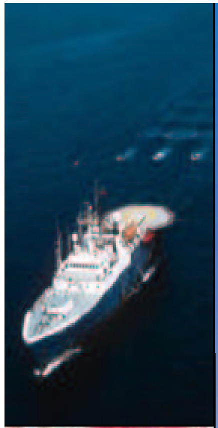
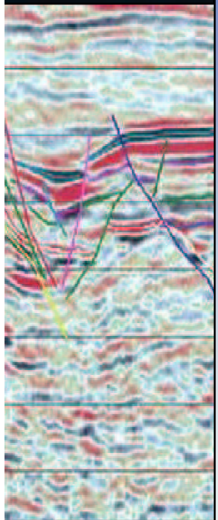
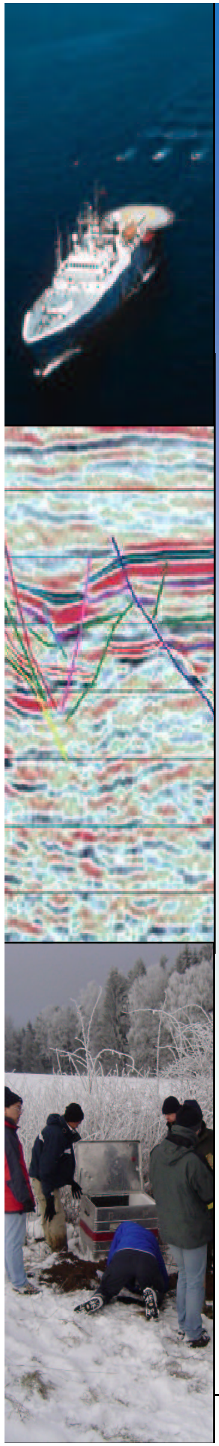


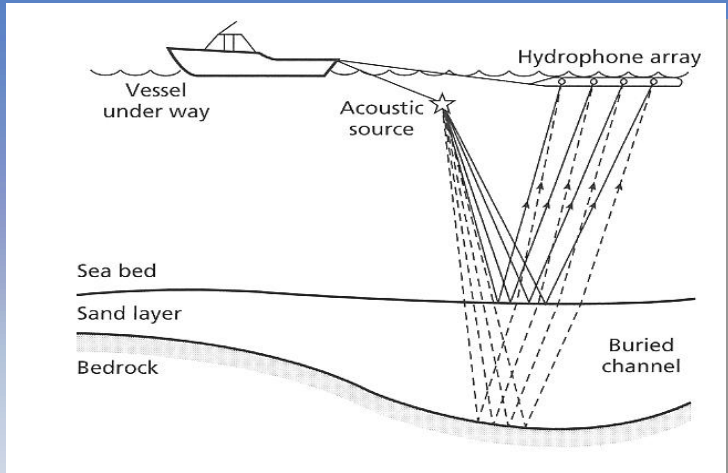


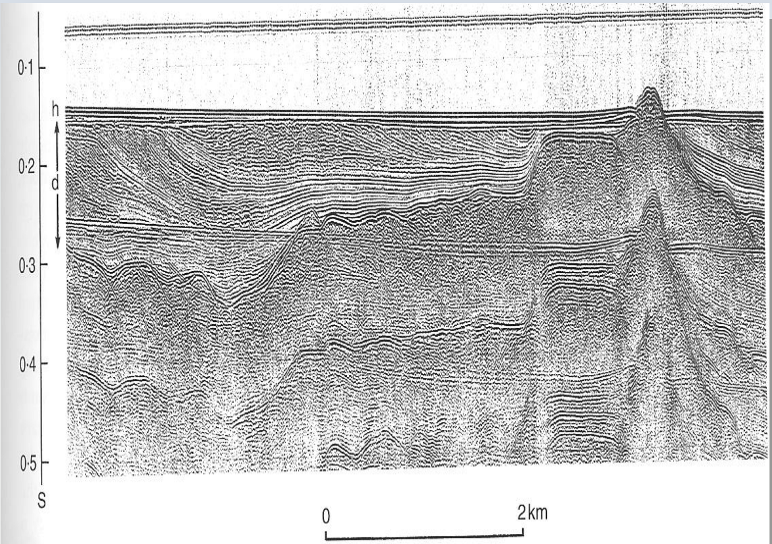
Seismic Reflection Surveying

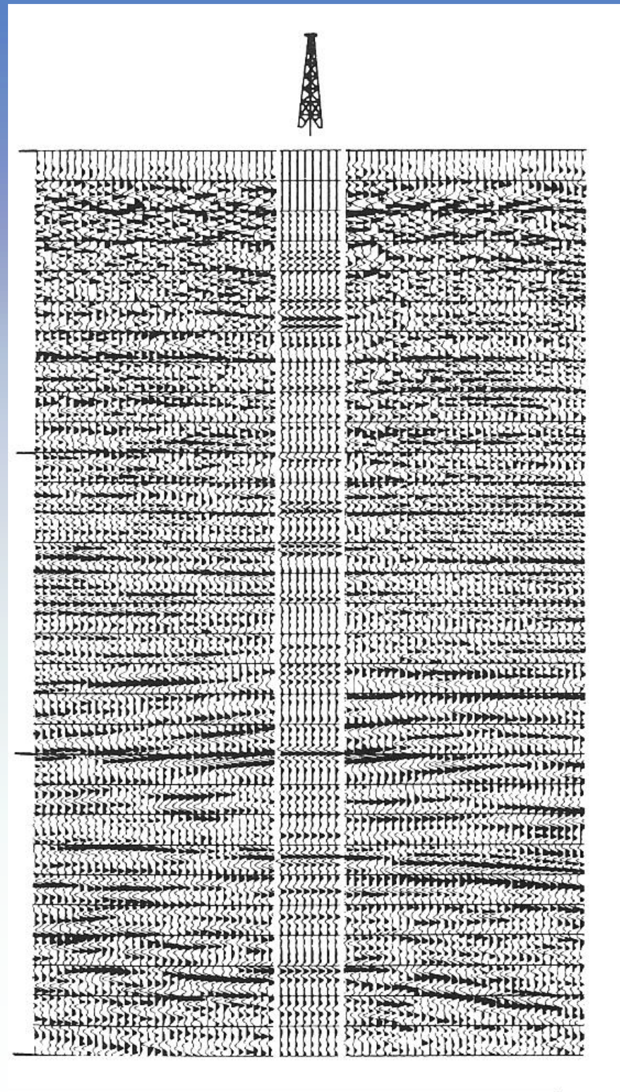
- Reflected ray paths
  - Horizontal reflectors
  - Reflector sequence
- Reflection seismograms
  - Shot gather
  - CMP gather
- Corrections and Filtering
- Migration of reflection data
- Interpretation
  - Structural analysis
  - Stratigraphy

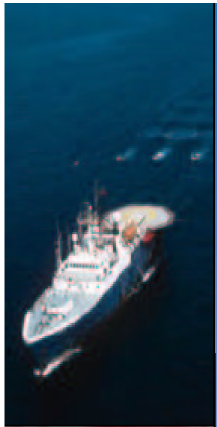
From a seismic experiment to drilling

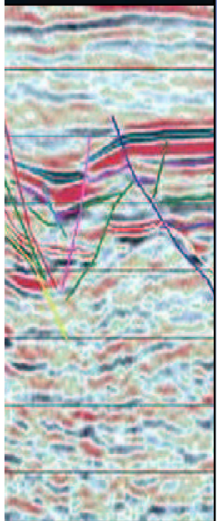




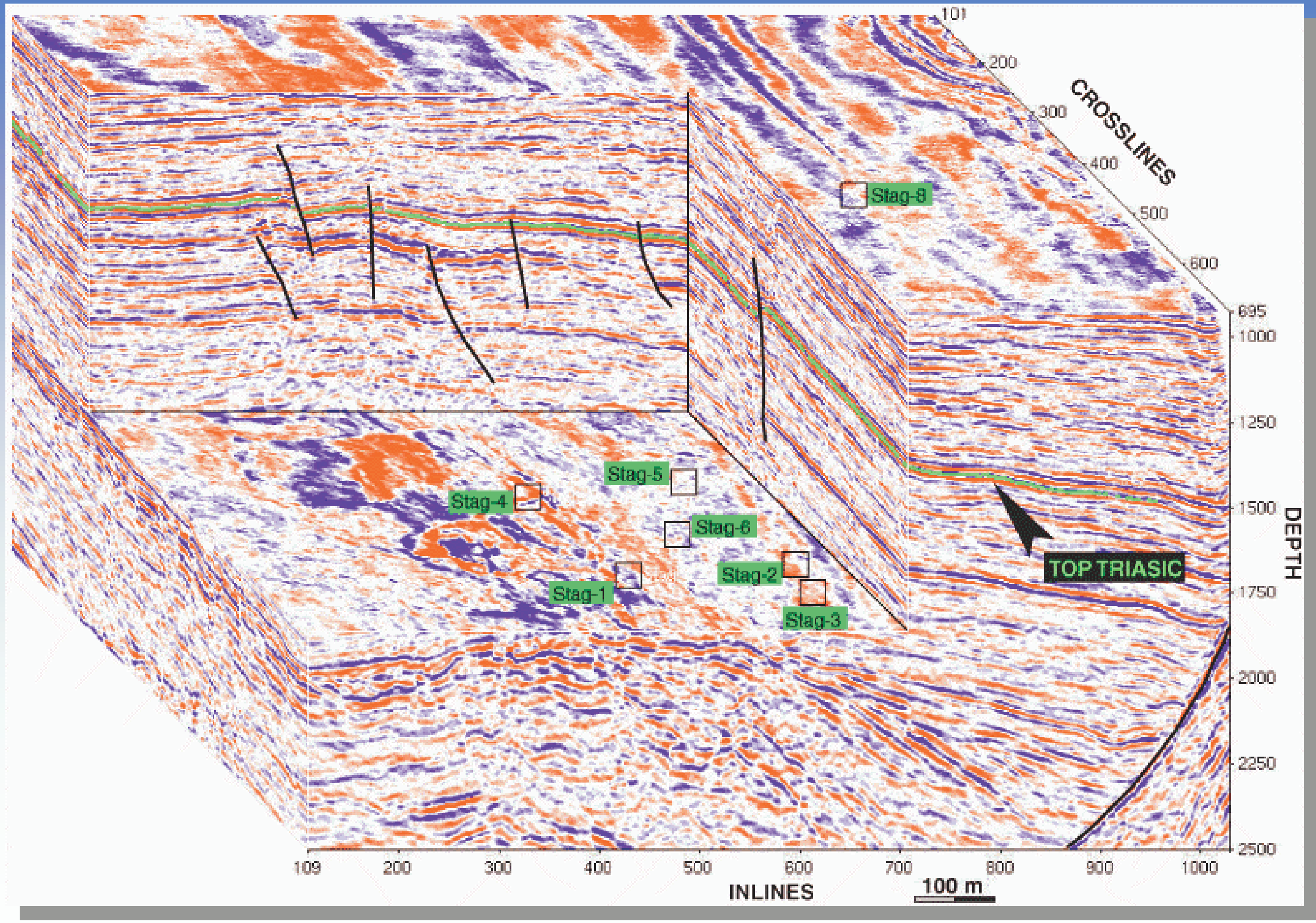


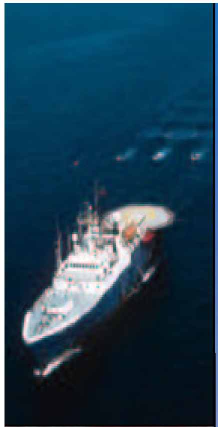


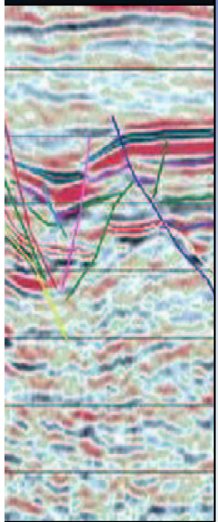




3D seismic section



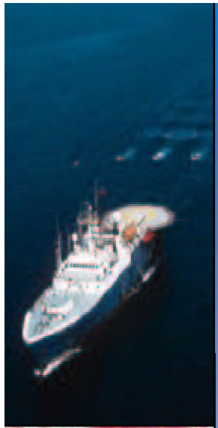
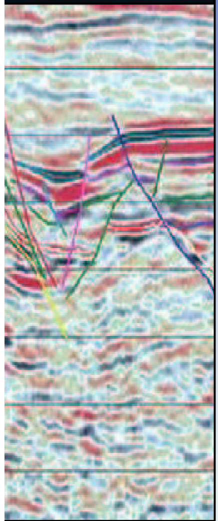




Seismic reflection methods

Seismic reflection surveying is the most widely used geophysical technique!

- in many cases the assumption of layered media is valid (small scale to large scale)
- Raw data can be processed so that an „image" of the subsurface emerges (migration)
- Data processing is today done by computers (not the interpretation!)


Reflected ray paths

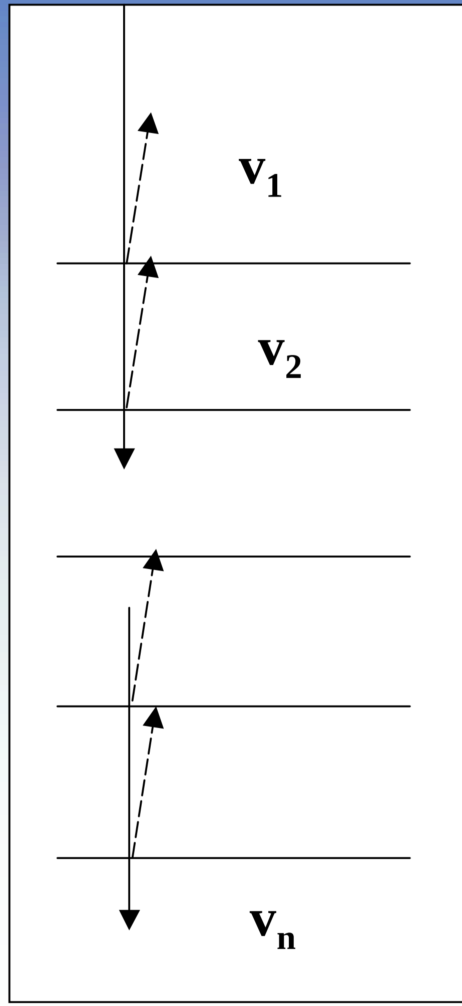
Interval velocity

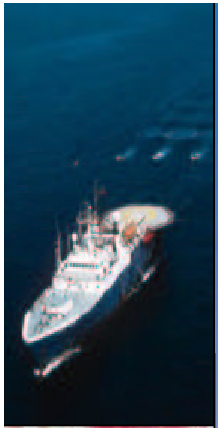
Velocity of one layer or an average Velocity over a depth section. The interval velocity is defined as:

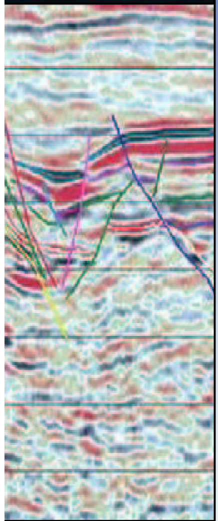
$$v_i = \frac{z_i}{\tau_i}$$

... and the average velocity:

$$\overline{V} = \frac{\sum_{i=1}^{n} z_i}{\sum_{i=1}^{n} \tau_i} = \frac{\sum_{i=1}^{n} v_i \tau_i}{\sum_{i=1}^{n} \tau_i} = \frac{Z_n}{T_n}$$



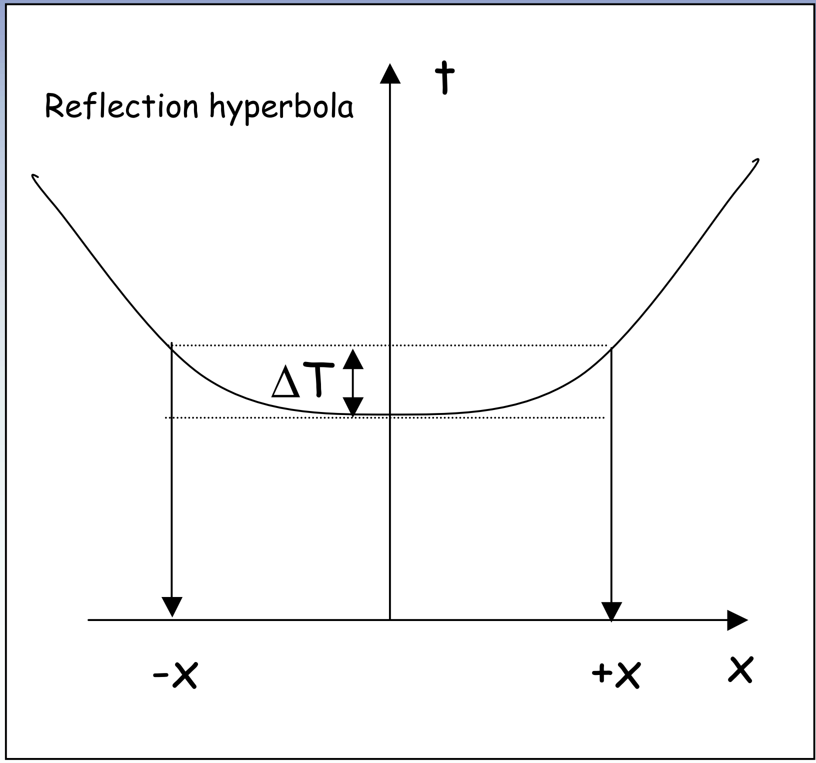




Reflection travel times

Moveout

The arrival times t(x) of reflections from an interface at depth z as a function of offset x are given as

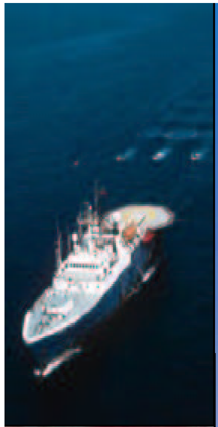


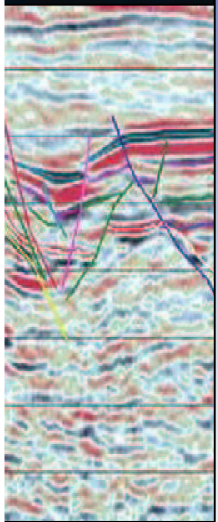
$$t(x) = \frac{1}{v}\sqrt{x^2 + 4z^2}$$

$$t^2 = \frac{4z^2}{v^2} + \frac{x^2}{v^2} = t_0^2 + \frac{x^2}{v^2}$$

$$\Delta T = t_x - t_0 \approx \frac{x^2}{2V^2 t_0}$$

Normal moveout (NMO)



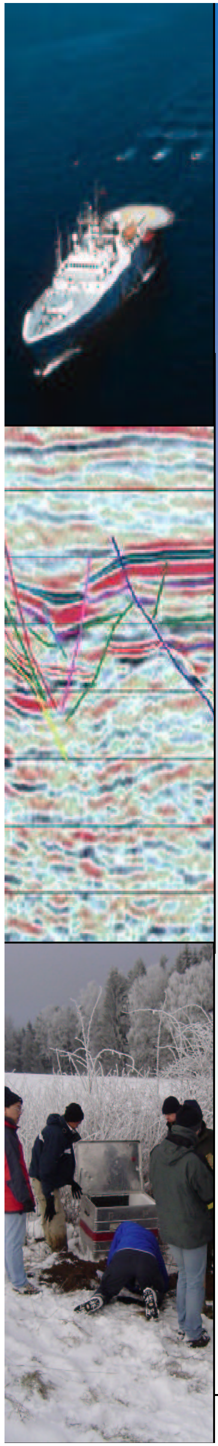


Reflector sequence
rms-velocity

Root-mean square (rms) velocity (better approximation than the average velocity) down to interface n with v_i the interval velocity, τ_i the one-way travel time in layer i:

$$\overline{V} = \left[\frac{\sum_{i=1}^{n} v_i^2 \tau_i}{\sum_{i=1}^{n} \tau_i} \right]^{1/2}$$

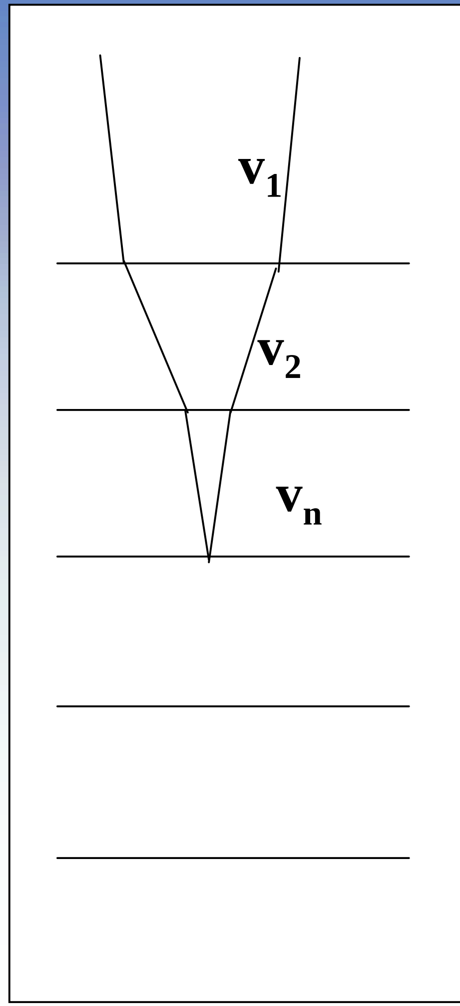
We assume here offset distances that are small compared to the reflector depths! Our goal: How can we estimate the velocities of the individual layers?

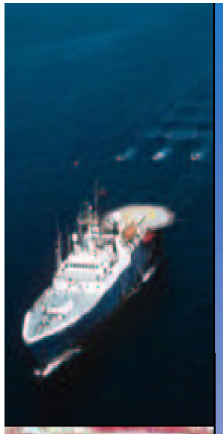


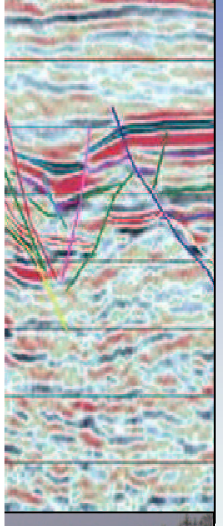
Reflector sequence
Dix formulae

The individual NMO can be used to estimate rms velocity down to a certain depth and values at different depths to estimate the interval velocities v_n (Dix formula)

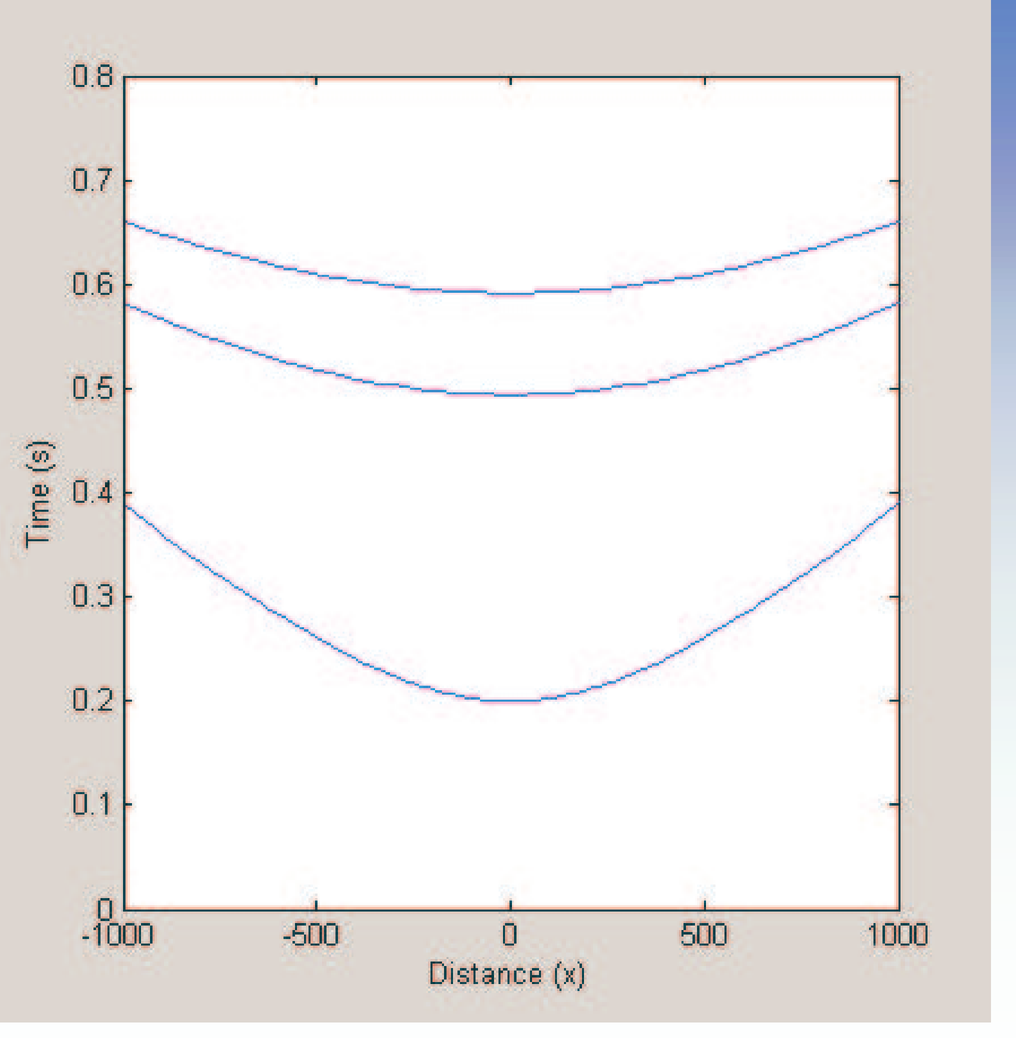
$$v_n = \left[\frac{V_{rms,n}^2 t_n - V_{rms,n-1}^2 t_{n-1}}{t_n - t_{n-1}} \right]^{1/2}$$

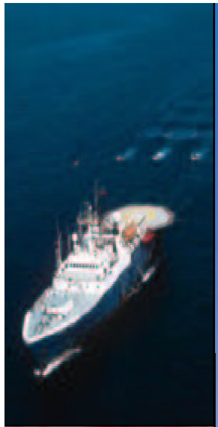


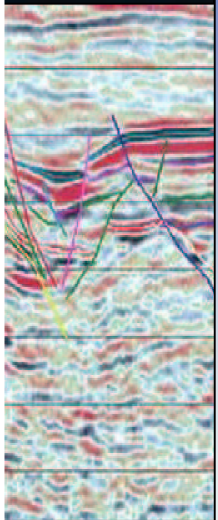




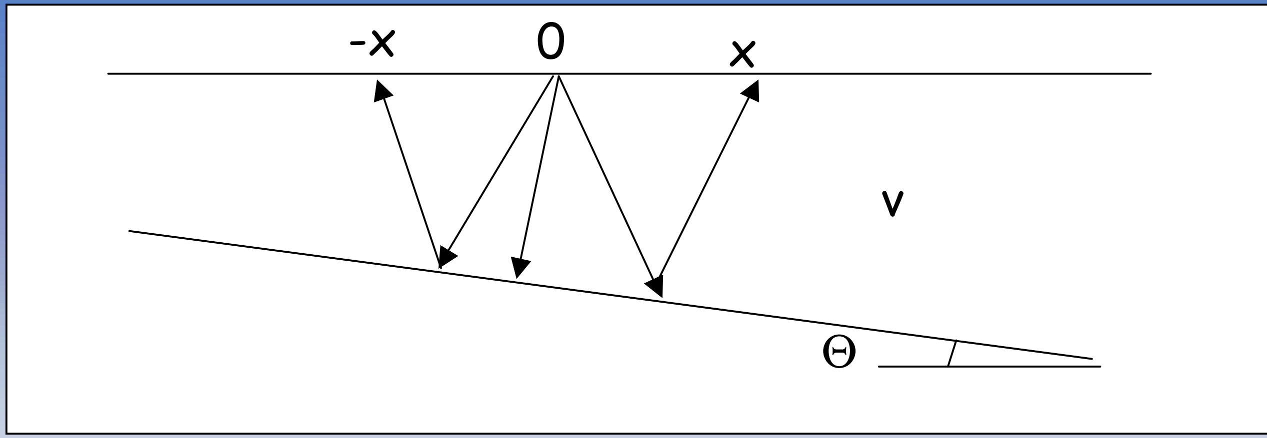
Travel-time curves







Dipping layers - Dip moveout

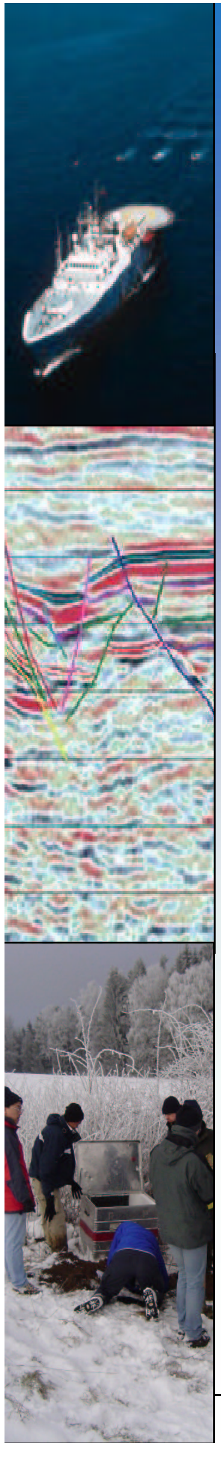


A dipping reflector leads to asymmetric arrival times for shots recorded in different directions. The dip moveout is defined as the difference in travel times at –x and x: Knowing the velocity v, the angle Θ can be estimated:

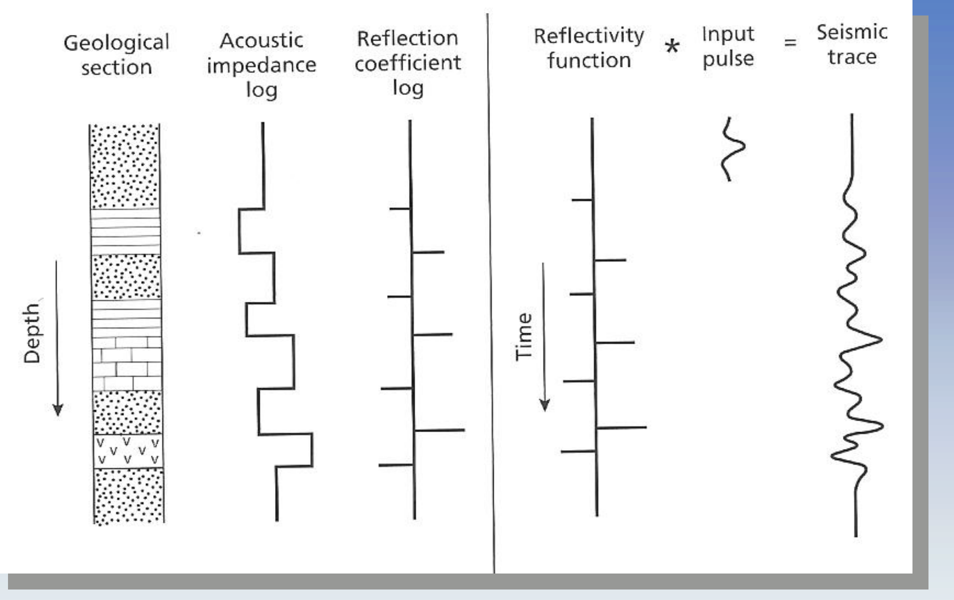
$$\Delta T_d = t_x - t_{-x}$$

$$\Delta T_d = 2x \sin\Theta / V$$

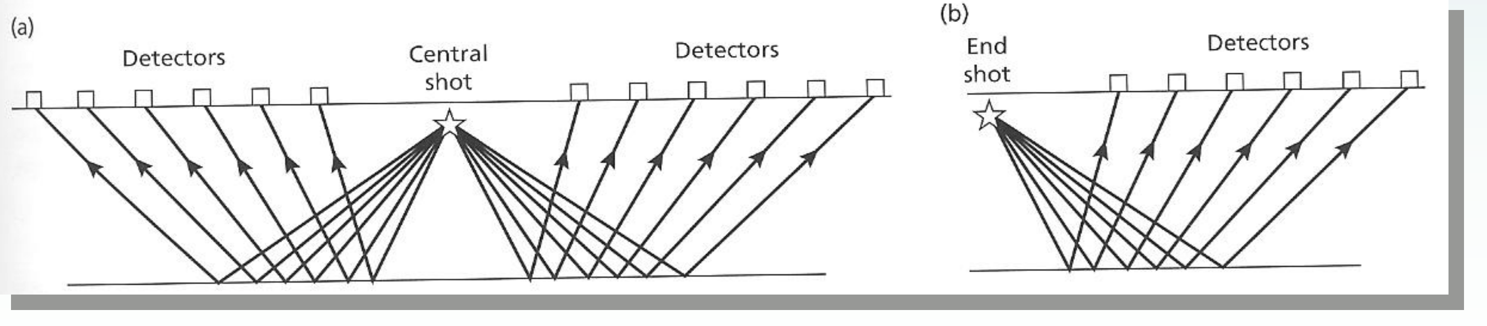
$$\Theta \approx V \Delta T_d / (2x)$$



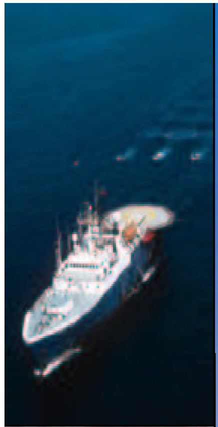
Convolutional model of reflection seismograms

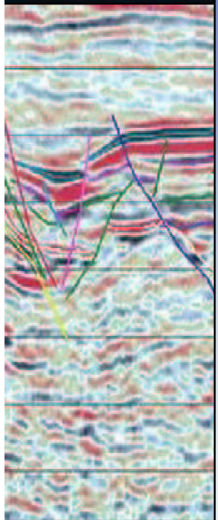


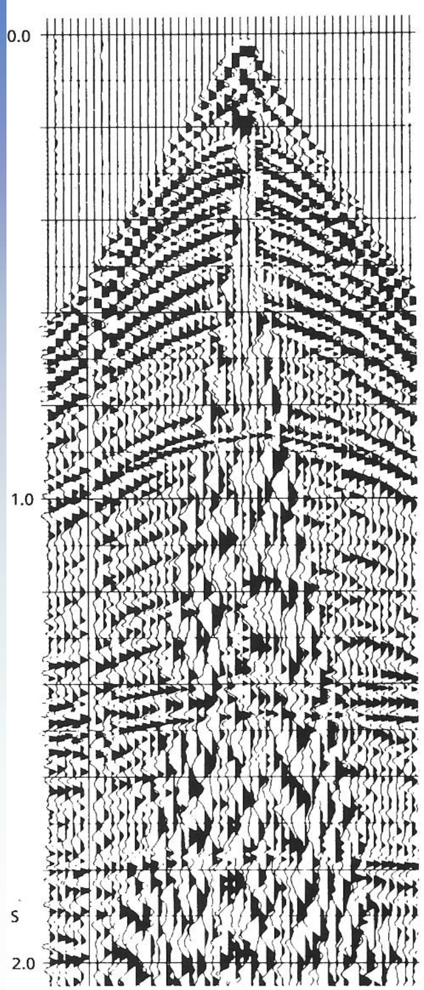
Shot-detector configurations



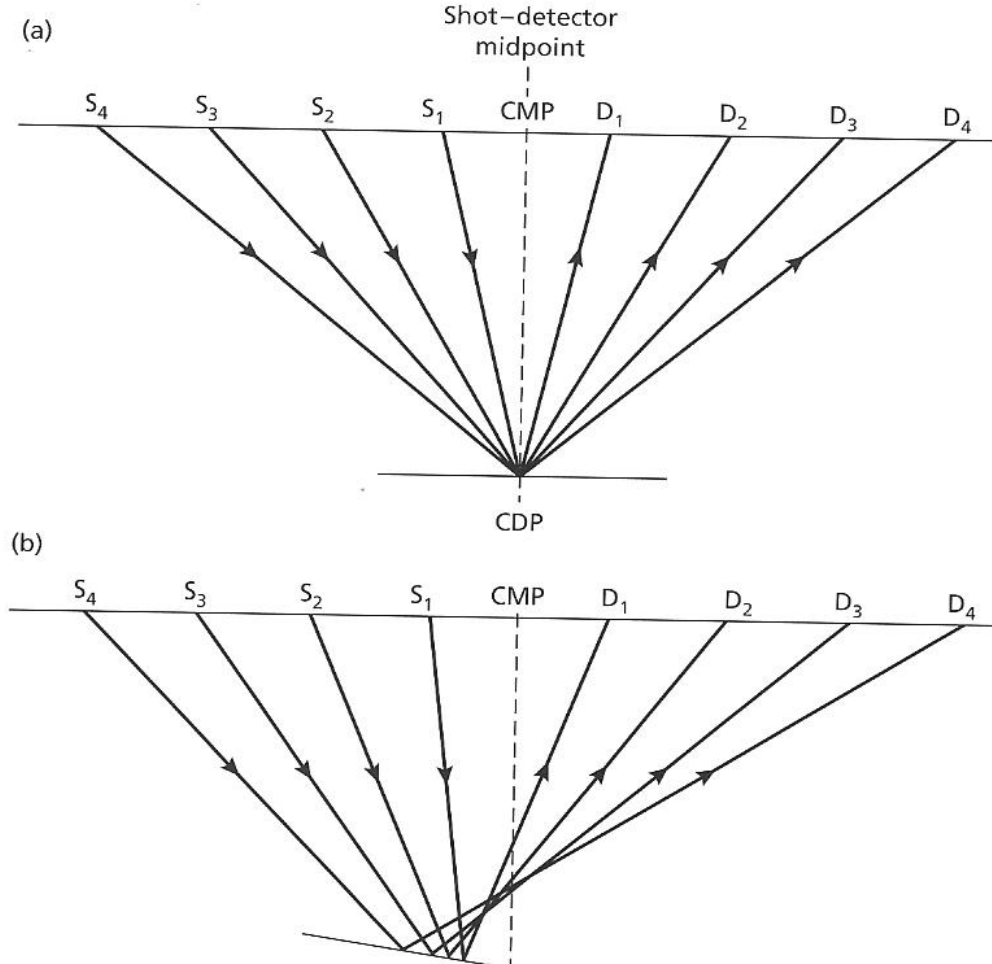
The shot gather
common-mid(depth)-point



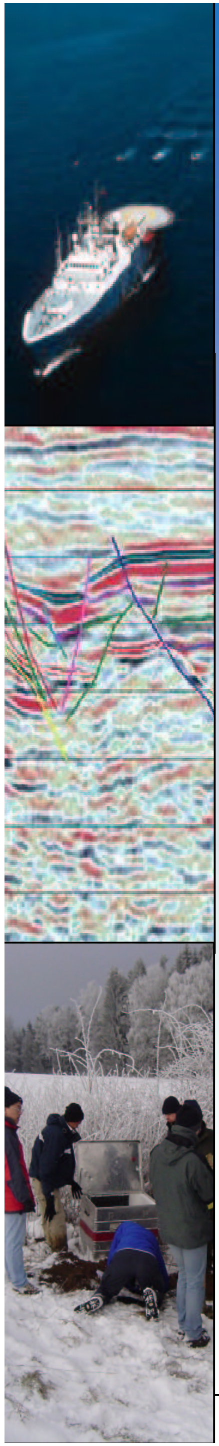




.8 A draped seismic record of a shot gather from a split



Vertical and horizontal resolution
Fresnel zone

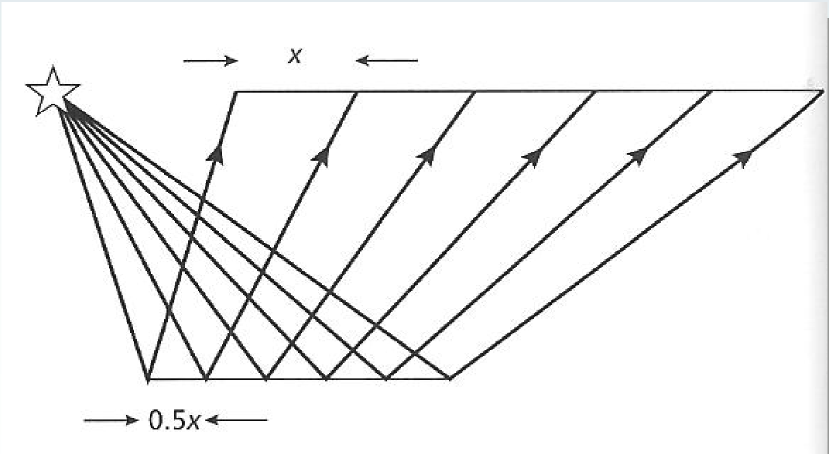


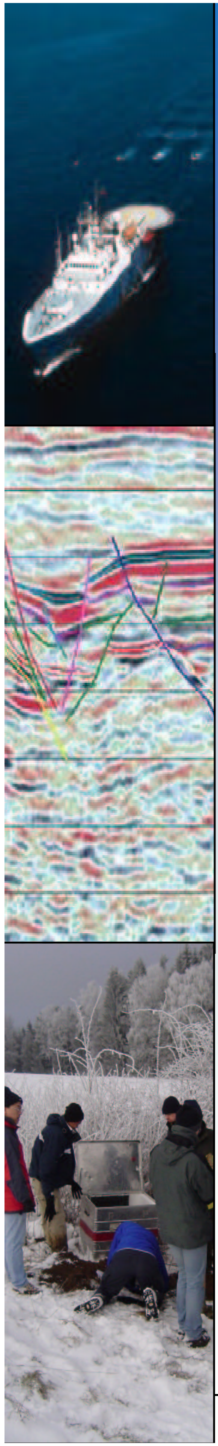
Vertical Resolution of a seismic pulse: $\frac{1}{4}$-1/8 of a wavelength

Example: v=2km/s, 50Hz -> resolution 10m

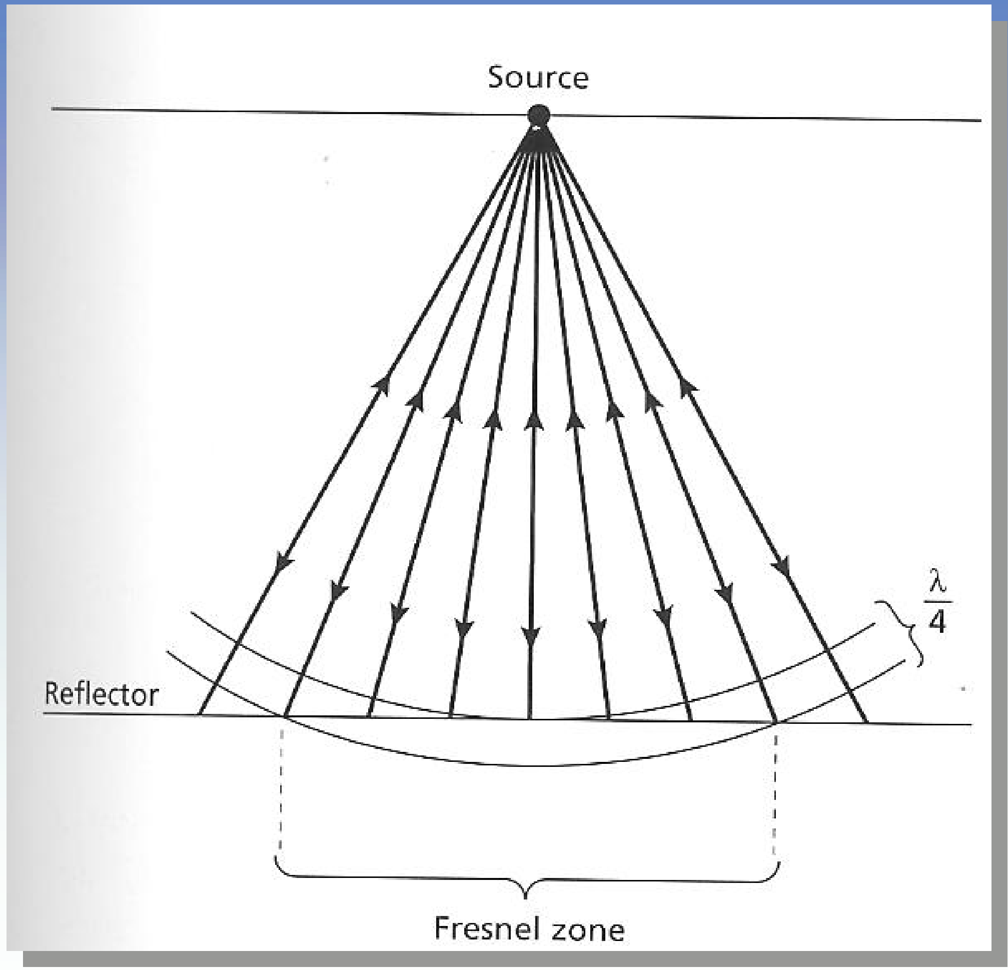
-> Sharpening of the pulse desirable -> Deconvolution -> towards impulse response of medium

Horizontal Resolution determined by the detector spacing and the Fresnel zone: $w=(2z\lambda)^{1/2}$ for $z \gg \lambda$.

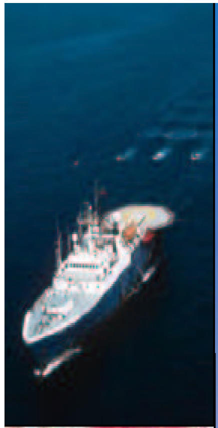


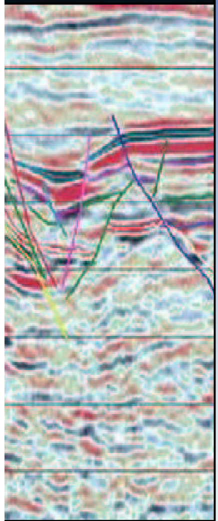


Vertical and horizontal resolution
Fresnel zone



CMP surveying
multi-channel reflection survey

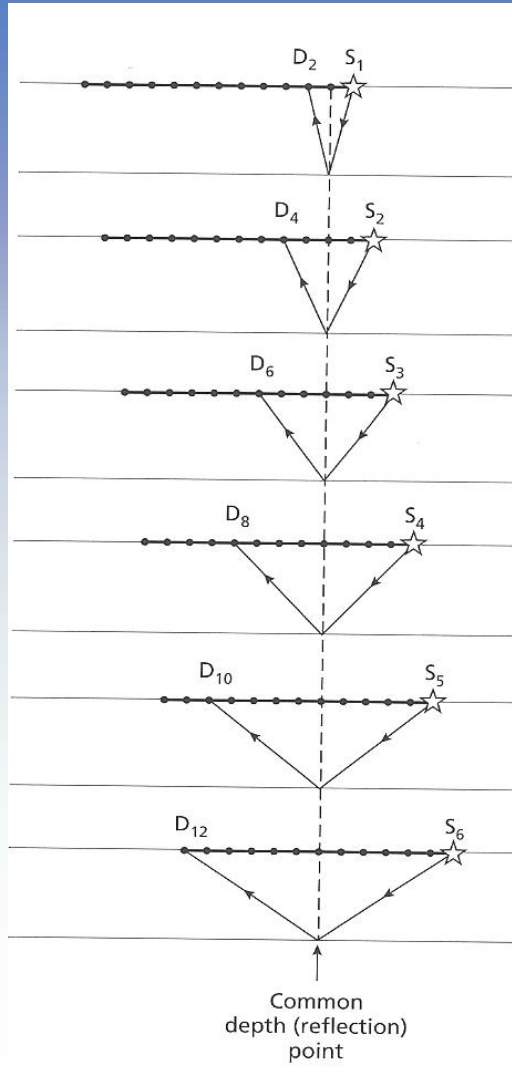


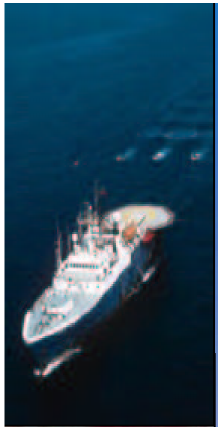
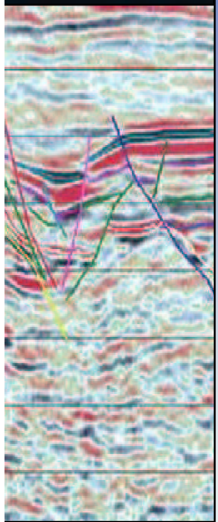


With appropriate source-receiver geometry seismic records can be stacked thereby considerable improving the signal-to-noise ratio!

The fold of a CMP gather is determined by m=N/2n, where N is the number of geophones, n is the number of array spacings the source is moved between shots. The improvement of the S/N-ratio from stacking m traces is sqrt(m).

Example: N=96, n=8: -> 96/16=6-fold. Improvement of S/N ratio is sqrt(6)≈2.5

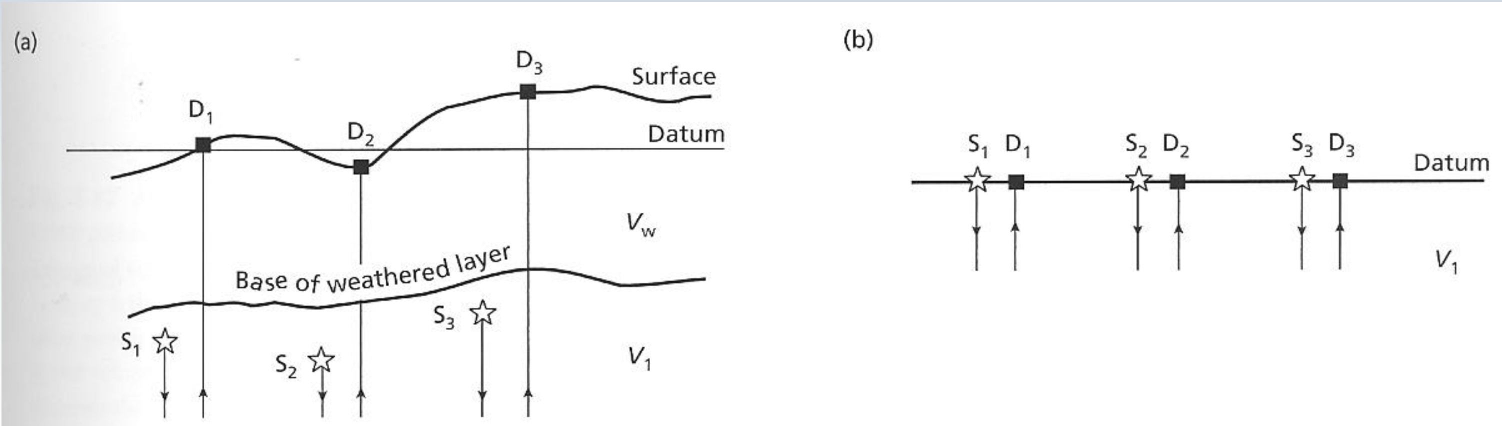



Static Corrections

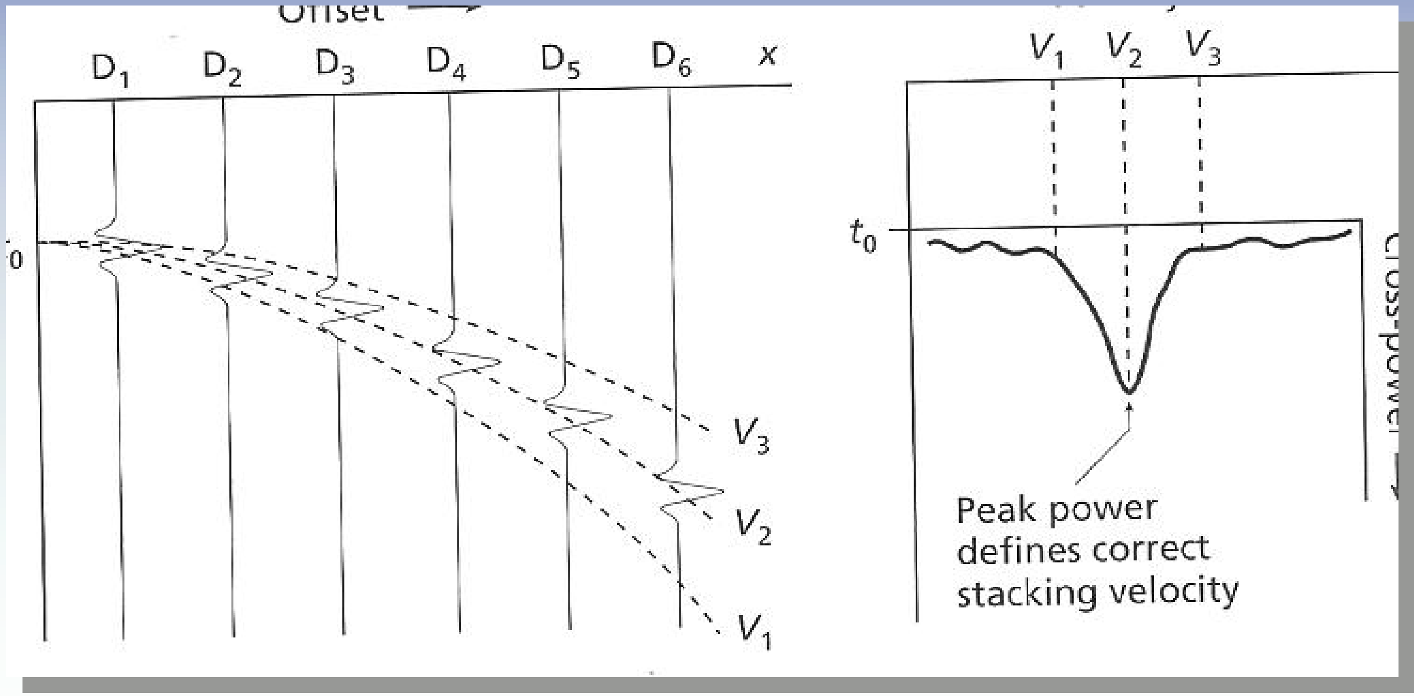
In general sources and receivers are not on the same level. We have to correct for

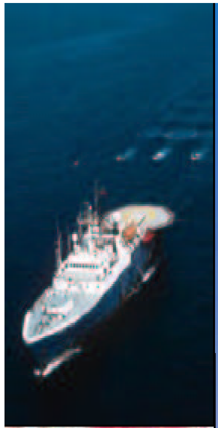
- Elevation
- Weathering layer

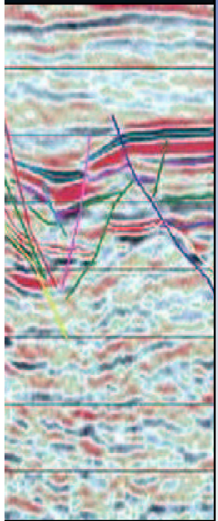


Dynamic (NMO) Corrections

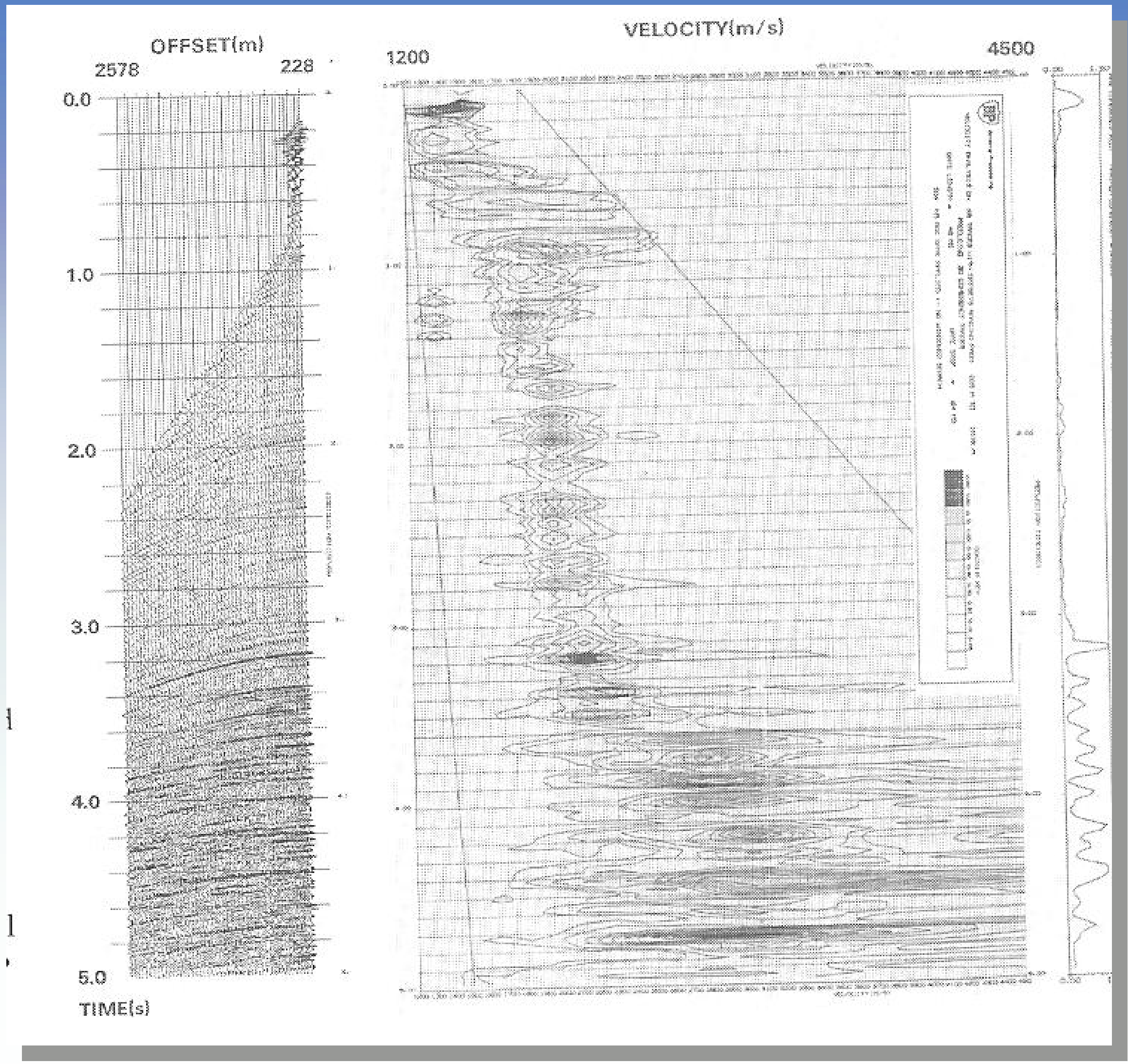
... are basically the compensation for the moveout of a particular reflection.



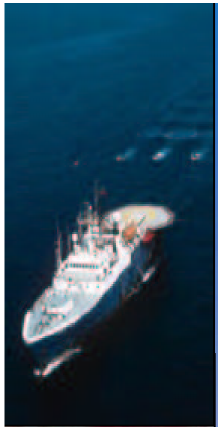


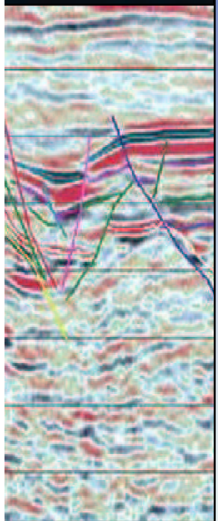


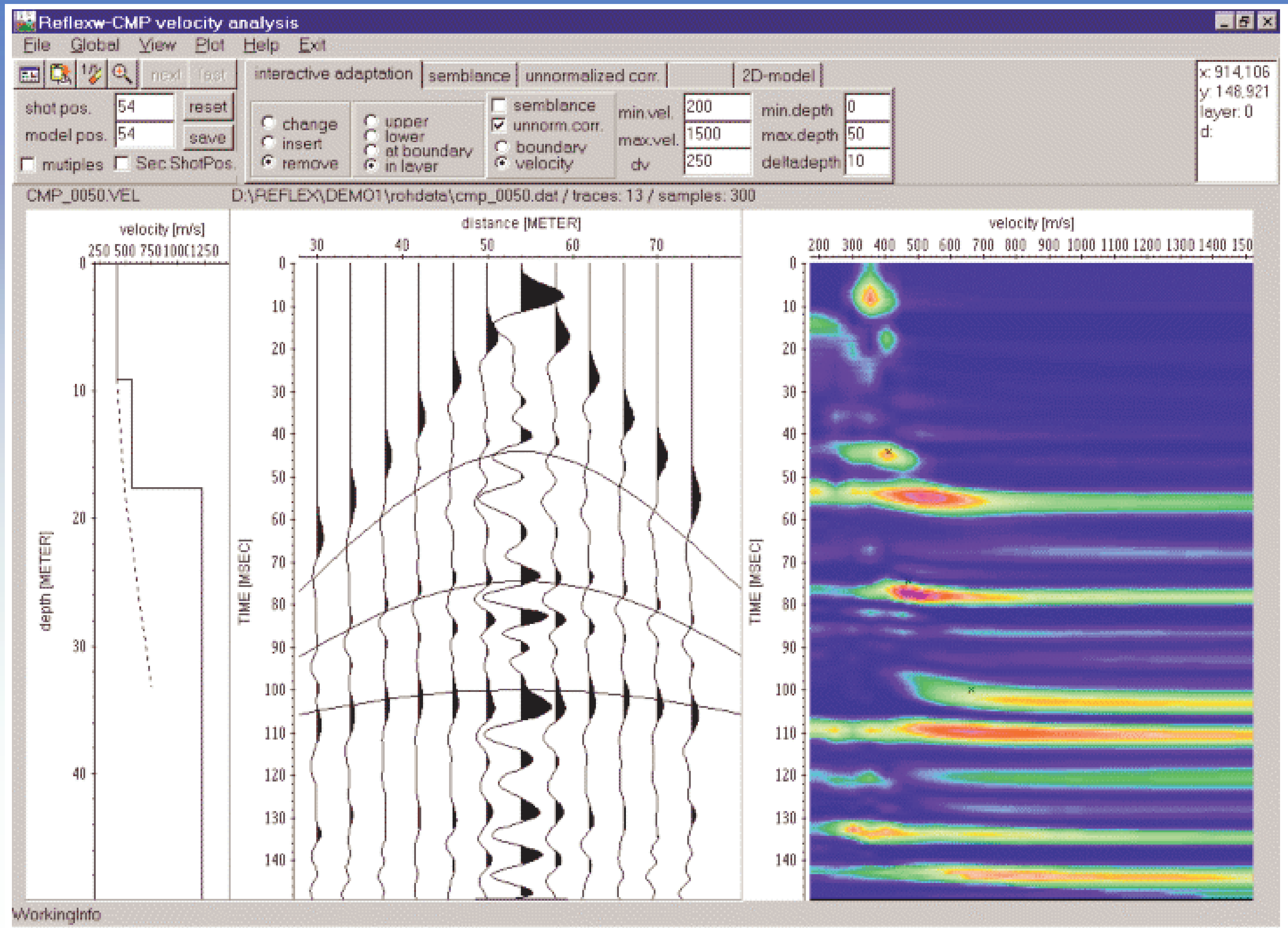
Dynamic (NMO) Corrections

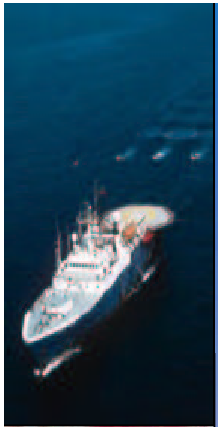


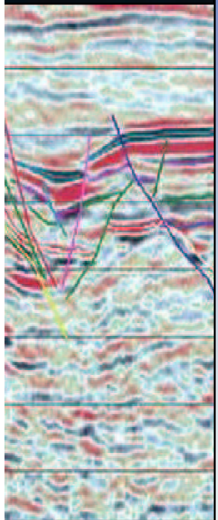
NMO moveout (CMP) analysis







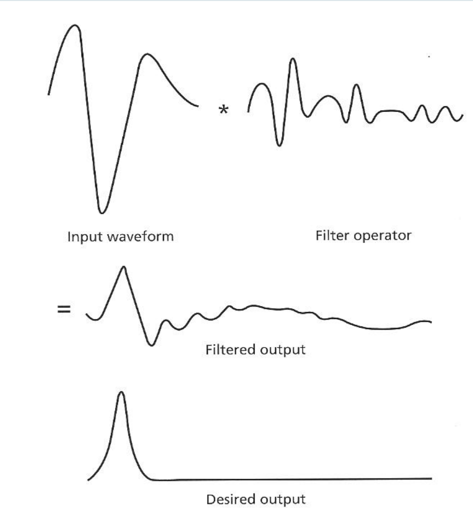


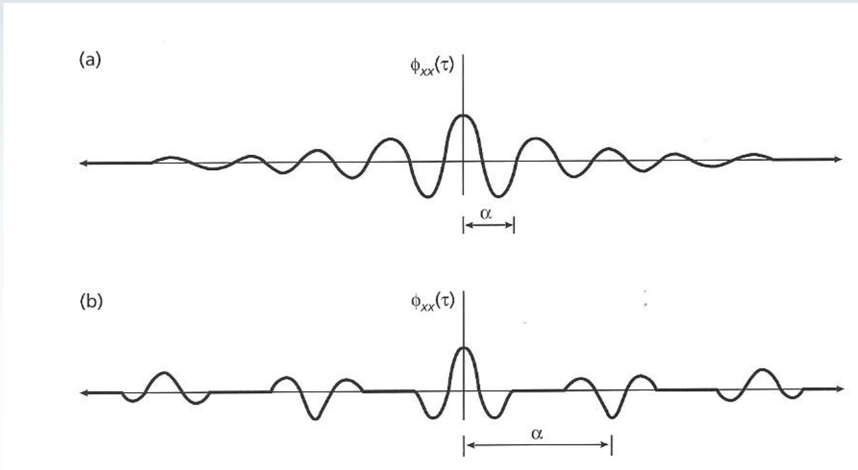


(Inverse-) filtering seismic data
Deconvolution

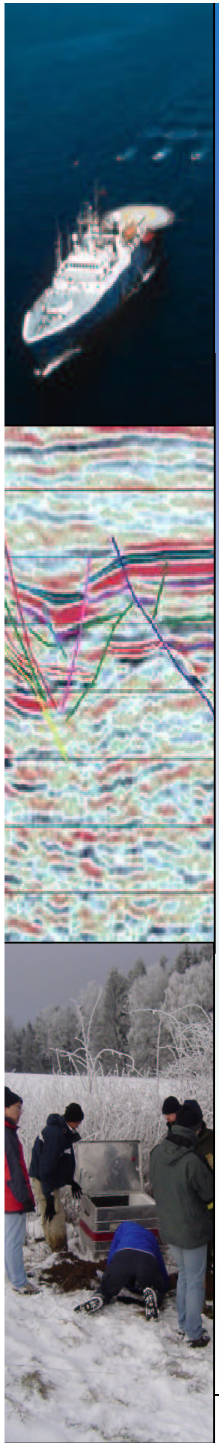
To improve the (visual) quality of the seismograms for imaging one attempts to suppress all unwanted signals

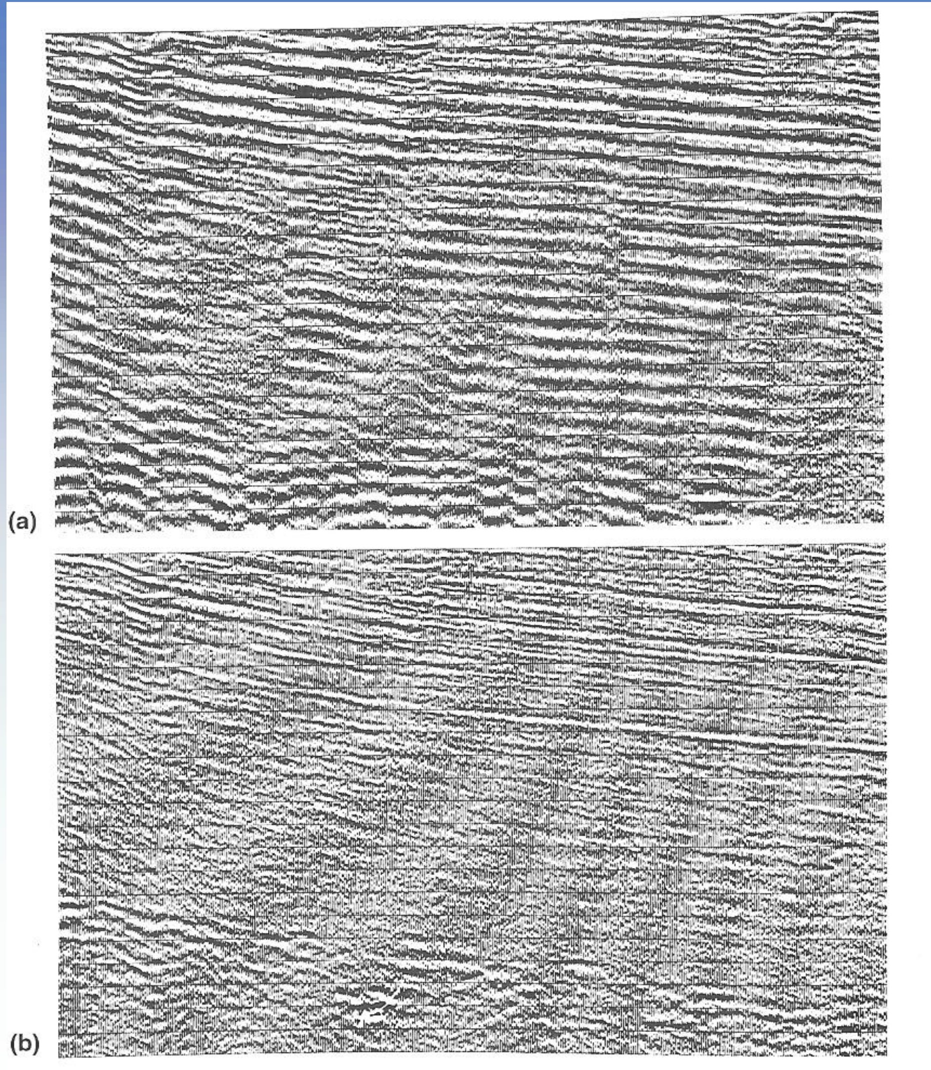
- Dereverberation (to remove ringing e.g. of the water layer, multiples)
- Deghosting (remove energy from upward-and-reflected signals from the source)
- Whitening (equalize amplitude of frequency components, what is the result on the time signal?)





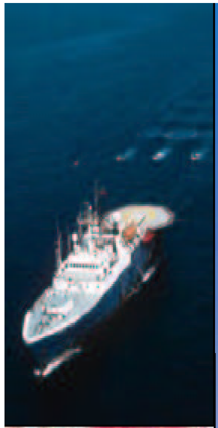
Filtering - example

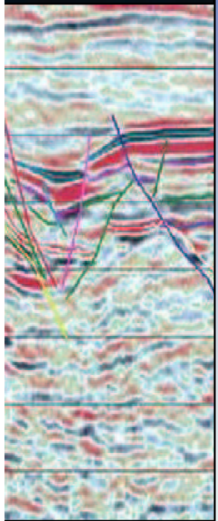




Before

After





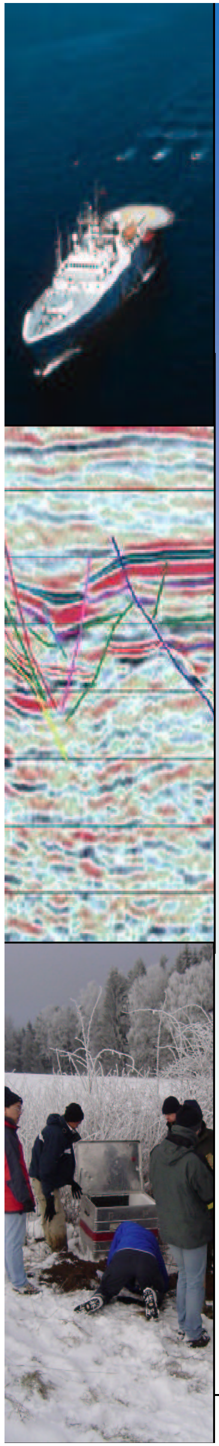
Migration

Migration is the concept of converting seismic sections (seismograms) into an image of the subsurface, repositioning reflection events under their correct surface location and at a corrected vertical reflection time.

Time migration: Migrated seismic sections have time (two-wave travel time) as vertical dimension.

Depth migration: Migrated reflection times are converted into reflector depths with appropriate velocity information.

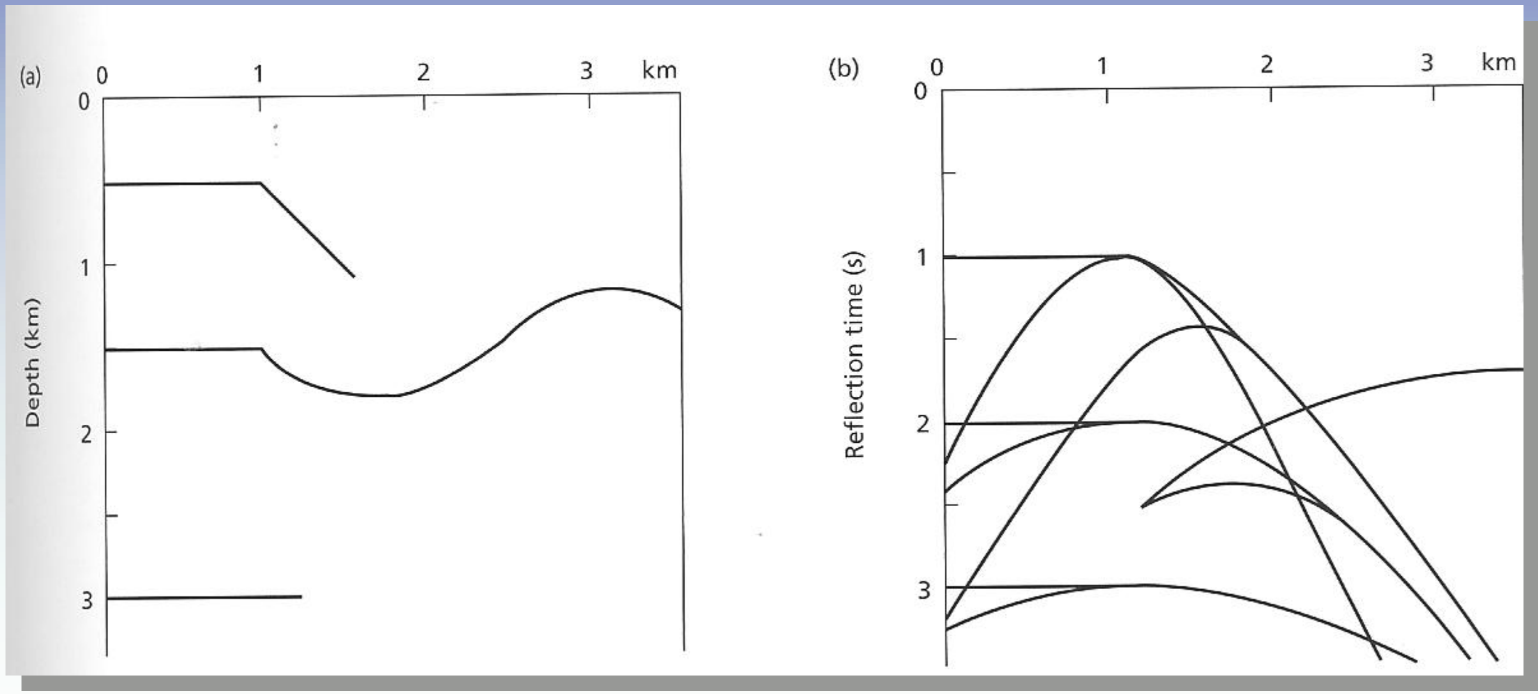
- Migration may remove distorting effects of dipping reflectors
- Migration may remove diffracted arrivals (corners, faults)

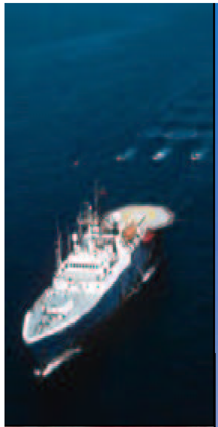


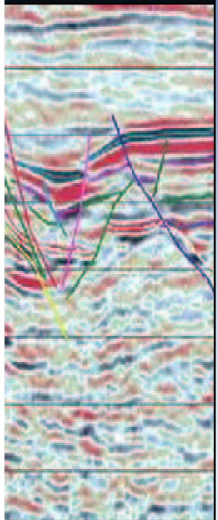
Migration

Reflectors

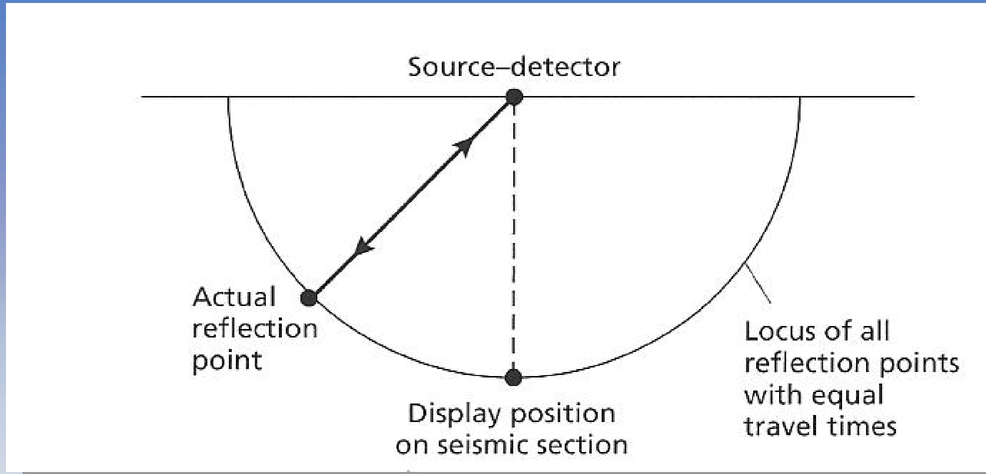
Seismic response

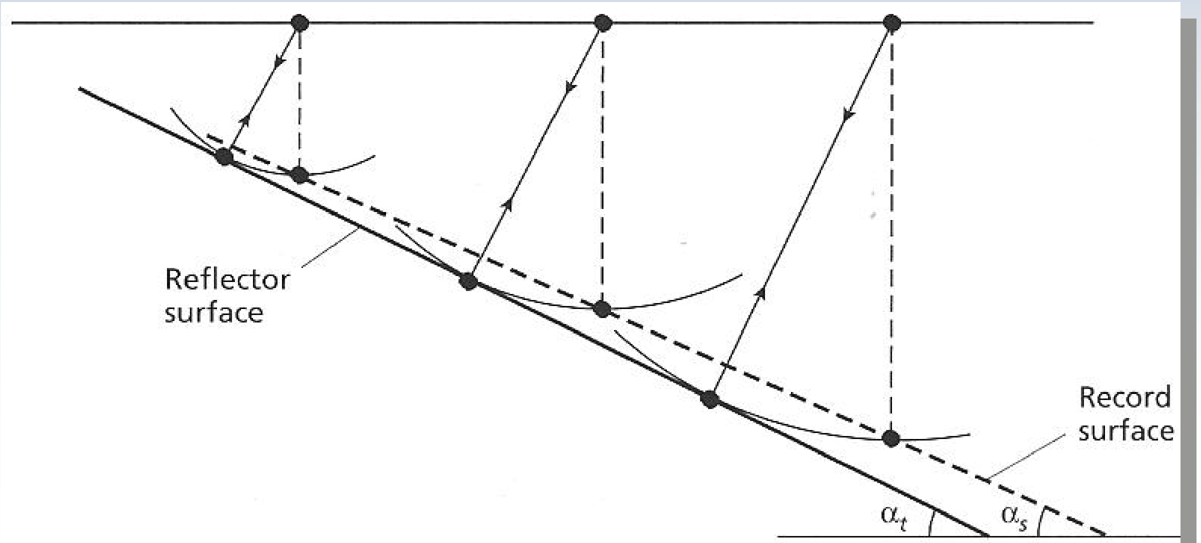


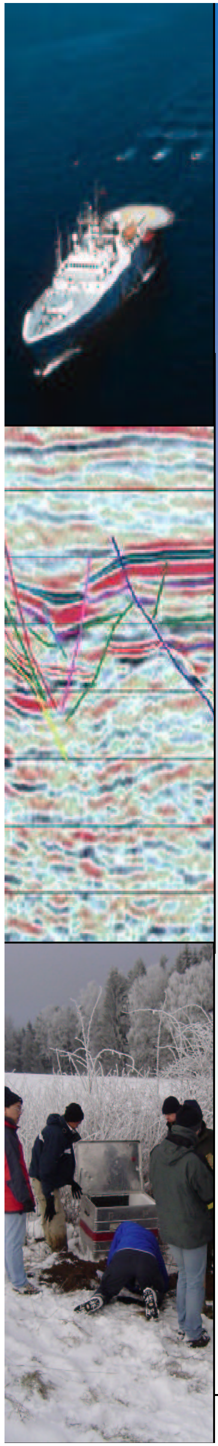




Wavefront method

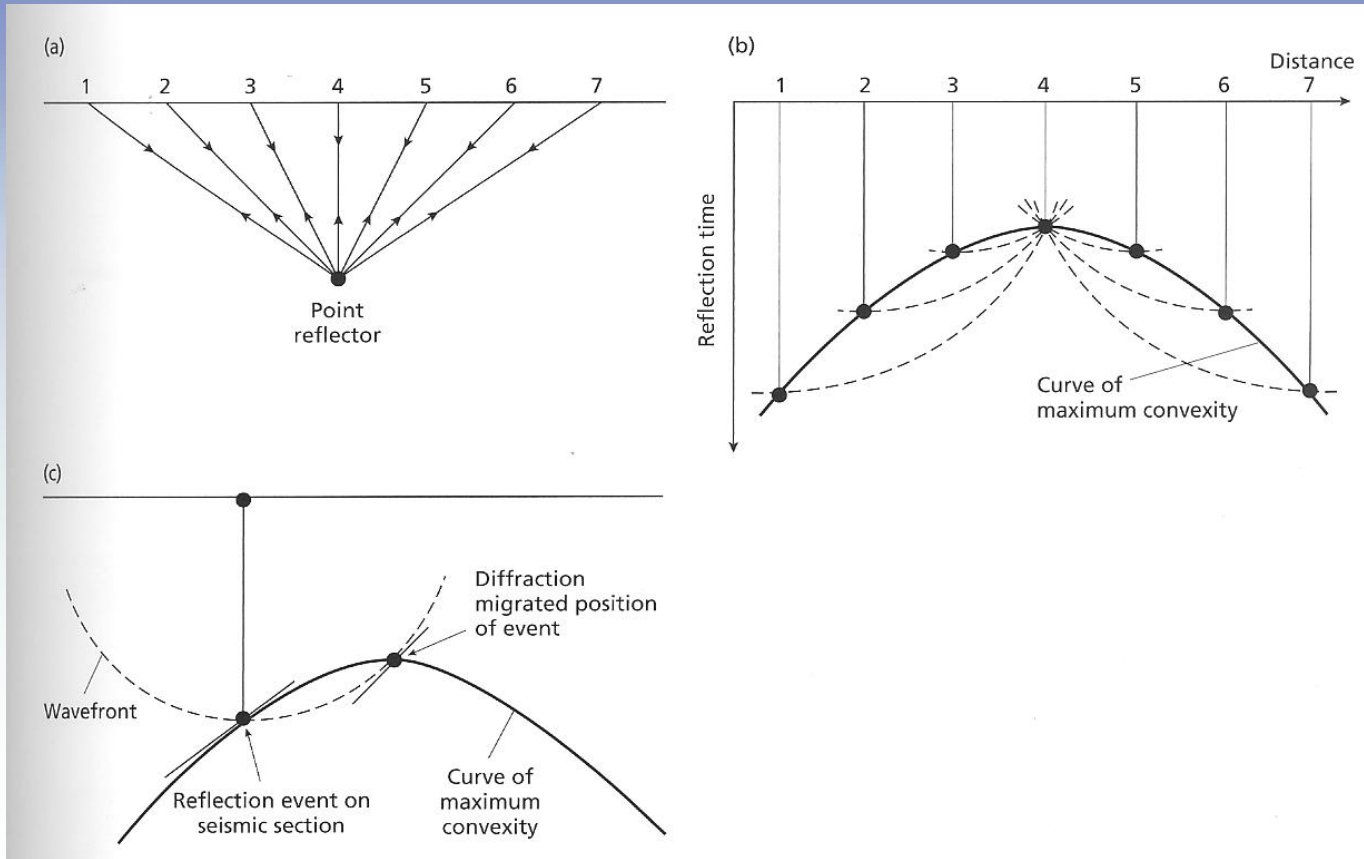


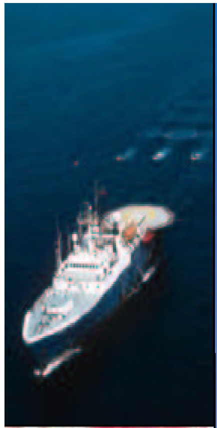


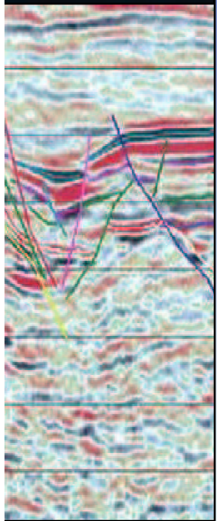


Diffraction Migration

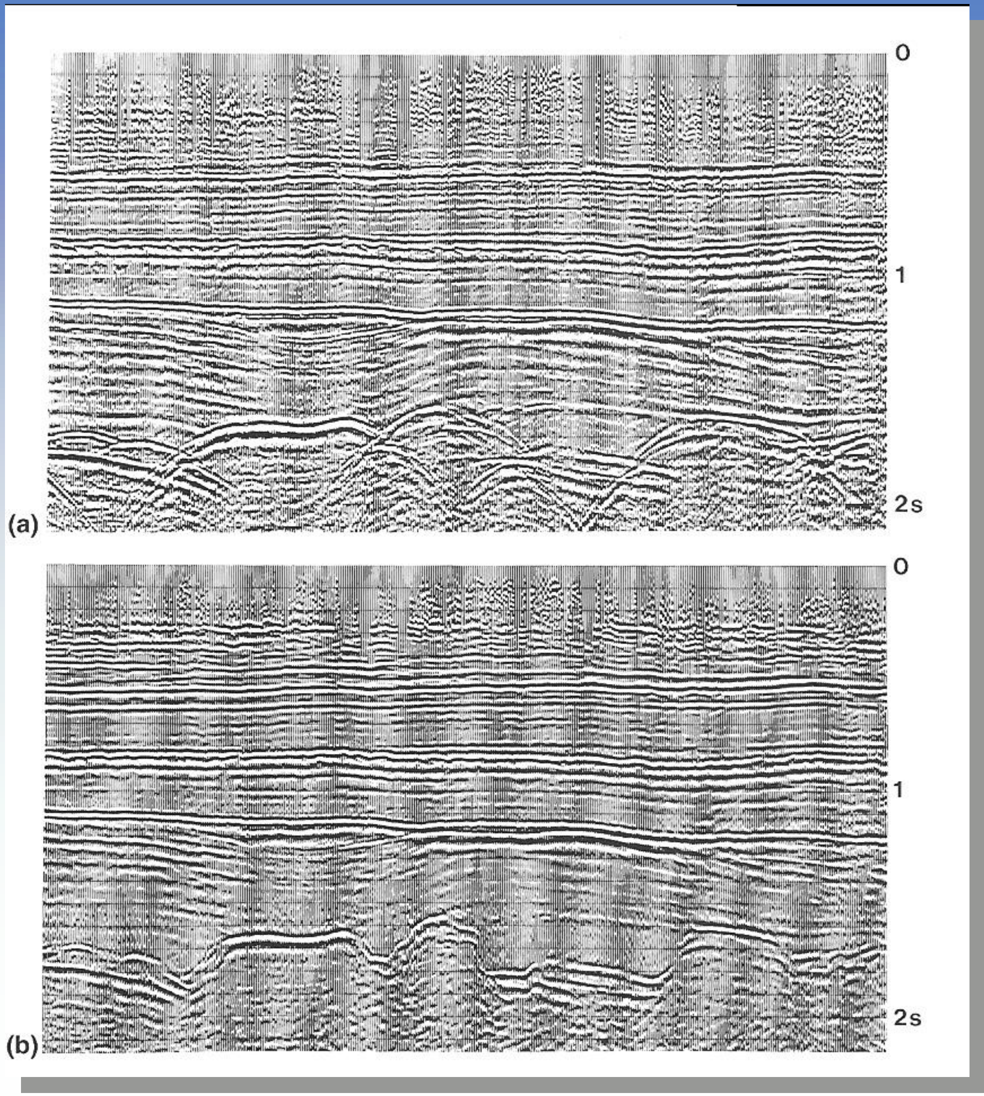
The assumption is that any continuous reflector is composed of a series of (closely spaced) reflection points (diffractors).





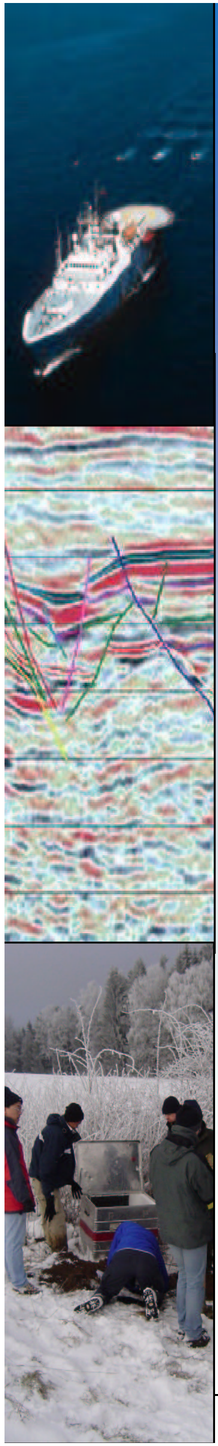


Migration

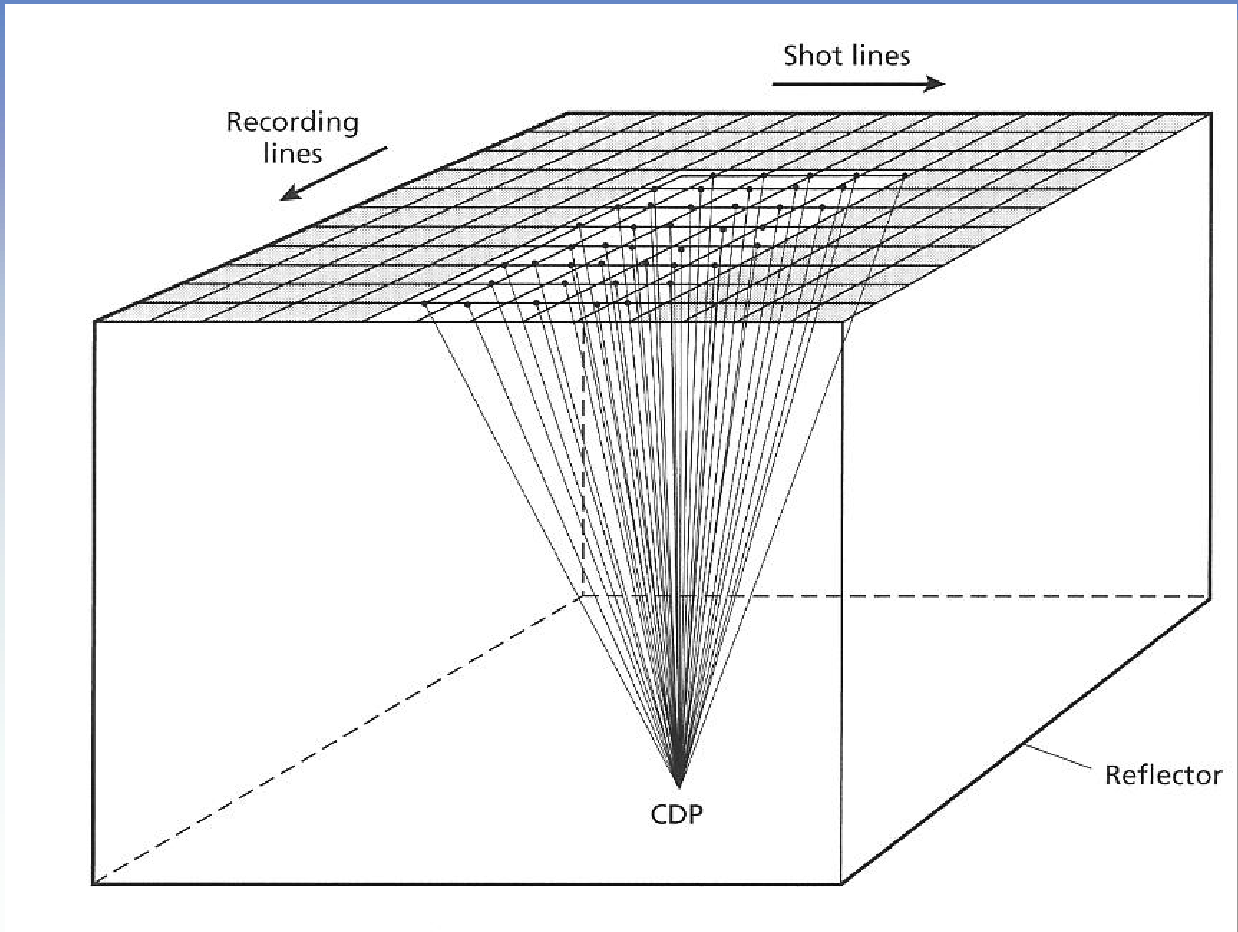


Before

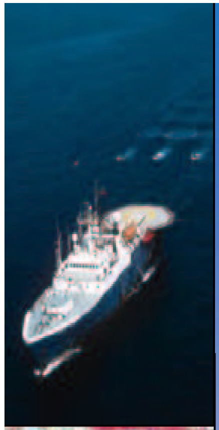
After

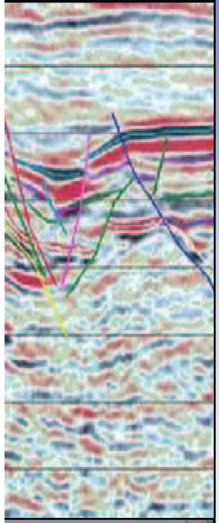


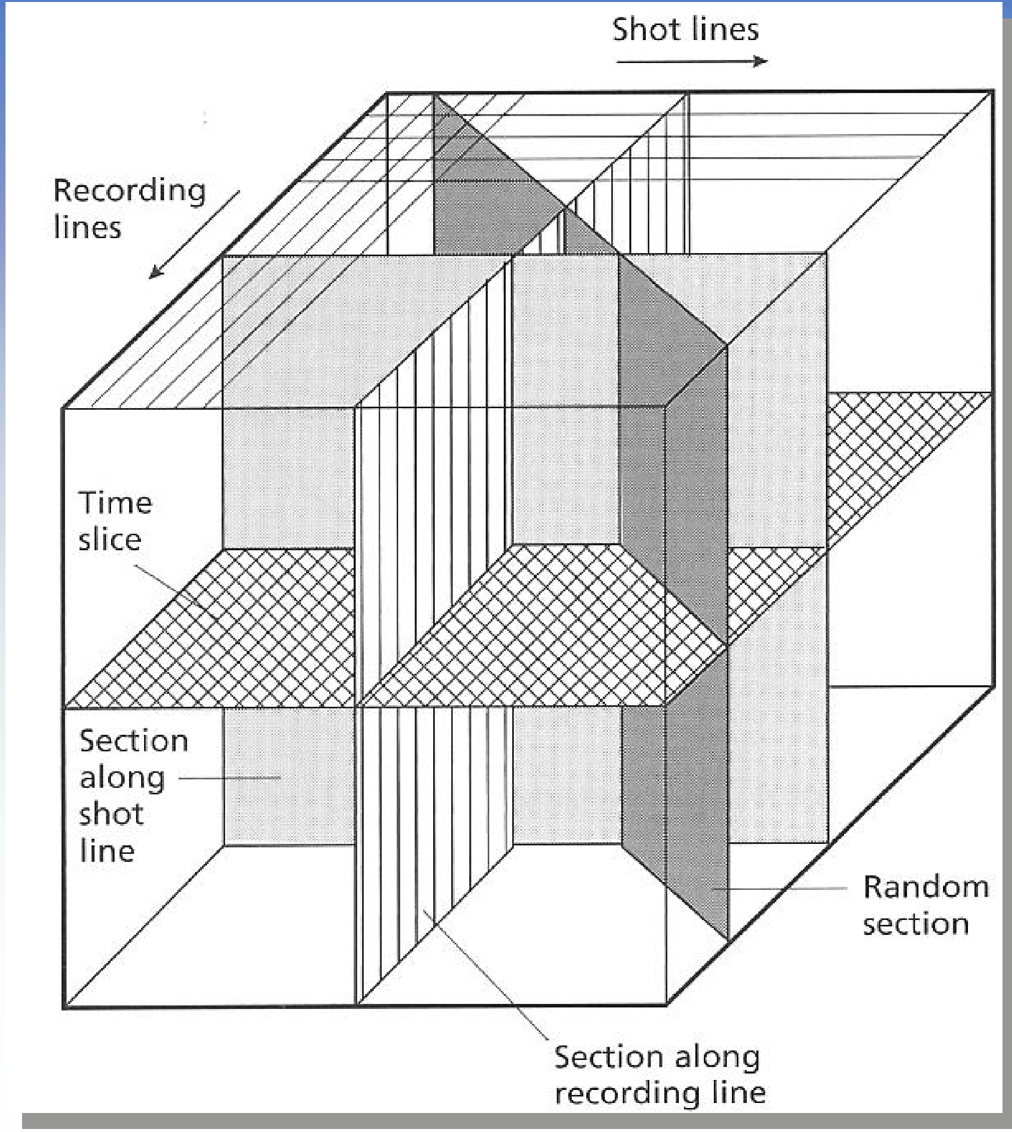
3D surveys

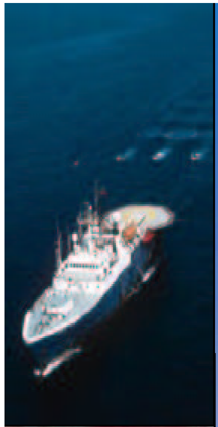


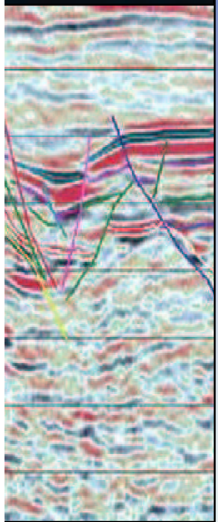
3D surveys



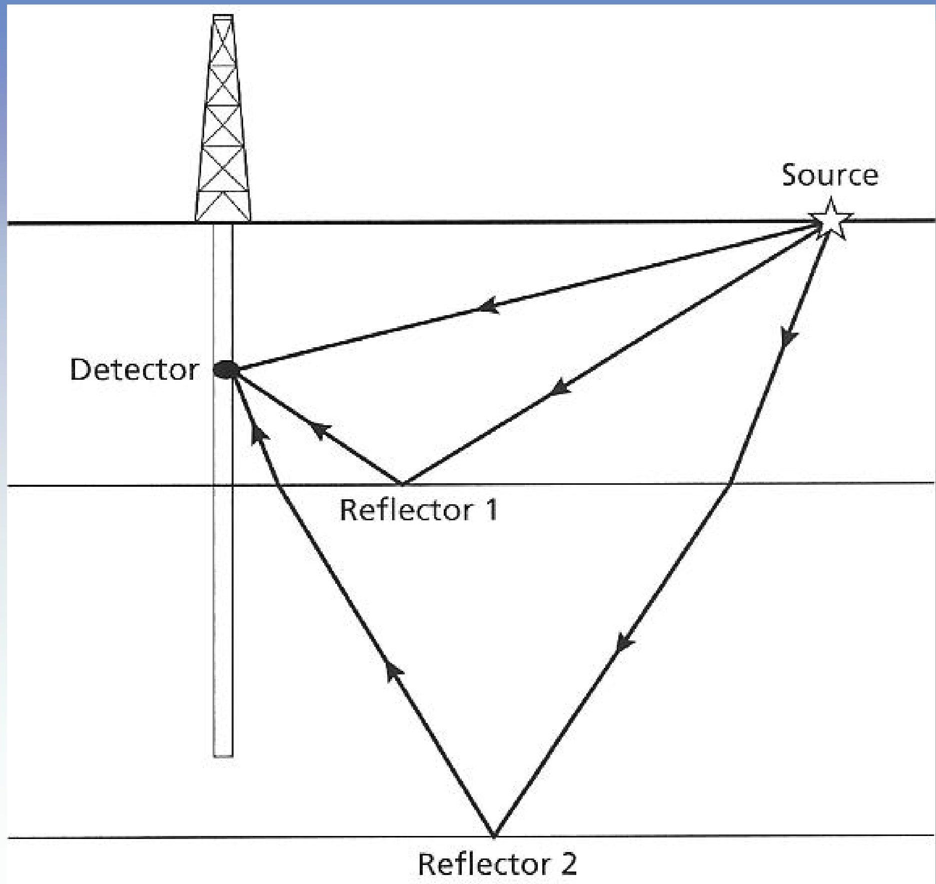


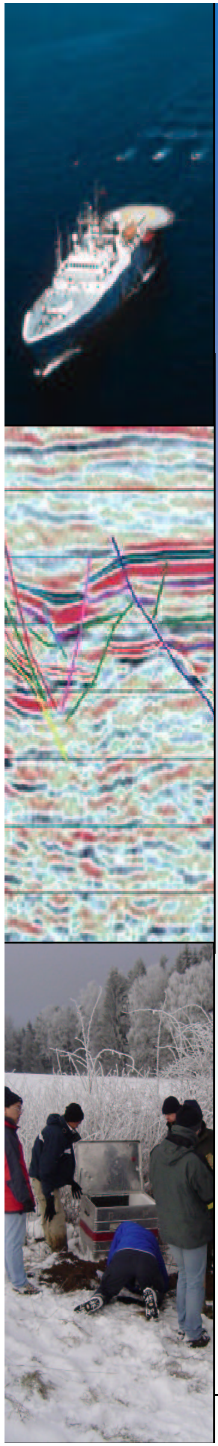

Shot lines
Recording lines
Time slice
Section along shot line
Random section
Section along recording line



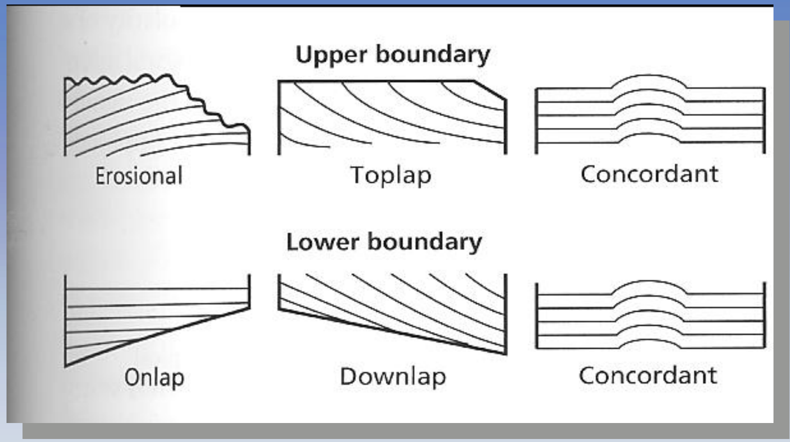


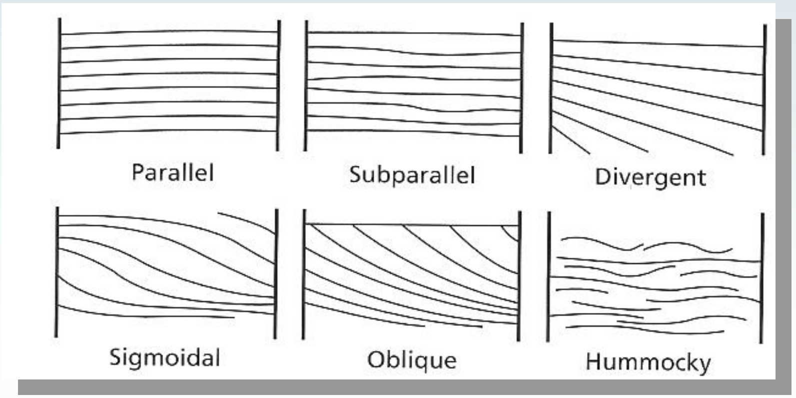
Vertical Seismic Profiling (VSP)

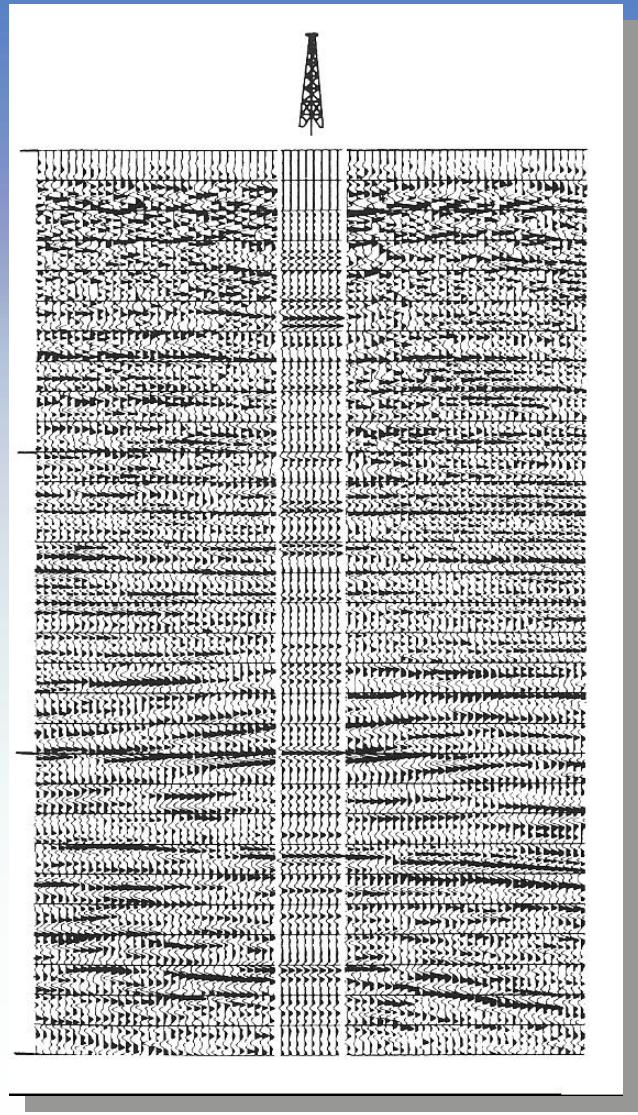




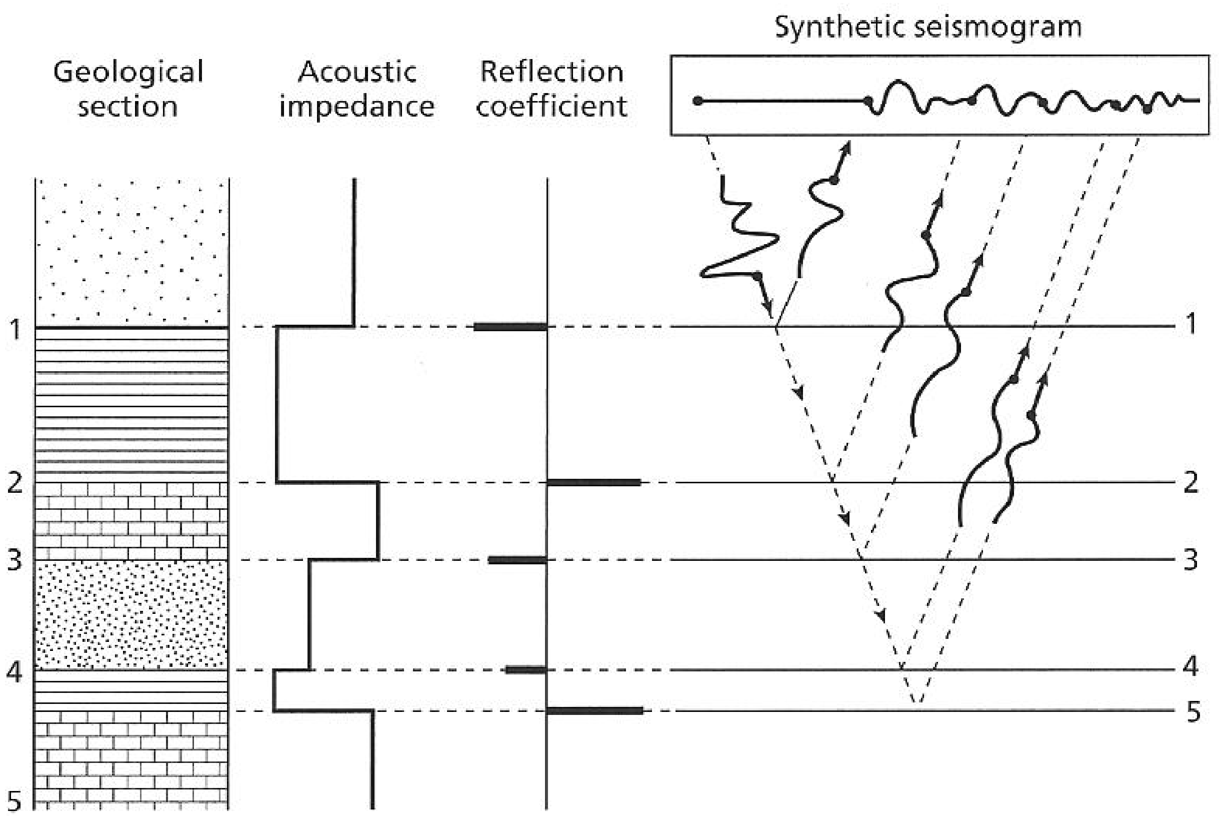
Structural analysis

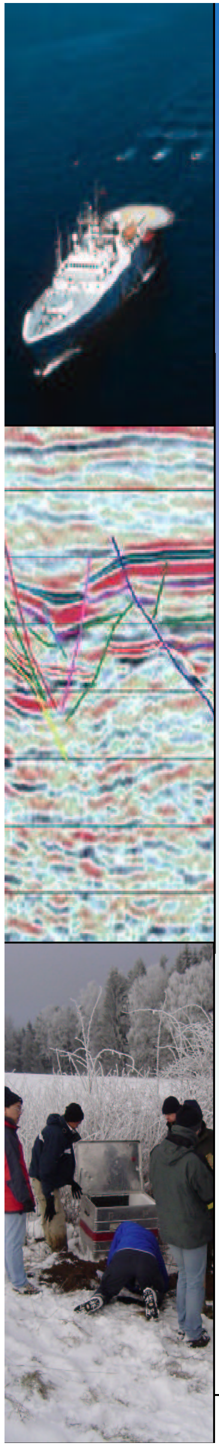


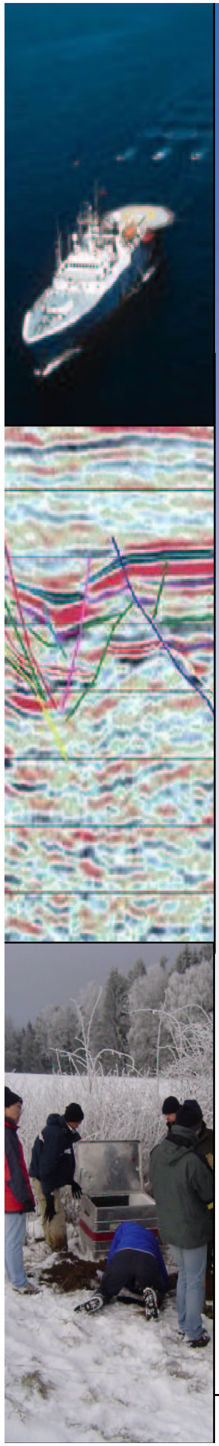




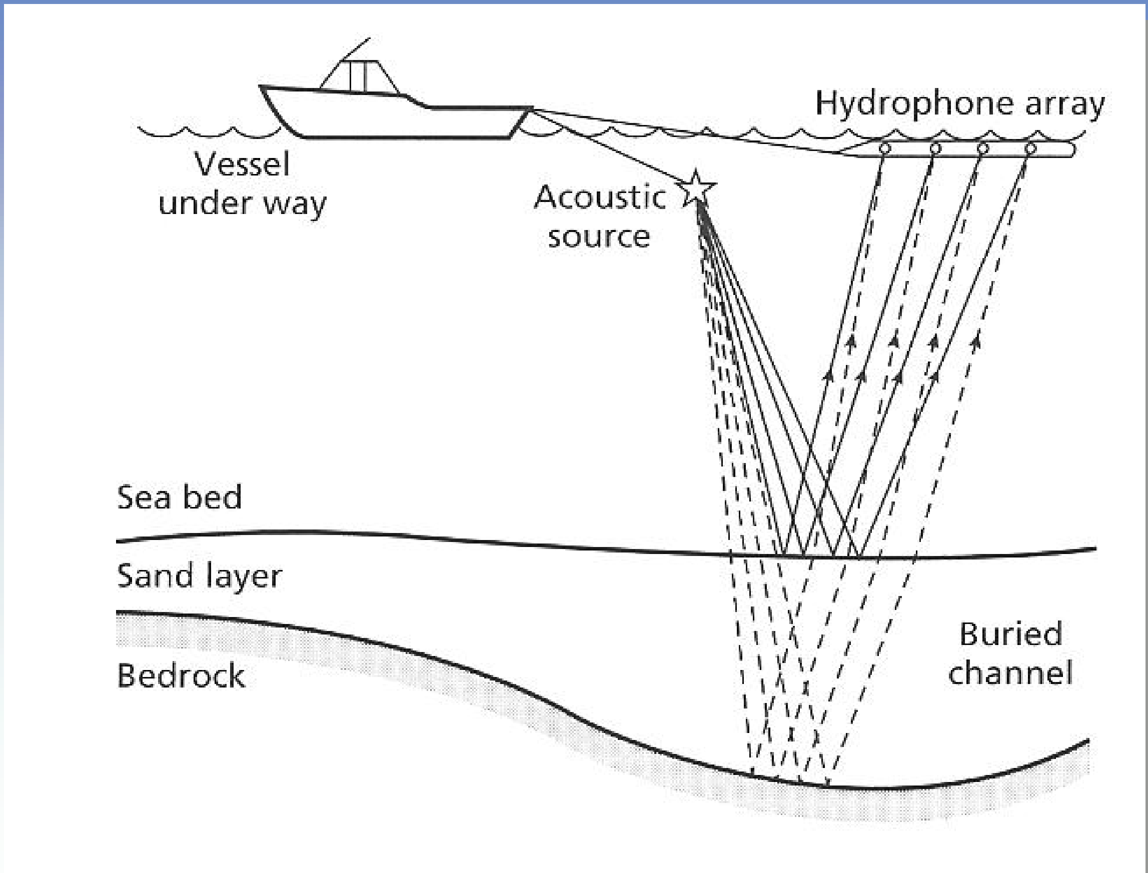
Synthetic seismograms

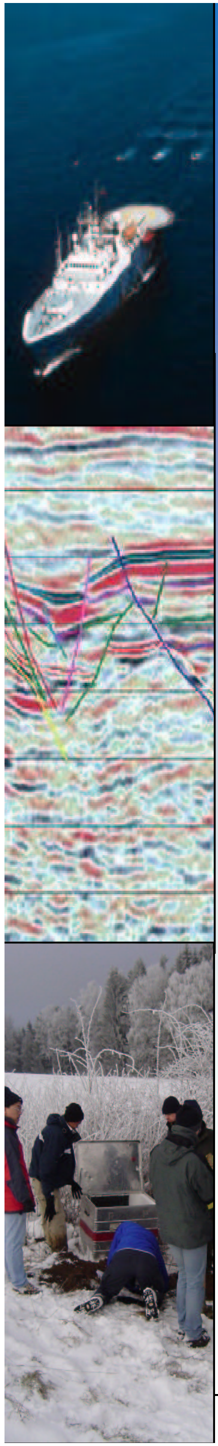




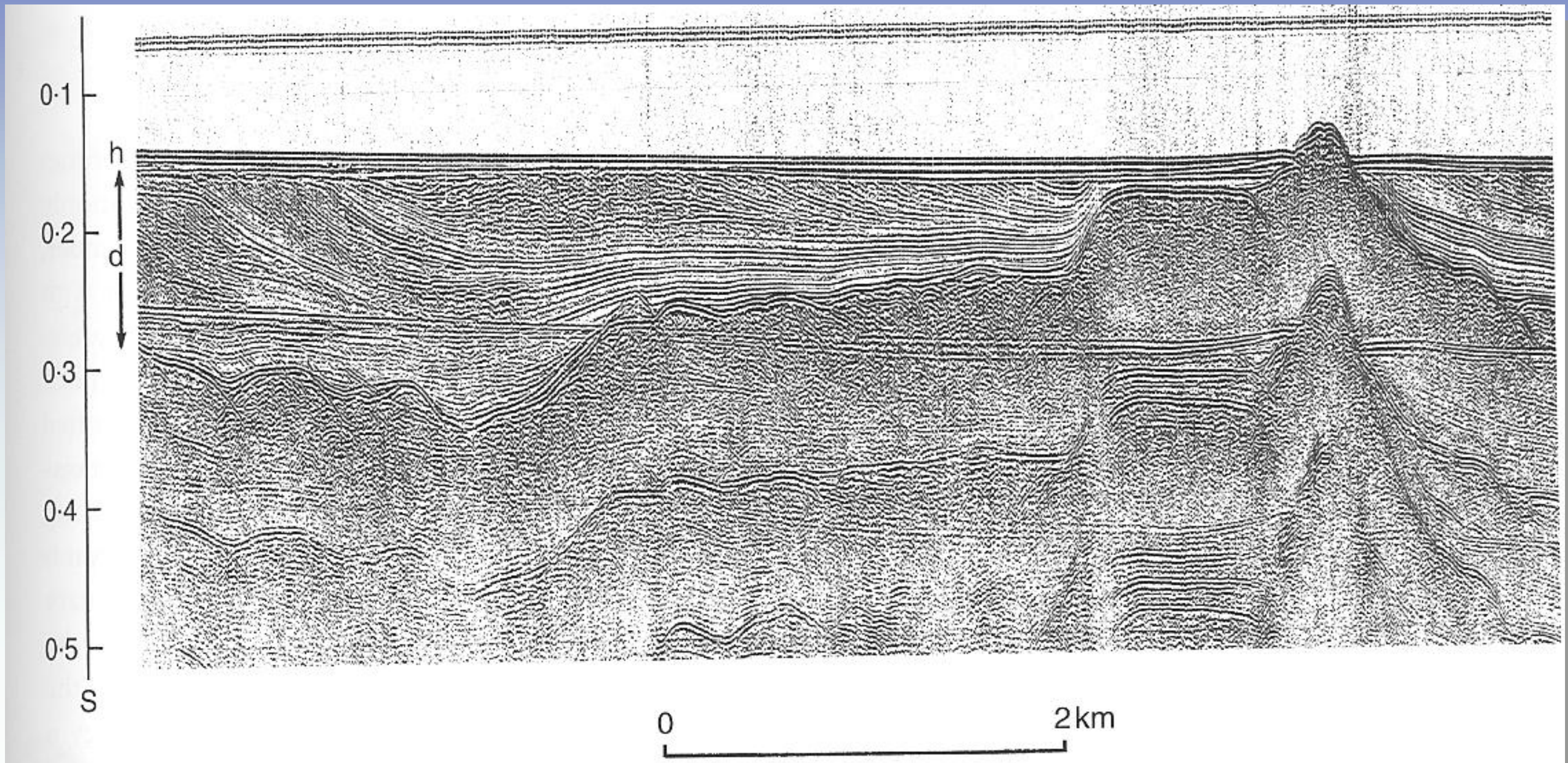


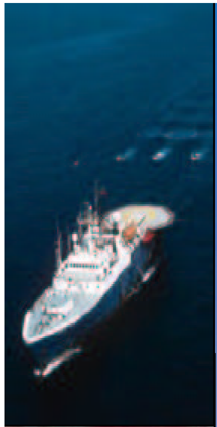
Marine reflection surveys

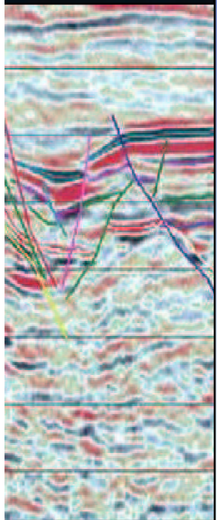




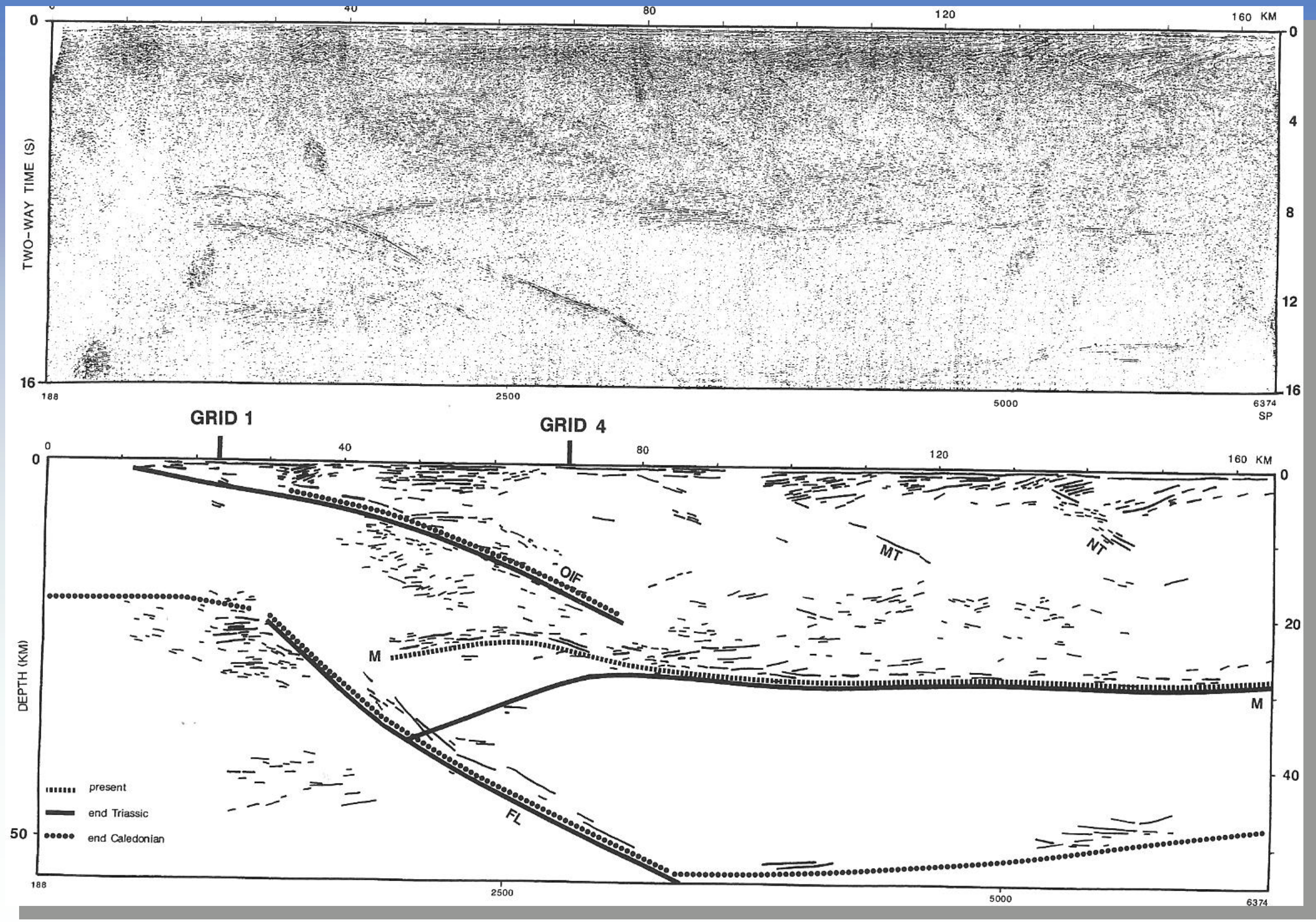
Reflection seismograms



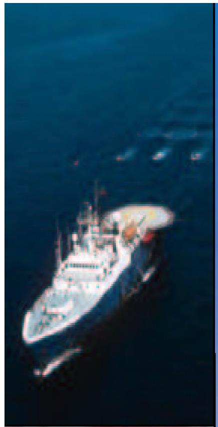


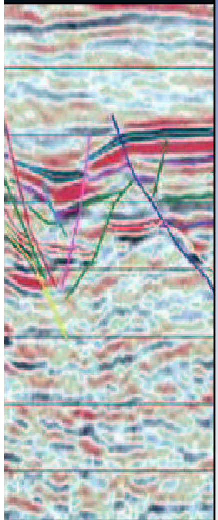


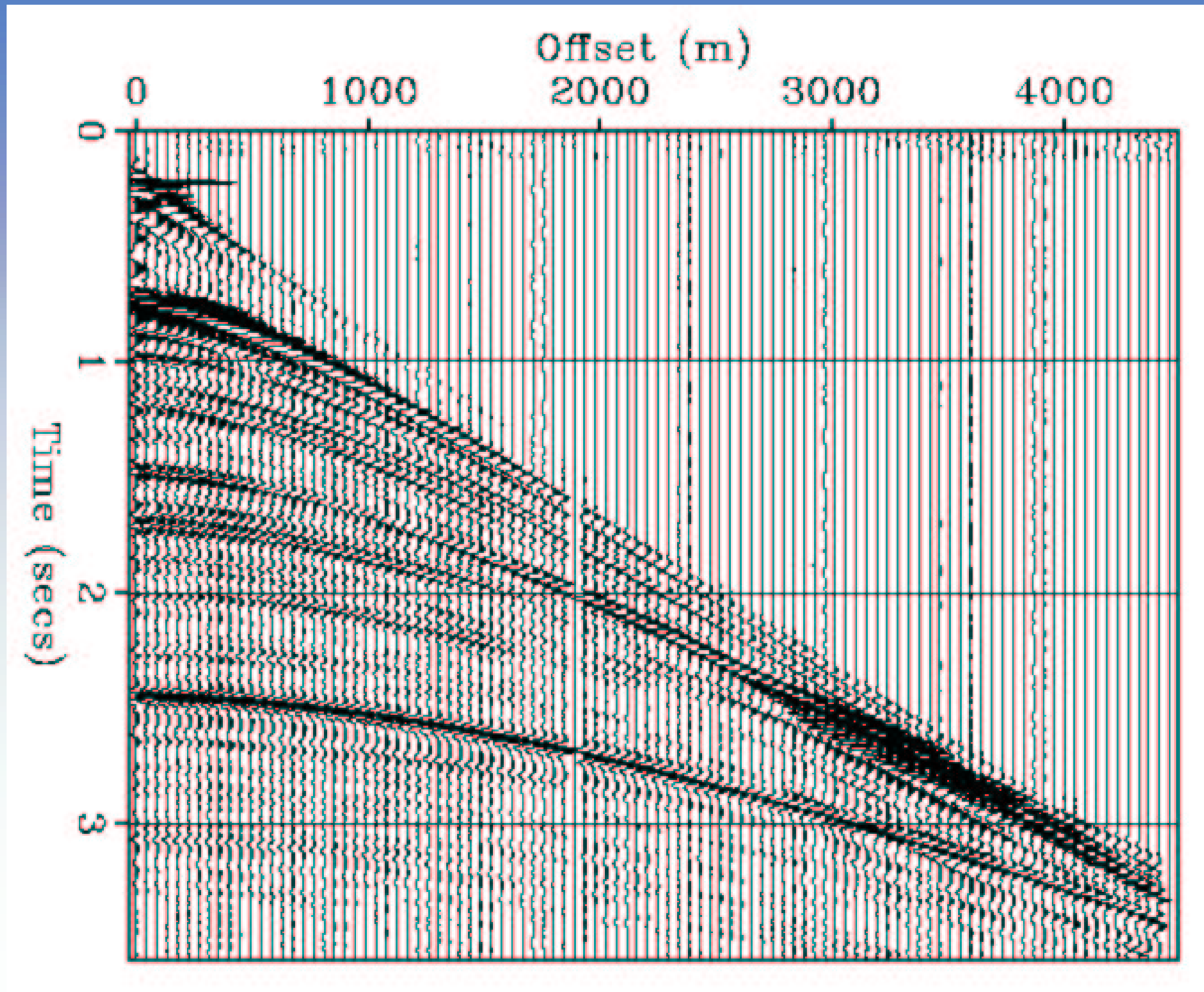
Onshore example

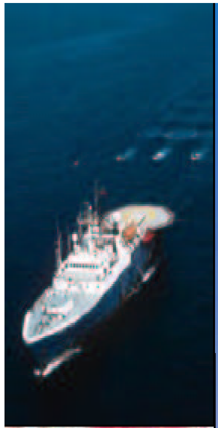


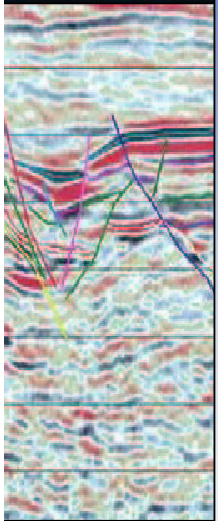
Towards refraction profiles





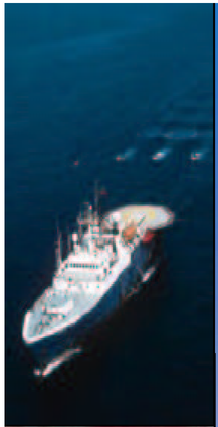


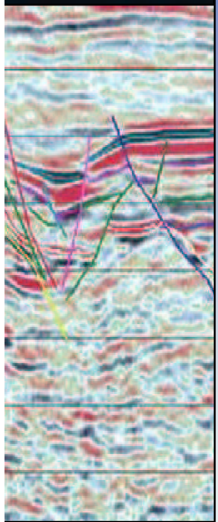




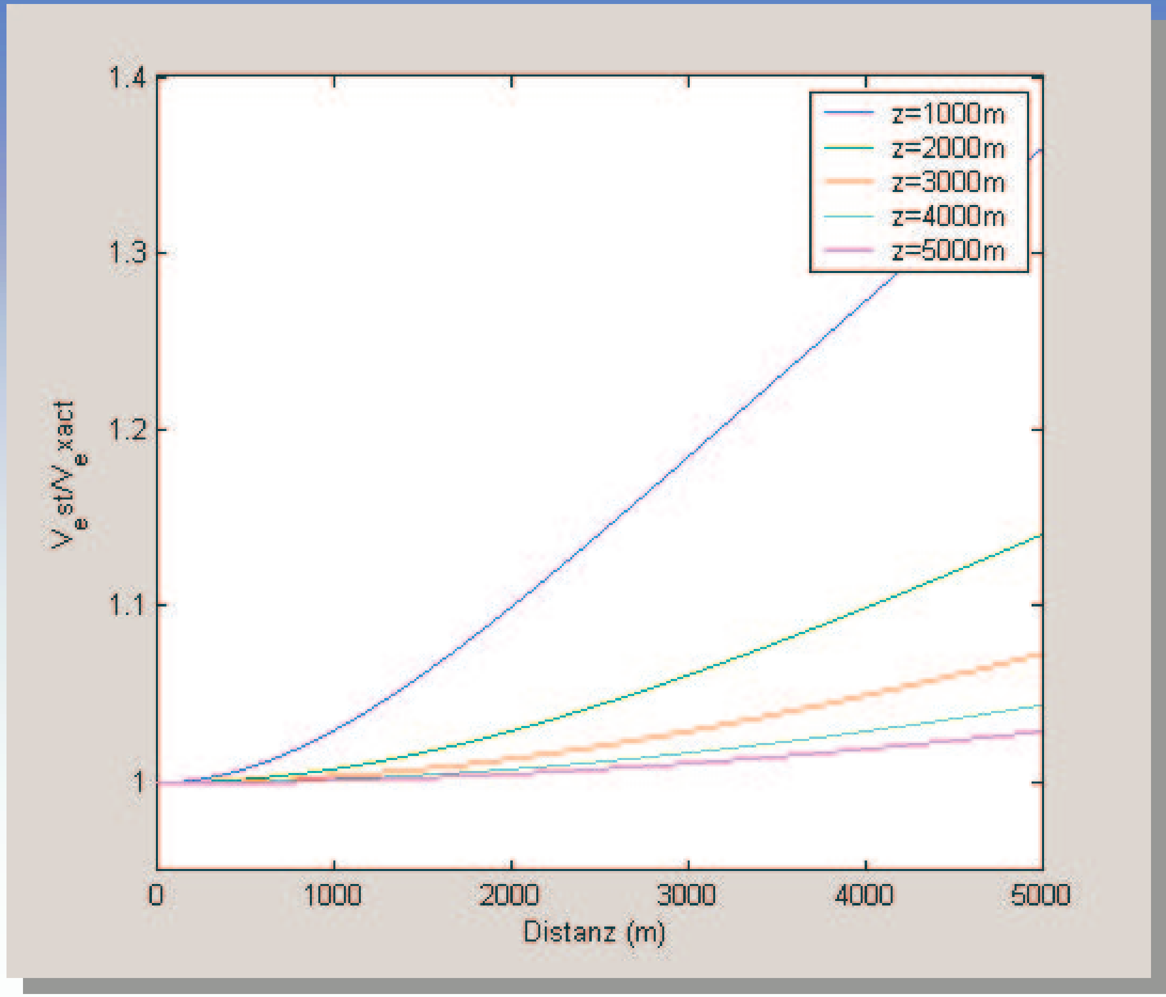
Summary

- Seismic reflection surveying is maybe the most important imaging tool on geophysics (particularly for near surface imaging)
- Seismic surveys are usually laid out to illuminate several times the same common mid-point (CMP) which – in case of horizontal layers – corresponds to the common depth point (CDP)
- The most important diagnostic featurer are abrupt changes of seismic velocities (interfaces) indicative of lithological changes
- The goal of reflection seismics is to map the recorded signals (reflections) into an image of the reflectors
- The most important processing step to do this is called migration





Exercise



1.4
1.3
1.2
1.1
1
0
1000
2000
3000
4000
5000
Distanz (m)
V_e st/V_e xact
z=1000m
z=2000m
z=3000m
z=4000m
z=5000m