GEOL483.
3

Reflection Seismic Data Processing

- General CMP processing sequence
- Highlights of some steps

- Reading:
  - Sheriff and Geldart, Chapter 9

Reflection
Seismic Processing

- Objective - transform redundant reflection seismic records in the *time domain* into an interpretable *depth image*.
- Four general stages of data processing:
  - 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.

Seismic Processing Systems

- Seismic processing requires extensive support by software
  - Highly integrated
  - High performance
  - Interactive and batch processing
- 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);
  - Echos (formerly Disco, Focus - Paradigm);
  - Vista (now Schlumberger/CGG)
- Universities:
  - Stanford Exploration Project;
  - Seismic UNIX (Colorado School of Mines);
  - FreeUSP (Amoco);
  - SIOSEIS (Scrippts, marine);
  - Our own (IGeoS)

CMP Processing Sequence
(initial data reduction)

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
(statics)

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.

CMP Processing Sequence (continued)

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.

8) Amplitude 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.

more steps will be continued later …

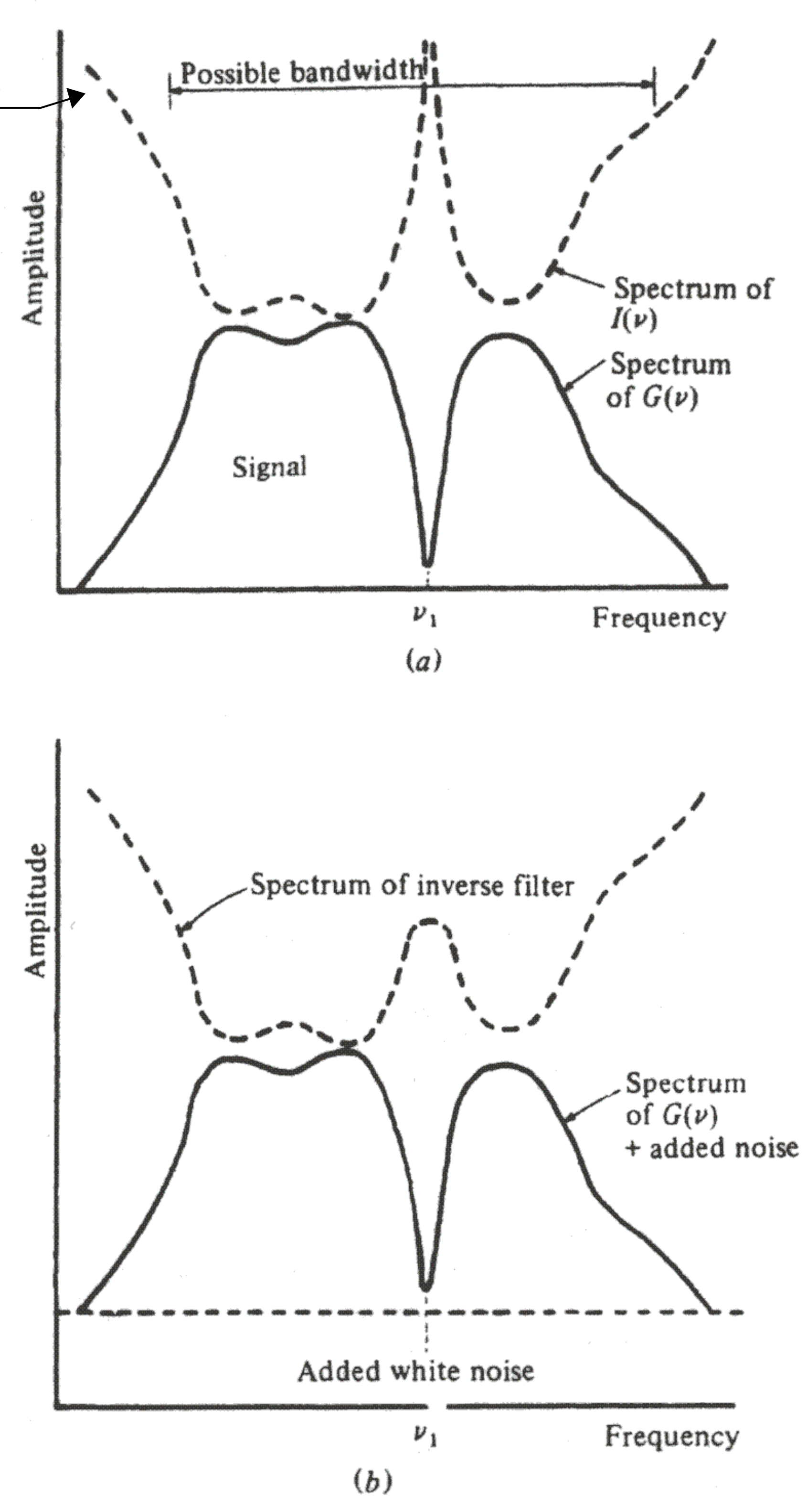
New!

Deconvolution

Deconvolving (inverse) Filter

- Objectives:
  1) Compress the wavelet into a sharper, minimum- or zero-phase shape;
  2) Remove predictable (short-period multiple) part of the signal;
  3) Broaden (flatten) the spectrum
- This **improves resolution** of seismic images

More on deconvolution in
Filtering
section later...

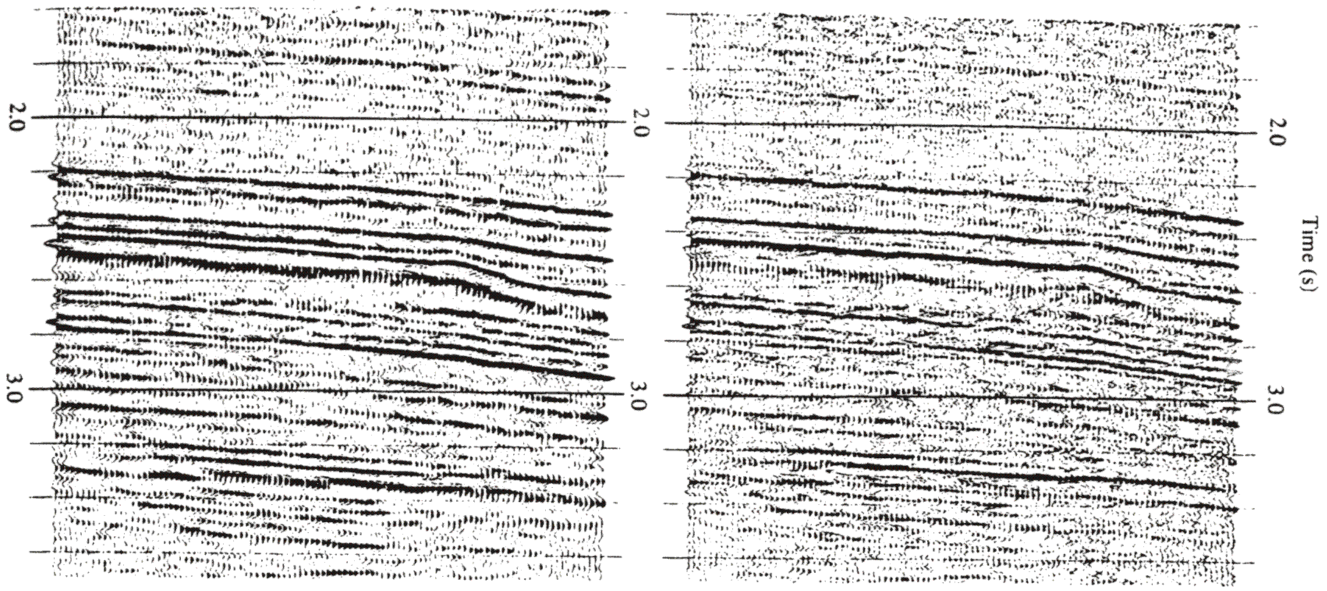


New!

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

Note the sharper resolution of layering after wavelet improvement



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

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

more steps will be continued later, and now, let us consider velocity analysis, NMO and DMO …

Normal Moveout (NMO) correction and stretching

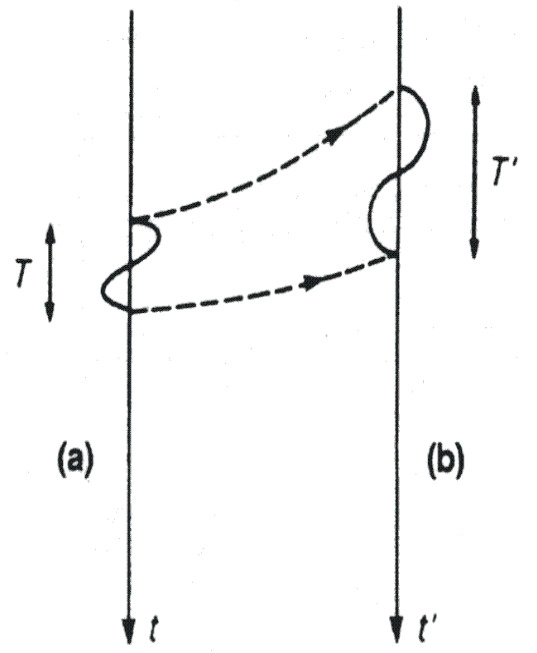
- NMO correction transforms a reflection record at offset *x* into a normal-incidence (*x*=0) record:

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

"Stacking velocity"

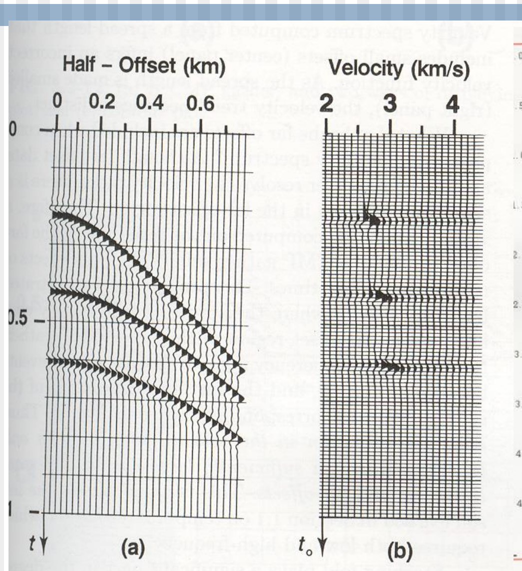
NMO correction

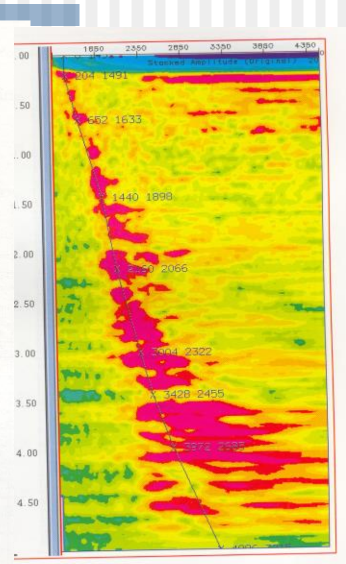
- NMO correction stretches shallower and slower reflections stronger
  - This affects the spectrum of the stack
  - This distortion is controlled during processing by setting a limit in relative stretch (typically ~25%)

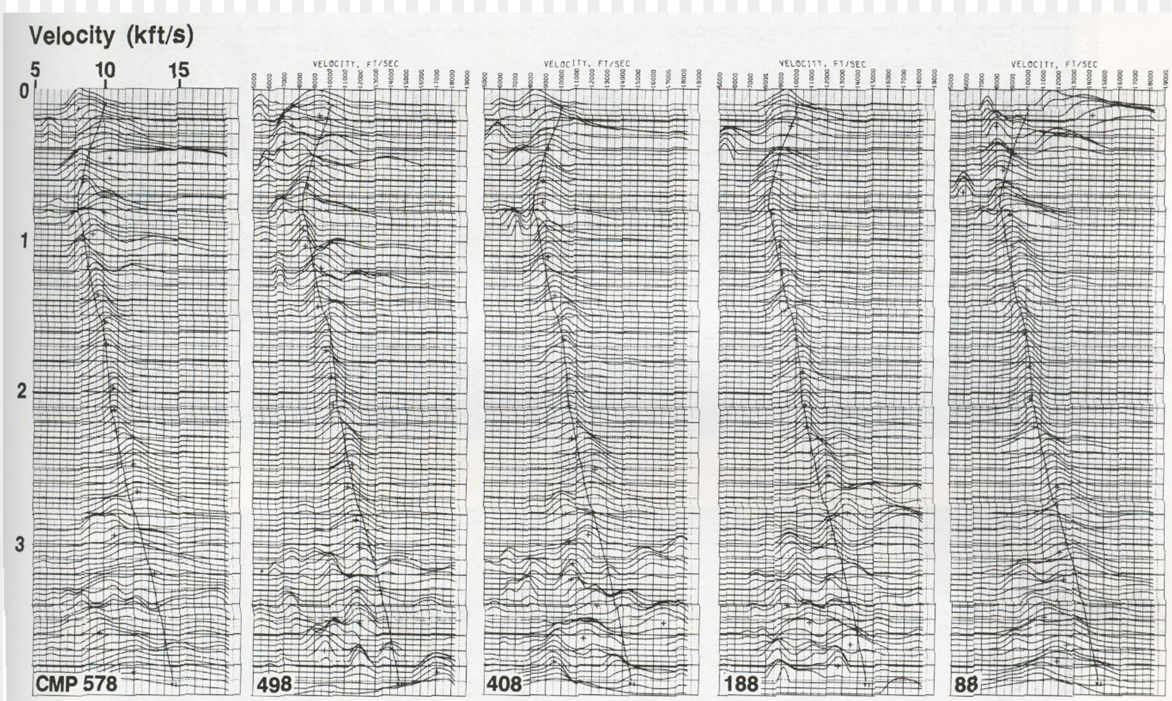


Velocity Analysis

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

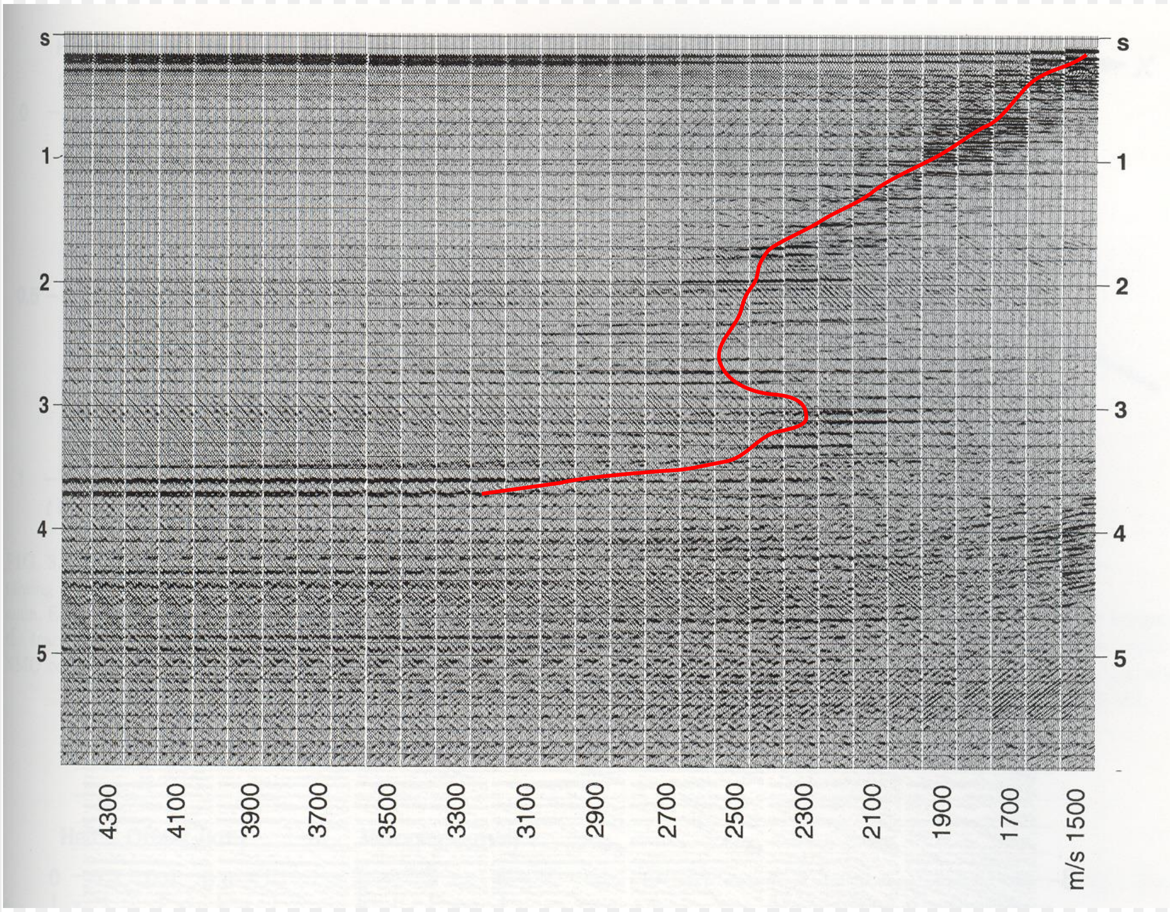






Velocity analysis
(Common-Velocity Stacks)

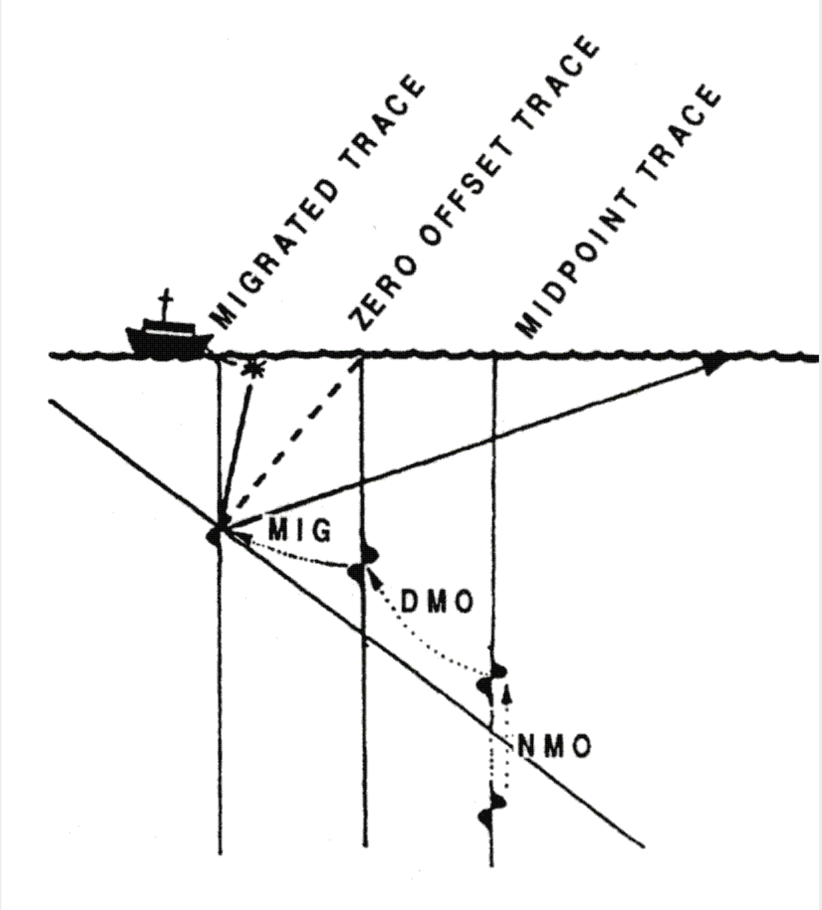
- Groups of CMP gathers are NMO-corrected (hyperbolas flattened) using a range of trial velocities and stacked.
- Velocities are picked at the amplitude peaks and best resolution in the stacks.



New!

NMO→DMO→Migration

- DMO assists NMO by correcting for the time delay on an offset trace assuming zero dip.
- For a dipping reflector and a given source-receiver pair, DMO shifts the time of the NMO-corrected reflection and its position to those of the correct zero-offset trace. Migration finally moves it to the correct subsurface location of the reflection.



Deregowski, 1986

CMP Processing Sequence (continued)

17) 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*

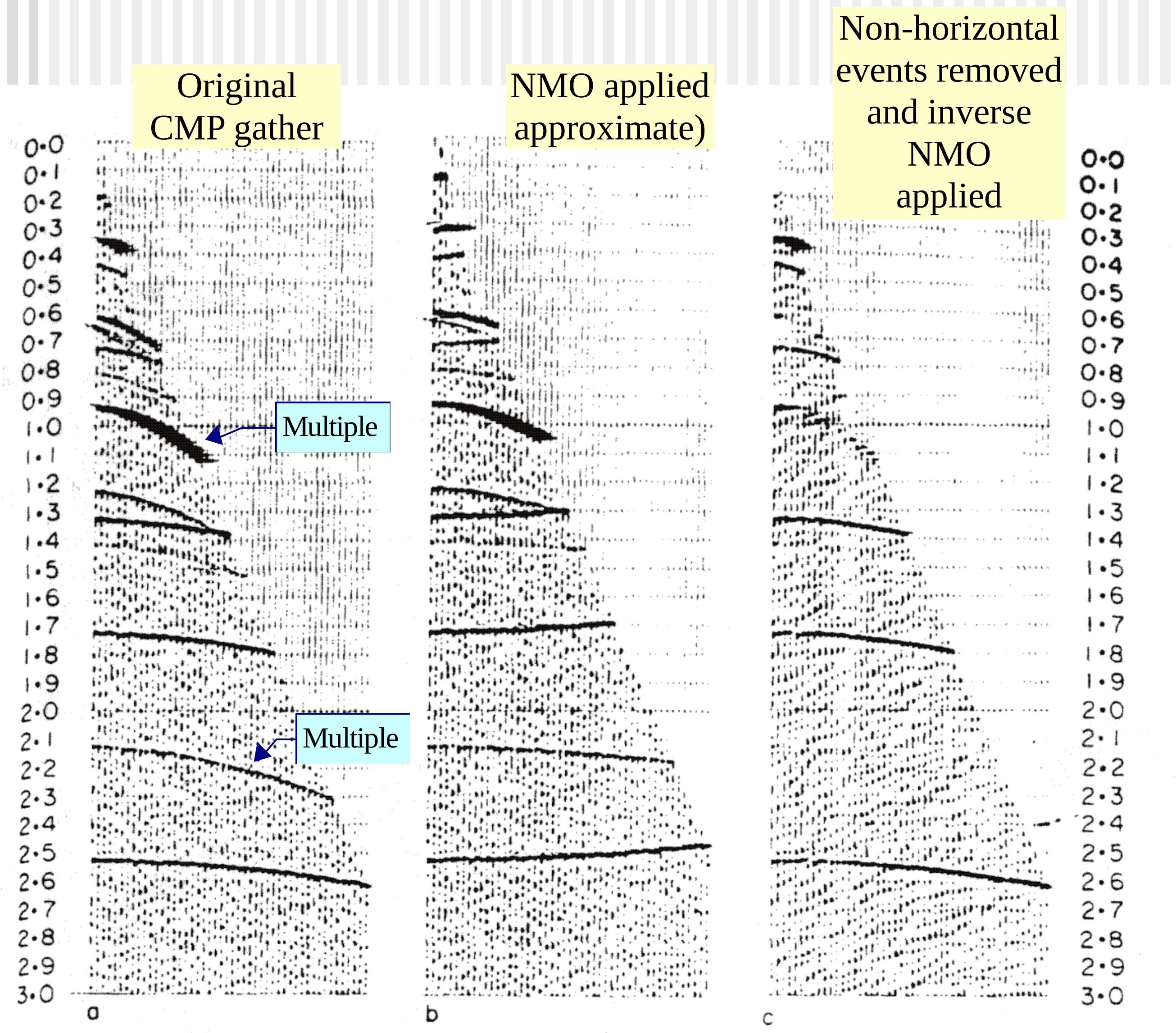
18) Migration
- Transforms the zero-offset *time* section into a depth image;
- Establishes correct extents and dips of the reflectors.

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

New!

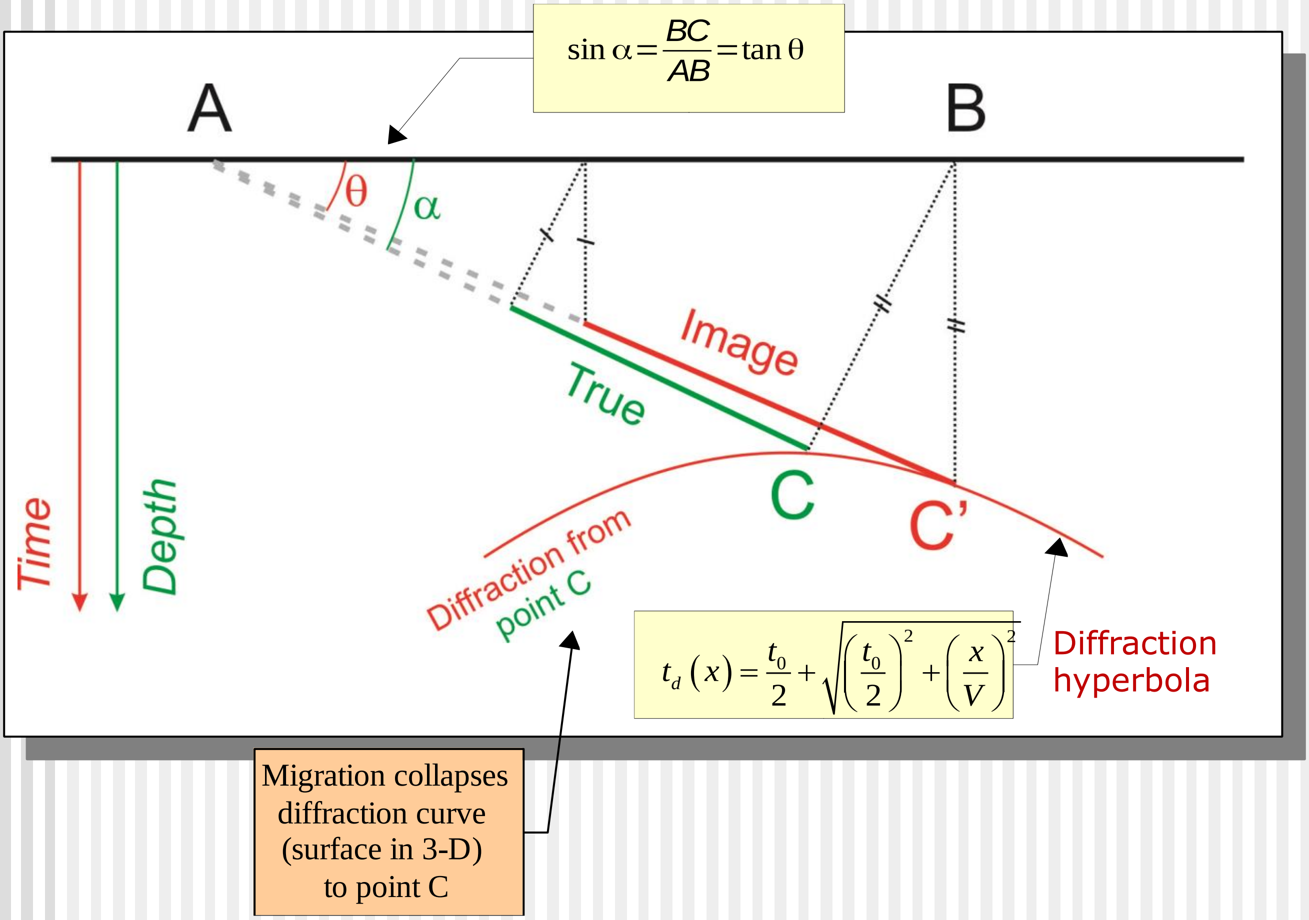
Moveout (*f*-*k*, *τ*-*p*) filtering

- Removes coherent events with <u>undesired moveouts</u>



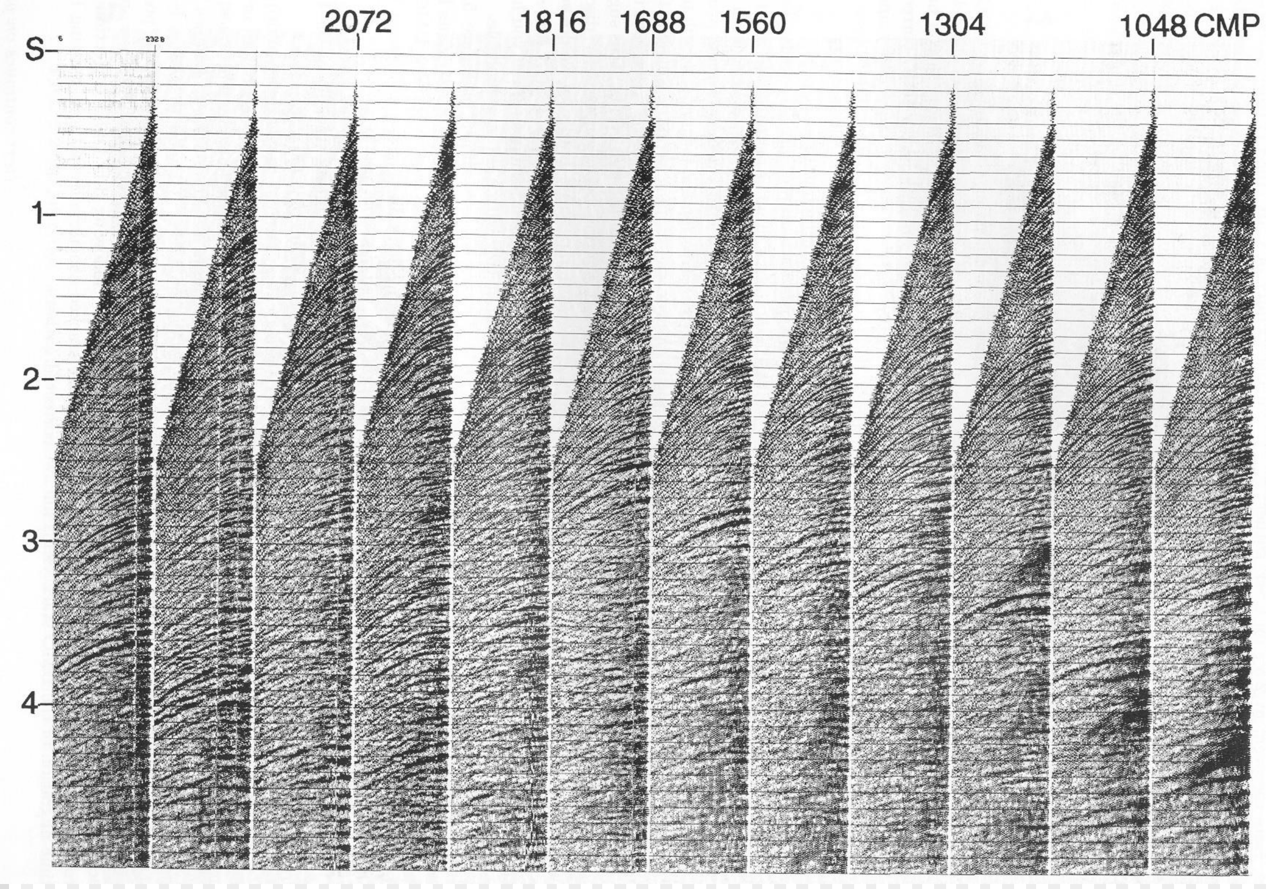
Migration

- A simplified variant of '*inversion*' (without changing amplitudes)
  - Inverts 'time section' for true 'depth image'
- Establishes true positions (AC in plot) and dips (α) of reflectors.
- Collapses diffractions



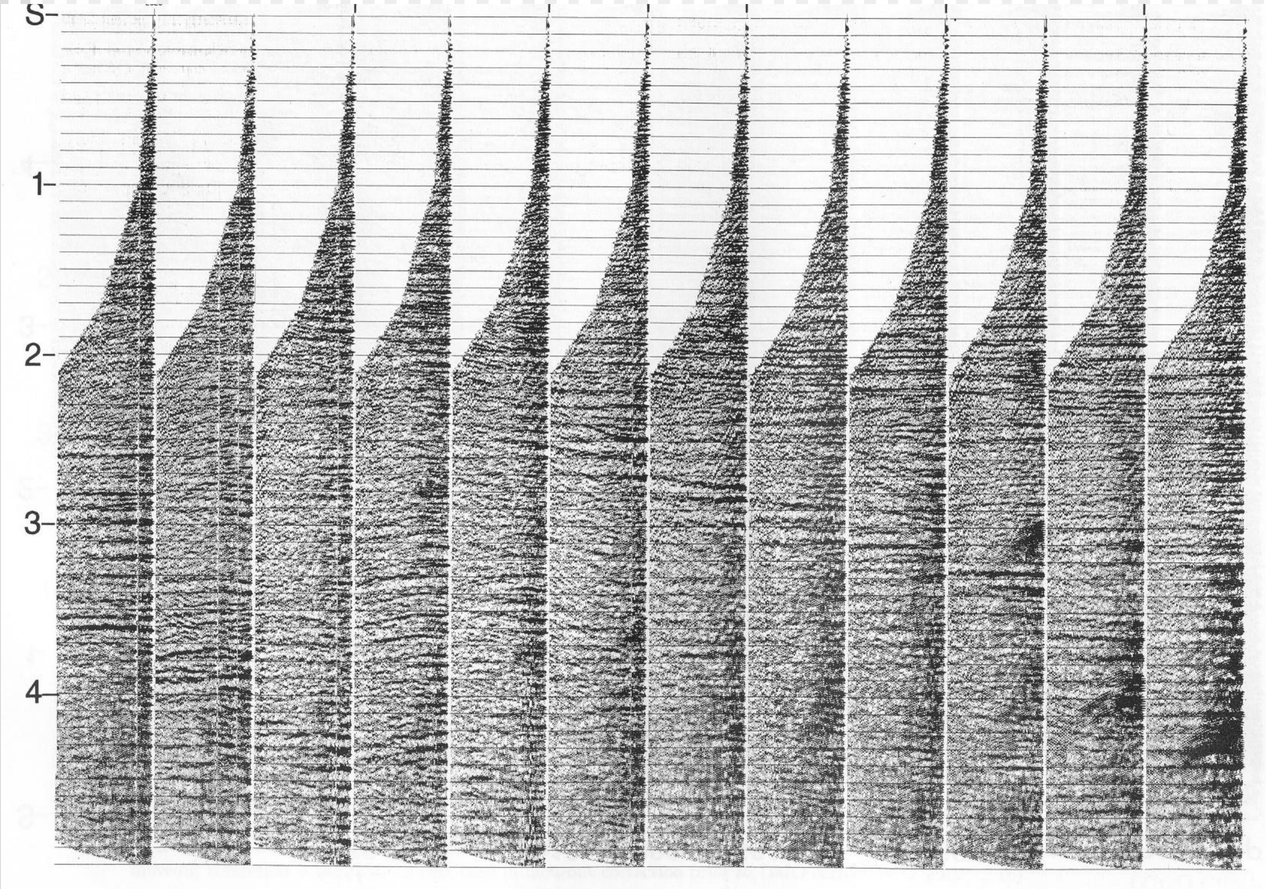
New!

Example: CMP gathers



New!

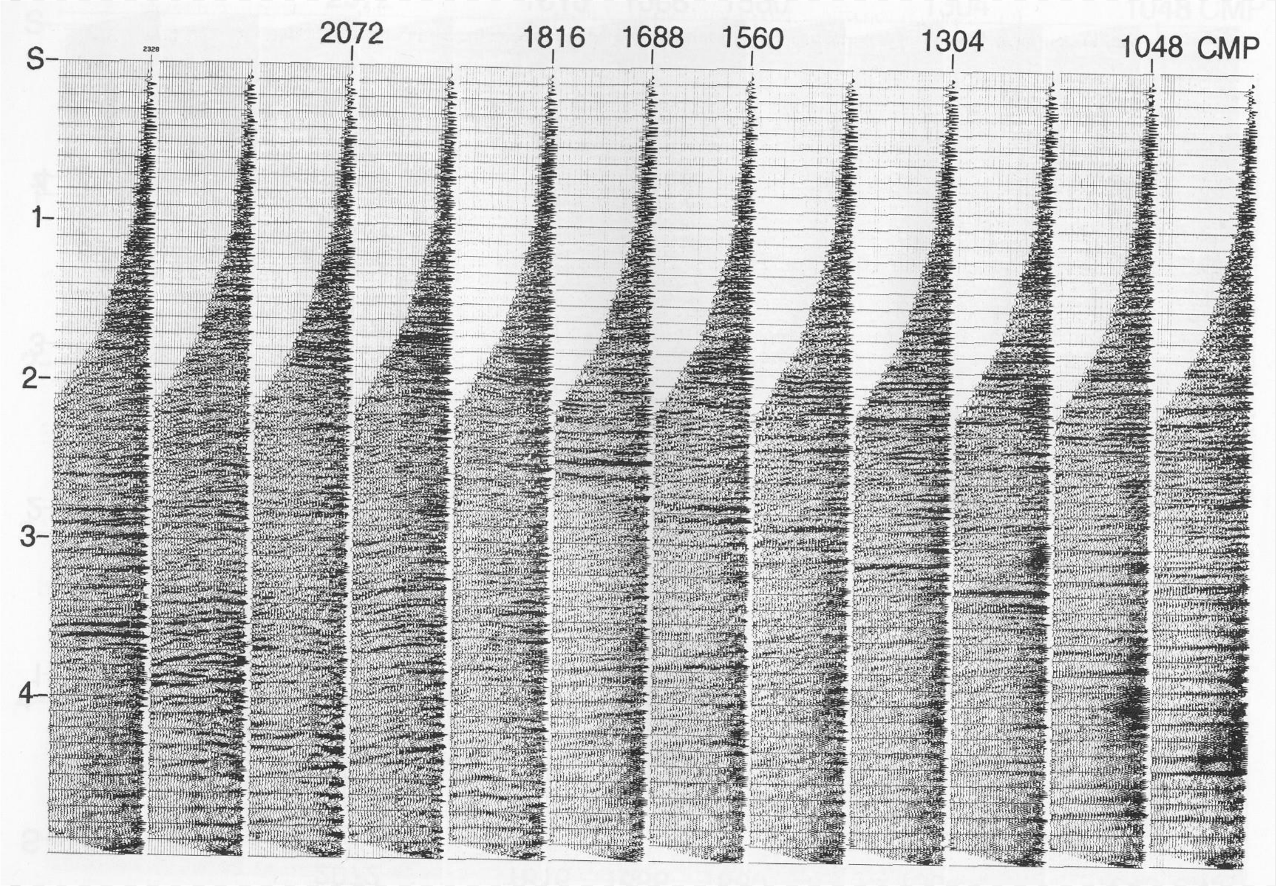
Example:
CMP gathers after NMO correction



- Note some imperfectly corrected reflections because of stacking velocities being dependent on conflicting dips
- Also, multiples are “frowning” (under-corrected), because stacking velocities for multiples are typically lower than for primary reflections at the same depth.

New!

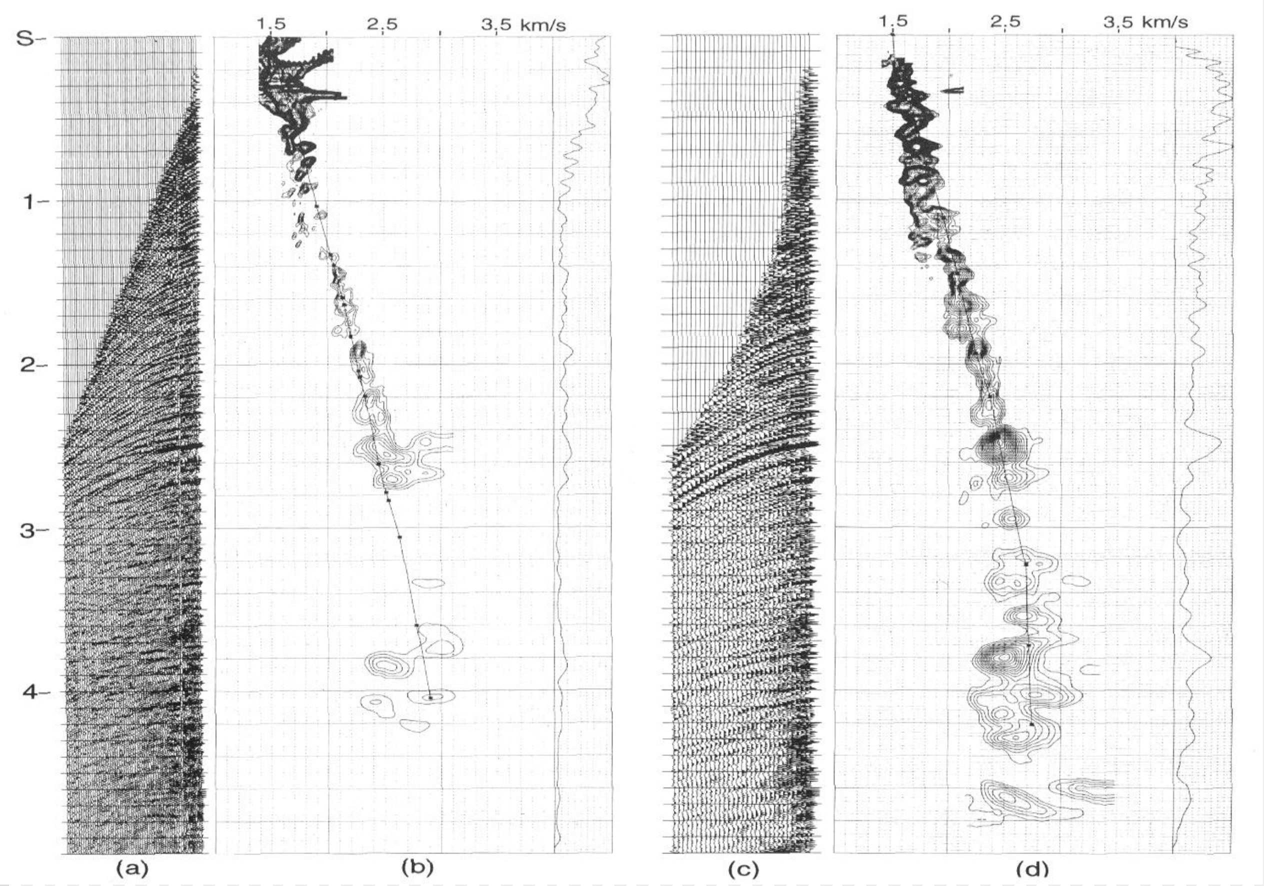
Example:
CMP gathers after NMO+DMO corrections



- Note that after DMO, the problem of conflicting dips is resolved
- Some multiples are still “frowning”, but this means that they will be removed by stacking

New!

Example:
Velocity analysis



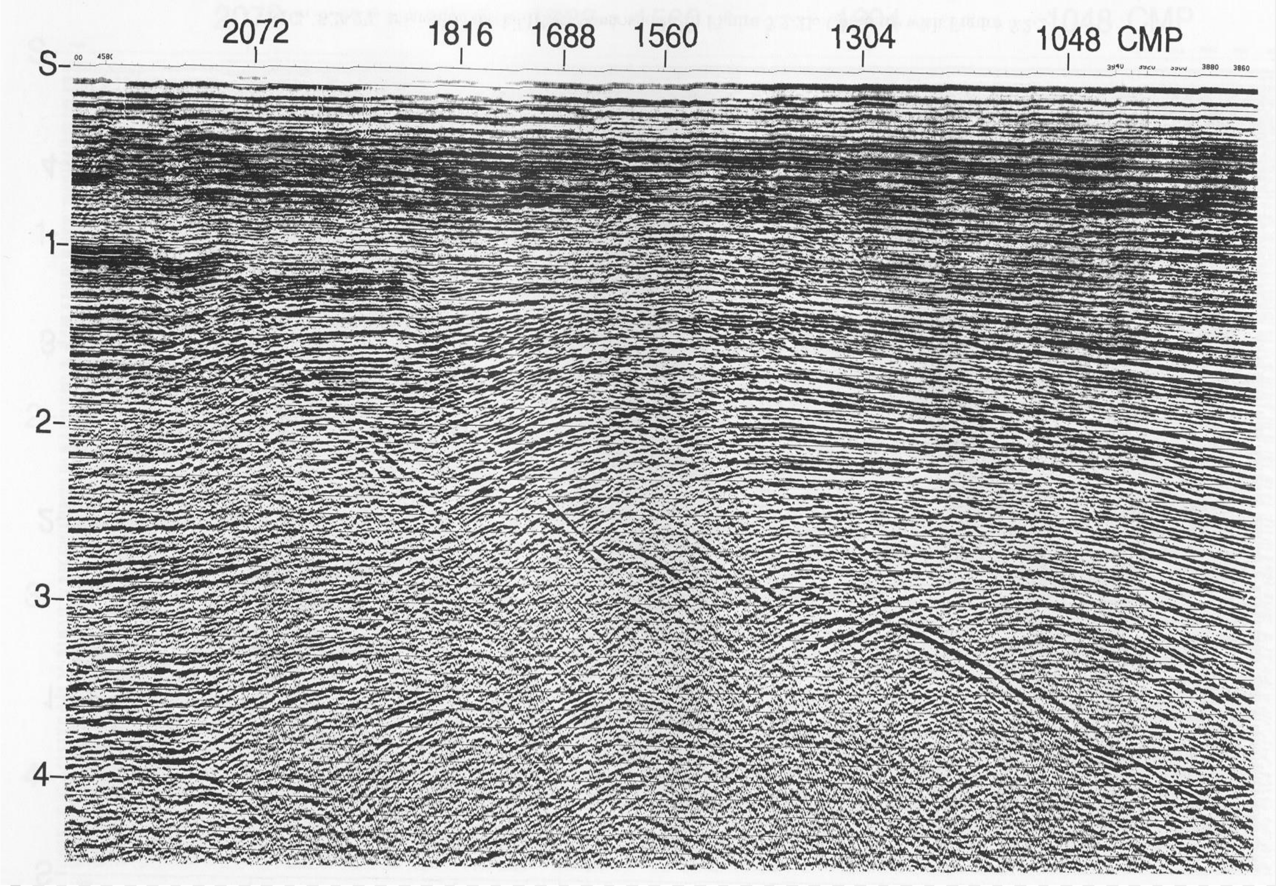
Without DMO

With DMO

- Note the improved accuracy of velocity picking and increased semblance values after DMO

New!

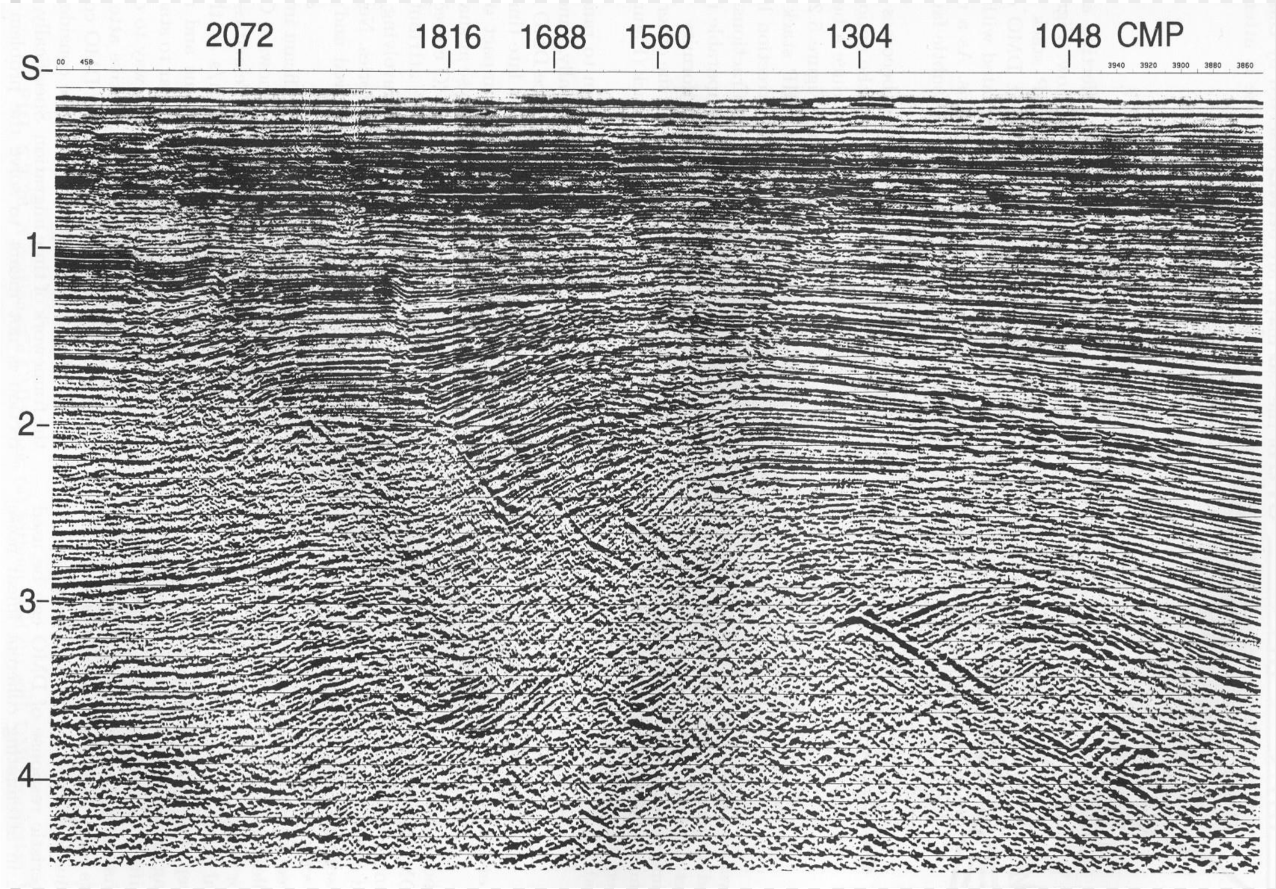
Example:
NMO (with DMO) stack
Zero-offset section



- Note the criss-crossing reflections and incorrect positions of dipping structures in the time section before migration

New!

Example:
Final migrated stack



- Note that structures, positions, and dips are finally correct