SEISMIC RESOLUTION

ability to distinguish separated features within a seismic profile

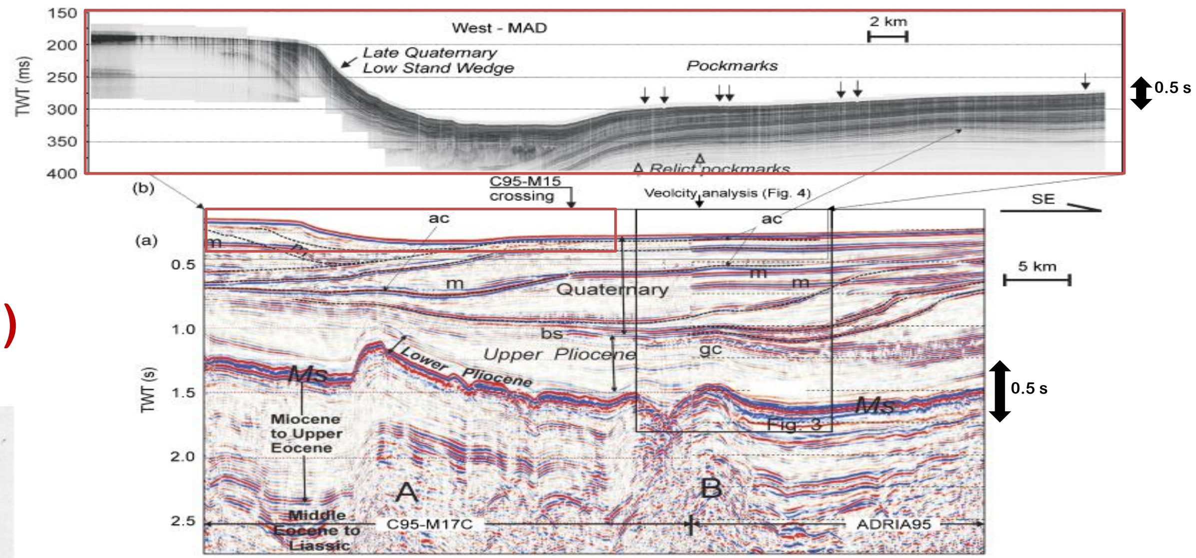
It is generally expressed as a minimum distance between the "resolved" objects that means: the two objects are individually defined

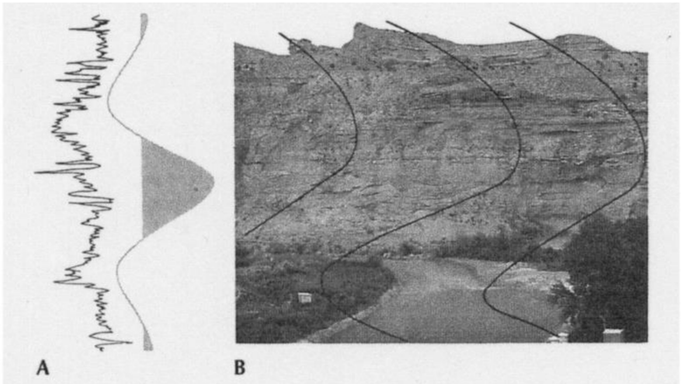
It differs in:

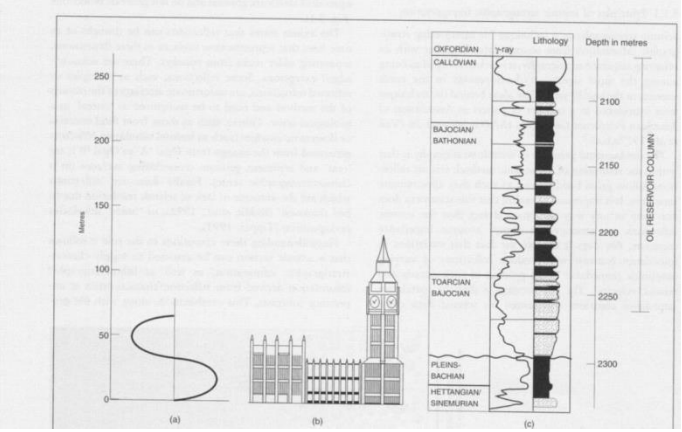
- **vertical resolution**
- **lateral resolution**

High resolution seismic (Chirp profile) →

Middle resolution ↓ **or Low → (crustal profile)**







Vertical Resolution:

minimum vertical separation between two separated reflecting features.

It represents the limit that allows to recognize separately the two features in a seismic profile.

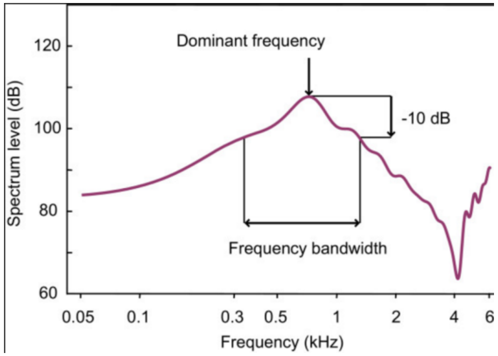
The fundamental parameter is the dominant frequency

Dominant frequency

The sismic energy that we enter into the subsurface is characterized by a frequency package. The seismic energy crossing the subsurface tends to distribute in a frequency range centered on the **dominant frequency**.

Within a seismic profile, the dominant frequency depends on :

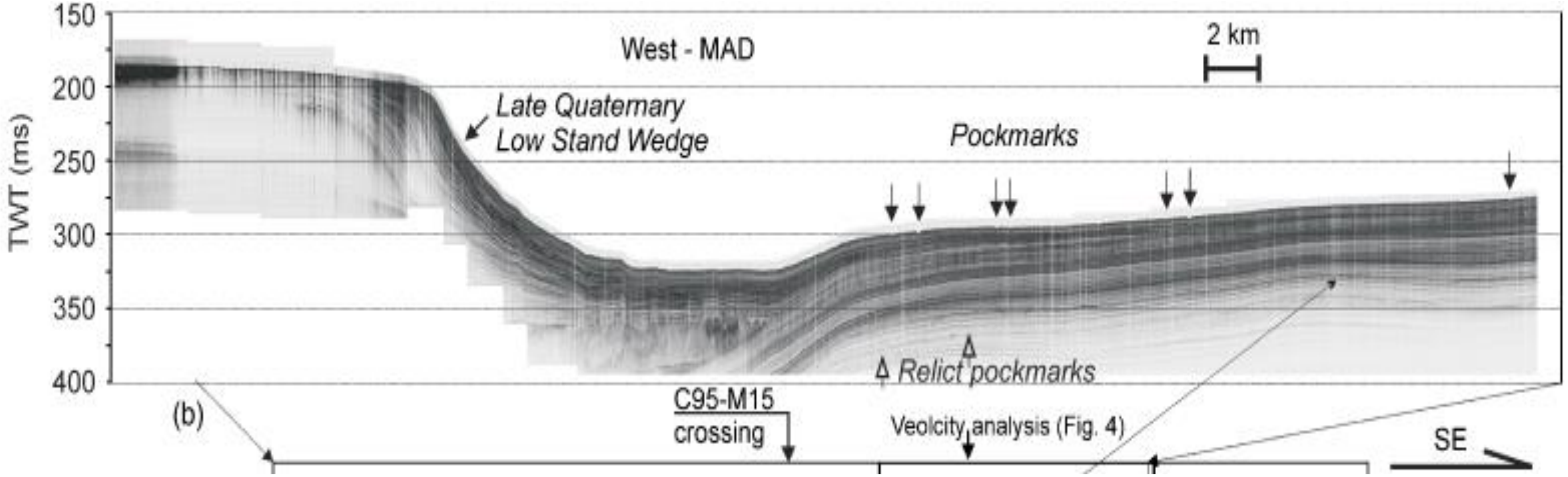
- frequencies that have been introduced in the subsurface;
- physic properties of the subsurface;
- record parameters;
- *processing* of the seismic data;
- plotting.



We cannot change the physical properties of the subsurface, but we can change some parameteres as:
- acquisition (→ only when we project a new acquisition),
- *processing* (→ only when we have availability of the field data)
- plotting (→ if we use a paper copy of the data).

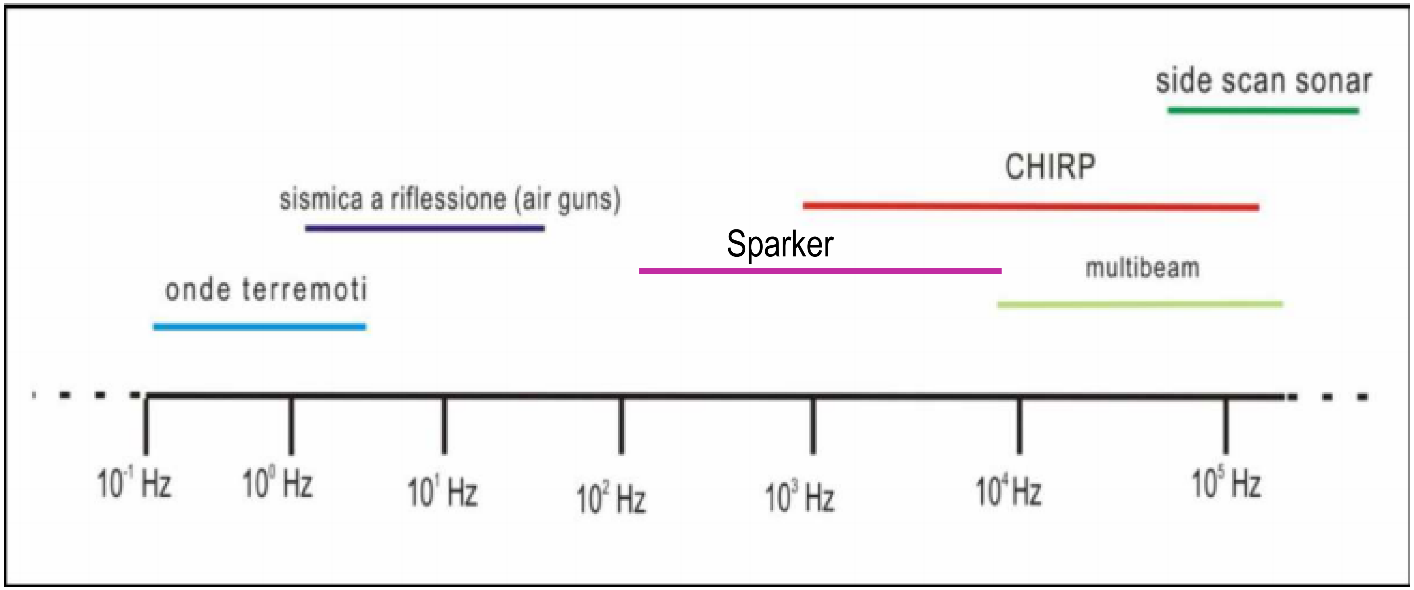
Therefore, we should use the frequencies which are appropriate to our specific aims:
- *high frequencies range* for shallow exploration of small objects;
- *middle frequencies range* for hydrocarbon, deformation structures and fault systems exploration;
- *low frequencies range* for regional crustal exploration.

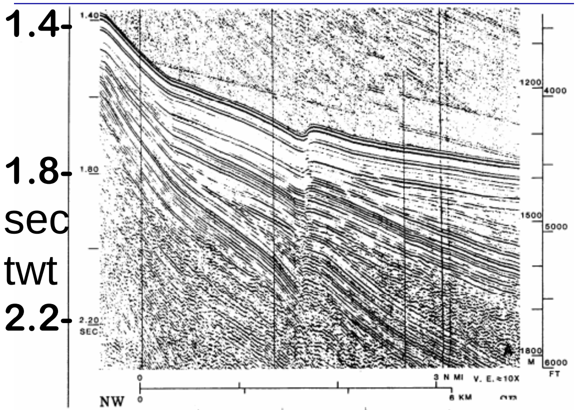
High resolution seismic



The high seismic resolution is characterized by relatively lower acquisition cost than the classic multichannel seismic reflection. Furthermore, it doesn't requires complex processing phases.
The high resolution seismic is generally acquired in the offshore. It is related to:
1) low power seismic sources;
2) generally single channel acquisition;
3) direct imaging of the acquired profiles.

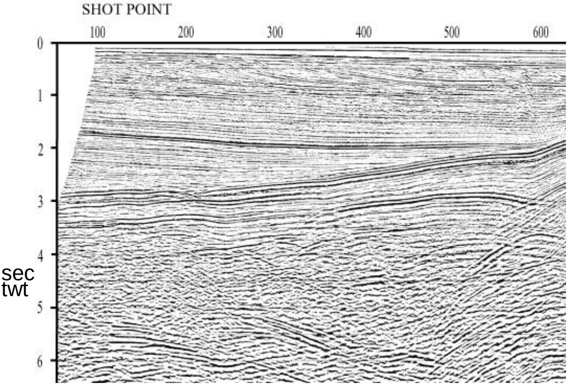
The high resolution seismic profiles provide detailed information on geometries of the sedimentary series below the seabed. Anyway, they have a penetration limited to tens, maximum a few hundred meters. It is therefore mostly used to study superficial sedimentary sequences, often associated with morpho-bathymetric acquisitions (Multibeam).

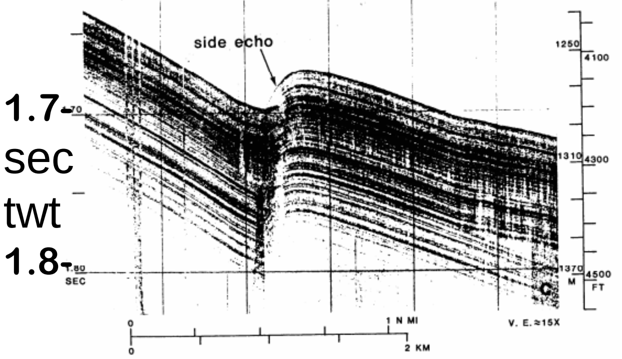




← **Sparker**

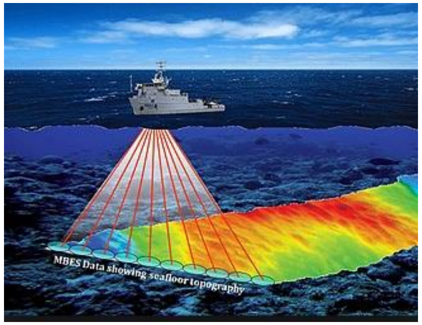
Multichannel seismic (air gun) →





← **Chirp (Sub Bottom profile)**

Multibeam →



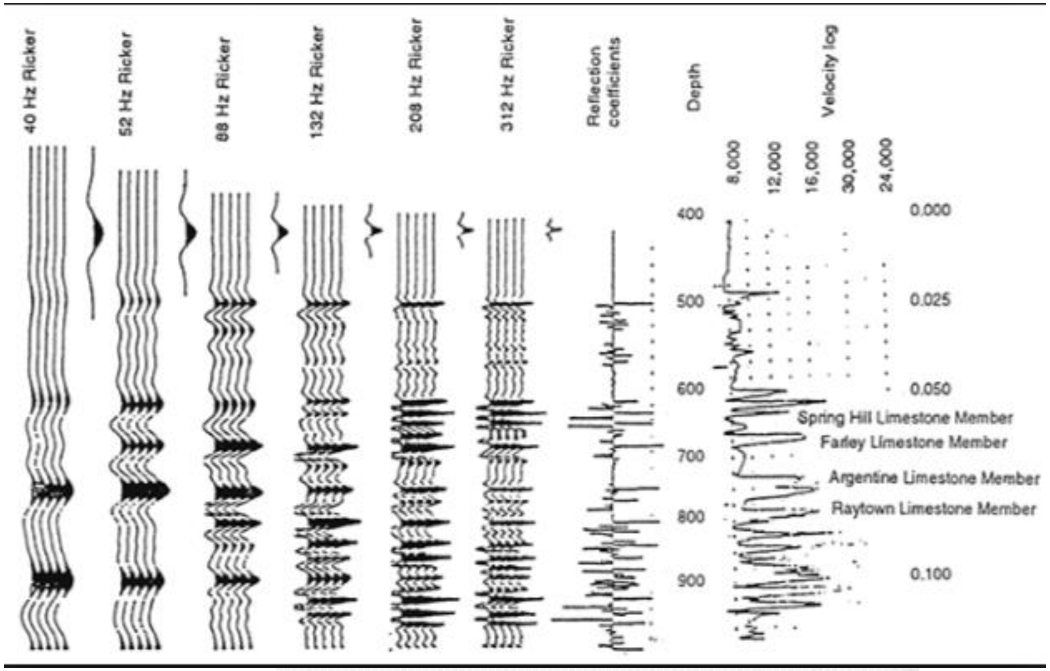
$\lambda = v\,t = v / f$

λ = *dominant wavelength*
(40 – 250 m)

v = *P waves velocity*
(2000-5000 m/sec)

f = *dominant frequency*
(50 -20 Hz)

… but the high frequencies are gradually absorbed in depth, where the Vp are higher…



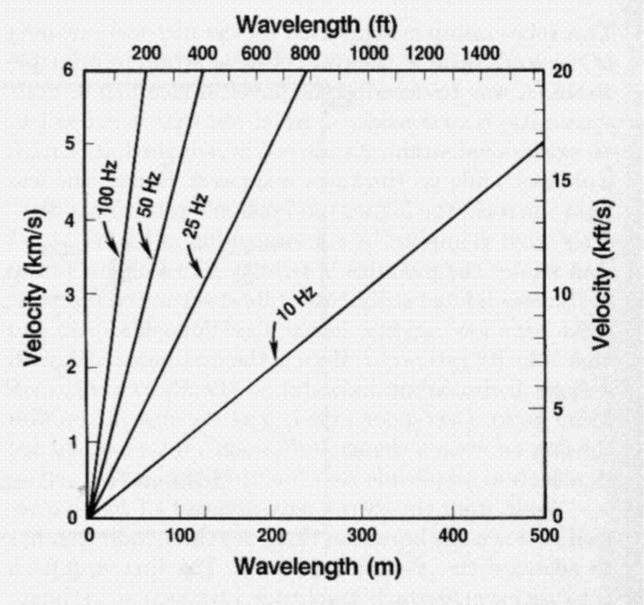
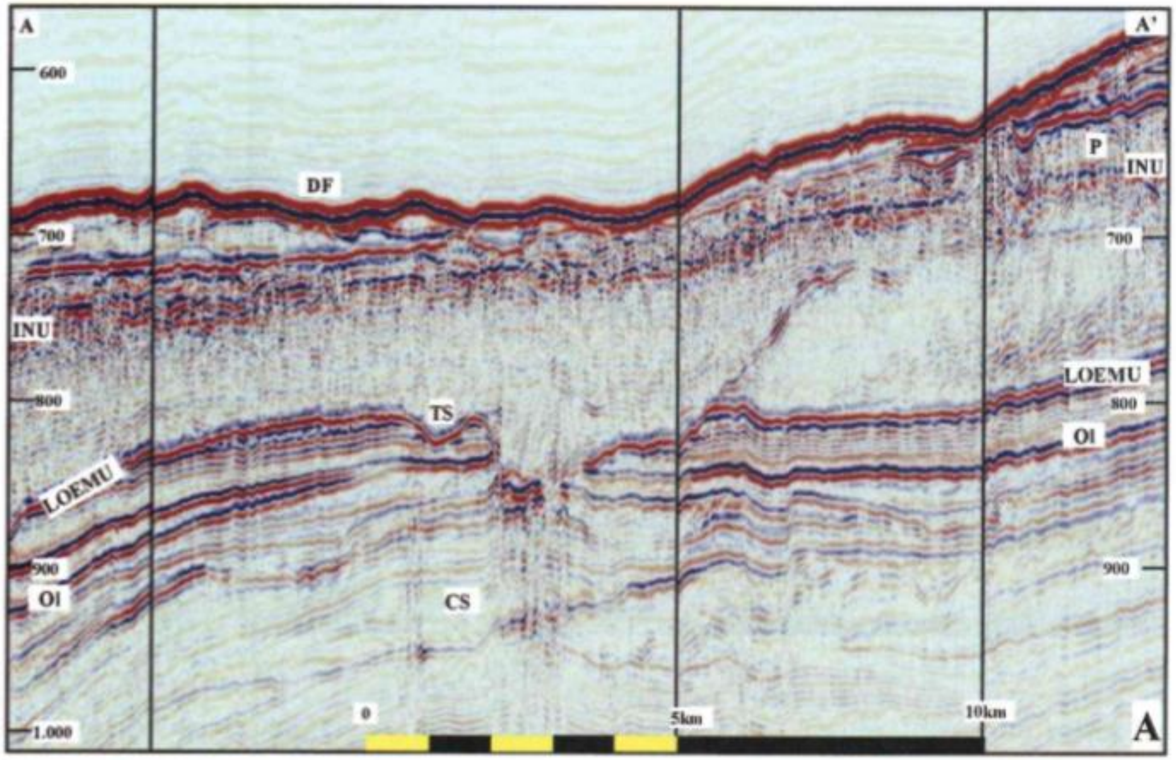
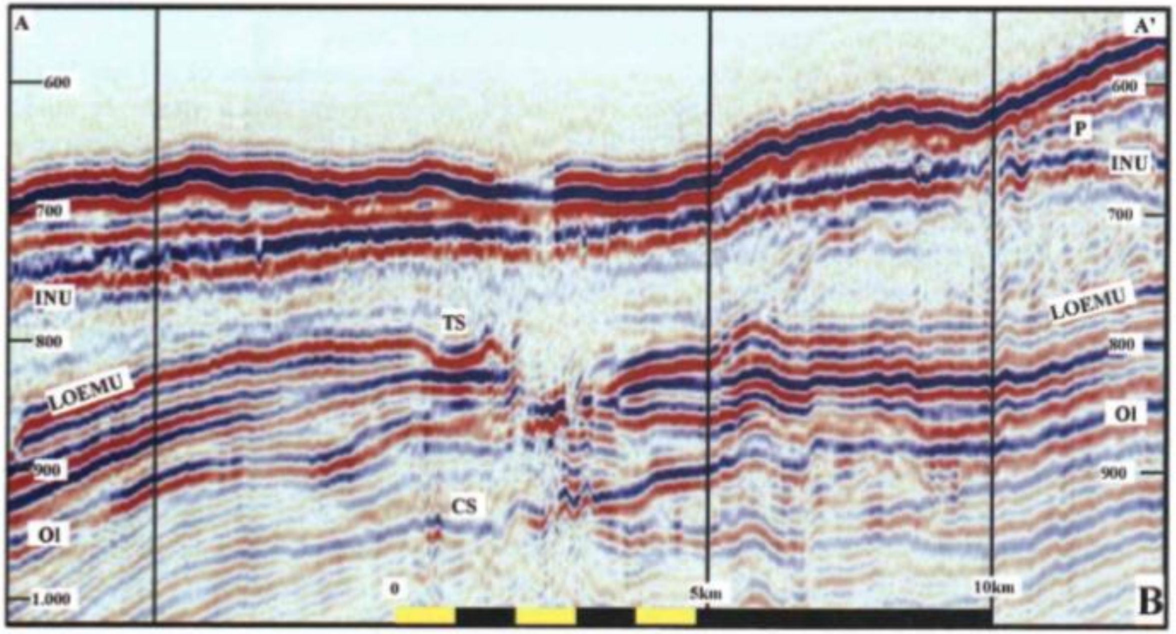


FIG. 11.1-1. The relationship between velocity, dominant frequency, and wavelength.



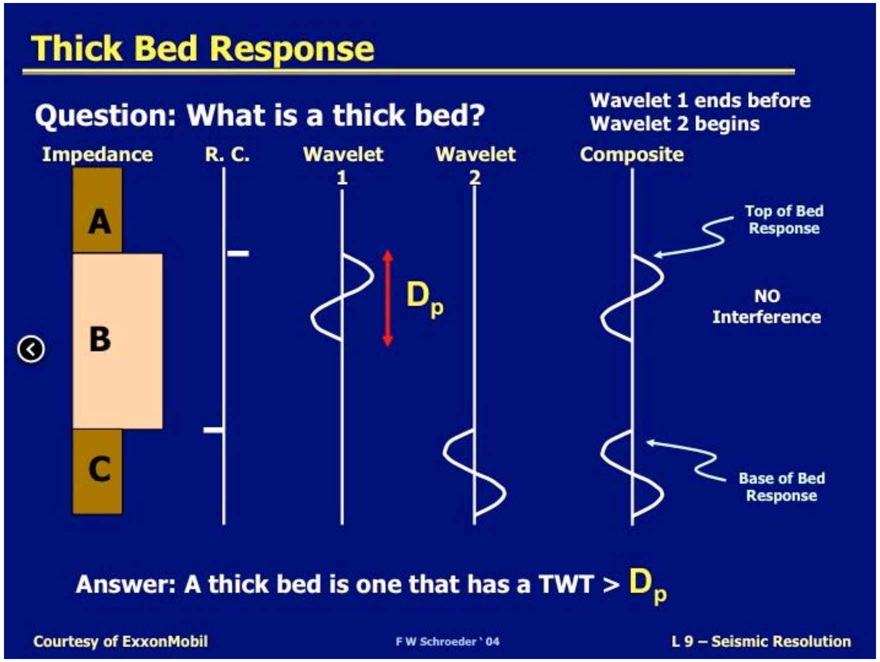


Shetland slope

Examples of seismic acquisition with dfferent seismic resolution.

The 2D profile at the top has higher resolution than the profile to the bottom, which has been extracted by a 3D dataset.

Good resolution for the B unit



Thick Bed Response

Question: What is a thick bed?

Wavelet 1 ends before Wavelet 2 begins

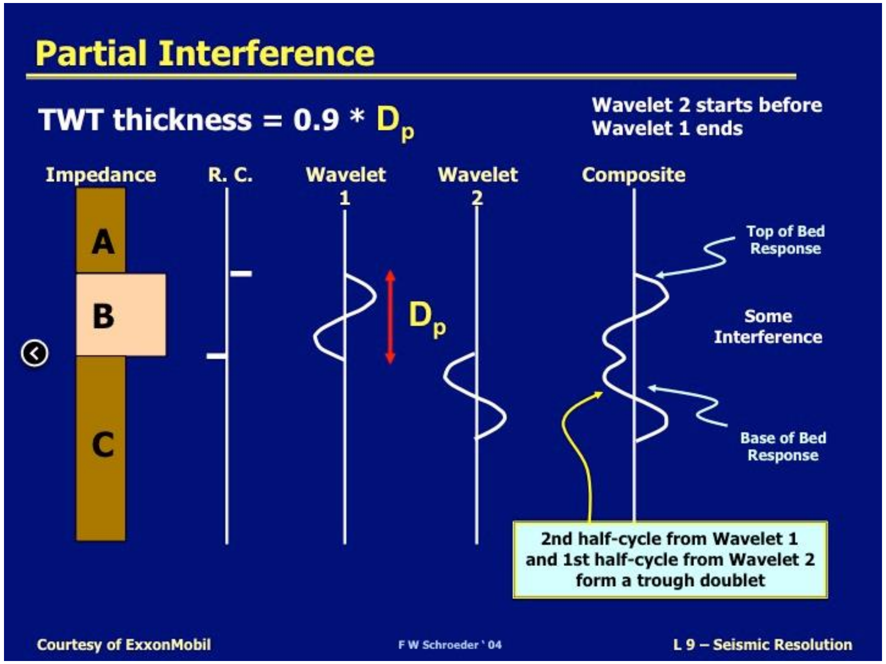
Answer: A thick bed is one that has a TWT > D_p

Courtesy of ExxonMobil

F W Schroeder ' 04

L 9 – Seismic Resolution

No resolution for the B unit



Partial Interference

TWT thickness = 0.9 * D_p

Wavelet 2 starts before Wavelet 1 ends

2nd half-cycle from Wavelet 1 and 1st half-cycle from Wavelet 2 form a trough doublet

Courtesy of ExxonMobil

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L 9 – Seismic Resolution

"How thin is a thin bed?"

With this paper Widess (1973) focused on the vertical seismic resolution in the seismic data :

-a constant thickness(vel. 6 km/s)

Inside a medium with vel. 3 km/s

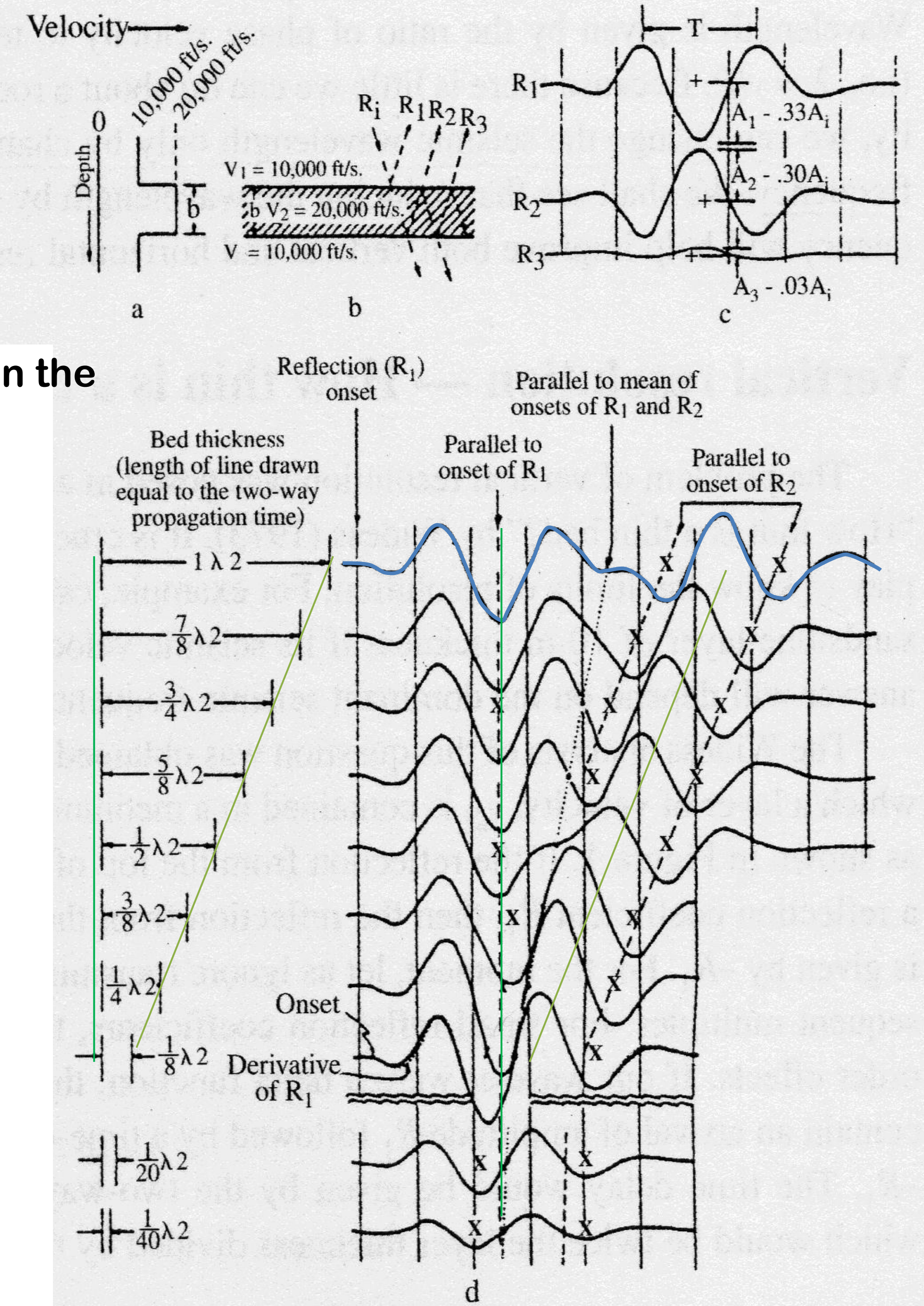
⇒Reflection coefficients : 0,33 and -0,33

-Disregarding absorption and multiples

=> 2 amplitude peacks, equal and opposite.

The sum of the reflected arrivals, repited for several thickness/wavelenght rate , suggested to the Author to conclude that the two reflectors could be distinguised separatley until a maximun thickness/ distance equal to **1/8 of the wavelength**.

Figure 1. Resolution of a thin bed, as illustrated by Widess (1973).



VERTICAL RESOLUTION

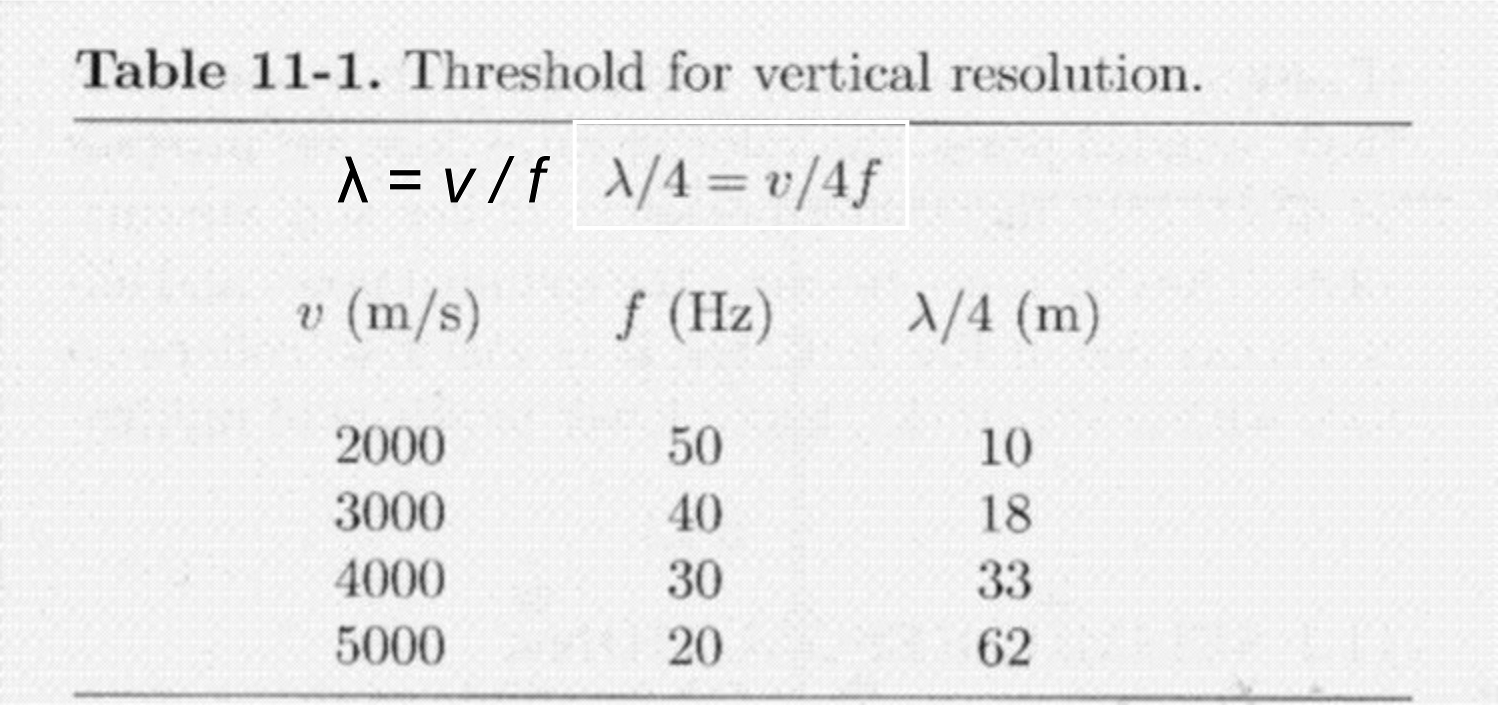


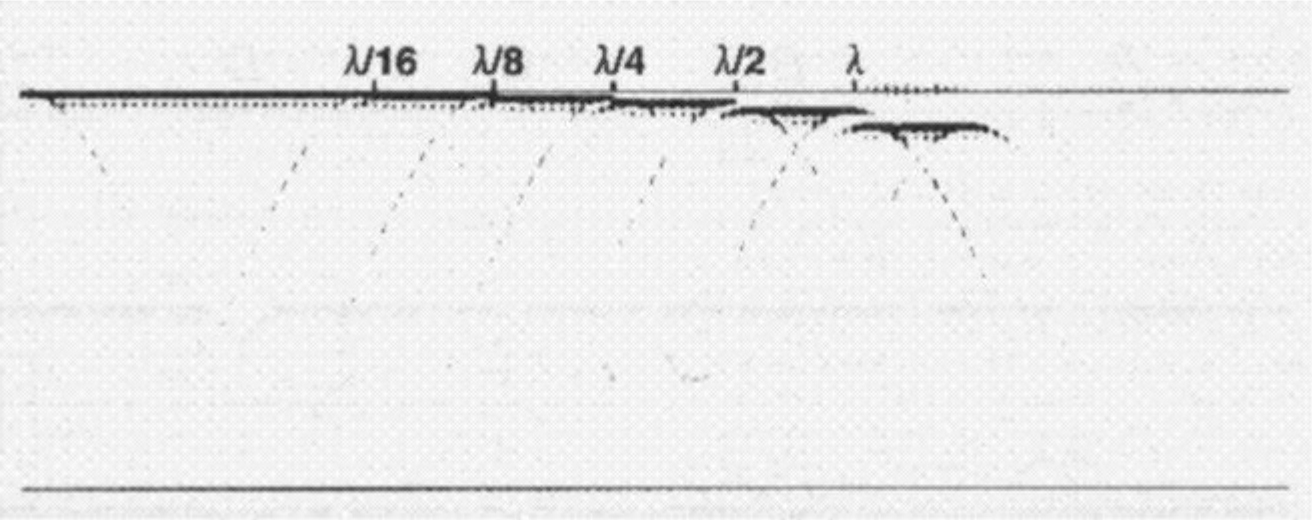
Table 11-1. Threshold for vertical resolution.

$\lambda = v / f$ $\quad \lambda/4 = v/4f$

v (m/s)	f (Hz)	$\lambda/4$ (m)
2000	50	10
3000	40	18
4000	30	33
5000	20	62

The rate of 1/8 established by Widess (1973) is valid for ideal conditions, but in the main part of the seismic profiles we can assume that the vertical resolution is ¼ of the dominant wavelength. In the table the vertical resolution for lithologies that are characterized by different velocities and dominant frequencies are evidenced. The dominant frequency, as we have mentioned, depends also on the acquisition parameters.

VERTICAL RESOLUTION

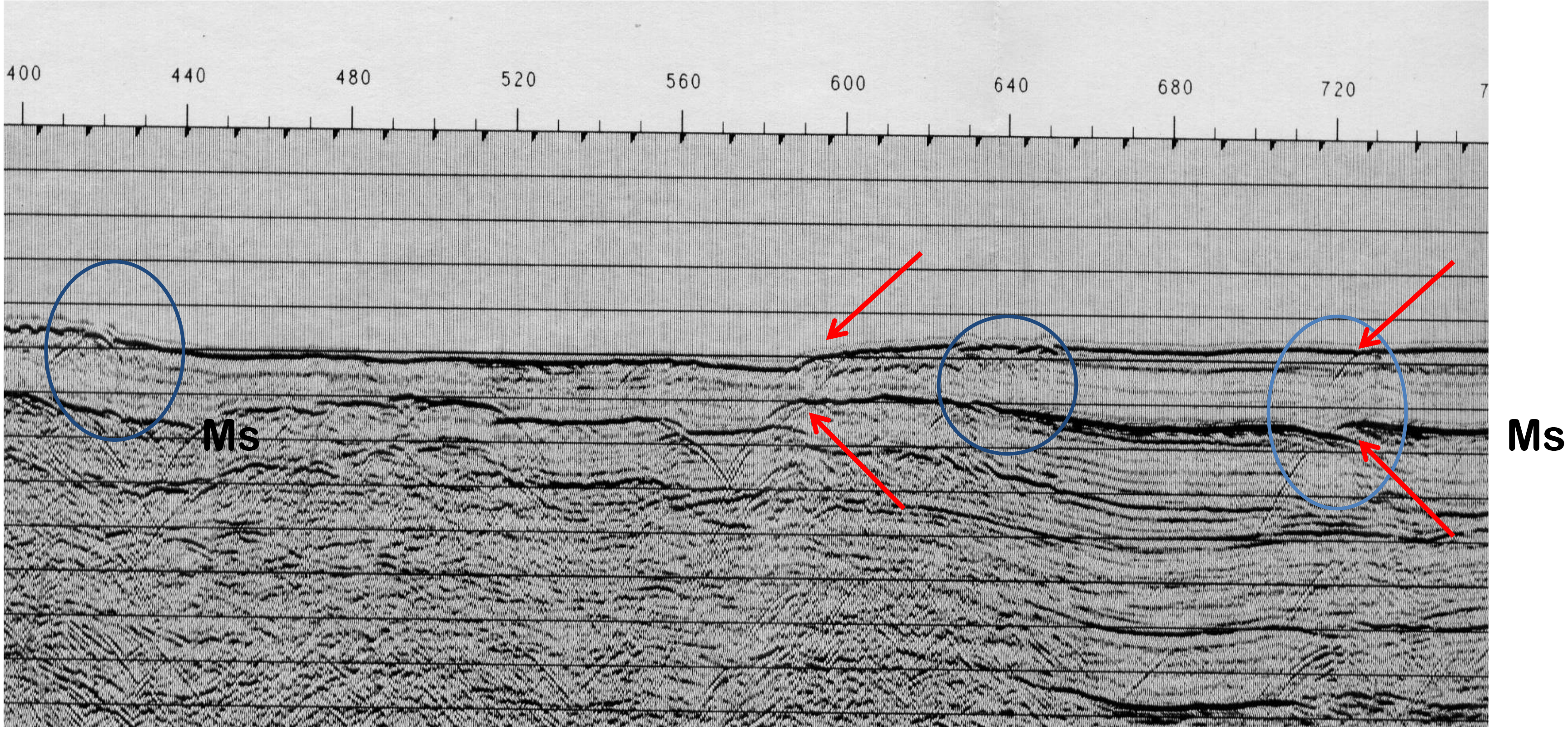


The vertical throw is “recognizable” when it reaches or is more than ¼ of the wavelength (vertical resolution).

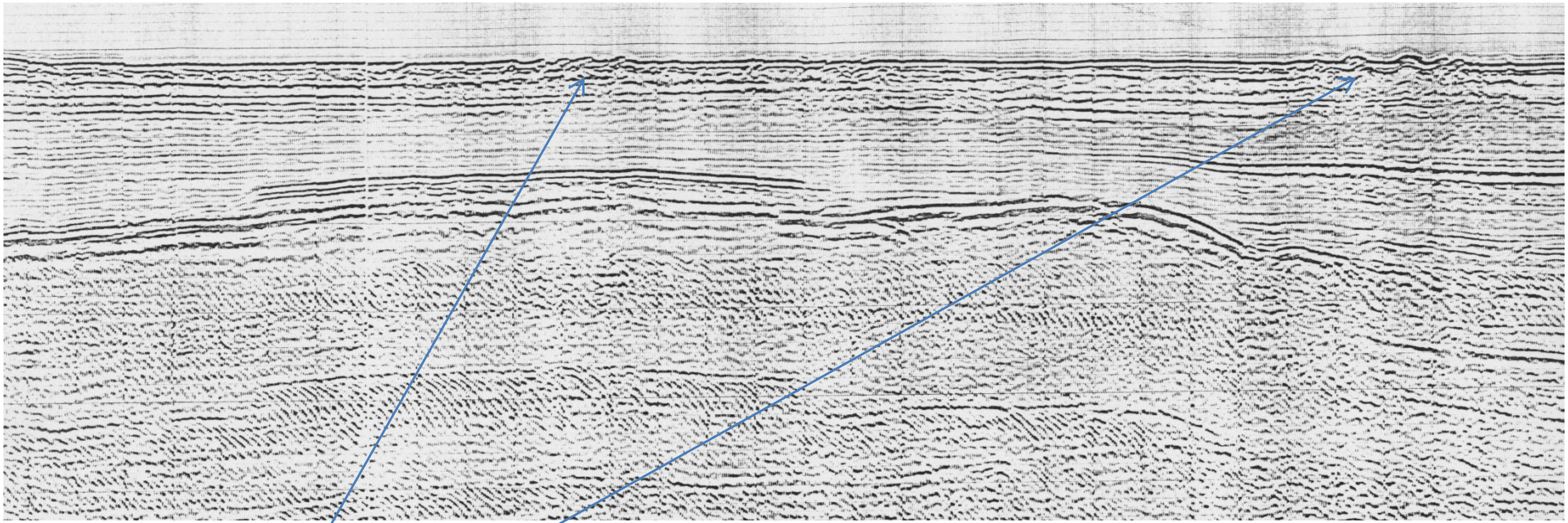
However, if the throw is smaller, we can interprete a hinomogeneity presence (*detection*) on the base of some diffraction hyperboles.

=> When we interpret, we can sometimes use the *stack profiles,* they are, in this way, complementary to the migrated profiles

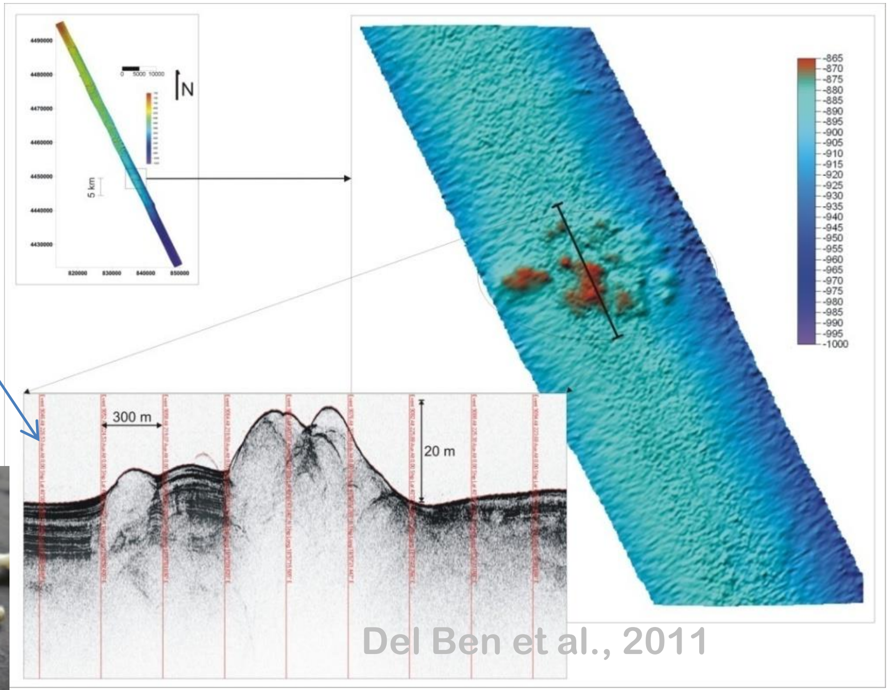
Example of seismic profiles in the Ionian Sea



The vertical throws of the faults are especially evident where they cut the Messinian horizon Ms, characterized by high amplitude. The seabed is also disturbed in some points (this is often a witness of active faults!). In the fault on the right the vertical throw of the Ms reflector can be seen, while at the seabed the fault can be interpreted thanks to diffraction. The reflectors below Ms, although less defined, are parallel to Ms: this means that the fault was activated after the deposition of Ms, that is in the Plio-Quaternary (it cuts Ms) and still active (it cuts the sea bottom).

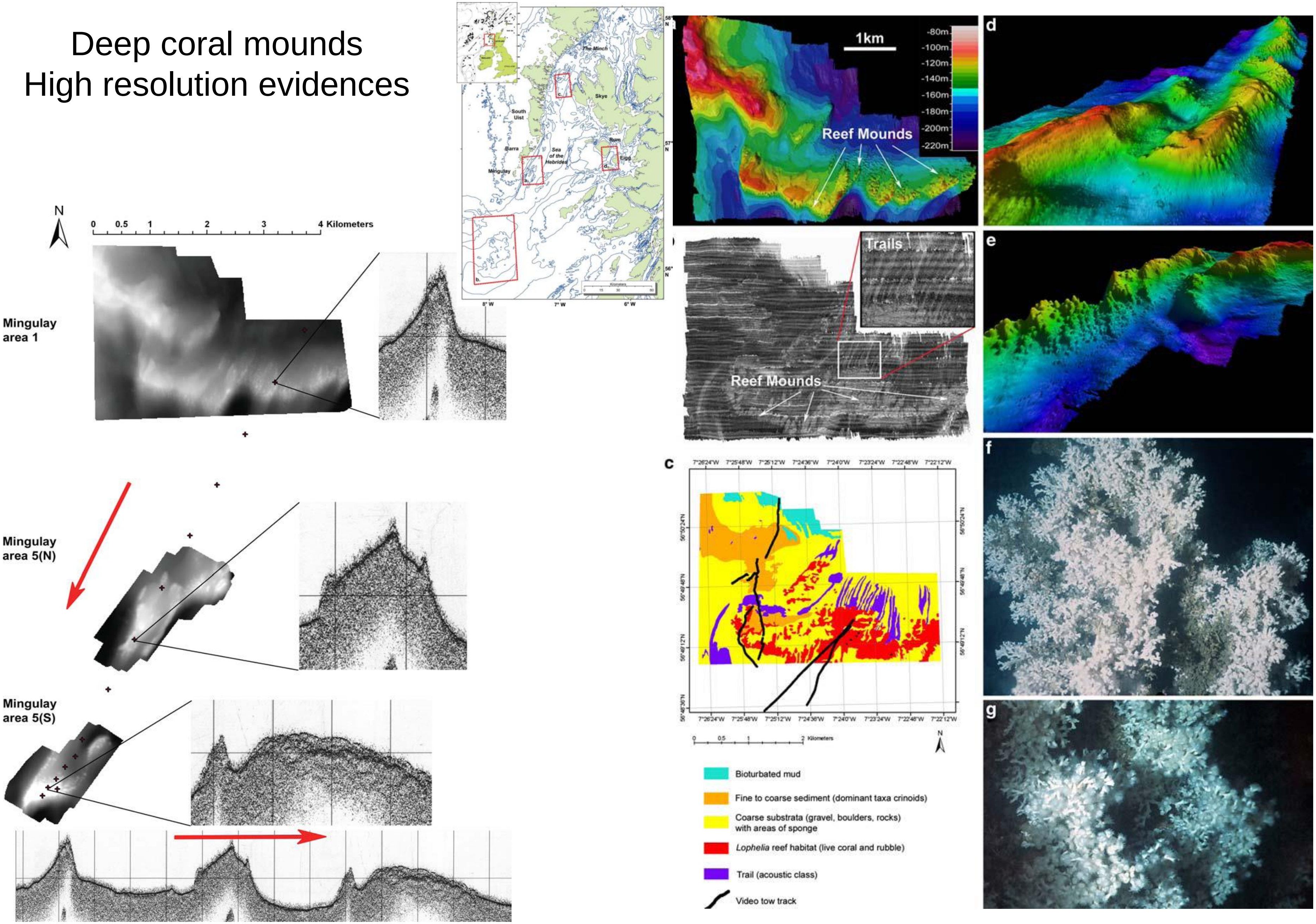


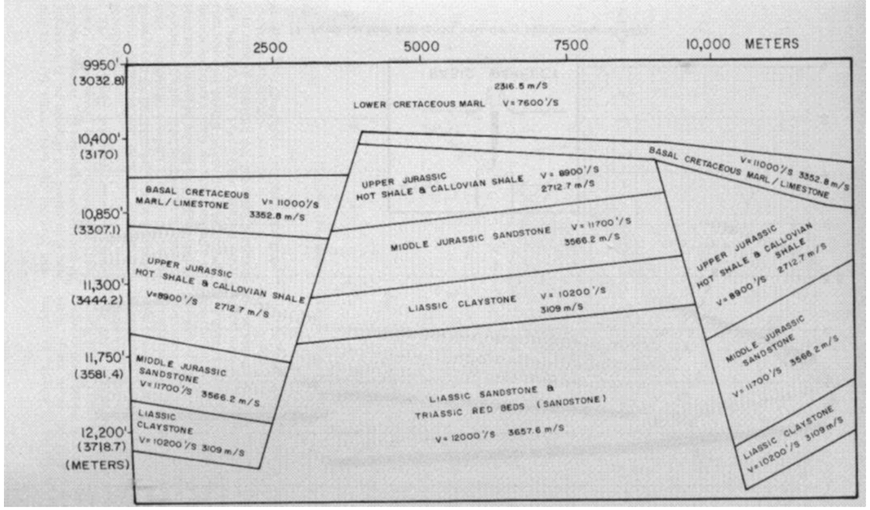
Bottom: example of reflection seismic profile in the Otranto Channel: on the sea bottom some small structures were explored during the year 2008 with a *Chirp sub-bottom profiler* (higher frequencies => higher resolution). The structures were related to coral mounds, successively dradged by the OGS-Explora in the year 2011.



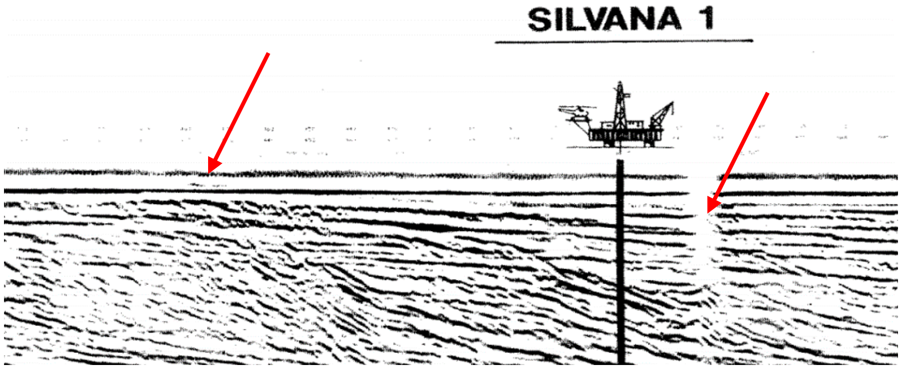
Del Ben et al., 2011

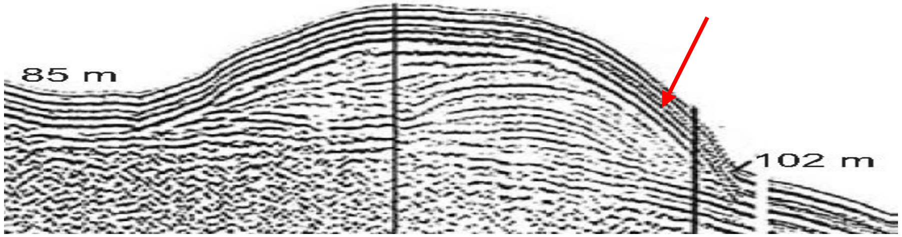
Deep coral mounds
High resolution evidences





Effect of the **wave shape** and of **deconvolution** on the vertical resolution
→ *ringing*





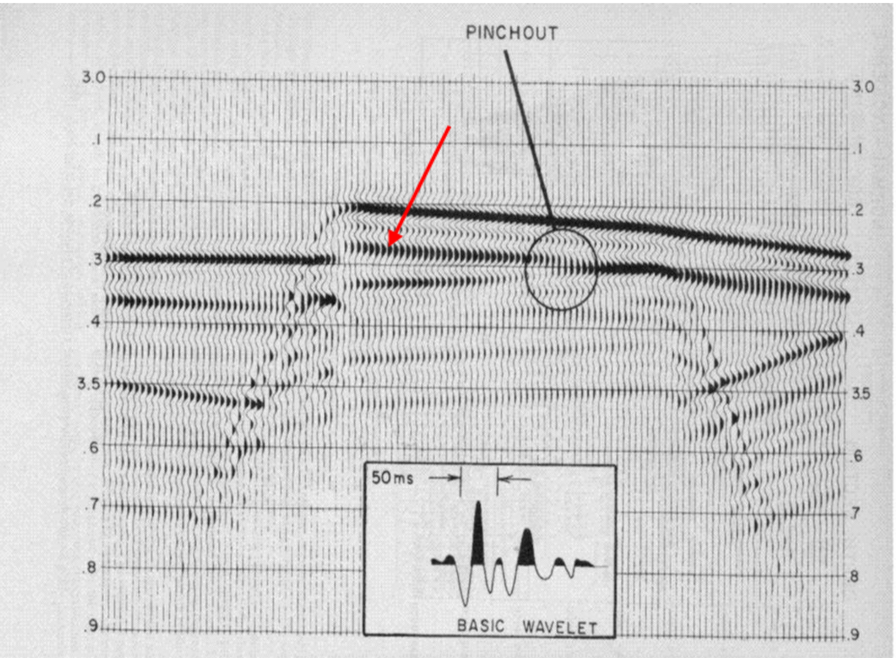


FIG. 17—North Sea horst-fault model, wave-theory solution (primaries only).

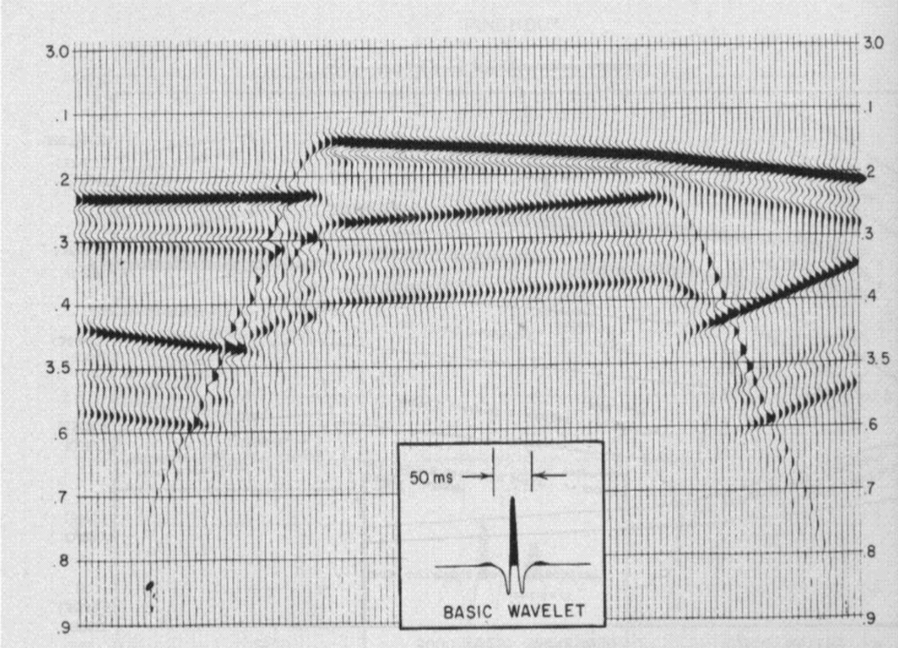


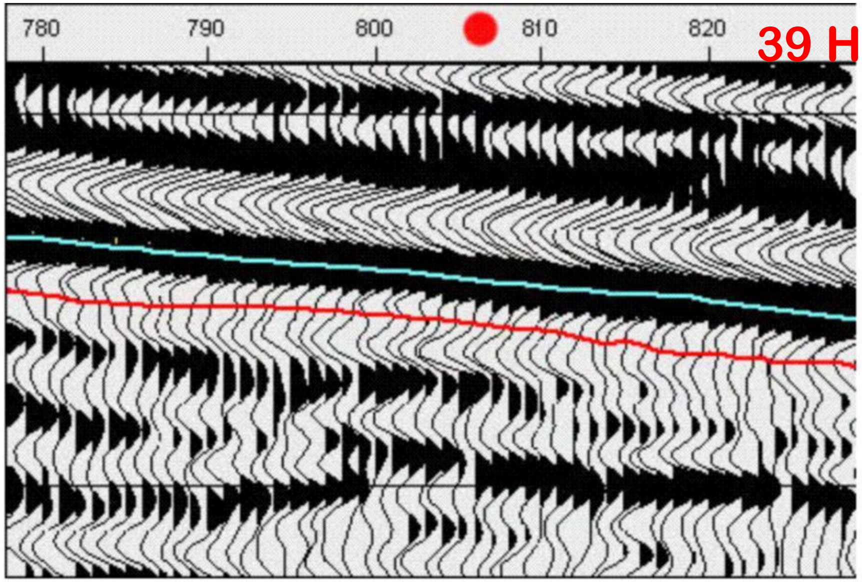
FIG. 19—North Sea horst-fault model, wave-theory solution (primaries only).

Effect of the **dominant frequency** and of the deconvolution on the vertical resolution.
In interpreting seismic data, it is also importnat to know the limits of the technique.

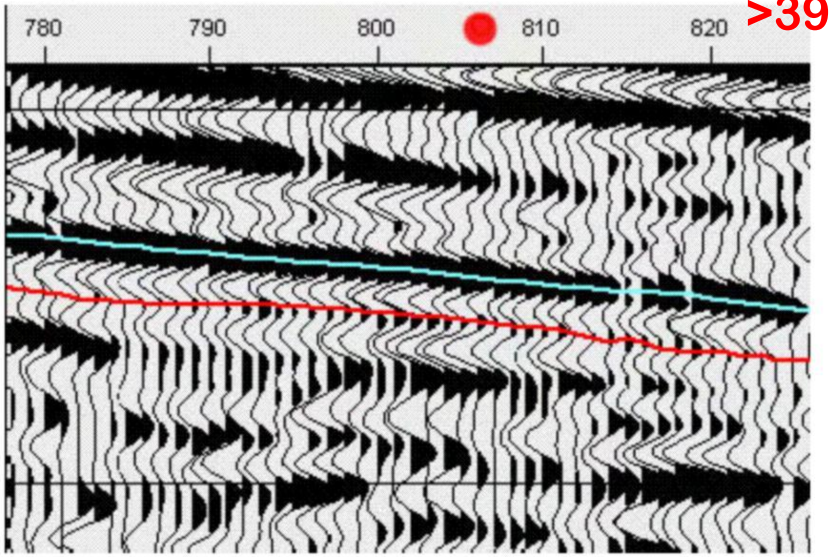
Vertical resolution depends, as well as on the dominant frequency, on:

- the presence of **noise** in the datum
- **reflection coefficient**.

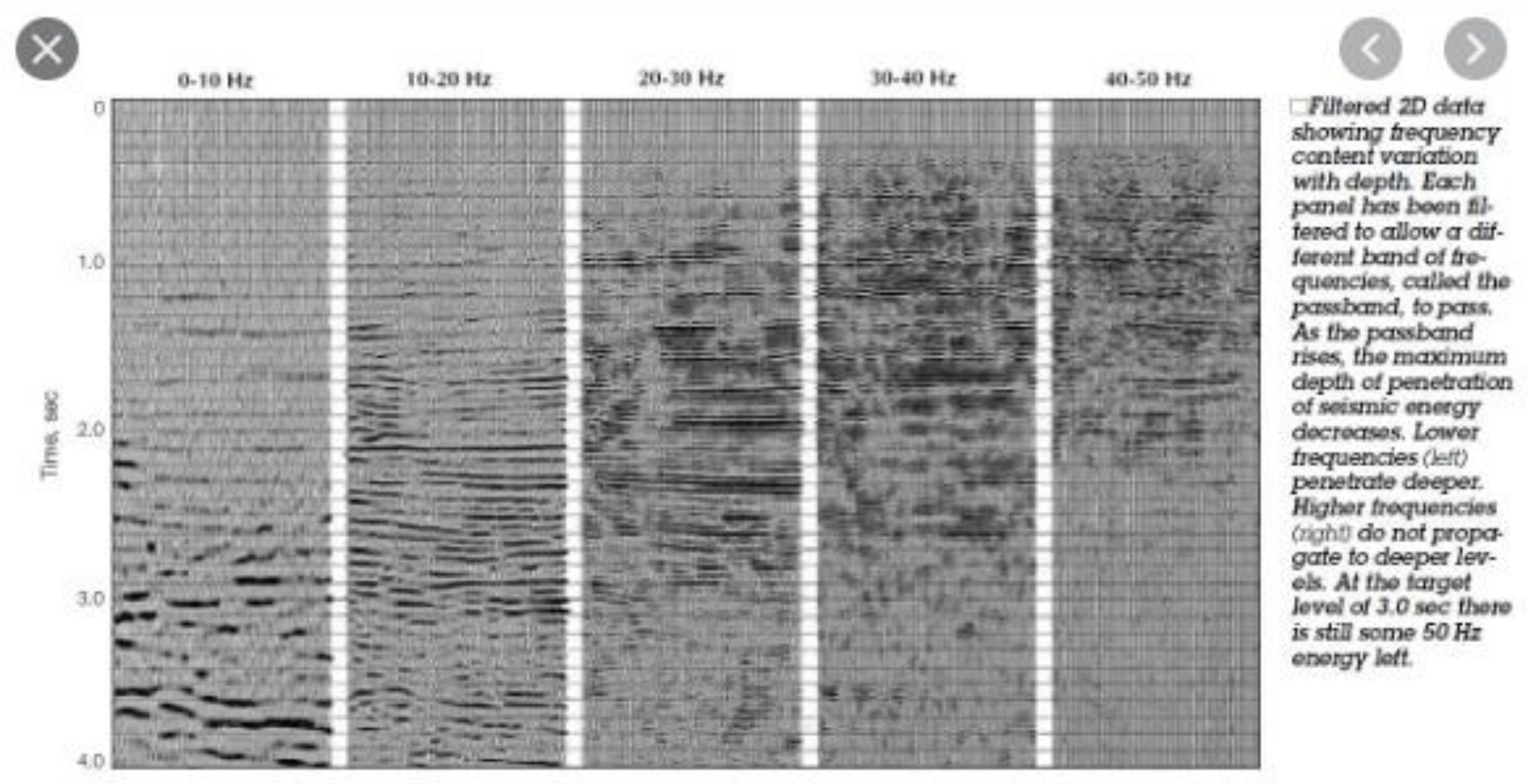
Sometimes “***detection*** *not* ***resolution*** *is the problem*”
(Yilmaz, 2001)



Original section from a 3D survey.



Reconstruction with wavelets of dominant frequencies larger than 39 Hz.

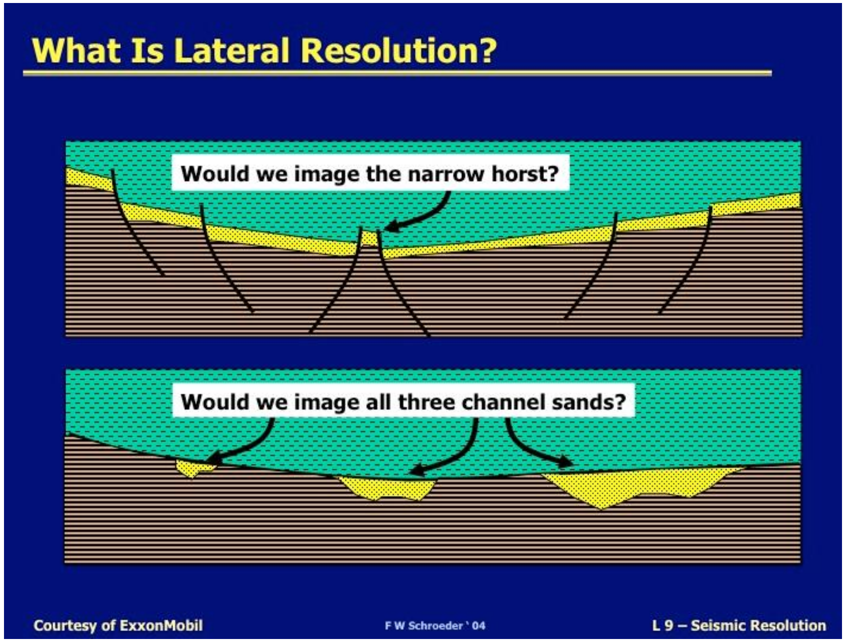


Filtered 2D data showing frequency content variation with depth. Each panel has been filtered to allow a different band of frequencies, called the passband, to pass. As the passband rises, the maximum depth of penetration of seismic energy decreases. Lower frequencies (left) penetrate deeper. Higher frequencies (right) do not propagate to deeper levels. At the target level of 3.0 sec there is still some 50 Hz energy left.

Lateral Resolution:

minimum lateral distance between two reflecting points which can be distinguished individually along a seismic profile.

The lateral reslution is related to the ray of the “Fresnel Zone”



What Is Lateral Resolution?

Would we image the narrow horst?

Would we image all three channel sands?

Courtesy of ExxonMobil

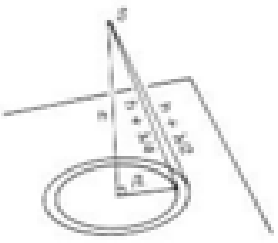
F W Schroeder ‘ 04

L 9 – Seismic Resolution

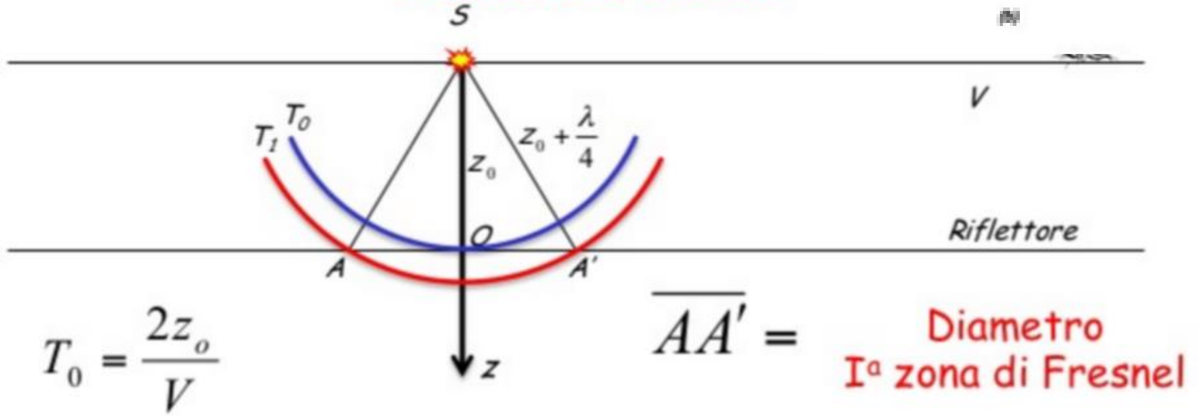
LATERAL RESOLUTION

As already mentioned, we can consider a reflecting surface as a set of diffracting points. If S is source and record point, a constructive interference will be within the circonference with ray R (=OA).

When distance is smaller than R, the constructive interference doesn’t allow to distinguish two different objectives.



Risoluzione laterale



$\overline{AA'} =$ Diametro Iª zona di Fresnel

R depends from:

- wavelength or frequence
- velocity above the reflector
- depth, represented by z_0 o da t_0

$$T_0 = \frac{2z_o}{V}$$

$$T_1 = \frac{2(z_o + \lambda/4)}{V}$$

Risoluzione laterale $R \cong \sqrt{z_0 \frac{\lambda}{2}} = \frac{V}{2}\sqrt{\frac{T_0}{f}}$

Fresnel Zone for reflectors placed at different depths

$$R \cong \sqrt{z_0 \frac{\lambda}{2}} = \frac{V}{2}\sqrt{\frac{T_0}{f}}$$

=> Note as lateral resolution depends on wavelength / dominant frequency

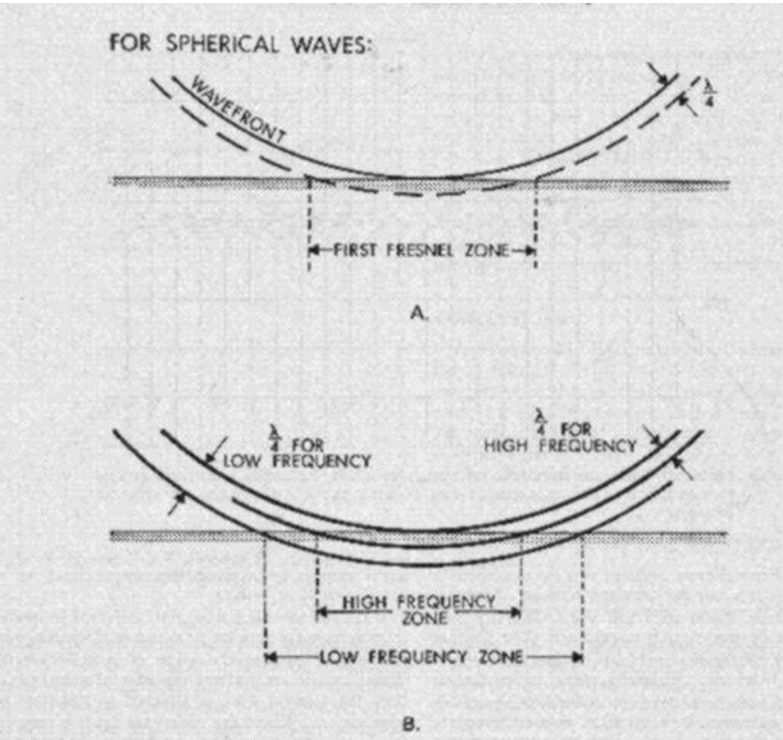


FIG. 7—First Fresnel zone for (A) spherical waves reflected from plane interface. (B) shows how size of the Fresnel zone depends on frequency.

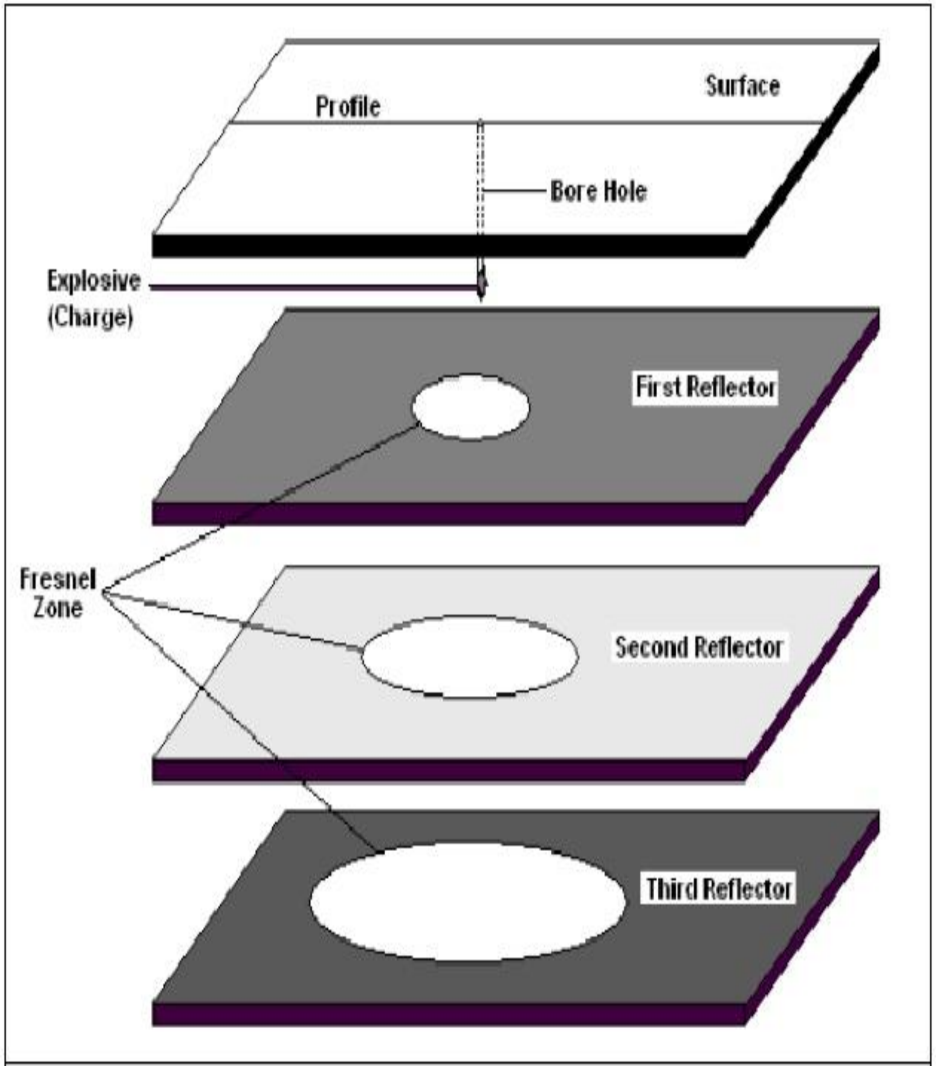
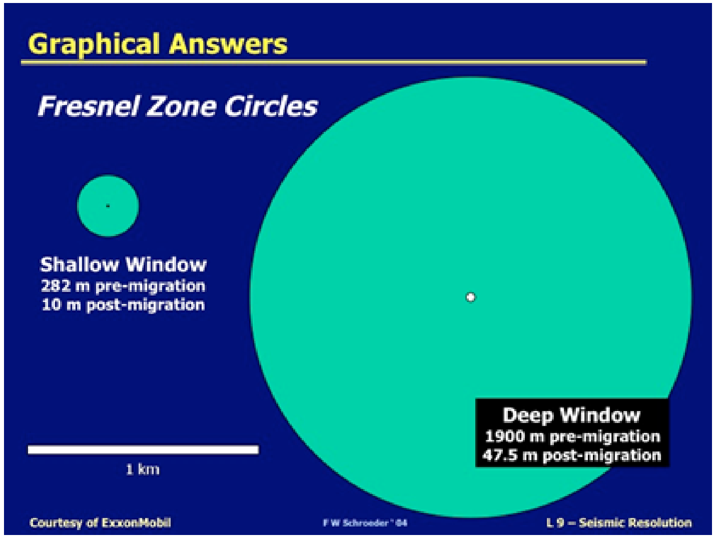


Fig 7(b) Fresnel Zone

The lateral resolution is sometimes approximately equal to the dominant wavelength

The migration, particularly the depth migration, improves the lateral migration.



Graphical Answers

Fresnel Zone Circles

Shallow Window
282 m pre-migration
10 m post-migration

Deep Window
1900 m pre-migration
47.5 m post-migration

Courtesy of ExxonMobil
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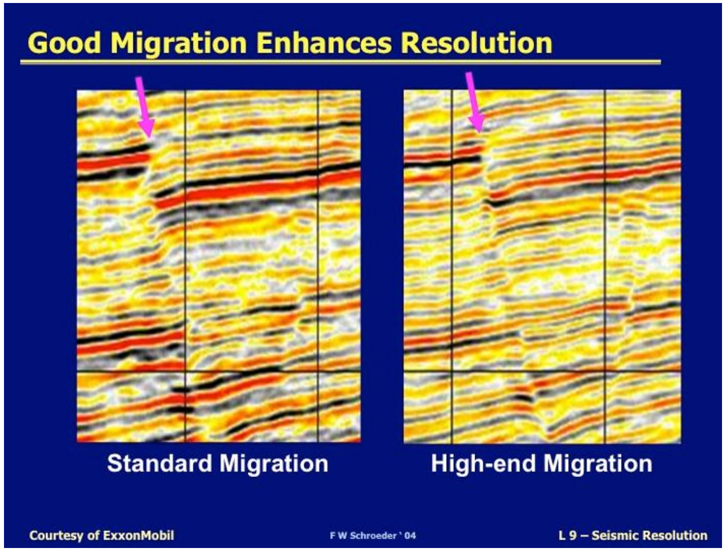
L 9 – Seismic Resolution



Good Migration Enhances Resolution

Courtesy of ExxonMobil
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L 9 – Seismic Resolution

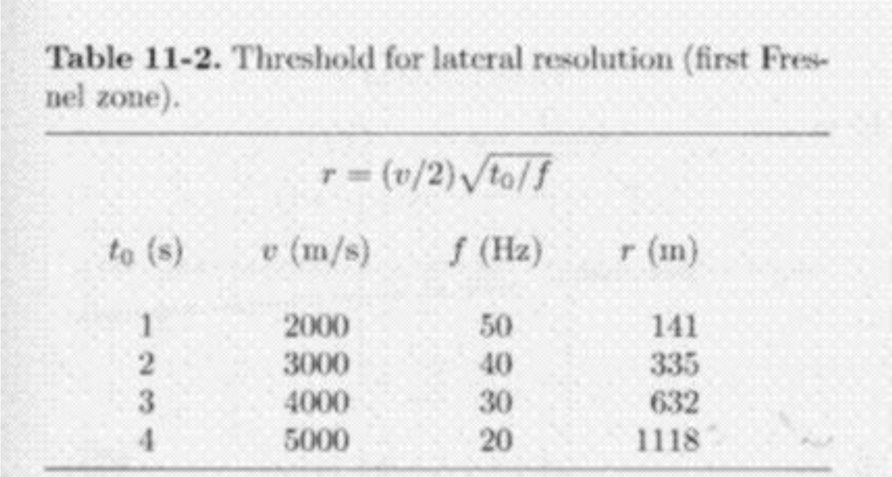


Table 11-2. Threshold for lateral resolution (first Fresnel zone).

$$r = (v/2)\sqrt{t_0/f}$$

t_0 (s)	v (m/s)	f (Hz)	r (m)
1	2000	50	141
2	3000	40	335
3	4000	30	632
4	5000	20	1118

$$R \cong \sqrt{z_0 \frac{\lambda}{2}} = \frac{V}{2}\sqrt{\frac{T_0}{f}} \qquad (11-2b)$$

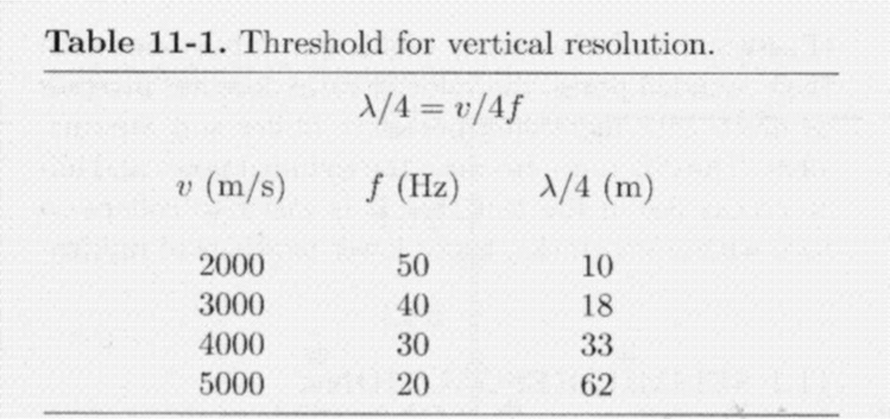


Table 11-1. Threshold for vertical resolution.

$$\lambda/4 = v/4f$$

v (m/s)	f (Hz)	$\lambda/4$ (m)
2000	50	10
3000	40	18
4000	30	33
5000	20	62

Example in the Nigeria offshore

acquisition at different depths

$r = (z_0 \lambda / 2)^{1/2}$

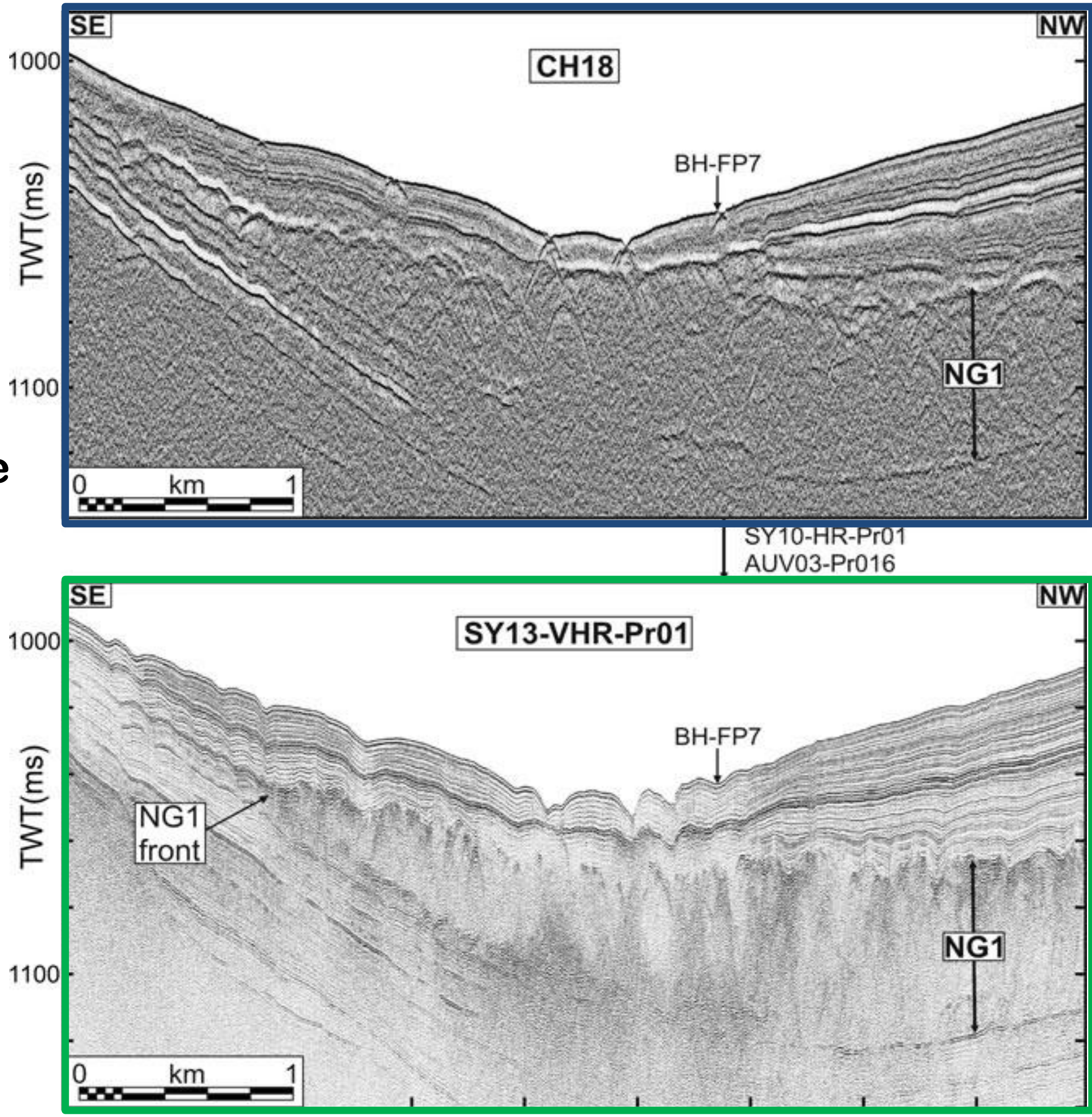
Comparison between

-the sub-bottom profile (mean frequency 3000 Hz => resolution=14 m) and

-the seismic profile (mean frequency 1200 Hz ⇒res. = 6 m), with an altitude of 80 m above the seabed.

The lateral resolution improvement in the seismic line is obvious, despite its lower frequency, thus making possible the interpretation of the front of NG1 (a Mass Transport Complex) whereas the SBP image is blurred with hyperbolae.

This comparison illustrates the increase in lateral resolution obtained by the deep-towed acquisition.



Effect of the reflectors depth

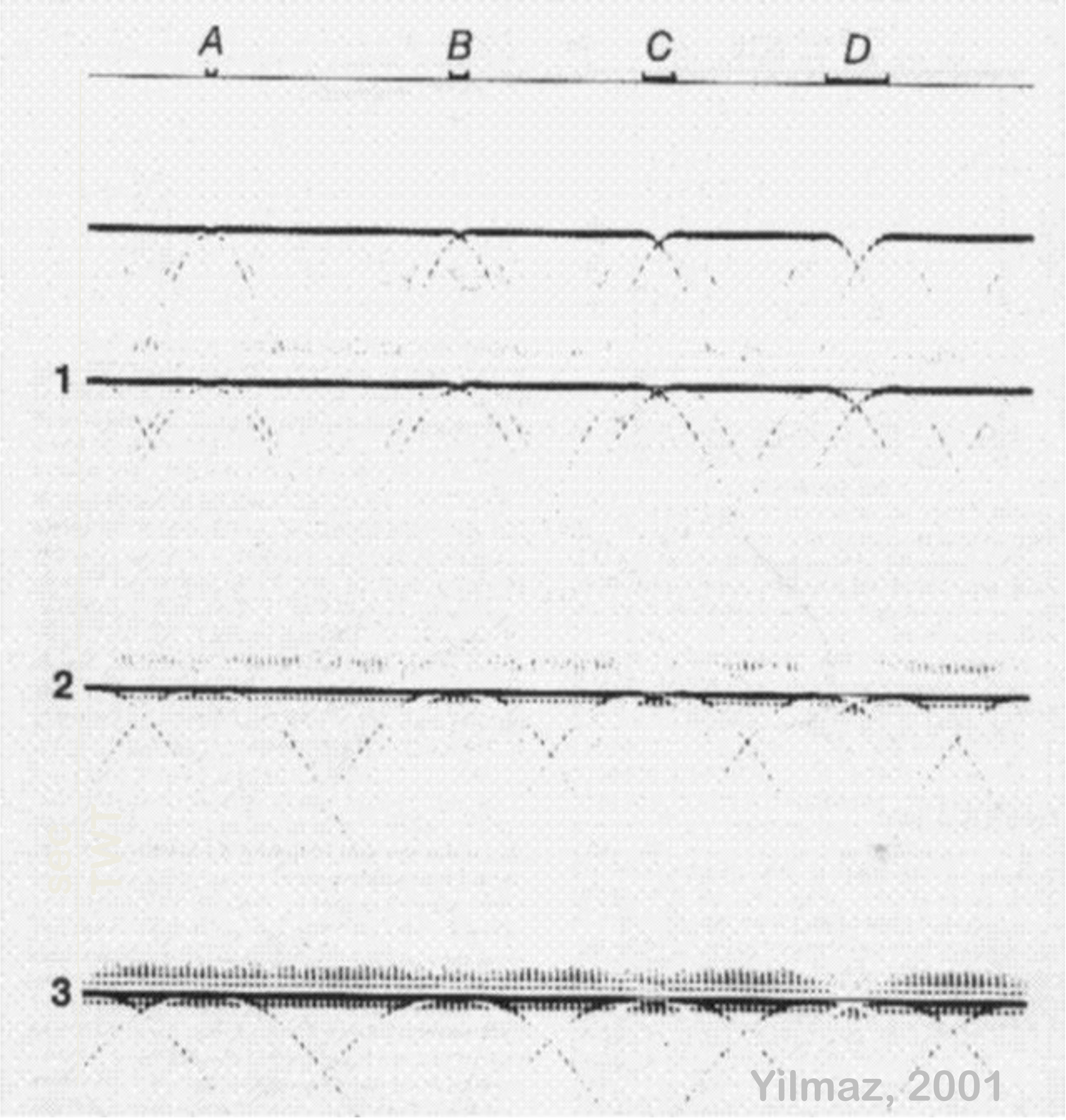
(0.5, 1, 2 e 3 sec 2wt)

on the lateral resolution

$$R \cong \sqrt{z_0 \frac{\lambda}{2}} = \frac{V}{2}\sqrt{\frac{T_0}{f}}$$

A, B, C, D are segments with different length related to <u>absence of reflectivity</u>:

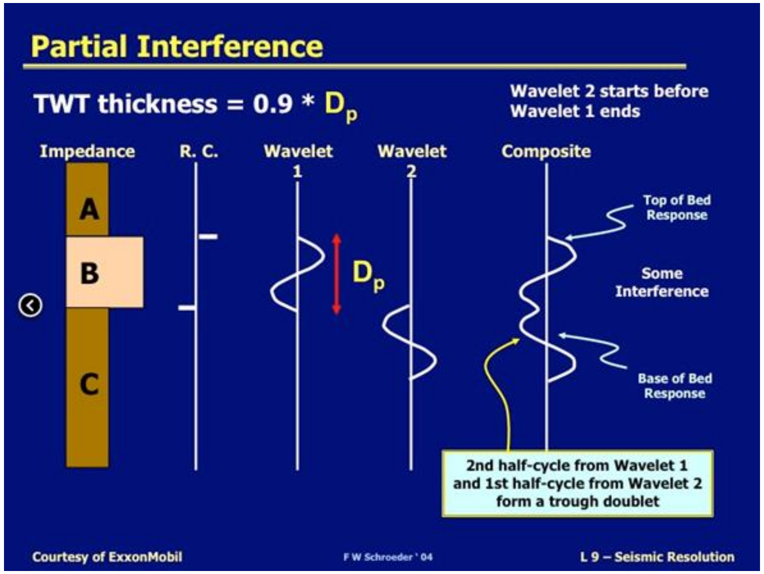
the presence of diffraction becomes an important element



Yilmaz, 2001

Correlations between vertical and lateral resolution.

As already seen by Widess (1973), a sedimentary wedge is bounded by an upper reflector at the top (negative Rc) and a lower reflector at the bottom (positive Rc), which laterally tend to converge. Note the interference between the two riflectors (amplitude decreasing toward left due to negative interference).
This represents a common stratigraphic condition, for example where there is an erosional surface or an *on-lap* or *pinch-out configuration*.



Partial Interference

TWT thickness = 0.9 * D_p

Wavelet 2 starts before Wavelet 1 ends

2nd half-cycle from Wavelet 1 and 1st half-cycle from Wavelet 2 form a trough doublet

Courtesy of ExxonMobil

F W Schroeder ' 04

L 9 – Seismic Resolution

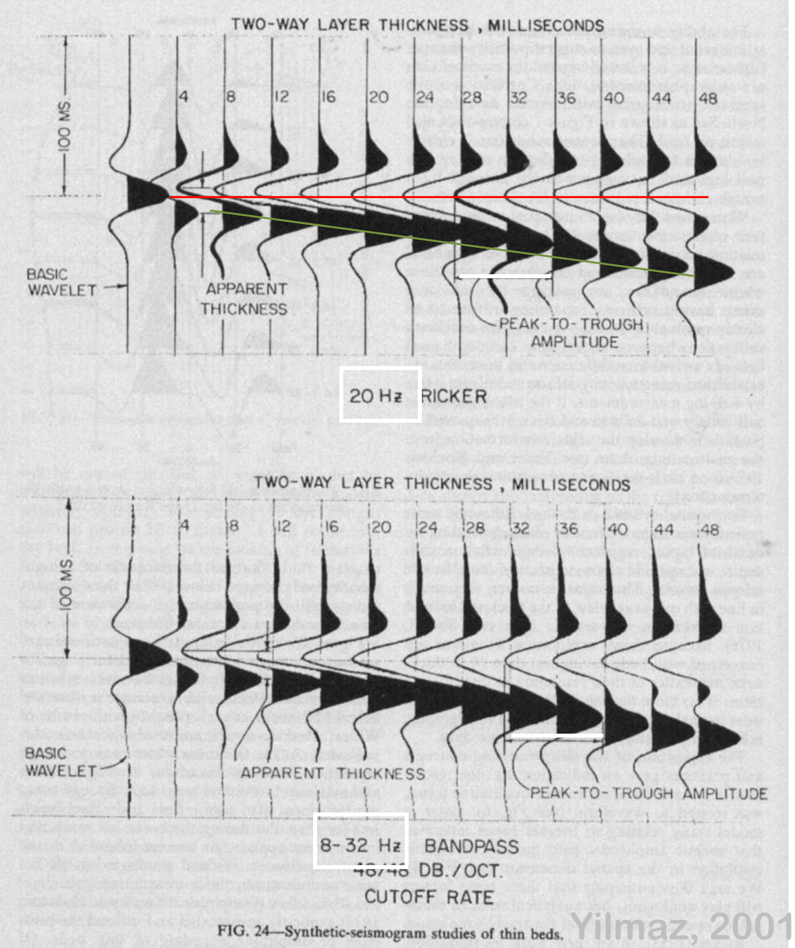
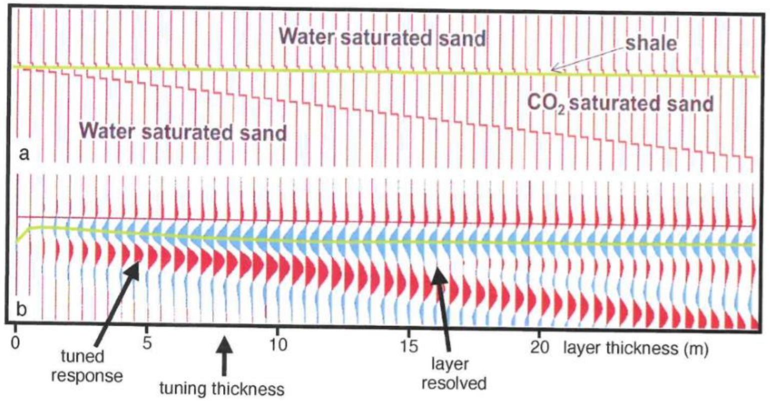


FIG. 24—Synthetic-seismogram studies of thin beds.

Yilmaz, 2001

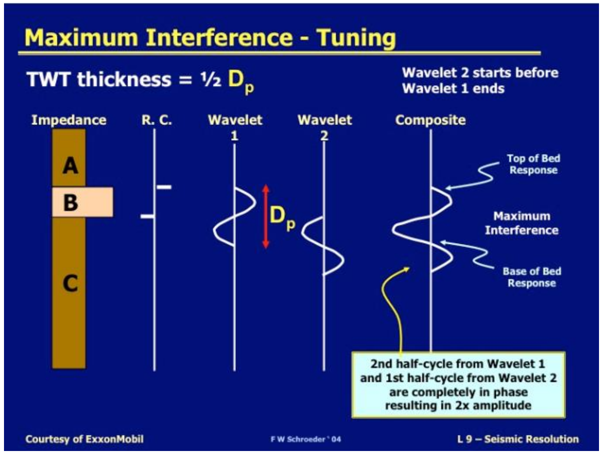


Ex.: sedimentary wedge characterized by equal Rc at the top and bottom; thicknesses are in m.
The velocity of the intermediate layer is 2500 m/sec

In a, b, e c the dominant frequency is changeable (vertical resolution – position of B - v/4f = 31,25; 21,08 e 16 m)

A= wedge closure
B= limit of the seismic resolution
C = point of extreme interference

In AB => ***Tuning*** effect



Maximum Interference - Tuning

TWT thickness = ½ D_p

Wavelet 2 starts before Wavelet 1 ends

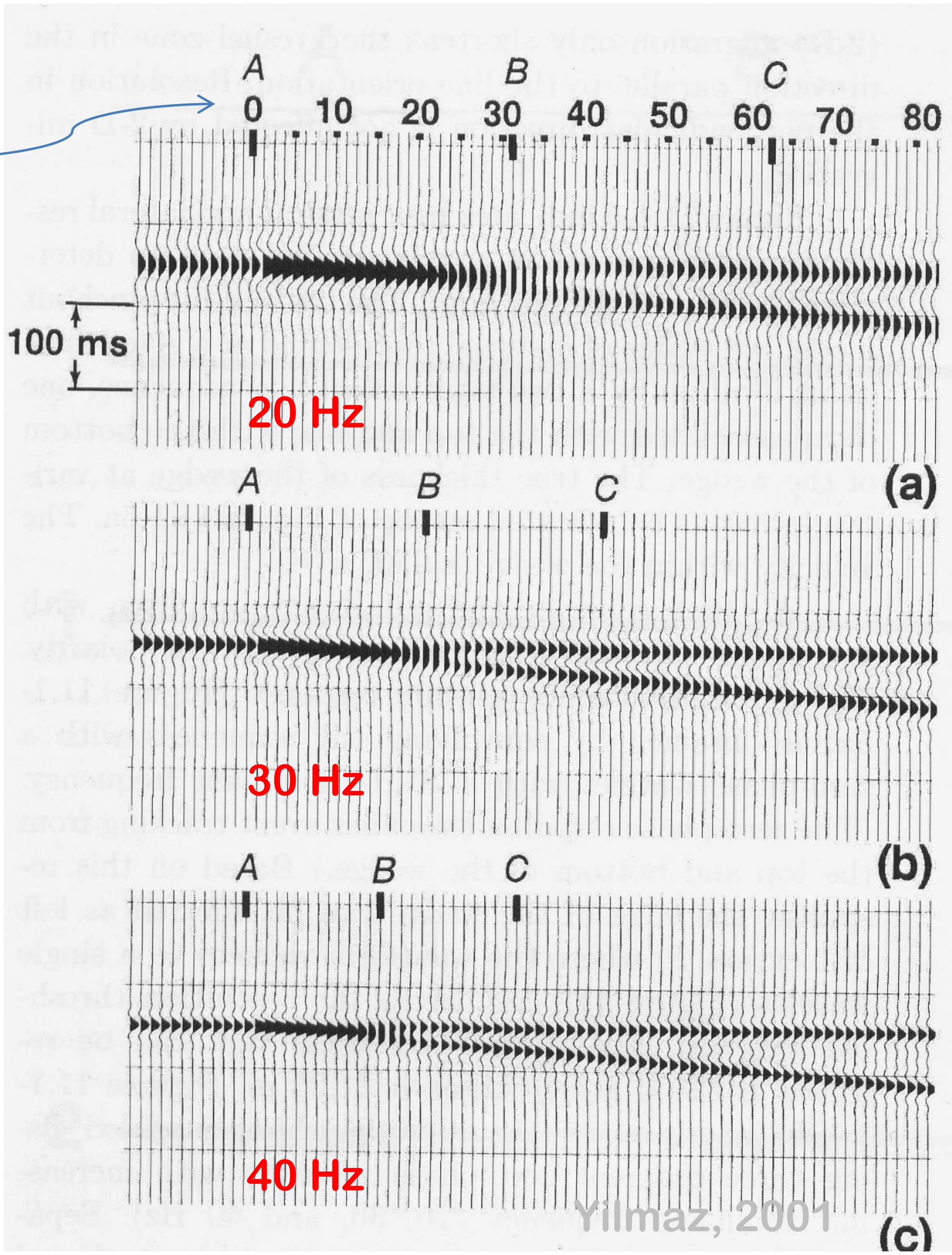
2nd half-cycle from Wavelet 1 and 1st half-cycle from Wavelet 2 are completely in phase resulting in 2x amplitude

Courtesy of ExxonMobil

F W Schroeder '04

L 9 – Seismic Resolution

It allows to go beyond the resolution vertical limit, with the amplitude variation, as long as the S/N ratio is high.

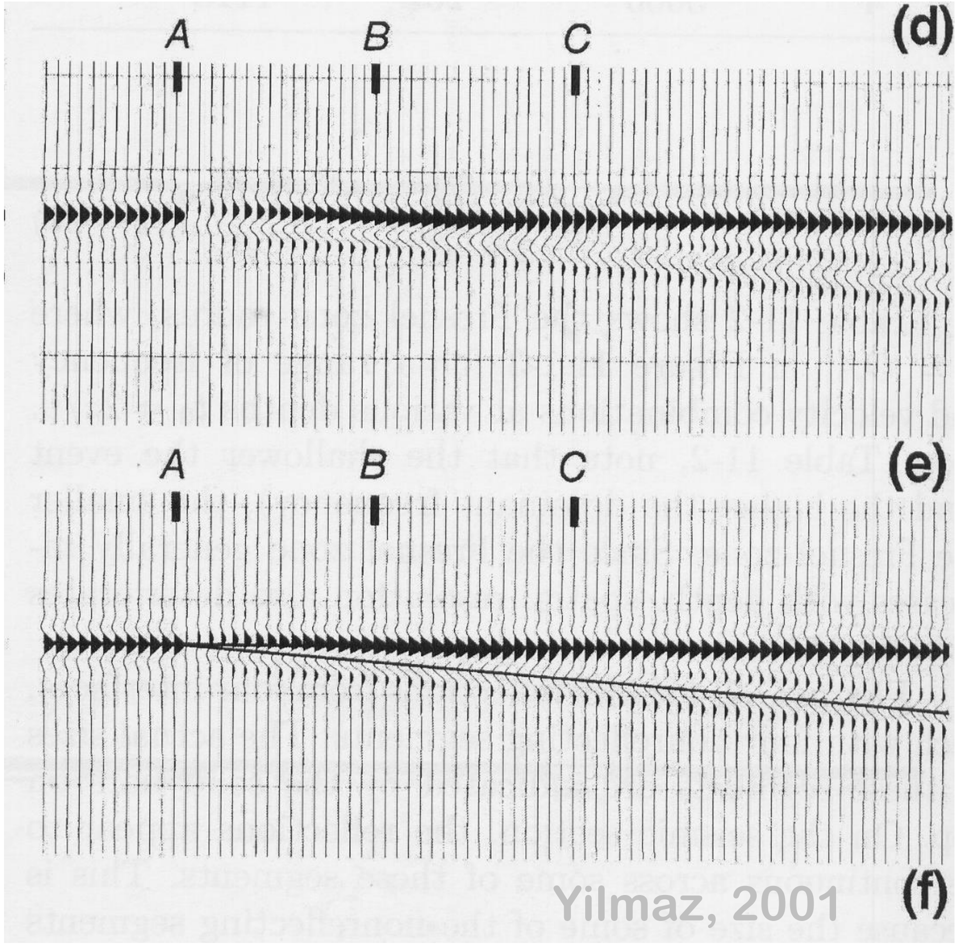


Yilmaz, 2001

As in the previous figure but the wedge bottom has a negative reflection coefficient (high velocity wedge).

The interference between the two wavelet due to the two reflectors will be distructive between A and B, costructive between B and C.

Also here we can interprete below the seismic resolution.



Yilmaz, 2001

Wedge models are particularly useful for determining the expected seismic response where there is a variation in thickness. Wedge models provide an analogue for where a stratigraphic layer thins or pinches out. At the thickest part of the wedge, there is no interference between neighbouring events, the reflectors are resolved as a uniform boundary of constant grey color, which equates to an equal and intermediate contribution from each frequency band. As the reflectors converge, interference occurs and manifests as a distinct color within the RGB blend, focused in between the upper and lower reflectors. Reducing thickness in the wedge causes a change in color in the blend. This is due to variation in frequency caused by cycles of constructive and destructive interference and results in a spectral interference pattern along the wedge.

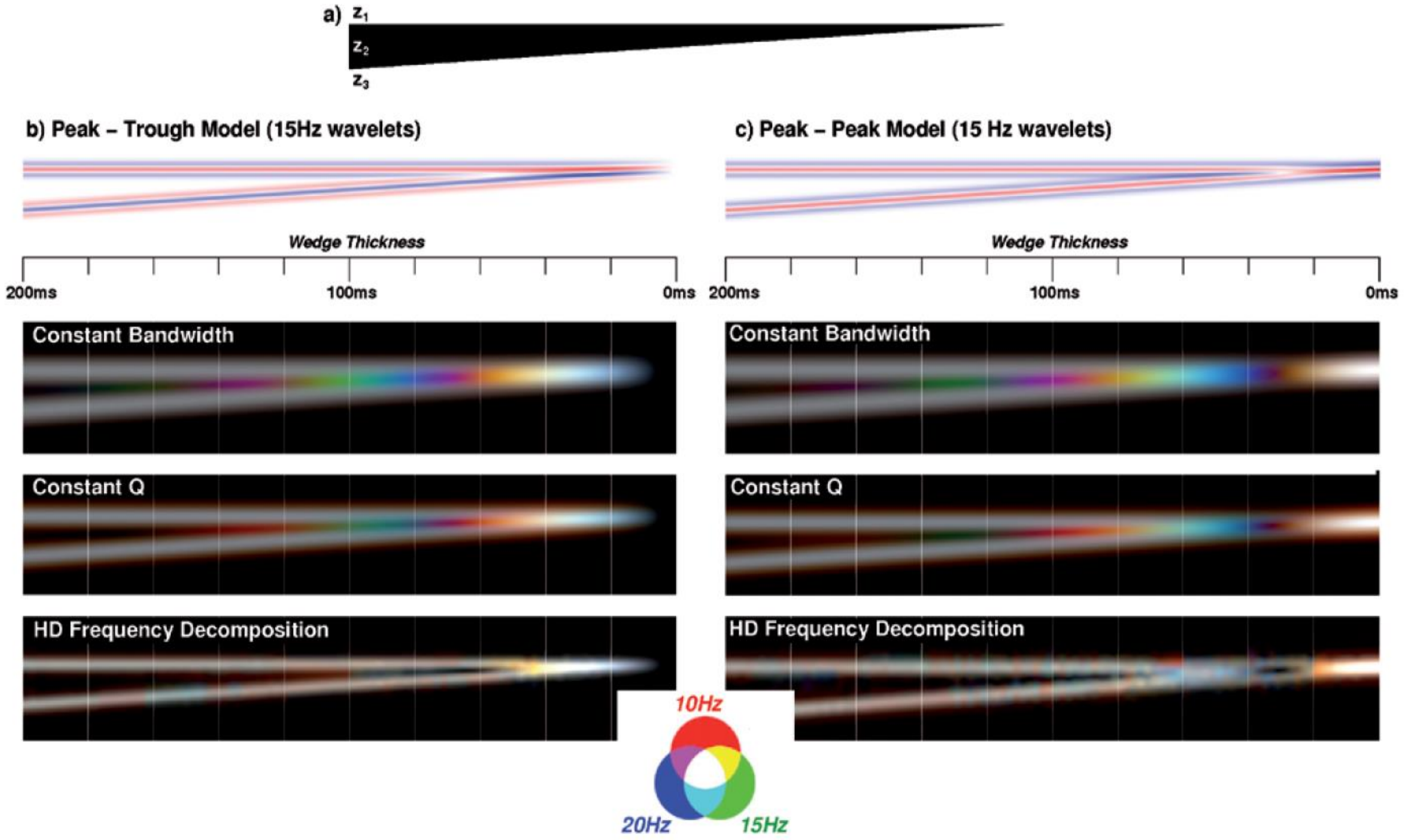


Figure 2 *(a) Three-layer wedge model, where acoustic impedances of the upper, mid and lower layers are denoted* Z_1, Z_2 *and* Z_3, *respectively. (b) RGB blends using the three magnitude volumes with a 15 Hz Ricker wavelet for a peak-trough model with* $Z_1 < Z_2 > Z_3$. *RGB blends using the three magnitude volumes with a 15 Hz Ricker wavelet for a peak-peak model with* $Z_1 < Z_2 < Z_3$.

Some examples