A physical model investigation of P and S wave azimuthal anisotropy on transmission

Khaled Al Dulaijan*, Gary Margrave, and Joe Wong
kaldulai@ucalgary.ca

ABSTRACT

Information related to fracture orientation and intensity is vital for the development of unconventional hydrocarbons, such as tight sand gas and shale gas. Numerical modeling provides a valuable tool for geophysicists to test and validate their methodologies that provide them with information about reservoirs. Fractures make numerical modeling more complicated and introduce complexities that might even require geophysicists to validate their numerical models before using them to test and validate their methodologies. Alternatively, physical modeling provides a unique opportunity to test, validate, and develop methods for characterizing fractured reservoirs. This report utilizes seismic physical modeling for fracture characterization, is a continuation to previous work conducted within CREWES, and is an in-progress work.

A two-layer model was built using vertically laminated Phenolic overlaid by Plexiglas to represent a fractured reservoir overlaid by an isotropic overburden. Three 9-component common-receiver gathers were acquired over that model in the laboratory. For each gather, 90 shot locations are distributed along a circle of radii 250 m, 500 m, or 1000 m and separated by 4o to cover all azimuths. P-wave first-arrival times were analyzed on all three gathers and fracture orientation was predicted. S-wave analysis suggests an error in the polarization direction of the horizontal transducers. An Alford rotation was applied to the four horizontal components and successfully minimized energy on components other than those two that have fast S wave and slow S wave.

FIG. 1. A physical model consisting of a Phenolic layer under a Plexiglas layer, and representing a fractured reservoir overlaid by isotropic overburden. Laboratory to field scale is 1:10,000 in both length and time. Scaled thicknesses of Plexiglas and Phenolic layers are 480 m and 450 m respectively.

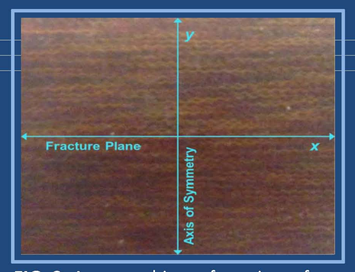

FIG. 2. A zoomed-in surface view of laminated Phenolic layer. Lamination direction is along x-axis and represents the reservoir fracture plane. Axis of symmetry is along y-axis.

	P-wave velocity (m/s)	S-wave velocity (m/s)	Density (g/cc)
Plexiglas	2745	1380	1.19
Phenolic	3570/2900	1700/1520	1.39

Table 1. Velocities and densities of Plexiglas and Phenolic.

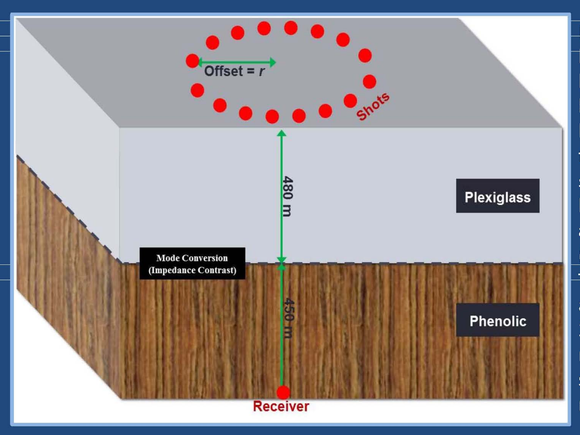

FIG. 3. Acquisition layout. One receiver location is located at the bottom of the Phenolic layer and centered at the middle of its surface. 90 shot locations are distributed along a circle of radius (r) and separated by 4°. Three receiver gathers are acquired with r = 250 m, 500 m and 1000 m. 3-C receiver and 3-C source yield into 9-C receiver gathers.

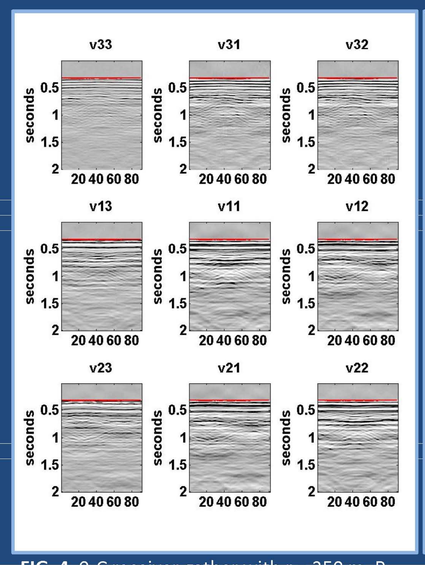

FIG. 4. 9-C receiver gather with r = 250 m. P-wave first arrival times are indicated by red. The horizontal axis is the trace number. Traces 1 to 90 represent azimuth angles from 0° to 360° with a 4° increment.

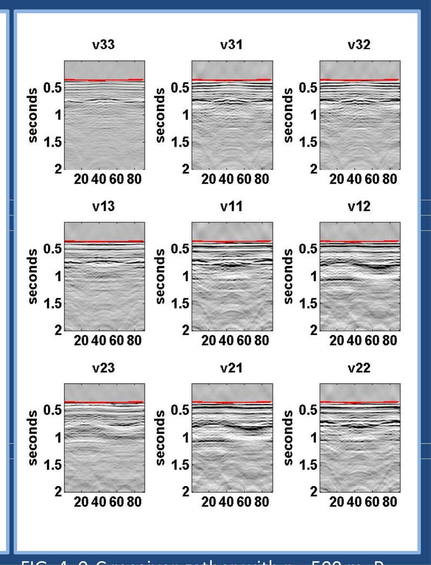

FIG. 4. 9-C receiver gather with r = 500 m. P-wave first arrival times are indicated by red. The horizontal axis is the trace number. Traces 1 to 90 represent azimuth angles from 0° to 360° with a 4° increment.

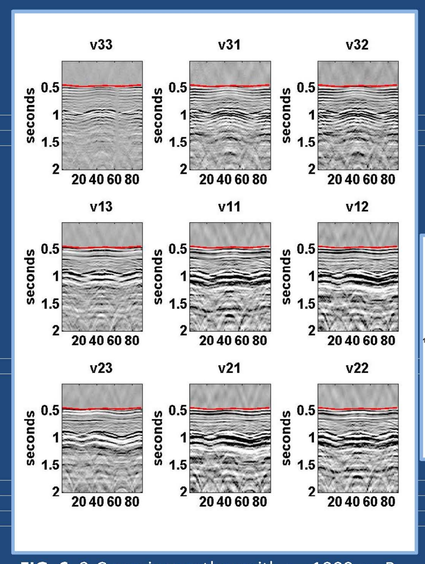

FIG. 6. 9-C receiver gather with r = 1000 m. P-wave first arrival times are indicated by red. The horizontal axis is the trace number. Traces 1 to 90 represent azimuth angles from 0° to 360° with a 4° increment.

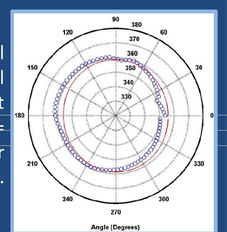

FIG. 7. Elliptical fitting of first-arrival times for the first receiver gather (r = 250 m). The minor axis is at 5°.

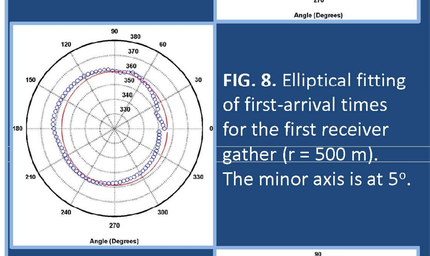

FIG. 8. Elliptical fitting of first-arrival times for the first receiver gather (r = 500 m). The minor axis is at 5°.

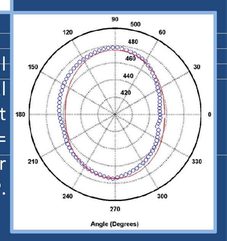

FIG. 9. Elliptical fitting of first-arrival times for the first receiver gather (r = 1000 m). The minor axis is at 1°.

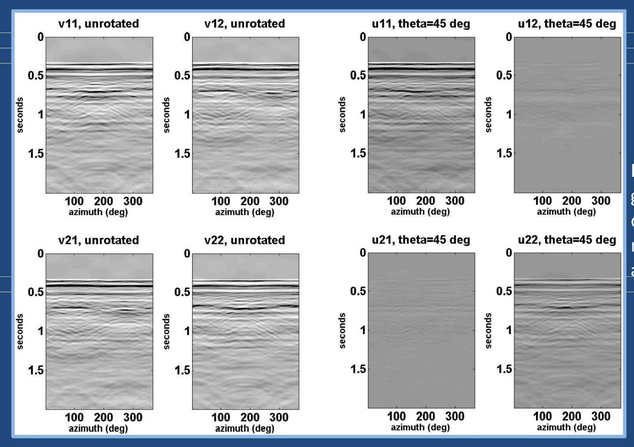

FIG. 10. 1st receiver gather: 4 Horizontal components before rotation (left) and after rotation (right).

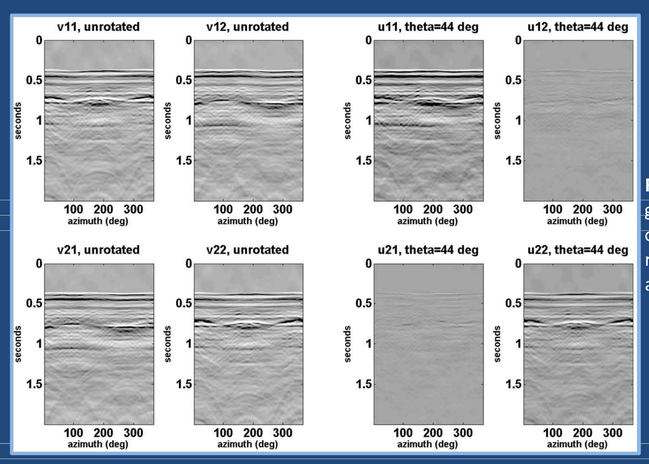

FIG. 11. 2nd receiver gather: 4 Horizontal components before rotation (left) and after rotation (right).

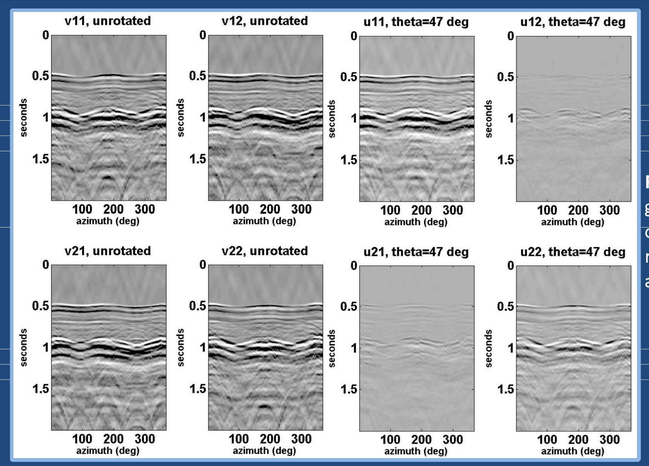

FIG. 12. 3rd receiver gather: 4 Horizontal components before rotation (left) and after rotation (right).

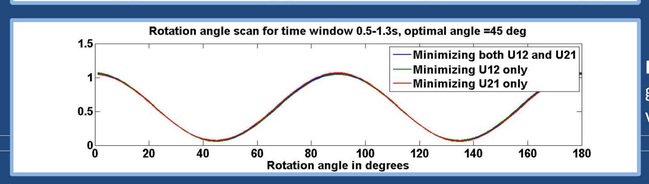

FIG. 13. 3rd receiver gather: cross energy vs. rotation angle.

SUMMARY & CONCLUSION

Physical modeling is a valuable tool that can assist in the evaluation and development of practices for fracture characterization. This report has utilized physical modeling, and in summary:

- A physical model was constructed in the laboratory to represent a vertically-fractured reservoir overlaid by isotropic overburden.
- Three common-receiver gathers were acquired; each has a constant offset (r = 250 m, 500 m and 1000 m) and variant azimuth angles (00- 360°).
- Fracture plane orientation was easily identified from the third common-receiver gather (r = 1000 m) by P-wave first-arrival times.
- Elliptical fitting of P-wave first-arrival times was employed to identify the fracture plane orientation from the three common-receiver gather.
- S-wave analysis has suggested an error in the polarization direction of the horizontal transducers.
- An Alford rotation was successfully applied to the four horizontal components of the three common-receiver gather to transform the data from acquisition system coordinate to natural system coordinate.

This report is still in progress, and currently we are planning to repeat the experiment after calibrating transducers. Also, the acquisition system coordinate will intentionally be different from the natural system coordinate, and Alford rotation will be used to predict the fracture plane orientation.