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 (Scripps, 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
     - 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 ...
Deconvolution

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...
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:

\[
\begin{align*}
t_0 &= \sqrt{t^2(x) - \left(\frac{x}{V}\right)^2} \\
&\approx t(x) - \frac{1}{2t_0}\left(\frac{x}{V}\right)^2
\end{align*}
\]

- 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 \( \sim 25\% \))
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.
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
Moveout \((f-k, \tau-p)\) filtering

- Removes coherent events with undesired moveouts

Original CMP gather

NMO applied (approximate)

Non-horizontal events removed and inverse NMO applied

Multiple
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

\[
\sin \alpha = \frac{BC}{AB} = \tan \theta
\]

\[
t_d(x) = \frac{t_0}{2} + \sqrt{\left(\frac{t_0}{2}\right)^2 + \left(\frac{x}{V}\right)^2}
\]

Migration collapses diffraction curve (surface in 3-D) to point C
Example: CMP gathers
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.
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
Example:
Velocity analysis

- Note the improved accuracy of velocity picking and increased semblance values after DMO.
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
Example: Final migrated stack

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