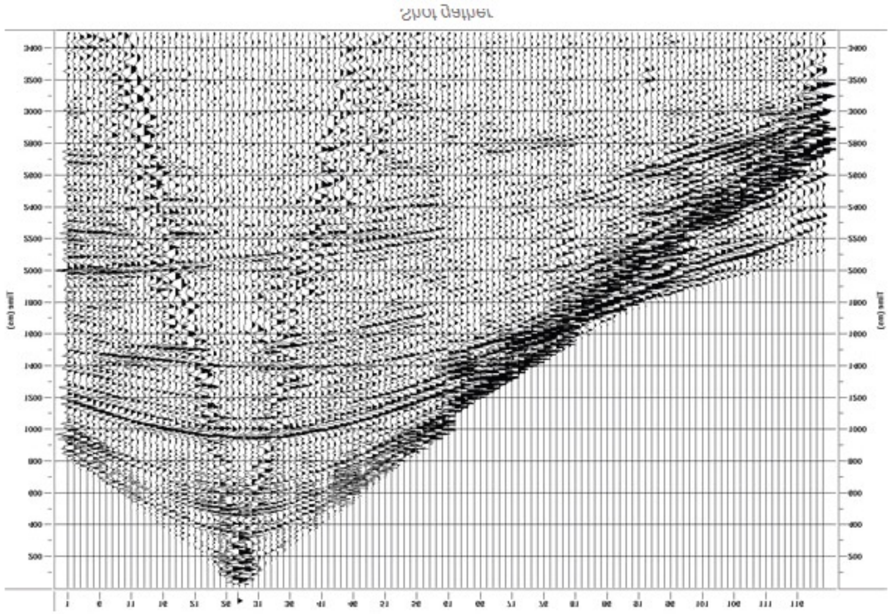
Seismic imaging
Lecture 3



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Module outline

Day 1 morning- Introduction to seismic data

Lecture 1: Physical principles

Lecture 2: Data acquisition

Lecture 3: Key data processing steps

Day 1 afternoon- Exercises

Exercise 1: Synthetic seismic models

Exercise 2: NMO corrections and velocity analysis

Lecture outline

Objectives of lecture 3:

Learn about some of the fundamental seismic processing steps

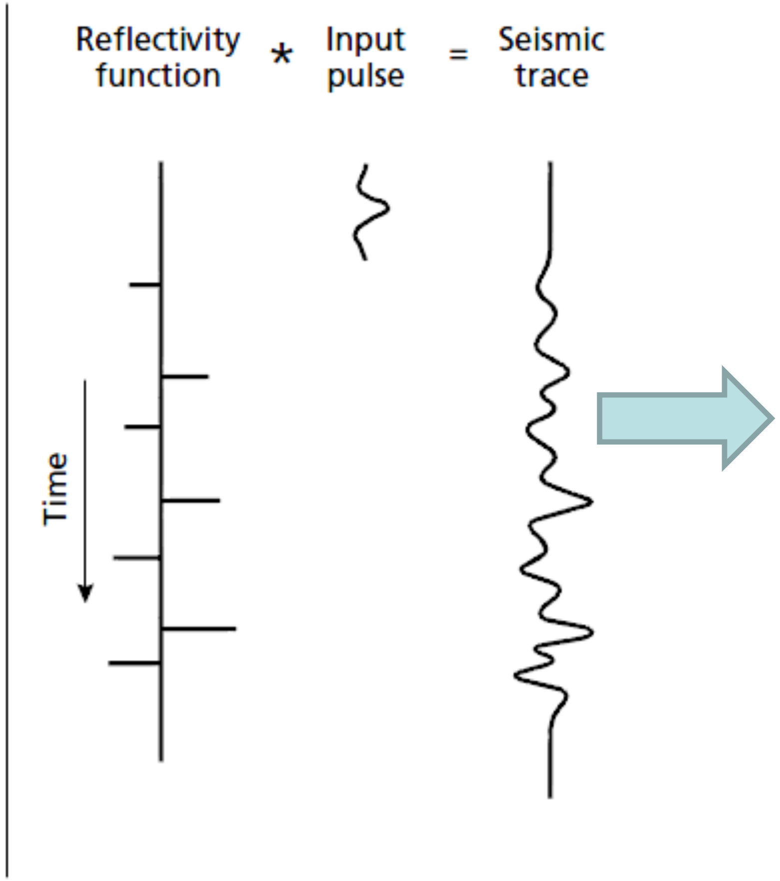
1) Common mid-point (CMP) gathers

2) Normal Moveout corrections

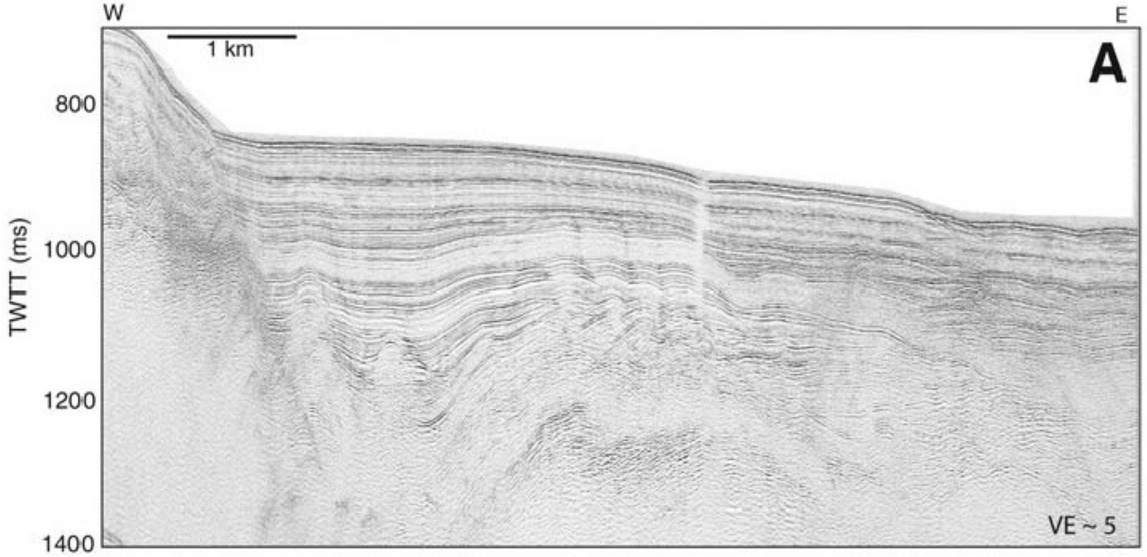
3) Velocity analysis

This lecture directly links to Ex 2 – NMO corrections

Creating a seismic section....



Seismic section

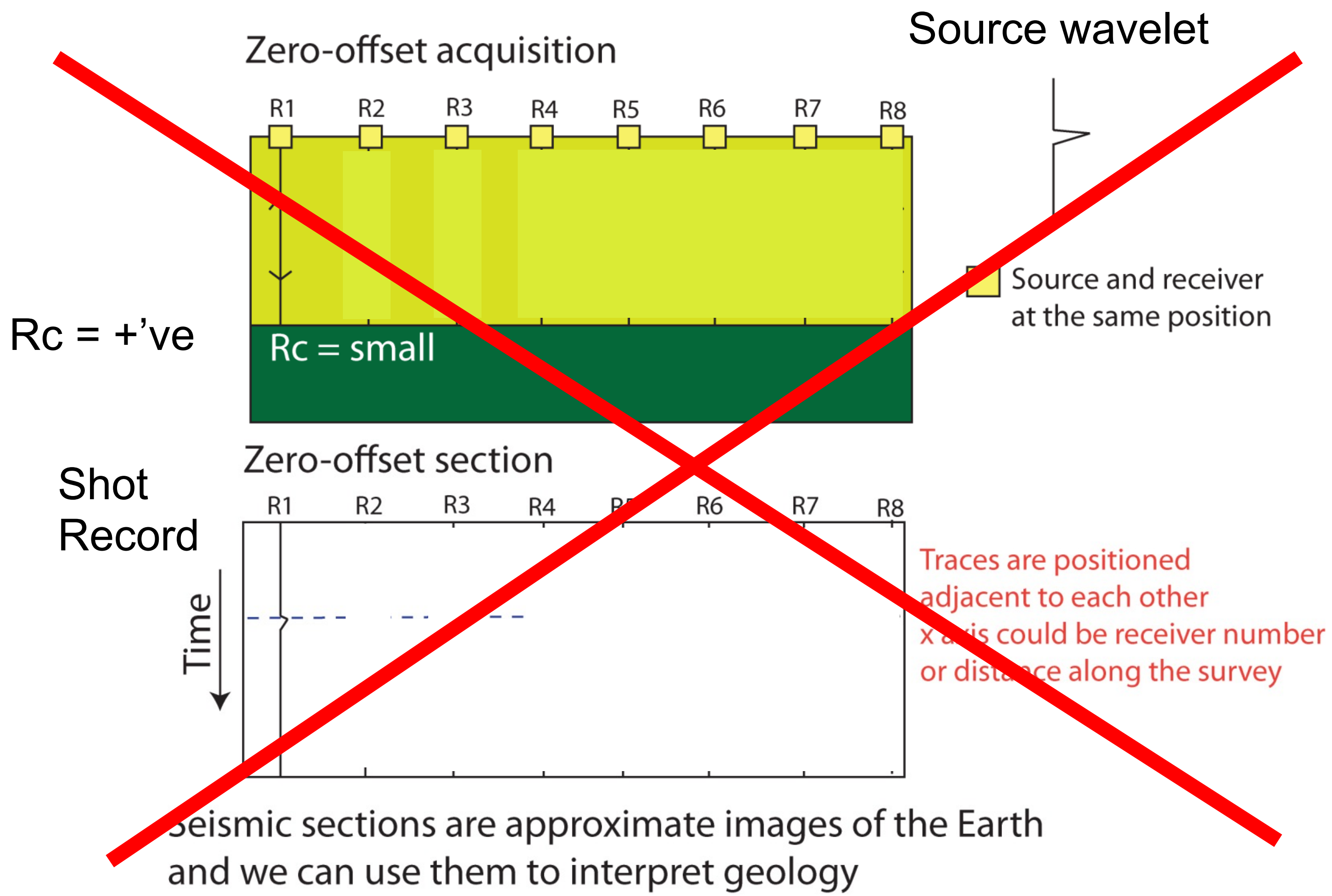


In order to create a seismic section from seismic traces requires a significant amount of processing…

We are just going to talk about a few key processing steps: Normal Moveout (NMO) correction, velocity (semblance) analysis and stacking. You will explore this for yourself in Ex 2

Zero-offset/single-channel survey

The easiest way to create a SEISMIC SECTION is to conduct a zero-offset survey:



But we don't collect seismic data in this way as reflection coefficients are very small, so the reflections would have very low amplitudes and the data would be noisy

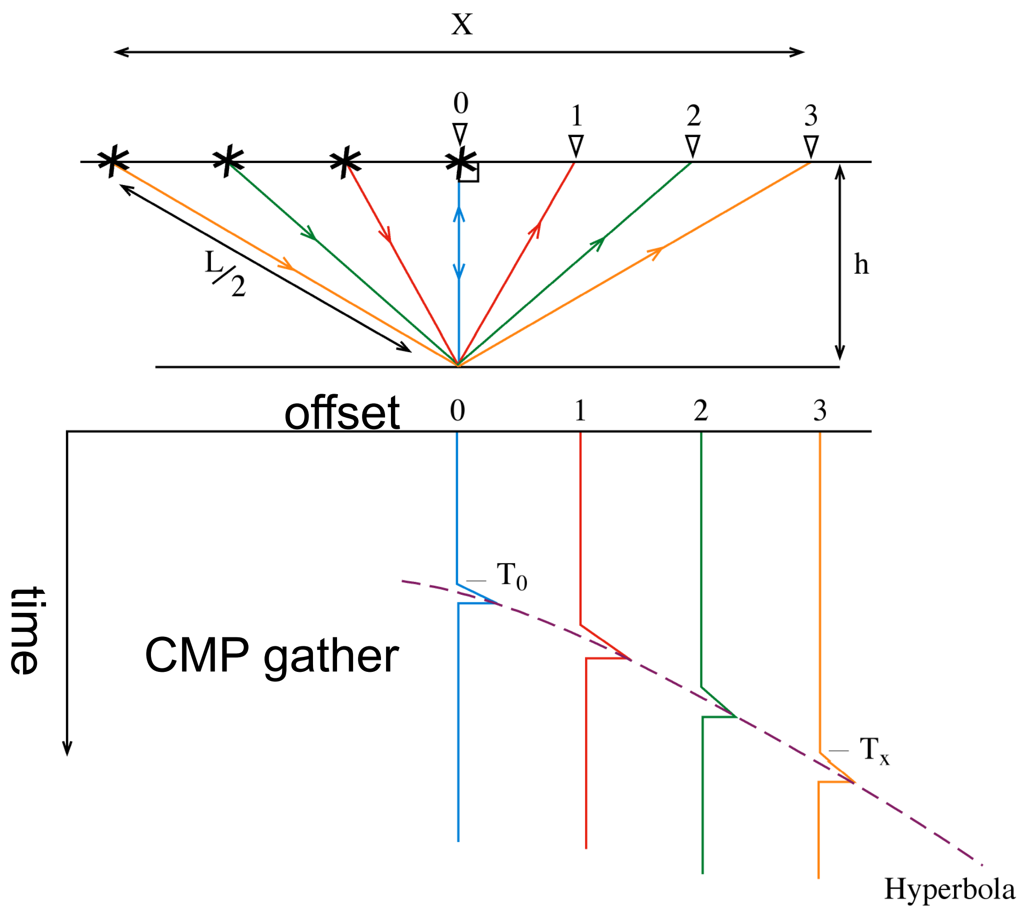
Common mid-point gathers

• We design seismic surveys so points in the sub-surface are sampled more than once

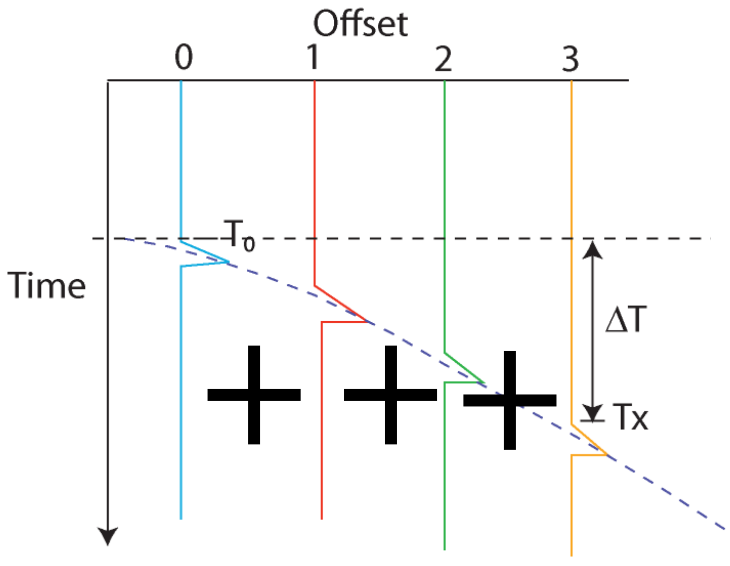
• We arrange traces into **Common-Mid-Point Gathers (CMP gathers).** These are graphs made up of seismic traces that all image the same point in the subsurface. They are plotted with offset between source and receiver on the x axis and time on the y axis

•Stacking together (adding together) these traces that image the same point in the subsurface improves signal-to-noise

BUT- there is a problem…



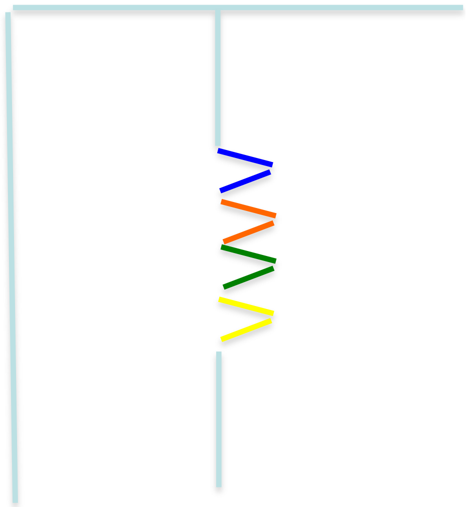
Normal Move-Out



Because the travel path is longer for traces with greater offset the time that a reflection is detected will increase with offset.

This is called Normal Moveout

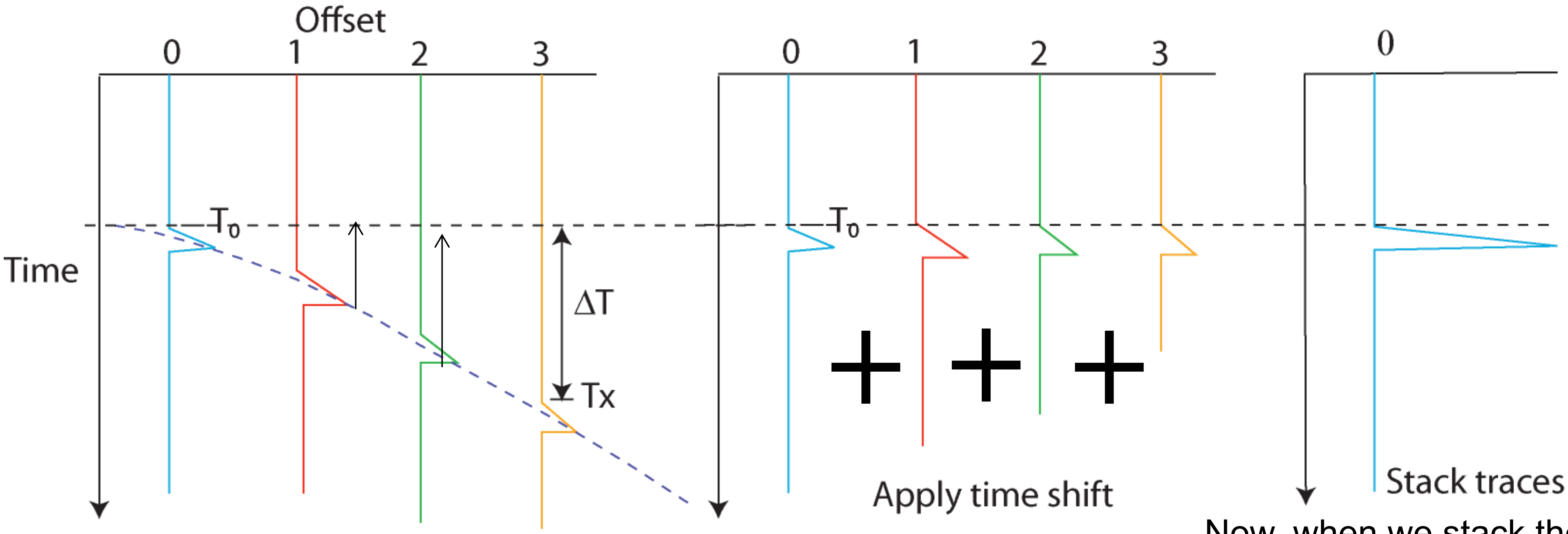
Summed/
Stacked trace



If we were to simply add (stack) these four traces together we would end up with a complex trace. We haven't improved the signal to noise ratio at all…

Normal Move-Out

- We need to apply an offset dependent static time shift (ΔT) to our CMP gather in order to stack them effectively. This is called a Normal Move-Out Correction



Now, when we stack the traces we have increased the amplitude (and improved S/N)

Deriving an equation for the NMO correction -ΔT

- Setting X = offset, L=path length (in m), h=depth (m), T_0 = TWT at zero offset, and T_X = TWT at offset X. Pythagoras allows us to calculate:

$$\left(\frac{X}{2}\right)^2 + h^2 = \left(\frac{L}{2}\right)^2$$

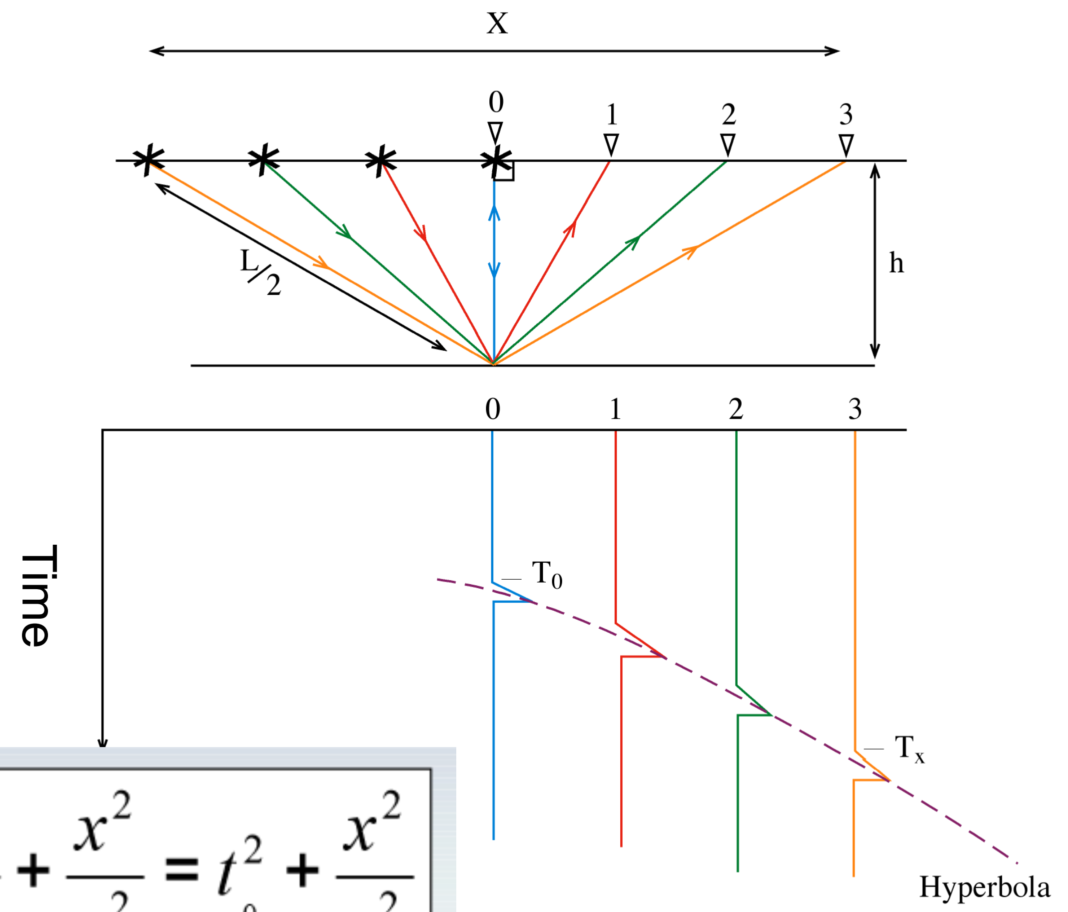
- We're working in time, so:

$$L = VT_x \qquad h = \frac{VT_0}{2}$$

- Hence:

$$\left(\frac{X}{2}\right)^2 + \left(\frac{VT_0}{2}\right)^2 = \left(\frac{VT_x}{2}\right)^2$$

$$T_X^2 = T_0^2 + \frac{X^2}{V^2}$$



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

Normal Move-Out

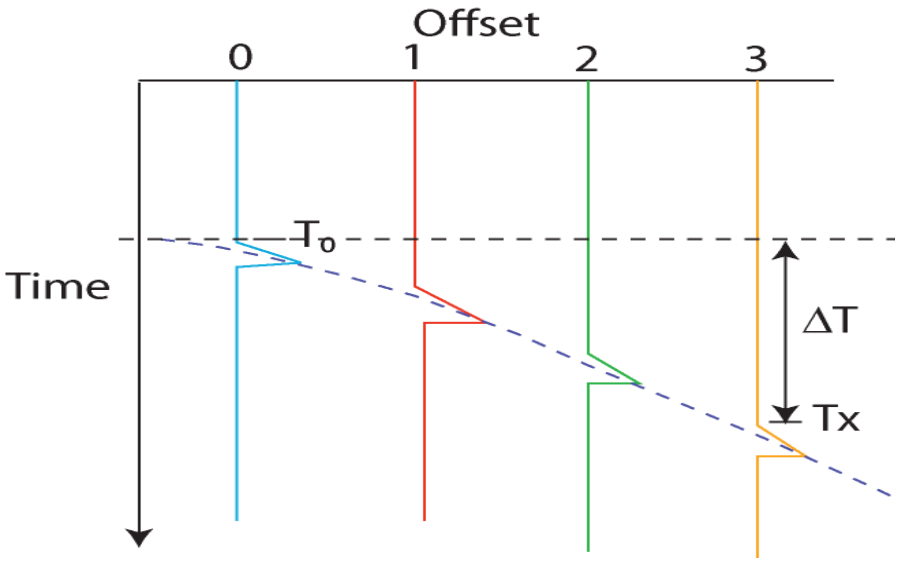
- Substituting T_X from before gives:

$$T_x^2 = T_0^2 + \frac{X^2}{V^2}$$

$$\Delta T = T_X - T_0$$

$$\Delta T = \left(T_0^2 + \frac{X^2}{V^2}\right)^{\frac{1}{2}} - T_0$$

$$\Delta T = T_0\left(1 + \frac{X^2}{V^2 T_0^2}\right)^{\frac{1}{2}} - T_0$$



This equation can be simplified using Binomial expansion….

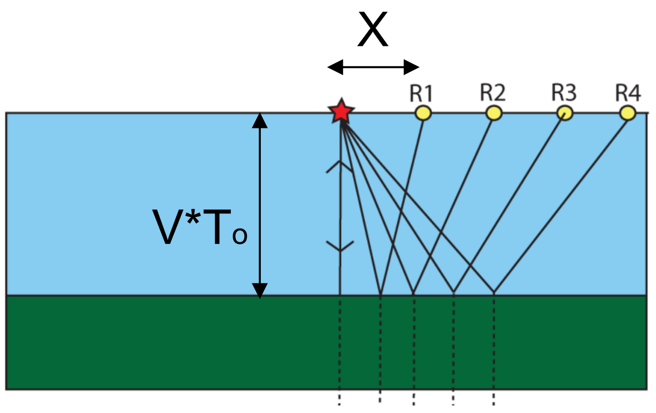
Normal Move-Out

Binomial expansion:

$$(1+x)^n = 1 + nx + \frac{n(n-1)}{1\times 2}x^2 + \ldots + \frac{n(n-1)\ldots(n-r+1)}{1\times 2\times \ldots \times r}x^r + \ldots$$

$$\boxed{\Delta T = T_0\left(1 + \frac{X^2}{V^2T_0^2}\right)^{\frac{1}{2}} - T_0}$$

$$\boxed{\Delta T = T_0\left(1 + \frac{X^2}{2V^2T_0^2} - \frac{X^4}{8V^4T_0^4} + \cdots\right) - T_0}$$



Can assume: $\frac{X}{VT_0} \ll 1$

$$\boxed{\Delta T \approx \frac{X^2}{2V^2T_0}}$$

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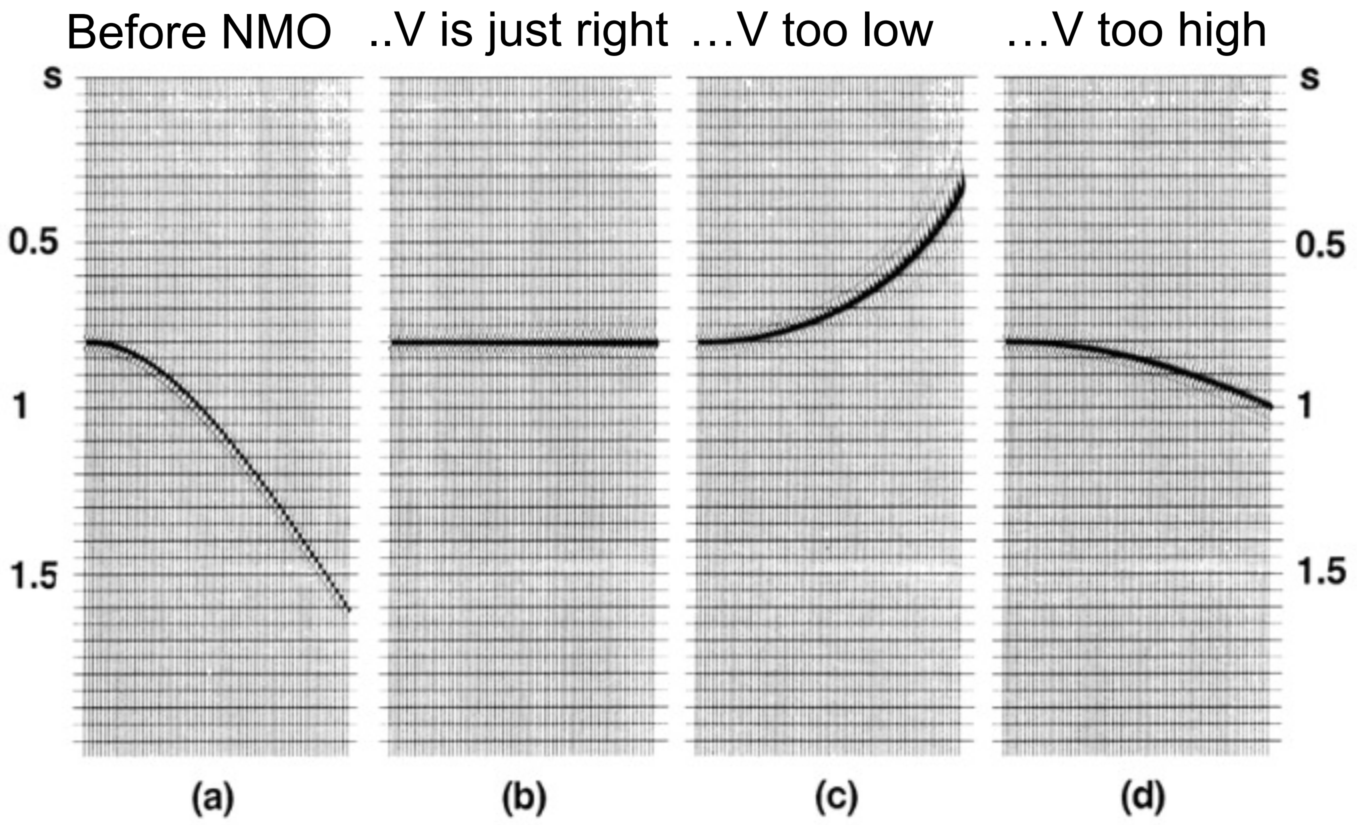


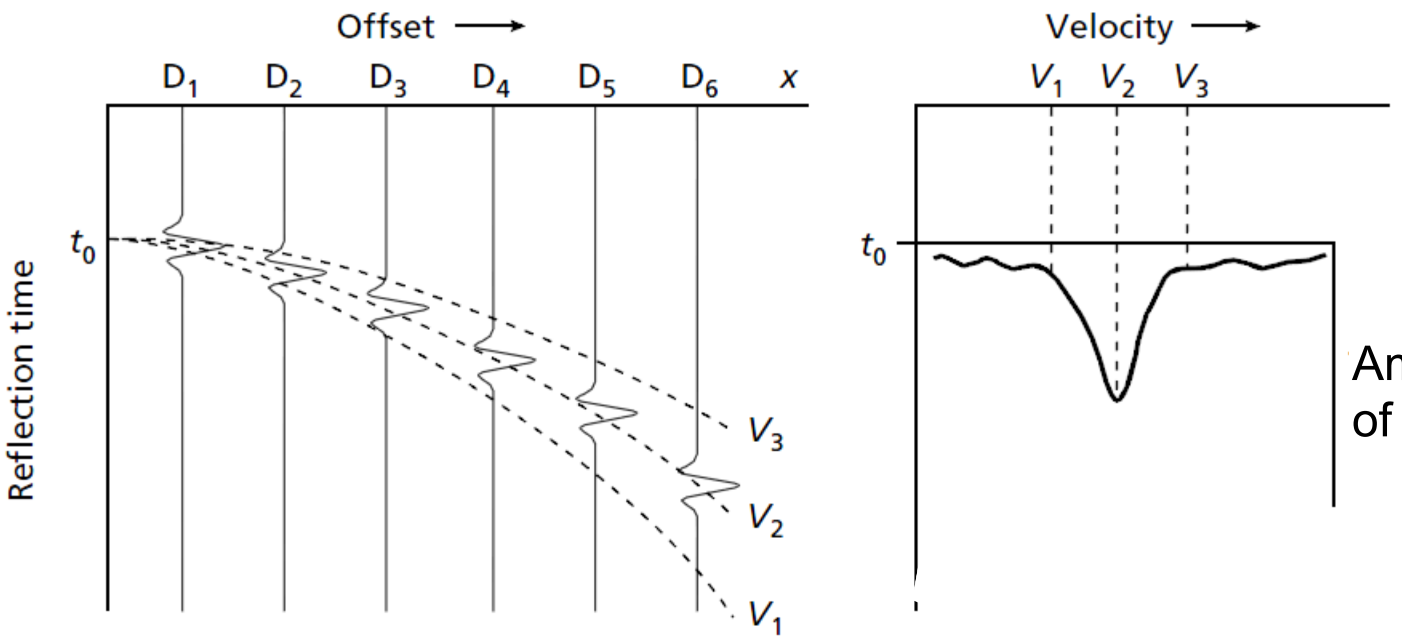
NMO-Correction of a Reflection. (a) Reflection is not corrected; (b) with proper Velocity; (c) Velocity is too low; (d) Velocity is too high.

Let's explore this ourselves – NMO.ipynb

http://www.bairdpetro.com/pdf_files/p58-62.pdf

How can we determine NMO velocity (and how can ML help?)

- In practice, NMO corrections are made for a range of velocities and corrected traces stacked



Amplitude magnitude of stacked trace

Kearey, Brooks & Hill

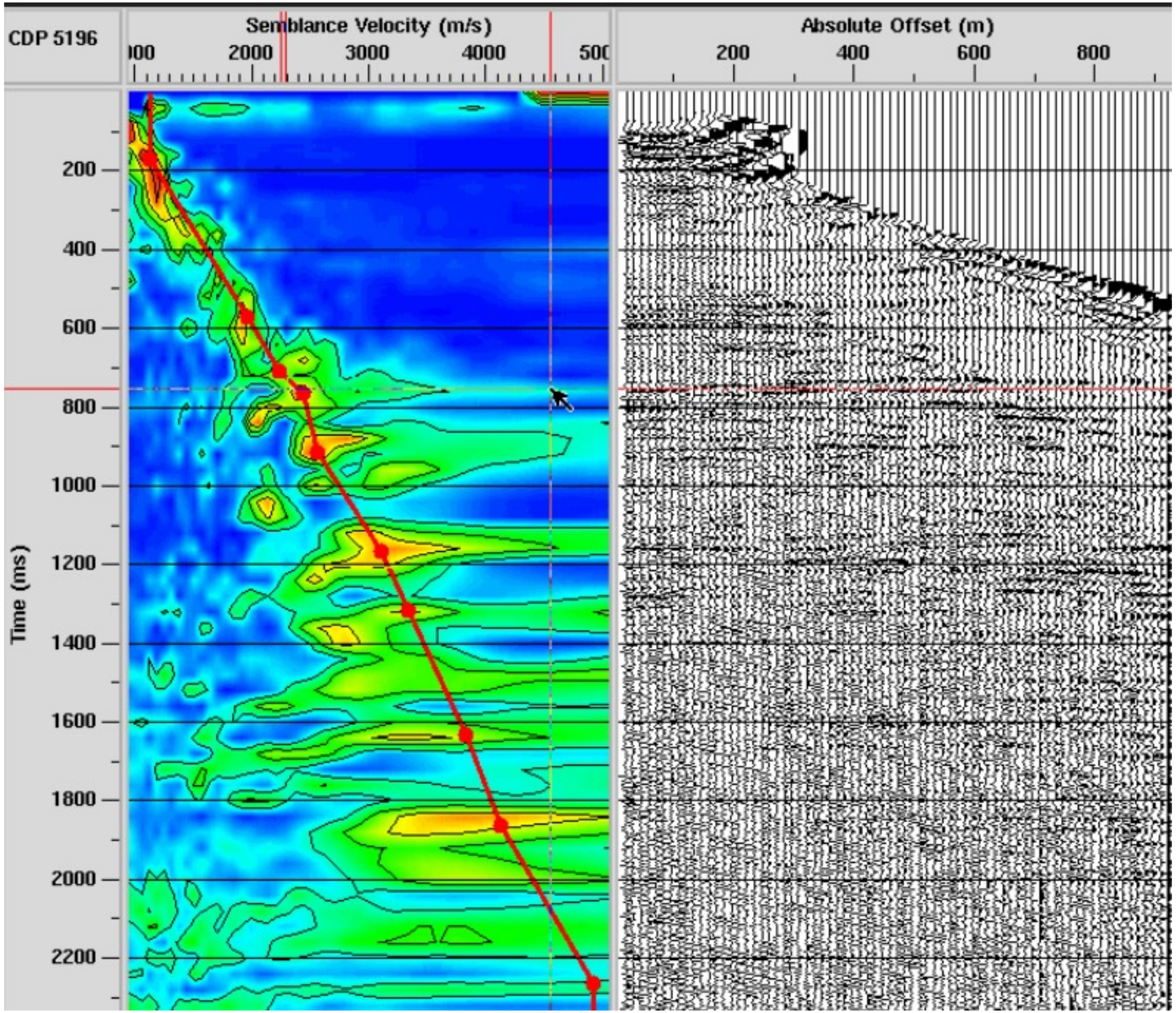
Semblance plots measure the magnitude of the amplitude present in stacked traces

Semblance plots

- A range of velocities is used to determine the correct NMO correction velocity to use, as a function of reflection time

- The amplitude of the stacked, NMO corrected trace is calculated over a large number of narrow time windows down the seismic trace and for a range of velocities for each time window- **you will do this in Ex 2 for synthetic data**

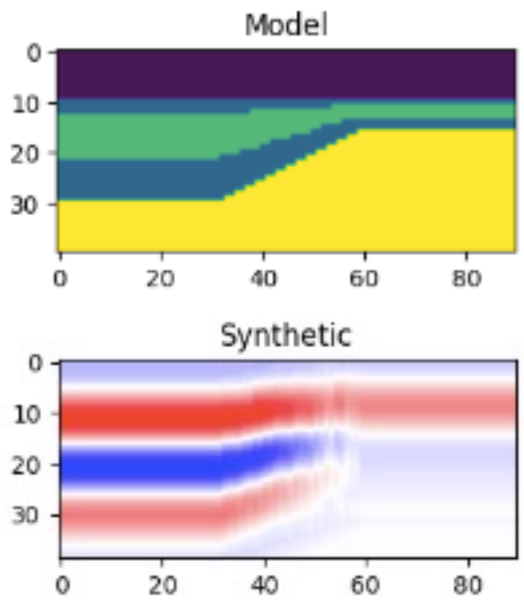
If you have time there is a bonus exercise to conduct semblance analysis with real data



Dragoset, 2005

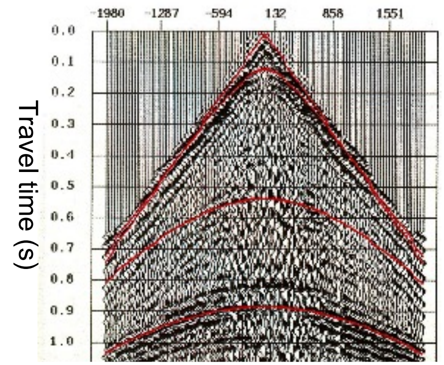
Types of data you will see in this course…

Exercise 1

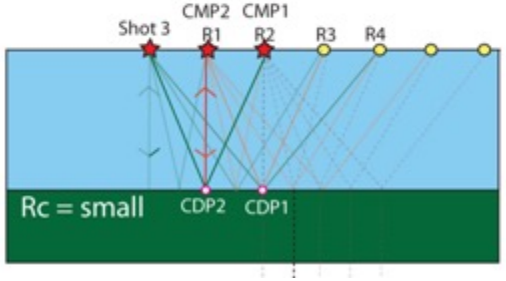


Exercise 2

Common mid-point gather



Offset between shot and receiver

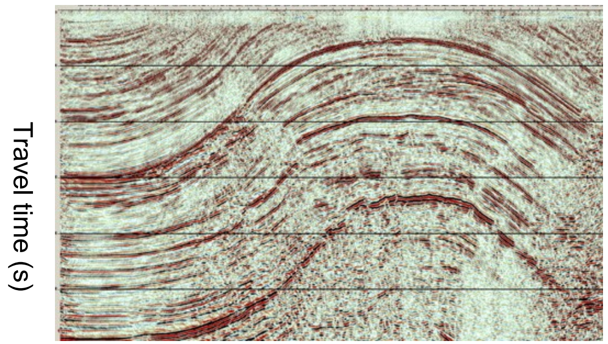


Straight lines= direct waves/
head waves
Hyperbola= reflections

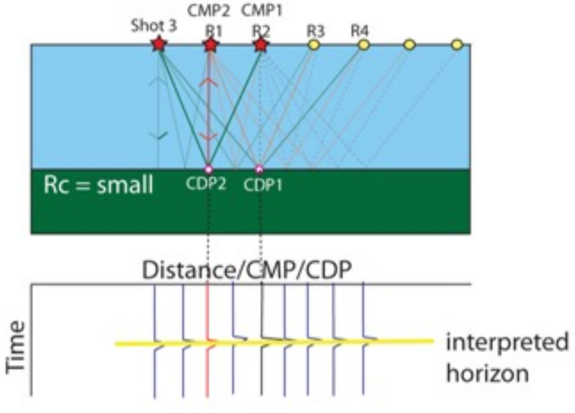
Compilation from multiple shots

Exercise 3 and 4

Seismic section



CMP/CDP number



Images a cross-section through the
Earth- we can now identify geological features

Key points

- Seismic data is collected using multiple source-receiver pairs that have the same common mid-point and image the same point in the subsurface
- In order to stack these traces to improve the signal to noise ratio an NMO correction must be applied
- This NMO correction depends on velocity. We must establish the correct NMO velocity for every reflection in our data. We can automate this process somewhat by doing semblance analysis, but it still involves some user input- ripe for automation