Reflection Seismic Processing

- General CMP processing sequence
- Highlights of some key steps

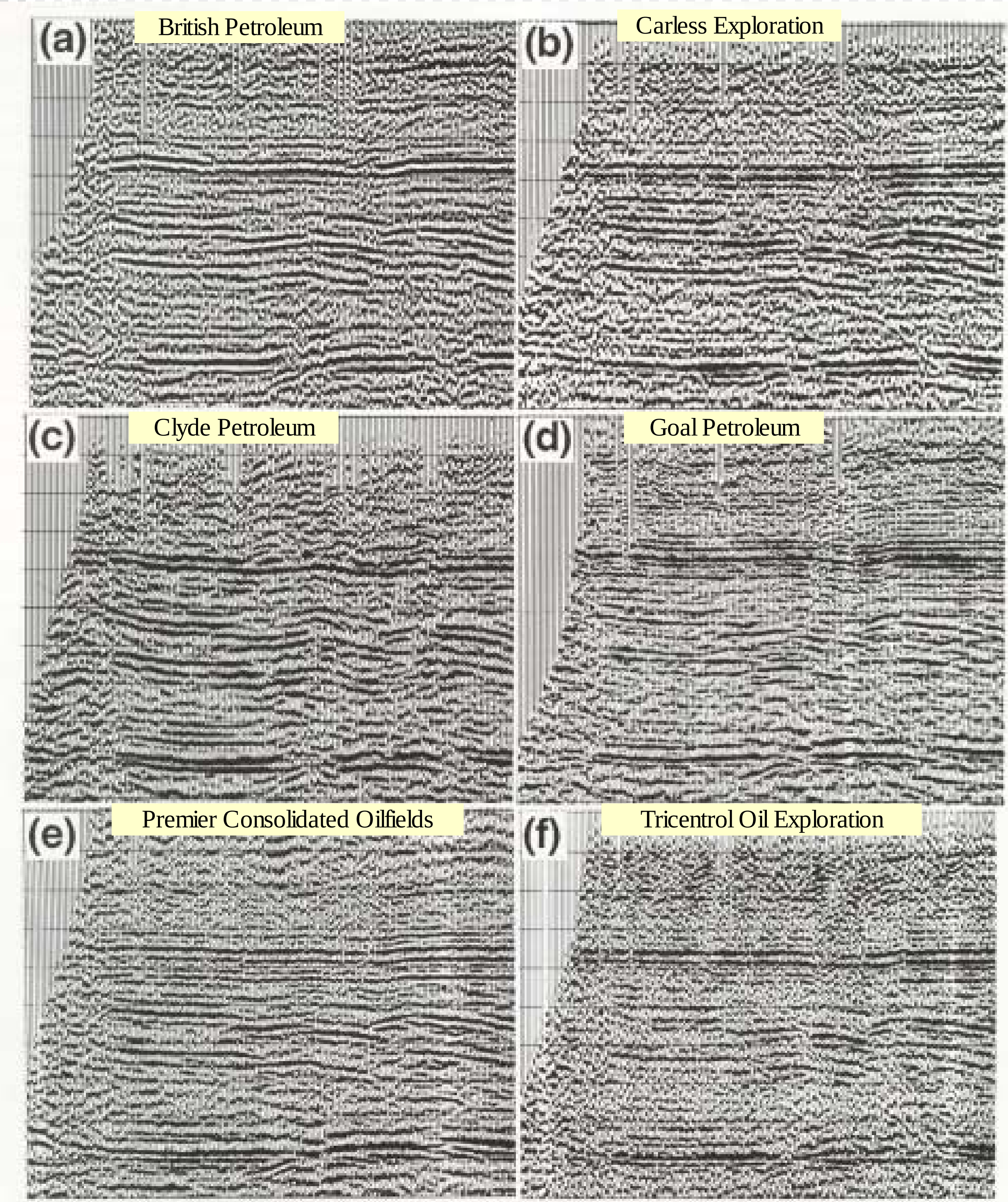
- <u>Reading:</u>
  - Sheriff and Geldart, Chapter 9

Reflection Seismic Processing

- Objective - transform redundant reflection seismic records in the *time domain* into an interpretable *depth image*.
  - Data reduction and editing;
    - Transformation into conveniently computer-manageable form;
    - Removal of bad records;
  - Gathering;
    - CMP sorting;
  - Filtering in time and space;
    - Attenuation of noise;
  - Imaging
    - Final velocity and reflectivity image.

Importance of processing

A line processed by several contractors



Seismic Processing Systems

- Usually geared to a particular type of application
  - Mostly CMP reflection processing;
  - Land or marine, 2D or 3D.
- Commercial:
  - ProMAX (Landmark);
  - Omega (Western Geophysical, marine);
  - Focus (Paradigm);
  - Amoco and almost every other company have their own…
  - Vista (Seismic Image Soft.).
- Universities:
  - Stanford Exploration Project;
  - Seismic UNIX (Colorado School of Mines);
  - FreeUSP (Amoco);
  - SIOSEIS (Scrippts, marine);
  - Our very own

CMP Processing Sequence

1) Demultiplex, Vibroseis correlation, Gain recovery
   - Conversion from file formats produced by field data loggers into processing-oriented formats
     - SEG-Y, SEG-2.
     - ProMax, Focus, Omega, SU, Vista, etc., internal formats.
   - Often done in the field.
2) Field Geometry
   - Assignment of source-receiver coordinates, offsets, etc. in the *trace headers*.
3) Edit
   - Removal of bad traces (noisy channels, poorly planted geophones, channels contaminated by power line noise, etc.).

CMP Processing Sequence (continued)

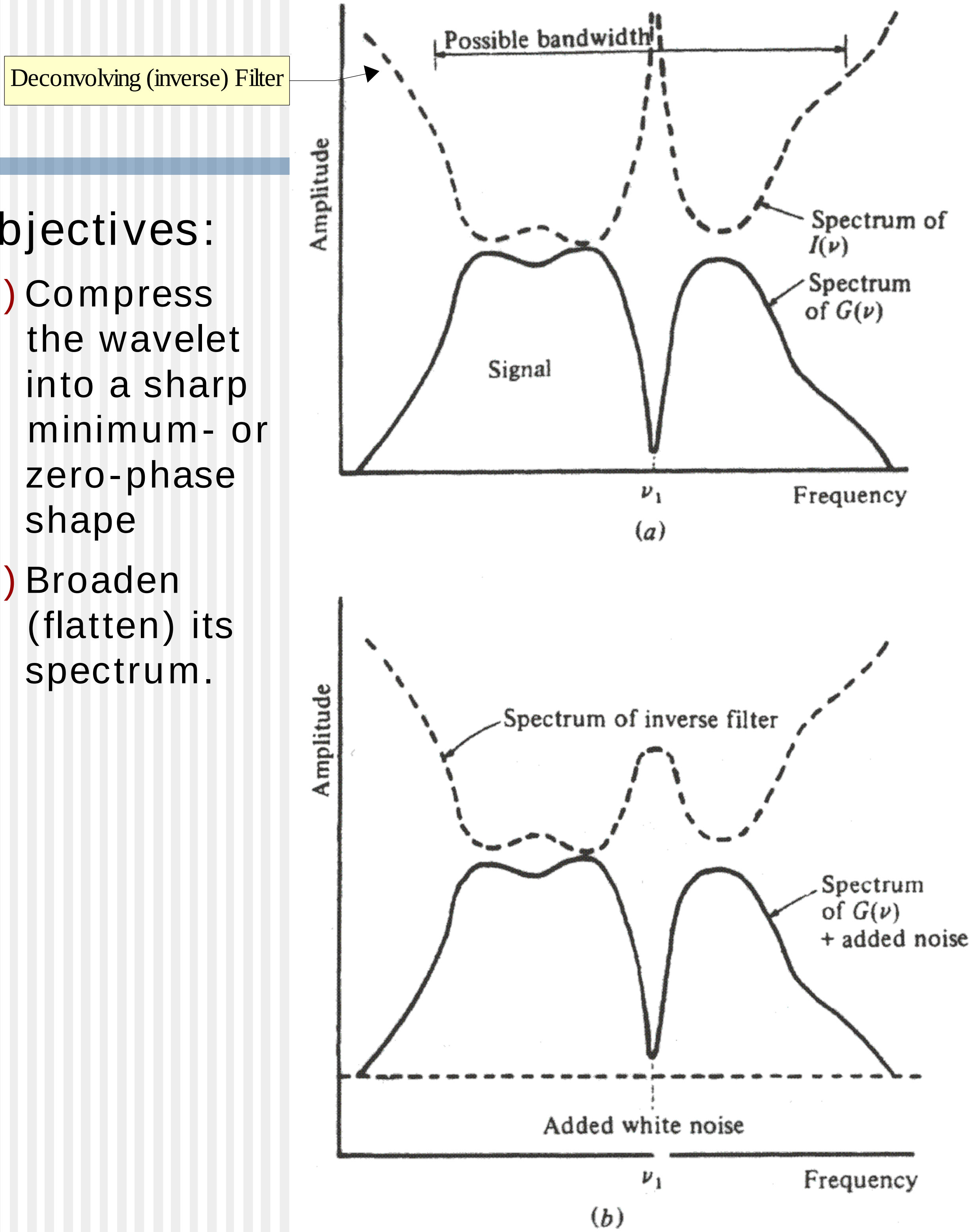
4) First arrival picking
   - May be semi-automatic or manual;
   - Required for generation of *refraction statics*; models and for designing the *mutes*.
5) Elevation statics
   - Based on geometry information, compensates the travel-time variations caused by variations in source/receiver elevations.
   - Transforms the records as if recorded at a common horizontal *datum* surface.
6) Refraction statics
   - Builds a model for the shallow, low-velocity subsurface;
   - Compensates travel-time variations caused by the shallow velocities.
7) ‘Top’, ‘bottom’, and ‘surgical’ *mute*
   - Eliminates (sets amplitude=0) the time intervals where strong non-reflection energy is present:
     - First arrivals, ground roll, airwave.

CMP Processing Sequence (continued)

8) Gain recovery
   - Compensates geometrical spreading;
   - Based on a simple heuristic relation.
9) Trace balance
   - Equalizes the variations in amplitudes caused by differences in *coupling*;
   - In true-amplitude processing, replaced with '*surface-consistent deconvolution'*.
10) Deconvolution or wavelet processing
    - Compresses the wavelet in time, attenuates reverberations.
    - Converts the wavelet to zero-phase for viewing
11) Gather, CMP sort
    - Often (in ProMax, Omega, Vista) done by using *trace lookup* tables instead of creating additional copies of the dataset.
12) Moveout (Radon, τ-*p*, *f*-*k*) filtering
    - Attenuates multiples, ground roll.

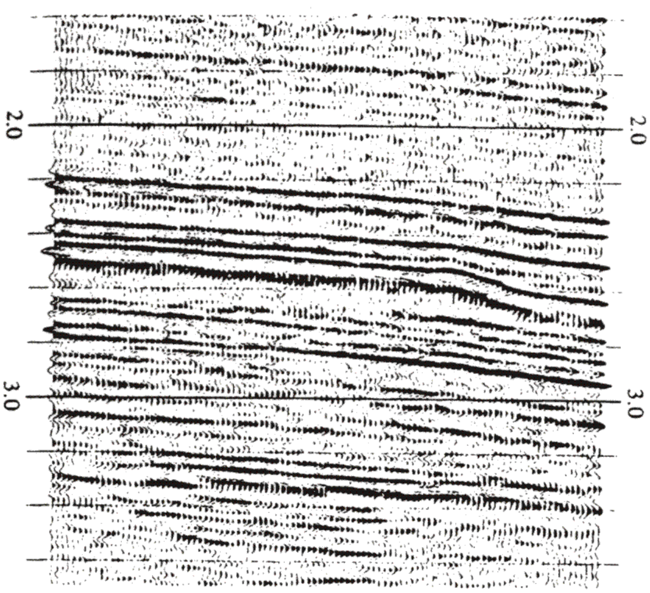
Deconvolution

- Objectives:
  1) Compress the wavelet into a sharp minimum- or zero-phase shape
  2) Broaden (flatten) its spectrum.

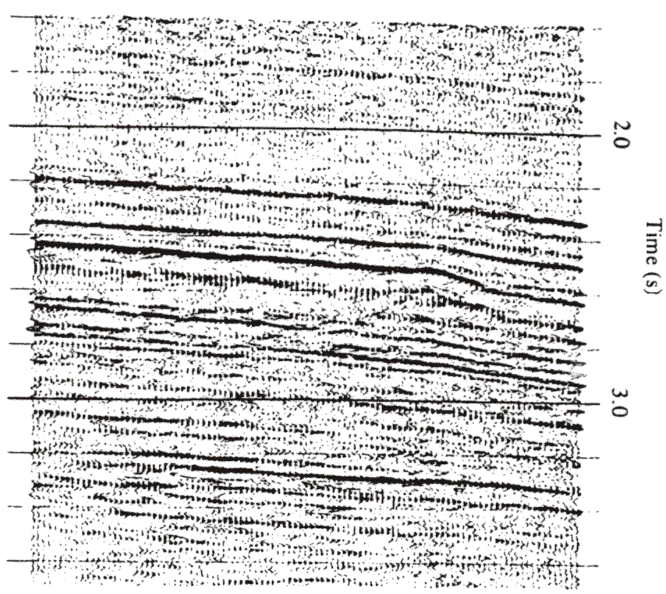


Wavelet shaping

- Shape of the source wavelet is estimated from autocorrelation of the data
- Time-variant "spectral whitening" (flattening within an estimated bandwidth) is applied
- A filter is designed to convert the wavelet into zero-phase



Migrated stack before wavelet processing



Migrated stack after wavelet processing

CMP Processing Sequence (continued)

13) Velocity analysis
- For each of the CMP gathers, determines the optimal *stacking velocity*.

14) Dip Moveout (DMO) correction
- Transforms the records so that the subsequent NMO+stack work well even in the presence of dipping reflectors.

15) Normal Moveout (NMO) correction
- Removes the effects of source-receiver separation from reflection records;
- Transforms the records as if recorded at normal incidence.

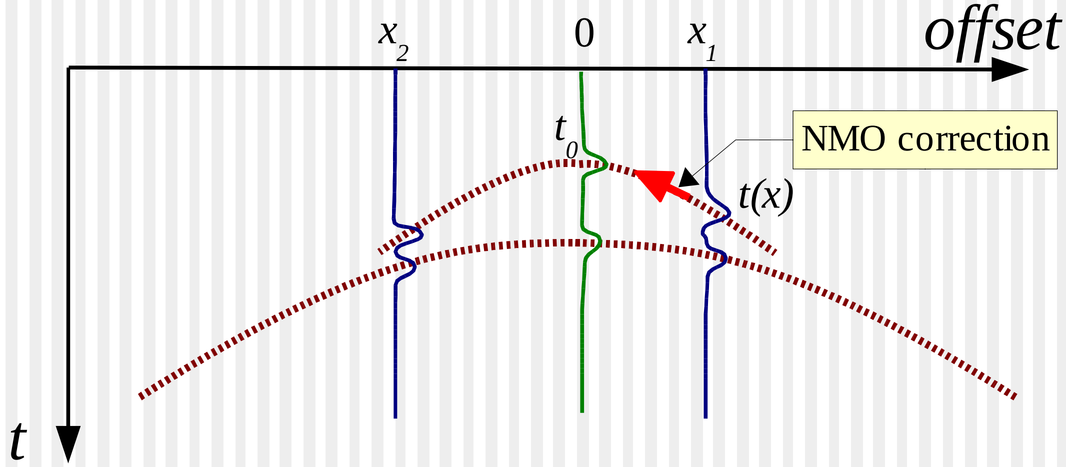
16) Residual statics
- Removes the remaining small travel-time variations caused by inaccurate statics or velocity model

Normal Moveout (NMO) correction

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

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

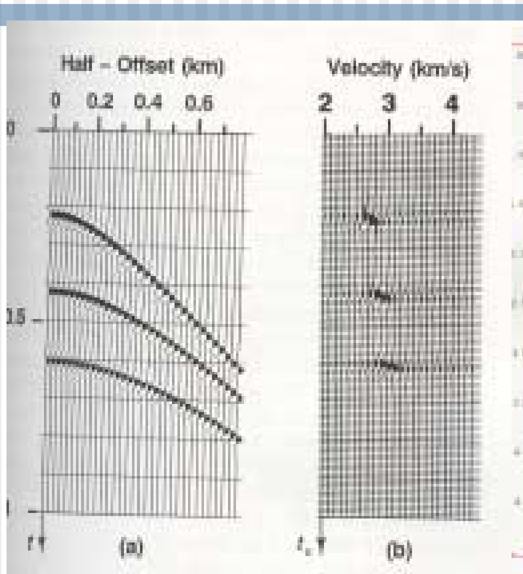
"*Stacking velocity*"

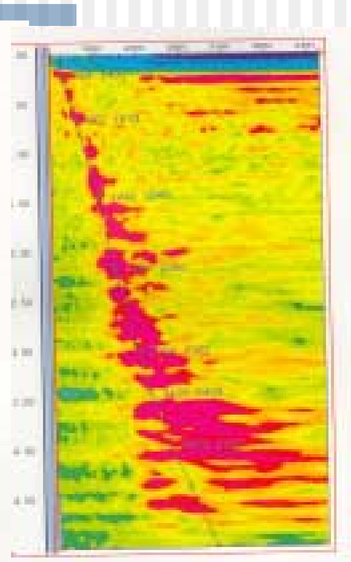


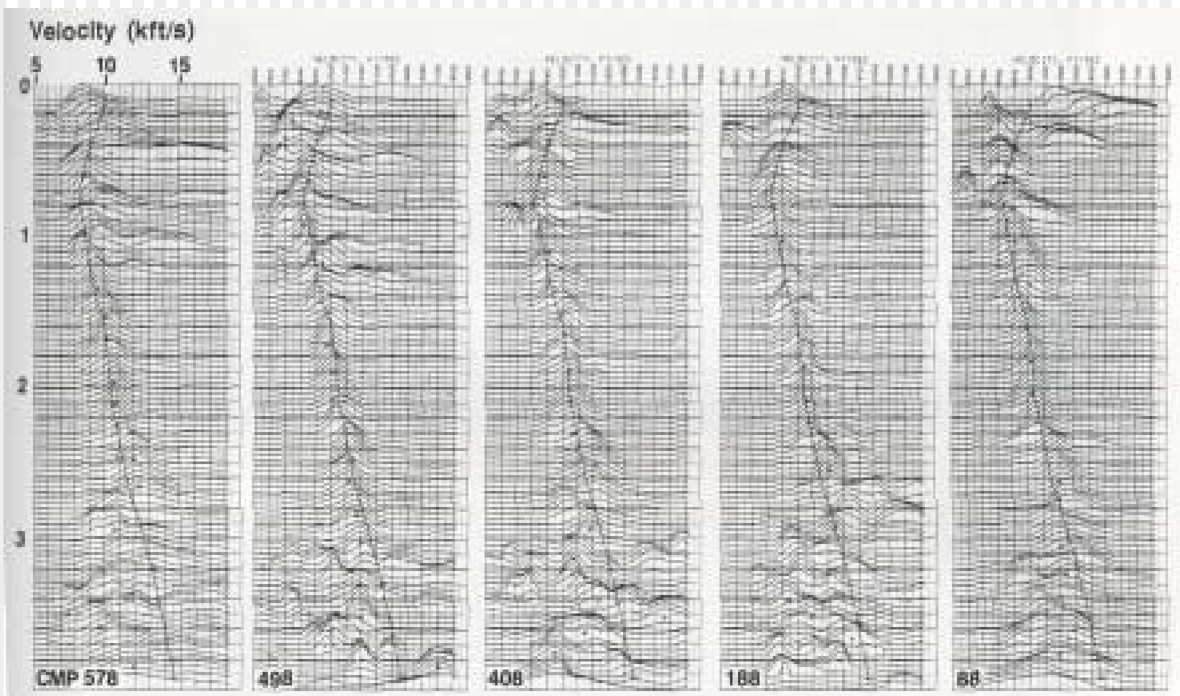
- *Stacking velocity* is determined from the data, as a measure of the reflection hyperbola best aligned of with the reflection.

Velocity Analysis

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



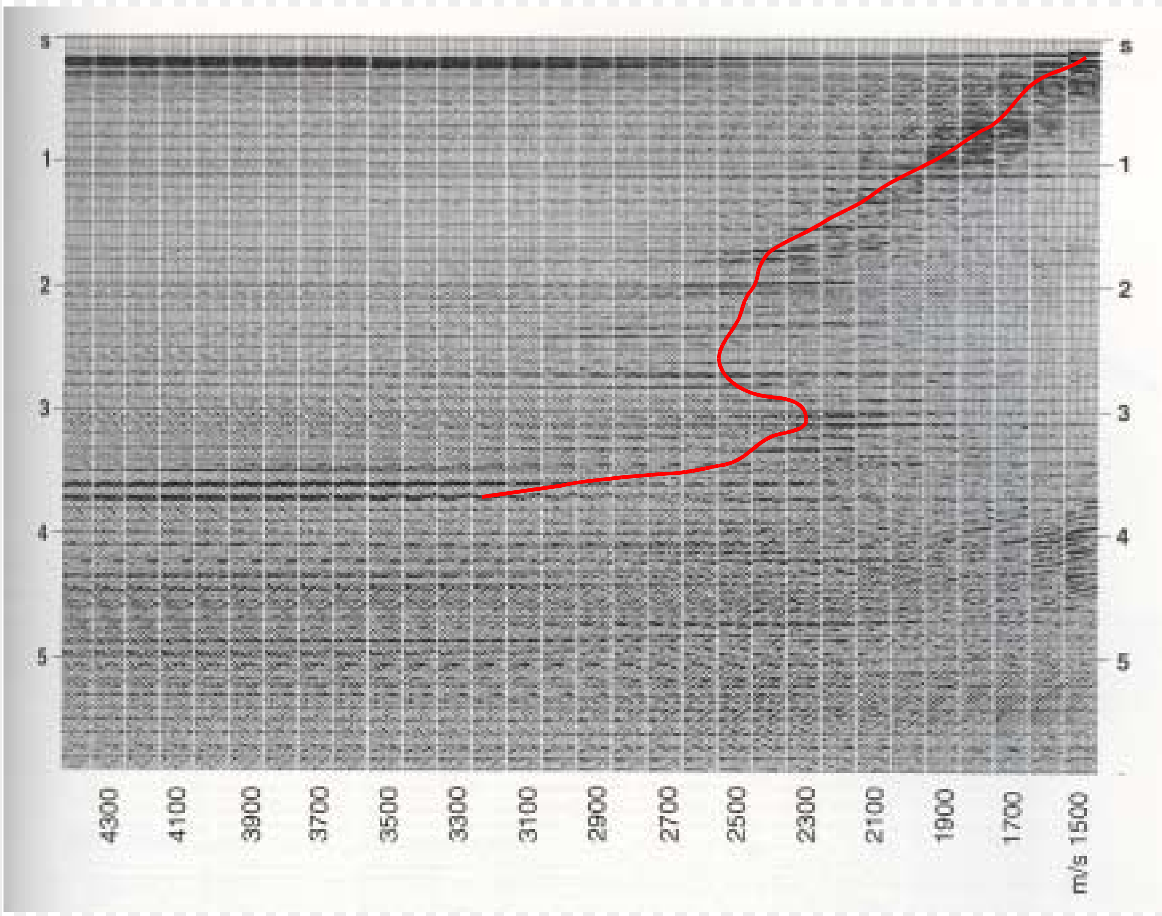




Velocity analysis

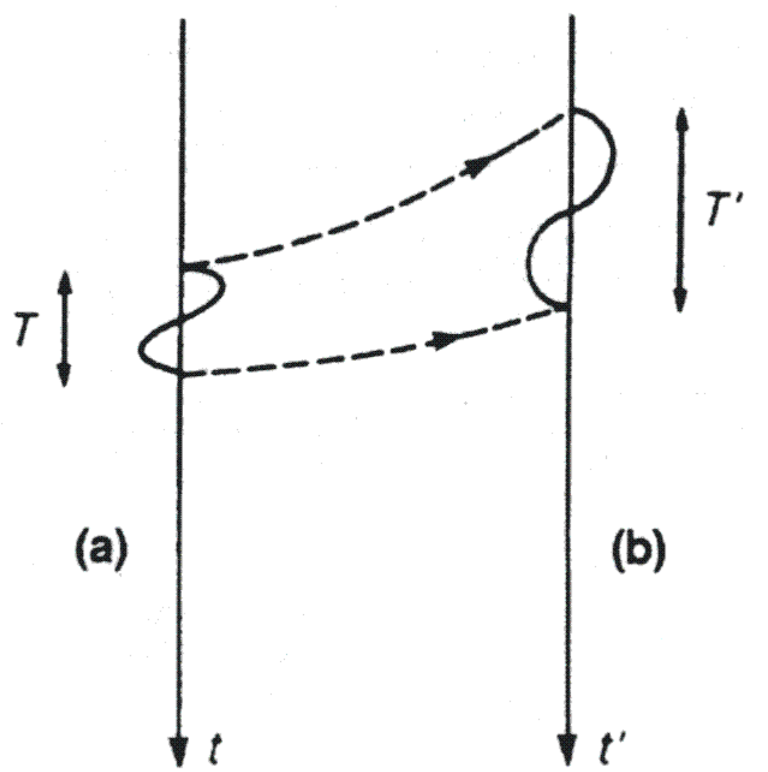
(Common-Velocity Stacks)

- Groups of 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.



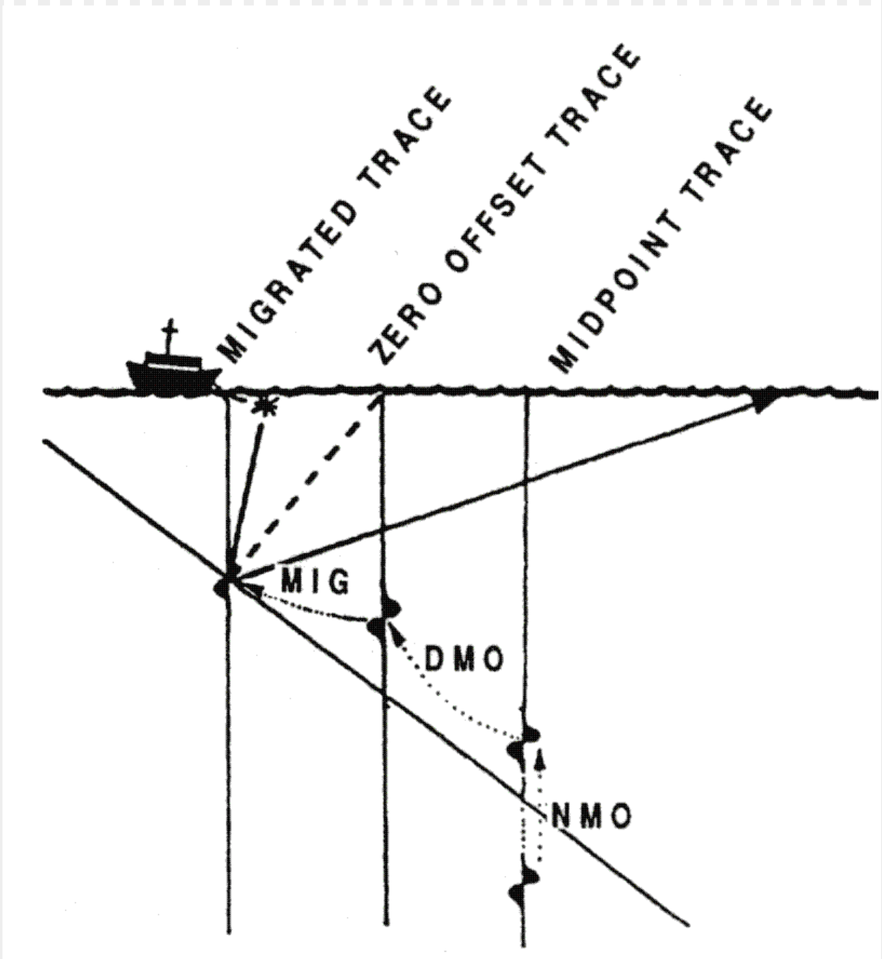
NMO stretching

- Note that NMO correction affects the shallower and slower reflections stronger
  - This is called "*NMO stretching*"
  - This distortion is controlled during processing by setting a limit in relative stretching (typically ~25%)



NMO→DMO→Migration

- DMO assists NMO by correcting for the time delay on an offset trace assuming zero dip.
- For a dipping reflector, DMO moves the data to the correct zero-offset trace. Migration further moves it to the subsurface location.



Deregowski, 1986

CMP Processing Sequence (continued)

17) Steps 13-16 above are usually iterated 3-5 times to produce accurate *velocity* and *residual statics* models.
    - Success of velocity analysis depends on the quality of DMO/NMO and residual statics, and vice versa.

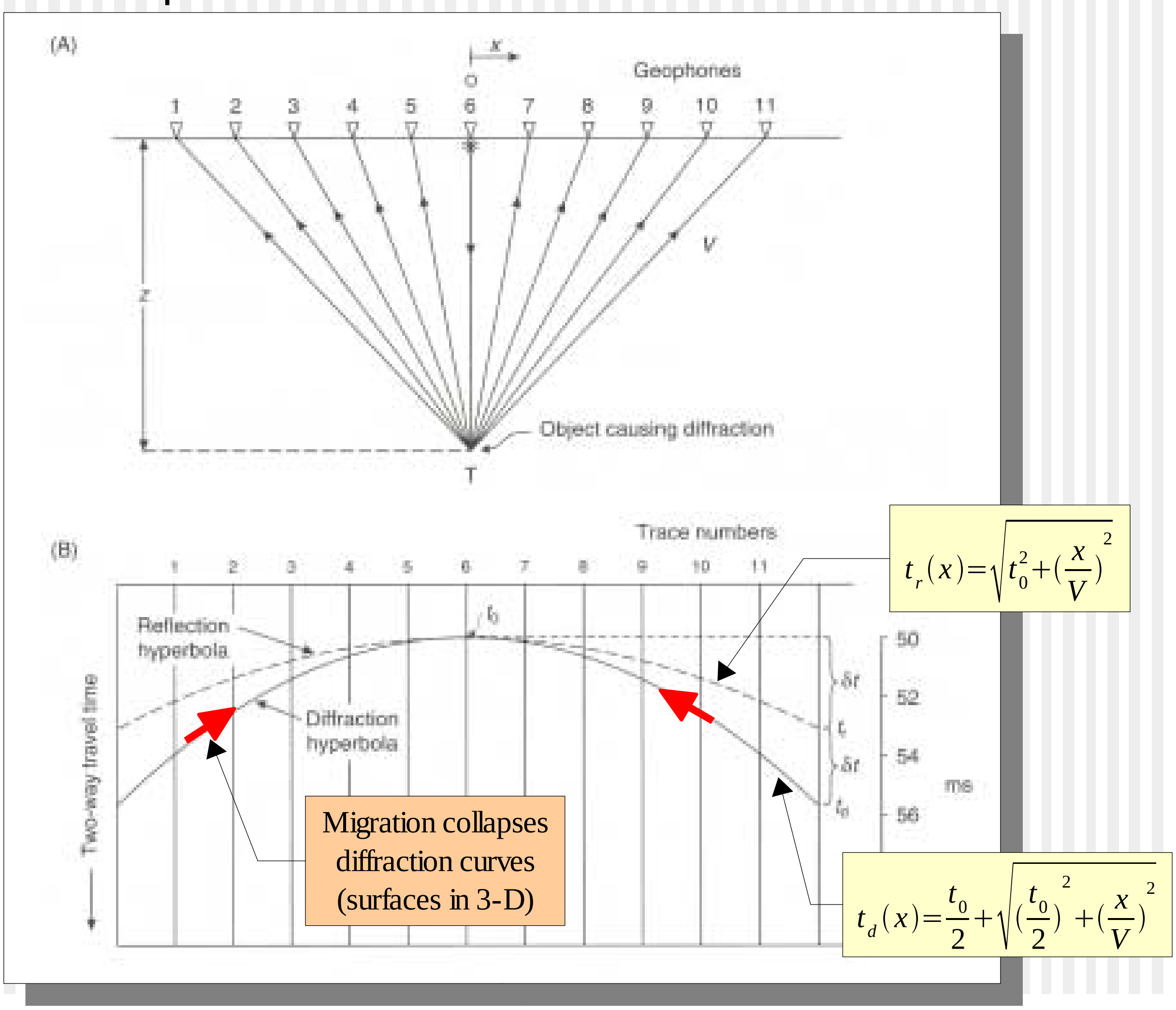
18) CMP Stack
    - Produces a *zero-offset section*;
    - Utilizes CMP redundancy to increase the *Signal/Noise ratio.*
    - Can employ various normalization ideas, e.g., *diversity stack*

19) Migration
    - Transforms the zero-offset *time* section into a depth image;
    - Establishes correct extents and dips of the reflectors.

20) Frequency filtering and display
    - Attenuates noise
    - Provides best display for interpretation

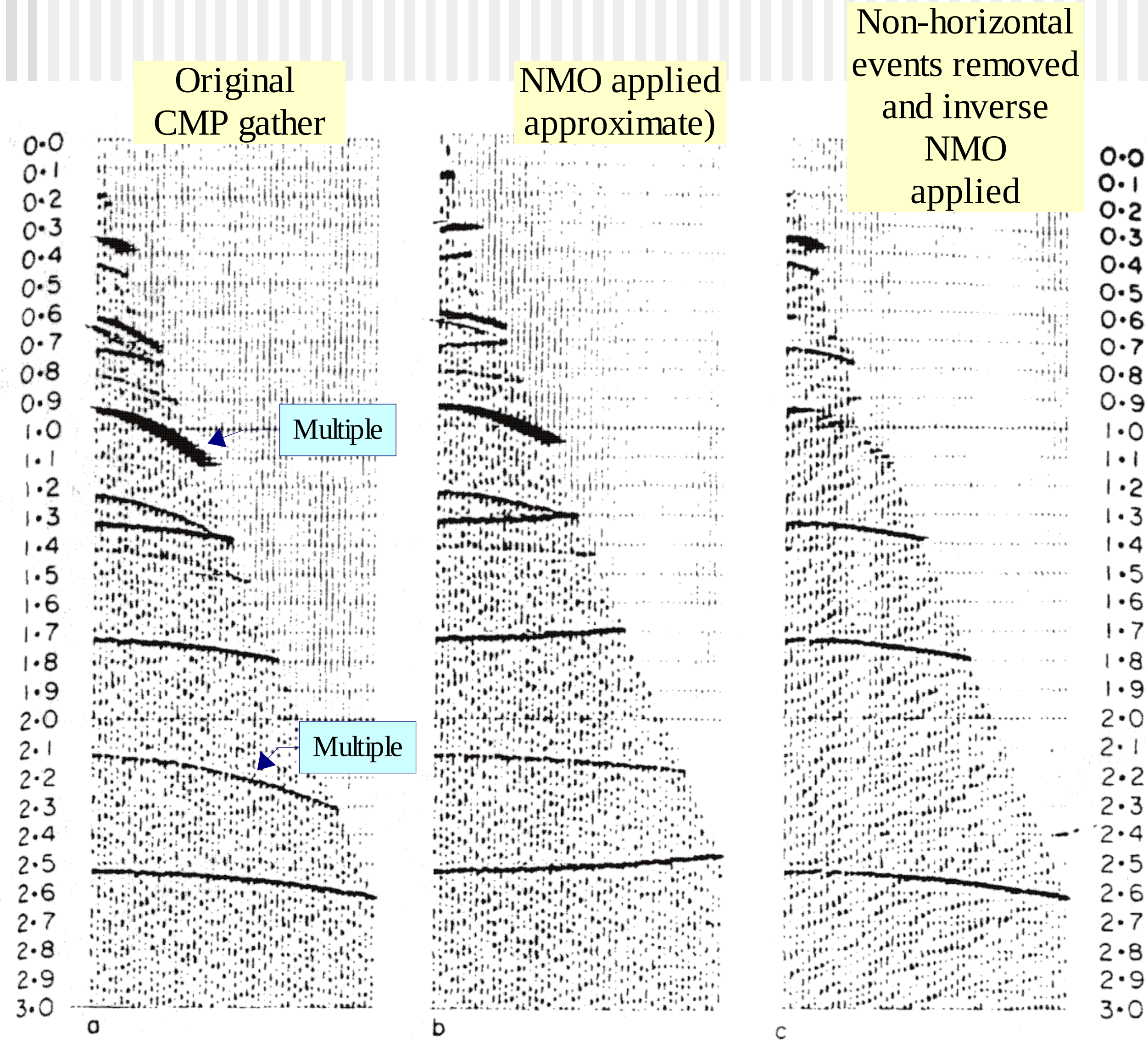
Migration

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

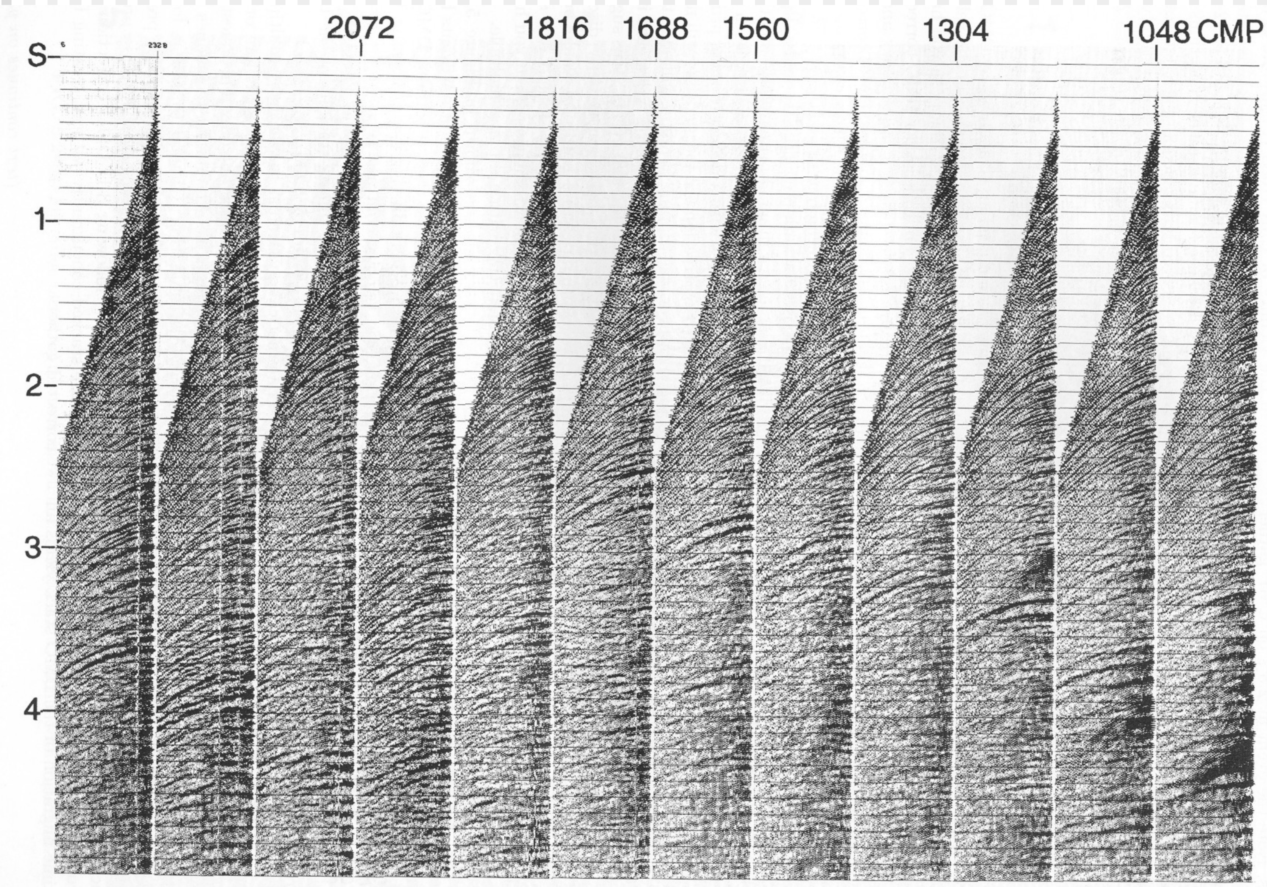


Moveout (*f*-*k*, *τ*-*p*) filtering

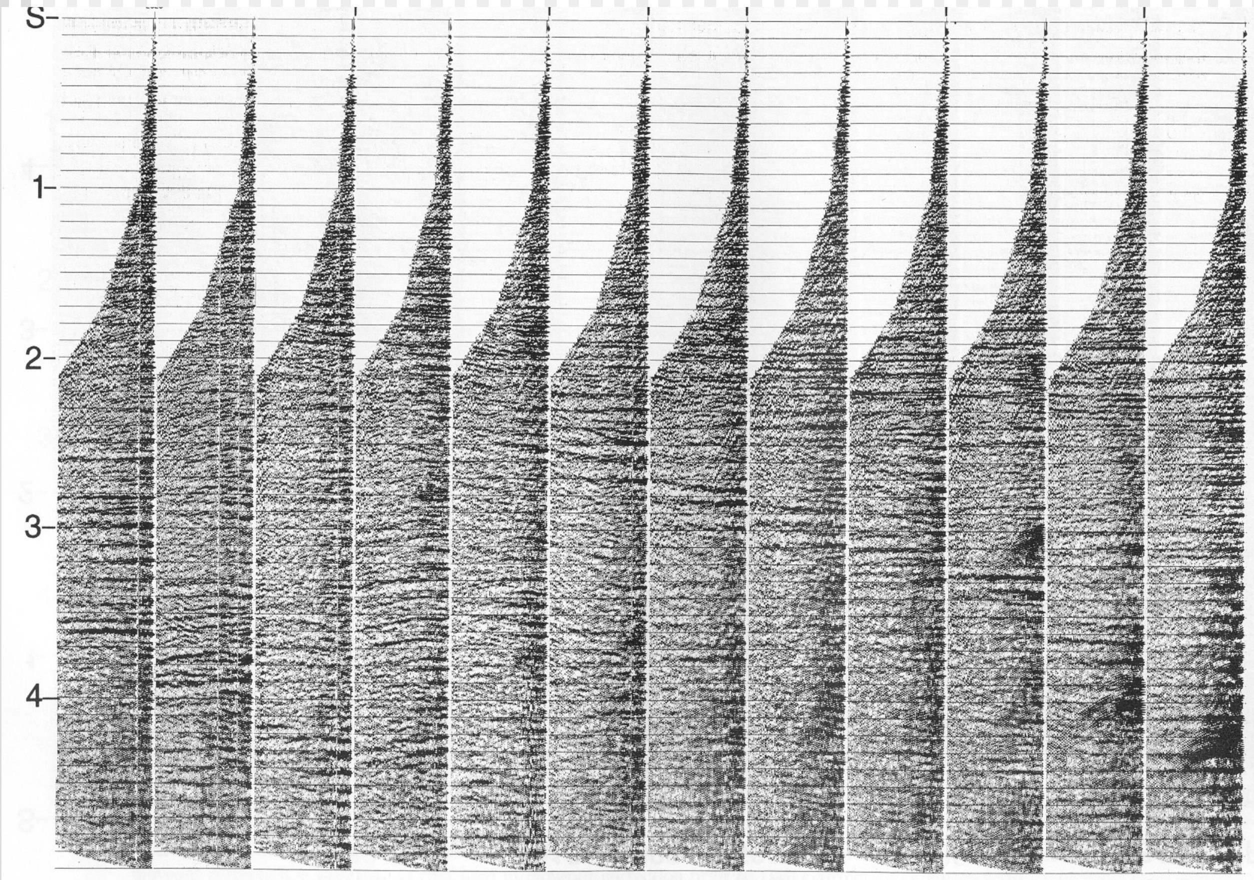
- Removes coherent events with undesired moveouts



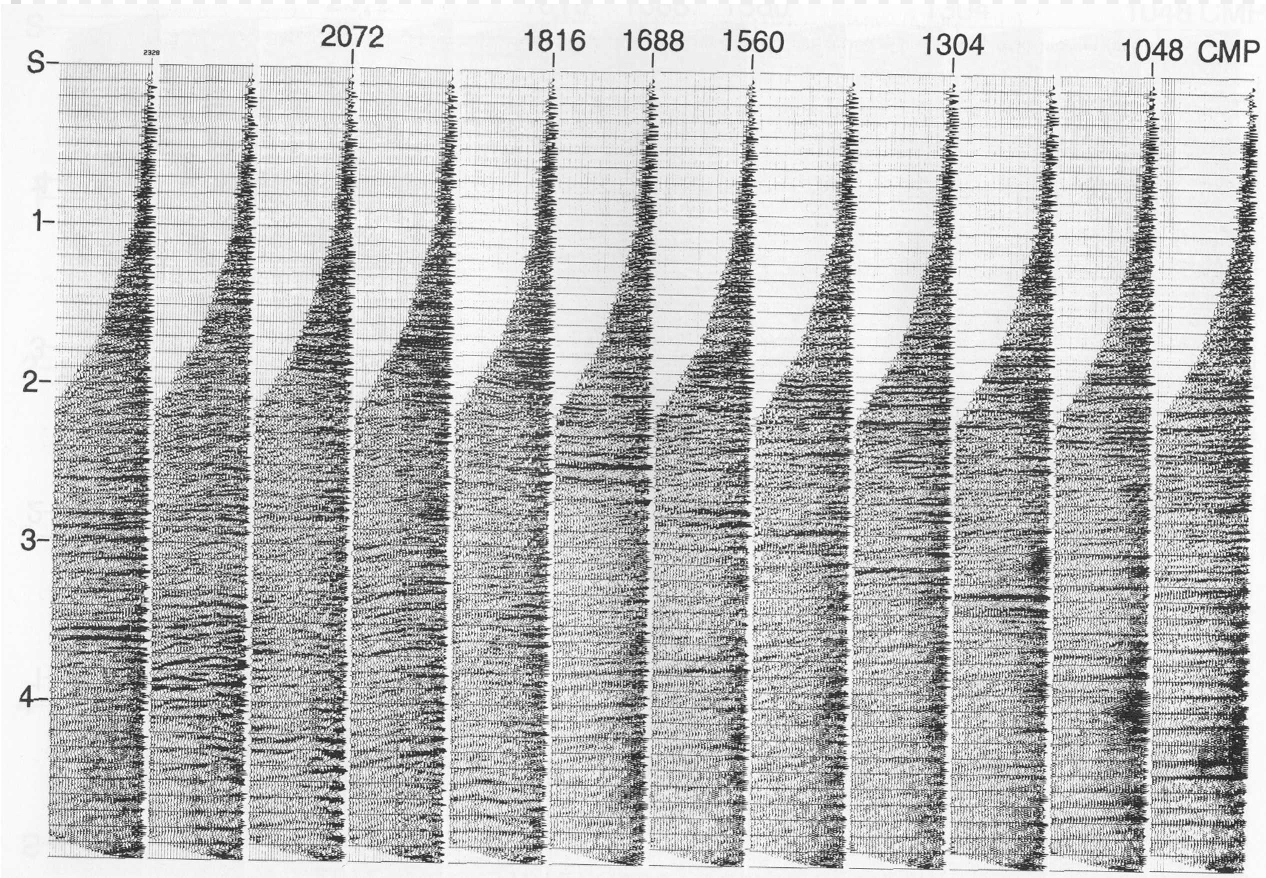
Example: CMP gathers



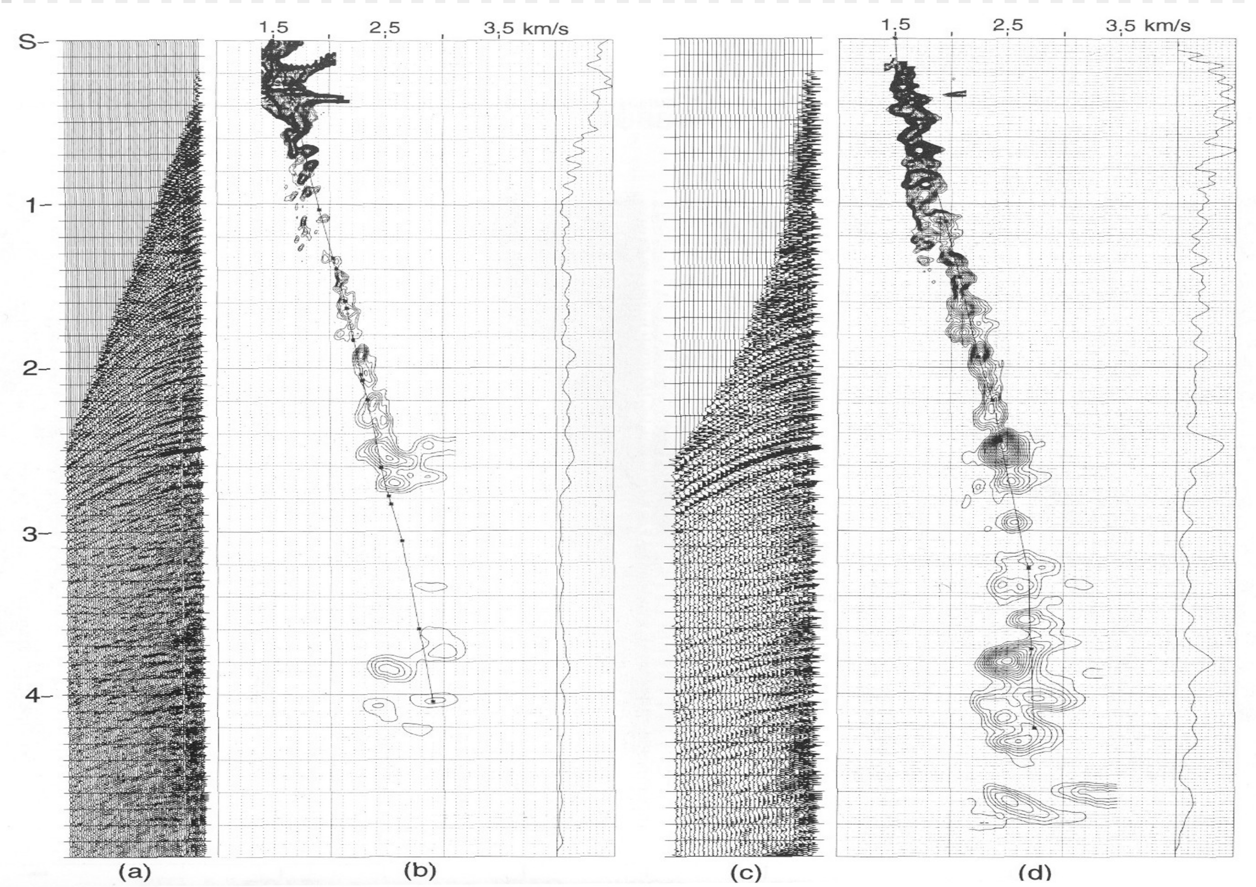
Example:
CMP gathers after NMO correction



Example:
CMP gathers after NMO+DMO corrections



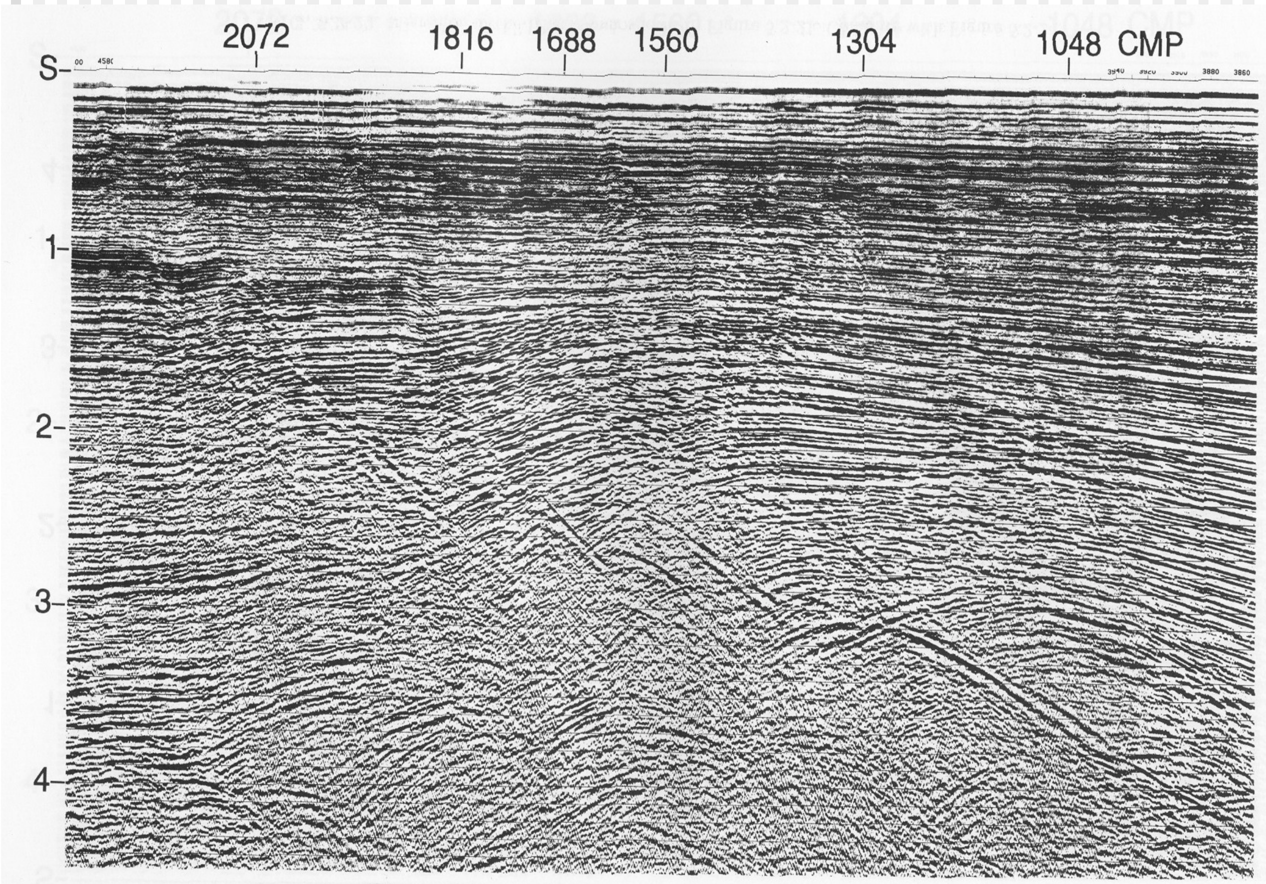
Example: Velocity analysis



Without DMO

With DMO

Example:
NMO(with DMO) stack
Zero-offset section



Example: Final migrated stack