Reflection Seismic Method

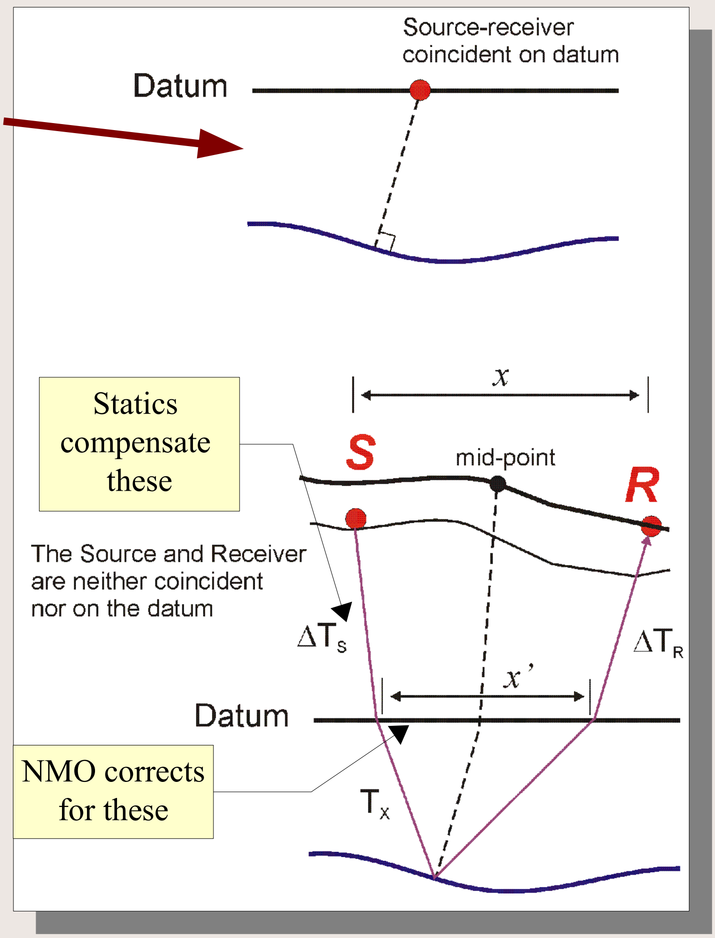
- Data and Image sort orders;
- Seismic Impedance;
- 2-D field acquisition geometries;
- CMP binning and fold;
- Resolution,
- Stacking charts;
- Normal Moveout and correction for it;
- Stacking;
- Zero-Offset reflection section;
- Migration.

- Reading:
  - Reynolds, Chapter 6
  - Shearer, 7.1-7.5
  - Telford *et al.*, Sections 4.3, 4.7, 4.8, 4.10

Zero-Offset Section

(*The goal of reflection imaging*)

- **The ideal of reflection imaging** *is sources* and receivers *collocated* on a flat horizontal surface ("*datum*").
- In reality, we have to record at *source-receiver offsets*, and over complex *topography.*



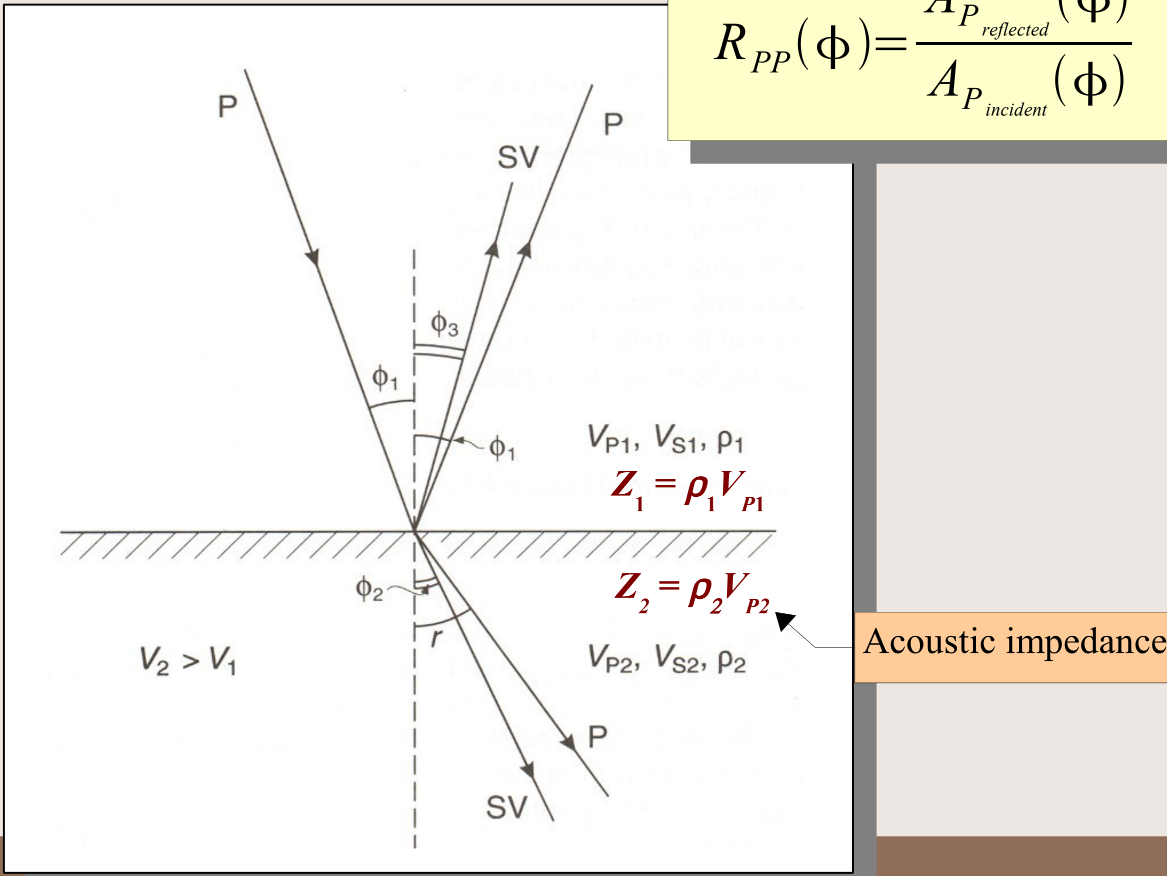
- **Two types of corrections** are applied to compensate these factors:
  - Statics "place" sources and receivers onto the datum;
  - Normal Moveout Corrections "transform" the records into as if they were recorded at collocated sources and receivers.
- **As a result** of these corrections (plus stacking to suppress noise), we obtain a *zero-offset section*.

Reflection coefficient

Quantity imaged in reflection sections

- At *near-normal* incidence:
  - *P*-to-*S*-wave conversions are negligible;
  - *P*-wave reflection and transmission *amplitudes* are determined by the contrast in *acoustic impedance* $Z=\rho V$ (see next page).
- *P*- and *S*-wave *reflection* amplitudes usually *vary with incidence angles*.

$$R_{PP}(\phi)=\frac{A_{P_{reflected}}(\phi)}{A_{P_{incident}}(\phi)}$$



Acoustic Impedance

- Reflection-coefficient relations follow from: 1) continuity of displacement, and 2) conservation of energy upon reflection/transmission
- Acoustic impedance measures the energy flux within the wave:

$$E_{flux} = V E_{density} = V \frac{\rho}{2}(\omega A)^2 = \frac{\omega^2}{2} \boxed{\rho V} A^2$$

Kinetic energy

Z

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

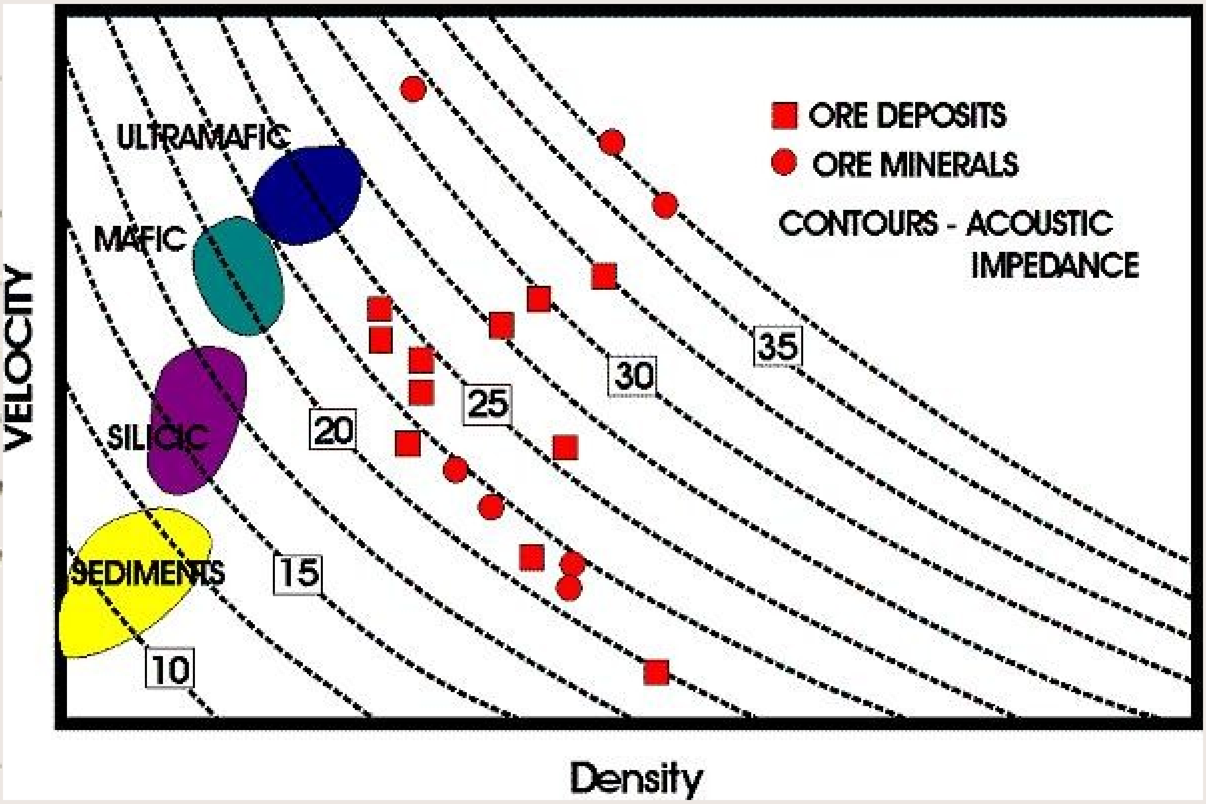
P-wave Transmission Coefficient

$$T_{PP} = 1 - R_{PP} = \frac{2Z_1}{Z_1 + Z_2}$$

This follows from the continuity of displacement across the boundary

Acoustic Impedance

Typical values



From Salisbury, 1996

Spatial resolution

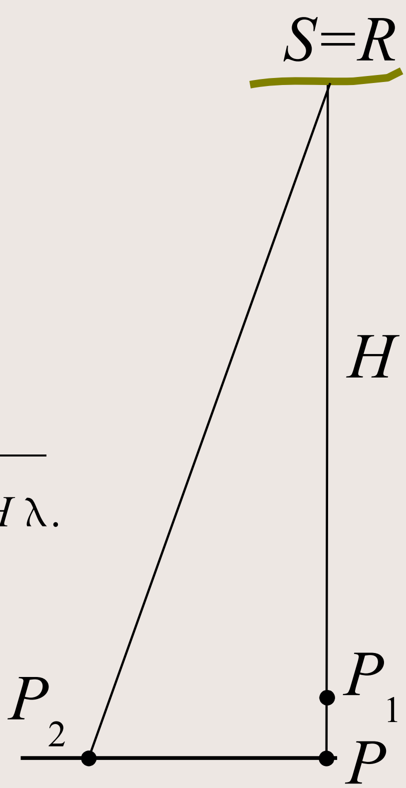
- Two points are considered *unresolvable* when their reflection travel times are separated by less than *half the dominant period* of the signal: $\delta t < T/2$.
- Therefore,
  - vertical resolution:

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

  - horizontal resolution:

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

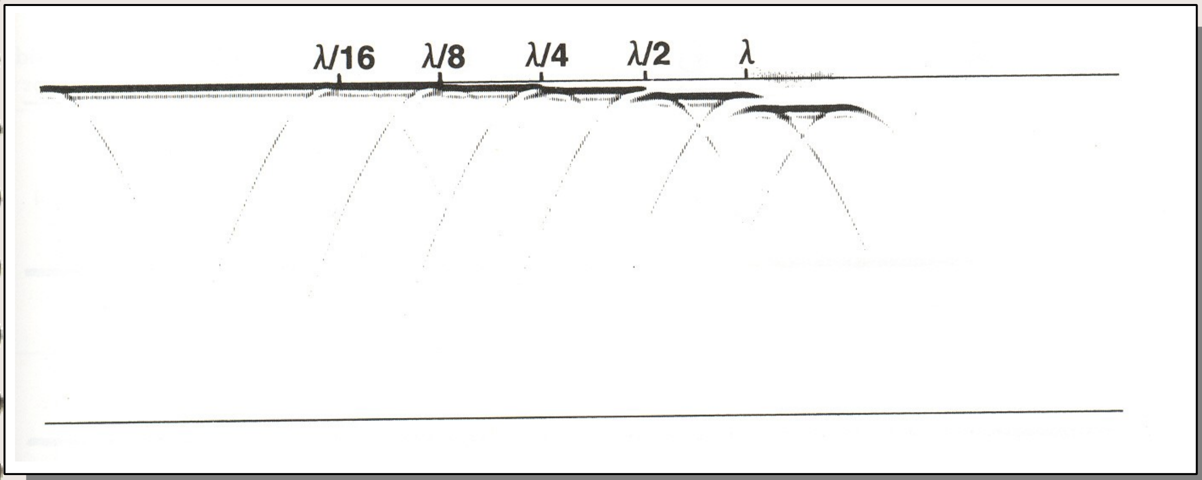
This is called *Fresnel Zone* radius



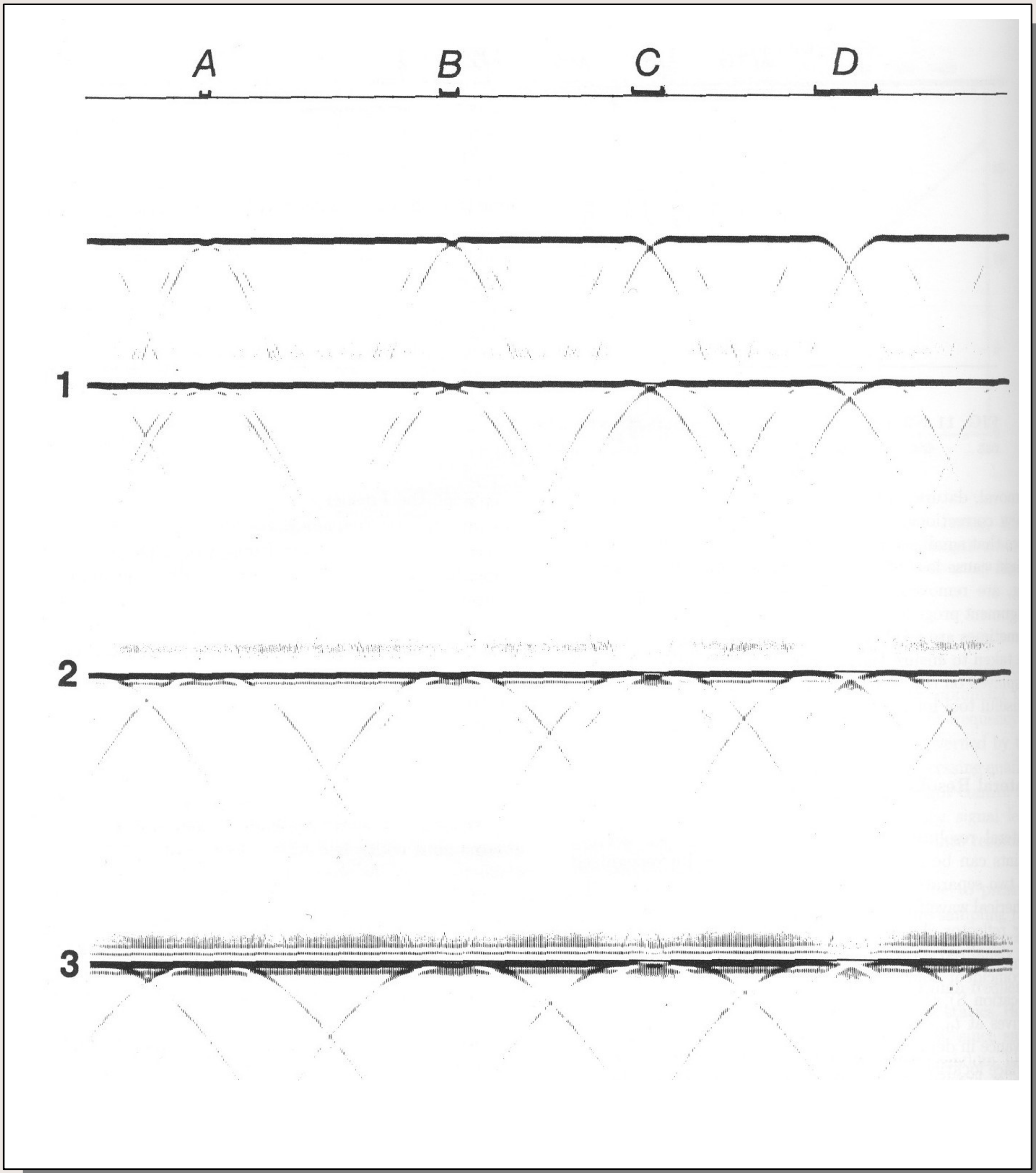
- Note that *horizontal resolution decreases with depth*.

Vertical resolution

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

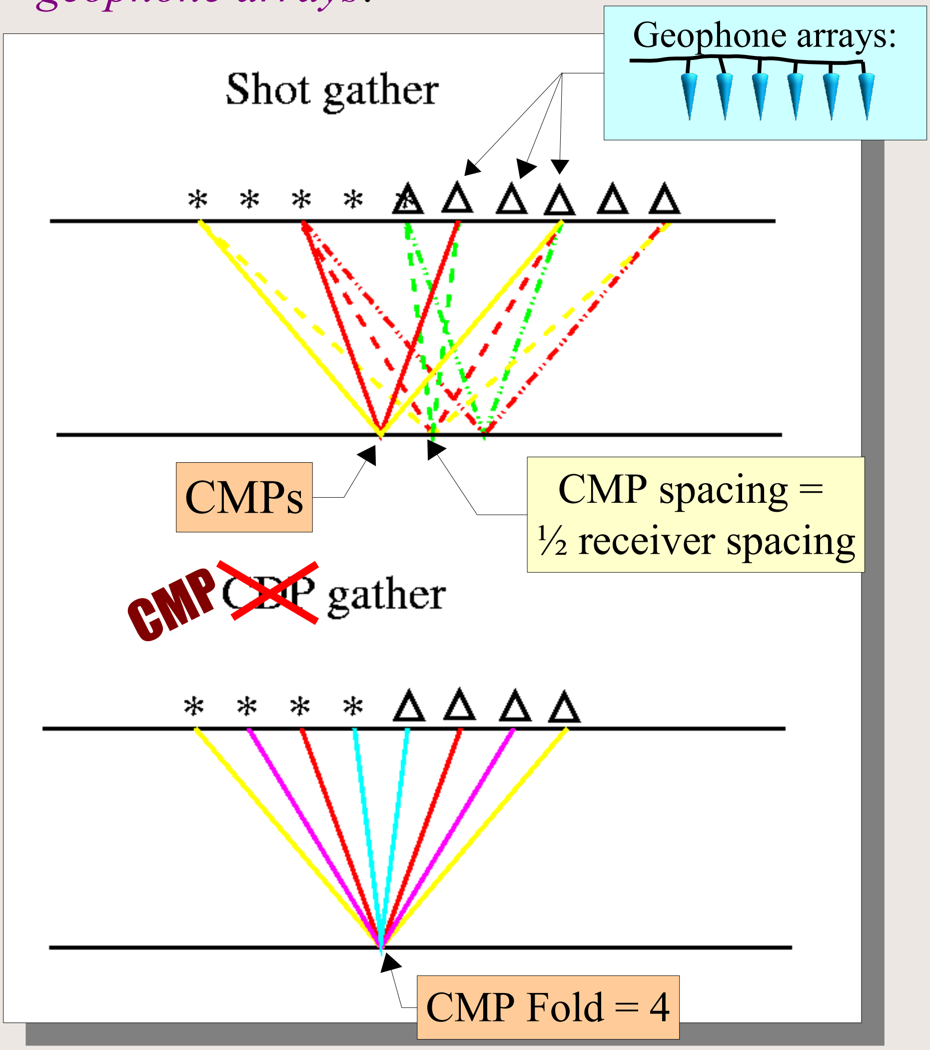


Horizontal resolution



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

- Common-Midpoint survey:
  - Helps in reduction of random noise and multiples via *redundant coverage* of the subsurface;
  - Ground roll is attenuated through the use of *geophone arrays*.

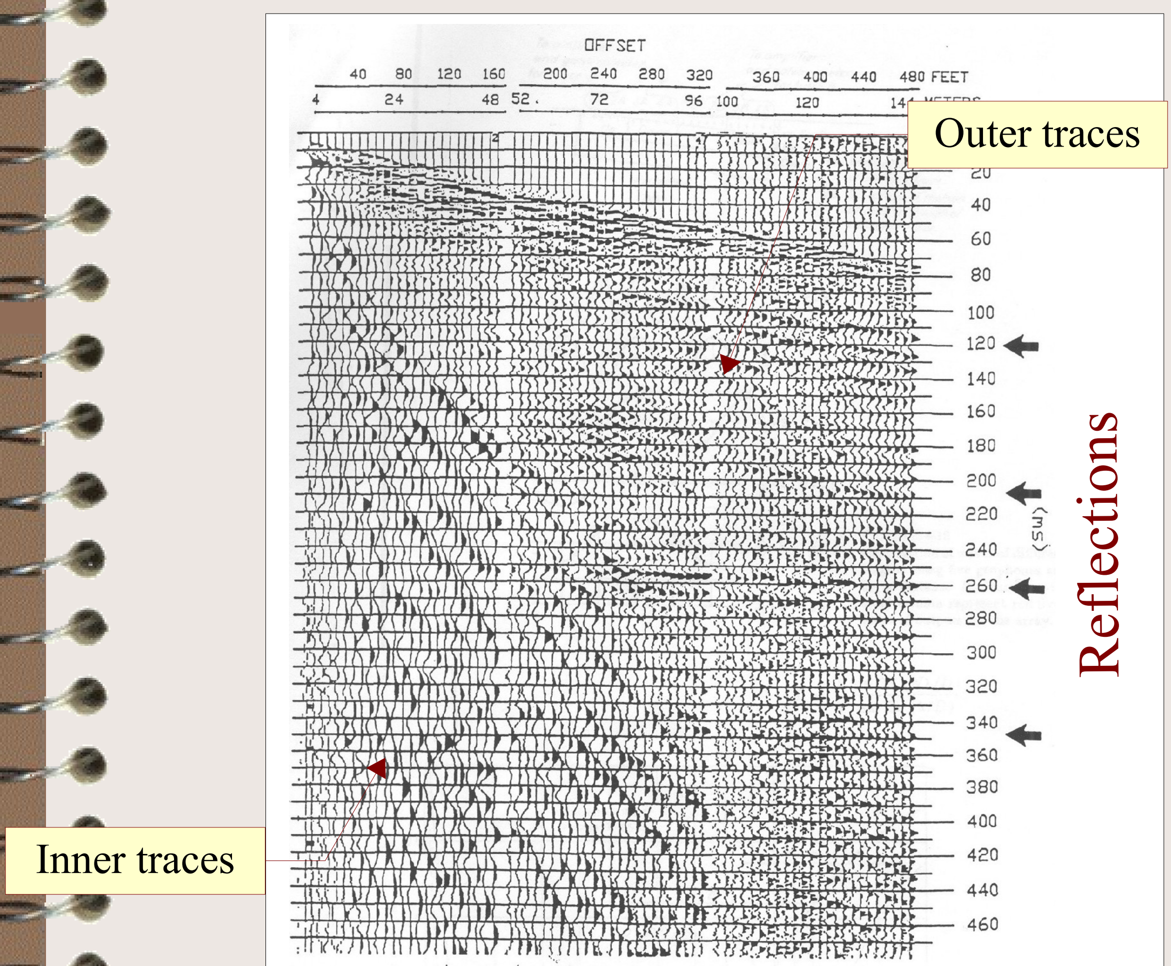


Field geometry
survey and observer's logs, "chaining notes"

- Survey file
  - Produced by surveyors (usually comes out of GPS unit);
- Observer's Notes
  - A record of shooting and recording sequence
    - Lists shot positions, record ("field file") numbers (FFIDs), spread positions ("first live station");
    - Records weather, interruptions, usual and unusual noise, state of recording system.

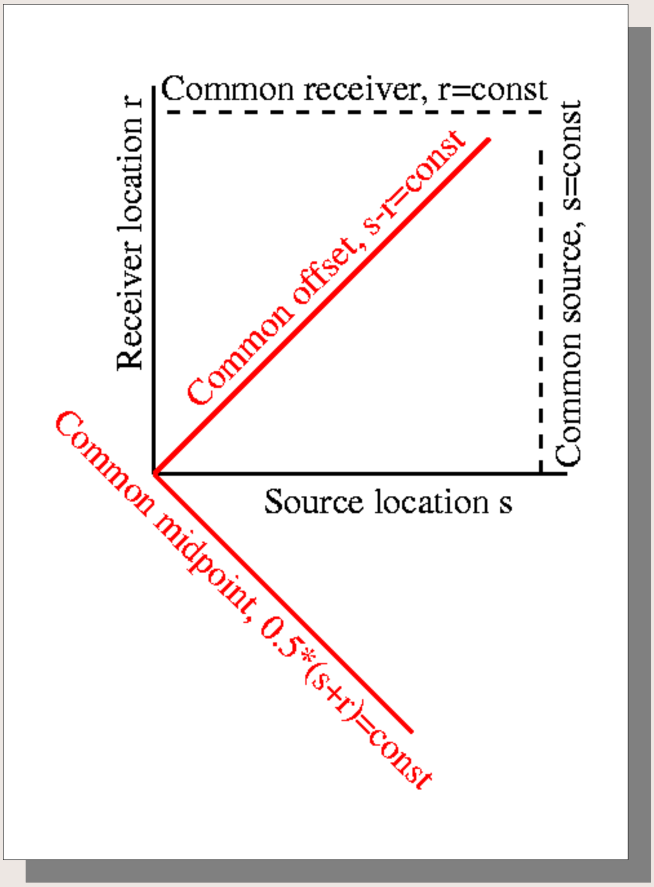
Noise (Wave) Test

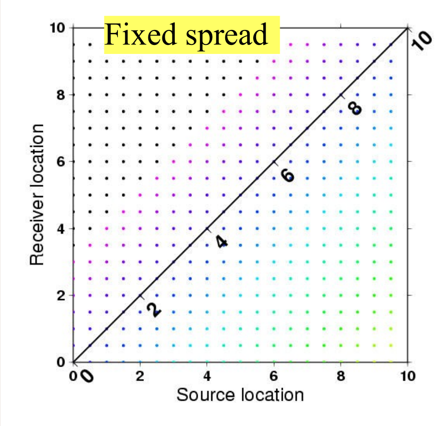
- Conducted prior to the acquisition in order to evaluate the appropriate survey design
  - Offset range;
  - Noise (ground roll, airwave) characteristics;
  - Offset range for useful reflections.

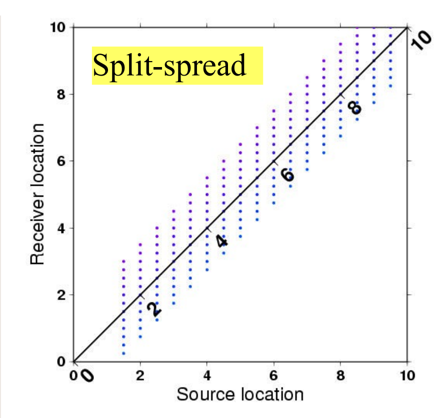


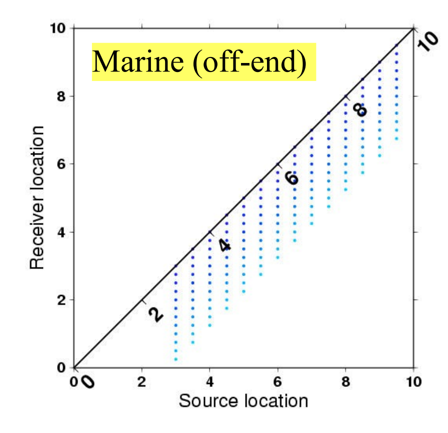
Stacking chart

- Visualization of source-receiver geometry





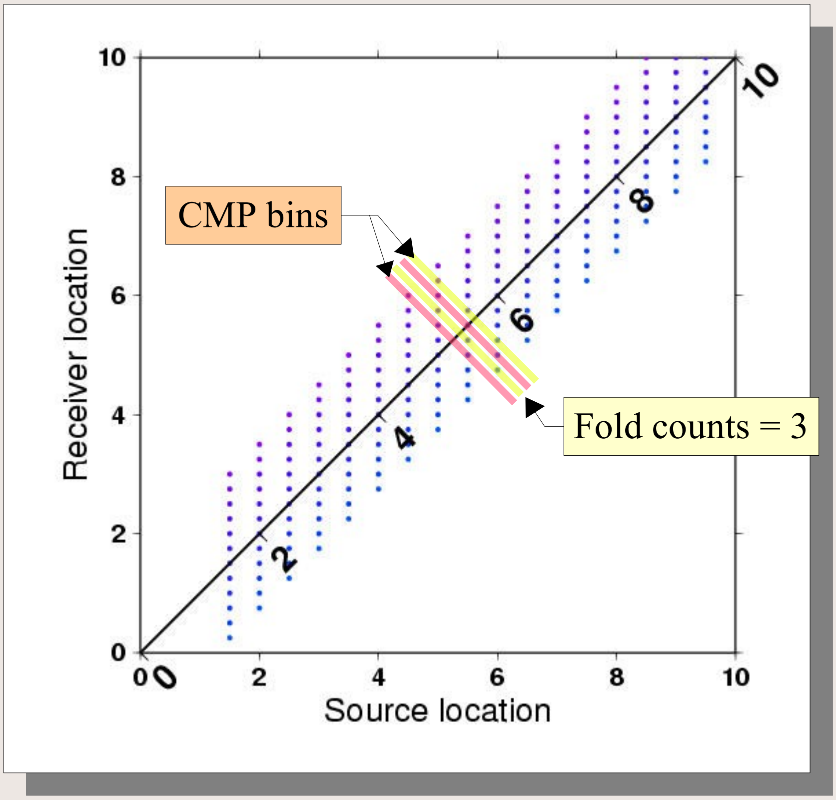




CMP Fold

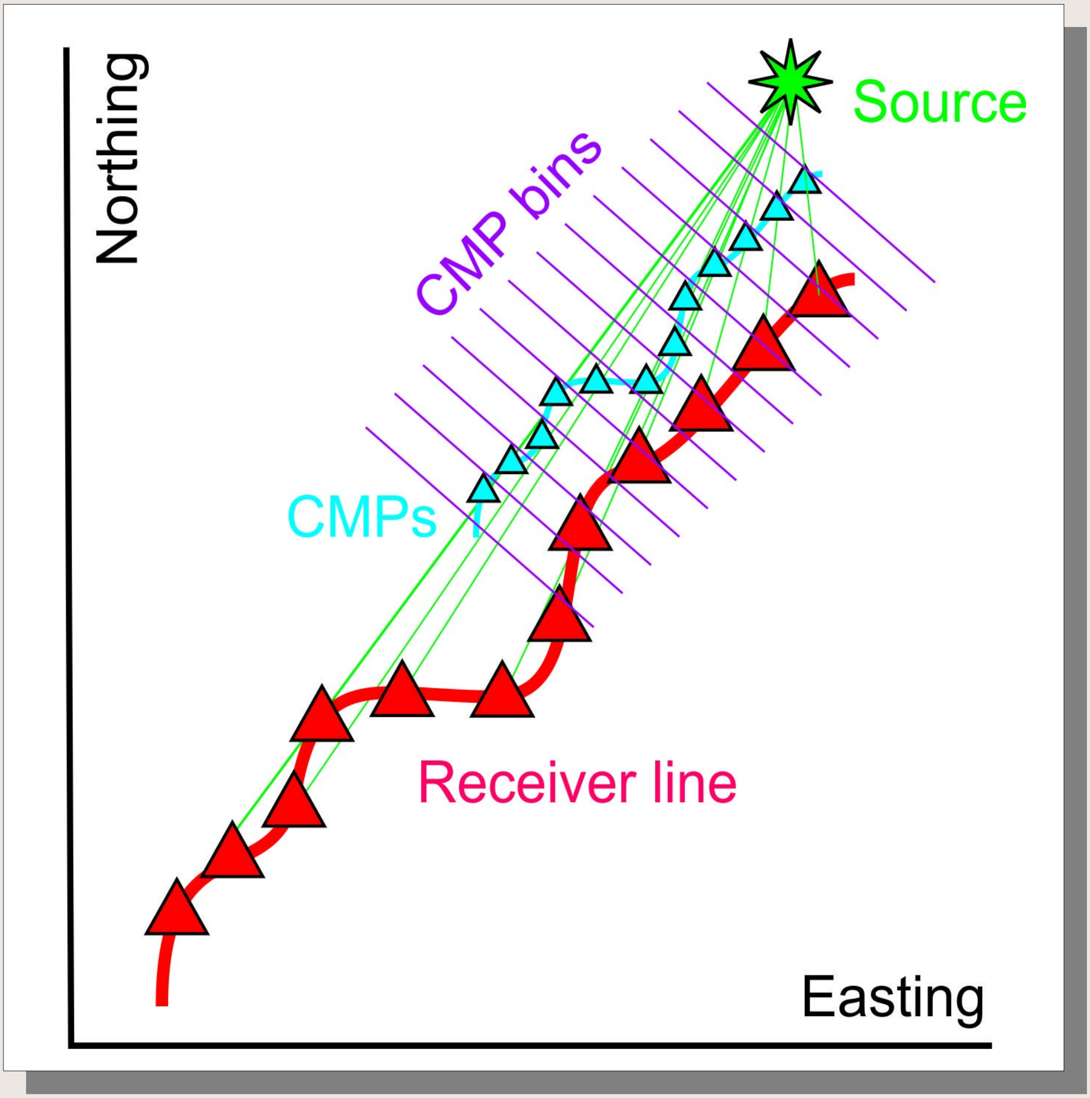
- Fold is the Number of records per CMP
  - Should be optimal (typically, 10-40);
  - Should be uniform (this is particularly an issue with 3D).

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



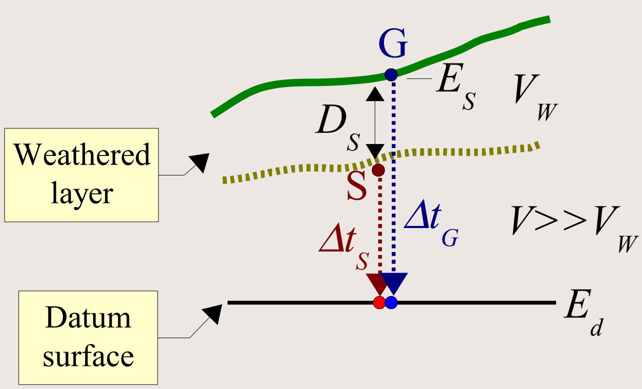
Crooked-line binning

- Real seismic lines are often “crooked”
- CMP bins are then defined for an averaged, smooth line of midpoints



Statics

- Statics are time shifts associated with source (Δt_S) and receiver (Δt_R) positions
  - When subtracted ('*applied*') from the travel-times, place the source and receiver on a common datum.
- (*Field statics*) = (*Elevation Correction*) + (*Weathering Correction*);
  - Elevation correction 'moves' the source and geophone to a common datum surface;
  - Weathering correction removes the effect of slow (~600 m/s) unconsolidated layer.
    - Obtained from *first arrivals*, using the plus-minus, GRM, or similar methods.
- Where field statics are not accurate enough, *residual statics* are also applied.

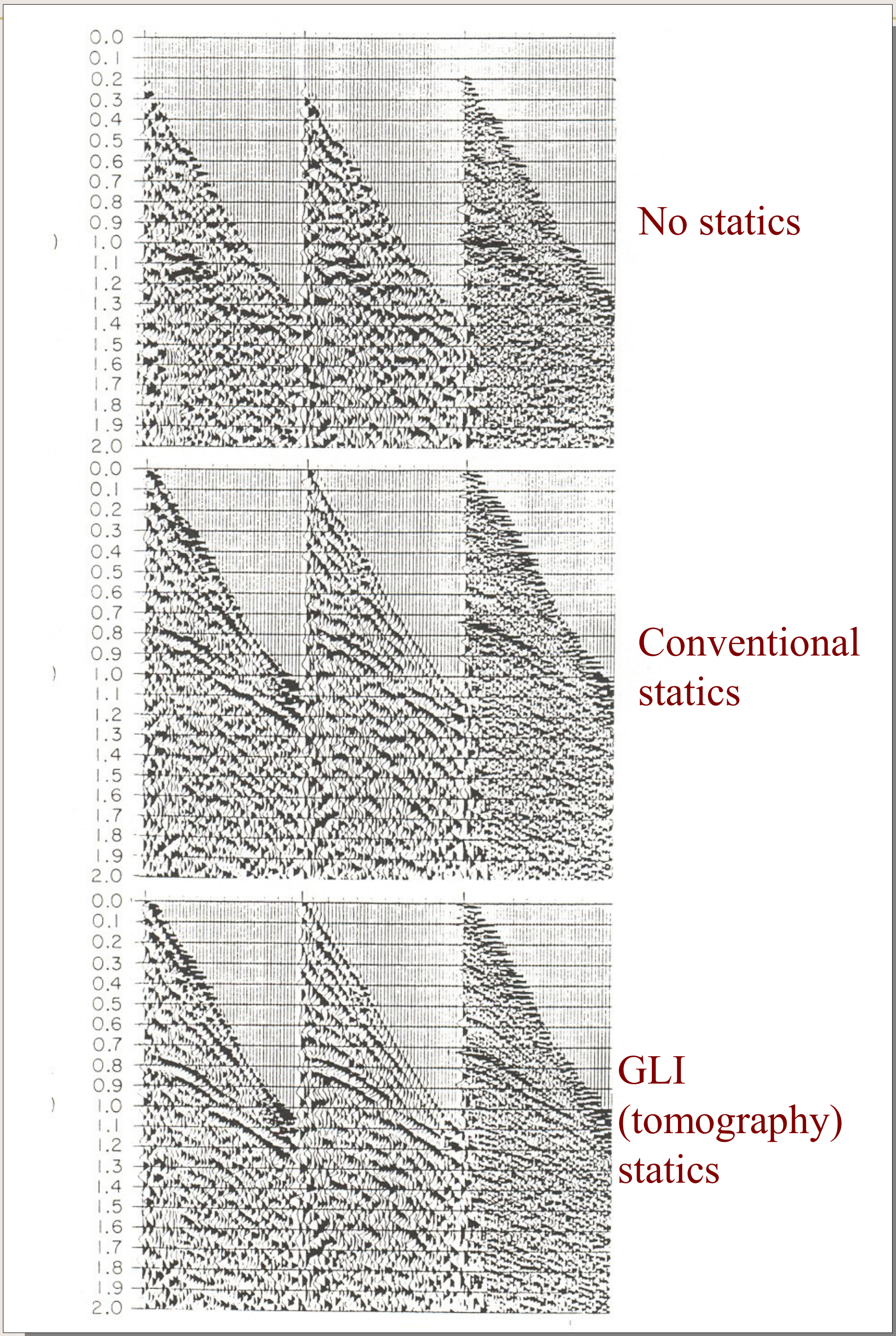


Elevation statics:

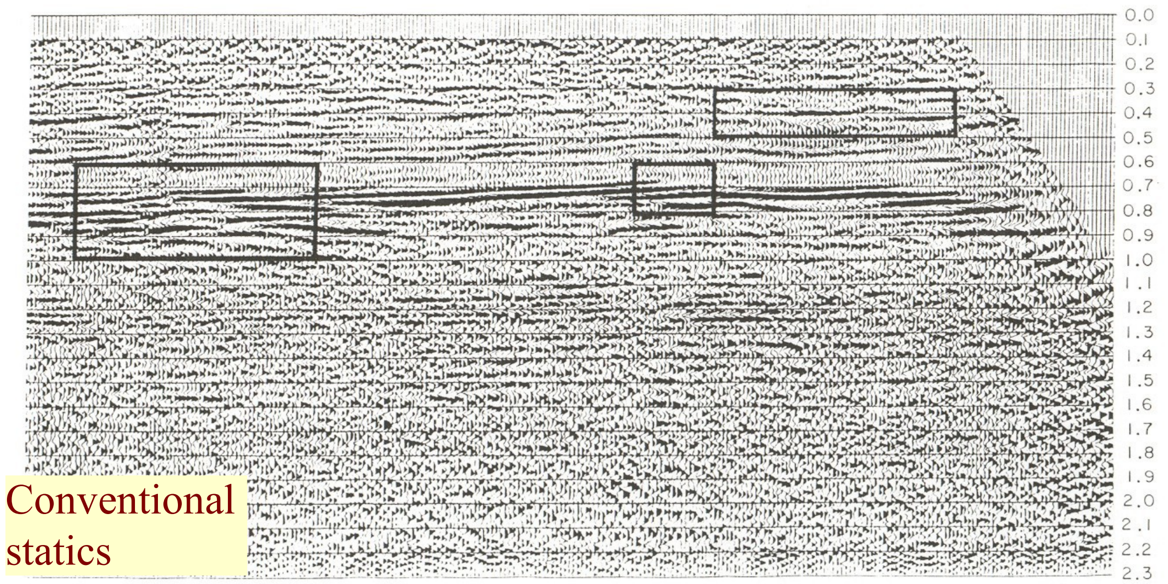
$$\Delta t_S = \frac{E_S - D_S - E_d}{V},$$

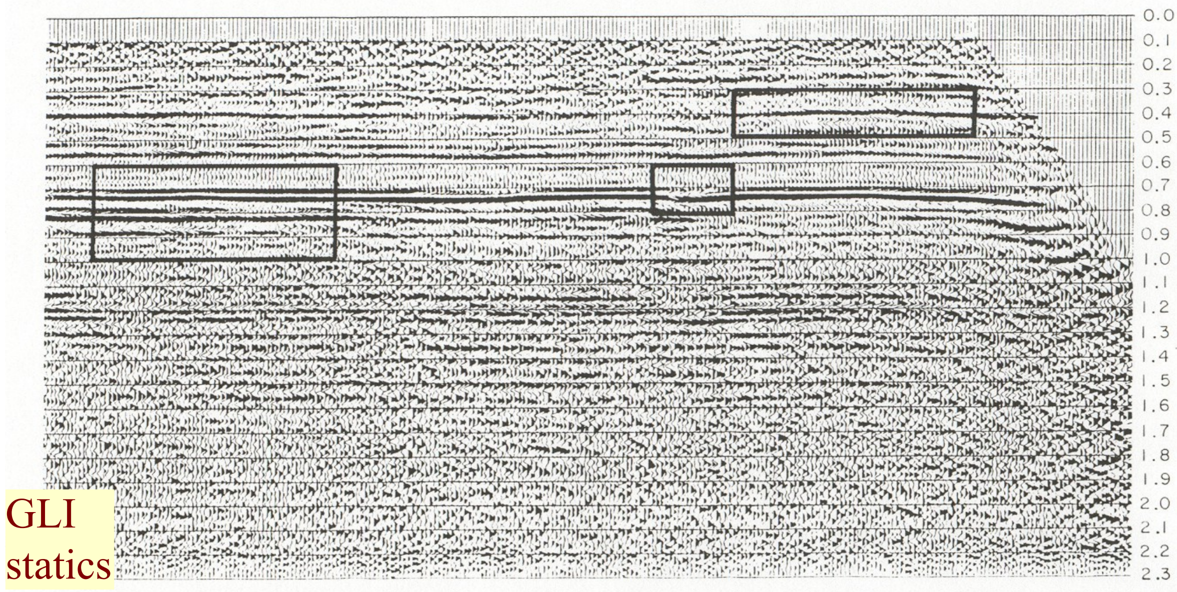
$$\Delta t_G = \Delta t_S + t_{uphole}$$

Effects of statics in shot gathers

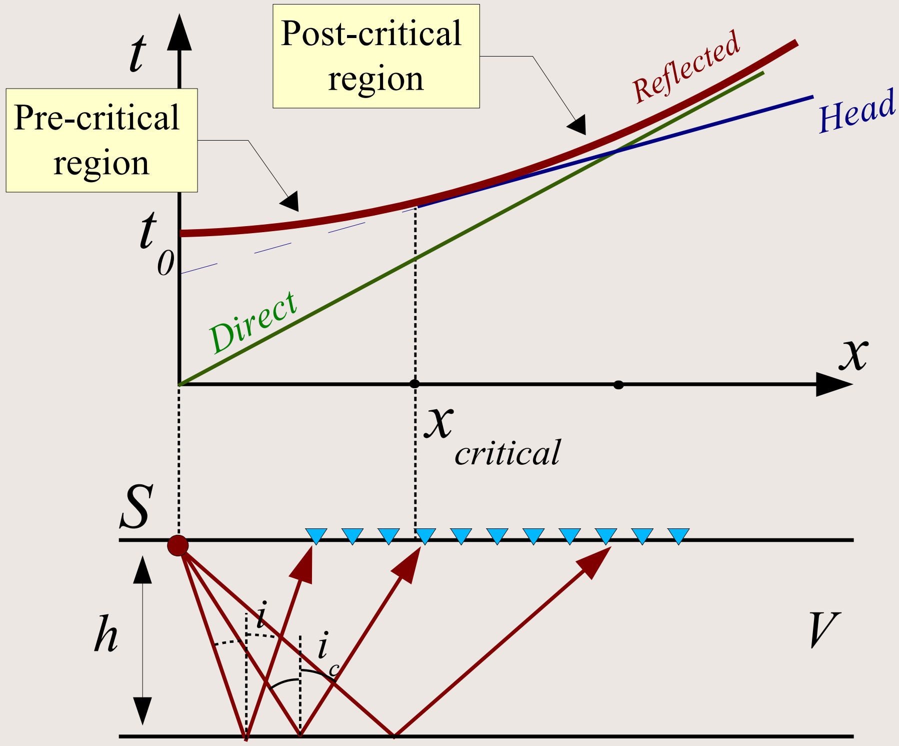


Effects of statics in stacked image





Reflection travel-times
(*Single layer*)



$$t(x) = \frac{\sqrt{4h^2 + x^2}}{V} = \sqrt{\left(\frac{2h}{V}\right)^2 + \left(\frac{x}{V}\right)^2} = \sqrt{t_0^2 + \left(\frac{x}{V}\right)^2}$$

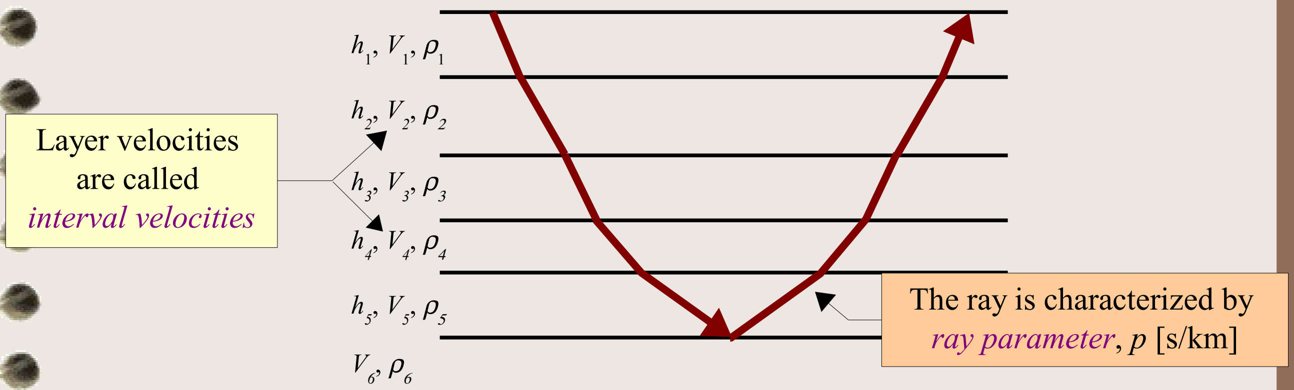
- $t(x)$ is called (hyperbolic) Normal reflection Moveout (NMO)
  - Approximation for $x \ll h$ (parabolic):

$$t(x) \approx t_0 + \frac{1}{2t_0}\left(\frac{x}{V}\right)^2$$

Note that deeper reflections in faster layers have smaller moveouts

Reflection travel-times
(*Multiple layers*)

- For multiple layers, $t(x)$ is no longer hyperbolic:



- For practical applications (near-vertical incidence, pV_i<<1), $t(x)$ still can be approximated as:

$$x_n(p)=\sum_{i=1}^{n}\frac{h_i p V_i}{\sqrt{1-(pV_i)^2}}\approx p\sum_{i=1}^{n}h_iV_i[1+\frac{1}{2}(pV_i)^2]\approx p\sum_{i=1}^{n}h_iV_i,$$

hence: $$p=\frac{x_n(p)}{\sum_{i=1}^{n}h_iV_i},$$

$$t_n(p)=\sum_{i=1}^{n}\frac{h_i}{V_i\sqrt{1-(pV_i)^2}}\approx\sum_{i=1}^{n}\frac{h_i}{V_i}[1+\frac{1}{2}(pV_i)^2]=t_0+\frac{1}{2}p^2\sum_{i=1}^{n}h_iV_i$$

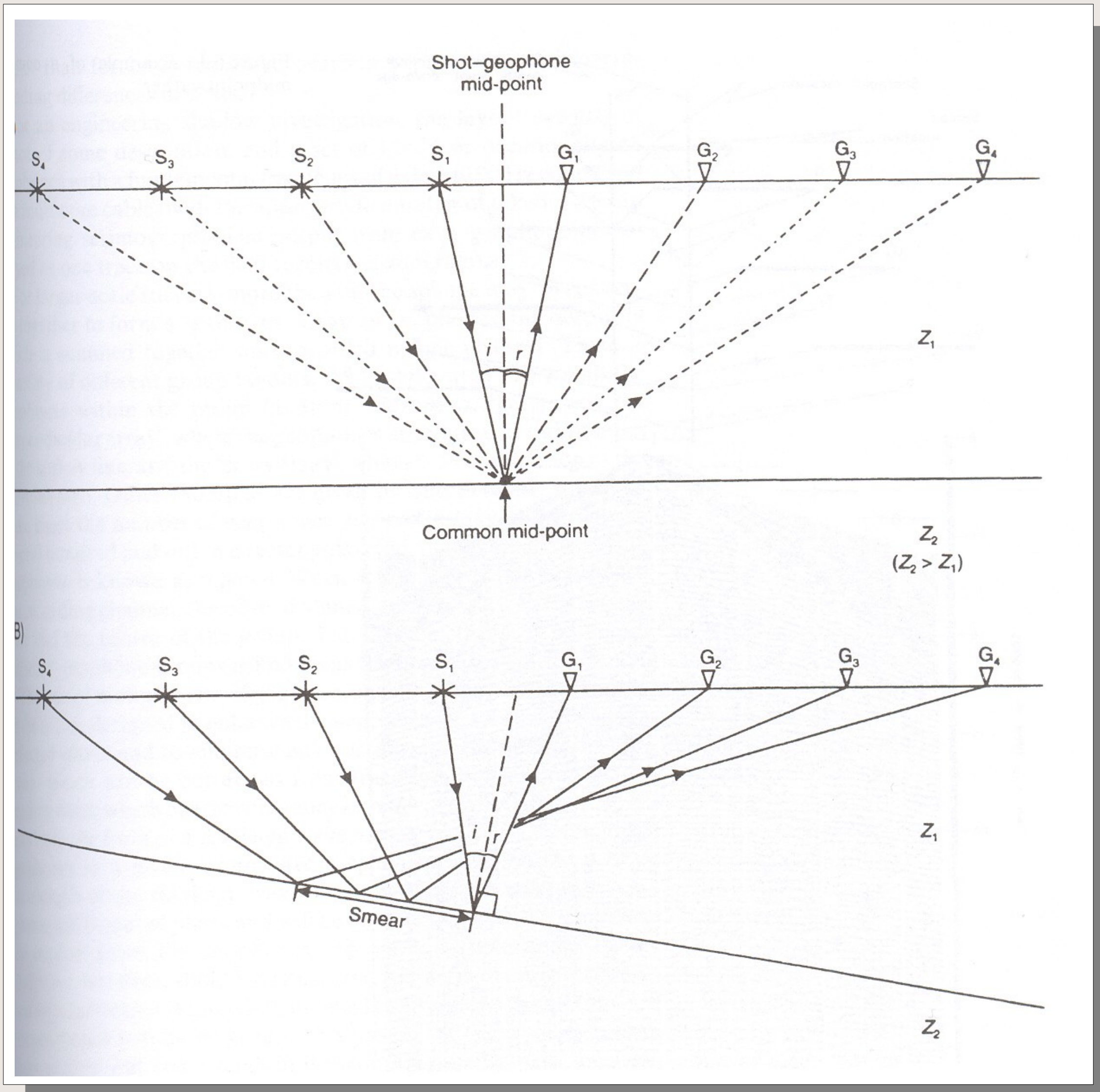
$$t_n(x)\approx t_0+\frac{1}{2t_0}\left(\frac{x}{V_{RMS}}\right)^2$$

- where V_{RMS} is the RMS (root-mean-square) velocity:

$$V_{RMS}=\sqrt{\frac{\sum_{i=1}^{n}h_iV_i}{t_0}}=\sqrt{\frac{\sum_{i=1}^{n}t_iV_i^2}{\sum_{i=1}^{n}t_i}}.$$

Dipping reflector

- For a dipping reflector, the image is *smeared up-dip* and the stacking velocity is *over-estimated*.

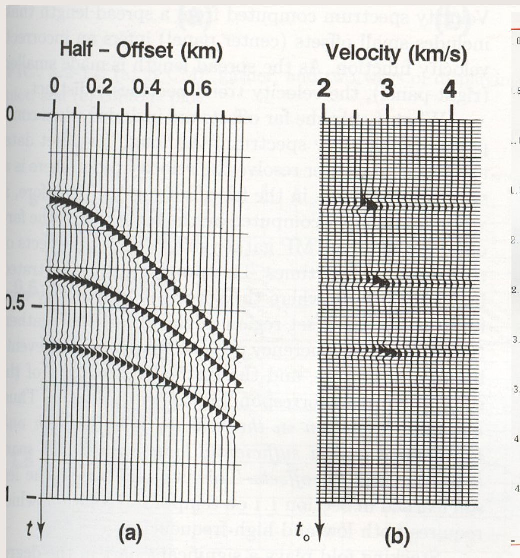


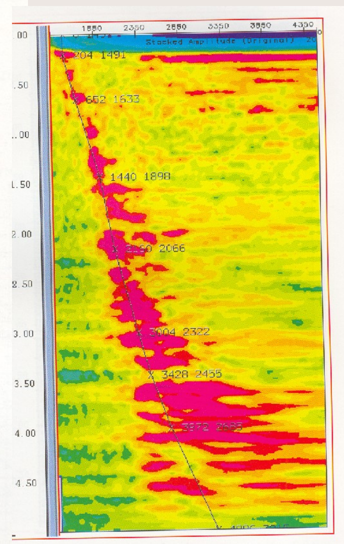
Measurement of velocities
(*Velocity analysis*)

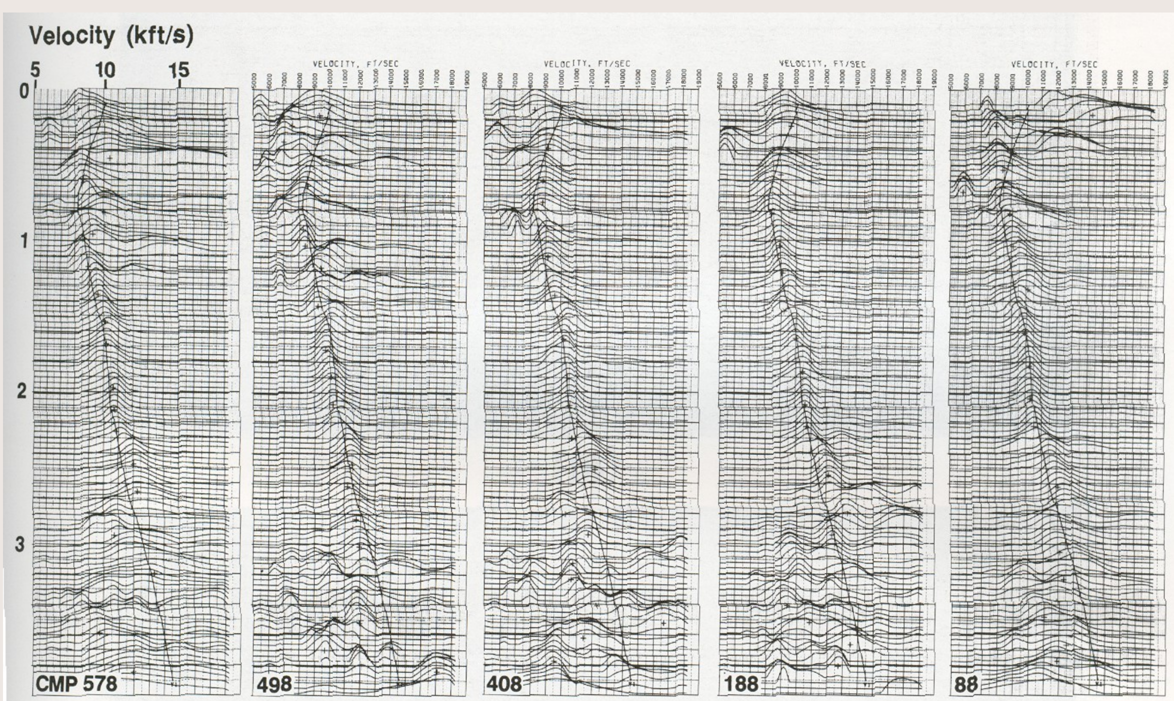
- Reflection (*stacking*) velocity analysis is usually performed in CMP gathers
  - because they pertain to specific locations within the subsurface.
- <u>Travel-time</u> approach - T^2-X^2 method: $t^2(x^2)$ is a linear function. Slope of the graph in $t^2(x^2)$ diagram is $(1/V_{Stacking})^2$.
- <u>Waveform</u> approach (*velocity spectrum* and *common velocity stacks (CVS)*)
  - stack the records along trial reflection hyperbolas;
  - plot the resulting amplitude in a (*time*, V_{trial}) diagram;
  - pick amplitude peaks - this results in a V(*time*) profile.

Velocity Spectra

CMP gathers are stacked along trial velocities and presented in time-velocity diagrams.

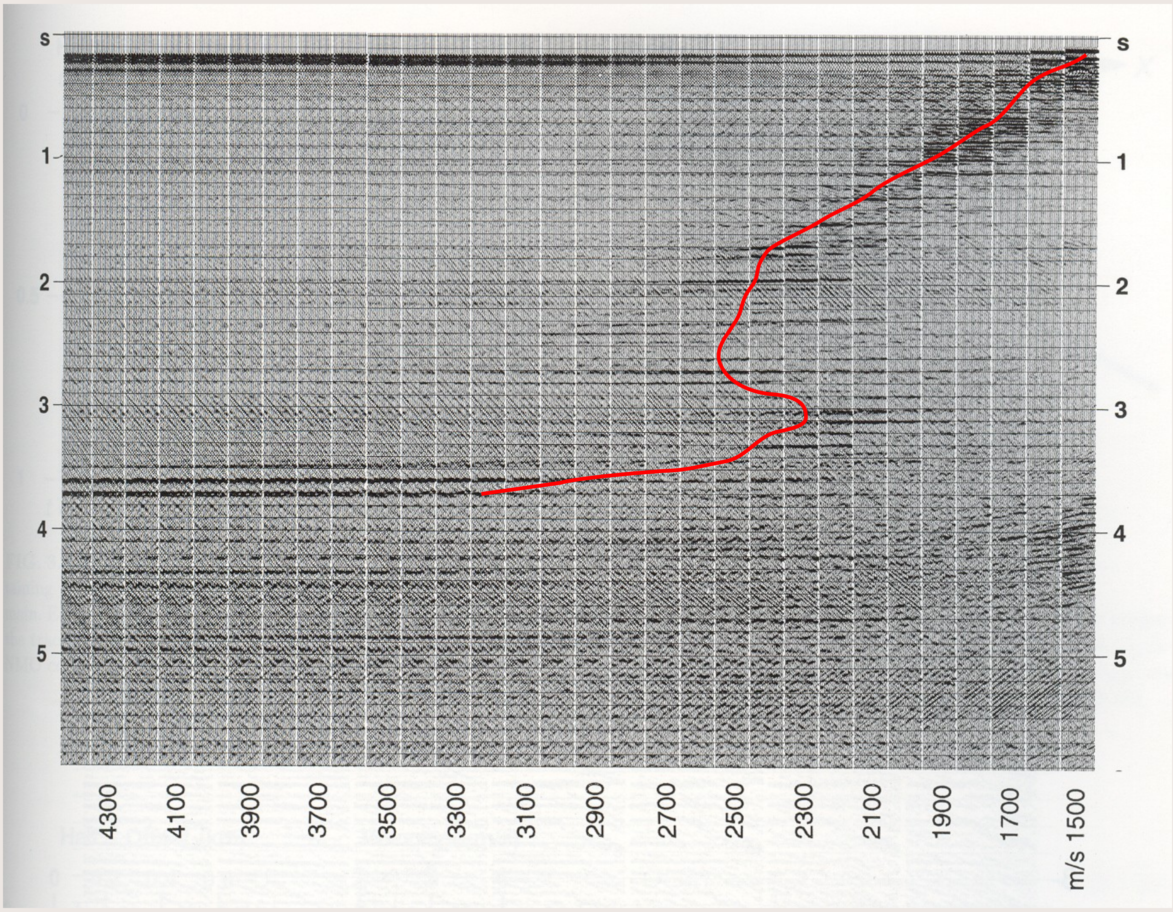






Common-Velocity Stacks
(*Velocity analysis*)

- CMP gathers are NMO-corrected (hyperbolas flattened) using a range of trial velocities and stacked.
- Velocities are picked at the amplitude peaks and best resolution in the stacks.



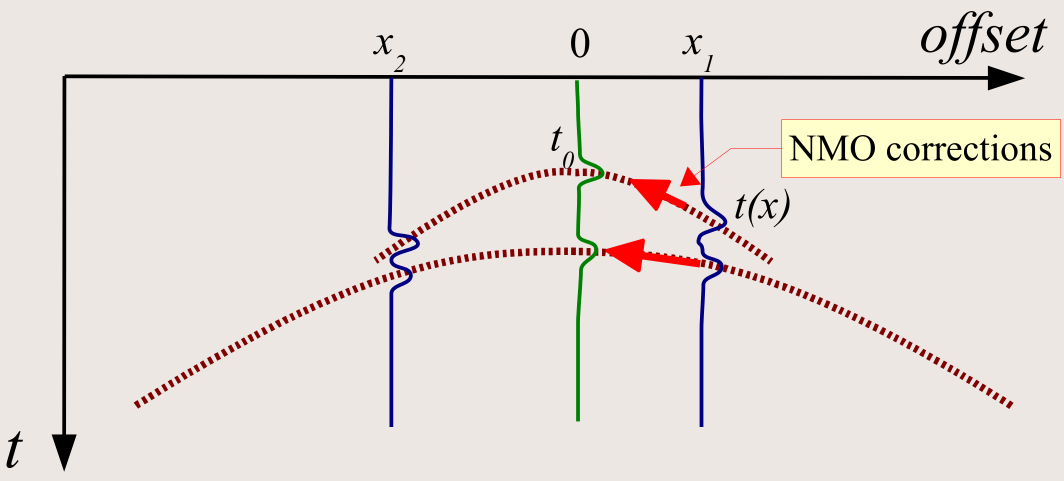
Normal Moveout (NMO) correction

- NMO correction transforms a reflection record at offset x into a normal-incidence ($x = 0$) record:

$$t(x) \rightarrow t_0 = t(x) - \delta t_{NMO}$$

$$\delta t_{NMO} = \sqrt{t^2 - \left(\frac{x}{V}\right)^2} - t_0 \approx \frac{1}{2t}\left(\frac{x}{V}\right)^2$$

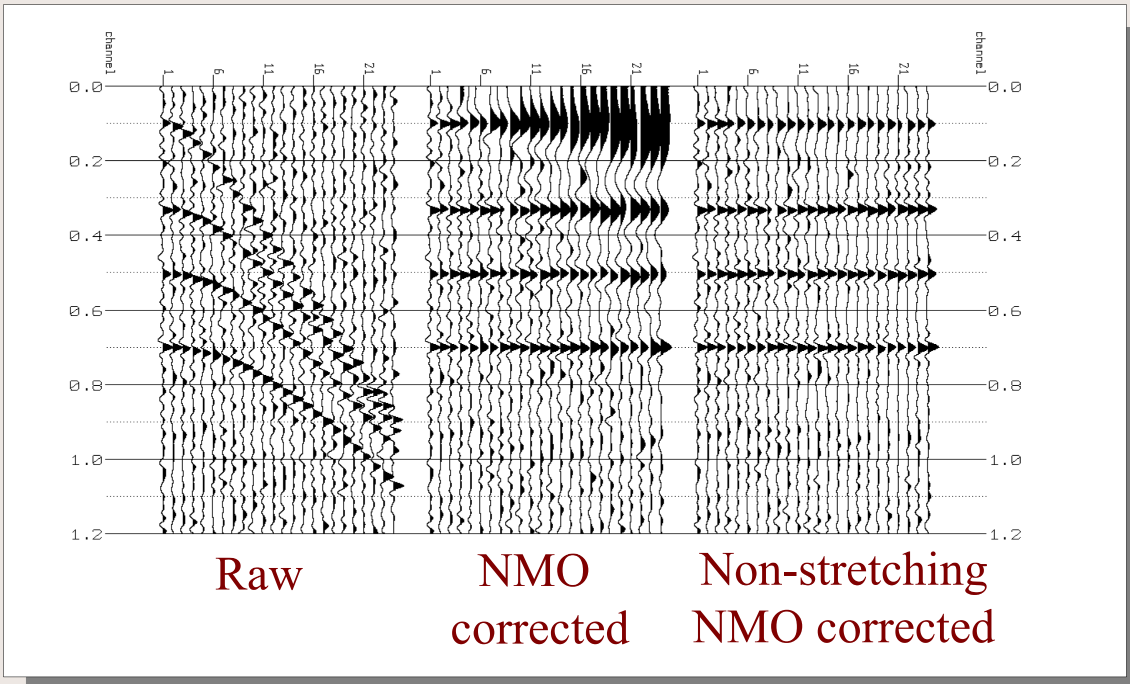
"Stacking velocity"



- *Stacking velocity* is determined from the data, as a measure of the reflection hyperbola best aligned of with the reflection.

NMO stretch

- NMO correction affects the shallower and slower reflections stronger
  - This is called "*NMO stretch*"
  - There is a considerable effort in creating "non-stretching" NMO algorithms

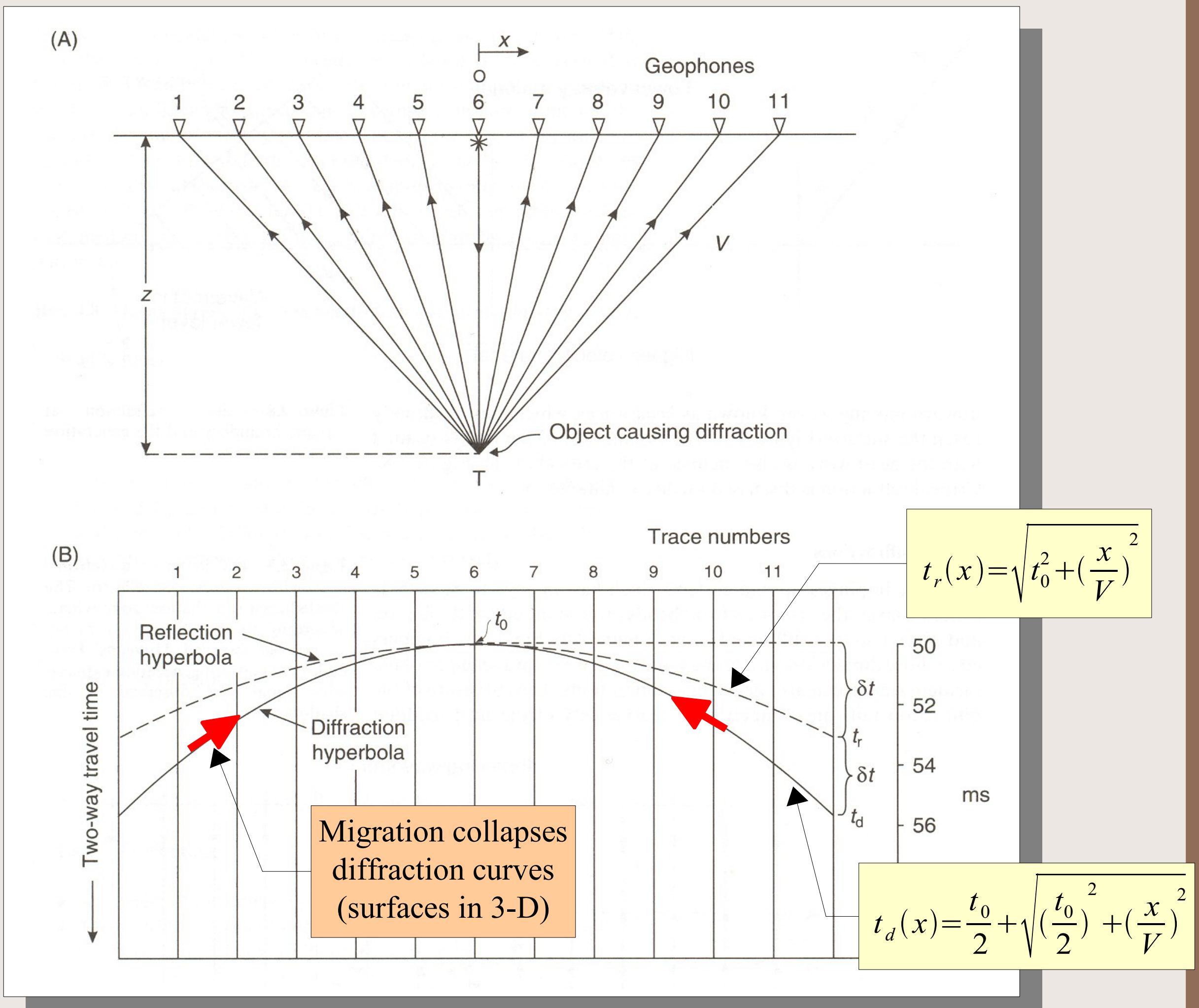


Exercise: derive the sensitivities of NMO correction to δt, δV, and δx:

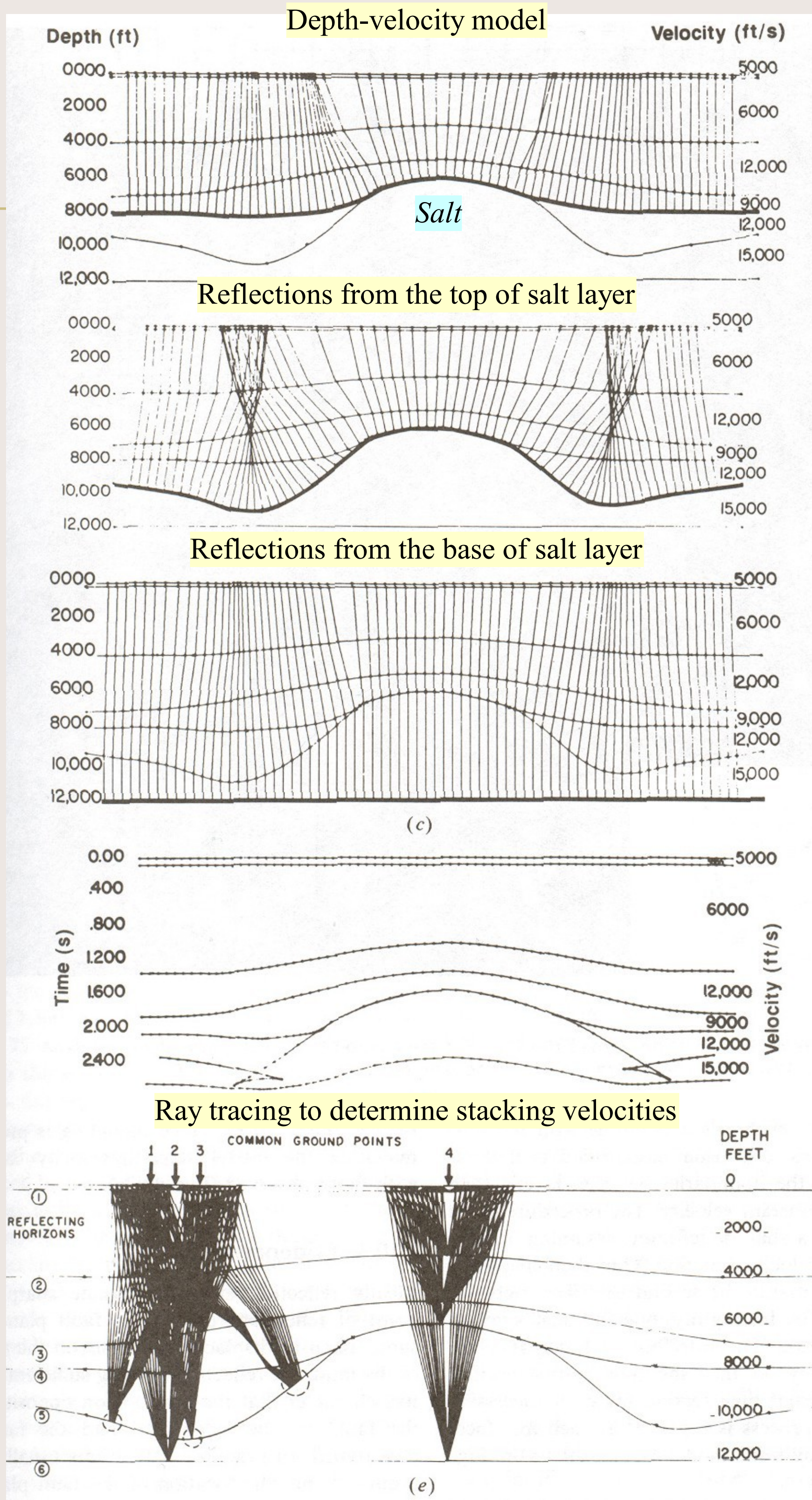
$$\partial(\delta t_{NMO})/\partial t,\ \partial(\delta t_{NMO})/\partial V,\ \partial(\delta t_{NMO})/\partial x.$$

Migration

- A simplified variant of '*inversion*'
  - Transforms the 'time section' into true 'depth image'.
- Establishes true positions and dips of reflectors.
- Collapses diffractions.

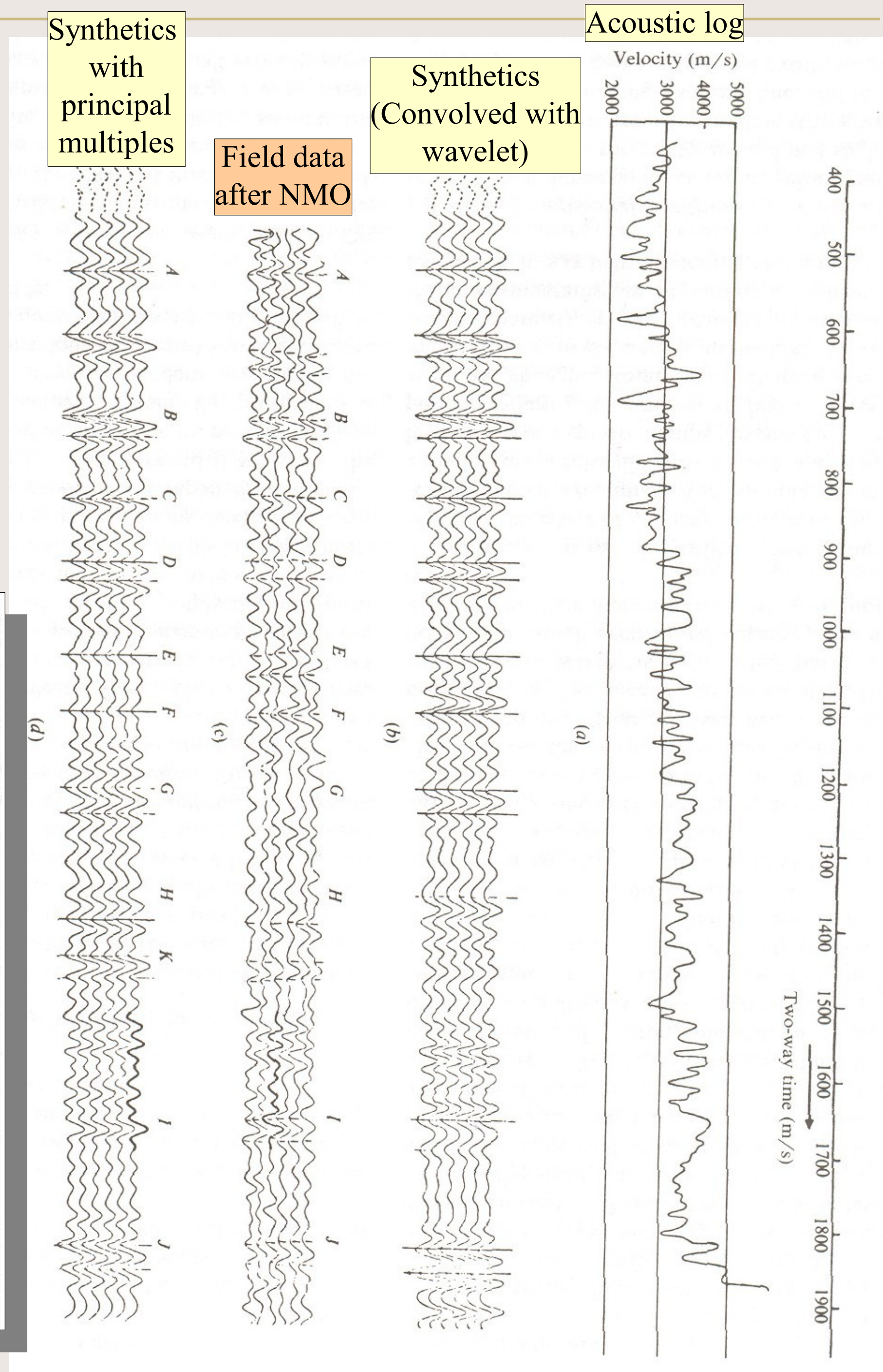


Modeling


Depth-velocity model
Depth (ft)
Velocity (ft/s)
Salt
Reflections from the top of salt layer
Reflections from the base of salt layer
(c)
Time (s)
Velocity (ft/s)
Ray tracing to determine stacking velocities
COMMON GROUND POINTS
DEPTH FEET
REFLECTING HORIZONS
(e)

Synthetic seismograms

Proceed



Synthetics is spliced into CMP section for comparison