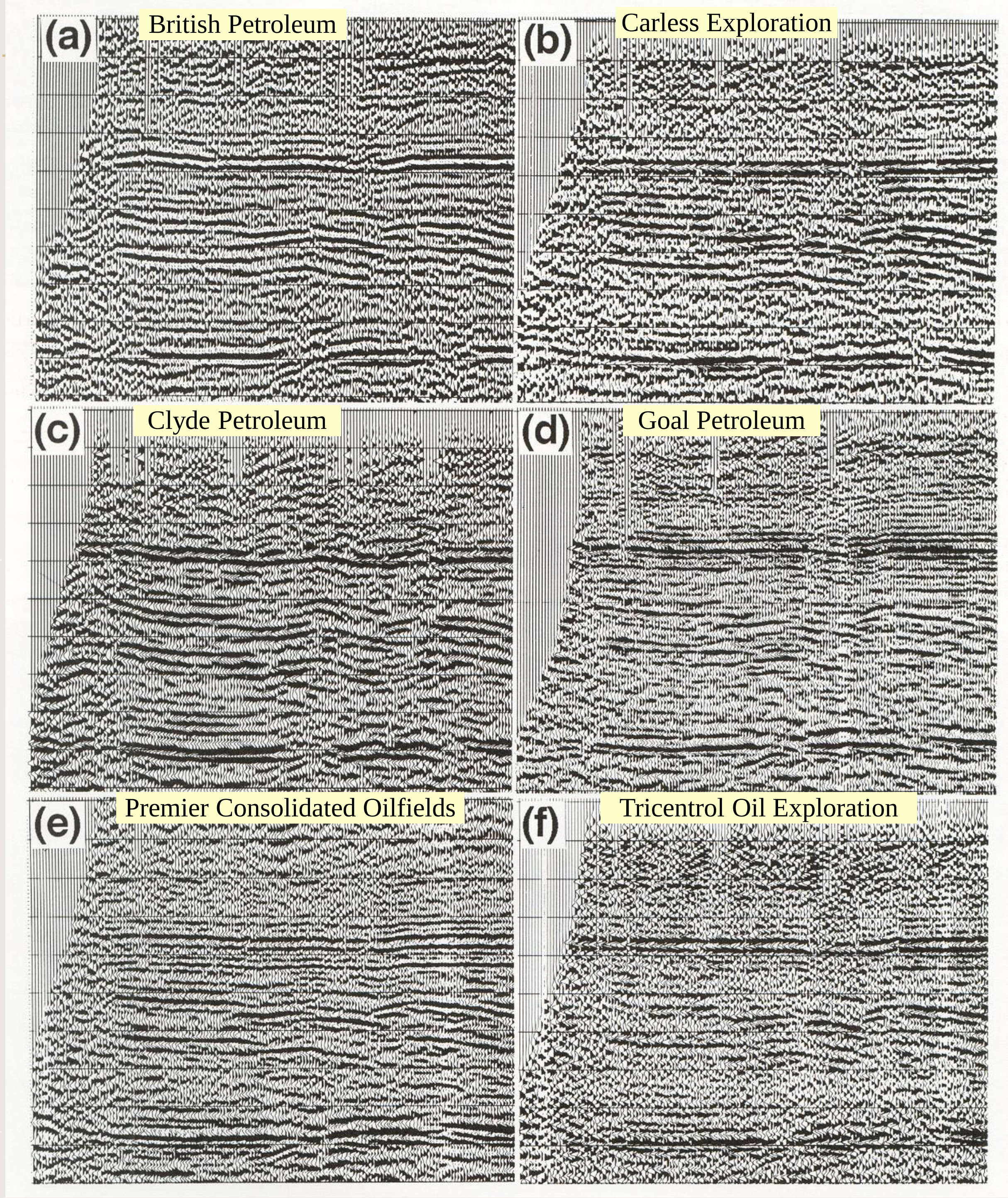
Reflection Seismic Processing

- 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

A seismic line processed by different contractors



Seismic Processing Systems

- Reflection seismic processing requires high-performance processing systems:
  - Millions of data records, complex databases
  - Hundreds of tools applied in sequences
  - Interactive and “batch” processing steps
- Usually geared to a particular type of application
  - Mostly CMP reflection processing, but sometimes “wide-angle” and earthquake
  - 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.).
- Open-source/Universities:
  - Stanford Exploration Project;
  - Seismic UNIX (Colorado School of Mines);
  - FreeUSP (Amoco);
  - SIOSEIS (Scrippts institution for Oceanography, marine, not free!);
  - I. Morozov’s very own:

    http://seisweb.usask.ca/igeos

Seismic data formats
SEG-Y

- Many seismic data formats are similar, and include:
  - Text file header (comments for the user, line description);
  - Binary file header (number of traces, other vital formatting information);
  - ‘Traces’, each including:
    - Binary trace header (channel number, coordinate, offset, statics, mute times, filter parameters, etc.). Some formats allow user-defined trace headers.
    - Trace sample values (integer or floating-point).
- SEG-Y format (adopted by SEG as the standard for data exchange):
  - Text file header of 3200 bytes (40 80-character lines);
  - Binary file header of 400 bytes;
  - Each trace includes:
    - 240-byte headers, fixed predefined format.
    - Samples in any of the 2- or 4-byte formats (usually stored as 4-byte IBM REAL).
- A moderate 2-D seismic line with 800 shots recorded on 96 channels at 1500 samples per trace takes about 500 Mb of storage in SEG-Y format (verify this!)

Processing Hardware

Terabytes and Teraflops

- Memory
  - 1 byte = 8 bits
  - 1 kbyte (kilo-) = 1024 bytes
  - 1 Mbyte (mega-) = 1024^2 bytes
  - 1 Gbyte(giga-) = 1024^3 bytes
  - 1 Tbyte(tera-) = 1024^4 bytes
- Flop
  - Number of floating-point operations per second ('+', '-', '*', '/');
  - Sqrt() takes ~10-15 operations;
  - Multiples:
    - 1 Mflop = 10^6 flop
    - 1 Gflop = 10^9 flop
    - 1 Tflop (tera-) = 10^{12} flop
    - 1 Pflop (penta-) = 10^{15} flop
    - 1 Eflop (exa-) = 10^{18} flop
- For top performers, check: http://www.netlib.org/benchmark/top500/top500.list.html
- 3-D seismic processing routinely utilizes *massively* parallel systems (*e.g.*, ~5000 processors at Veritas DGC in Houston and 2000 in Calgary)
- In recent years Graphics Processing Units (GPU) are broadly used for seismic data processing
  - 100's of processors on a single board

CMP Processing Sequence

Data reduction, pre-processing

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
   - These days, may not be required (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
First arrivals and Mute

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 the 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
Amplitudes and waveforms

8) True amplitude recovery (optional)

- 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

- Compresses the wavelet in time, attenuates reverberations.

11) Gathering, CMP sorting

- In modern processing systems (ProMax, Omega, Vista) done by using *trace lookup spreadsheets* or databases rather than by creating additional copies of the dataset

CMP Processing Sequence

Stacking velocity analysis and NMO

12) Velocity analysis

- For each of the CMP gathers, determines the optimal *stacking velocity*.

13) Dip Moveout (DMO) correction

- Transforms the records so that the subsequent NMO+stack work well even in the presence of dipping reflectors.

14) Normal Moveout (NMO) correction

- Removes the effects of source-receiver separation from reflection records;
- Transforms the records as if recorded at normal incidence.

15) Residual statics

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

Steps 12-15 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*

CMP Processing Sequence
Stacking and Imaging

16) CMP Stack

- Produces a *zero-offset section*;
- Utilizes CMP redundancy to increase the *Signal/Noise ratio.*

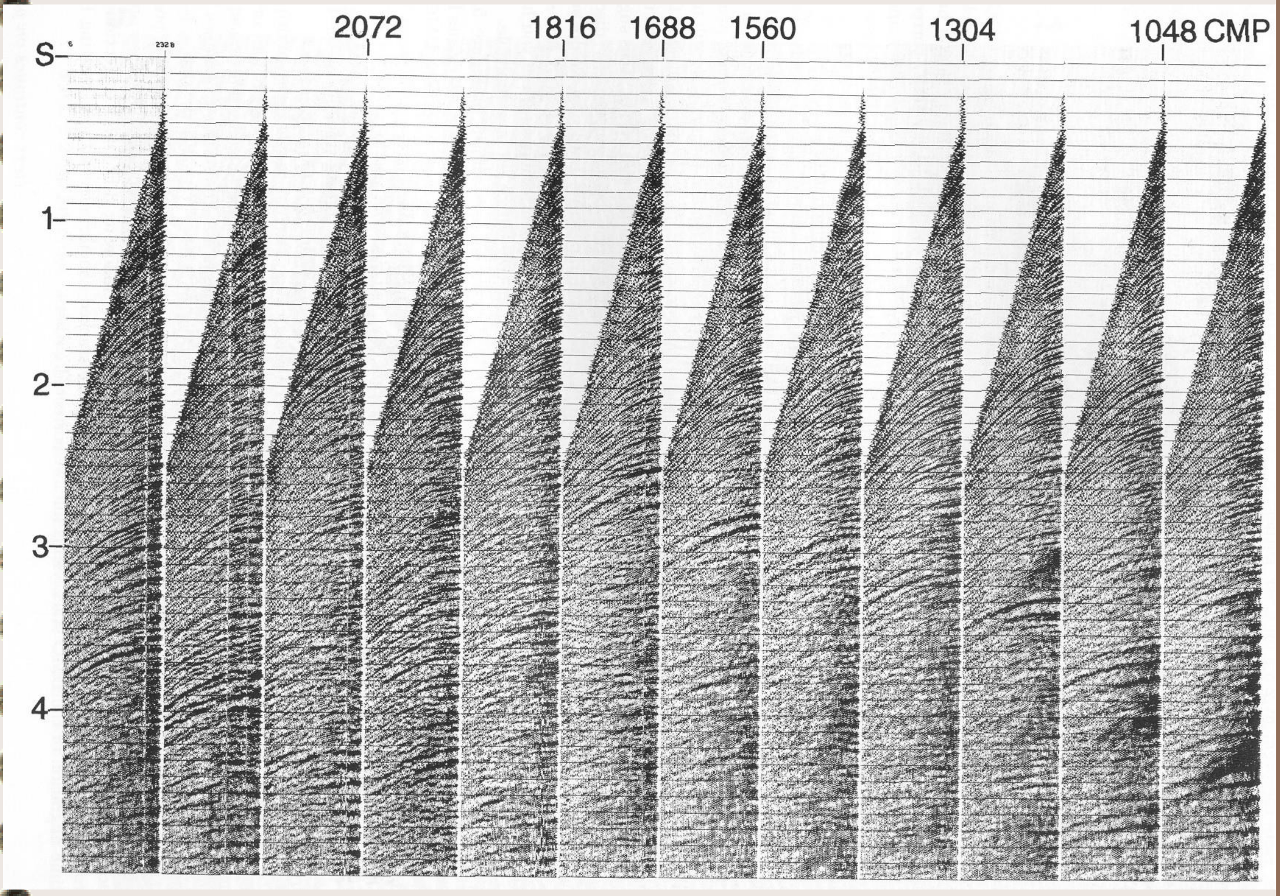
17) Migration

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

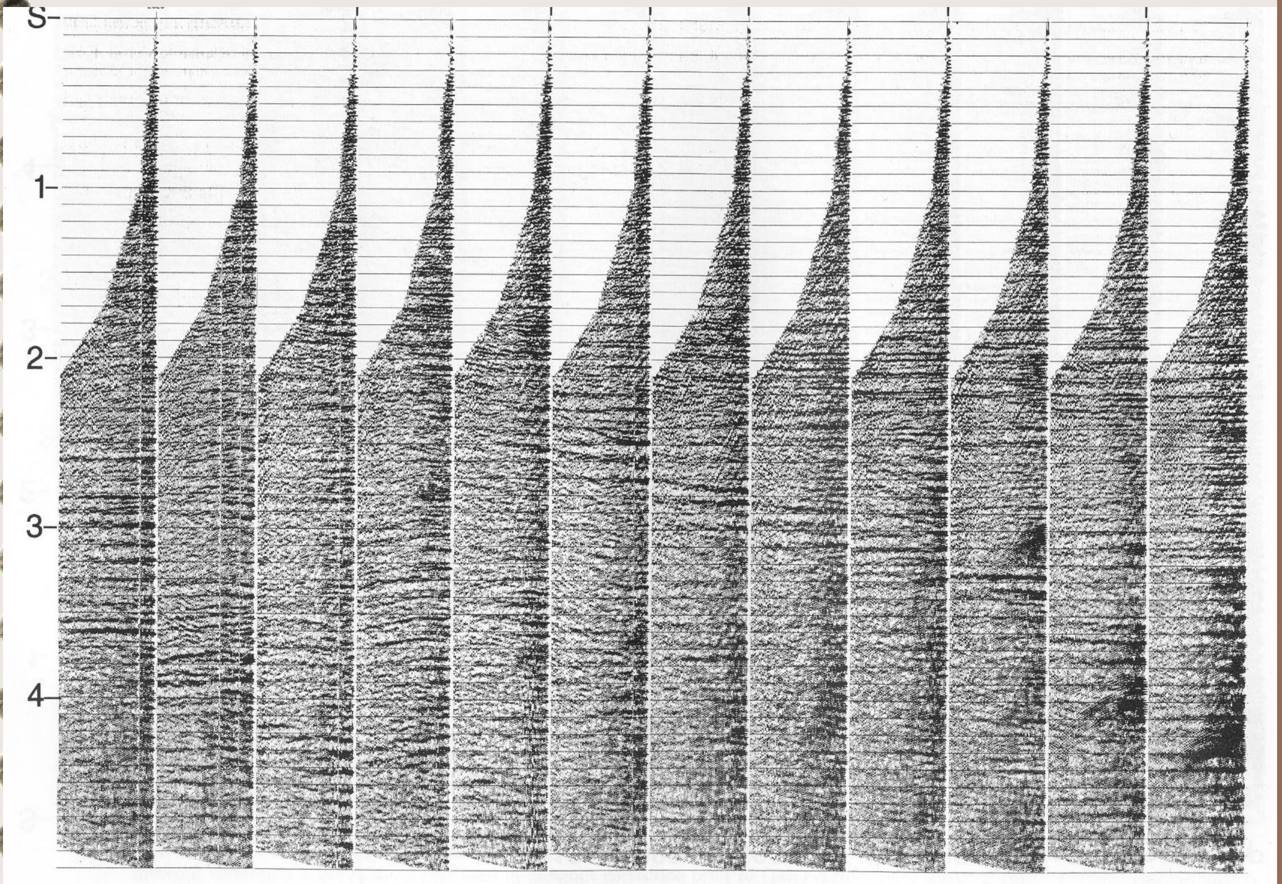
18) Frequency filtering and display

- Band-pass filtering is often time-variant
- Attenuates noise
- Provides best display for interpretation

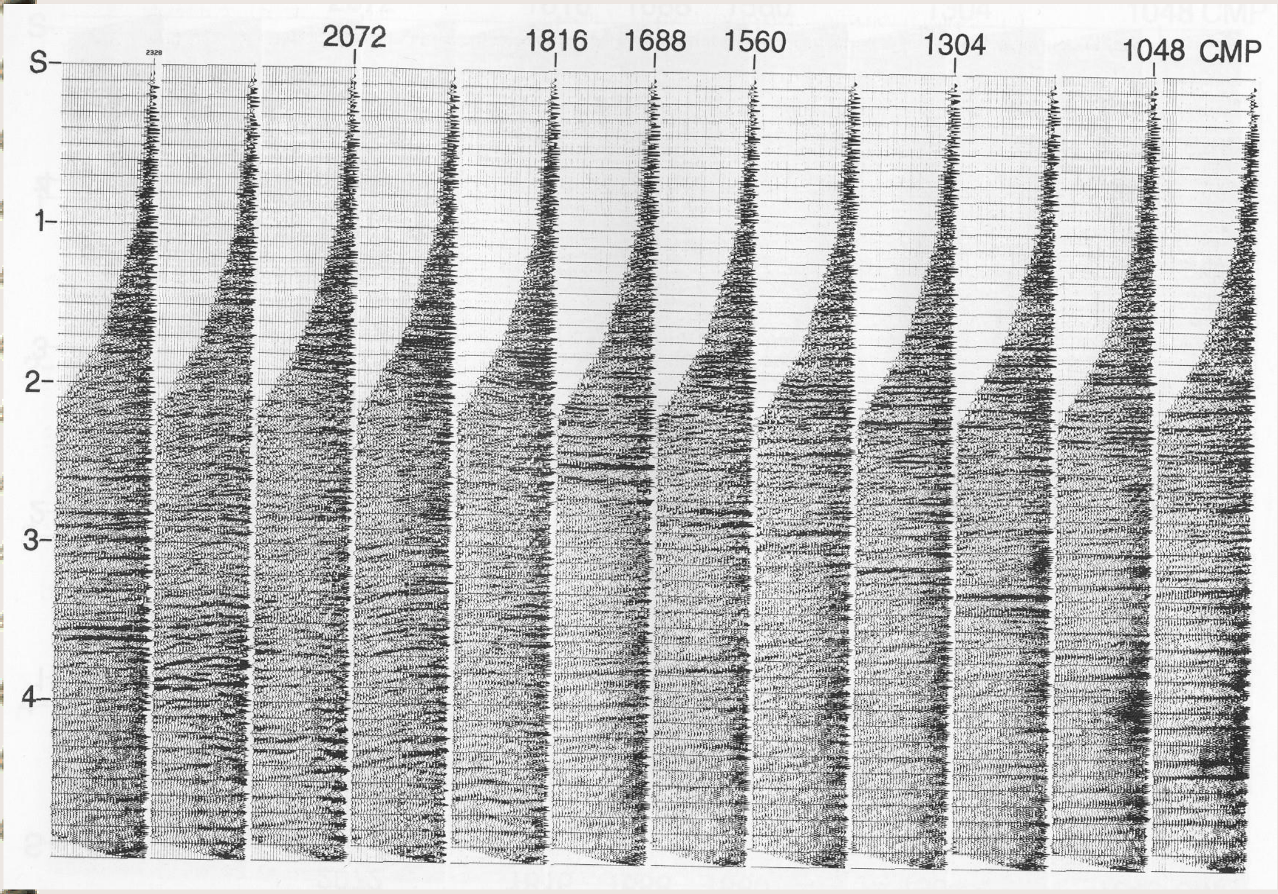
Example:
CMP gathers



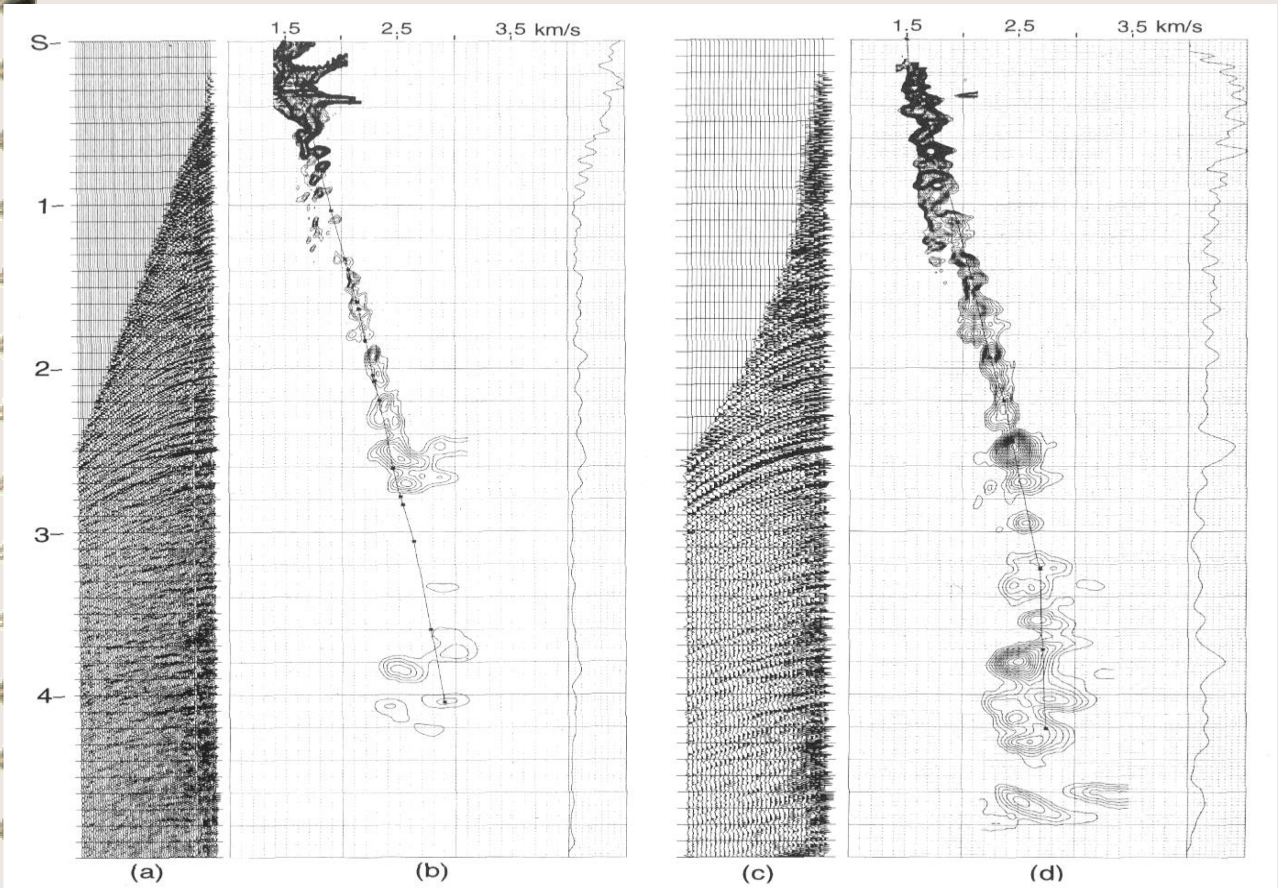
Example:
CMP gathers after NMO correction



Example:
CMP gathers after NMO+DMO corrections



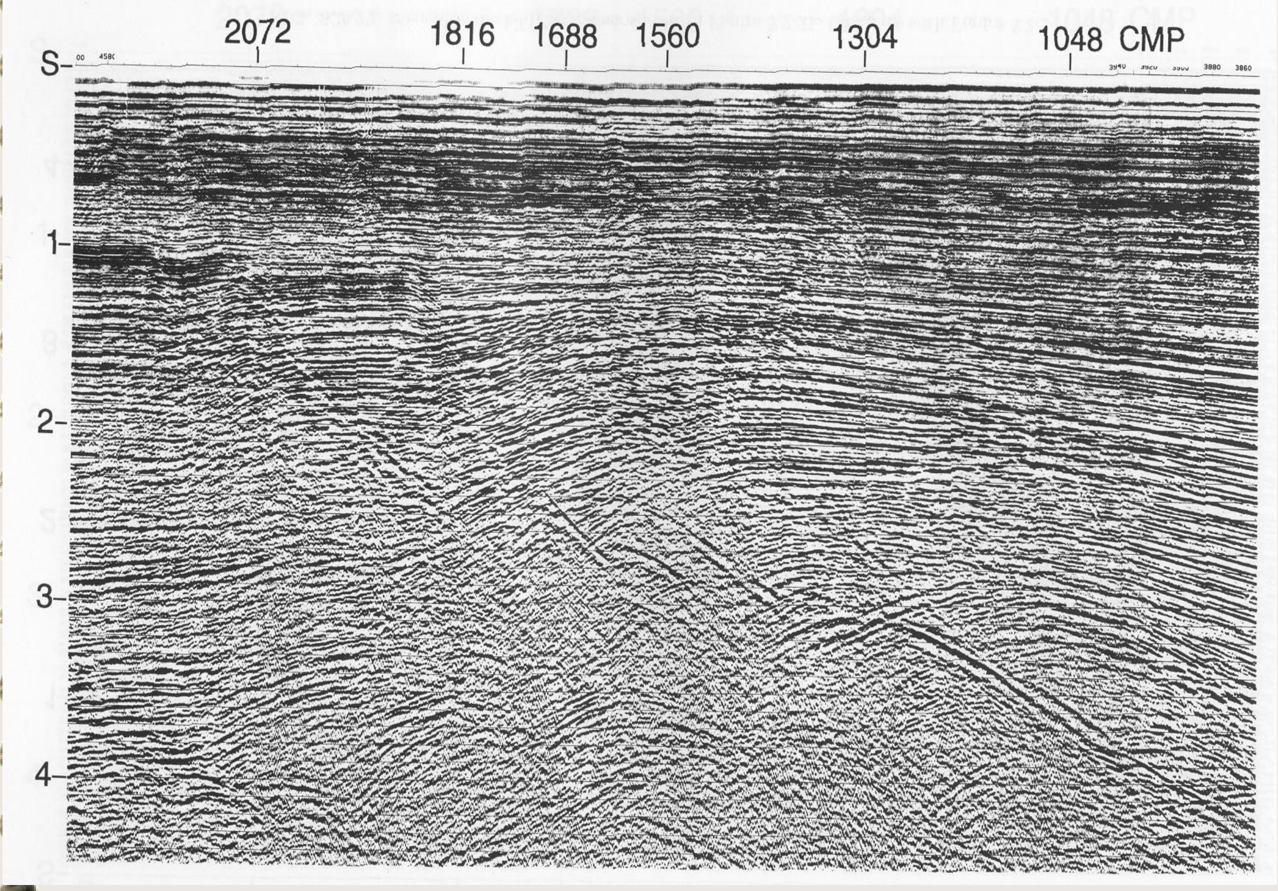
Example:
Velocity analysis



Without DMO

With DMO

Example:
NMO(+DMO) correction and stack



Example:
Final migrated stack