S-WAVE SPLITTING ANALYSIS OF 4-C VSP IN ALTAMONT-BLUEBELL FIELD

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Method

An Alford 4-component rotation (Alford, 1986) can be used to statistically rotate horizontal components (***V***) recorded in acquisition recorded system into anisotropy natural coordinate system (***U***) using rotation matrix ($\boldsymbol{R}(\theta)$):

$$V = \begin{bmatrix} v_{11} & v_{12} \\ v_{21} & v_{22} \end{bmatrix}, \qquad (1)$$

and

$$R(\theta) = \begin{bmatrix} \cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \qquad (2)$$

The rotation matrix, $\boldsymbol{R}(\theta)$ is an orthogonal matrix that gives the identity matrix when multiplied by its transpose or its inverse. To find a new basis of the natural coordinate system, the counterclockwise rotation by angle (θ) is

$$U = R(\theta)\, V\, R^T(\theta). \qquad (3)$$

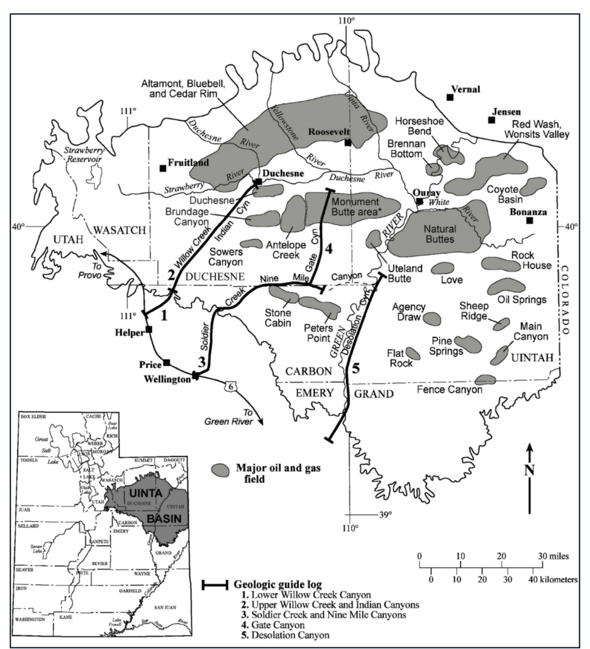
Substituting equations (6), (7), and (8) into equation (9):

$$\begin{bmatrix} u_{11} & u_{12} \\ u_{21} & u_{22} \end{bmatrix} = \begin{bmatrix} \cos^2\theta\, v_{11} + \sin^2\theta\, v_{22} + 0.5\sin 2\theta\,(v_{21}+v_{12}) & \cos^2\theta\, v_{12} - \sin^2\theta\, v_{21} + 0.5\sin 2\theta\,(v_{22}-v_{11}) \\ \cos^2\theta\, v_{21} - \sin^2\theta\, v_{12} + 0.5\sin 2\theta\,(v_{22}-v_{11}) & \cos^2\theta\, v_{22} + \sin^2\theta\, v_{11} - 0.5\sin 2\theta\,(v_{21}-v_{12}) \end{bmatrix}. \qquad (4)$$

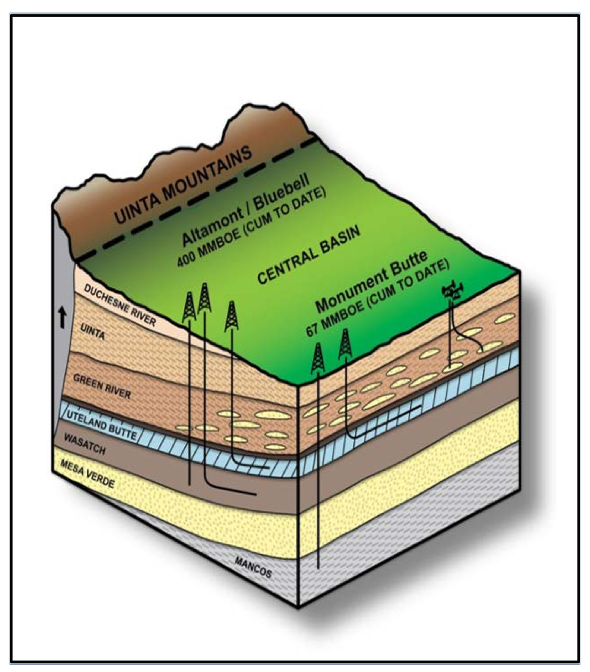
Equation (10) transforms ***V***, horizontal components in acquisition coordinate system into the natural coordinate system (Alford, 1986).

For layer stripping, all data below the depth at which S-wave polarization change is rotated with the rotation angle. Then, a static time shift is applied to remove the lag between fast and slow S waves at that depth. This technique simulates placing a source at the depth where S-wave polarization changes.

Altamont-Bluebell Field

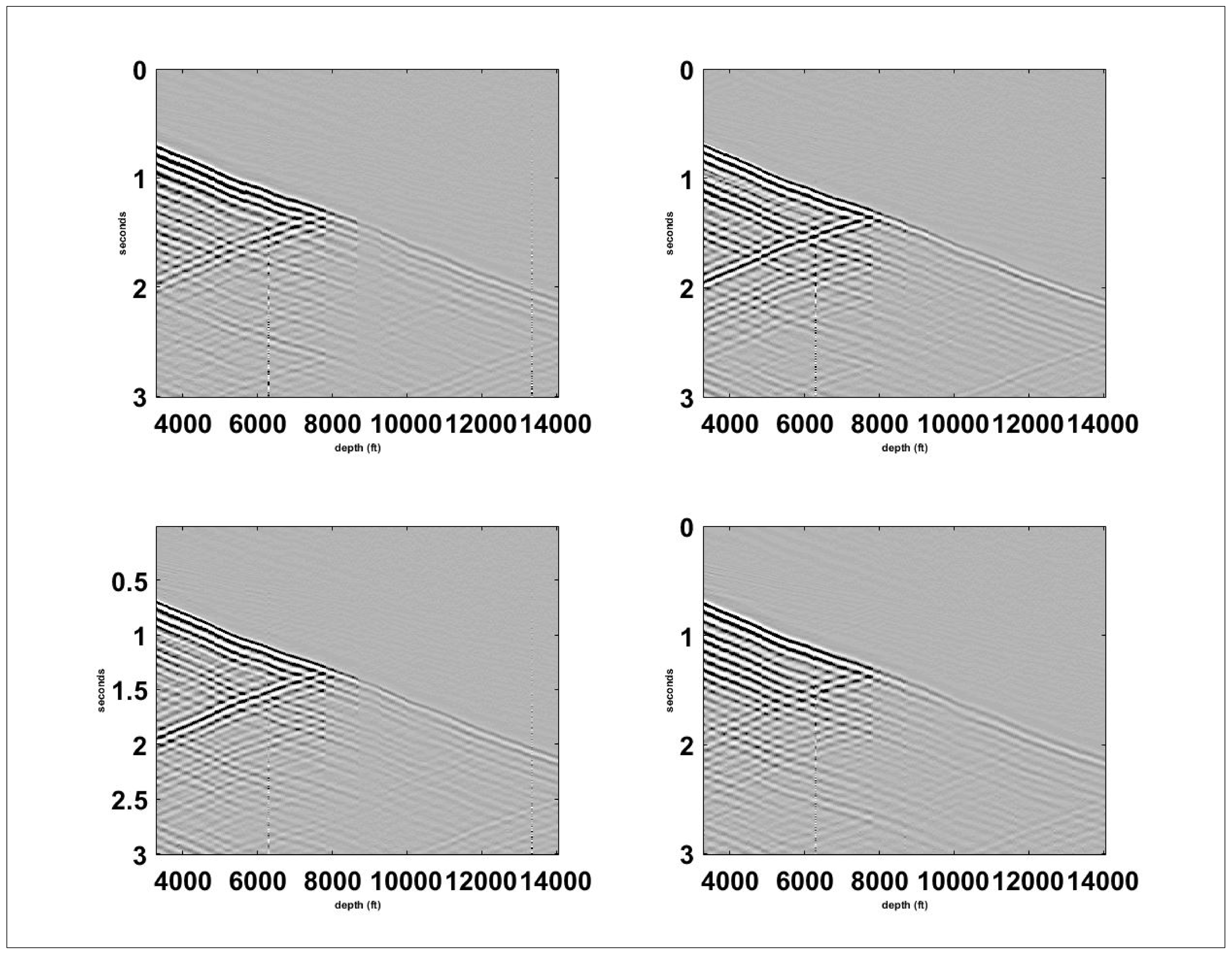


Location of Uinta basin, Utah (bottom left) and major oil and gas fields within Uinta basin (after Morgan, 2003).



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.

4-C Rotation



4-C VSP before rotation: N-S shot components (top), E-W shot components (bottom), N-S receiver componets (left), and E-W receiver components (right)

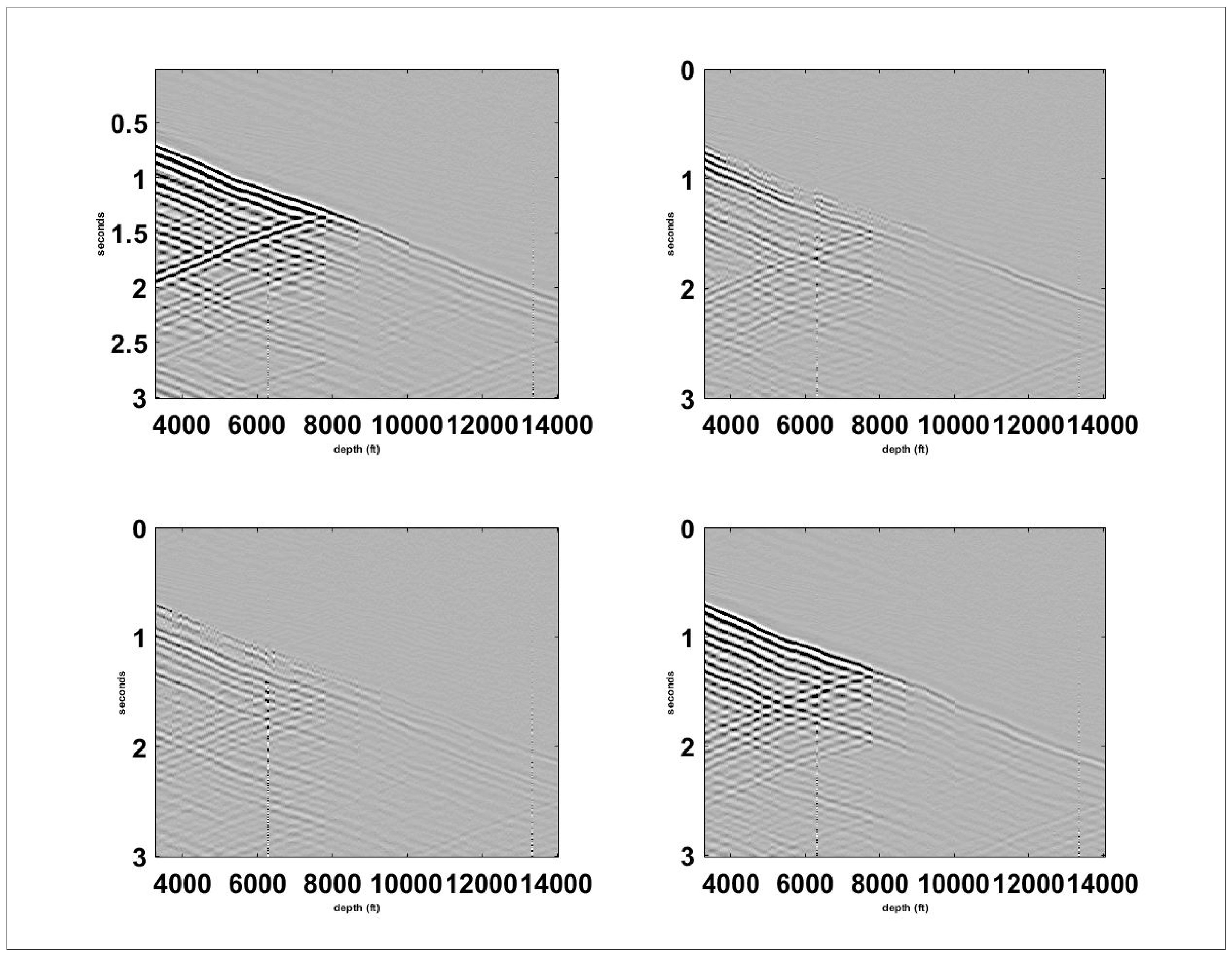


FIG. 3. 4-C VSP after rotation and layer stripping: N-S shot components (top), E-W shot components (bottom), N-S receiver componets (left), and E-W receiver components (bottom).

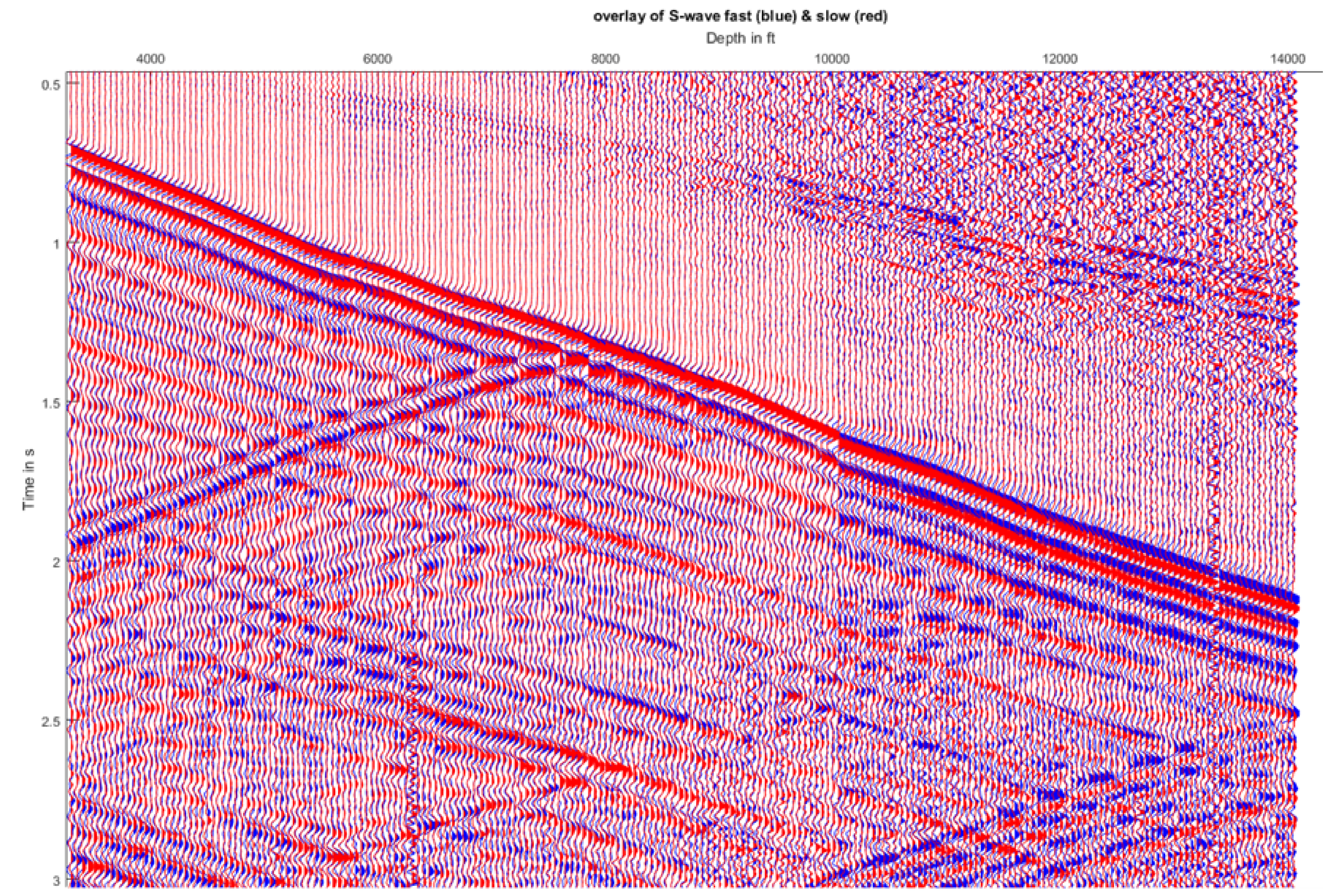
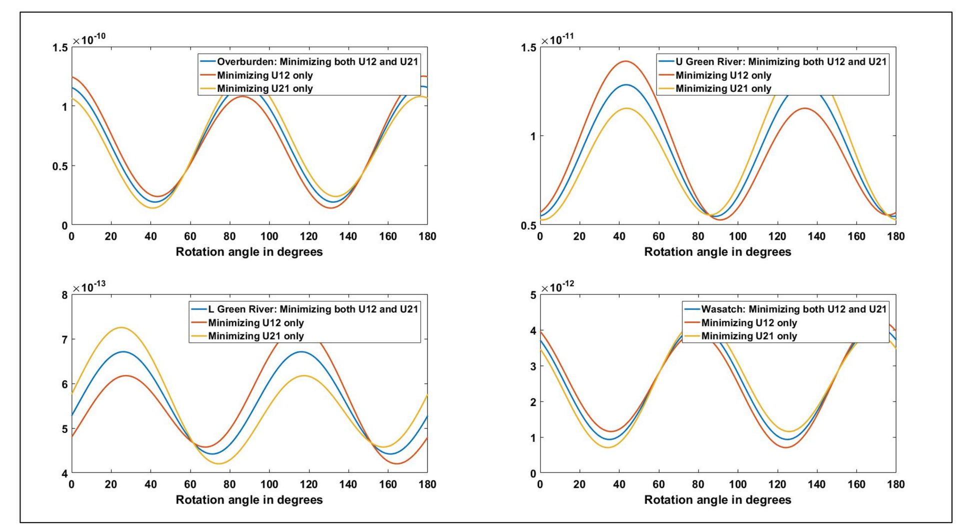
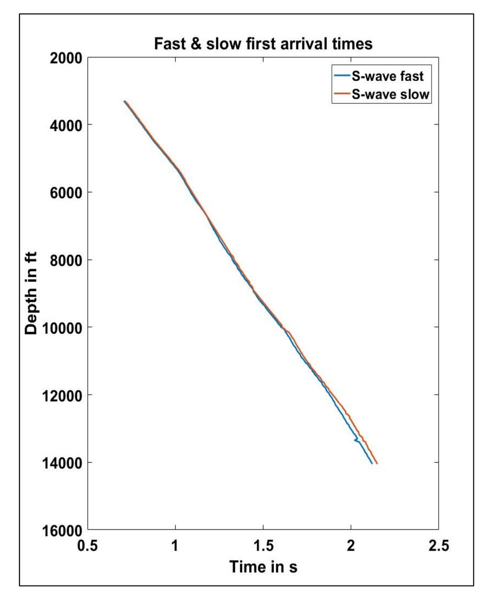


FIG. 4. S-wave data after rotation and layer stripping of 4-C VSP. The S-wave fast is indicated by blue traces, while slow is indicated by red traces.

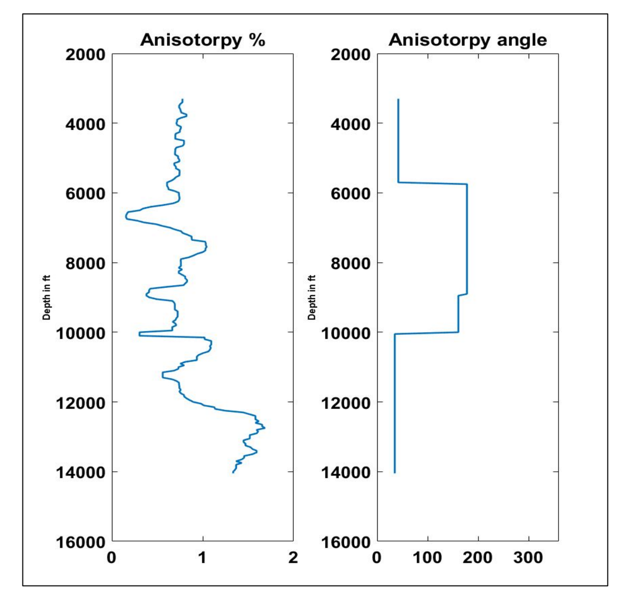


4-C VSP cross energy vs. rotation angle of: overburden, Upper Green River, Lower Green River, and Wastach



Fast S-wave first arrival times indicated by blue, and slow S-wave indicated by red

S-wave analysis: anisotropy intensity (left) and direction (right).



Summary

S-wave splitting can be useful for fracture-induced anisotropy. Therefore, this paper utilizes S-wave splitting to estimate the direction and intensity of fractured-induced anisotropy within the three main reservoirs using 4-C VSP data. S-wave analysis is carried using Alford (1986) 4-C rotation to separate fast and slow modes. This method assumes that the symmetry axis is vertically invariant. In order to overcome this assumption, a layer stripping technique was applied using Winterstien and Meadows (1991).

From S-wave splitting analysis, the Upper and Lower green river formation were found to have an anisotropy orientation of NW-SE, while the overburden and Wasatch formation have anisotropy orientation of NE-SW. Also, the Wasatch formation was found to have the highest anisotropy intensity.