GC Rock Physics and the Case for Multicomponent Seismic Data*

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General Statement

Examples of P-P and P-SV seismic images of deep geologic targets across the northern shelf of the Gulf of Mexico (GOM) are illustrated in Figure 1, with the P-SV data *warped* to P-P image-time coordinates. This *time warping* is a first-order depth registration of P-P and P-SV images, implemented by using an averaged VP/VS velocity ratio function for the area to adjust P-SV image time to P-P image time.

This first-order adjustment of P-SV image time to P-P image time is sufficiently accurate to allow equivalent geology to be identified in side-by-side comparisons of P-P and P-SV data. Comparing the seismic responses at the primed and unprimed number locations in each image space shows that each elastic wave mode provides different – but equally valid – sequence and facies information about subsurface geology, which is a fundamental principle of elastic wavefield stratigraphy.

P-P Images vs. P-SV Images

Structural features A and B (Figure 1) are interpreted to be depth equivalent. The time-warping process positions A and B in time-warped P-SV space to within 100 ms of their positions in P-P image space. A salt structure blanks out both P-P and P-SV images approximately midway between CDP coordinates 19,600 and 21,000. Features 1 through 4 on the P-SV image indicate a cyclic depositional process that is not obvious in the P-P image (1’ through 4’).

Feature 5 is an example of P-SV data showing strata that are not present in the P-P data (position 5’). Feature 6 is an example of the P-P mode providing a better image of high-dip strata than does the P-SV mode (event 6’) along this particular profile. On other profiles in the area, the P-SV mode often images high-dip strata better than does the P-P mode.

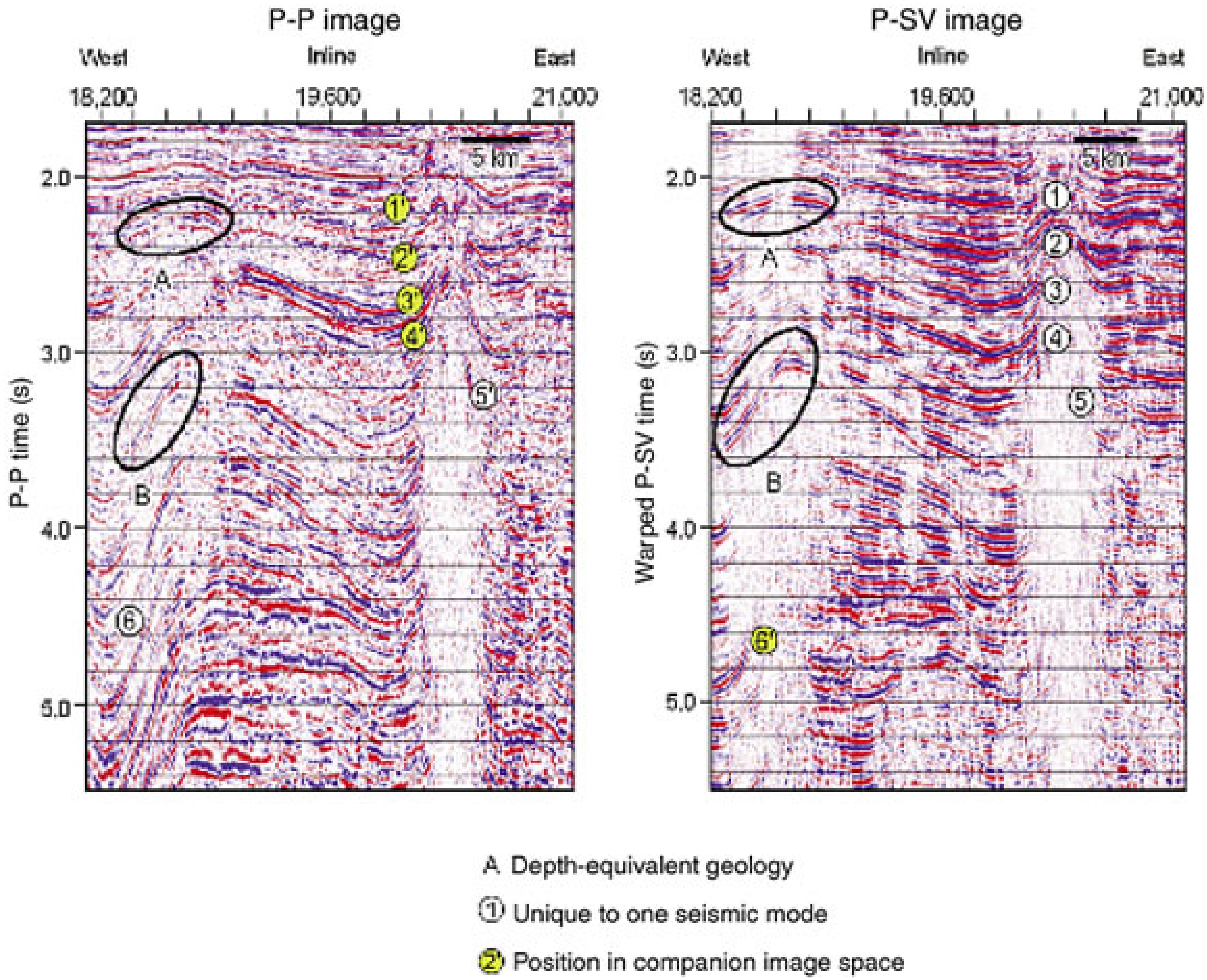

Figure 1. Depth-equivalent P-P and P-SV images of deep Gulf of Mexico geology. A and B define depth-equivalent geology. Numbers 1, 2, … indicate a sequence or a facies in one image space that is not seen in the companion image space. Prime numbers 1, 2, … show where numbered sequence or facies should appear in the companion image space.

Application of Rock-Physics Theory

Rock-physics theory helps us understand why these P-P and P-SV reflection images are both correct depictions of deep geology, and yet they still have the spectacular differences illustrated by features 1 through 5. A key concept to realize is that the GOM rocks imaged in Figure 1 have a significant amount of clay.

Laboratory analysis of GOM core samples by Han et al. (1986) has led to the relationships between P-wave velocity (V_P), S-wave velocity (V_S), porosity, and clay content that are noted for layer 2 of the stratigraphic model in Figure 2. These rock-physics equations are important because:

1) They are based on laboratory measurements made on real rocks.
2) The rock samples come from geology imaged by the seismic data in Figure 1.
3) The rocks that were analyzed in the laboratory had a wide range of clay content.

To illustrate the value of this rock-physics theory we used the simple, two-layer Earth model in Figure 2 to represent a typical reservoir target beneath the northern shelf of the GOM. The upper layer of this model was kept constant, with its petrophysical values defined by the equations in the figure, whereas clay content and pore fluid were varied in the lower layer.

Resulting P-P and P-SV reflectivities from the two-layer interface, assuming a porosity of 20 percent for the sandstone reservoir, are displayed in Figure 3. These reflectivity curves provide an important message concerning P-P and P-SV images of siliciclastic rocks that have spatially variable clay content:

1) For certain clay-content concentrations (c), the target layer is practically invisible to the P-P seismic mode, but generates a strong P-SV reflection. For example, when c = 20 percent, P-P reflectivity is small and changes algebraic sign near an incidence angle of 20 degrees for both gas-filled and brine-filled sands. These two reflectivity characteristics are classic examples of a reflection event that is minor – and probably invisible – in a final-processed P-P image. In contrast, P-SV reflectivity for each sand facies (gas or brine) when c = 20 percent is reasonably robust and has a constant algebraic sign at all incidence angles. This P-SV reflectivity behavior should create a significant P-SV reflection event. Cyclic clay deposition of this concentration level appears to be a strong contributor to the different appearances of P-P and P-SV events labeled with primed and unprimed numbers 1 through 4.

2) At other clay-content concentrations, the target layer is a poor P-SV reflector but a robust P-P reflector. For example, when c=40 percent, P-P reflectivity is 6 to 10 percent across the total angle range for a gas-filled sand (left) and 3 to 5 percent for a brine-filled sand (right). In contrast, P-SV reflectivity does not reach a 2 percent value for either sand facies until the incidence angle is 30 degrees to 45 degrees. This level of clay concentration will produce bold P-P reflections and weak P-SV reflections, similar to the image windows between primed and unprimed numbers 3 and 4.

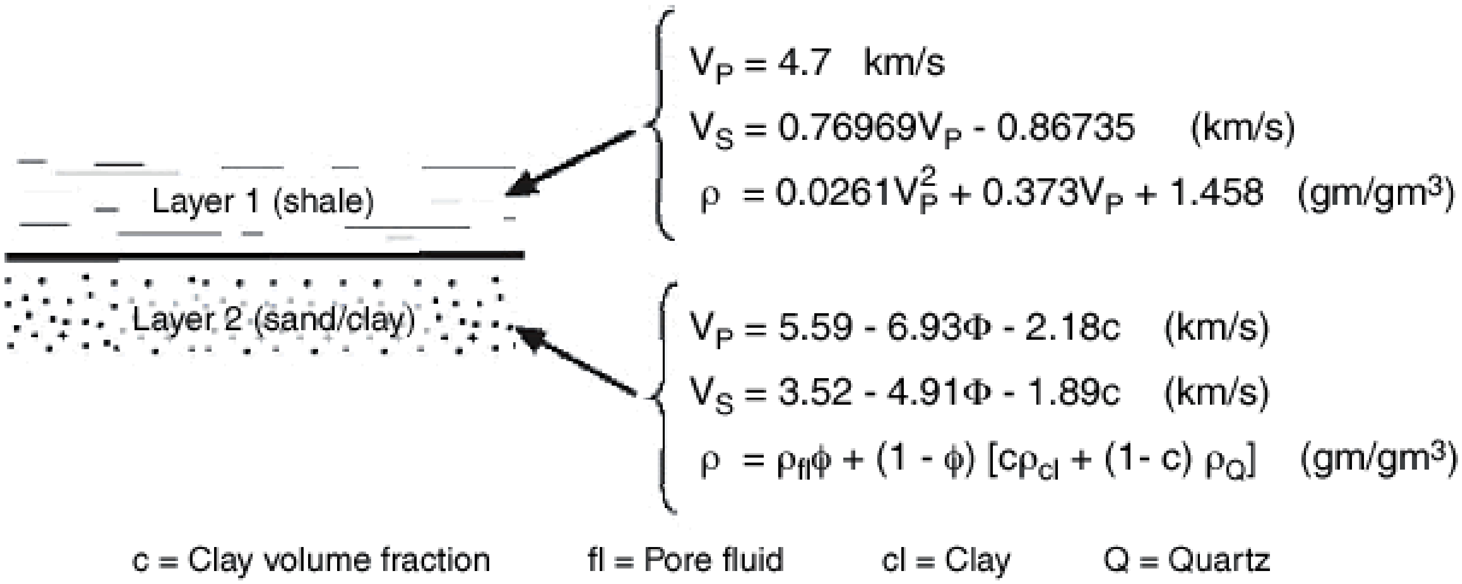

Figure 2. Earth model used to demonstrate the effect of clay content on P-P and P-SV reflectivities. Equations used to specify the properties of Layer 1 (shale) come from Castagna et al. (1993). Those used to specify the properties of Layer 2 are from Han et al. (1986).

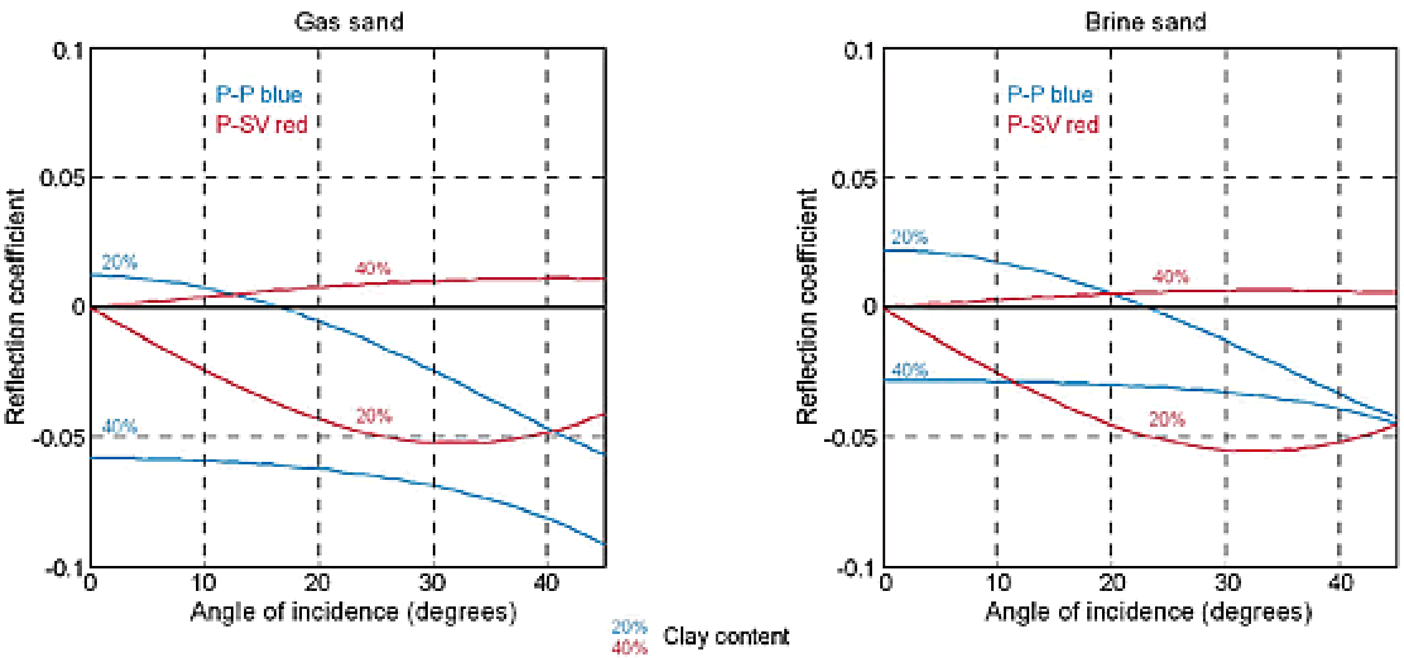

Figure 3. P-P and P-SV AVA behaviors for varying clay content in a target layer. Layer 2 is assumed to be a sand unit with a porosity of 20 percent. Pore fluid (left) is 100 percent gas; pore fluid (right) is 100 percent brine.

Conclusion

Variations of clay content in GOM sandstones can thus cause certain intervals of depth-registered P-P and P-SV data to have P-SV seismic sequences and facies that differ from P-P seismic sequences and facies – and yet both the P-P image and the P-SV image are correct images of the geology. Features 1 through 5 on the data displayed in Figure 1 are examples of such reflectivity behaviors.

These differing P-P and P-SV sequences and facies provide a deeper and richer insight into rock physics and geology than do seismic sequences and facies produced by single component seismic data. Explorationists working in areas having clay-dominated siliciclastic rock units should consider utilizing multicomponent seismic data to evaluate prospects rather than relying on P-wave data alone.

References

Castagna, J.P., M.L. Batzle, and T.K. Kan, 1993, Rock-physics – the link between the rock properties and AVO response, *in* Castagna, J.P., and Backus, M.M., eds., Offset-dependent reflectivity theory and practice of AVO analysis: Tulsa, Society of Exploration Geophysicists.

Han, De-hua, A. Nur, and Dale Morgan, 1986, Effects of porosity and clay content on wave velocities in sandstones: Geophysics, v. 51, p. 2093-2107.

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