Reflection seismic Method - 2D

- Acoustic Impedance
- Seismic events
- Wavelets
- Convolutional model
- Resolution
- Stacking and Signal/Noise
- Data orders

- Reading:
  - Sheriff and Geldart, Chapters 6, 8

Acoustic Impedance

What we image in reflection sections

- At *near-vertical* incidence:
  - *P*-to-*S*-wave conversions are negligible;
  - *P*-wave reflection and transmission *amplitudes* are sensitive to *acoustic impedance* ($Z=\rho V$) contrasts:

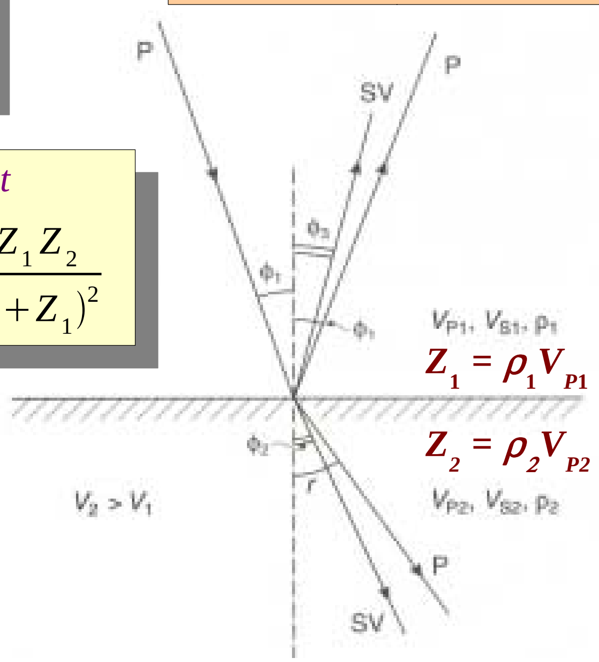
P-wave Reflection Coefficient

$$R_{PP}=\frac{A_{P_{reflected}}}{A_{P_{incident}}}=\frac{Z_2-Z_1}{Z_2+Z_1}$$

Note: if $Z_2 < Z_1$, $R<0$.
This means *polarity reversal* upon reflection

P-wave Transmission Coefficient

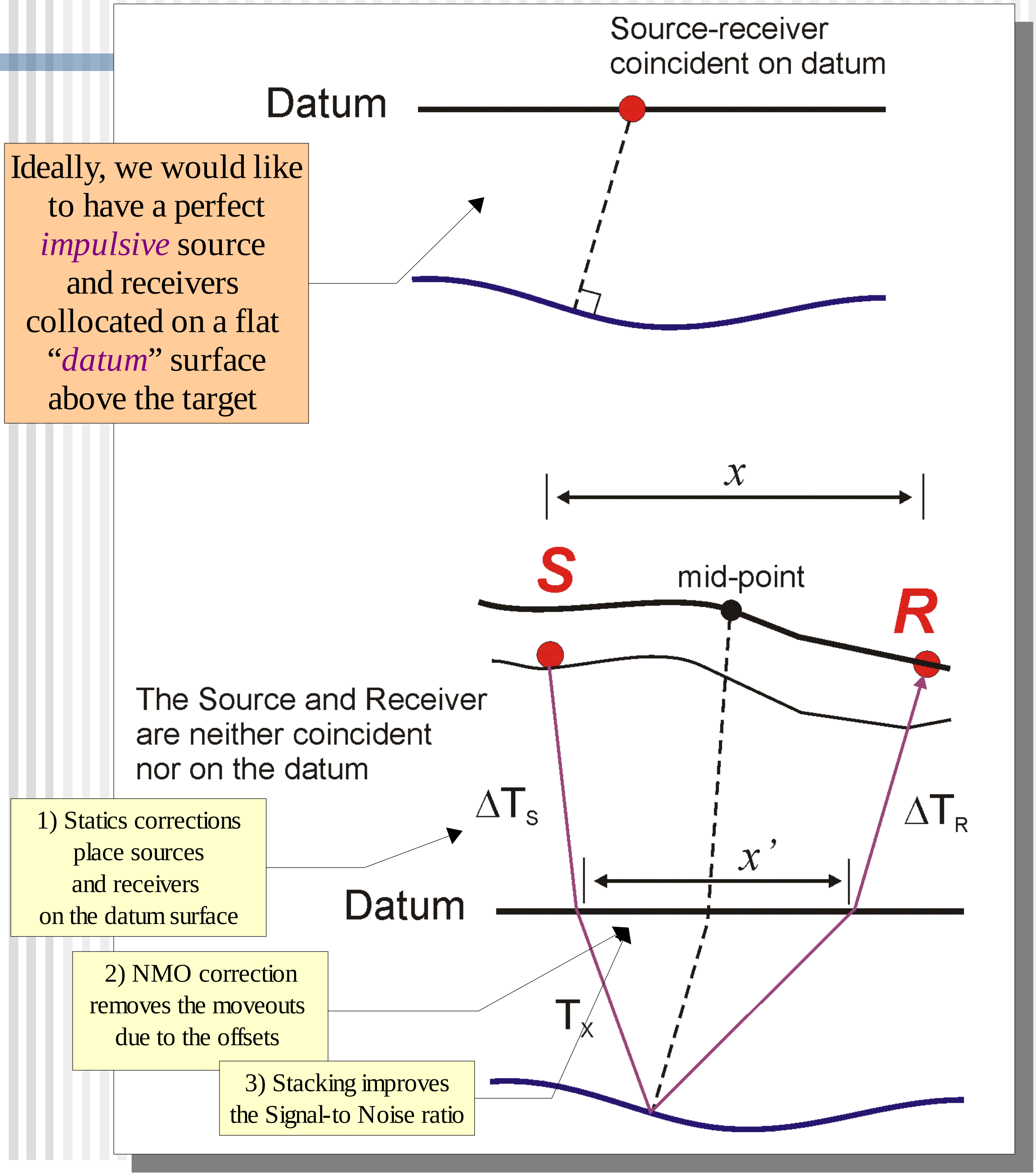
$$T_{PP}^2\equiv\left(\frac{A_{P_{refracted}}}{A_{P_{incident}}}\right)^2=1-R_{PP}^2=\frac{4Z_1Z_2}{(Z_2+Z_1)^2}$$



- *P*- and *S*-wave *reflection* amplitudes *increase with incidence angle.*

Zero-Offset Section

the objective of pre-migration processing

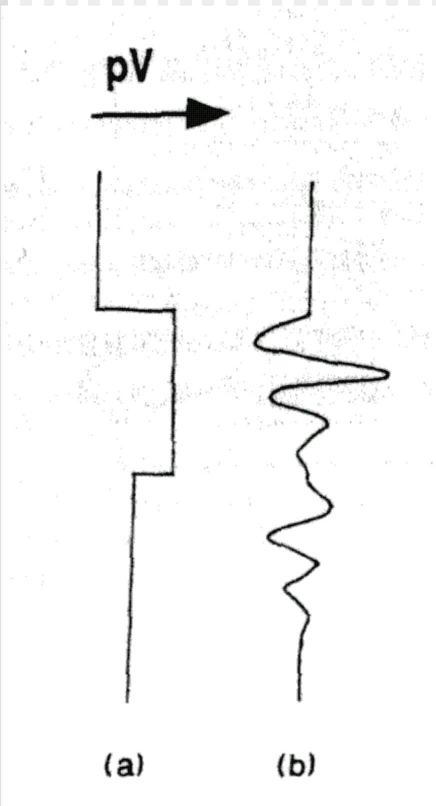


Reflection imaging

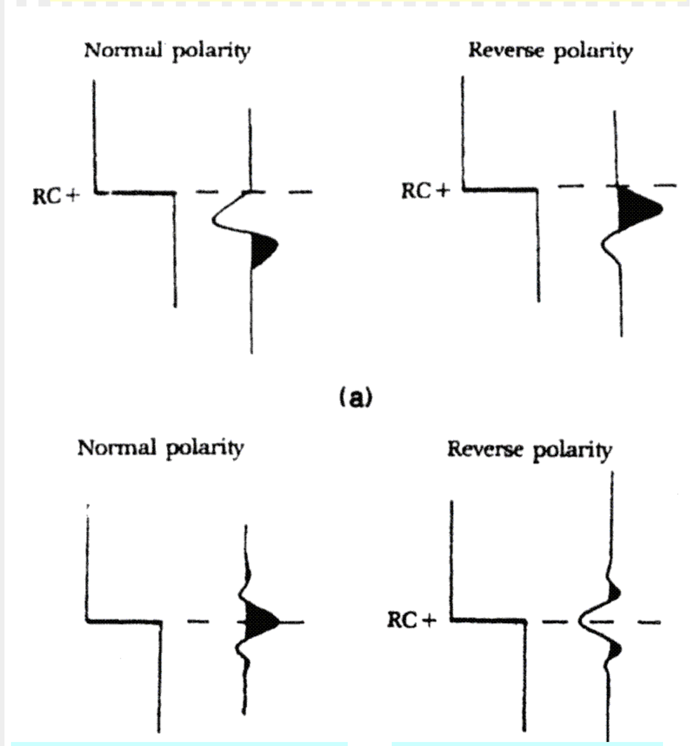
- Multi-offset data are transformed into a *zero-offset section*:
  - Statics place sources and receivers on a flat reference (datum) surface;
  - Deconvolution compresses the wavelet into a “spike” and attenuates “short-period” multiples;
  - Filtering attenuates noise and other multiples.
- *Migration* transforms the zero-offset section into a depth image

Wavelets

- Impedance contrasts are assumed to be sharp, yet the wavelet always imposes its signature on the record



Standard polarity convention



"Minimum-phase" wavelet

"Zero-phase" wavelet

Minimum-, maximum-, and zero-phase wavelets
Key facts

- Consider a wavelet consisting of two spikes: $w=(1,a)$:
  - For $|a| < 1$, it is called *minimum-phase*;
  - For $|a| > 1$, it is *maximum-phase*;
  - Note that its *z*-transform is $W(z)=1+az$, *and* $1/W(z)$ represents a convergent series near $z=0$. This means that there exists a filter that could convert the wavelet into a spike.
- A convolution of all minimum- (maximum-) phase wavelets is also a minimum- (maximum-) phase wavelet:

$$W(z)=\prod_{i=0}^{N}\left(1+a_i z\right)$$

- When minimum- and maximum-phase factors are intermixed in the convolution, the wavelet is called *mixed-phase.*
- Minimum- (maximum-) phase wavelets have the fastest (slowest) rate of energy build-up with time
- Minimum-phase wavelets are associated with *causal* processes.

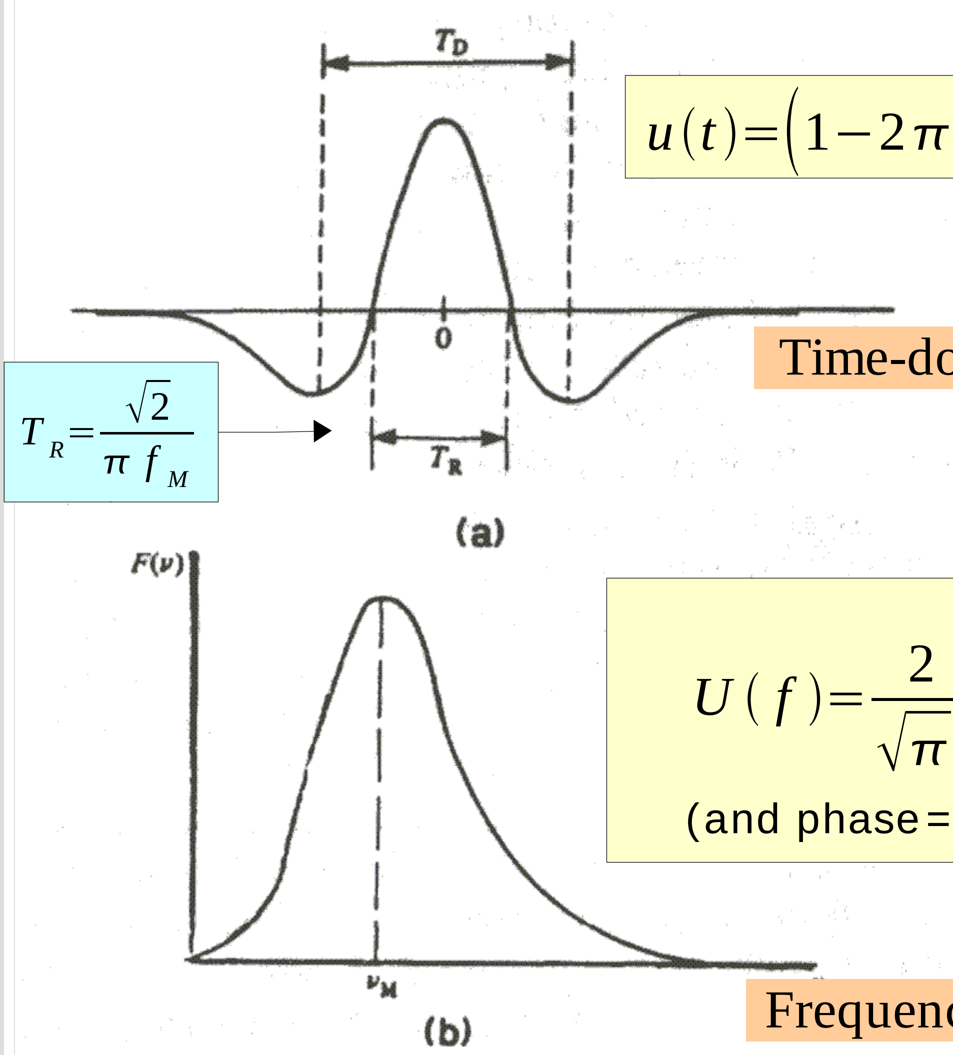
Ricker wavelet

- A common zero-phase wavelet (Ricker):

  (f_M is the *peak frequency*)

$$u(t) = \left(1 - 2\pi^2 f_M^2 t^2\right) e^{-(\pi f_M t)^2}$$

$$T_R = \frac{\sqrt{2}}{\pi f_M}$$



Time-domain

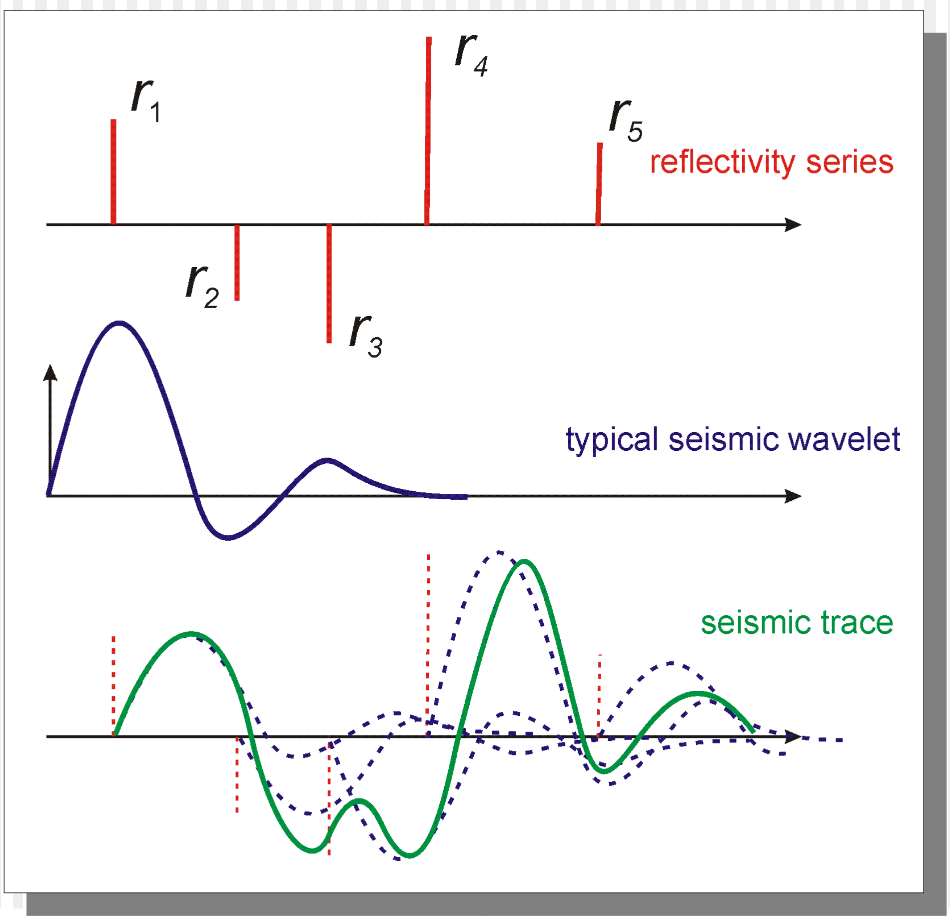
$$U(f) = \frac{2 f^2}{\sqrt{\pi} f_M^2} e^{-\left(\frac{f}{f_M}\right)^2}$$

(and phase=0)

Frequency-domain

Convolutional model

- Reflection seismic trace is a convolution of the source wavelet with the Earth's 'reflectivity series'
- The reflectivity series includes:
  - primary reflections;
  - multiples.



Convolution

- Mathematically, convolution of two time series, u_i, and w_i, denoted $u*w$, is:

$$(u*w)_k = \sum_i u_{k-i} w_i$$

- In *Z* or *frequency* domains, convolution becomes simple multiplication of polynomials (show this!):

$$u*w \leftrightarrow Z(u)Z(w) \leftrightarrow F(u)F(w)$$

- This is the key property facilitating efficient digital filtering.
- As multiplication, it is symmetric (commutative):

$$u*w = w*u$$

Convolutional model

Calibration of the section using logs

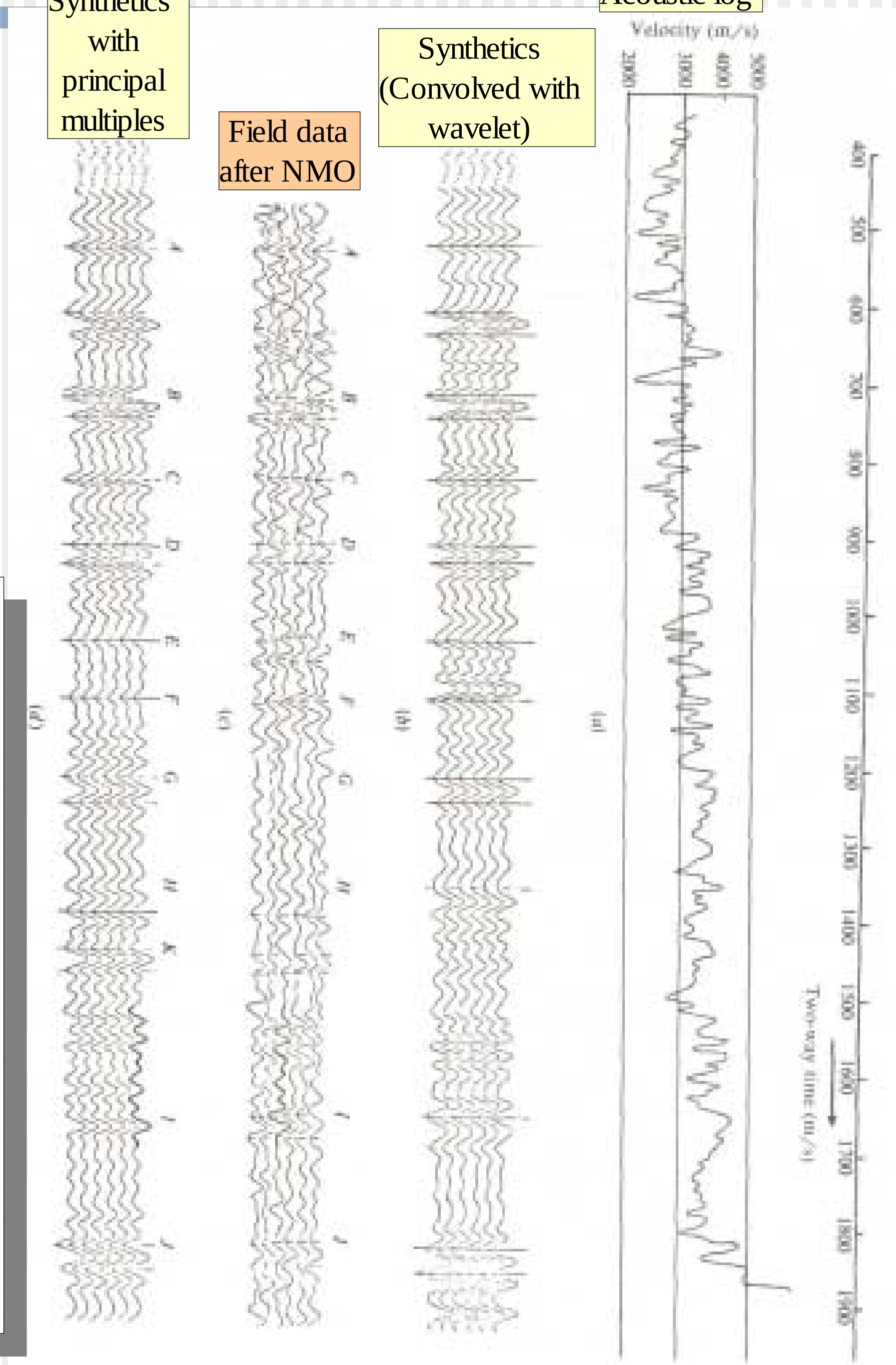
Proceed

Synthetics with principal multiples

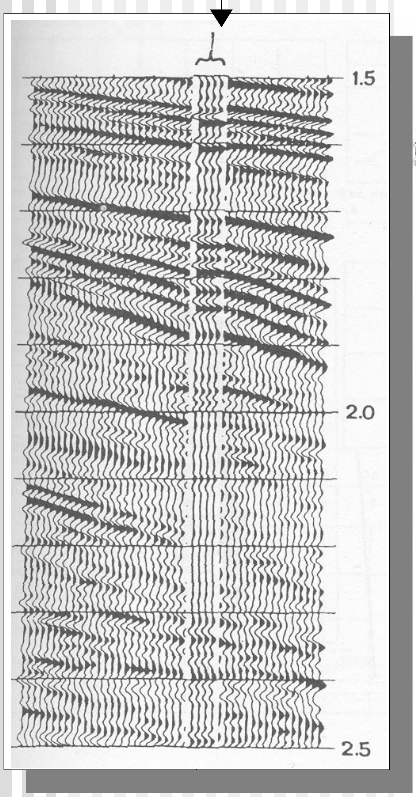
Field data after NMO

Synthetics (Convolved with wavelet)

Acoustic log

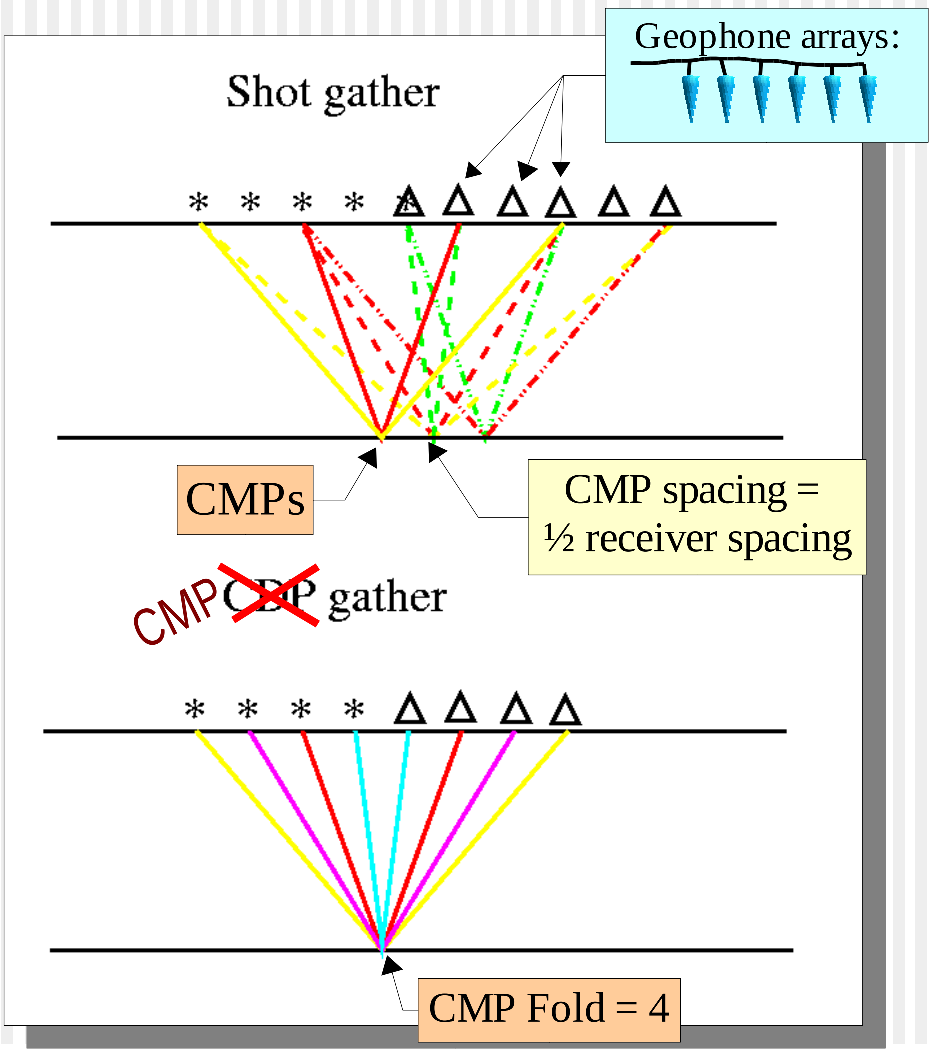


Synthetics is spliced into CMP section for comparison



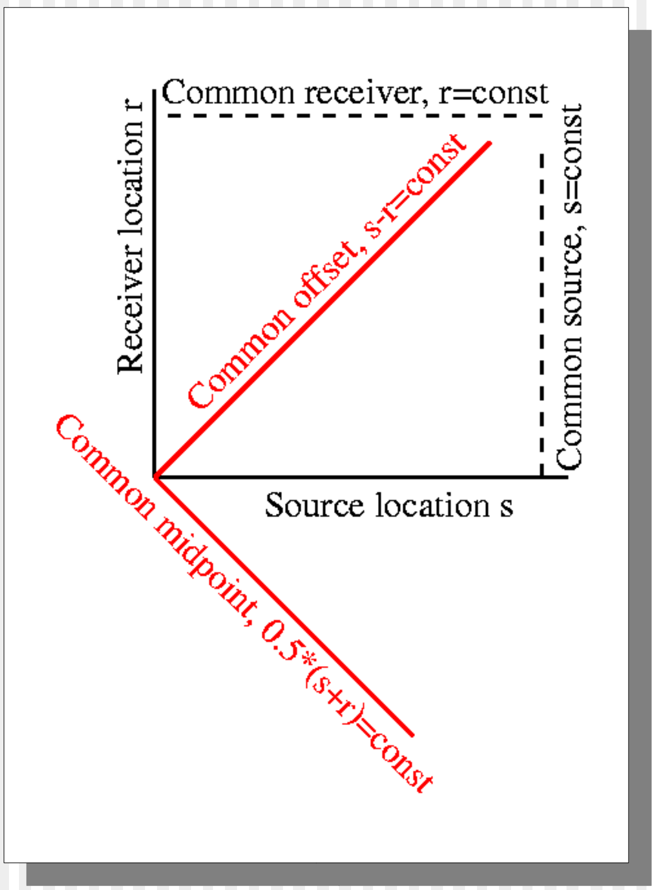
Shot (field) and Common-Midpoint (image) sort orders

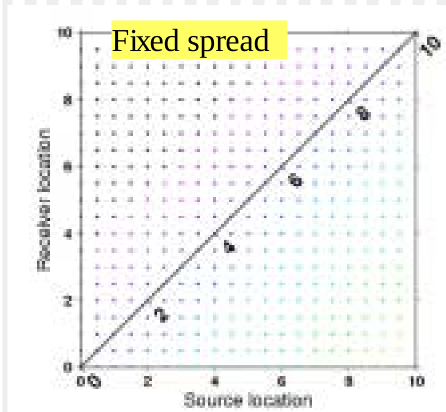
- Common-Midpoint reflection imaging:
  - Helps in reduction of random noise and multiples via *redundant coverage* of the subsurface;
  - Provides offset coverage for Amplitude-vs. Offset (AVO) analysis

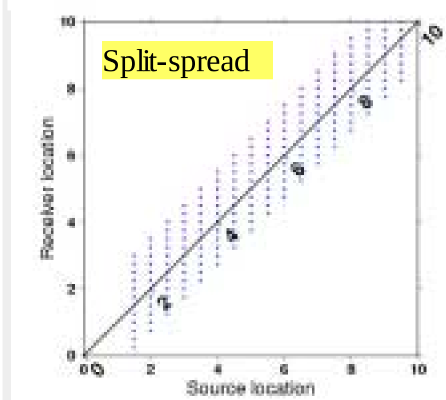


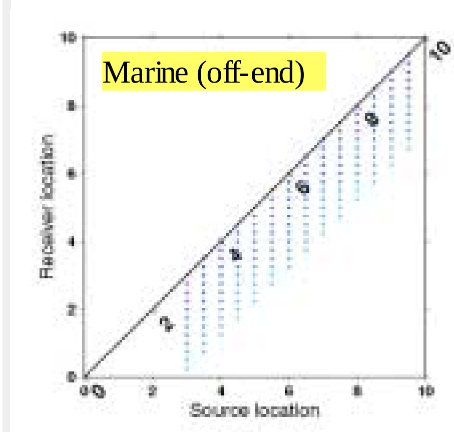
Stacking chart

- Visualization of 2D source-receiver geometry





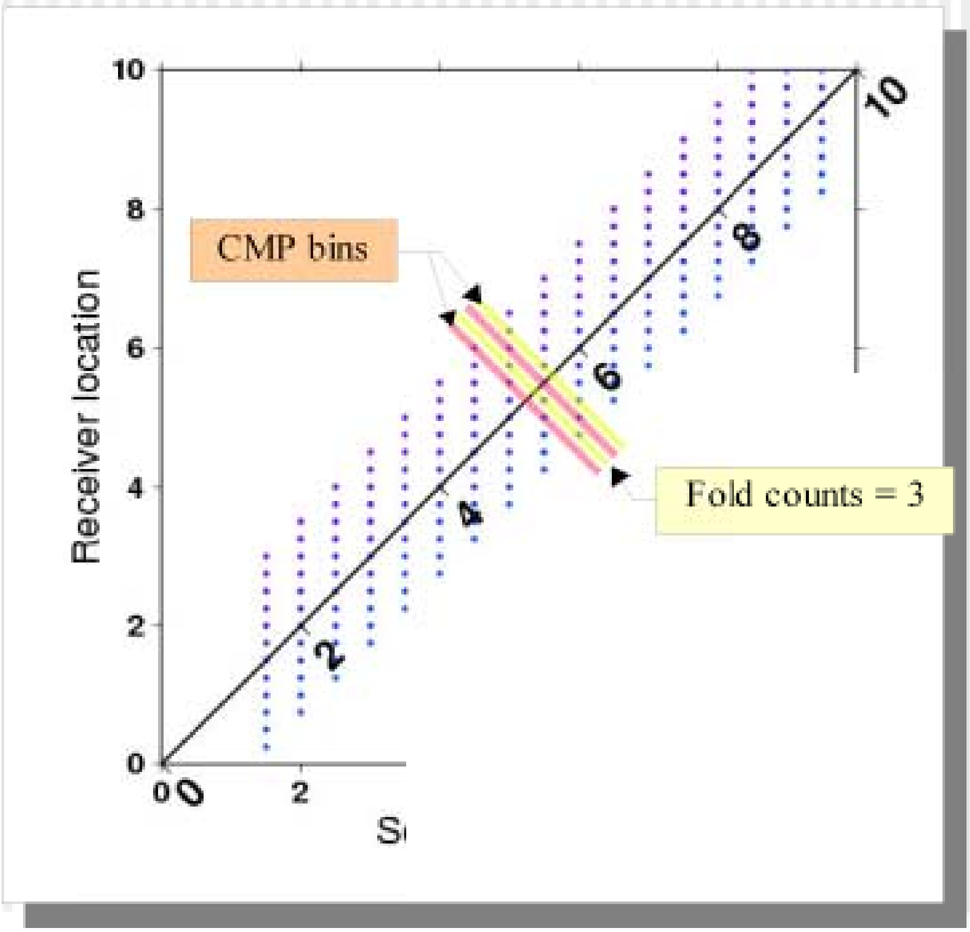




CMP Fold

- Fold is the Number of records per CMP
  - Should be optimal (typically, 10-40);
  - Should be uniform (this is particularly an issue with 3D).

$$Fold = \frac{Number\ of\ recording\ channels}{2\left(Num.\ of\ Shot\ Point\ advances\ by\ Receiver\ spacing\right)}$$



Stacking

- In order to suppress *incoherent noise*, stacking is commonly employed
  - *Vertical stacking* – summation of the records from multilke shots at the same locations.
  - *CMP stacking* – summation of multiple NMO-corrected records corresponding to the same midpoint.

$$u_i = S + n_i$$

$$\sum u_i = NS + \sum n_i$$

Mean noise power (variance)

$$Noise^2 = \left(\sum u_i^2 - NS\right)^2 = \left(\sum n_i\right)^2 = \sum n_i^2 = N\sigma_n$$

$$\frac{Signal}{Noise} = \frac{NS}{\sqrt{N\sigma_n}} = \sqrt{N}\frac{S}{\sigma_n}.$$

- Thus, stacking of *N* traces reduces the incoherent noise by a factor of $\sqrt{N}$

Spatial resolution

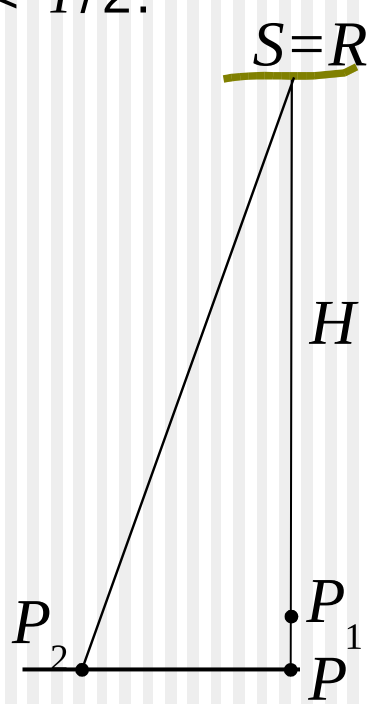
- Resolution is limited by the dominant wavelength of reflected signal.
- Two points are considered *unresolvable* when their reflection travel times are separated by less than *half the dominant period* of the signal: $\delta t < T/2$.
- Therefore,
  - vertical resolution:

$$\delta z = PP_1 = \frac{\lambda}{4}.$$

  - horizontal resolution:

$$\delta x = PP_2 = \sqrt{\left(H + \frac{\lambda}{4}\right)^2 - H^2} \approx \sqrt{\frac{1}{2} H \lambda}.$$

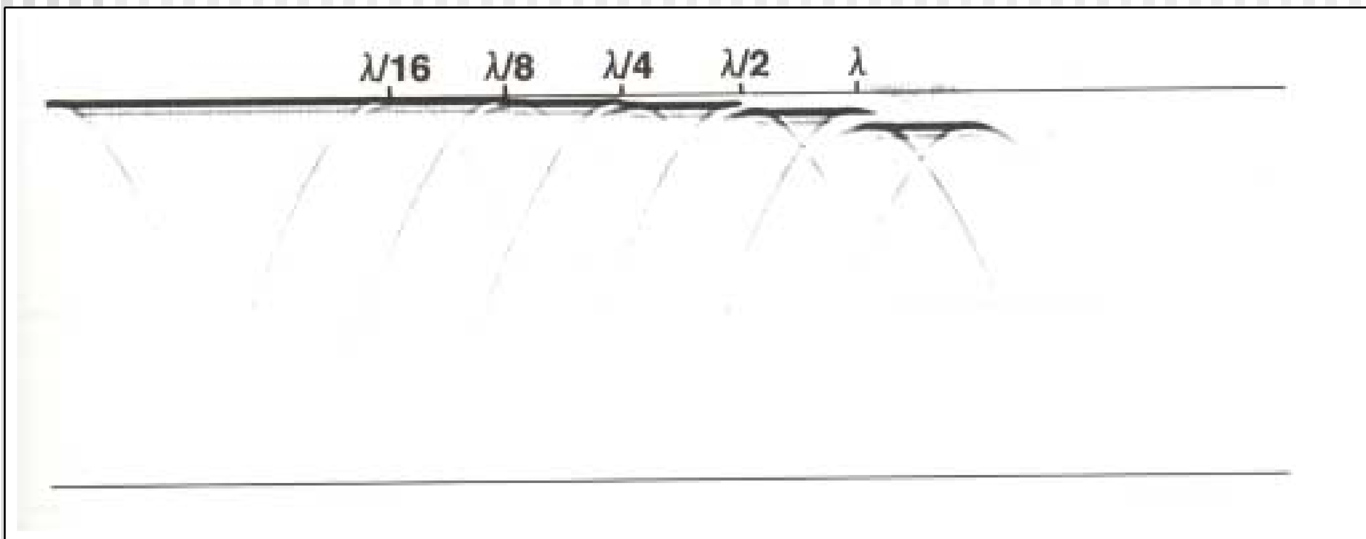
This is called the *Fresnel Zone* radius



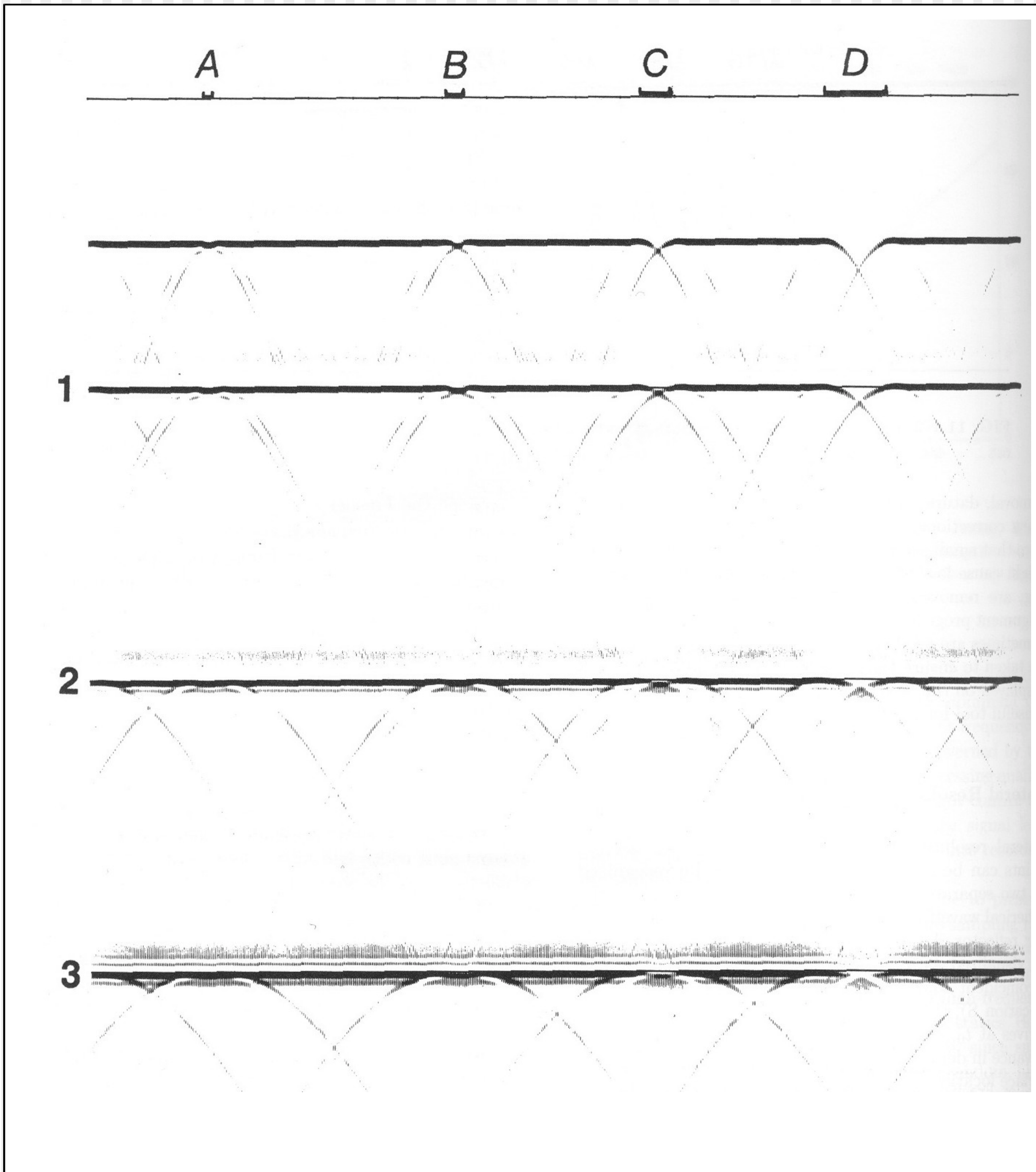
- Note that the *resolution decreases with depth* as a result of 1) increasing *H*; 2) attenuation

Vertical resolution

- $\lambda/4$ is generally considered the vertical resolution limit
- Example: Faults with different amounts of vertical throws, compared to the dominant wavelength:



Horizontal resolution



Subsurface sampling

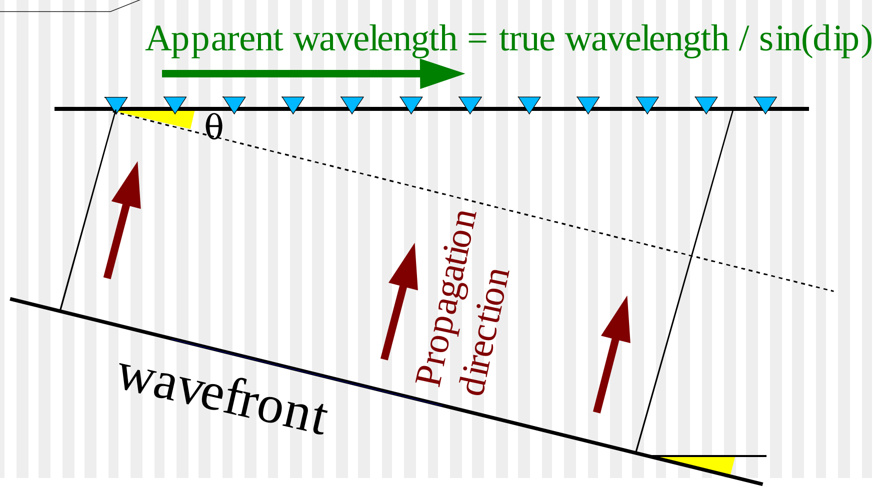
- Seismic surreys are designed with some knowledge of geology and with specific targets in mind:
  - Limiting factors: velocities, depths, frequencies (thin beds)
- Maximum allowable geophone spacing in order to record reflections from dipping interfaces

$$\mathit{Geophone\ Spacing}_{max} < \frac{\lambda_{apparent}}{2} = \frac{\lambda_{min}}{2 \sin\theta} = \frac{V_{min}}{2 f_{max} \sin\theta}$$

- The same, in terms of moveout ($\sin\theta$ = tan *moveout*):

$$\mathit{Geophone\ Spacing}_{max} < \frac{V_{min}}{2 f_{max} \frac{dt}{dx}}$$

More conservatively, this factor is usually taken = 4



Voxel
(Elementary cell of seismic volume)

- “Voxel” is determined by the spatial and time sampling of the data
  - For a typical time sampling of 2 ms (3 m two-way at 3000 m/s), it is typically 3 by 15 m^2 in 2D;
  - 3 by 15 by 25 m^3 in 3D.
- For a properly designed survey, voxel represents the smallest potentially resolvable volume
  - Note that the Fresnel zone limitation is partially removed by *migration* where sufficiently broad reflection aperture is available.
  - Migration is essentially summation of the amplitudes over the Fresnel zones that collapses them laterally.
  - Migration is particularly important and successful in 3D.