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:

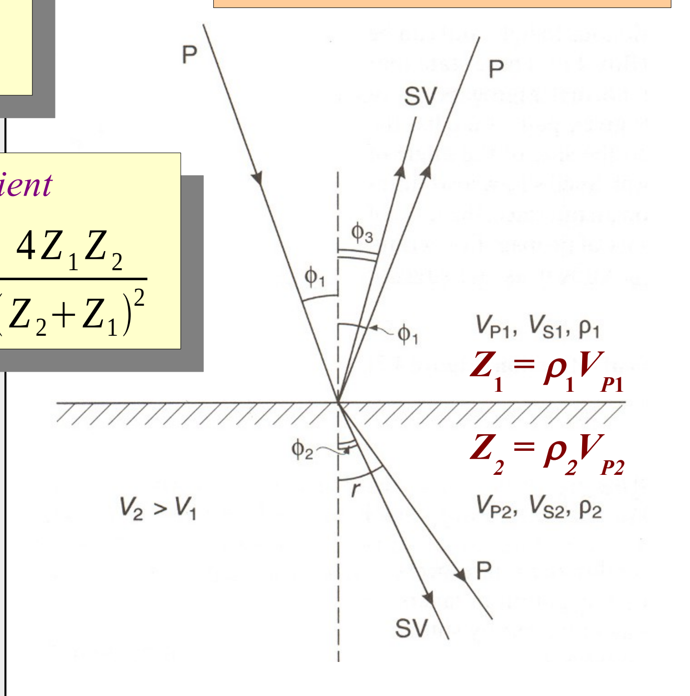
Note: if $Z_2 < Z_1$, $R<0$.
This means *polarity reversal* upon reflection

P-wave Reflection Coefficient

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

P-wave Transmission Coefficient

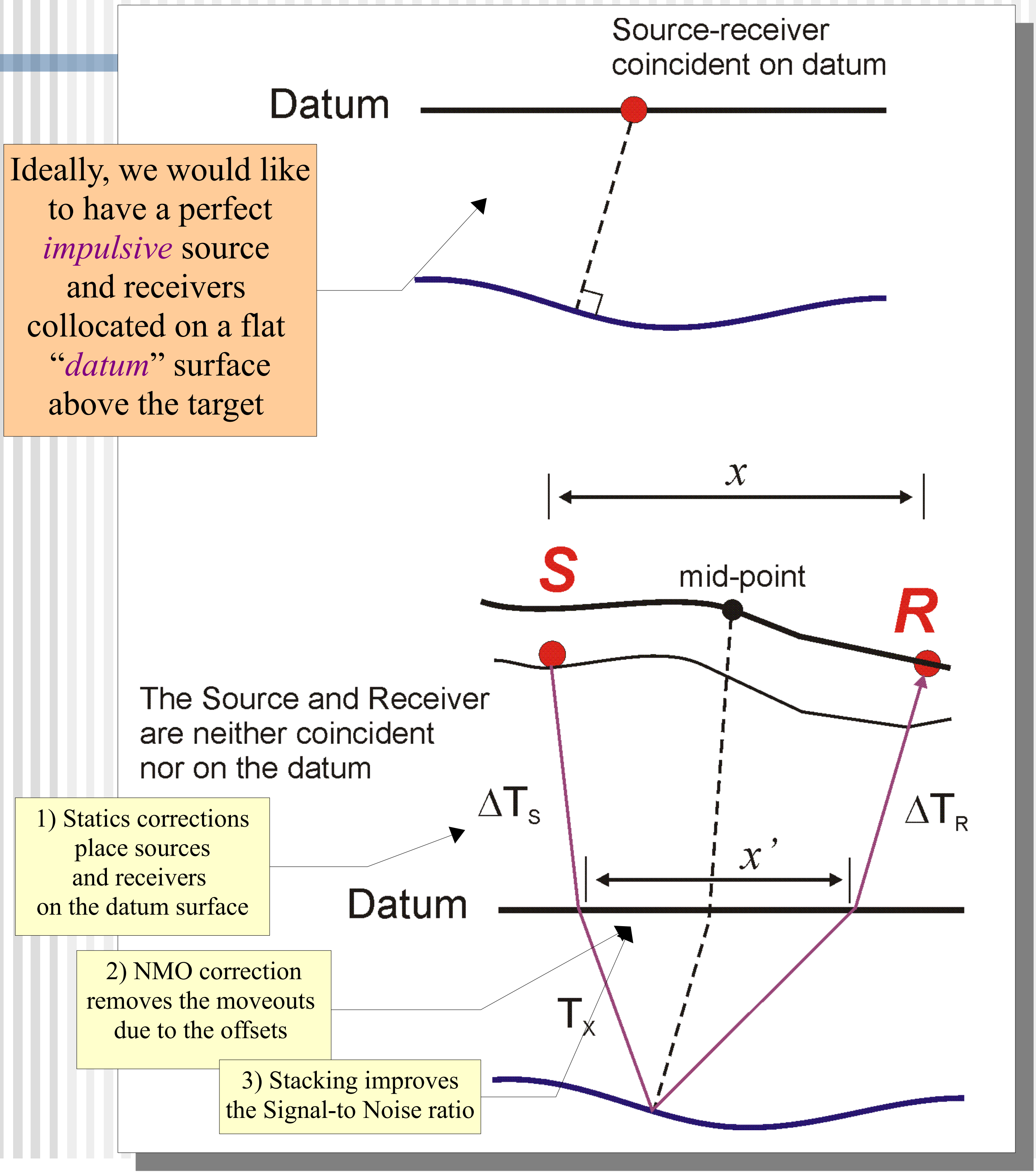
$$T_{PP}^2\equiv\left(\frac{A_{P_{refracted}}}{A_{P_{incident}}}\right)^2=1-R_{PP}^2=\frac{4Z_1Z_2}{(Z_2+Z_1)^2}$$



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

Zero-Offset Section

the objective of pre-migration processing



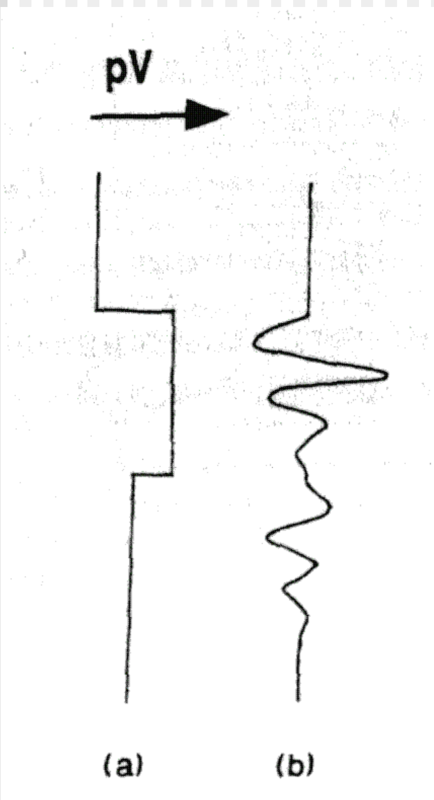
Reflection imaging

- 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

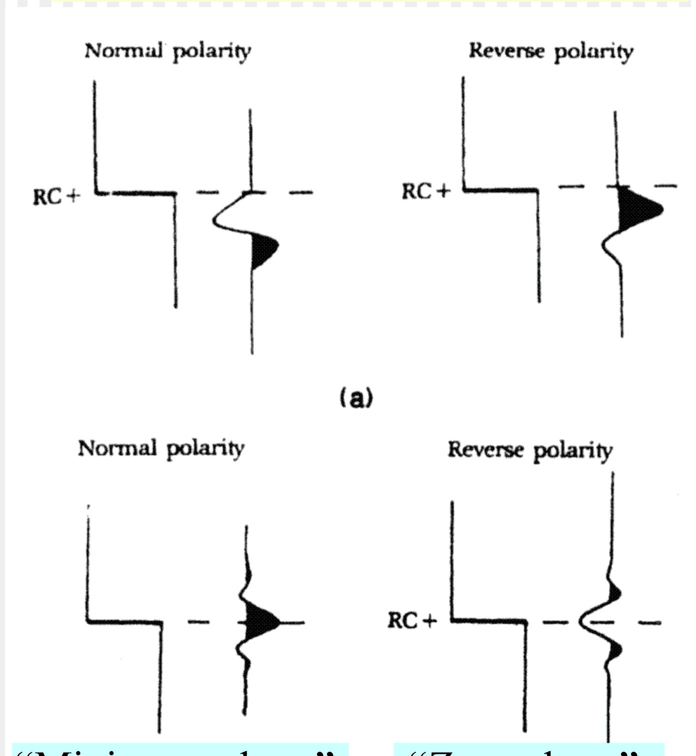
New!

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

New!

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

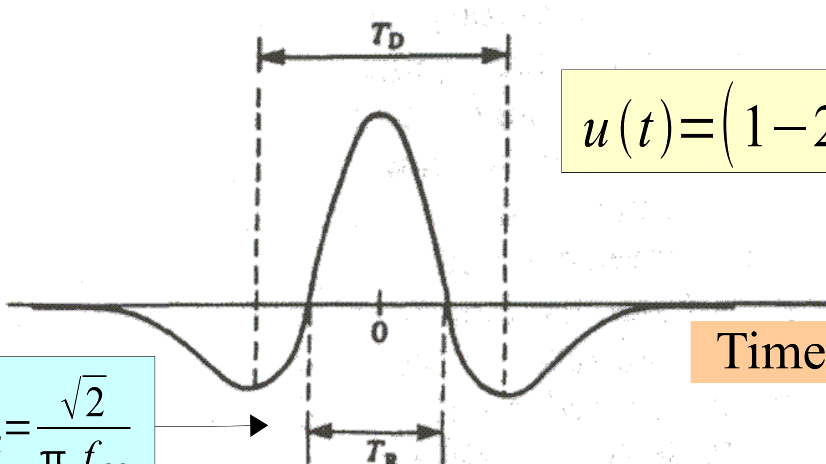
Minimum-phase wavelets are associated with *causal processes*.

New!

Ricker wavelet

A common zero-phase wavelet (Ricker):

(f_M is the *peak frequency*)

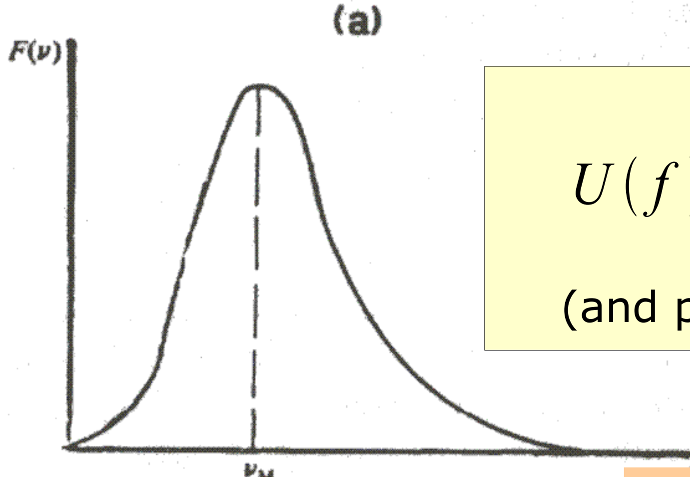


$$u(t) = \left(1 - 2\pi^2 f_M^2 t^2\right) e^{-(\pi f_M t)^2}$$

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

Time-domain

(a)



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

(and phase=0)

Frequency-domain

(b)

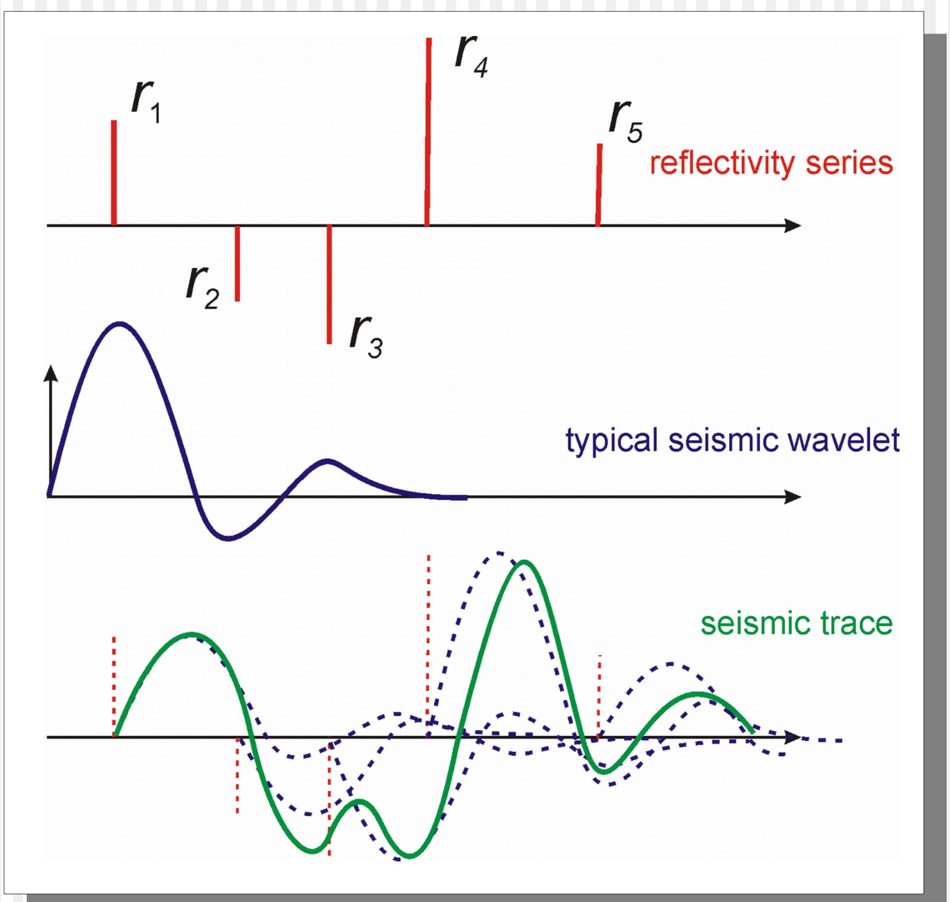
Convolutional model

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!):

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

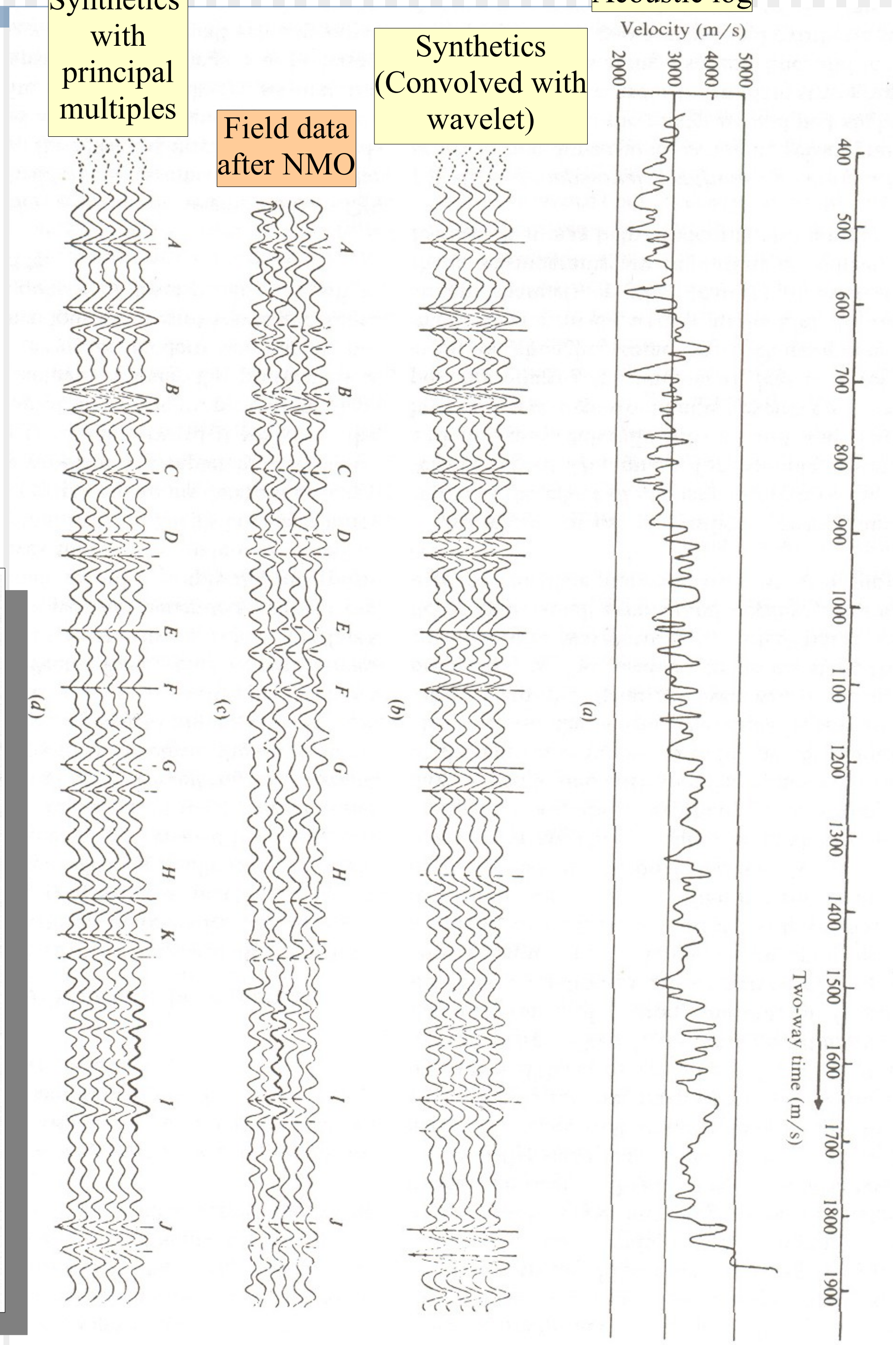
This is the key property facilitating efficient digital filtering.

As multiplication, it is symmetric (commutative):

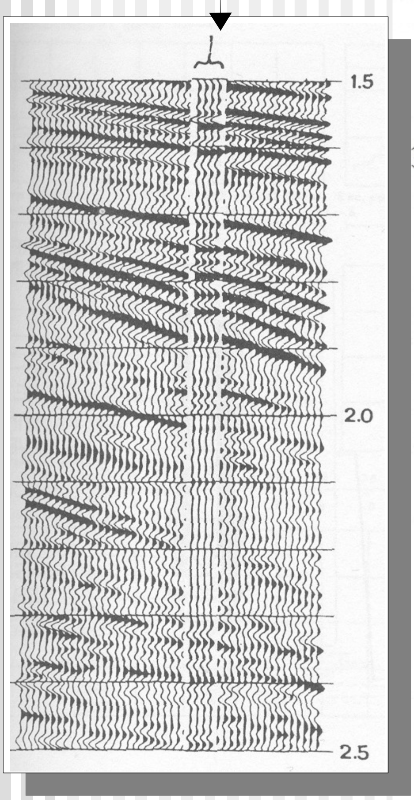
$$u*w = w*u$$

Convolutional model

Calibration of the section using logs



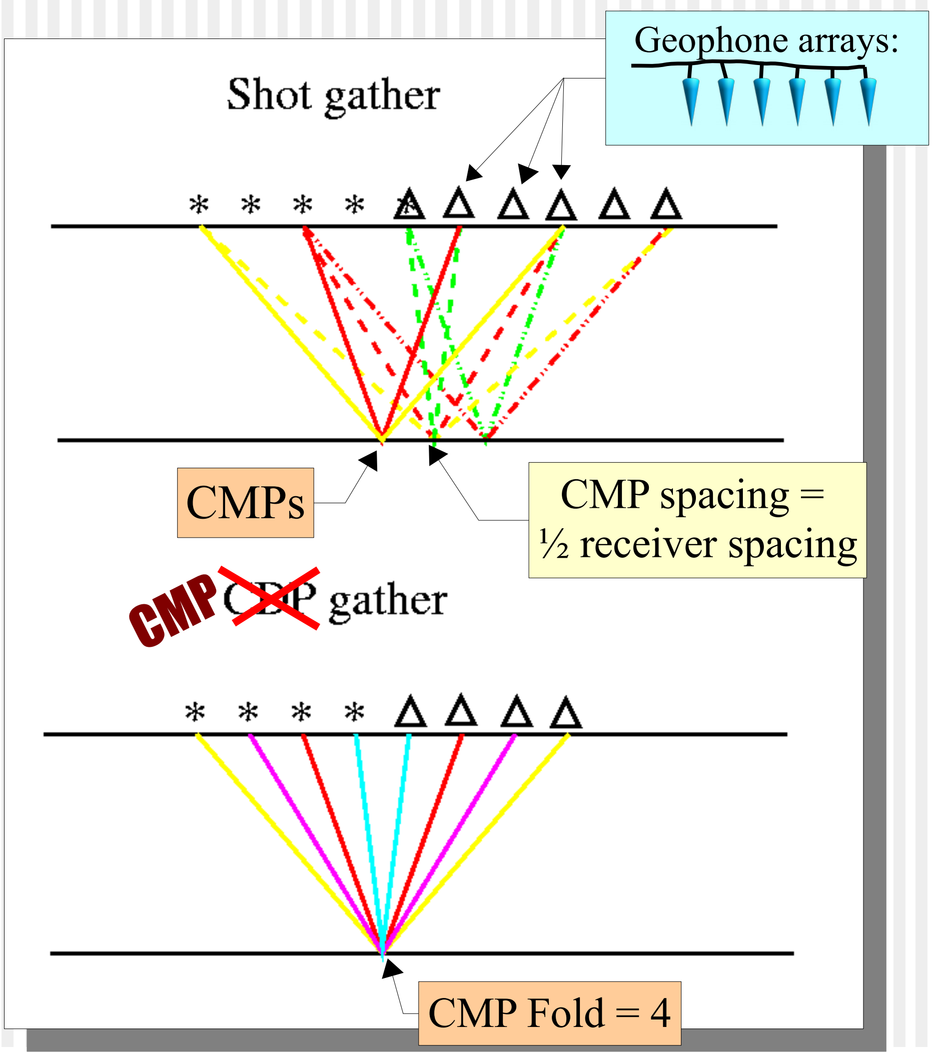
Synthetics is spliced into CMP section for comparison



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

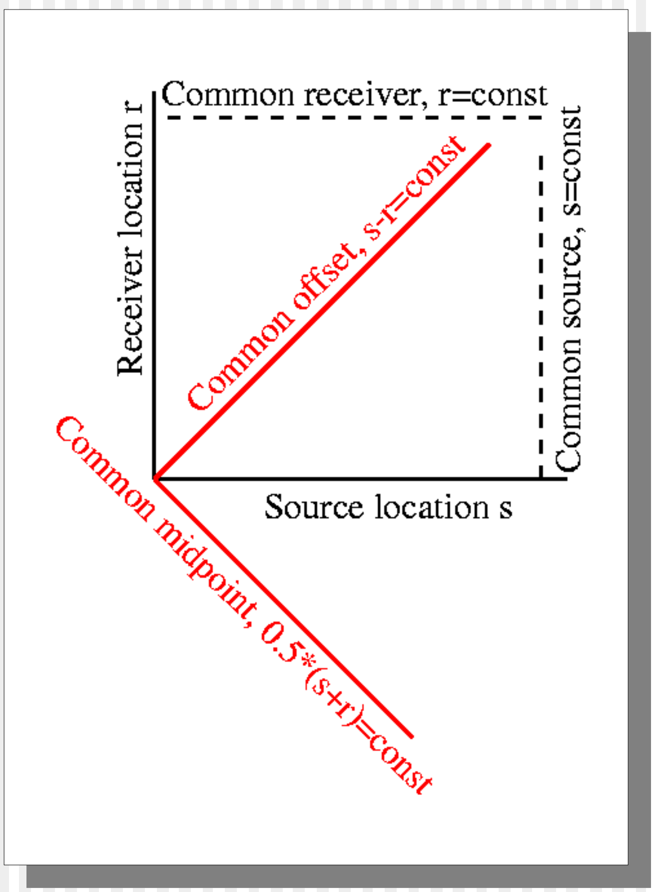
Common-Midpoint reflection imaging:

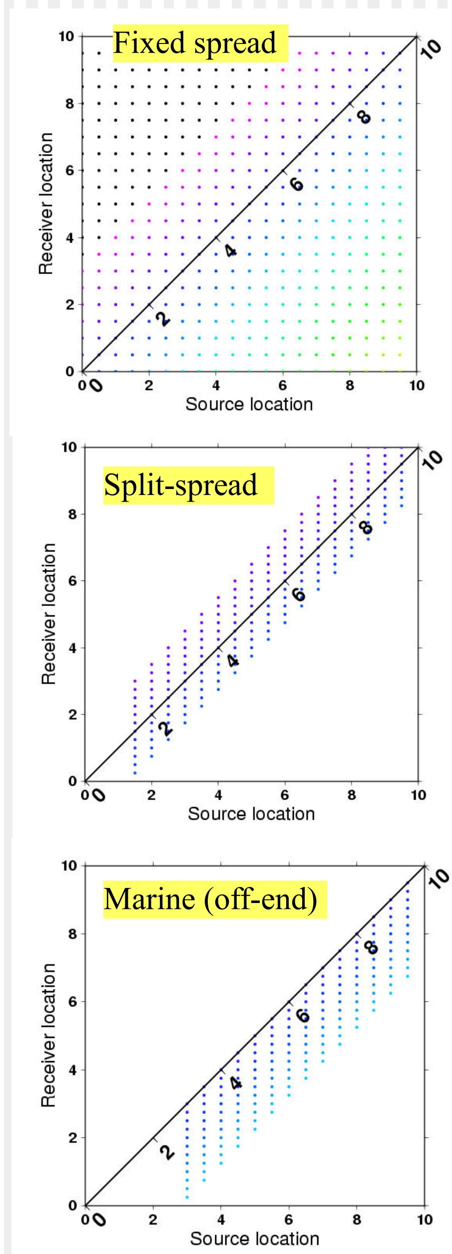
- Helps in reduction of random noise and multiples via *redundant coverage* of the subsurface;
- Provides offset coverage for Amplitude-vs. Offset (AVO) analysis



Stacking chart

Visualization of 2D source-receiver geometry



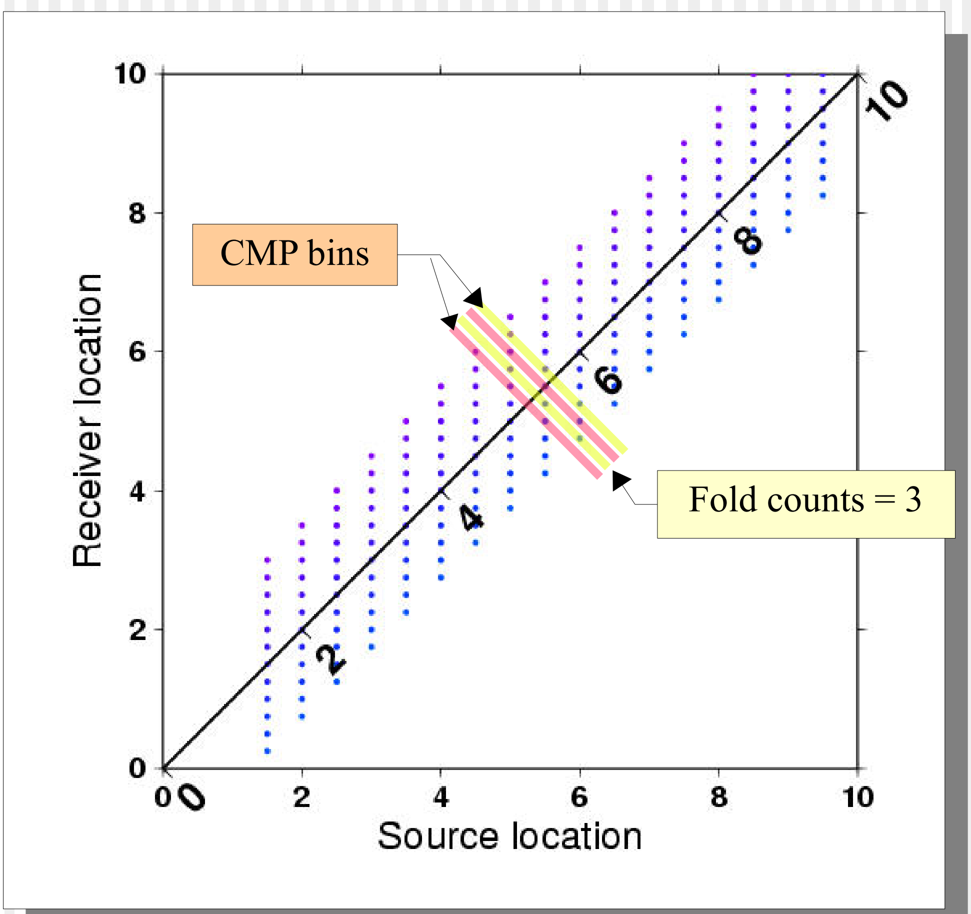


CMP Fold

Fold is the Number of records per CMP

- Should be optimal (typically, 10-40);
- Should be uniform (this is particularly an issue with 3D).

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



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 factor $\sqrt{N}$

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,

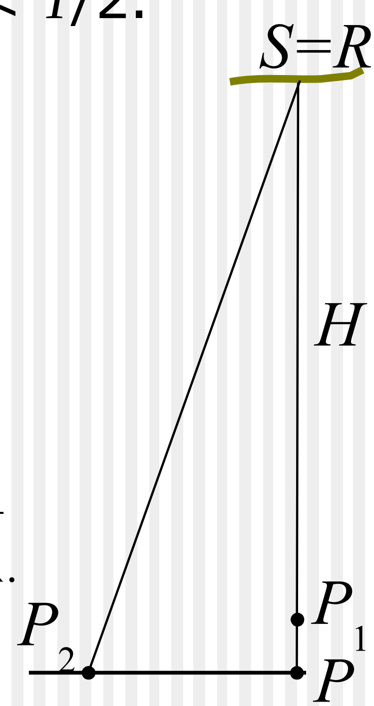
vertical resolution:

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

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

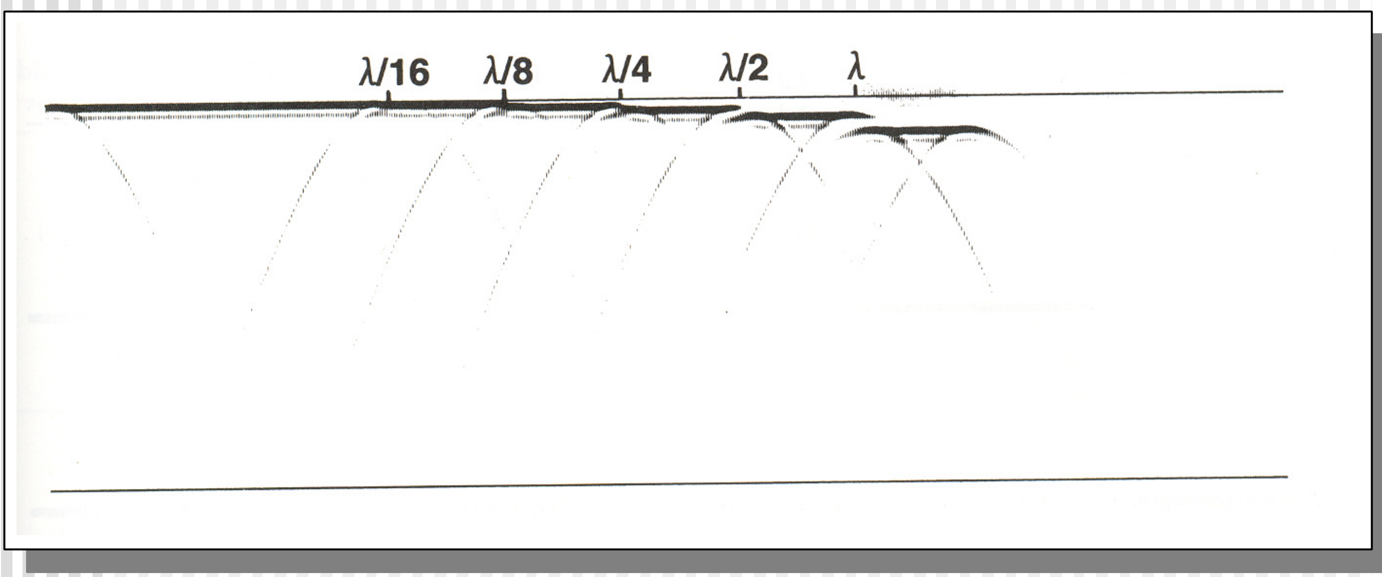


Note that the *resolution decreases with depth* as a result of 1) increasing *H*; 2) attenuation

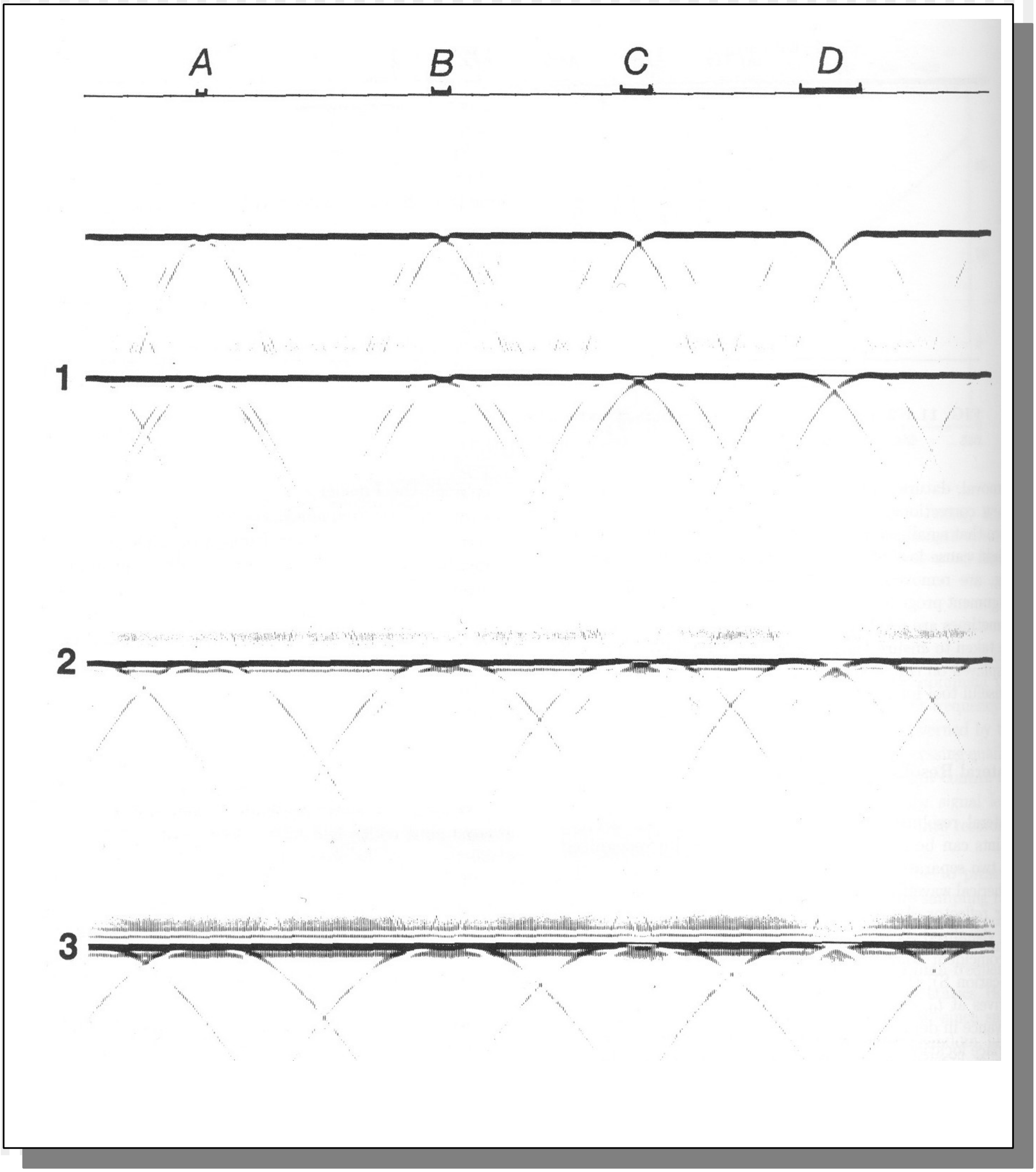
Vertical resolution

$\lambda/4$ is generally considered the vertical resolution limit

Example: Faults with different amounts of vertical throws, compared to the dominant wavelength:



Horizontal resolution



New!

Subsurface sampling

Seismic surreys are designed with some knowledge of geology and with specific targets in mind:

- Limiting factors: velocities, depths, frequencies (thin beds), dips.

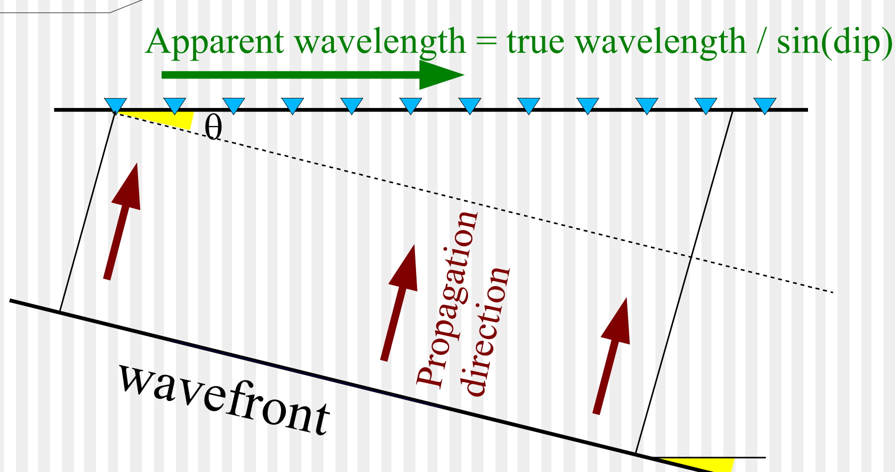
Maximum allowable geophone spacing in order to record reflections from dipping interfaces

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

The same, in terms of moveout *dt/dx* (sin θ = tan (*moveout*)):

$$Geophone\ Spacing_{max} < \frac{1}{2 f_{max} \frac{dt}{dx}}$$

More conservatively, this factor is usually taken = 4



New!

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.