ of the gas layer is generally small, and it is less than 0.8, which provides the fundamental rock physics basis for the subsequent pre-stack inversion [2].

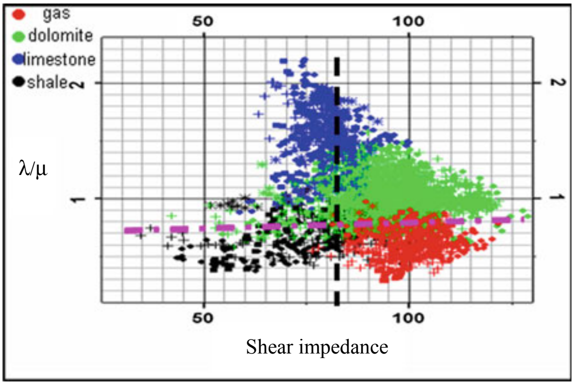

Fig. 2. Shear impedance versus λ/μ

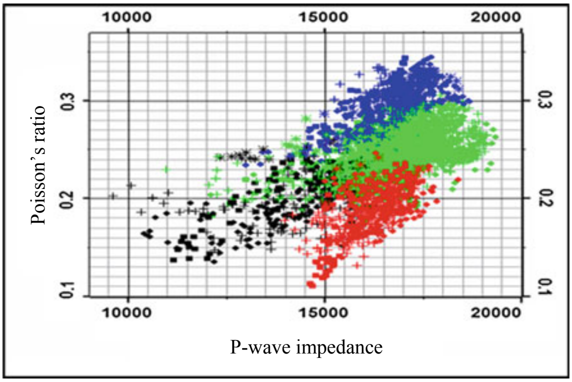

Fig. 3. P-wave impedance versus Poisson's ratio

3.2 Attribute Analysis At Frequency Domain

Fluid movement attribute can be considered to predict the fluid properties at the porous reservoir with fully saturated fluids [3]. Specifically, it means the absolute value of seismic reflection amplitude versus frequency. Meanwhile, it indicates the variation of frequency spectrum between the permeable reservoir and tight reservoir, which is proportional to the permeability. According to the theory of high-frequency attenuating and low-frequency resonance when wave passing the fluids saturated porous rock, the variation ratio between the permeable reservoir and tight reservoir should be positive abnormal at low-frequency band, while that is negative abnormal at high frequency. Simply speaking, gas reservoir at low-frequency band appears large slope and high positive abnormal, while that does small slope and high negative abnormal at high-frequency bands. Comparing the seismic frequency spectrum between the wells located in the good reservoir zone and low-quality zone, the sensitive frequency band of $Ma_5{}^{7-9}$ layer is 50–64 Hz. Furthermore, it appears negative abnormal at high-frequency band. When the parameters are determined, Fig. 4 displays both the pre-stack λ/μ inversion profile and fluid movement profile. Well T74 is high-producing well, low λ/μ can be observed around the well spot; meanwhile, the fluid movement appears negative abnormal at high-frequency band. Therefore, it can conclude that this reservoir is well developed with good gas content. In addition, it also verifies the validity of using fluid movement technique to predict the gas content at $Ma_5{}^{7-9}$ dolomite reservoir.

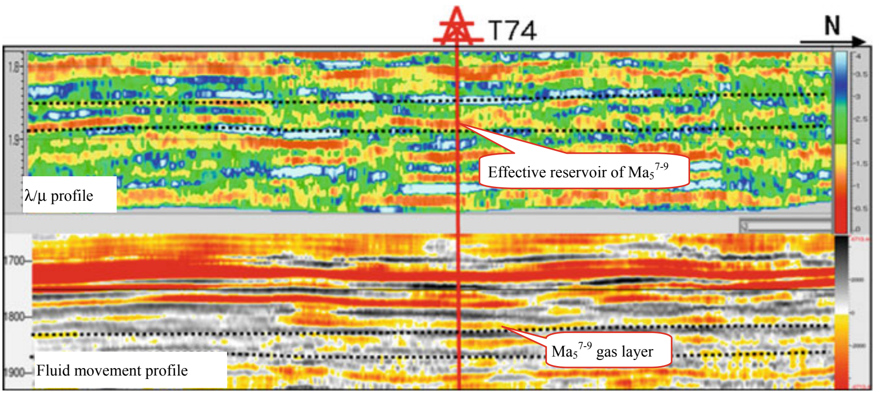

Fig. 4. Pre-stack inversion and fluid movement profile of line 98Y

4 Field Example

According to the previous mode analysis, pre-stack inversion and fluid movement attribute, the well J6 is deployed, the seismic profile of $Ma_5{}^{7-10}$ appears weak complex wave reflection with widen phase as shown in the example Fig. 5; meanwhile, the weak wave peak reflection can be observed in the $Ma_5{}^6$ gypsum-salt layer, which suggests that both dolomite gas reservoir of $Ma_5{}^{7-9}$ and gypsum-salt of $Ma_5{}^{6}$ layer are well developed. The pre-stack inversion results of $Ma_5{}^{7-9}$ indicate a low fluid movement attribute at high frequency presents negative abnormal, which is a good gas content indicator. In addition, the well log data suggests that the gas thickness of $Ma_5{}^{7}$ layer is 5.1 m, and gas layer is 10.8 m, which approximately matches well with prediction.

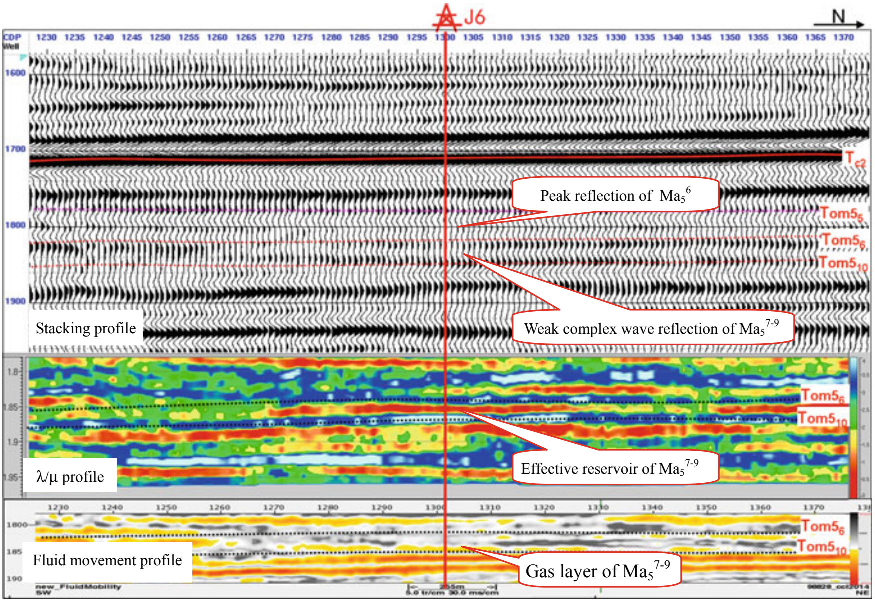

Fig. 5. Stacking, pre-stack inversion, and fluid movement profile of line 98Y

5 Conclusions

(1) The forward modeling is a vital technique to understand the seismic response when waves passing the complicated reservoir, the seismic reflection feature of $Ma_5{}^{6}$ gypsum-salt layer and reservoirs of subsalt are determined by analyzing the forwarding model results.
(2) Although the carbonate reservoir is tight, the rock physical modeling indicates that the combinatorial elastic parameters can significantly improve the distinguishing ability between reservoir and non-reservoir.
(3) The combination of pre-stack inversion and post-stack attribute analysis in the frequency domain can effectively predict the gas content in the dolomite reservoir.

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