AVO analysis and Impedance Inversion

Okey Ileka
AVO Analysis

- Introduction
- AVO Pre-processing
- AVO modeling
- AVO parameters
- AVO crossplot analysis
- AVO attributes
- Some application of AVO
- Probabilistic AVO analysis
Impedance Inversion

- Post stack 1D Impedance Inversion
- Far-offset elastic Impedance
- Lambda-mu-rho estimation
- P to S elastic Inversion
- Anisotropic elastic Impedance
- Interpretation of Rock physics template
Introduction

• AVO is the amplitude variation with offset
Introduction
Introduction

\[ R(\theta) \approx A + B \sin^2 \theta \]

\[ A = R_p \]

\[ B \approx R_p - 2R_s \]

\[ A \approx \frac{1}{2} \left( \frac{\Delta V_p}{V_p} + \frac{\Delta \rho}{\rho} \right) \]

\[ B \approx -2 \frac{V_s^2}{V_p^2} \frac{\Delta \rho}{\rho} + \frac{1}{2} \frac{\Delta V_p}{V_p} - 4 \frac{V_s^2}{V_p^2} \frac{\Delta V_s}{V_s} \]
Third Order Approximation

\[ R(\theta) \approx A + B \sin^2 \theta + C \sin^2 \theta \tan^2 \theta \]

\[ A = \frac{1}{2} \left( \frac{\Delta V_p}{V_p} + \frac{\Delta \rho}{\rho} \right) \]

\[ C \approx \frac{1}{2} \frac{\Delta V_p}{V_p} \]

\[ A - C \approx \frac{1}{2} \frac{\Delta \rho}{\rho} \]
Hiltermann Approximation

\[ R(\theta) \approx A \cos^2 \theta + 2.25\Delta\sigma \sin^2 \theta \]

\[ G = A + B \]

Castagna lecture note
AVO preprocessing

Factors which affect amplitude
After Sheriff, 1975
SOME FACTORS AFFECTING AMPLITUDE

- Offset
- Near surface effects
  - Weathering
  - Geophysics
  - Plants
  - Arrays
- Instruments
- Transmission loss
  - Transmission coefficient T(θ)
- Intrabed multiples
  - Each layer acts as a filter - up and down
- Reflection coefficient
- Geology
- Fresnel zone

Q: Attenuation
  - (e^{-αT})

S: Source strength

Starting wavelet

Spreading loss
  - (1/VT)

Source array

Reflecting horizon

Density: ρ
Velocity: V

In situ: P₀V₀

Reflection: P₁V₁

(P from M. Grant, Seismic Lithostratigraphy, GeoQuest Industries)
Factors that amplitudes

- Earth effects
- Acquisition related effects
- Noise
Earth effects

- Spherical divergence
- Absorption
- Transmission losses
- Interbed multiples
- Converted phases
- Tunning effect
- Anisotropy
- structure
Acquisition-related effects and noise

- Acquisition-related effects
- Source receiver arrays
- Receiver sensitivity

- Noise
- Source generated noise
- Coherent or random noise
AVO Pre-processing

- Spiking deconvolution and wavelet processing
- Spherical divergence correction
- Surface consistent amplitude balancing
- Multiple removal
- NMO correction
- DMO correction
- Pre-stack migration
AVO preprocessing

- Source Signature
- Addition of ghost reflection(s)
- Geometrical spreading
- Absorption
- Scattering
- Transmission decay offset by short-path multiples
- Instrument response (filter)
- Processing (decon, filter)
- Observed reflection pulse

Time-variant effect on pulse form

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AVO modeling
Physical Interpretation

\[ R(\theta) \approx A + B \sin^2 \theta \]

(a) Small window from gather  
(b) Peak/trough picks vs. \( \sin^2 \theta \)

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(Russel, 1999)
AVO parameters
AMPLITUDE-VERSUS-OFFSET ANALYSIS

\[ R(\theta) = A + B \sin^2 \theta \]

A Section

\[ \Delta \rho \]
\[ \Delta V_p \]
\[ \Delta V_s \]

B Section

\[ \Delta \rho \]
\[ \Delta V_p \]
\[ \Delta V_s \]

A-B Cross Plot

\begin{array}{c}
\text{gas} \\
\text{wet}
\end{array}

astagna lecture notes
AVO crossplot
From Simm et al., 2000

Castagna lecture notes
AVO attributes
AVO Indicators/Attributes

- Intercept
- Gradient
- Near and far stacks
- Curvature
- CDP stack
- Change in Poisson’s ratio
- Fluid Factor

- Intercept minus Gradient
- Intercept plus Gradient
- Intercept times Gradient
- Rp-Rs
- P and S wave velocity contrast
- Density Contrast
- Amoco Indicator F(F-N)
- Lambda-mu-rho
Calculated AVO Attributes

\[ A = \text{intercept} \]
\[ B = \text{gradient} \]
\[ r^2 = \text{correlation} \]
\[ A \times B \]
\[ (A + B)/2 \sim Rp - Rs \]
\[ (A - B)/2 \sim Rs \]

\[ A = \text{intercept} \]
\[ B = \text{gradient} \]
\[ C = \text{curvature} \]
\[ r^2 = \text{correlation} \]
\[ A \times B \]
\[ (A + B)/2 \sim Rp - Rs \]
\[ (A - B)/2 \sim Rs \]
\[ A - C \]

\[ NI = \text{normal intercept} \]
\[ PR = \text{Poisson reflectivity} \]
\[ r^2 = \text{correlation} \]
\[ NI \times PR \]

Shuey 2 Term
\[ RC(\theta) = A + B \sin^2\theta \]

Shuey 3 Term
\[ RC(\theta) = A + B \sin^2\theta + C \sin^2\theta \tan^2\theta \]

Verm-Hilterman
\[ RC(\theta) = NI \cos^2\theta + PR \sin^2\theta \]

Castagna lecture notes

Roden, 2005
Some application of AVO

• Residual gas saturation (converted waves)

• Flat spot analysis

• Overpressure detection

• Density estimation
Probabilistic AVO analysis

• In probabilistic AVO analysis the AVO parameters and attributes are assigned probability density function (PDF) or cumulative density function (CDF)
Impedance Inversion

• The goal of geophysical inversion is to estimate model parameter from observed data
Impedance Inversion

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- Interpretation of Rock physics template
Poststack 1D impedance Inversion

• Inversion of near stack traces
Acoustic Impedance Inversion

- Near Angle Stack
- Sonic, Density Logs
- Horizons

- Wavelet
- Bandlimited Inversion
- Merged AI

- AI Earth Model
- Trend Model

Castagna lecture note
Sena, 1997
Far offset elastic Impedance

• Inversion of far offset traces
The Elastic Impedance

\[ E = V_p^\alpha V_s^\beta \rho^\gamma \]

\[ \alpha = 1/\cos^2\theta \]
\[ \beta = -8(V_s/V_p)^2\sin^2\theta \]
\[ \gamma = 1 + \beta/2 \]

Sena, 1997
Elastic Impedance Inversion

- Far Angle Stack
- Sonic, Shear Sonic and Density Logs
- Horizons
- Wavelet
- Bandlimited Inversion
- Merged EI
- EI Earth Model
- Trend Model

Sena, 1997

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Lambda Rho estimation

Generalization of $\lambda_\rho$

$\Delta G = \text{Fluid Discriminator}$

$\lambda_\rho = (AI)^2 - 2(SI)^2$

$\lambda_\rho = (AI - \sqrt{2} SI) (AI + \sqrt{2} SI)$

Difference term is most significant discriminator

$\Delta G \equiv (AI - \sqrt{2} SI)$

$\Delta G \equiv (AI - 1.414 SI)$

In more general terms (Simm),

$AVOImpedance \equiv (AI - \gamma SI)$

$\Delta G = \text{attribute similar to Fluid Factor and Lambda Rho}$

Hilterman’s lecture note
P –to- S elastic Inversion
Reflection Coefficients: Angle vs. Offset

Stewart and Gasier lecture note
P-S Reflection Coefficient

(Aki & Richards, 1980)

\[ R_{ps} = \frac{-p\alpha}{2\cos\phi} \left[ \left( 1 - 2\beta^2 p^2 \right) + 2 \beta^2 \frac{\cos\theta}{\alpha} \frac{\cos\varphi}{\beta} \right] \frac{\Delta p}{p} \]

First Order

Relative S-velocity change

Relative density change

Stewart and Gasier lecture note
Anisotropic elastic Inversion
Anisotropy

VTI Wave Propagation Effect

Anisotropic horizontal velocity ≠ Anisotropic vertical velocity
Isotropic incident angle (θ) ≠ Anisotropic incident angle (ϕ)
At x = 0, Isotropic wavefront curvature ≠ Anisotropic wavefront curvature
Anisotropic Inversion

**VTI Reflection Coefficient Contribution**

Shale: $\varepsilon = 0.14$, $\delta = 0.09$

$$RC(\theta) = RC_{ISO}(\theta) + RC_{VTI}(\theta)$$

$$RC_{VTI}(\theta) = \frac{1}{2}(\delta_2 - \delta_1)\sin^2\theta + \frac{1}{2}(\varepsilon_2 - \varepsilon_1)\sin^2\theta \tan^2\theta$$
Interpretation of Rock Physics Template

• The rock physics template is based on a compiled catalog or atlas of RPT’s calculated by a rock physics expert.

• The seismic interpreter can interpret elastic inversion results without in-depth knowledge about rock physics theory.
• Thank you