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Application of pre-stack simultaneous inversion on the reservoir identification and fluid prediction: A case history of Es2 member reservoir in Shengli Oilfield

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Abstract. Es2 member reservoir of Guojuzi sag is located in the east Bohai Bay Basin in China, mainly composed of beach bar sediments, which are thin and in irregular distribution. Conventional post-stack seismic attributes cannot predict the reservoir effectively, while pre-stack seismic inversion also has difficulties in application for the low SNR seismic data. A number of amplitude preserved processes are taken to obtain high SNR seismic data. Then AVA simultaneous inversion is adopted to achieve elastic parameters. Well log analysis shows that μ and lower Vp/Vs can be good indicators for our target reservoir, therefore we extract μ and Vp/Vs attribute sections and slices from the result of AVA simultaneous inversion and have successfully delineate the spatial distribution of Es2 member reservoir, which are in consistent with the known well log data.

1. Introduction

Es2 member reservoir of Guojuzi sag is located in the east Bohai Bay Basin in China, which is mainly composed of beach bar sediments. There are small delta fans and nearshore subaqueous fans developed in southern northern slope of Guojuzi sag. Es2 member formation is about 300m in thickness with sandstone, mudstone and interlaminated argillaceous siltstone

The present exploration shows that Es2 member reservoir of Guojuzi sag is formed in the paleo-shallow lake system. During the depositional period, the monolayer of beach bar and mudstone formed thin interbedded sediments. In the past, post-stack amplitude attribute was used to delineate the distribution of Es2 member reservoir. However, large lateral variation and small thickness of single sand body made it is impossible to predict Es2 member reservoir correctly. Therefore, we use pre-stack simultaneous inversion method to predict the reservoir.

In last decades, pre-stack AVA simultaneous inversion technology has made great progress. It can simultaneously invert multiple pre-stack gathers to acquire the elastic parameters such as P-wave velocity, S-wave velocity and density, and then get other elastic parameters such as Poisson's ratio, Young's modulus, Lamé's constant and so on, to carry out reservoir classification and fluid prediction.



Pre-stack simultaneous inversion has been addressed by many scholars. Ma (2001, 2002) developed a method for estimating P-wave impedance and S-wave impedance simultaneously [1,2]. Bruun (2005) used pre-stack simultaneous inversion to improve the reliability of porosity prediction [3]. Based on the study and research of Simmons & Backus et al (1996) [4], Hampson & Russell (2005) proposed the pre-stack simultaneous inversion technique, which can invert the P-wave impedance, S-wave impedance and density at the same time [5]. Contreras (2006) successfully applied simultaneous inversion to lithology prediction of deep water reservoirs in Gulf of Mexico [6,7]. Misra (2007, 2008) published papers on global optimization methods in AVA simultaneous inversion [8,9]. The pre-stack simultaneous inversion preserves the consistency of various elastic inversion parameters, enhances the stability and reliability of the inversion results, and favorable to the best prediction of the underground geological body. In this paper, the pre-stack AVA simultaneous inversion method is applied to predict Es2 member reservoir, and the inverted results are consistent with the well log data.

2. Pre-stack seismic attributes and inversion

2.1. Seismic data processing

AVO inversion requires high SNR data. Therefore, we take a series of amplitude-preserved processes, such as spherical compensation, surface consistent deconvolution, random noise attenuation, inverse Q filter, pre-stack time migration, to make sure the final pre-stack amplitudes represent the reflection strength of the subsurface interfaces. Figure 1 shows the comparison of the CRP gathers before processing (left) and after processing (right). We can see that after the processes mentioned above, the quality of the CRP gathers has been much improved. Except for the improved SNR of the data, our target zone Es2 member reservoir (denoted with purple square between 1800 m/s and 2400 m/s) also expresses its AVO characteristics, which is the premise of the followed AVO inversion.

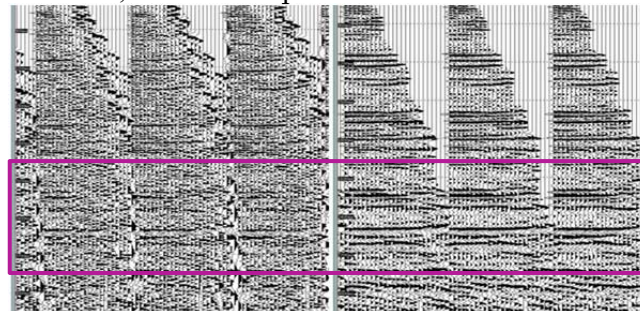


Figure 1. CRP gathers before preprocess (left) and after preprocess (right).

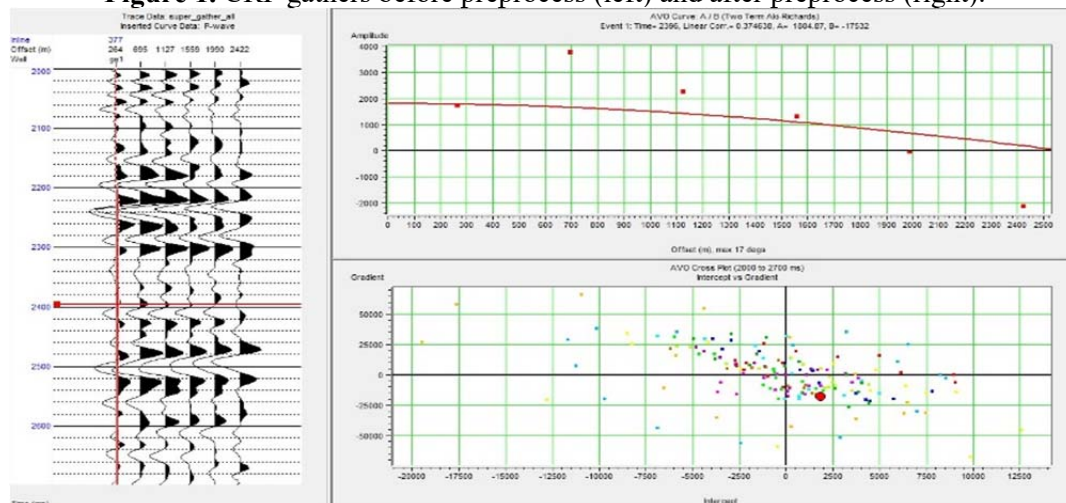


Figure 2. The cross plot of intercept and gradient of the reflection amplitude at 2400 m/s.

We extract a CRP gather near gs1 well, and calculate its amplitude intercept and gradient at around 2400 m/s (where gs1 well has drilled oil sand). As shown in figure2, the AVO anomaly of our target reservoir belongs to Class 1 AVO.

2.2. Well logging data analysis

To further confirm the AVO characteristics of our target reservoir, and using the AVO consistency between the log analysis results and the seismic processing results to illustrate the reliability of the seismic processing results, we use the logging curves Vp, Vs and density of gs1 well to calculate the reflection coefficients at around 2400 m/s, convolve with the extracted wavelet and then obtain the angle gathers, as shown in figure 3. It is clear that the amplitude of the target reservoir decrease with the incident angle increase, which is a typical Class 1 AVO anomaly. This result agrees with the initial analysis of the CRP gathers in last section.

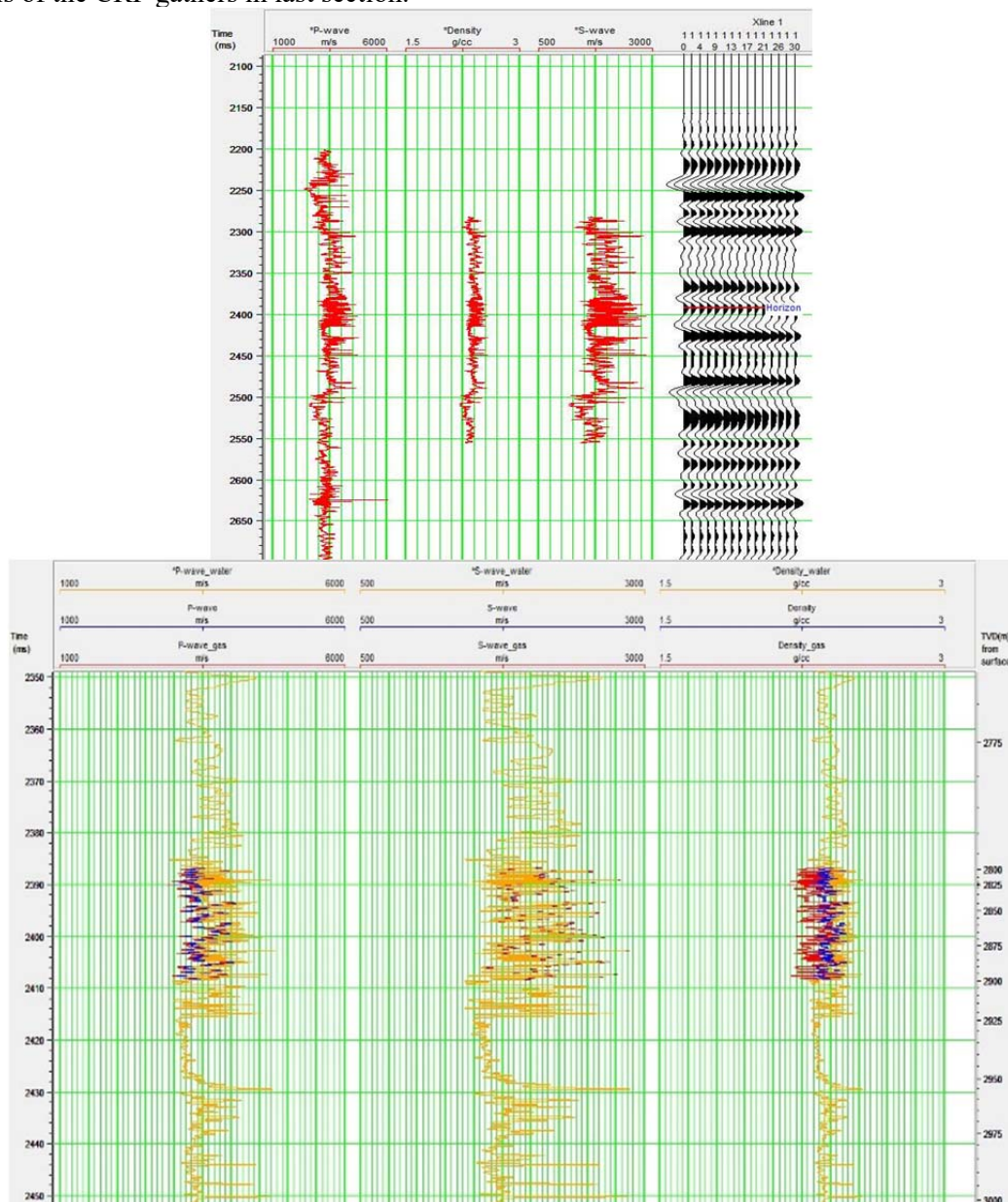


Figure 3. Forward modeling and fluid replacement with gs1 well logs.

We use the fluid replacement method on the reservoir, replacing the oil-bearing reservoir fluid with saturated gas and water, and calculate corresponding log curves. From the well data analysis, we found that V_p of the oil sand is lower than the dry sand, but still higher than that of the surrounding mudstone, while V_s of the oil sand will not be influenced with the fluid, so V_s of oil sand is still high. Therefore, we did many tests to choose the elastic parameters sensitive to the oil sand prediction, which will guide our future AVO inversion. Finally, we found that V_p/V_s and $\mu\rho$ can be used to indicate the oil sand. Figure 4 are the cross plot of $\lambda\rho$ vs. $\mu\rho$ and P-wave impedance vs. V_p/V_s respectively, which show that the oil sand (in brown ellipse) has relatively higher $\mu\rho$ and lower V_p/V_s compared with the surrounding mudstone.

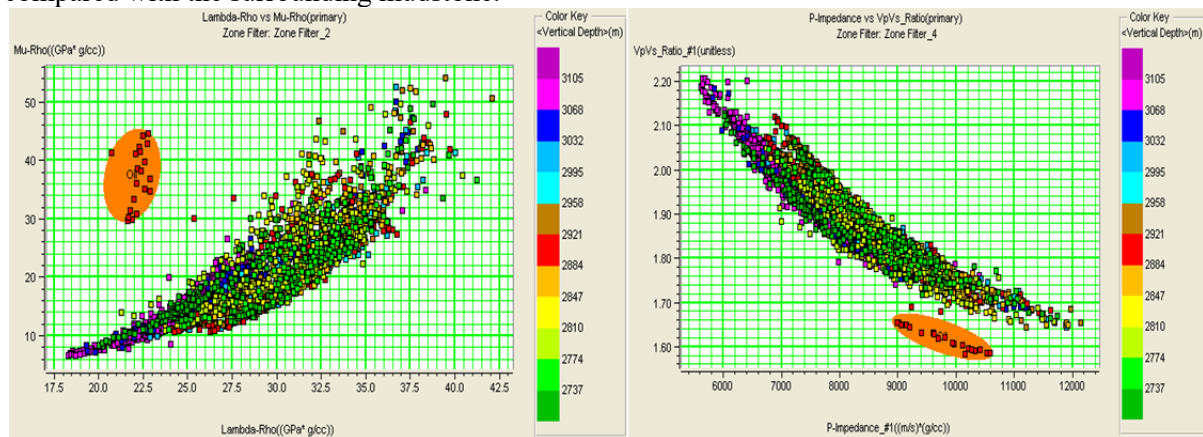


Figure 4. Cross plot of $\lambda\rho$ vs. $\mu\rho$ and I_p vs. V_p/V_s of well-log data (brown ellipse denotes the oil sand).

2.3. Pre-stack AVA simultaneous inversion

Conventional pre-stack inversion involves two separate steps. The first step is to achieve the reflection coefficient of each angle gather and the second step is to calculate P-wave velocity, S-wave velocity, density or other elastic parameters using AVO approximation [10,11,12]. In this kind of inversion, the angle gathers are inverted individually without fully utilizing their mutual difference as constraint, which worsens the reliability and stability of the in-version. In last decades, pre-stack AVA simultaneous inversion technology has made great progress [13]. It can simultaneously invert multiple pre-stack gathers to acquire the elastic parameters such as P-wave velocity, S-wave velocity and density.

Hampson proposed an AVA simultaneous inversion in 2005. It establishes initial P-wave and S-wave impedance through the extrapolation of the low-frequency well log data, calculates the reflection coefficients of each layers with Fatti's AVO approximation [14], obtains the synthetic angle gathers by convolving the reflection coefficients with the known wavelet, compares with the observed seismic data to calculate the errors between them, and then minimize the error using conjugate gradient method. Once there is no big error between the synthetic gathers and observed seismic data, the corresponding inverted model parameters are considered as the resultant model. When we have estimated P-wave impedance, S-wave impedance and density, we can easily achieve other elastic parameters such as Poisson's ratio, Young's modulus, Lamé's constant and so on, to carry out reservoir classification and fluid prediction. This simultaneous inversion is based on the fact that both the S-wave impedance and density are linear correlated with P-wave impedance after taking logarithm, which makes the inversion stable.

We did AVA simultaneous inversion to this area with gs1 well included in the model for pre-stack inversion. After we got the inverted P-wave impedance, S-wave impedance and density volume, we calculated $\mu\rho$ and V_p/V_s as we discussed in well log data analysis section.

Figure 5 and figure 6 show $\mu\rho$ and V_p/V_s sections along with Well gs1, da21 and da211. All these three wells have encountered the oil sand as the white ellipses denote. We can see that the inverted

result has shown the reservoir has relatively higher μ_p and lower V_p/V_s compared with surrounding mudstone, which agrees with the well log data analysis.

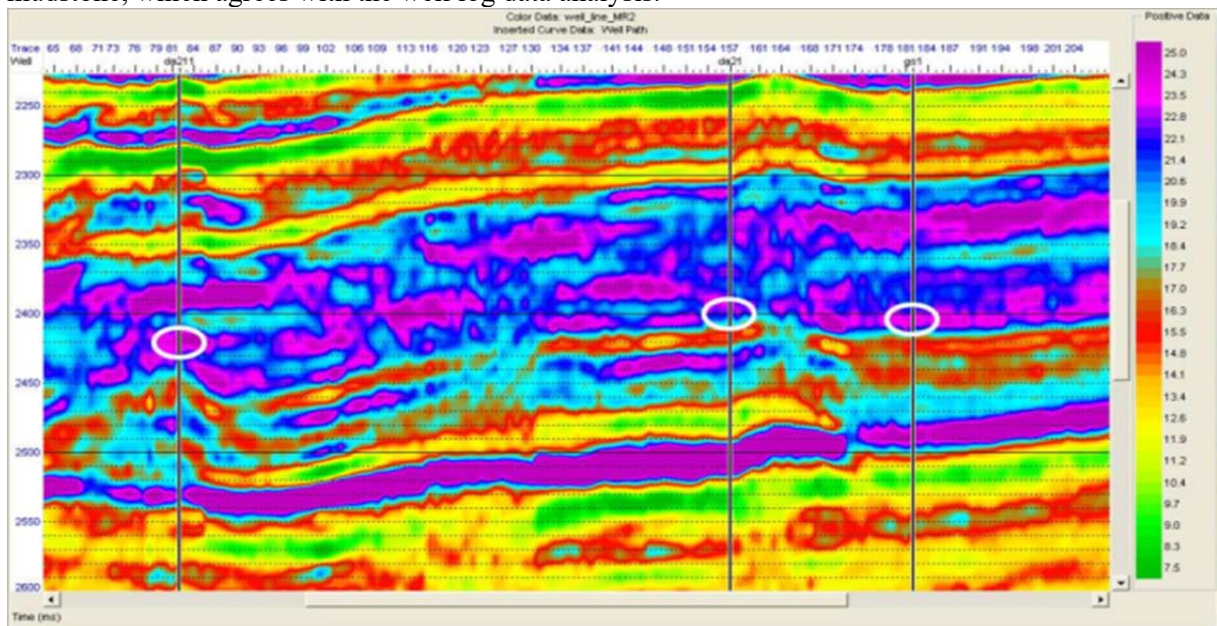


Figure 5. Inverted μ_p section along with a cross well line (white ellipse denotes the drilled reservoir).

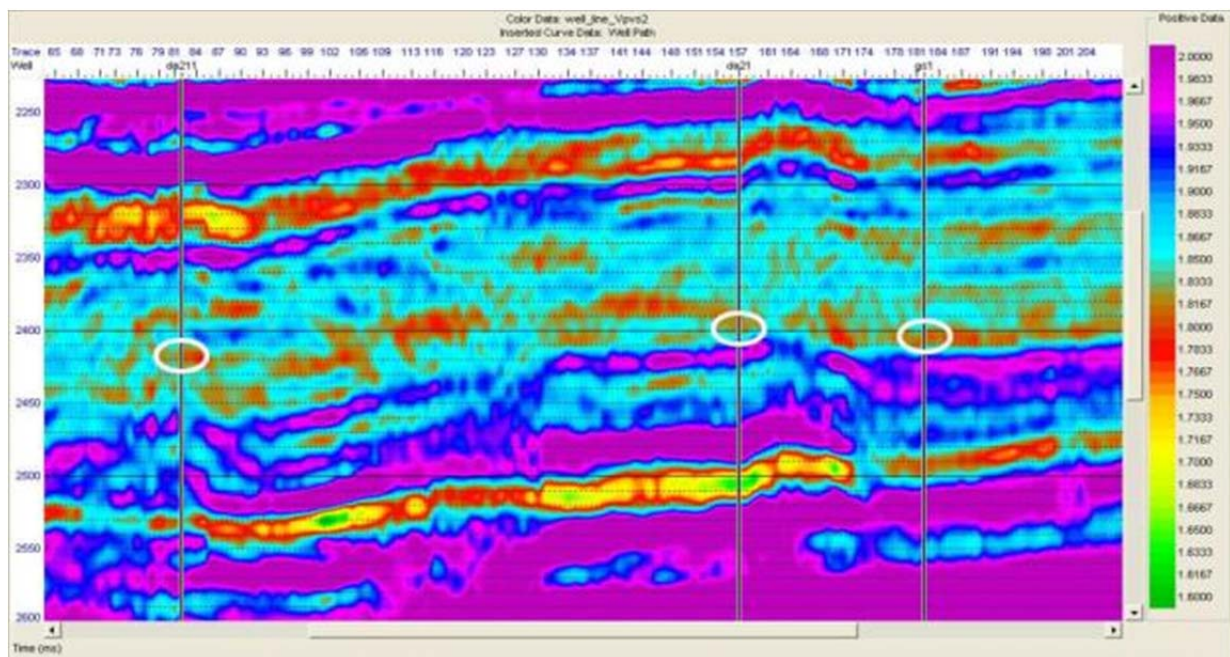


Figure 6. Inverted V_p/V_s section along with a cross well line (white ellipse denotes the drilled reservoir).

3. Reservoir prediction

Many wells were drilled in the Guojuzi sag area, among which gs1, da21 and da211 well all obtain oil flow in Es2 member reservoir, while guo1 and da15 are dry wells.

The main purpose of AVO inversion is to obtain parameters which can reflect the characteristics of lithology and fluid, which then can be used for reservoir prediction. As we discussed before, $\mu\rho$ and V_p/V_s are sensitive to the change of lithology and fluid, so we choose $\mu\rho$ and V_p/V_s to delineate the spatial distribution of Es2 member reservoir.

$\mu\rho$ can be obtained from S-wave impedance. Because it is not affected by the fluid, it has advantages in indicating lithology. Figure 7 shows the horizon slice of $\mu\rho$ attribute along with the oil-bearing reflection event. High $\mu\rho$ represent the sandstone development area. We can see that gs1, da21 and da211 well are located in the sandstone development area, while guo1 and da15 well are not located in the sandstone area, which is consistent with the drilling results. Therefore, $\mu\rho$ is a good indicator for the discrimination of sandstone development area.

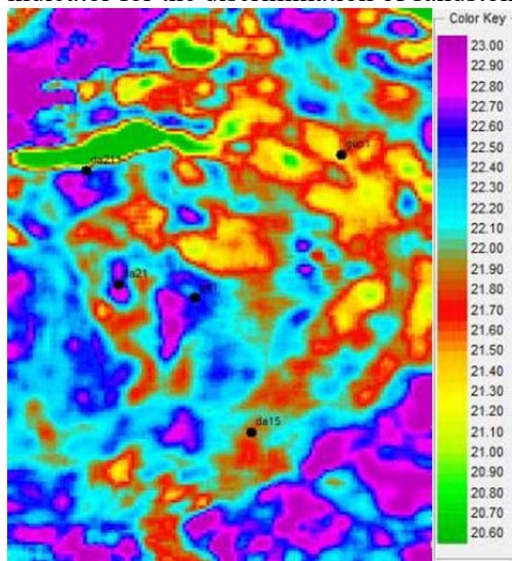


Figure 7. The horizon slice of $\mu\rho$ attribute along with the oil-bearing reflection event.

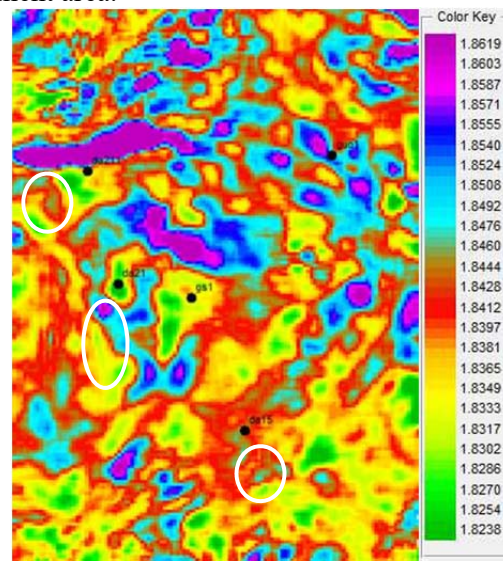


Figure 8. The horizon slice of V_p/V_s attribute along with the oil-bearing reflection event (white ellipses are potential oil reservoirs).

V_p/V_s can be considered equivalent with Poisson's ratio, which is an important parameter for the discrimination of lithology and fluid. Figure 8 shows the horizon slice of V_p/V_s attribute along with the oil-bearing reflection event. Low V_p/V_s represents the oil-bearing sand. We can see that gs1, da21 and da211 well are located in the low V_p/V_s area, while guo1 and da15 have high V_p/V_s , which is consistent with the drilling results. Therefore, V_p/V_s is a good indicator for the anomaly of oil and gas.

With the above analysis, Es2 member reservoir has relatively high $\mu\rho$ and lower V_p/V_s . Combining the results of figure 7 and figure 8, we can draw a conclusion that there may exist big area oil reservoirs at the west of da211 well, the west of gs1 well and the southeast of da15 well, which are denoted with white ellipses in figure 8.

4. Conclusions

Es2 member reservoir of Guojuzi sag is mainly bank and bar sands, which are thin and in irregular distribution. Because of its small thickness, lateral variation and deep burial depth (about 3000 m), conventional post-stack seismic attributes cannot predict the reservoir effectively. Pre-stack inversion also meets a challenge. With the analysis of well log data and seismic forward modeling, we confirmed Es2 member reservoir has Class 1 AVO anomaly and found that $\mu\rho$ and V_p/V_s can be good indicators of oil sand in this area. After the careful amplitude preserved processing, we obtain high quality of seismic data and then applied AVA simultaneous inversion to achieve $\mu\rho$ and V_p/V_s sections. The attributes sections are in agreement with the known drilling well, which means pre-stack inversion has great potential in predicting such thin and deep reservoir. Finally, we extracted the corresponding attributes slice to delineate the spatial distribution of the oil reservoirs.

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