ConocoPhillips
SCHOOL OF GEOLOGY & GEOPHYSICS
The University of Oklahoma

Lecture 2. The Seismic Experiment

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Learner Objectives

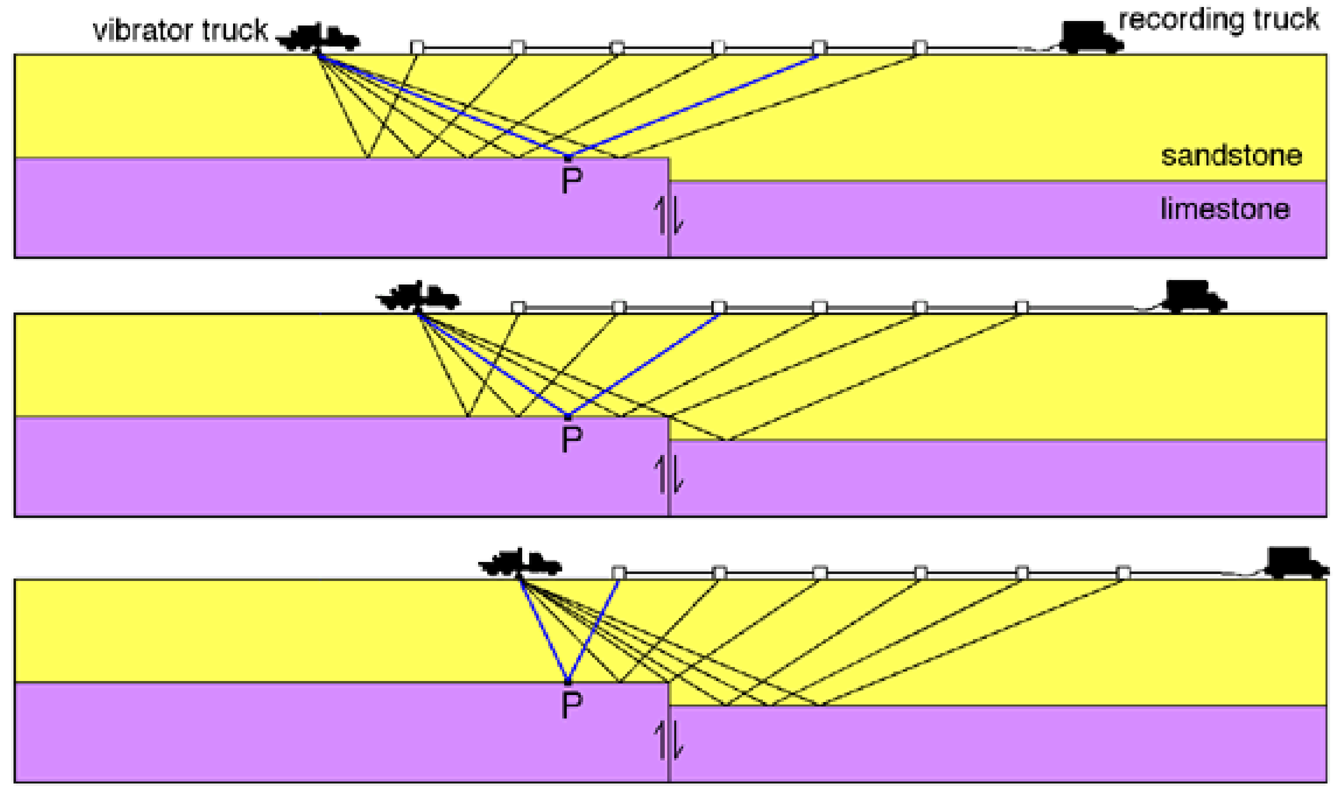
- ***Be able to enumerate the various components of modern multifold 3D land and marine seismic acquisition programs***

- ***Correlate changes in impedance to seismic reflections***

- ***Recognize the appearance and causes of acquisition footprint***

1. The goal of seismic acquisition:

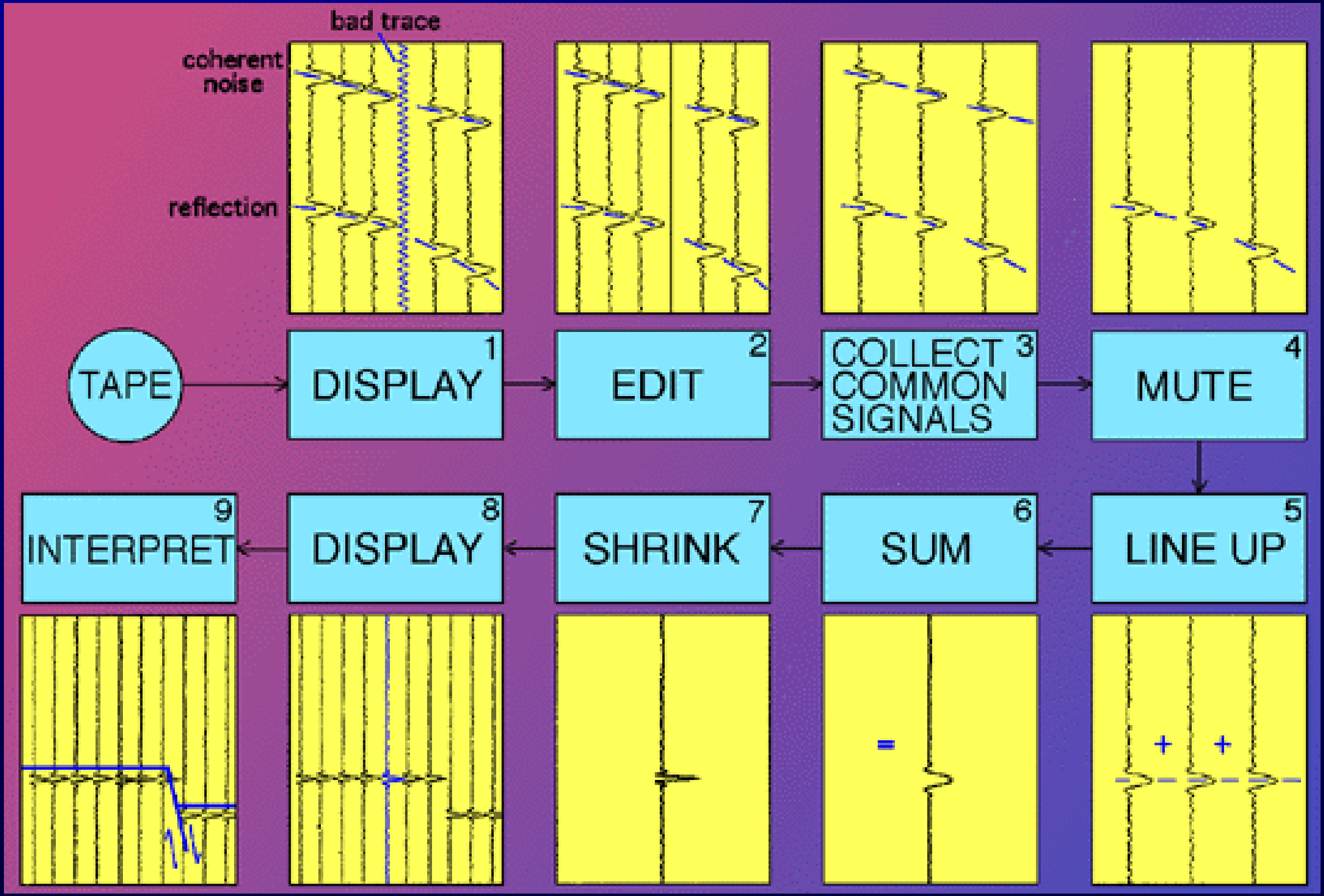
To illuminate the subsurface with elastic wave energy



(http://www.litho.ucalgary.ca/atlas/seismic.html)

2. The goal of seismic processing:

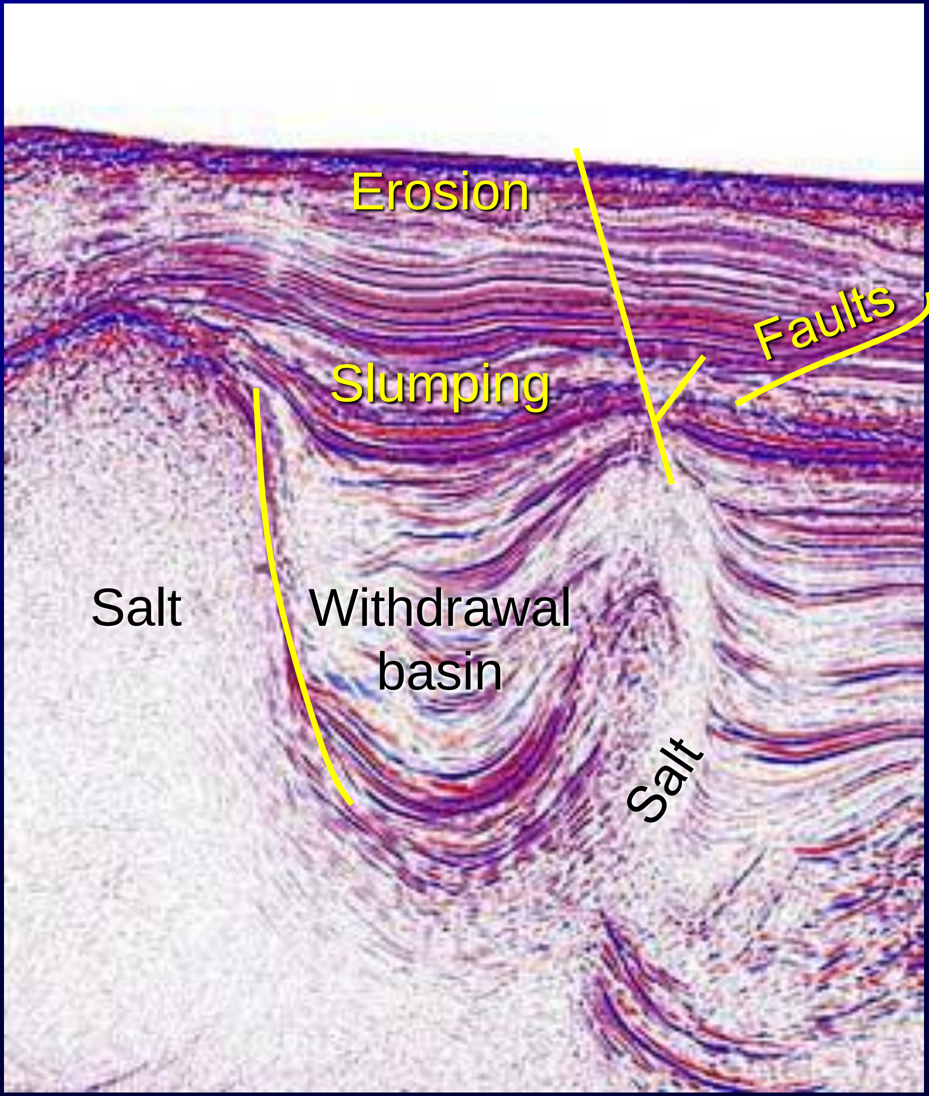
To generate an image of the earth's subsurface



(http://www.litho.ucalgary.ca/atlas/seismic.html)

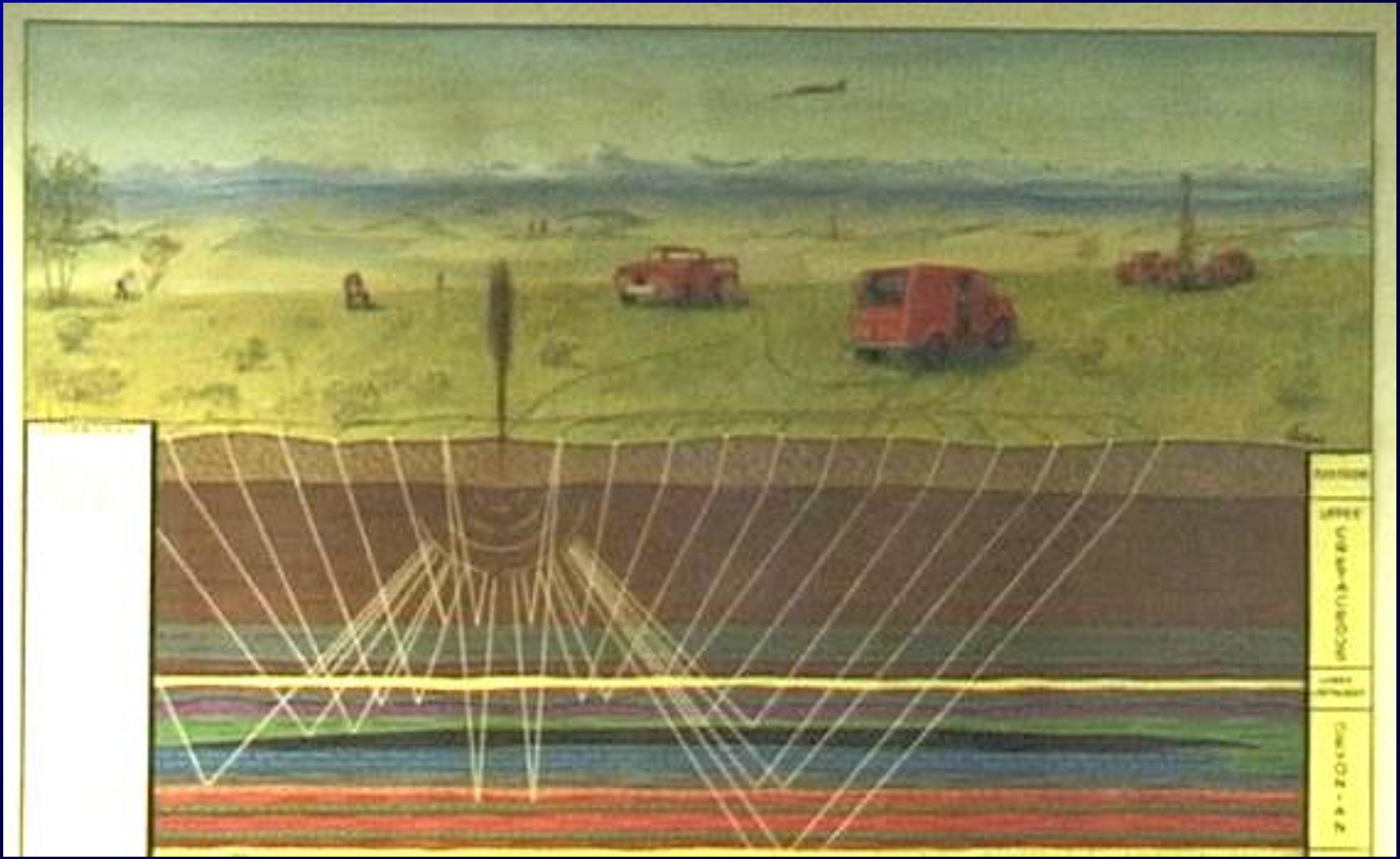
3. The goal of seismic interpretation:

To convert seismic reflections into a geologic model



Seismic Acquisition

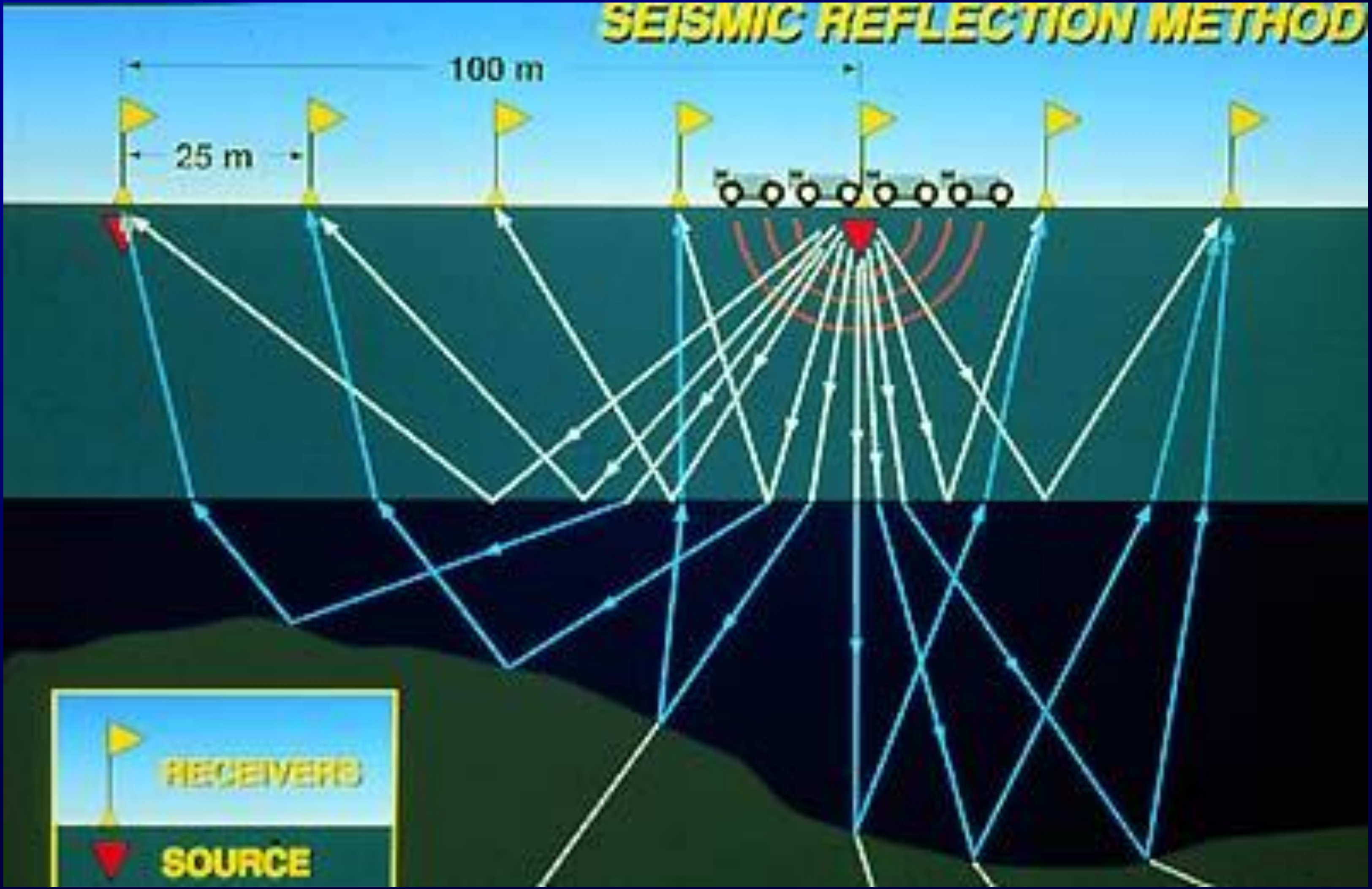
The seismic reflection method



Dynamite sources

(lots of energy NOT put into the ground!)

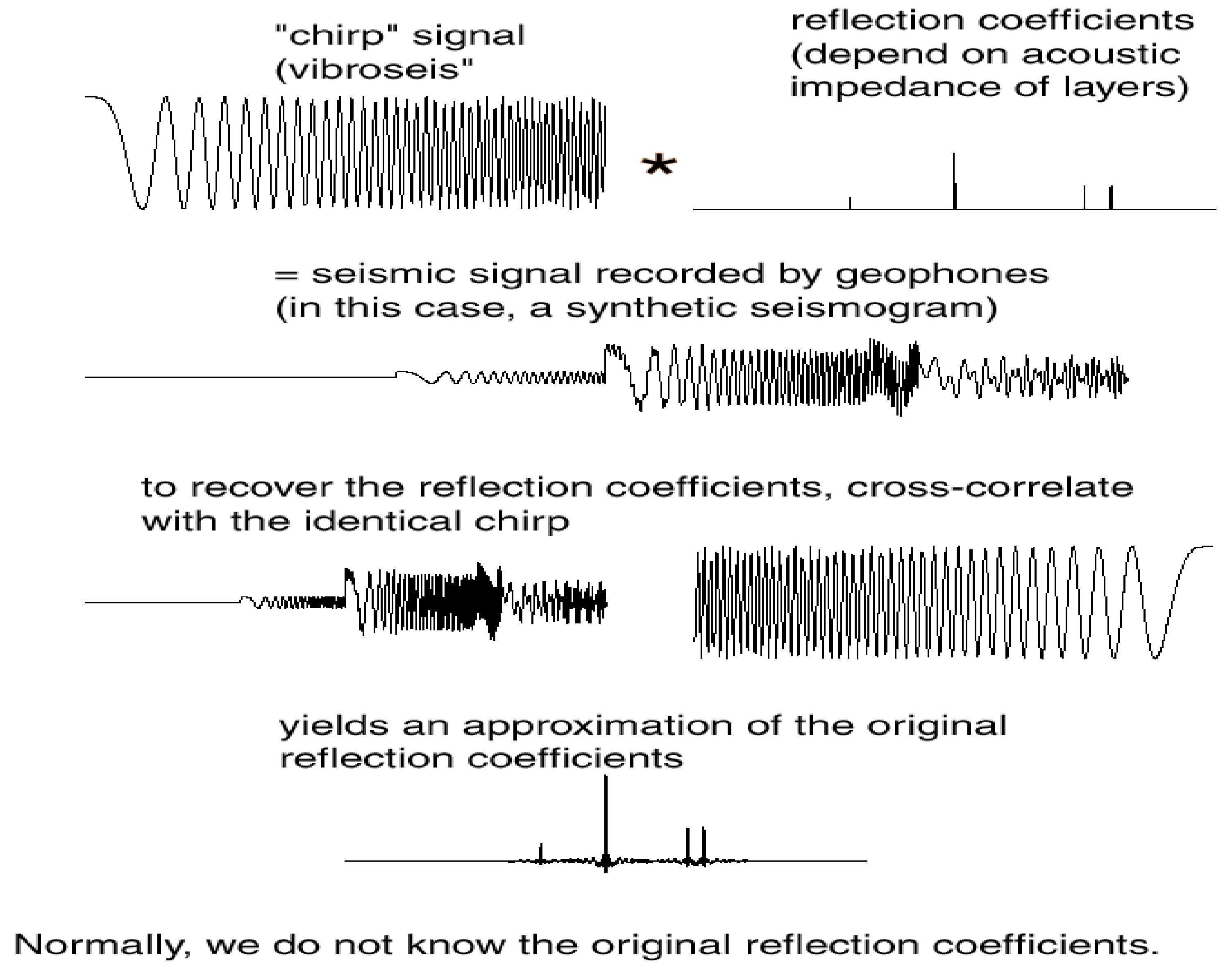
The seismic reflection method



Vibroseis

www.indvehicles.com

Vibroseis



"chirp" signal
(vibroseis"

$*$

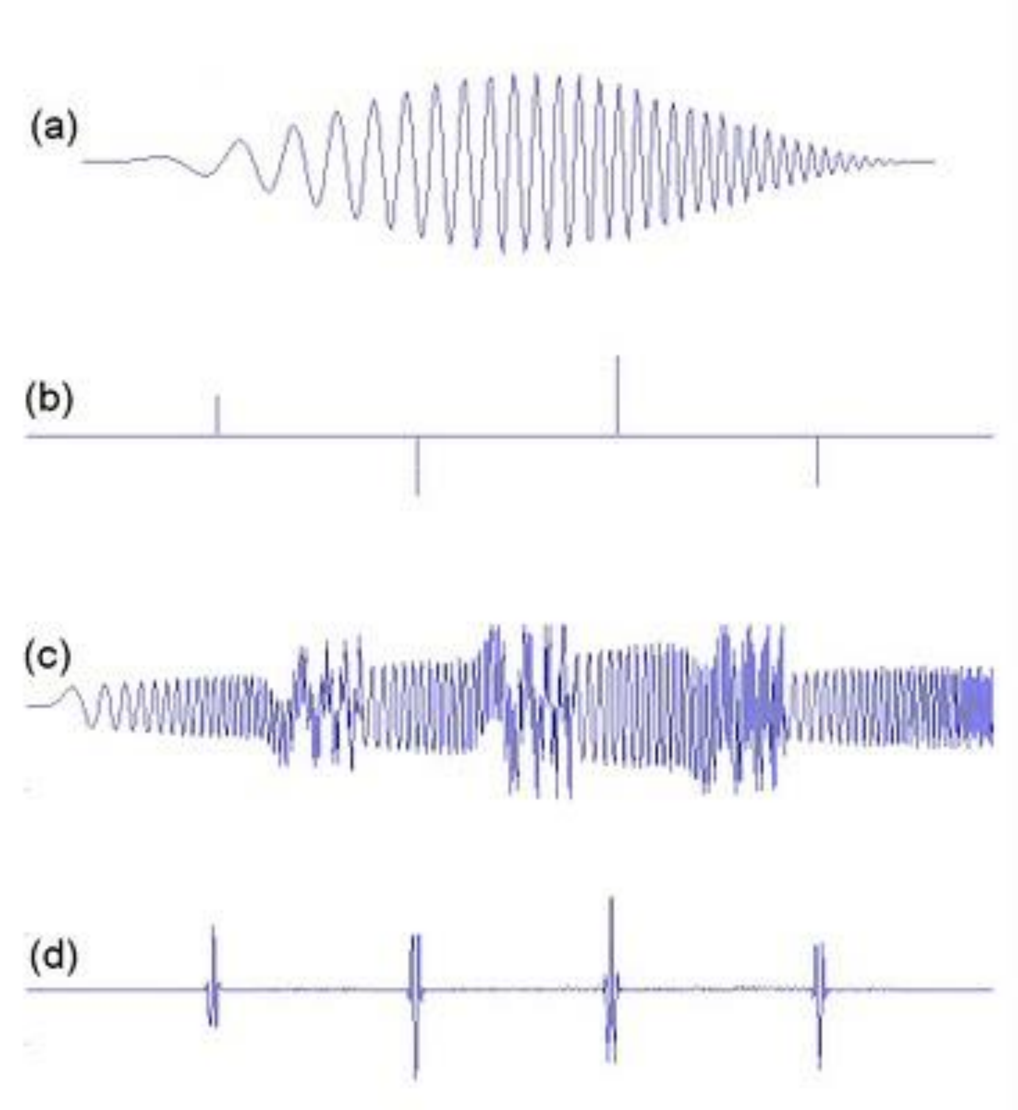
reflection coefficients
(depend on acoustic
impedance of layers)

= seismic signal recorded by geophones
(in this case, a synthetic seismogram)

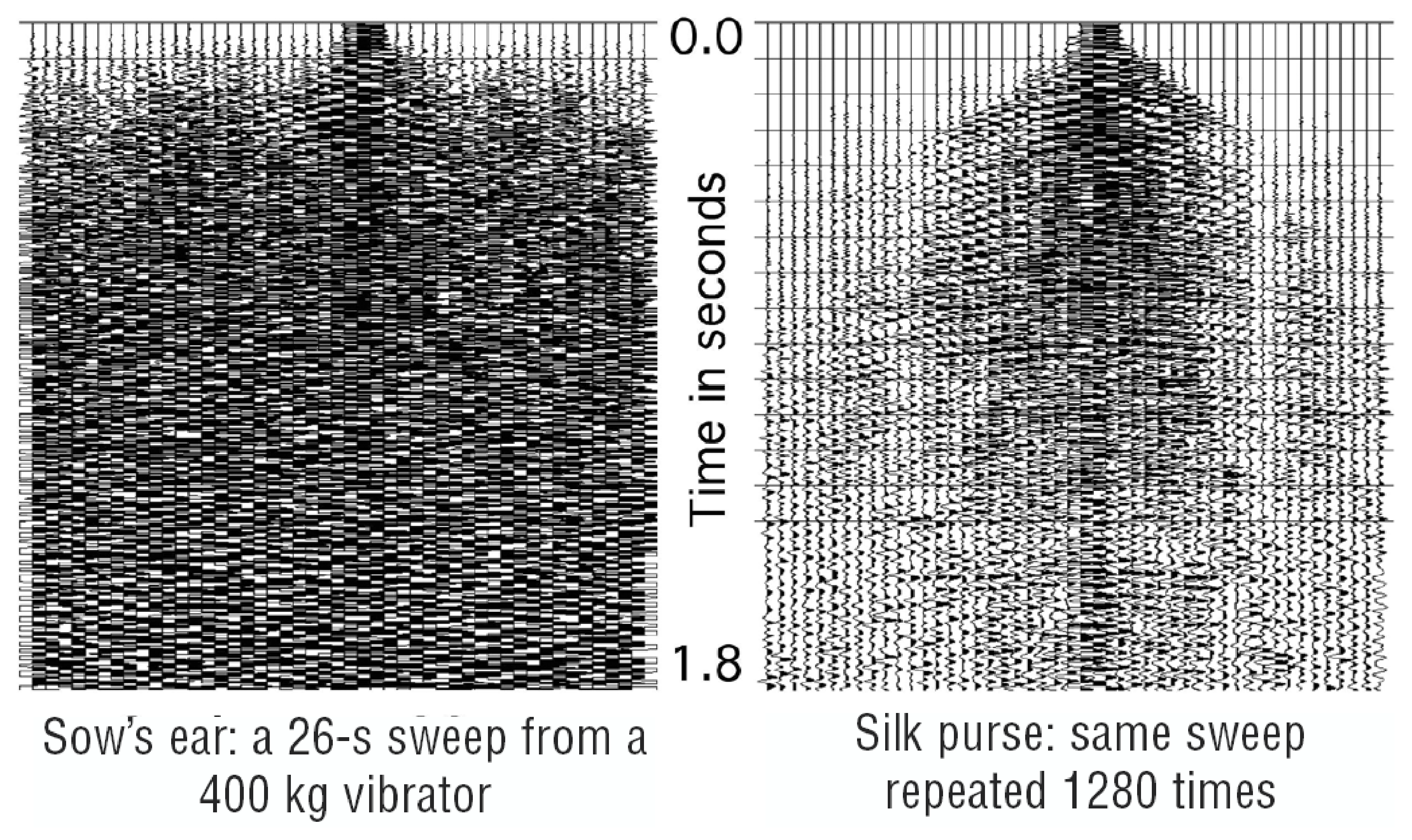
to recover the reflection coefficients, cross-correlate
with the identical chirp

yields an approximation of the original
reflection coefficients

Normally, we do not know the original reflection coefficients.


(a)
(b)
(c)
(d)

Vibroseis



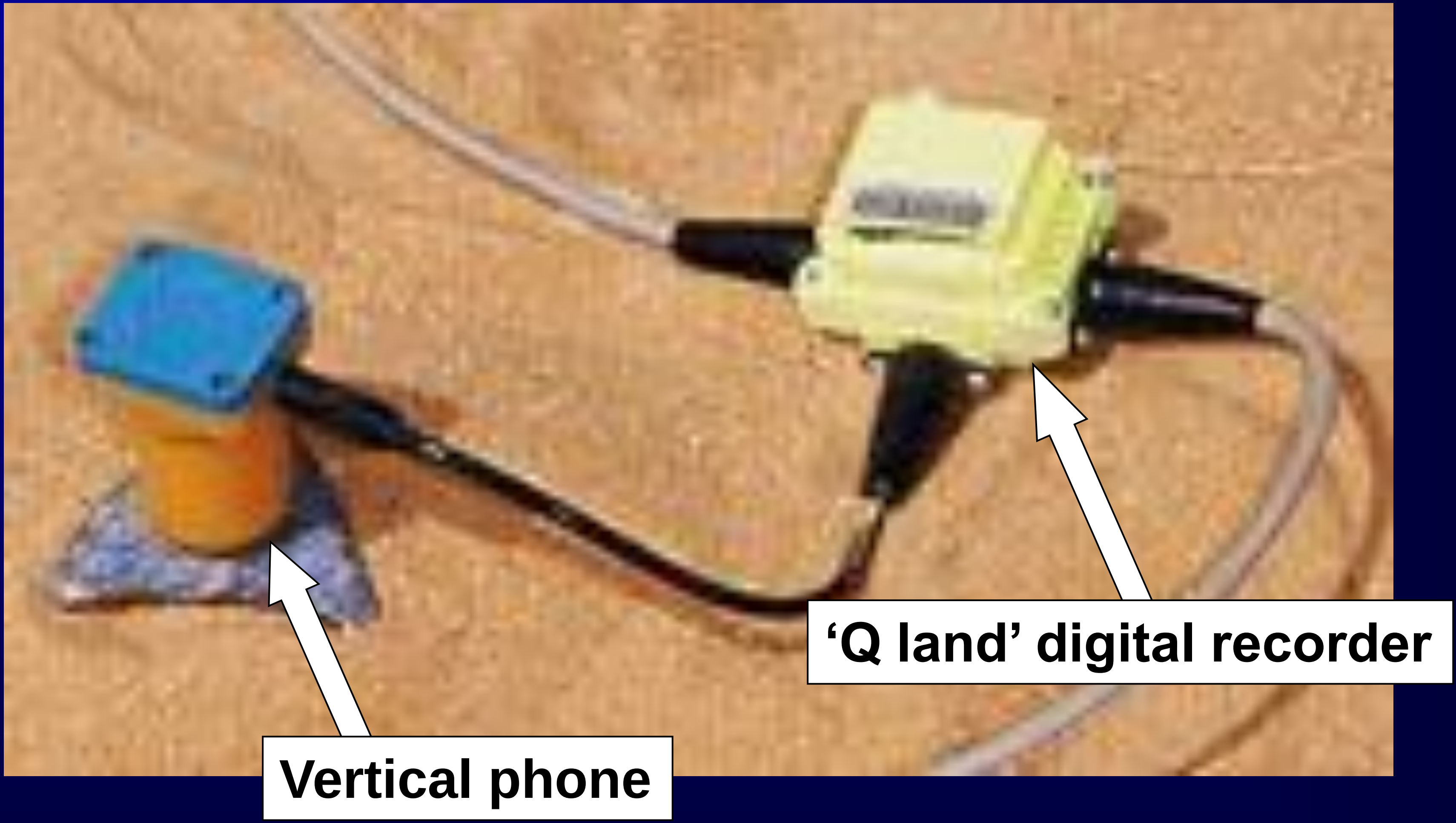
Sow's ear: a 26-s sweep from a 400 kg vibrator

Silk purse: same sweep repeated 1280 times

If the ground is not permanently deformed, each vibroseis experiment is repeatable. It the noise is random, and the experiment repeated N times, the signal to noise ratio increases by SQRT(N).

(Cambois, 2002)

Geophones



‘Q land’ digital recorder

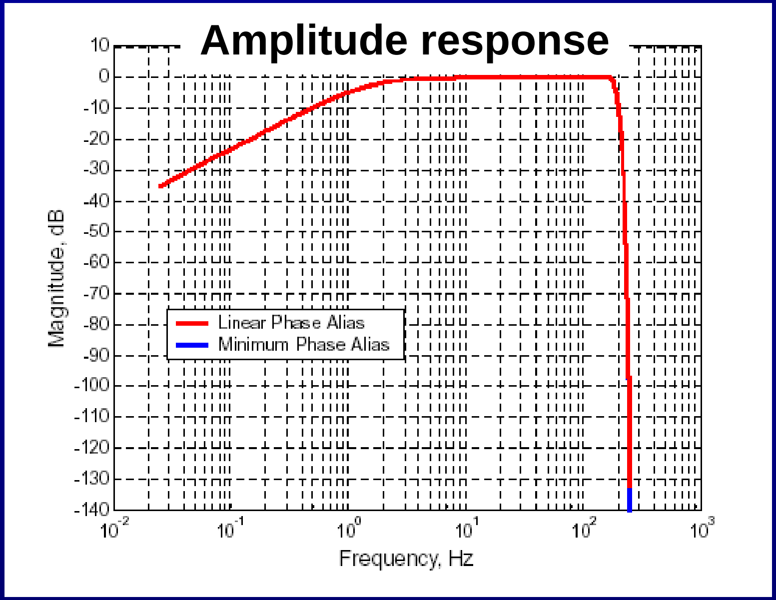
Vertical phone

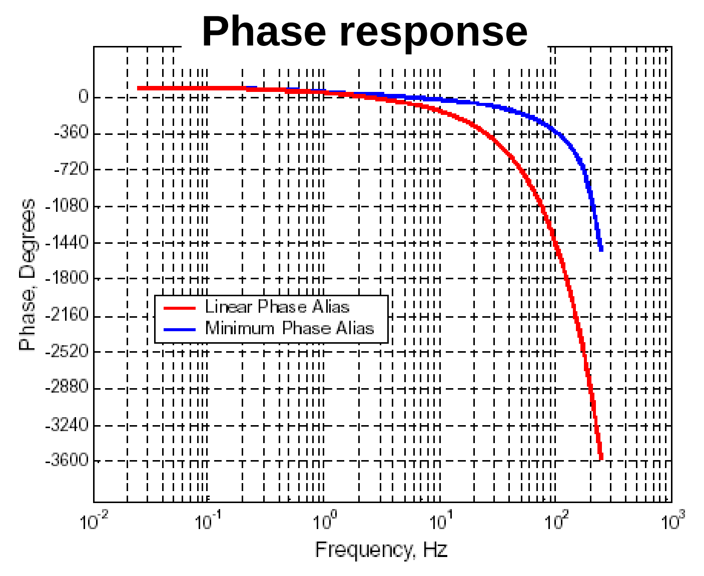
Input-Output 3-C digital receiver

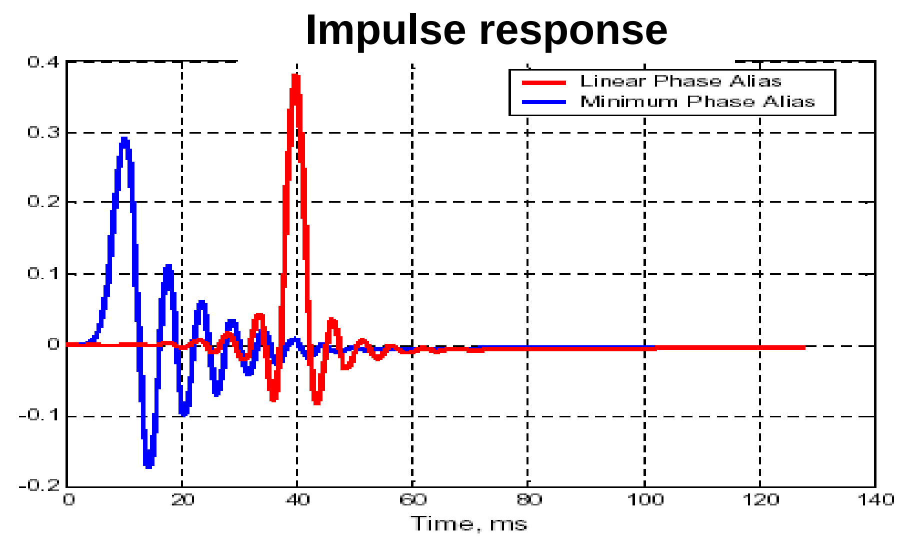
SVSM receiver

- **Three identical accelerometers are mounted orthogonally on a precision-machined aluminum cube for stability and industry-leading vector fidelity**
- **Accelerometers are mounted low in the module for better ground coupling and less wind noise susceptibility**
- **Sensors are decoupled from line cables for isolation from cable transmitted noise and for ease of sensor handling separate from the line**
- **Full wave-field vector recording enable multicomponent and enhanced p-wave acquisition**
- **Flat frequency and phase response offer broadband dynamic range**
- **High vector fidelity provides sharp, high resolution 3C images**

Input-Output 3-C digital receiver







Single Geophone vs. Group Recording

Conventional recording:

- Uses fixed linear or areal geophone arrays with fixed noise rejection characteristics.
- Reduces the number of independent channels to be recorded
- Can attenuate non-vertical arrivals

‘Q-land’ or individual phone recording:

- Can optimally remove noise and preserve non-vertical arrivals.
- Has the capacity to record 30000 channels of data in real time at a 2 ms sample rate
- Avoids electronic pick up of noise during transmission

Planting a geophone

Arrays

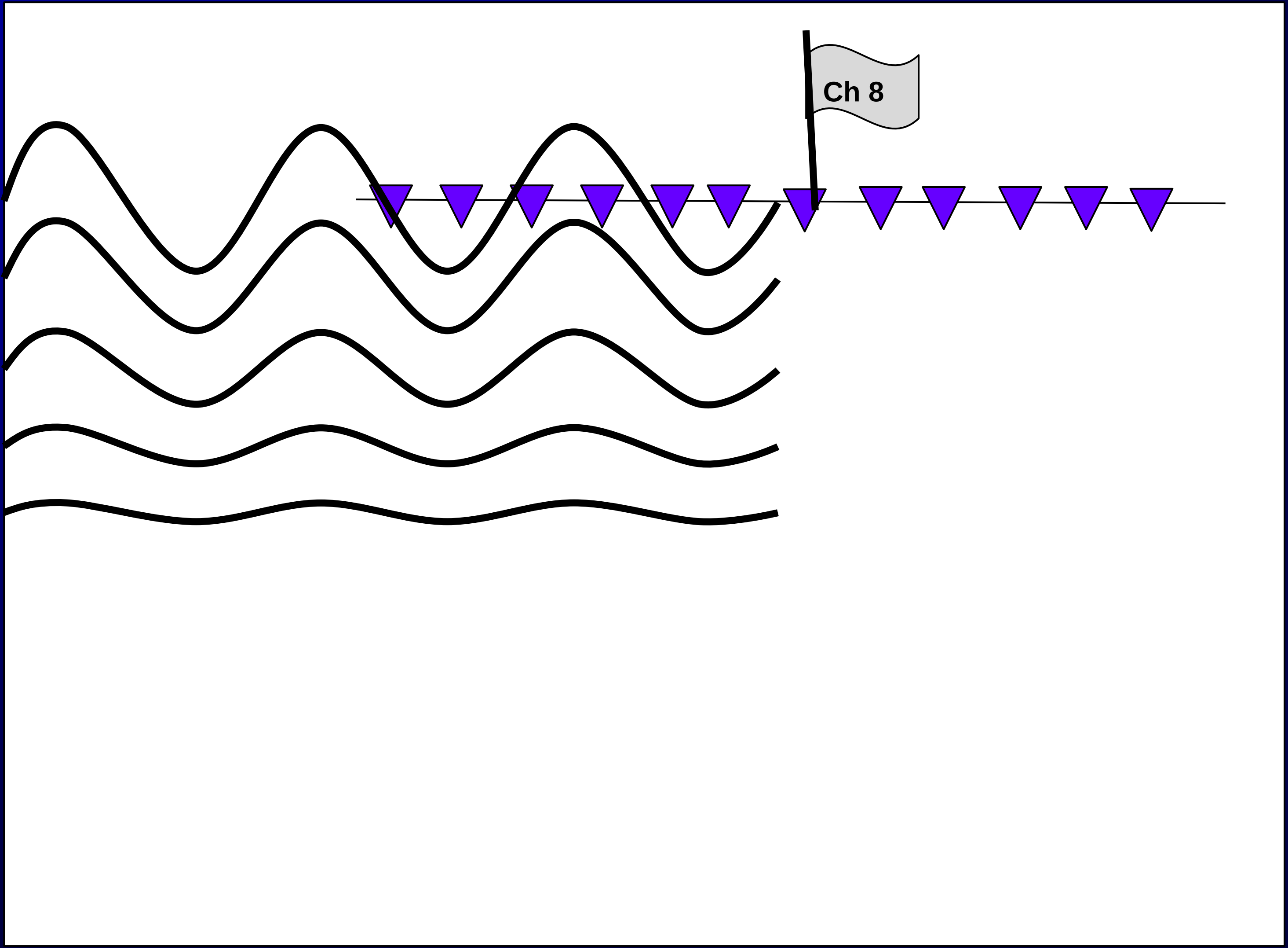
Receiver array (or group)

Source arrays

www.westerngeco.com

(http://www.geo.cornell.edu/geology/cocorp)

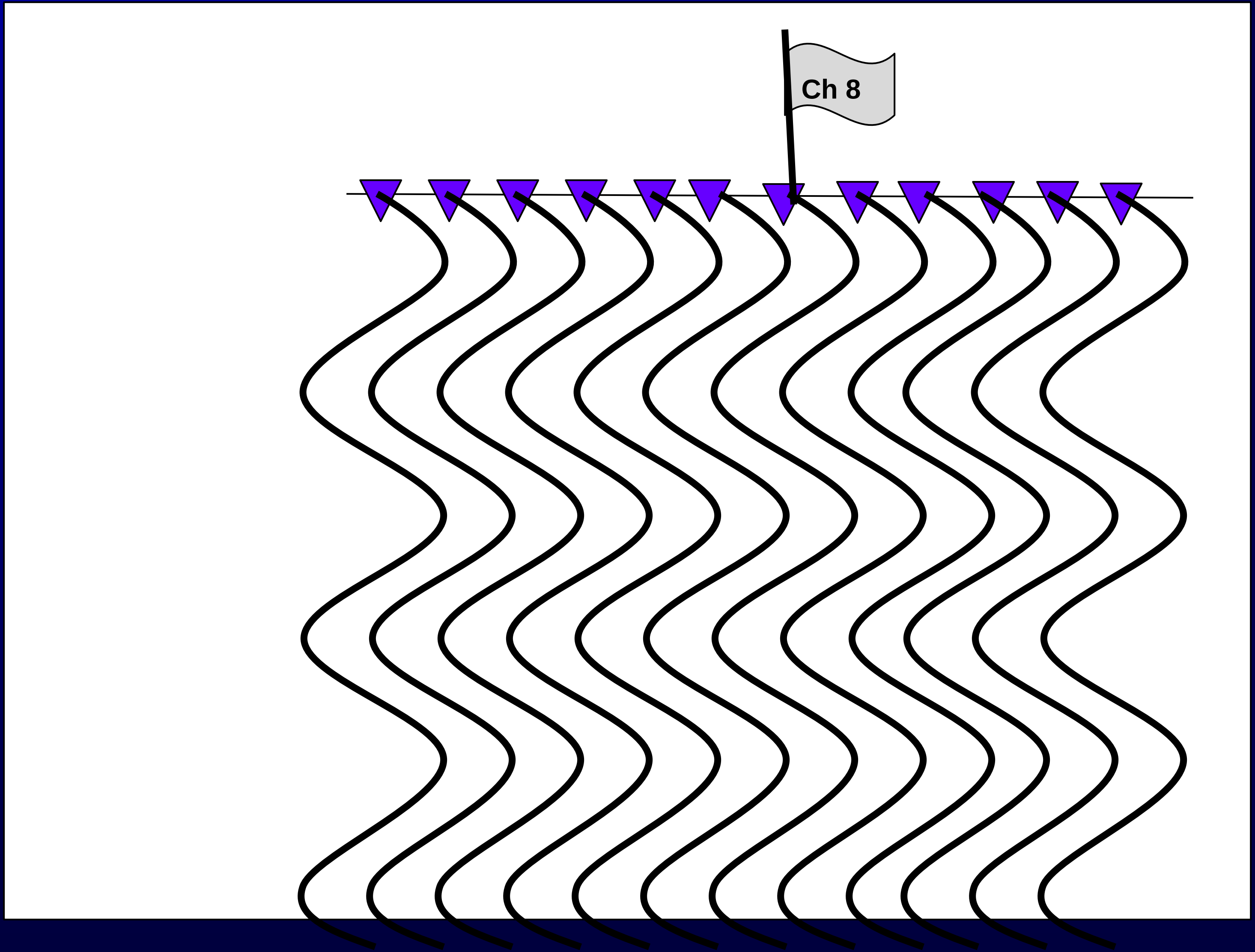
Source and Receiver Arrays



Goal:

- Reduce horizontally traveling ground roll
- Enhance vertically traveling signal

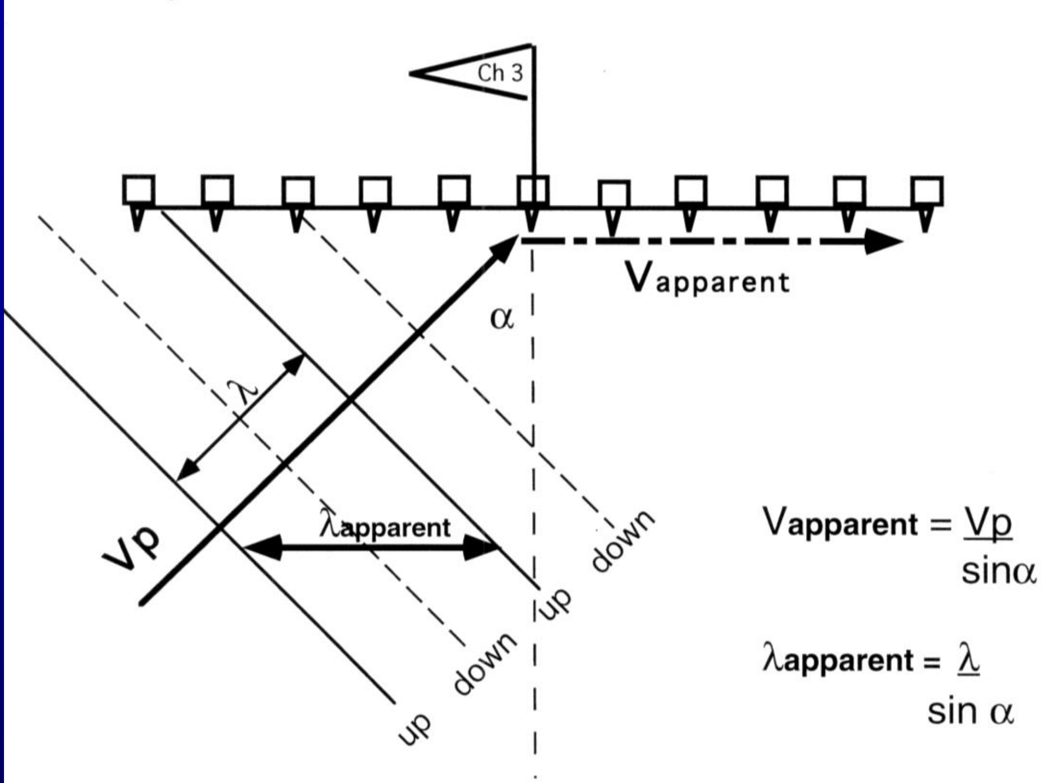
Source and Receiver Arrays



Goal:

- **Reduce horizontally traveling ground roll**
- **Enhance vertically traveling signal**

Source and Receiver Arrays



$V_{apparent} = \frac{V_p}{\sin\alpha}$

$\lambda_{apparent} = \frac{\lambda}{\sin\alpha}$

For vertically incident waves:
(e.g. $\alpha = 0°$)

$V_{apparent} = \infty$

$\lambda_{apparent} = \infty$

For horizontally incident waves:
(e.g. $\alpha = 90°$)

$V_{apparent} = V_p$

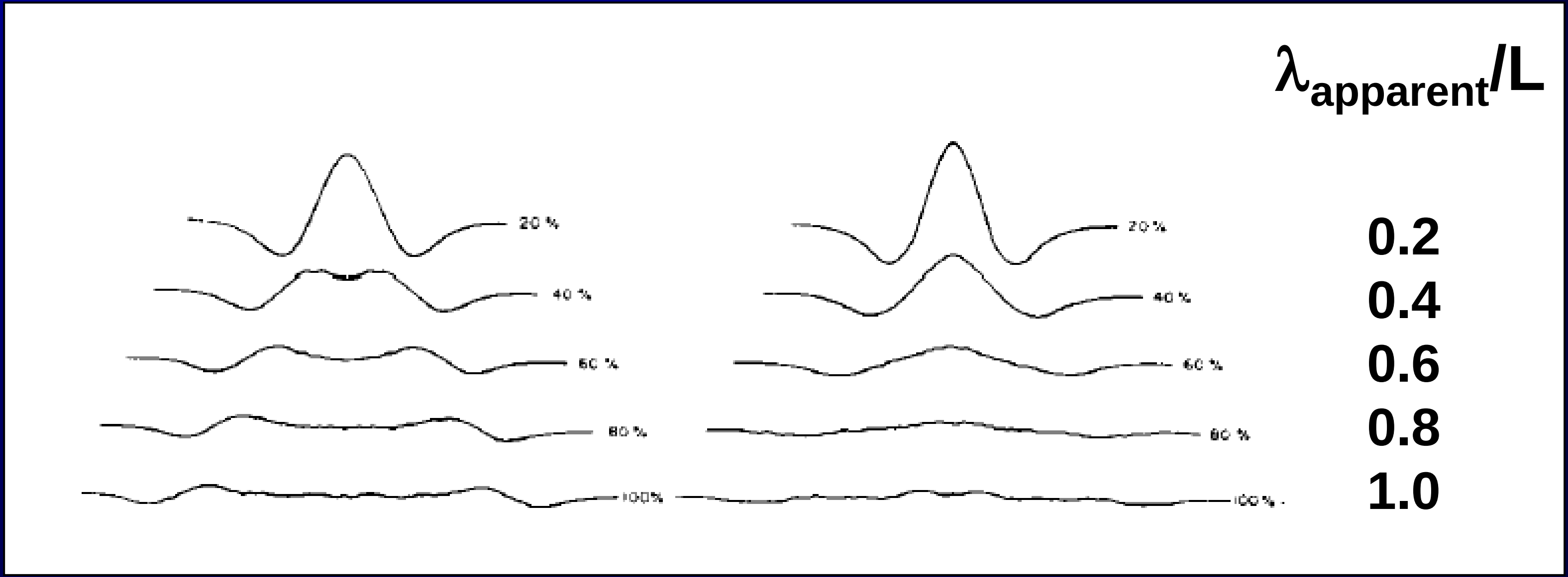
$\lambda_{apparent} = \lambda$

Goal:

- **Reduce horizontally traveling ground roll**
- **Enhance vertically traveling signal**

(courtesy Cornell Univ)

Response of weighted 6-phone arrays

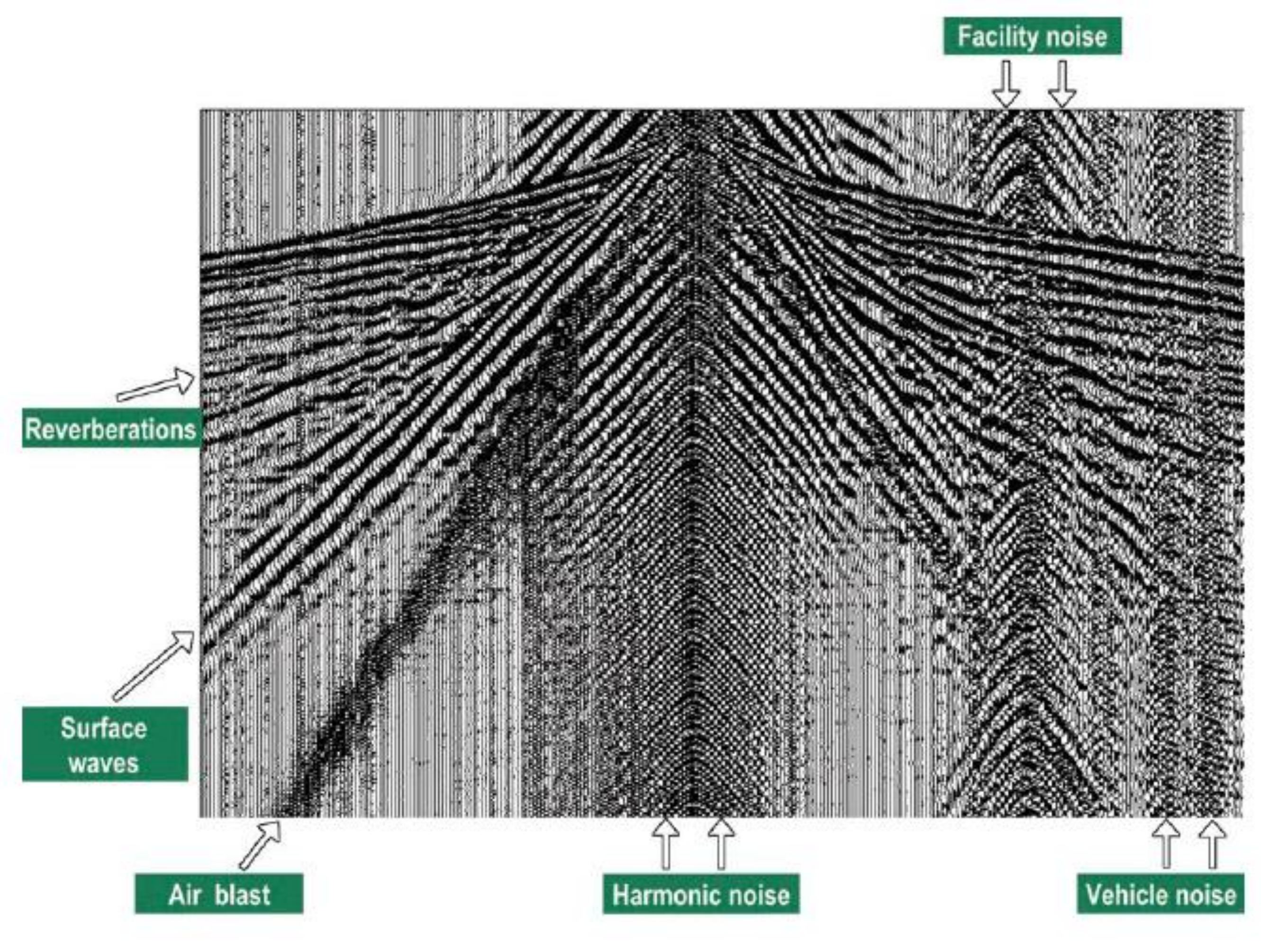


1 1 1 1 1 1

1 2 3 3 2 1 ← **weights**

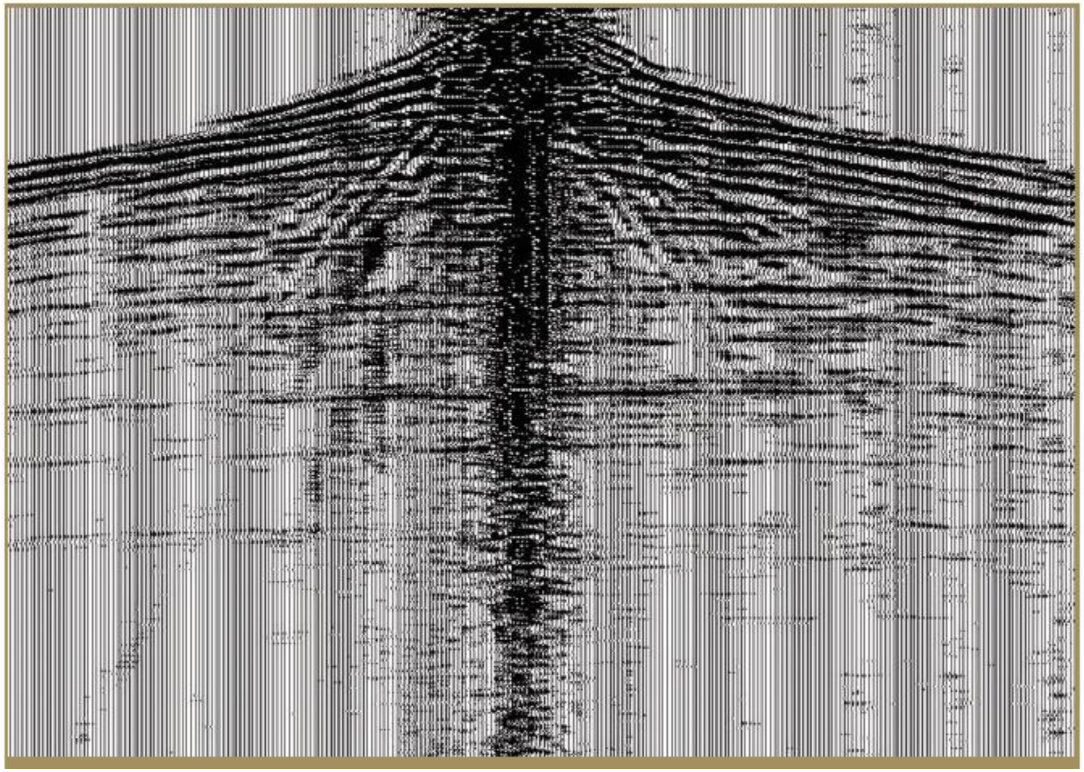
(Verma and Roy, 1970)

Example of seismic signal and noise (single receiver recording)



(Dragoset, 2006)

Example of seismic signal and noise (digital receiver group recording)



(Dragoset, 2006)

P-wave (vertical) land vibrator arrays

(Dawson ad, AAPG Explorer, November 2008)

Land vibrator arrays

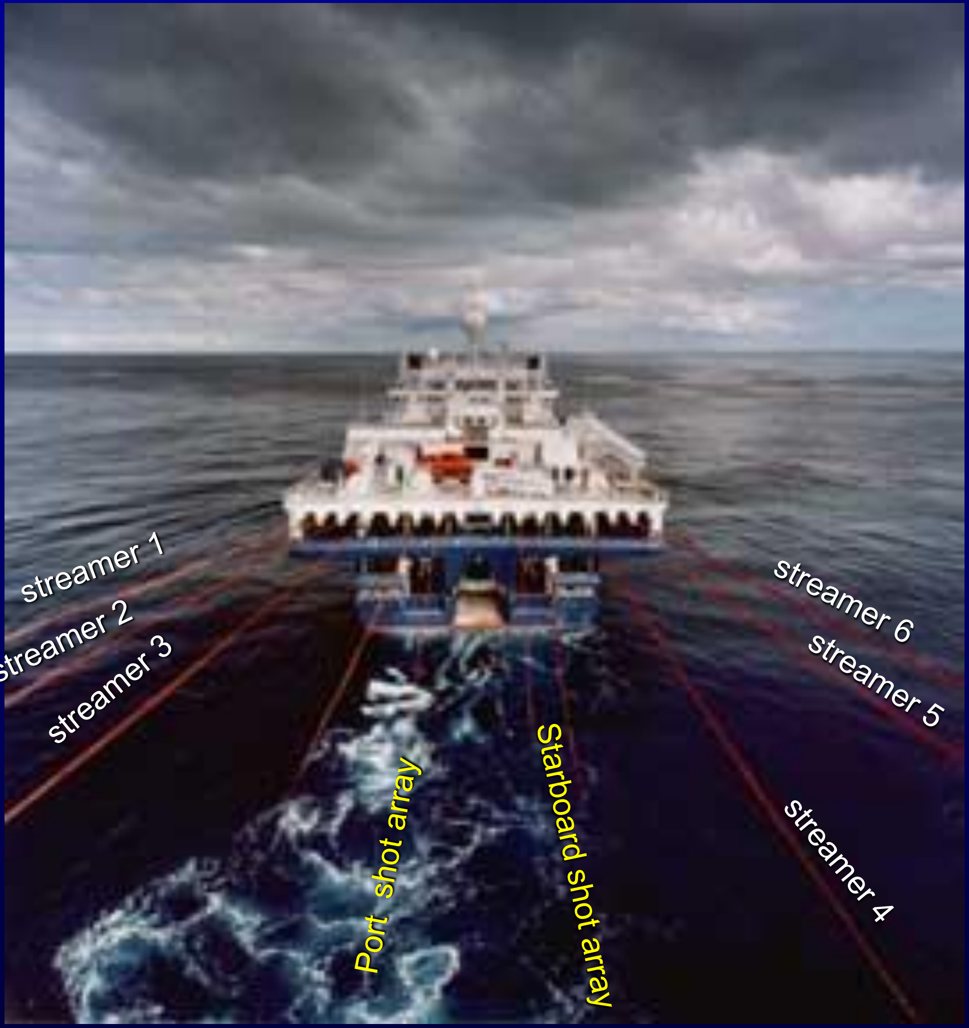
Simultaneous shaking

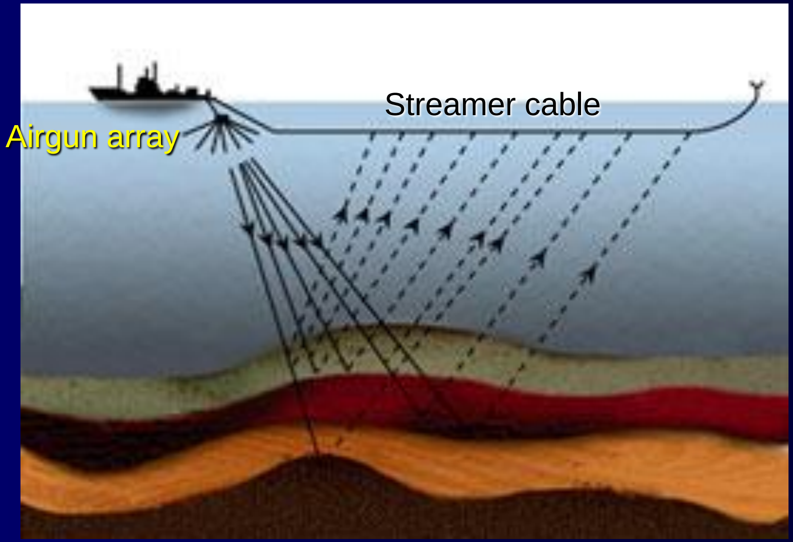
(Durham, AAPG Explorer, November 2008)

Marine acquisition with airguns

(Fugro ad, AAPG Explorer, November 2008)

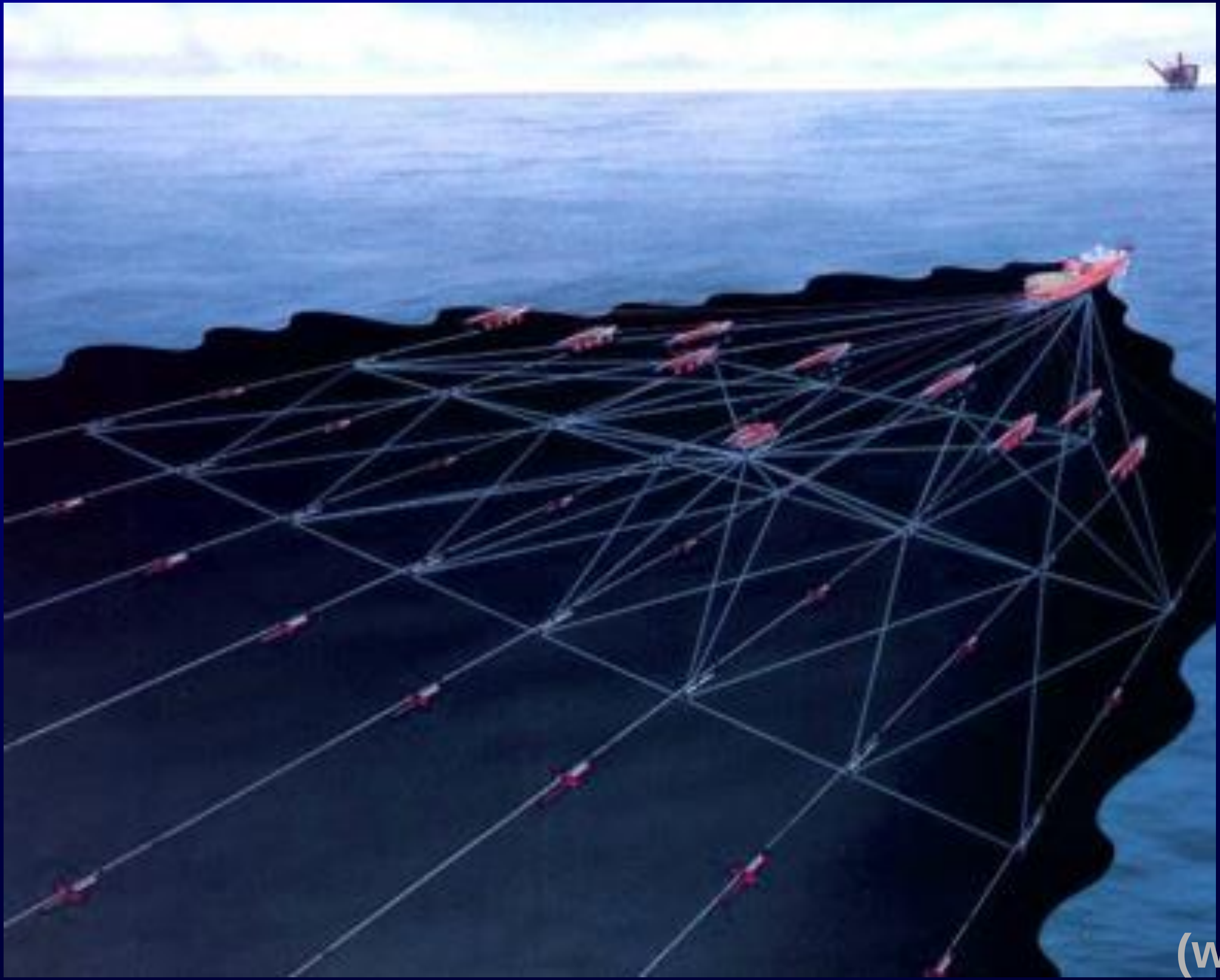
Marine streamer acquisition





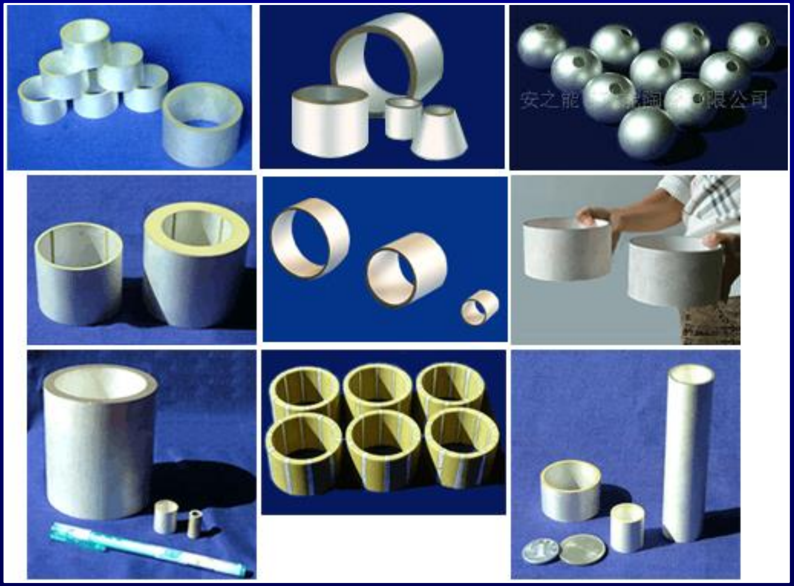
(www.norskhydro.com)

Multistreamer marine acquisition

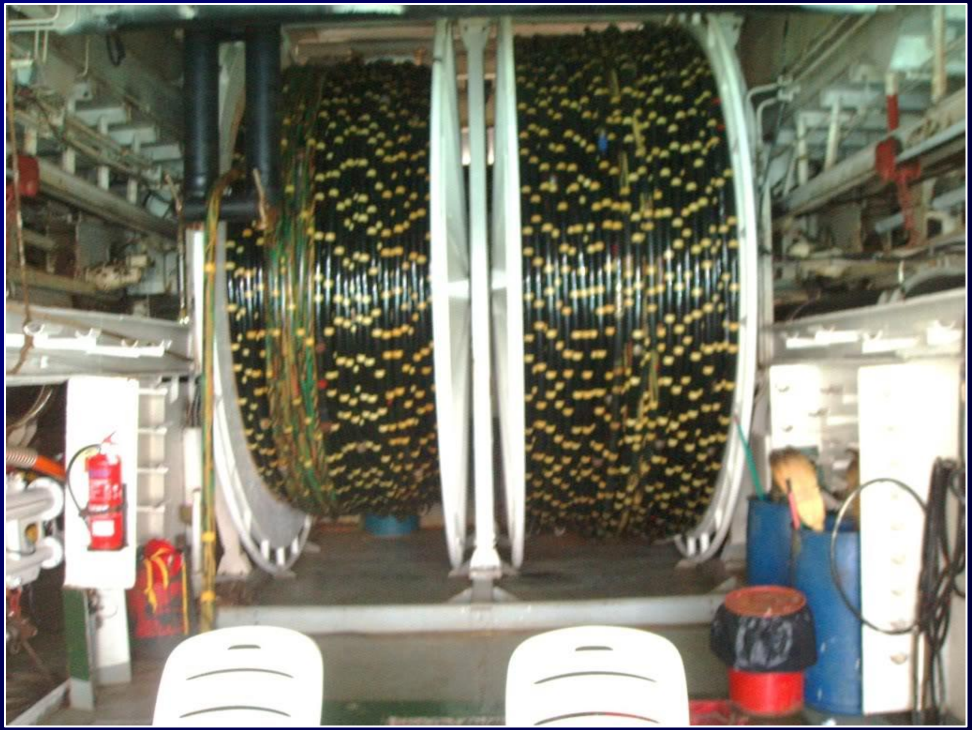


(www.i-o.com)

Hydrophones in kerosene-filled streamers



Piezoelectric hydrophone elements



Hydrophones on a reel prior to deployment

Airguns

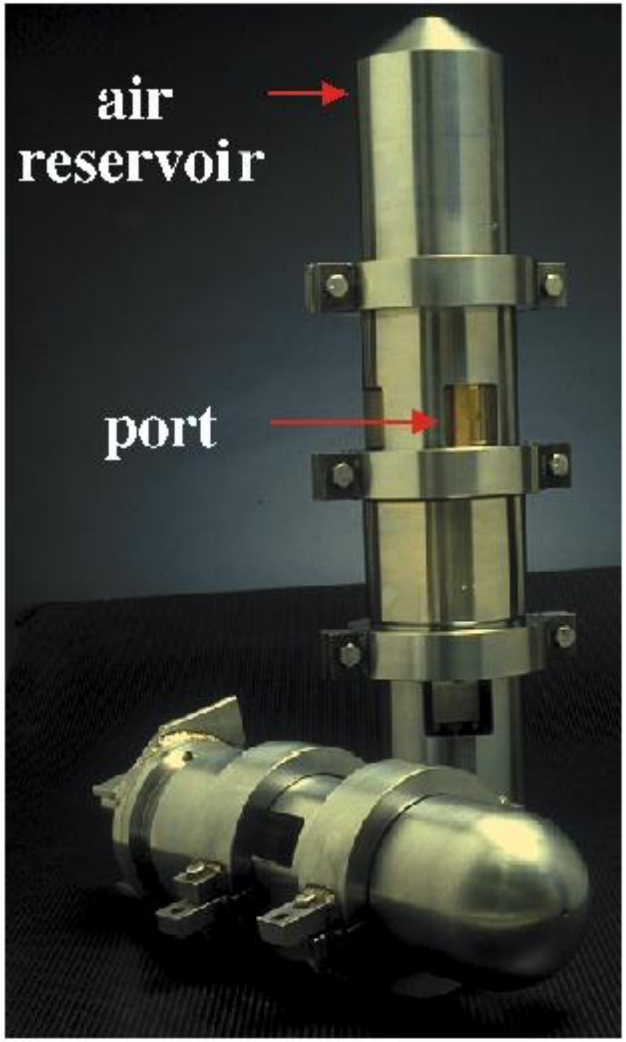


Figure 1. Two typical internal-shuttle air guns.

(Dragoset, 2000)

Sleeve guns

(www.i-o.com)

Single Airgun Impulse Response

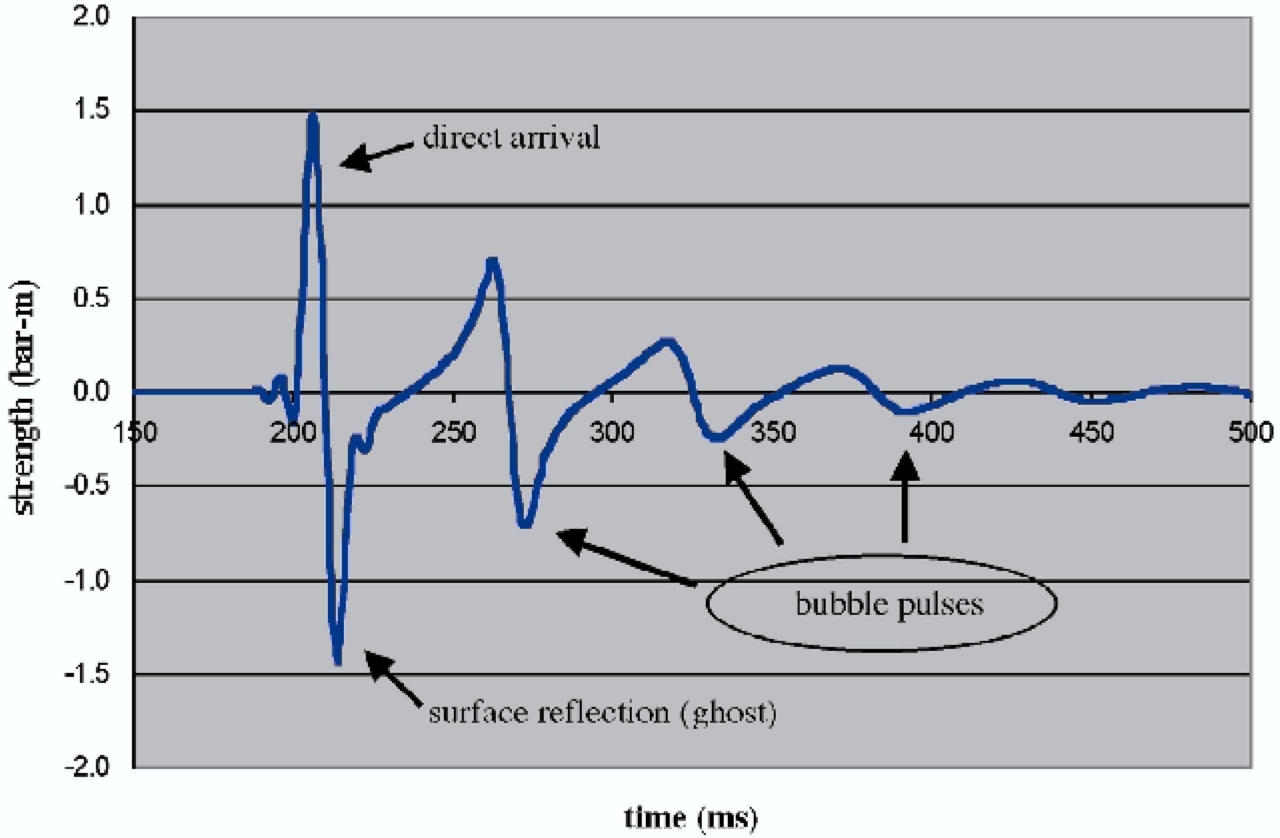


Figure 2. Signature of a single 40-in^3 air gun as recorded by a hydrophone 300 m below the gun.

(Dragoset, 2000)

Airgun Array Impulse Response (An ideal source wavelet)

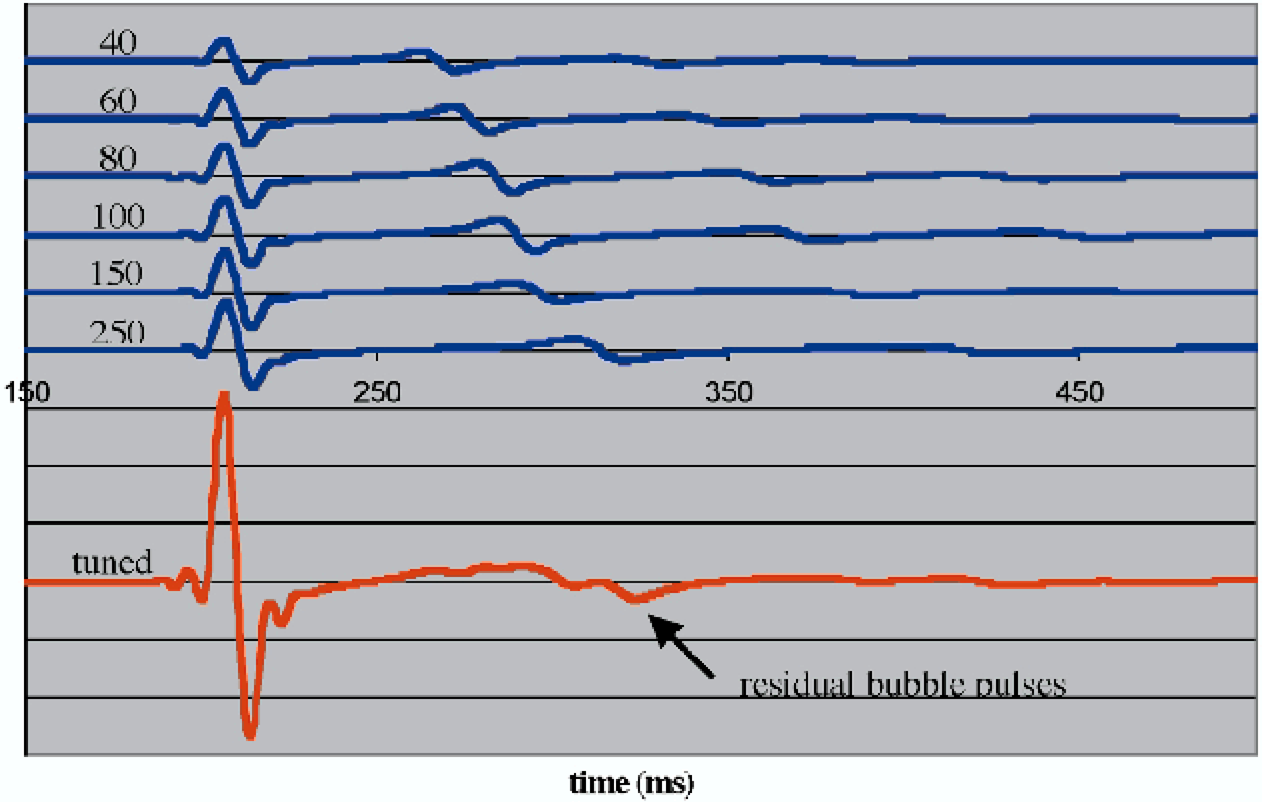


Figure 3. Concept of tuned air-gun array. Blue signatures come from individual guns whose volumes, in cubic inches, are on the left. If those six guns are placed in an array and fired simultaneously, they produce the red signature at a hydrophone 300 m below the array. The array's PBR is 8.6.

(Dragoset, 2000)

Airgun Arrays

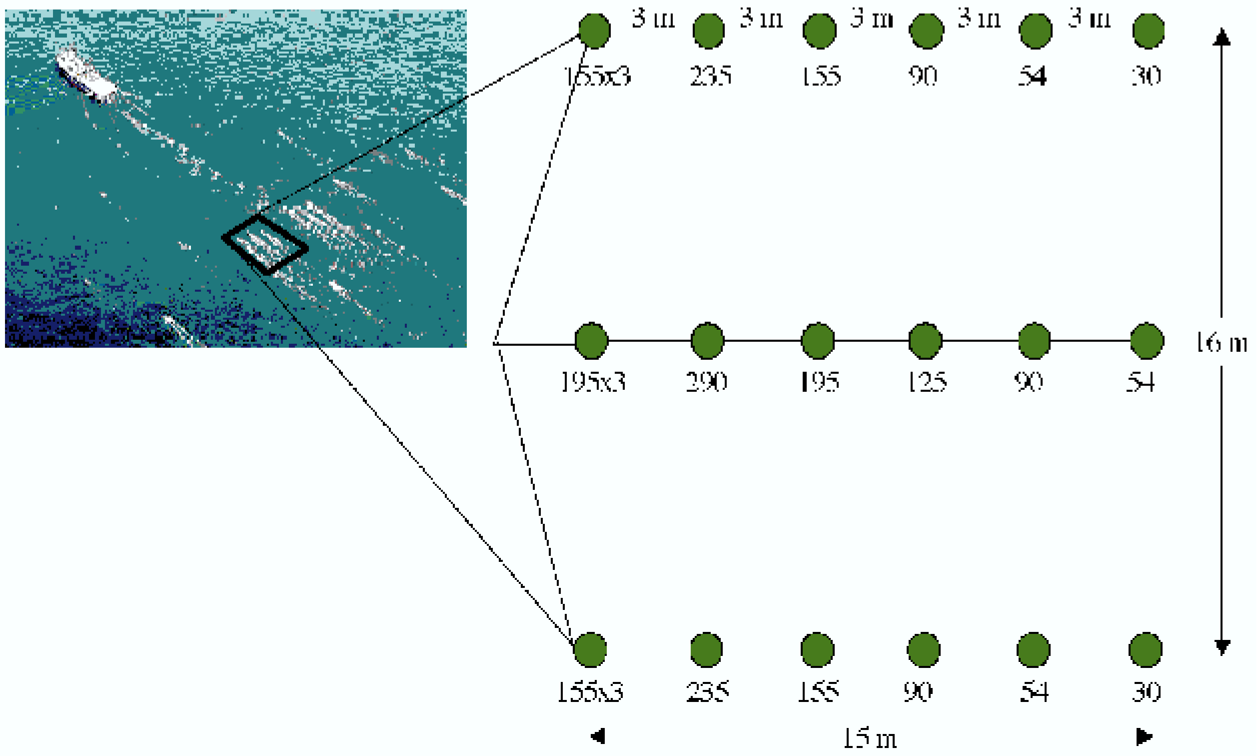


Figure 4. Plan view of typical air-gun array. Numbers below the gun stations (green circles) are gun volumes (in^3). The 155 × 3 notation indicates three guns, each with a volume of 155 in^3, so close together that their air bubbles coalesce after the guns fire. Such so-called "cluster guns" produce sound more efficiently than a single large gun. (Figure courtesy of Schlumberger).

(Dragoset, 2000)

Direct measurement of the seismic wavelet

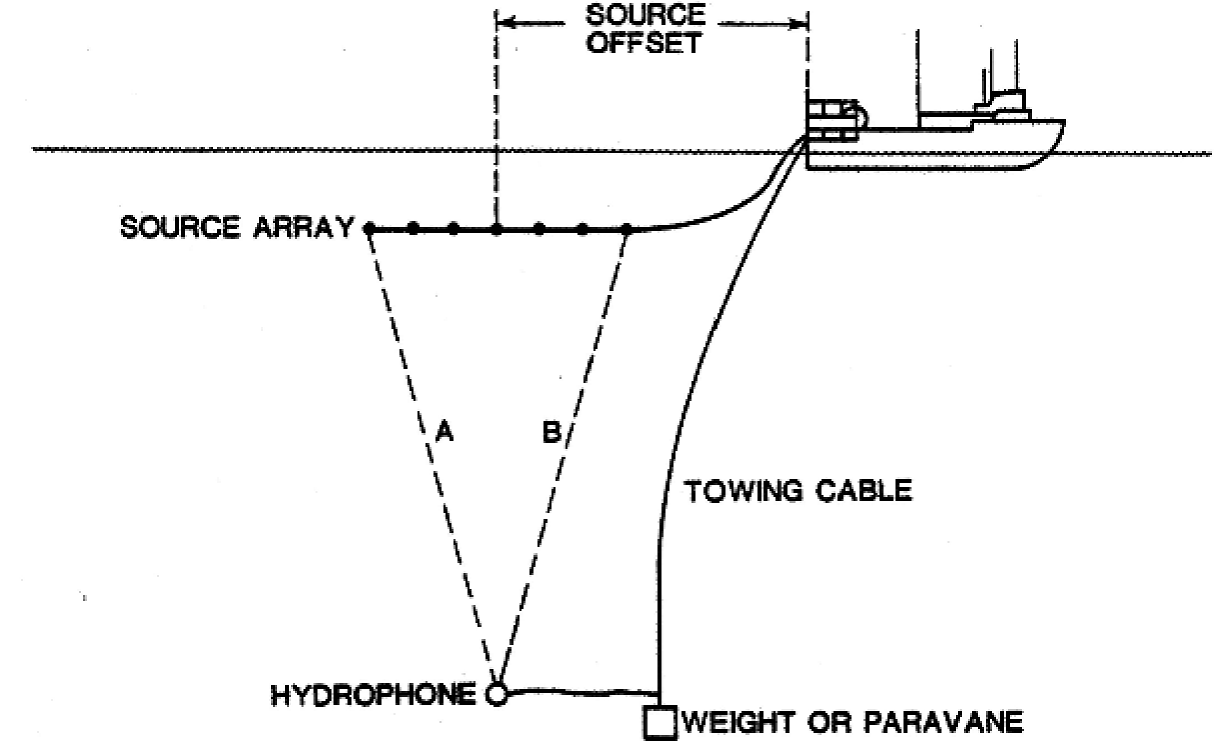
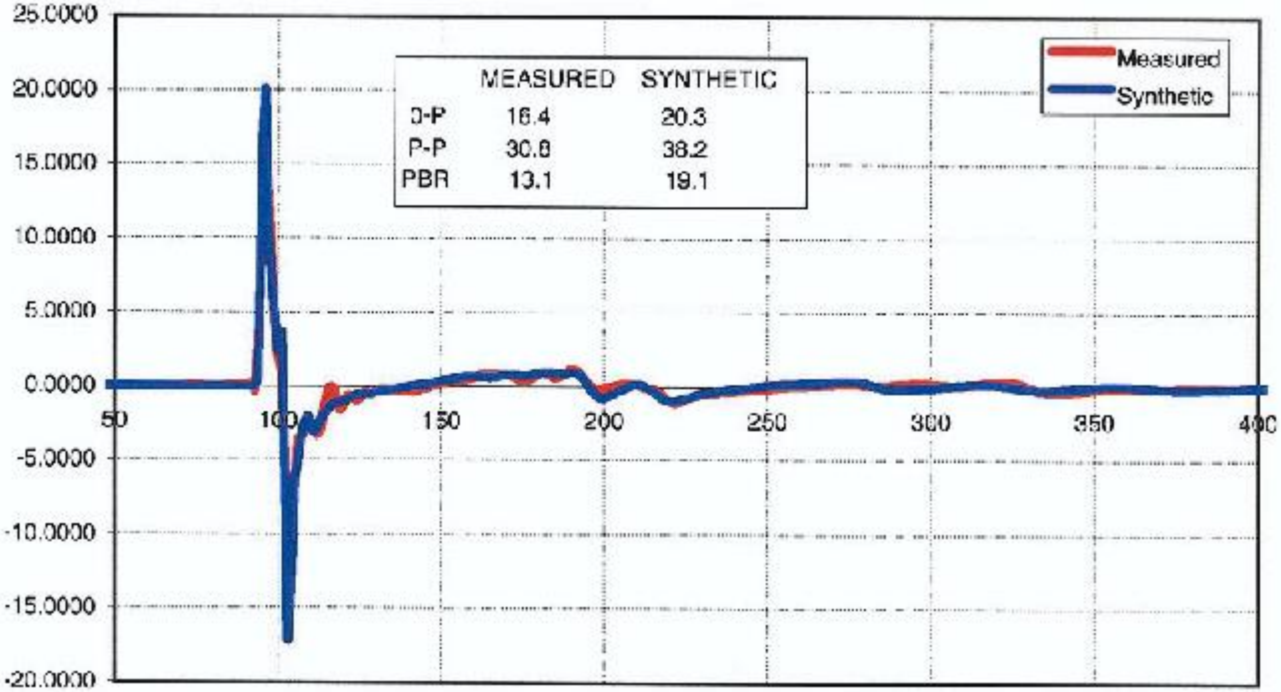


Figure 5. Equipment configuration for a far-field signature measurement. For a typical array, distance A = 300 m.

(Dragoset, 2000)

Measured versus modeled seismic wavelet



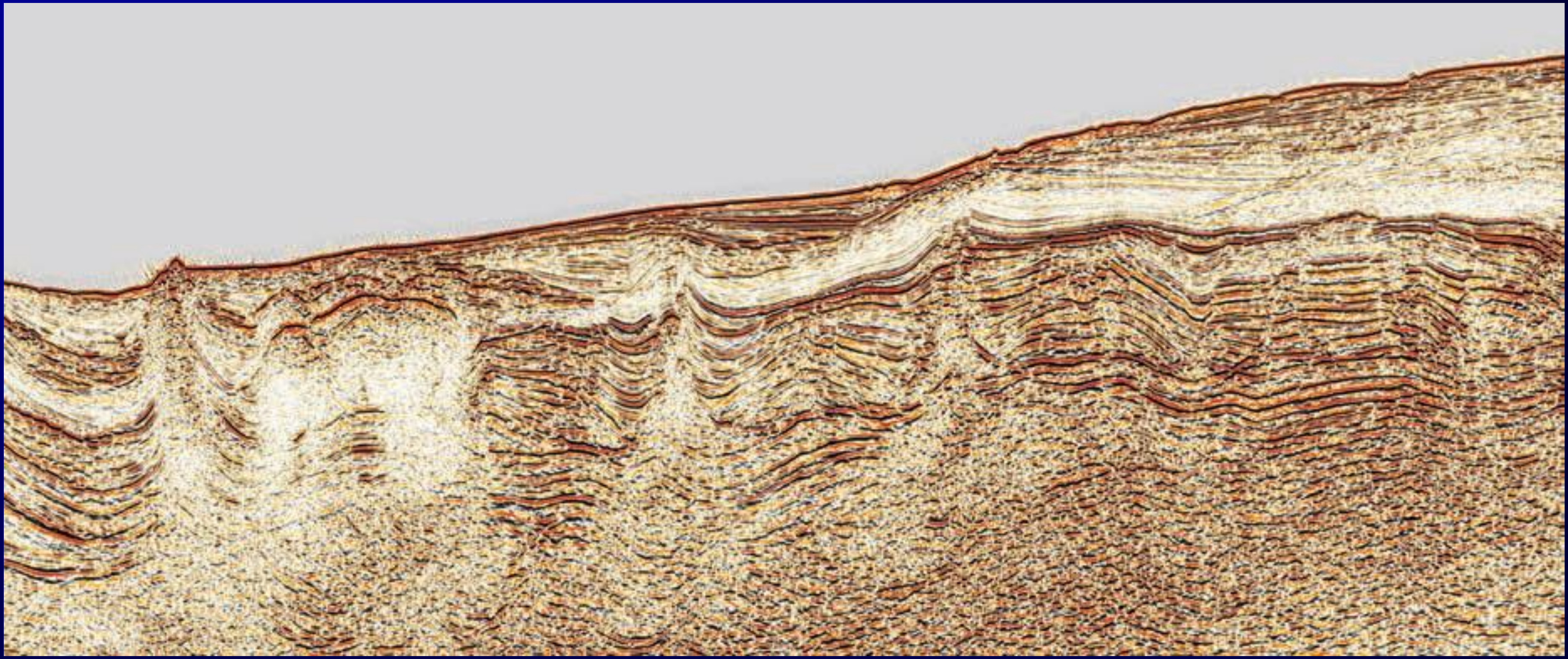
	MEASURED	SYNTHETIC
0-P	16.4	20.3
P-P	30.8	38.2
PBR	13.1	19.1

Figure 6. Comparison of measured and modeled signatures for a small air-gun array.

(Dragoset, 2000)

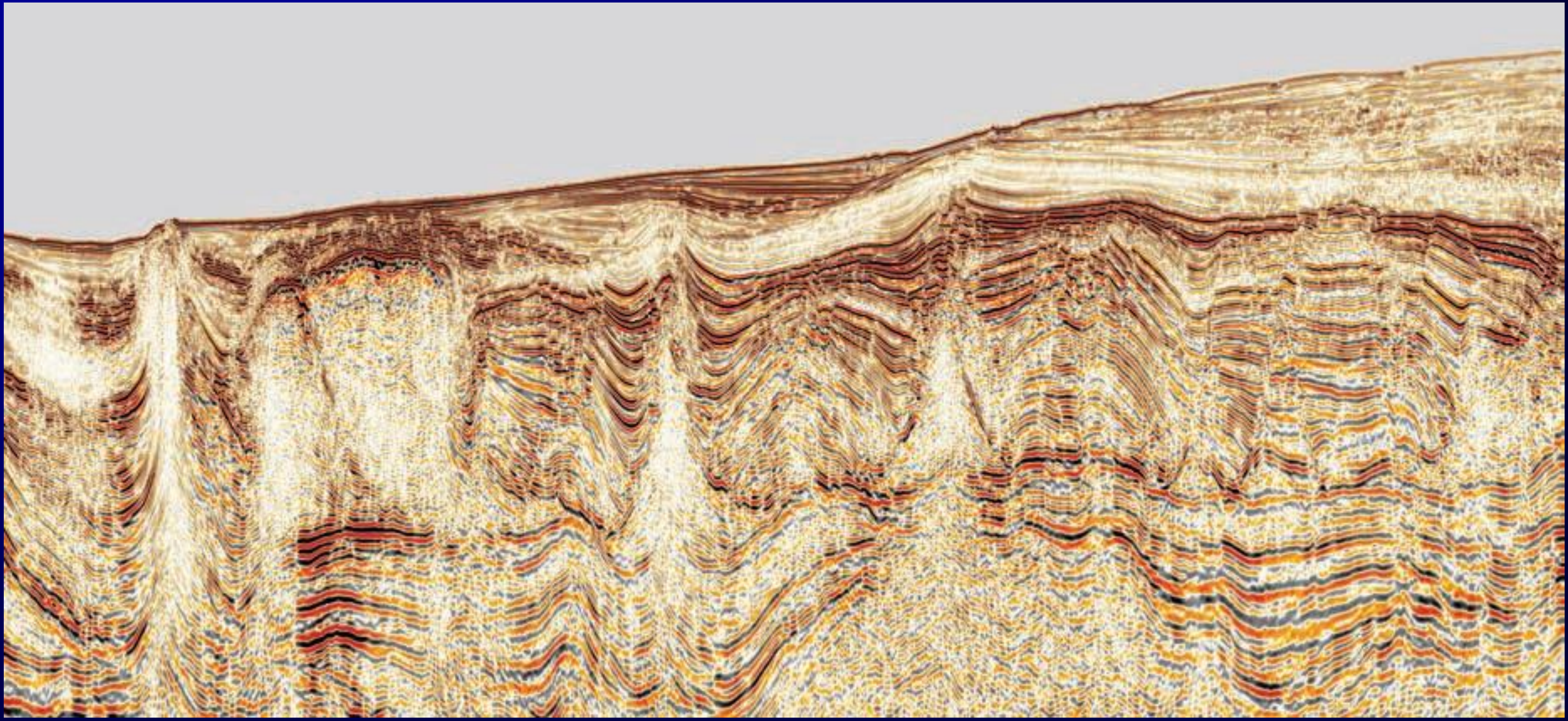
Recent advances in seismic acquisition and processing

West Africa – 2D time migrated



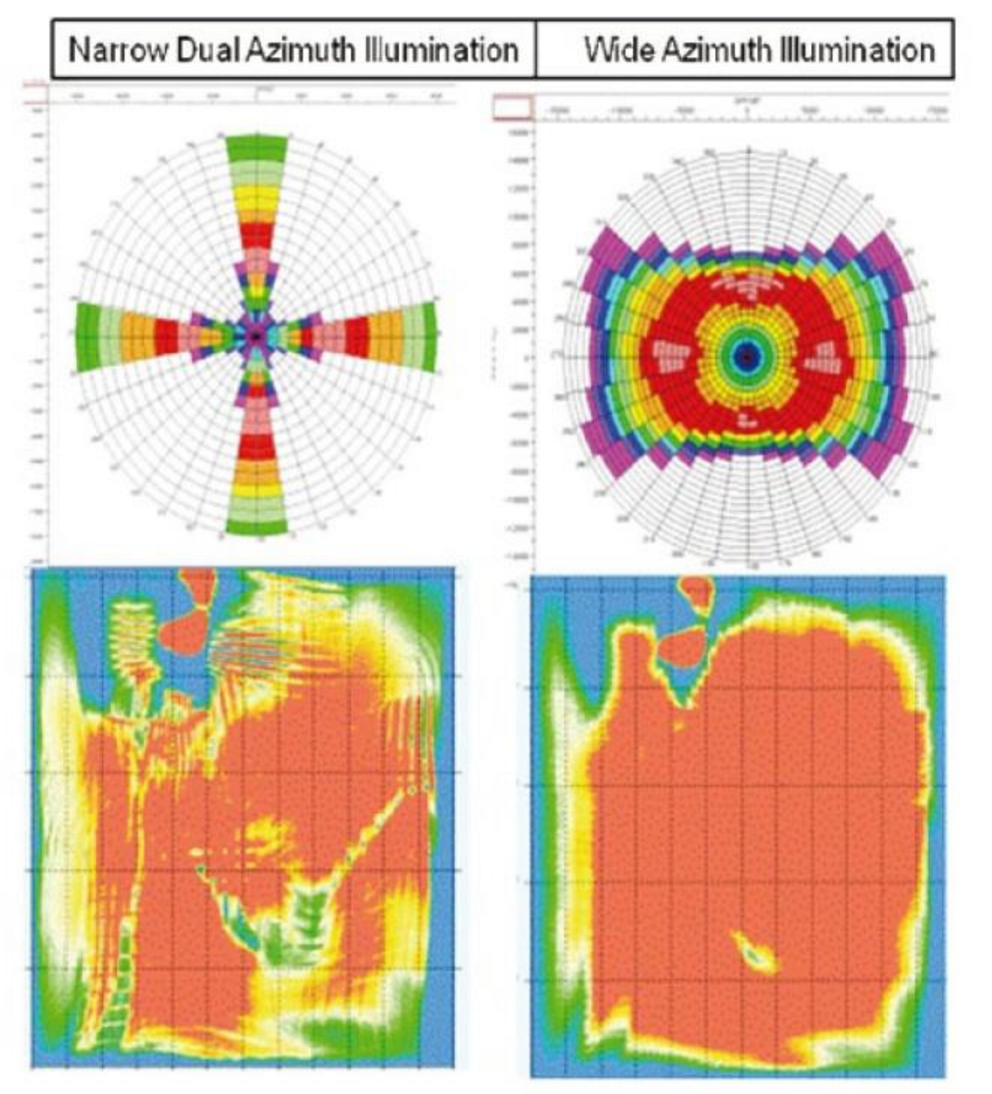
(WesternGeco ad, AAPG Explorer, November 2008)

West Africa – 2D depth migrated



(WesternGeco ad, AAPG Explorer, November 2008)

Wide-azimuth towed streamers (WATS)

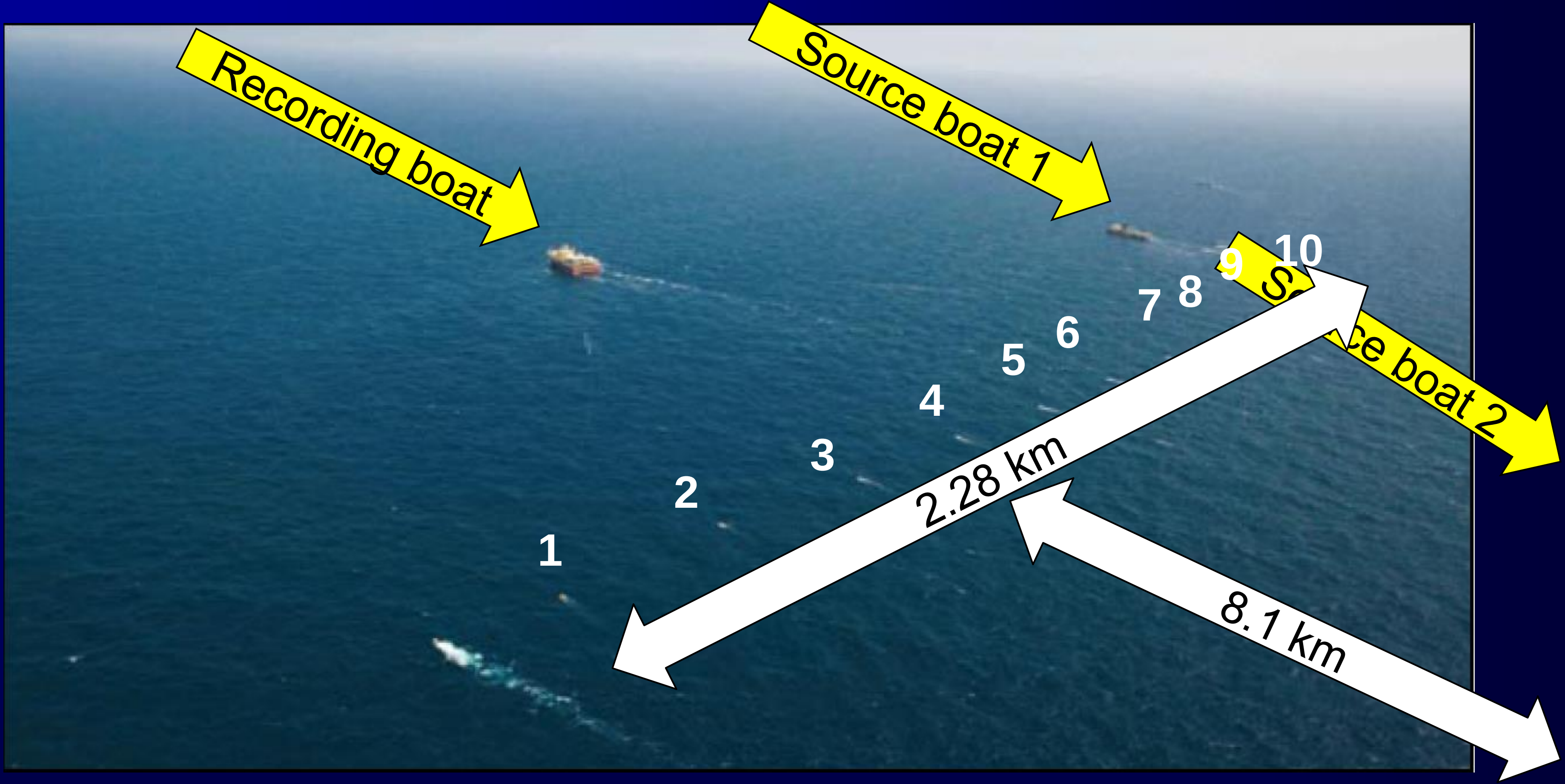


Illumination as a function of azimuth

Fold

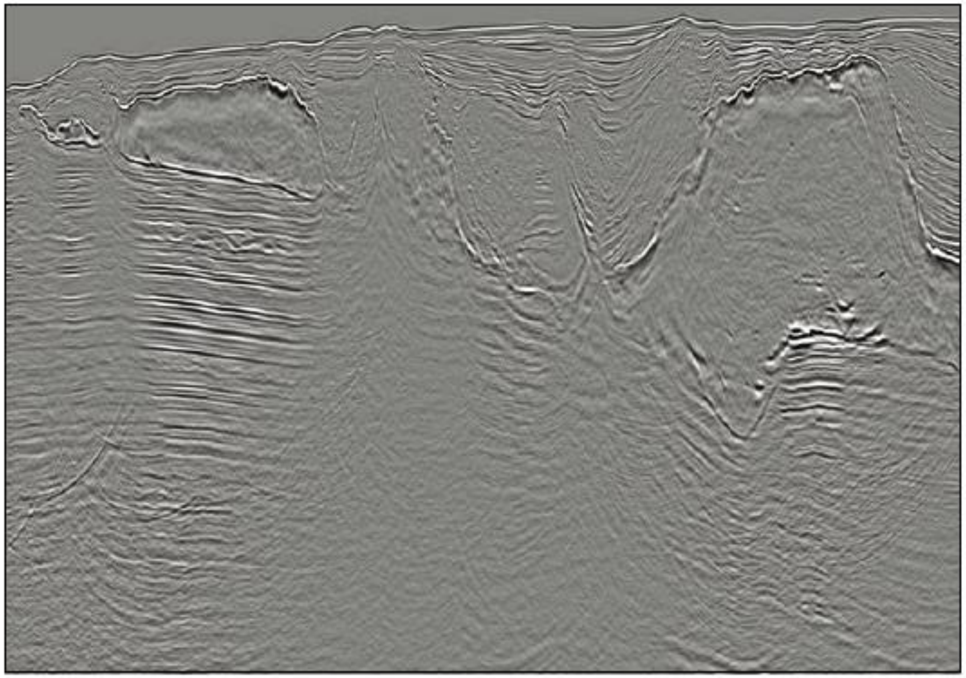
(Fromyr et al., 2011)

Wide-azimuth towed streamers (WATS)

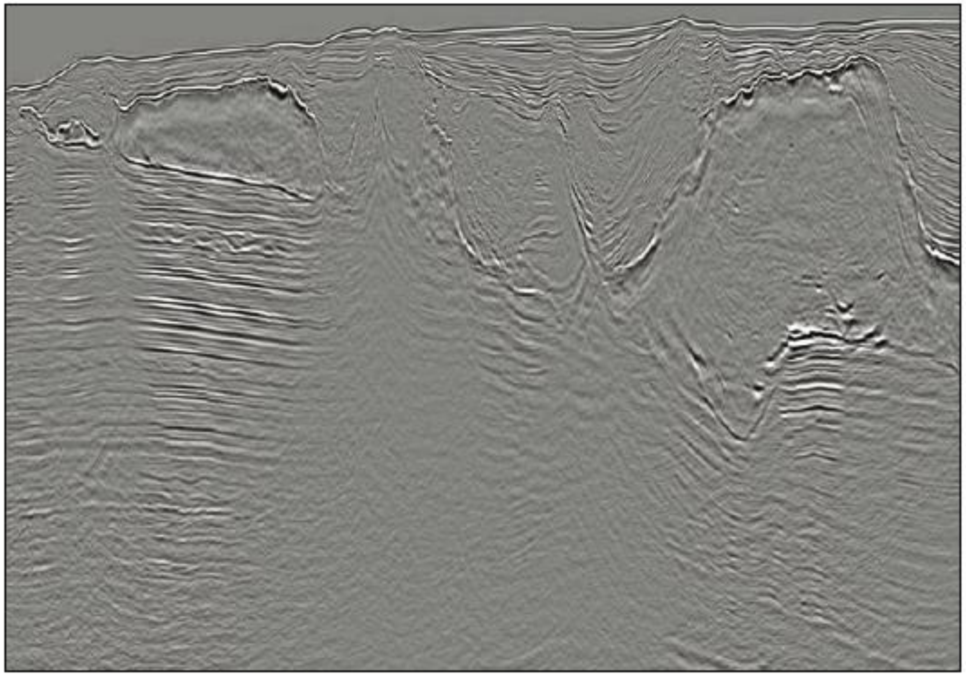


(Fromyr et al., 2011)

Gulf of Mexico



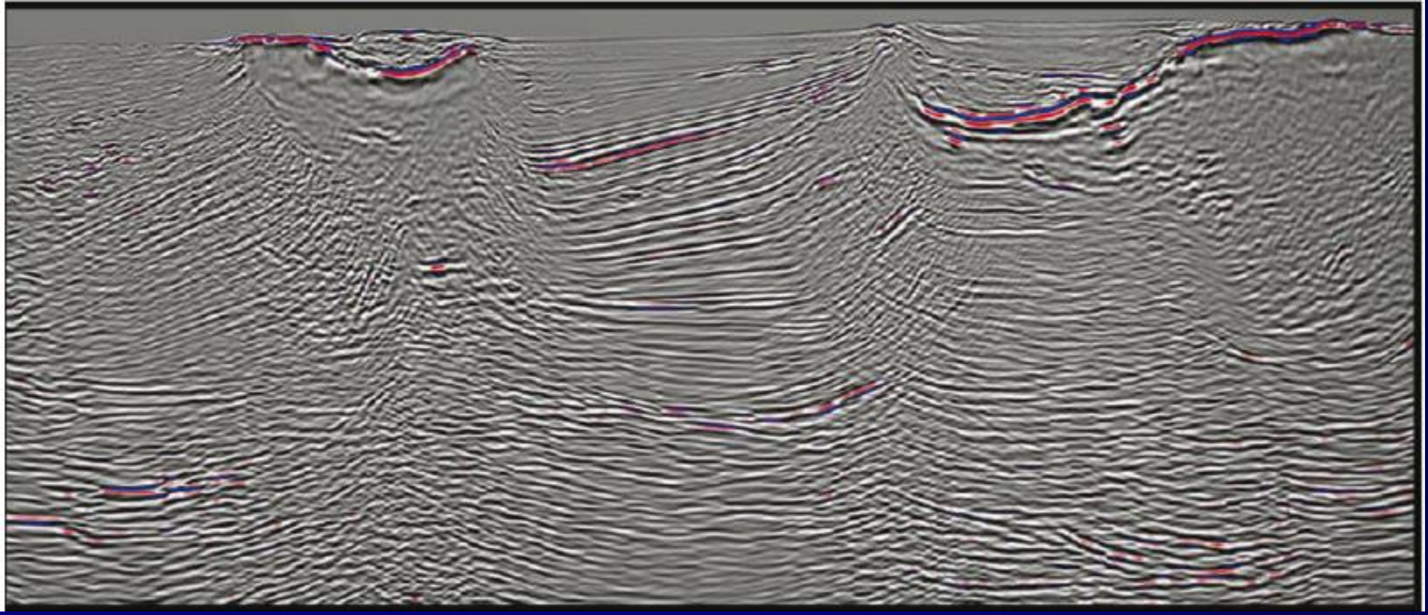
Narrow-azimuth acquisition



Wide-azimuth acquisition

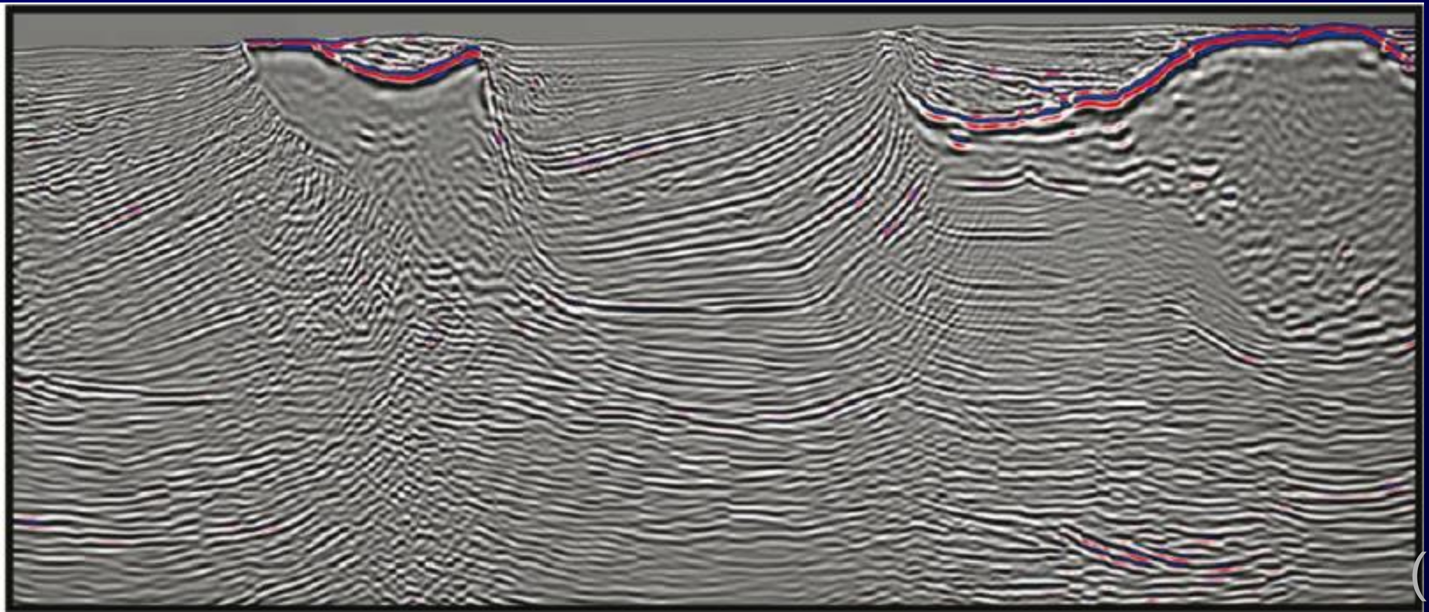
(Fromyr et al., 2011)

Gulf of Mexico



Narrow-azimuth acquisition

One-way wave equation migration

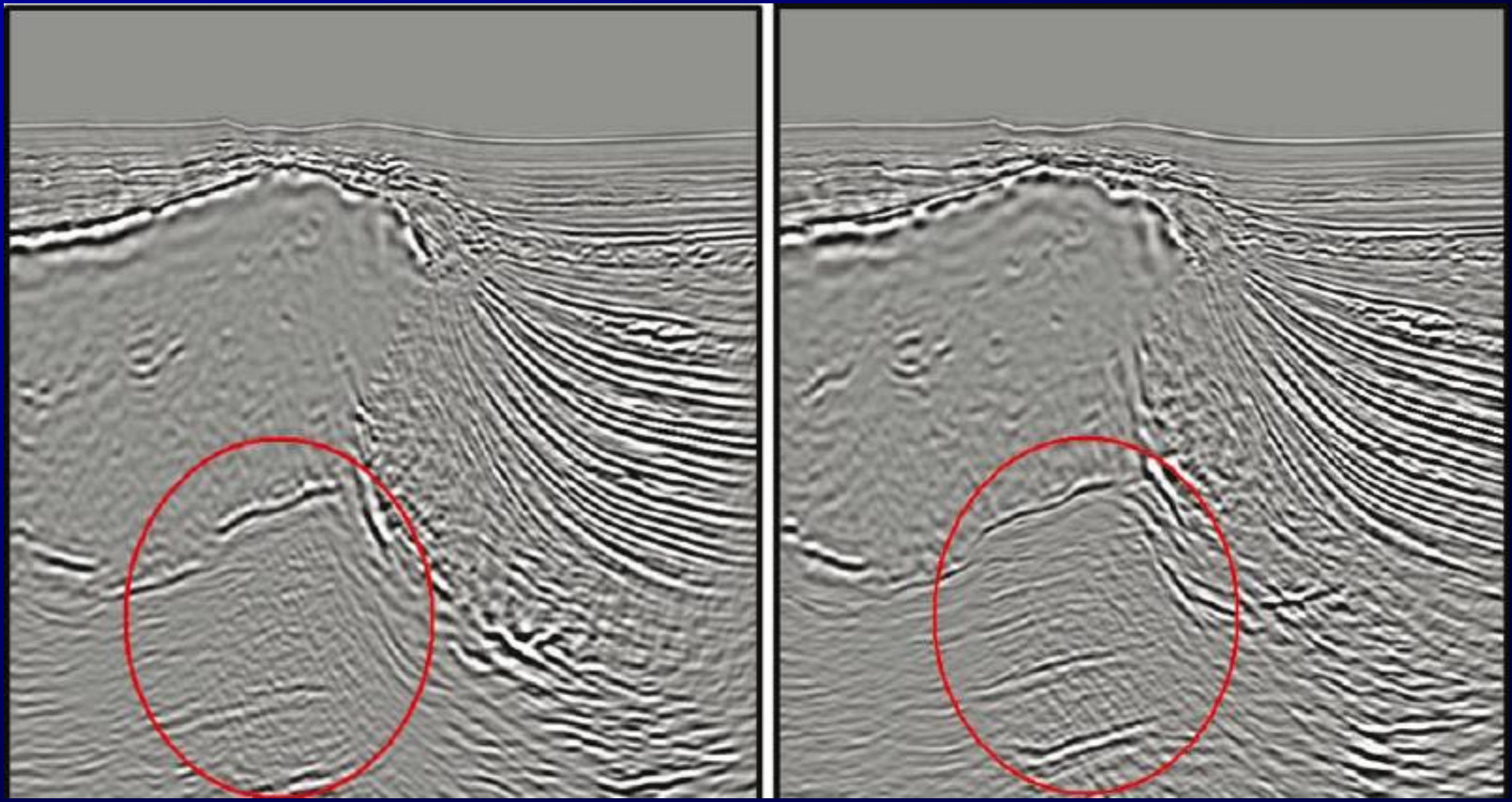


Wide-azimuth acquisition

Two-way wave equation migration (RTM)

(Fromyr et al., 2011)

Gulf of Mexico



Narrow-azimuth acquisition

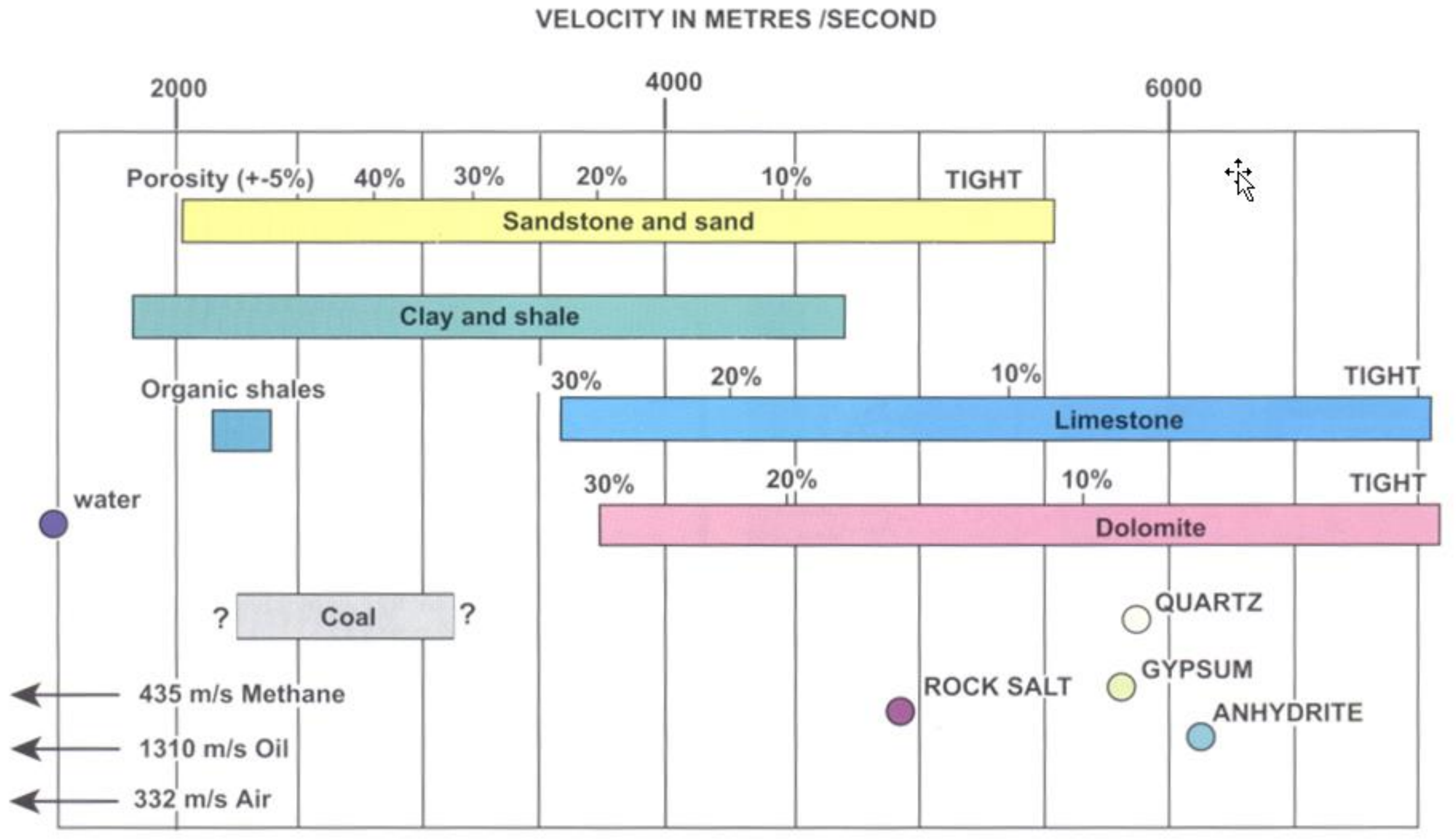
One-way wave equation migration

Wide-azimuth acquisition

Two-way wave equation migration (RTM)

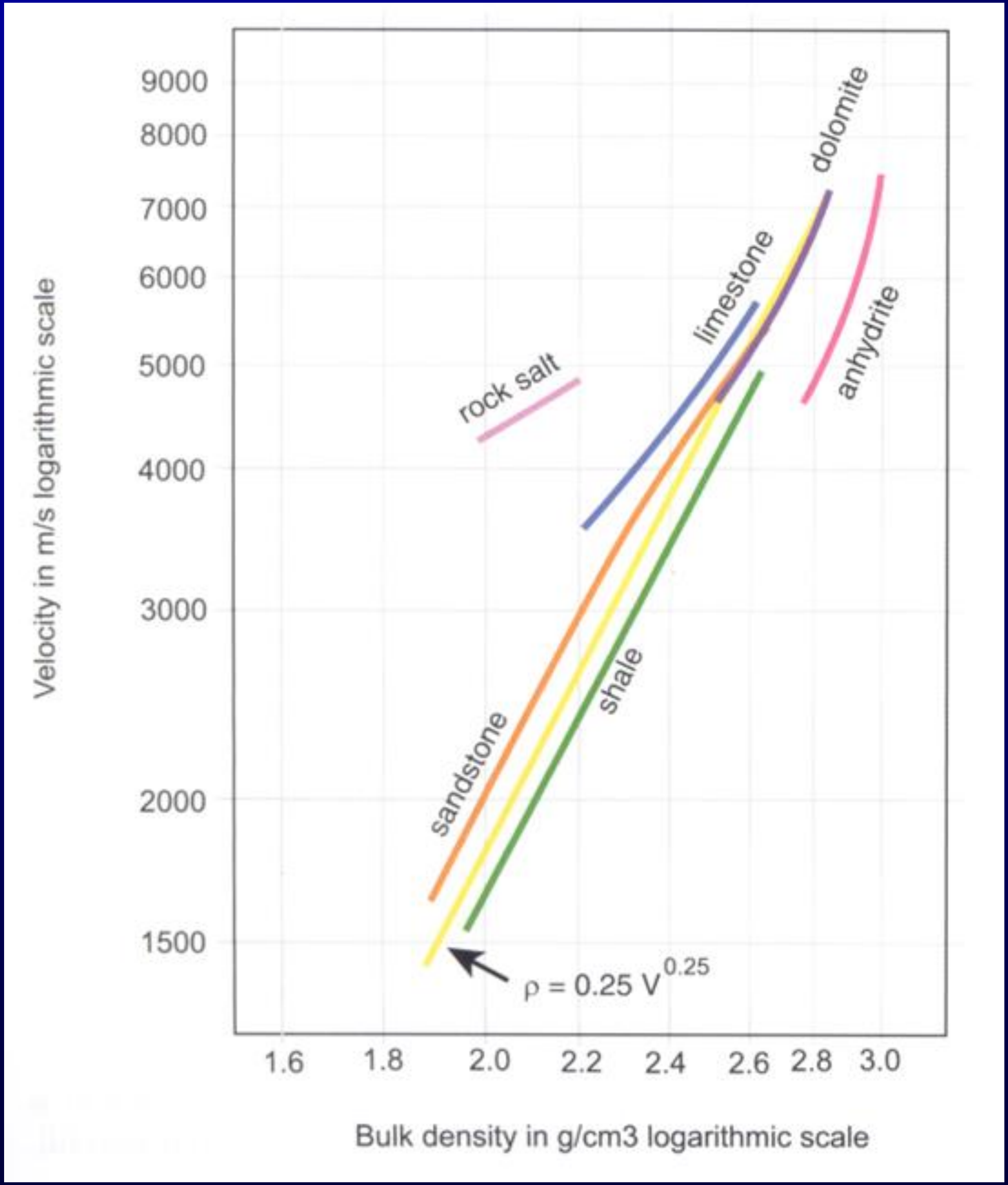
(Fromyr et al., 2011)

Rock Properties, Impedance and Seismic Reflectivity

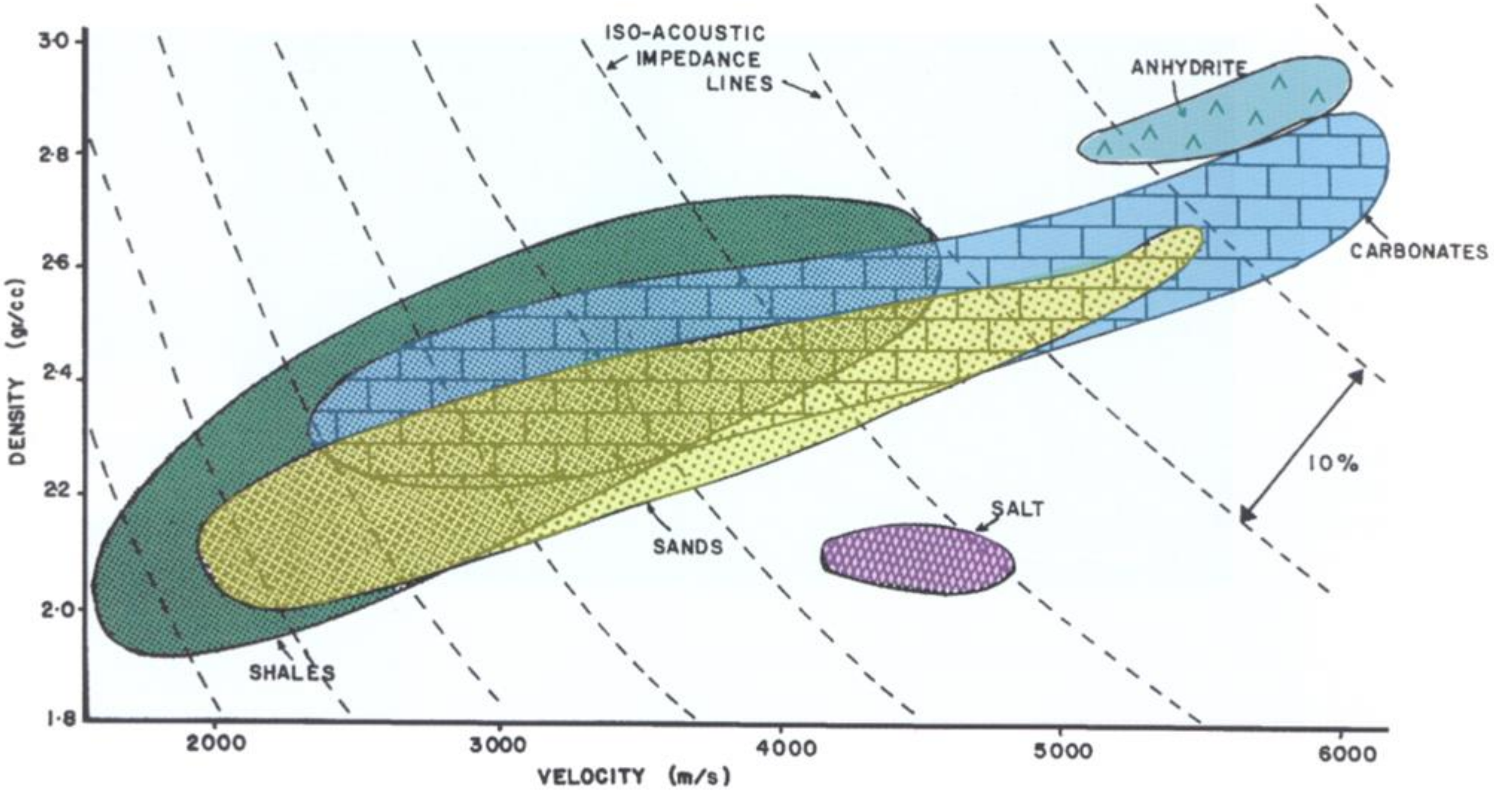


P-WAVE VELOCITIES IN SEDIMENTS AND SOME MINERALS.

(Veeken, 2007)

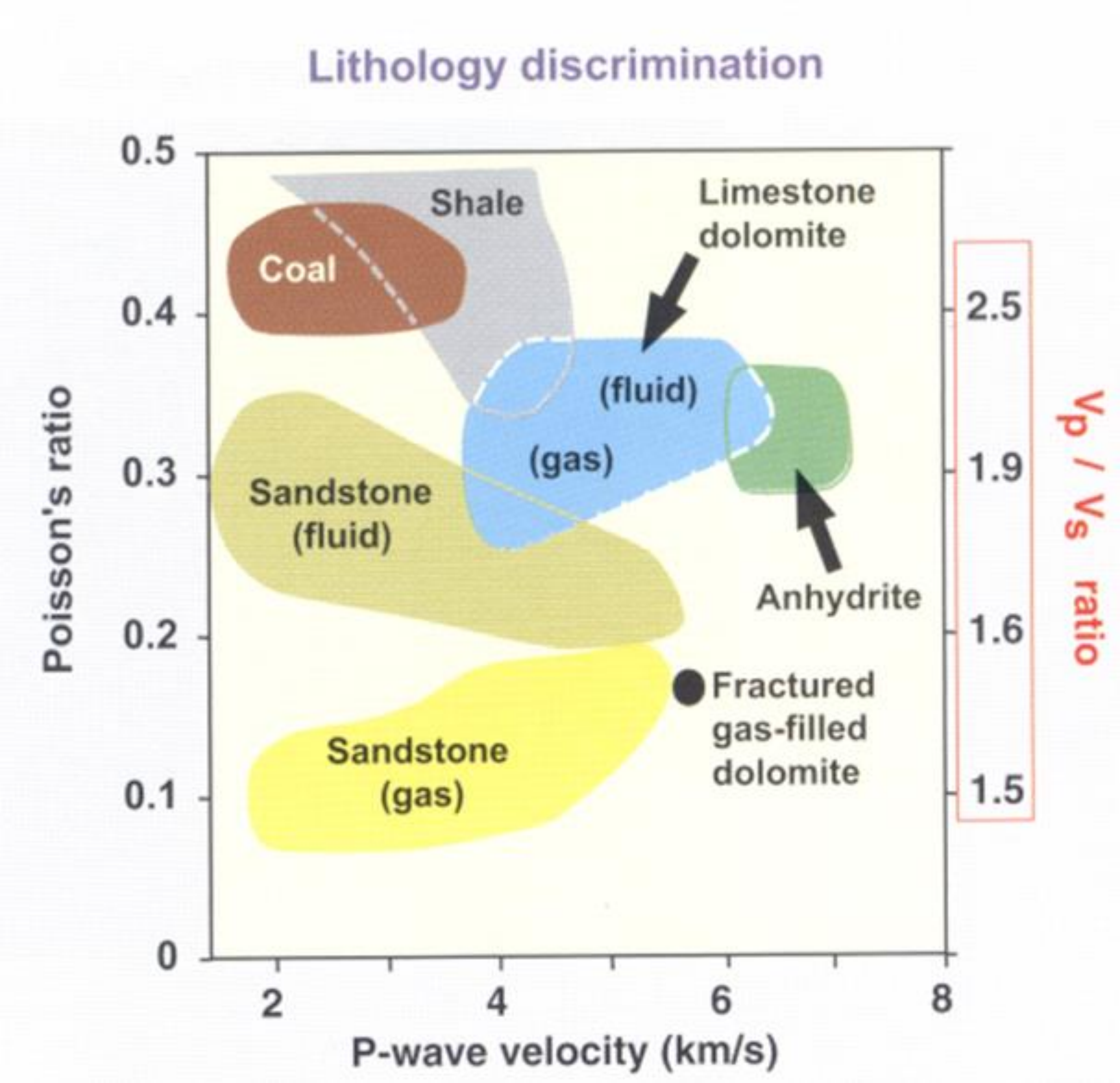

9000
8000
7000
6000
5000
4000
3000
2000
1500
Velocity in m/s logarithmic scale
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
Bulk density in g/cm3 logarithmic scale
dolomite
limestone
anhydrite
rock salt
sandstone
shale
$\rho = 0.25 V^{0.25}$

(Veeken, 2007)



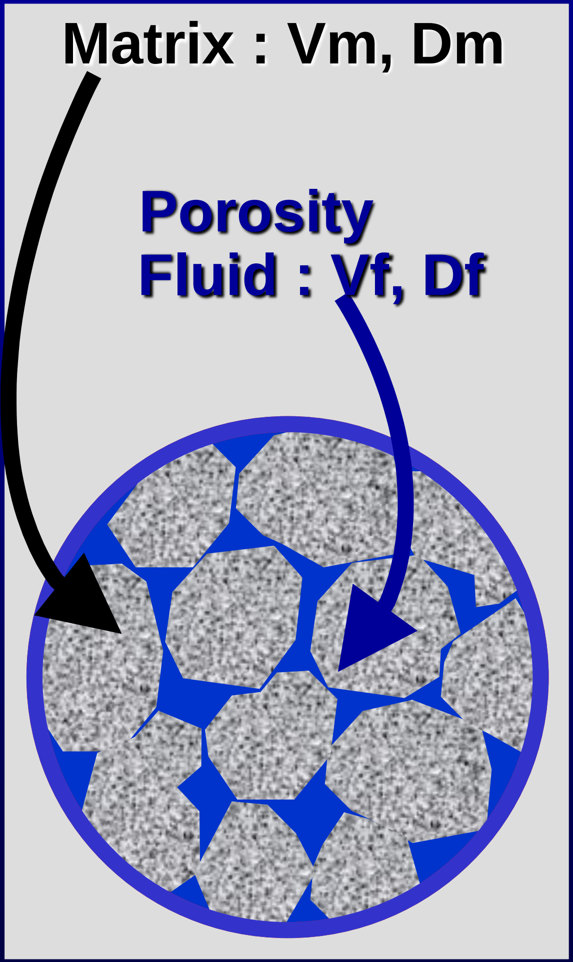
VELOCITY/DENSITY PLOT FOR DIFFERENT SEDIMENTARY LITHOLOGIES

(Veeken, 2007)


Lithology discrimination
0.5
0.4
0.3
0.2
0.1
0
Poisson's ratio
2
4
6
8
P-wave velocity (km/s)
2.5
1.9
1.6
1.5
Vp / Vs ratio
Shale
Coal
Limestone dolomite
(fluid)
(gas)
Sandstone (fluid)
Anhydrite
Fractured gas-filled dolomite
Sandstone (gas)

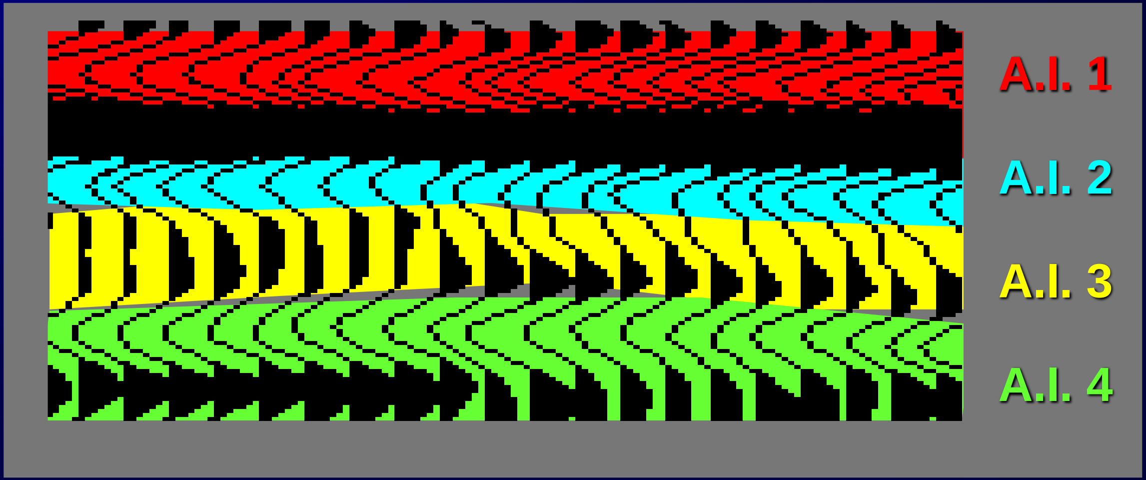
(Veeken, 2007)

Acoustic Impedance



Acoustic impedance = Velocity x Density

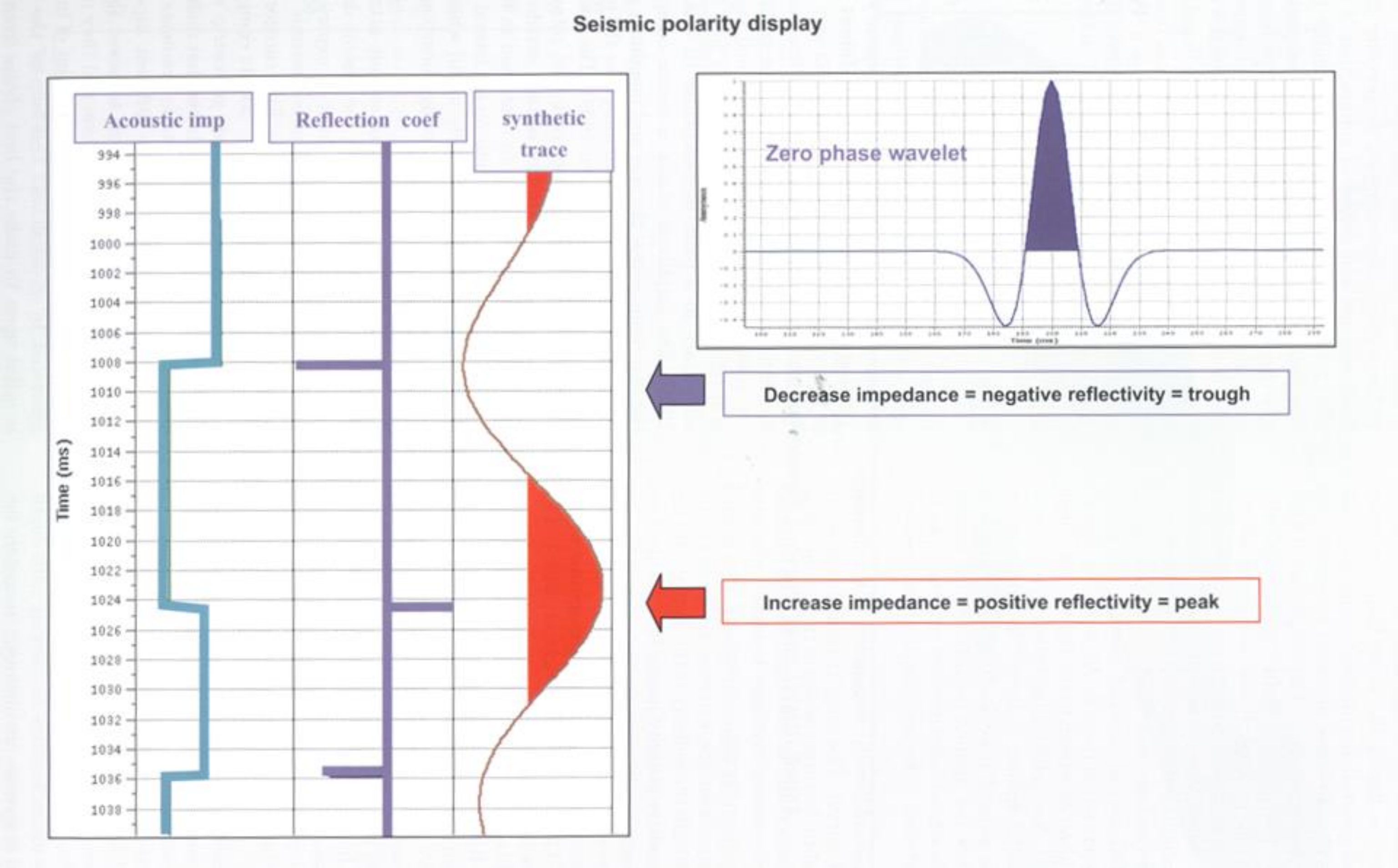
A.I. of a rock is a function of :
- Matrix (lithology),
- porosity,
- the fluid content
- and maybe the shape of the pores!



(Veeken et al., 2002)

The Convolutional Model

Impedance, reflection coefficients, and the seismic trace

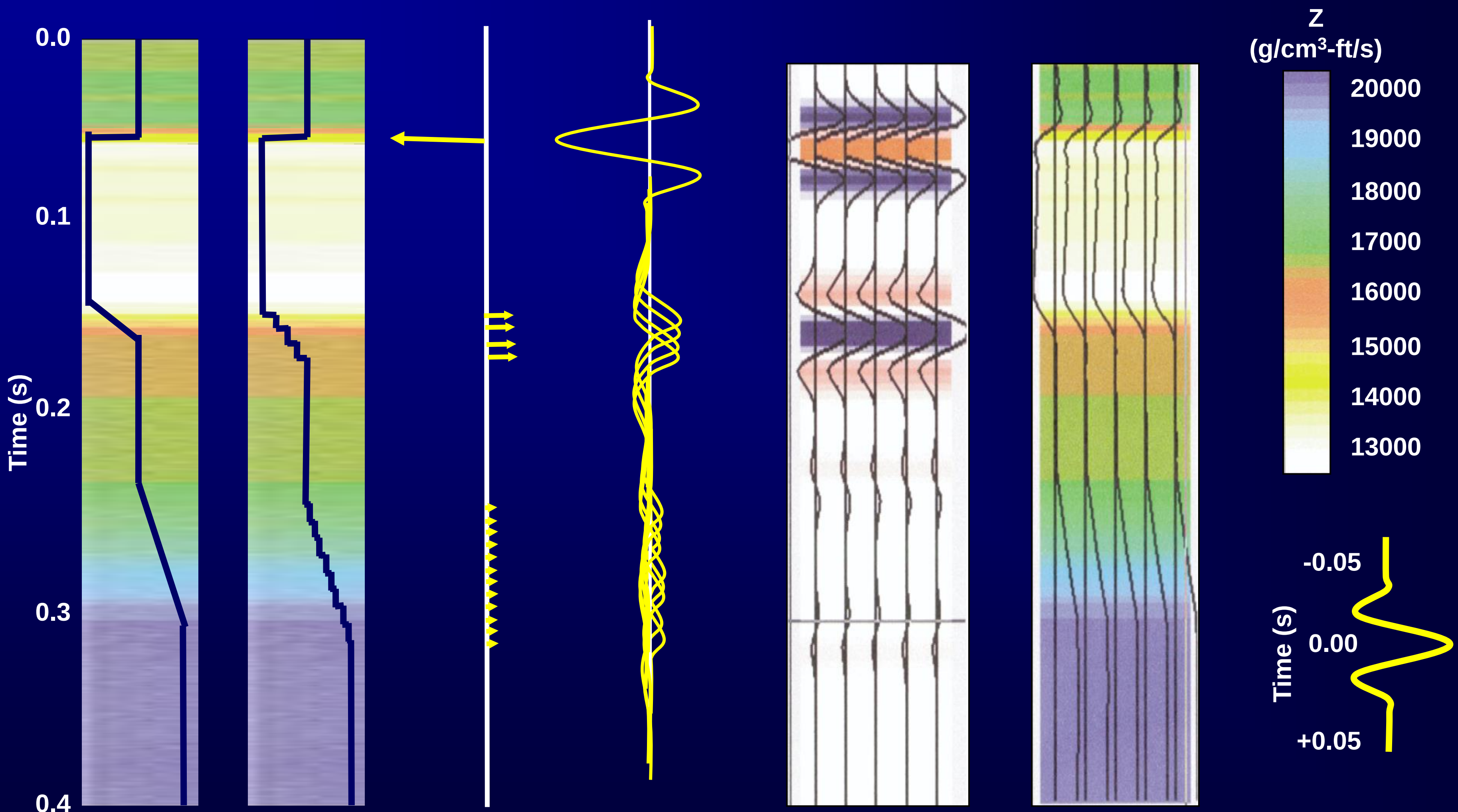


Decrease impedance = negative reflectivity = trough

Increase impedance = positive reflectivity = peak

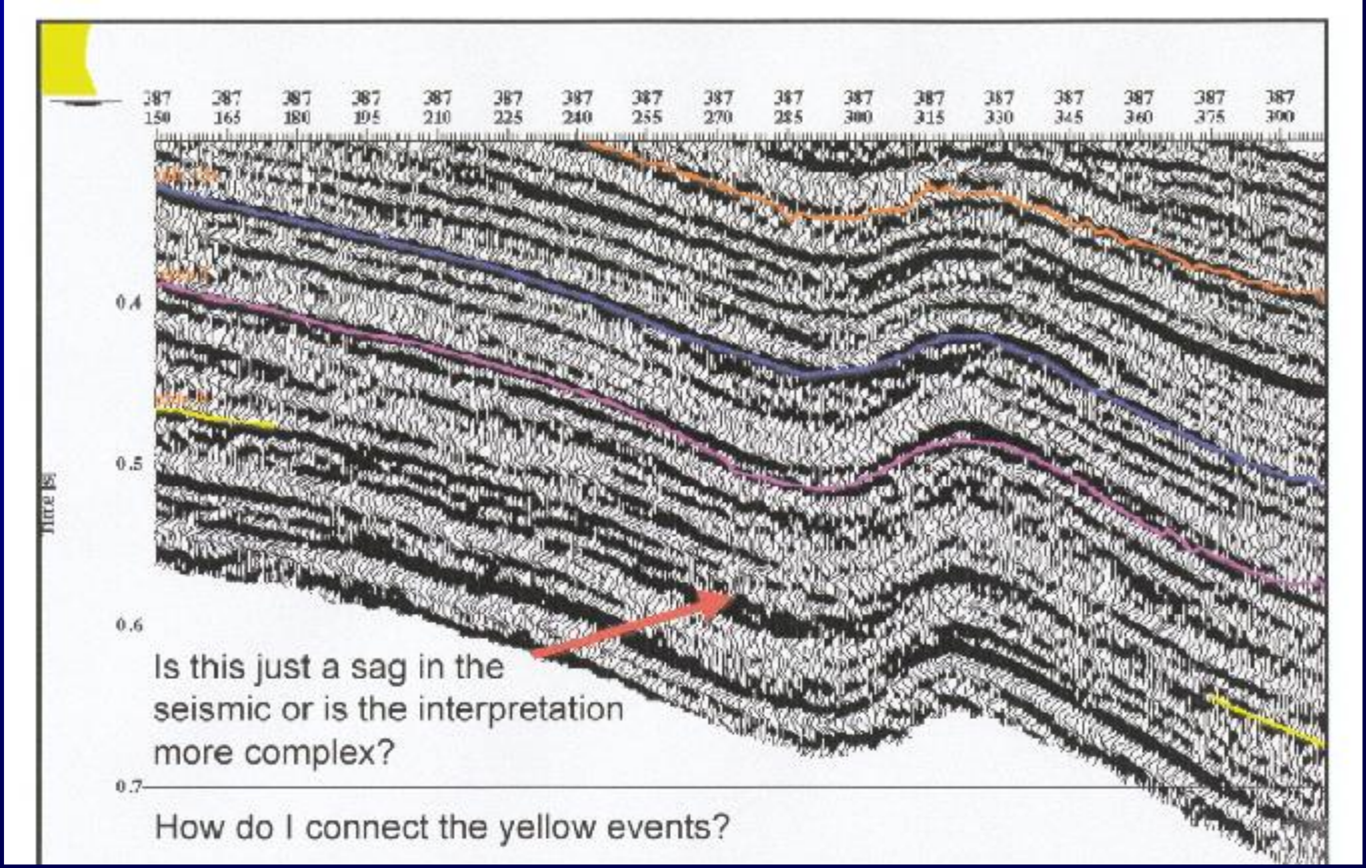
(Veeken, 2007)

Inversion for acoustic impedance (ramp model)



(Latimer et al., 2000)

Conventional seismic data, d

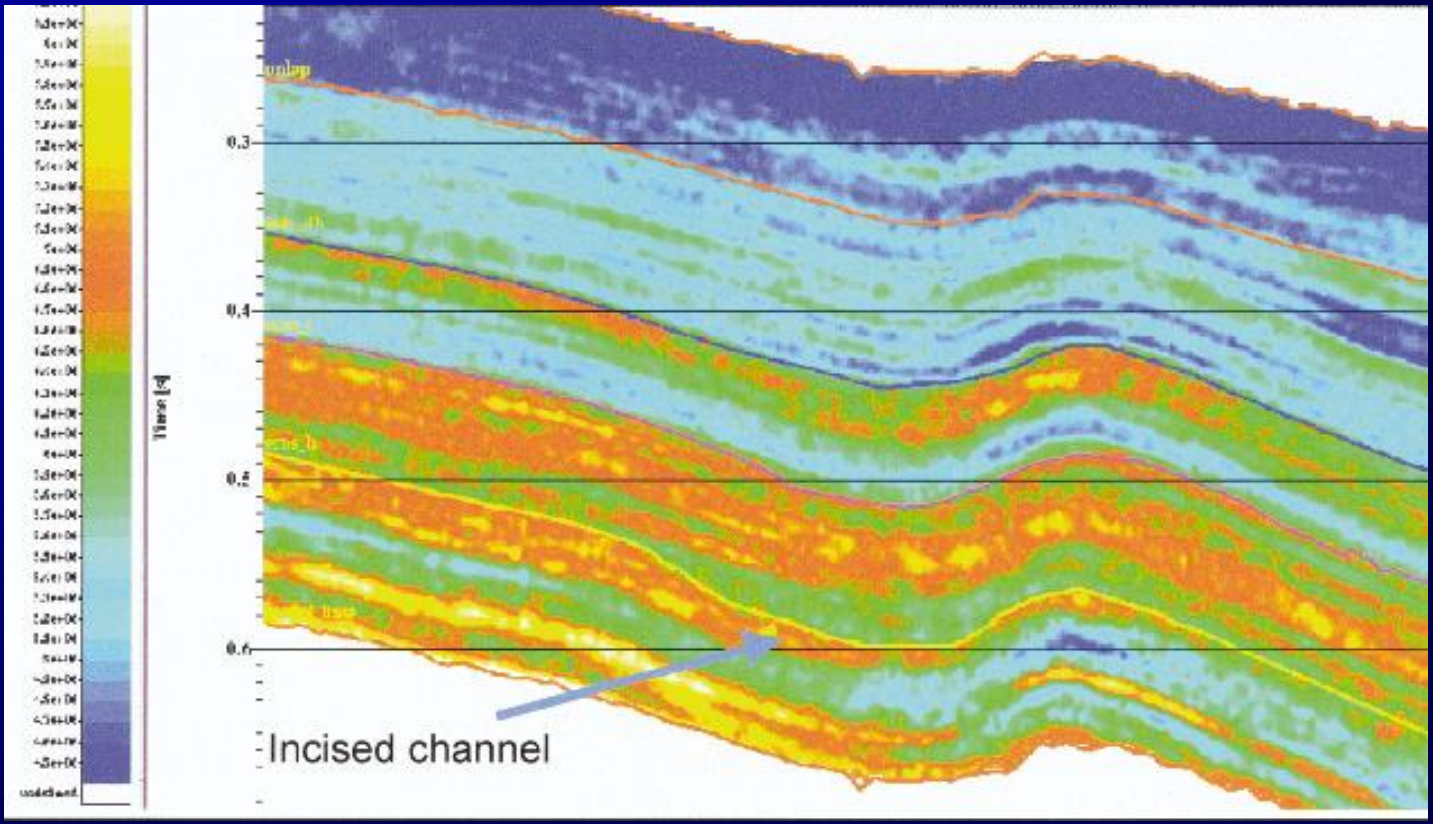


Is this just a sag in the seismic or is the interpretation more complex?

How do I connect the yellow events?

(Latimer et al.. 2000)

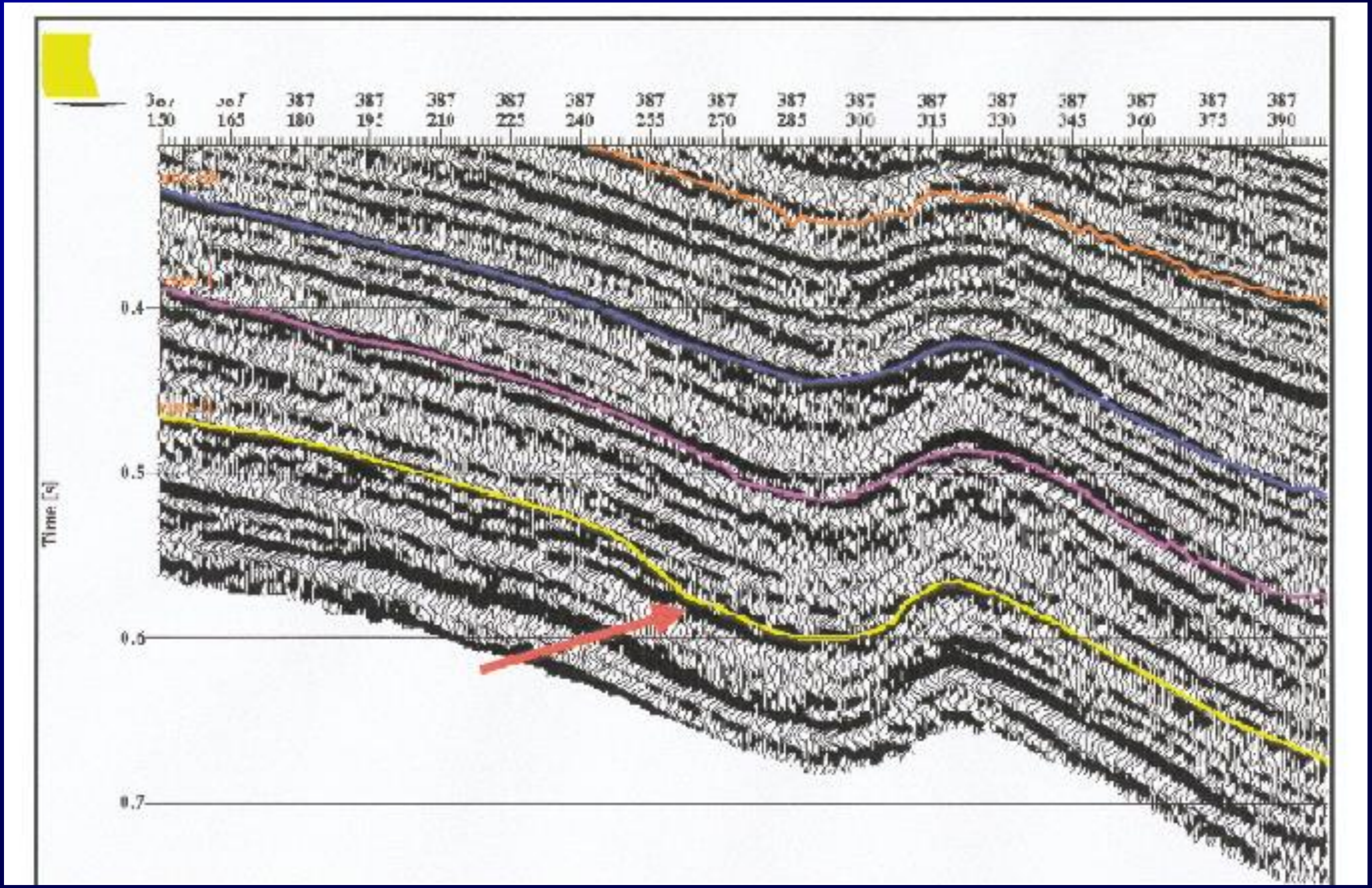
Inversion for acoustic impedance, AI



Incised channel

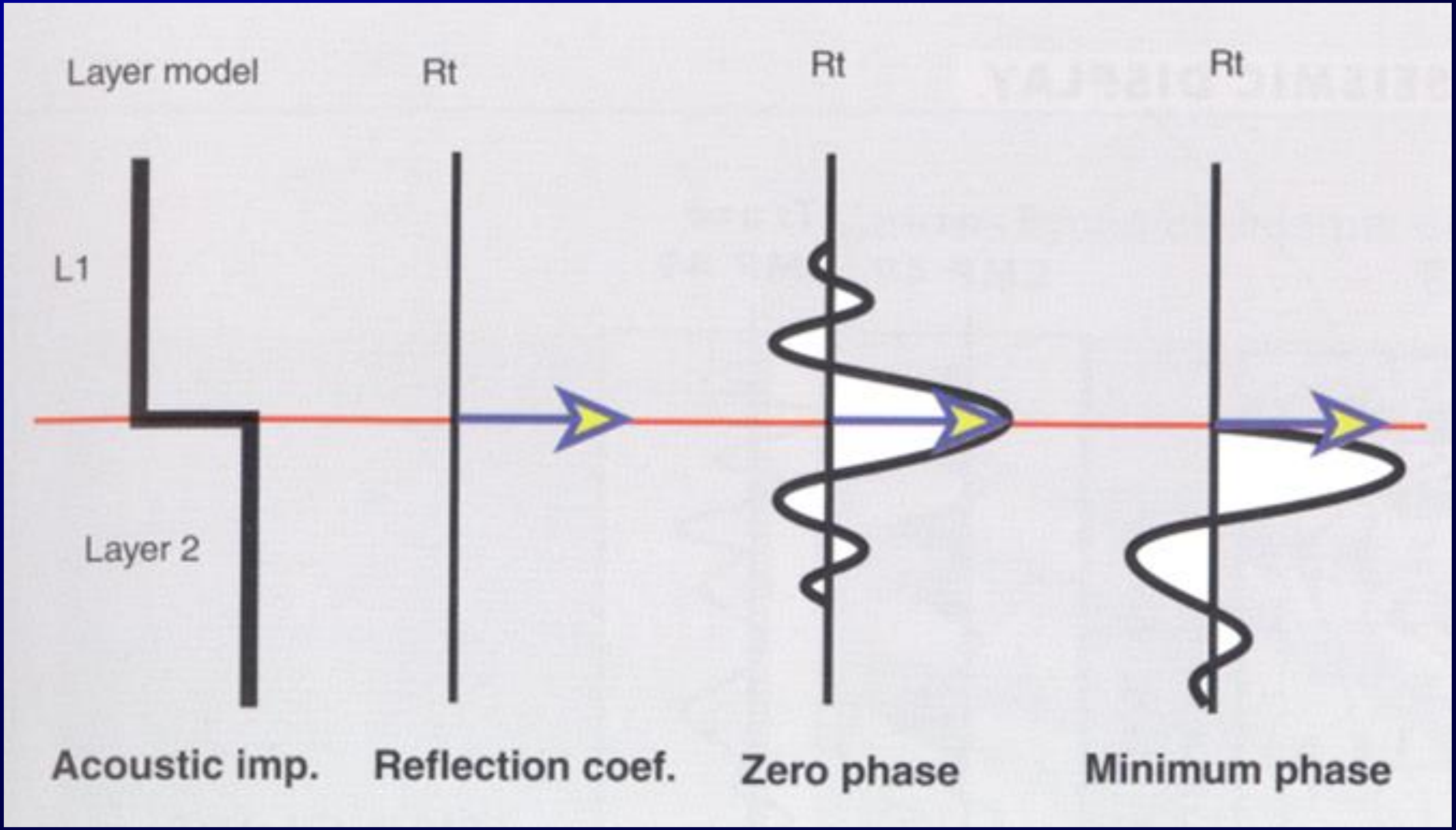
(Latimer et al.. 2000)

Conventional seismic data, d



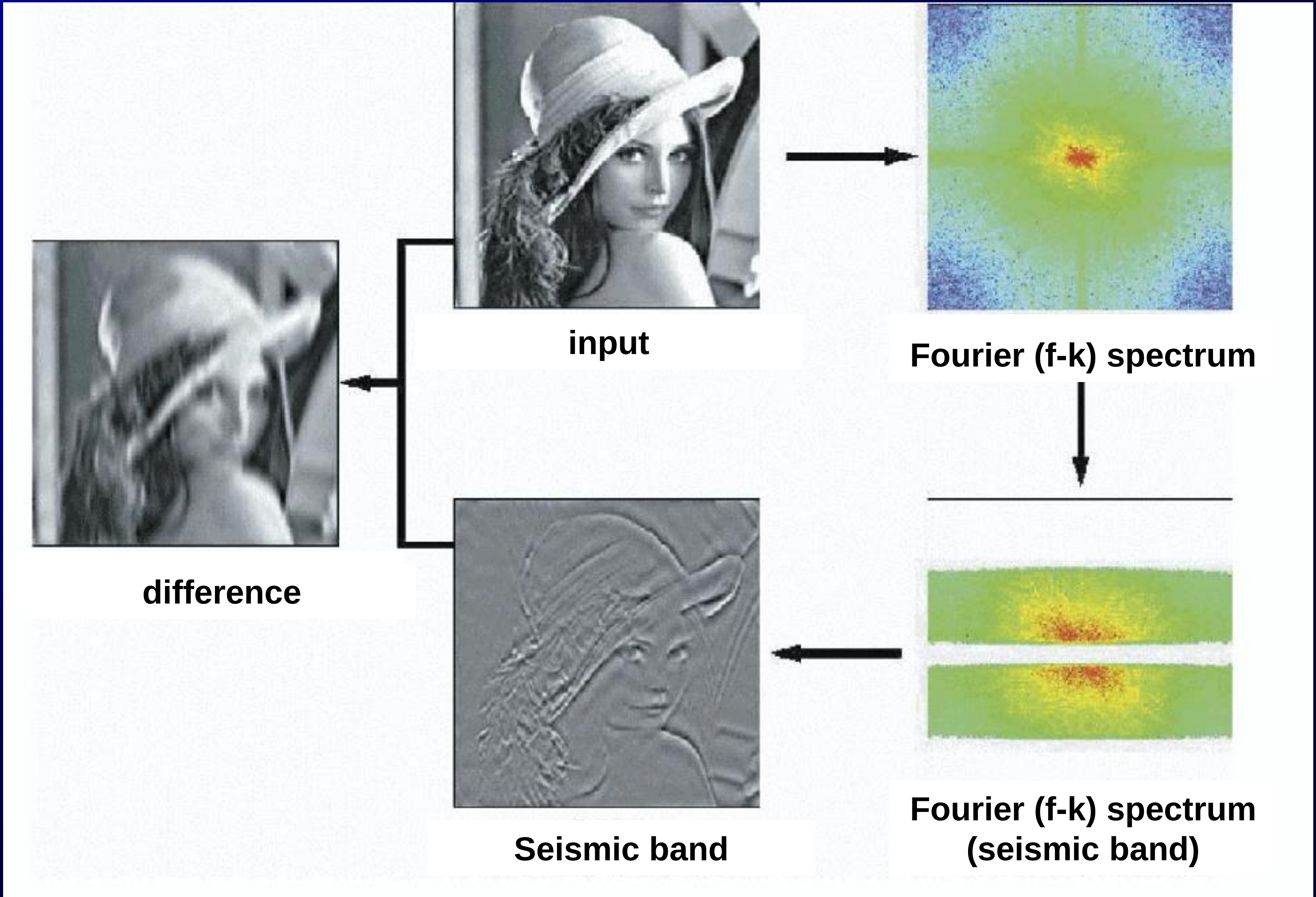
(Latimer et al.. 2000)

Zero-phase wavelets used in interpretation
Minimum-phase wavelets used in processing



(Veeken, 2007)

What is the impact of missing low frequencies?



input

Fourier (f-k) spectrum

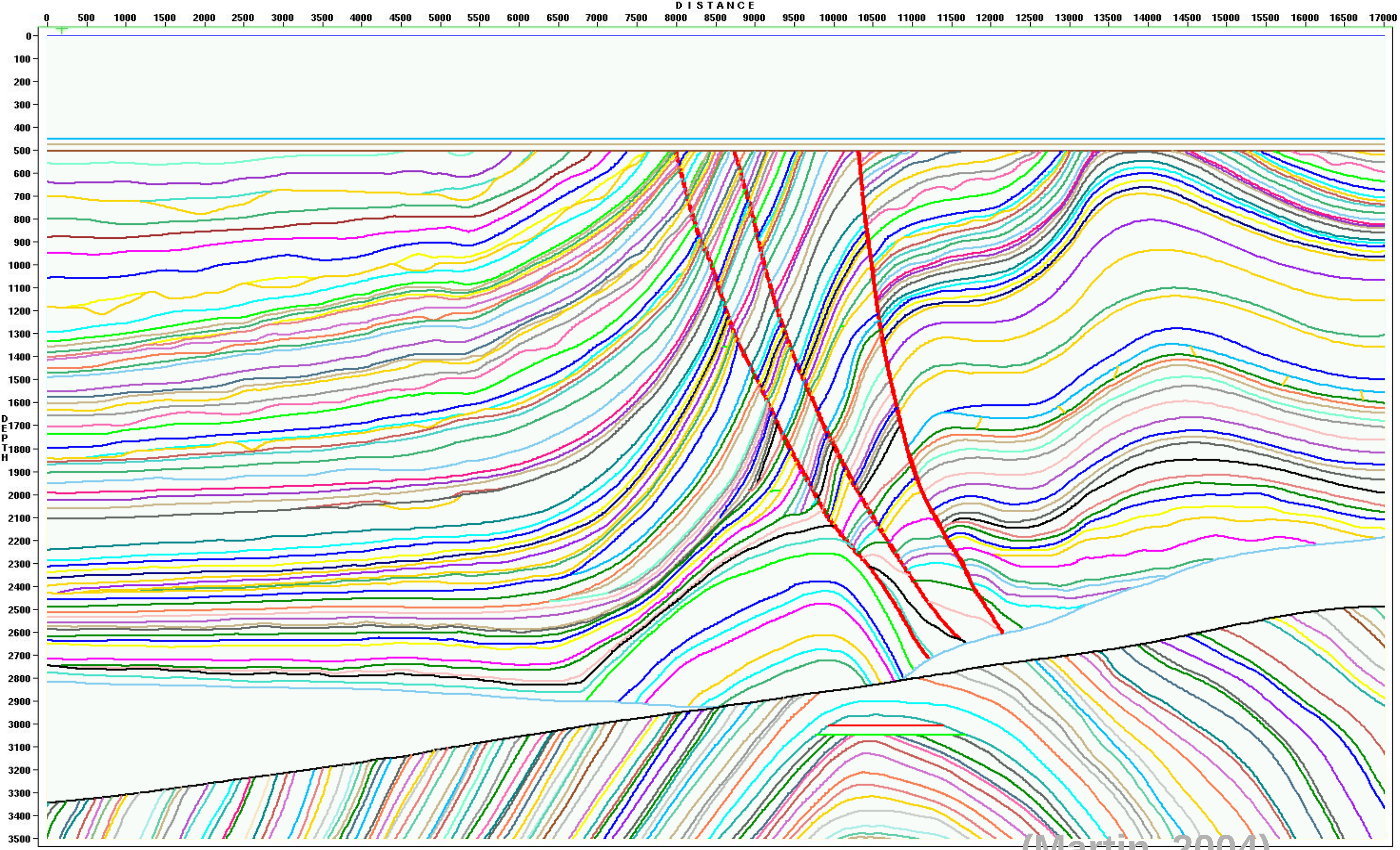
difference

Seismic band

Fourier (f-k) spectrum
(seismic band)

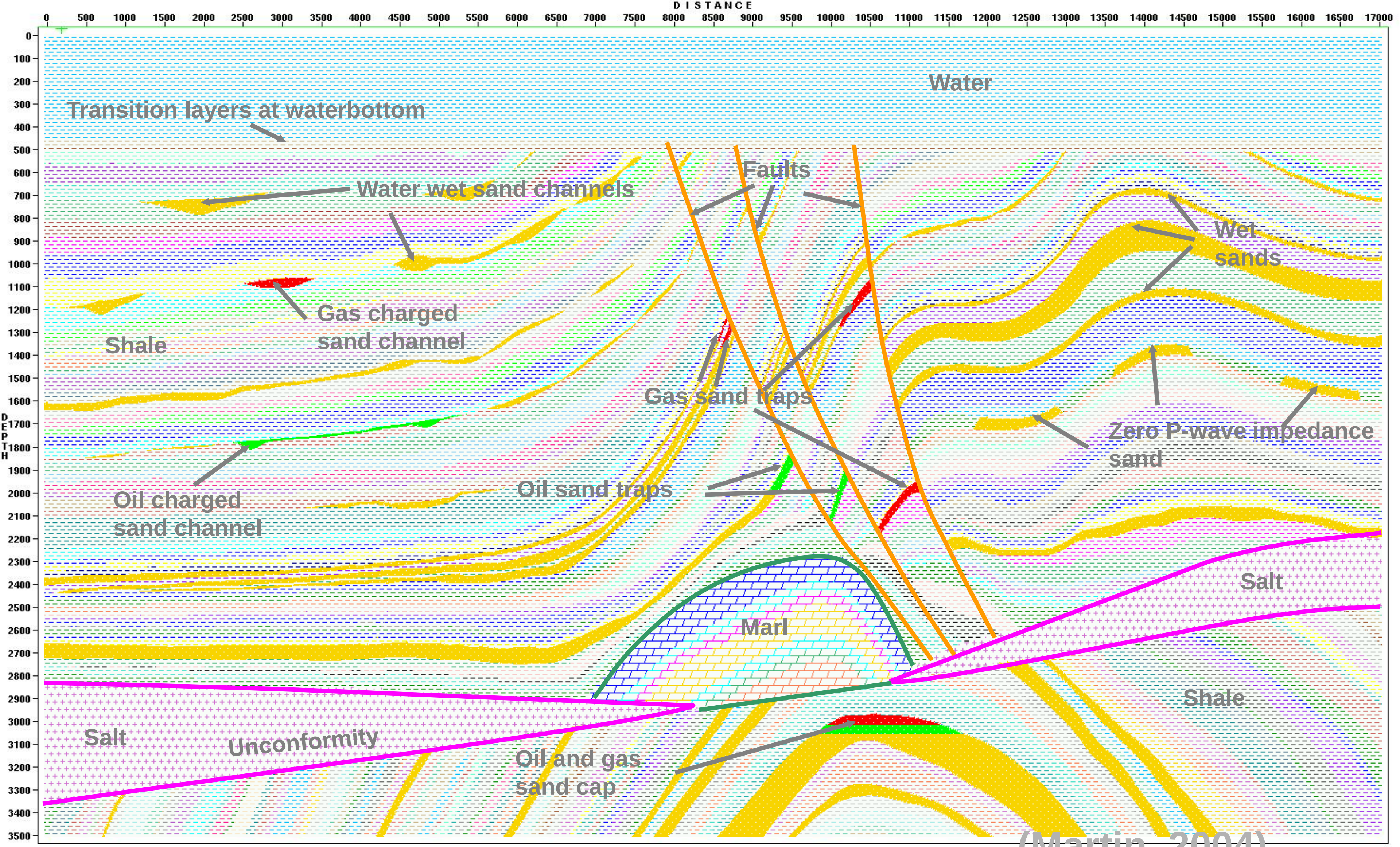
(Monk, 2002)

Horizons



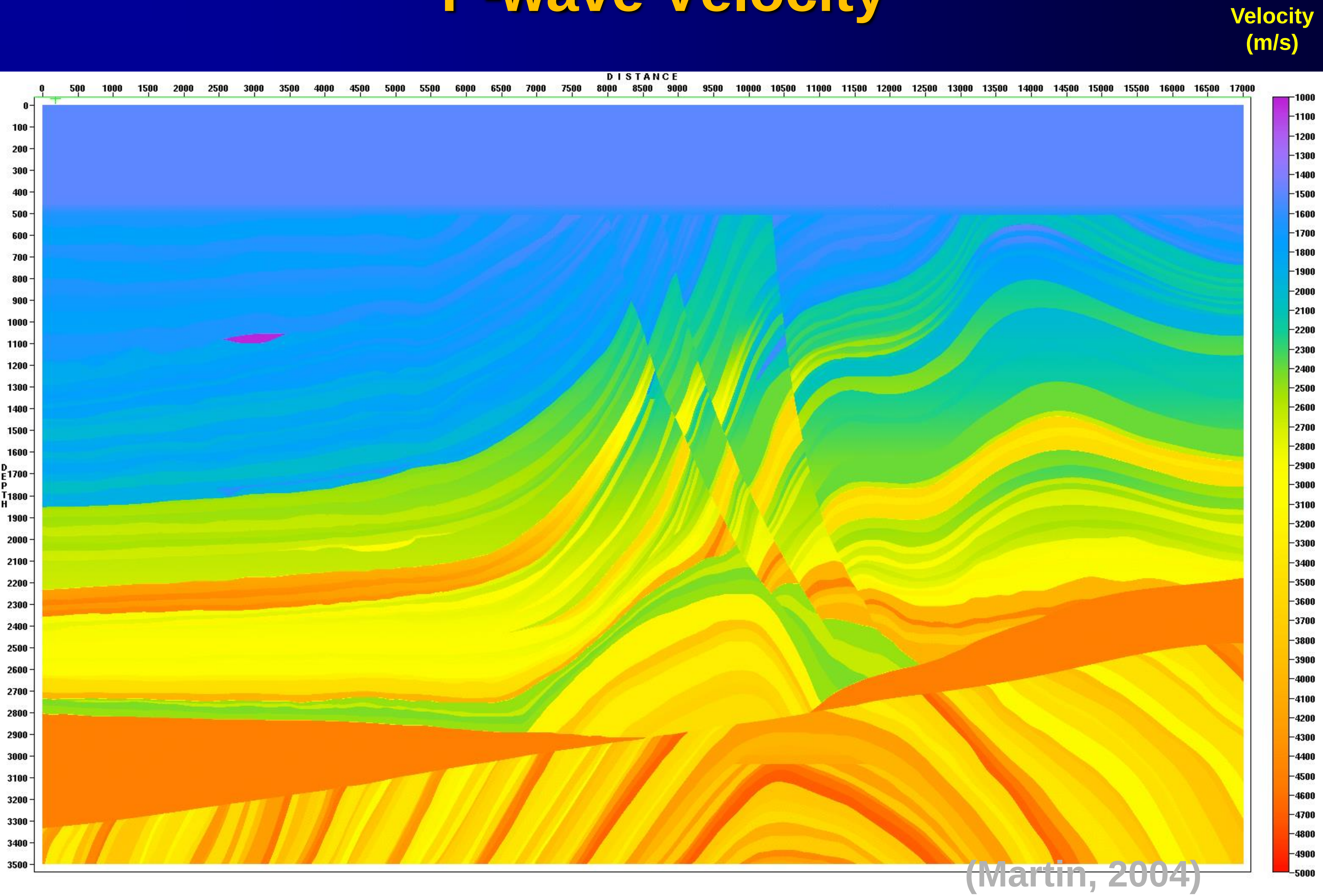
(Martin, 2004)

Lithology & Features



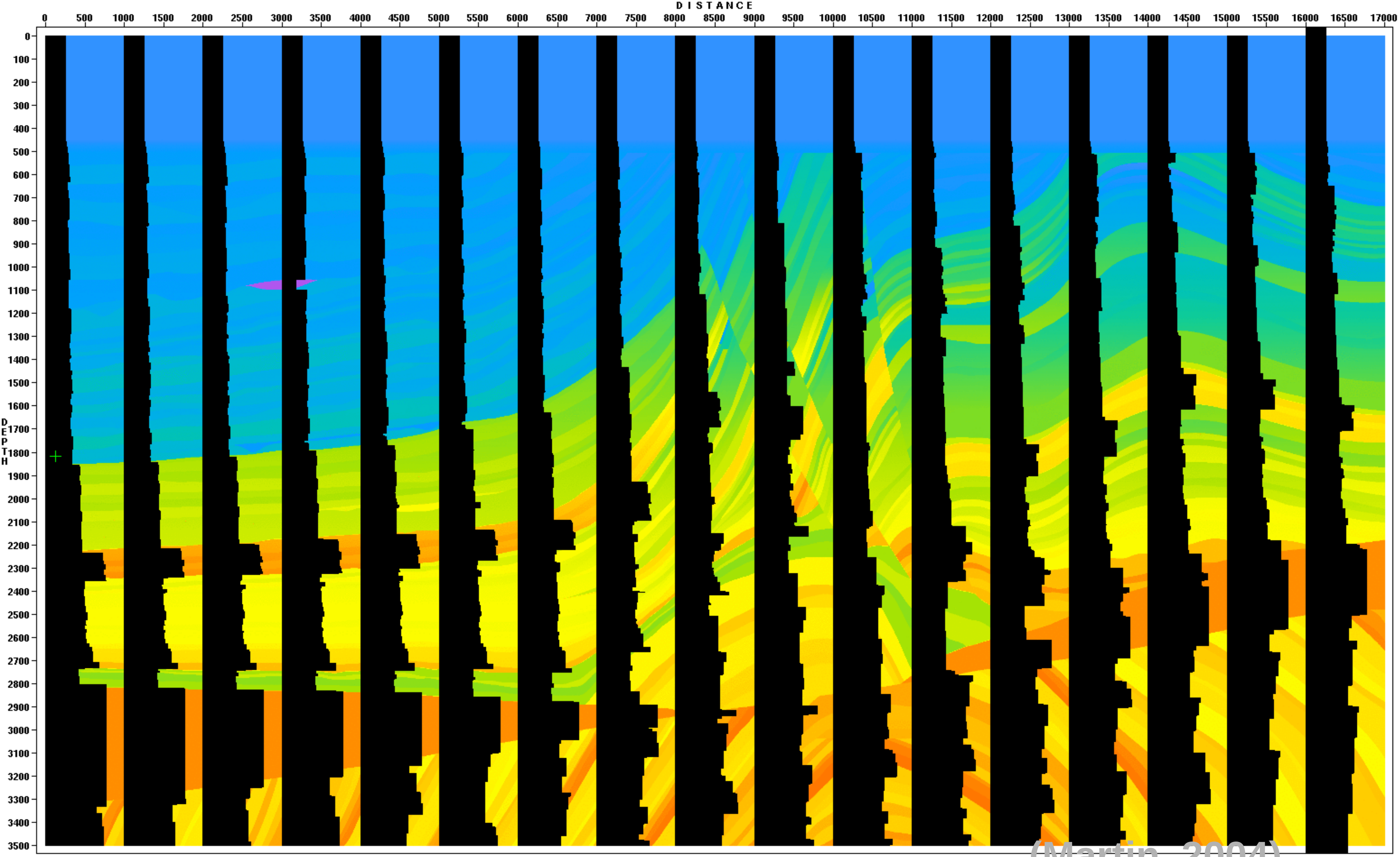
(Martin, 2004)

P-wave Velocity



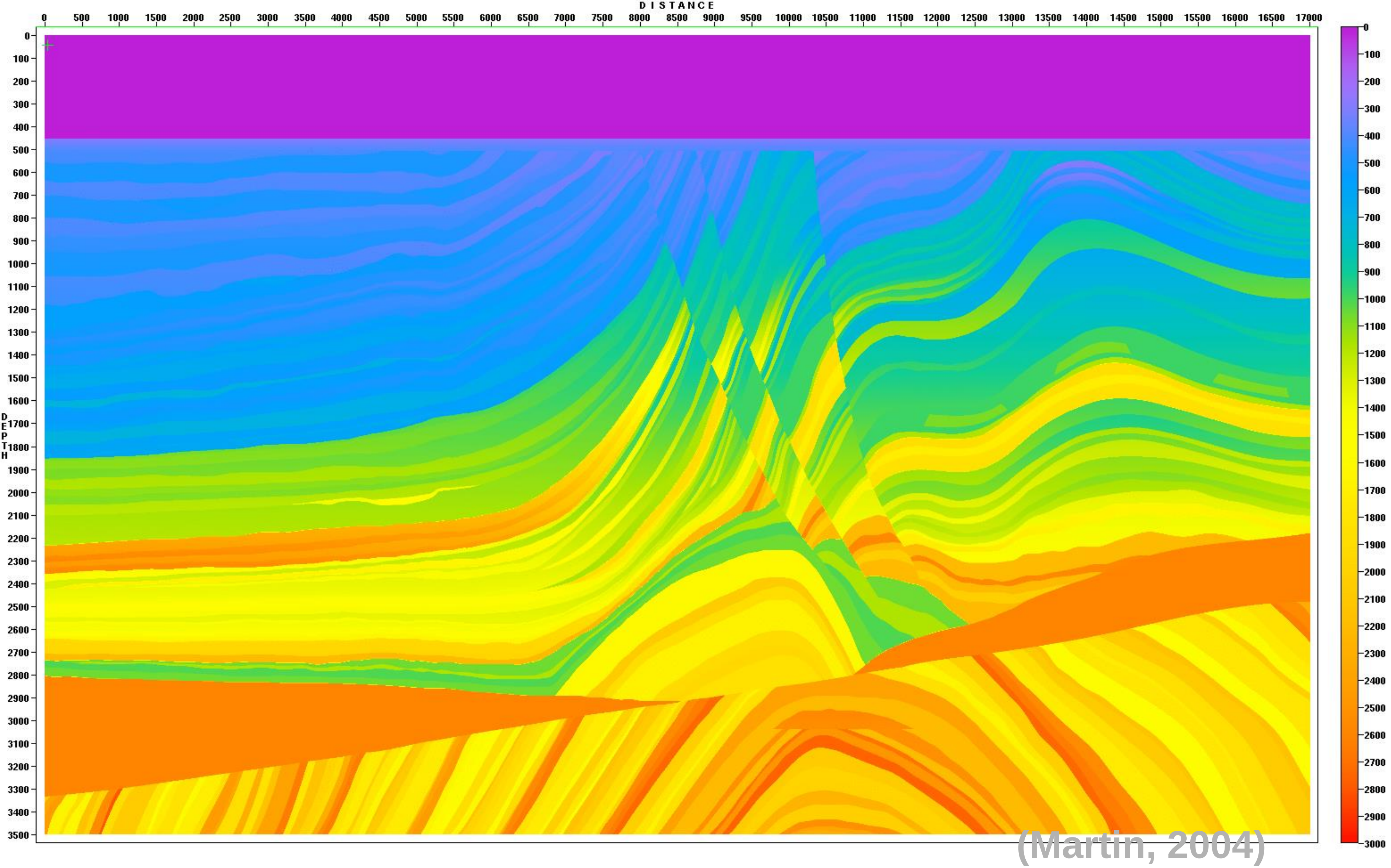
(Martin, 2004)

P-wave Velocity



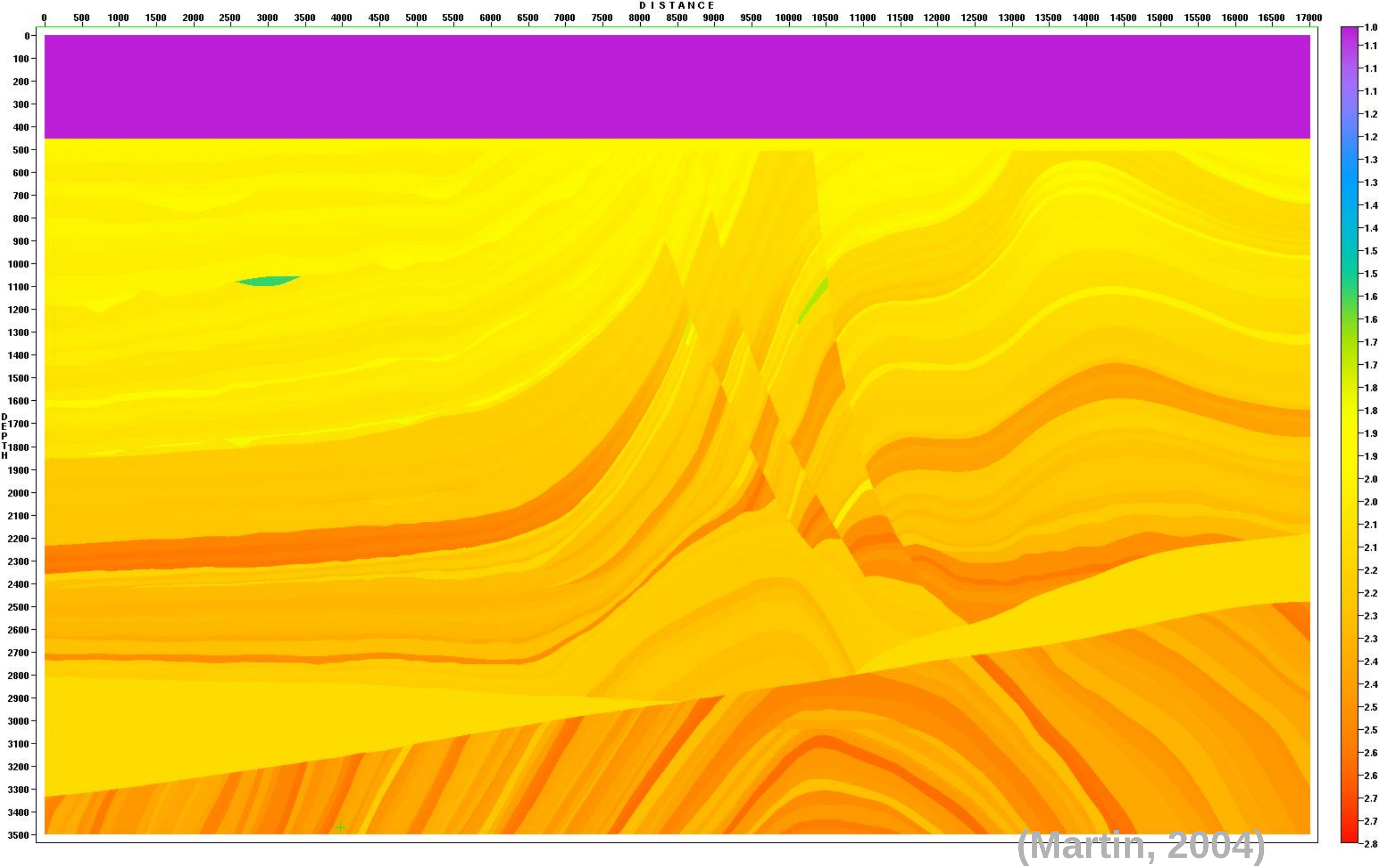
(Martin, 2004)

S-wave Velocity



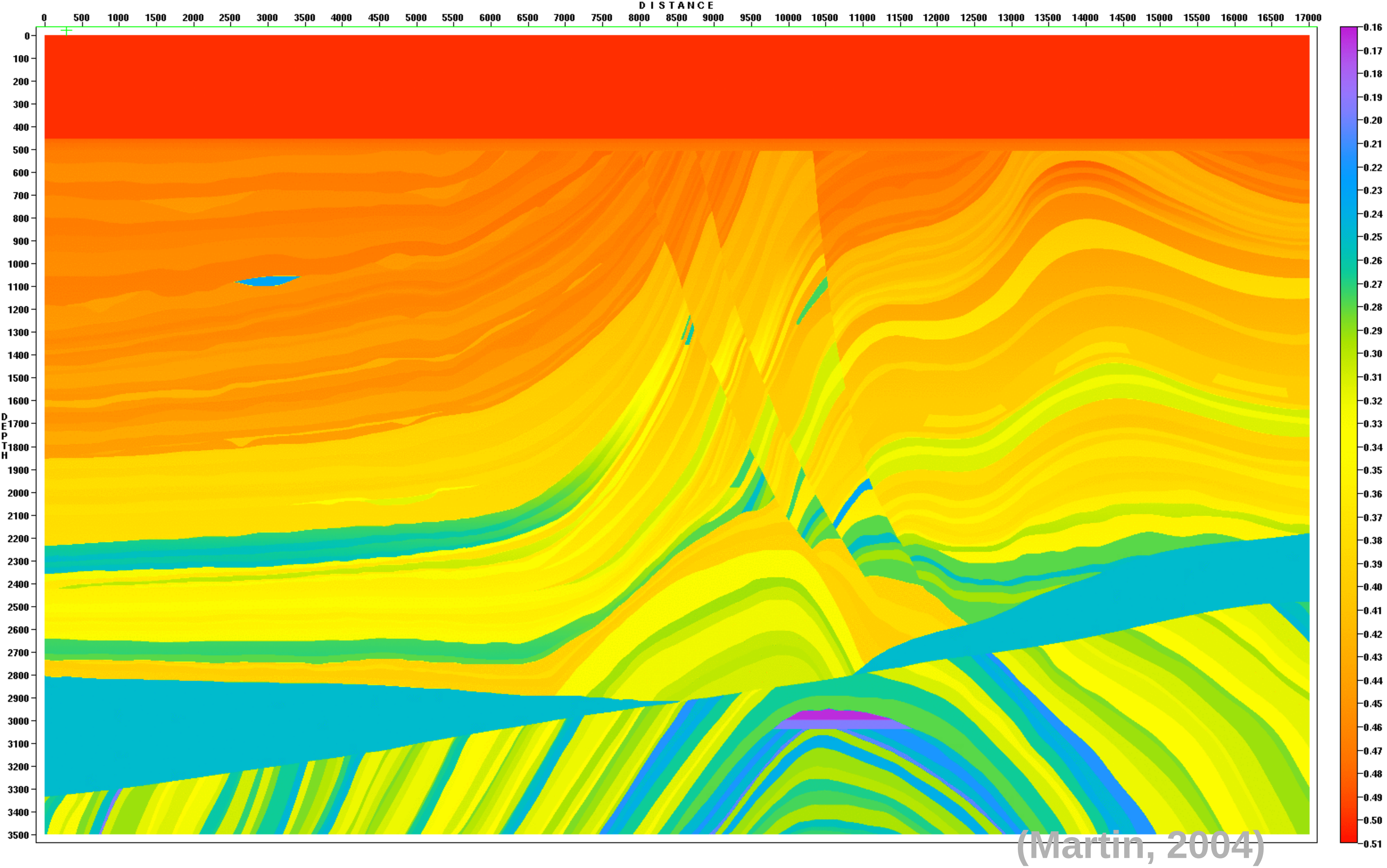
(Martin, 2004)

Density



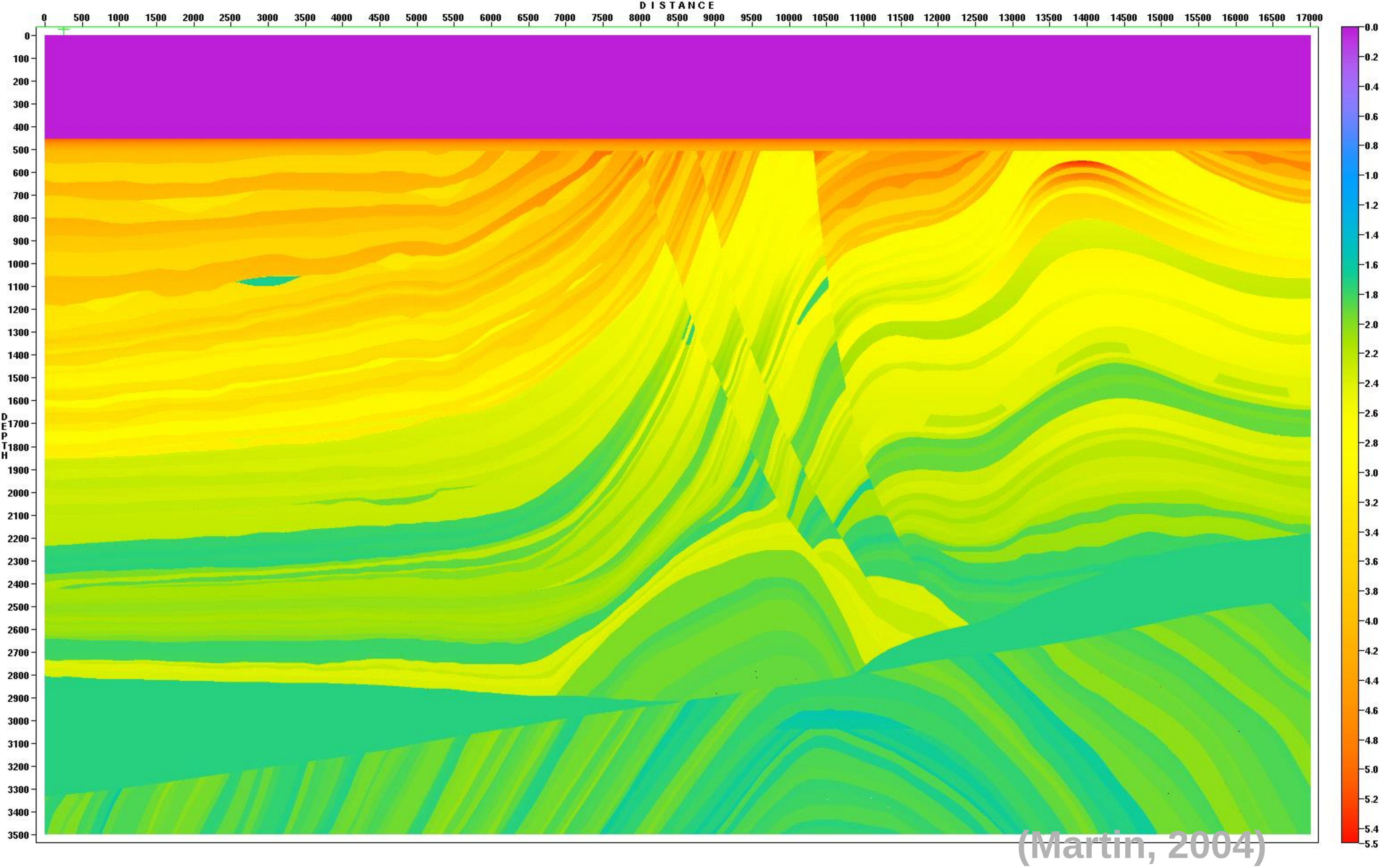
(Martin, 2004)

Poisson's Ratio



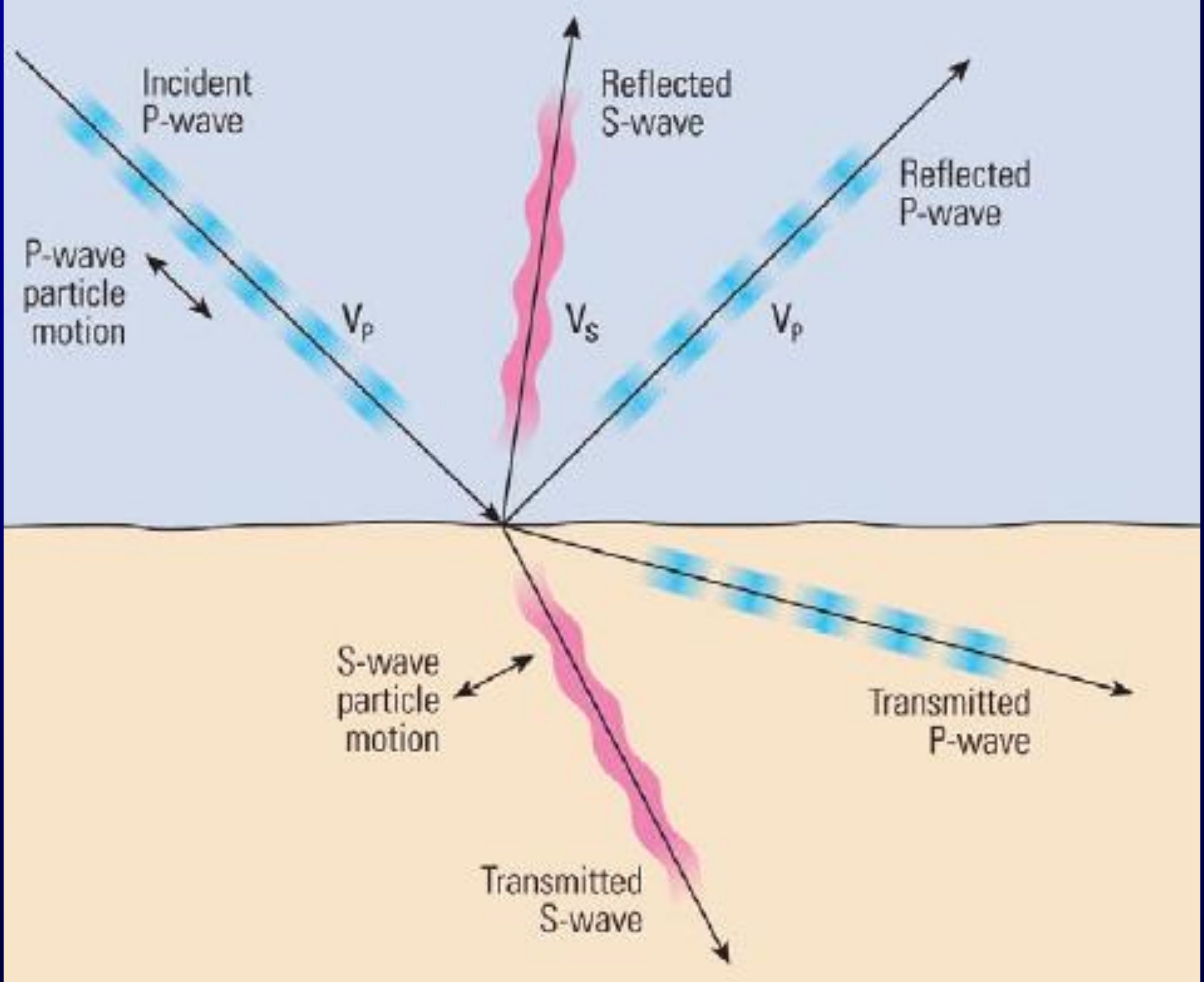
(Martin, 2004)

Vp/Vs Ratio



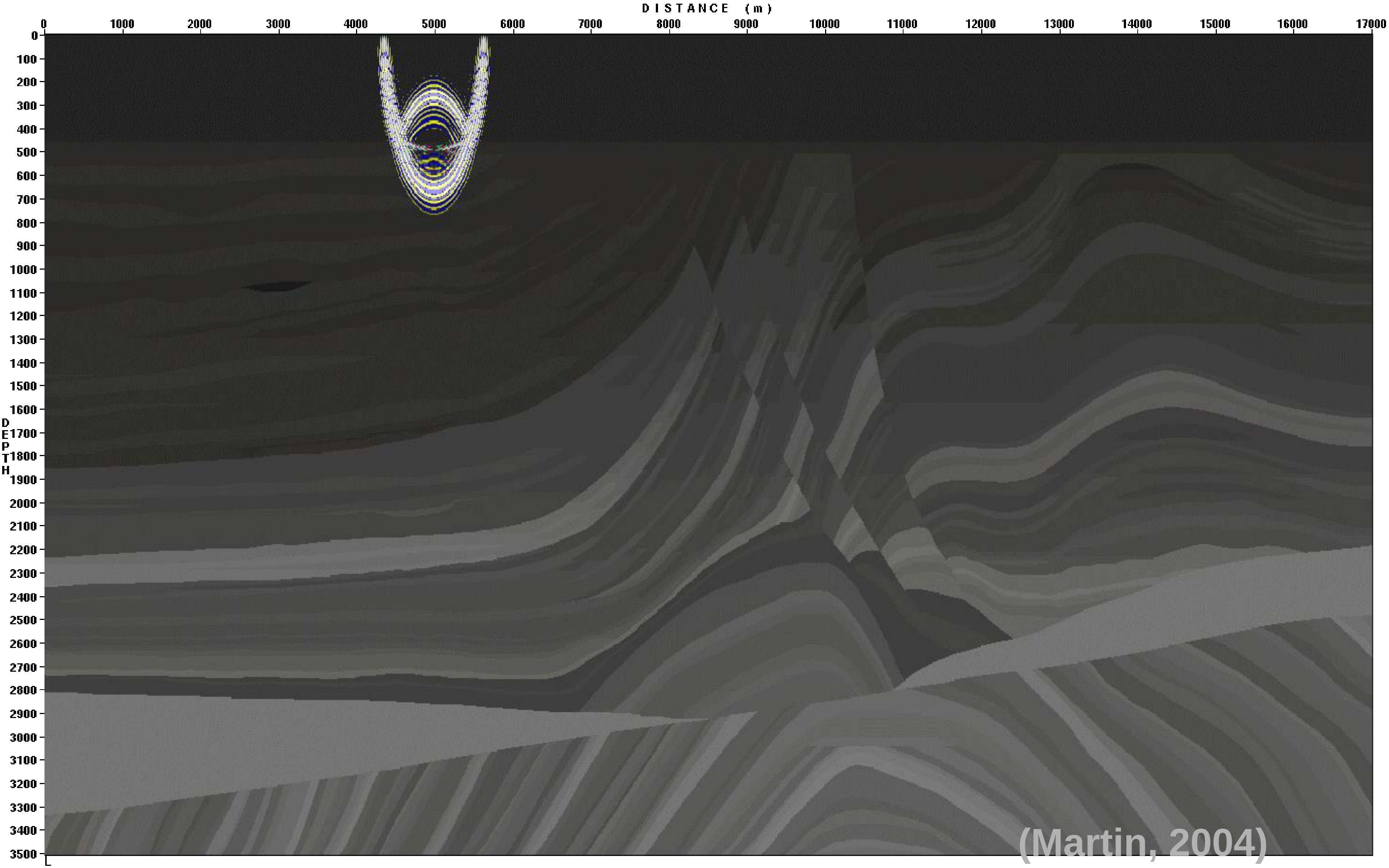
(Martin, 2004)

P- and S-waves



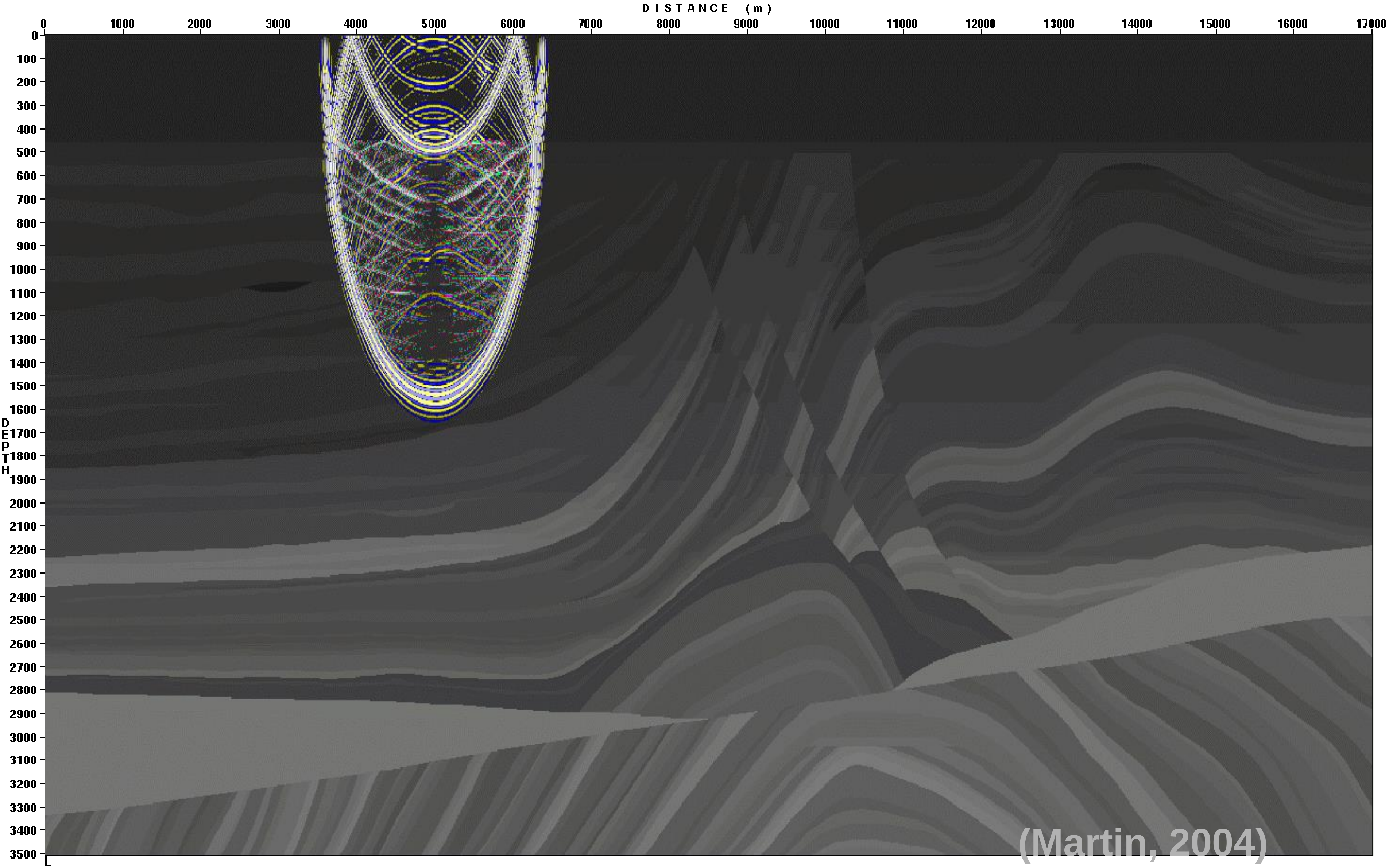
(Dragoset, 2006)

Snapshot: t=0.5 s



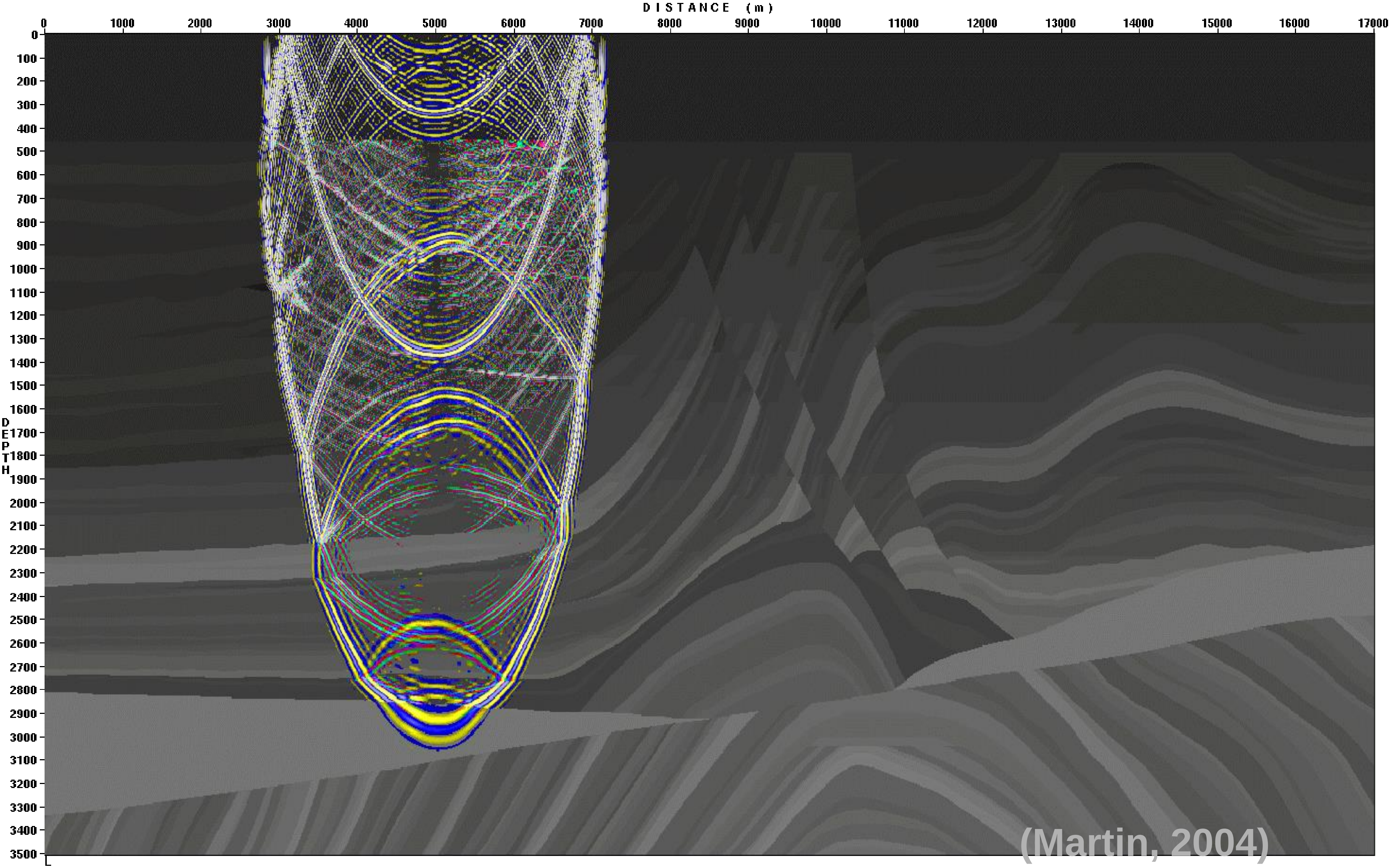
(Martin, 2004)

Snapshot: t=1.0 s



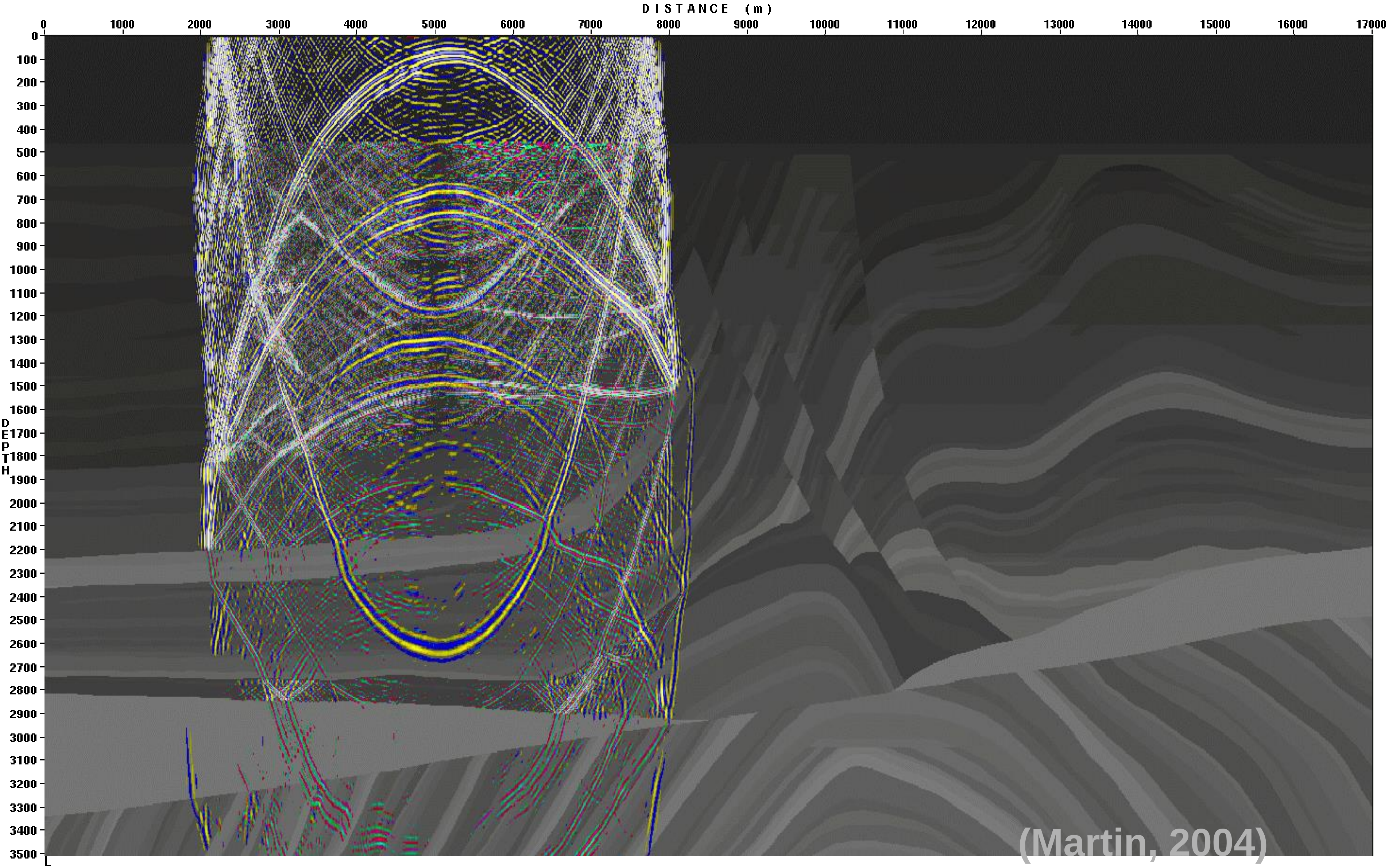
(Martin, 2004)

Snapshot: t=1.5 s



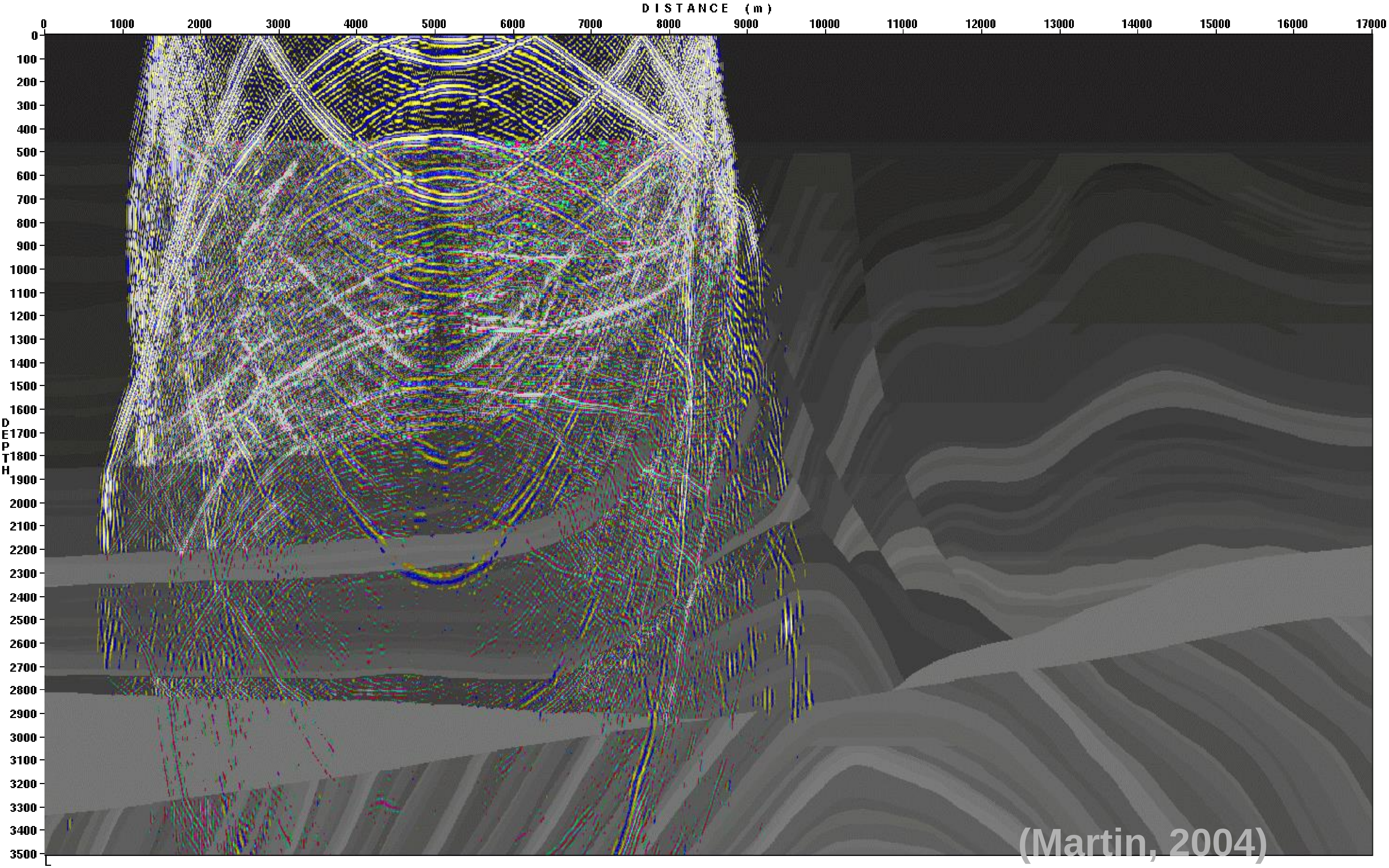
(Martin, 2004)

Snapshot: t=2.0 s



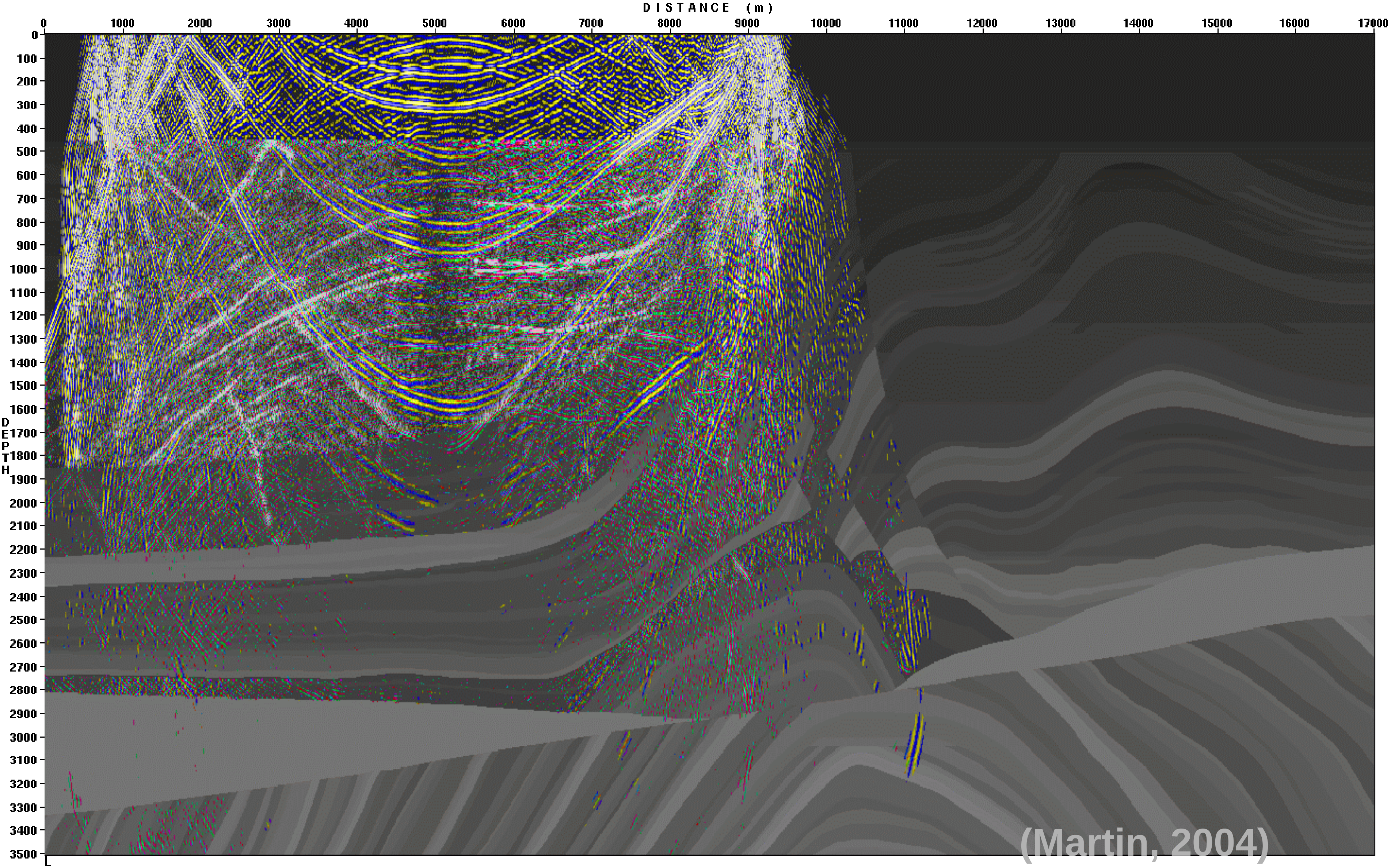
(Martin, 2004)

Snapshot: t=2.5 s



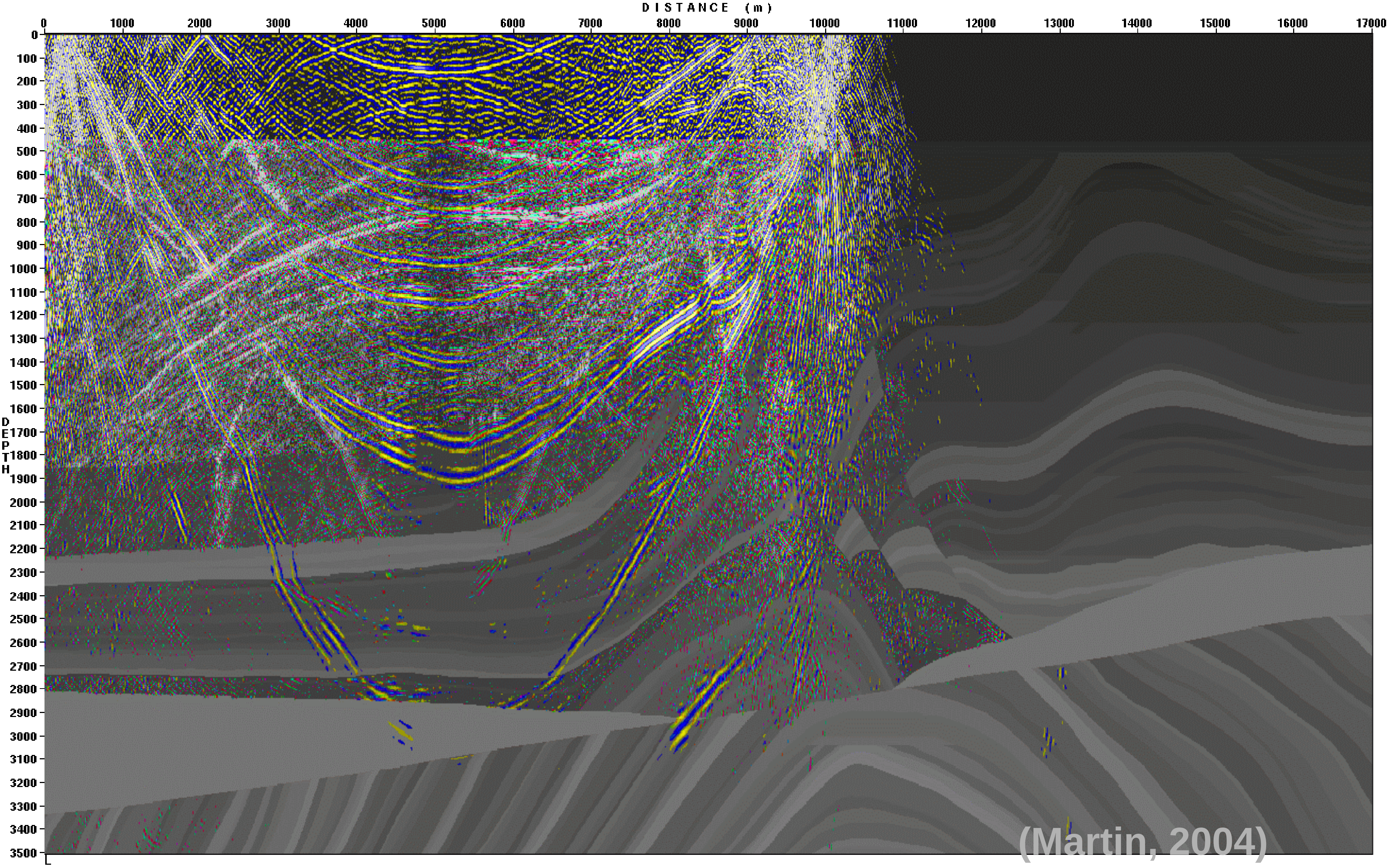
(Martin, 2004)

Snapshot: t=3.0 s



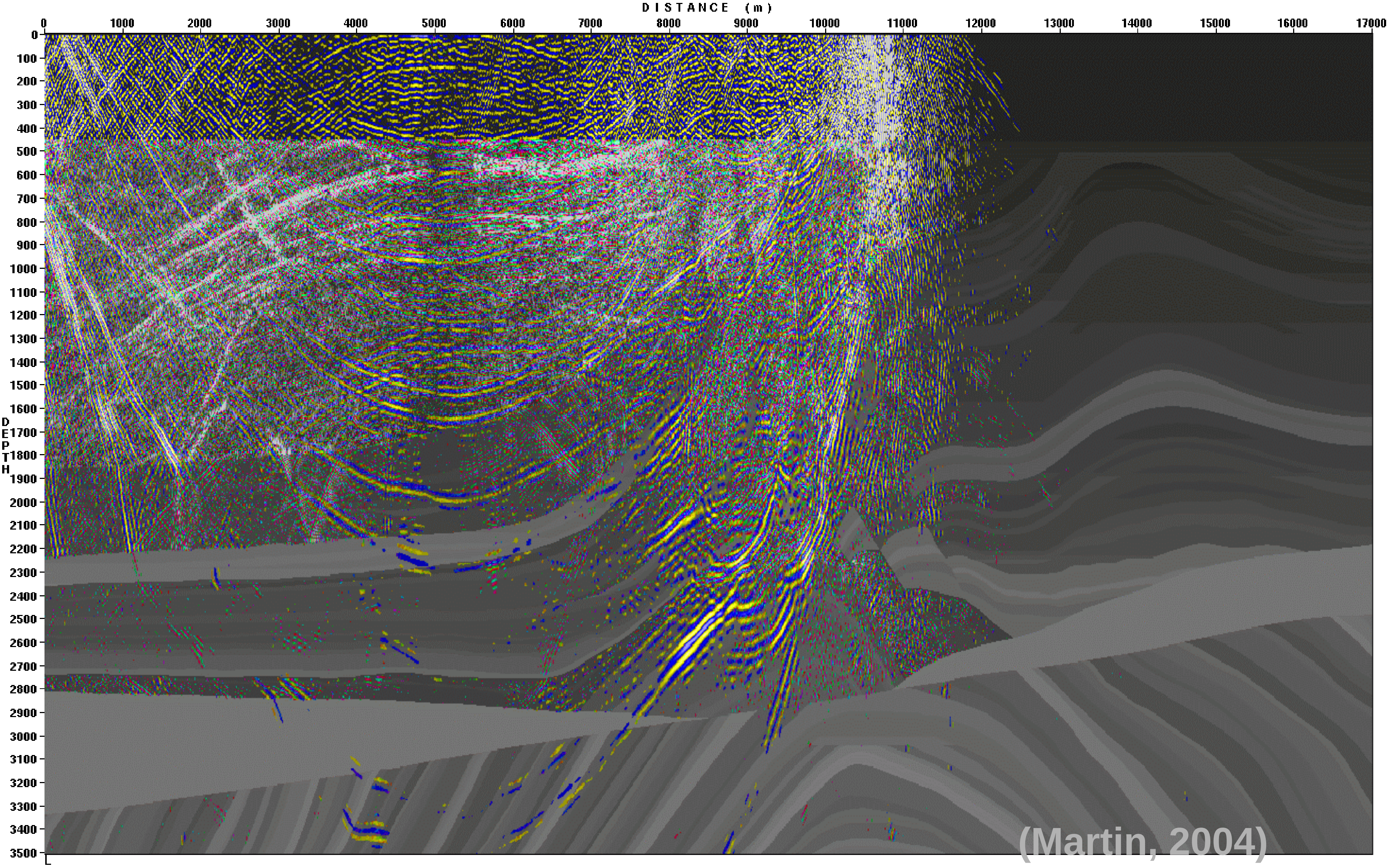
(Martin, 2004)

Snapshot: t=3.5 s



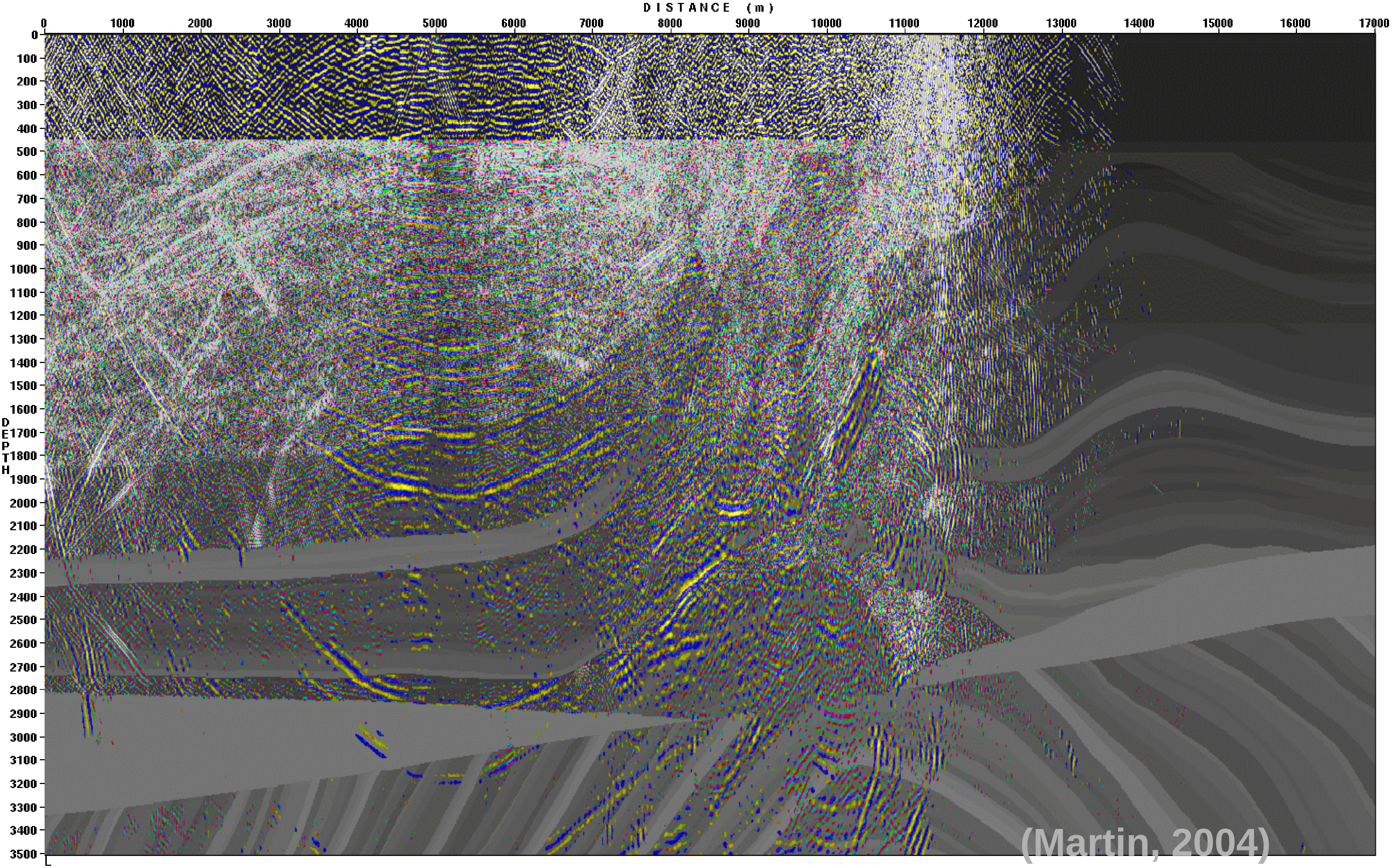
(Martin, 2004)

Snapshot: t=4.0 s



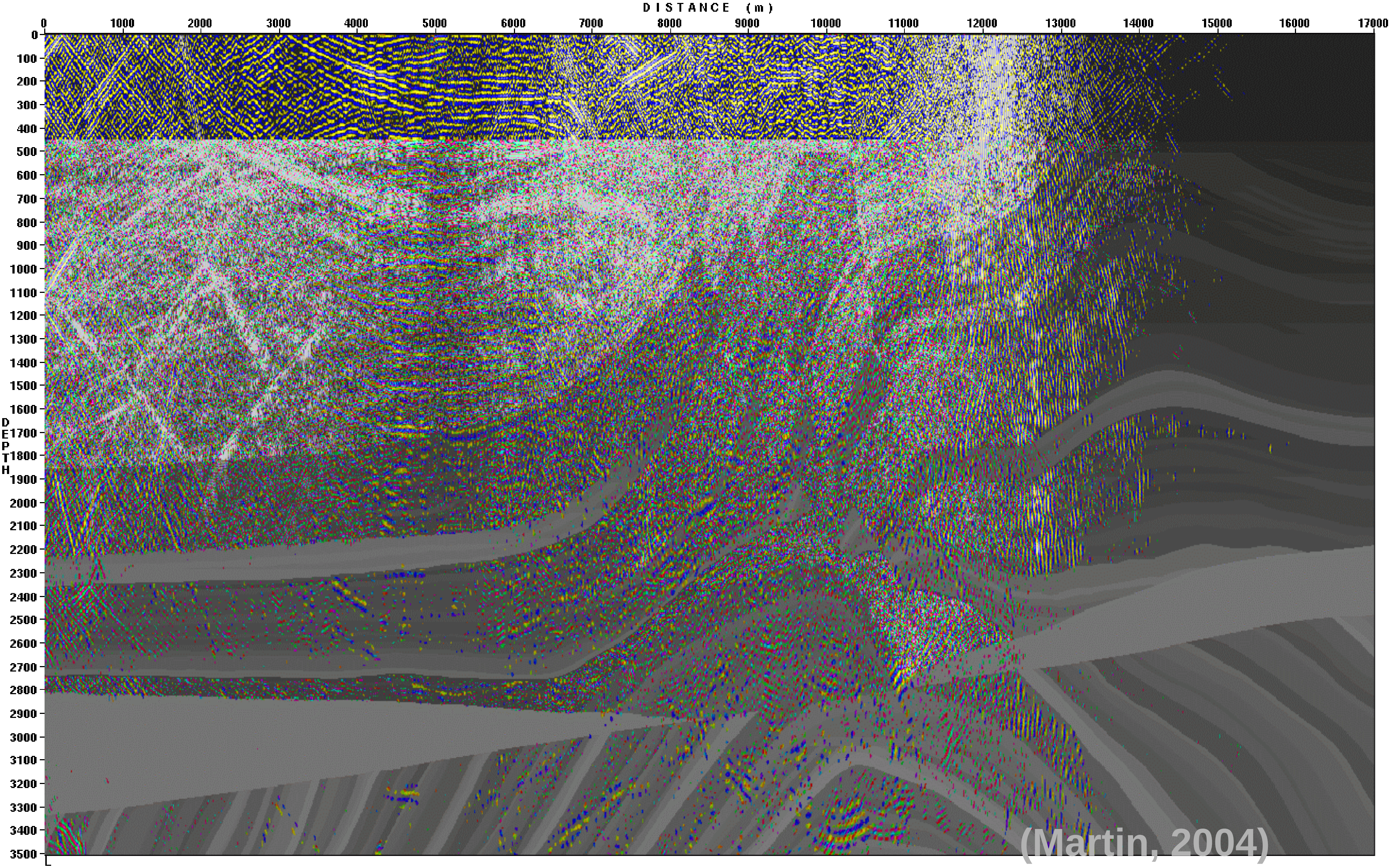
(Martin, 2004)

Snapshot: t=4.5 s



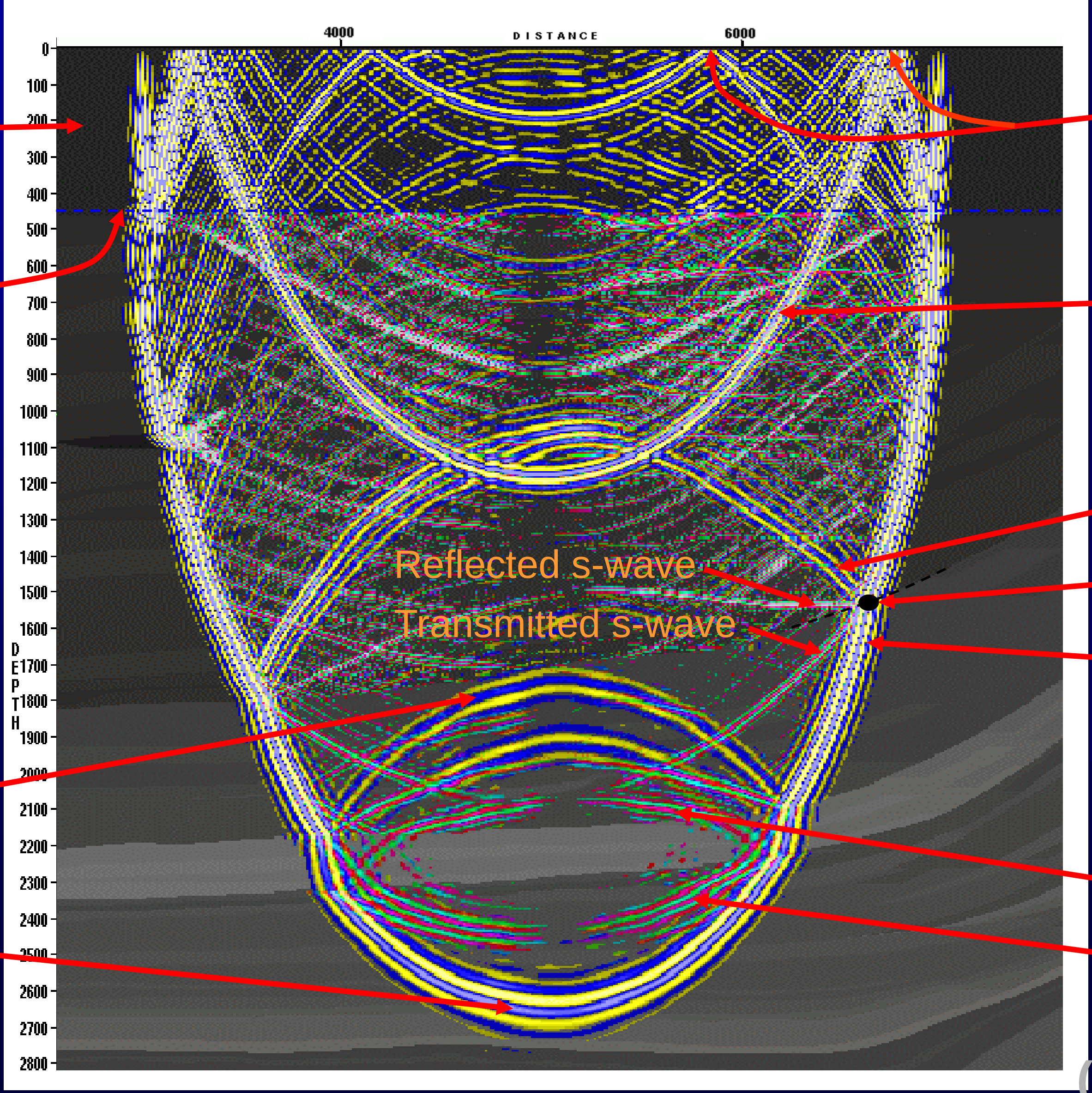
(Martin, 2004)

Snapshot: t=5.0 s



(Martin, 2004)

Snapshot Details: t=1.4s



No shear waves in water

Water bottom

Upgoing p-wave

Downgoing p-wave

Free surface reflection

Downgoing 1st order water bottom multiple

Reflected p-wave

Reflection point

Transmitted p-wave

Reflected s-wave

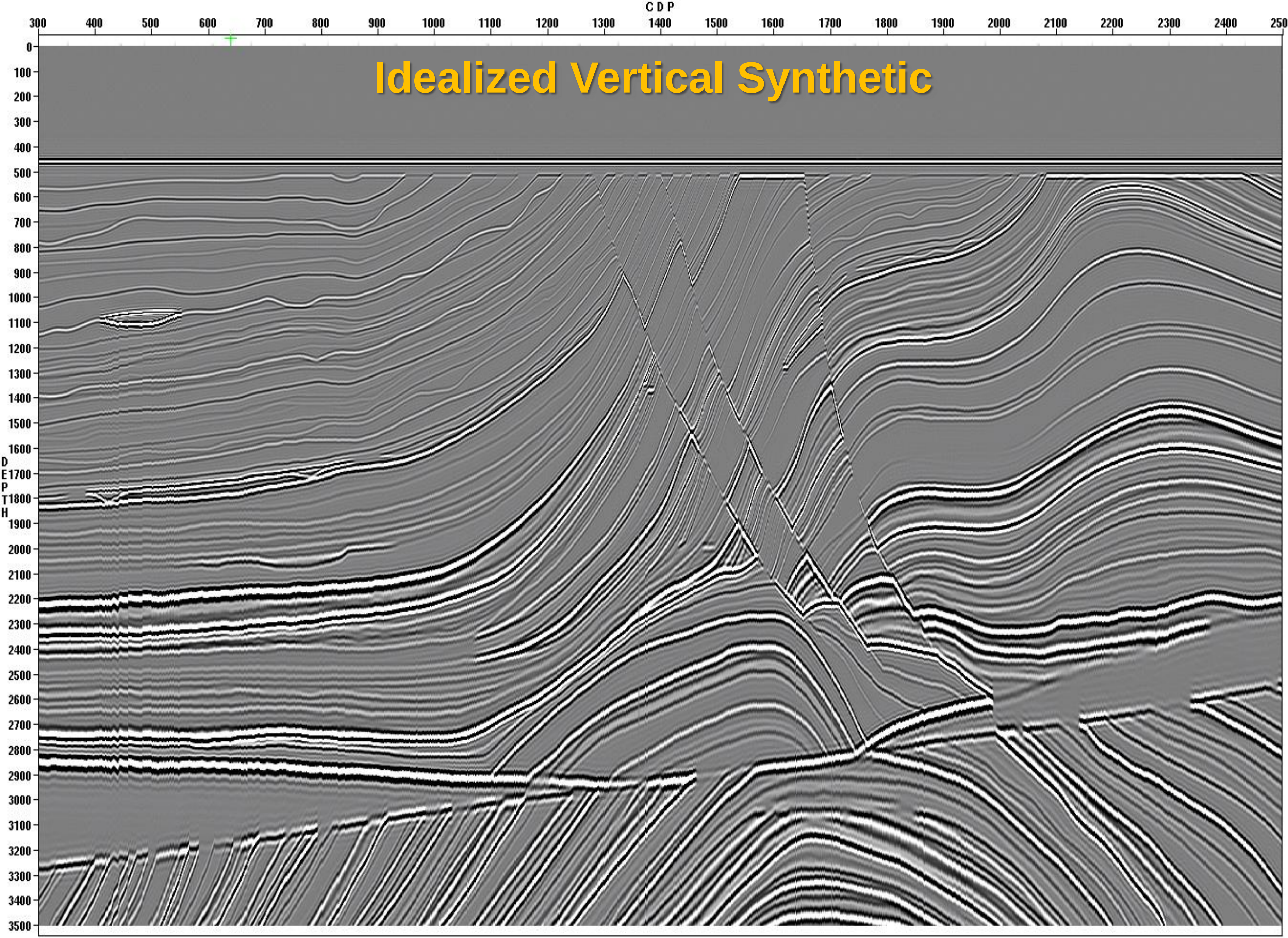
Transmitted s-wave

Upgoing s-wave

Downgoing s-wave

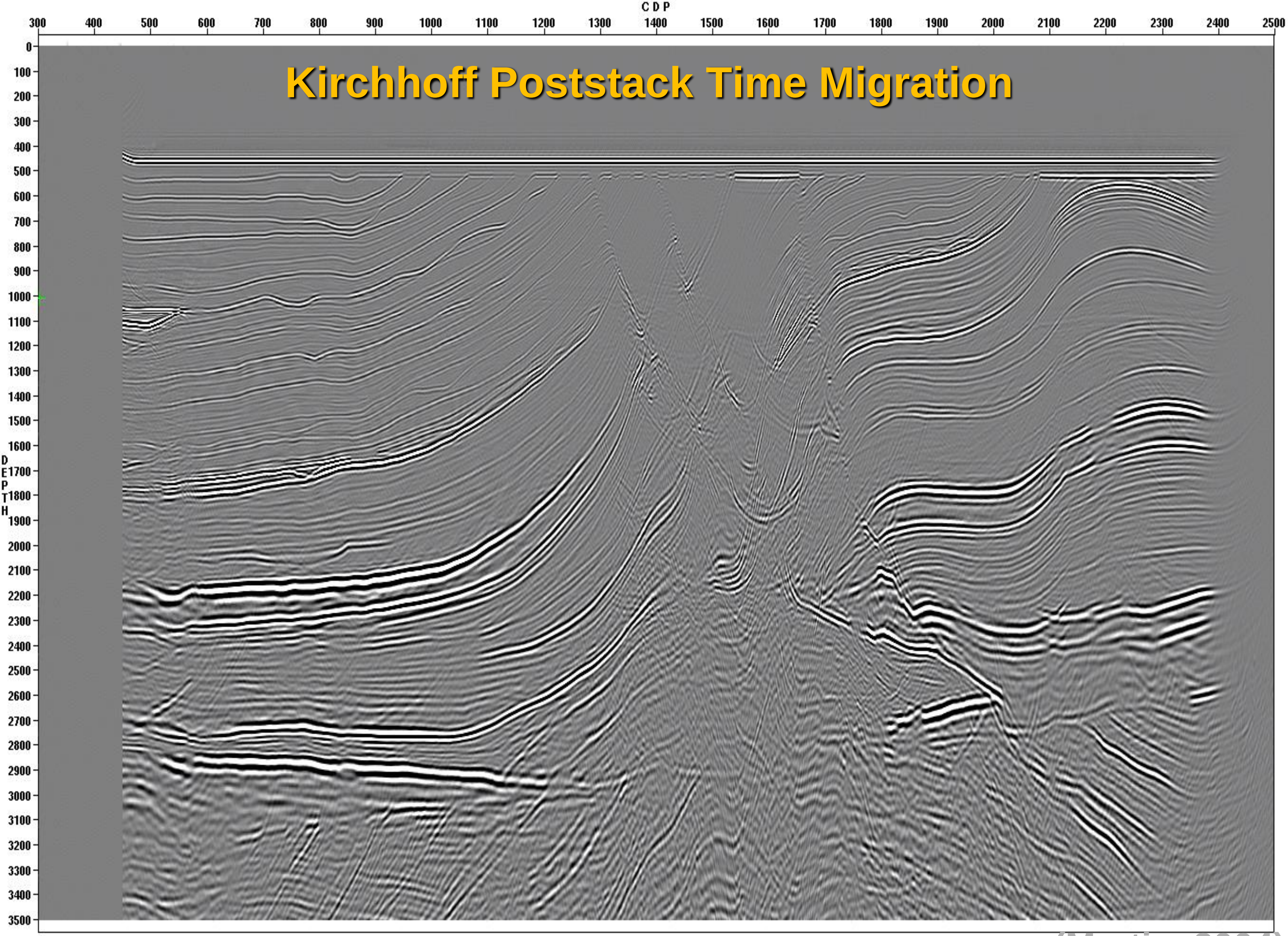
(Martin, 2004)

Idealized Vertical Synthetic



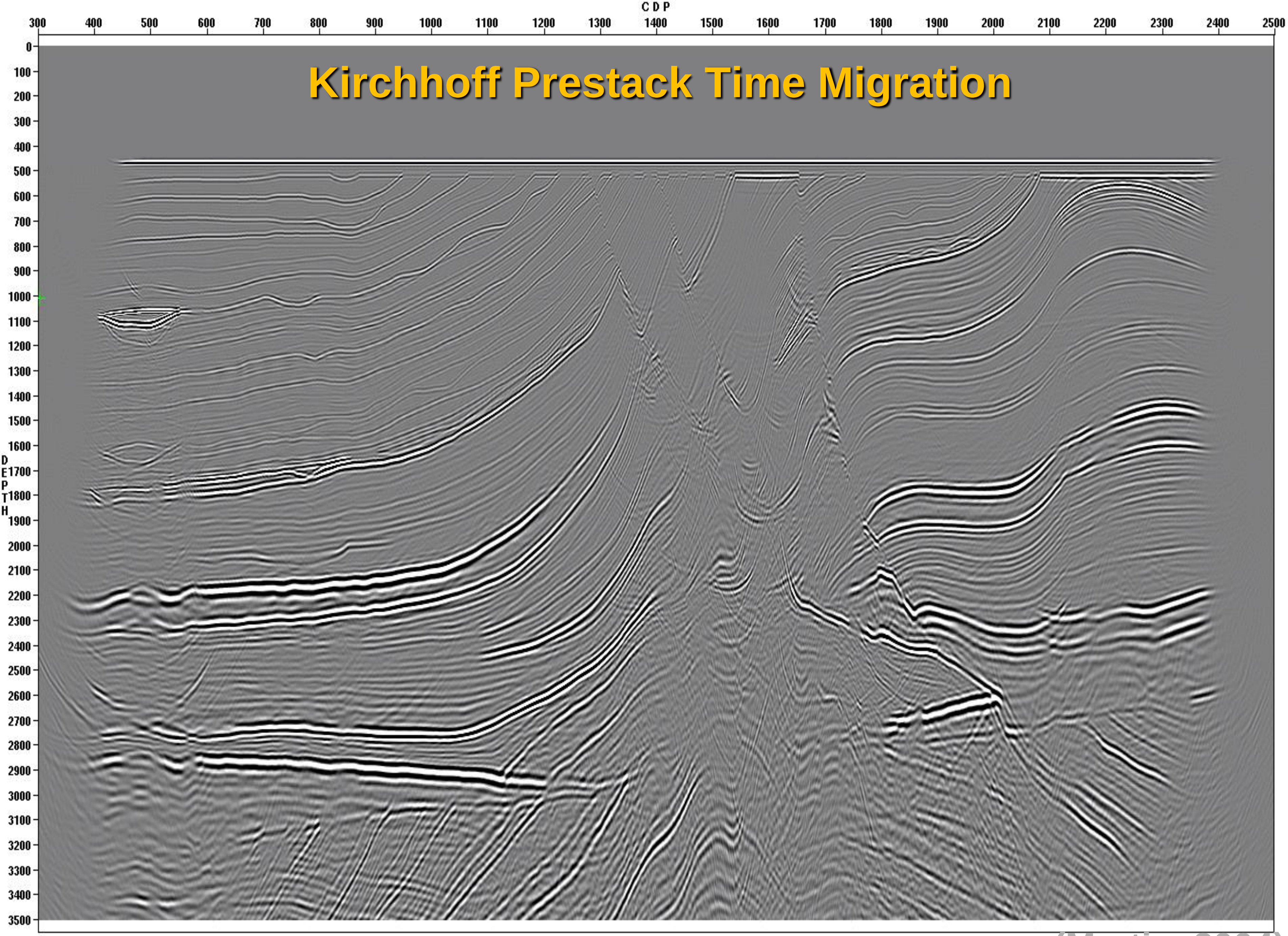
(Martin, 2004)

Kirchhoff Poststack Time Migration



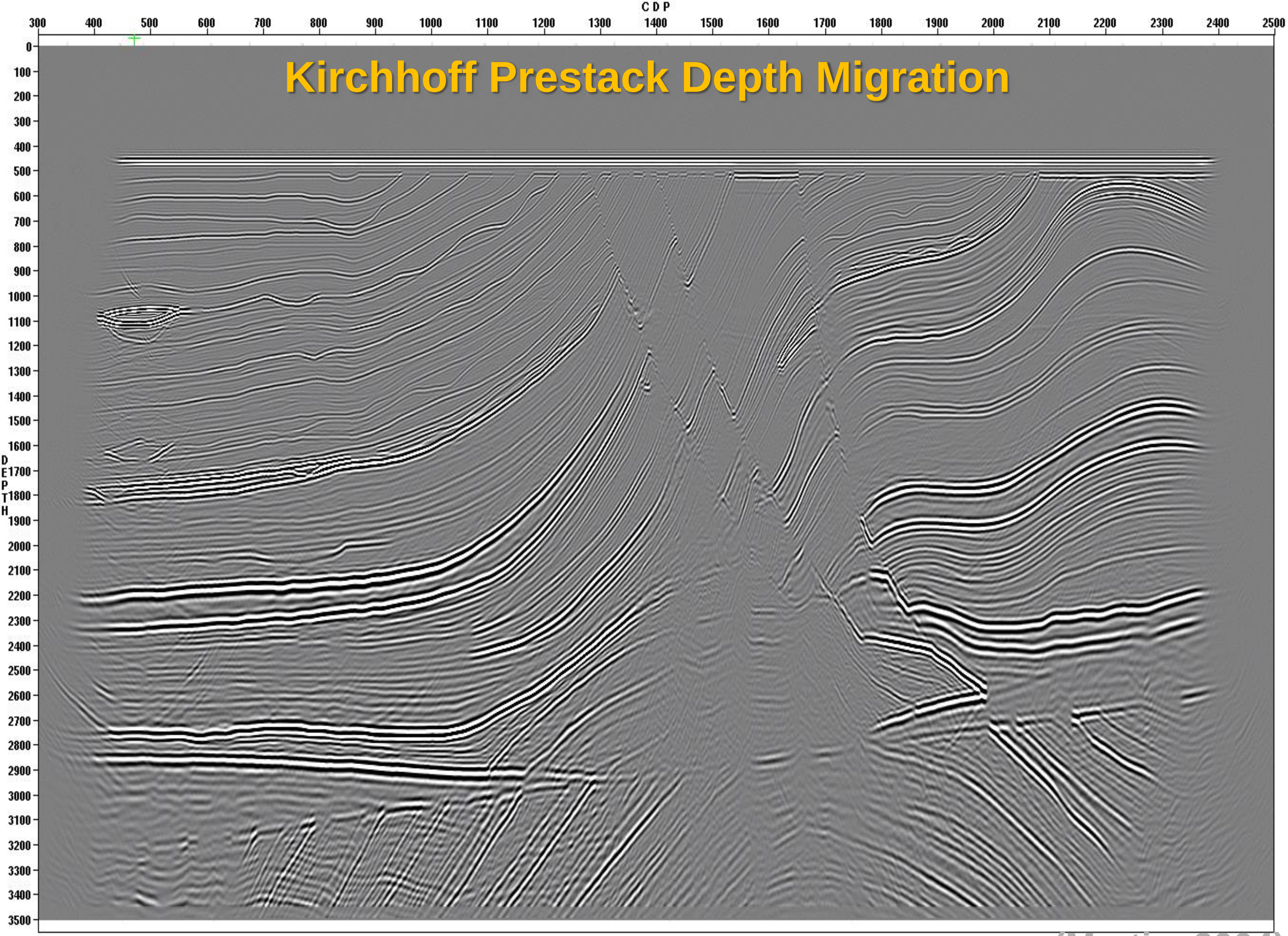
(Martin, 2004)

Kirchhoff Prestack Time Migration



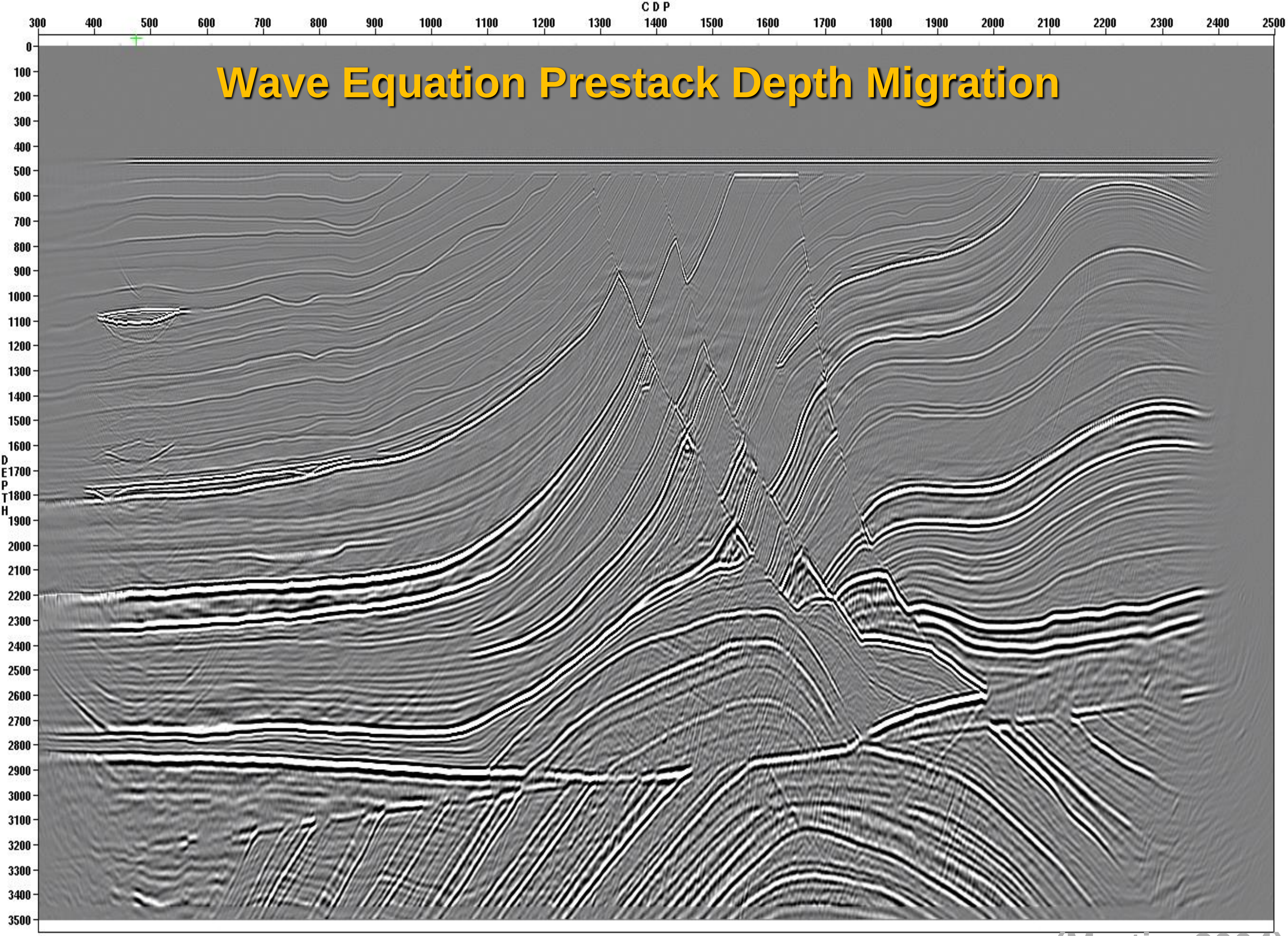
(Martin, 2004)

Kirchhoff Prestack Depth Migration



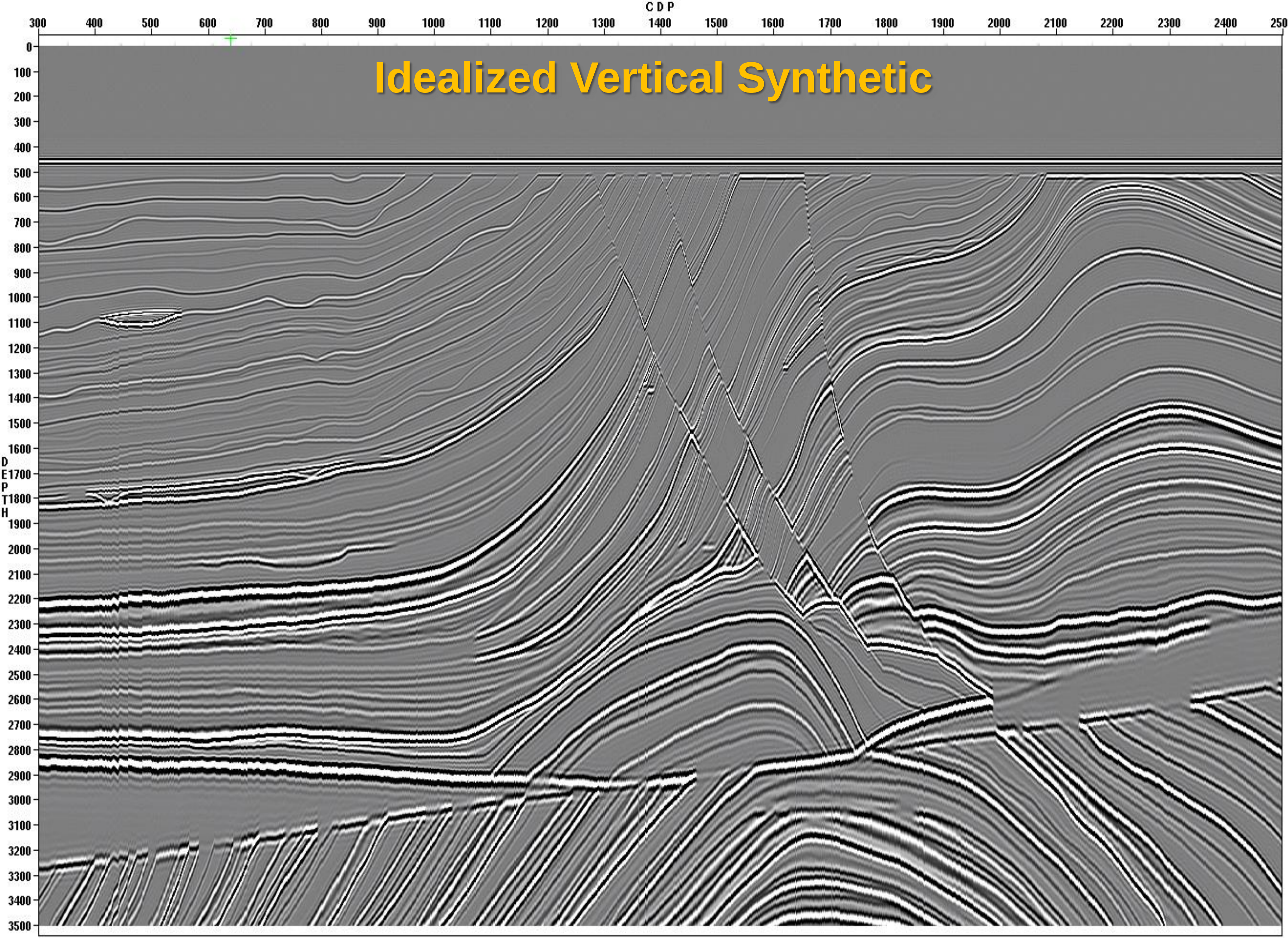
(Martin, 2004)

Wave Equation Prestack Depth Migration



(Martin, 2004)

Idealized Vertical Synthetic



(Martin, 2004)

Acquisition Footprint

Common causes of acquisition footprint

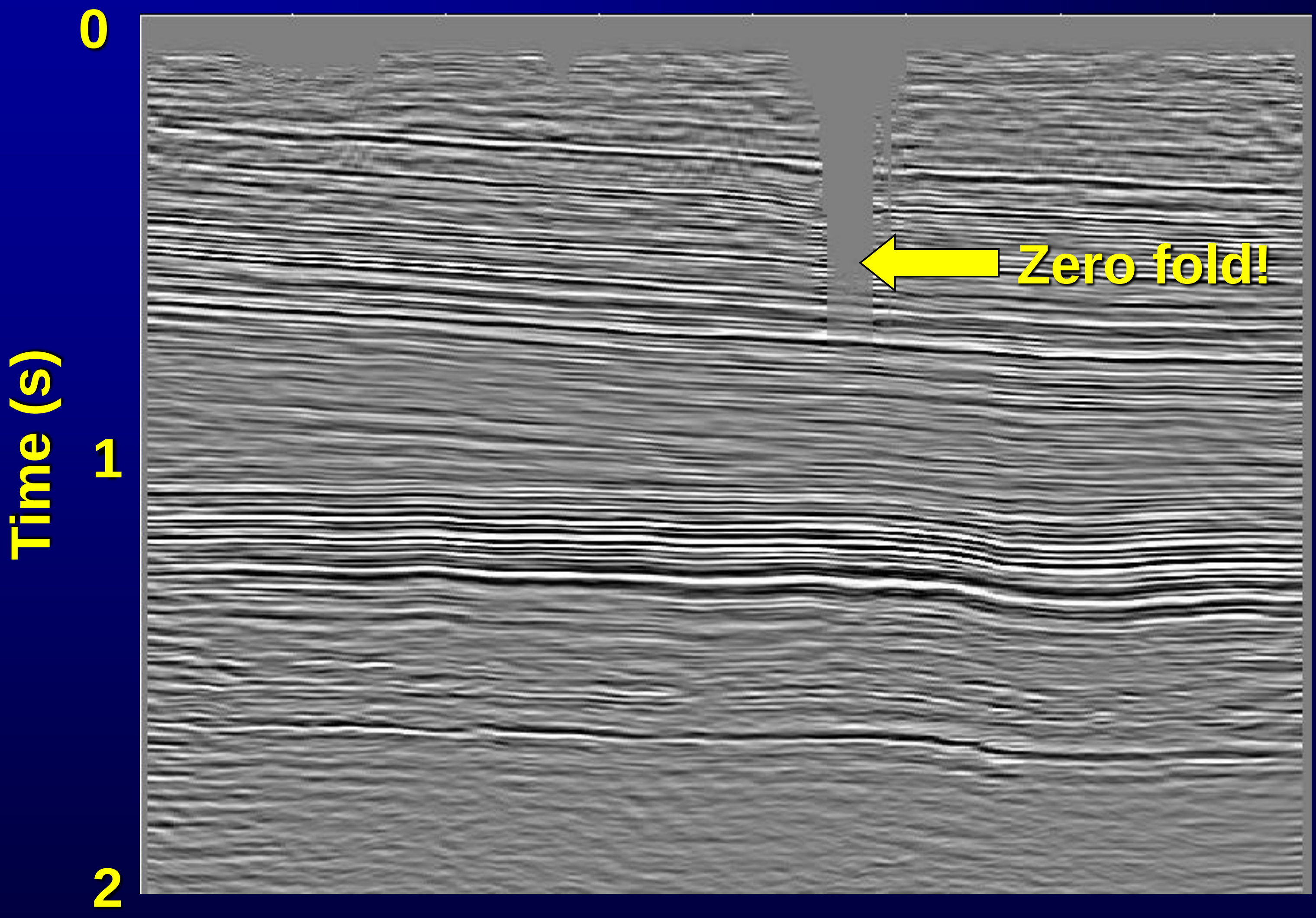
Problems due to acquisition program

- Non-uniform fold (s:n ratio goes as SQRT(fold))
- Non-uniform offsets and azimuths in bins
- Non-uniform backscattered noise suppression
- Obstacles such as lakes, villages, or platforms
- Currents and tides

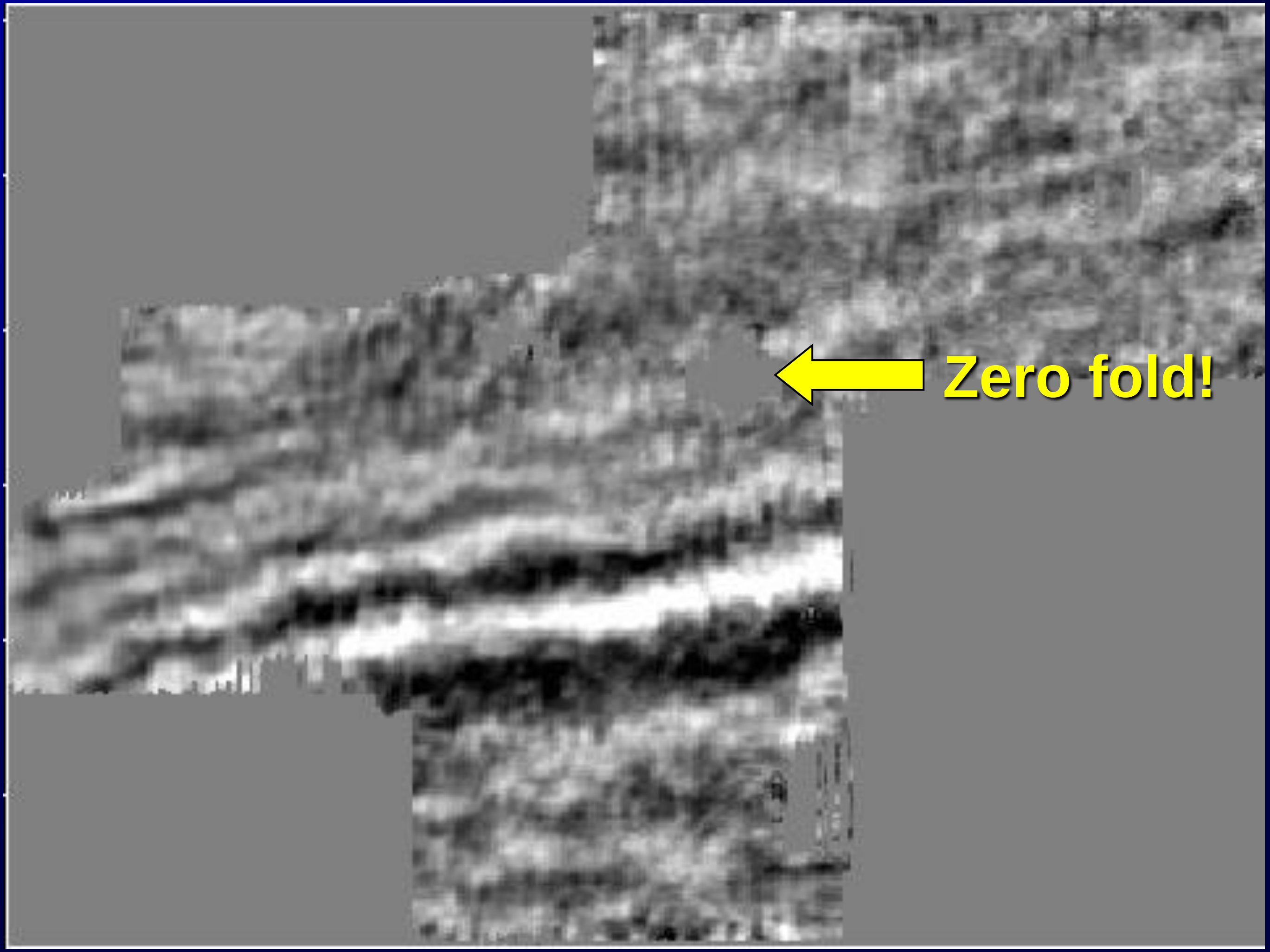
Problems due to processing

- Incorrect velocities
- Migration operator aliasing

Decrease in fold due to ‘obstacles’

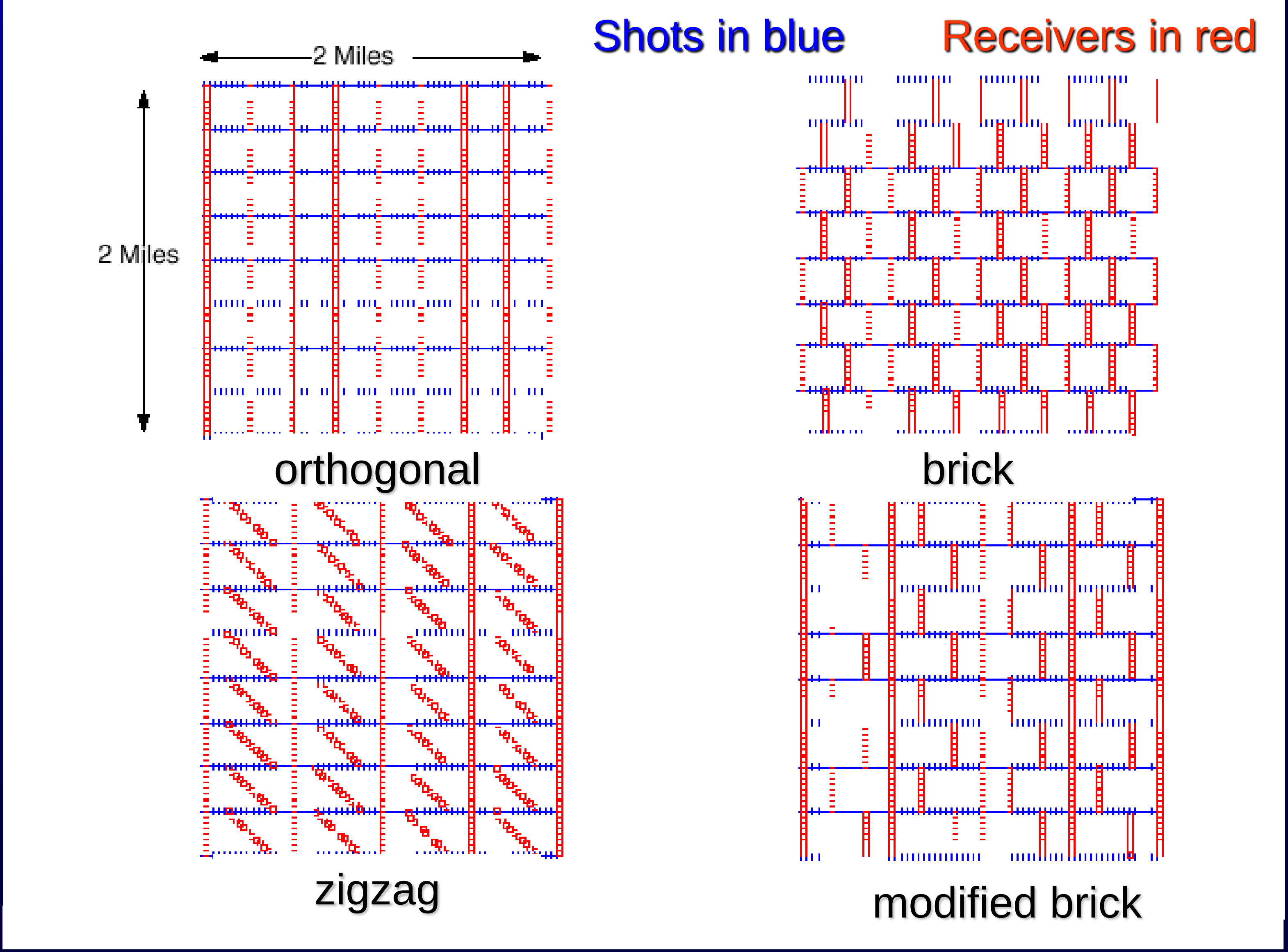


Decrease in fold due to 'obstacles'



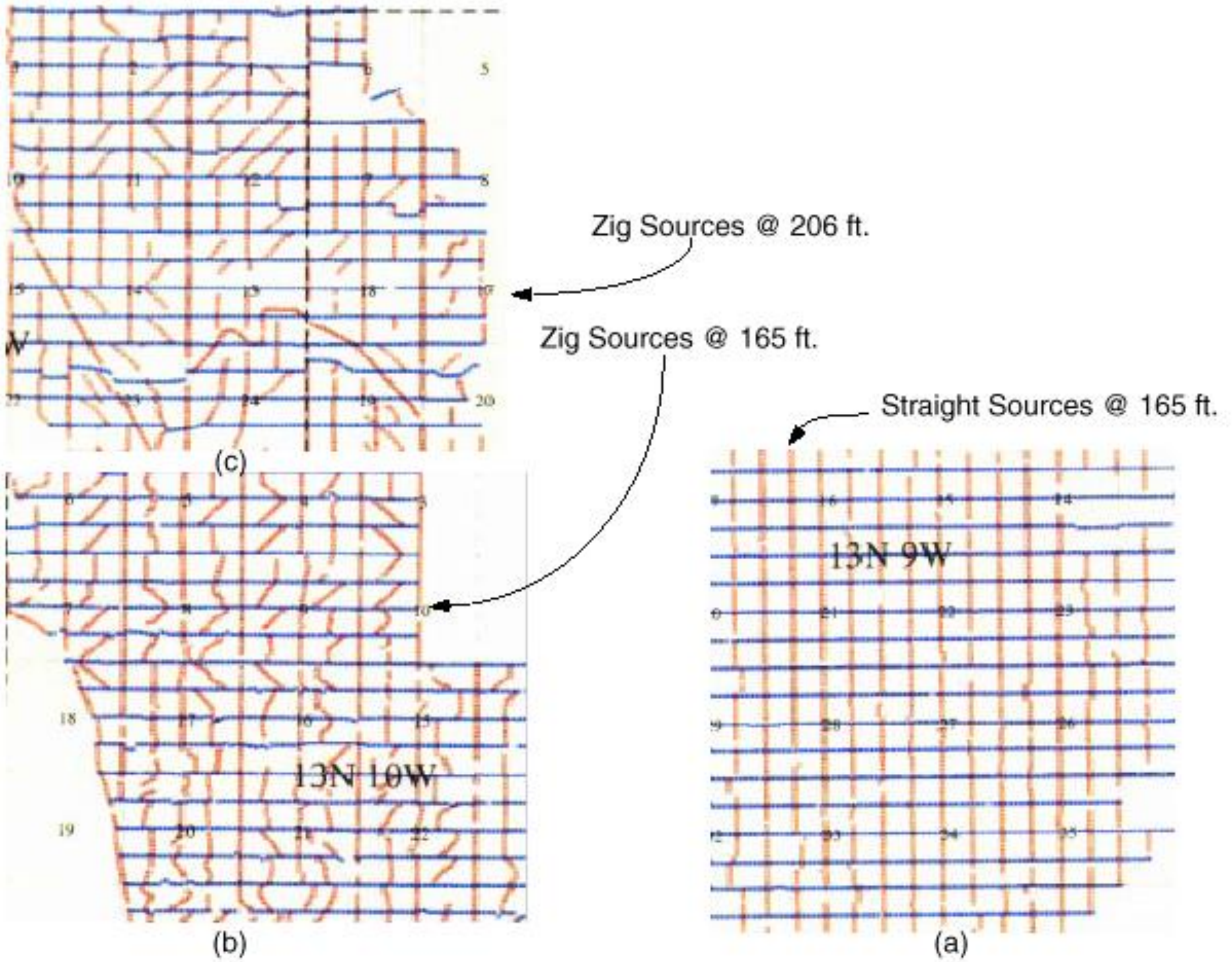
Time slice at 0.3 s

A analysis of alternative acquisition patterns



(Smith et al., 1998)

Acquisition design experiment



Zig Sources @ 206 ft.

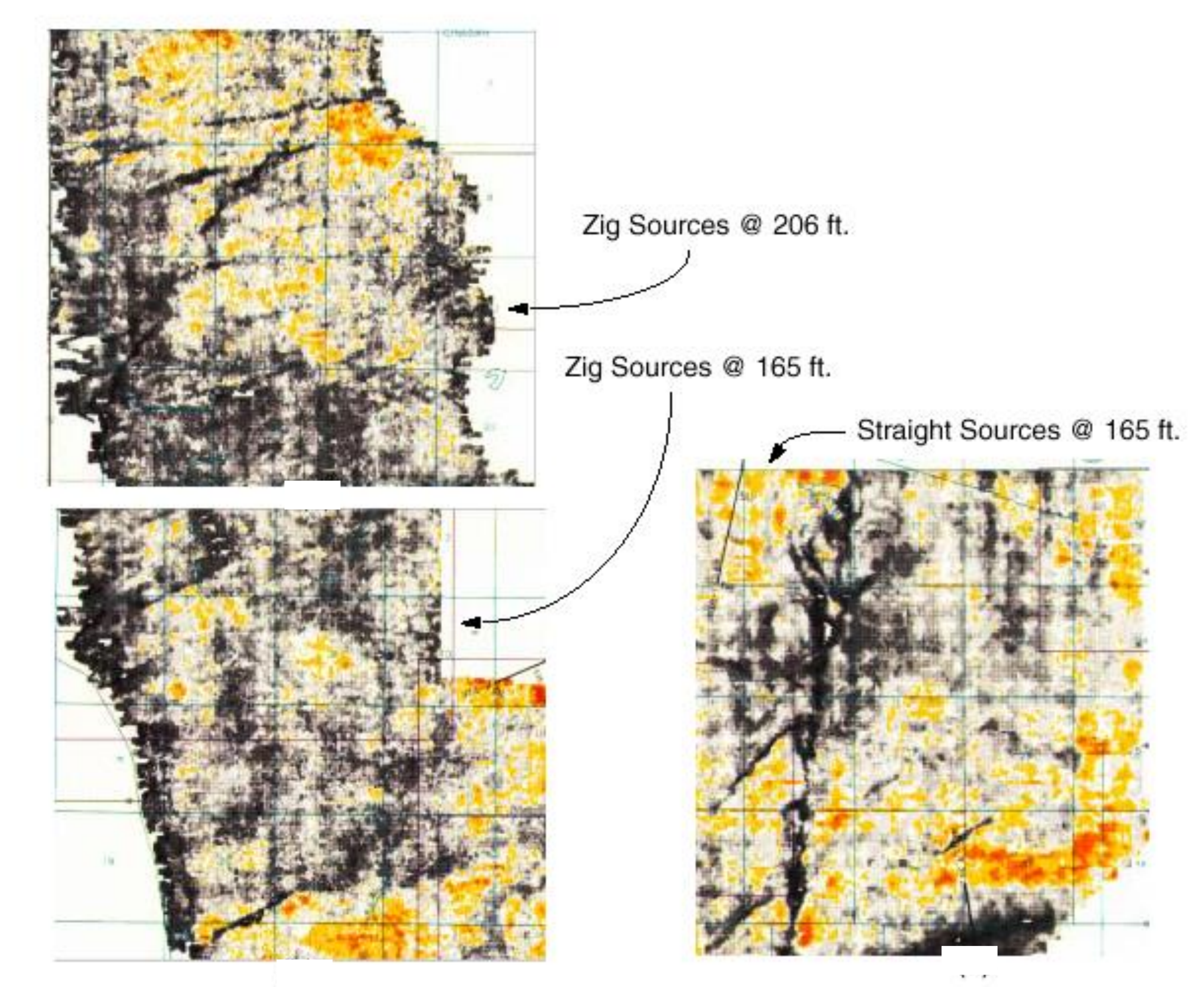
Zig Sources @ 165 ft.

Straight Sources @ 165 ft.

Figure 5. The designs used for the real acquisition are displayed. Shot location are in red, and receiver locations are in blue. A four-line recording patch was active for each shot.

(Smith et al., 1998)

Horizon slices through real data



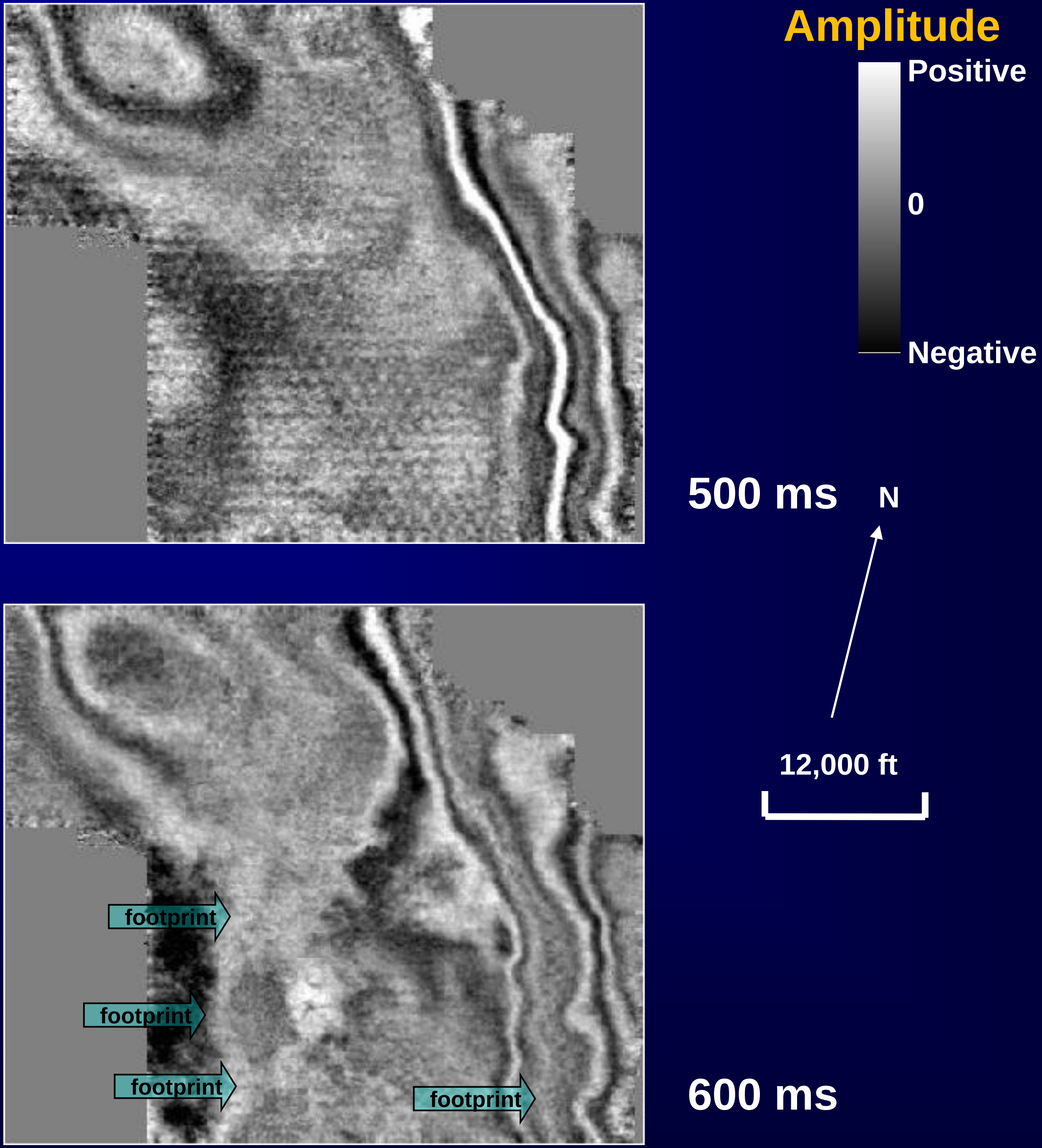
Zig Sources @ 206 ft.

Zig Sources @ 165 ft.

Straight Sources @ 165 ft.

(Smith et al., 1998)

Footprint seen on seismic amplitude volumes – Central Basin Platform, TX

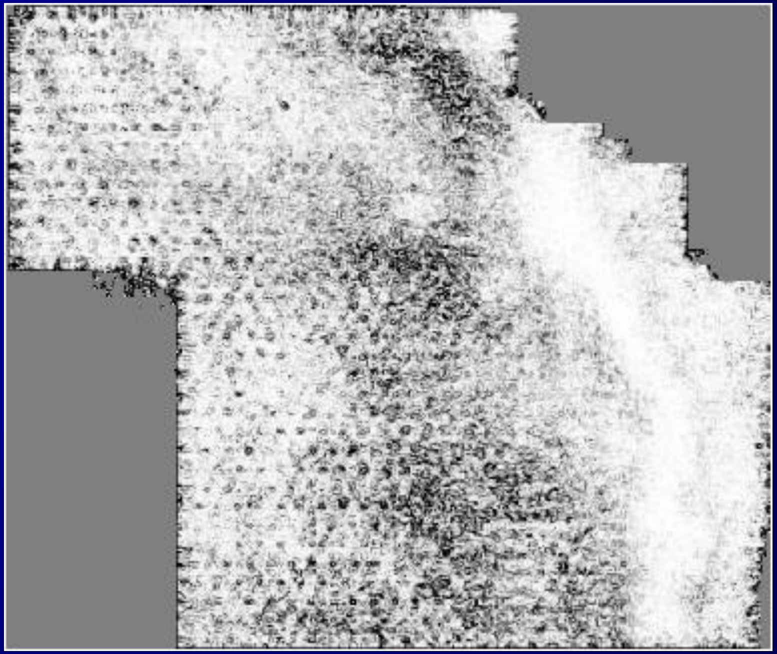


Footprint seen on seismic attribute volumes – Central Basin Platform, TX

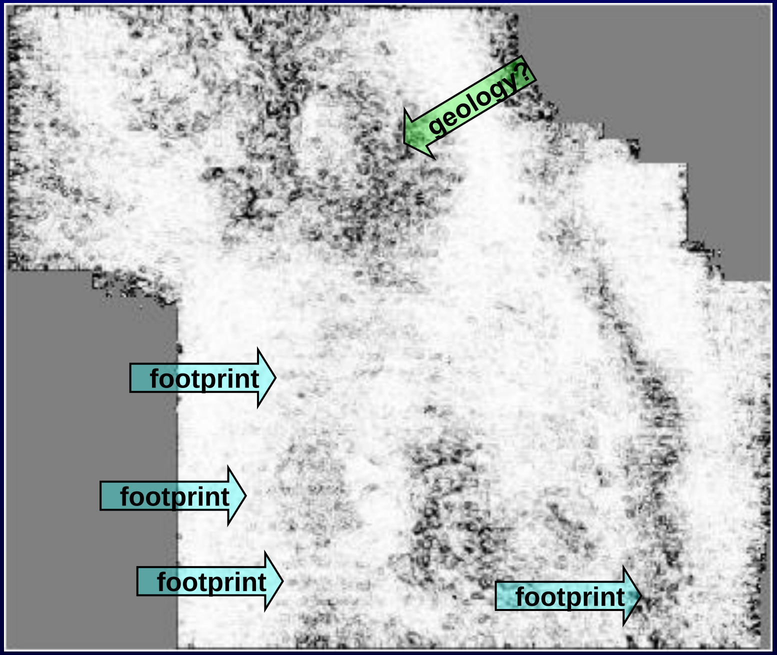
Sobel Attribute

High

Low



500 ms



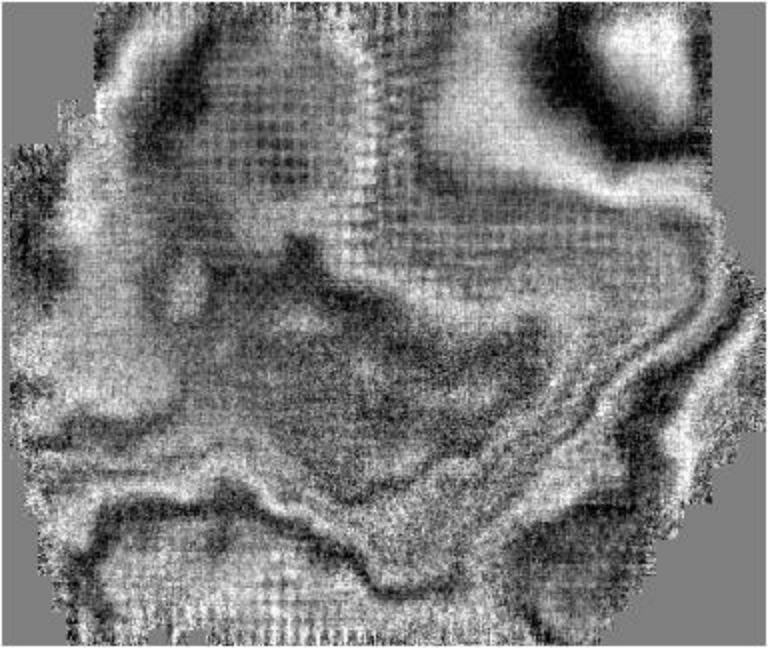
600 ms

N

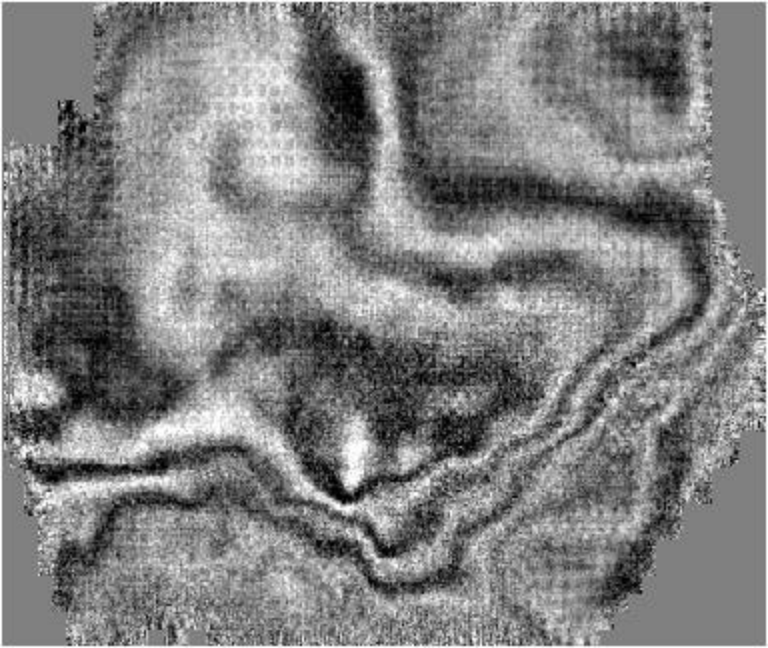
12,000 ft

Seismic time slices

Delaware Basin, NM

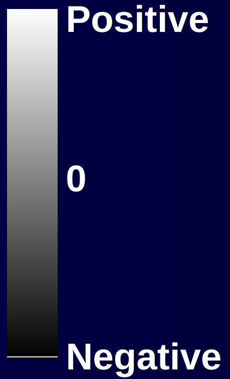


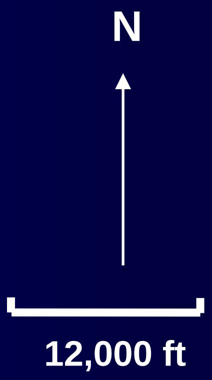
650 ms



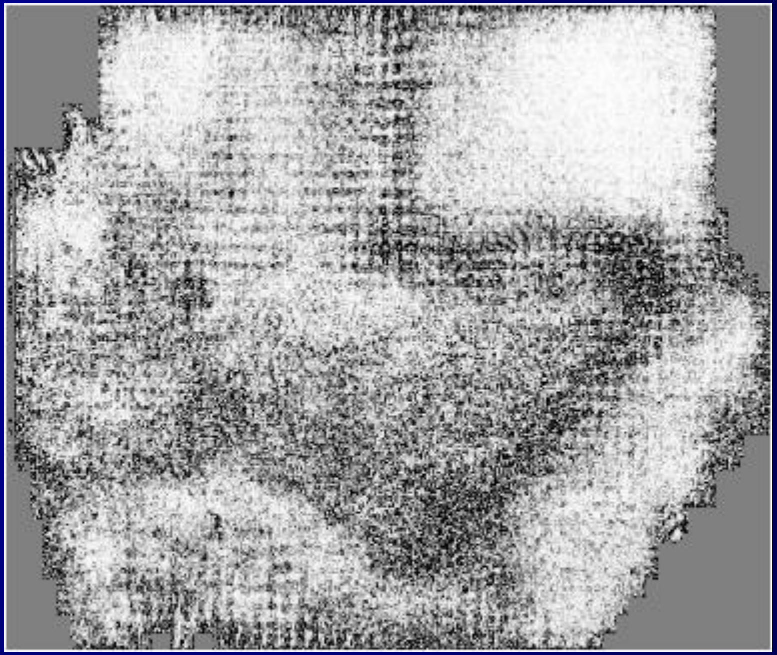
700 ms

Amplitude

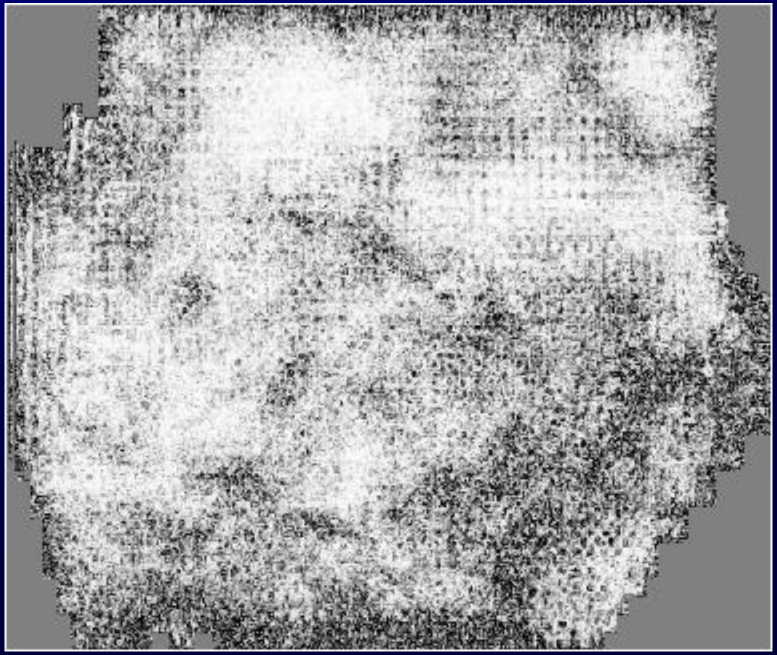




Sobel attribute

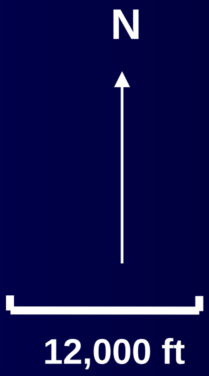


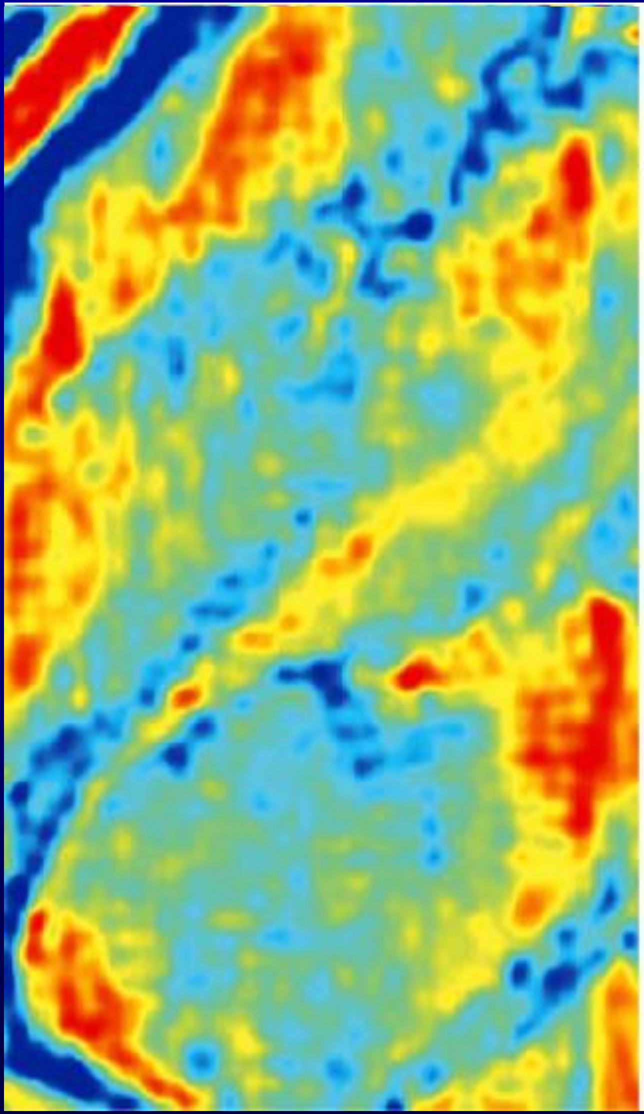
650 ms



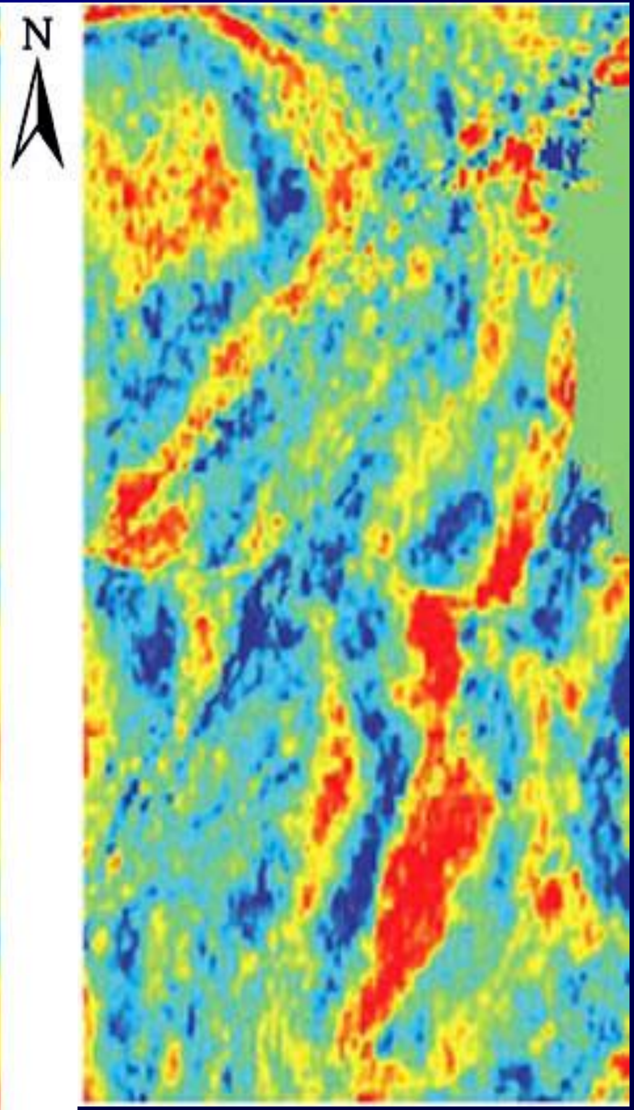
700 ms

Sobel Attribute





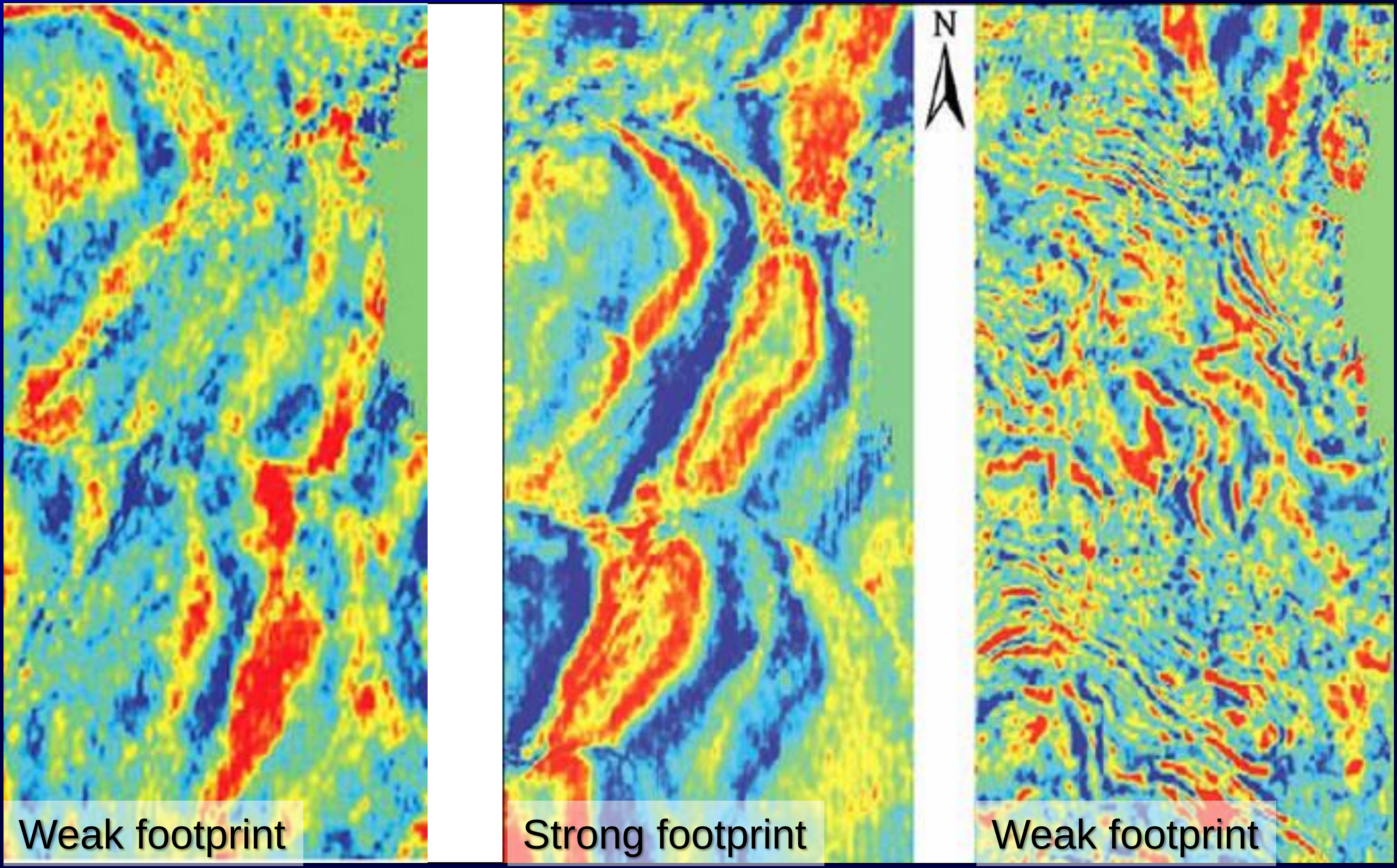
Orthogonal acquisition (after k_x-k_y filtering)



Mirrored zig-zag acquisition

(Sahai and Soofi, 2009)

Mirrored zig-zag acquisition



1020 ms 1200 ms 1550 ms

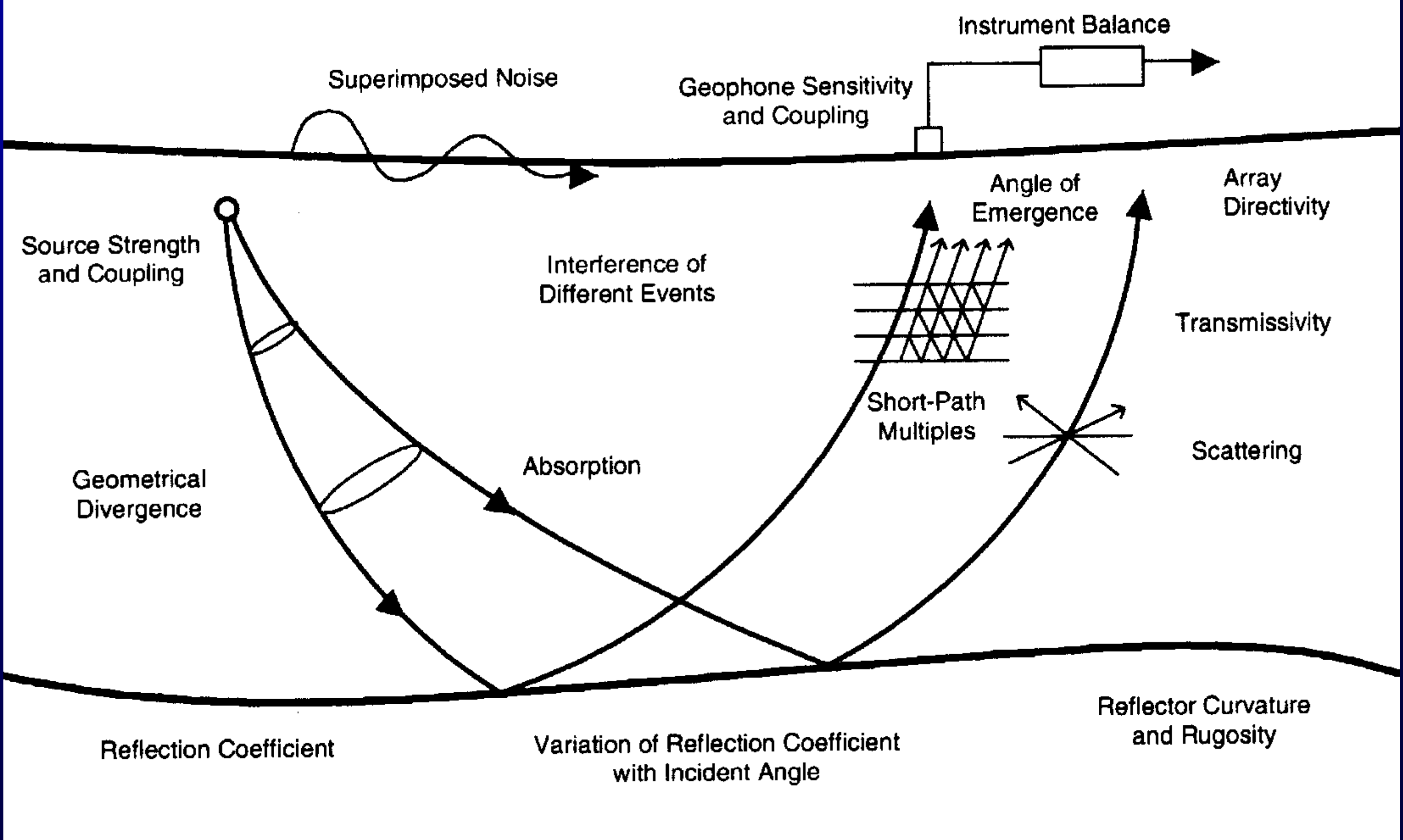
(Sahai and Soofi, 2009)

Seismic amplitude

Factors effecting seismic amplitudes

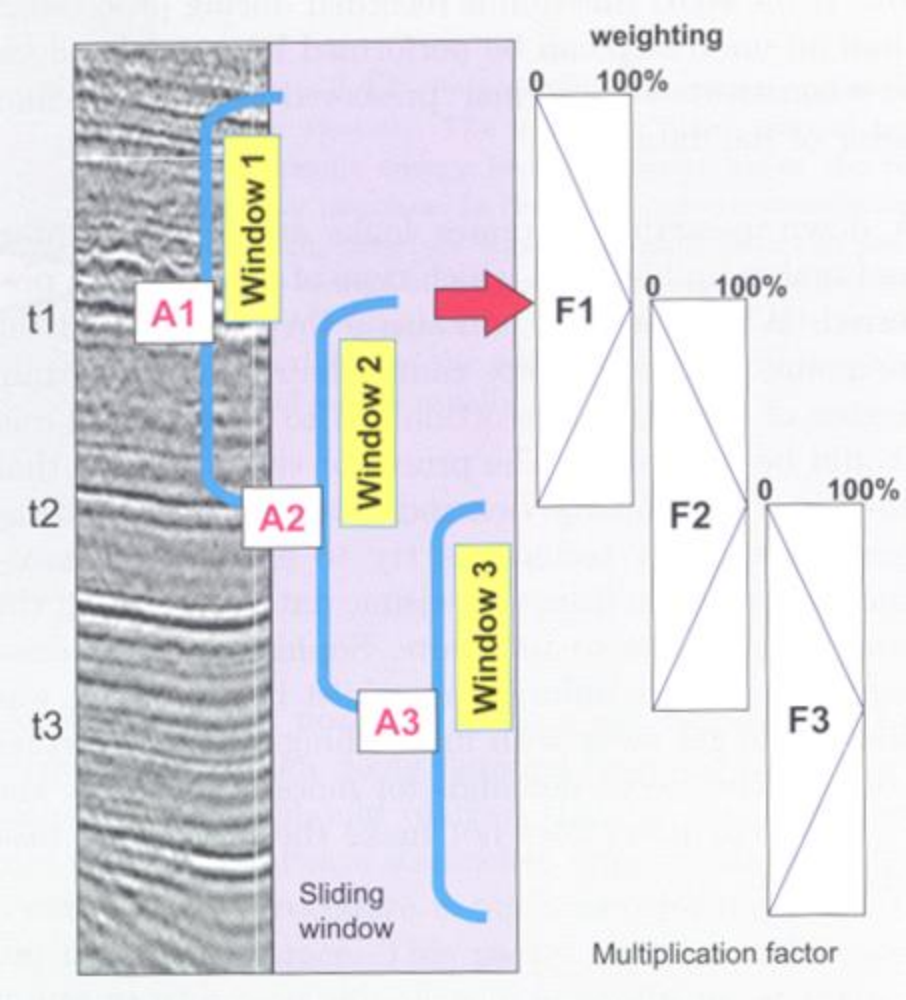
- source coupling
- receiver coupling
- source array directivity
- receiver array directivity
- intrinsic attenuation (Q)
- transmission loss due to reflections
- transmission loss due to scattering
- friendly multiples
- geometric spreading
- reflector curvature
- reflector specularity
- thin bed tuning
- effect of the overburden

Factors effecting seismic amplitudes



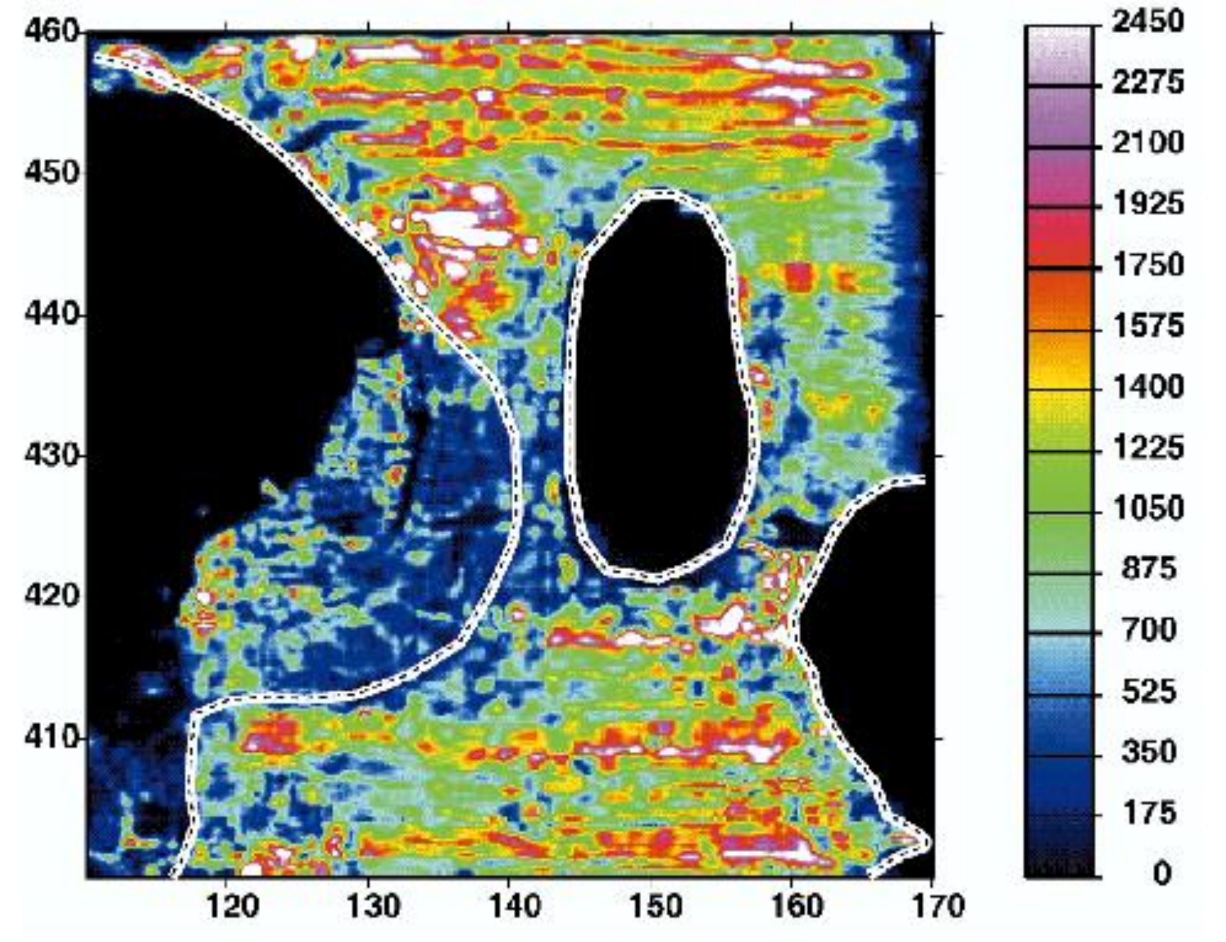
(Sheriff, 1975)

Statistical compensation for energy loss: Automatic gain control



(Veeken, 2007)

Subsurface illumination



Subsalt illumination using 3D ray tracing and a proposed survey design

(Bear et al. 2000)

Subsurface illumination

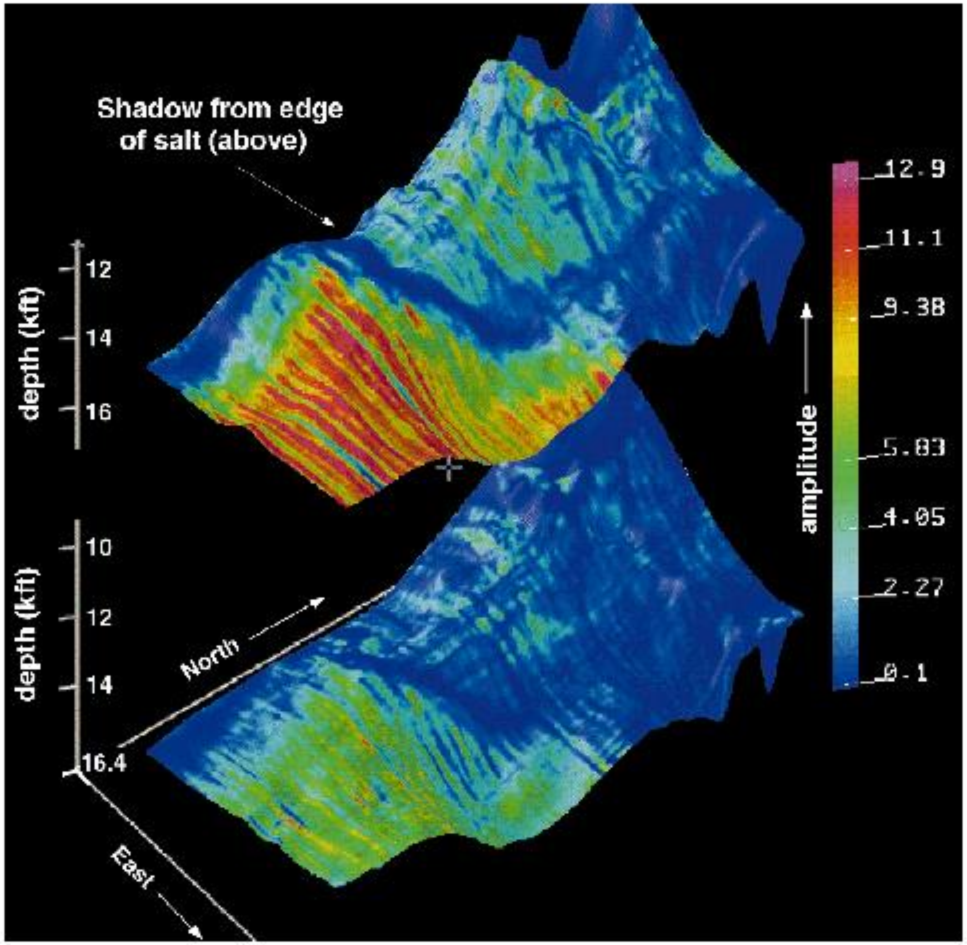


Figure 3. Modeled amplitude distributions on two subsurface (subsalt) horizons at Mica. These maps were constructed using the source and receiver locations from a previously collected 3-D survey in the region and indicate the illumination achieved by acquisition along east-west lines.

(Bear et al. 2000)

Subsurface illumination

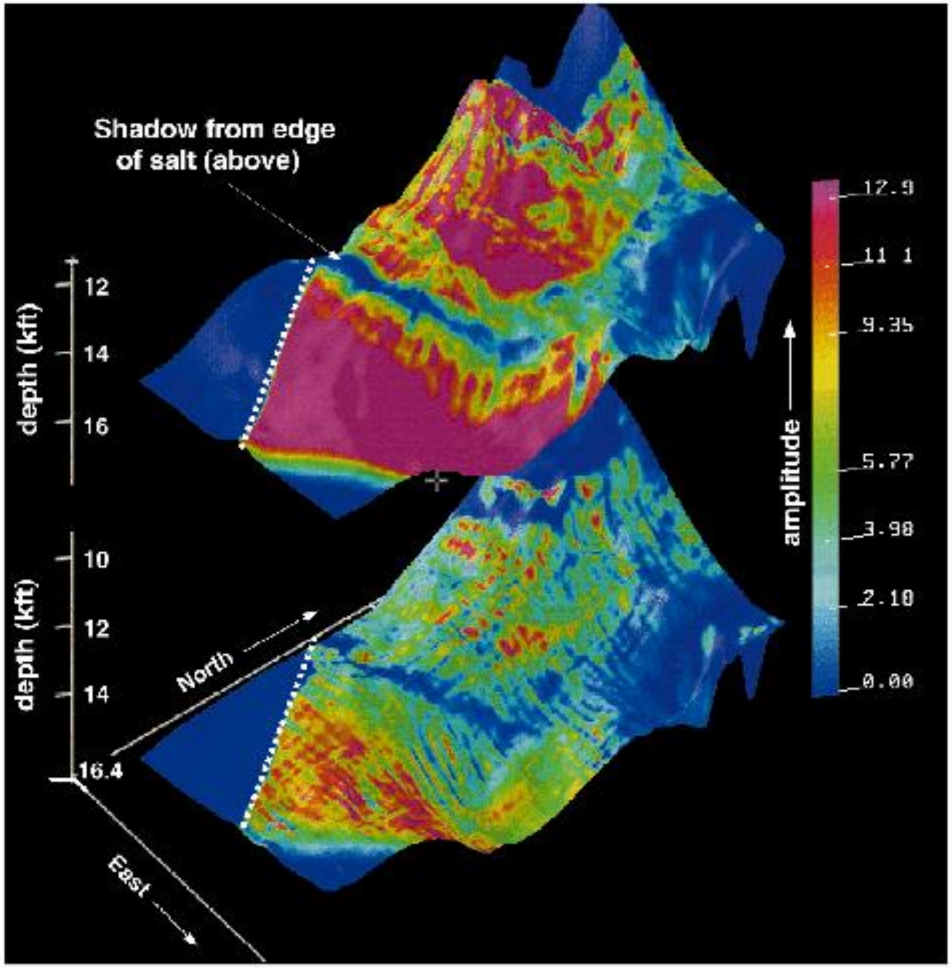


Figure 4. Modeled amplitude on two subsurface horizons at Mica. Here, we have simulated the amplitude that might be achieved by a 3-D survey with acquisition along lines oriented northwest-southeast. More energy appears to reach the subsalt horizons with acquisition in this direction. Dashed white lines indicate limit of proposed survey.

(Bear et al. 2000)

Summary

- Seismic sources are band limited – typically missing data below 8 Hz and above 80 Hz – thereby limiting our resolution

- Seismic sources are designed and seismic data are processed to generate zero phase reflections that will align with discrete changes in acoustic impedance

- The seismic reflection experiment measures *changes* in acoustic impedance
-
- Predicted seismic amplitudes can be modeled as the convolution of reflection coefficients with the source wavelet.

- Because of the differences in measuring pressure, acceleration, and particle velocity, the relationship of the sign of the measured seismic amplitude and the sign of the reflection coefficient may be unknown.

- Changes in fold and azimuth from bin to bin gives rise to acquisition footprint

- Measured seismic amplitudes depend on a mix of wave propagation and acquisition phenomena, including geometric spreading, scattering, interbed multiples, coupling, geophone array directivity, etc.