Improving Facies Classification in the Presence of Gas with Joint PP-PS Inversion

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Summary

This paper shows the case where fluid effects, primarily expected to affect the P-impedance, cause unwanted artifacts on the S-impedance and density volumes obtained through AVO inversion of P-wave data. When converted-wave data is included in a prestack joint inversion, these artifacts are eliminated. The improvement is not just limited to the values in the S-impedance and density volumes, but it is also shown that the classified facies derived from the joint inversion are more robust.

Introduction

The incorporation of converted-wave (PS) data in quantitative interpretation has been demonstrated to provide a distinct benefit over conventional P-wave (PP) data alone. PS data are influenced by two of the same parameters, S-impedance and density, as PP data; however, they form an independent set of measurements. By inverting these two data sets for the same earth model, it is possible to improve the matches to well data, reduce the effect of noise, and often improve resolution of the inverted models.

Although PP data is influenced by I_P, I_S, and density, the contribution from density is minimal, especially at small incidence angles. PS data is similarly controlled by I_S and density, however more strongly than PP data (Figure 1). Although the relationships used to stabilize the inversion of I_S and density (Hampson et al., 2005) greatly improve the results, they can lead to unintended artifacts when the I_P changes are dominant. This dominance is the case in gas-saturated oil sands formations, where the I_P changes significantly, while the I_S and density are much less affected. Density, in particular, is a critical attribute for facies classification, ad it relates strongly to the clay content of the formation. It is therefore important to obtain the most accurate estimates possible, which involves the minimization of these leakage artifacts.

In this example, a joint AVO inversion of PP and PS data provides an improvement of facies characterization in the presence of top gas. The gas strongly affects the I_P, which leads to artifacts on the I_S and density values when the PP data is considered alone. When PS data is incorporated, the leakage of the I_P change onto the other attributes is minimized, and the resulting classified facies more accurately match those at the wells.

Background

The inversion algorithm used in this demonstration is a model-based inversion (Hampson et al., 2005). The input data includes angle gathers, the angle-dependent seismic wavelet, and initial low-frequency models of I_P, I_S, and density. The output of the inversion are models of I_P, I_S, and density. Because I_S and density are more susceptible to the influence of noise, stabilizing relationships between I_P and I_S, and between I_P and density are used. There is a tradeoff between the freedom of these parameters to break the trend and the sensitivity to noise in the data.

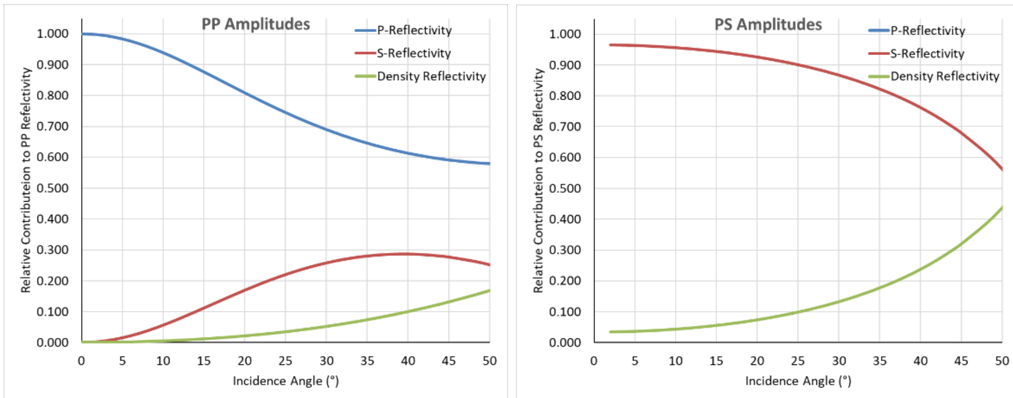

Figure 1 Relative contribution of changes in I_P (blue) I_S (red) and density (green) to reflectivity. The PP amplitudes (left) are less affected by changes in density and I_S than the PS amplitudes (right).

Joint inversion involves inverting two types of data for a common set of model parameters. In this case, inverting PP angle gathers and PS angle gathers for a common model of I_P, I_S, and density. The joint inversion effectively uses the same algorithm as for the PP data alone, with the inclusion of the PS gathers and their AVO behaviour. Assuming that the noise levels in the PS data are similar to the PP data, the addition of the second data set reduces the impact of noise in the process.

The PP and PS data are registered in PP time so that the estimated I_P, I_S, and density models share a common time reference. The first iteration of registration uses the P-wave velocity (v_P) and S-wave velocity (v_S) models to calculate the equivalent PP time (t_{PP}) for a PS time (t_{PS})

$$t_{\mathrm{PP}} = \frac{2t_{\mathrm{PS}}}{v_P\left(\frac{1}{v_P}+\frac{1}{v_S}\right)}.$$

This step is generally a good approximation to register the data and is applicable over the time range defined in the velocity models. However, there are typically discrepancies in the time match due to lateral changes in the velocity that are not incorporated into the velocity models. The second step of the registration uses the alignment of horizons to adjust the registration further.

Analysis

Both PP and PS data followed the same steps for preconditioning prior to inversion. These steps included phase rotation, amplitude normalization, transformation to angle gathers, and residual moveout corrections. The PS data have the weakest amplitudes at near offsets, and are noisier than the PP data in this range.

Registration of the PS data to PP time was done in manner described above. P-wave and S-wave velocity models were built using a total of 25 wells and 4 wells respectively. Two horizons bounding the zone of interest were used for the refinement of the registration, with a smoother applied to both sets of horizons to prevent small amounts of noise from having a large impact on the registration.

The PP data were first inverted on their own using well-based initial modes and three wavelets covering near (0 - 17°), mid (18 - 31°), and far (32 - 44°) angle ranges. The inversion was carried out to a maximum angle of 44°. Figure 2 shows the inverted results along with well logs corresponding to the property shown. Wells with top gas present are indicated. There is a very good match between the I_P estimate and the well logs. The density, however, shows a clear under-estimation of the properties where the gas cap is present. Although there is limited dipole data to calculate I_S for the gas cap, the same low-impedance zone is seen to an extent that is not expected simply by the removal of bitumen.

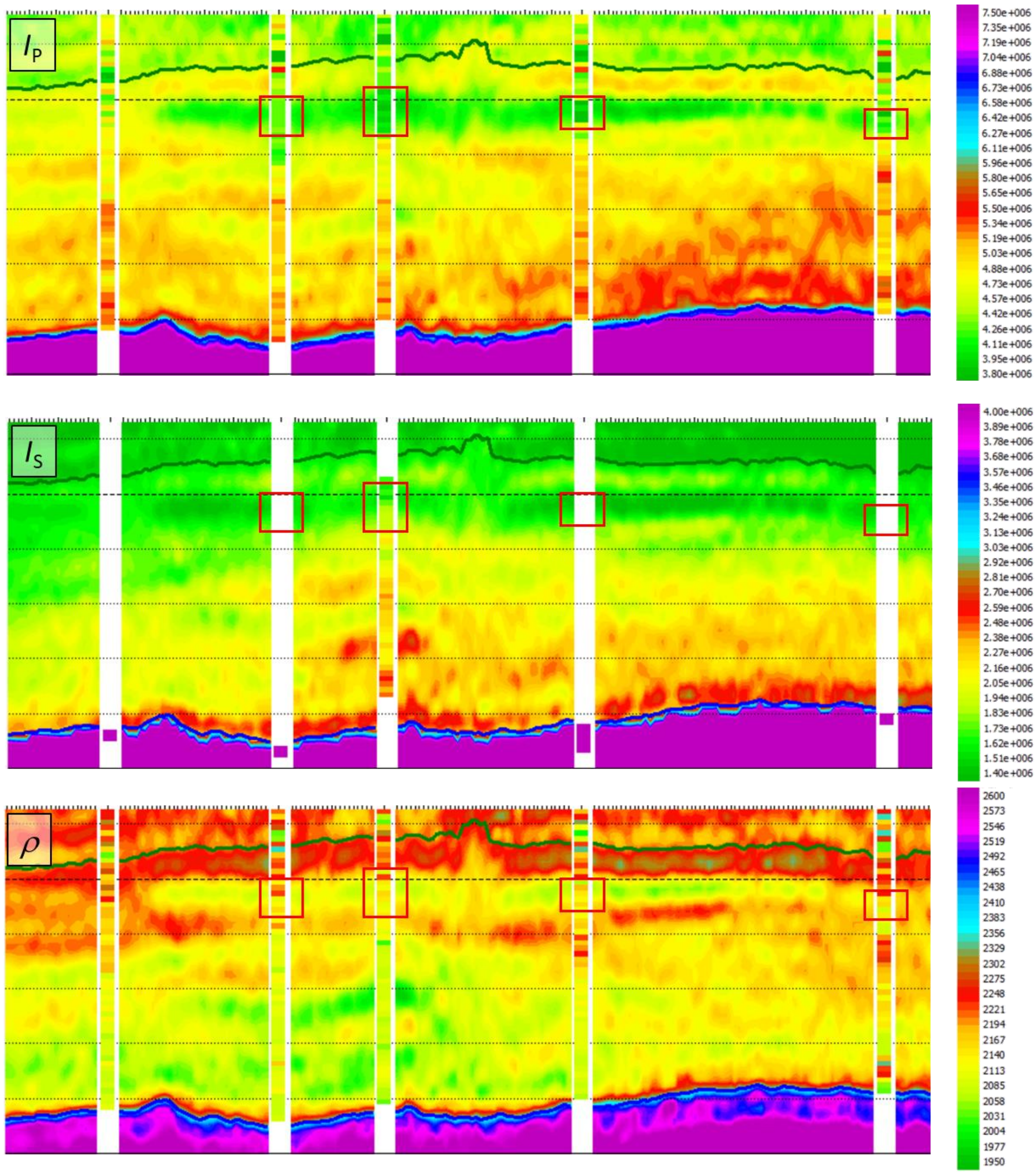

Figure 2 Inverted volumes of I_P (top), I_S (middle), and density (bottom) for the PP data inversion. Wells with a gas cap are indicated in red boxes. The gas cap present on the I_P volume also imprints on the other two attributes.

The joint inversion followed the same procedure as the PP inversion but included the PS angle gathers. These were extended to 54°, because of its inherent increase in PS incidence angles given the same offset as a PP trace. The PS prestack wavelets were similarly extracted from the PS angle gathers over three different angle ranges. Figure 3 shows the inverted results along with well logs corresponding to the property shown. There is still a very good match between the I_P estimate and the well logs, however there is a distinct improvement in the match with the density volume, and neither the density nor I_S volume show the gas zone artifact.

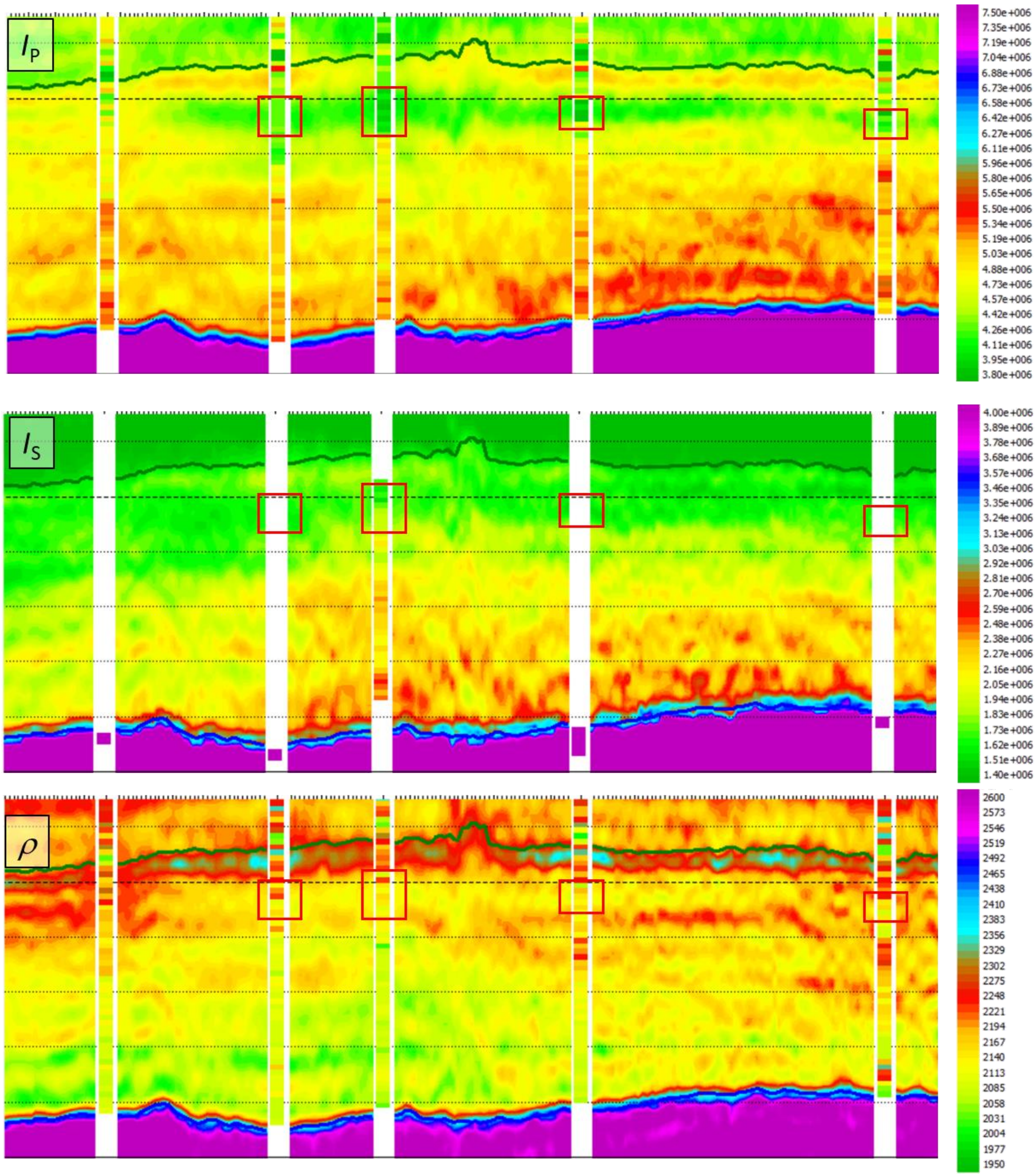

Figure 3 Inverted volumes of I_P (top), I_S (middle), and density (bottom) for the joint PP-PS data inversion. Wells with a gas cap are indicated in red boxes. The gas cap present on the I_P volume is no longer dominant on the other two attributes.

Conclusions

The use of PS data in a joint inversion eliminates the artifacts on S-impedance and density volumes caused by an extremely low P-impedance gas cap. This improvement in the estimate allows for better facies classification, which was otherwise obscured by the artifacts.

References

Hampson, D.P., B.H. Russell, and B. Bankhead, 2005, Simultaneous inversion of pre-stack seismic data: 75th Annual Meeting, SEG, 1633-1637.