# Seismic imaging
# Lecture 3



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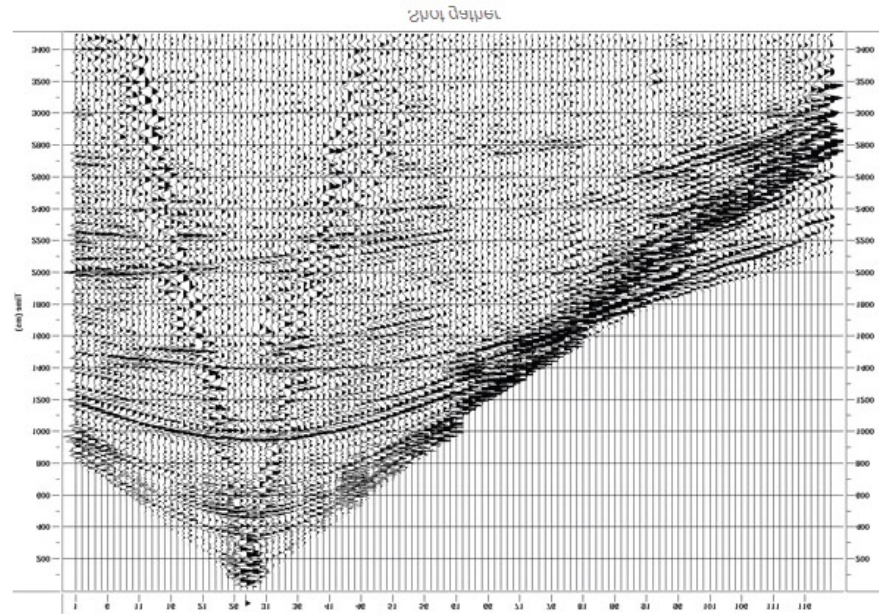
# Module outline

**Day 1 morning- Introduction to seismic data**

Lecture 1: Physical principles

Lecture 2: Data acquisition

<span style="color:red">Lecture 3: Key data processing steps</span>

**Day 1 afternoon- Exercises**

Exercise 1: Synthetic seismic models

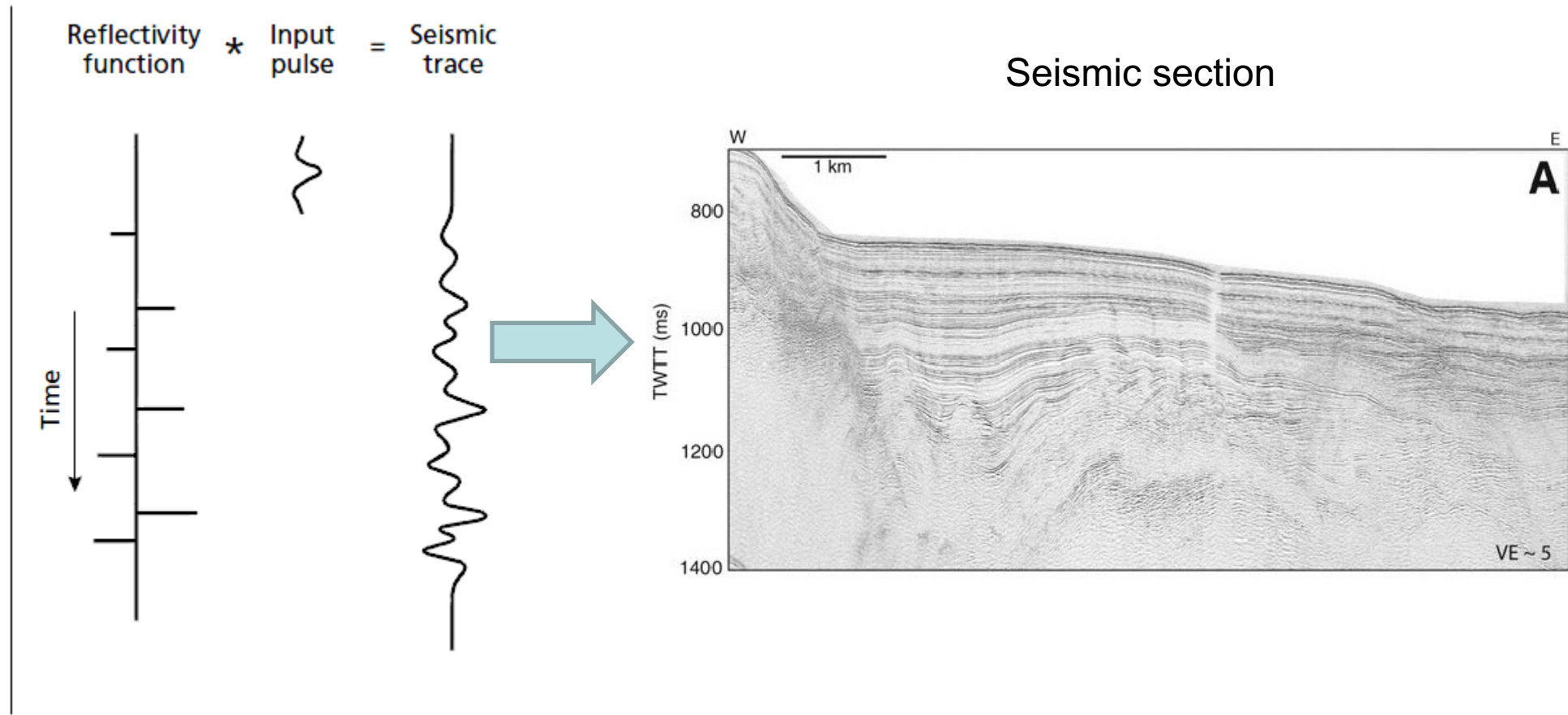Exercise 2: NMO corrections and velocity analysis

# 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**
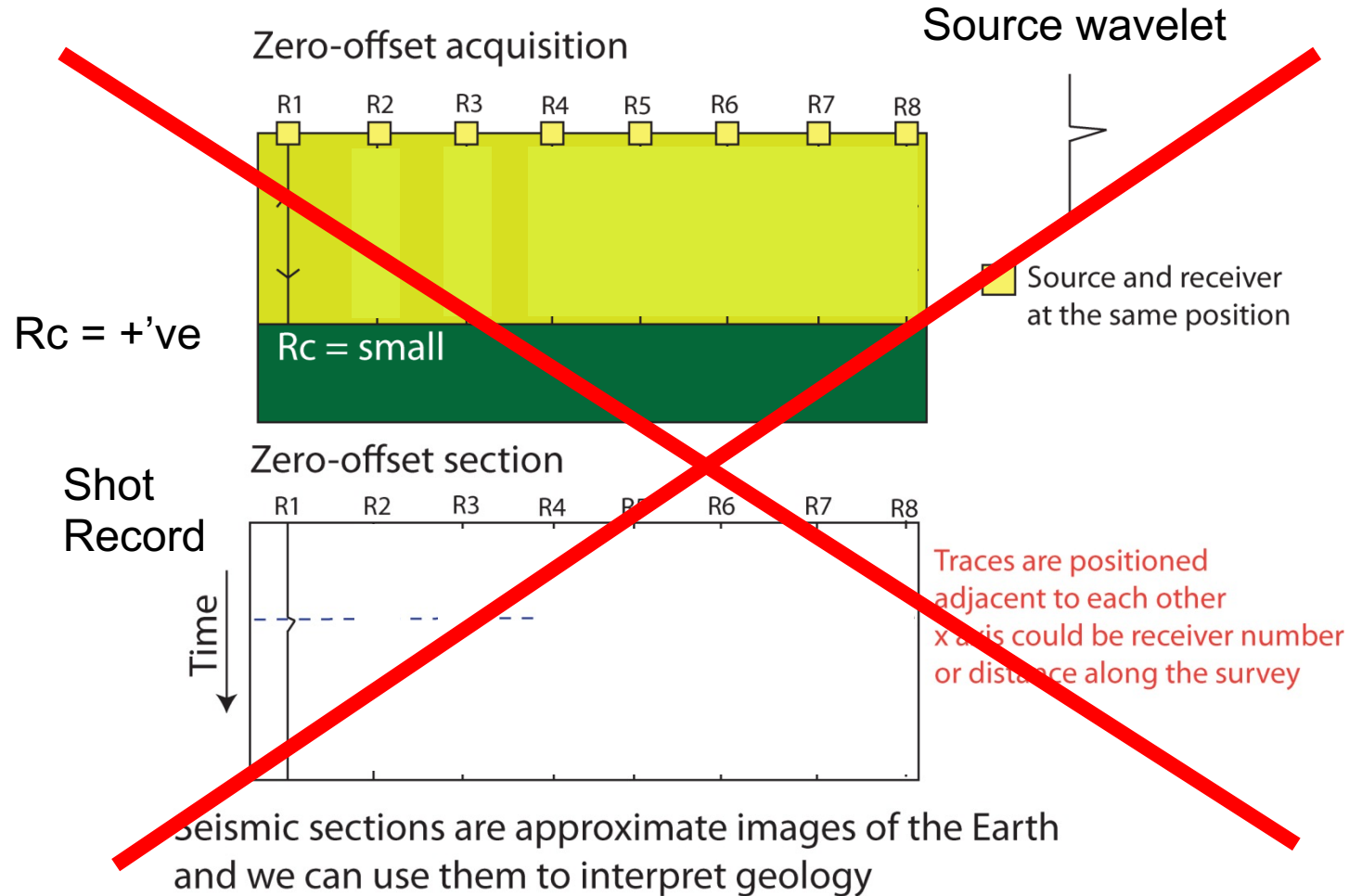
# Creating a seismic section....



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

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

Source wavelet

Zero-offset acquisition

R1  R2  R3  R4  R5  R6  R7  R8

☐ Source and receiver at the same position

Rc = +'ve

Rc = small

Zero-offset section

Shot Record

R1  R2  R3  R4  R5  R6  R7  R8

Time

Traces are positioned adjacent to each other x axis could be receiver number or distance along the survey

Seismic sections are approximate images of the Earth and we can use them to interpret geology

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

• 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
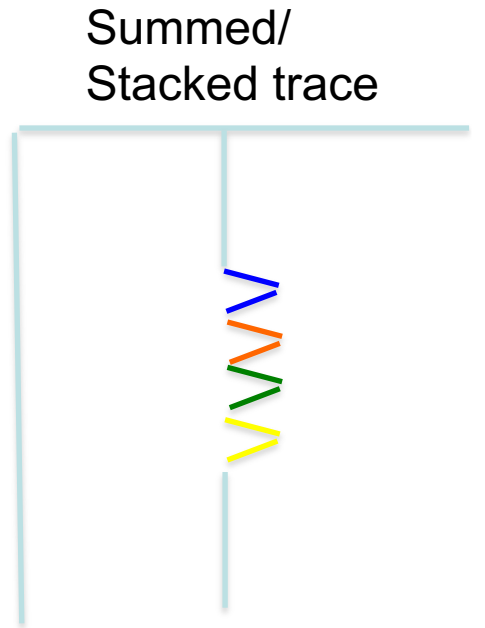
BUT- there is a problem…
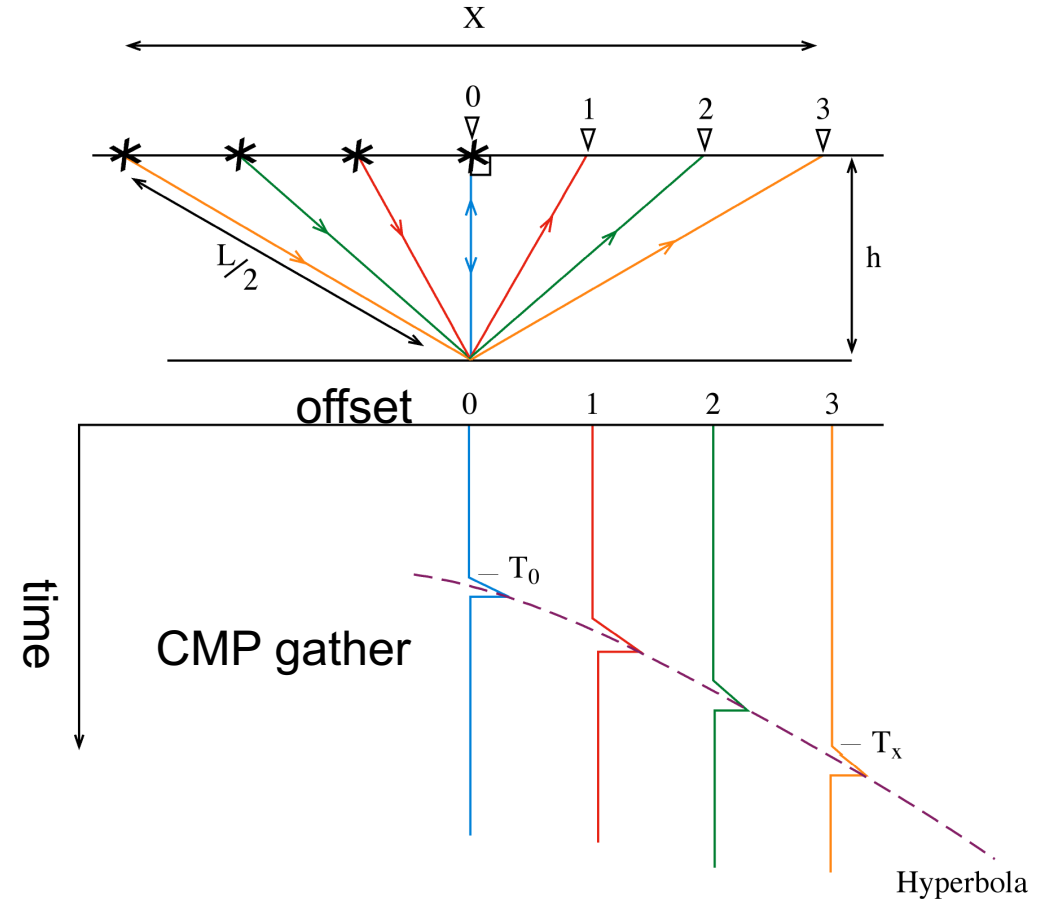
# Normal Move-Out
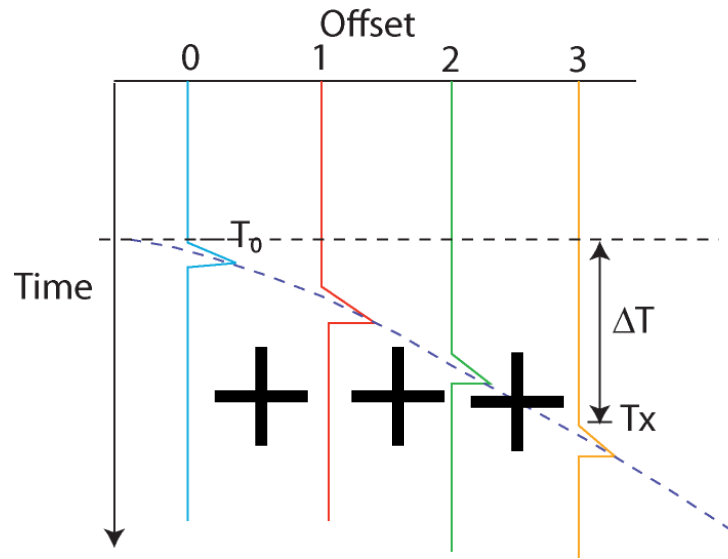


Because the travel path is longer for traces with greater offset the time that a reflection is detected will increase with offset.
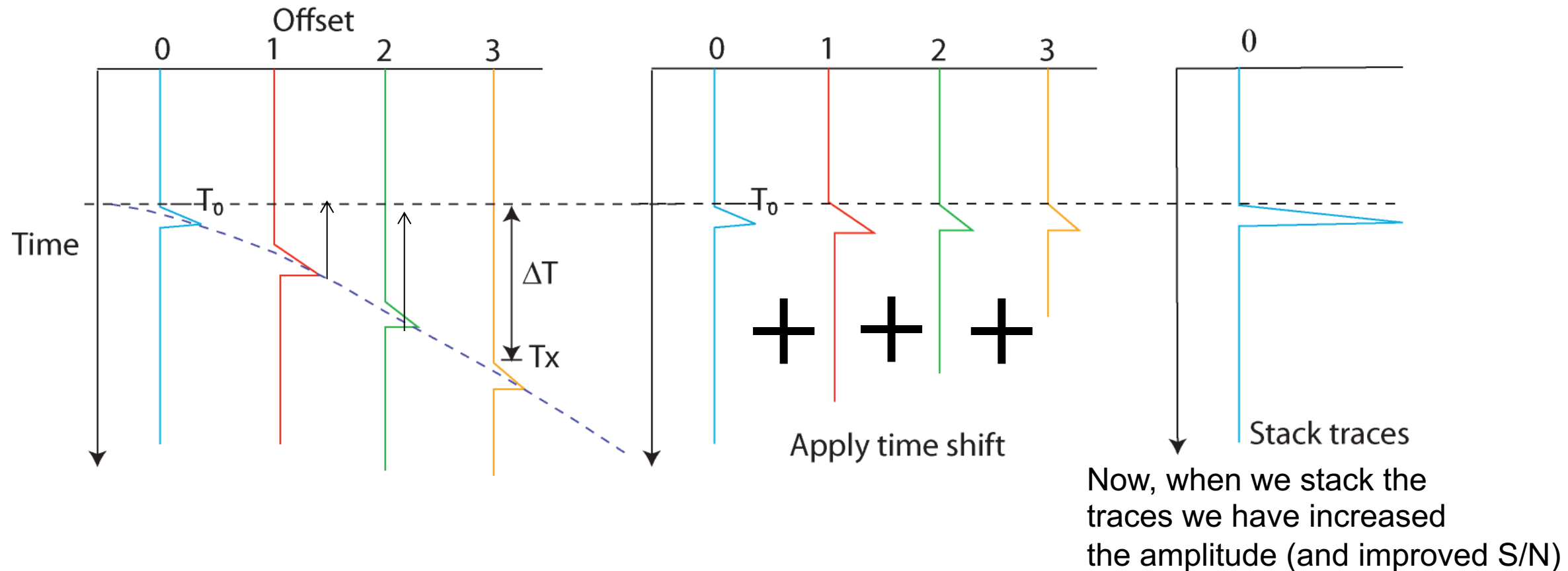
This is called Normal Moveout

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…

- 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



Apply time shift

Stack traces

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:

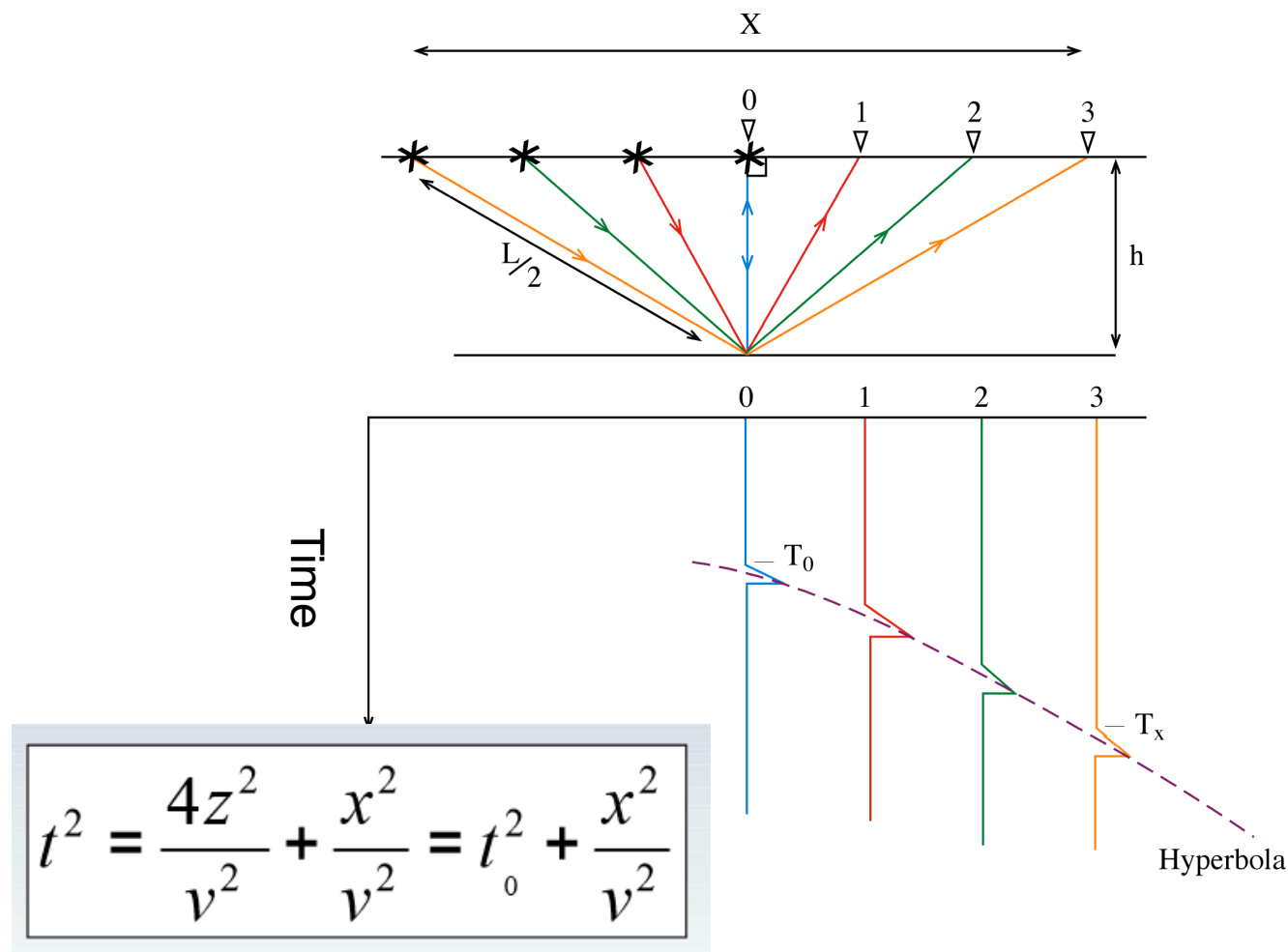$$\left(\frac{X}{2}\right)^2 + h^2 = \left(\frac{L}{2}\right)^2$$

- We're working in time, so:

$$L = VT_x$$

$$h = \frac{VT_0}{2}$$

- Hence:

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

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

$$t^2 = \frac{4z^2}{v^2} + \frac{x^2}{v^2} = t_0^2 + \frac{x^2}{v^2}$$
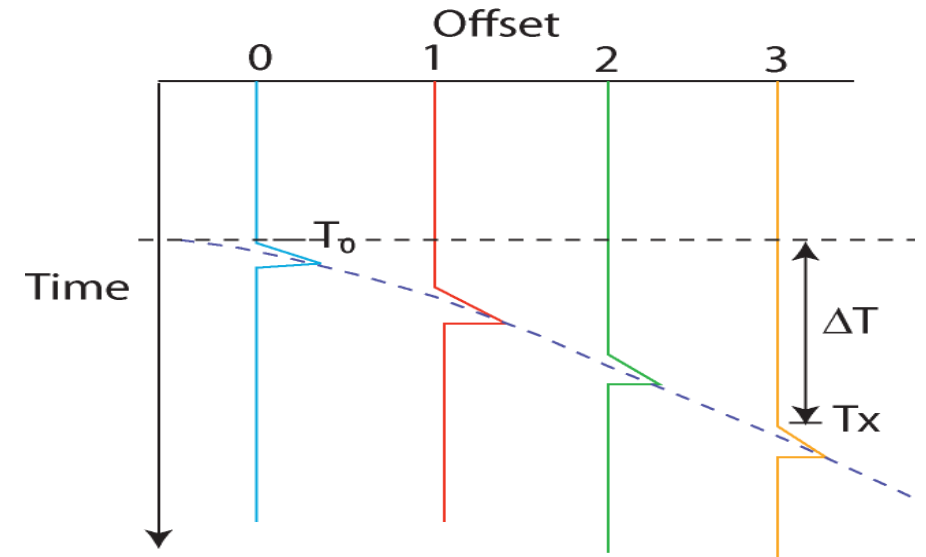
# Normal Move-Out

- Substituting $T_X$ from before gives:

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

$$\Delta T = T_X - T_o$$



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

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

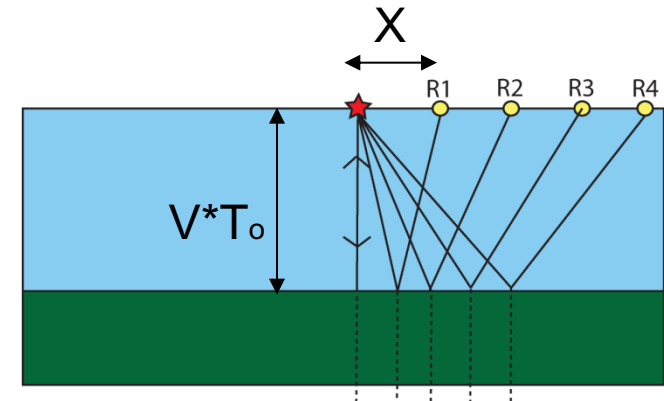This equation can be simplified using Binomial expansion....

# Normal Move-Out

Binomial expansion:

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

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

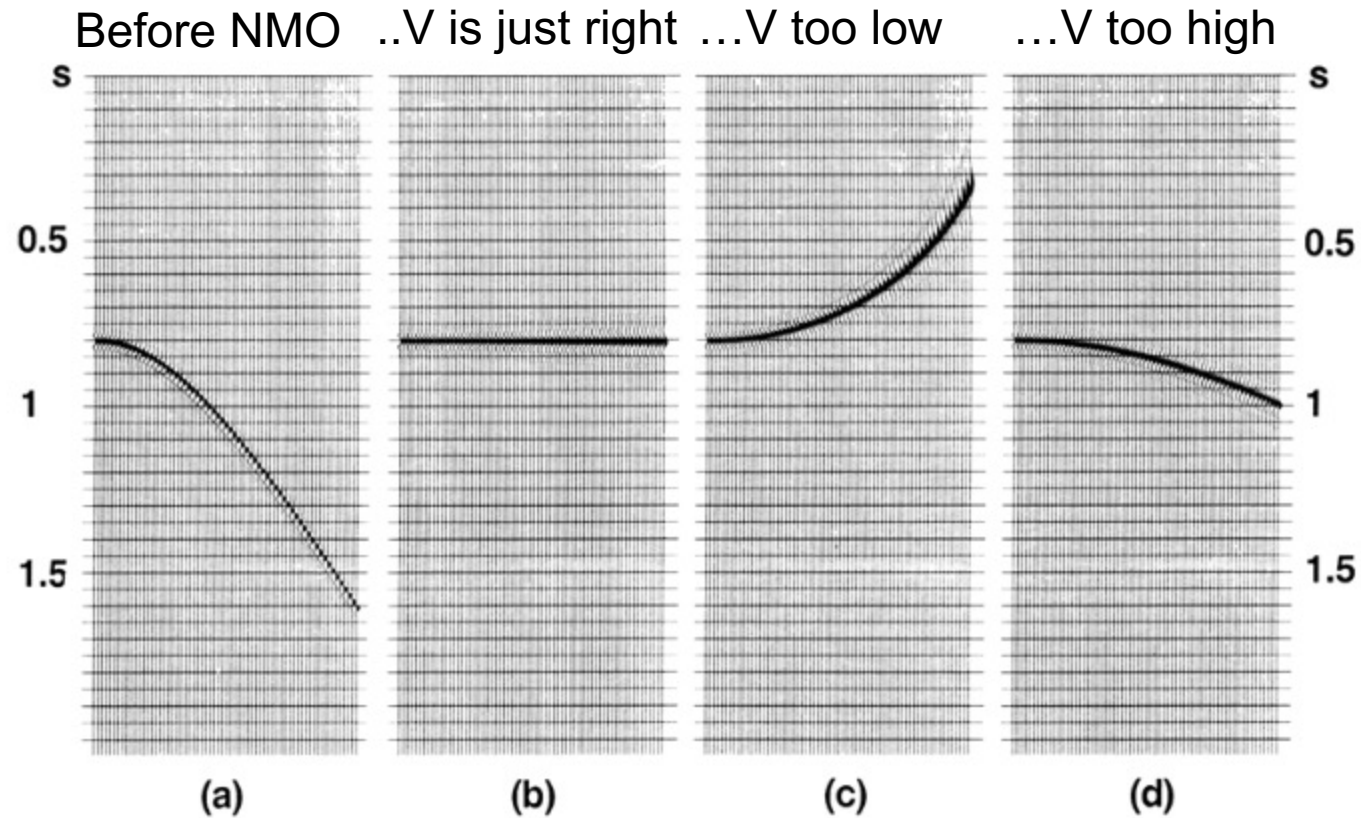$$\Delta T = T_0\left(1 + \frac{X^2}{2V^2 T_0^2} - \frac{X^4}{8V^4 T_0^4} + \ldots\right) - T_0$$



Can assume:

$$\frac{X}{VT_0} \ll 1$$

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

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

Before NMO    ..V is just right   …V too low      …V too high



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

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



Amplitude magnitude of stacked trace
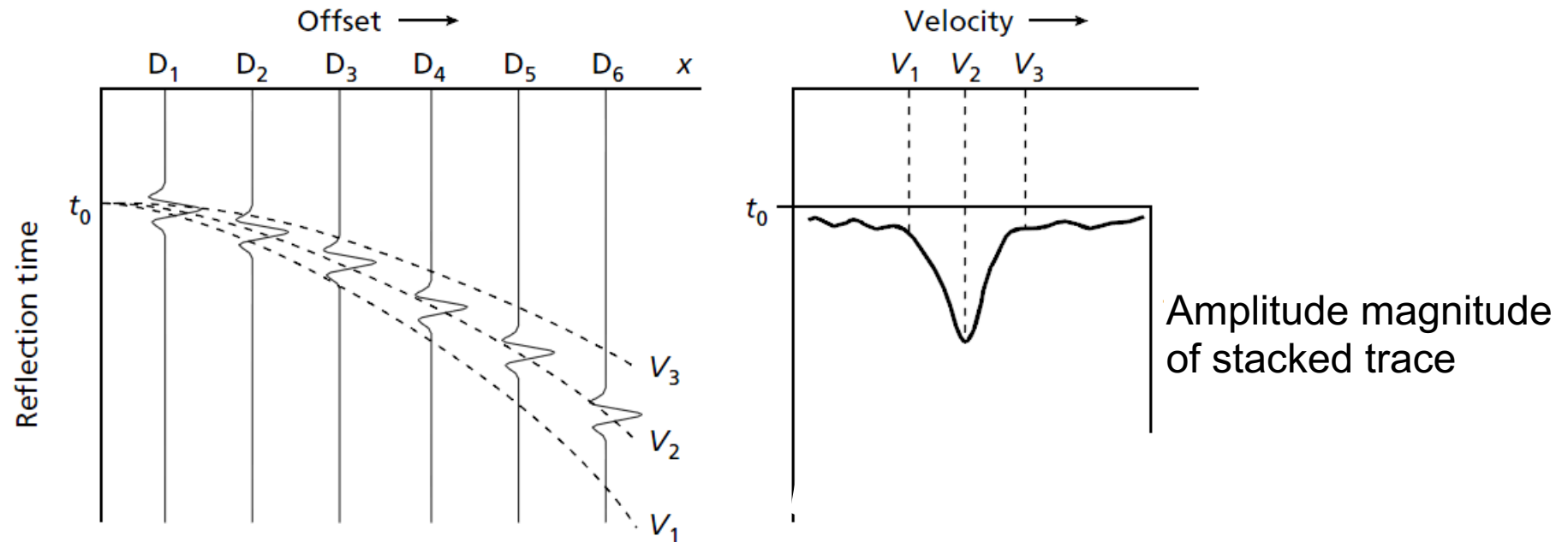
Kearey, Brooks & Hill

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**

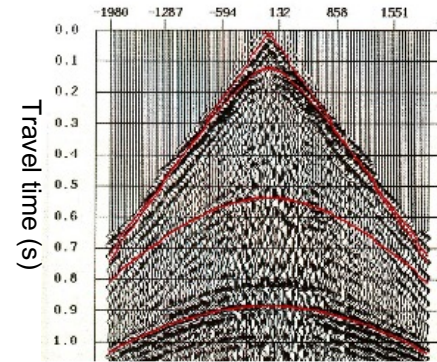**If you have time there is a bonus exercise to conduct semblance analysis with real data**

Dragoset, 2005
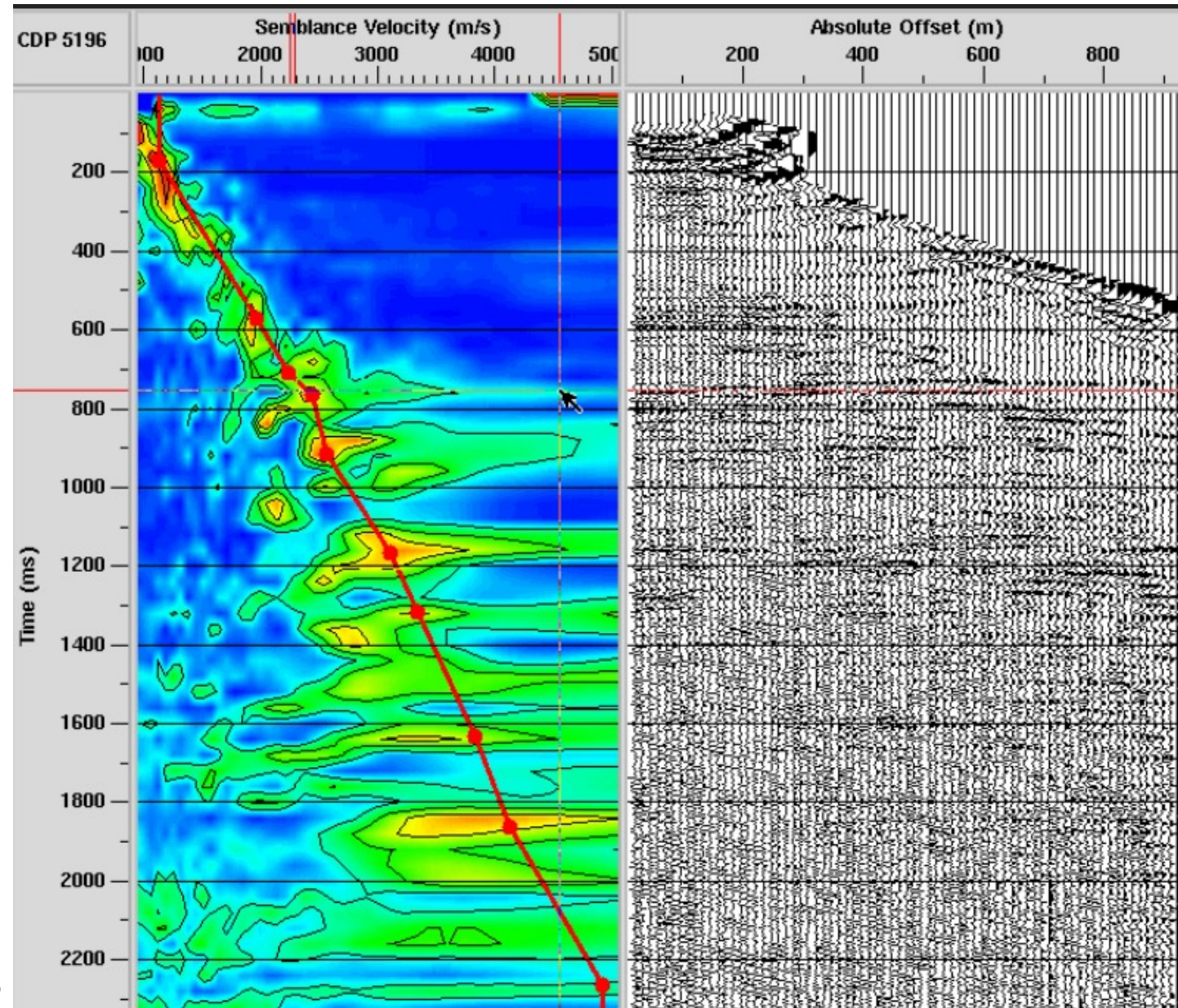
# Types of data you will see in this course…

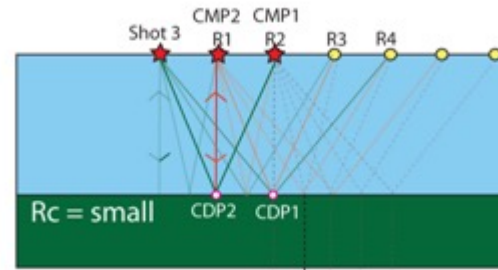## Exercise 1



Model

Synthetic
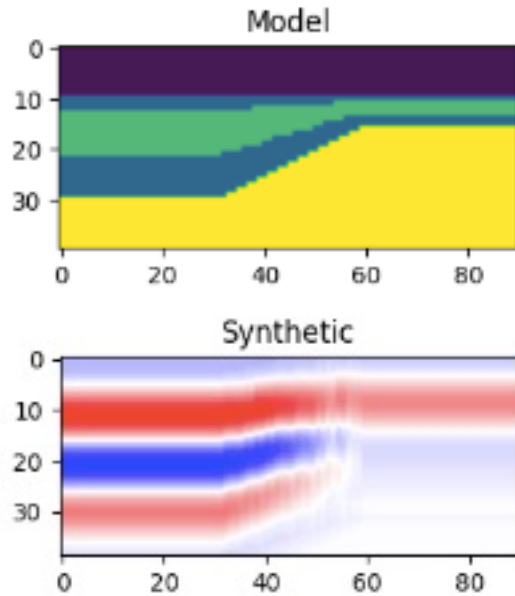
## Exercise 2

Common mid-point gather



Travel time (s)

Offset between shot and receiver
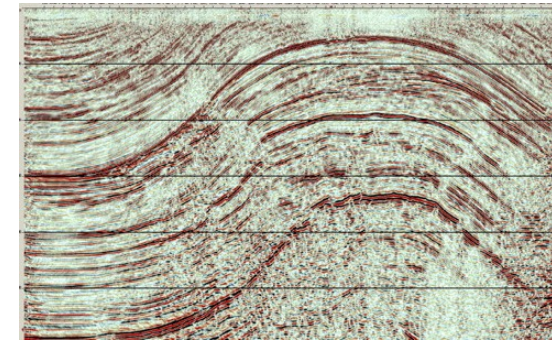
Straight lines= direct waves/
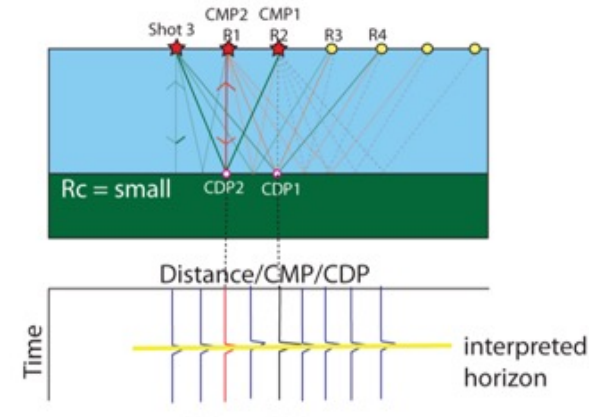head waves
Hyperbola= reflections

Compilation from multiple shots

## Exercise 3 and 4

Seismic section



Travel time (s)

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