On the extraction of angle dependent wavelets from synthetic shear wave sonic logs

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ABSTRACT

The extraction of angle dependent wavelets requires the use of a shear wave sonic log. However, shear wave measurements are often not acquired in a conventional logging suite and must be estimated to produce a synthetic result. The errors associated with the synthetic shear propagate through to the angle dependent reflectivity with a sine squared dependence of the incidence angle. Therefore, the reflectivity becomes unreliable at larger angles and a least squares extraction using the convolutional model could yield erroneous results. To reduce the errors associated with wavelet extraction at larger angles, a near angle wavelet was estimated with an acceptable amount of error using a least squares approach. Subsequently, an estimate of the angle dependent wavelet amplitude spectrum and a constant *Q* attenuation model was used to evolve the amplitude and phase respectively to estimate the wavelets at larger angles.

INTRODUCTION

- Amplitude variation with offset (AVO) inversion
  - Seismic wavelet used in the forward modeling process
    - Convolved with a model reflectivity to generate synthetic data
- Earth attenuation effects
  - Wavelet is non-stationary and alterations in the amplitude and phase occur throughout its propagation history
  - Separate wavelets used for different incidence angles to compensate for attenuation effects
- Wavelet extraction from well logs
  - Convolutional model
  - Requires compressional and shear wave sonic and density logs to generate angle reflectivity
    - Shear wave logs often not acquired
  - Synthetic shear contains errors that will subsequently propagate through wavelet extraction process
- Investigate errors associated with wavelet extraction using a synthetic shear
- Propose the use of a constant *Q* attenuation model to reduce errors in wavelet extraction

SYNTHETIC SHEAR GENERATION

- Apply a linear transformation relationship between compressional and shear wave velocities
  - Transform relation derived from nearby wells with measured shear
- Separate into distinct lithologies using various log measurements
- Perform linear regression for each defined lithology
  - Regression line forms a sort of mudrock line
  - Shales typically exhibit a tighter distribution resulting in less errors in regression

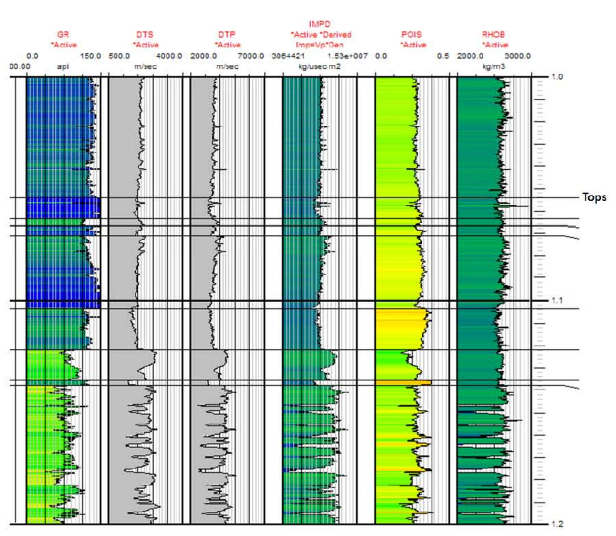

FIG. 1. Defined lithologies using a suite of well log measurements.

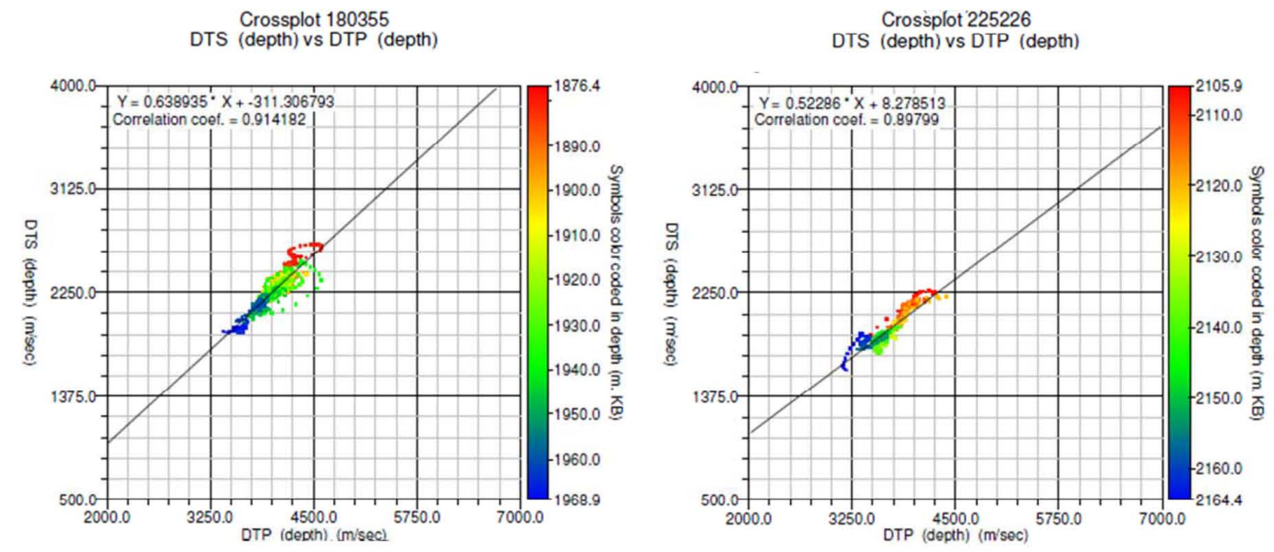

FIG. 2. Regression analysis for compression and shear wave velocities.

WAVELET ESTIMATION ERRORS

- Least squares extraction of wavelet

$$\underline{s(\theta)} = \underline{R(\theta)}\,\underline{w(\theta)}$$

$$\underline{w(\theta)} = \left[\underline{R(\theta)^T}\,\underline{R(\theta)}\right]^{-1}\underline{R(\theta)^T}\,\underline{s(\theta)}$$

- Reflectivity errors

$$r(\theta) = A + B\sin^2\theta$$

$$dr(\theta) = \sin^2\theta\, dB$$

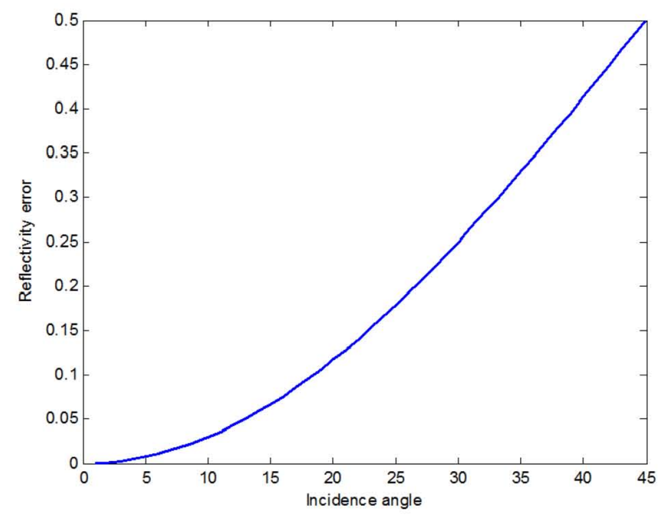

FIG. 3. Reflectivity error as a function of incidence angle. Note the sine squared dependence of the error with angle of incidence, therefore, the reflectivity calculations become increasingly unreliable at larger angles.

WAVELET ESTIMATION USING CONSTANT *Q*

- Consider the smoothed spectrum of four angles stacks used in an AVO inversion
  - Assume white reflectivity
  - Attribute all spectral character to wavelet
  - Figure 4 represents an estimate of the wavelet amplitude spectrum
  - Loss of high frequencies with increased propagation distance
    - Characteristic of constant *Q* attenuation
    - Use properties of constant *Q* attenuation to estimate wavelets
      - Minimum phase dispersion (Futterman, 1962)
- Given that a reliable near angle wavelet (pilot) can be extracted using a least squares approach (Cho et al., 2010)

$$w_p(t) = F^{-1}\left[A_p(\omega)\exp\left(i\phi_p(\omega)\right)\right]$$

$$\phi_p(\omega) = \phi_p^{(ss)}(\omega)\phi_p^{(mp)}(\omega) = \phi_p^{(ss)}(\omega)H\left[\ln\left(A_p(\omega)\right)\right]$$

$$\gamma_i = \frac{\exp\left(i\phi_i^{(mp)}(\omega)\right)}{\exp\left(i\phi_p^{(mp)}(\omega)\right)}$$

$$w_i(t) = F^{-1}\left[A_i(\omega)\exp\left(i\phi_p(\omega) + i\phi_i^{(mp)}(\omega) - i\phi_p^{(mp)}(\omega)\right)\right]$$

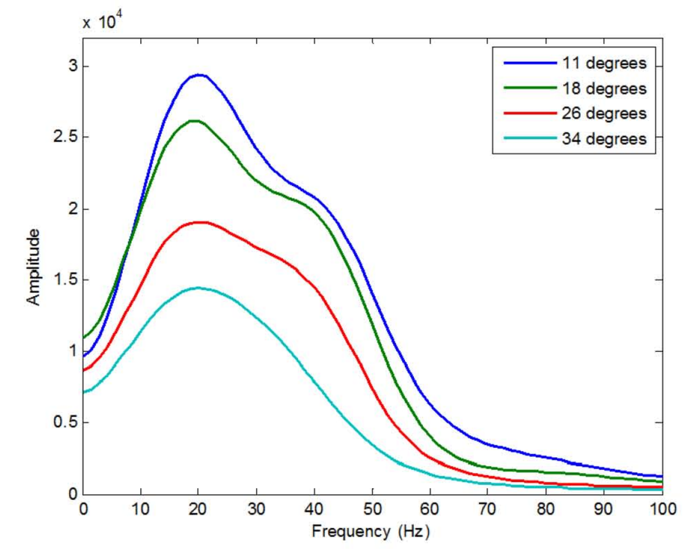

FIG. 4. Smoothed amplitude spectrum of four angle stacks used in an AVO inversion.

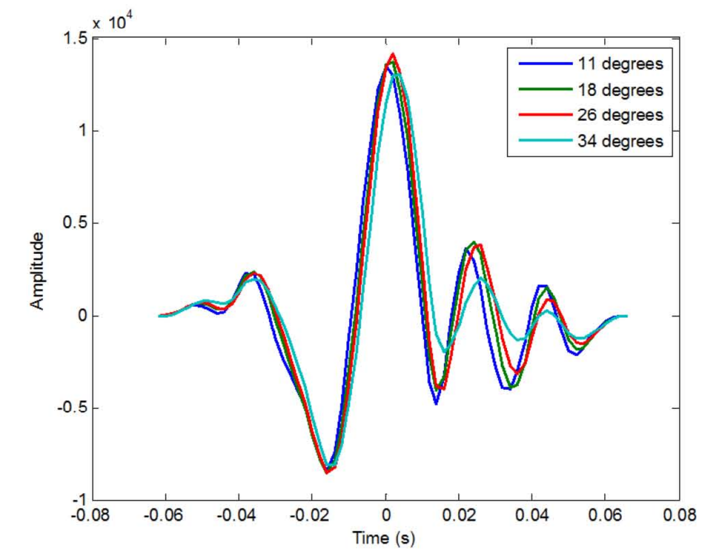

FIG. 5. Normalized angle dependent wavelets derived from equation 8.

CONCLUSIONS

- Errors associated with a least squares extraction of the seismic wavelet using synthetic shear wave velocities grow with an increasing incidence angle
- Given that a near angle wavelet can be extracted with an acceptable amount of error, a methodology for estimating larger angle wavelets was proposed
- Using an estimate of the angle dependent wavelet amplitude spectrum and a constant *Q* attenuation model, we can evolve the amplitude and phase spectrum of the wavelet respectively
- Avoid the errors associated with the reflectivity calculations using synthetic shear wave velocities

ACKNOWLEDGEMENTS

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