Three-Dimensional Prestack Inversion, Lobo Trend, South Texas

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Summary

We demonstrate the difficulty with mapping a Lobo (Paleocene) hydrocarbon reservoir directly from stacked seismic data. A strong response in the stacked volume is ambiguous, indicating either a large impedance contrast or a contrast in Poisson's ratio. That is, stacking of reflection amplitudes over offset (or reflection angle) incorporates reflections from impedance perturbations with those due to a change in Poisson's ratio.

Dipole sonic log data indicate Poisson's ratio, but not impedance, distinguishes this particular Lobo reservoir from shale. The hydrocarbon reservoir impedance is similar to that of encasing shales. On the other hand, Poisson's ratio decreases over 30% in the reservoir sand.

In this paper, we invert the prestack amplitudes of a 3-D data volume to distinguish perturbations in impedance from Poisson's ratio perturbations. We may, therefore, recognize and map this Lobo reservoir as a decrease in Poisson's ratio accompanied by little or no change in impedance.

Historical Perspective

The Upper Paleocene to Eocene Wilcox Lobo trend is a major low-permeability natural gas producer of the Texas Gulf Coast, already yielding approximately 4.5 TCF of gas. Both structural and stratigraphic complexity can complicate exploration and exploitation of the Lobo trend. Multiple episodes of faulting and erosion can make sand correlation difficult from fault block to fault block.

Previous Lobo exploration tools consisted of open-hole logs and dipmeter data combined with 2-D seismic data. These techniques were useful for exploring large slump block features. Over time the success of these techniques diminished as the size of potential targets decreased.

Continuous improvements in 3-D acquisition and processing over the last ten years have positively impacted Lobo exploration and development success. Current 3-D stack volumes resolve much smaller slump blocks. This improved structural definition helps identify acreage that yields superior drilling results.

Modern dipole sonic log measurements through the Lobo section point to Poisson's ratio as a distinguishing reservoir property. Prestack imaging and inversion thus represent a logical next step in the evolution of Lobo exploration and exploitation technology.

In this paper we directly image a Lobo reservoir by inverting amplitudes before stack. A signature decrease in Poisson's ratio tracks the reservoir across faulting.

Lobo Petrophysical Evidence

The well data of Figures 1 and 2 make the case for prestack, rather than poststack, inversion in this area of the Lobo trend. Impedance alone fails to discriminate these Lobo hydrocarbon reservoirs from surrounding shale. On the other hand, Poisson's ratio decreases over 30% in the reservoir intervals.

Prestack Process

One can invert throughout the 3-D volume for perturbations in Poisson's ratio, along with impedance perturbations. This inversion requires reflection amplitudes from different angles, incident on the same image point in the volume.

Figures 3 and 4 give time slices of the resulting inversion output. These pictures show, respectively, an image of the perturbations in impedance and Poisson's ratio. The Lobo reservoir at 9650 ft, for example, exhibits a large drop in Poisson's ratio but no impedance signature. See Figure 5 for a color bar.

Though this prestack inversion result is consistent with log data (Figures 1 and 2) it was not constrained by log data. This inversion output derives entirely (seismic wavelet extraction excepted) from prestack amplitude data. We invert amplitudes via an expansion of the form

$$R(\theta) = A + B\sin^2\theta + C\sin^2\theta\tan^2\theta + \mathrm{K} \qquad (1)$$

Equation (1) expresses reflectivity R as a function of incidence angle θ. One derives this
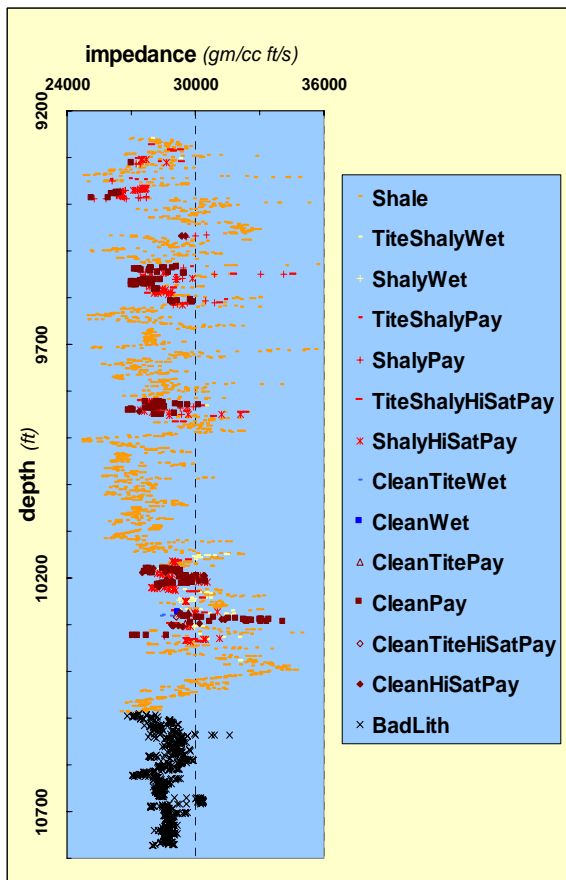

FIG.1. P-wave impedance well log, coded according to log-derived lithology. The legend provides the code. Lobo hydrocarbon reservoirs are centered at four depths: 9560 ft, 9840 ft, 10200 ft, 10300 ft. Impedance does not distinguish Lobo hydrocarbon lithologies.
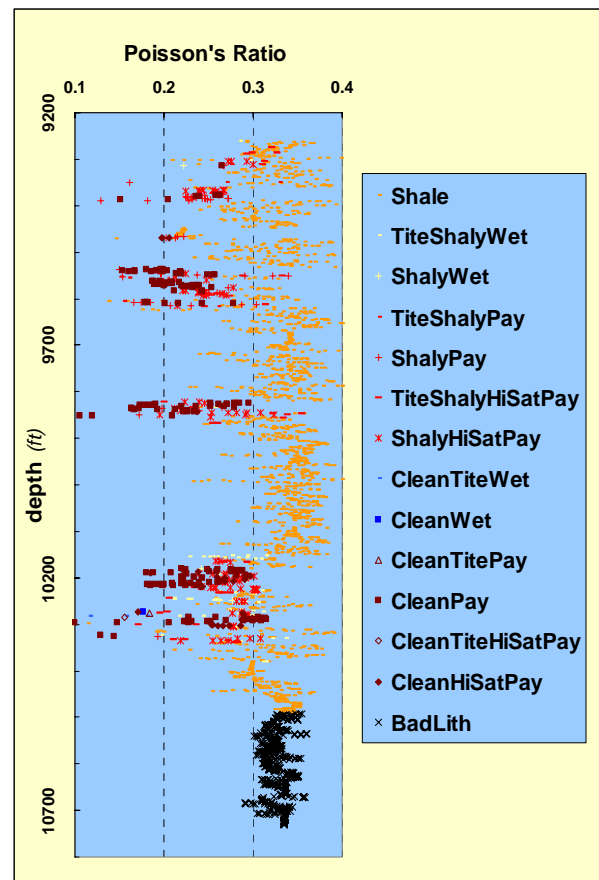
FIG.2. Poisson's Ratio well log, coded according to log-derived lithology. The legend provides the code. Poisson's Ratio discriminates Lobo hydrocarbons from much of the nonpay section, particularly shale.

equation following the approaches taken by Bortfeld (1961), and Aki and Richards (1980). Shuey (1985) presented a similar approximation.

Equation (1) also sets the goal of our entire prestack data processing sequence: *preserve this functional relationship between reflections recorded at different angles, while attenuating signals that do not conform to this reflectivity model.* This is, of course, "easier said than done". In the opinion of the first author, this processing goal encompasses most of the expertise required for robust prestack inversion.

Parameter A in equation (1) equates to a perturbation in impedance under the assumption of small perturbations.

Parameter B is the source of information on Poisson's ratio. It depends in part on the product of perturbations in both impedance and Poisson's ratio.

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We truncated equation (1) before parameter C for the inversion of Figures 3 and 4. One often neglects this third term for incidence angles less than 25°, the maximum angle preserved through our prestack processing sequence. This term in the expansion is fourth order in θ (for small θ).

Lobo Stack Comparison

Equation (1) thus makes it clear that stacking of reflection amplitudes over angle incorporates reflections from impedance perturbations with those due to a change in Poisson's ratio. The A-term contributes the former, the B-term the latter. A strong response in the stacked volume is therefore ambiguous in terms of rock properties.

Figures 6-8 taken together document this ambiguity for the Lobo section. The band of prominent reflections in the stack data, just above 1.8 s, originates mainly from impedance perturbations. The event marked by an arrow in these figures is an exception.
Inversion before stack attributes this event to low Poisson's ratio (Figure 6). This
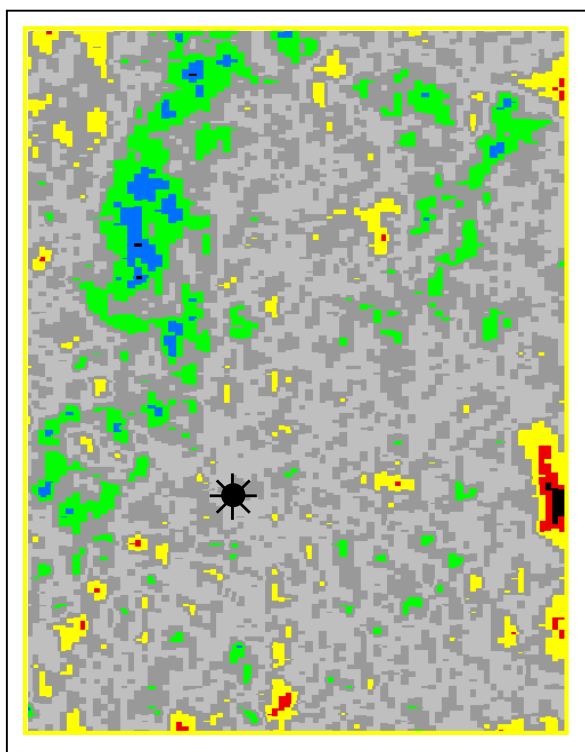

FIG.3. A time slice through the impedance perturbation cube from 3-D prestack inversion. The well symbol shows the location of the well of Figure 1. This slice intersects the reservoir centered at a depth of 9560 ft. Impedance from inversion does not reveal this Lobo reservoir, consistent with impedance log data in Figure 1.
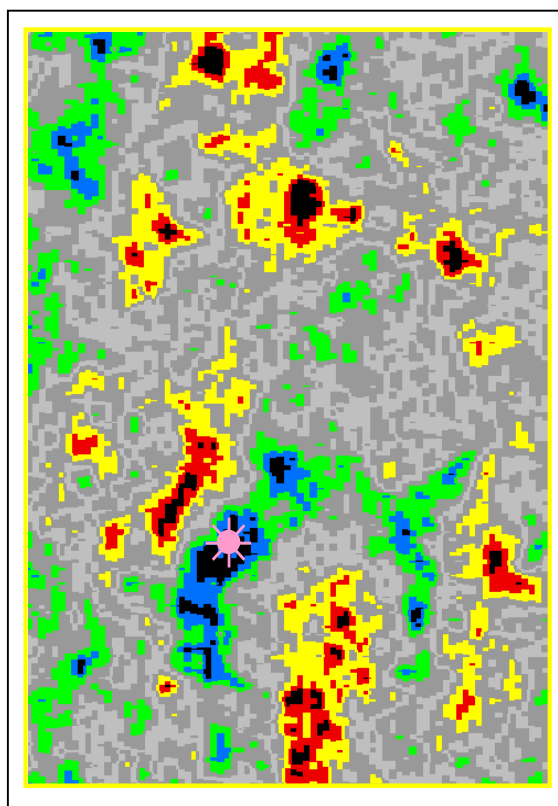

FIG.4. A time slice through the Poisson's Ratio perturbation cube from 3-D prestack inversion. The well symbol shows the location of the well of Figures 1 and 2. This slice intersects the reservoir centered at a depth of 9560 ft. Prestack inversion indicates an anomalous (large) decrease in Poisson's Ratio for this Lobo reservoir. This is consistent with Poisson's Ratio log data in Figure 2.

signature gives a direct image of the reservoir, mappable away from well control and across fault terminations. On the other hand, this Lobo hydrocarbon reservoir is virtually transparent by way of impedance (Figure 8).

Conclusions

Multiple episodes of faulting and erosion in the Lobo trend can frustrate seismic correlation and mapping. Moreover, these Lobo reservoirs often produce a faint expression in the stack volume, especially compared to reflections from large impedance contrasts.

Dipole sonic log data reveal the petrophysical key to this problem. These Lobo reservoirs are reflective at non-zero incidence angles via a decrease in Poisson's ratio. We may, therefore, directly image and map the reservoir by inverting prestack data for perturbations in Poisson's ratio. Inversion for impedance shows little or no contrast at the reservoirs, as expected.

References

Aki, K., and Richards, P.G., 1980, Quantitative seismology: Theory and methods: W.H. Freeman and Co.

Bortfeld, R., 1961, Approximation to the reflection and transmission coefficients of plane longitudinal and transverse waves: Geophys. Prosp., **9**, 485-503.

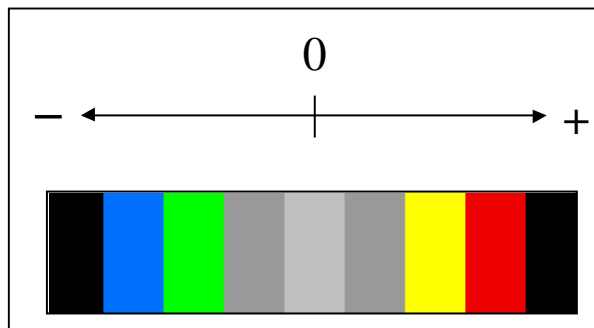Shuey, R.T., 1985, A simplification of the Zoeppritz equations: Geophysics, **50**, 609-614.

FIG.5. Color bar for Figures 3,4,6,7, and 8. Colors in Figures 3 and 4 indicate, respectively, the sign and magnitude of perturbations in impedance and Poisson's Ratio. These perturbations are with respect to background values. Colors in Figure 6 signify the sign and magnitude of reflection amplitudes.
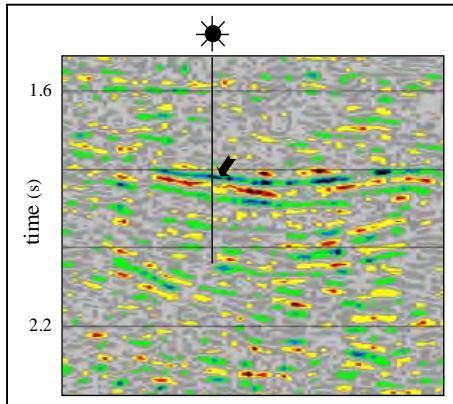
FIG.6. An inline slice through the Poisson's Ratio perturbation cube from 3-D prestack inversion.
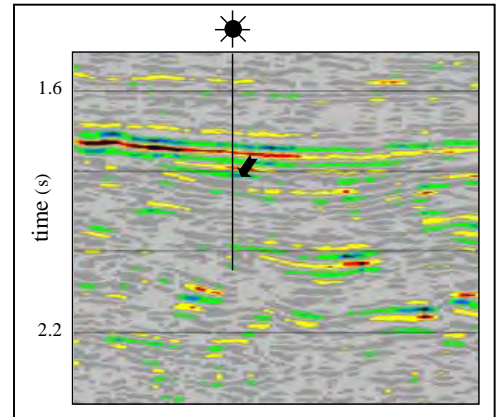

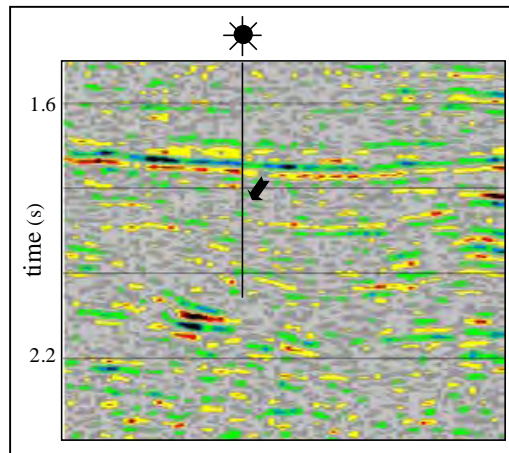FIG.7. An inline slice through the amplitude stack cube.

FIG.8. An inline slice through the impedance perturbation cube from prestack inversion.