VVAz for Azimuthal Anisotropy of 3D Pre-stack data: Physical Modeling & Altamont-Bluebell Field

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Method

Grechka and Tsvankin (1998) derived an elliptical NMO equation for TI media where source-receiver offset do no exceed the depth of the reflector. Hyperbolic NMO can be approximated by:

$$T^2 = T_0^2 + \frac{x^2}{V_{NMO}^2(\phi)} \qquad (1)$$

, where

$$\frac{1}{V_{NMO}^2(\phi)} = \frac{1}{V_{slow}^2} cos^2(\phi - \beta_s) + \frac{1}{V_{fast}^2} sin^2(\alpha - \beta_s) \qquad (2)$$

, where T is the total two-way traveltimes, T_0 is the zero-offset two-way traveltimes. x is the offset, V_{fast} and V_{slow} are the fast and slow NMO velocities respectively. β_s is the azimuth of the slow NMO velocity, while $V_{NMO}(\phi)$ is the NMO velocity as function of the source-receiver azimuth (Figure 8).

Equation (2) can be written as:

$$\frac{1}{V_{NMO}^2(\phi)} = W_{11}\cos^2(\phi) + 2W_{12}\cos(\phi)\sin(\phi) + W_{12}\sin^2(\phi) \qquad (3)$$

, where W_{11}, W_{12}, and W_{22} are the ellipse coefficients that are related to the slow and fast NMO velocities and to the azimuth of the slow NMO velocity by

$$\frac{1}{V_{fast}^2} = \frac{1}{2}[W_{11} + W_{22} - \sqrt{(W_{11} - W_{22})^2 + 4W_{12}^2} \qquad (4)$$

$$\frac{1}{V_{slow}^2} = \frac{1}{2}[W_{11} + W_{22} + \sqrt{(W_{11} - W_{22})^2 + 4W_{12}^2} \qquad (5)$$

$$\beta_s = \tan^{-1}\frac{W_{11} - W_{22} + \sqrt{(W_{11} - W_{22})^2 + 4W_{12}^2}}{2W_{12}} \qquad (6)$$

The azimuth of the fast velocity is 90° away from the azimuth of the slow velocities as shown by Figure 8 (Jenner, 2001). The total travel can be written as:

$$T^2 = T_0^2 + x^2\cos^2(\phi)W_{11} + 2x\,cos(\phi)\sin(\phi)W_{12} + x^2\sin^2(\phi)W_{22}. \qquad (7)$$

Equation (7) can be written as:

$$d = Gm,$$

where d is n-dimensional data vector, m is the 6-dimensionl model parameter vector, and G is the n-by-4 data kernel as:

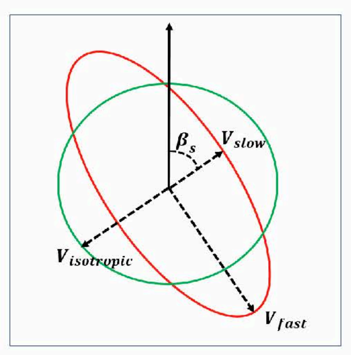
$$\begin{pmatrix} T_1^2 \\ T_2^2 \\ \vdots \\ T_n^2 \end{pmatrix} = \begin{pmatrix} 1 & x_1^2\cos^2(\phi_1) & 2x_1\,cos(\phi_1)\sin(\phi_1) & x_1^2\sin^2(\phi_1) \\ 1 & x_1^2\cos^2(\phi_1) & 2x_1\,cos(\phi_1)\sin(\phi_1) & x_1^2\sin^2(\phi_1) \\ \vdots & \vdots & \vdots & \vdots \\ 1 & x_{n1}^2\cos^2(\phi_n) & 2x_1\,cos(\phi_1)\sin(\phi_1) & x_1^2\sin^2(\phi_1) \end{pmatrix} \begin{pmatrix} T_0^2 \\ W_{11} \\ W_{12} \\ W_{22} \end{pmatrix}. \qquad (8)$$

Isotropic NMO velocities V_{NMO} and zero-offset traveltimes T_0 are used along with azimuthally variant time residuals, dT_ϕ to estimate azimuthal traveltimes, T, as follows:

$$T = T_x + dT_\phi \qquad (9)$$

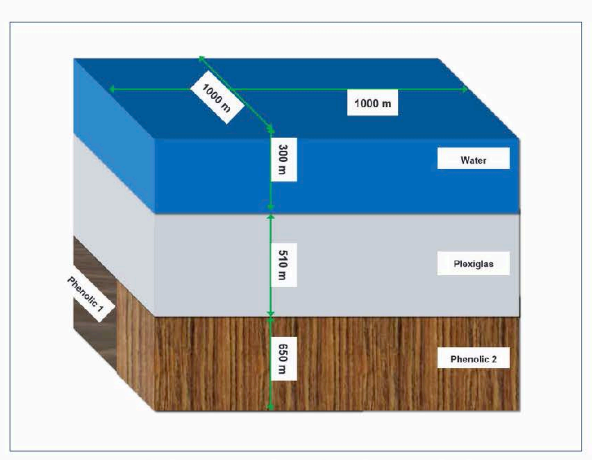
, where

$$T_x = \sqrt{T_0^2 + \frac{x^2}{V_{NMO}{}^{\wedge}2}} \qquad (10)$$

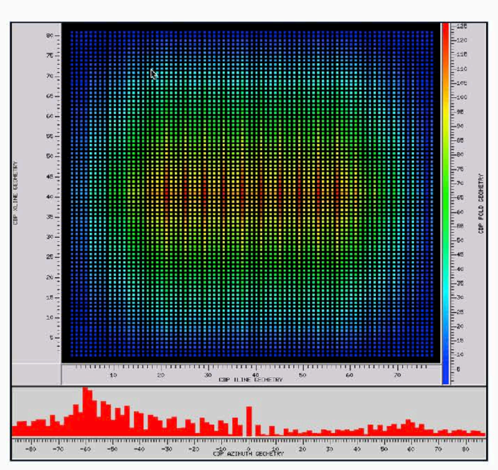


Isotropic RMS velocity vs azimuthally variant RMS velocity.

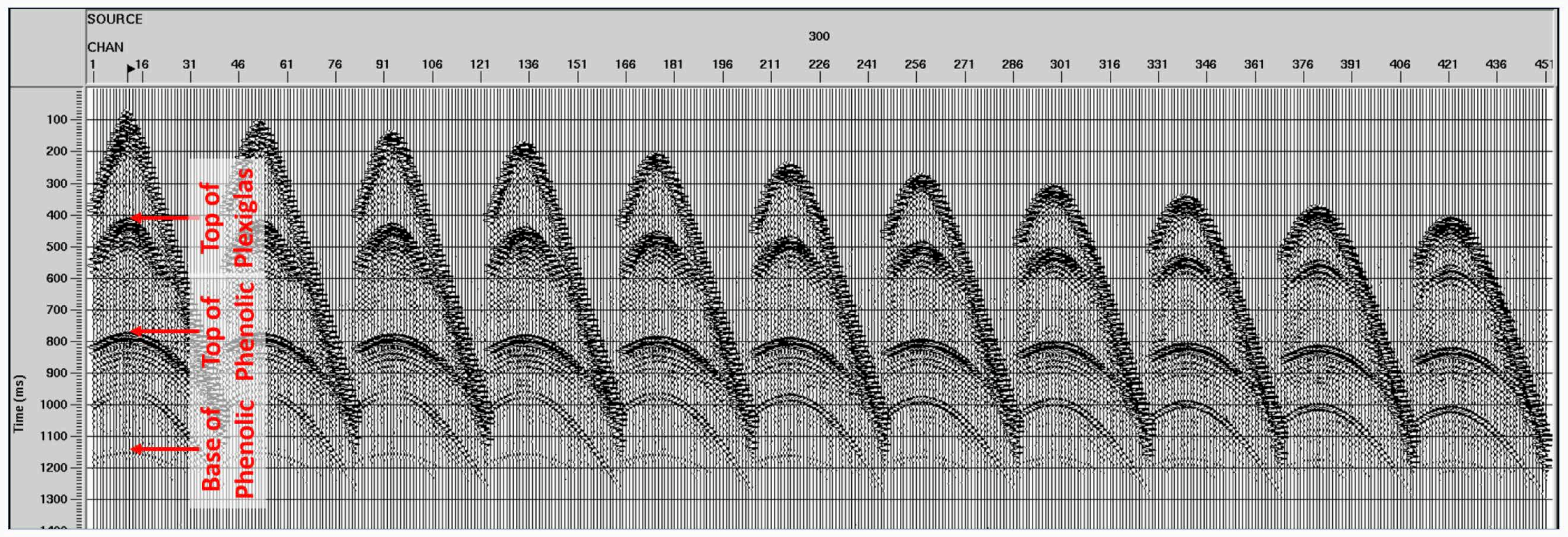
Physical Modelling



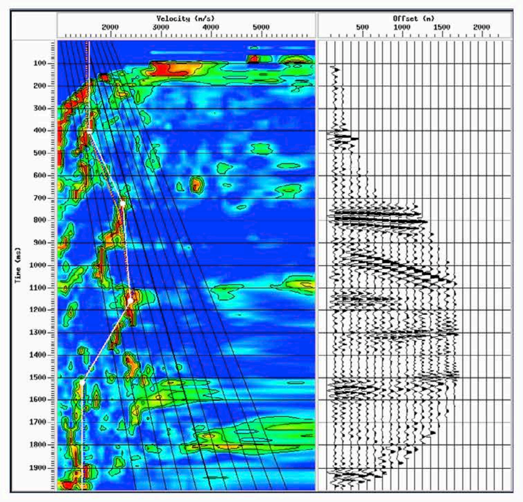
A 3-layer physical model, constructed using vertically laminated Phenolic overlain by Plexiglas. HTI planes of phenolic have an orientation in northern half of the model that is orthogonal to HTI planes in southern half. A third layer of water is added to the model. Laboratory to field scale is 1:10,000 in both length and time



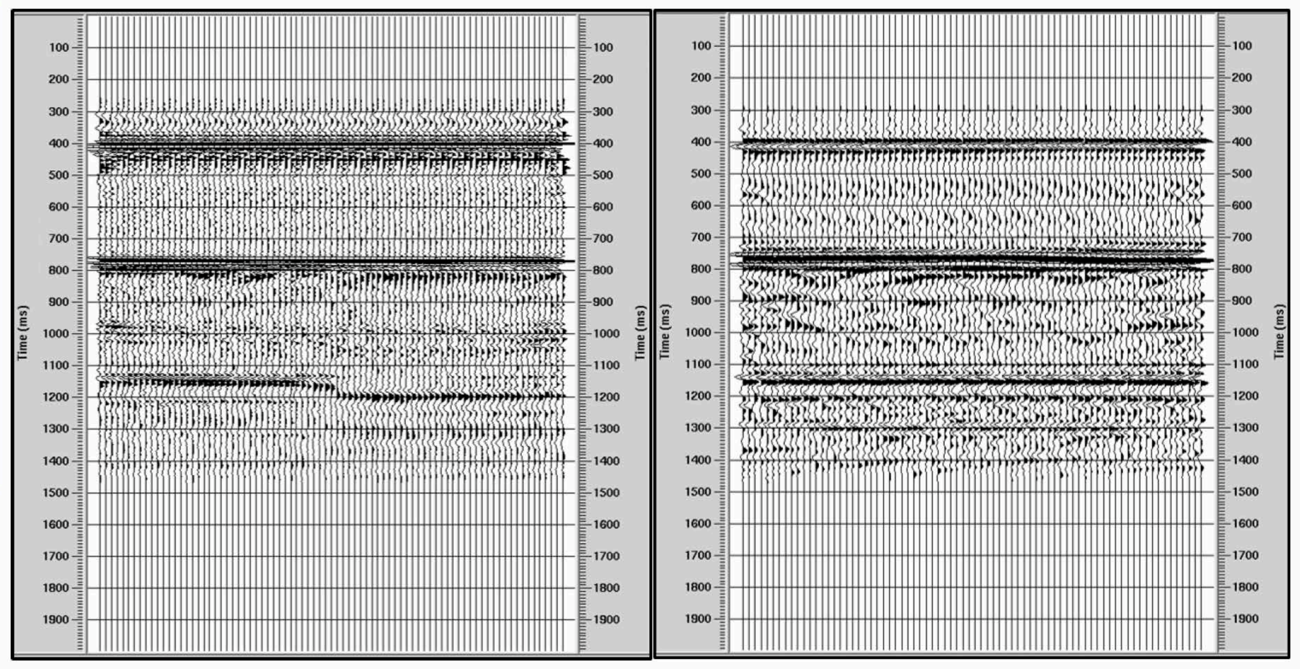
A basemap of 3D seismic physical modeling data. Color indicates fold of 50mx25m bins. High fold zone is indicated by red where fold is 120. Lower histogram indicates the azimuth distribution from -90o to 90o with reference to the north (y-axis).



A shot gather: 10 receiver lines. Target is Phenolic, between 2nd and 3rd reflector.



Velocity analysis: A semblance coherency with picks of maximum stacking indicated by white dots (left) and CDP gather with flat reflection events

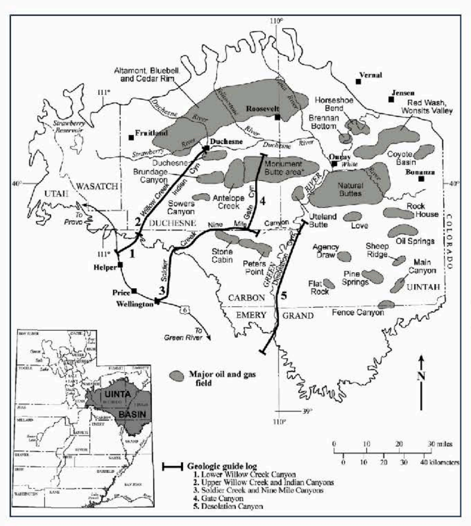


CDP Stacks: a N-S inline (top) and E-W crossline (bottom).

	T_0 from VVAz	β_s from VVAz	V_{slow} from VVAz	V_{fast} from VVAz	Aniso %	Actual β_s	Calc. T_0	Calc. V_{slow}	Calc. V_{fast}
North Half	1.1617	89.809	2454	2641.1	7.3	90	1.1616	2473.3	2764.7
South Half	1.1759	0.6368	2133.1	2623.2	20.6	0	1.1616	2473.3	2764.7

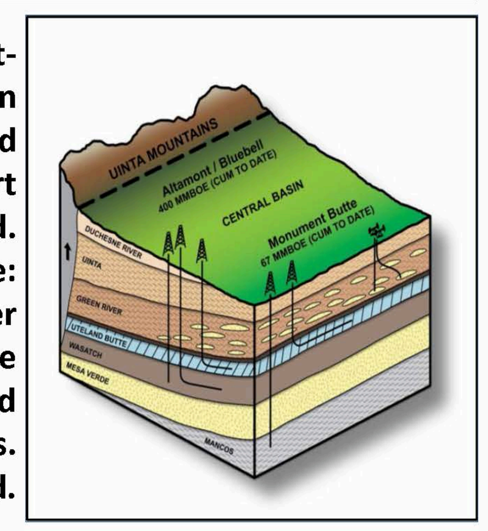
Comparison between VVAz results and calculated results.

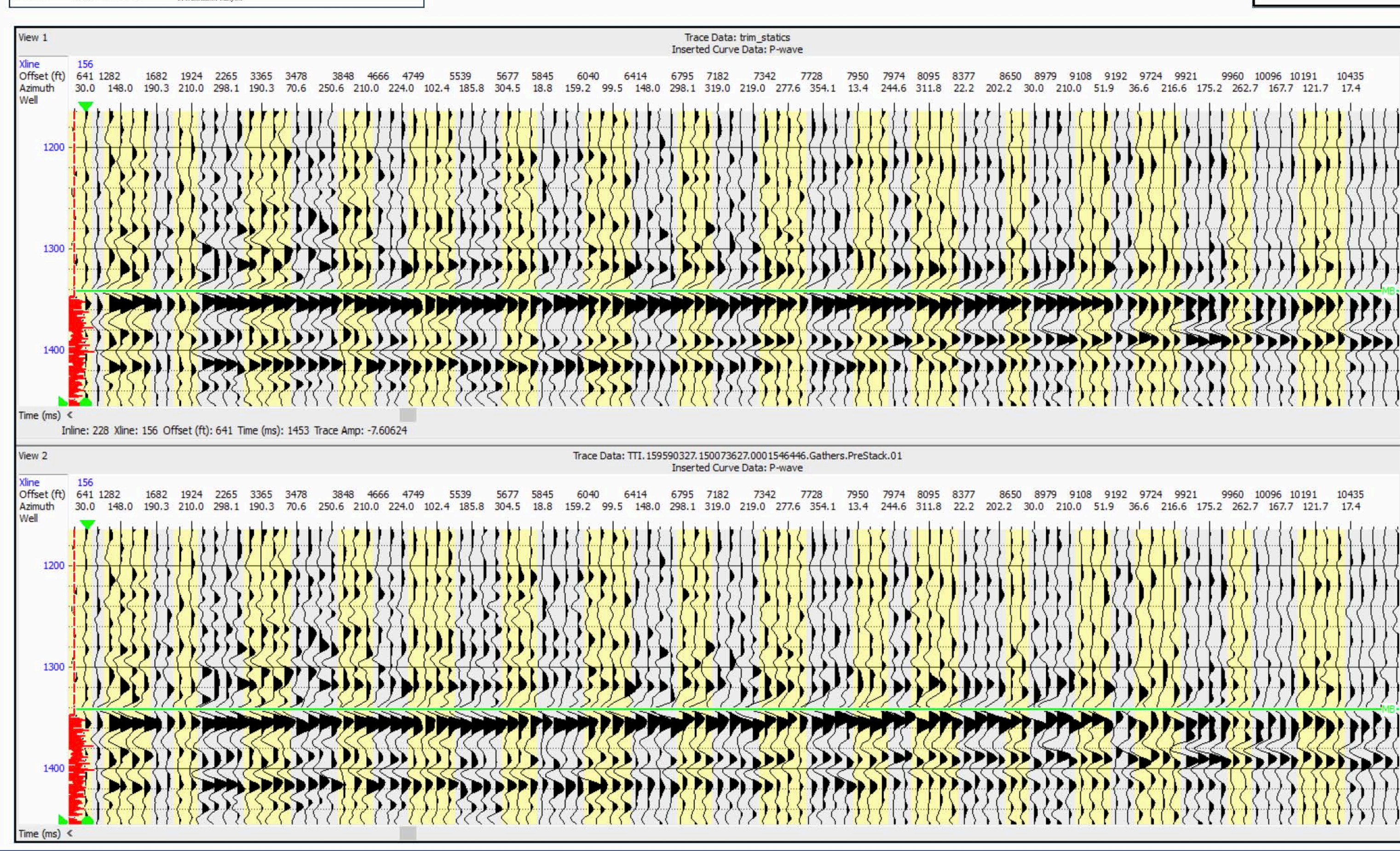
Altamont-Bluebell Field



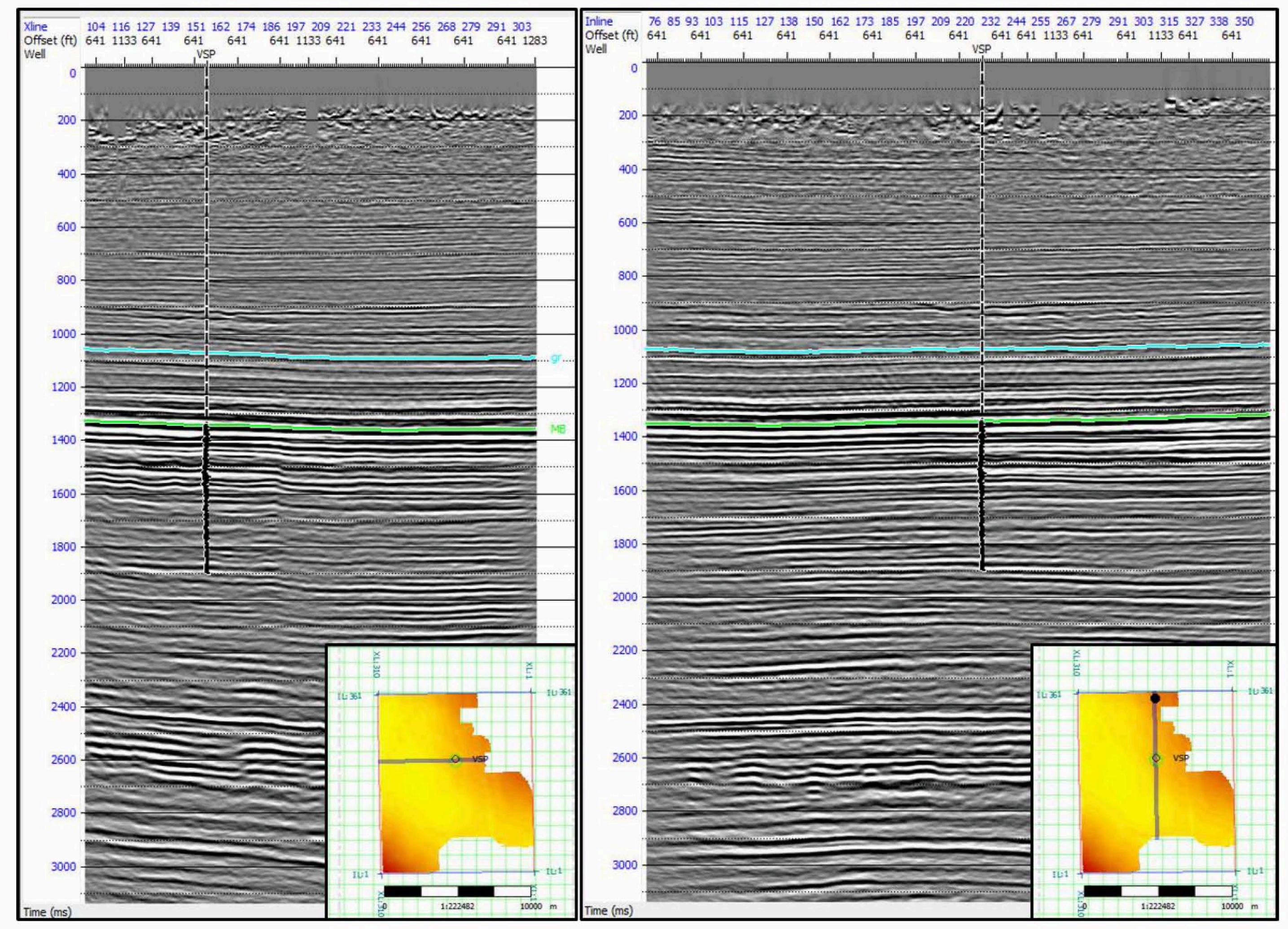
Location of Uinta basin, Utah (bottom left) and major oil and gas fields within Uinta basin (after Morgan, 2003).

Uinta Basin, Utah. Altamont-Bluebell field is the northern central part of the basin, and Bluebell is the eastern part of Altamont-Bluebell Field. Three main targets are: Upper Green River, Lower Green River (Uteland Butte and Castle Peak), and Wastach formations. Courtesy of: Newfield.

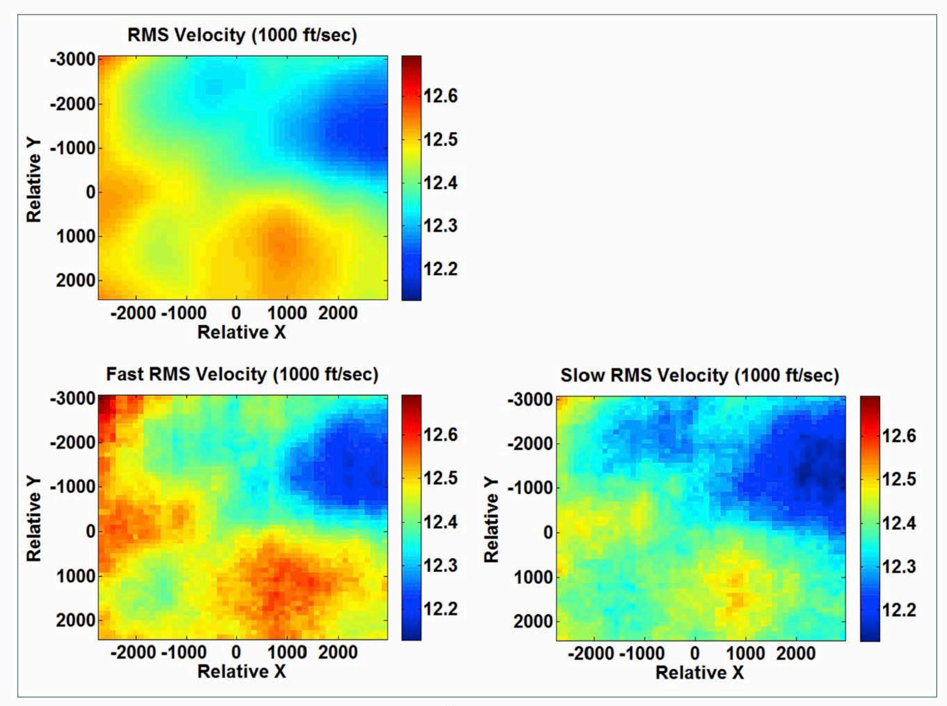




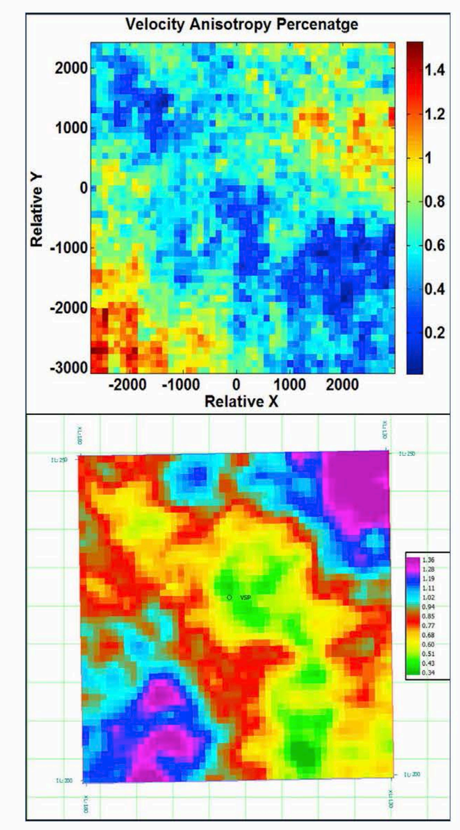
COV Gathers: Before (left) and after (right) applying azimuthal residuals.



CDP Stack: inline (left) and crossline (right). VSP borehole is indicated in the middle and basemap in the bottom right. Two horizons are indicated: Upper Green River (blue) and Mahogany bench (green)



Isotropic RMS velocity vs. fast RMS velocity vs. slow RMS velocity in (1000 ft/s).



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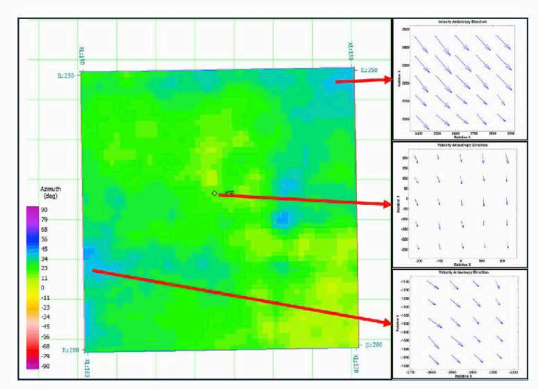

Comparison of two methods of VVAz. Color on left map indicates angle of fast velocity from the x-axis. Arrows on left map from top to bottom have values of 40º, 19º, and 43º from x-axis.

Summary

Physical modeling can be a valuable tool that to test and evaluate geophysical methods, especially for anisotropic media where numerical modeling becomes sophisticated. For the development of unconventional reservoirs, azimuthal variations of P-wave velocities can be a valuable tool for fracture information. In this paper:

- 3D pre-stack physical modeling dataset were acquired, processed and used to evaluate a VVAz method.
- The largest drawback found to be that the reflection of bottom of the phenolic layer was weak and contaminated by strong mode-converted PS waves generated by the top of the anisotropic layer. A time processing attempt to overcome this issue was a necessity to advance with azimuthal analysis of velocity variation.
- VVAz Results of the analysis proved to very accurate for the north part of the model, and less accurate for the south part of the model.
- An AVAz workflow was implemented to 3D pre-stack seismic data from Altamont-Bluebell field. Our target was the shallowest from the three targets of Uinta Basin, Upper Green River to Mahogany Bench.
- Maps of anisotropy intensity and direction were obtained and compared to maps that we obtained using Hampson-Russell Suites. Both direction and intensity maps correlate well in both models.