Seismic Reflection Surveying

- Reflected ray paths
  - Horizontal reflectors
  - Reflector sequence

- Reflection seismograms
  - Shot gather
  - CMP gather

- Corrections and Filtering

- Migration of reflection data

- Interpretation
  - Structural analysis
  - Stratigraphy
From a seismic experiment to drilling
3D seismic section
Seismic reflection methods

Seismic reflection surveying is the most widely used geophysical technique!

- in many cases the assumption of layered media is valid (small scale to large scale)
- Raw data can be processed so that an „image“ of the subsurface emerges (migration)
- Data processing is today done by computers (not the interpretation!)
Reflected ray paths

Interval velocity

Velocity of one layer or an average Velocity over a depth section. The interval velocity is defined as:

\[ v_i = \frac{z_i}{\tau_i} \]

... and the average velocity:

\[ \bar{V} = \frac{\sum_{i=1}^{n} z_i}{\sum_{i=1}^{n} \tau_i} = \frac{\sum_{i=1}^{n} v_i \tau_i}{\sum_{i=1}^{n} \tau_i} = \frac{Z_n}{T_n} \]
Reflection travel times

Moveout

The arrival times \( t(x) \) of reflections from an interface at depth \( z \) as a function of offset \( x \) are given as

\[
t(x) = \frac{1}{v} \sqrt{x^2 + 4z^2}
\]

\[
t^2 = \frac{4z^2}{v^2} + \frac{x^2}{v^2} = t_0^2 + \frac{x^2}{v^2}
\]

\[
\Delta T = t_x - t_0 \approx \frac{x^2}{2V^2 t_0}
\]

Normal moveout (NMO)
Reflector sequence

rms-velocity

Root-mean square (rms) velocity (better approximation than the average velocity) down to interface \( n \) with \( v_i \) the interval velocity, \( \tau_i \) the one-way travel time in layer \( i \):

\[
\overline{V} = \left[ \frac{\sum_{i=1}^{n} v_i^2 \tau_i}{\sum_{i=1}^{n} \tau_i} \right]^{1/2}
\]

We assume here offset distances that are small compared to the reflector depths! Our goal: How can we estimate the velocities of the individual layers?
The individual NMO can be used to estimate rms velocity down to a certain depth and values at different depths to estimate the interval velocities $v_n$ (Dix formula)

$$v_n = \left[ \frac{V_{rms,n}^2 t_n - V_{rms,n-1}^2 t_{n-1}}{t_n - t_{n-1}} \right]^{1/2}$$
Travel-time curves
A dipping reflector leads to asymmetric arrival times for shots recorded in different directions. The **dip moveout** is defined as the difference in travel times at \(-x\) and \(x\):

Knowing the velocity \(v\), the angle \(\Theta\) can be estimated:

\[
\Delta T_d = t_x - t_{-x}
\]

\[
\Delta T_d = 2x \sin \Theta / V
\]

\[
\Theta \approx V \Delta T_d / (2x)
\]
Convolutional model of reflection seismograms

Shot-detector configurations
The shot gather
common-mid(depth)-point

(a) Shot-detector midpoint

(b) CDP

A draped seismic record of a shot gather from a split
**Vertical and horizontal resolution**

**Fresnel zone**

**Vertical Resolution** of a seismic pulse: $\frac{1}{4}-1/8$ of a wavelength

Example: $v=2\text{km/s}$, $50\text{Hz}$ $\rightarrow$ resolution $10\text{m}$

$\rightarrow$ Sharpening of the pulse desirable $\rightarrow$ Deconvolution $\rightarrow$ towards impulse response of medium

**Horizontal Resolution** determined by the detector spacing and the Fresnel zone: $w=(2z\lambda)^{1/2}$ for $z \gg \lambda$. 

---

*Seismic reflection surveying  Slide 13*
Vertical and horizontal resolution

Fresnel zone
With appropriate source-receiver geometry seismic records can be stacked thereby considerable improving the signal-to-noise ratio!

The fold of a CMP gather is determined by $m=N/2n$, where $N$ is the number of geophones, $n$ is the number of array spacings the source is moved between shots. The improvement of the $S/N$-ratio from stacking $m$ traces is $\sqrt{m}$.

Example: $N=96$, $n=8$: -> $96/16=6$-fold. Improvement of $S/N$ ratio is $\sqrt{6} \approx 2.5$
Static Corrections

In general sources and receivers are not on the same level. We have to correct for
- Elevation
- Weathering layer
Dynamic (NMO) Corrections

... are basically the compensation for the moveout of a particular reflection.
Dynamic (NMO) Corrections
NMO moveout (CMP) analysis
To improve the (visual) quality of the seismograms for imaging one attempts to suppress all unwanted signals

- Dereverberation (to remove ringing e.g. of the water layer, multiples)
- Deghosting (remove energy from upward-and-reflected signals from the source)
- Whitening (equalize amplitude of frequency components, what is the result on the time signal?)
Filtering - example

Before

After
Migration

Migration is the concept of converting seismic sections (seismograms) into an image of the subsurface, repositioning reflection events under their correct surface location and at a corrected vertical reflection time.

Time migration: Migrated seismic sections have time (two-wave travel time) as vertical dimension.

Depth migration: Migrated reflection times are converted into reflector depths with appropriate velocity information.

- Migration may remove distorting effects of dipping reflectors
- Migration may remove diffracted arrivals (corners, faults)
Migration

Reflectors

Seismic response

(a) Depth (km)

(b) Reflection time (s)
Wavefront method

Source–detector

Actual reflection point

Display position on seismic section

Locus of all reflection points with equal travel times

Reflector surface

Record surface
Diffraction Migration

The assumption is that any continuous reflector is composed of a series of (closely spaced) reflection points (diffractors).
Migration

Before

After
3D surveys

- Recording lines
- Shot lines
- CDP
- Reflector
3D surveys

- Shot lines
- Recording lines
- Time slice
- Section along shot line
- Random section
- Section along recording line
Vertical Seismic Profiling (VSP)
Structural analysis

Upper boundary
- Erosional
- Toplap
- Concordant

Lower boundary
- Onlap
- Downlap
- Concordant

Parallel
- Subparallel
- Divergent

Sigmoidal
- Oblique
- Hummocky
Synthetic seismograms

Geological section | Acoustic impedance | Reflection coefficient
--- | --- | ---
1 | | |
2 | | |
3 | | |
4 | | |
5 | | |

Synthetic seismogram
Marine reflection surveys

- Vessel under way
- Hydrophone array
- Acoustic source
- Sea bed
- Sand layer
- Bedrock
- Buried channel
Reflection seismograms
Towards refraction profiles
Seismic reflection surveying is maybe the most important imaging tool on geophysics (particularly for near surface imaging).

- Seismic surveys are usually laid out to illuminate several times the same common mid-point (CMP) which - in case of horizontal layers - corresponds to the common depth point (CDP).

- The most important diagnostic feature are abrupt changes of seismic velocities (interfaces) indicative of lithological changes.

- The goal of reflection seismics is to map the recorded signals (reflections) into an image of the reflectors.

- The most important processing step to do this is called migration.