Seismic Reflection Data Processing

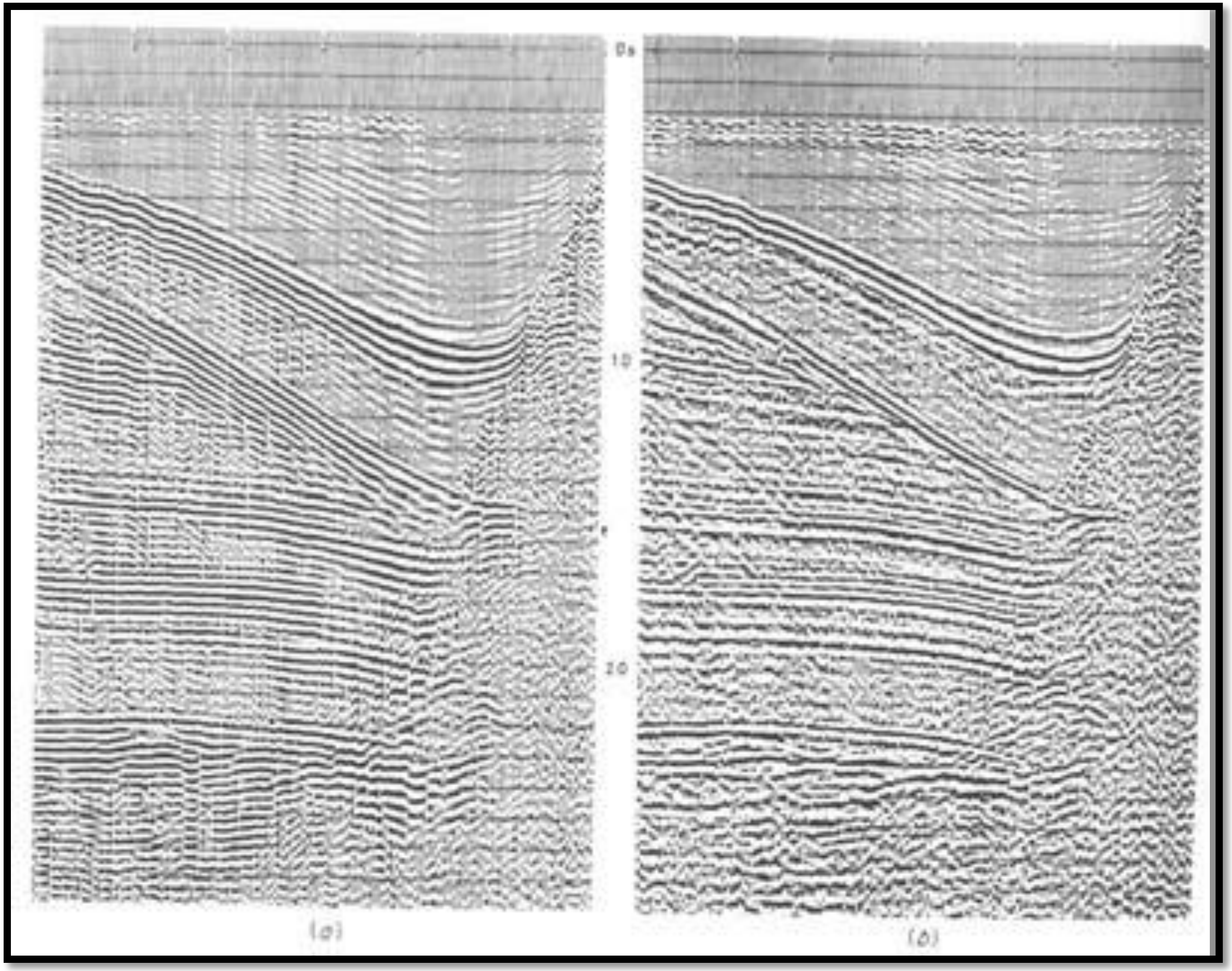
Emad A. Al-Heety
Department of Applied Geology
University of Anbar
Email: emadsalah@ uoanbar.edu.iq

Deconvolution

- A step in seismic signal processing to recover high frequencies, attenuate multiples, equalize amplitudes, produce a zero-phase wavelet or for other purposes that generally affect the wave shape.

Deconvolution

- Deconvolution, or inverse filtering, can improve seismic data that were adversely affected by filtering, or convolution that occurs naturally as seismic energy is filtered by the Earth.
- Deconvolution can also be performed on other types of data, such as gravity, magnetic or well log data.



Original Section

After Deconvolution

Deconvolution using correlation

- **Correlation**

  The comparison of seismic waveforms in the time domain, similar to coherence in the frequency domain.

- **Autocorrelation**

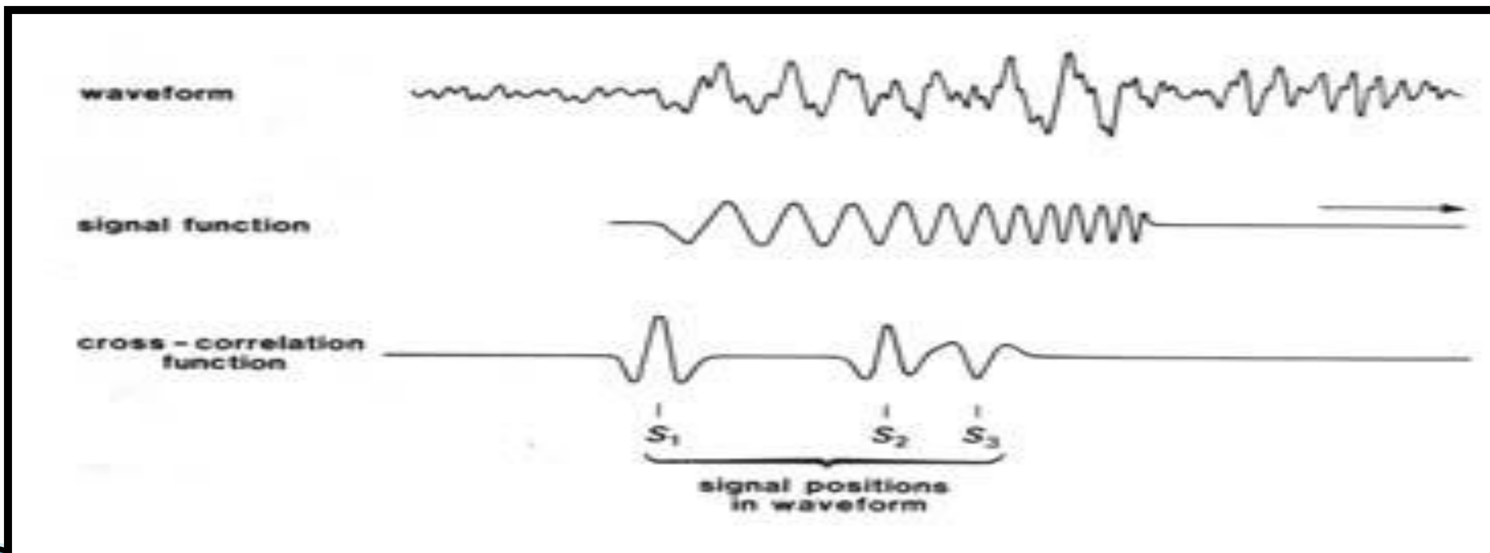
  The comparison of a waveform to itself. Autocorrelation is useful in the identification of multiples or other regularly repeating signals, and in designing deconvolution filters to suppress them.

Deconvolution using correlation

- **Cross-correlation**
- The comparison of different waveforms in digital form to quantify their similarity.
- A normalized crosscorrelation, or a correlation coefficient, equals to unity indicates a perfect match, whereas a poor match will yield a value close to zero.

Deconvolution using correlation

- If we know the source pulse, then cross-correlating it with the recorded waveform gets us back (closer) to the reflectivity function.



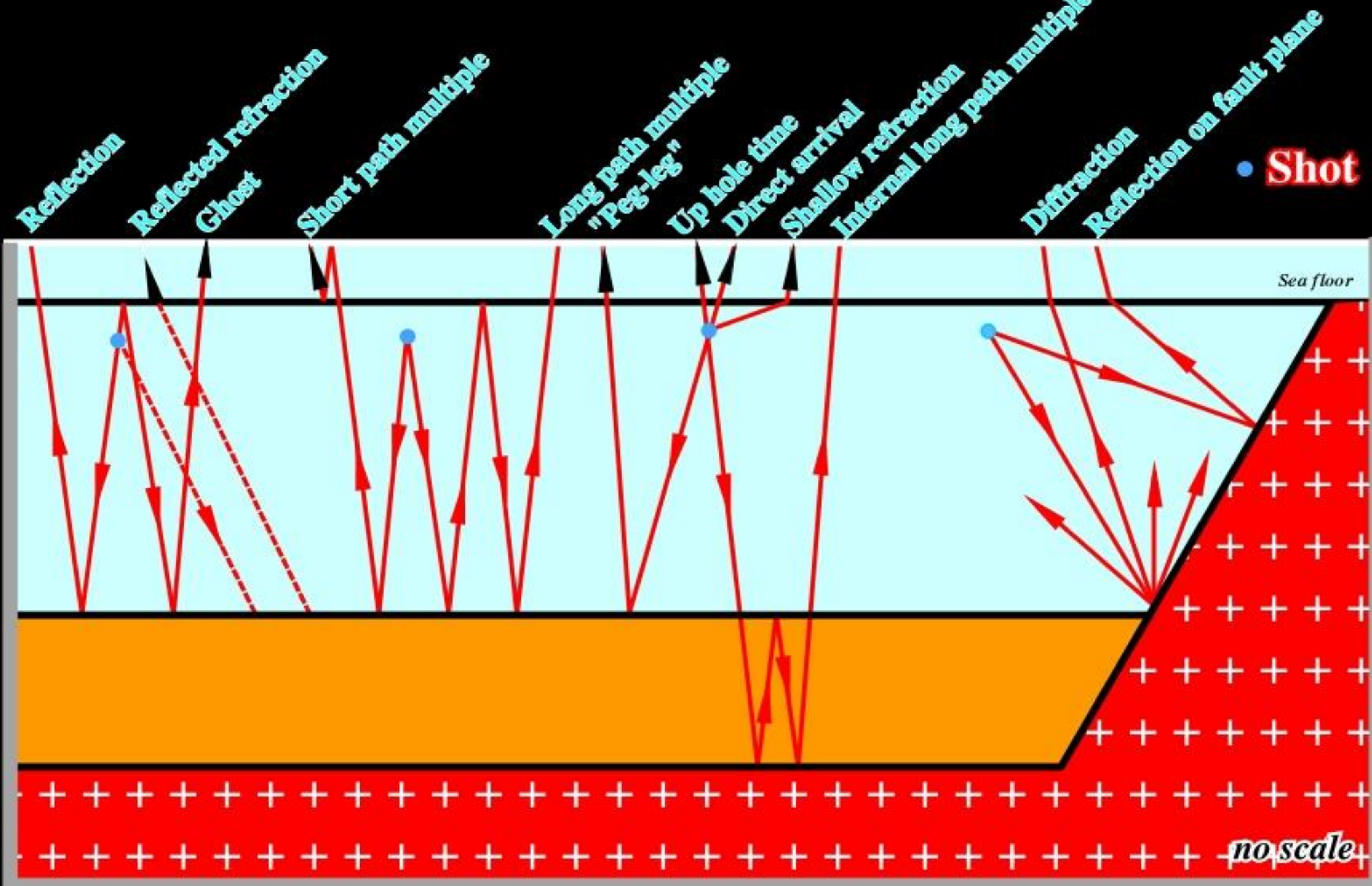
Deconvolution using correlation

- If we don't know the source pulse, then autocorrelation of the waveform gives us something similar to the input plus multiples.
- Cross-correlating the autocorrelation with the waveform then provides a better approximation to the reflectivity function.

Multiples

- Multiply reflected seismic energy, or any event in seismic data that has subjected to more than one reflection in its travel path.
- Multiples from the water bottom (the interface of the base of water and the rock or sediment beneath it) and the air-water interface are common in marine seismic data, and are suppressed by seismic processing.

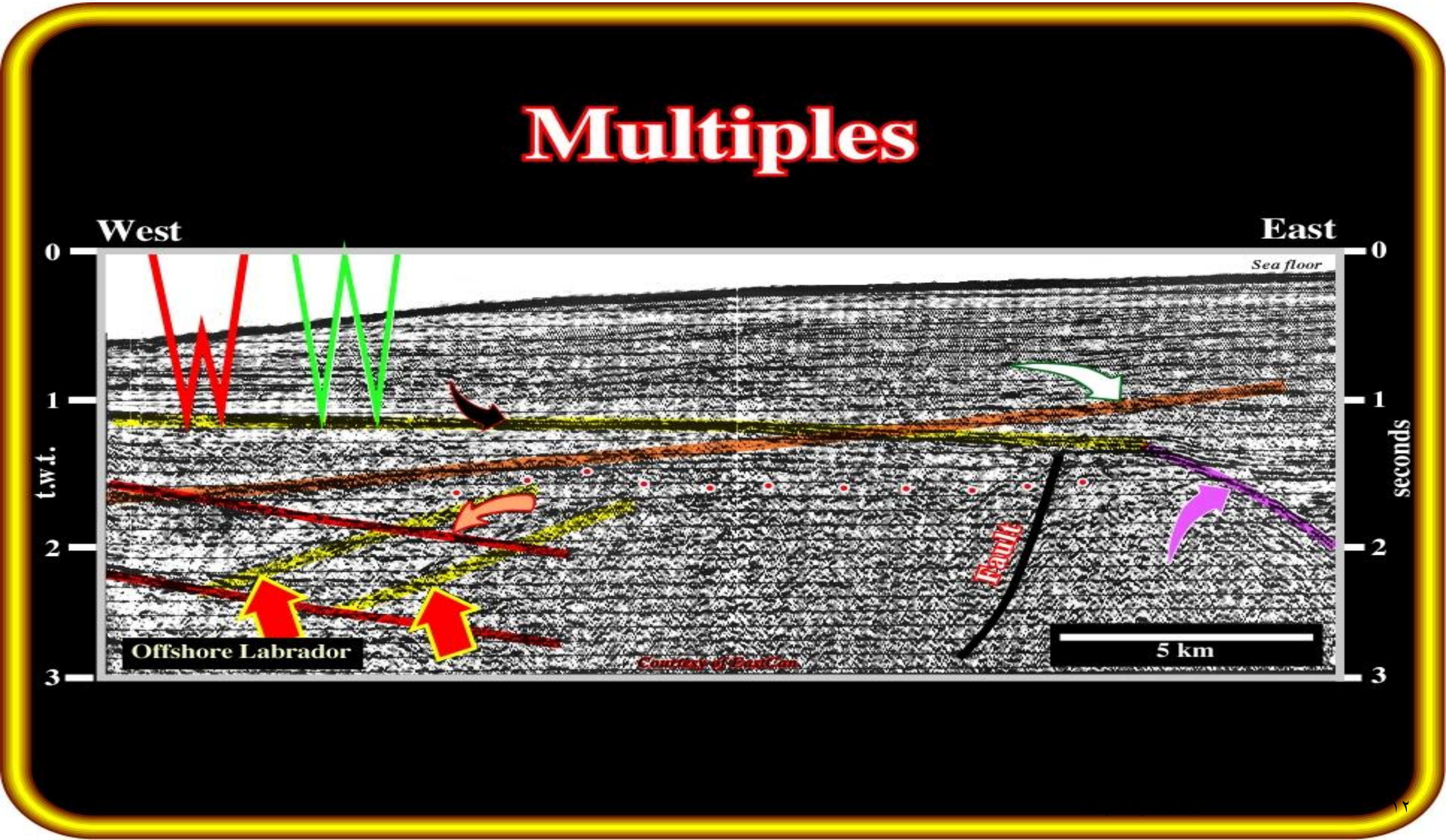
Different Energy Paths

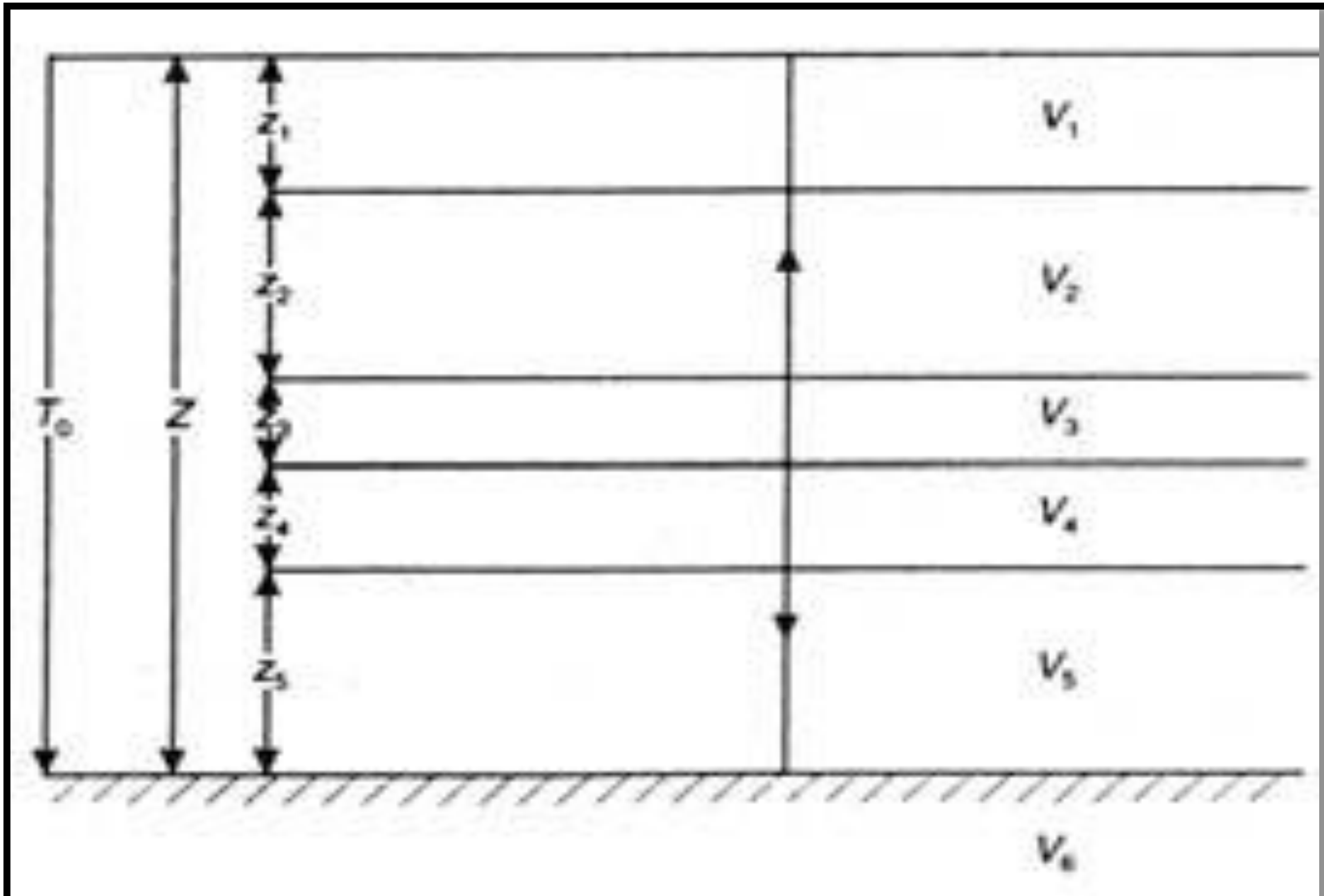


Multiples

- **Multiples** are also removed with deconvolution
- **Multiples** easily identified with an autocorrelation
- **Multiples** removed using cross-correlation of the autocorrelation with the waveform.

Multiples
Example

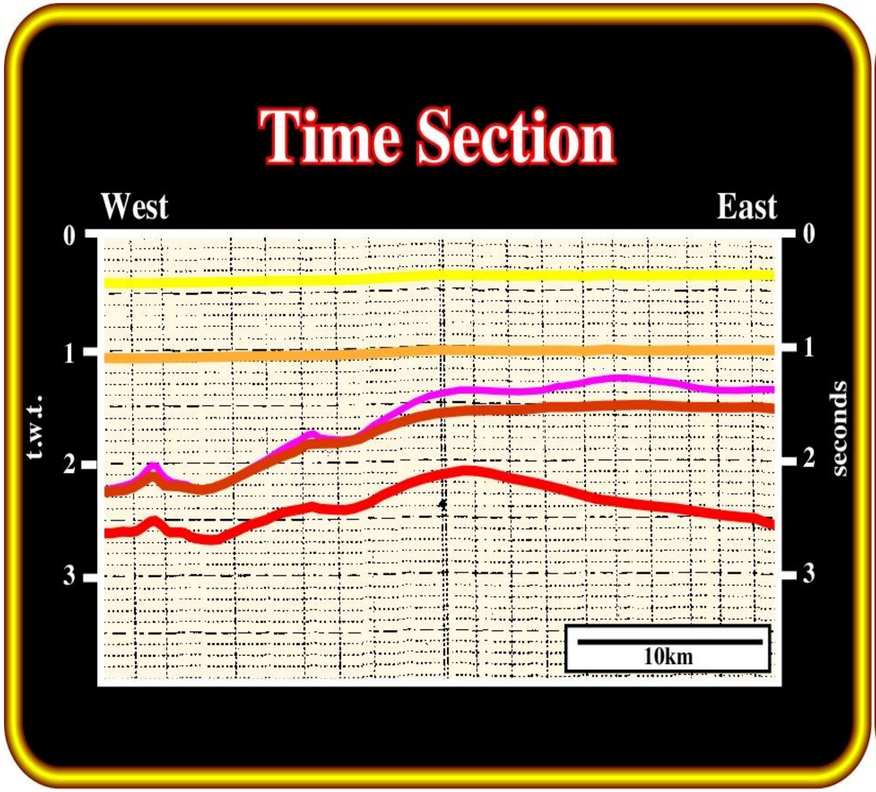


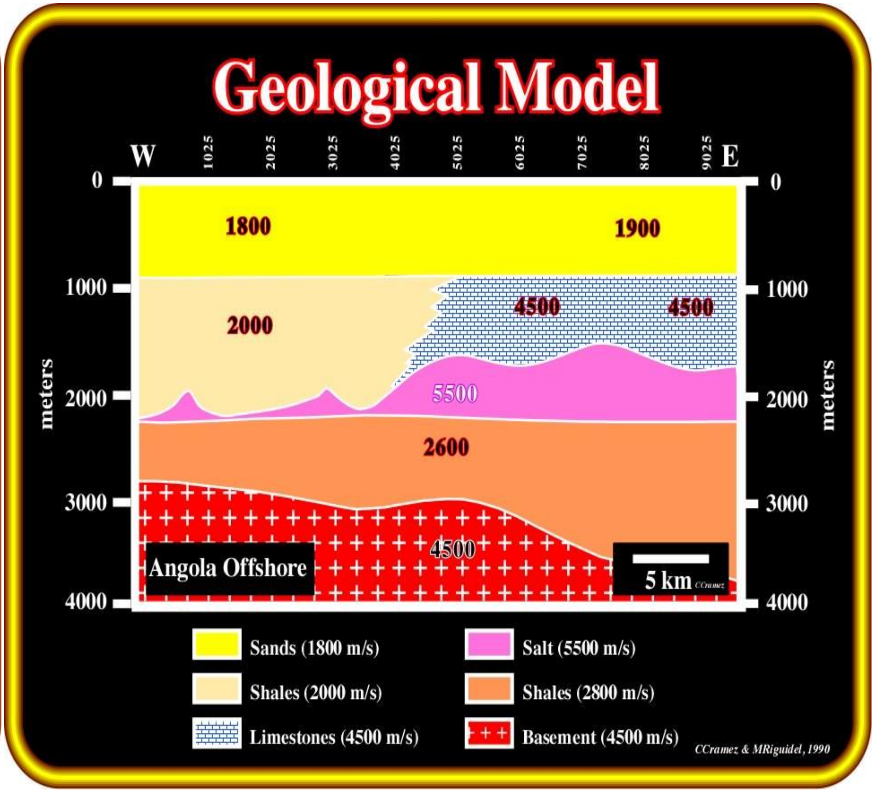


Multiple layers

Velocity analysis

- **Determination of seismic velocity is a key to seismic method.**
- Velocity is needed to convert the time-sections into depth-sections i.e. geological cross-sections.
- **Unfortunately reflection surveys are not very sensitive to velocity.**
- Often complimentary refraction surveys are conducted to provide better estimates of velocity.


Time Section
West
East
t.w.t.
seconds
0
1
2
3
10km


Geological Model
W
E
1025
2025
3025
4025
5025
6025
7025
8025
9025
meters
0
1000
2000
3000
4000
1800
1900
2000
4500
4500
5500
2600
4500
Angola Offshore
5 km
Sands (1800 m/s)
Shales (2000 m/s)
Limestones (4500 m/s)
Salt (5500 m/s)
Shales (2800 m/s)
Basement (4500 m/s)
CCramez & MRiguidel, 1990

Types of Velocity

- Because of the inhomogeneous nature of the crustal part of the Earth (which is typically made up of layered rock media), several types of velocity functions are needed to express velocity variation as function of travelled distance.
- Five velocity-types are in common use in seismic exploration.

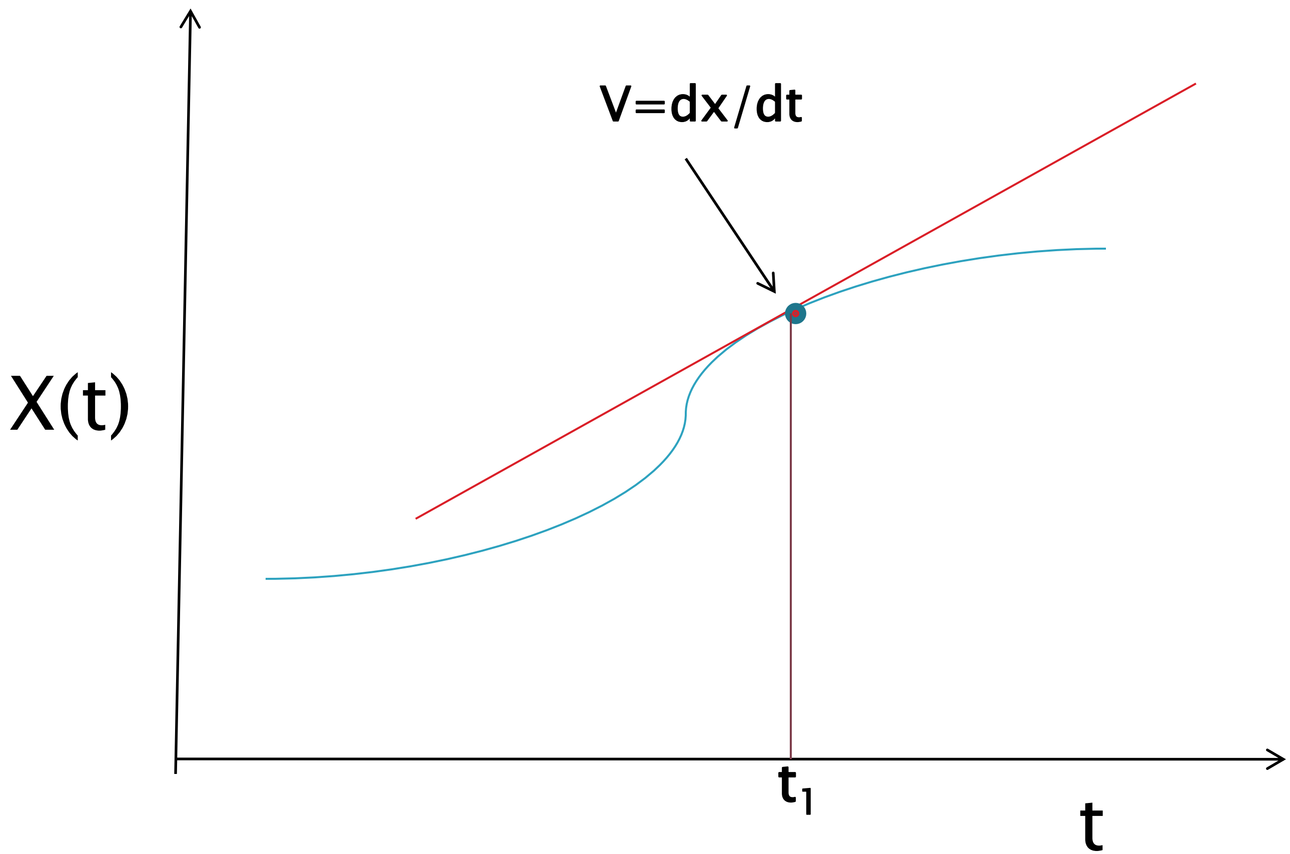
Types of Velocity

I. Instantaneous Velocity (V)
II. Interval Velocity (IV)
III. Average Velocity (AV)
IV. Root Mean Square (RMS) Velocity (RV)
V. Stacking Velocity (SV)

Instantaneous Velocity (V)

- The instantaneous velocity is defined as velocity of wave motion at a given point in a medium traversed by an advancing seismic wave.
- The instantaneous velocity, (v) of a wave moving along a distance (x) is defined as:

$$V = dx/dt$$



Definition of instantaneous velocity

Interval Velocity (IV)

- The interval velocity (IV)is defined to be the average velocity over an interval of the travel-path.
- It is usually measured or computed for individual geological layers.
- Thus, the interval velocity, of a geological formation of thicknesses (Δh) and interval transit time (Δt), is given by

$$IV = \Delta h / \Delta t$$

Average Velocity (AV)

- As the name implies, the average velocity (AV) is obtained from dividing the total distance travelled by the wave by the time spent in covering that distance.
- In seismic exploration work, the average velocity is computed for a set of layers, usually starting from the datum plane down to the required reflector level.

Average Velocity (AV)

- For a vertical travel-path, the average velocity of a geological section made up of (n) layers will be given by dividing the total thickness h_n by t_n :

$$AV_n = h_n/t_n$$

- The average velocity (AV) can be calculated for a multi-layer section, given the interval velocities (IV) for each of the section layers. This can be done by the following formula:

$$AV_n = (\Sigma IV_n \cdot \Delta t_n)/\Sigma \Delta t_n$$

Datum plane

Layer -1 Δh_1 , Δt_1	$AV_1 = \Delta h_1 / \Delta t_1$
Layer -2 Δh_2 , Δt_2	$AV_2 = (\Delta h_1 + \Delta h_2)/(\Delta t_1 + \Delta t_2)$
Layer -3 Δh_3 , Δt_3	$AV_2 = (\Delta h_1 + \Delta h_2 + \Delta h_3)/(\Delta t_1 + \Delta t_2 + \Delta t_3)$

Depth, h

Average velocity (AV) for three layer case

Root Mean Square (RMS) Velocity (RV)

- Root mean square (RMS) velocity (RV)is defined as the square root of the average of the squares of the weighted interval-velocities, where the weighting factors are the layer thicknesses or the interval transit times.
- In seismic exploration, the RMS velocity, like other types of velocities, is usually computed for vertical ray paths of waves traversing a medium made up of horizontal layers of different interval velocities.

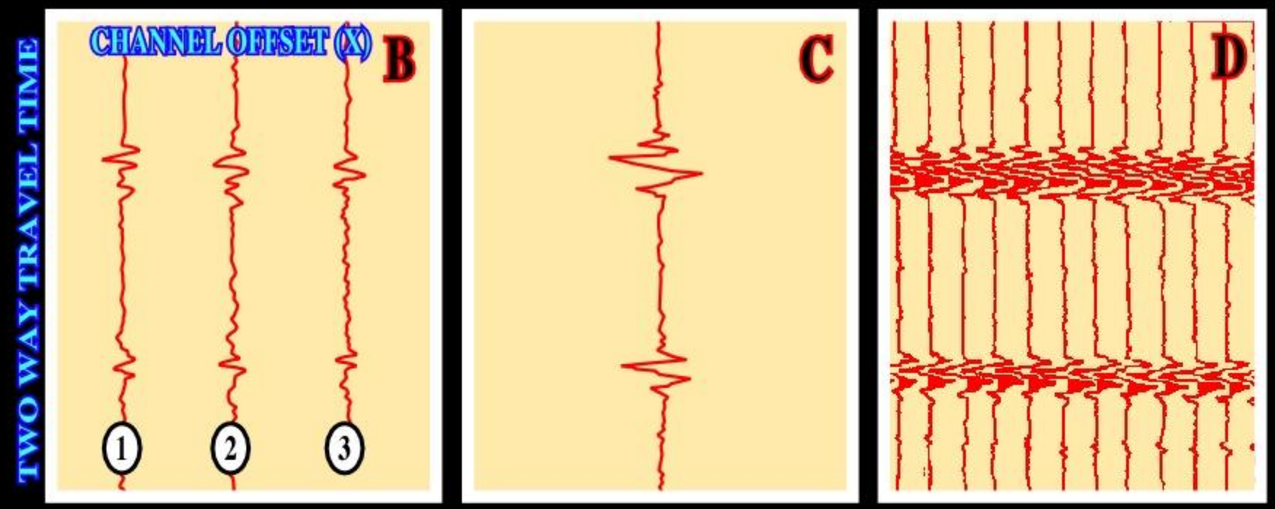
Layer -1 Δh_1 , Δt_1	$RV_1 = IV_1$
Layer -2 Δh_2 , Δt_2	$RV_2 = [(IV^2_1 \Delta t_1 + IV^2_2 \Delta t_2)]/(\Delta t_1 + \Delta t_2)^{1/2}$
Layer -3 Δh_3 , Δt_3	$RV_3 = [(IV^2_1 \Delta t_1 + IV^2_2 \Delta t_2 + IV^2_3 \Delta t_3)]/(\Delta t_1 + \Delta t_2 + \Delta t_3)^2$

Root mean square (RMS) velocity

Stacking velocity (SV)

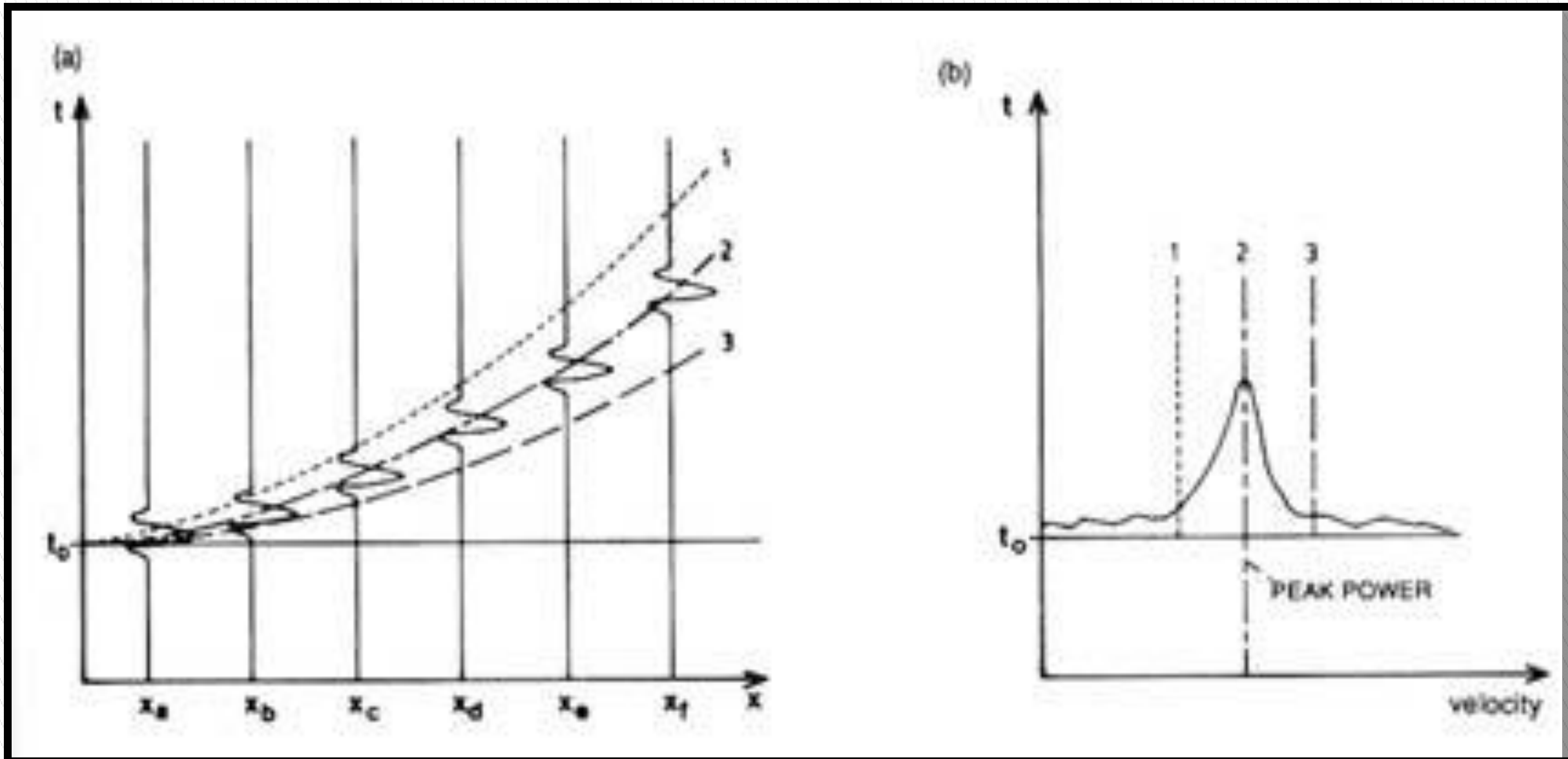
- **Stacking**
- A processed seismic record that contains traces that have been added together from different records to reduce noise and improve overall data quality.
- The number of traces that have been added together during stacking is called the fold.

Stacking of Seismic Data



Stacking velocity (SV)

- In order to stack the waveforms we need to know the velocity. We find the velocity by trial and error:
- For each velocity we calculate the hyperbolae and stack the waveforms.
- The correct velocity will stack the reflections on top of one another
- So, we choose the velocity which produces the most power in the stack



V2 causes the waveforms to stack on top of one another

Textbook

Alsadi, H.N. (2017) Seismic Hydrocarbon Exploration: 2D and 3D Techniques. Springer International Publishing, Switzerland, 331p.