Delineating oil in sand reservoirs by high resolution PP/PS processing and joint inversion in Junggar Basin, Northwest China
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Summary

Dramatic lateral lithological variations in the fluvial sediments in Chepaizi, Junggar Basin of Northwest China, have posed potential challenges and difficulties to distinguish between true and false “bright spots” in oil–bearing sand reservoirs. A high resolution multi-component seismic survey and joint prestack PP and PS inversion conducted recently in the area, have provided an effective technique to solve the problem and successfully delineate the characteristics of the reservoir, due to the additional benefits obtained from the different reflection response to lithology and fluid content of shear waves, and their capability of resolving thin layers. Surface consistent amplitude and resolution preserving processing has produced high quality prestack PP and PS migrated gathers and stacks for extracting seismic attributes. Application of the joint prestack PP and PS inversion has demonstrated higher fluid factors and lower Vp/Vs ratio at the location of oil-bearing sands compared with the dry sands in this area. From the correlation between the inversion and the existing well data, it is concluded that a promising exploration technology, such as the high resolution multi-component AVO, can reduce drilling risks and provide more accurate reservoir characterization for seismic exploration.

Introduction

The Chepaizi area is located in Junggar basin, Northwest China. In 2006, an exploration well Che89 was drilled, which turned out to be highly productive, producing from the Shawan formation group of the Pliocene. Consequently, more wells have been drilled, but five out of eight wells were dry, even though the reflection characters at these wells looked like the so called “bright spots,” similar to Che89. It has been believed that the extreme lateral lithological variation due to the fluvial sediments lead to these difficulties. To understand better the character of the reservoir, a high resolution 2D3C seismic line was deployed. It went through the two test wells, Che89 (good producer) and Che97 (dry well), using DSU3 digital sensor units, based on MEMs technology. The survey was acquired with a sample rate of 1 ms and CDP interval of 5 m and with an average fold of 50. For better reservoir characterization, high resolution data processing and a joint prestack PP and PS inversion have been performed, the results of which are presented in this paper.

Theory and method

Conventional AVO inversion with a single mode P wave tries to invert three unknowns, Vp, Vs and density from two seismic attributes - P-wave gradient and intercept time. This causes uncertainties in the inversion. The joint PP and PS inversion has stabilized the problem by introducing PS gradients (Hampson et. al, 2006). However, in practice, the noise in both PP and PS gradients also causes some difficulties in the inversion. Garotta et al. (2002) proposed a dual inversion scheme, which uses the vertical Vp/Vs ratio from PP and PS travel time registration combined with PP and PS AVO attributes in the elastic inversion. The method has been successfully used in OBC data from North Sea, as well as in land data from Daging area of China (Shen et al. 2008). The inversion involves mainly two steps, the first step is to extract AVO attribute sections (Rpp intercept section, Gpp gradient section), derived from the migrated P-wave gathers, and the PS gradient section from the migrated PS-wave gatherers. Assuming a 1D elastic isotropic earth model, a simulated annealing technique is used during the inversion to find a global minima in this complex optimization and then to compute the elastic parameters for the target area in the second step.

Data preprocessing

![Figure 1. P wave sections before (upper) and after (lower) surface consistent deconvolution. Resolution has been enhanced by deconvolution.](image)
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The three component data are of good quality. Even though there is strong coherent noise, and some random noise, the spectral analysis of valid signals for the original shots demonstrated broad frequency bandwidths for both P-waves (up to 200Hz) and PS-waves (up to 100Hz). The dominant frequencies are around 70-90 Hz for the P waves and 35-40 Hz for PS waves. It provides a good basis for us to perform high resolution PP and PS inversion. The key steps involved in pre-processing include good noise attenuation for broadband data, shear wave statics, surface consistent amplitude correction, surface consistent deconvolution and statics, and prestack time migration.

Figure 2. PP and PS wave prestack time migration sections and spectra: upper: PP section; lower: PS section.

Figure 1 shows a comparison of the P-wave seismic data before and after deconvolution. It is obvious that deconvolution has enhanced seismic resolution - more thin layers can be resolved and the continuity events has been improved. To enhance the seismic resolution for PP and PS data, higher order moveout corrections were also performed during the PP and PS prestack time migrations, so that the smearing caused by un-flattened long offset data could be reduced. Figure 2 shows the final PP and PS prestack time migrated sections and their corresponding spectra. The PS section has been squeezed to PP time by using the vertical Vp/Vs ratio obtained from the PP and PS registration.

PP/PS data matching and event registration

The most important step is registration of P wave reflection events with their equivalent reflections on the converted wave data. Since the two data have different frequency bands, we have designed a matching filter which matches the amplitude spectra of the P waves to the amplitude spectra of the PS waves, without changing their phase spectra prior to the correlation of the events. The synthetic seismic traces are created based on P-wave sonic log information using wavelets derived from the PSTM sections for both P and PS waves. It is noticed that when calibrating surface the PS wave seismic section with well logs, an 180° phase rotation is

Figure 3. The well log curves, computed PP impedances and synthetic seismograms (blue traces) compared with P-wave surface seismic (red and black traces) for the wells Che 89 (left) and Che97 (right).

Figure 4. The computed PS impedances from log curves and synthetic seismograms (blue traces) compared with surface PS-seismic section at well locations (black traces). The surface PS- wave section has an 180° phase rotation and is plotted in red.
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needed. For both wells, it is obvious that the synthetic seismograms correlate well with the prestack time migrated sections for both P and PS waves as seen in Figure 3 and 4.

Then the PP and PS event registration is carried out with the matched P-wave and PS-wave sections for the target zone, which is at a depth of 900-2000 m and 1s in PP time. Three horizons were picked for both P and PS waves. The initial Gamma (Vp/Vs ratio) obtained from events registration is used to squeeze PS section to PP time. After several iterations to adjust the horizons, the PP and PS sections match very well (See Figure 5), and the updated Gamma will be used as a reference model in the joint inversion.

Before the joint inversion, a comparison analysis was conducted. Table 1 is the comparison of the P wave, the matched P wave and the old 3D P-wave sections at the target formation for both wells. At the location of well Che97, similar bright spots between the matched P-wave and the old 3D P-wave sections, which have a lower frequency bandwidth, are observed. But in the original P-wave section without matching, the bright spot does not exist. It is replaced by multiple formations in the high resolution processing result (see Table 1 P-wave section at Che89). Table 2 is a comparison of the P-wave, the matched P-wave and the PS-wave sections at the target zone for both wells. At well Che89 the same bright spot is shown in both original and matched P-wave sections, but it disappears in the PS-wave section, which implies that the bright spot in the P-wave section is due to a hydrocarbon existence.

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![Figure 5: The effect of PP/PS event registration at CDP 1800. The P-wave section is plotted on the left; the PS section is plotted on the right. After event registration, horizons can be traced continuously on both sections.](image)

![Table 1: A comparison of the PP, matched PP to the PS spectra and the old 3D P wave sections in the target formation for both wells.](image)

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<table>
<thead>
<tr>
<th>Well</th>
<th>PP (Freq. matched to PS)</th>
<th>Old 3D P wave survey</th>
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<tr>
<td>Che89</td>
<td><img src="image" alt="Image" /></td>
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<td>Che97</td>
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![Table 2: A comparison of the PP, the matched PP to the PS spectra section and the PS sections in the target formation for both wells.](image)

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**PP and PS joint inversion**

The inputs to the PP/PS joint inversion are AVO attributes: the P-wave gradient, Rpp, and intercept time, Gpp and the PS-wave gradient, Gps. The reference Vp/Vs ratio model from the event registration is also used as the initial model for the joint inversion. The simulated annealing scheme was started at a temperature of 900, and the error tolerance was set to 0.0001 for program termination. After the joint inversion, we got an inverted Vp/Vs ratio, which is showed in Figure 6, the fluid factors (see Figure 7), and Poisson ratio.

Correlation with the log curves and the inversion results, distribution of the dry sands with Vp/Vs ratio values around 2.1 are displayed as yellow to red colors; the shale layers with Vp/Vs ratio values around 2.6 are displayed as blue to purple colors (see Figure 6). At well Che89 of the target formation, the Vp/Vs ratio values demonstrate a strong anomaly with values around 1.7, which are displayed by green color in Figure 6. At well Che97, no any anomaly in the target formation is observed. Therefore, according to the inversion result, hydrocarbons, dry sands and shales can be discriminated clearly by Vp/Vs ratio values. The fluid factors and Poisson’s ratio were calculated from the inverted Vp/Vs ratio. Both of them also indicate an anomaly in the saturated sandstone at well Che89 location. Figure 7 shows the fluid factors for the target zone, which also illustrates a higher value of fluid content at well Che89, but lack of anomaly at well Che97.
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Discussion
As mentioned earlier, with high resolution processing in the P-wave section exactly below the “false” bright spot at well Che97, two reflections are observed (see Figure 3, indicated by a red arrow on the right) instead of only one strong reflection in the conventional processed section and the matched P-wave section. Is it real geologically? To confirm this, we have checked the well log curves for well Che97 and found out that a thin sand layer exists exactly below the “false” bright spot (see Figure 3, indicated by a red arrow on the right). In addition, by registration of the synthetic seismogram with the petrophysical data, the thin sand layer exactly below the “false” bright spot can be clearly identified in the synthetic seismograms, which is also consistent with the surface seismic. Therefore, it is safe to say that the P-wave section with high resolution acquisition and processing delineates the detailed geological information.

According to the petrophysical analysis, the Vp/Vs ratio of the saturated sandstones normally changes from 1.6 to 2.0 (displayed in green in Figure 6). Without the dipole sonic log data available in the survey, we built an AVO fluid replacement model (three phases with 90% oil, 5% gas plus 5% water) to simulate the Vs variation caused by existence of the oil and gas within the target zone. It is noticed that the Vp/Vs ratio dramatically decreases to less than 2.0 (1.6-2.0) within the oil sand reservoir which is quite consistent with the assumption. Theoretically, Vs will generally increase but Vp will not change too much within the saturated sandstones due to different sensitivities to pore fluids of the P and shear waves. Consequently, the Vp/Vs ratio will dramatically decrease and result in a much lower value than that is seen in the dry sand formations.

Conclusions
Multi-component high resolution amplitude preserving processing on Chepaizi 3C data has resolved a false bright spot into two thin layers at well Che97. The PS section also shows different amplitude characters from the P-wave section and lack of a fluid factor anomaly at well Che89, but similar amplitude characters at well Che97. Based on these inputs, the joint PP-PS inversion has successfully inverted high resolution Vp/Vs ratios, fluid factors, and Poisson ratios. The low Vp/Vs ratio values and low Poisson’s ratio clearly characterized the reservoir at well Che89, whereas at the location of the false bright spot at well Che97, these characteristics were absent.

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![Figure 6. The inverted Vp/Vs ratio, gamma, at wells Che89 (right) and well Che97 (left).](image)

![Figure 7. The inverted fluid factors at the target zone. Well Che97 is on the left and well Che89 is on right.](image)