SEISMIC RESOLUTION

ability to distinguish separated features within a seismic profile

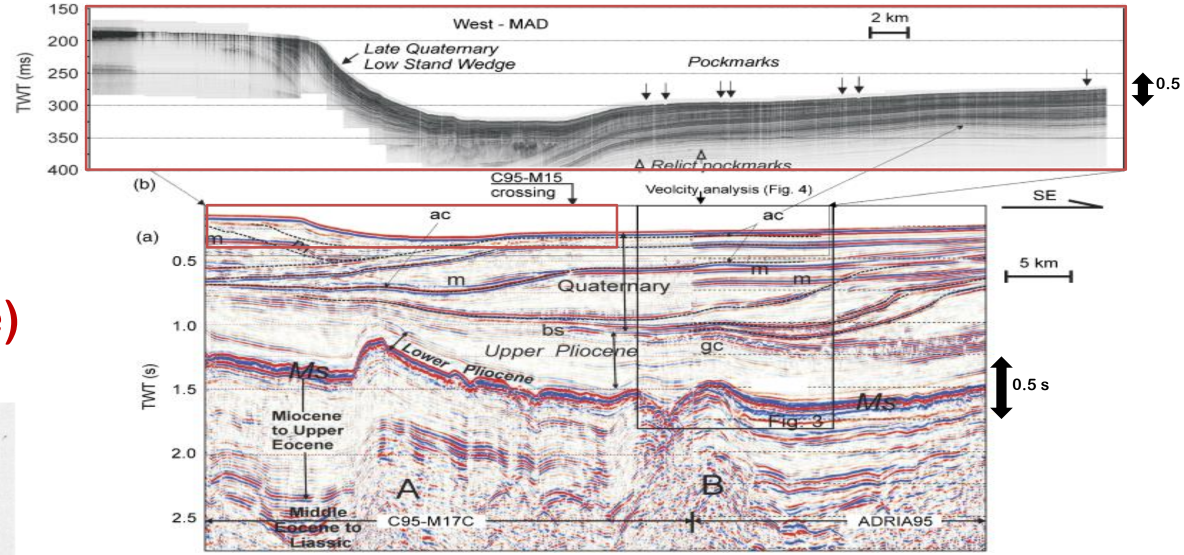
It is generally expressed as a minimum distance between the "resolved" objects that means: the two objects are individually defined

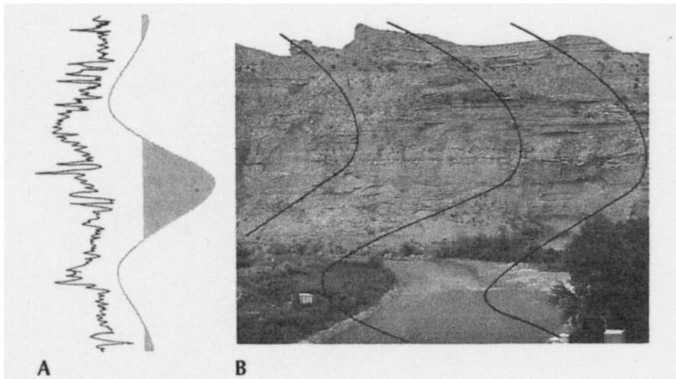
It differs in:

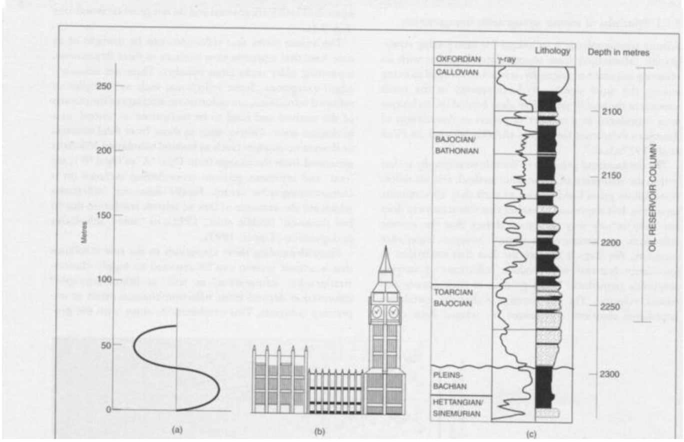
- **vertical resolution**
- **lateral resolution**

High resolution seismic (Chirp profile) →

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







Vertical Resolution:

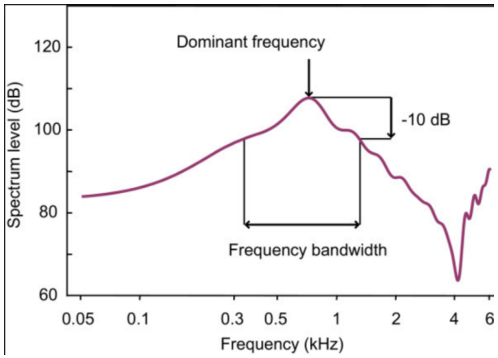
minimum vertical separation between two separated reflecting features.

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**.



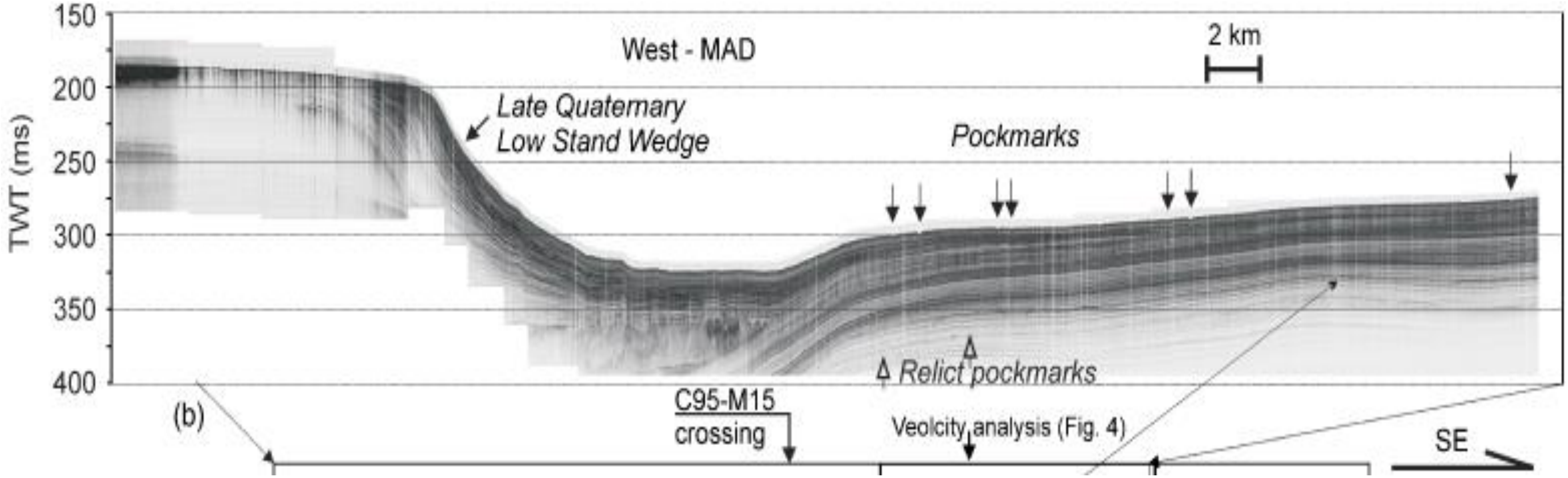
Within a seismic profile, the dominant frequency depends on :

- 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.

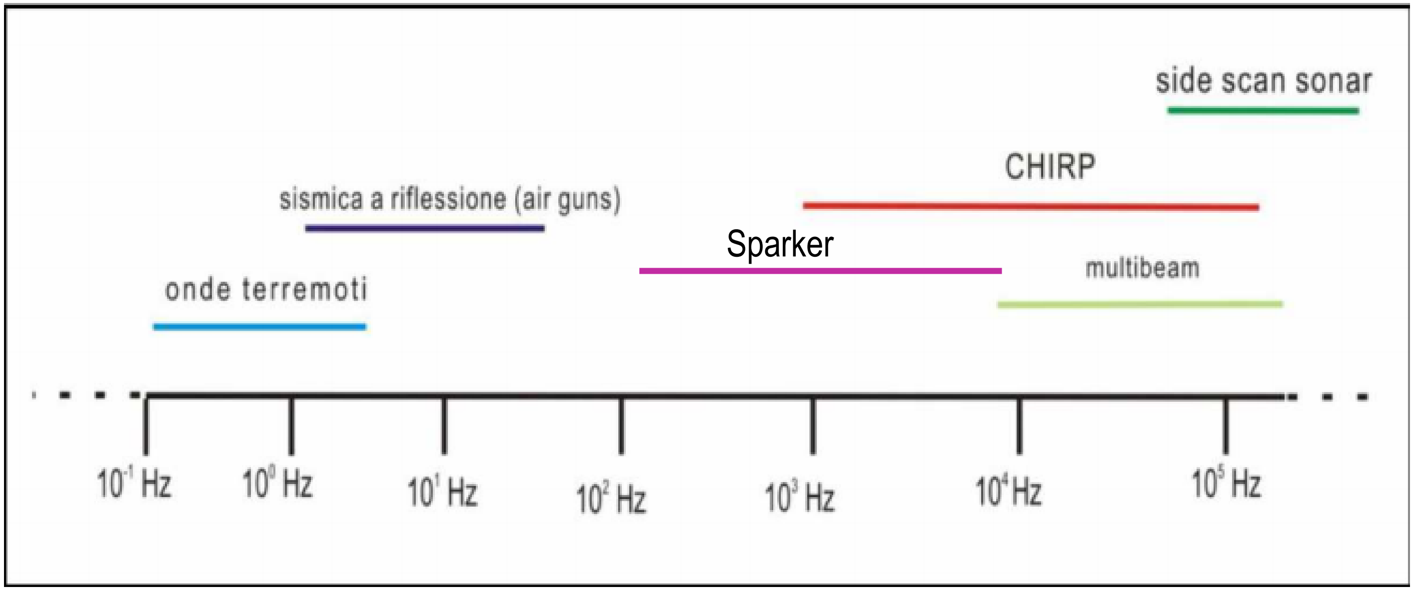
High resolution seismic

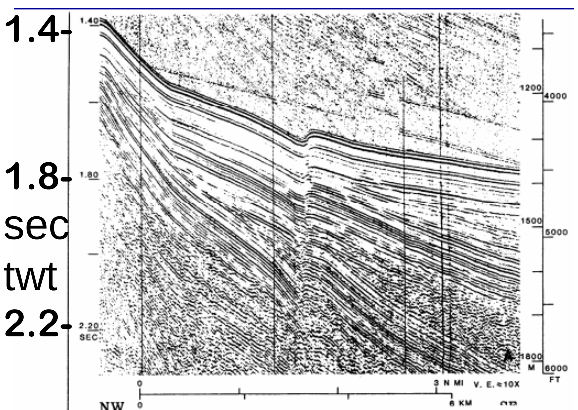


The high seismic resolution is characterized by relatively lower acquisition cost than the classic multichannel seismic reflection. Furthermore, it doesn't requires complex processing phases. The high resolution seismic is generally acquired in the offshore. It is related to:

1) low power seismic sources;
2) generally single channel acquisition;
3) direct imaging of the acquired profiles.

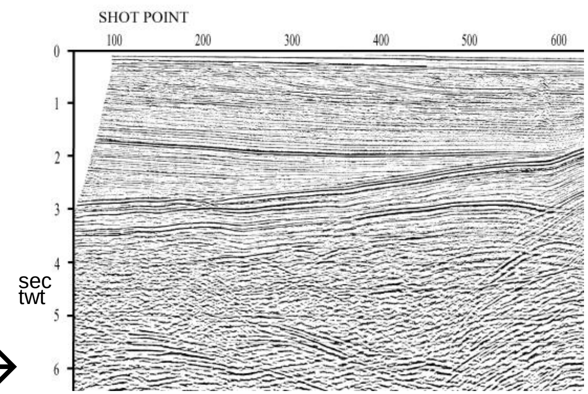
The high resolution seismic profiles provide detailed information on geometries of the sedimentary series below the seabed. Anyway, they have a penetration limited to tens, maximum a few hundred meters. It is therefore mostly used to study superficial sedimentary sequences, often associated with morpho-bathymetric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

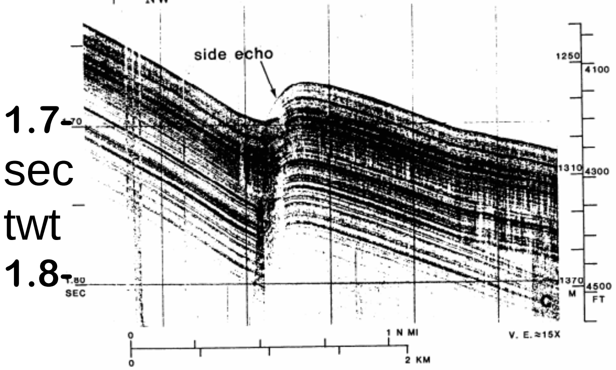




← Sparker

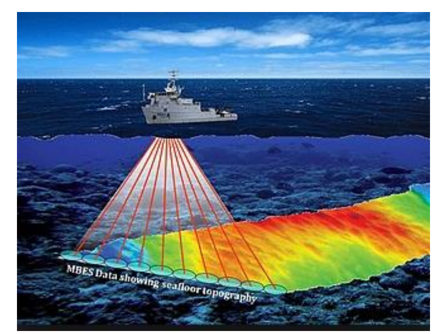
Multichannel seismic (air gun) →





← Chirp (Sub Bottom profile)

Multibeam →



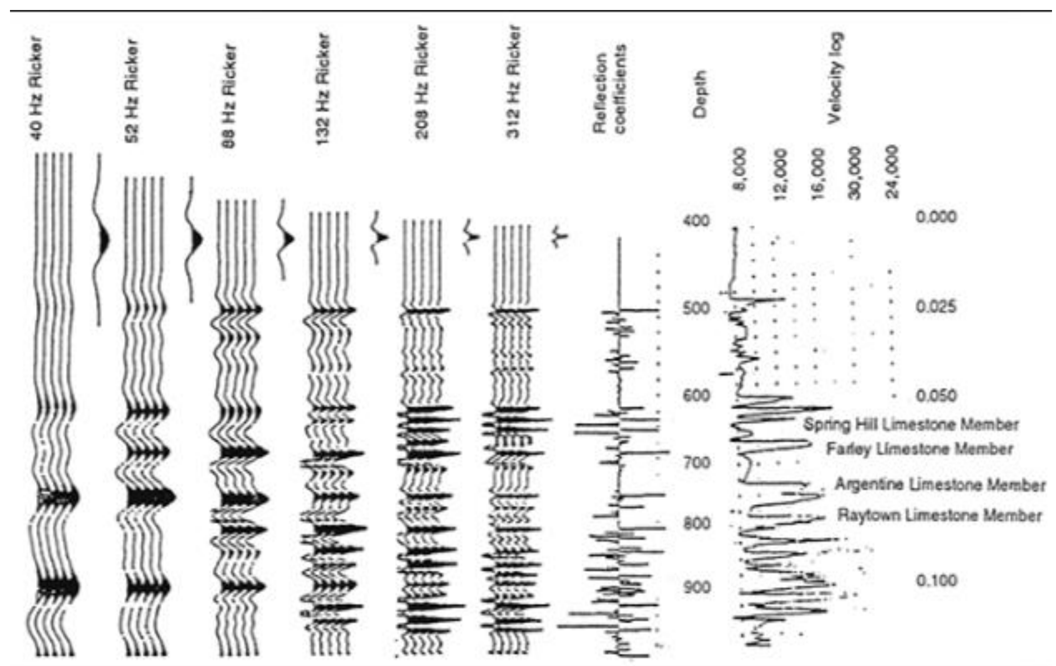
λ = *v t* = *v / f*

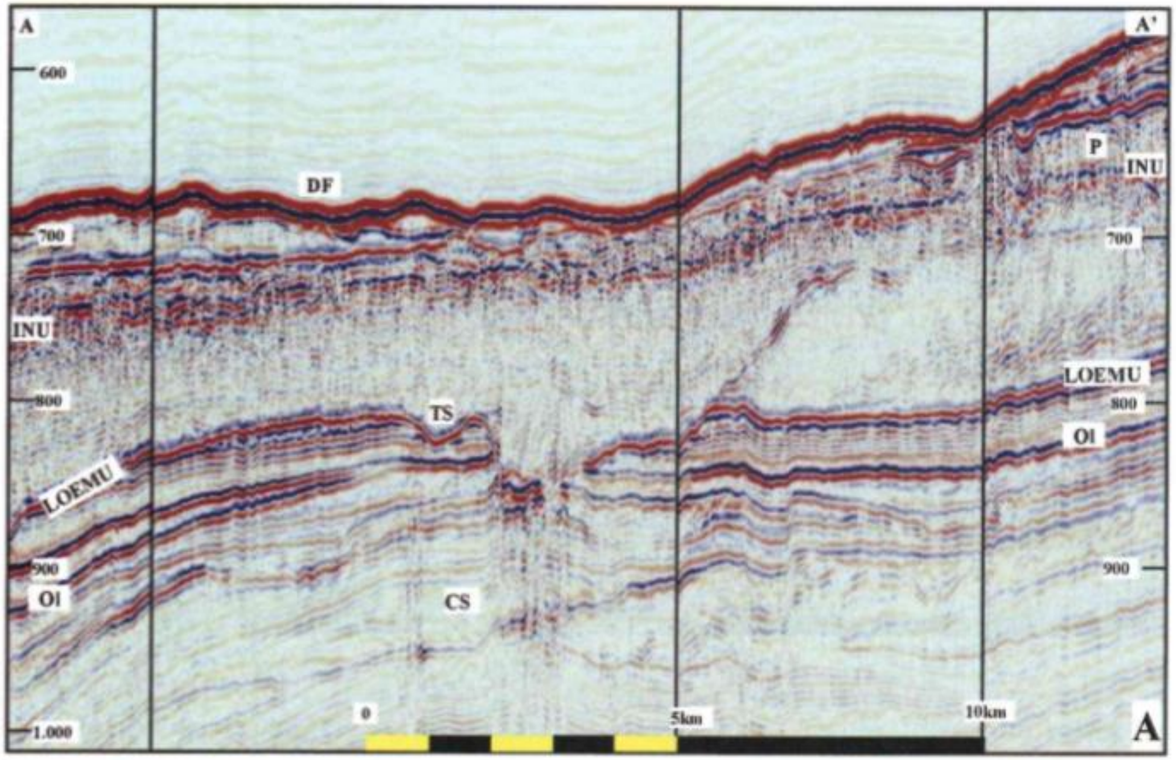
***λ* =** *dominant wavelength (40 – 250 m)*

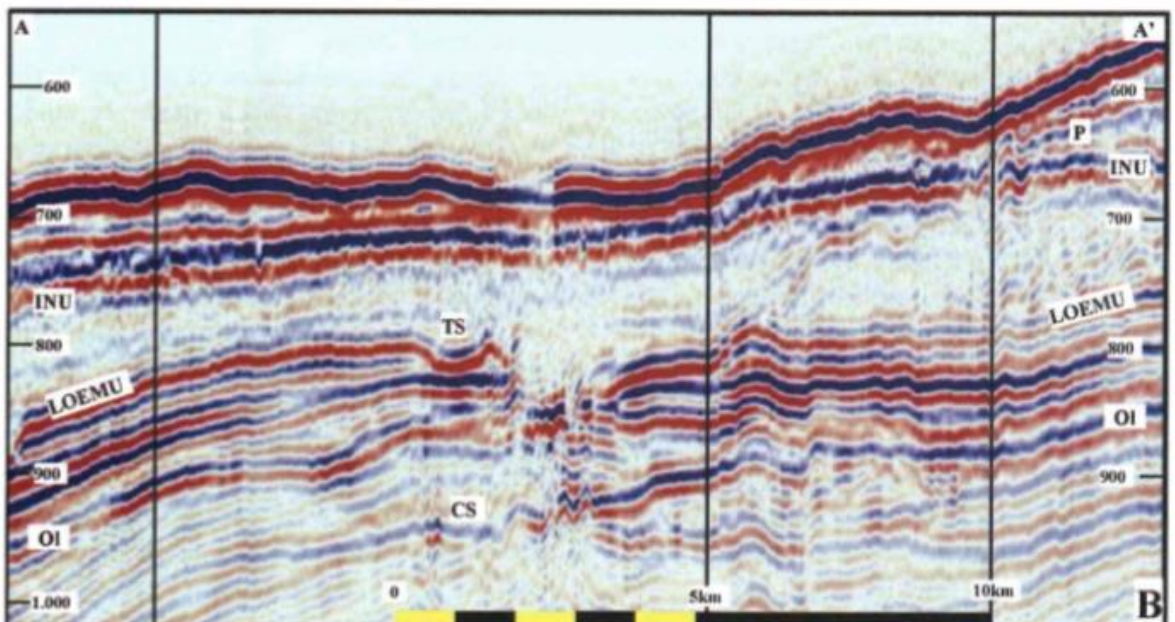
***v* =** *P waves velocity (2000-5000 m/sec)*

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

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





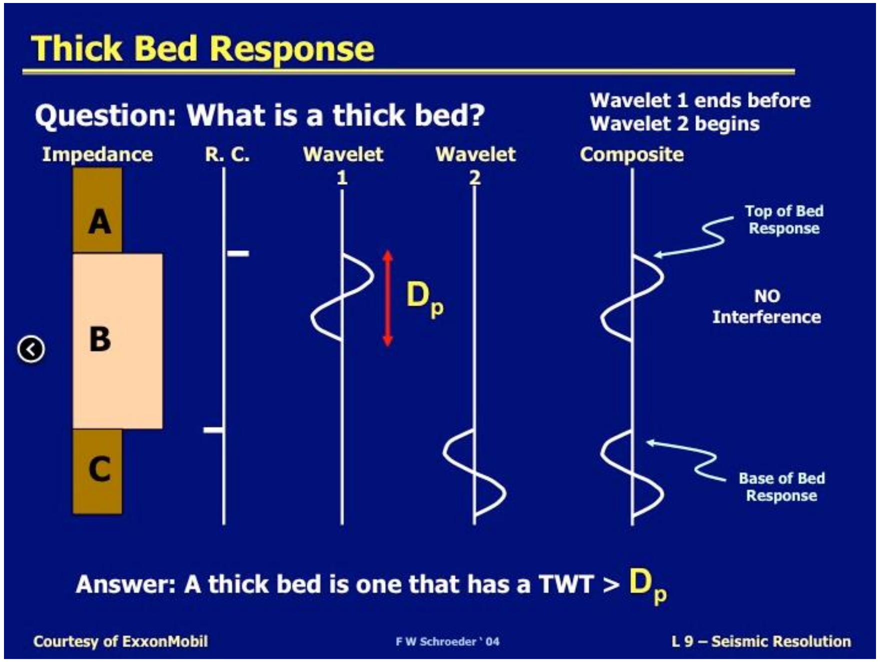


Shetland slope

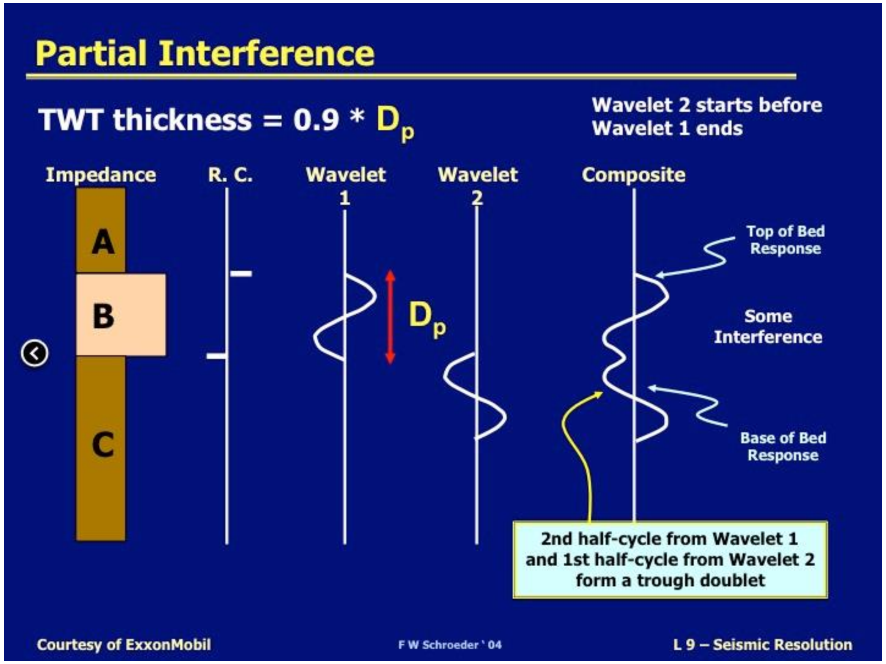
Examples of seismic acquisition with different seismic resolution.

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

Good resolution for the B unit



No resolution for the B unit



“*How thin is a thin bed?*”

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

-a constant thickness with vel 6 km/s inside a medium with vel 3 km/s

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

- Regardless absorption and multiples

=> 2 amplitude peacks, equal and opposite.

The sum of the reflected arrivals, repeated 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**.

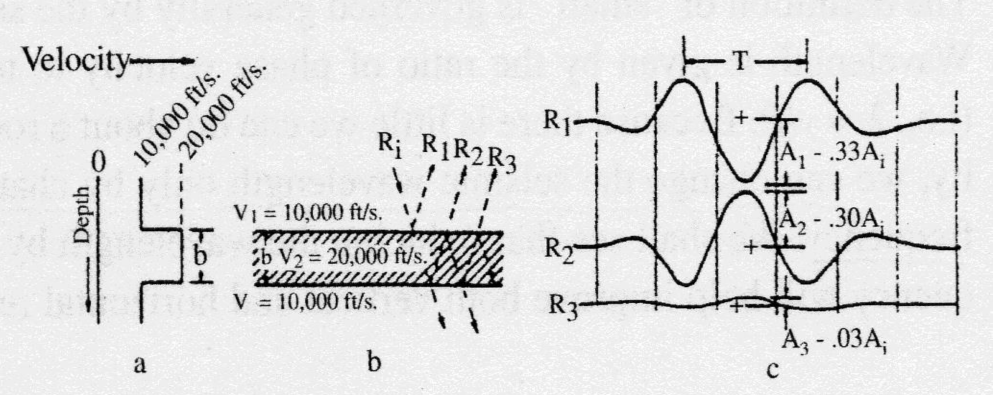
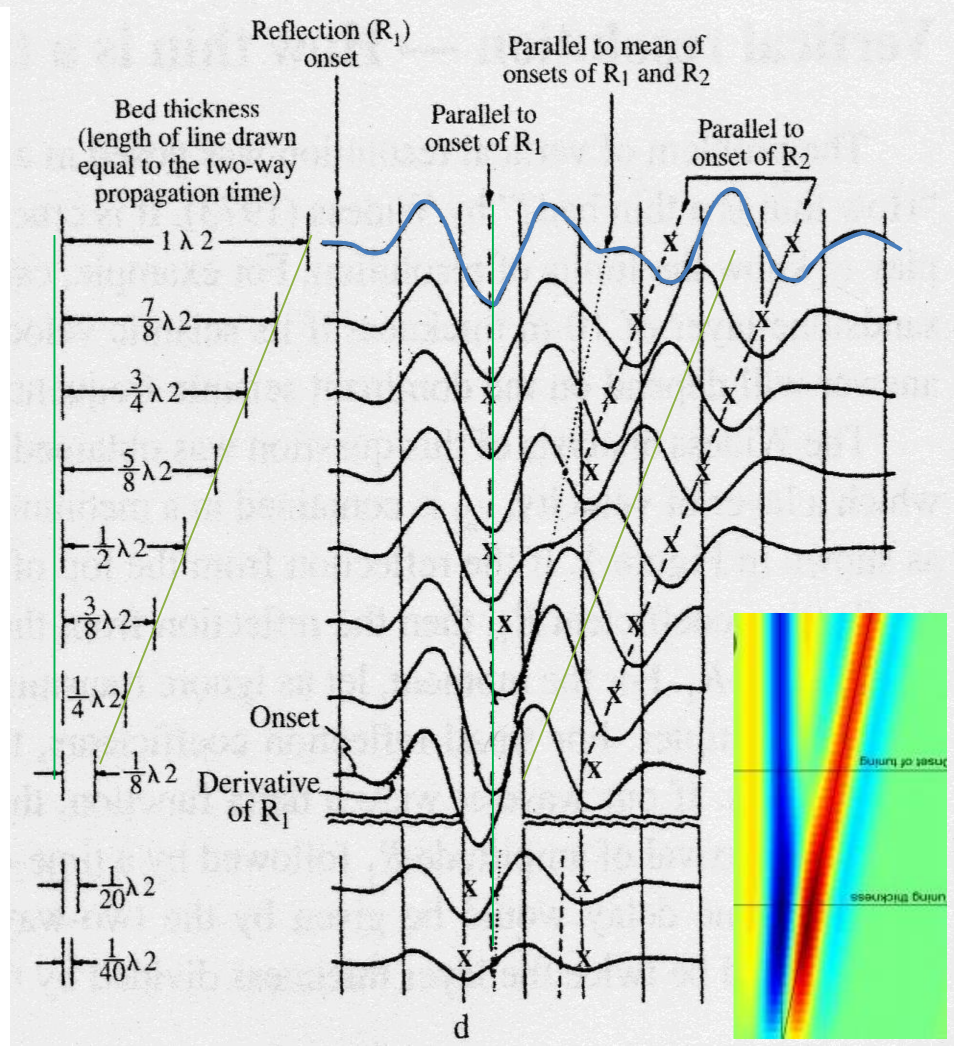


Figure 1. Resolution of a thin bed, as illustrated by Widess (1973).



VERTICAL RESOLUTION

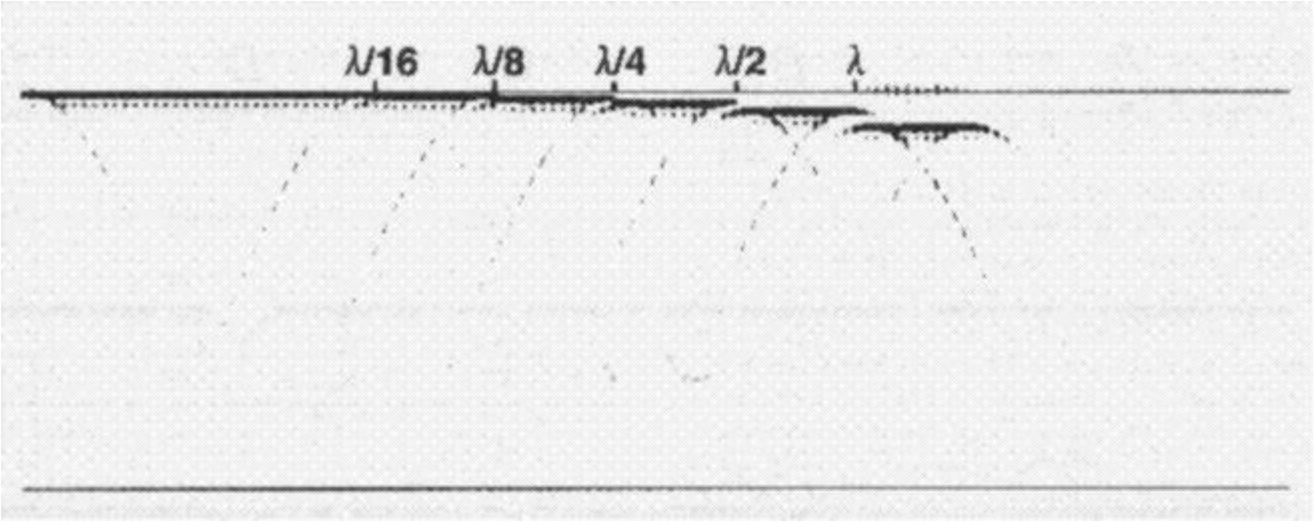
Table 11-1. Threshold for vertical resolution.

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

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

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

VERTICAL RESOLUTION

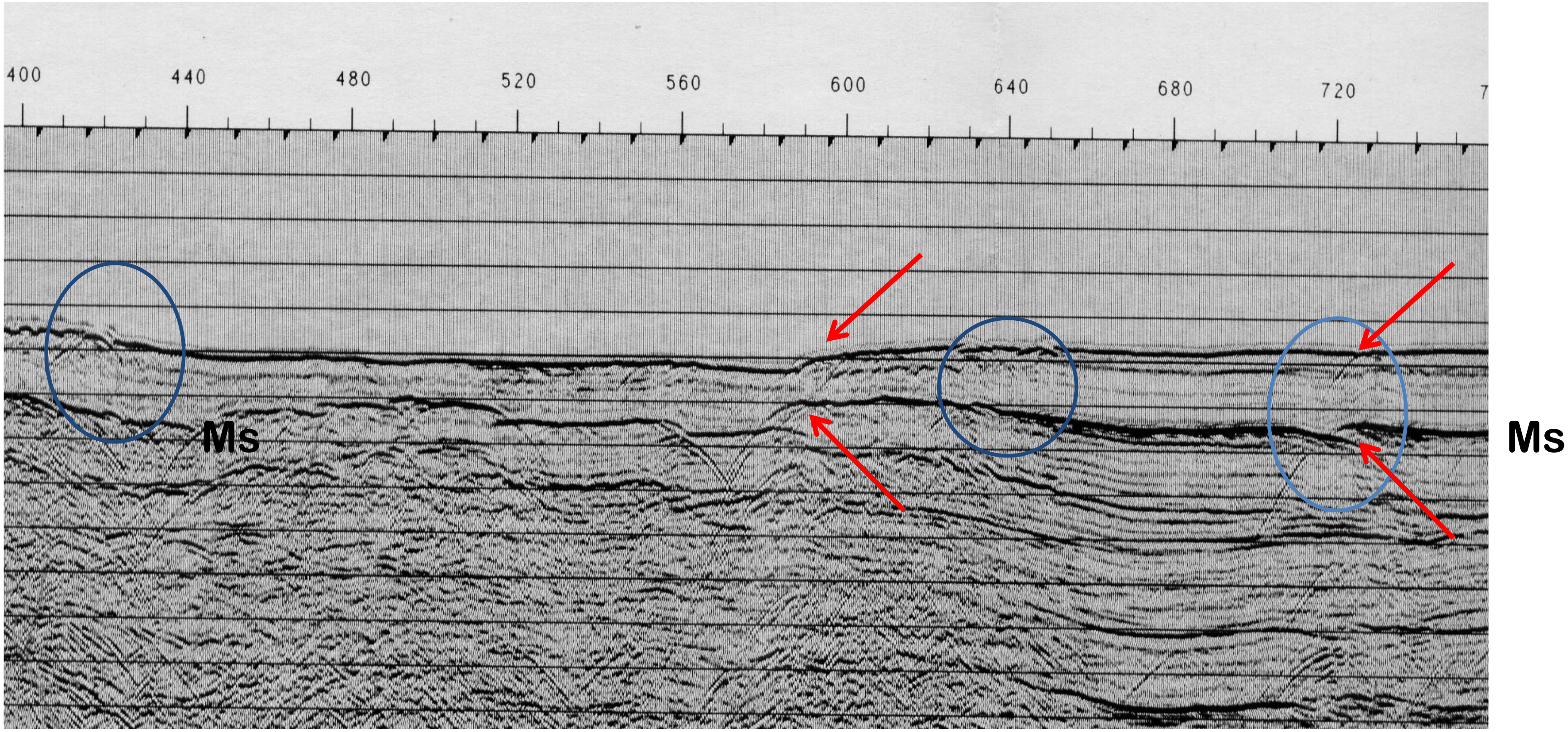


The vertical throw is “recognizable” when it reaches or exceeds ¼ of the wavelength (vertical resolution).

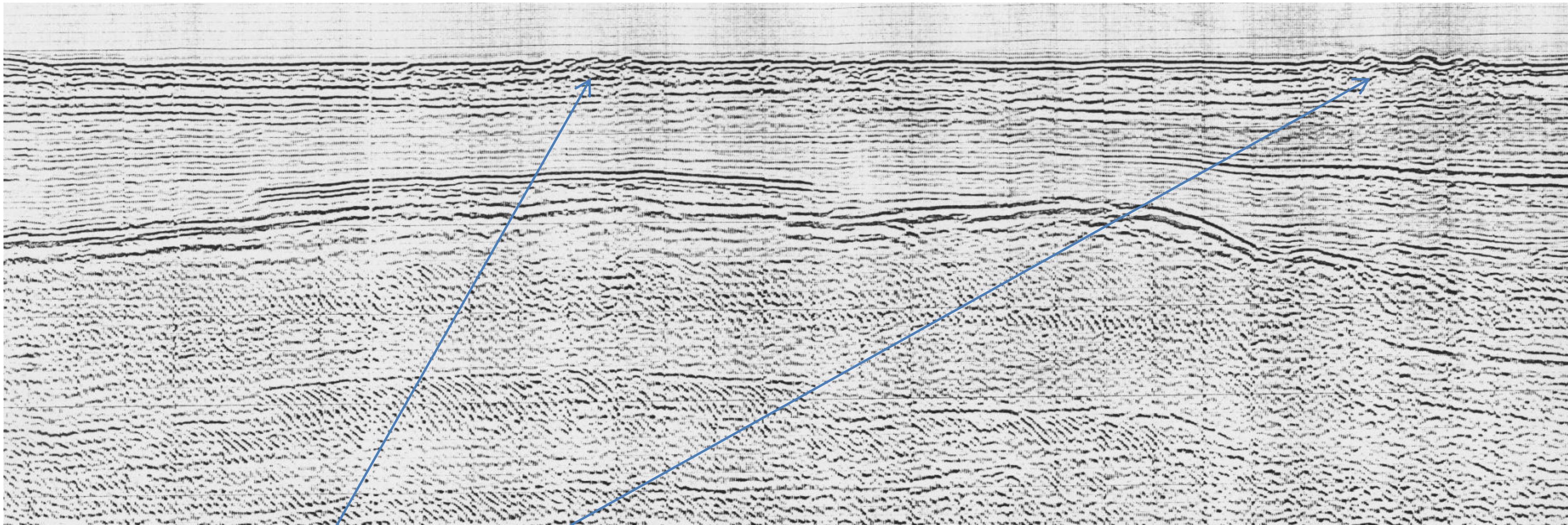
However, if the throw is smaller, we can interprete the presence of an inhomogeneity (***detection***) on the base of some diffraction hyperboles.

=> When we interpret, we can sometimes use *stack profiles,* which are complementary to the migrated profiles

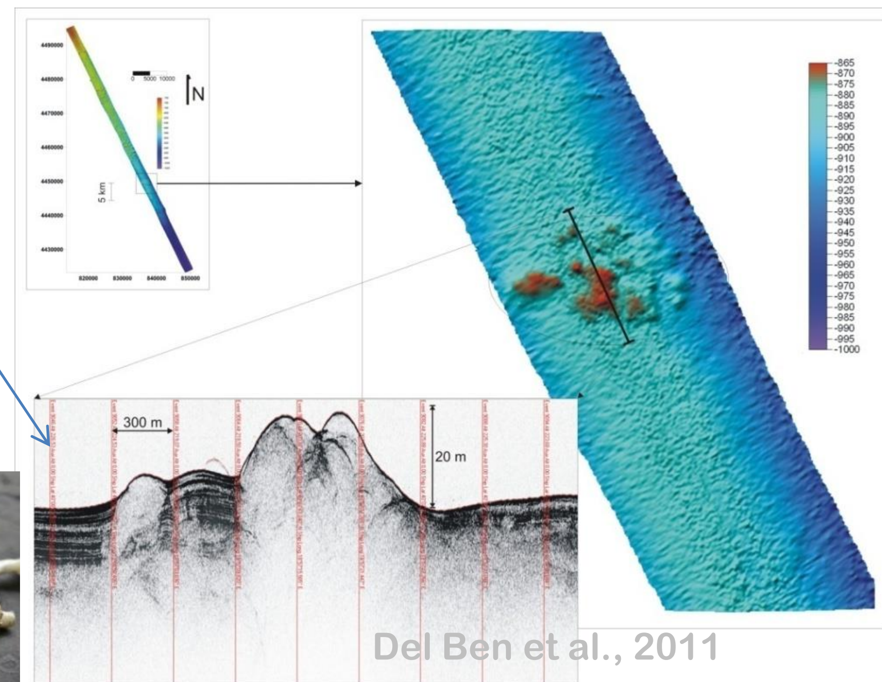
Example of seismic profiles in the Ionian Sea



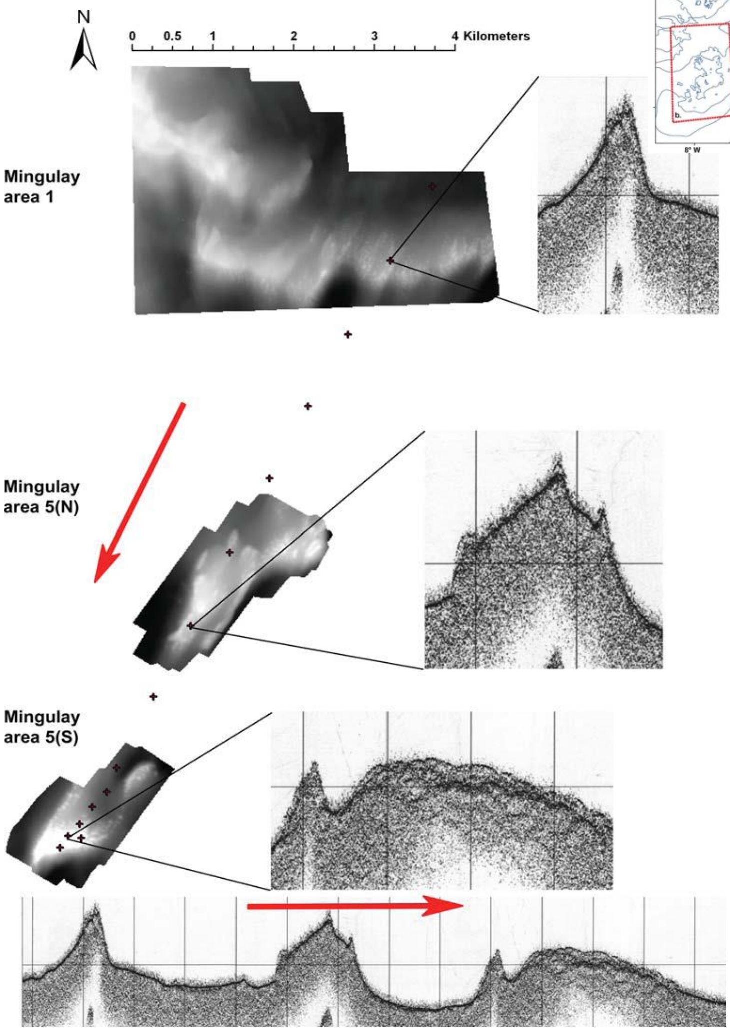
The vertical throws of the faults are especially evident where they cut the Messinian horizon Ms, characterized by high amplitude. The seabed is also disturbed in some points (this is often a witness of active faults!). In the fault on the right ou can see the vertical throw of the Ms reflector, while 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).

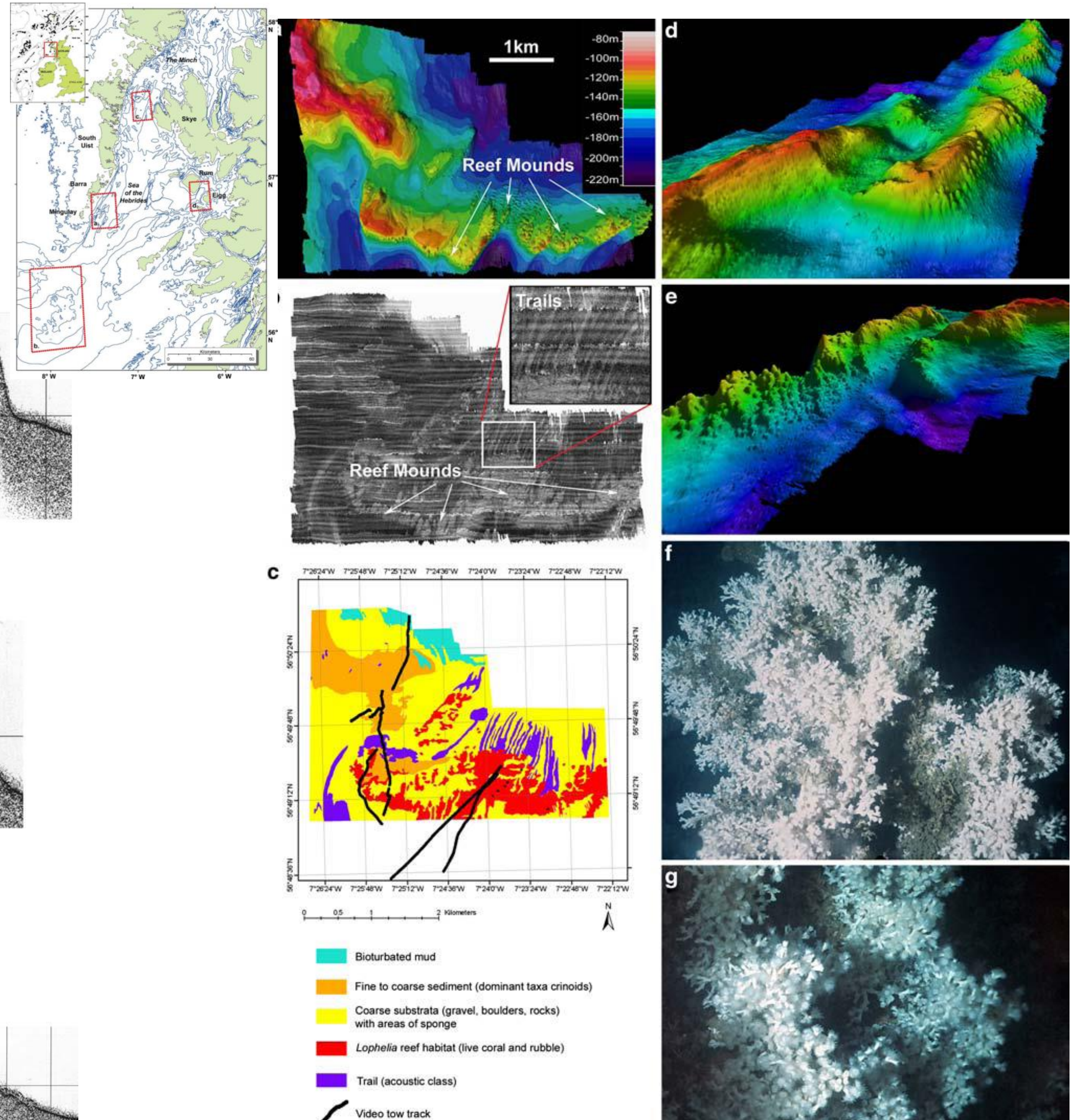


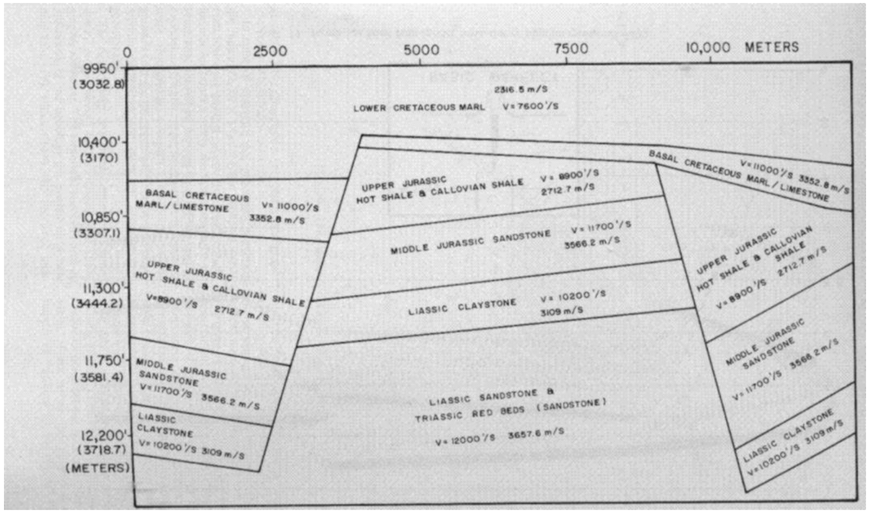
Bottom: example of reflection seismic profile in the Otranto Channel: on the sea bottom some small structures were explored during the year 2008 with a *Chirp sub-bottom profiler* (higher frequencies => higher resolution). The structures were related to coral mounds, successively dradged by the OGS-Explora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



Deep coral mounds
High resolution evidences

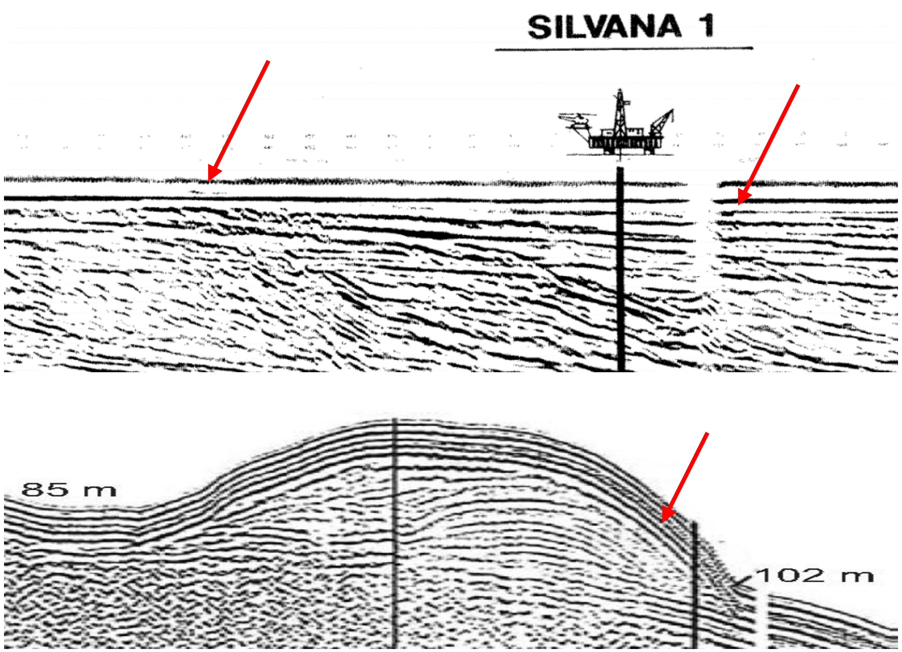






Effect of the **wave shape** and of **deconvolution** on the vertical resolution

→ ***ringing***



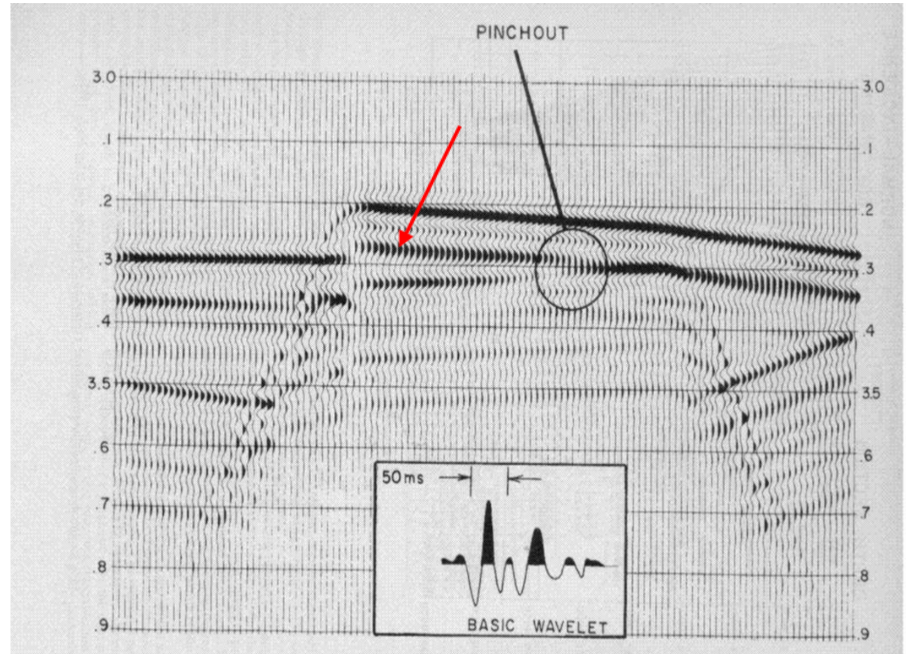


FIG. 17—North Sea horst-fault model, wave-theory solution (primaries only).

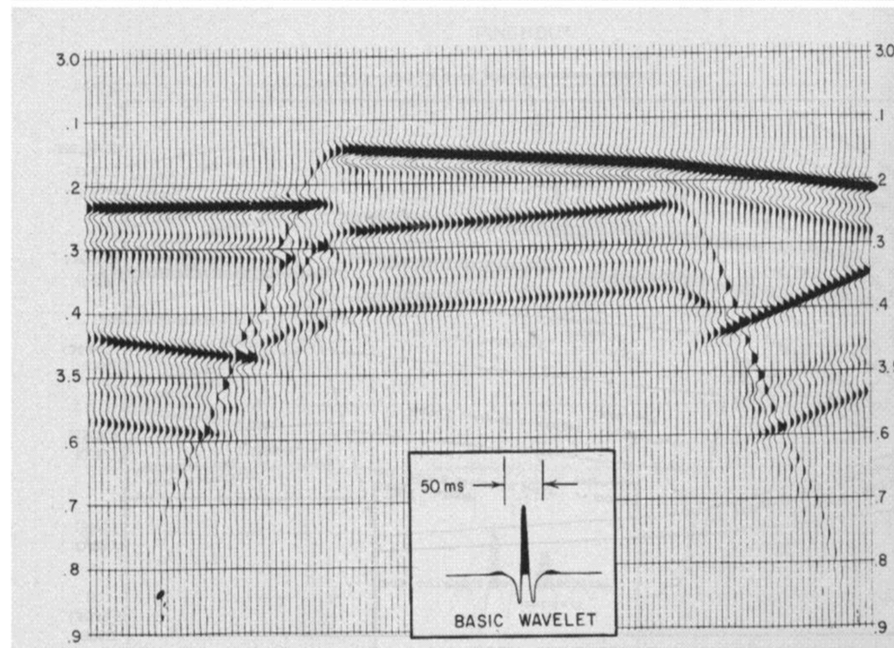


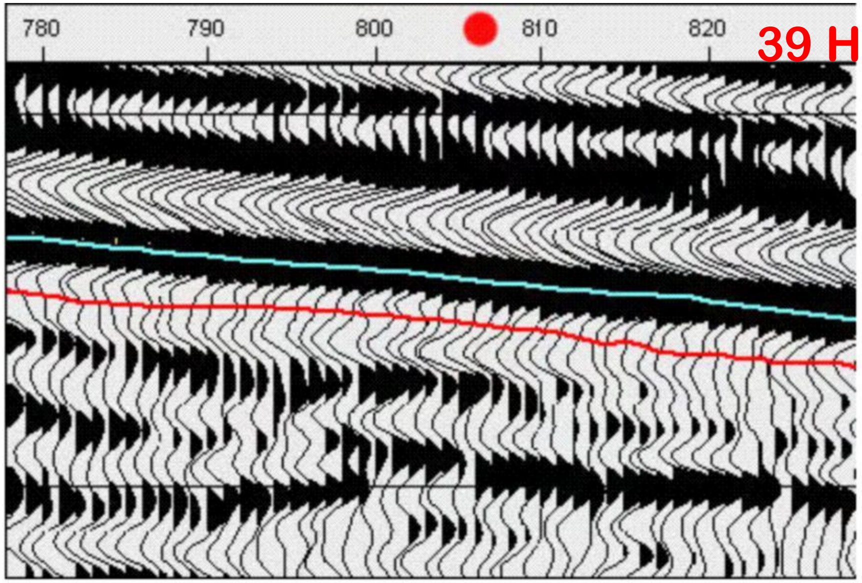
FIG. 19—North Sea horst-fault model, wave-theory solution (primaries only).

Effect of the **<u>dominant frequency</u>** 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**.

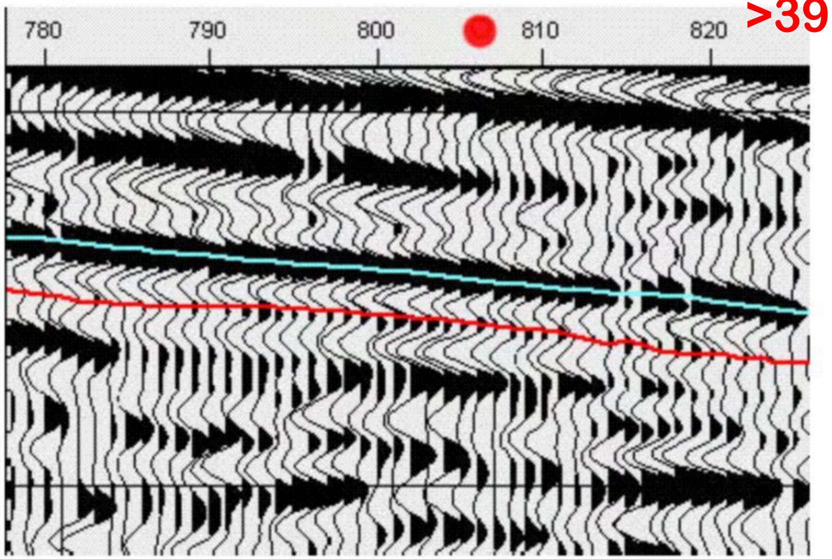
Sometimes "***detection** not* ***resolution** is the problem*" (Yilmaz, 2001)

39 Hz

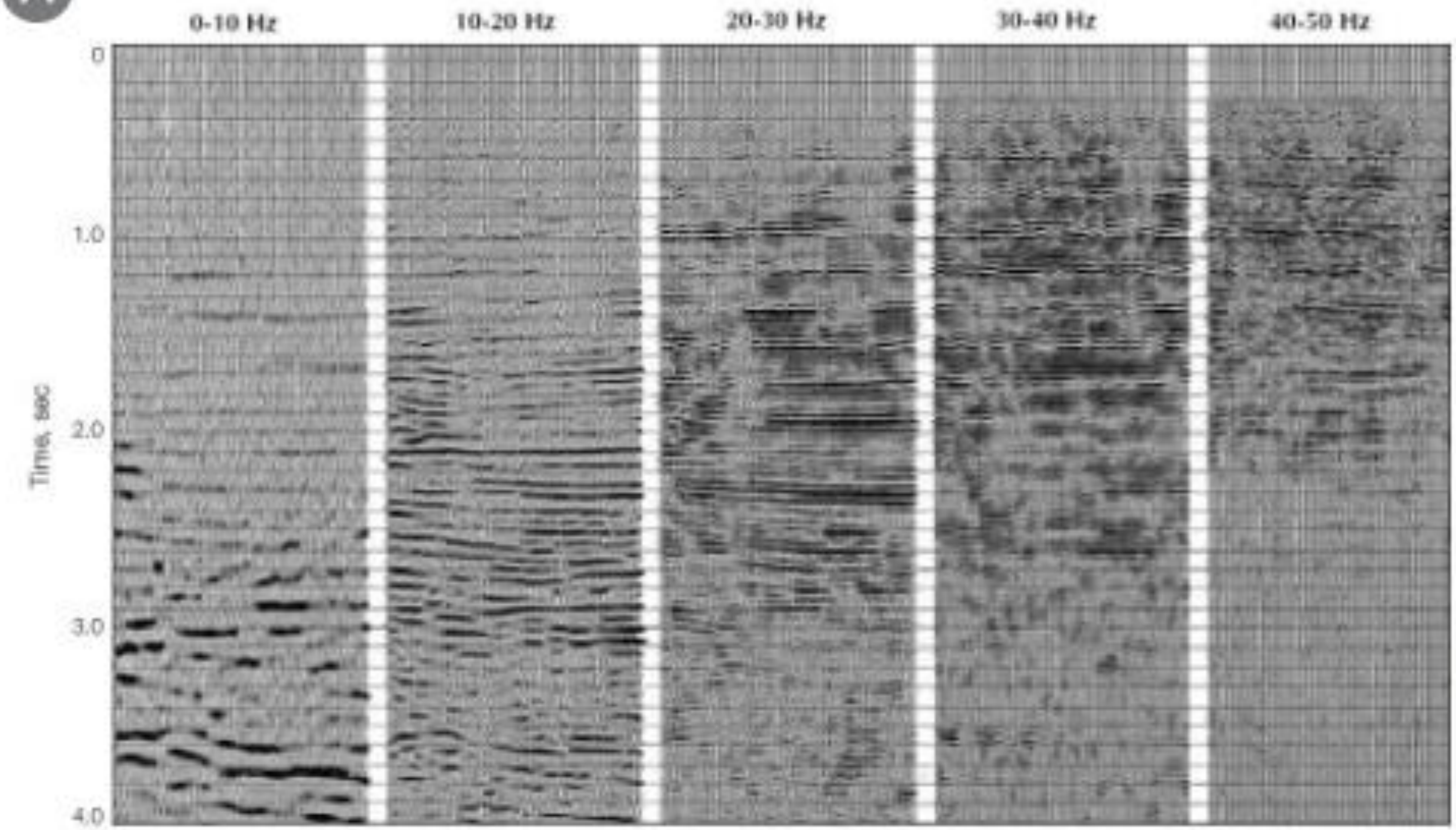


Original section from a 3D survey.

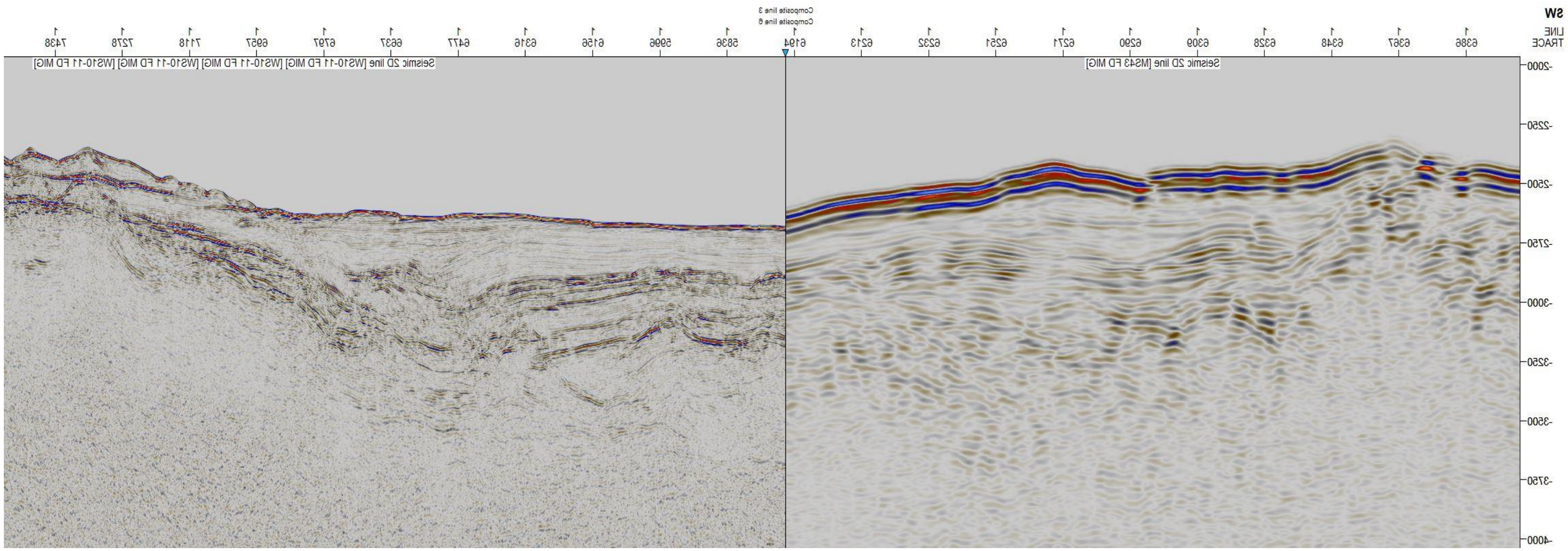
>39 Hz



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.



WS_10 profile

MS profile

Acquisition parameters of seismic reflection data

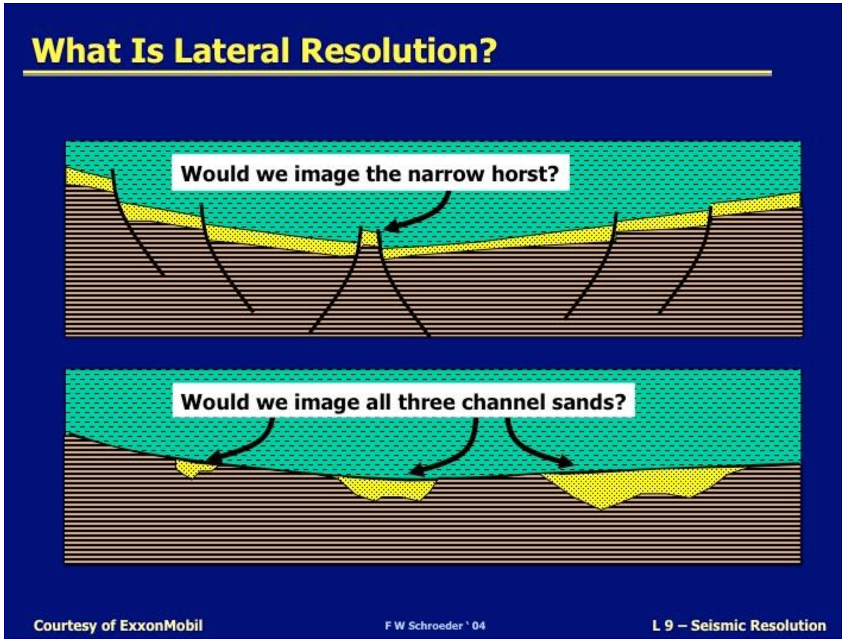
Project name	WS10	MS
Line name	WS10-01 to WS10-15	MS39, MS40, MS43, MS44, MS95, MS99
Vessel	OGS EXPLORA	MARSILI
Recording date	2010	1972
Recorder	Sercel Seal	T.I. DFS/10.000
Data length	8 s	6–10 s
Sample rate	1 ms	4 ms
Field filters	Low 3 Hz, high 500 Hz	Low 10–high 72 Hz
Coverage	30	12, 24
Navsystem	GPS Topcon	Loran — C
Energy source	GI-gun Sercel	Flexotir
Source array	1 × 2 guns = 355 cubic inches	3 guns, microcharges of 50 gr, Geodin — B
Depth of source	4 m	14 m
Streamer	1500 m	2400 m
Number of traces	120	48
Groups interval	12.5 m	100 m
Shot interval	25 m	100, 50 m
Depth of streamer	5 m	10 m
Near offset	25 m	320 m
Far offset	1512.5	2720 m

data by OGS
Table by Geletti et al., 2014

Lateral Resolution:

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

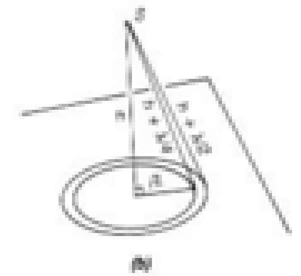
The lateral reslution is related to the ray of the “Fresnel Zone”



LATERAL RESOLUTION

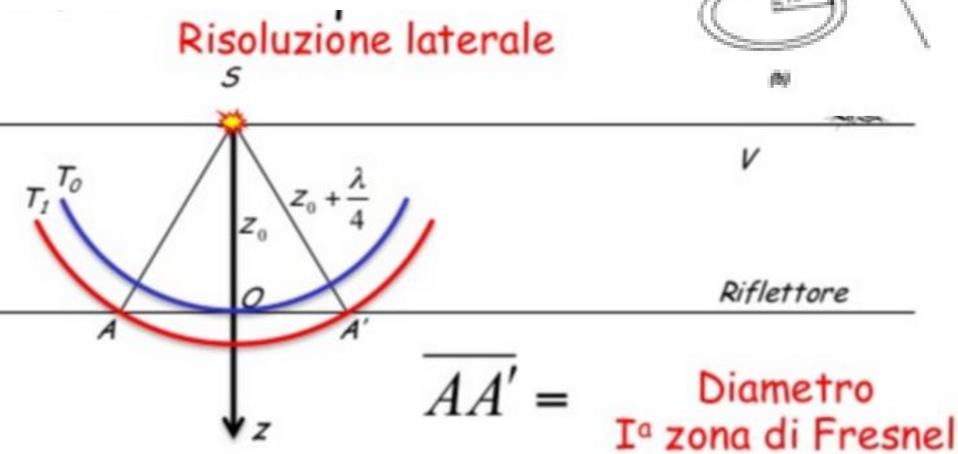
As already mentioned, we can consider a reflecting surface as a set of diffracting points. If S is source and record point, a constructive interference will be within the circonference with ray R (=OA).

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



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

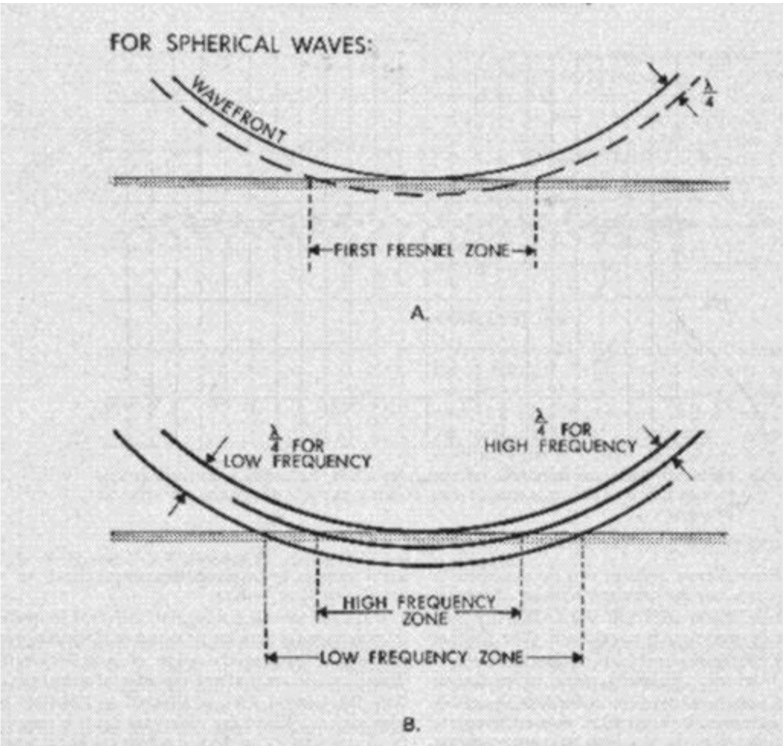


FIG. 7—First Fresnel zone for (A) spherical waves reflected from plane interface. (B) shows how size of the Fresnel zone depends on frequency.

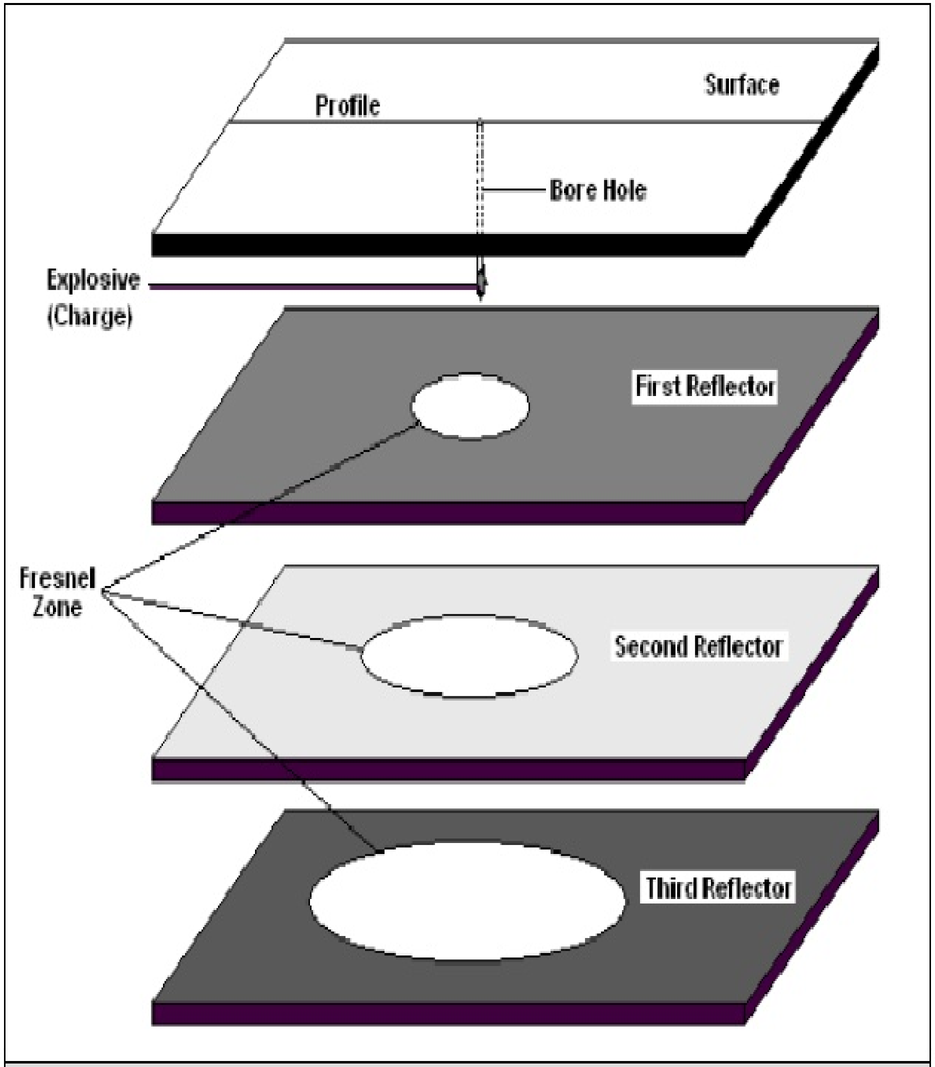
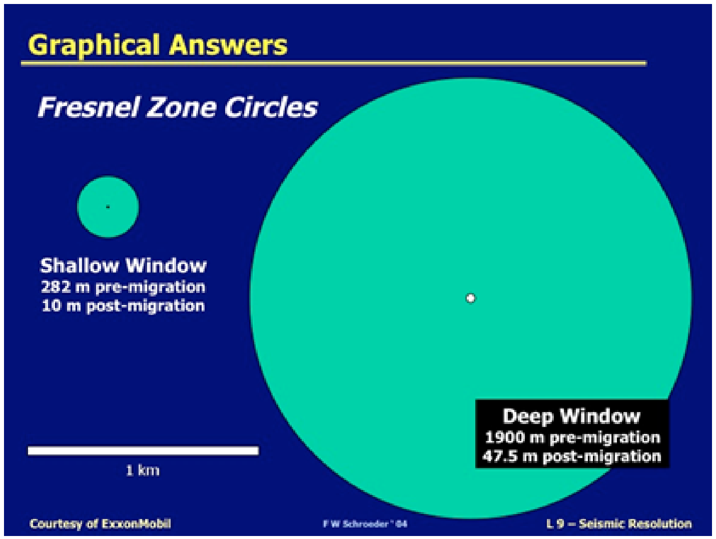


Fig 7(b) Fresnel Zone

The lateral resolution is sometimes approximately equal to the dominant wavelength

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



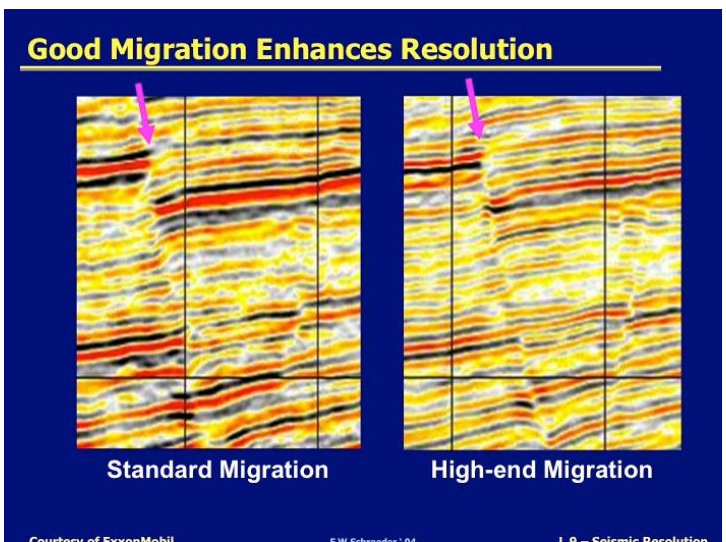


Table 11-2. Threshold for lateral resolution (first Fresnel zone).

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

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

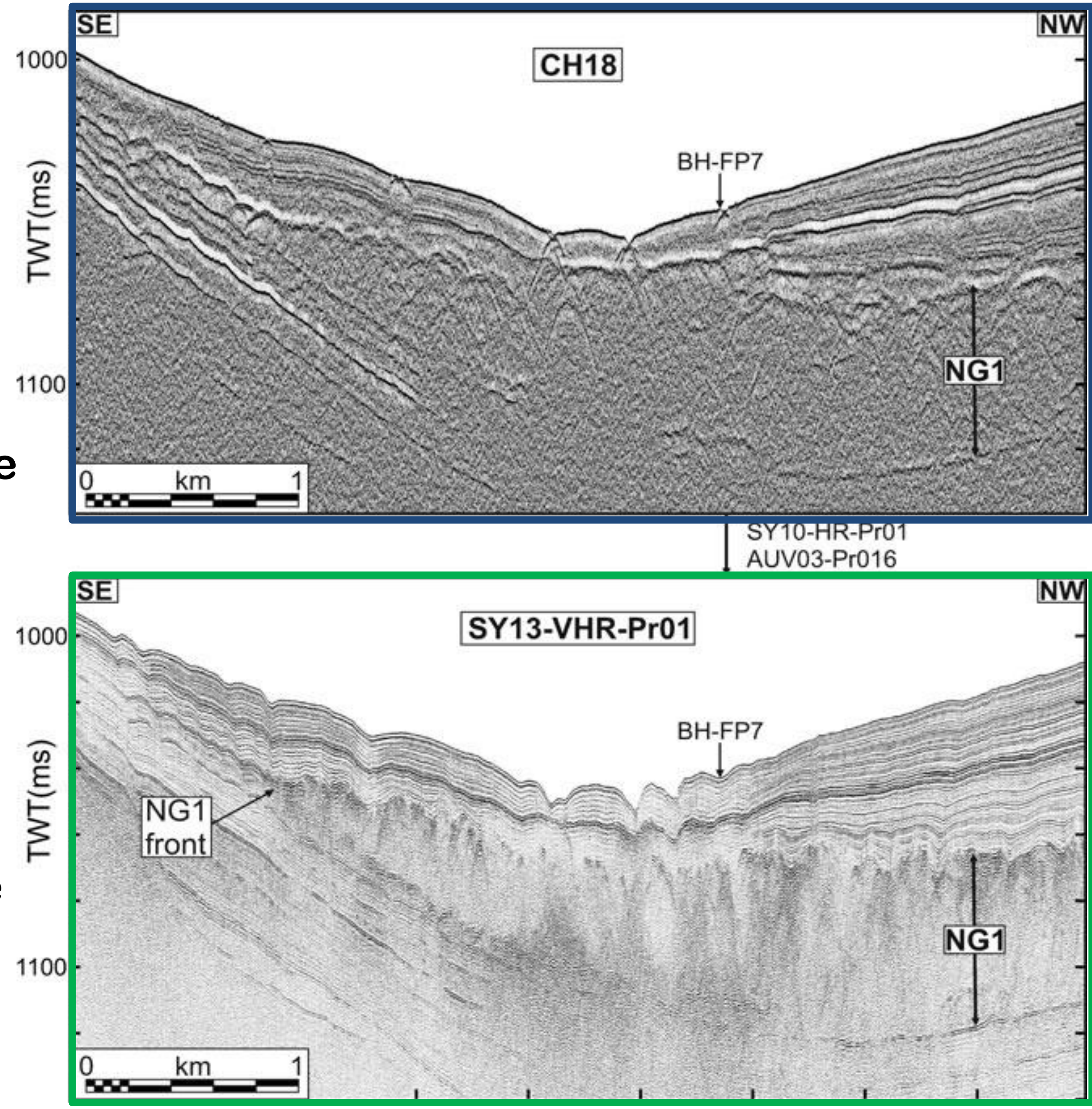
Example in the Nigeria offshore

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.

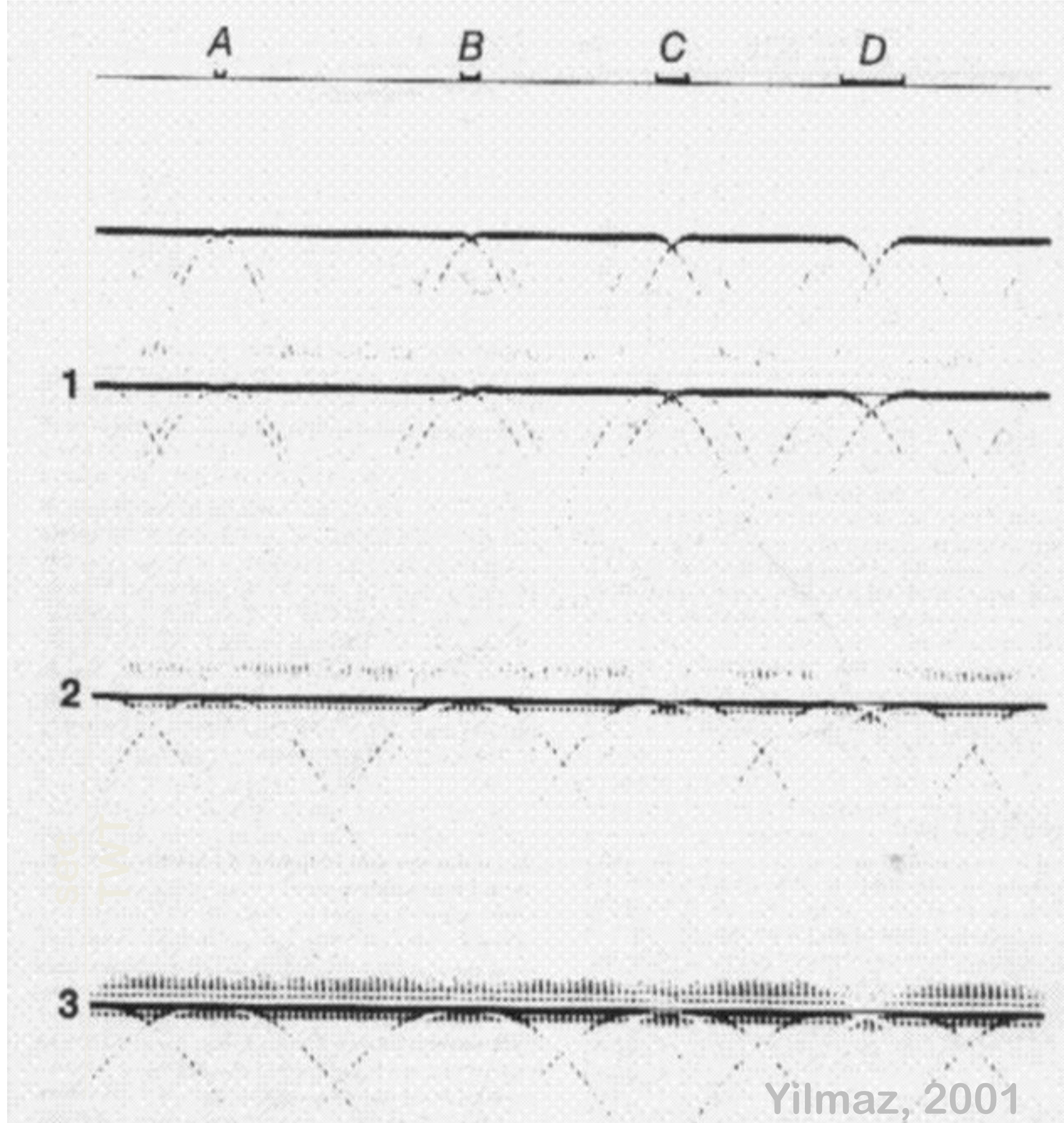


Effect of the reflectors depth
(0.5, 1, 2 e 3 sec 2wt)
on the lateral resolution

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

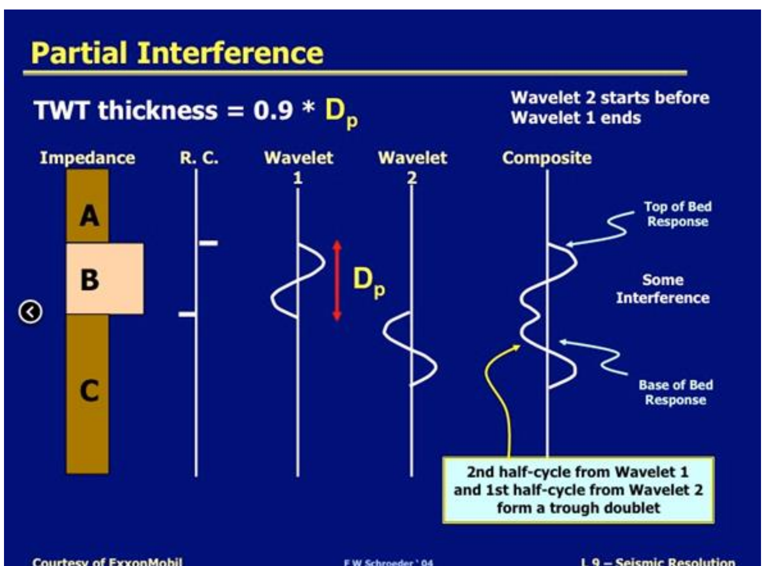
A, B, C, D are segments with different length related to <u>absence of reflectivity</u>:

the presence of diffraction becomes an important element



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*.



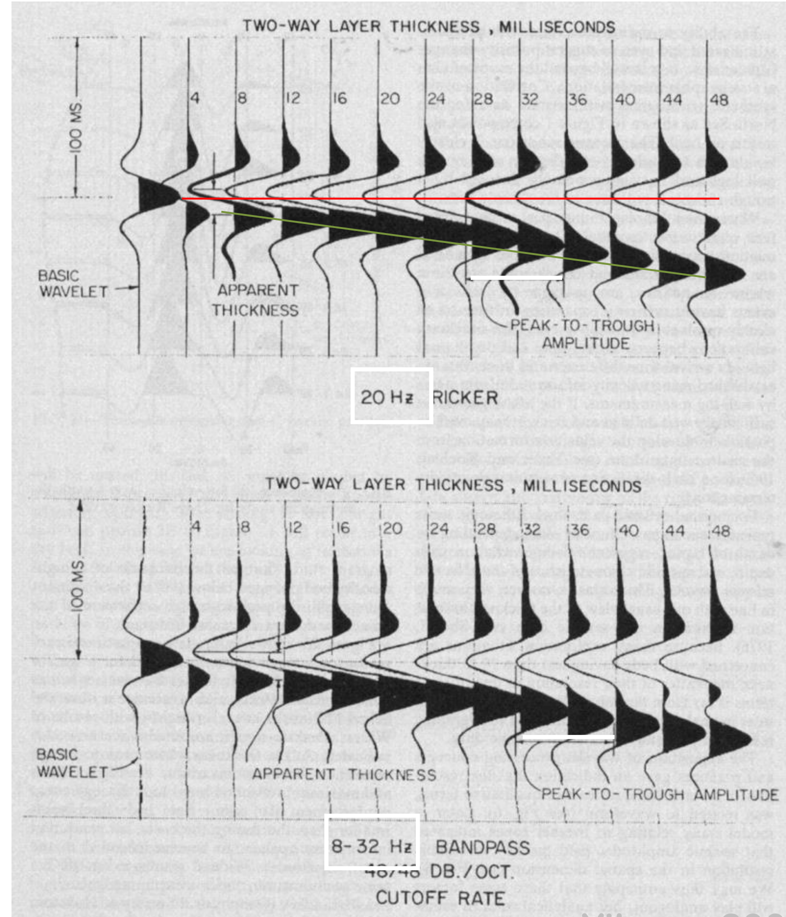
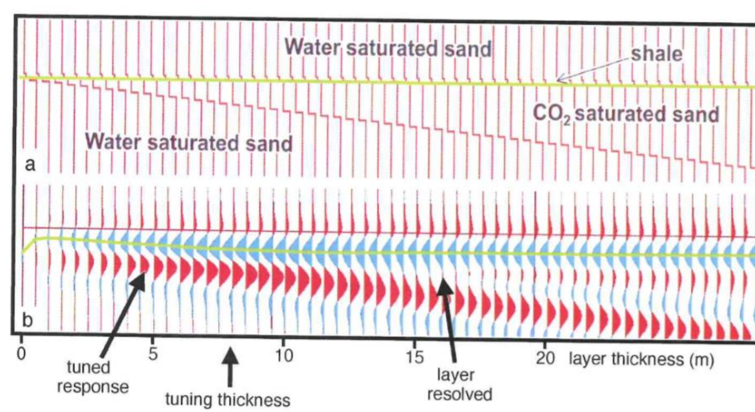


FIG. 24—Synthetic-seismogram studies of thin beds. Yilmaz, 2001



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

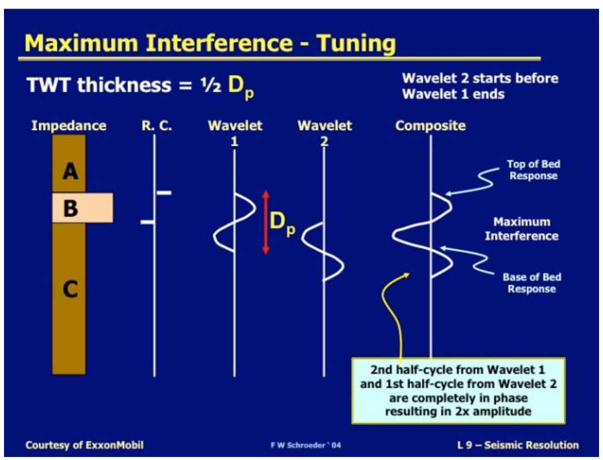
In a, b, e c the dominant frequency is changeable (vertical resolution – position of B - v/4f = 31,25; 21,08 e 16 m)

A= wedge closure

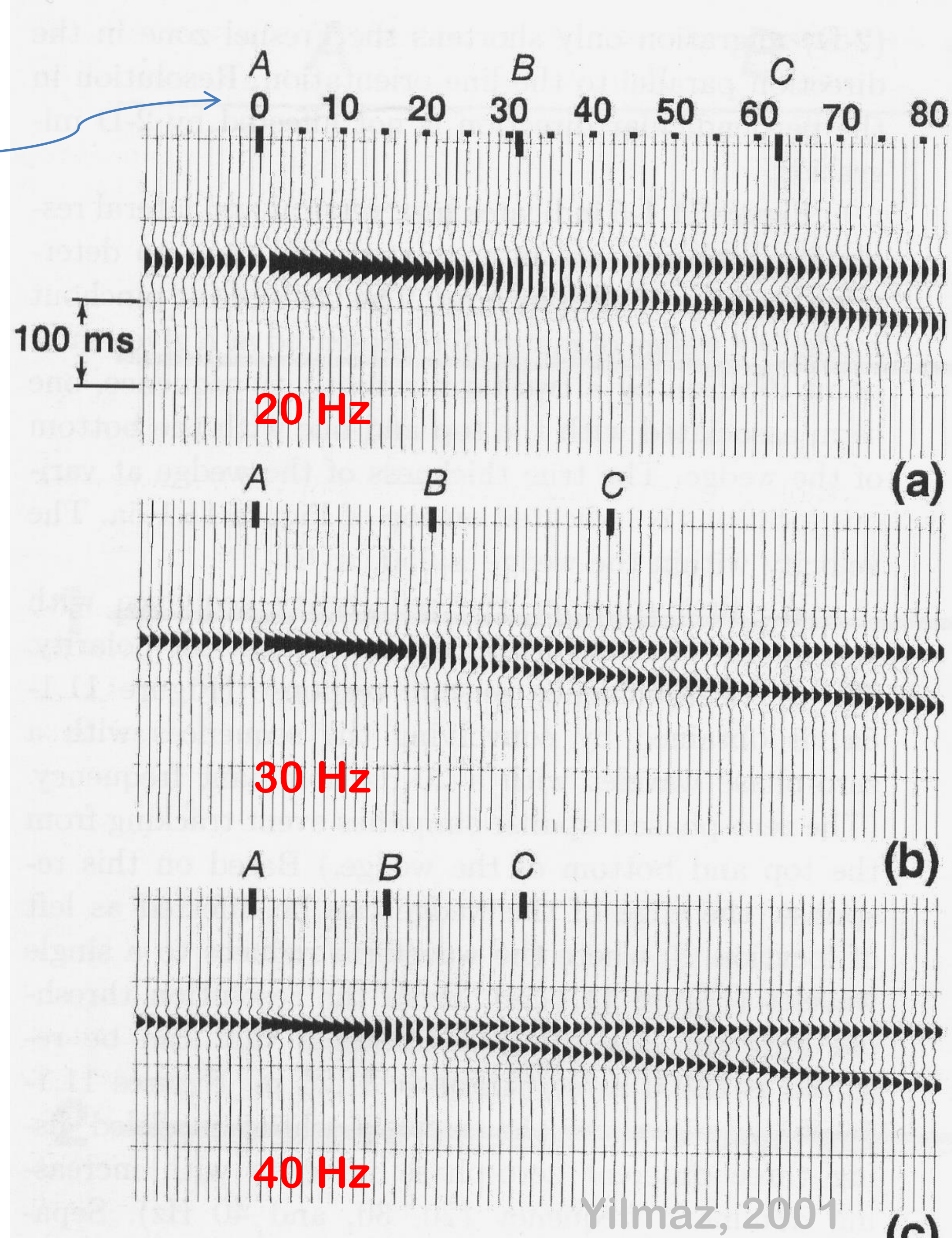
B= limit of the seismic resolution

C = point of extreme interference

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



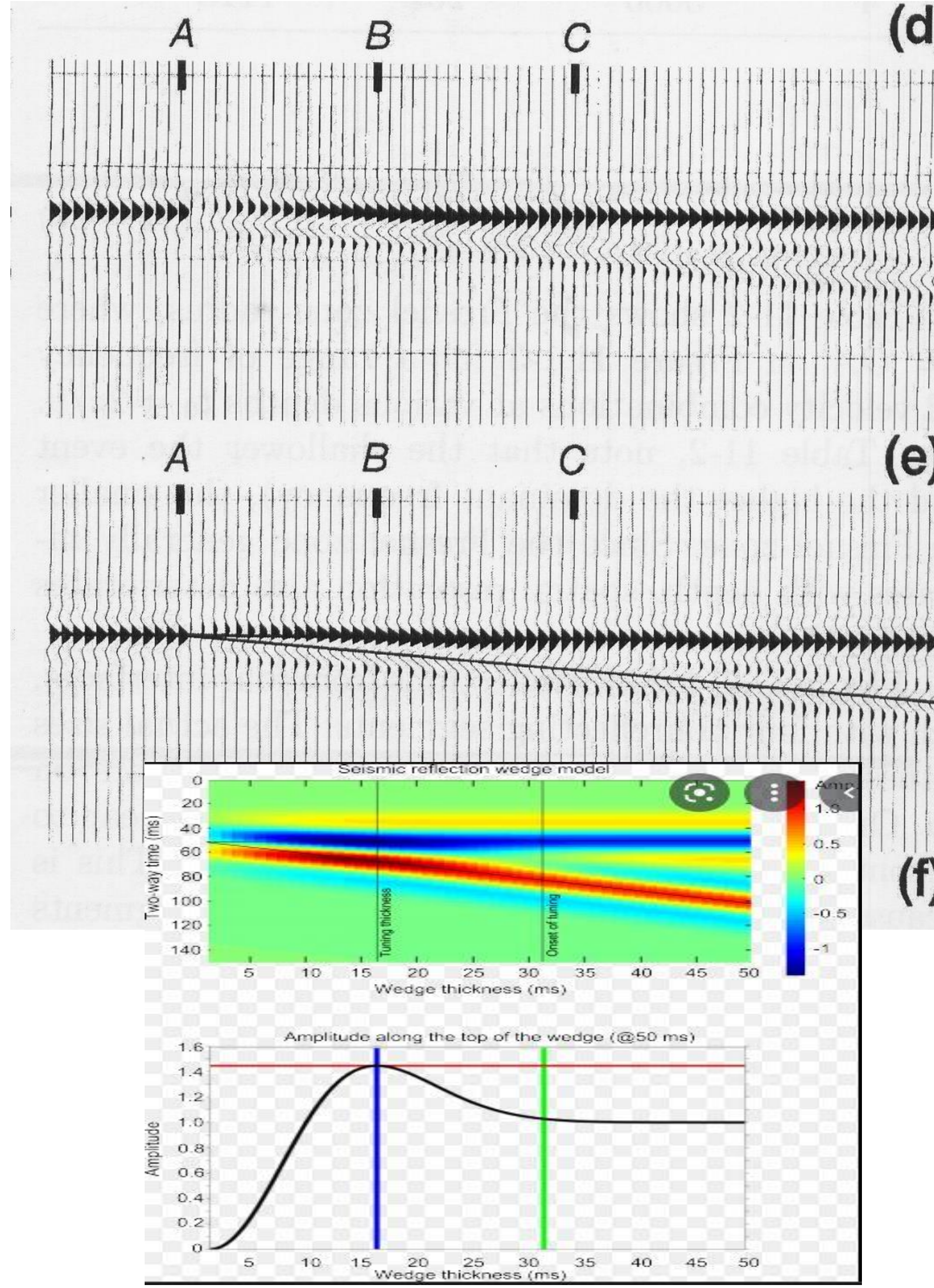
It allows to go beyond the resolution vertical limit, with the amplitude variation, as long as the S/N ratio is high.



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.



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.

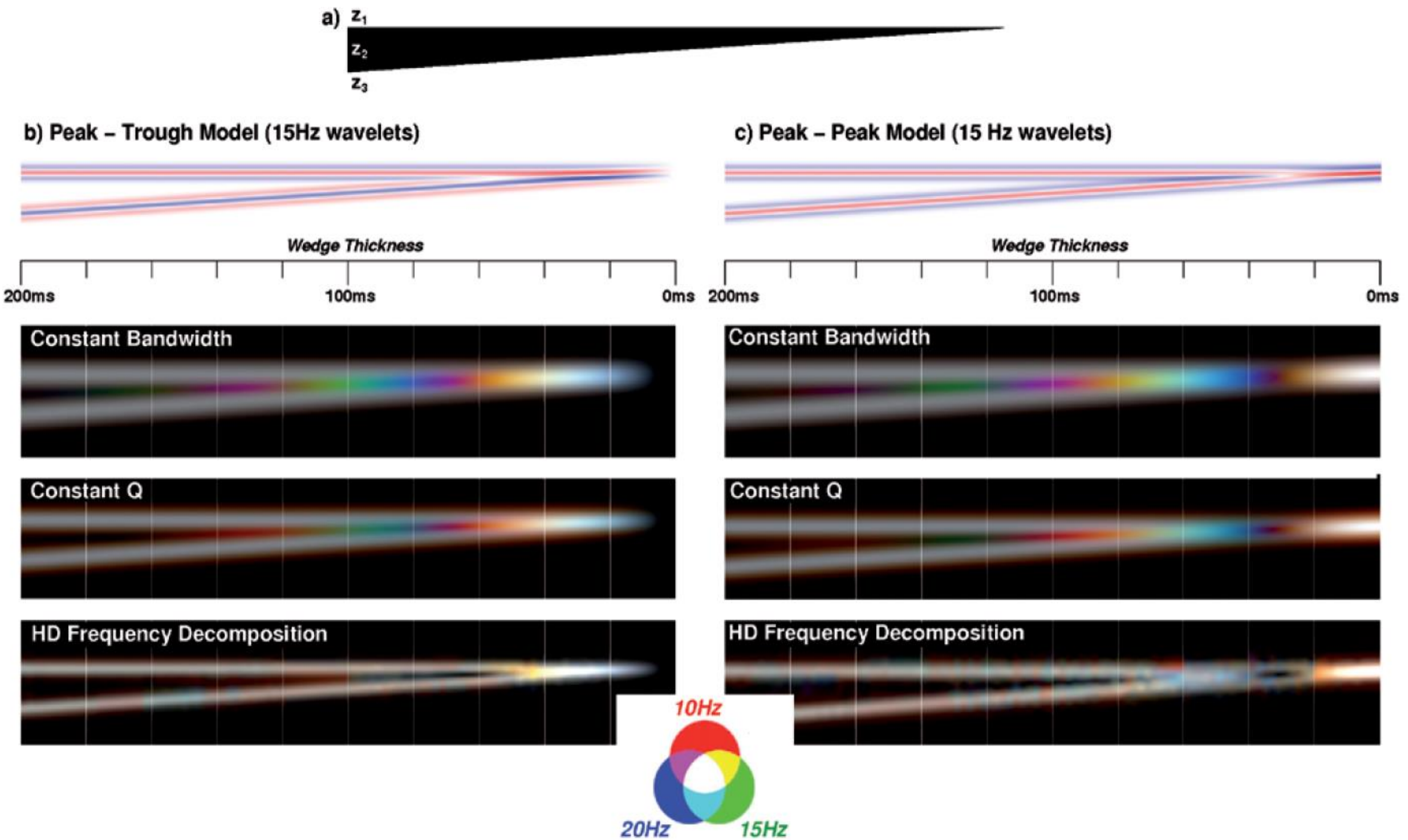


Figure 2 *(a) Three-layer wedge model, where acoustic impedances of the upper, mid and lower layers are denoted Z_1, Z_2 and Z_3, respectively. (b) RGB blends using the three magnitude volumes with a 15 Hz Ricker wavelet for a peak-trough model with $Z_1 < Z_2 > Z_3$. RGB blends using the three magnitude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

Some examples