NPTEL ONLINE CERTIFICATION COURSES

EARTHQUAKE SEISMOLOGY

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Module 05 : Refraction and Reflection seismology

Lecture 05: Multi Channel Data Geometry, CMP stacking, NMO correction and Deconvolution

CONCEPTS COVERED

- Recap
- Multi Channel Data Geometry
- Common Mid Point Stacking & NMO correction
- Deconvolution
- Summary

Recap

- For a continuous increasing velocity model, at the deepest point, the turning, or bottoming, depth z_p the velocity is the reciprocal of the ray parameter, $p = 1/v(z_p)$.

- Distance travelled by the ray: $x(p) = 2\int_0^{z_p} \tan i \, dz = 2p \int_0^{z_p} \left(\frac{1}{v^2(z)} - p^2 \right) dz$

- Time taken to cover distance x(p) by the ray: $\Delta T_j = \frac{x_j \sin i_j}{v_j} + \frac{h_j \sin i_j}{v_j} = p_j x_j + \eta_j h_j$

- The function τ(p) is called the *intercept-slowness* representation of the travel time curve.

- *p* is the slope of the travel time curve, T(x), the distance, x, is minus the slope of the τ(p) curve.

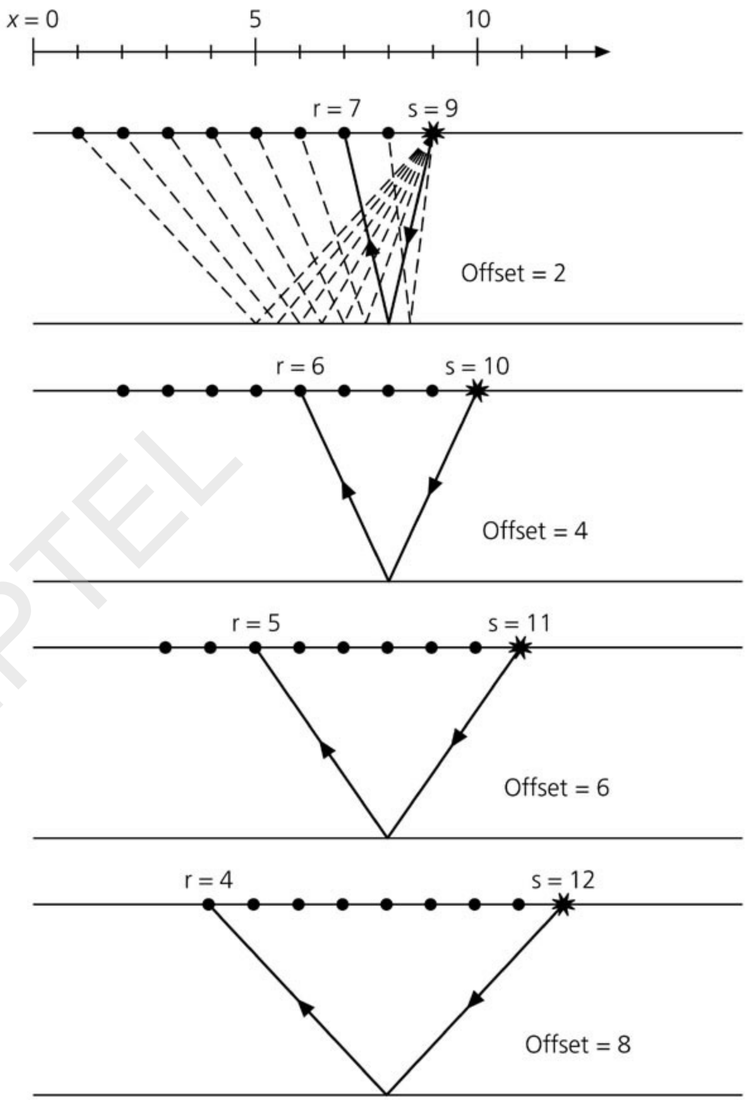
- The head wave maps into a point and hyperbola maps as ellipse on τ-p plane

Multichannel Data Geometry

We use different geometries of multiple source and receiver positions (ofter termed as 'gathers') to increase the signal to noise ratios.

- **Multiple source and receivers are used to sample the points on reflector multiple times. Here is an example with 8 geophones and a source.**
- **Each time the source is activated, multiple seismograms, or traces, are recorded.**
- **Source and receivers are then moved and the experiment is repeated, eight more traces.**
- **Eventually, we get four time sampling of each point, producing "four fold coverage".**

Figure 3.3-10: Cartoon geometry of a multichannel seismic reflection profile.



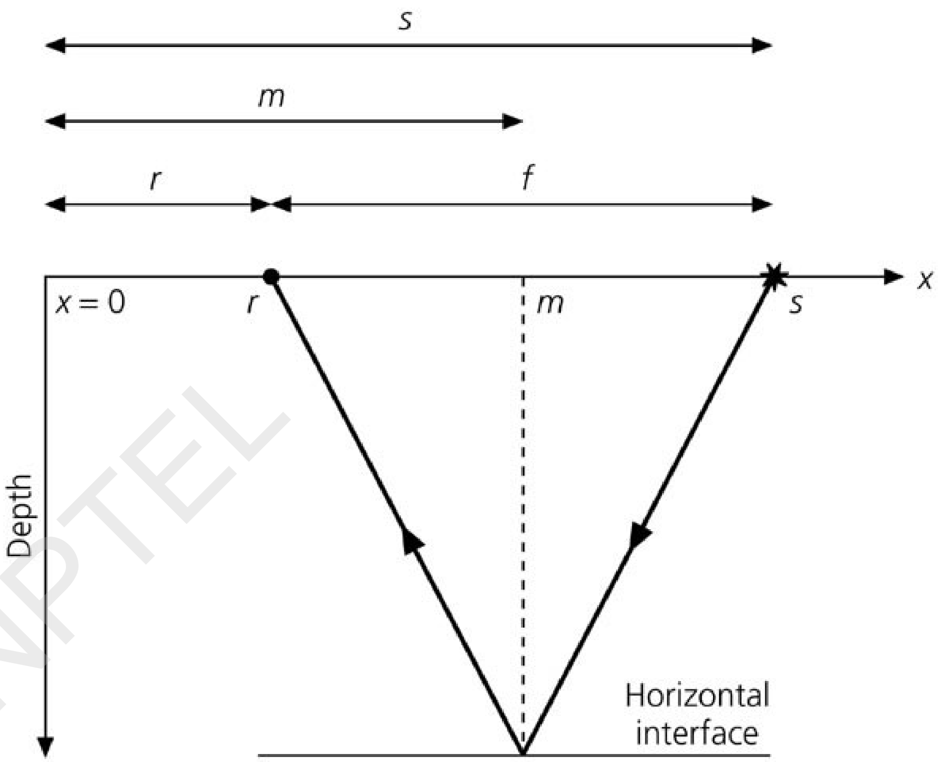
- **Assumptions**: Earth has layered depth variations in seismic velocities.

- To improve the S/N ratio, same point is sampled repeatedly to analyse the data.

- For flat layered model, these seismograms have the same point, known as midpoint, halfway between the source and the receiver.

- For each midpoint, there is a set of traces with different offsets.

Figure 3.3-11: Relation between source, receiver, midpoint, and offset.



$$\text{midpoint} \equiv m = (s + r)/2 \quad , \quad \text{offset} \equiv f = (s + r)$$

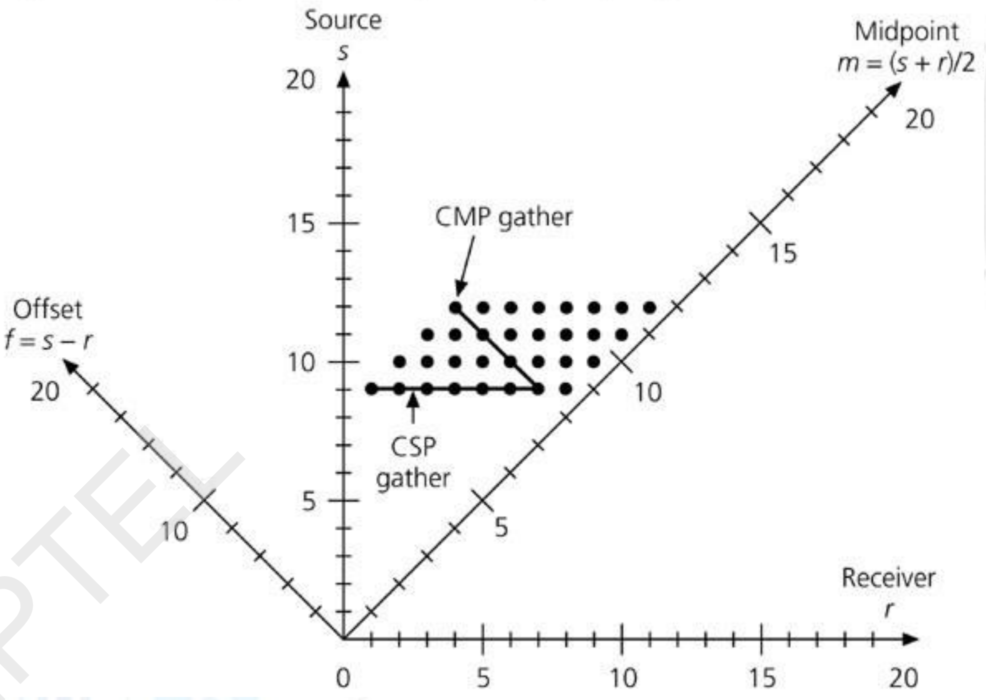
Seismogram can be identified by

Source(s) and Receiver(r) position

The midpoint and offset

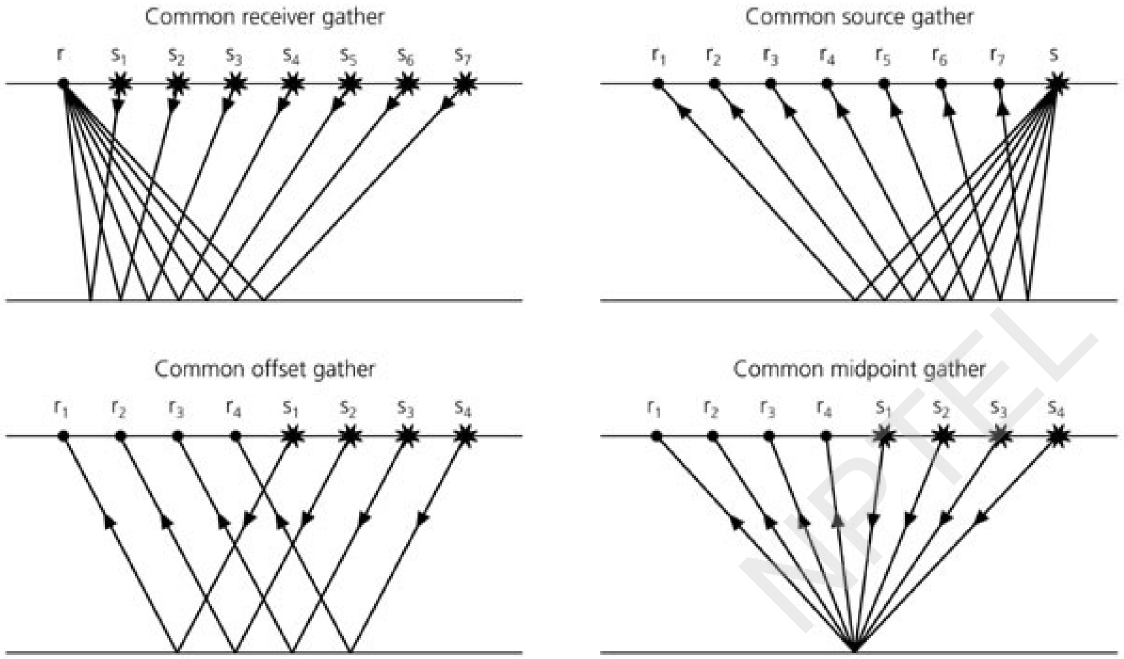
- **They are plotted using two perpendicular axis one for source and one for receiver position.**
- **The midpoint and offset for each seismogram are indicated by distance along axis 45^0 from the s and r axis.**

Figure 3.3-12: Diagram of source, receiver, midpoint, and offset coordinates.



Sorting and combination of data

Figure 3.3-13: Cartoon of the four different gather types.

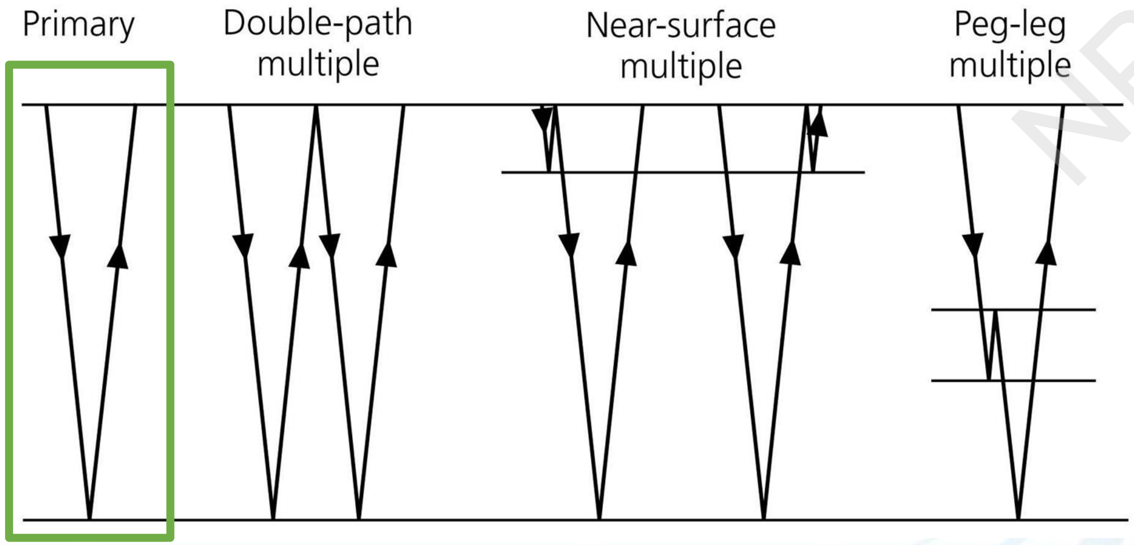


- Common offset gathers are handy for small scale projects since in the travel time equation $T(x)^2 = \frac{x^2}{v_0^2} + t_0^2$ where x and v_0 are constant. This is a good approach for finding the top of a near-surface layer (i.e. bedrock).

Common Midpoint Stacking and NMO correction

- **We're going to focus on Common Midpoint (CMP) Gathers since its application is quite common in oil and gas industry.**
- **Our goal is to find a way to suppress head waves, direct waves, surface waves, air waves, and multiple reflections (as shown below), and emphasize primary reflections.**

Figure 3.3-14: Geometry of various multiple reflections.



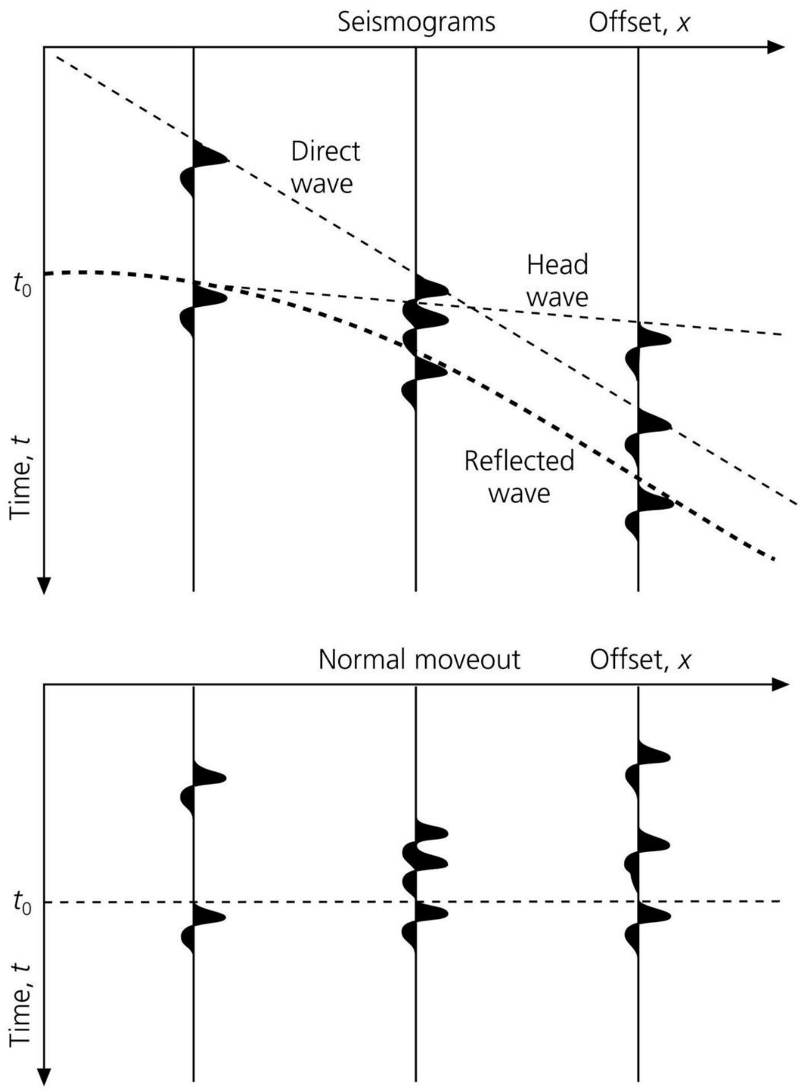
Multiples: Which reflected more than once before recording in the geophone.

Common Midpoint Stacking and NMO correction

- Our primary aim is to enhance primary reflections and suppress everything else.
- Reflections have hyperbolic travel time curves, whereas direct waves, head waves, surface waves, and airwaves have linear travel time curves.
- Consider a reflection whose variation in travel time with offset is the normal moveout (NMO), where t_0 and are the vertical two-way time and rms velocity.

$$T(x) - t_o = \left(\frac{x^2}{\bar{V}^2} + t_o^2\right)^{1/2} - t_o$$

Figure 3.3-15: Diagram of the normal moveout correction.



- **If each trace is shifted forward in time by the appropriate NMO, this reflection appears at the same time for all offsets**
- **By contrast, arrivals with different moveouts, such as the direct wave, do not align.**
- **Multiple reflections do not align, because they reflected off shallower interfaces than primary reflections with a similar arrival time, and thus have a lower rms velocity.**

Common Midpoint Stacking and NMO correction

- **If the traces are added after this time shift, the resulting sum, in theory, is the single trace that would have been recorded at zero offset, with coincident source and receiver.**

- **The reflection that was aligned is in phase on all traces, and thus sums constructively and gives a strong arrival.**

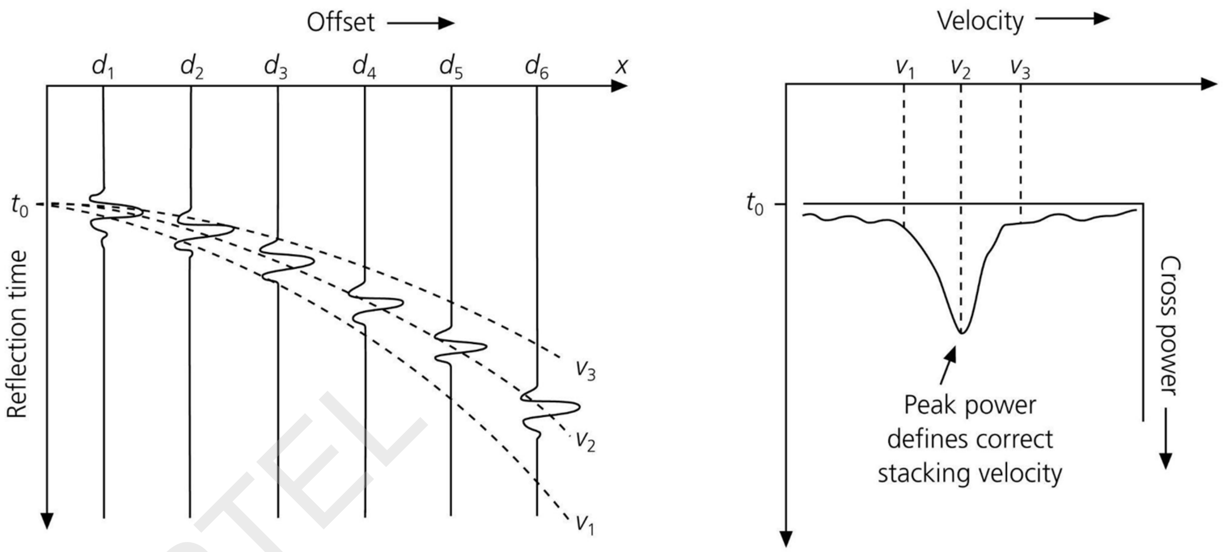
- **By contrast, other arrivals will have been shifted such that they are sometimes out of phase, and thus sum destructively, yielding weaker arrivals.**

- **The process of time shifting and then summing the traces with different offsets for a given midpoint is called common mid-point (CMP) stacking.**

- **A reflected wave variation in travel time, with offset, is given by the normal moveout (NMO) equation.**

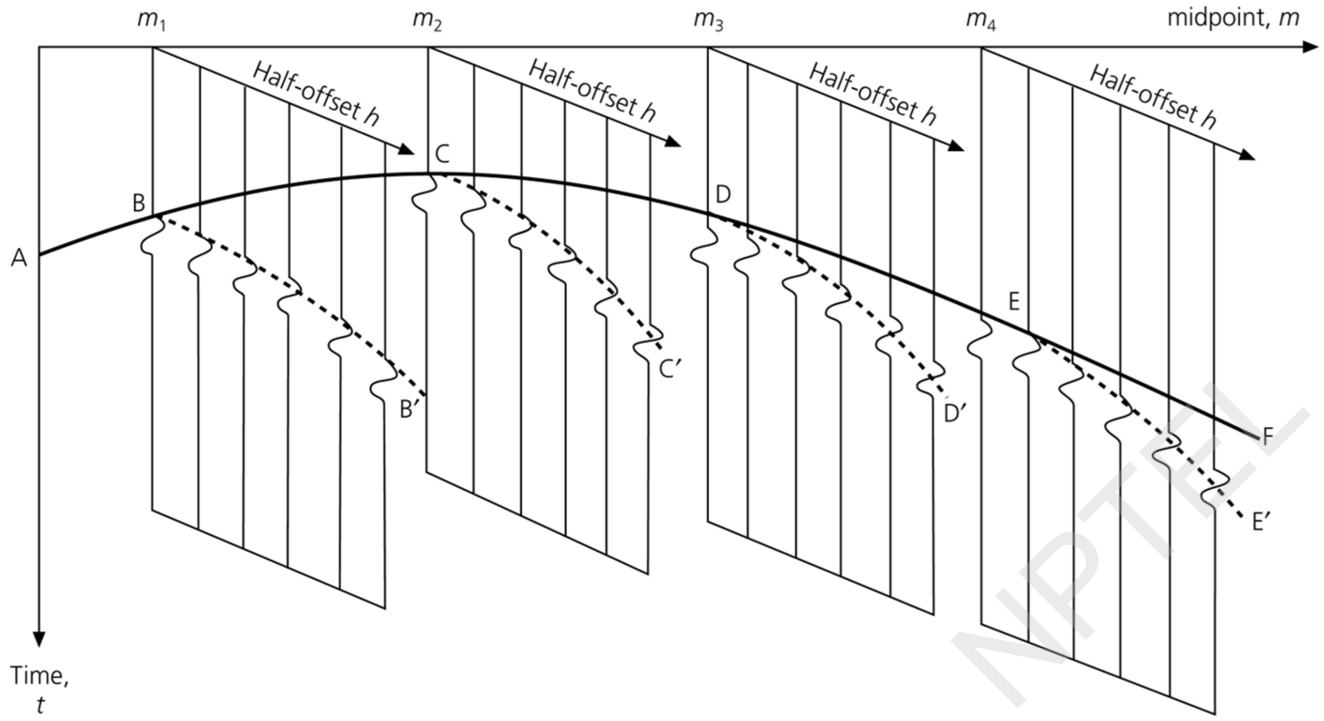
$$T(x) - t_0 = 2[(\frac{x}{\bar{V}^2})^2 + t_0^{\ 2}]^{\frac{1}{2}} - t_0$$

Figure 3.3-16: Cartoon of CMP stacking and velocity analysis.



- **To amplify the reflection, we sum or "stack" the traces with a common midpoint along a hyperbolic trajectory. We can try values for V-bar until the maximum crosspower is obtained.**

Figure 3.3-18: Illustration of forming a zero-offset section by CMP stacking.



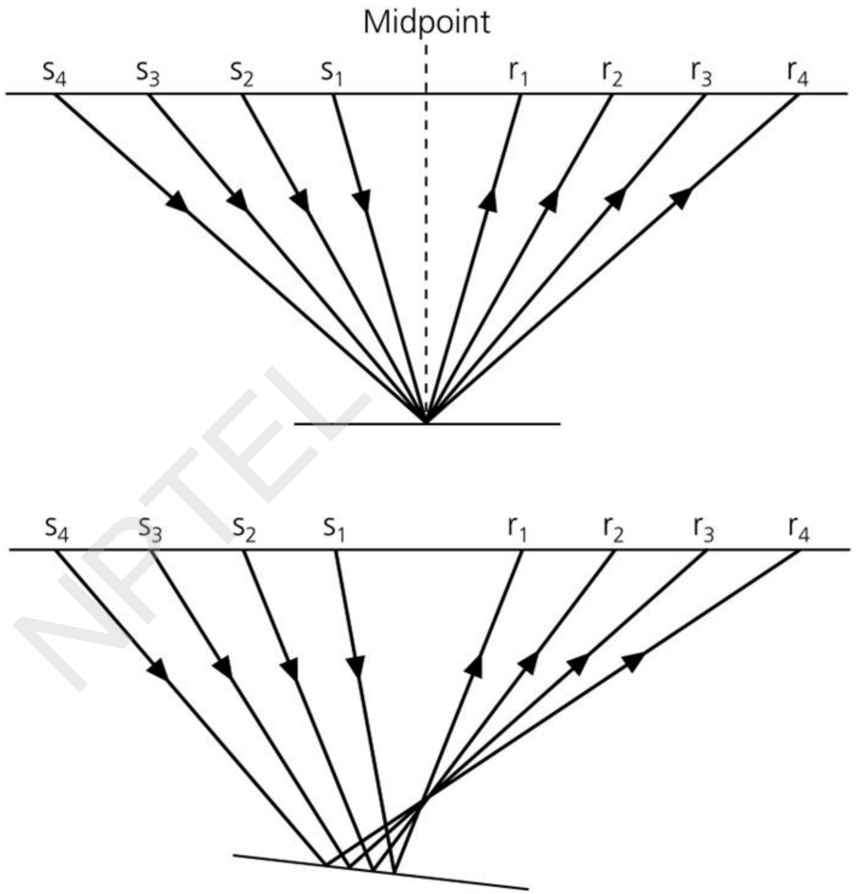
Stacking different midpoints

Points A, B, C, etc., show the location of the reflection, as if the source and receiver were right over them.

In case of dipping interface, there will be no common midpoint.

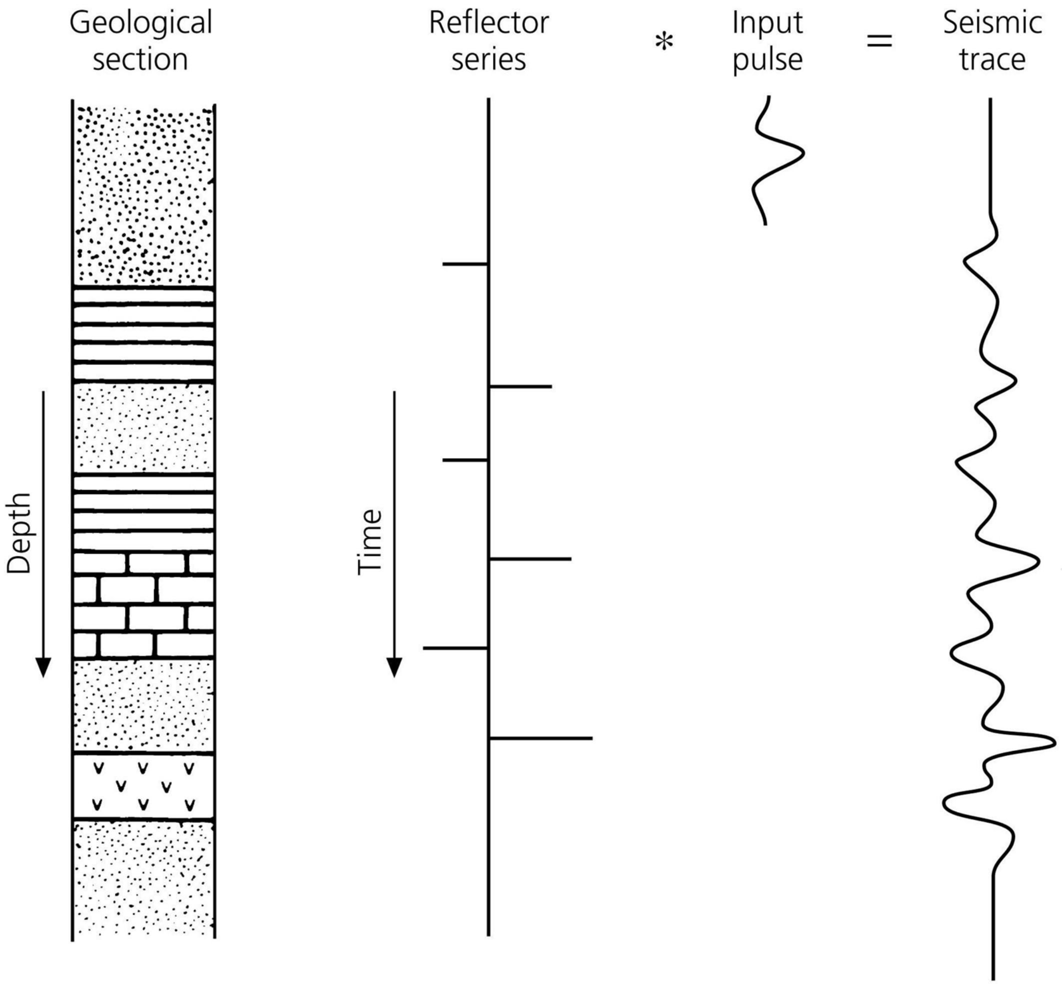
But it generally works quite well.

Figure 3.3-19: CMP stacking for flat and dipping layers.



Deconvolution

Figure 3.3-28: Reflection seismogram as the convolution of a source pulse with a reflector series.



A reflection seismogram can be viewed as the convolution of a source wavelet with a reflector series representing the structure.

The reflector series has impulses at times corresponding to the arrival times of reflections with amplitudes given by the reflection coefficients.

"Deconvolution attempts to "spike" the wavelets in the data, revealing the reflector series."

Deconvolution

The resulting seismogram (s(t)) is given by an operation known as the convolution of wavelet (w(t)) and reflectivity series (r(t)), which is written

$$s(t) = w(t) * r(t) = \int_{-\infty}^{\infty} w(t-\tau) r(\tau) d\tau$$

In the Fourier transform of a convolution equals the product of the Fourier transforms,

$$S(\omega) = W(\omega) R(\omega)$$

if w(t) = δ(t), the seismogram would equal the reflector series.

Although a physical source wavelet is not a delta function, the seismograms can be manipulated mathematically to simulate such a wavelet.

Deconvolution

This can be done by creating an inverse filter $w^{-1}(t)$, that, when convolved with the wavelet, yields a delta function.

$$w^{-1}(t) * w(t) = \delta(t)$$

Applying this filter, which “spikes” the wavelet, leaves only the reflector series

$$w^{-1}(t) * s(t) = w^{-1}(t) * w(t) * r(t) = r(t)$$

“Because this operation is the inverse of convolution, it is called deconvolution.”

To create the inverse filter, we know that:

$$W^{-1}(\omega)W(\omega) = 1$$

so the transform of the inverse filter is just $1/W(\omega)$. Hence deconvolution can be done by dividing the Fourier transforms

$$S(\omega)/W(\omega) = R(\omega)$$

Summary

- It's an use of multiple source and receiver locations, so that points on reflecting interfaces are sampled repeatedly
- Each trace we get is a record of displacement, or pressure, as a function of time, t. Let say call it as u(s,r,t) characterized by the source and receiver positions
- Individual seismogram is specified by source and receiver position or midpoint and offset
- Sorting and combining of data can be done using common midpoint gathers, common offset gathers, common receiver gathers and common source gathers.
- NMO correction for CMP stacking can be done with $T(x) - t_o = \left(\frac{x^2}{\bar{V}^2} + t_o^2 \right)^{1/2} - t_o$
- Deconvolution(to get reflectivity series) in time and frequency domain are

$$w^{-1}(t) * s(t) = w^{-1}(t) * w(t) * r(t) = r(t) \qquad S(\omega)/W(\omega) = R(\omega)$$

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THANK YOU !