# 11. Seismic processing

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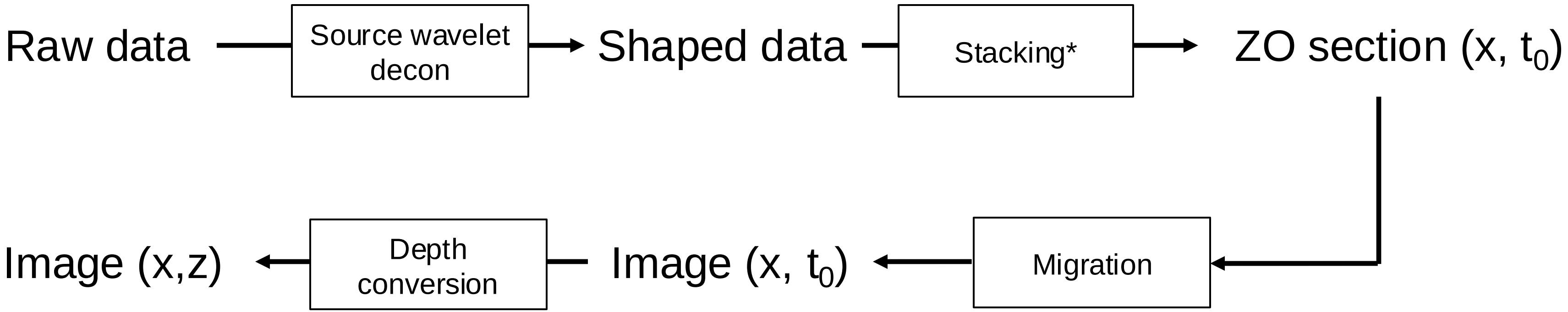
ERSE 210 Seismology

# Basic Seismic Processing Flow

Historically, seismic data processing was composed of a few simple steps, mostly aimed at **stacking** traces to enhance the SNR of the recorded data.




* This also includes a step of velocity estimation

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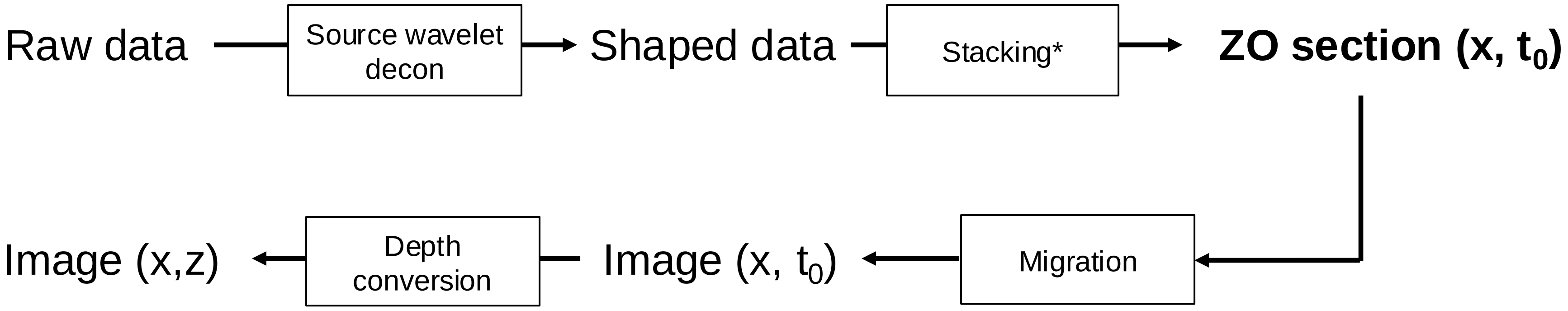
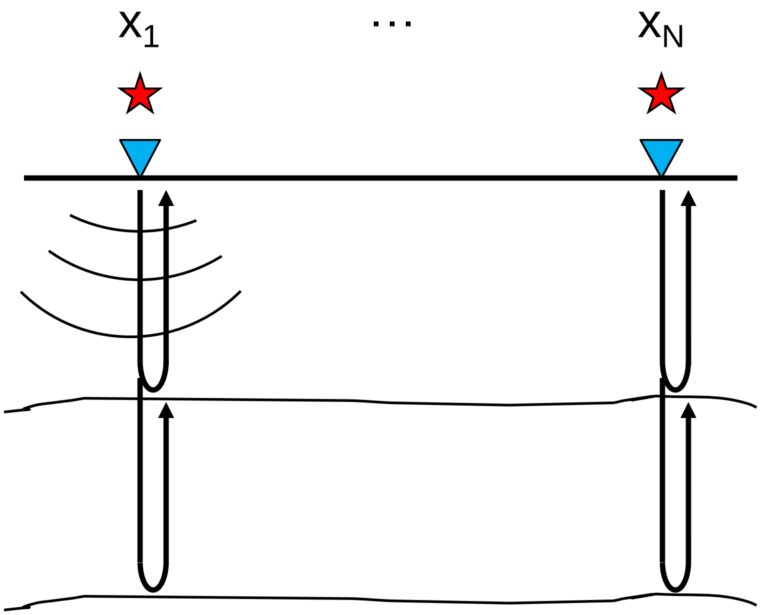
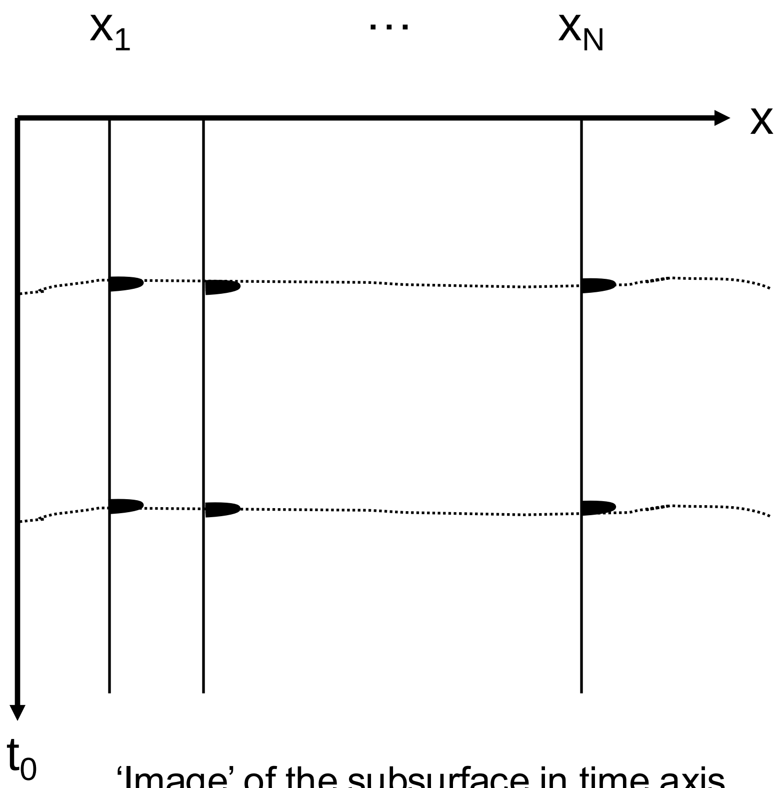



* This also includes a step of velocity estimation

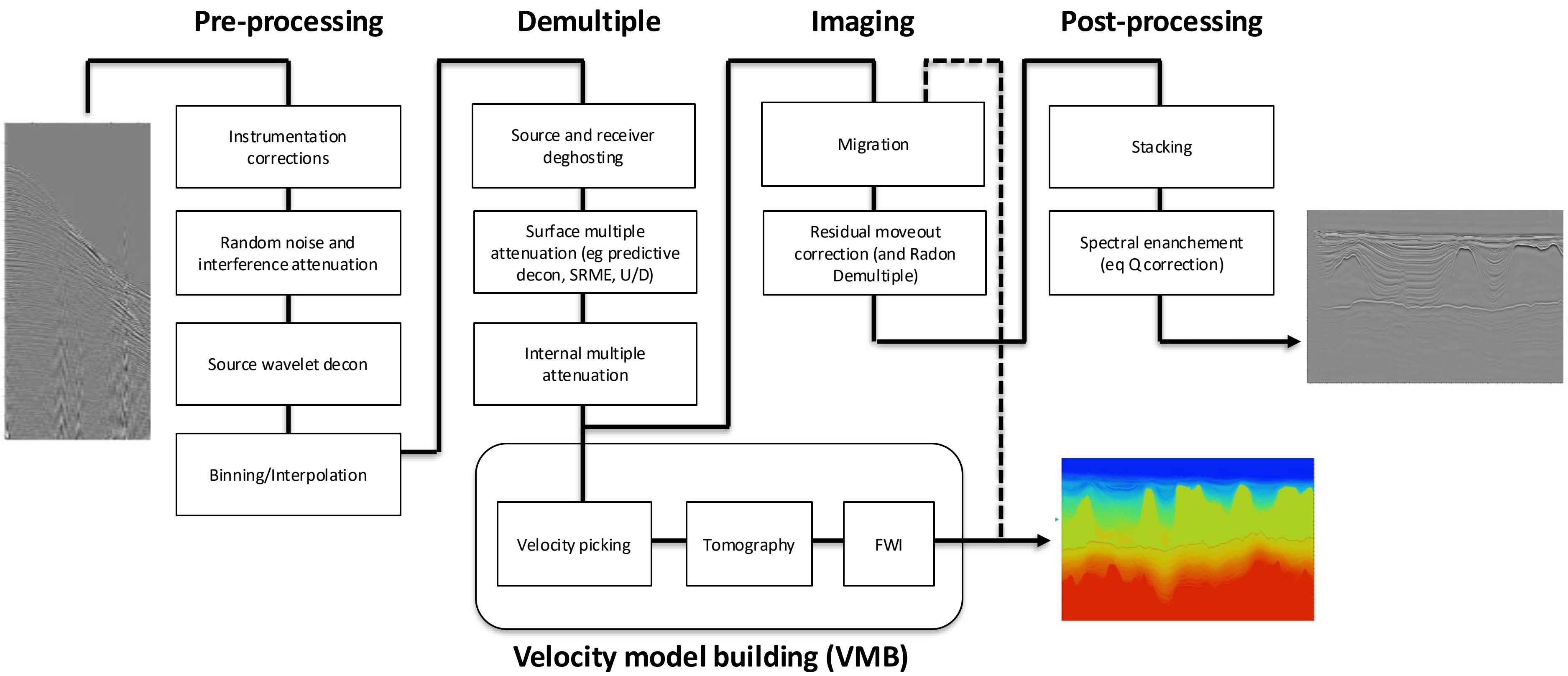
# Zero-offset section



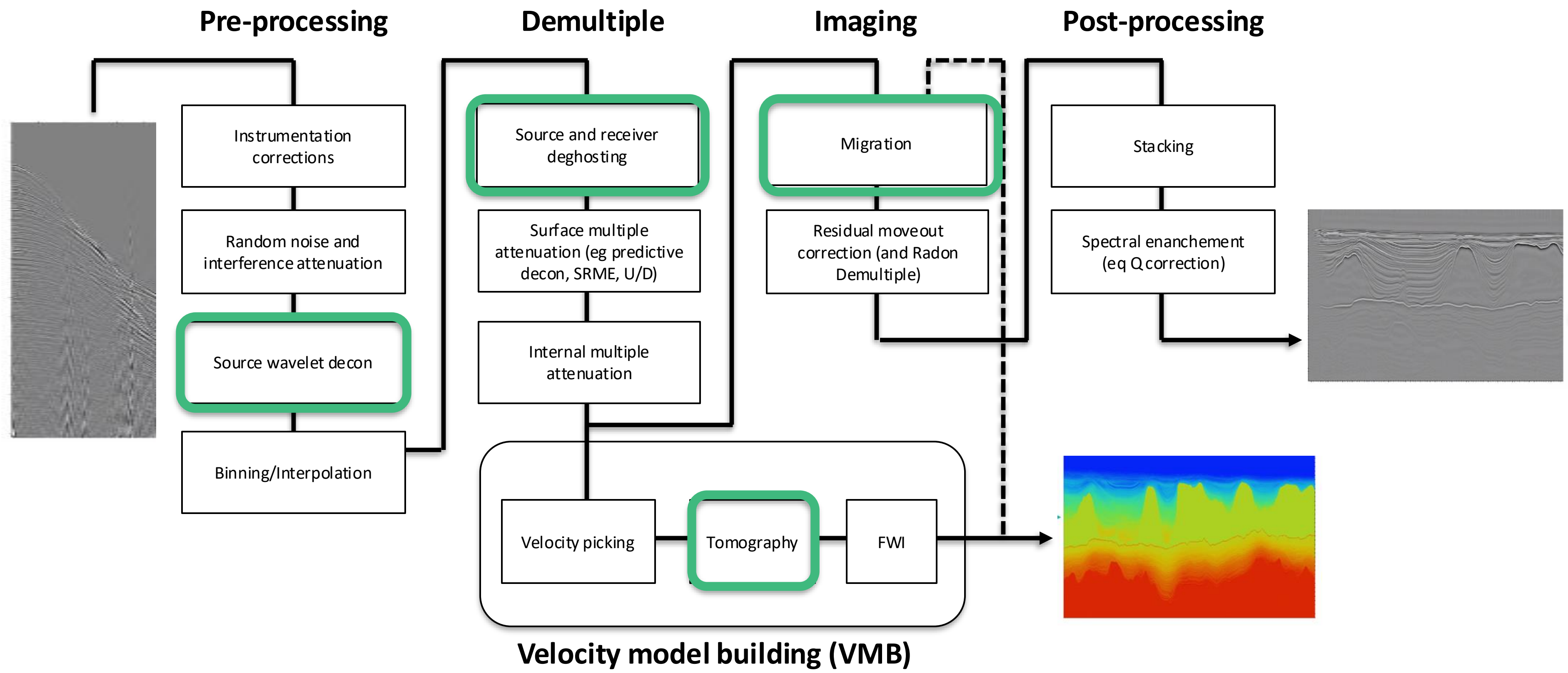




‘Image’ of the subsurface in time axis

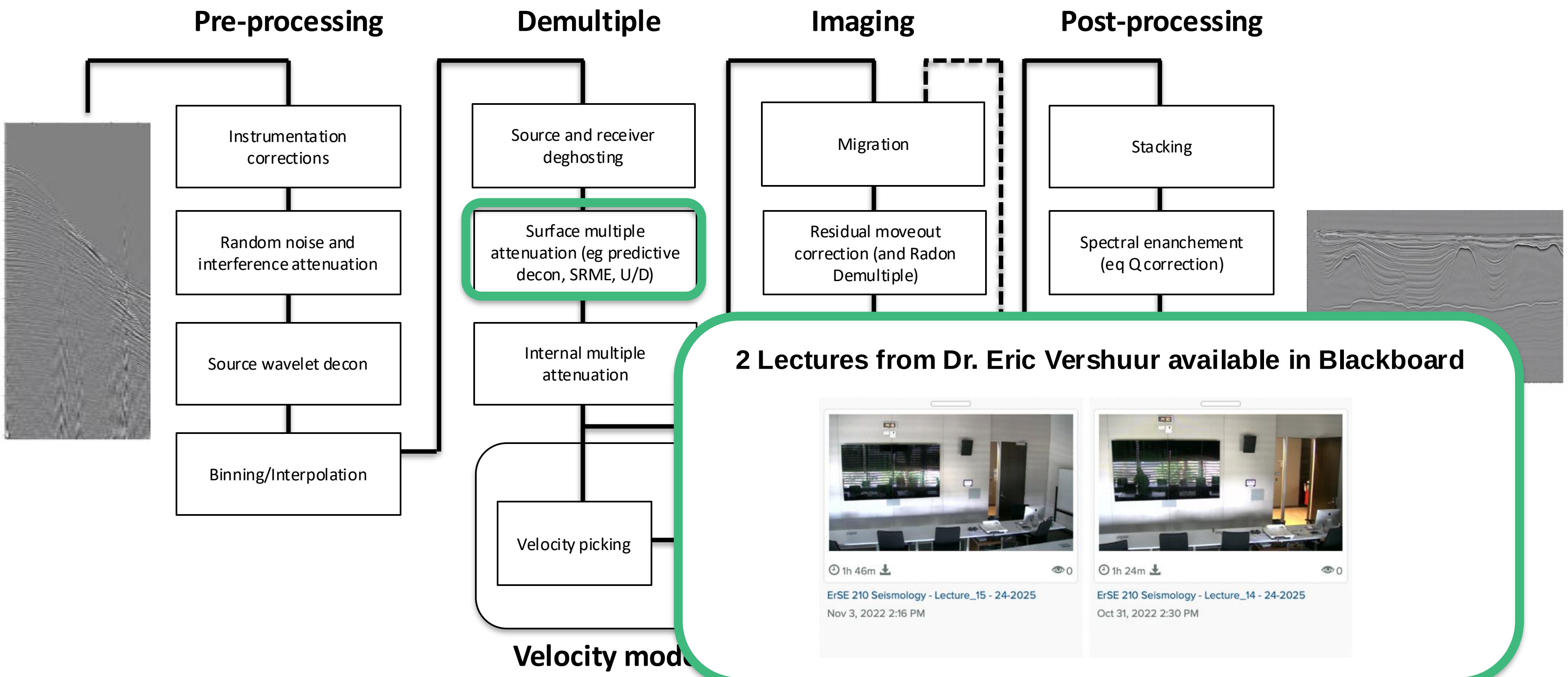
# Modern Seismic Processing flow



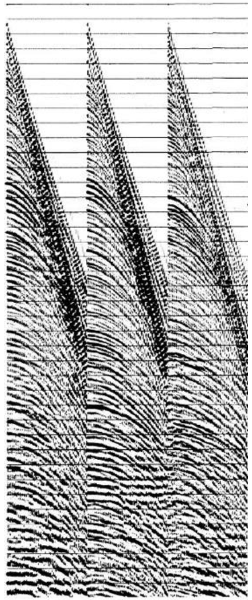
# Modern Seismic Processing flow



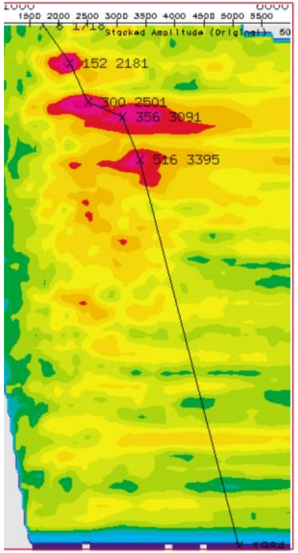
# Modern Seismic Processing flow



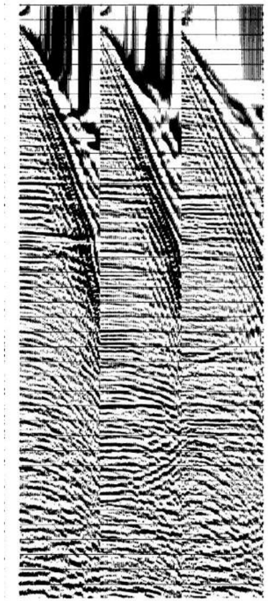
# Common midpoint stacking = NMO analysis



Velocity analysis

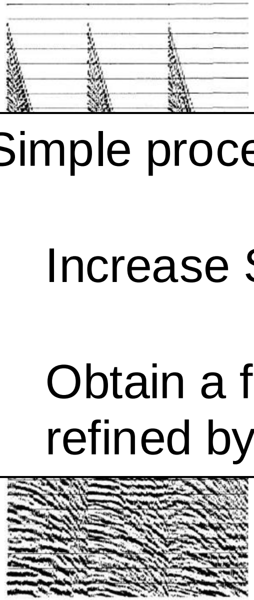


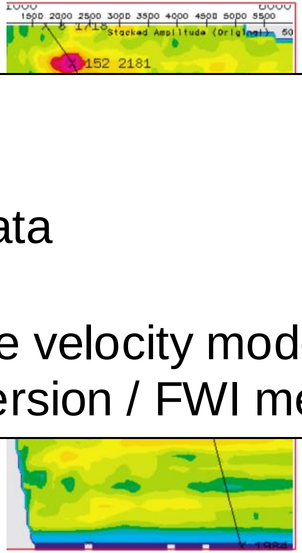

NMO Correction

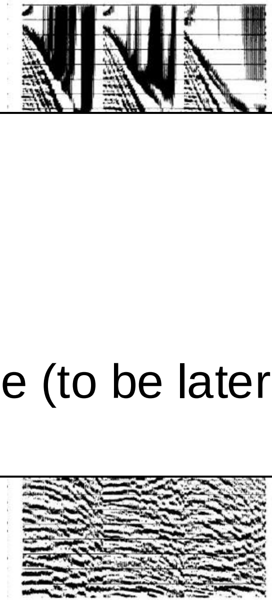


* Figures from Yilmaz book

# Common midpoint stacking = NMO analysis





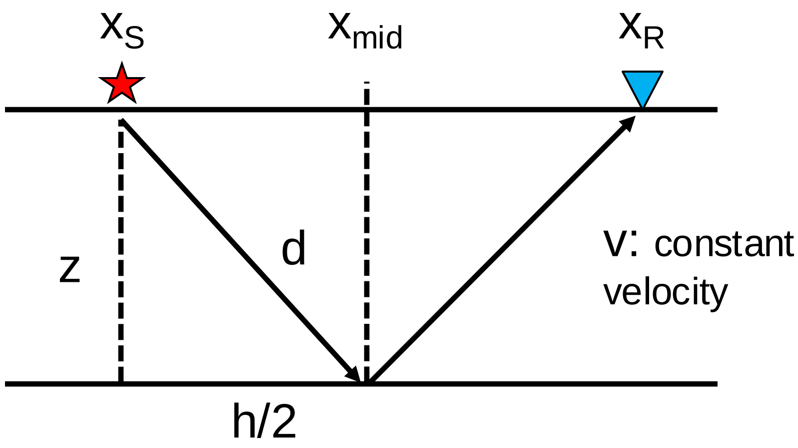



Simple procedure to:

- Increase SNR of seismic data
- Obtain a first estimate of the velocity model of the subsurface (to be later refined by tomographic inversion / FWI methods)

* Figures from Yilmaz book

# Normal moveout




- If $x_s = x_r$

Two-way traveltime

$$d_0 = z \rightarrow t_0 = 2z/v$$

- If $x_s \neq x_r$

$$d = \sqrt{z^2 + \frac{h^2}{4}} \rightarrow t = 2\sqrt{\frac{z^2}{v^2} + \frac{h^2}{4v^2}}$$

$$= \sqrt{t_0^2 + \frac{h^2}{v^2}}$$

# Normal moveout

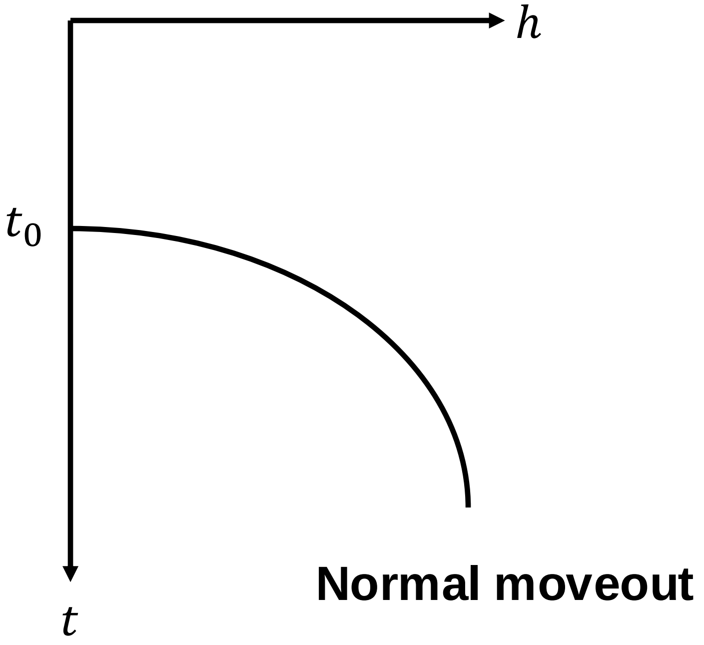
Rearranging the traveltime equation:

$$t^2 = t_0^2 + \frac{h^2}{v^2}$$

$$\Updownarrow$$

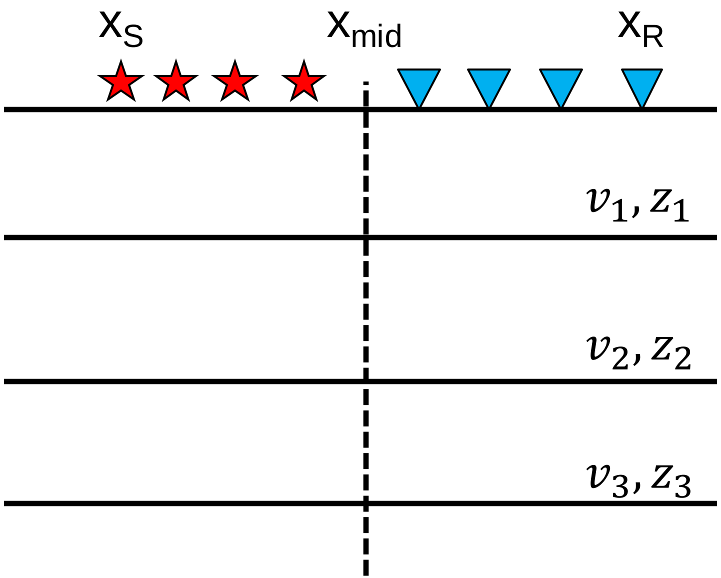
$$t^2 - \frac{h^2}{v^2} = t_0^2$$

Hyperbola in h-t axes



# Normal moveout

This equation is not only valid for a single layer of constant velocity; a simple extension exists for a stack of N layers:




$$t^2 = t_0^2 + \frac{h^2}{v_{RMS}^2}$$

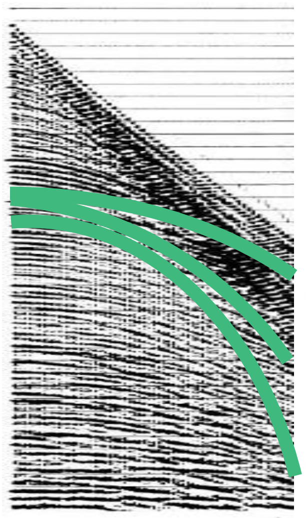
Root-Mean Squared Velocity

$$v_{RMS}^2 = \frac{1}{t_0} \sum_i v_i^2 \Delta\tau_i$$

$$\Delta\tau_i = \frac{2z_i}{v_i}, t_0 = \sum_i \Delta\tau_i$$

# Semblance analysis

$t_0$

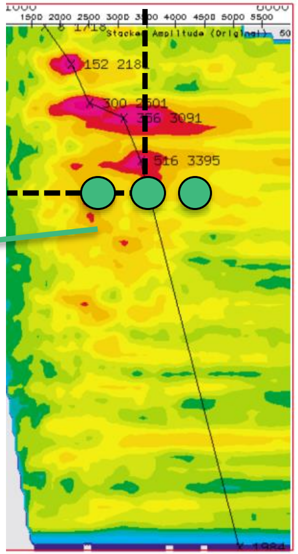


$$t = \sqrt{t_0^2 + \frac{h^2}{v_{RMS}^2}}$$

$$S(t_0, v_{rms}) = \frac{\left(\sum_h d\left(t = \sqrt{t_0^2 + h^2/v_{rms}^2}, h\right)\right)^2}{N_h \sum_h d^2\left(t = \sqrt{t_0^2 + h^2/v_{rms}^2}, h\right)}$$

$v_{RMS}$

$t_0$

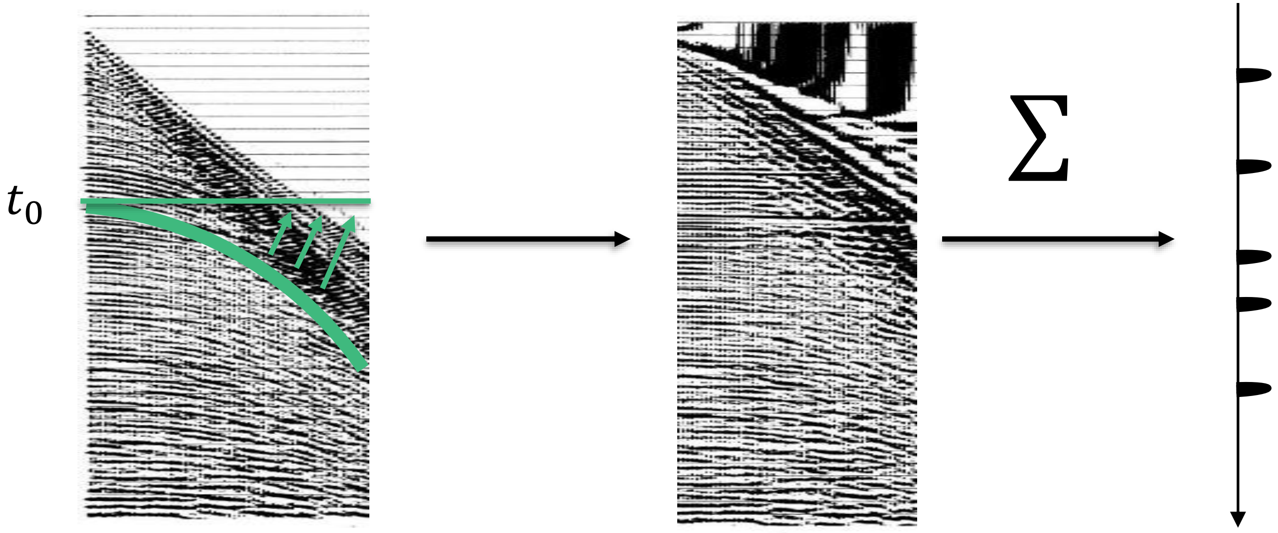


Fit all possible parametric curves with $(t_0, v_{RMS})$ and ‘sum’

# NMO correction and CMP stacking

SNR increase by a factor of $\sqrt{N}$

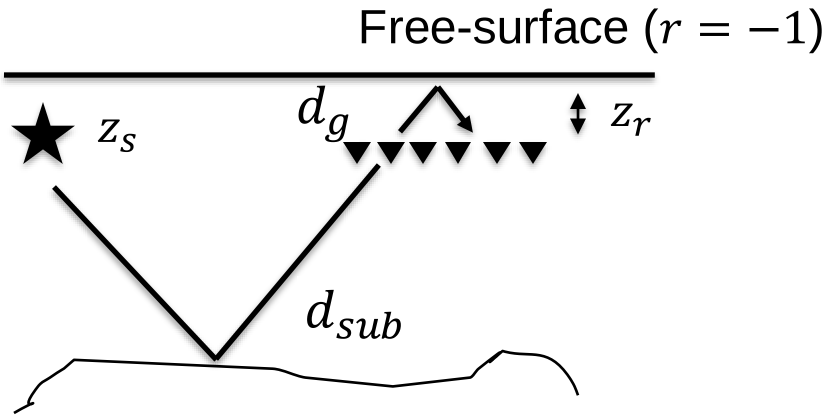
$N$: number of traces or fold




Flatten CMP gather and sum along best fitting line $\tilde{t} = \sqrt{\tilde{t}_0^2 + \frac{h^2}{\tilde{v}_{RMS}^2}}$

# Deghosting

Marine seismic data are acquired placing sources and receivers below the water-air interface (= free surface); this creates a **ghost** effect in the data




$$
\begin{aligned}
d(t) &= d_{sub}(t) + d_{ghost}(t) \\
&= d_{sub}(t) + r d_{sub}(t - t_g) \\
&= d_{sub}(t) - d_{sub}(t - t_g)
\end{aligned}
$$

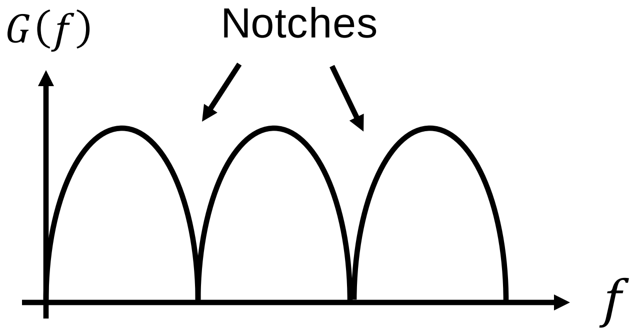
$t_g \approx 2z_R/v_{water}$ at zero incidence

# Deghosting

The effect of the ghost arrival on the recorded seismic data is better understood in the frequency domain:

$$d(t) = d_{sub}(t) - d_{sub}(t - t_g) \longleftrightarrow D(f) = D_{sub}(f) - D_{sub}(f)e^{-j2\pi f t_g}$$

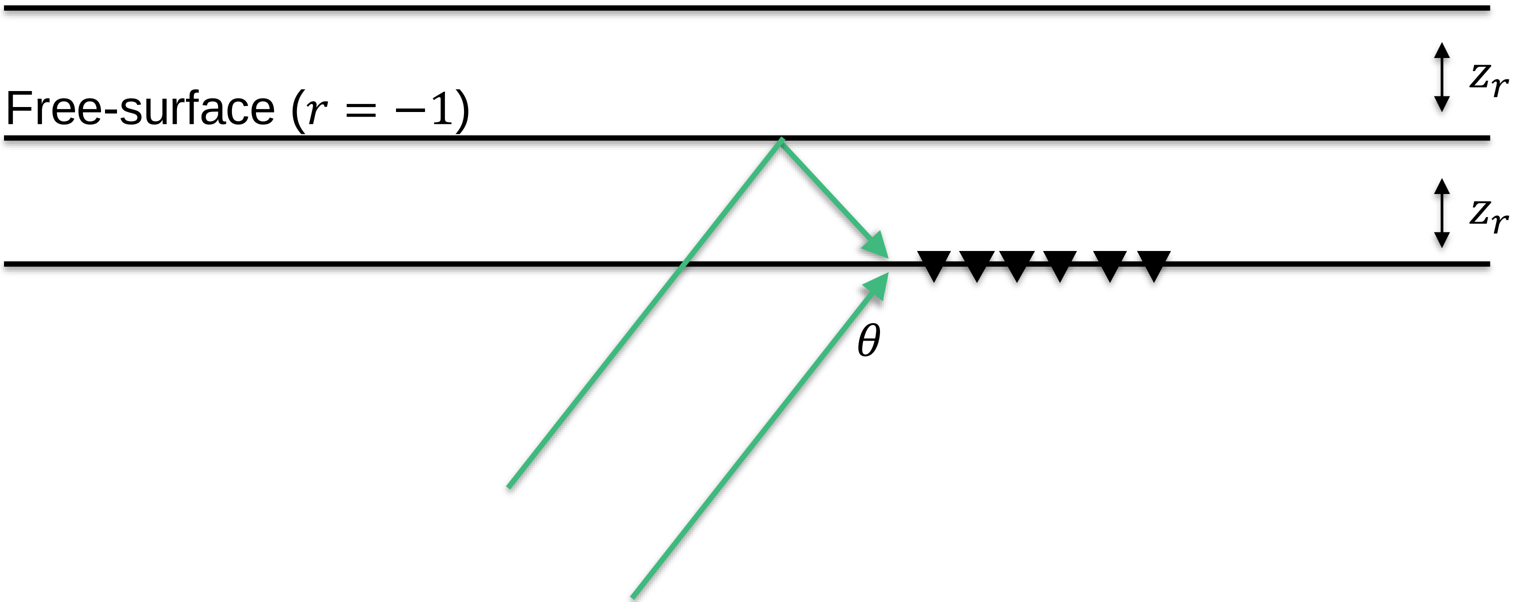
$$D(f) = D_{sub}(f)\underbrace{[1 - e^{-j2\pi f t_g}]}_{G(f)\text{: ghost model}}$$




$$\boxed{f_{notch} = \frac{n v_{water}}{2 z_r} \quad \text{where} \quad \frac{2\pi f 2 z_r}{v_{water}} = 0 + 2\pi n}$$

# Deghosting

We can model the ghost more accurately by considering the angle of incidence $\theta$



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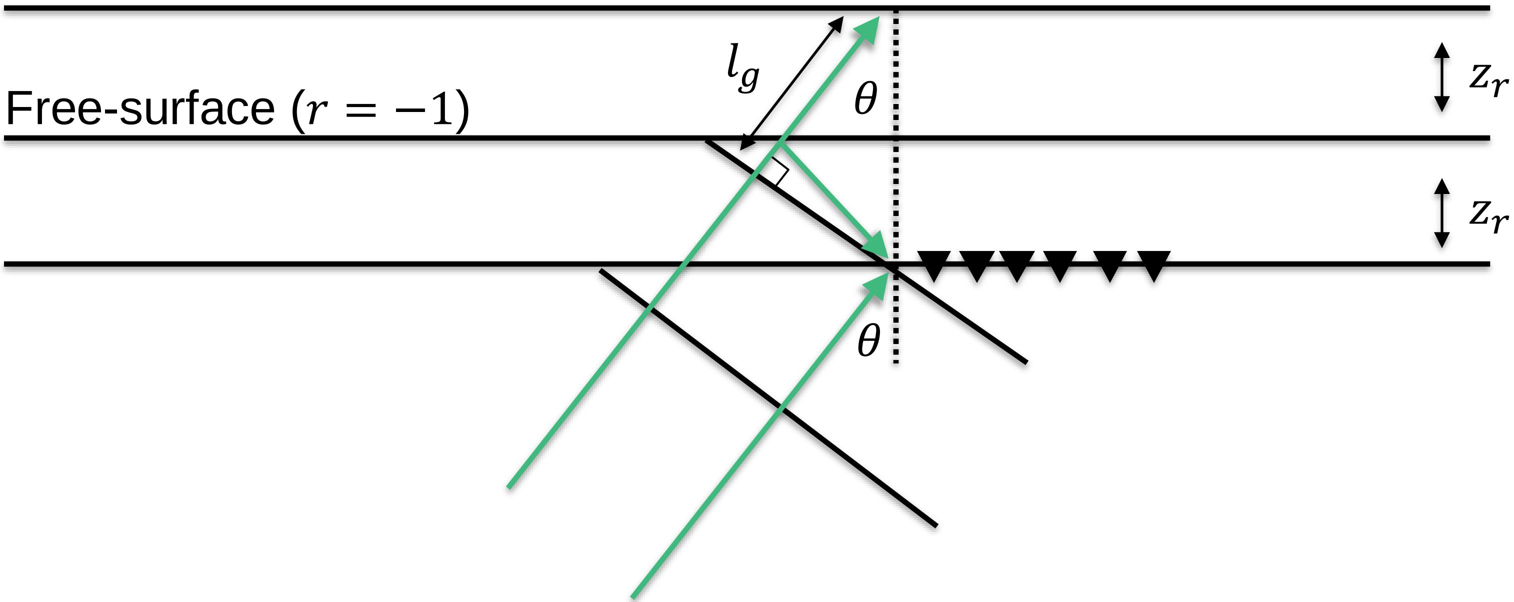

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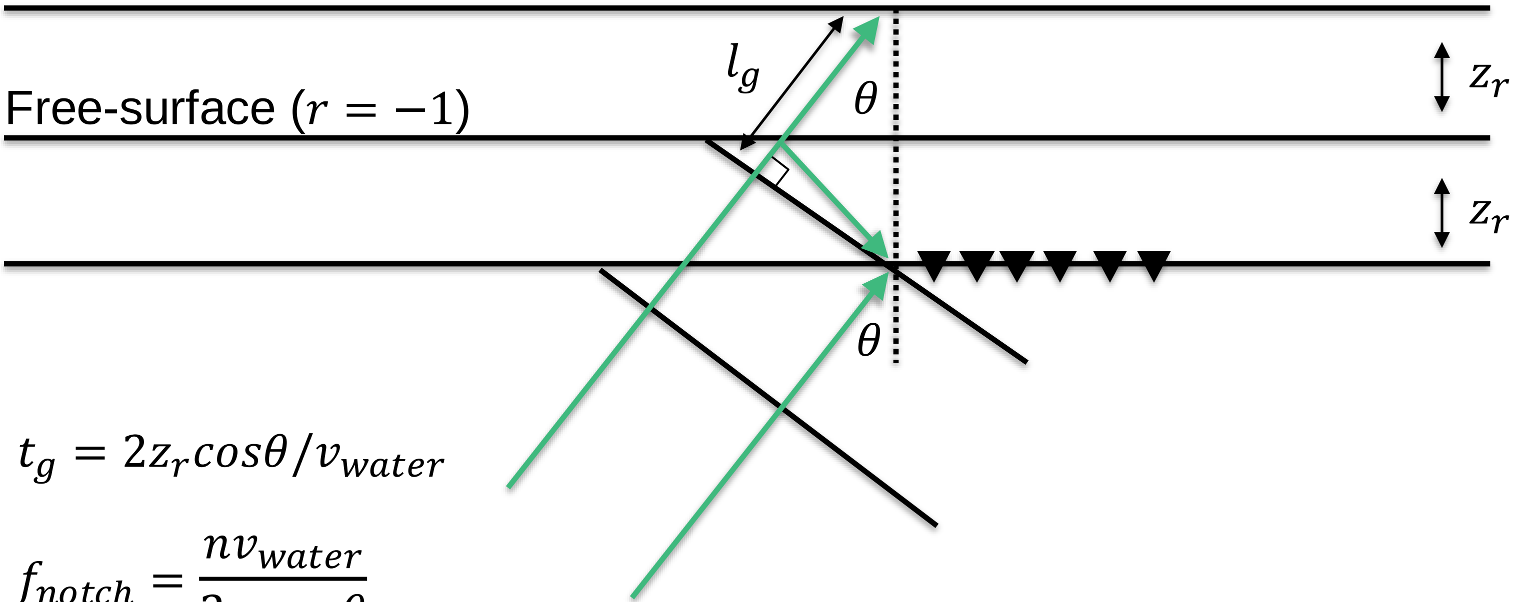


$$t_g = 2z_r cos\theta / v_{water}$$

$$f_{notch} = \frac{n v_{water}}{2 z_r cos\theta}$$

# Deghosting

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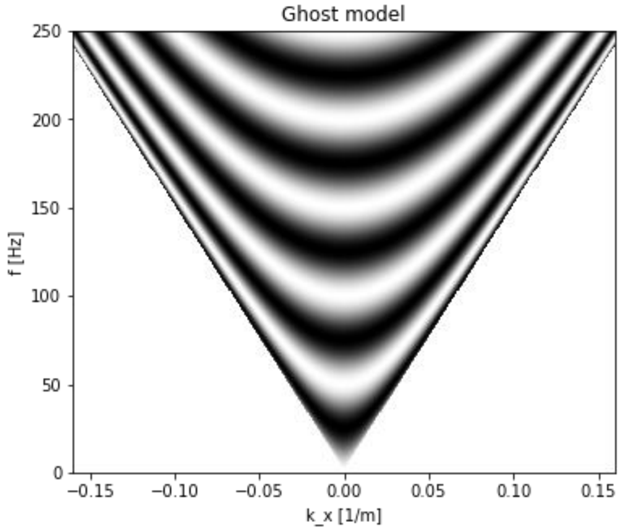
$$f_{notch} = \frac{n v_{water}}{2 z_r cos\theta}$$

$$D(f, k_x) = D_{sub}(f, k_x)\left[1 - e^{-j2\pi k_z (2z_r)}\right]$$



# Deghosting

Deghosting is the process of 'deconvolving' the ghost model from data:]

$$D_{sub}(f, k_x) \approx \frac{D(f, k_x)}{[1 - e^{-j2\pi k_z(2z_r)}]}$$

Since this process allows recovering some frequencies that the free-surface had suppressed (ghost notches), **broadband seismic** refers to the combination of acquisition and processing strategies to remove/attenuate ghost effects.

A similar effect also exist on the source side (source-deghosting).