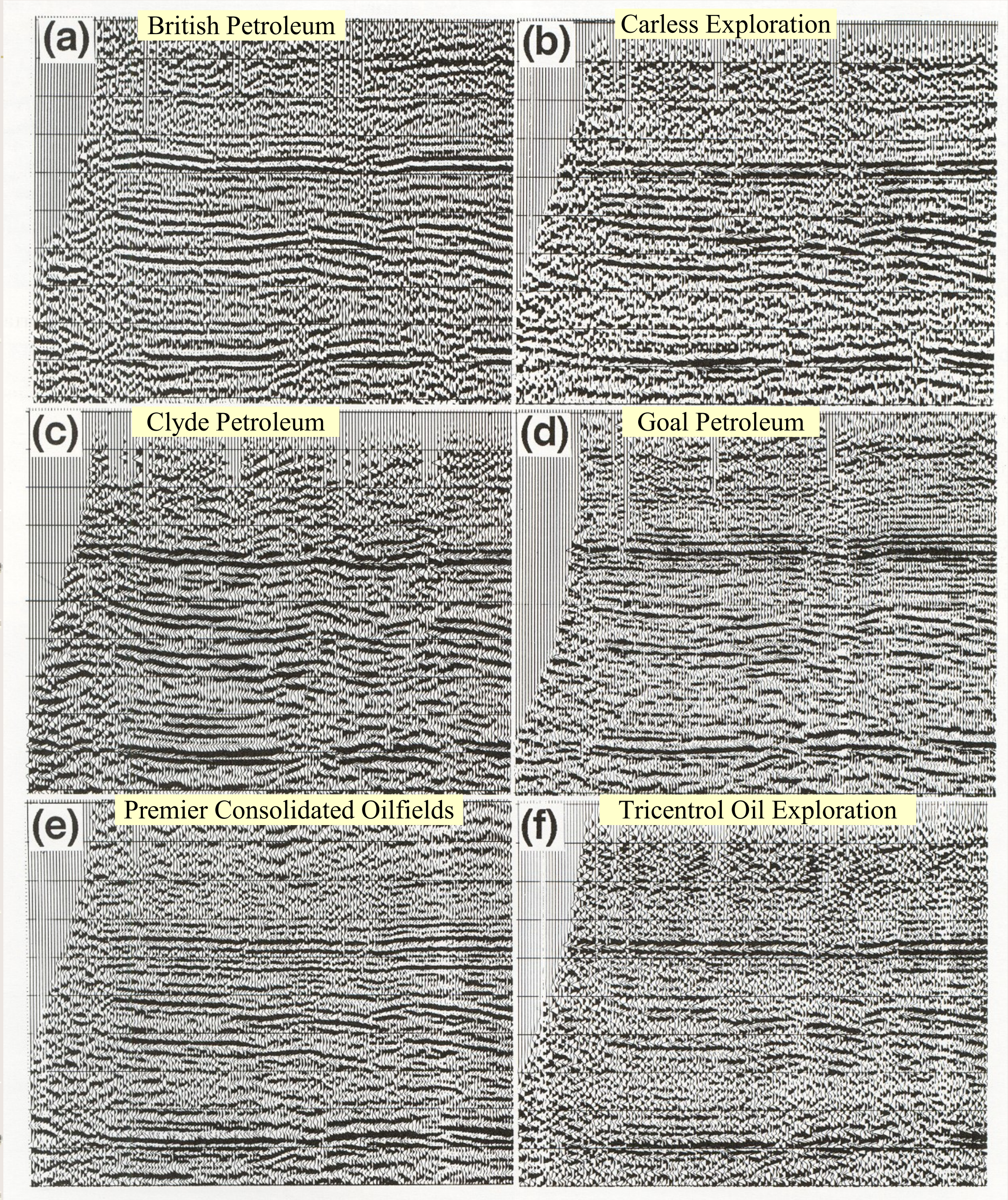
Reflection Seismic Processing

- 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

- 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.).
- Open-source/Universities:
  - Stanford Exploration Project;
  - Seismic UNIX (Colorado School of Mines);
  - FreeUSP (Amoco);
  - SIOSEIS (Scrippts, 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 (<u>verify this!)</u>

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)

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.
   - 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 (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 the travel-time variations caused by the shallow velocities.

4) ‘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

- Compresses the wavelet in time, attenuates reverberations.

11) Gather, CMP sort

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

CMP Processing Sequence (continued)

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

CMP Processing Sequence (continued)

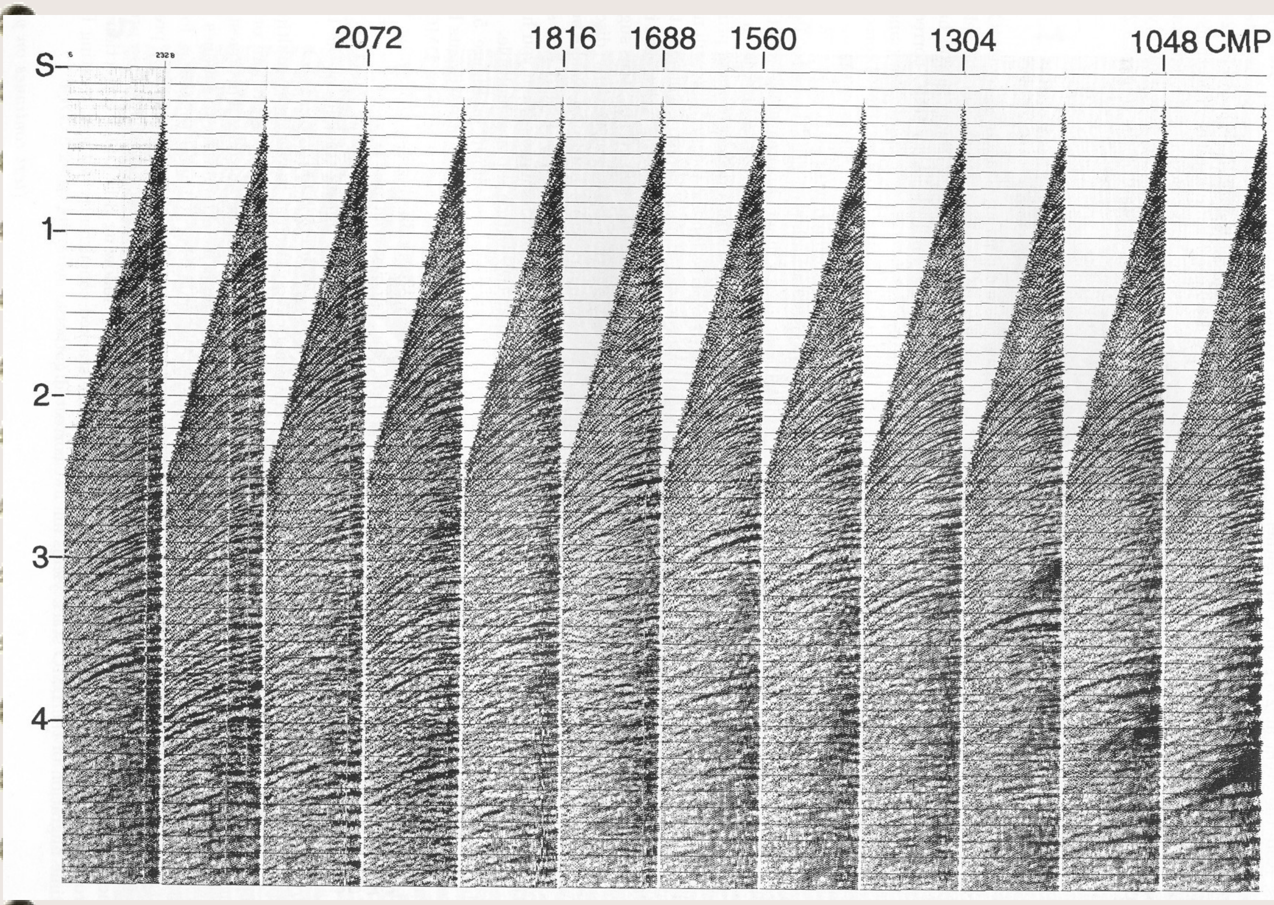
16) Steps 12-15 above are usually <u>iterated</u> 3-5 times to produce accurate *velocity* and *residual statics* models.
   - Success of velocity analysis depends on the quality of DMO/NMO and residual statics, and *vice versa*.

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

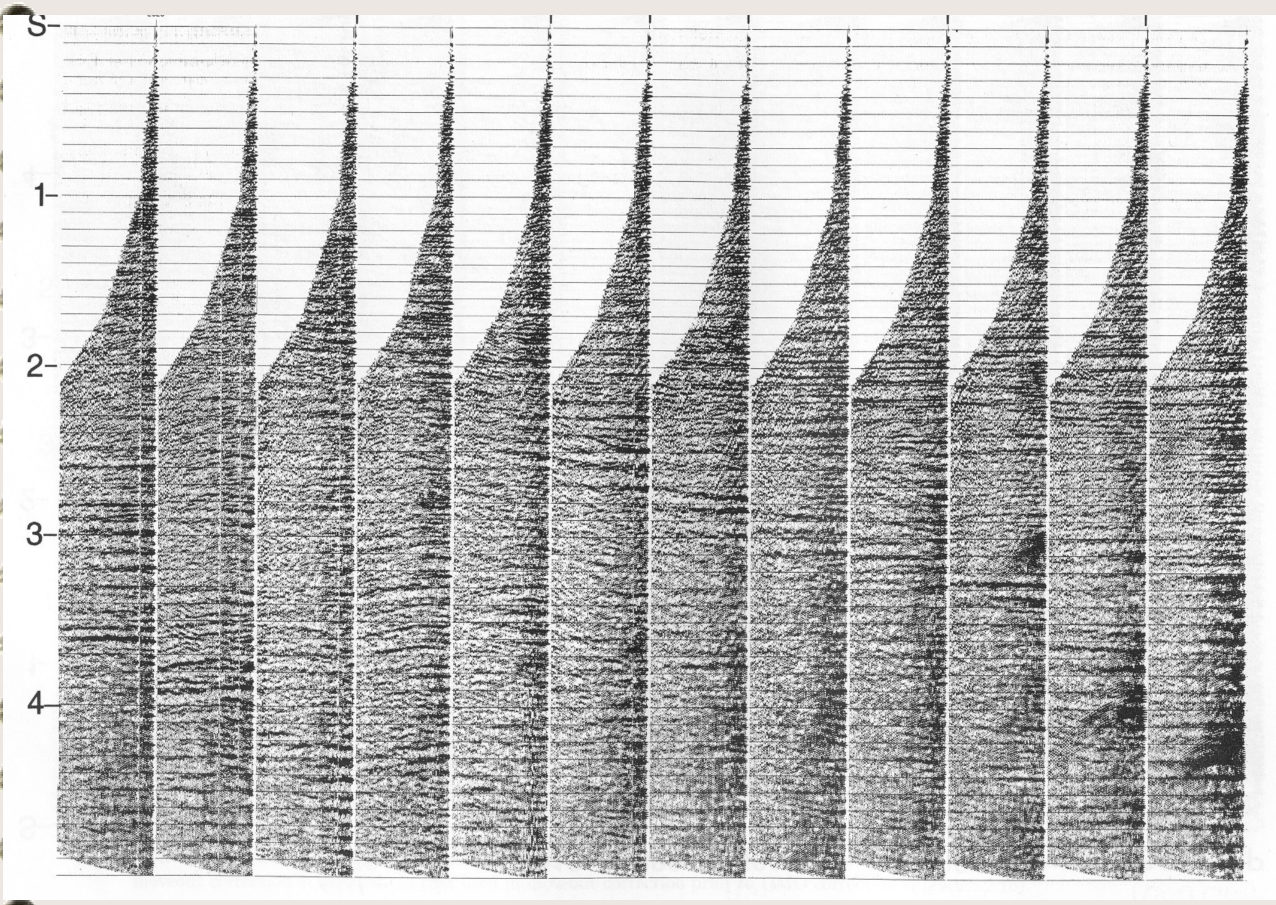
17) Migration
   - Transforms the zero-offset *time* section into a depth image;
   - Establishes correct extents and dips of the reflectors.

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

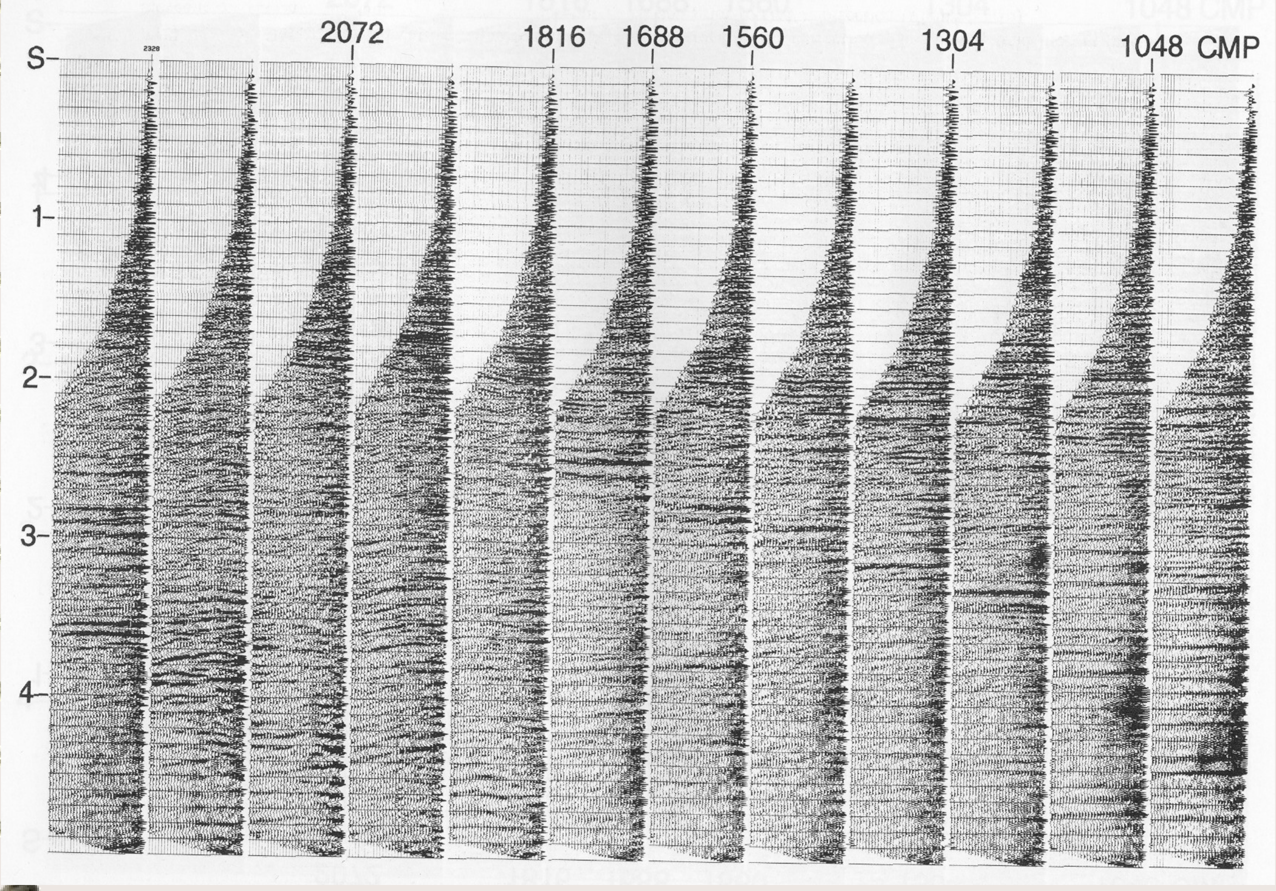
Example: CMP gathers



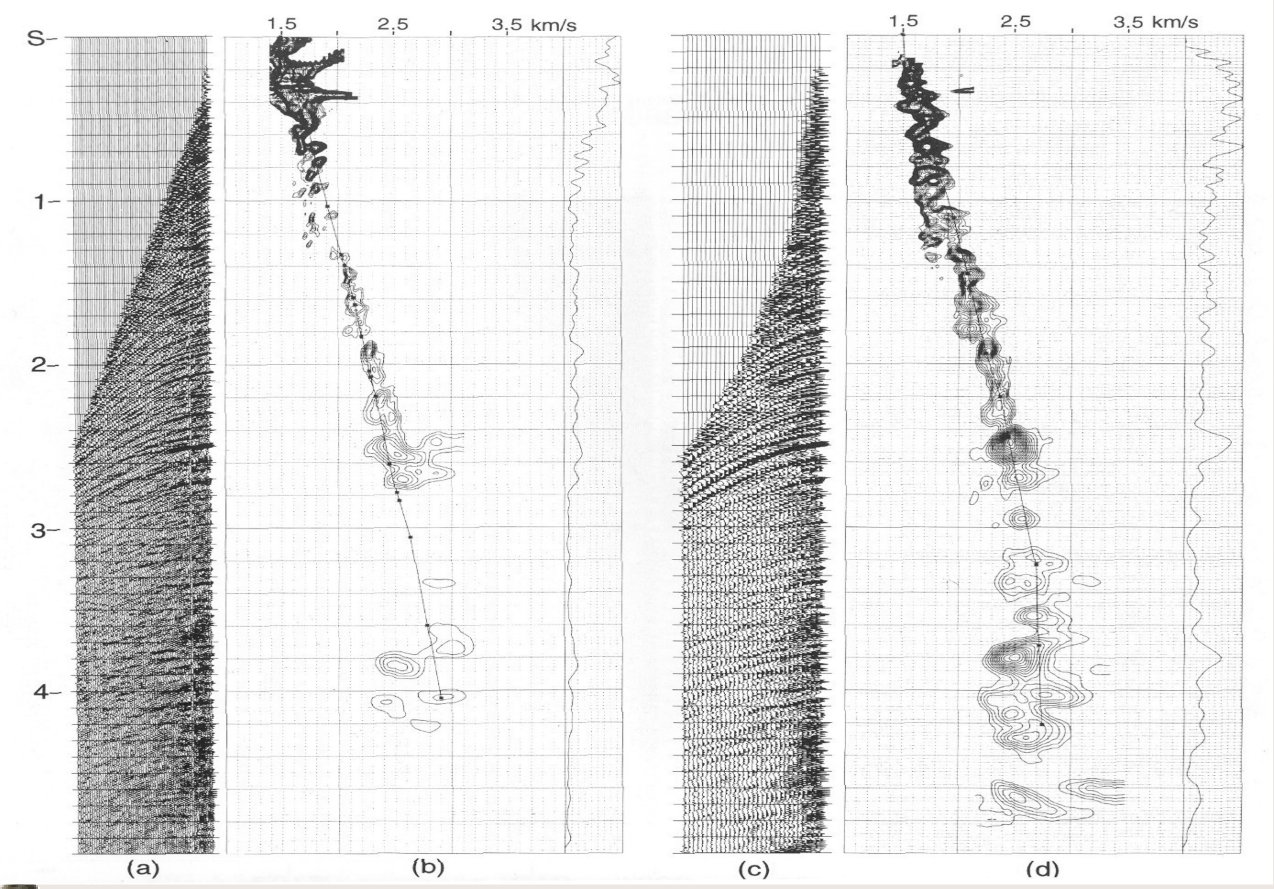
Example:
CMP gathers after NMO correction



Example:
CMP gathers after NMO+DMO corrections



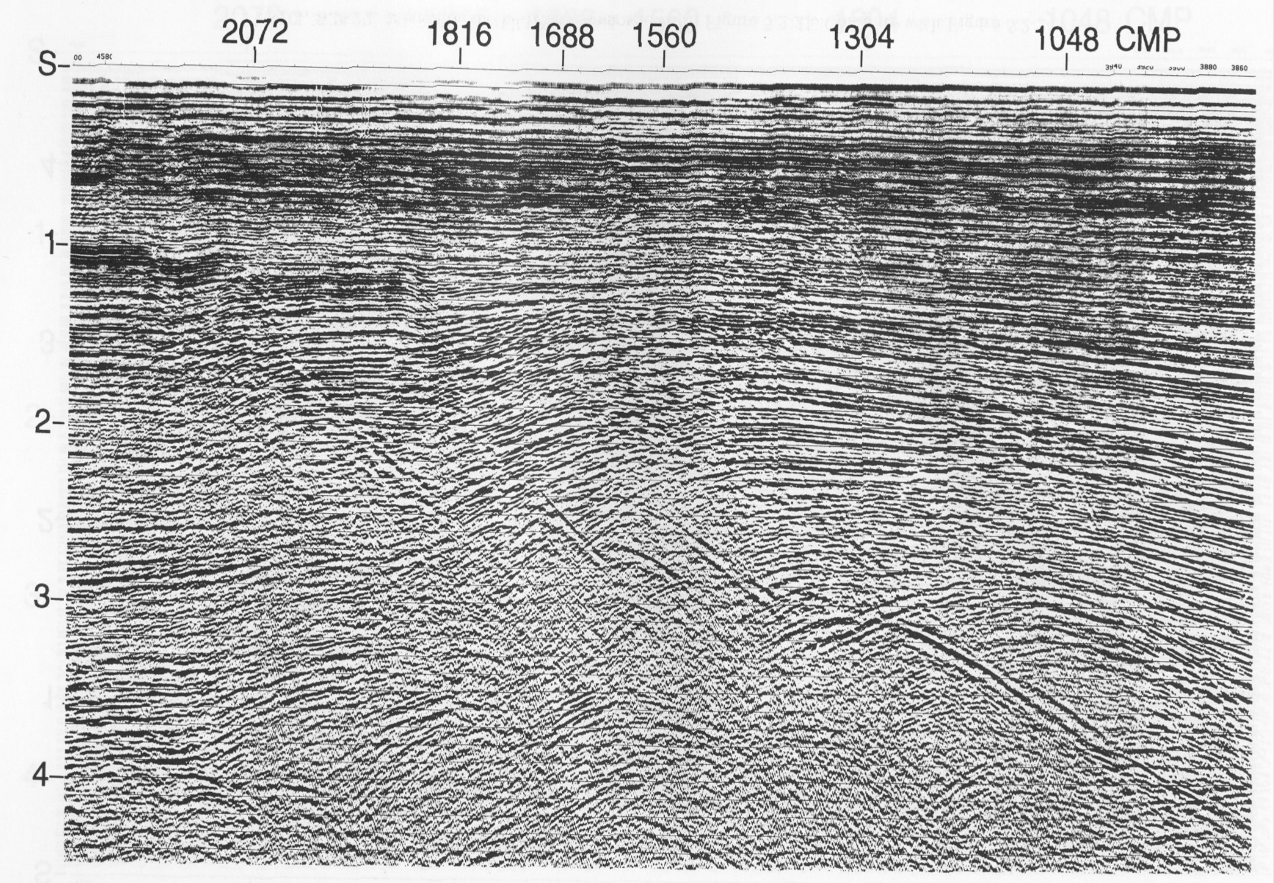
Example: Velocity analysis



Without DMO

With DMO

Example:
NMO(+DMO) stack



Example: Migrated stack