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

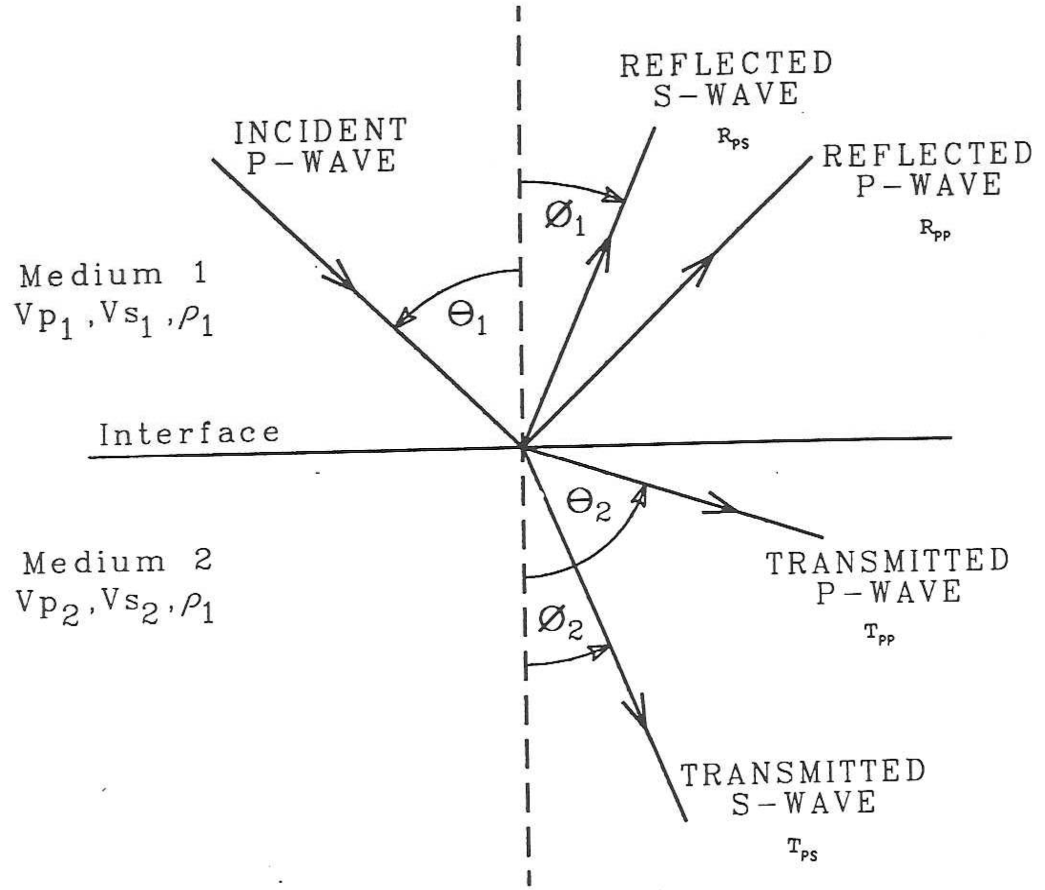
Impedance Inversion

- 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

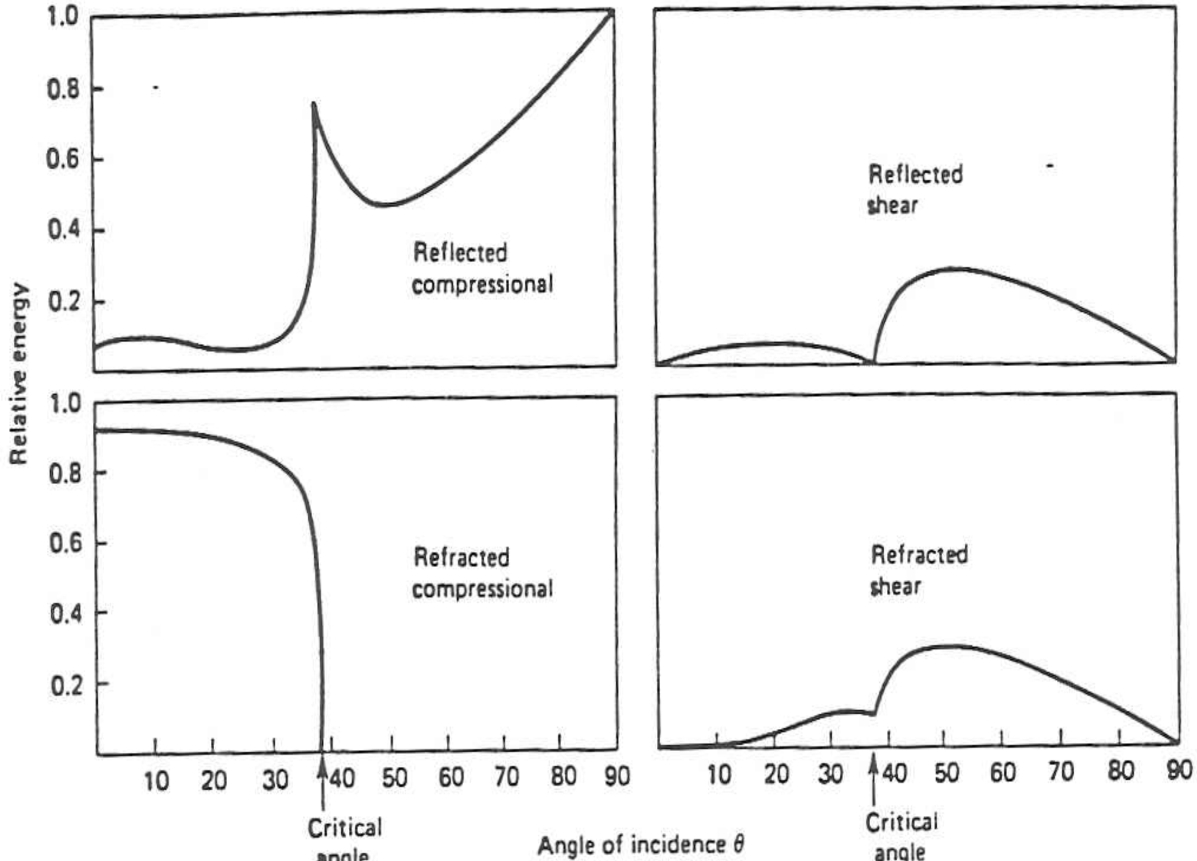
- AVO is the amplitude variation with offset

Introduction



Castagna lecture notes

Introduction



Castagna lecture notes

Simplified Shuey (1985) Form of the Richards and Frazier (1976) Approximation

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

$$A = R_p \qquad\qquad B \approx R_p - 2R_s$$

$$A \approx \frac{1}{2}\left(\frac{\Delta V_p}{V_p} + \frac{\Delta\rho}{\rho}\right) \qquad B \approx -2\frac{V_s^{\ 2}}{V_p^2}\frac{\Delta\rho}{\rho} + \frac{1}{2}\frac{\Delta V_p}{V_p} - 4\frac{V_s^{\ 2}}{V_p^2}\frac{\Delta V_s}{V_s}$$

Third Order Approximation

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

$$A = \frac{1}{2}\left(\frac{\Delta V_p}{V_p} + \frac{\Delta\rho}{\rho}\right) \qquad C \approx \frac{1}{2}\frac{\Delta V_p}{V_p}$$

$$A - C \approx \frac{1}{2}\frac{\Delta\rho}{\rho}$$

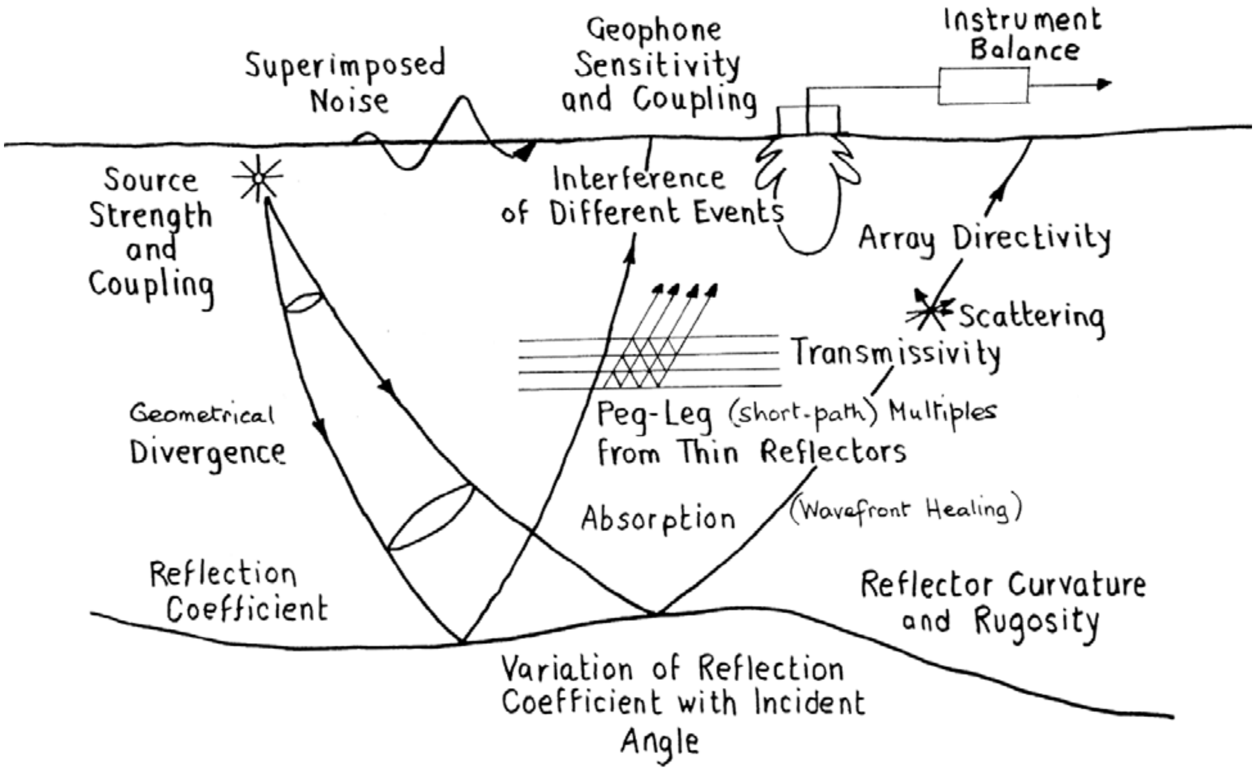
Hiltermann Approximation

$$R(\theta) \approx A\cos^2\theta + \overbrace{2.25\Delta\sigma}^{G}\sin^2\theta$$

$$G = A + B$$

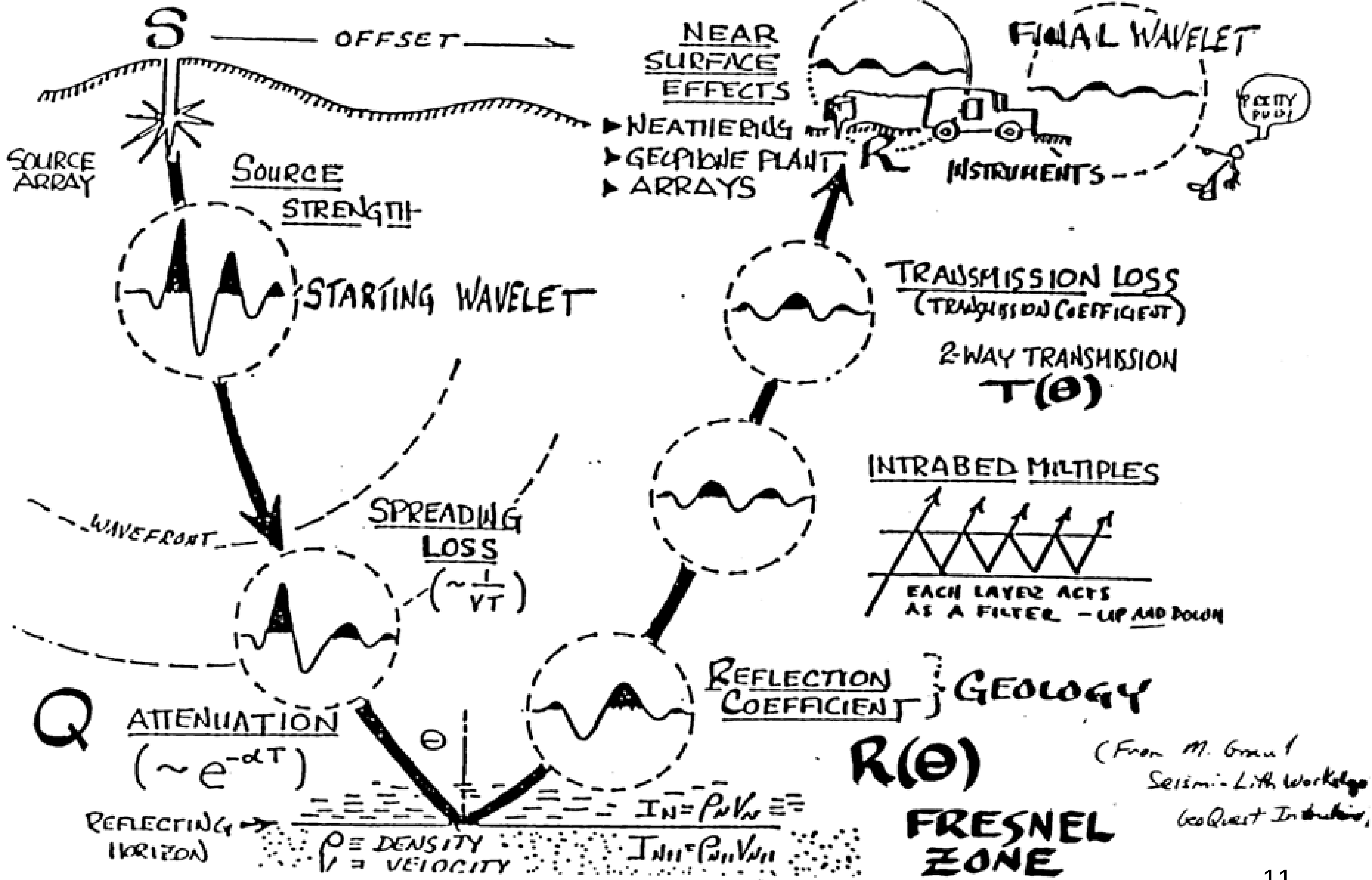
Castagna lecture note

AVO preprocessing



FACTORS WHICH AFFECT AMPLITUDE
After Sheriff, 1975

SOME FACTORS AFFECTING AMPLITUDE



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

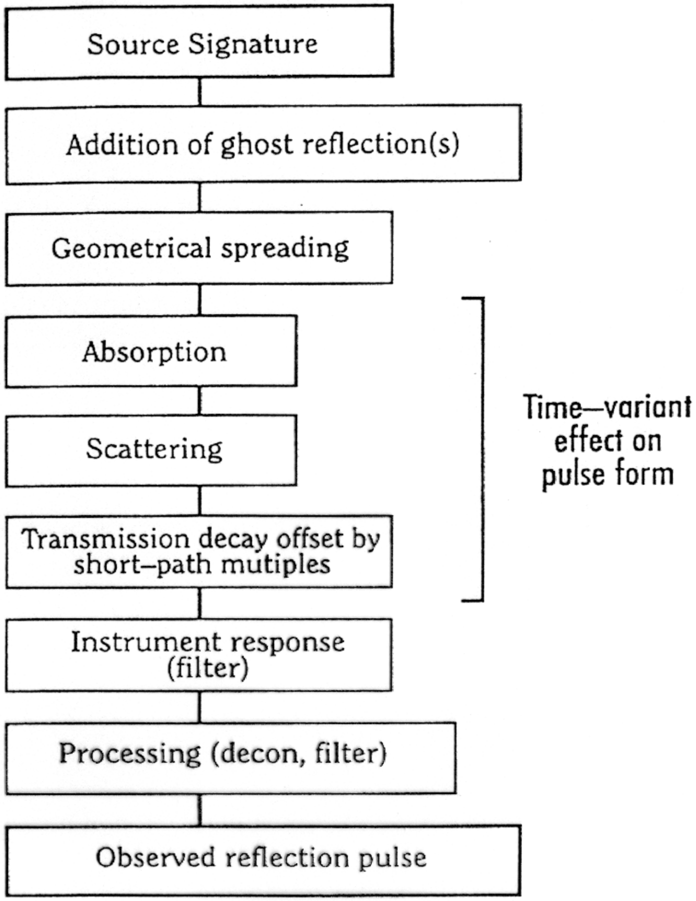
- Acquisition-related effects
- Source reciever arrays
- Reciever sensitivity

- Noise
- Source generated noise
- Coherent or random noise

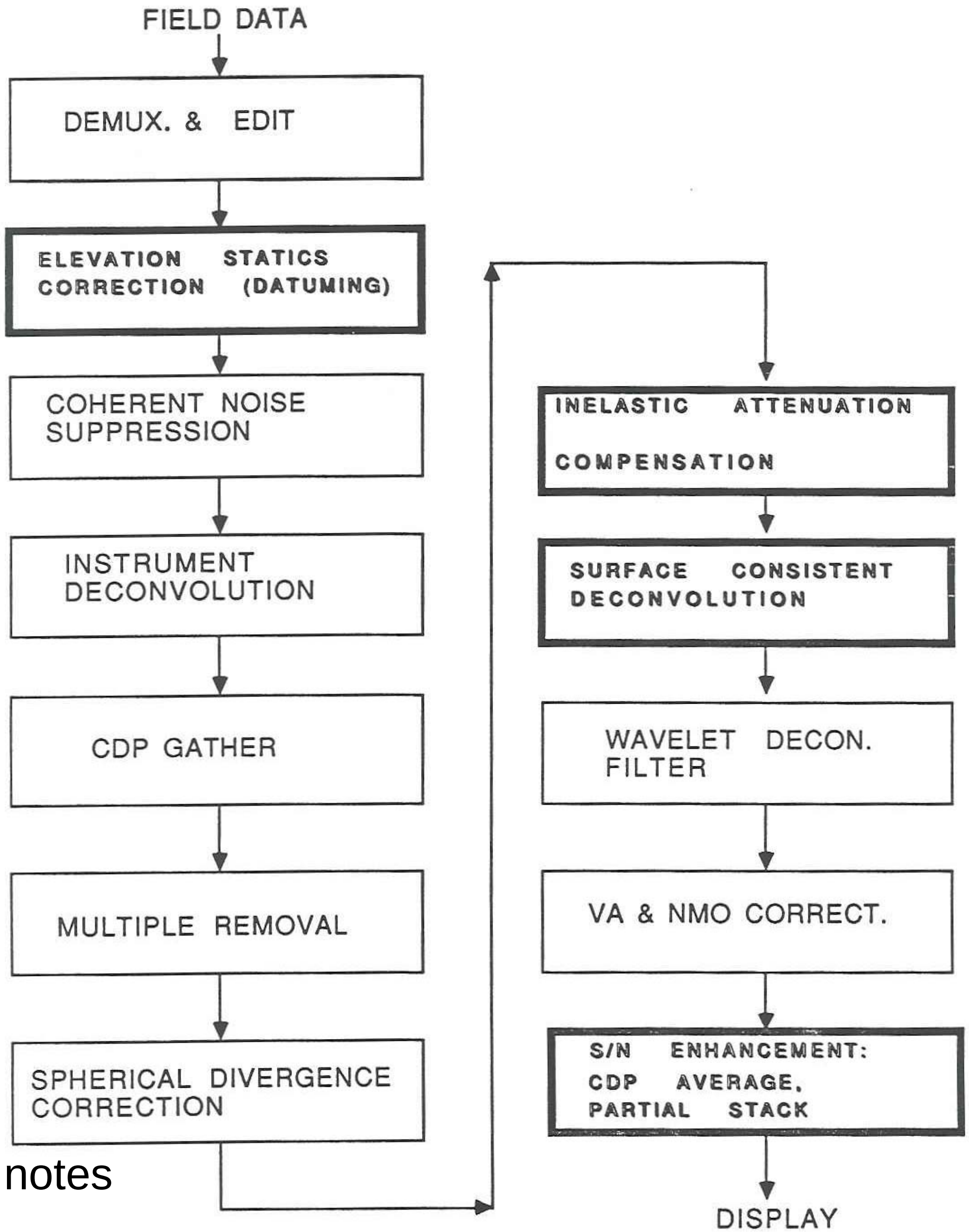
AVO Pre-processing

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

AVO preprocesing

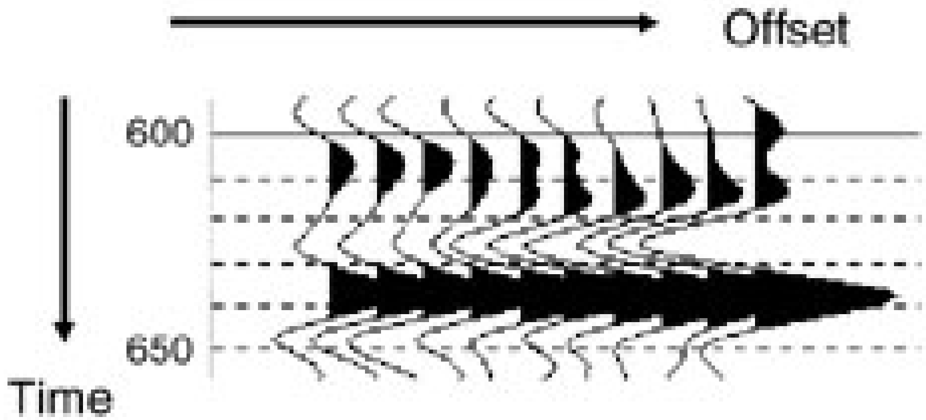


Castagna lecture notes

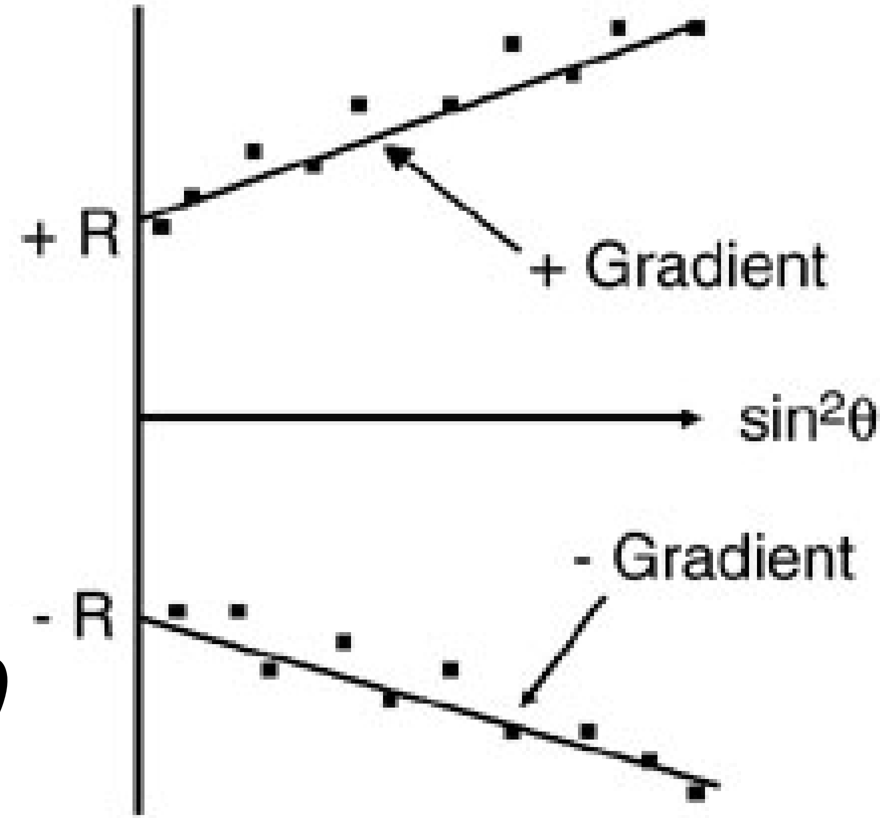

FIELD DATA
DEMUX. & EDIT
ELEVATION STATICS CORRECTION (DATUMING)
COHERENT NOISE SUPPRESSION
INSTRUMENT DECONVOLUTION
CDP GATHER
MULTIPLE REMOVAL
SPHERICAL DIVERGENCE CORRECTION
INELASTIC ATTENUATION COMPENSATION
SURFACE CONSISTENT DECONVOLUTION
WAVELET DECON. FILTER
VA & NMO CORRECT.
S/N ENHANCEMENT: CDP AVERAGE, PARTIAL STACK
DISPLAY

AVO modeling

Physical Interpretation



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



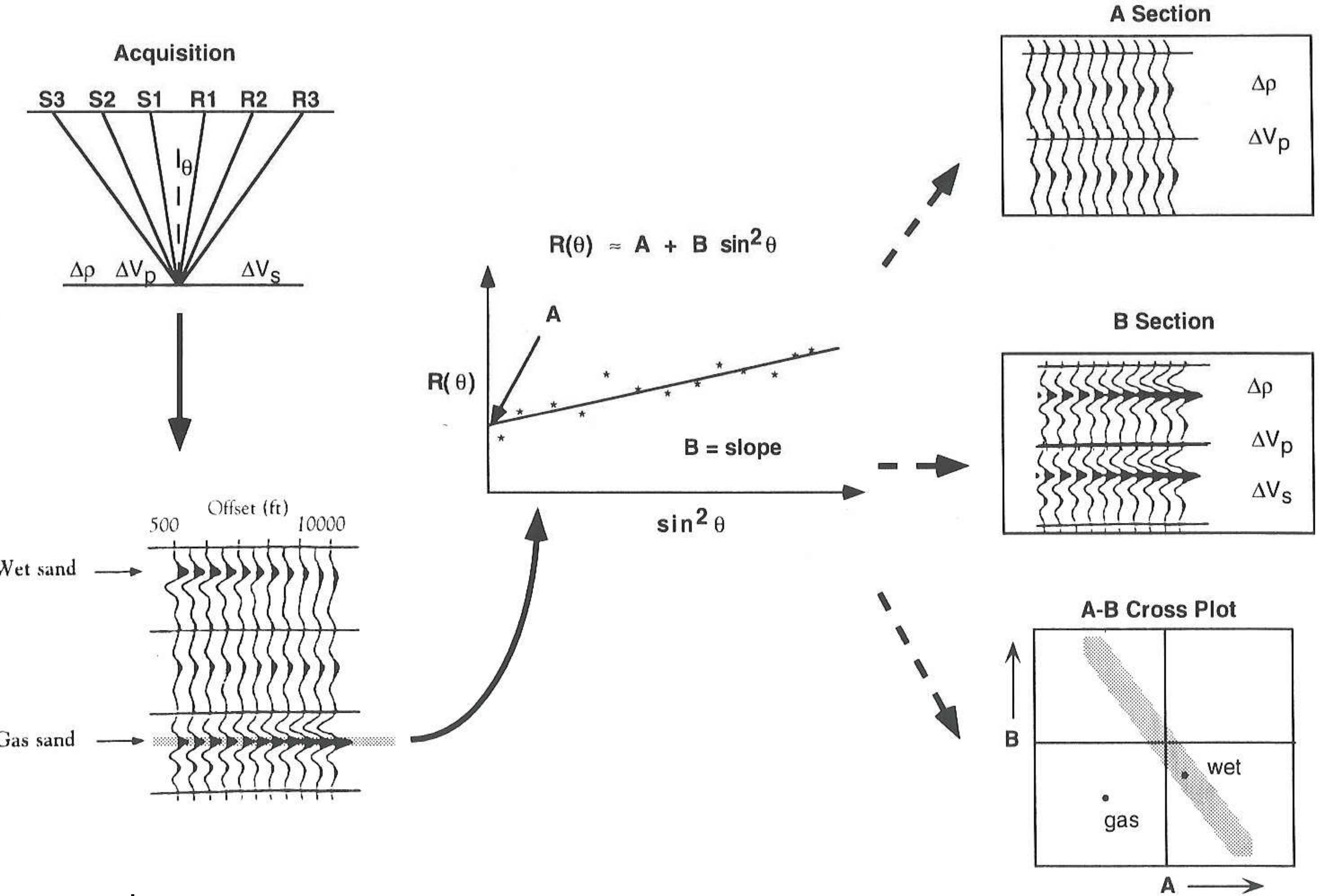
(a) Small window from gather

(b) Peak/trough picks vs. $\sin^2\theta$

(Russel, 1999)

AVO parameters

AMPLITUDE-VERSUS-OFFSET ANALYSIS



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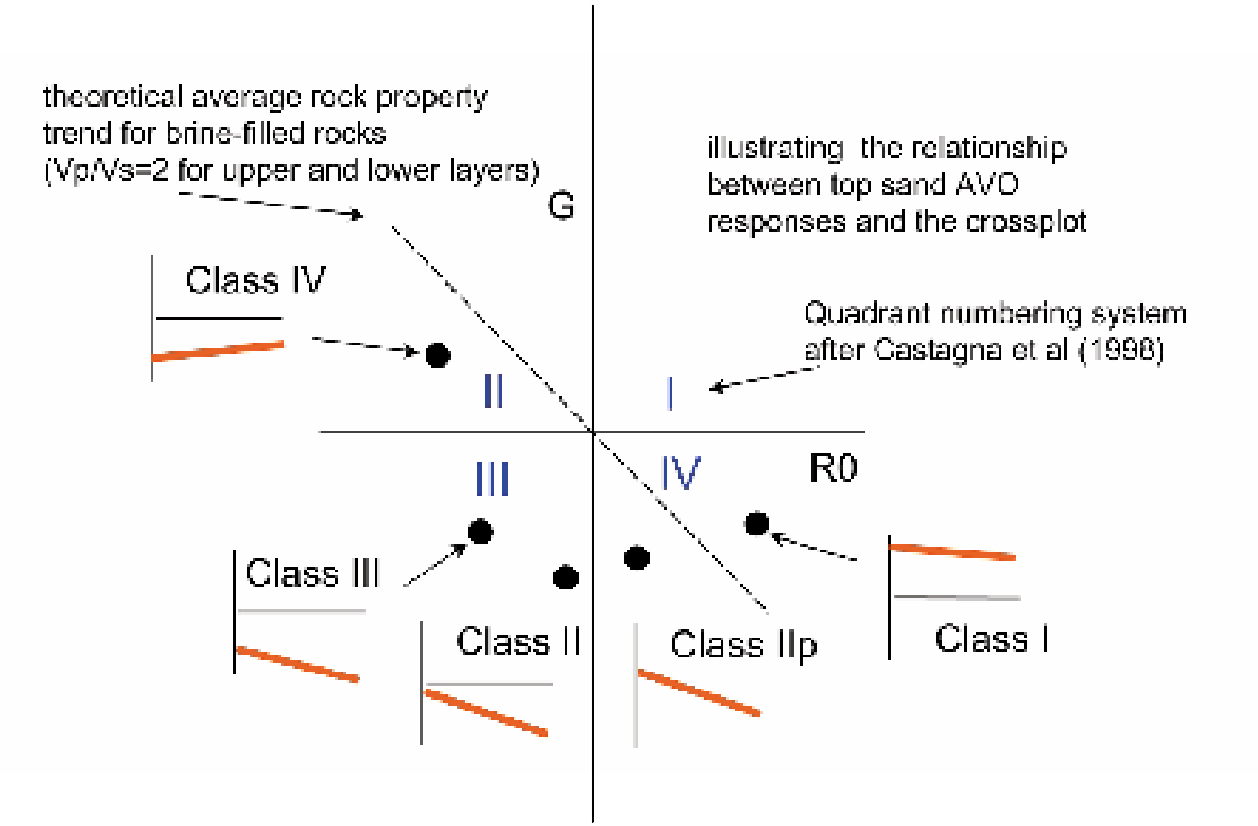
AVO crossplot



From Simm et al., 2000

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)
- Lamba-mu-rho

Calculated AVO Attributes

A = intercept
B = gradient
r^2 = correlation
A × B
(A + B)/2 ~ Rp - Rs
(A – B)/2 ~ Rs

Shuey 2 Term

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

A = intercept
B = gradient
C = curvature
r^2 = correlation
A × B
(A + B)/2 ~ Rp - Rs
(A – B)/2 ~ Rs
A – C

Shuey 3 Term

$$RC(\theta) = A + B(\sin^2\theta) + C(\sin^2\theta)(\tan^2\theta)$$

NI = normal intercept
PR = Poisson reflectivity
r^2 = correlation
NI × PR

Verm-Hilterman

$$RC(\theta) = NI(\cos^2\theta) + PR(\sin^2\theta)$$

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

- Post stack 1D Impedance Inversion
- Far-offset elastic Impedance
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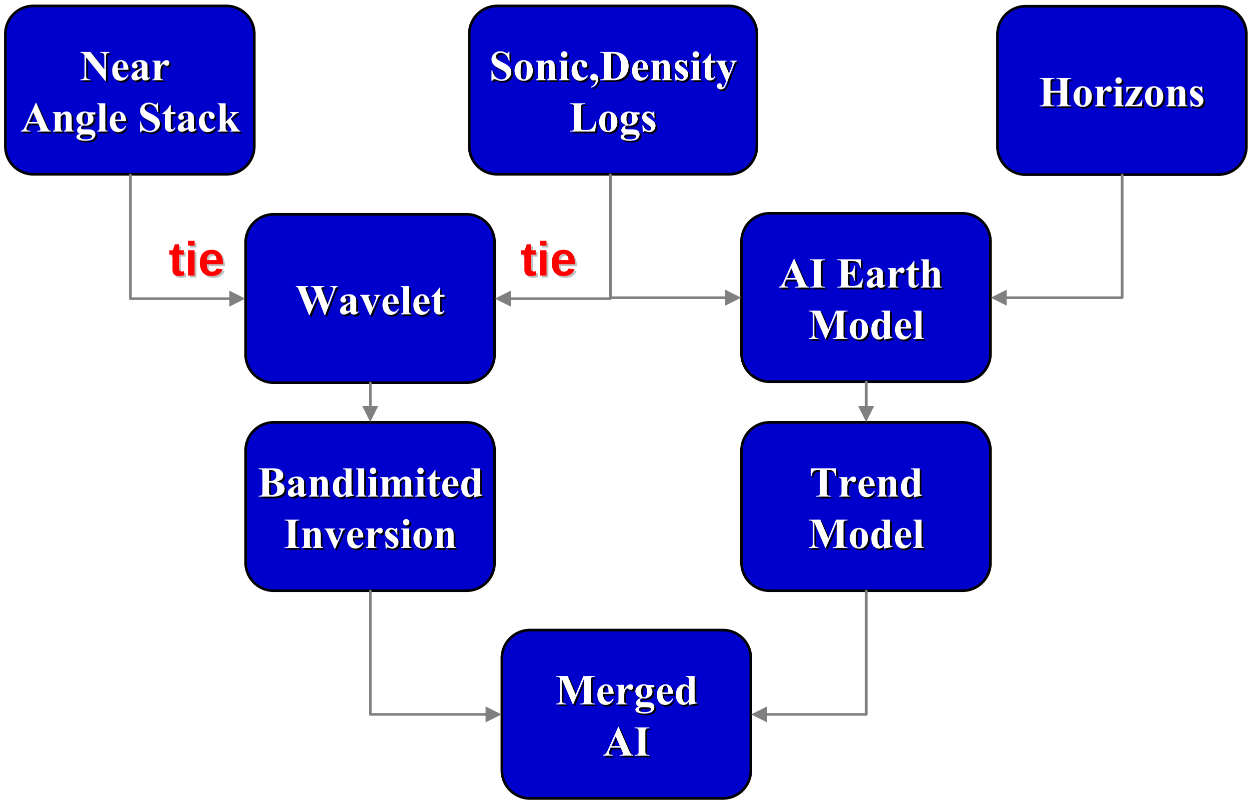
- Interpretation of Rock physics template

Poststack 1D impedance Inversion

- Inversion of near stack traces

Acoustic Impedance Inversion



Sena, 1997

Far offset elastic Impedance

- Inversion of far offset traces

The Elastic Impedance

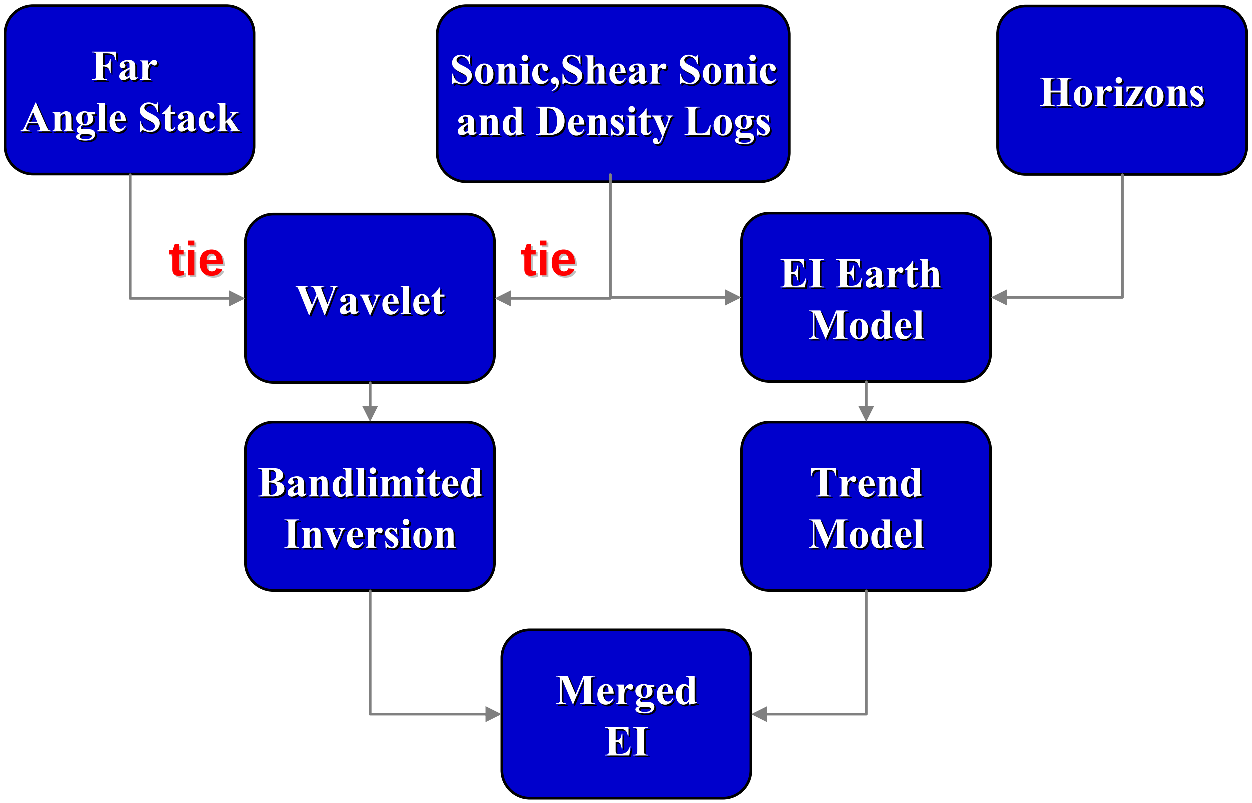
$$E = V_p^{\alpha} V_s^{\beta} \rho^{\gamma}$$

$$\alpha = 1/\cos^2\theta \qquad \beta = -8(V_s/V_p)^2\sin^2\theta$$

$$\gamma = 1 + \beta/2$$

Sena, 1997

Elastic Impedance Inversion



Sena, 1997

Lambda Rho estimation

Generalization of $\lambda\rho$

ΔG = 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),

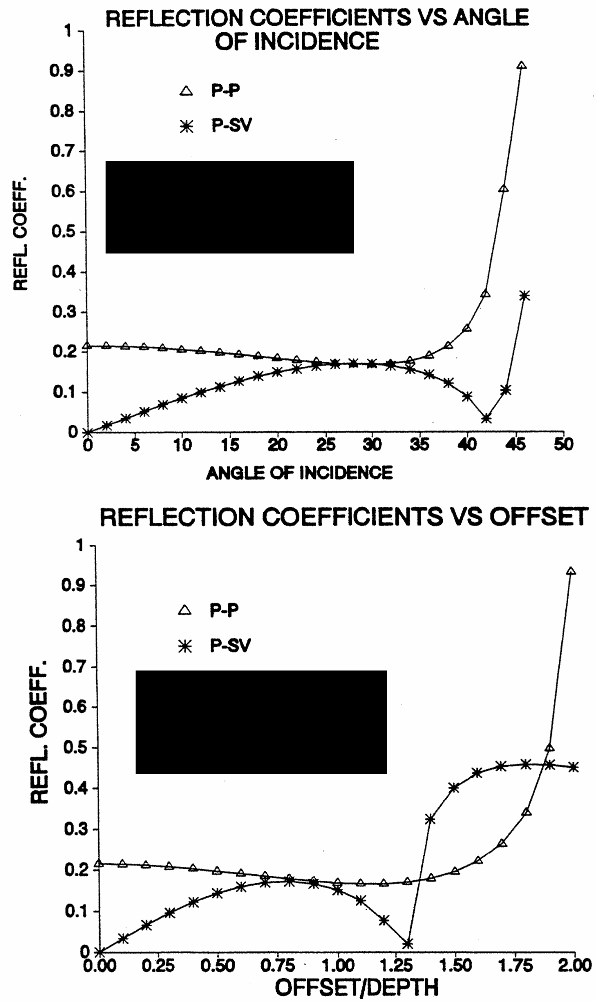
$$AVOImpedance \equiv (AI - \gamma\,SI)$$

ΔG = 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)

$$Rps = \frac{-p\alpha}{2\cos\varphi}\left[\left(1-2\beta^2p^2 + 2\beta^2\frac{\cos\theta}{\alpha}\frac{\cos\varphi}{\beta}\right)\frac{\Delta\rho}{\rho} - \left(4\beta^2p^2 - 4\beta^2\frac{\cos\theta}{\alpha}\frac{\cos\varphi}{\beta}\right)\frac{\Delta\beta}{\beta}\right]$$

First Order

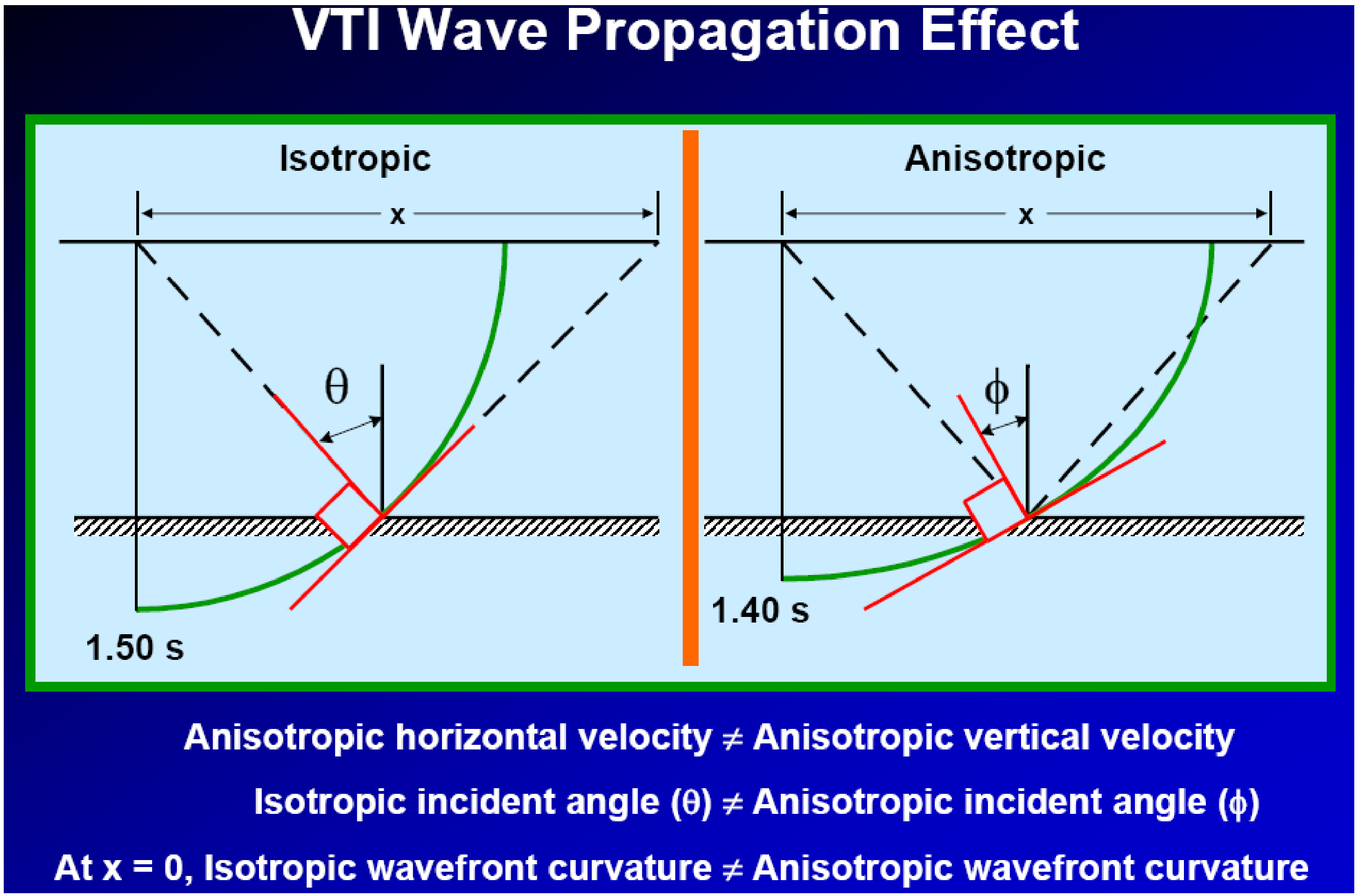
Relative S-velocity change

Relative density change

Stewart and Gasier lecture note

Anisotropic elastic Inversion

Anisotropy


VTI Wave Propagation Effect
Isotropic
x
θ
1.50 s
Anisotropic
x
φ
1.40 s
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: $\varepsilon = 0.14$, $\delta = 0.09$

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

$$RC_{VTI}(\theta) = \tfrac{1}{2}(\delta_2 - \delta_1)\sin^2\theta + \tfrac{1}{2}(\varepsilon_2 - \varepsilon_1)\sin^2\theta \tan^2\theta$$

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