Simultaneous AVO Inversion to P Impedance and Vp/Vs

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ABSTRACT

Summary

In many areas, rock properties which control seismic response are closely related to critical reservoir parameters such as porosity and lithotype. Using seismic and well log data to estimate seismic rock properties directly, provides a useful bridge to reservoir parameter estimation. Seismic amplitude variations with offset contain information on both the compressional and shear properties of rock as well as density. We simultaneously invert multiple offset P-P partial angle or offset stacks to these properties. The outcomes are volumes of P Impedance (Ip), Vp/Vs and density. They can be interpreted together or transformed to other geophysical parameters which might more optimally discriminate between facies. Accurate density inversions require high angle input data. When this is not available, the inversion can be constrained to have the density character follow that of Ip.

For each input partial stack, a unique wavelet is estimated. 3D models of Ip, Vp/Vs and density are also computed from the available logs. As in post-stack inversions, only the low frequencies from these models are used to complete the low frequency band of the final inversion. They in no way affect the higher inversion frequencies and the wells can be effectively considered to be "blind". All the models, all the partial stacks and all the wavelets are input to a single inversion procedure. There are no separate inversions of P and S components. This enables the inversion to effectively compensate for offset-dependent phase, bandwidth, tuning and NMO stretch effects.

The analysis of the final inversion is most easily done in cross-plot space. Cross-plots of Vp/Vs vs P Impedance (for example) from logs often show the reservoir to be separable from other facies. Comparable cross-plots can be made from the inversion data, yielding a calibrated interpretation. Viewing the results in 3D gives a unique reservoir perspective.

Introduction

The analysis of P-wave full-stack seismic reflection data is non-unique in many exploration situations. One example is the Lower Cretaceous Glauconitic-incised valleys of Central Alberta. In the Blackfoot area, three different incised-valleys are present: Upper, Lithic, and Lower. Only the Upper and Lower valleys are prospective (Dufour et al. 2002). Here, differentiation of prospective porous sandstone and non-productive shale is problematic due to the similarity in their P impedances. Modelling has shown that discrimination of sandstone and shale should be possible with the addition of elastic information. The elastic effect should also translate to a P-wave AVO effect. We depart from traditional AVO analyses in that seismic inversion to impedances is done simultaneously using a set of P-wave partial-offset stacks. The outputs of the inversion are volume estimates of P impedance, Vp/Vs and density.

Method

Well log cross-plotting and modelling can provide an understanding of the expected angle-dependent effects in the seismic reflection data. The results (*Fig. 1a*) show that the Glauconitic gas bearing porous sandstone should exhibit anomalously high S Impedance when compared to shales with the same P Impedance. This implies a relatively low values of Vp/Vs for these sandstones (*Fig. 1b*). The figures show that measurements of P Impedance alone, could not differentiate between sandstones and shales.

To compensate for low frequencies lost during seismic acquisition, we build a 3D geologic model of Ip, Vp/Vs and density. The model is defined by the interpreted horizons and is populated by well logs, which have been integrated to time and drift-corrected to tie the seismic. The raw inversion would be poorly constrained at frequencies below the seismic band and we replace them with information from the model. Nothing is used from the model within the seismic band.

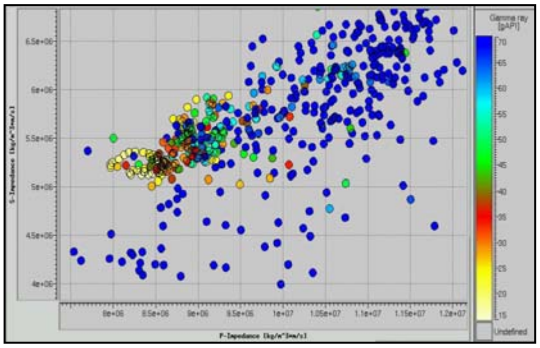

Fig. 1a. S Impedance is plotted vs P Impedance for the Glauconitic in the 08-08 well. The data points are coloured by Gamma Ray. Note that the sandstones indicated by the low gamma values have higher S Impedances than do shales with the same P Impedances. The lowest Ip values are gas-charged sandstones

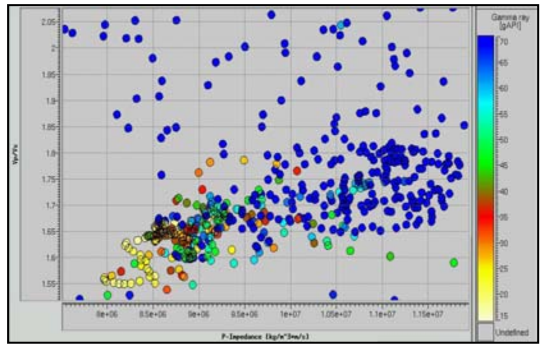

Fig. 1b: The same data from Fig. 1a is plotted for Vp/Vs vs P Impedance. The sandstones manifest as relatively low Vp/Vs.

Briefly, the inversion algorithm works by first estimating angle-dependent PP reflectivities for the input partial stacks. Next these are used with the Zoeppritz equations to find band-limited elastic reflectivities. These are in turn merged with their low frequency counterparts from the model and integrated to elastic properties. This approximate result is then improved in a final inversion for Ip, Vp/Vs and density, subject to various hard and soft constraints. One constraint can control the relation between density and compressional velocity. This is necessary when the range of angles, is not great enough to be diagnostic of density.

An important part in the inversion procedure is the estimation of the seismic wavelets. This is accomplished by computing a filter which best shapes the angle-dependent well log reflection coefficients in the region of interest to the corresponding offset stack at the well locations. Reflection coefficients are calculated from P-sonics, S-Sonics and density using the Zoeppritz equations. The wavelets, with amplitudes representative of each offset stack, are input directly into the inversion algorithm. Since a different wavelet is computed for each offset volume, compensation is automatically done for offset-dependent bandwidth, scaling and tuning effects.

No *a priori* knowledge of the elastic parameters and density beyond the solution space defined by any hard constraints is provided at the well locations. This makes comparison of the filtered well logs and the inversion outputs at these locations a natural quality control. As discussed above, the lowest frequencies from the inversion are replaced with information from the geologic model since they are poorly constrained by the seismic data. This is the *absolute* inversion. A second *relative* inversion is also computed which contains impedance information in the seismic band only. These data are uninfluenced by the model and any assumptions made to construct it.

Results

The north-west half of the Blackfoot 3C-3D survey was shot over a Glauconitic incised-valley. The data consists of 115 lines and 83 CMP's on 30*30 m bins. Log suites from 11 wells were available, 4 of which included dipole sonics. In the present analysis, we used two offset stacks. In the region of interest, they represented angles ranges from 0-19 deg and 11-36 deg. This amount of angle overlap and the large range of the angles is not optimum. We would usually prefer smaller ranges and more stacks.

The estimated wavelets were both near zero phase, varying mostly in their frequency content. They were input to the simultaneous inversion which produced in turn, volumes of P Impedance Vp/Vs and density as outputs. The density was poorly constrained by the input data and in the final product it was constrained to the density-P sonic relation observed in the logs. The presence of gas bearing porous sandstones was detected by making a series of stratigraphy-conformable maps of Ip and Vp/Vs from these outputs

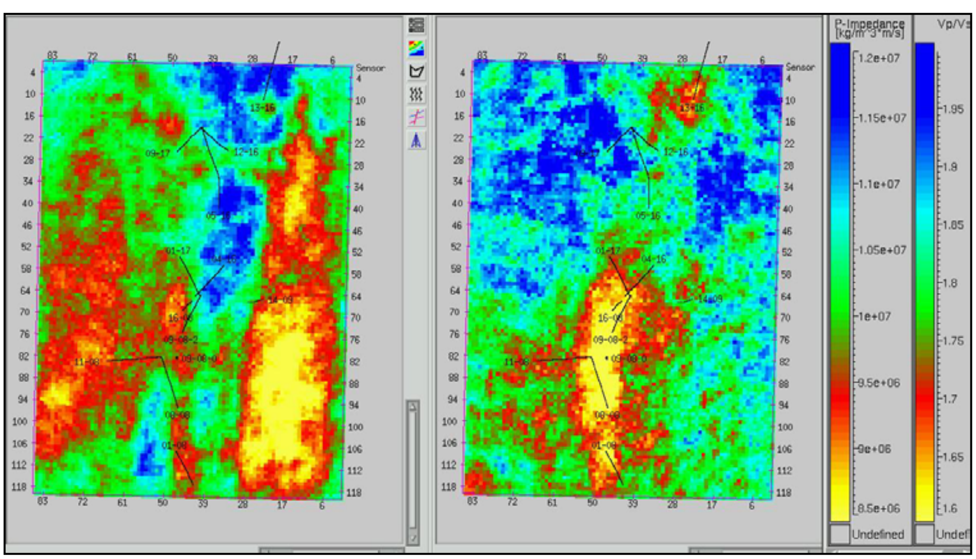

Fig. 2. Maps of the P Impedance (left) and Vp/Vs (right) within the Upper valley. In the left figure, low compressional impedances can result from either sands or shales. In the right figure the high

rigidity of the valley sands produces low values of Vp/Vs. These are distributed in a north-south direction in the centre of the right figure along the trend of wells.

Fig. 2 shows one set of these maps at the Upper valley level. The Ip map (left) shows low impedances due to both off-valley shales (regional Ostracod shale) and valley sandstones and shales. This is a result of the P-wave or compressional seismic data responding to both the Lame' parameters, Lambda (pure incompressibility) and Mu (pure rigidity), as pointed out by Goodway (1997). The valley complex has been better defined in the Vp/Vs map (right). Here, the more rigid valley sandstones manifest as low Vp/Vs.

Fig. 3 shows a partial volume of Vp/Vs with the Upper Valley on the near corner and the Lower Valley beneath it. They are separated by the Lithic valley with higher Vp/Vs. Figure 4a is a cross-plot of Ip and Vp/Vs from the inverted field data. The blue rectangle has been used to isolate the expected region where Valley sandstones should lie. In Figure 4b, we have shown those regions in 3D perspective. The Upper Valley and portions of the Lower Valley are clearly visible.

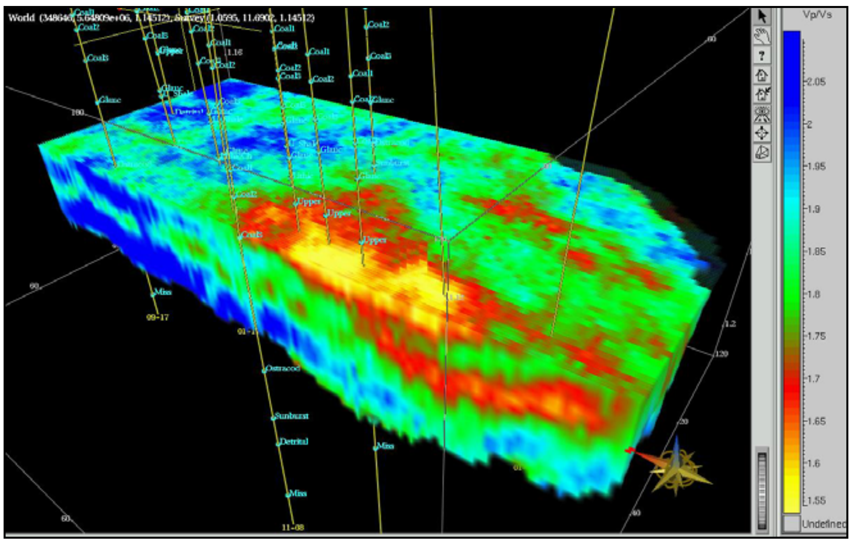

Fig. 3: The Vp/Vs volume from the inversion is shown in 3D perspective view. The Upper Valley manifests as low Vp/Vs along the upper edge of the volume. The Lower Valley can be seen beneath it. They are separated by the non-productive Lithic Valley.

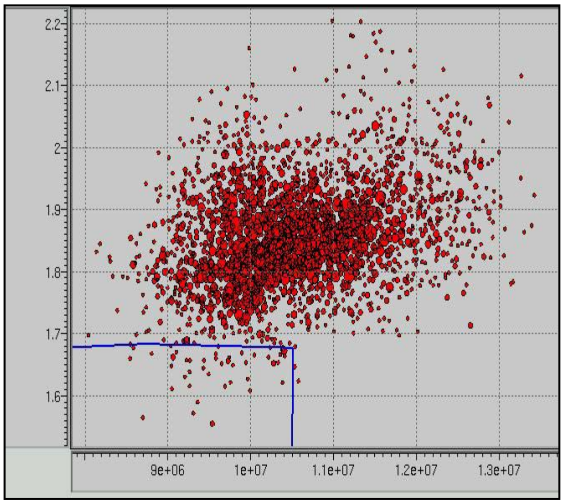

Fig. 4a:This cross-plot of Vp/Vs vs Ip was made from the inversion. The blue rectangle highlights the region where log analysis indicates that the Upper Valley facies should be found.

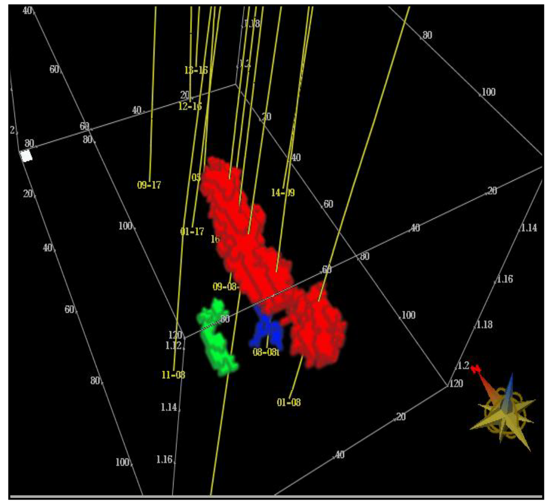

Fig.4b:Continuous regions in 3D space with P Impedance and Vp/Vs pairs within the blue rectangle in Fig. 4a. The log cross-plot in Fig.1 suggest that the region is sandstone.

Conclusions

We have shown that simultaneous inversion of seismic offset volumes to compressional and Vp/Vs can be used to improve the imaging and interpretability of Glauconitic incised-valley litho-facies and discriminate between gas-charged sandstones and shale.

Acknowledgements

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