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LAUREA MAGISTRALE IN GEOSCIENZE
Curriculum Geofisico
Curriculum Geologico Ambientale

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Geologia Marina

Parte I

Modulo 2.2 Metodi indiretti: Rilievi acustici e sismica a riflessione

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    - Seismic interpretation software
    - Seismic data web sites
    - Seismic trace display
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- Resolution: vertical and lateral
    - Deconvolution
    - Migration
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- Gas seeping features
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- # INTRODUCTION

The Seismic method is the powerful geophysical techniques for imaging the Earth's interior.

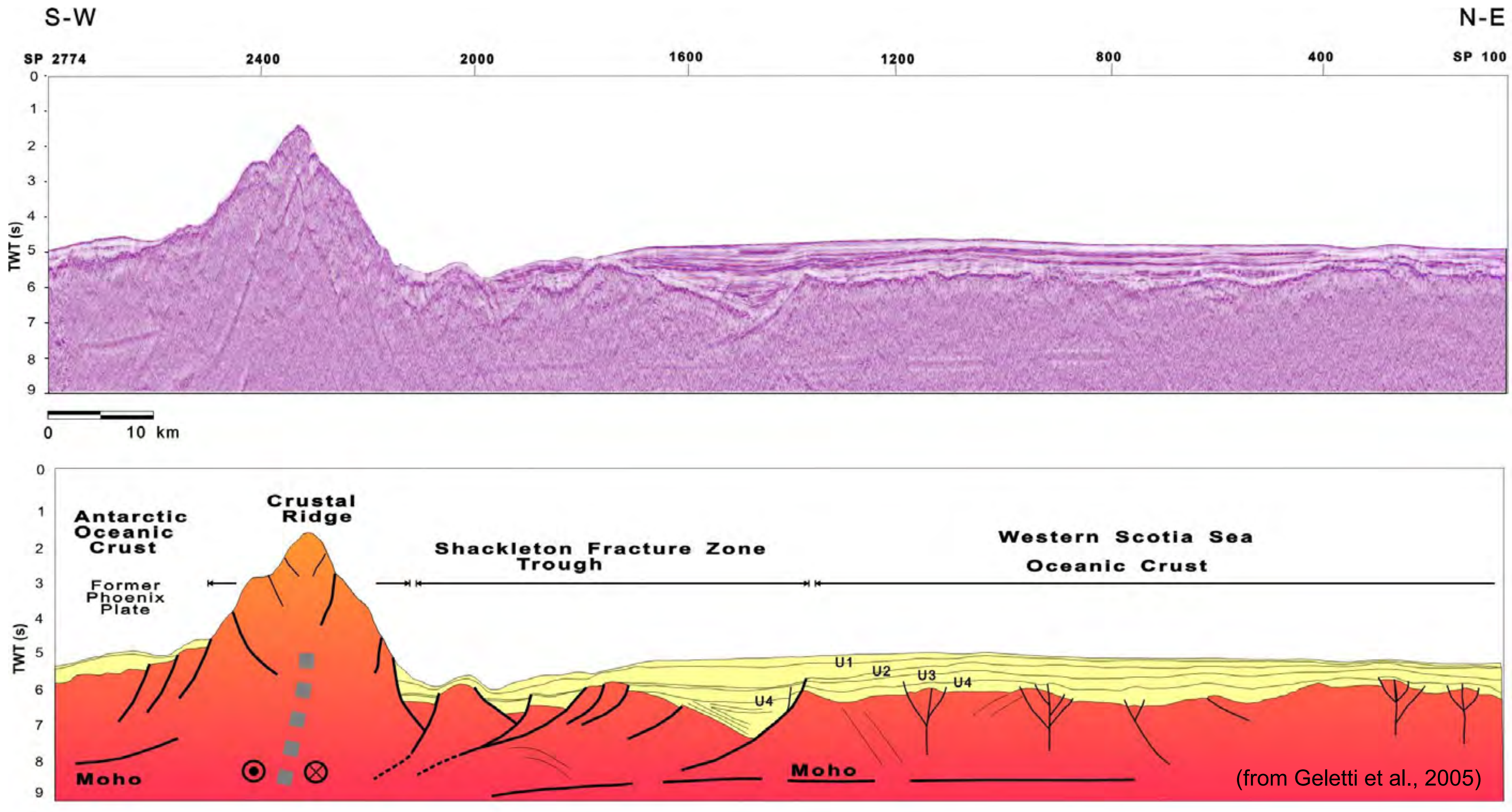
This artificial source method involve the generation of seismic waves whose propagation velocities and transmission paths through the subsurface are mapped to provide information on the distribution of geological boundaries at depth.

An alternative method of investigation subsurface geology is, of course, by drilling boreholes, but these are expensive and provide information only at discrete locations. Nevertheless, seismic surveying does not dispense with the need for drilling because it can give a geological meaning to the seismic reflectors.

Seismic Reflection Interpretation

- Fundamental in applied research to geosciences
- Provides information regarding:
  - geometries of stratigraphic sequences
  - geometries of structural and tectonic elements
  - velocity of seismic waves
  - lithological characteristics

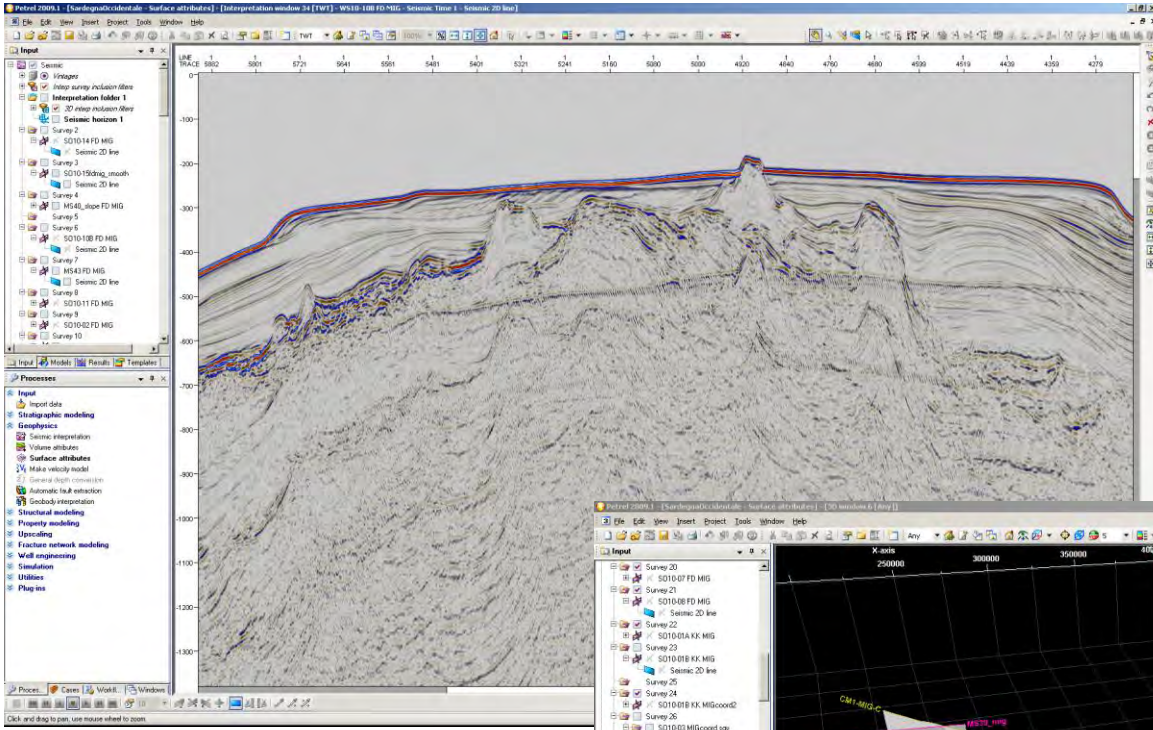
The seismic interpretation attributes geological meaning to geophysical data and produces reconstructions of:
2D sections, structural maps, fault systems, slumping and geo-hazard etc.



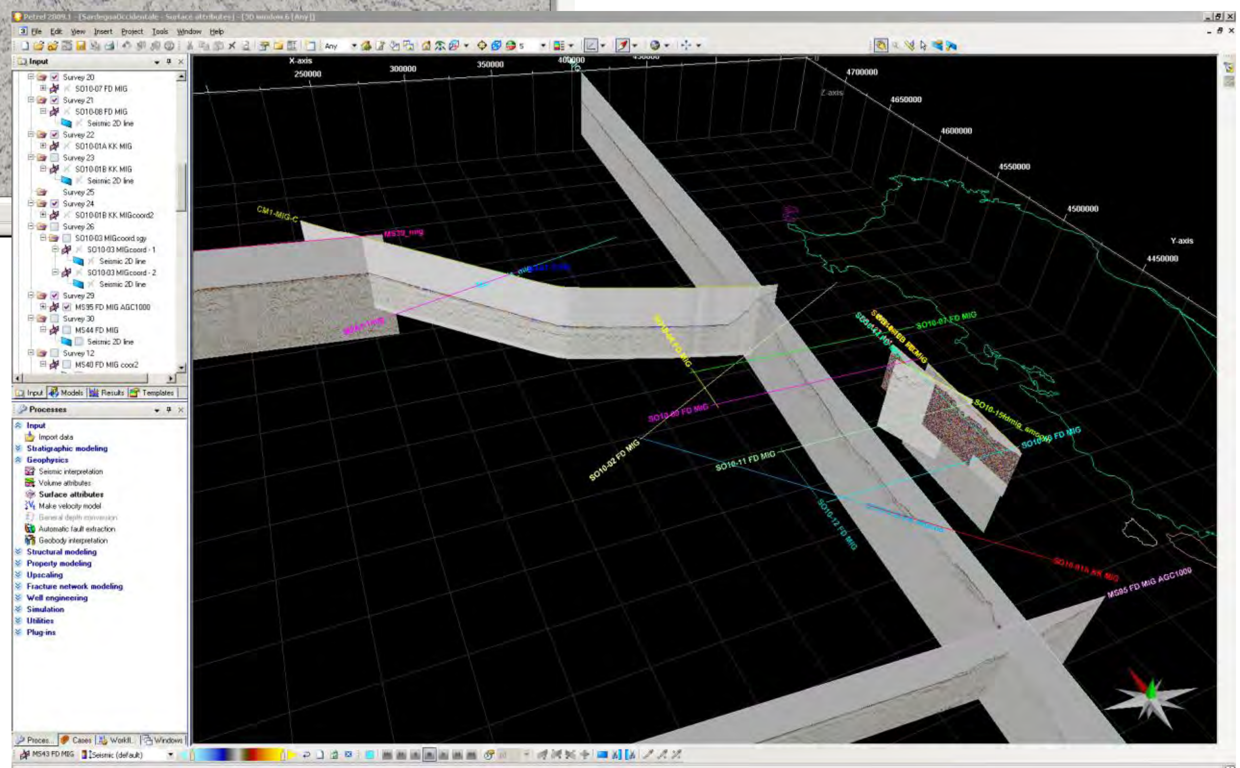
Crustal seismic section: example of seismic interpretation

The seismic interpretation attributes geological meaning to geophysical data and produces reconstructions of:
2D sections, structural maps, fault systems, slumping and geo-hazard etc.
In the image above, it shows a crustal seismic section. Water depth of 5 seconds of twt is a depth of 3.750 km because the velocity of the seismic wave in the water is 1.5 km/s. Under the seafloor the seismic velocities rise to 5/6 km/s at the Moho discontinuity that it is about 7 km deep. The Moho is the discontinuity between the solid crust and the upper mantle.

Interpretation software



Seismic section

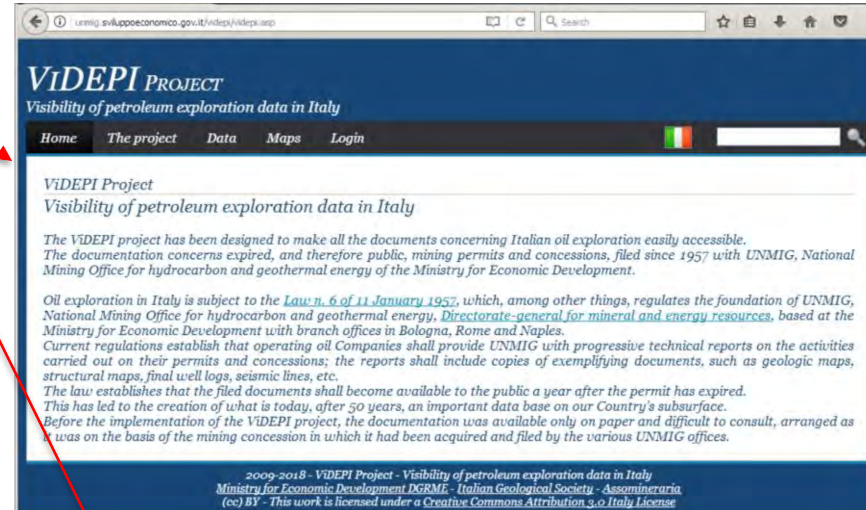


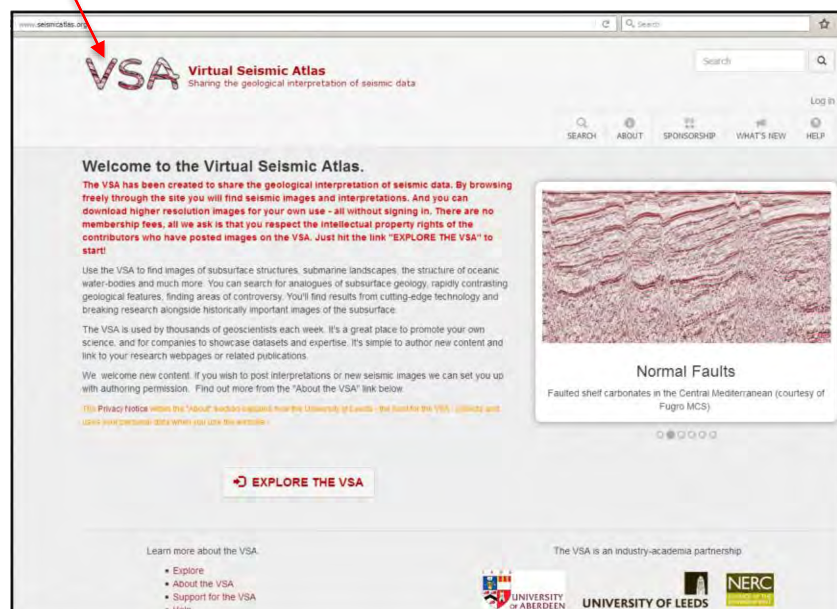
Position map of 2D seismic survey by an interpretation software

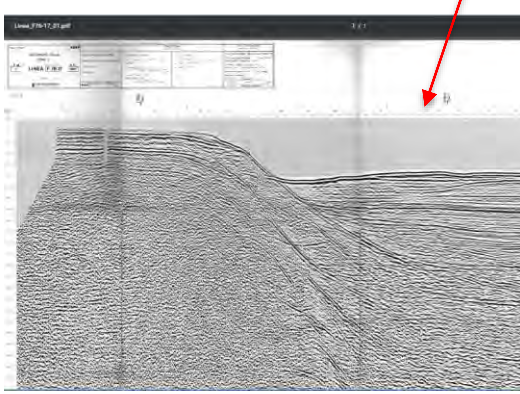
Where can we find the seismic profiles? There are public websites where we can view and download both the seismic lines and the well data. For example there are ViDEPI seismic website and Virtual Seismic Atlas also VSA.

Seismic data websites:

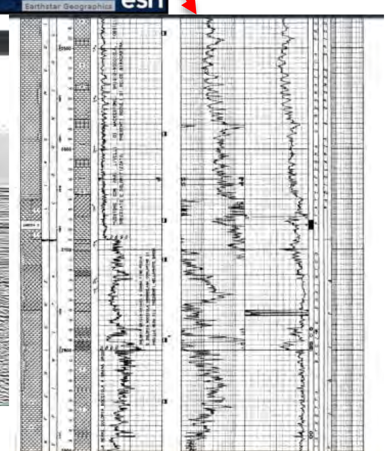
- http://unmig.sviluppoeconomico.gov.it/videpi/
- http://see-atlas.leeds.ac.uk:8080/home.jsp



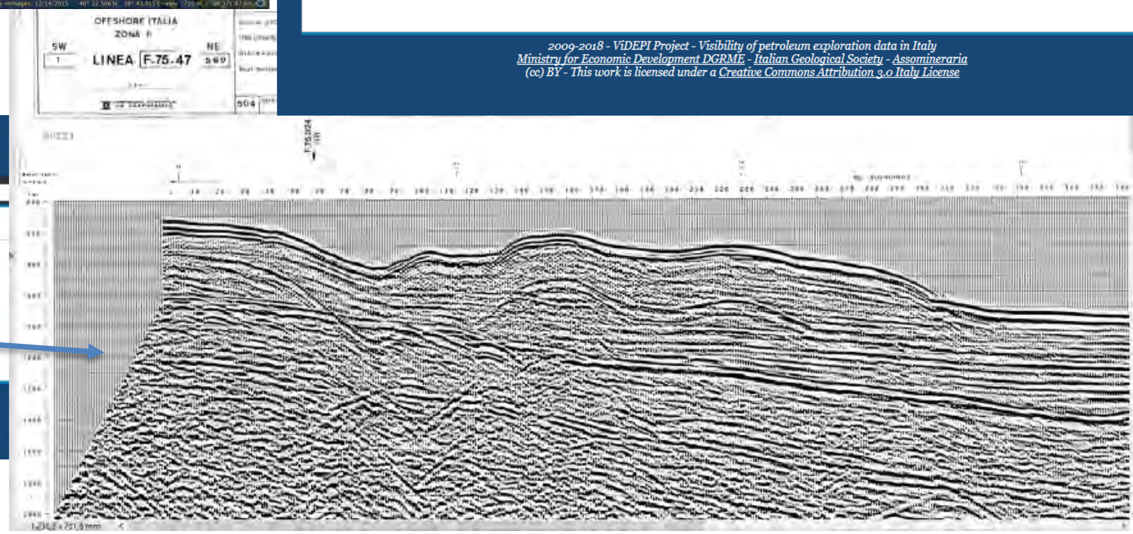




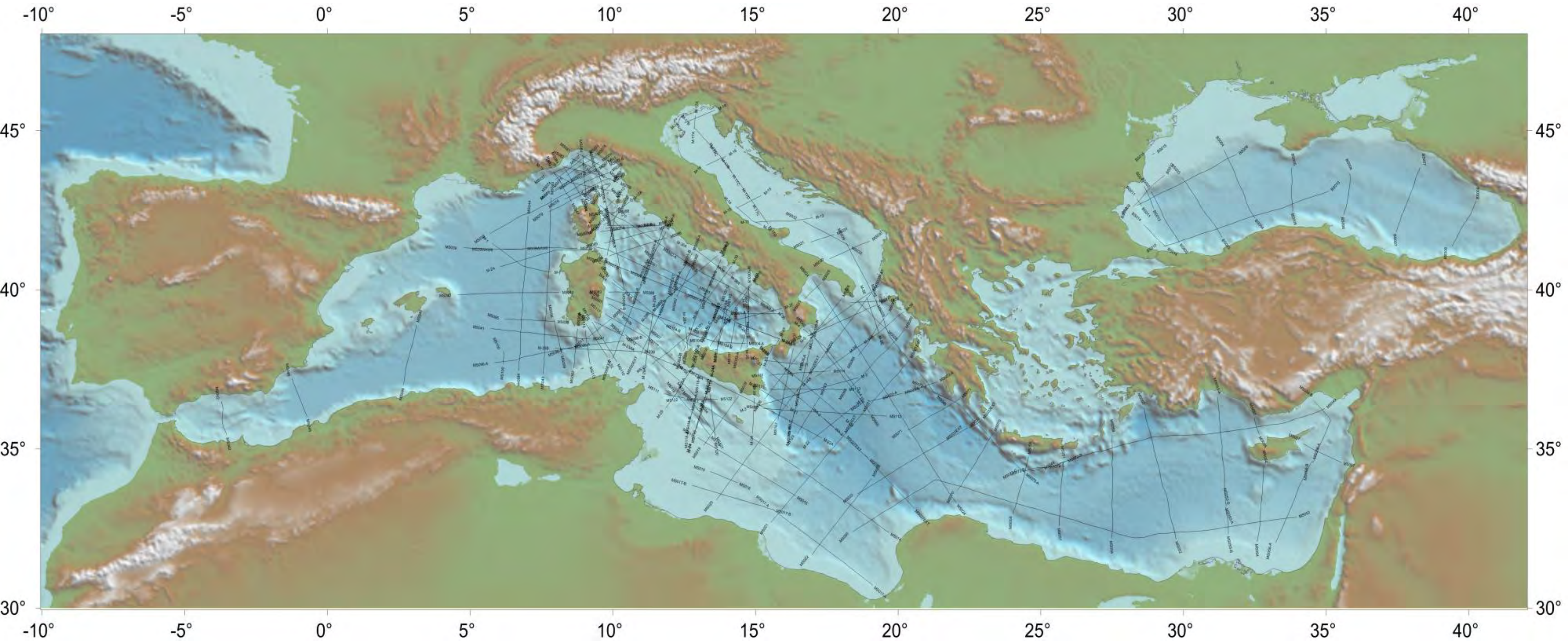
well



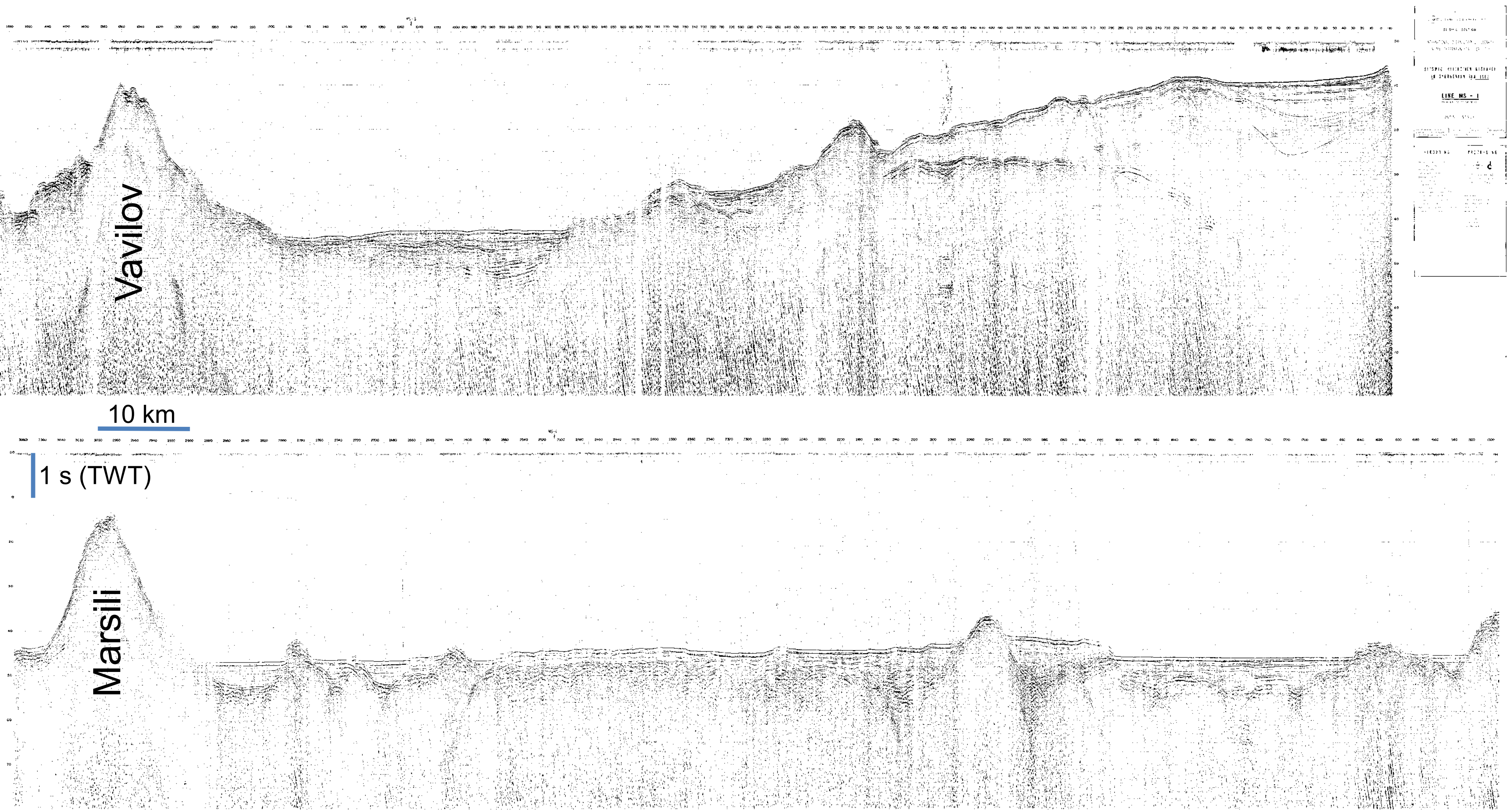
ViDEPI dataset



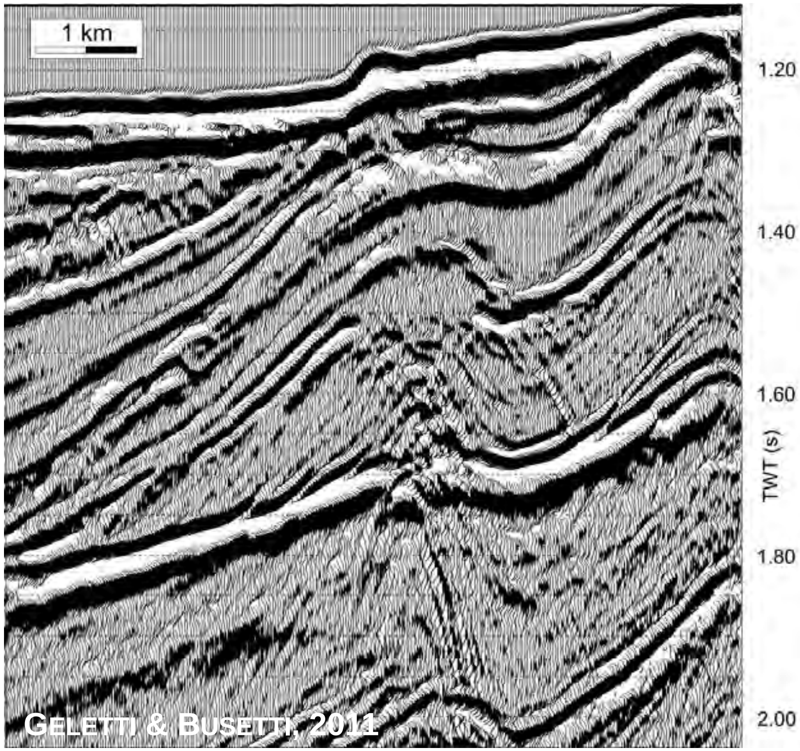
From the ViDEPI site you can view the position map of seismic lines divided into exploration areas. These seismic profiles and well have been acquired for oil exploration, but are now also available for scientific research. This page contains links to the position files in kml format that can be used with the Google Earth software. The seismic profiles can be downloaded in pdf format.



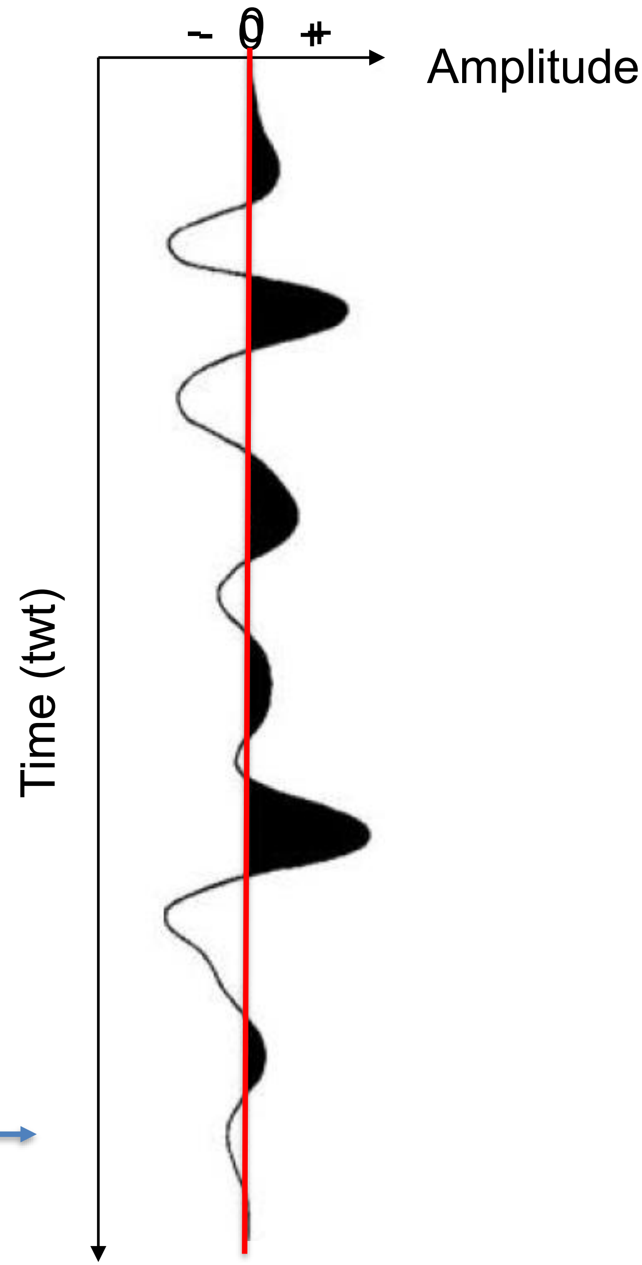
Position map of the seismic profiles of the Italian geophysical exploration projects MS and CROP acquired in 1969 – 1982 and 1991-1995 respectively



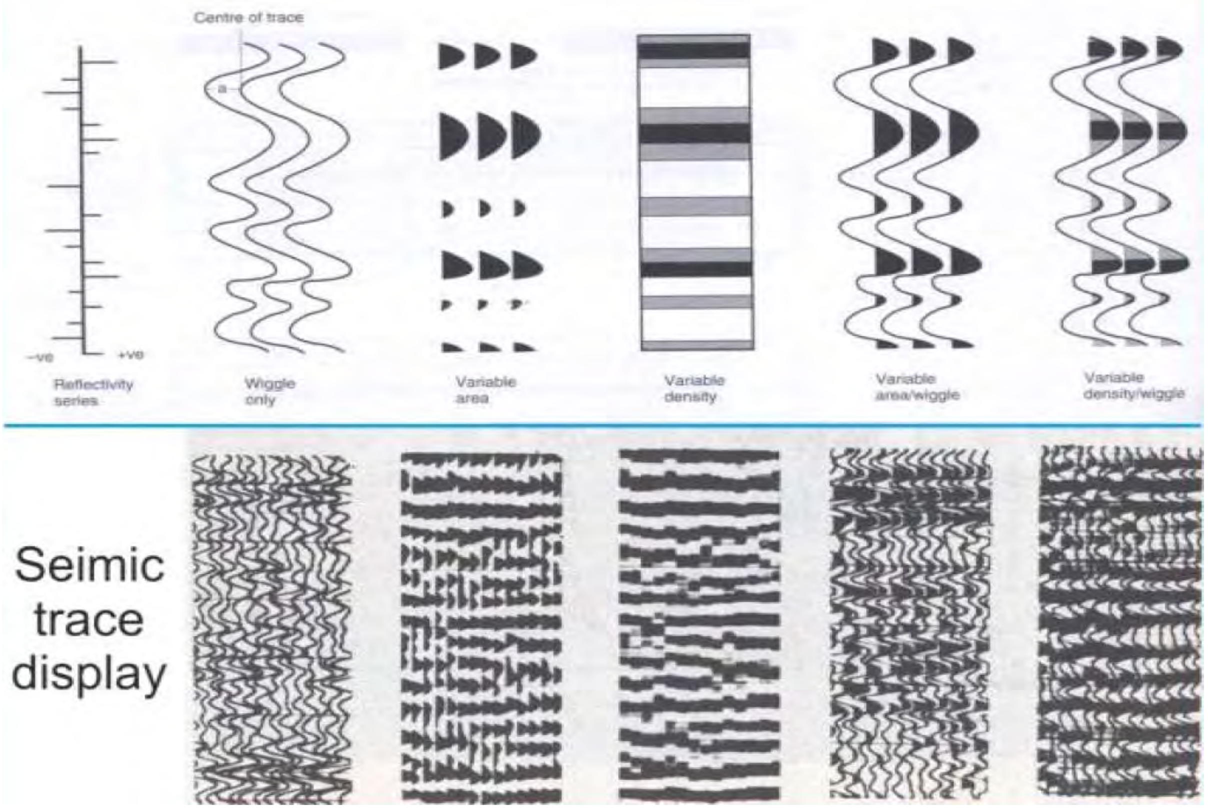
Examples of vintage crustal seismic sections MS 1 acquired in Tyrrenian Sea in 1969



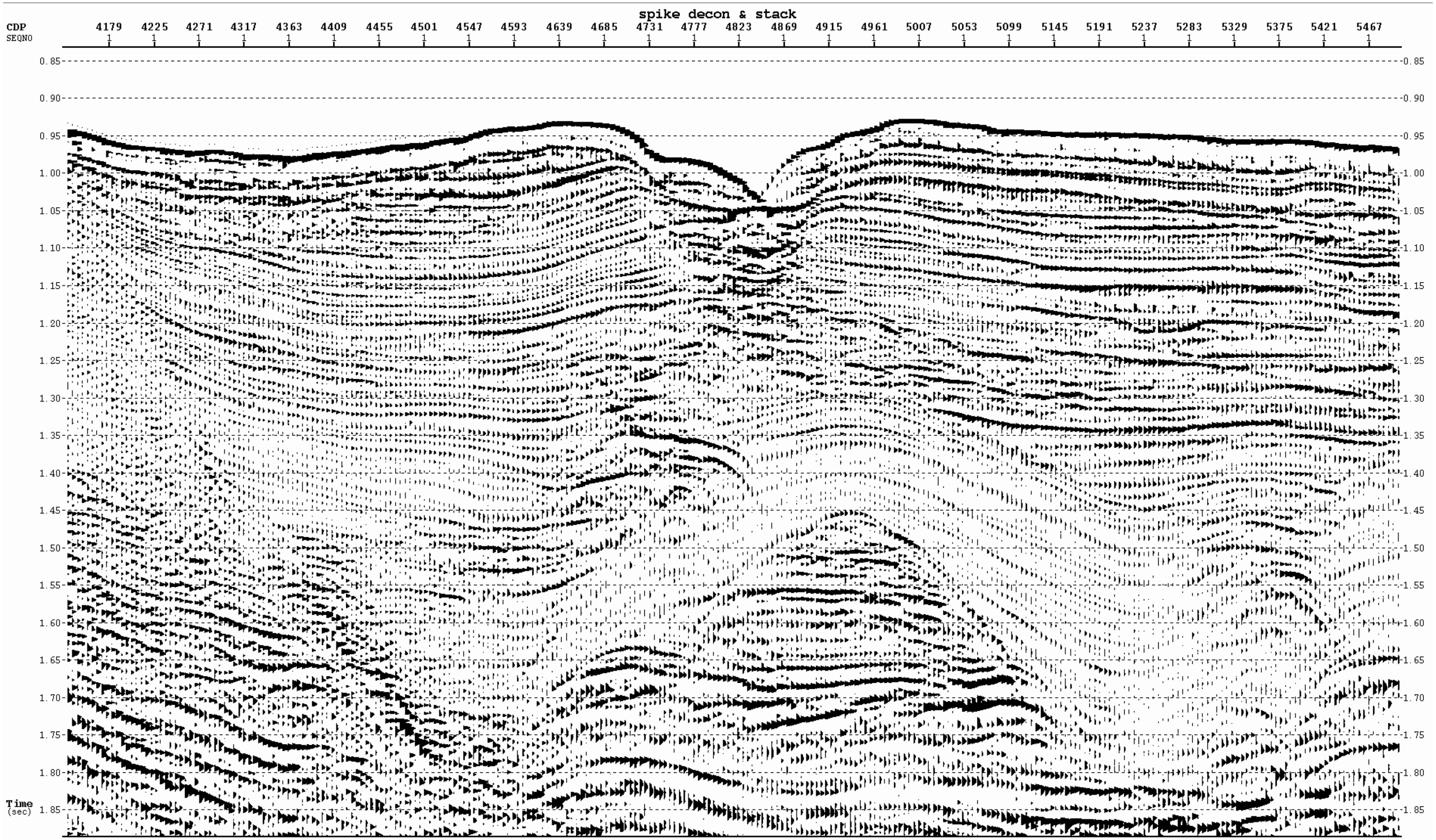
Example of a part of seismic line displayed in wiggle/variable area. On the right is shown a single trace that constitutes the section above (seismogram)



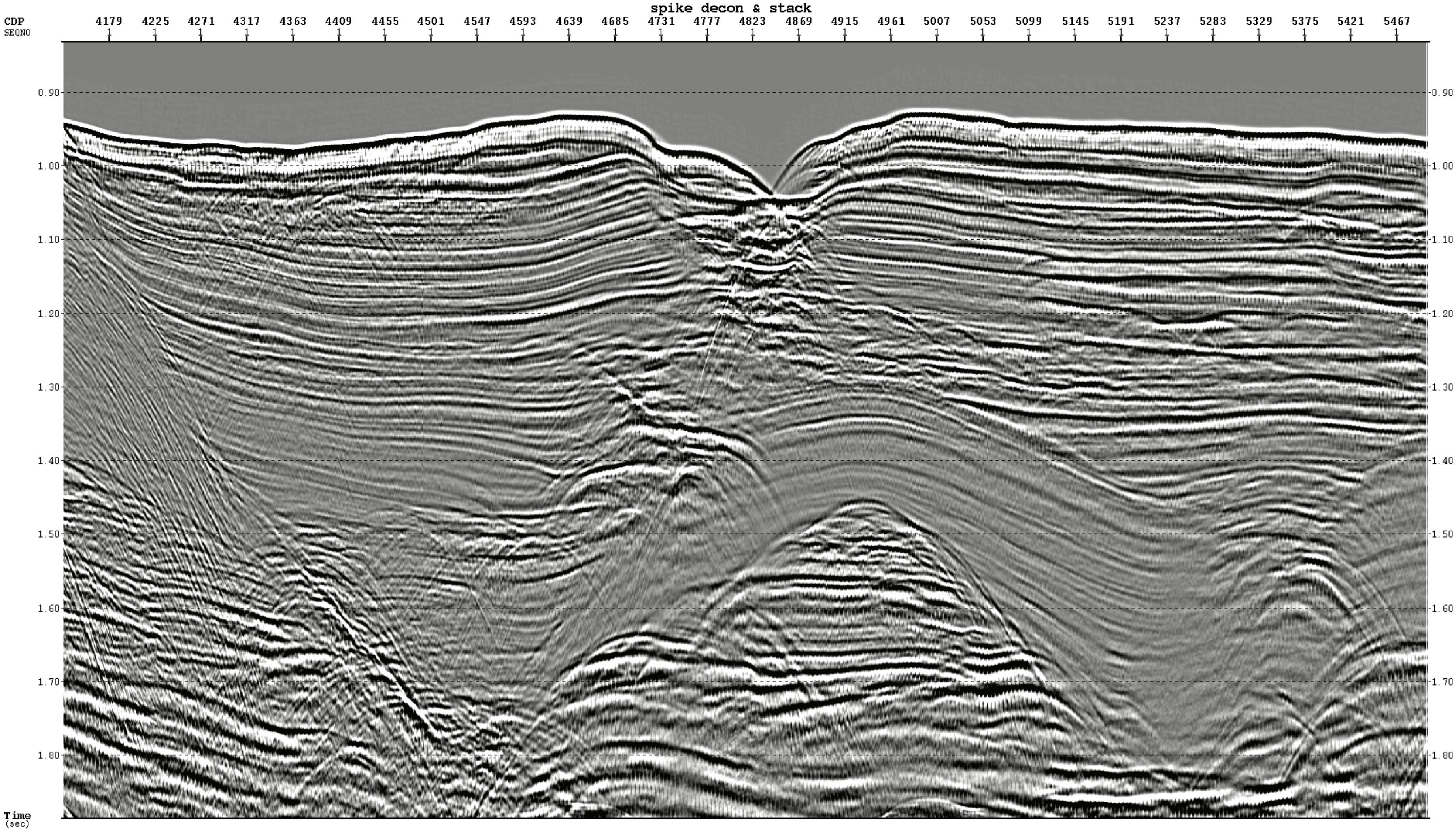
Seismogram: this is an example of a single trace of a seismic profile as shown in the figure above



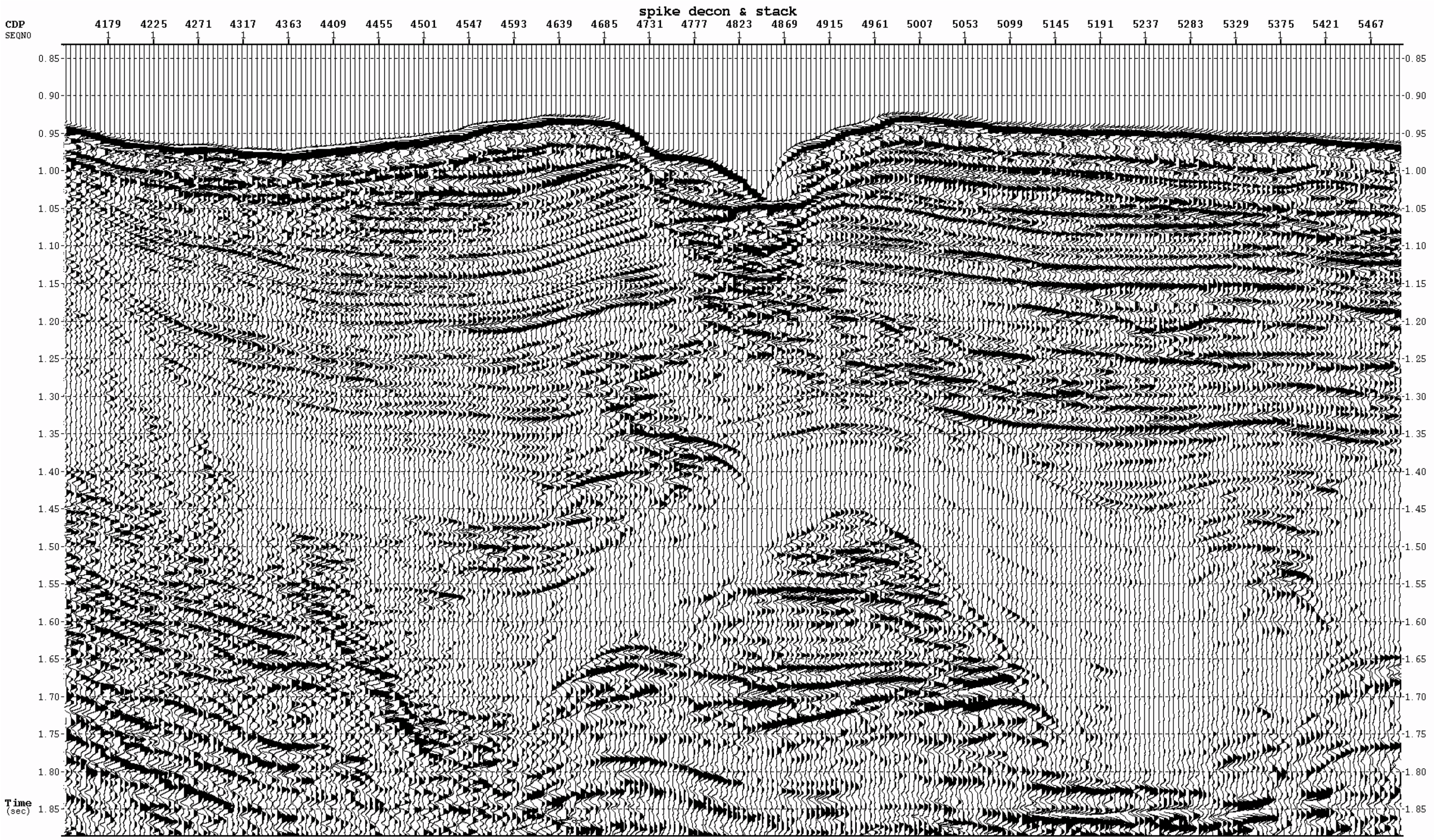
How can we display the seismic data? There are various ways to depict traces in a seismic sections. For example we can have the representation of the traces in wiggle only or in variable area where is present only the positive part of the seismogram like this! (see the figure). In Variable density in grey scale like this or they can also be in color as we'll see in the next slides. We can also depict traces in mixed composition like variable area plus wiggle or variable density plus wiggle.



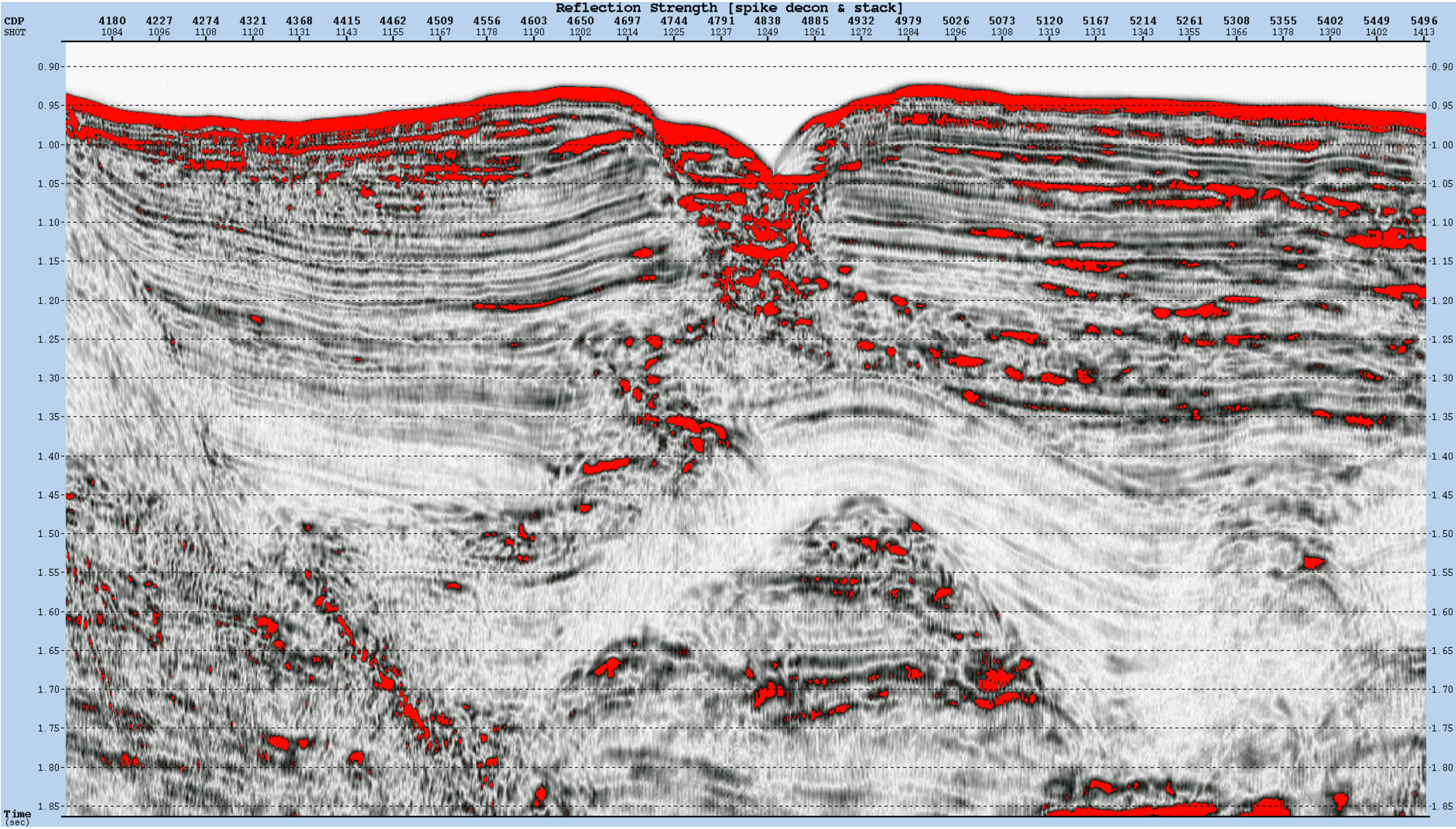
Seismic section displayed in “variable area”



Seismic section displayed in “variable density” in grey scale



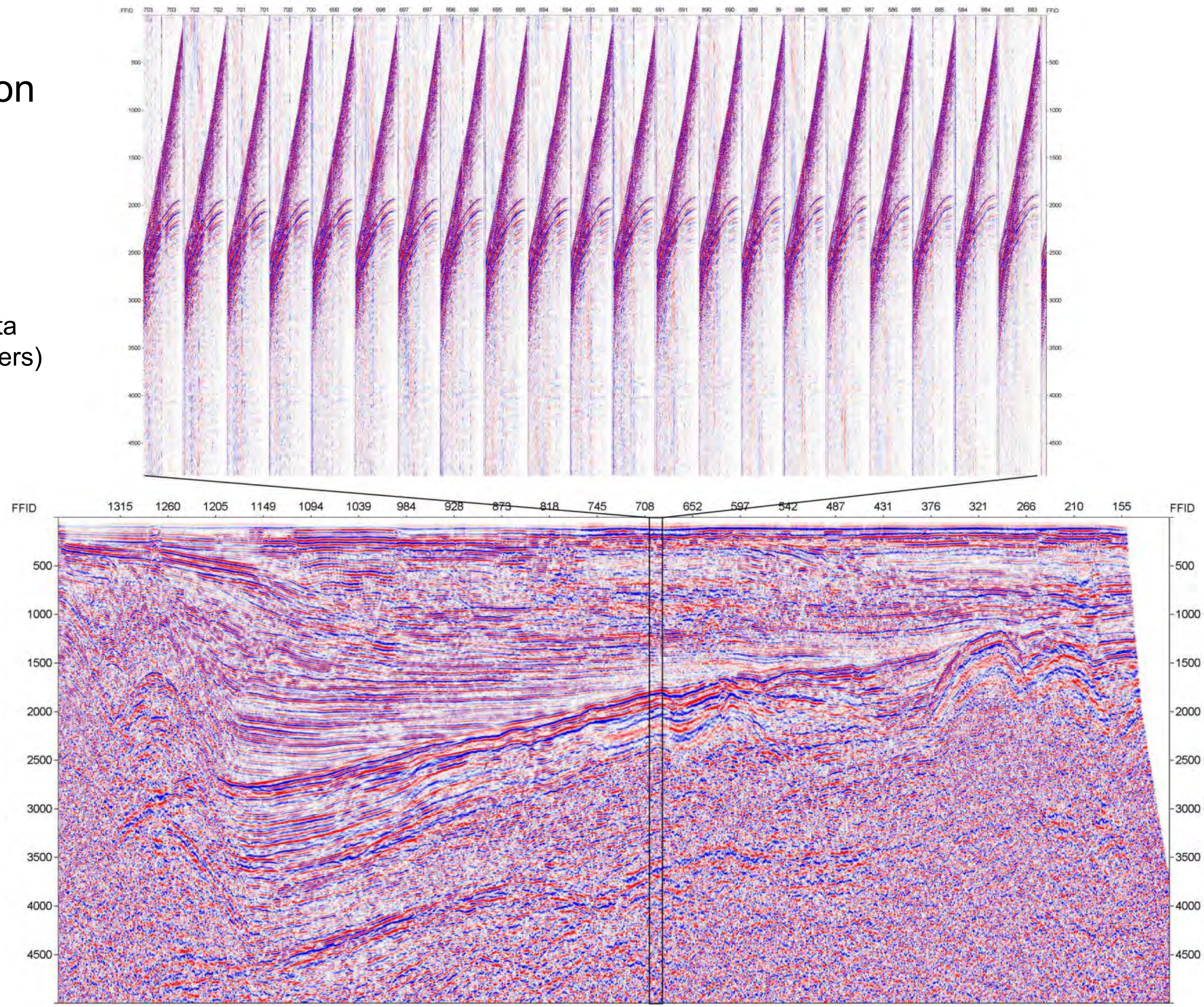
Seismic section displayed in “wiggle + variable area”



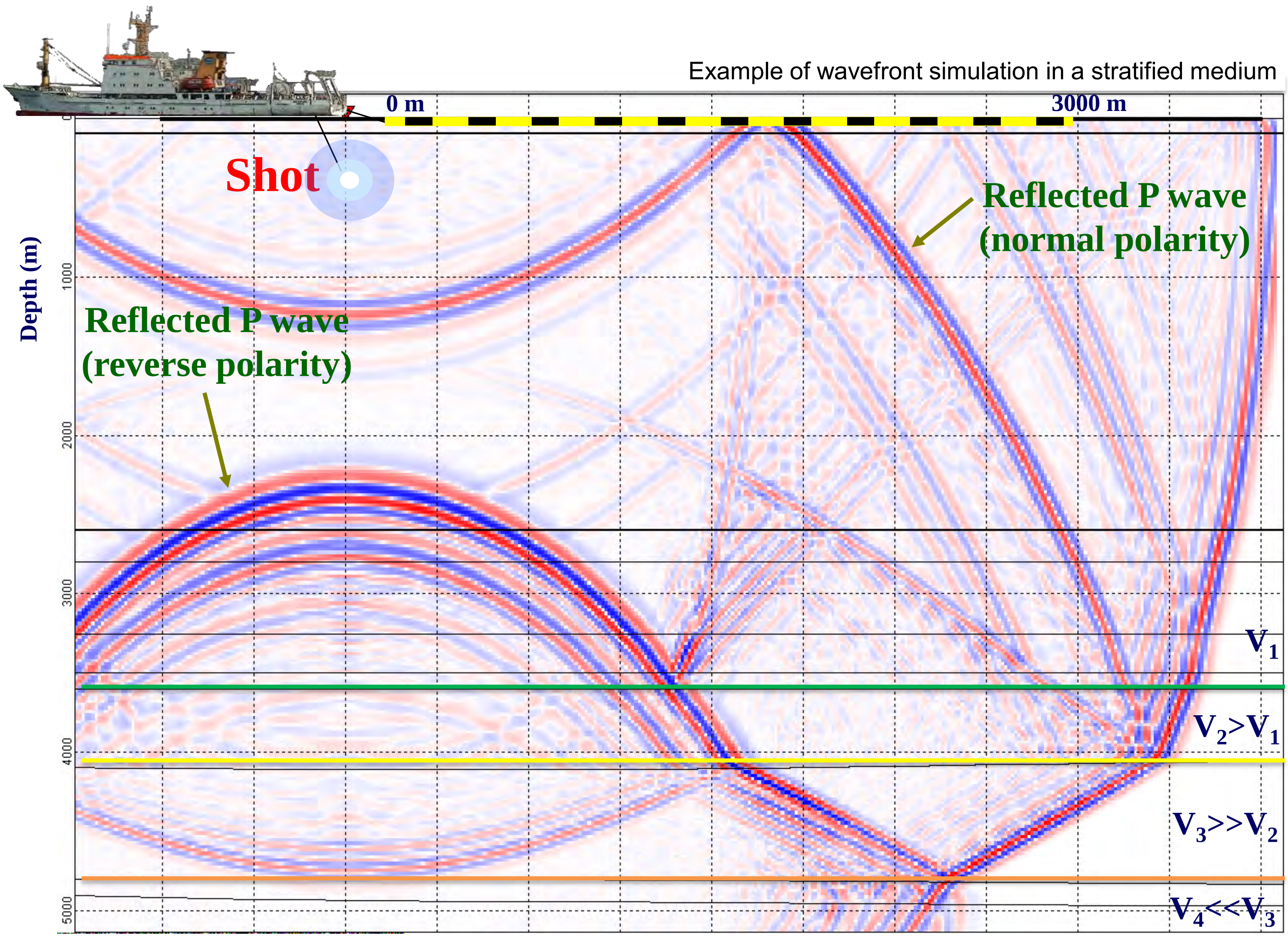
Seismic section displayed in grey scale variable density with the "enhanced reflections" in red colour

MultiChannel Seismic reflection data (MCS)

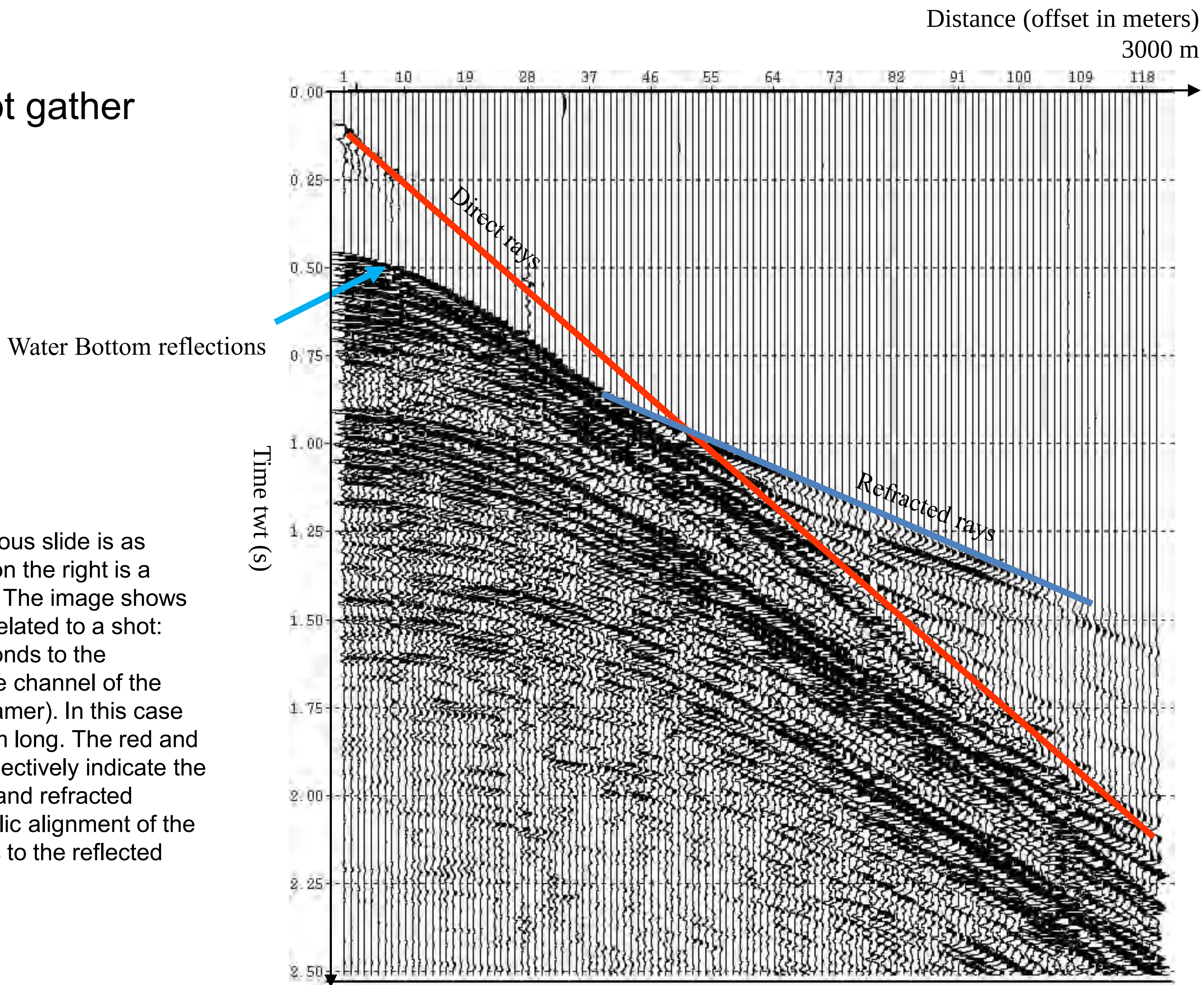
Raw data
(shot gathers)



Processed data
(stack section)


Example of wavefront simulation in a stratified medium
0 m
3000 m
Shot
Depth (m)
1000
2000
3000
4000
5000
Reflected P wave
(normal polarity)
Reflected P wave
(reverse polarity)
V_1
$V_2>V_1$
$V_3>>V_2$
$V_4<<V_3$

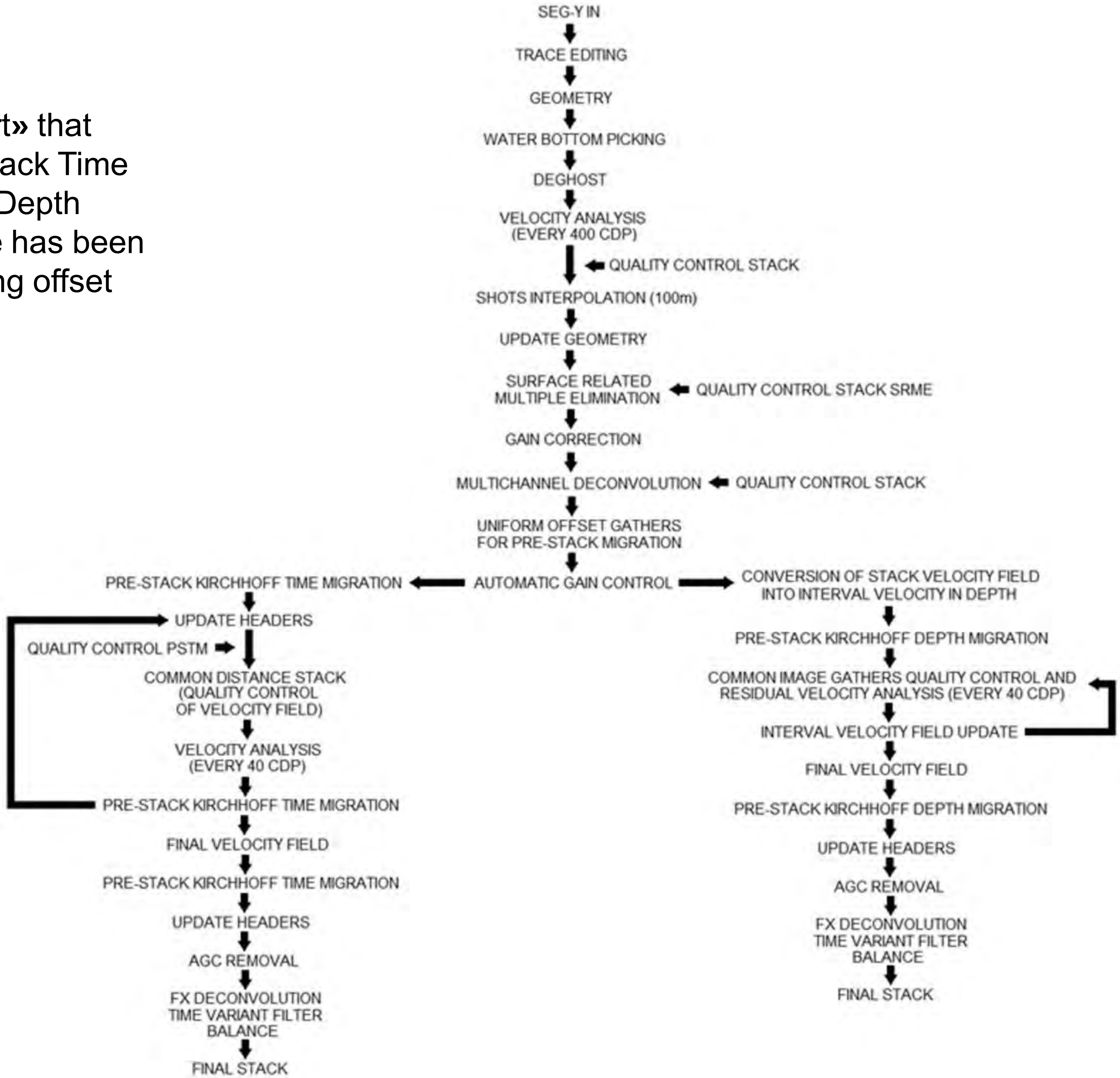
Shot gather



A result of the previous slide is as follows: the image on the right is a marine field record. The image shows 120 seismograms related to a shot: each trace corresponds to the recording of a single channel of the seismic cable (streamer). In this case the streamer is 3 km long. The red and blue segments respectively indicate the alignment of direct and refracted waves; the hyperbolic alignment of the events corresponds to the reflected events.

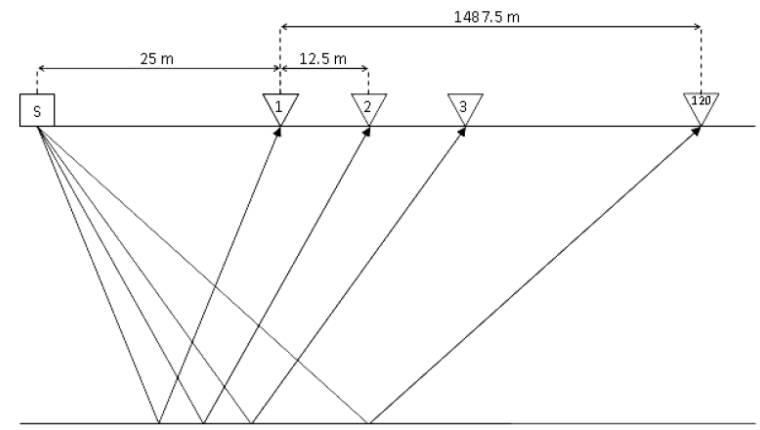
Example of «processing flow chart» that define two different output: Pre-Stack Time Migration (PSTM) and Pre-Stack Depth Migration (PSDM). This sequence has been applied to «crustal data» with «long offset streamer».

The main steps are the following:
Reformating
Editing
Sorting
Gaining
Deconvolution
Velocity analysis
NMO correction and stacking
Migration



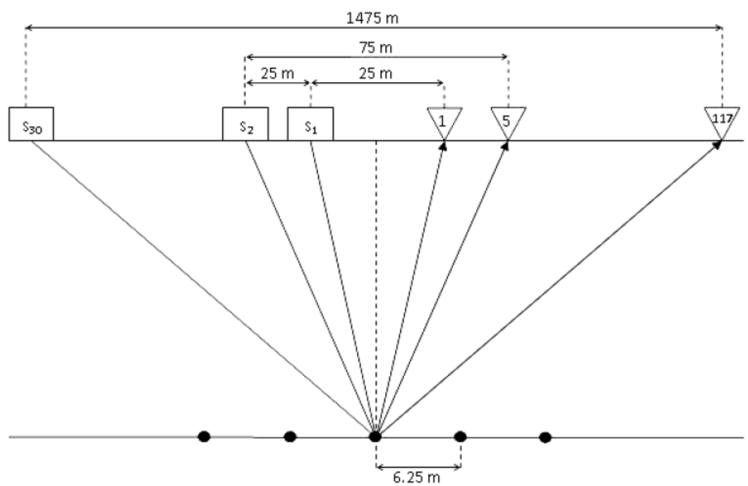
CDP Sort

Shot gather



to

CDP gather



Common Depth Point (CDP)

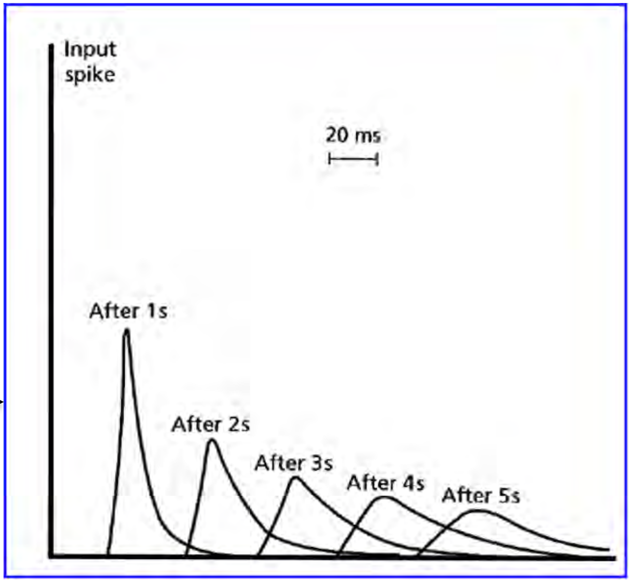
$$\text{Fold} = \frac{\text{n. Channel x Group int.}}{\text{2 x Shot int.}}$$

$$\text{Fold} = \frac{120 \times 12.5}{2 \times 25} = 30$$

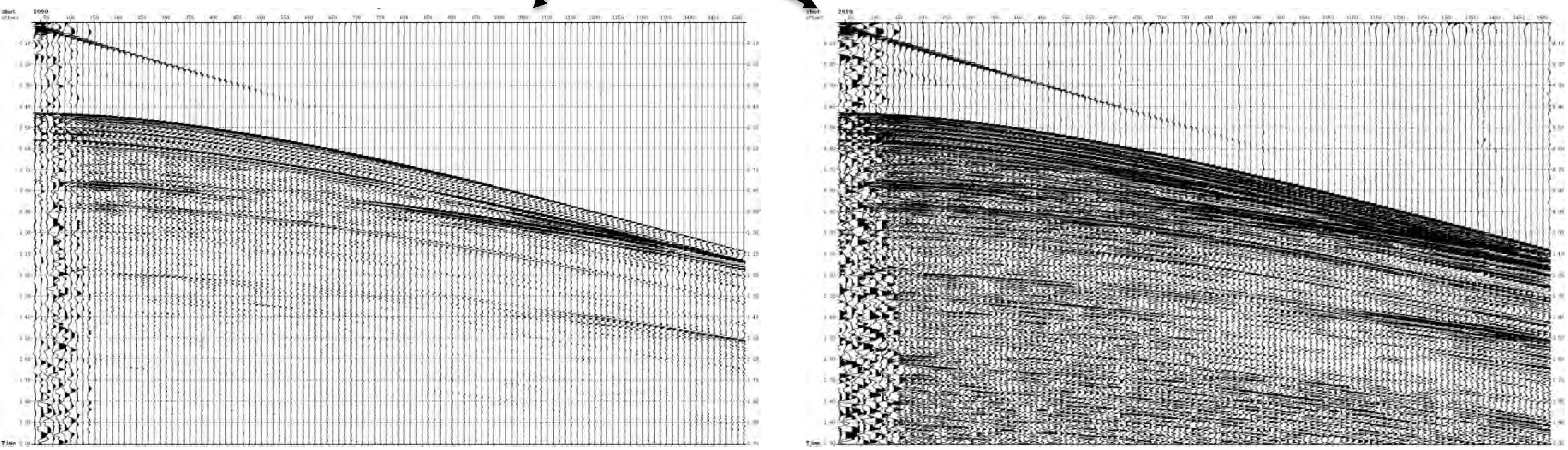
This image schematically depicts the geometry of multi-channel seismic reflection method where a reflection point is investigated several times with different paths of the wave rays. A shot investigates many points of reflection in depth only once. By repeating this shot, translating the same geometry of multiples of distance between the channels (25 m in the example), we obtain that each point is illuminated by n rays that depend on the coverage (fold) with paths gradually increasing. We obtain the Common Depth Point gather (CDP) by grouping together these n rays. The number of traces for each CDP is defined by the coverage or fold (see the formula above): the number of traces for each CDP is 30 in this case.

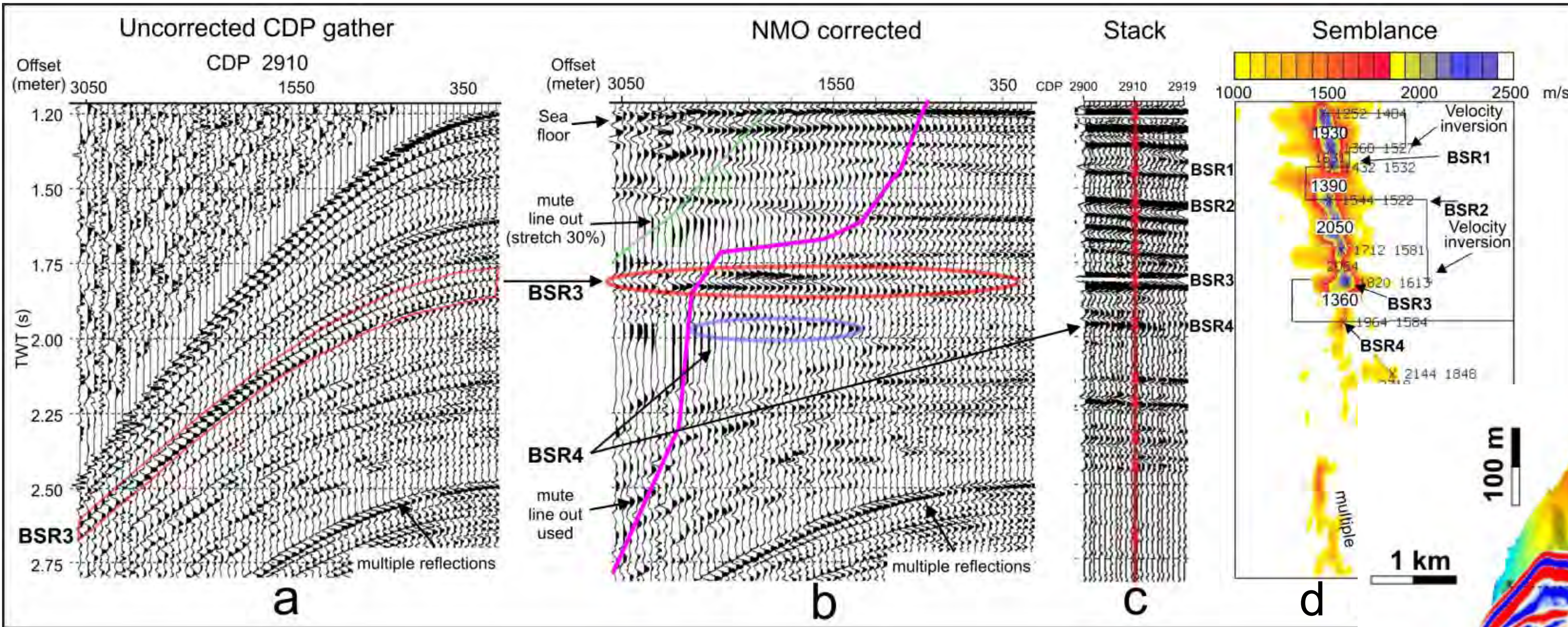
Gain correction

The progressive change of shape of an original spike pulse during its propagation through the ground due to the effects of absorption. (After Anstey, 1977)



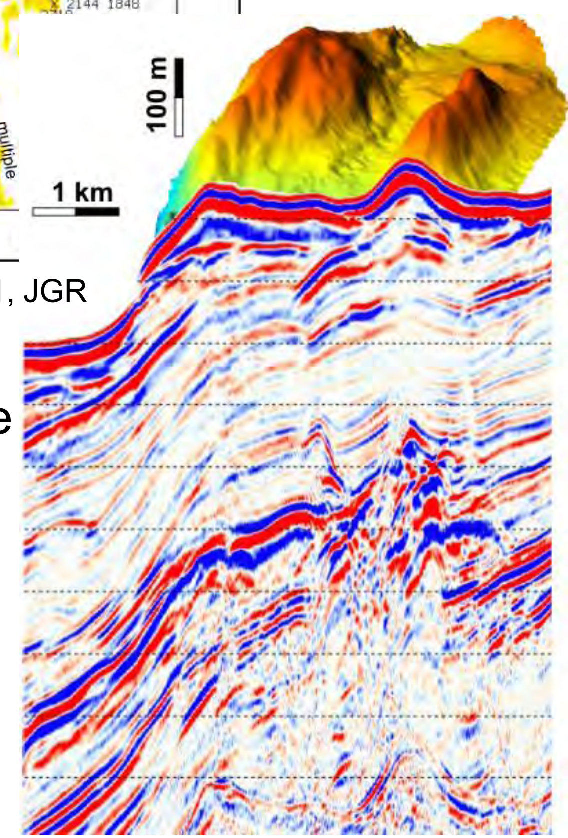
A shot before and after gain correction.





Some of the processing steps

From Geletti & Busetti 2011, JGR



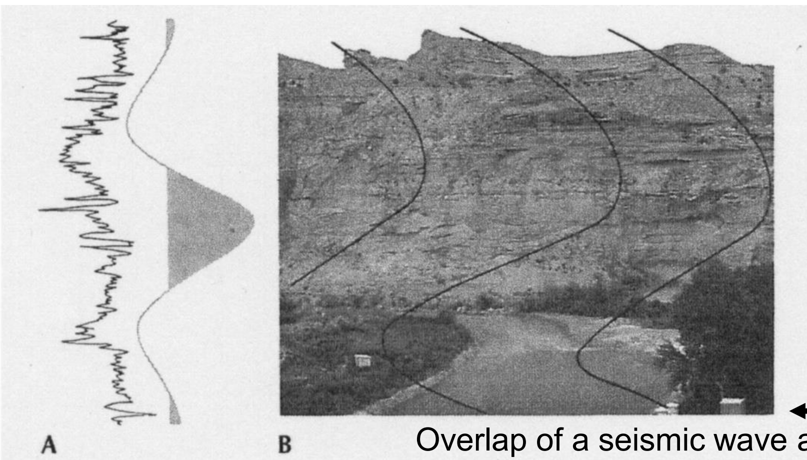
Processing flow

a) CDP gather (after Sorting operation);
b) NMO correction with the velocity function picked in d;
c) Stack on 20 CDP gathers after NMO correction;
d) Semblance with velocity function picked;
e) Migrated section & MB swath bathymetry

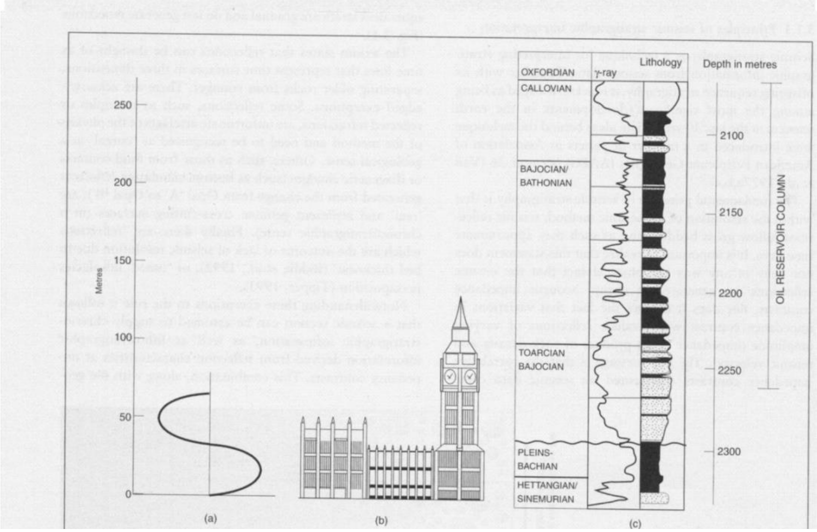
Seismic resolution

Vertical resolution   Lateral resolution

Examples of seismic wave resolution

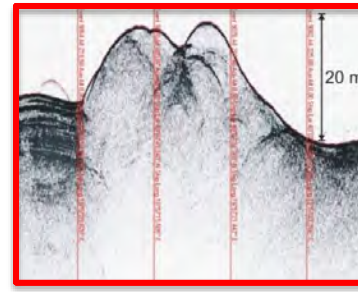


Overlap of a seismic wave and: A) a sonic log, B) a photo of a rock face of about 40 m

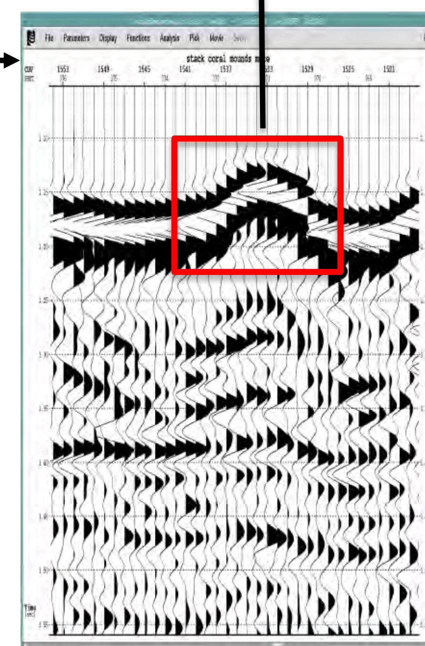


Comparison between a seismic wave and: b) Big Ben of London, c) a well data

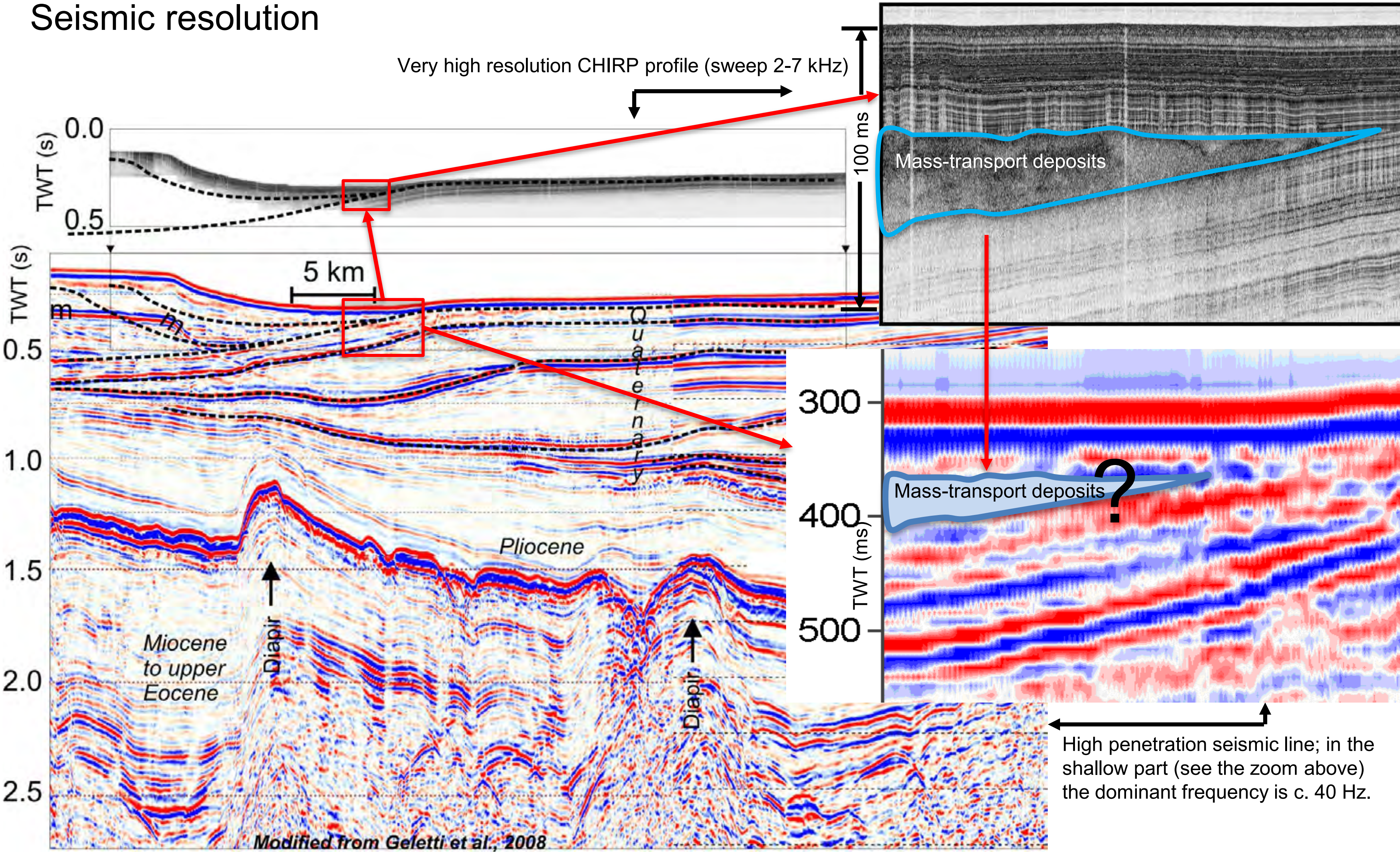
Very high resolution acoustic profile



Low resolution seismic profile (crustal data)

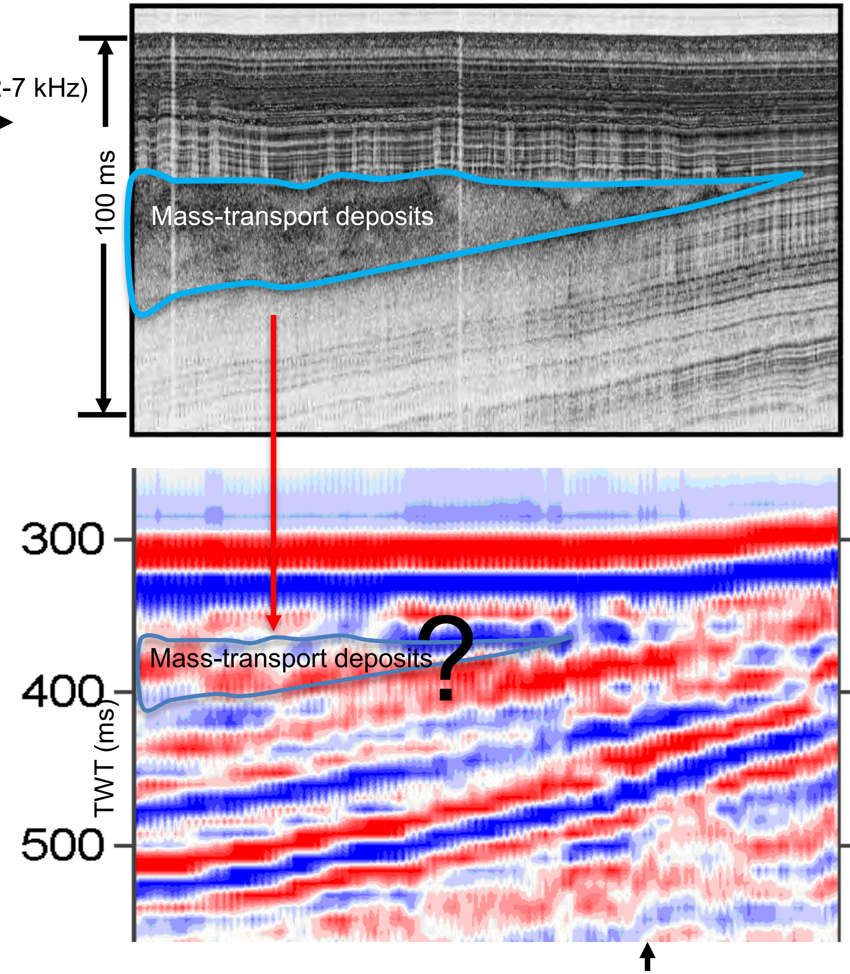


Seismic resolution



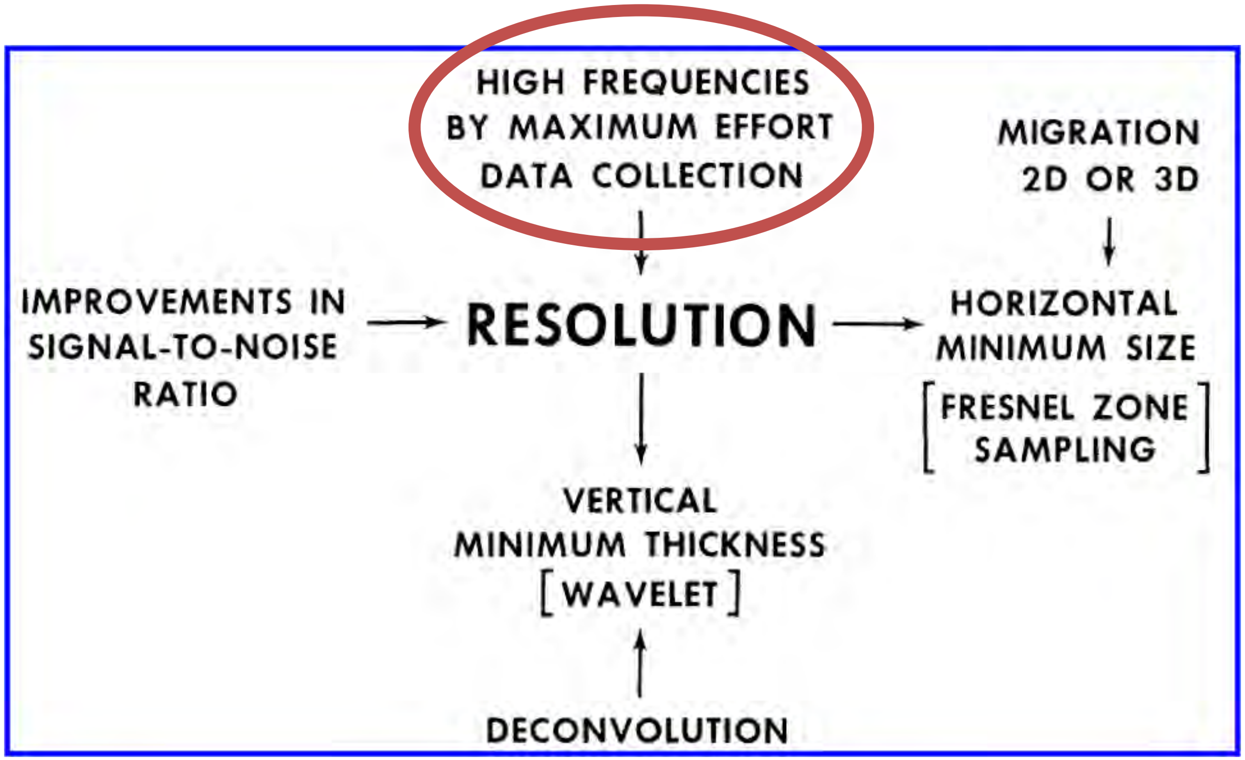
Seismic resolution

Very high resolution CHIRP profile (sweep 2-7 kHz)



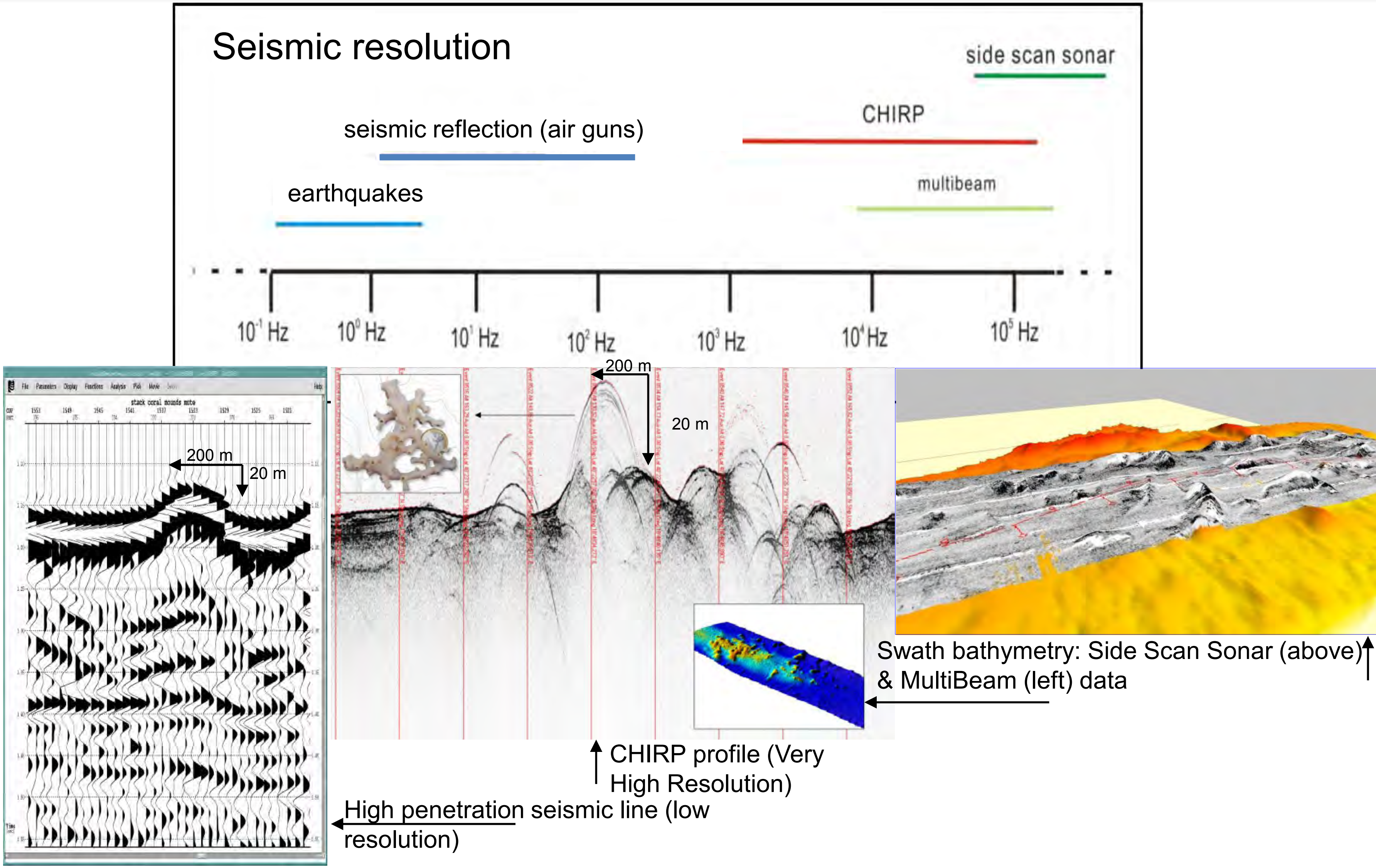
In the previous slide we compare two acoustic profiles on the same line: below we have a crustal seismic section and above a chirp profile. The maximum penetration of the last one is about 60/80 meters in this kind of sediments (very soft sediments) in this area and the seismic section shows the Messinian reflector at 1.5 seconds twt about 1.3 km below the seafloor. Its deformation is related to the deep diapiric bodies activity. Their activity is still ongoing in some case (Geletti et al., 2008). Note the layer of Mass-transport deposits that it is evident in the chirp profile, but it is not visible in the seismic section below. The frequency content of the chirp data is in the range of 2-7 kHz (some tens of centimeters of resolution), while the dominant frequency of the high penetration data is about 40 Hz in the subsurface horizons where the vertical resolution is about 10 m (lambda quarters). The maximum thickness of the layer in question is 10-15 m. This is at the limit of the resolution of the crustal seismic profile.

High penetration seismic line; in the shallow part (see the zoom above) the dominant frequency is c. 40 Hz.



Factors affecting horizontal and vertical seismic resolution.

The table summarizes resolution issues: the acquisition (above in the ellipse) and processing solutions.



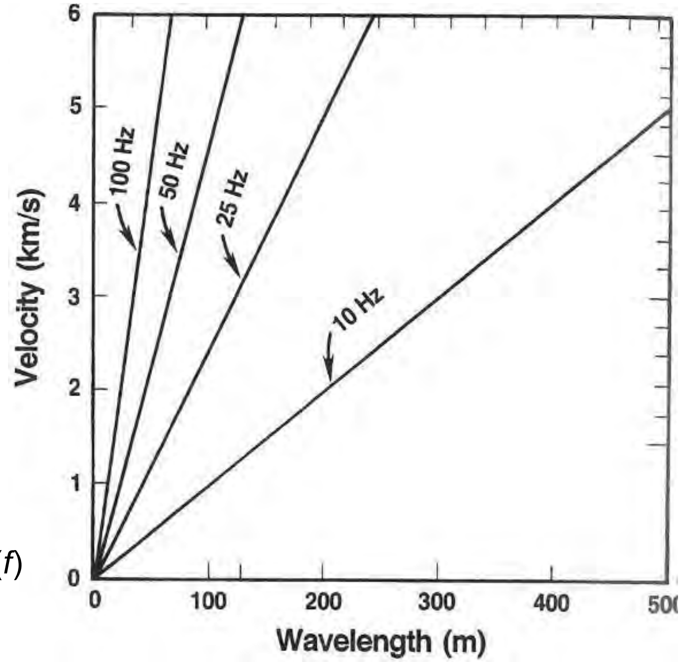
The factors that influence the resolution are linked to the type of data acquisition: geometry and source. The resolution decreases with the depth of investigation because it depends on the frequencies of the signal placed in the ground and the velocity of the seismic wave. The high frequencies decrease with depth. So we must find a good compromise between penetration and resolution. Resolution has both vertical and horizontal aspects. In the slide we can observe some types of acoustic data related to the same geological object of the coral mounds.

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

Threshold for vertical resolution



The relationship between velocity (v), dominant frequency (f) and waveleght ($\lambda = v/f$).

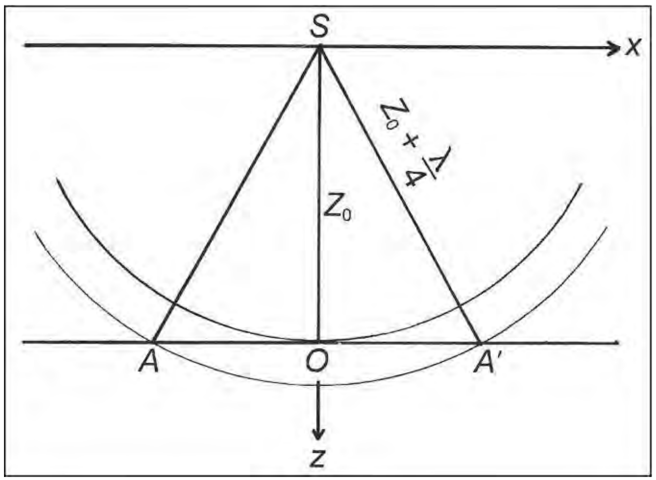
In vertical resolution, for two reflections, one from the top and one from the bottom of a thin layer, there is a limit on how close they can be, yet still be separable: this limit is a quarter of lambda, where lambda is the length of the seismic wavelet and it depends on the velocity and inversely on the frequency.
Velocity is a parameter that depends on the characteristics of the medium, so we will not be able to act on it for the purpose of resolution.
The fundamental parameter then becomes the frequency. When we put energy into the ground, it is characterized by a range of frequencies. In the ground crossed the energy tends to distribute itself in a frequency band centered on the dominant frequency. The dominant frequency depends on:

- physical properties of the crossed medium
- spectrum of the source or frequencies inserted into the ground
- registration system (hydrophones, etc.)
- Processing of the acquired signal

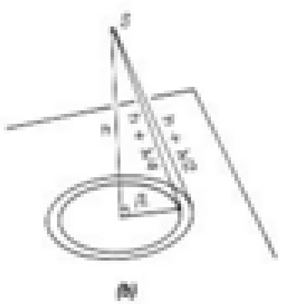
to improve the resolution we can act on the last three points

Lateral Resolution

The lateral resolution is defined as the minimum lateral distance between two reflecting elements, necessary to distinguish them individually within a seismic profile. The lateral resolution is determined by the radius of the Fresnel Zone, the area between the wave front tangent to the discontinuity surface and the subsequent remote wave front a quarter of lambda. For example we can see the threshold at 1 second with average velocity of 2000 m/s and 50 Hz of dominant frequency we have a radius of Frensnel zone of 140 m so if we have a syncline wide less than 280 meters we can not see it except for the diffractions.



Definition of the Frensnel zone AA'



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

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

Threshold for lateral resolution
(t0 = 2z/v, r=OA)

Seismic resolution

Example of high penetration (low resolution) multichannel seismic reflection profile (CROP project) in Central Adriatic Sea.

The image depicts a high penetration seismic profile. This is a deep crustal multichannel seismic reflection profile acquired in 1995 by R/V OGS Explora in the Central Adriatic Sea within the Italian Deep Crustal Exploration Project (CROP).

The deeper horizon is the Moho reflection at about 40 km (13 s twt) depth; The vertical resolution is about 75 meters (see the slide before). The wave length is about 300 m becouse the velocity is 6000 m/s and the dominant frequency is 20 Hz. The lateral resolution is about 4,800 meters.

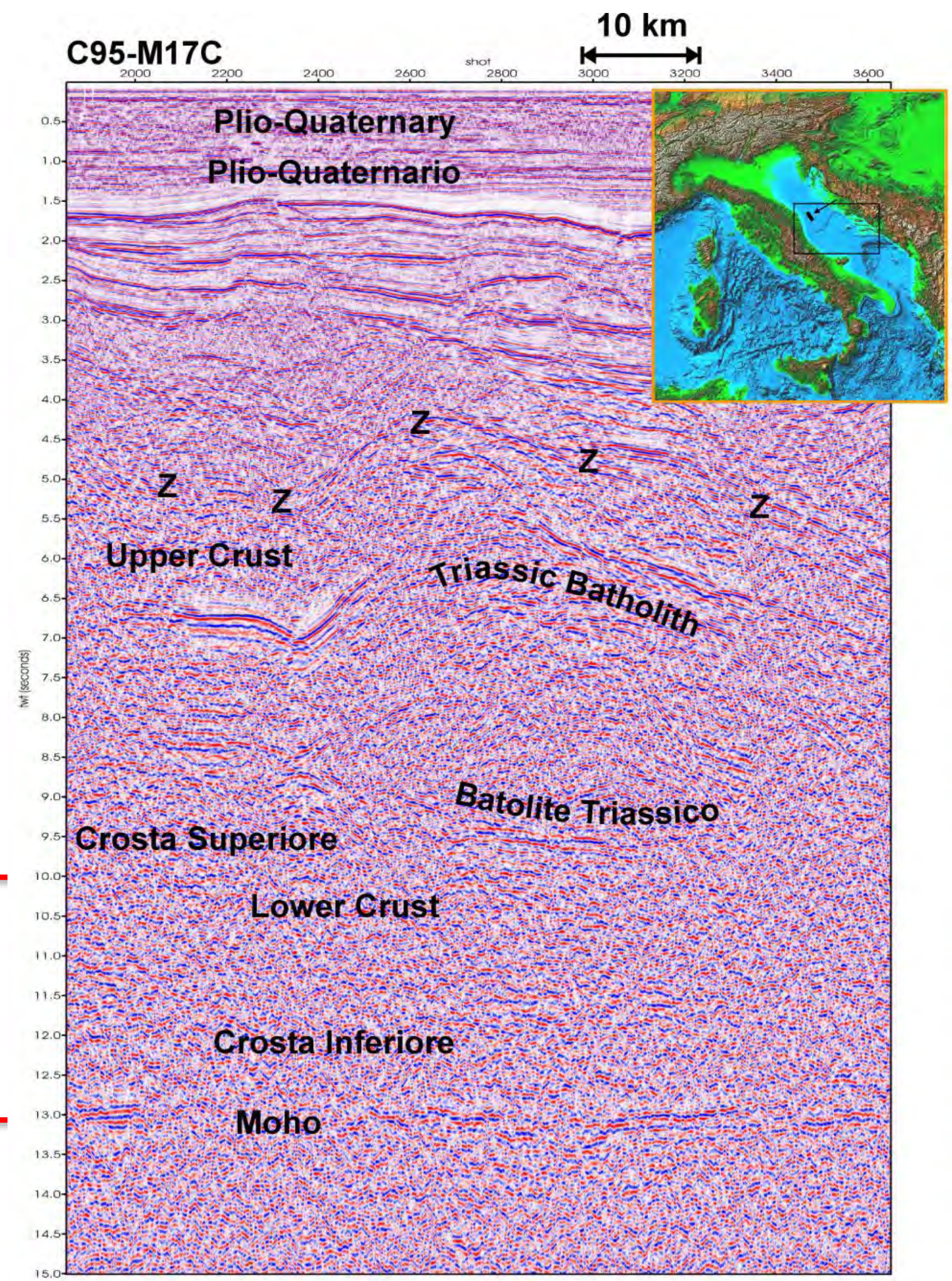
You can see the Lower/Upper Crust transition about 30 km depth (10 s twt); a Batholithic body is evident within the Upper Crust; the horizon Z is the base of sedimentary sequence about 7 km depth and the Plio-Quaternary sediments are about 1.5 km of thickness.

30 km depth

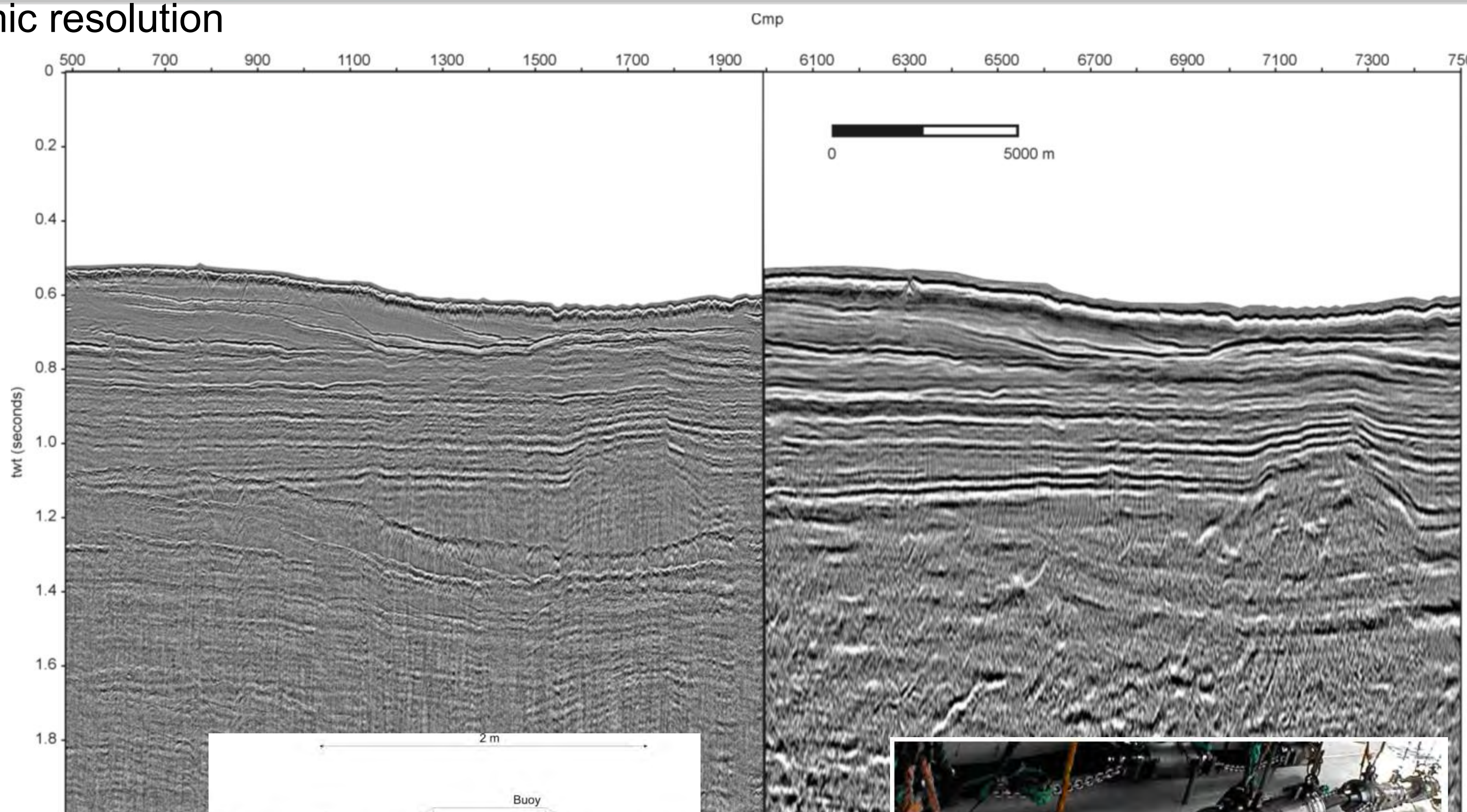
You can see the geological basement Z (the base of sedimentary sequence) and the acoustic basement at 13 s twt: the Moho discontinuity. This last one is the deep reflector that you can see in the seismic section.

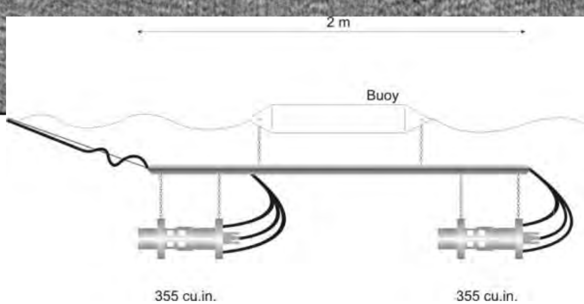
Vertical resolution = 75 m
Lateral resolution = 4840 m
(v=6 km/s; f = 20 Hz)

40 km depth

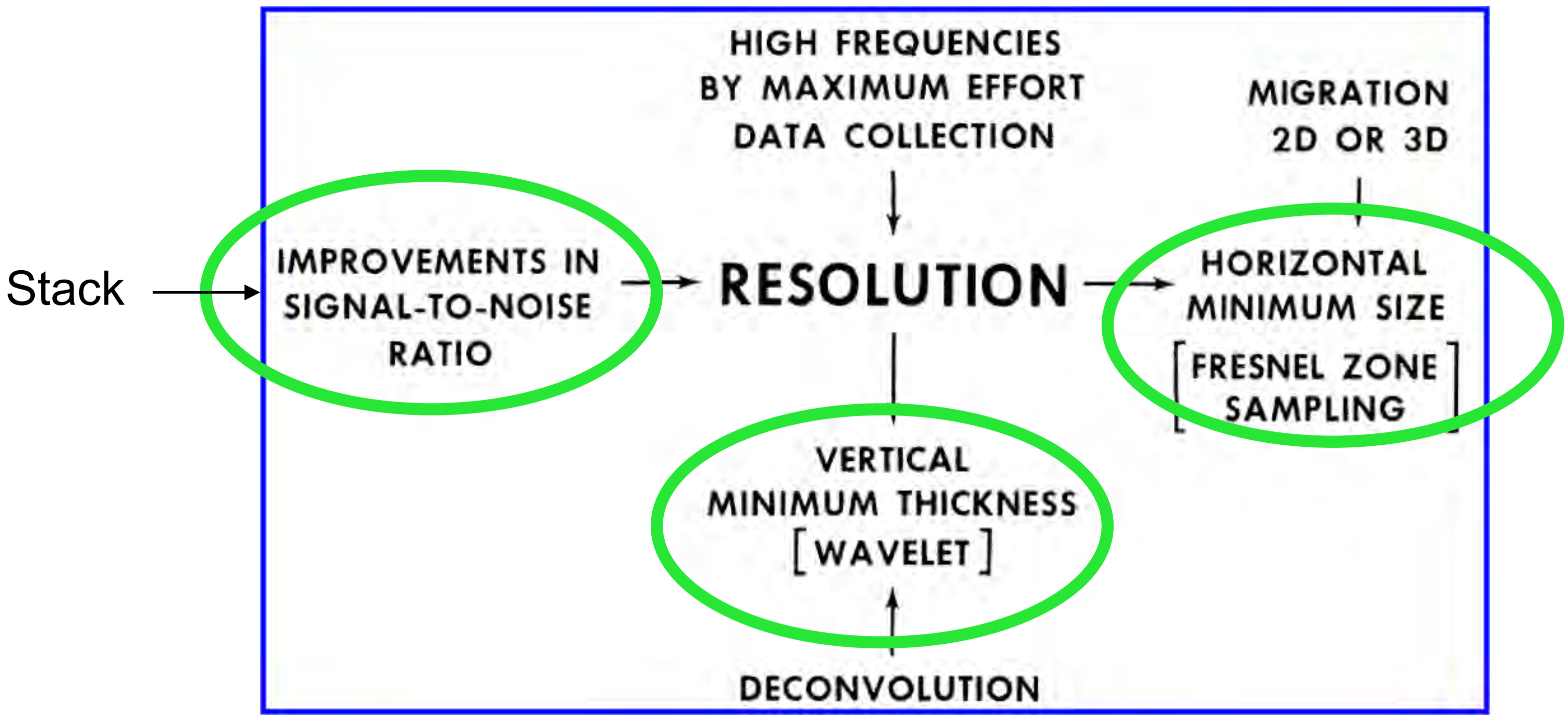


Seismic resolution





Examples of two seismic lines where the left was acquired by 2 GI guns (11,6 l) while on the right by an array of 16 air guns (70 l): notice the different higher resolution on the left than on the right. The dominant frequencies are 70/80 Hz and 40 Hz in the left and in the right profiles respectively. The velocity of the sub-superficial layers is about 1700 m/s, therefore the vertical resolution is 6 m on the left and 10 m on the right.



Factors affecting horizontal and vertical seismic resolution: processing solution.

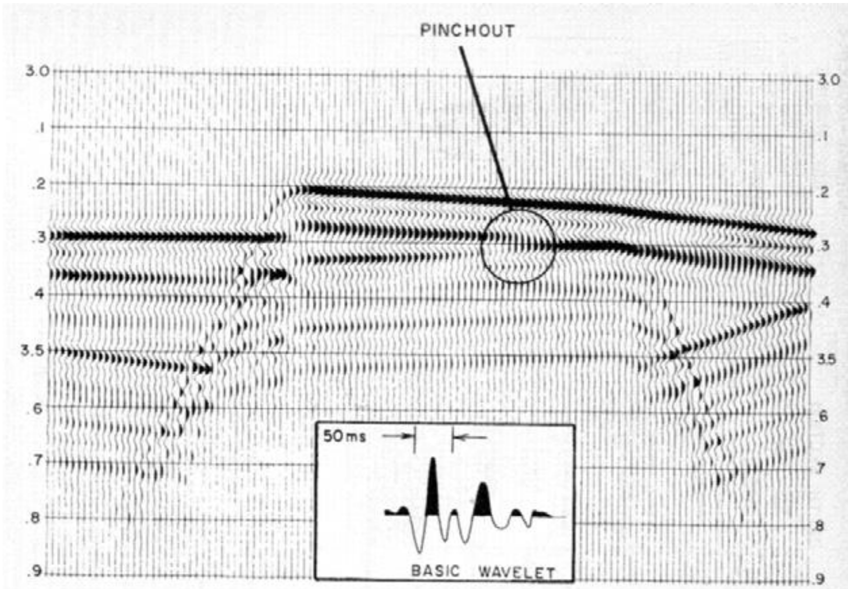
Deconvolution acts on the data along the time axis and increases temporal resolution (the vertical one). Stacking compresses the data volume in the offset direction and yields a stacked section where the random noise is attenuated. Migration then moves dipping events to their true subsurface positions and collapses diffractions, and thus increases lateral resolution.

Vertical resolution

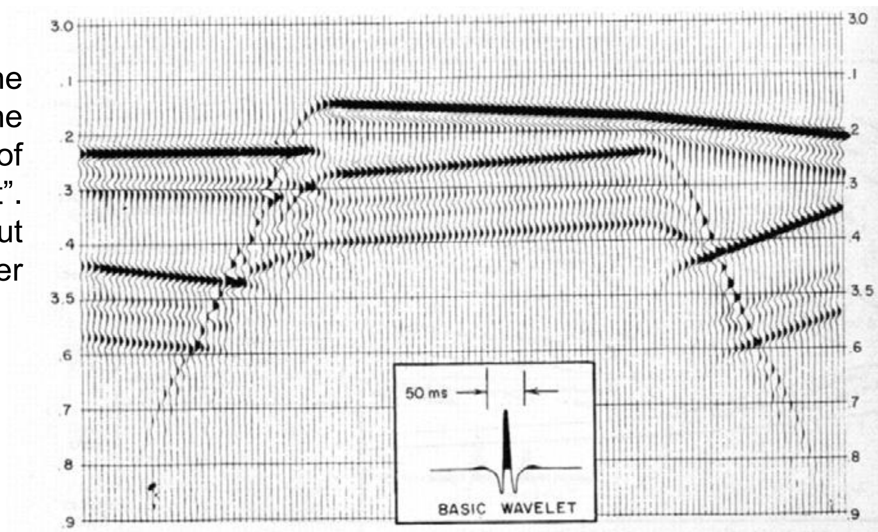
Deconvolution

Example of the effect of the deconvolution on the definition of seismic data (synthetic data). The deconvolution "shrinks" the wavelet as shown in the figure (synthetic data).

The deconvolution contracts the wavelet and attenuates the undulations related to the effect of the source called “bubble effect”. Notice how the artefact pinch out effect disappears in the section after deconvolution.

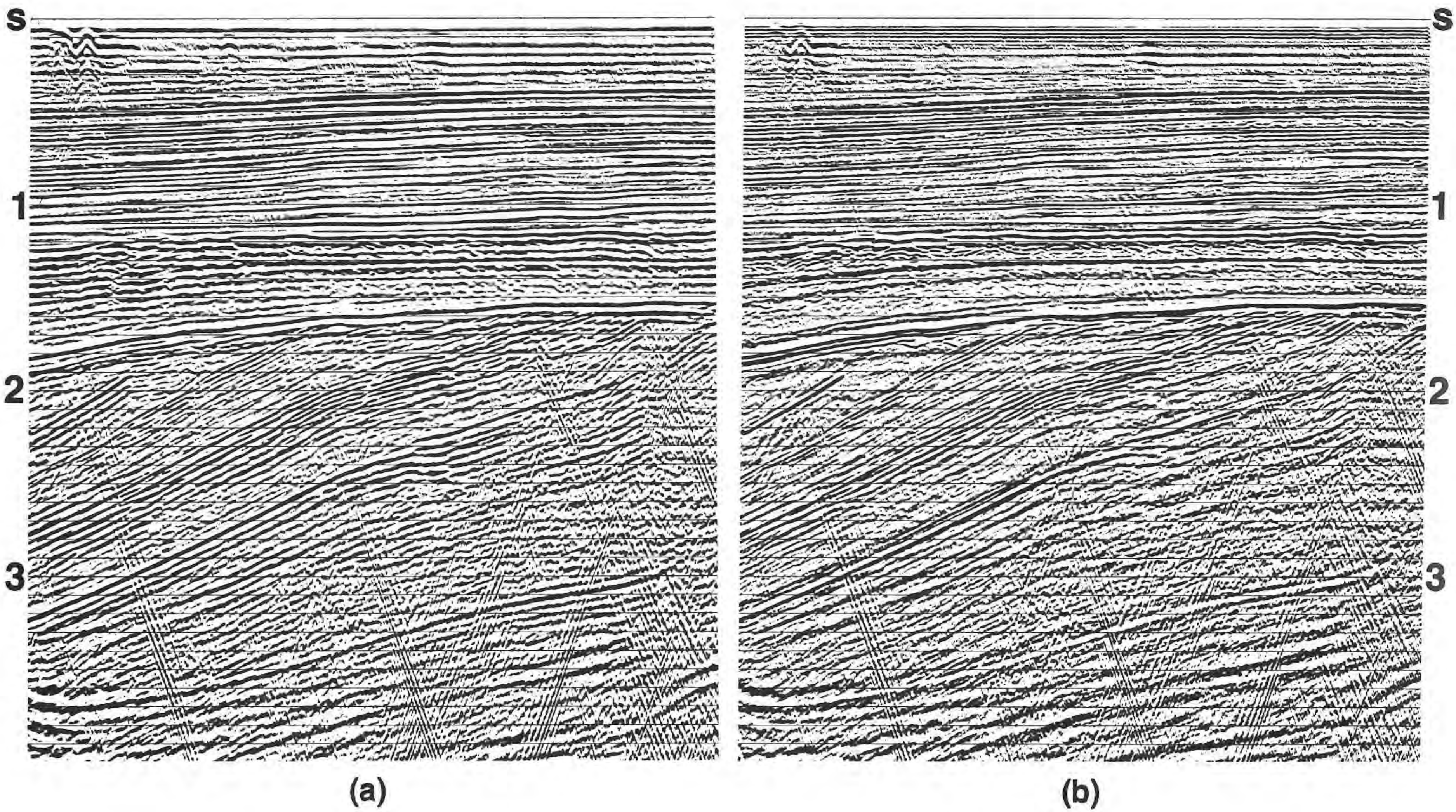


Before the deconvolution



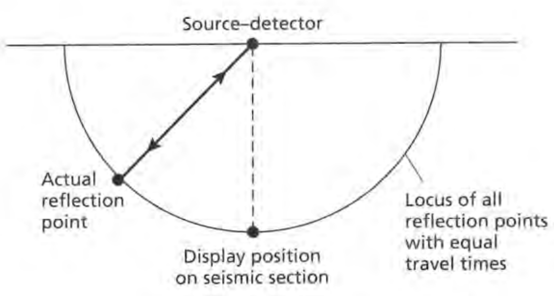
After the deconvolution

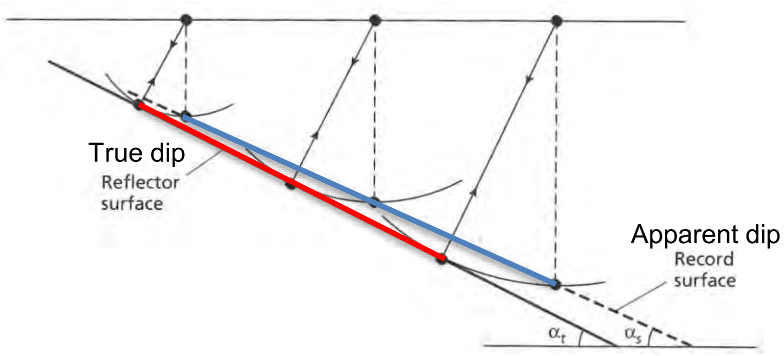
Vertical resolution



Seismic stack section a) before and b) after deconvolution (Yilmaz, 2001).
You can see better the reflection at a 1.2 s twt. And the dipping events below the reflector at 1.5 s twt. This is an erosional discontinuity where the dipping reflectors below are in top lap.

Lateral resolution



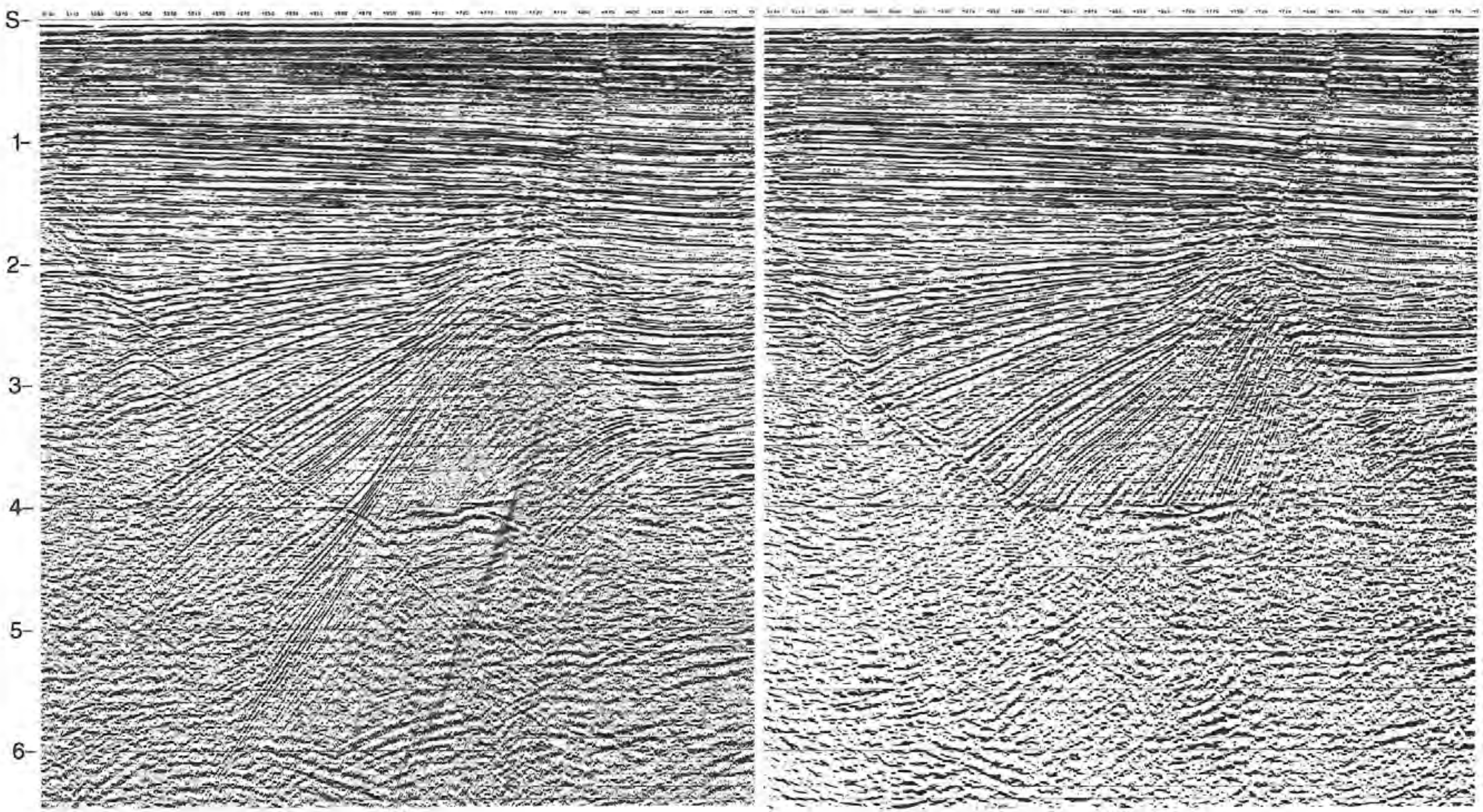


Migration

- Consider a source-detector (s-d) on the surface of a medium of costant seismic velocity. For a given reflection time, the reflection point may be anywhere on the arc of a circle centred on the s-d position. On a non migrated seismic section the point is mapped to be immediately below the s-d.

- A planar-dipping record surface derived from a non-migrated seismic section (blu line) and its associated reflector surface (red line).

Migration is the process of reconstructing a seismic section so that reflection events are repositioned under their correct surface location and at a corrected vertical reflection time. The migration also collapses the diffraction hyperboles and brings inclined reflectors back to the right angle. Migration is applied to stacked data (see an example in the next slide). In time migration, the migrated seismic sections still have time as the vertical dimension. In depth migration, the migrated reflection times are converted into reflector depths using appropriate velocity information.



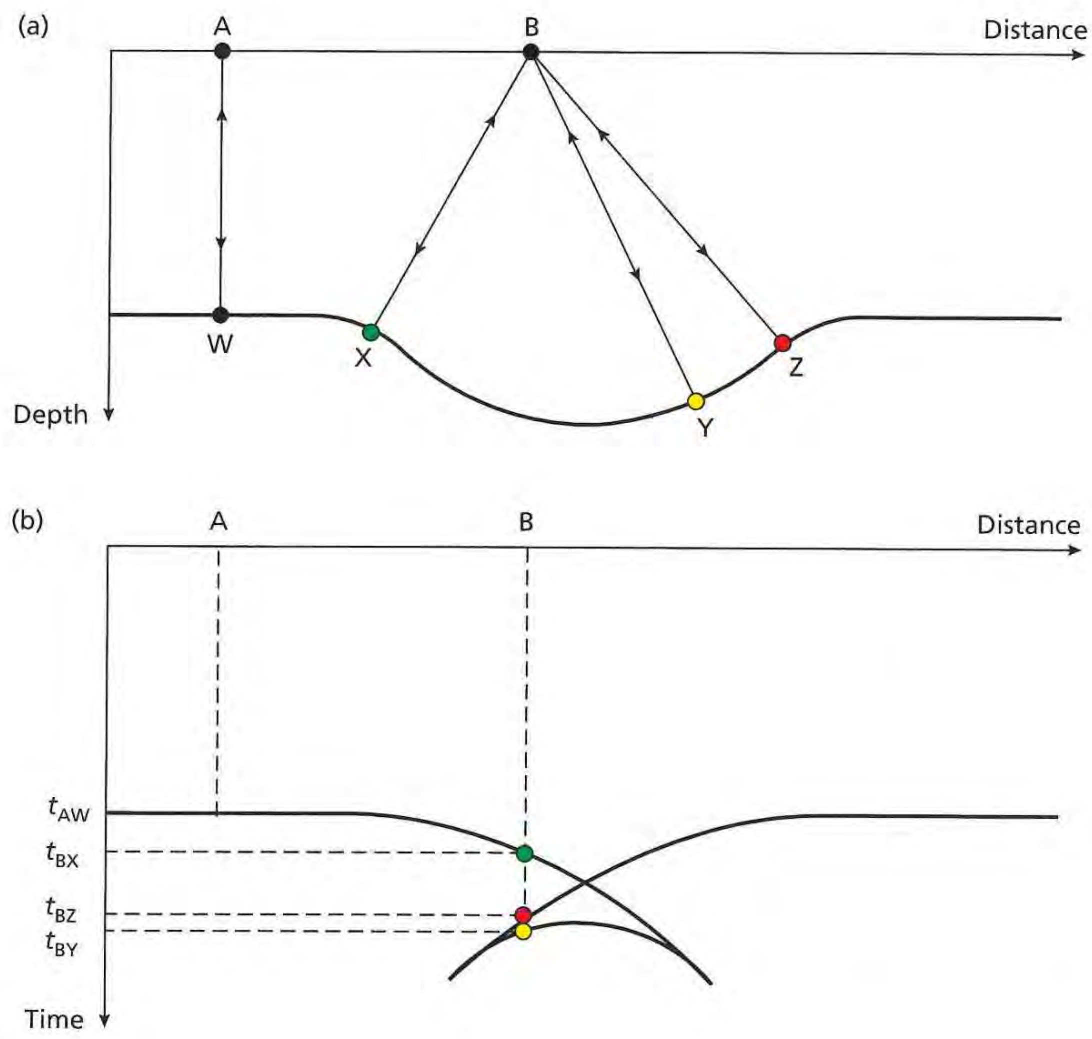
(a) (b)

Stack section (a) before and (b) after migration. (from Yilmaz 2001).

Note the group of events with a range of dips that fan out a fault plane. Migration has moved them in the updip direction, made them shorter and steeper.

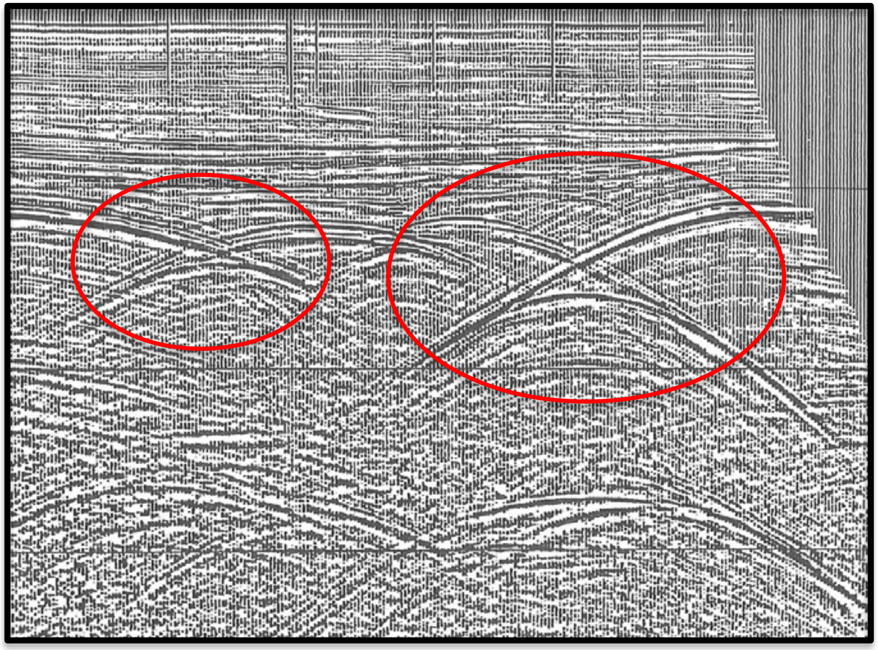
Lateral resolution

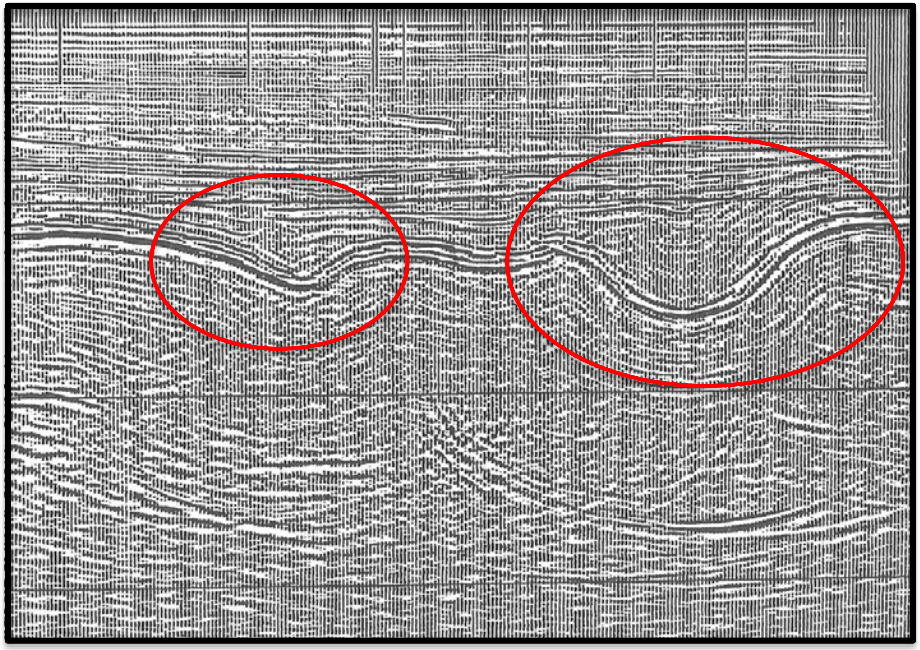
a) A sharp synclinal feature in a reflecting interface, and
b) the resultant «bow-tie» shape of the reflection event on the non-migrated seismic section.



When we have a synclines like in the section this is the effect then it shows in the slide. Synclines or channels within which the reflector curvature exceeds the curvature of the incident wavefront are represented on non-migrated seismic sections by a «bow-tie» event resulting from the existence of three discrete reflection points for any surface location.

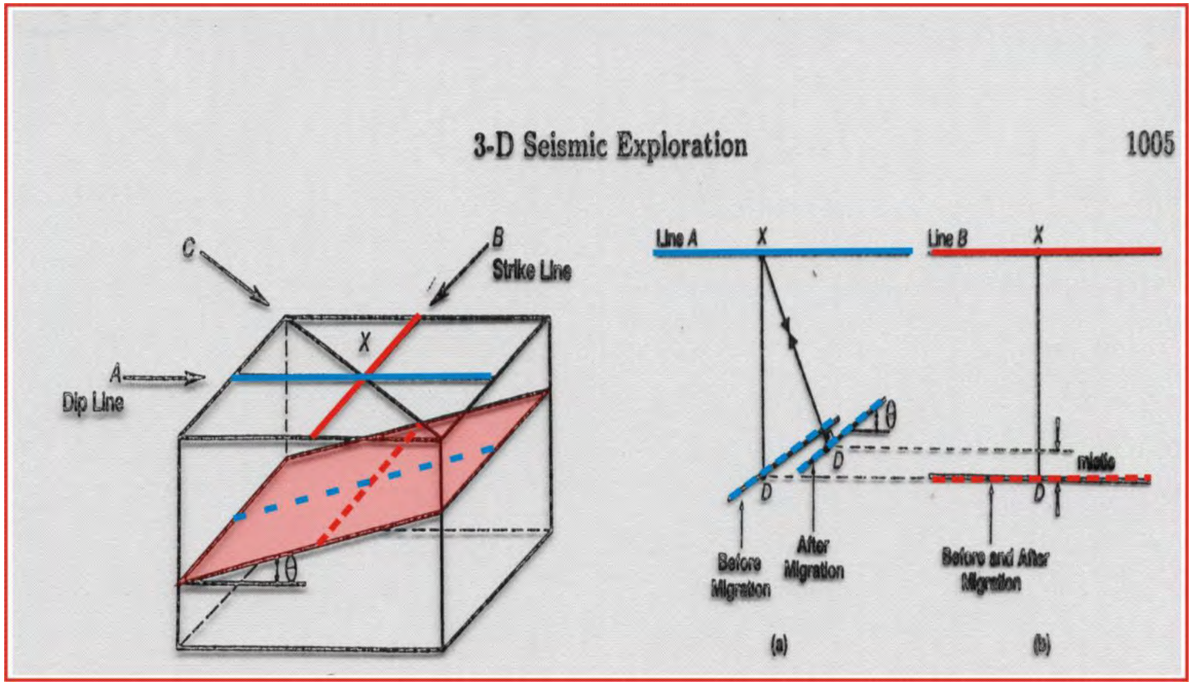
Lateral resolution: migration


a)


b)

Example of seismic reflection profile across two buried channels (a) non-migrated section with the presence of «bow-tie» effect (red ellipses) and b) after migration. Note in particular the clarification of structural detail, including the removal of bow-tie effects, and the repositioning of structural features in the migrated sections.

2D migration

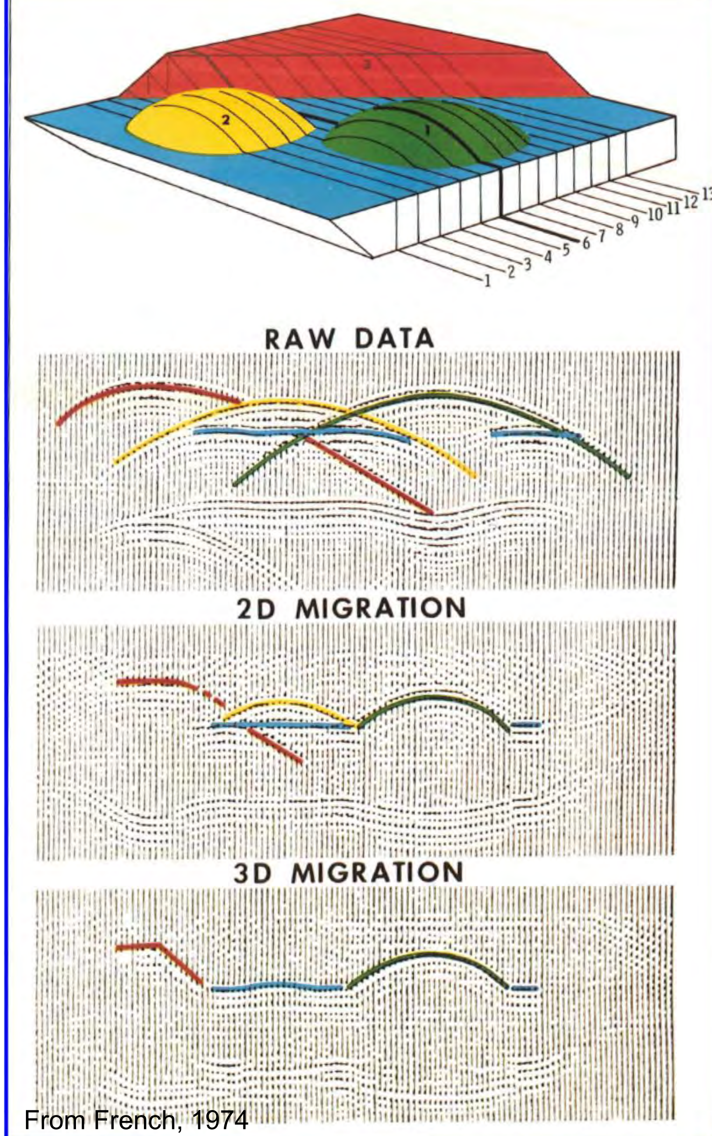


2D migration is an imperfect process on the «strike line».

In two-dimensional survey data, in the strike line (that they are parallel to the structures) the two-dimensional migration is clearly an imperfect process. Below the point X, the reflector in section A (dip line) after the migration moves to the right and becomes more pending. In section B (strike line) the reflector is not pending and the 2D migration don't work, but its position is not correct because the reflector is not under the point x with a vertical ray-path

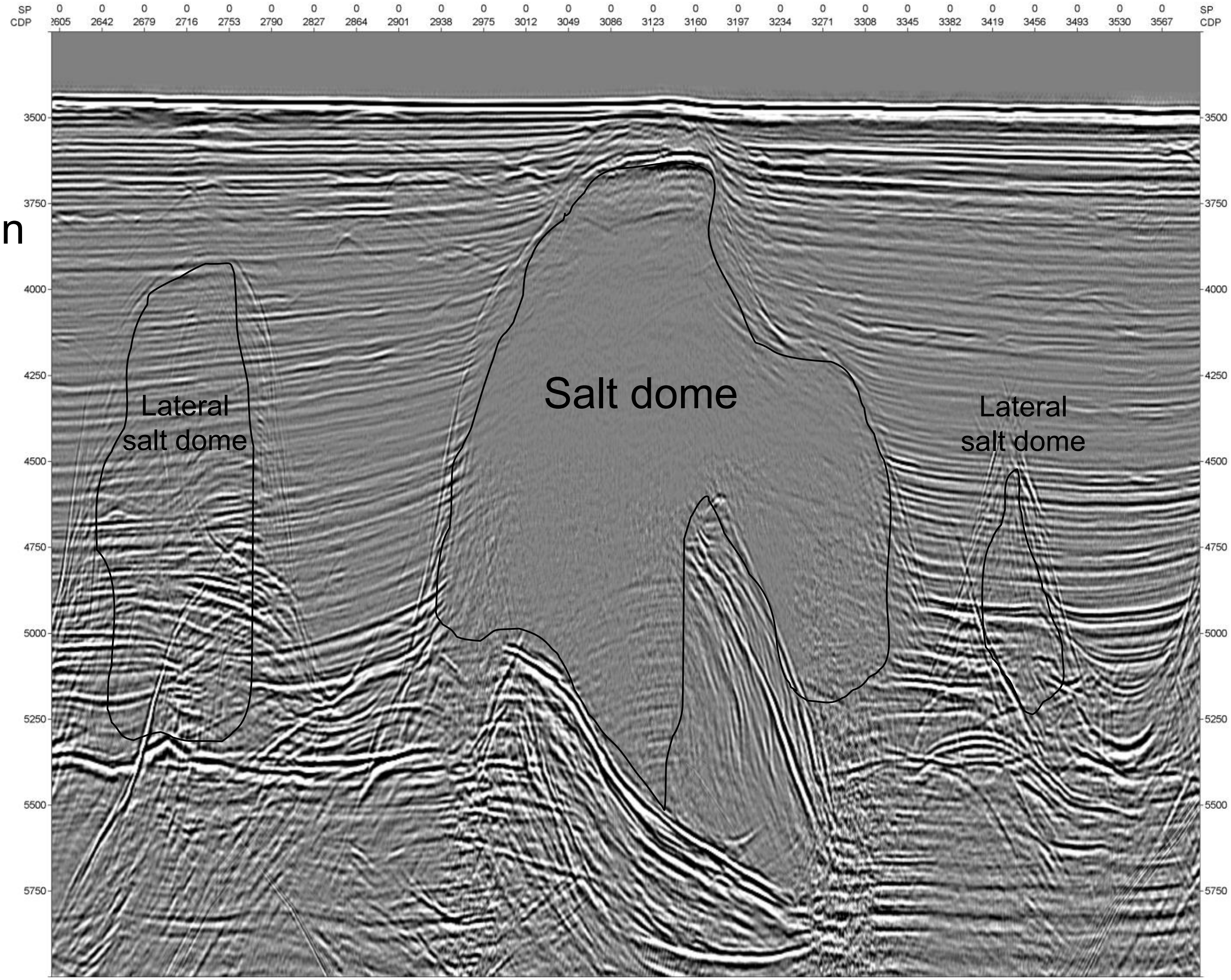
2D and 3D migration

The image shows an example of a 3D geological model with two anticlinals (green and yellow object) and a direct fault (red and blue objects).
The seismic data along line 6 shows the comparative effects of 2D and 3D migration (from French, 1974).
Only 3-D migration is able to provide a seismic profile faithful to the real situation of pending layers.
However, the 2-D migration provides an often satisfactory result for interpretation.



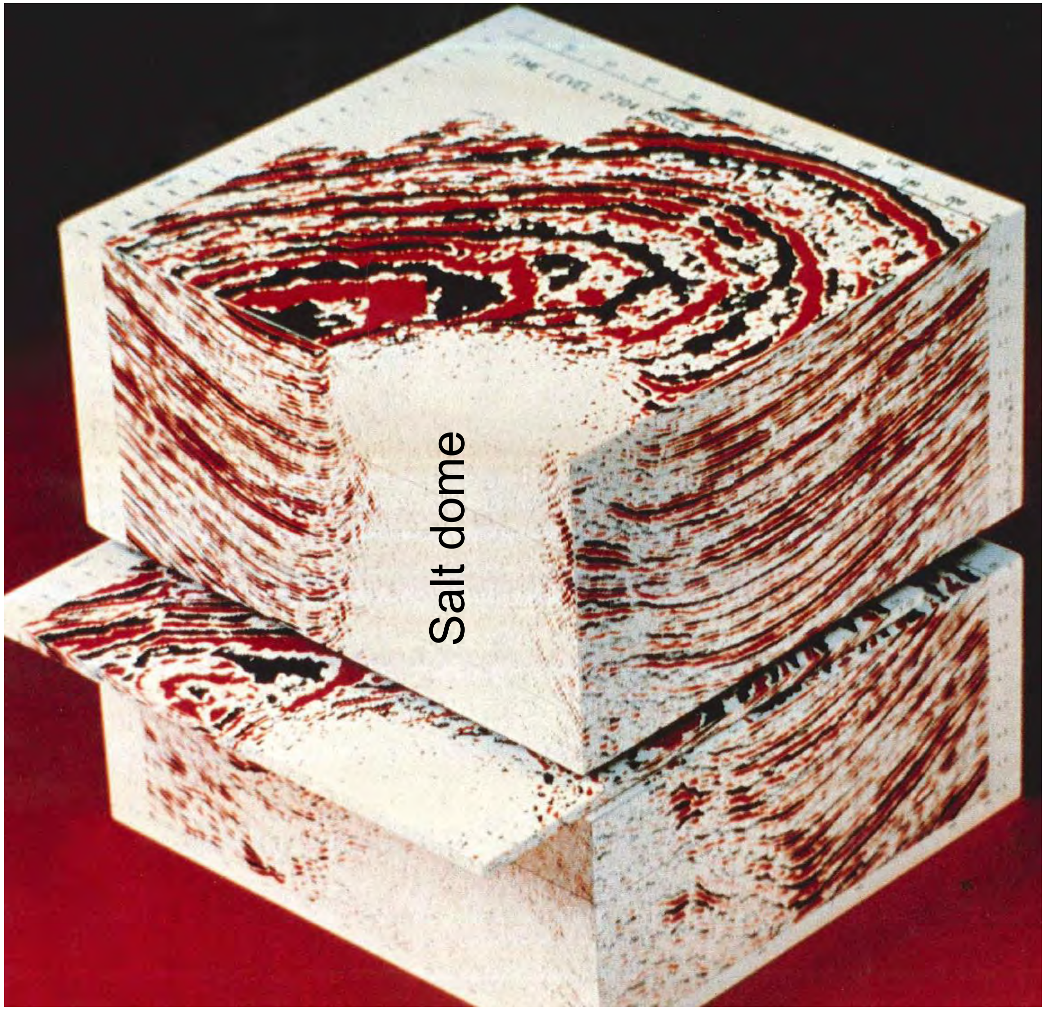
From French, 1974

2D migration



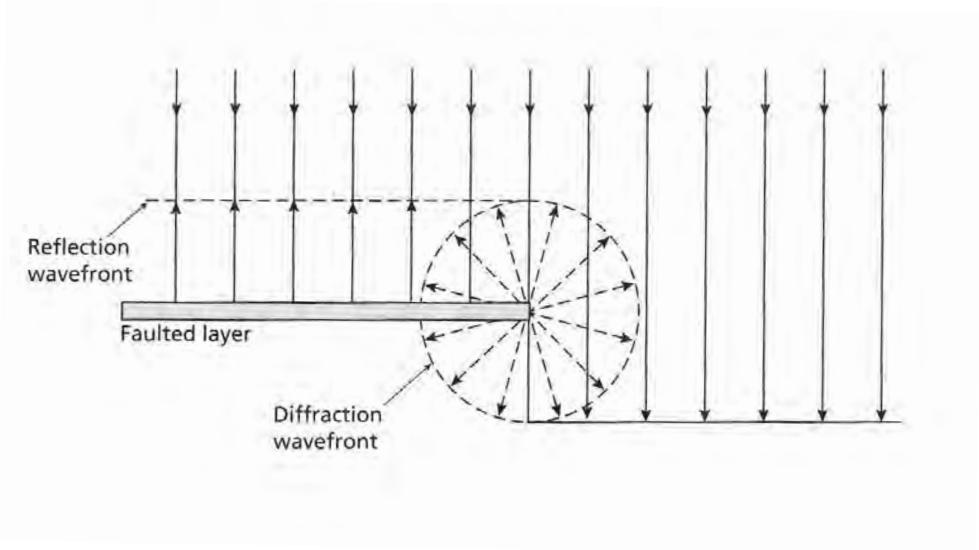
Example of 2D migrated seismic profile with the presence of salt domes, some of which are lateral to the vertical plane of the section. A dome-shaped structure in sedimentary rocks, formed where a large mass of salt has been forced upward. Such structures often form traps for oil or natural gas. Because of their buoyancy, halite beds may deform or rise and drag surrounding rocks, producing salt domes or act as fill or lubrication in geological faults.

3D migration

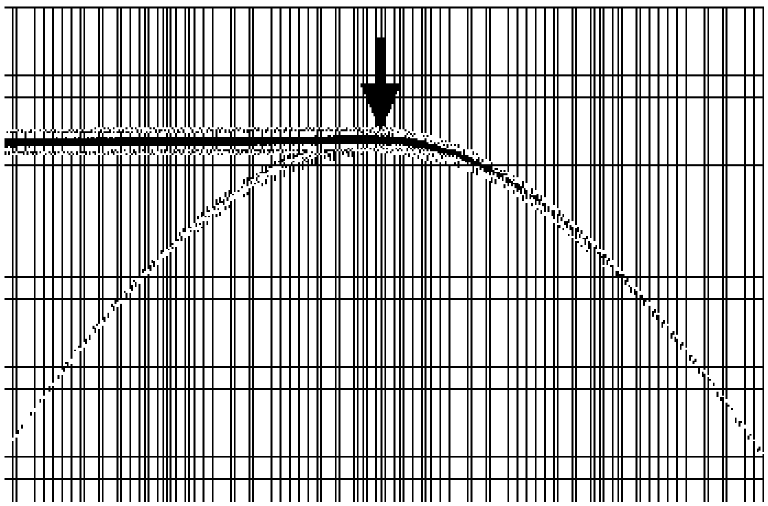


Example of "3D cube" from Brown (1986): the 3D migrated seismic data can be analyzed, as well as on vertical sections, also for horizontal "slices". The image shows the presence of a salt diapir that "pierces" the sedimentary sequence of the basin.

Migration: diffraction collapse



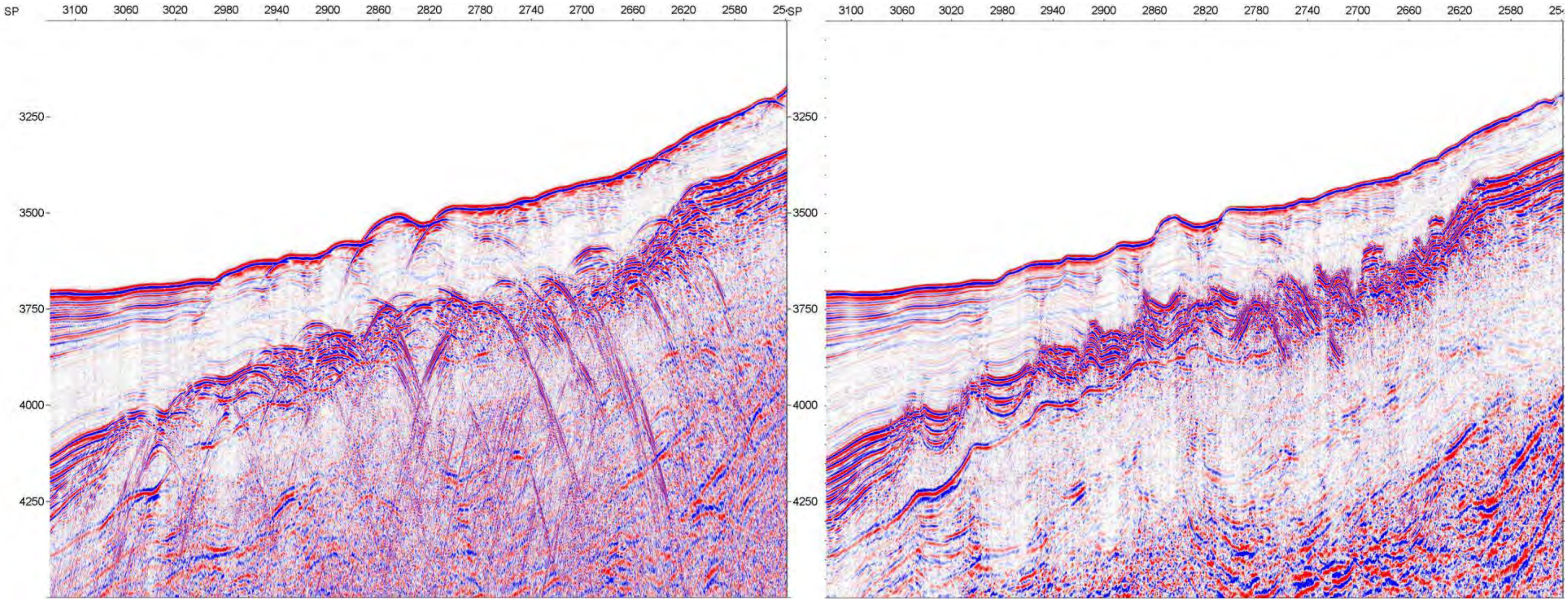
Diffraction from faulted layer



In general, the different depositional / erosional and tectonic events occurring during the geological evolution of an area, determine irregularities along the stratigraphic horizons (reflectors) due to fractures, erosion, sedimentary accumulations, etc. These represent points of inhomogeneity that originate diffractions. Below there is a synthetic seismic section with the diffraction caused by a fault for example.

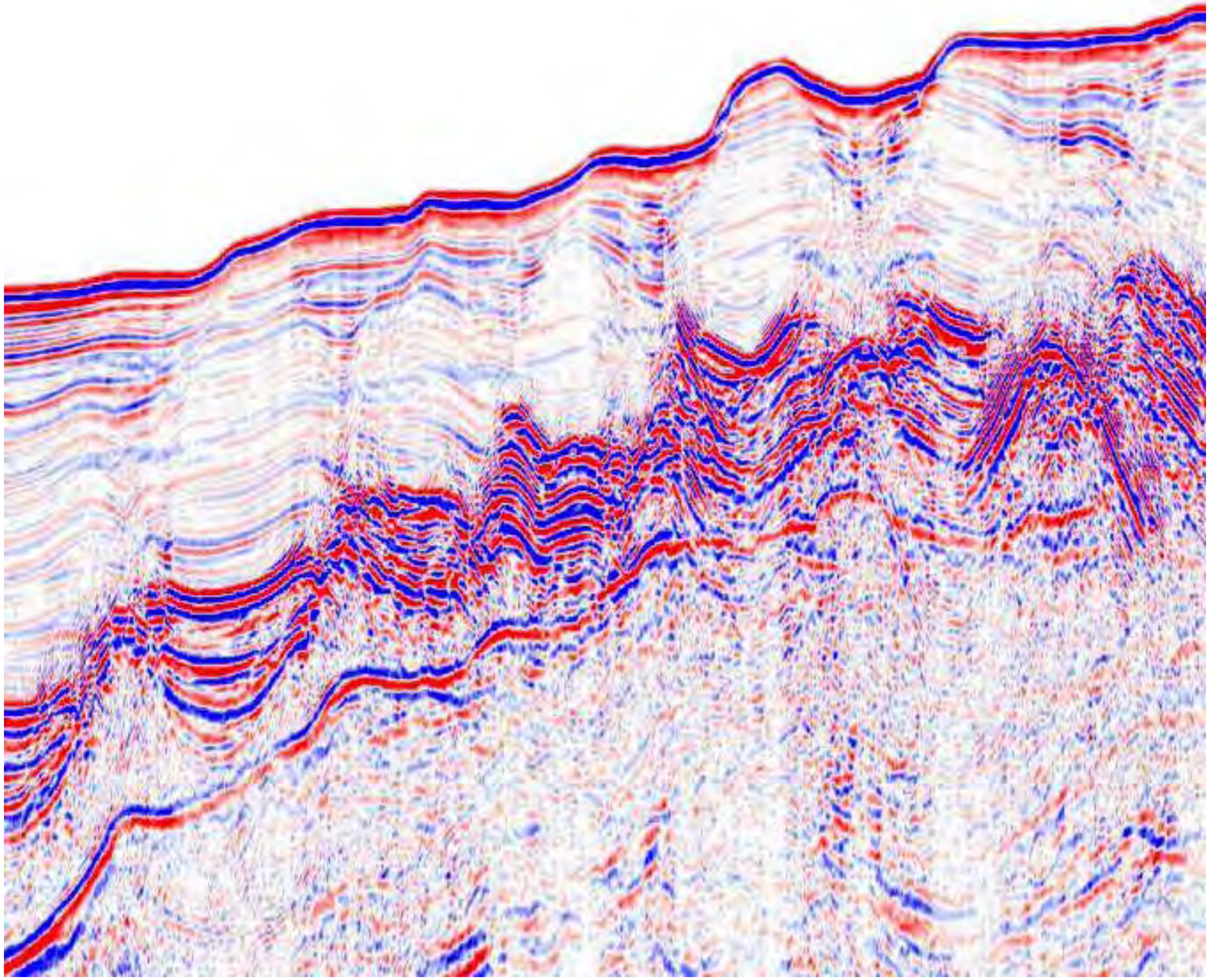
Example of faults in the geological layers.
The faults represent points of inhomogeneity that originate diffractions. You can see the geological layers that are dislocated by the faults

Migration: diffraction collapse



(a) (b)

Seismic section (a) before and (b) after migration: the diffractions have been collapsed and the faults are evident. The presence of diffractions can sometimes create difficulties of interpretation: the point of breakage of the reflector is not easily identifiable in the non-migrated section. In the case b) the section was migrated and the base of the salt layer is more evident then in stack section a)



Blow up of the previous seismic image

Migration

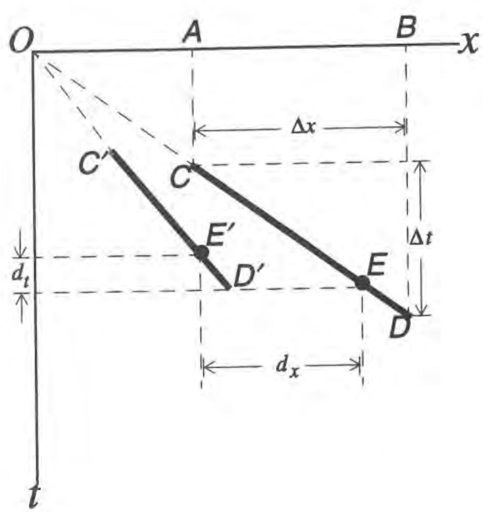
Chun & Jacewitz formulas (1981)

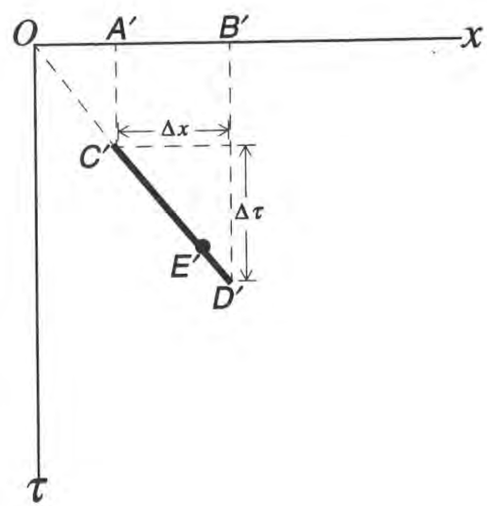
$$d_x = \frac{v^2\, t}{4} \frac{\Delta t}{\Delta x},$$

dx and dt: horizontal and vertical (time) dispalcements (migrated section);
Delta Tau / *Delta x*: dip on migrated section.

$$d_t = t\left[1 - \sqrt{1 - \left(\frac{v \Delta t}{2 \Delta x}\right)^2}\,\right],$$

$$\frac{\Delta \tau}{\Delta x} = \frac{\Delta t}{\Delta x} \frac{1}{\sqrt{1 - \left(\frac{v \Delta t}{2 \Delta x}\right)^2}}.$$





Geologic model
x,y,z

Velocity

Seismic section:
x,y,t

Velocity field of the seismic waves is the parameter that allow to get the geologic model from the seismic section

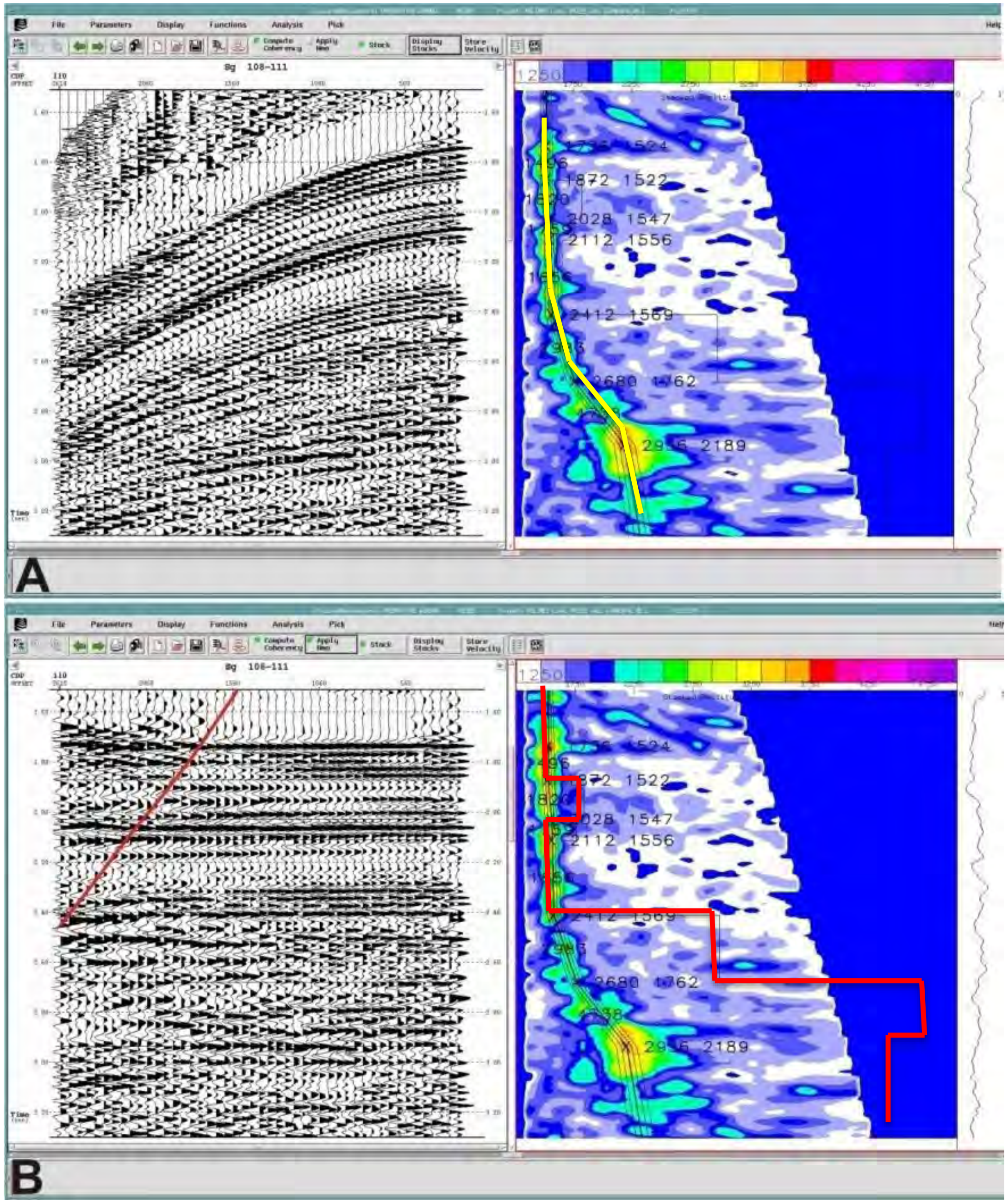
Velocity analysis

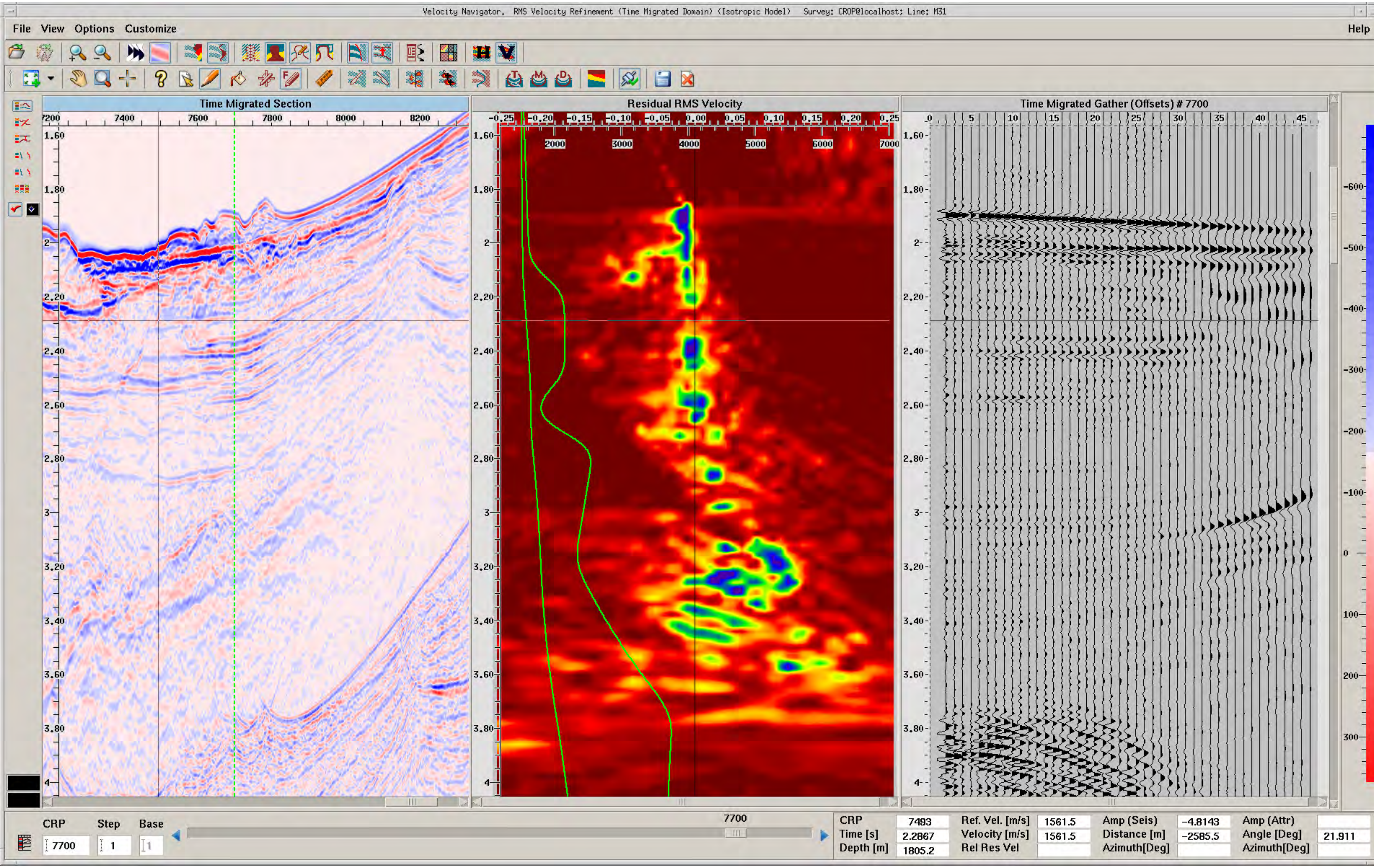
A: a common mid-point trace gather (left) and semblance coherence contour (right).

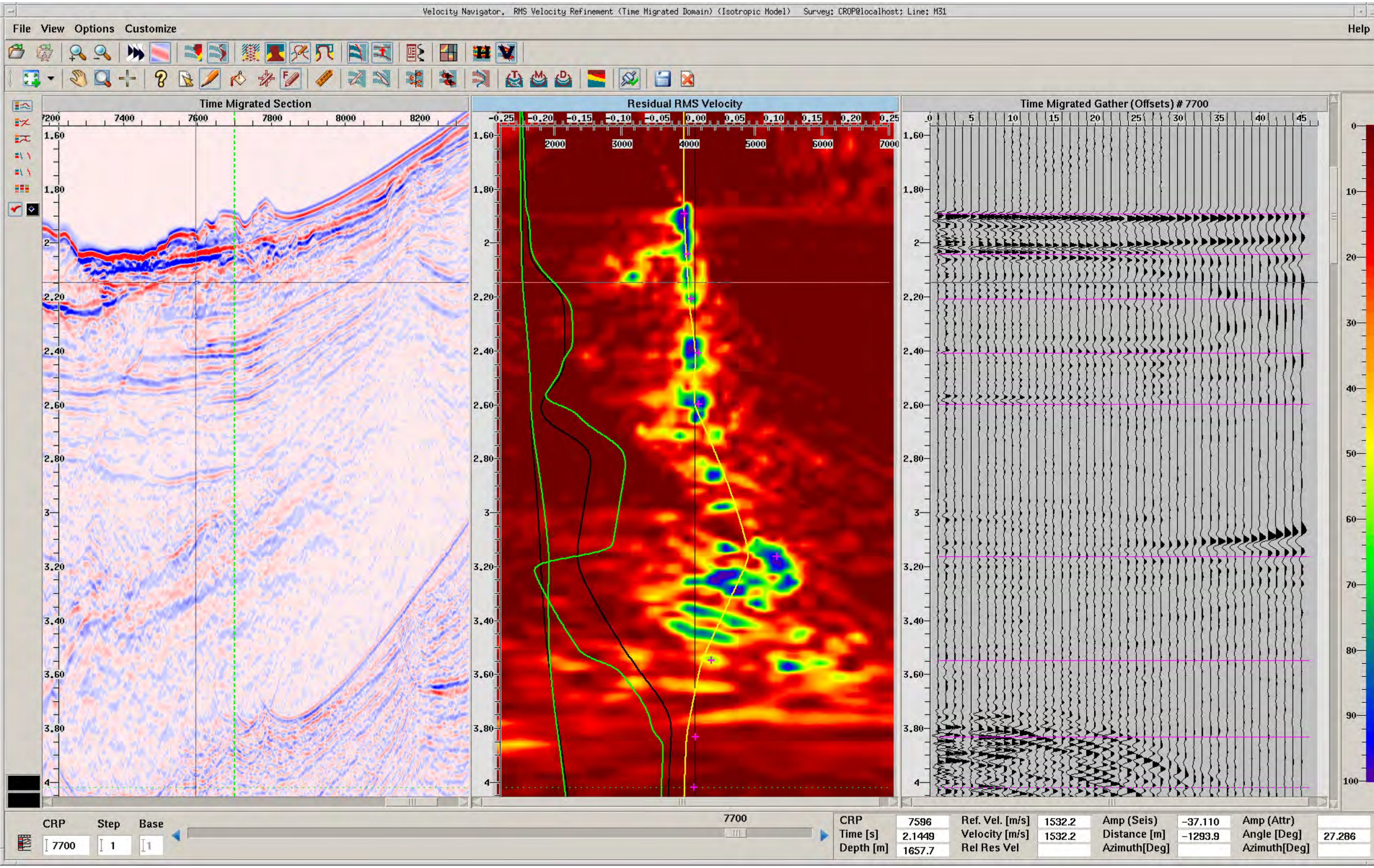
Peaks in coherence give the stacking velocity. (yellow line)

B: The same common mid-point trace gather of A with the normal move-out correction (NMO) after the velocity picking (yellow function). The interval velocity (red function) associated to this stacking velocity it will use in migration process.

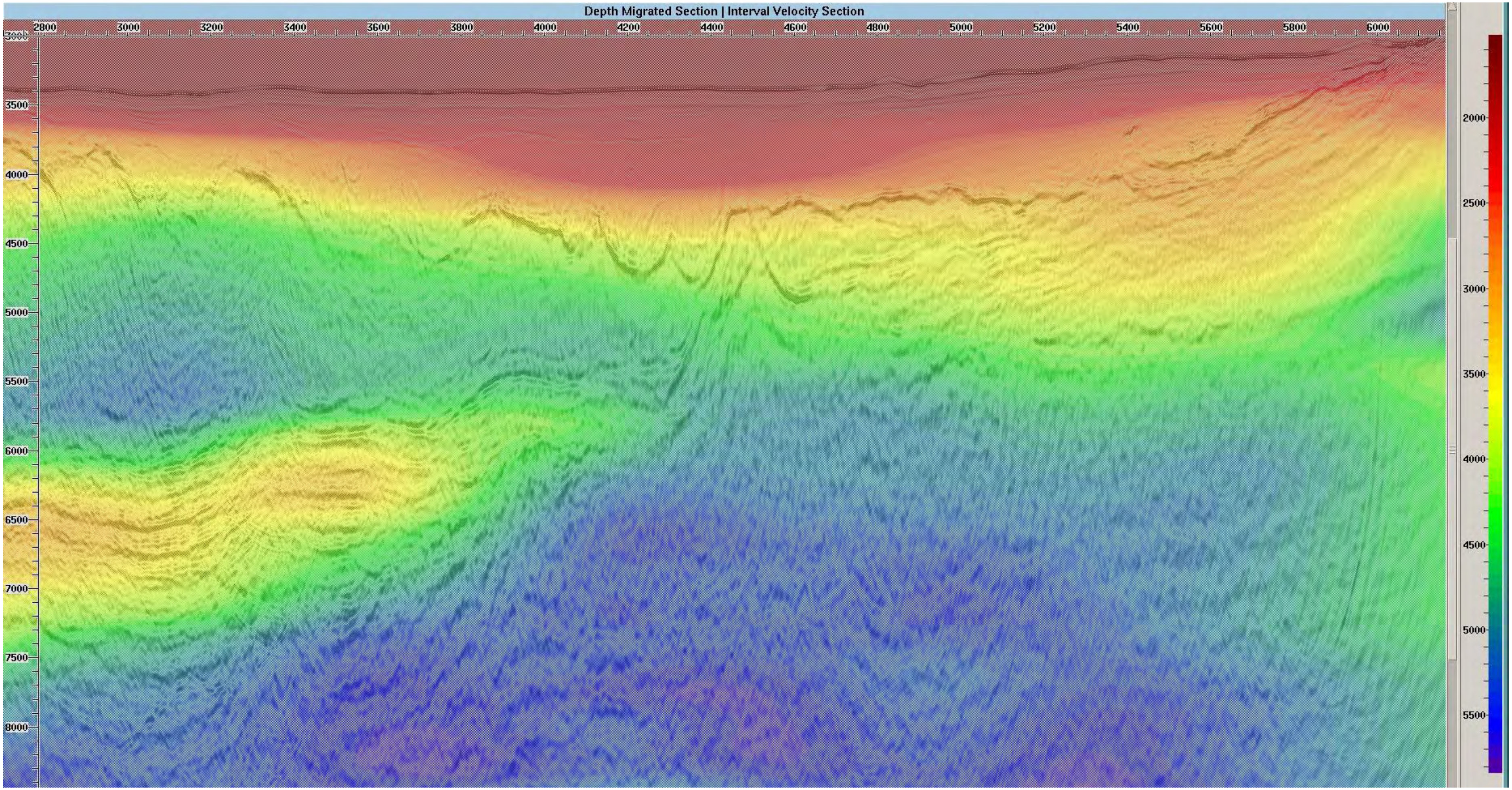
The field velocity section can be obtained from the seismic data using the stack velocities. We are going to flatten the reflections in CDP gather as in the image, picking the maximum coherence in the semblance. In this way velocity functions are obtained which we will interpolate with the others in order to have a section.




Velocity Navigator. RMS Velocity Refinement (Time Migrated Domain) (Isotropic Model) Survey: CROP@localhost; Line: M31
File View Options Customize
Help
Time Migrated Section
Residual RMS Velocity
Time Migrated Gather (Offsets) # 7700
CRP
Step
Base
7700
1
7700
CRP
Time [s]
Depth [m]
7493
2.2867
1805.2
Ref. Vel. [m/s]
Velocity [m/s]
Rel Res Vel
1561.5
1561.5
Amp (Seis)
Distance [m]
Azimuth[Deg]
-4.8143
-2585.5
Amp (Attr)
Angle [Deg]
Azimuth[Deg]
21.911

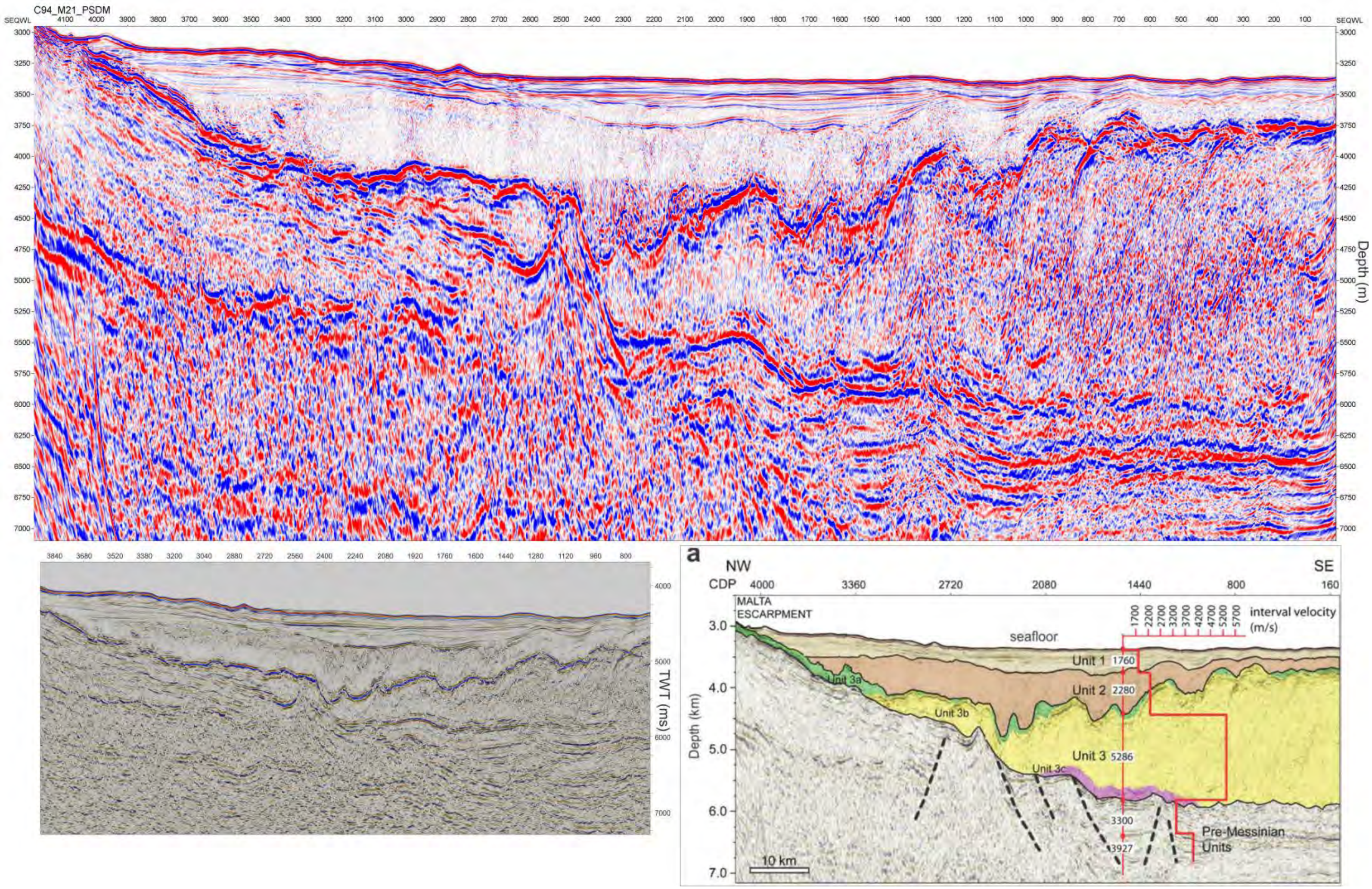

Velocity Navigator. RMS Velocity Refinement (Time Migrated Domain) (Isotropic Model) Survey: CROP@localhost; Line: M31
File View Options Customize
Help
Time Migrated Section
Residual RMS Velocity
Time Migrated Gather (Offsets) # 7700
CRP
Step
Base
7700
1
CRP 7596
Time [s] 2.1449
Depth [m] 1657.7
Ref. Vel. [m/s] 1532.2
Velocity [m/s] 1532.2
Rel Res Vel
Amp (Seis) -37.110
Distance [m] -1293.9
Azimuth[Deg]
Amp (Attr)
Angle [Deg] 27.286
Azimuth[Deg]

Velocity field and depth migrated seismic section



Example of Pre Stack Depth Migrated section with its velocity field superimposed (see next slide for the interpretation)

Depth migrated seismic section



(from Micallef et al., 2018)

Example of Pre Stack Time/Depth Migration section and the interpretation superimposed with velocity function (from Micallef et al., 2018).

Depth migrated seismic section

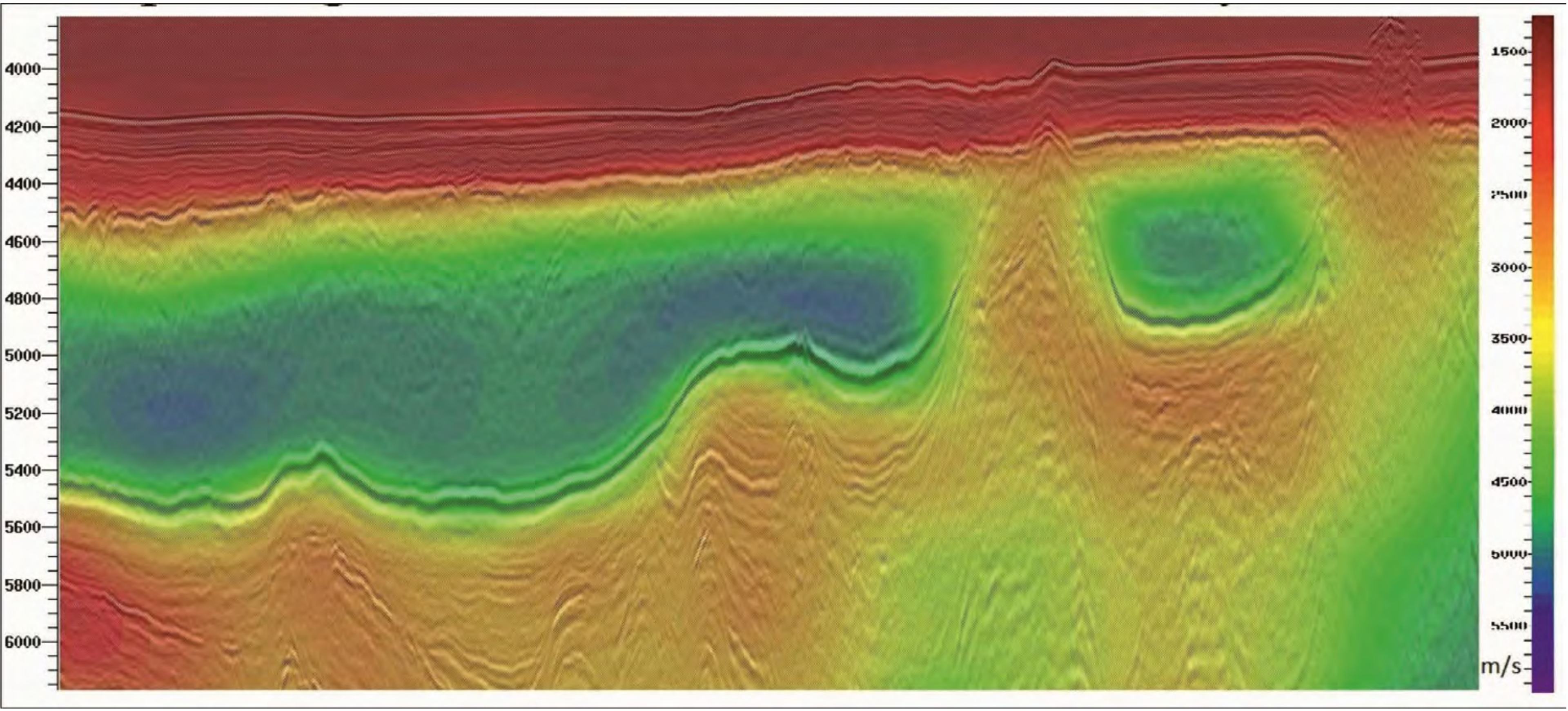
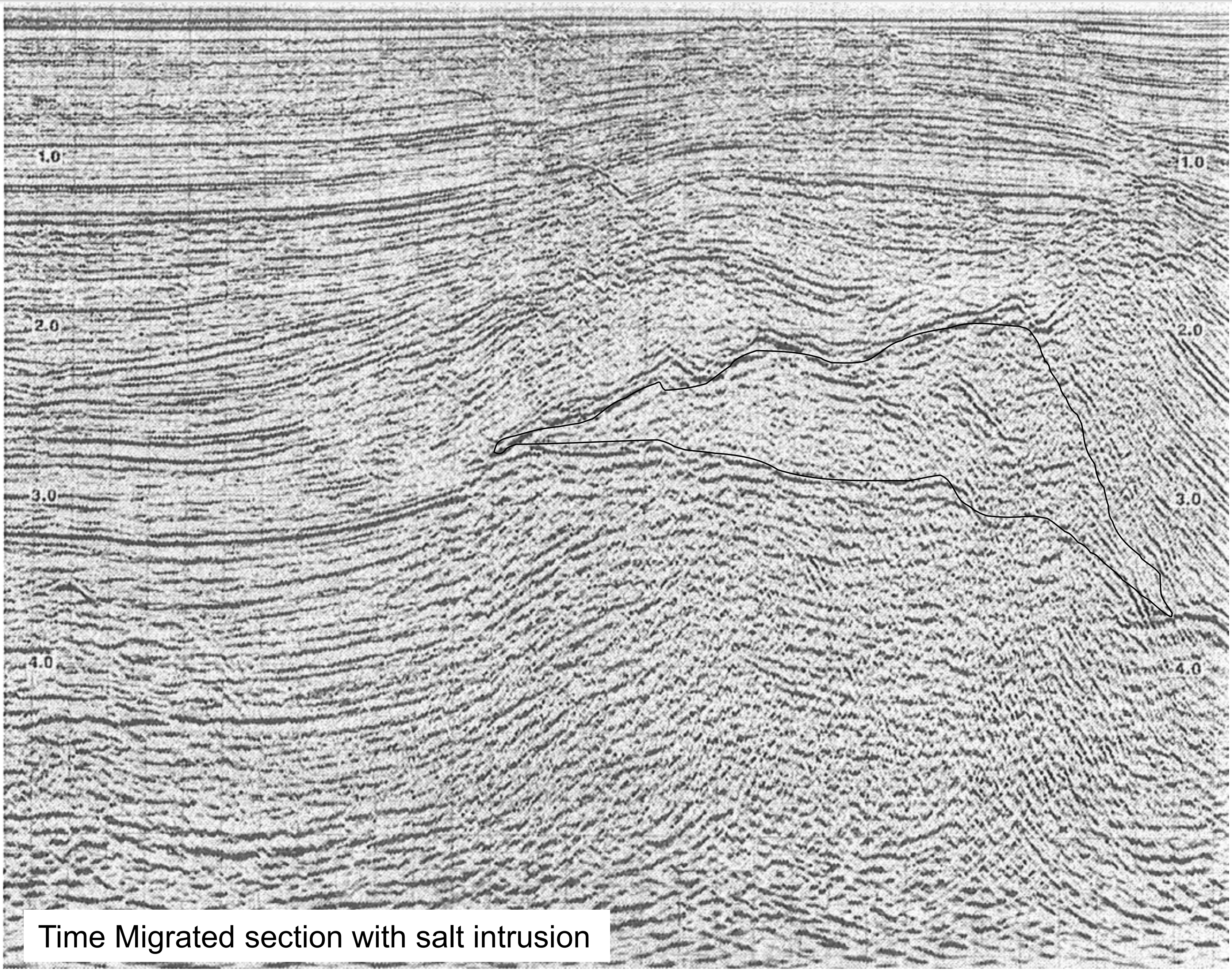
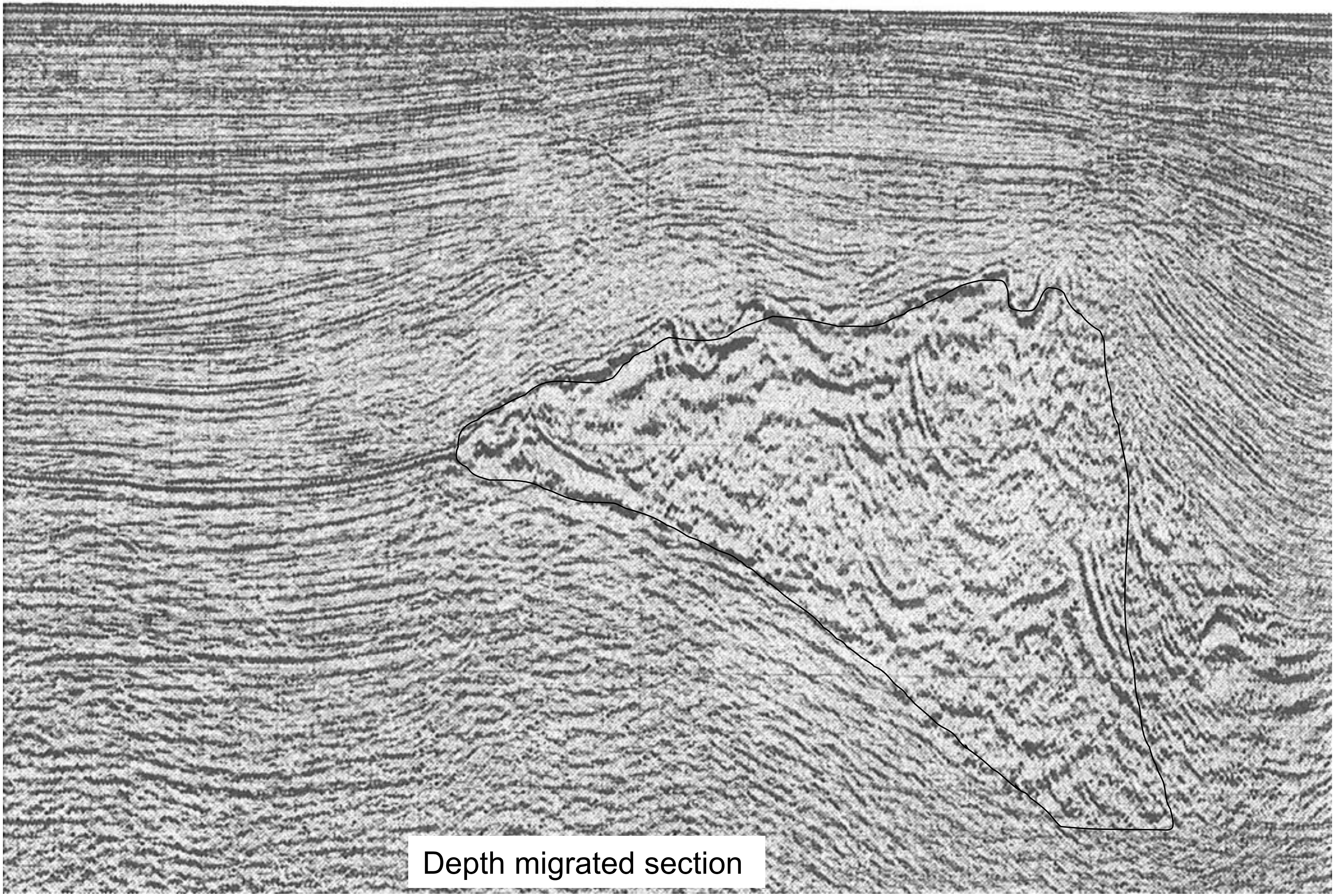


Image of a Pre-Stack Depth Migrated section (PSDM) and its velocity field used to migration (from Saule et al. 2016)

Note the high-velocity layer with a semi-transparent seismic signature with no stratification inside it. This is the Messinian salt layer (halite) in a seismic profile acquired in Ionian Sea.



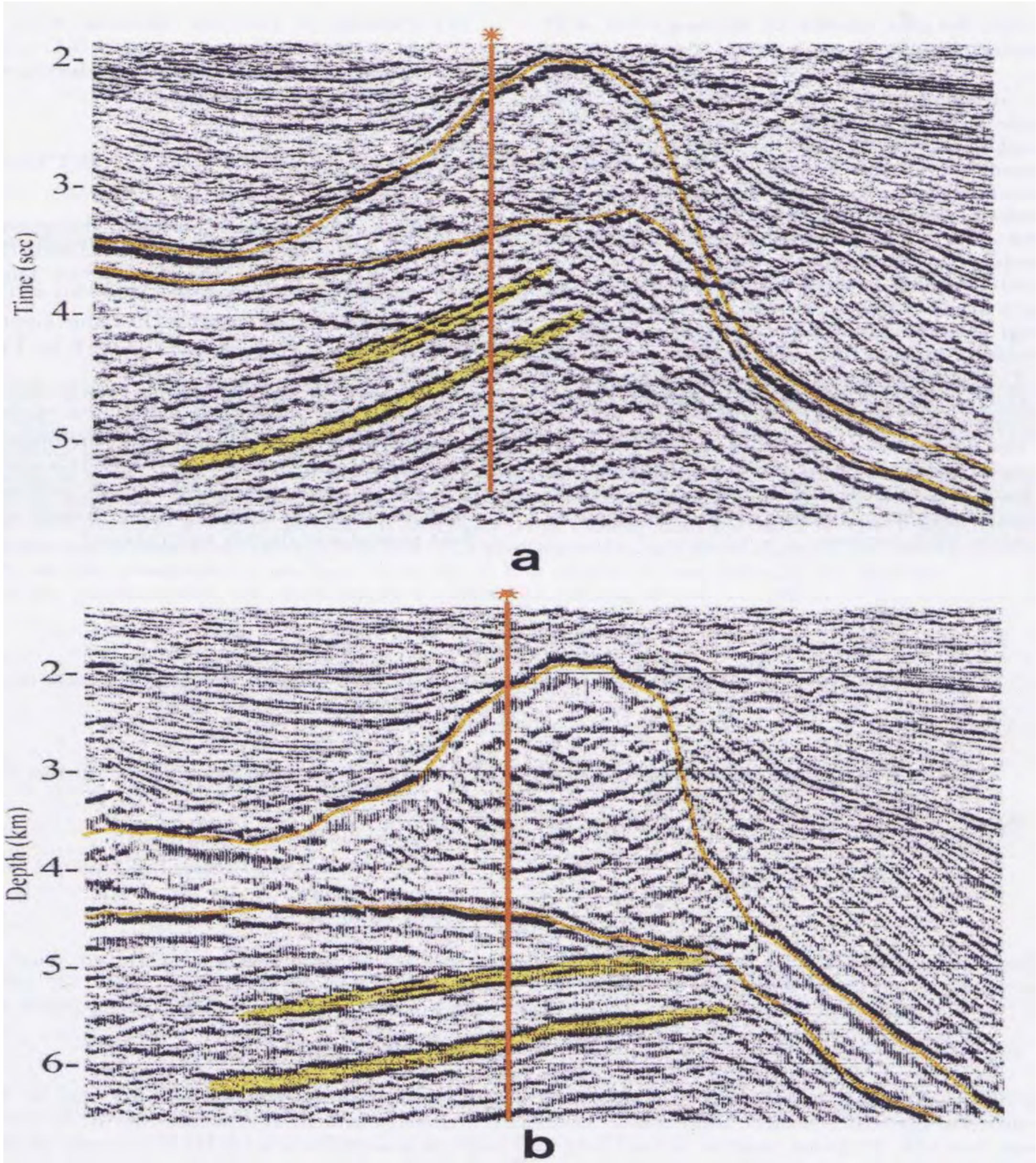
Time Migrated section with salt intrusion


Depth migrated section

Pull up velocity effect: example of a salt dome

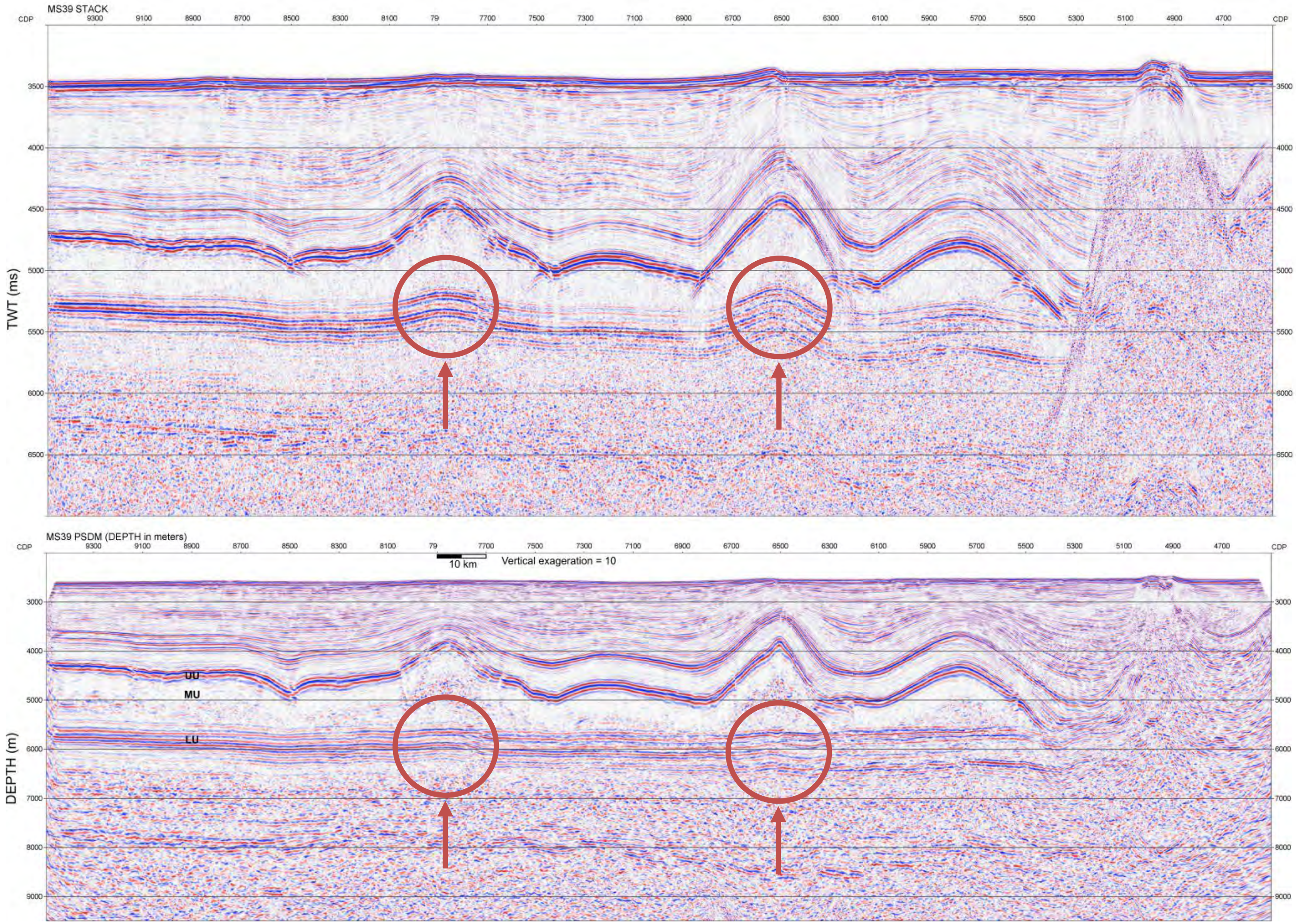
Time migrated section

Depth migrated section



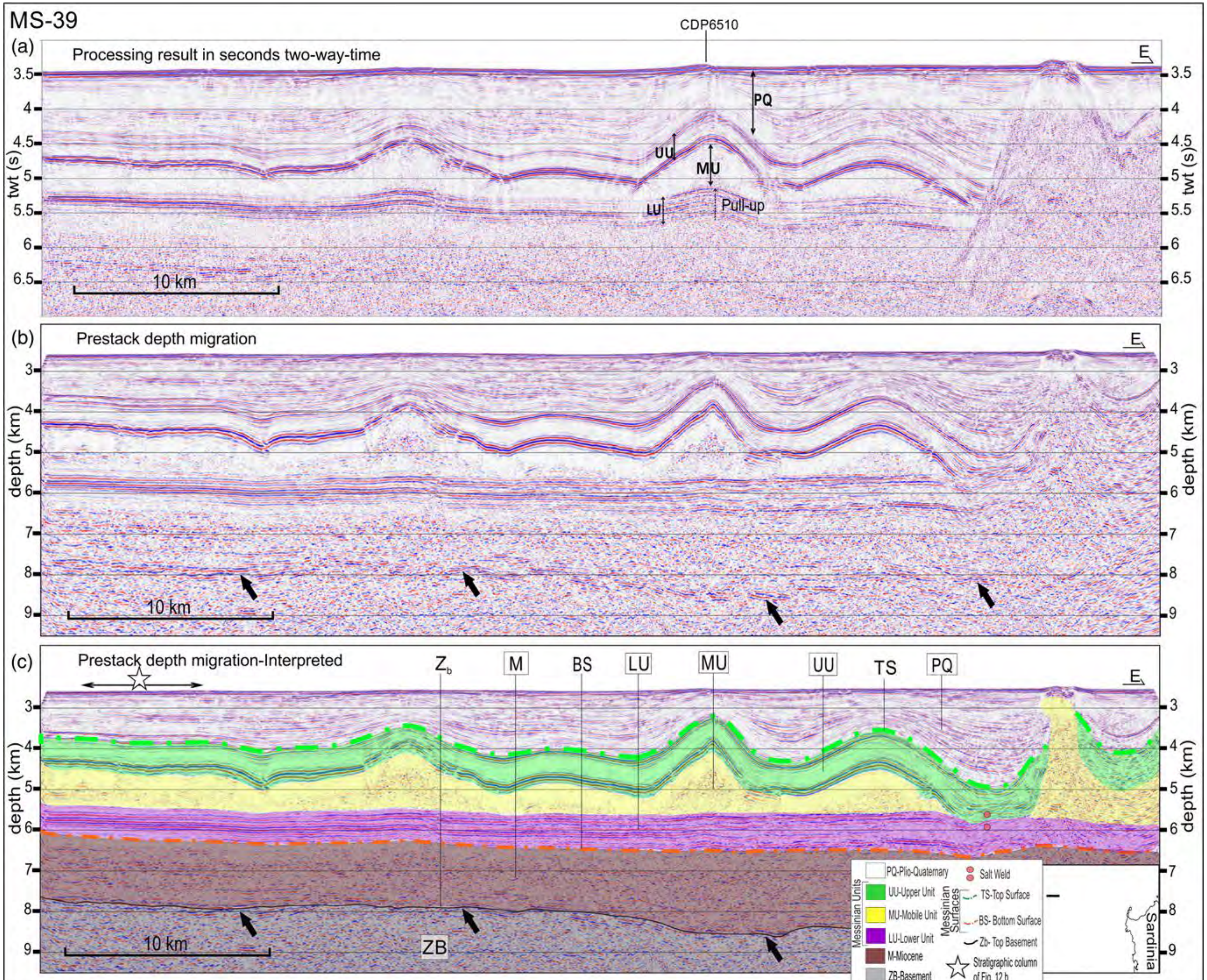
In presence of salt domes, in the seismic section we can observe the pull up velocity effect. This is due to the presence of high-velocity salt dome over the deep reflector in that sector of the profile. When we migrate in depth this effect is corrected with a right velocity function.

Pull up velocity effect

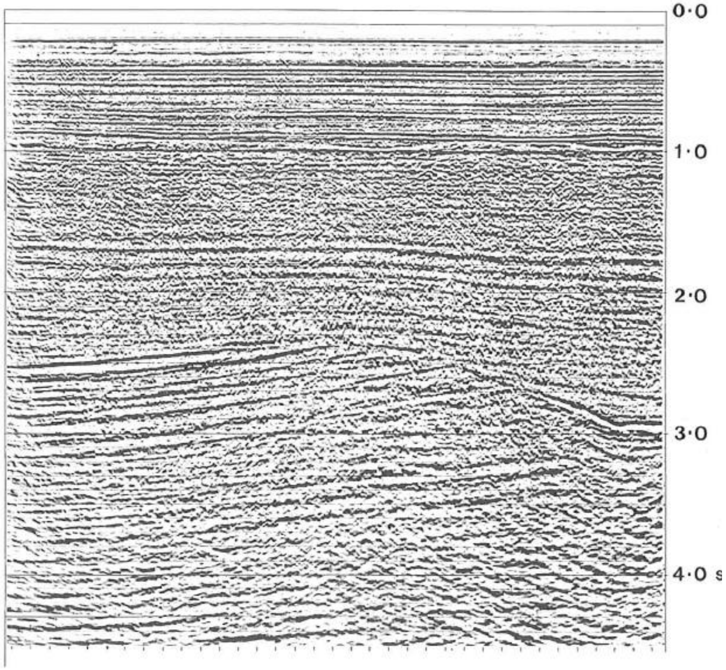


(Above) Result of data processing in time domain: the pull-up event (red circles) of about 200 ms occurs beneath a salt dome and affects the underlying layers. (below) Result of Pre-Stack Depth Migration (PSDM) showing flattened pullup event. (modified from Dal Cin et al. 2016)

Interpretation



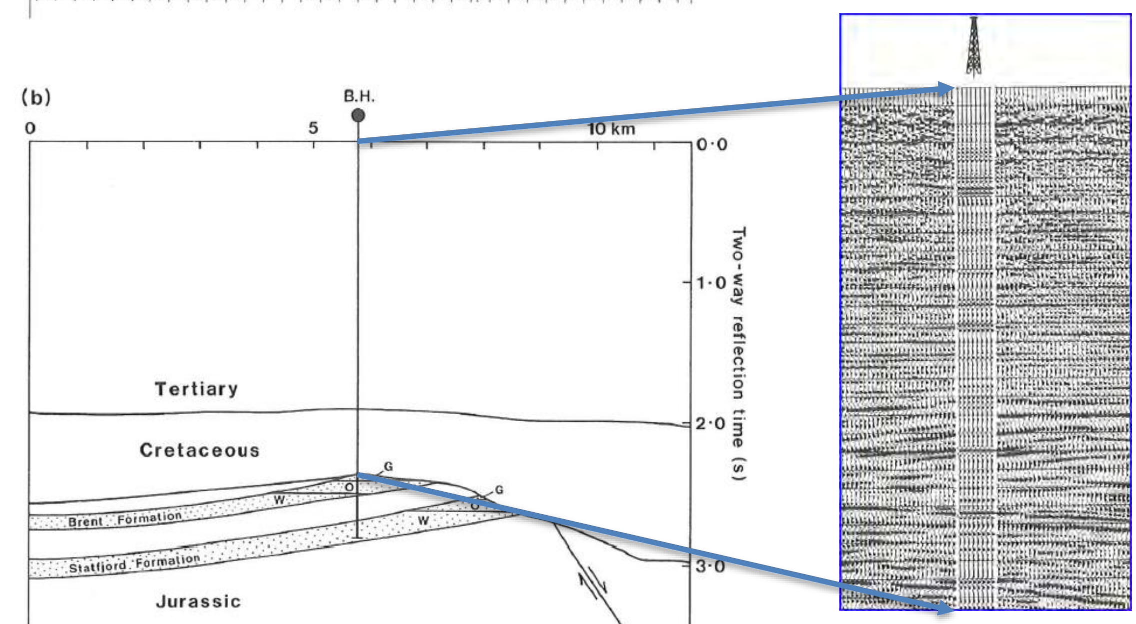
Dal Cin et al., 2016. Petroleum Geosciences



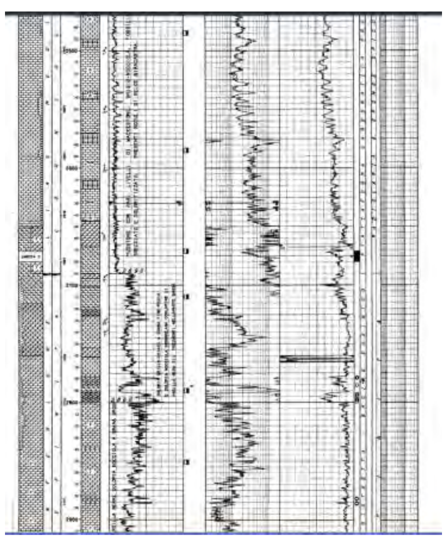
Vertical Seismic Profiling (VSP) in seismic interpretation

Example of correlation of well data (VSP) with the seismic section for geological interpretation

In some case we have a borehole across the seismic section and we can correlate these two type of data. From this we can therefore give a lithological meaning to the individual reflectors of the seismic profile passing through the well. In the image below and on the right, we can see an example of correlation between the seismic profile and the data obtained from the registration of the VSP in a borehole. The VSP was made after the geologic sampling in the same borehole.

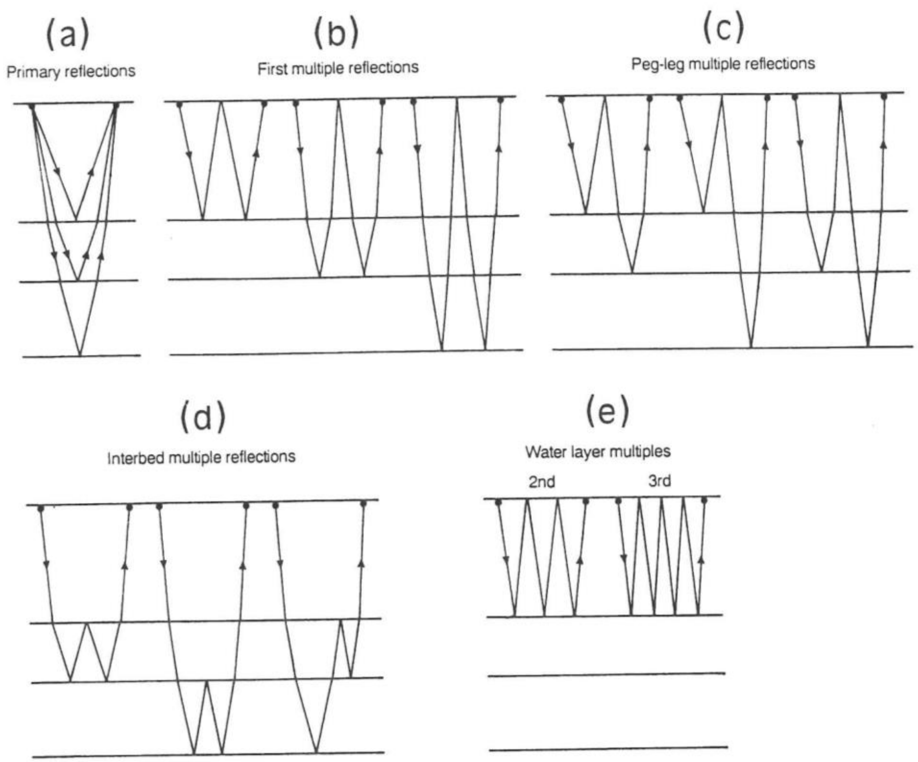


Well



- MULTIPLE REFLECTIONS –

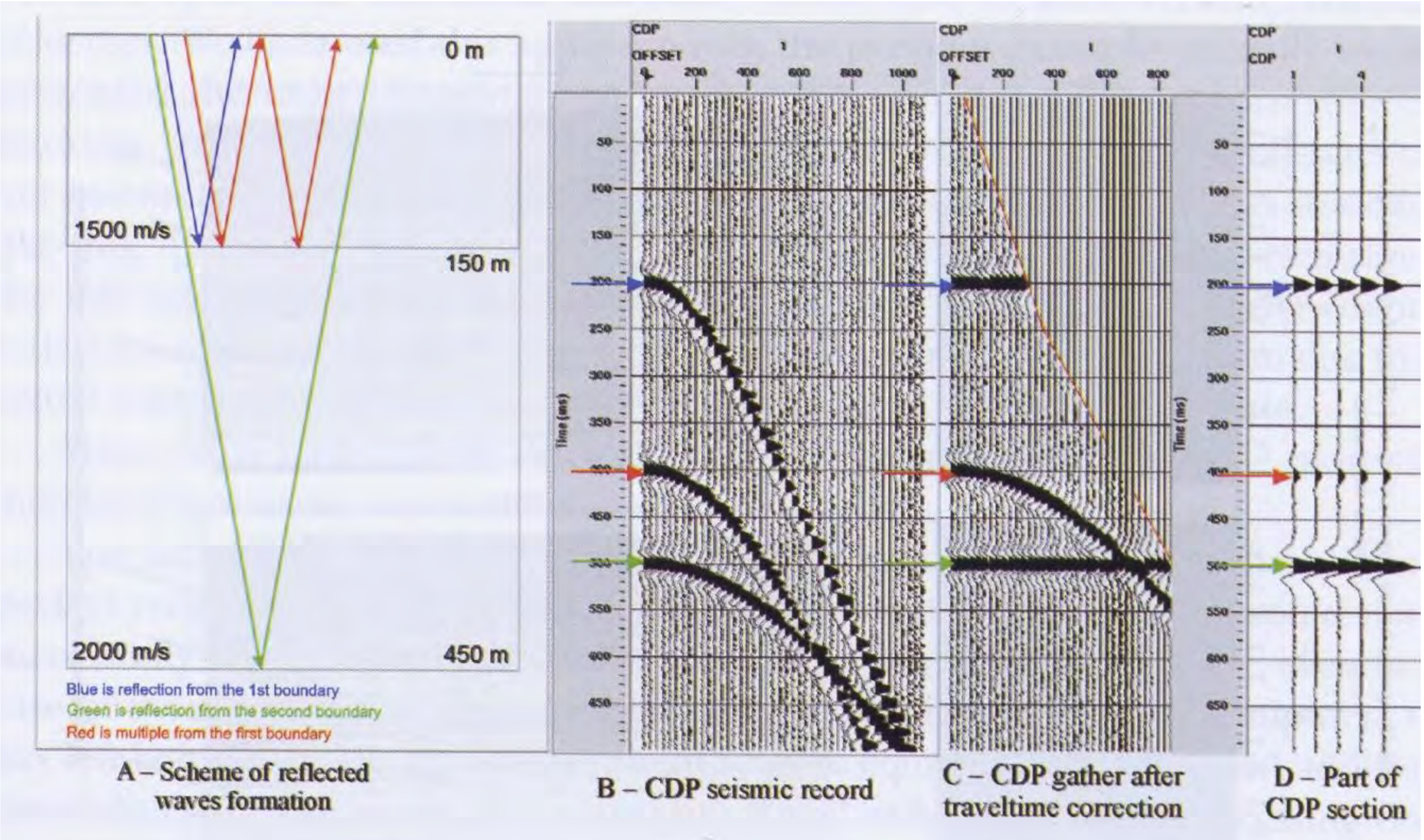
The problem of cherent noise in marine seismic profiles



Long-path multiples appear as distinct events. Short-path multiples are added to primary reflections and tend to come from shallow subsurface phenomena

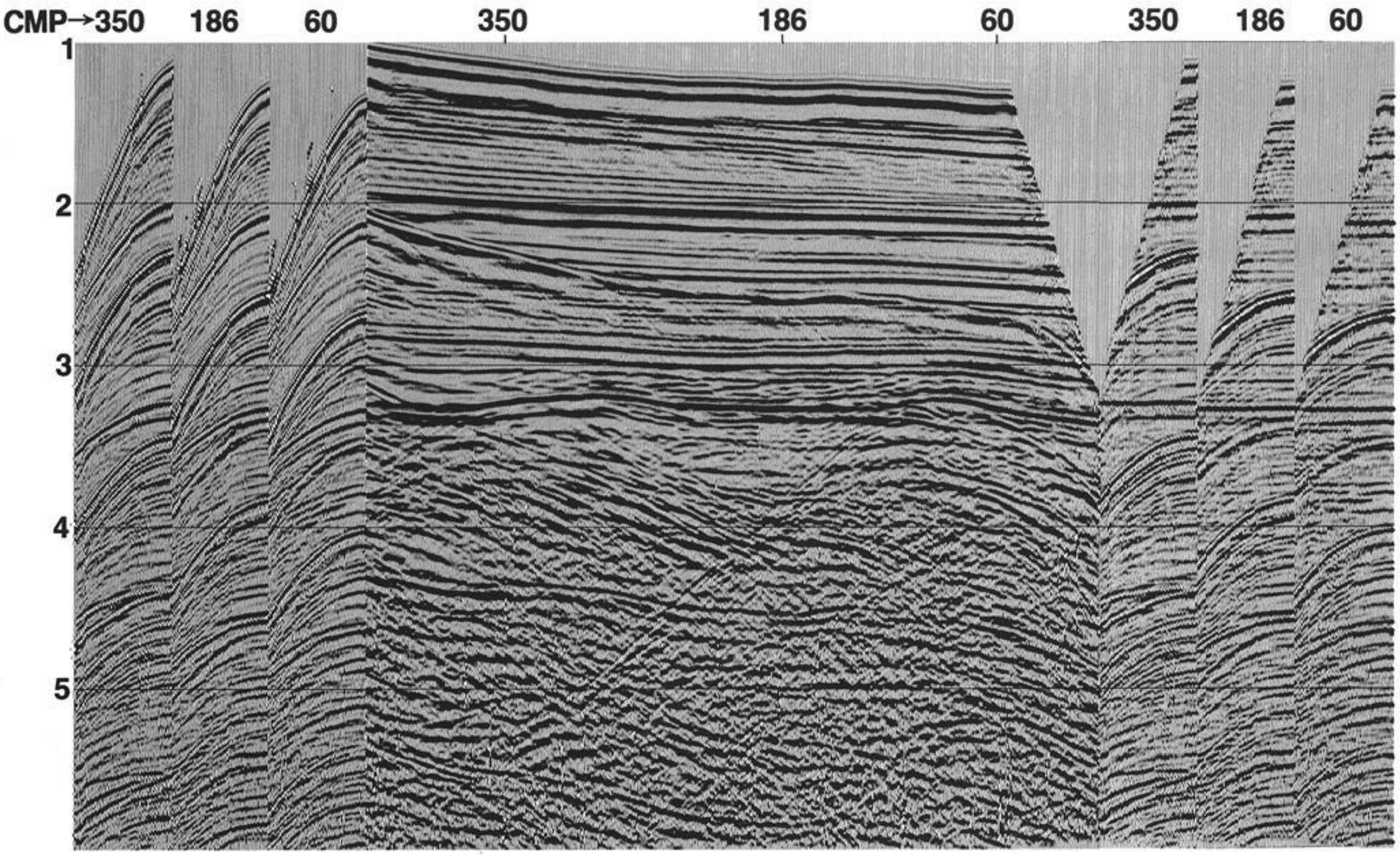
The marine seismic dataset is often characterized by the presence of multiple reflections that affect the quality of the section itself. The multiple are the coherent noise that it leads to the misinterpretation of real reflective horizons. There are a lot of type of coherence noise, but the first water bottom multiple reflections are the most frequently.

MULTIPLE REFLECTIONS



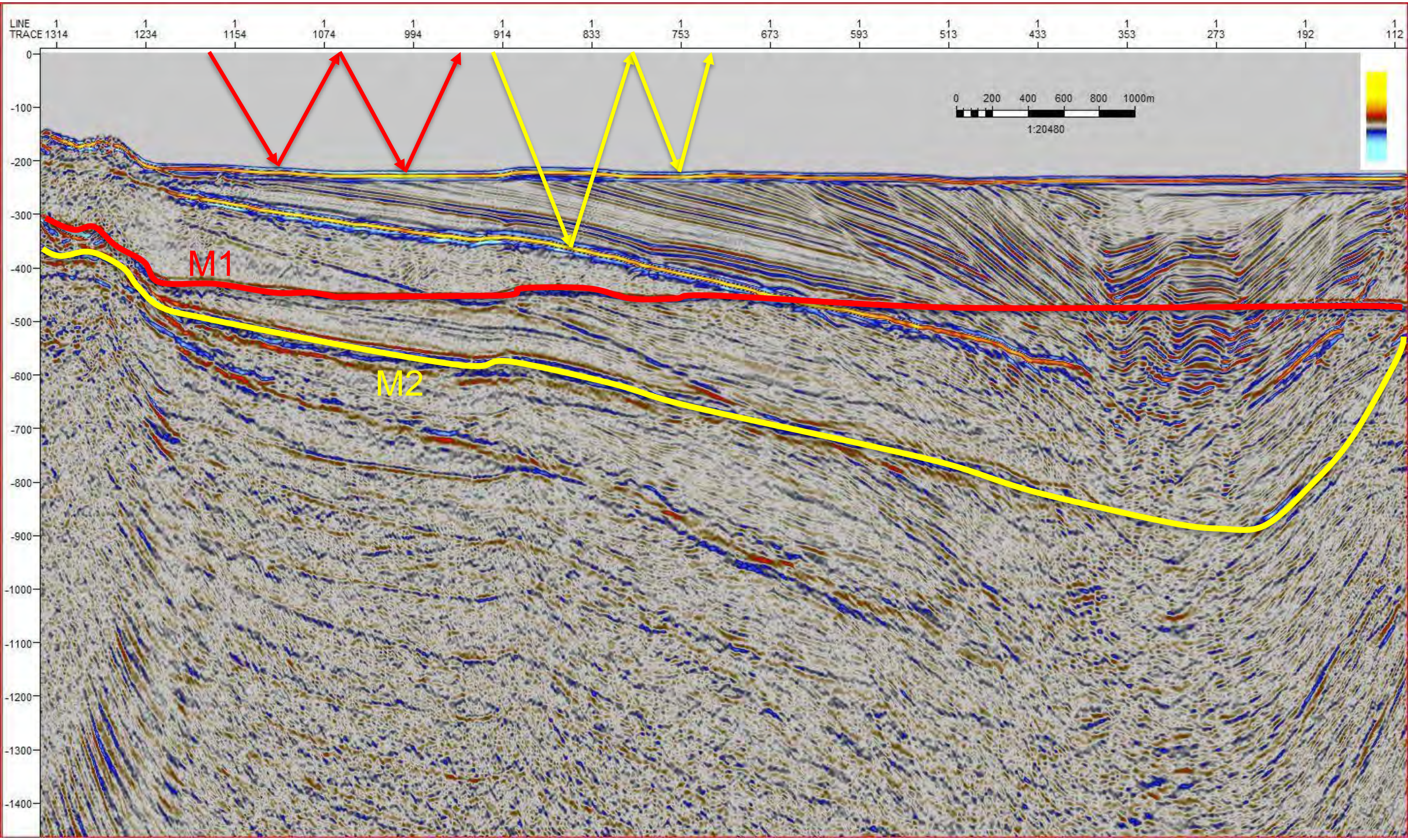
In this slide on the left it shows a schematic model of ray paths of the sea floor reflector (in blue color), a deep reflector at 450 m (in green color) and a multiple ray path in red. On the right there is a cdp gather before and after normal move out correction (velocity correction) and its stack section where you can see that the multiple reflection is attenuated, but no eliminated..

MULTIPLE REFLECTIONS



Three CMP gathers before (left) and after (right) NMO correction.Note that the primaries have been flattened and the multiples have been undercorrected after NMO correction. As a result, multiple energy has been attenuated on the stacked section (center) relative to primary energy (from Yilmaz 2001)

MULTIPLE REFLECTIONS

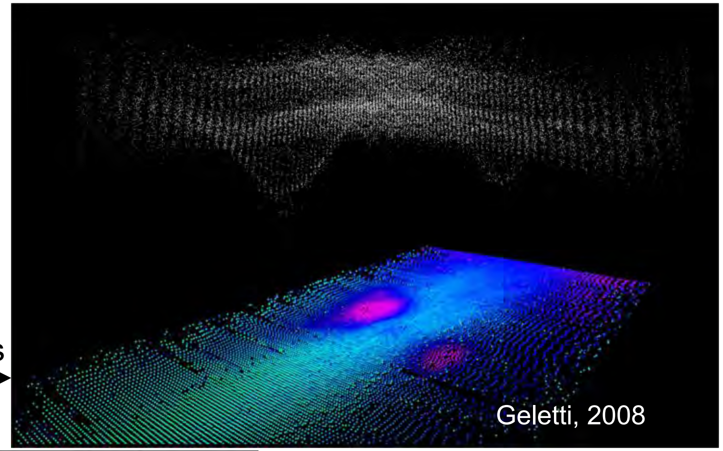


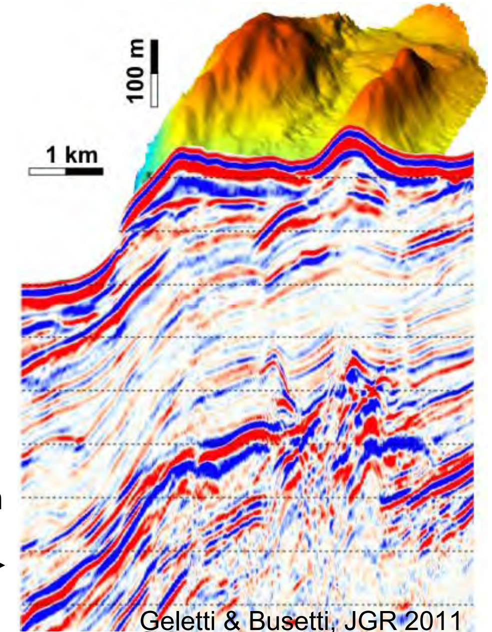
Example of seismic stack section with multiple reflections (M1 and M2)

Gas seeping features

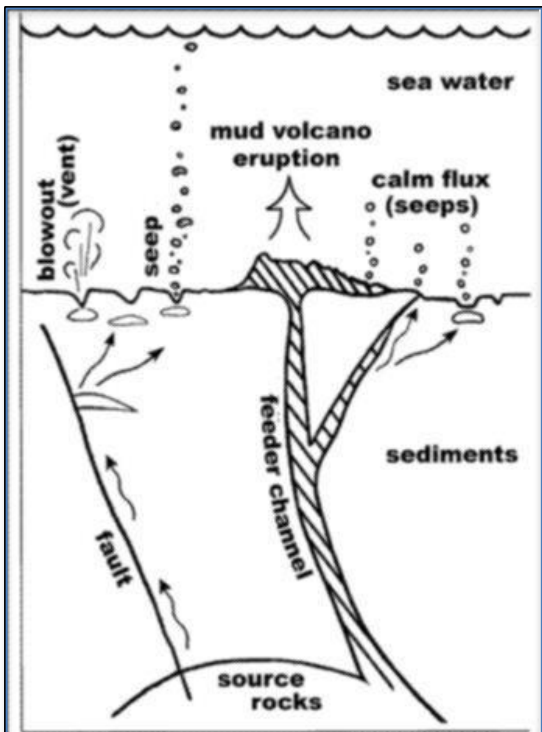
Mud volcanoes and pockmarks

MB data with pockmarks

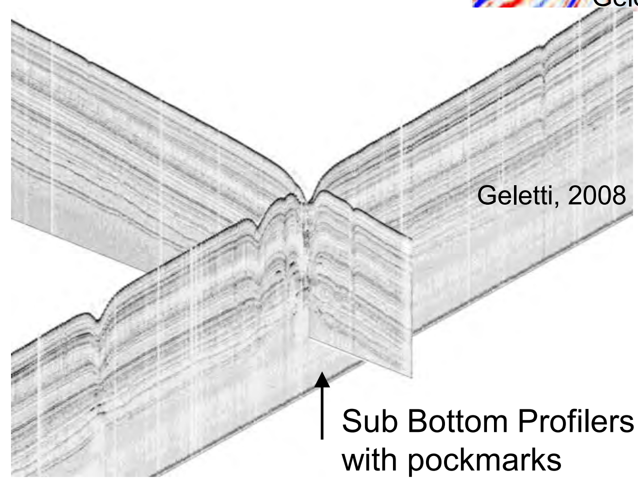




Seismic line & MB image with mud volcano



Schematic model of gas seeping related upward fluid migration

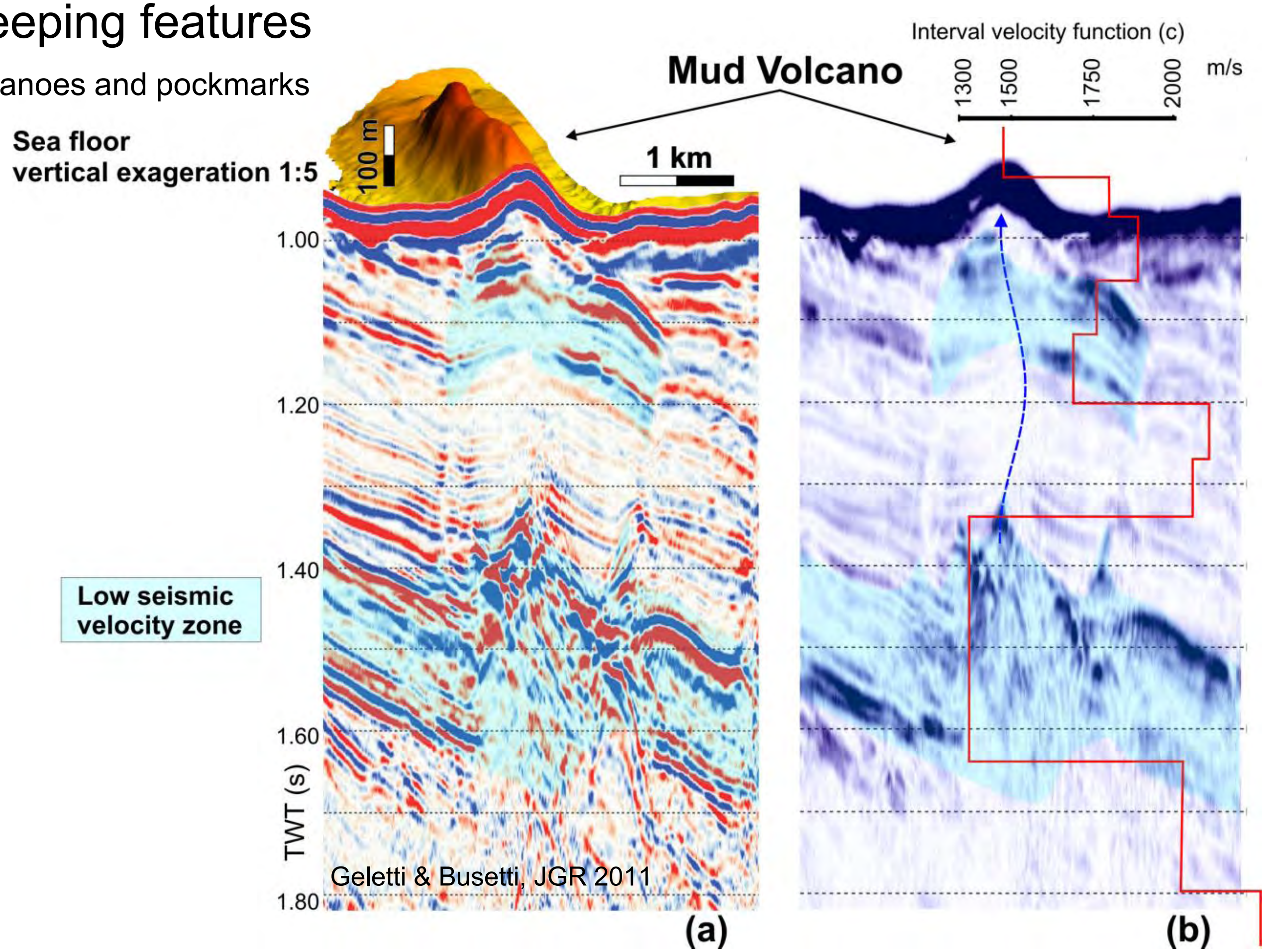


Sub Bottom Profilers (CHIRP) with pockmarks

Some example of gas seeping features. Sea bed fluid flow, also known as submarine seepages, involves the flow of gas and liquids through the seabed. This geological phenomenon has widespread implications in seabed slope instability, drilling hazard, hazards to seabed installations and so on. Seabed fluid flow affects seabed morphology (pockmarks, mud volcanoes). Natural fluid emissions also have a significant impact on the composition of the oceans and atmosphere: methane emissions have important implications for the global climate change.

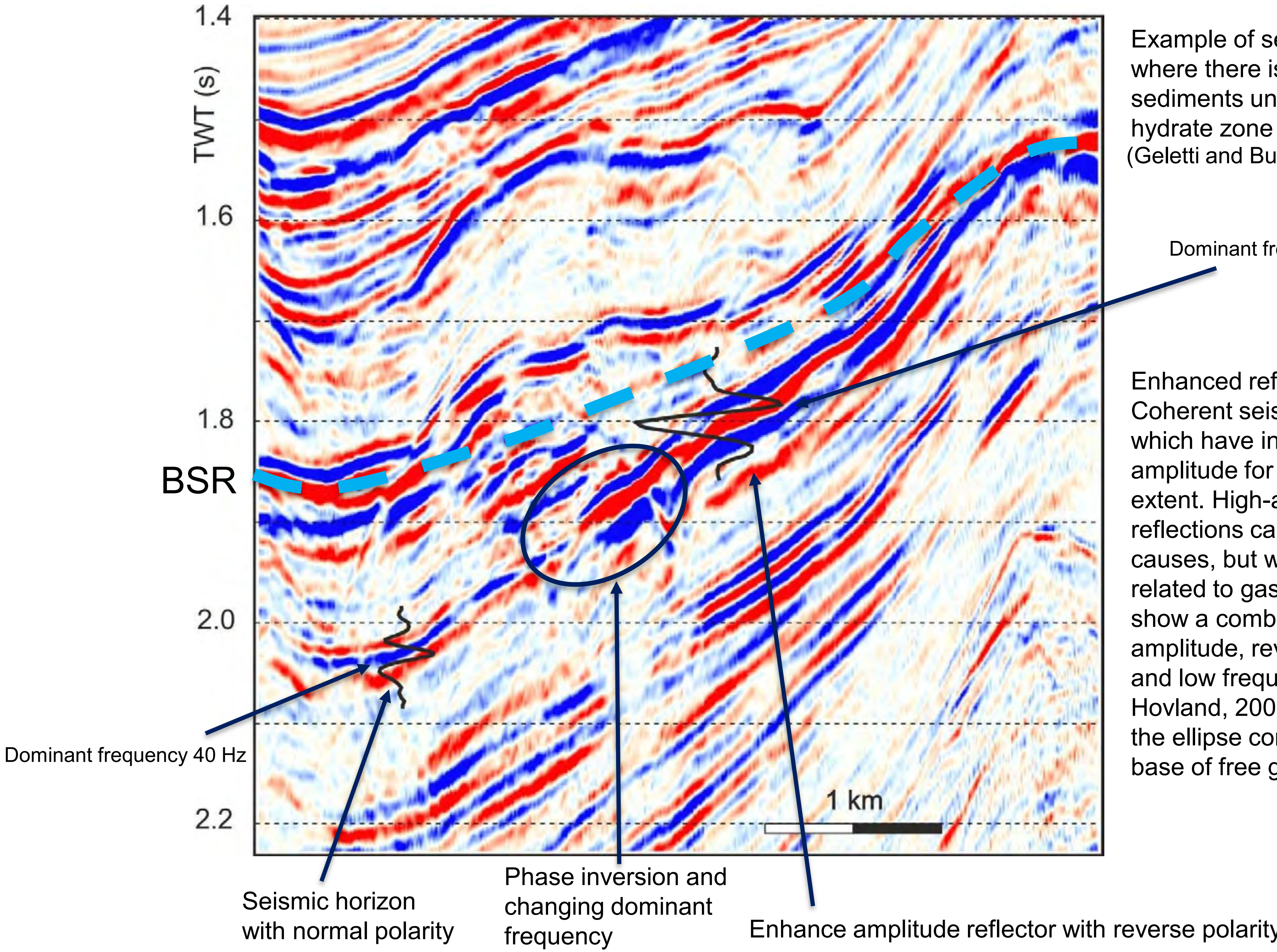
Gas seeping features

Mud volcanoes and pockmarks



Example of upward fluid migration and the correlated gas seepage features in a seismic profile

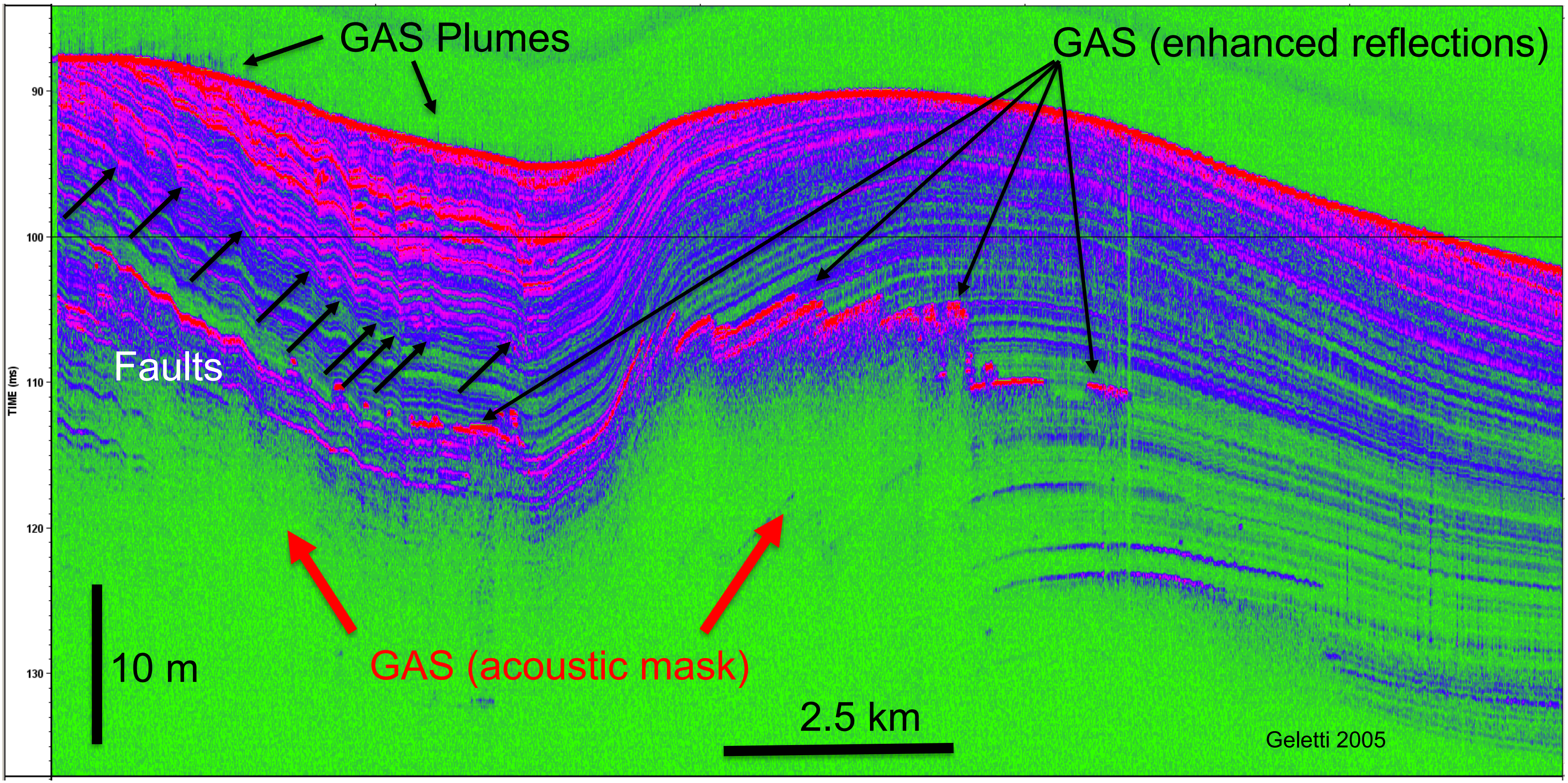
(modified from Geletti & Busetti, JGR - 2011)

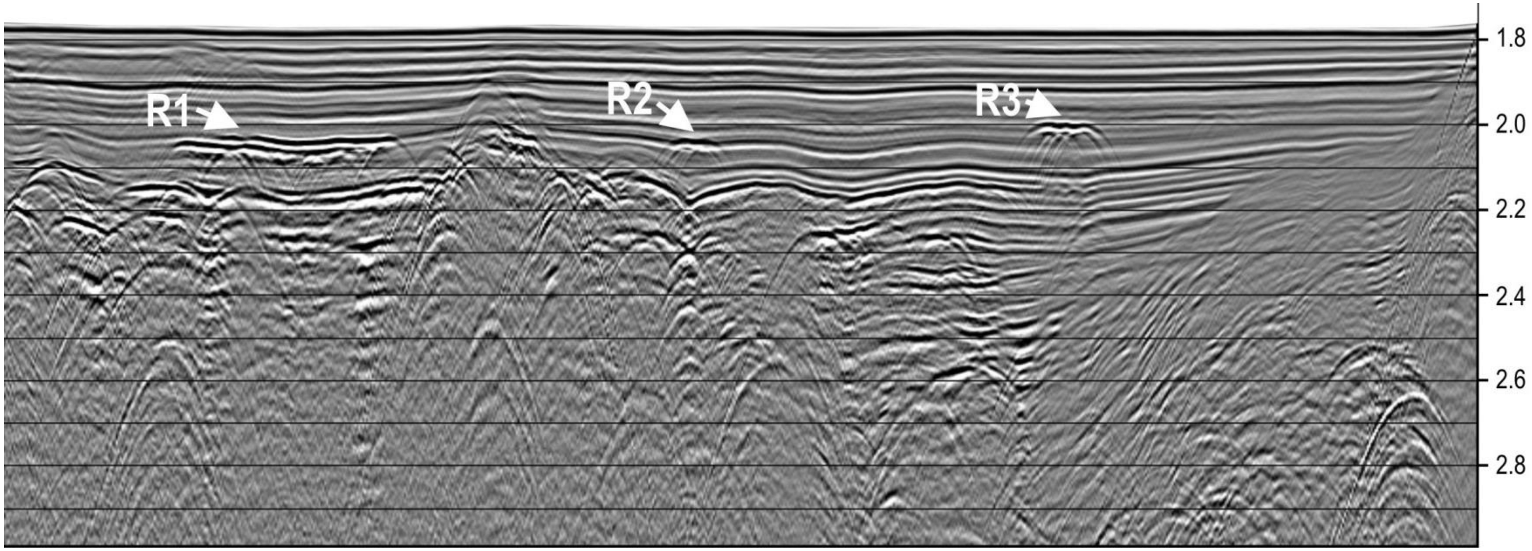


Example of seismic imaging where there is free gas in the sediments under the gas hydrate zone (Antarctica) (Geletti and Busetti, 2020)

Enhanced reflection: Coherent seismic reflections which have increased amplitude for part of their extent. High-amplitude reflections can have various causes, but when they are related to gas they generally show a combination of high amplitude, reverse polarity and low frequency (Judd and Hovland, 2007). The event in the ellipse corresponds to the base of free gas zone.

Example of very high resolution Echosounder CHIRP section in the Central Adriatic Sea: there are faults, folds and gas in the sediments of the most superficial layers up to a depth of 20/30 meters

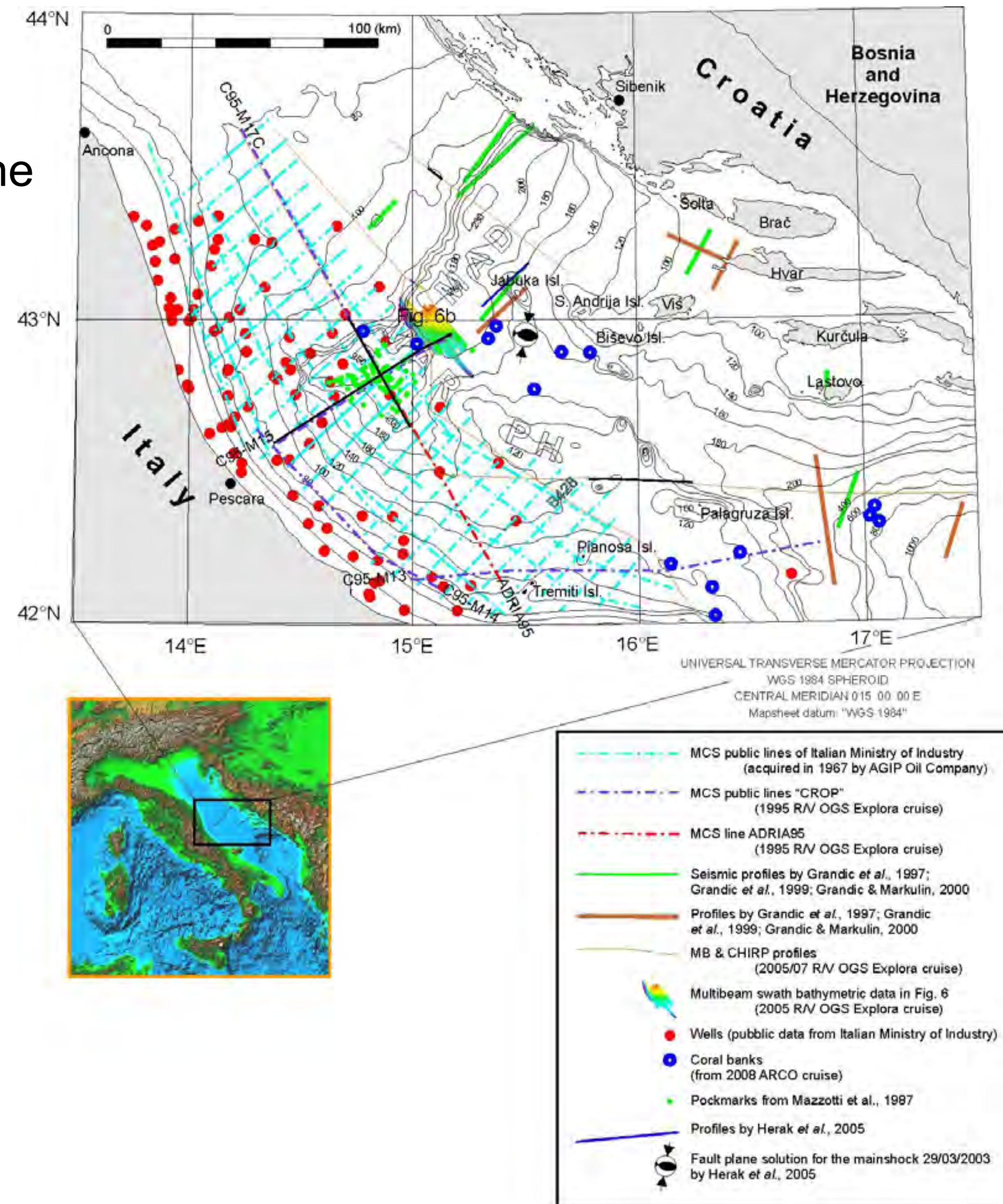




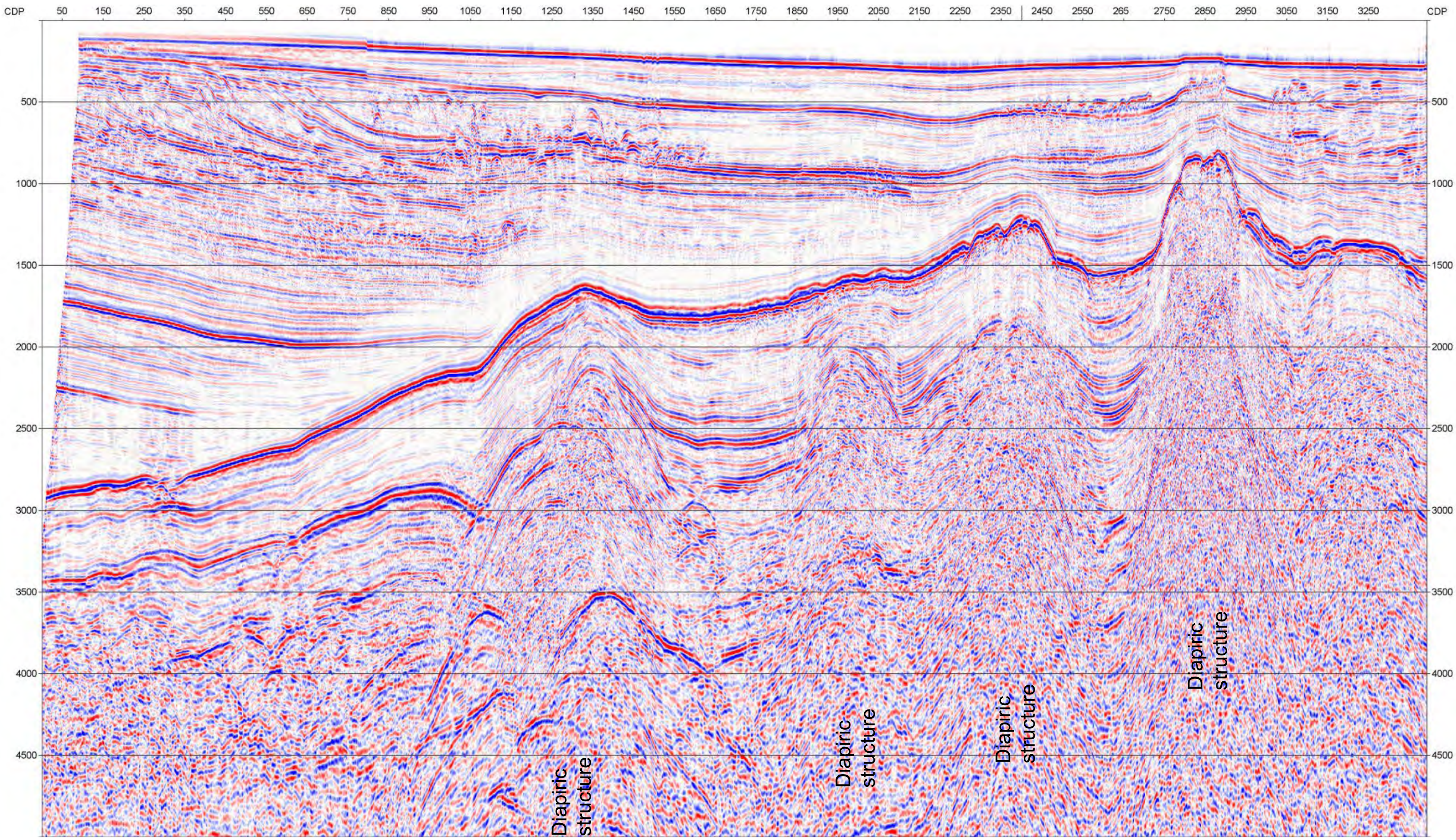
Examples of bright spot (R1, R2 and R3) in a seismic section (no migrated)

CASE HISTORY - 1:
Gas seeps linked to salt structures in the Central Adriatic Sea (Geletti et al., 2008)

The analyses of about 800 km of Chirp sub-bottom profilers and 600 km^2 of Multibeam data acquired during the 2005 and 2007 surveys of the R/V OGS Explora, and their correlation with one new, and several public, multichannel seismic profiles, allow us to propose a relation between the distribution of gas seepages, fracture systems and deep salt features present in the Central Adriatic Sea. Gas seepage is evident from pockmarks on the seabed and in the shallow sub-bottom, where acoustic chimneys and bright spots have been highlighted and analyzed. The Mid-Adriatic Depression (MAD) is a distinct morphological feature in the Central Adriatic Sea elongated in a NE-SW direction. The area is affected by salt doming of Triassic evaporites which cause the two main alignments of the Mid-Adriatic Ridge as far as the Palagruza High and the Jabuka Ridge. These salt tectonics have existed since, at least, Paleogene times and are still active: they characterize sectors with less resistance to deformation produced by successive regional compressive regimes that have affected the area differently during the different geodynamic phases. Gas- seep features are distributed preferentially above and along the fracture systems produced above and around the salt mounds.

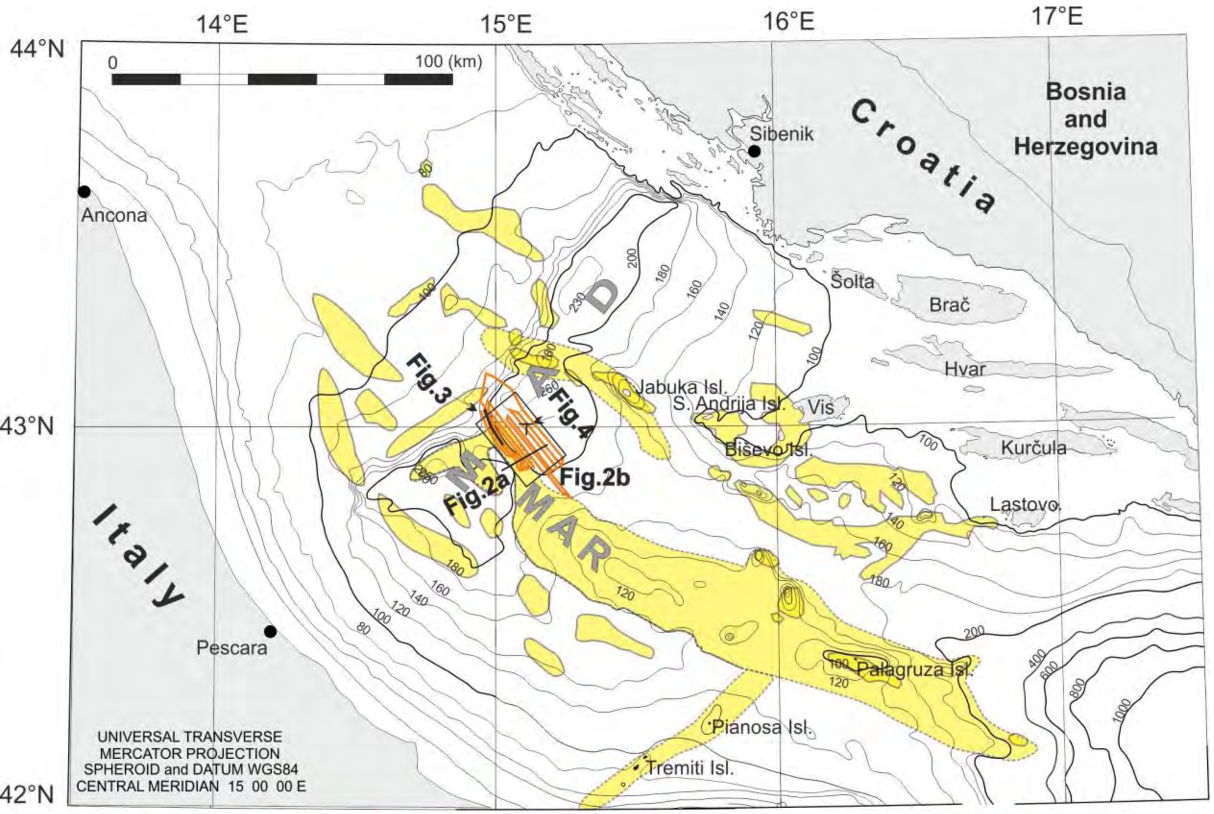


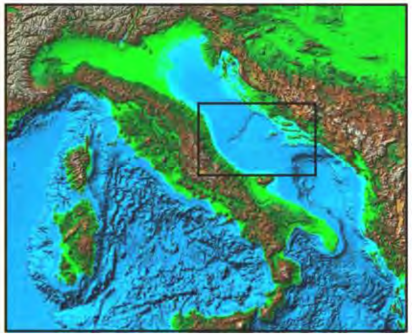
Central Adriatic Sea

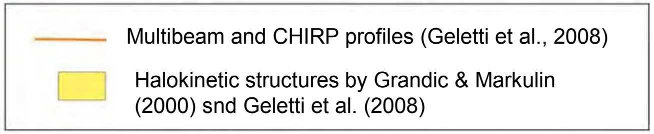


Crustal seismic profile CROP- M15

Central Adriatic Sea



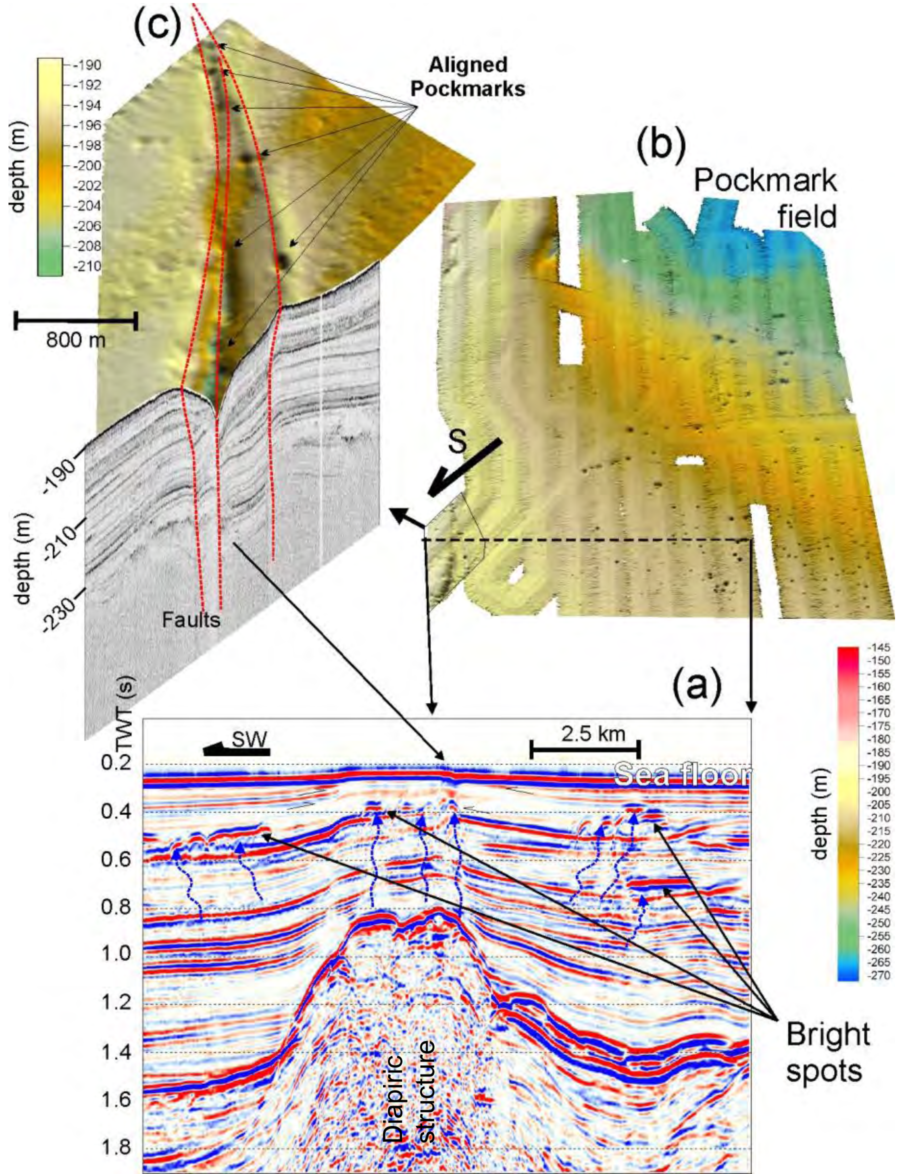




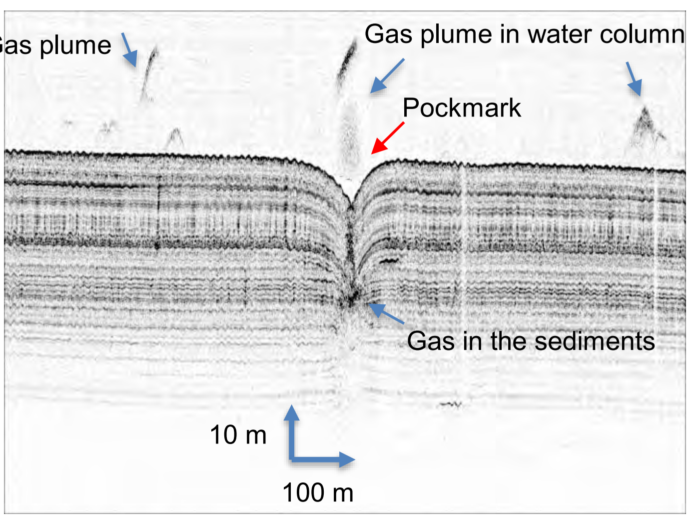
Bathymetric map of the Central Adriatic Sea, affected by gas seeping phenomena. There are mapped the CHIRP and multibeam profiles acquired in 2005 by the R/V OGS Explora (GELETTI *et al.*, 2008), the positions of the figures in the text and the indication of the main halokinetic structures present in the area (modified by GELETTI *et al.*, 2008)

Central Adriatic Sea

a) Image of the seismic reflection profile with the evidence of bright spots indicating the presence of gas in the Plio-Quaternary sediments, b) multibeam bathymetry (MB) and a pseudo 3D image (c) with CHIRP profile and MB where it is highlighting a system of active faults along which some pockmarks can be identified. The seismic line shows the presence of a deep diapiric structure that also deforms the sea floor



Detail of the CHIRP line with evidence of gas plume



Central Adriatic Sea

In this slide there are some images of gas/fluid presences within the sediments. On the right, above you see an image of pockmarks on swath bathymetry of multibeam. Below, two chirp profiles. On the left side you see a seismic section where at a deep of 400/450 m there are seismic anomalies below superficial gas evidence in chirp profiles

Seismic section with gas seeps features

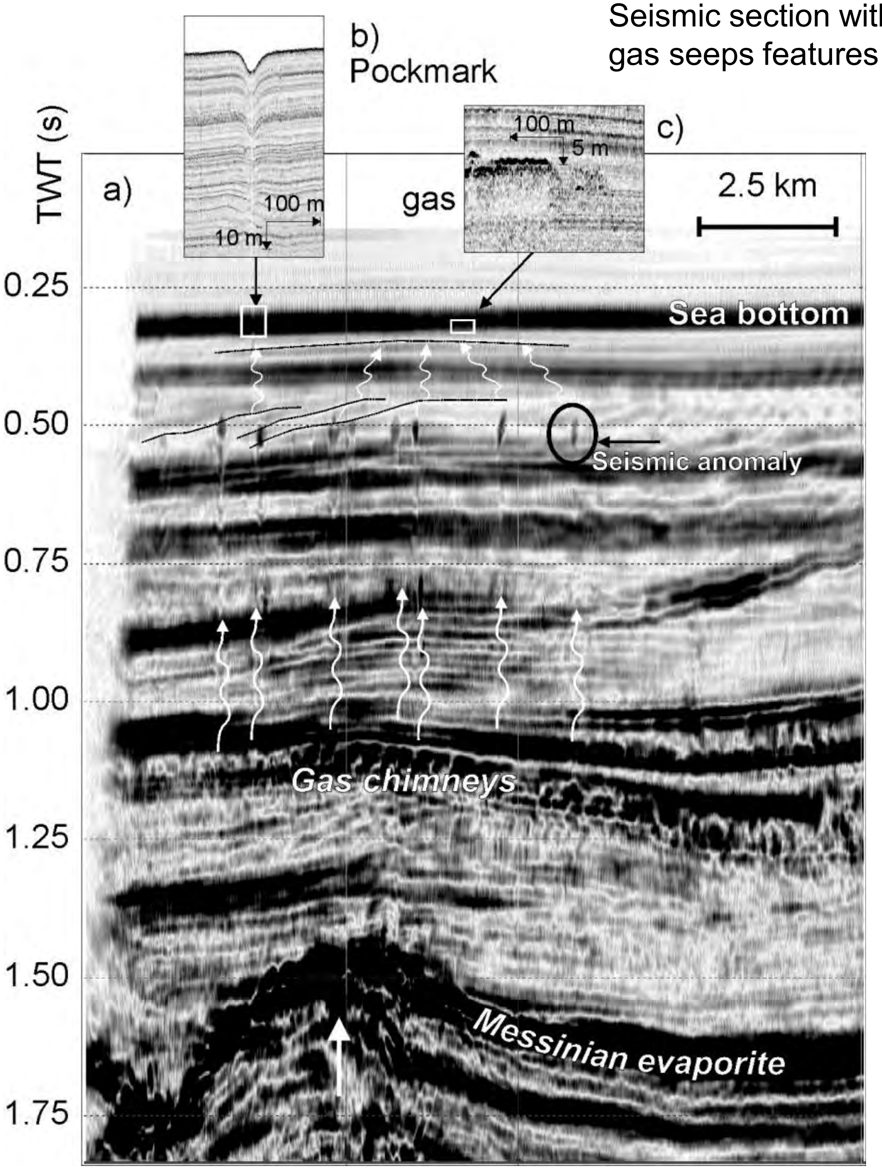
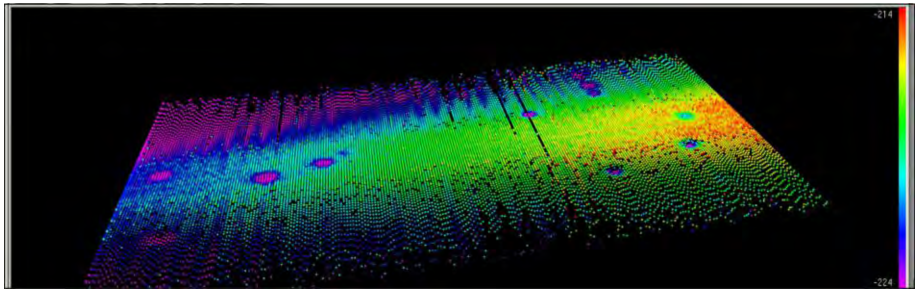
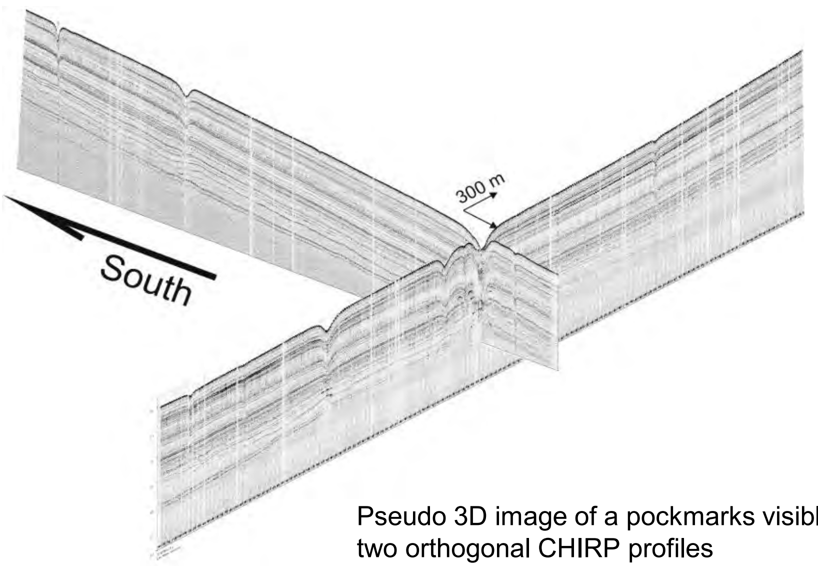


Image of Pockmarks in MB data

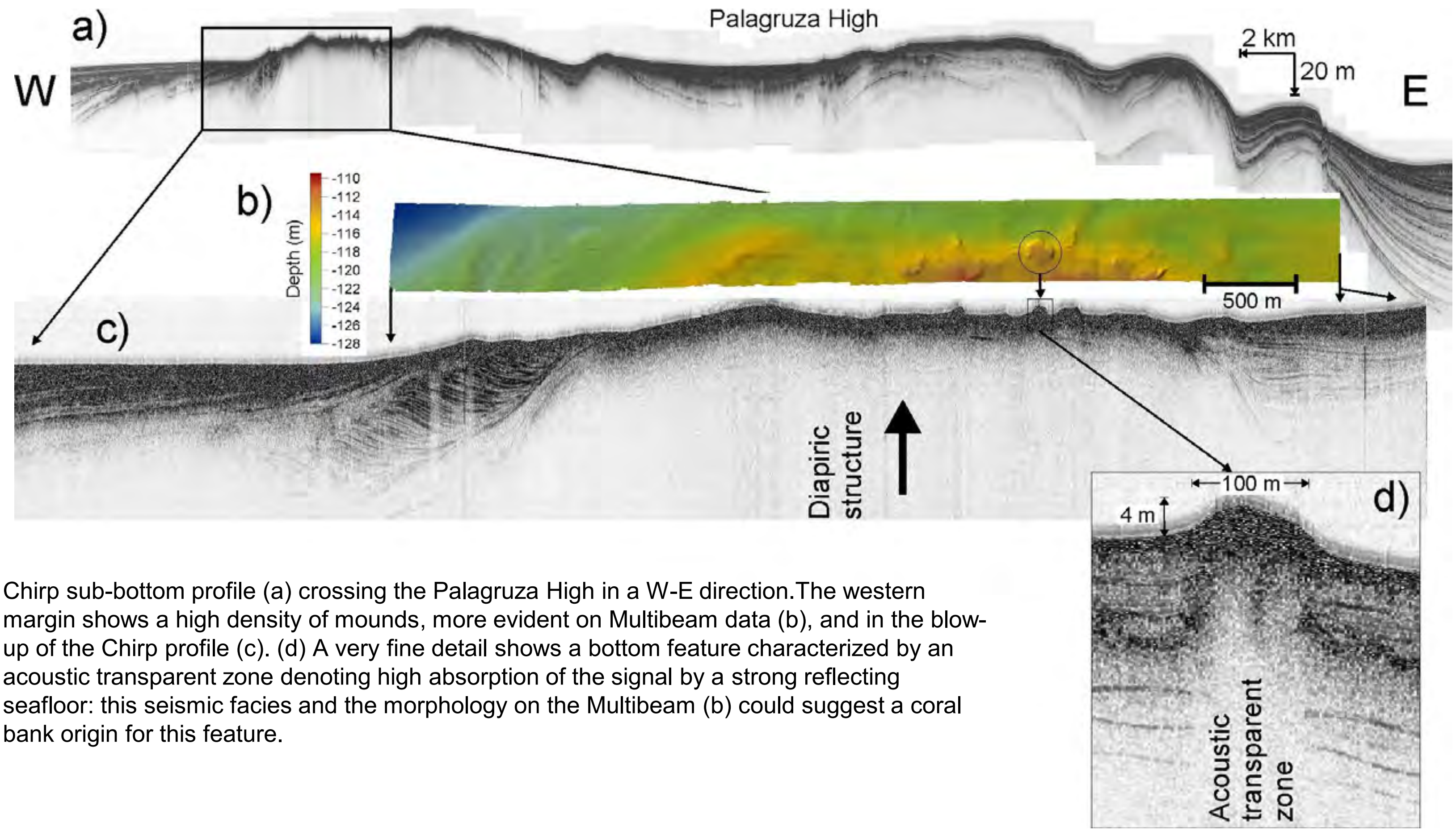




Pseudo 3D image of a pockmarks visible on two orthogonal CHIRP profiles

Central Adriatic Sea

In the area of the Central Adriatic Sea there is a diapiric structure below the Palagruza High, highlighted by the image of CHIRP profile

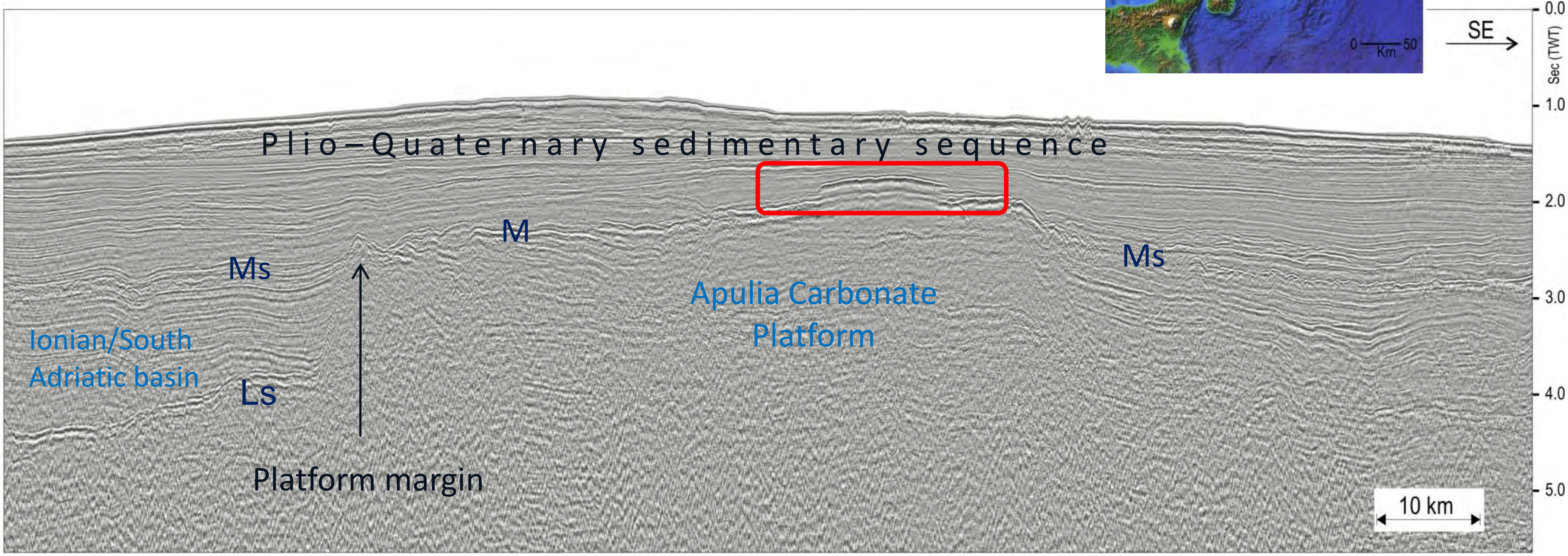


Chirp sub-bottom profile (a) crossing the Palagruza High in a W-E direction.The western margin shows a high density of mounds, more evident on Multibeam data (b), and in the blow-up of the Chirp profile (c). (d) A very fine detail shows a bottom feature characterized by an acoustic transparent zone denoting high absorption of the signal by a strong reflecting seafloor: this seismic facies and the morphology on the Multibeam (b) could suggest a coral bank origin for this feature.

CASE HISTORY - 2: THE OTRANTO CHANNEL

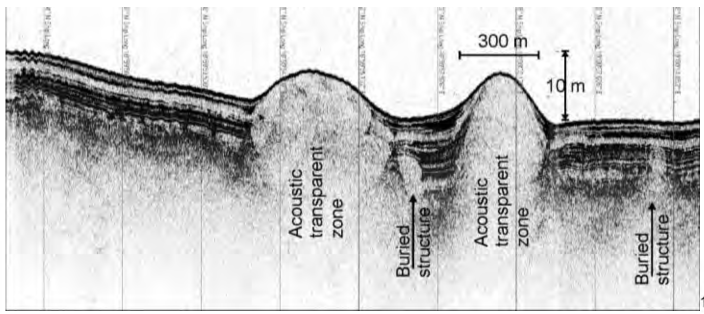
Gas seepages related to deep features in the Otranto Channel (South Adriatic Sea) - OCSS15 project - (**O**tranto **C**hannel ga**S** **S**eepages)

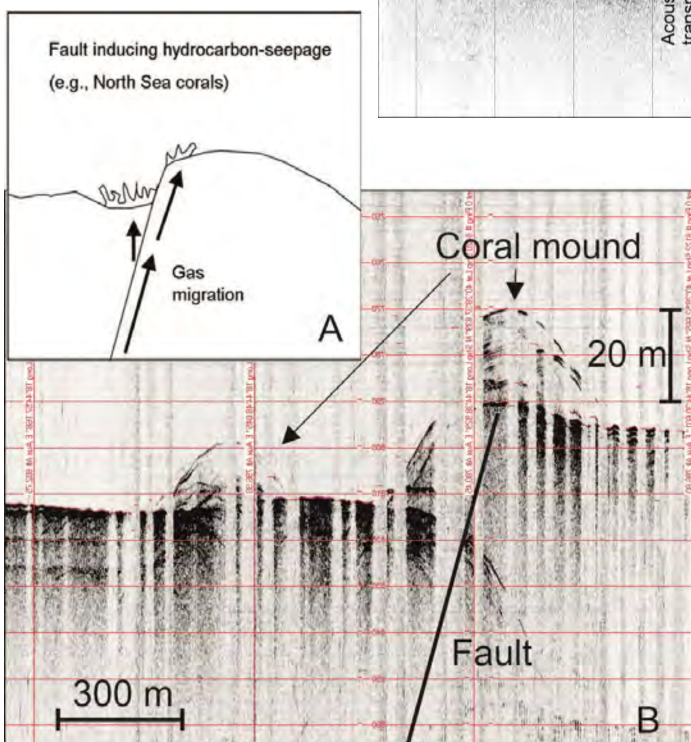
MS-29 seismic profile, Otranto Channel



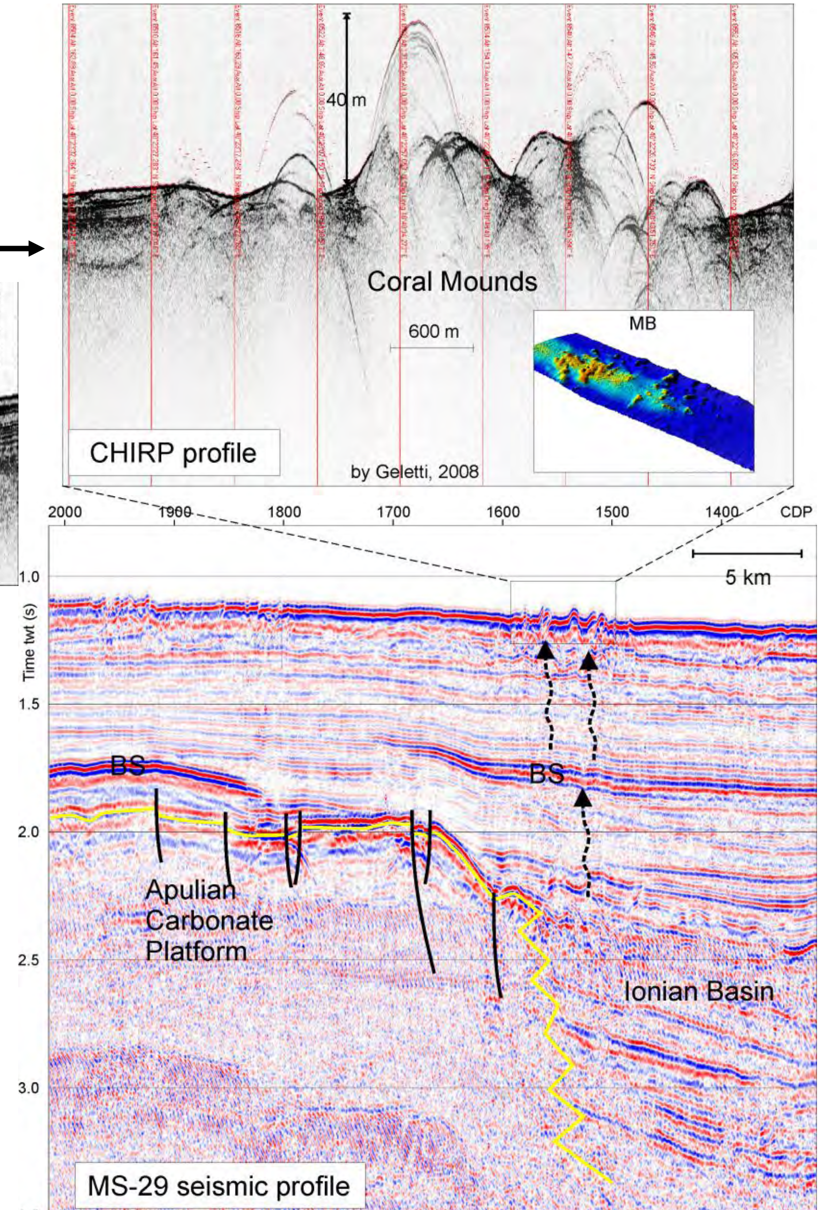
Otranto Channel

Seabed structures on Chirp profile, Multibeam data (GELETTI, 2008) corresponding to the bottom features previously highlighted on the MS-29 seismic profile (below). Sub-Bottom profile crossing the deep water mound, showing possible sediment drifts deposits with weak layers within the carbonate mound. The internal structures are poorly imaged due to the strong reflectivity of the sea floor. Along the MS-29 seismic profile a micro-fracture system (black arrows) was recognized and associated to differential sediment compaction. The micro-facture web represent the pathway along which the gas migrate from the bright spots (BS) toward the seabed.

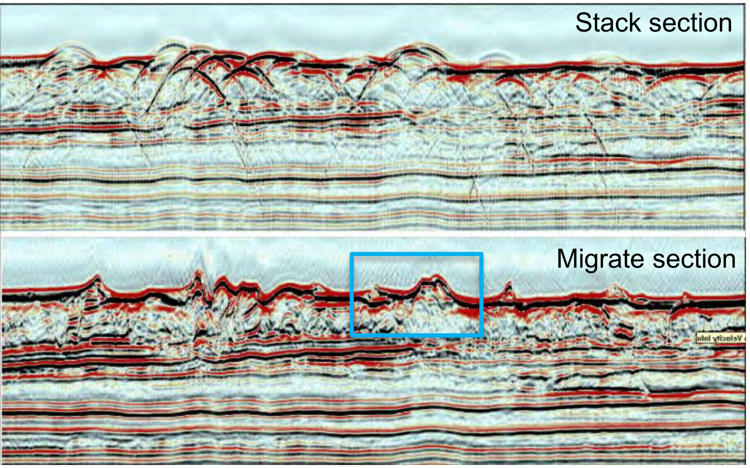


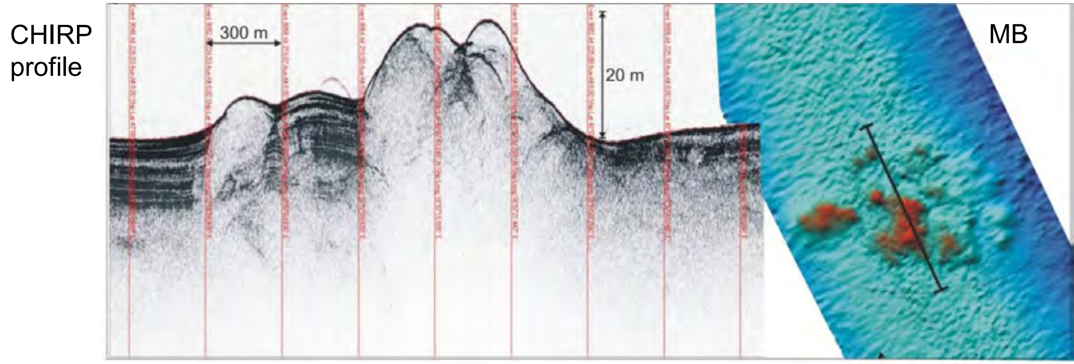


A) Sketch model of fault-linked development of deep-water coral mounds in the North Sea. The arrows indicate nutrient-rich fluid hydrocarbon seepage (from HOVLAND, 2005). B) CHIRP profile acquired during the OCSS15 cruise in the central Otranto Channel zone, showing Coral mounds over a fault

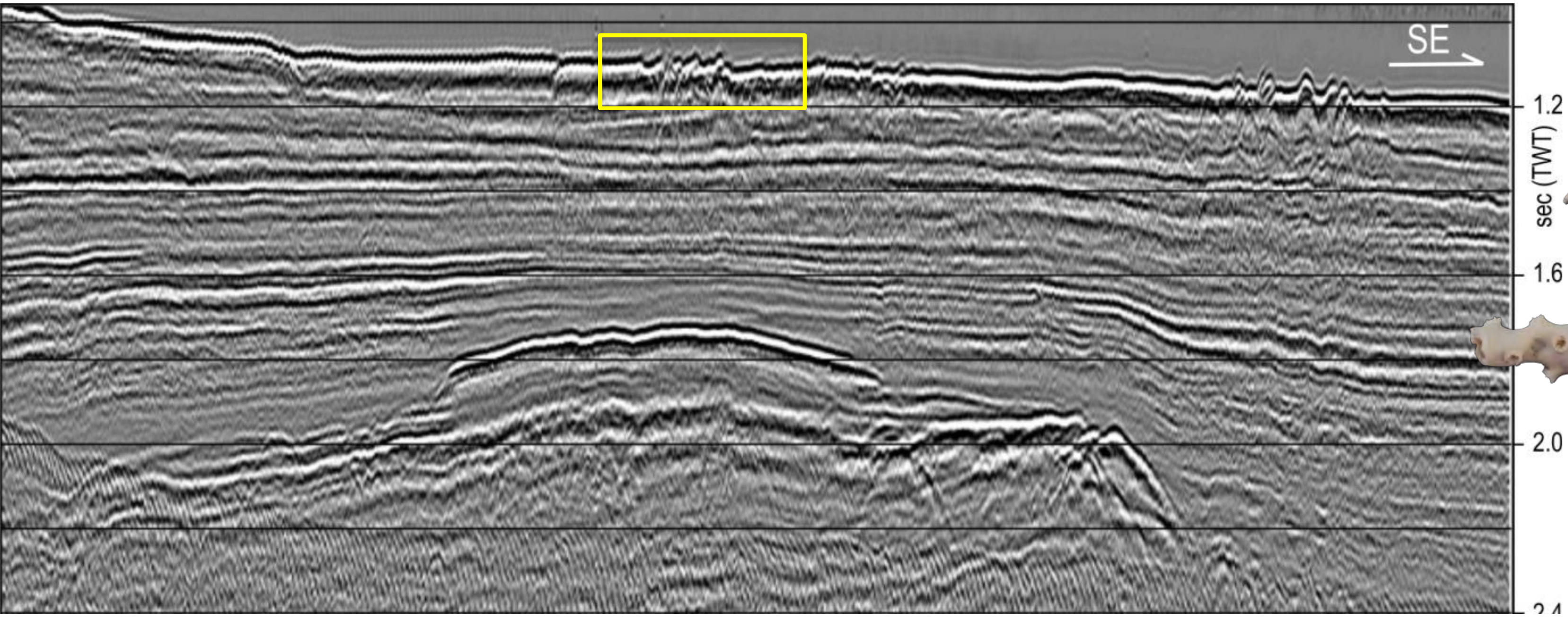


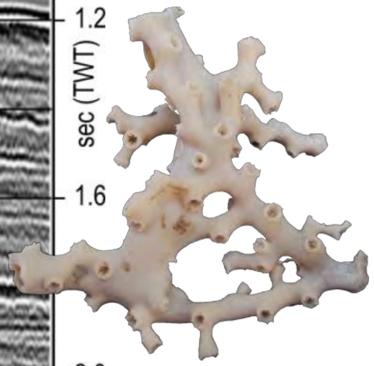
Otranto Channel





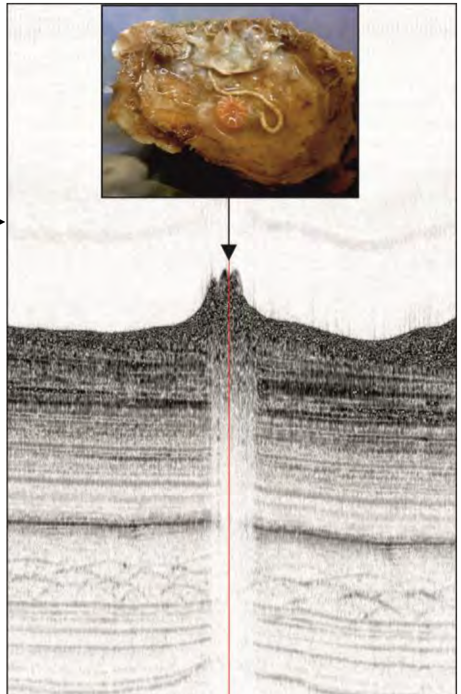
Seabed structures (carbonate mounds) on the seismic profiles (low & medium resolution), CHIRP and Multibeam (MB). (Geletti, 2008; Del Ben et al., 2008; Romeo et al. 2011).

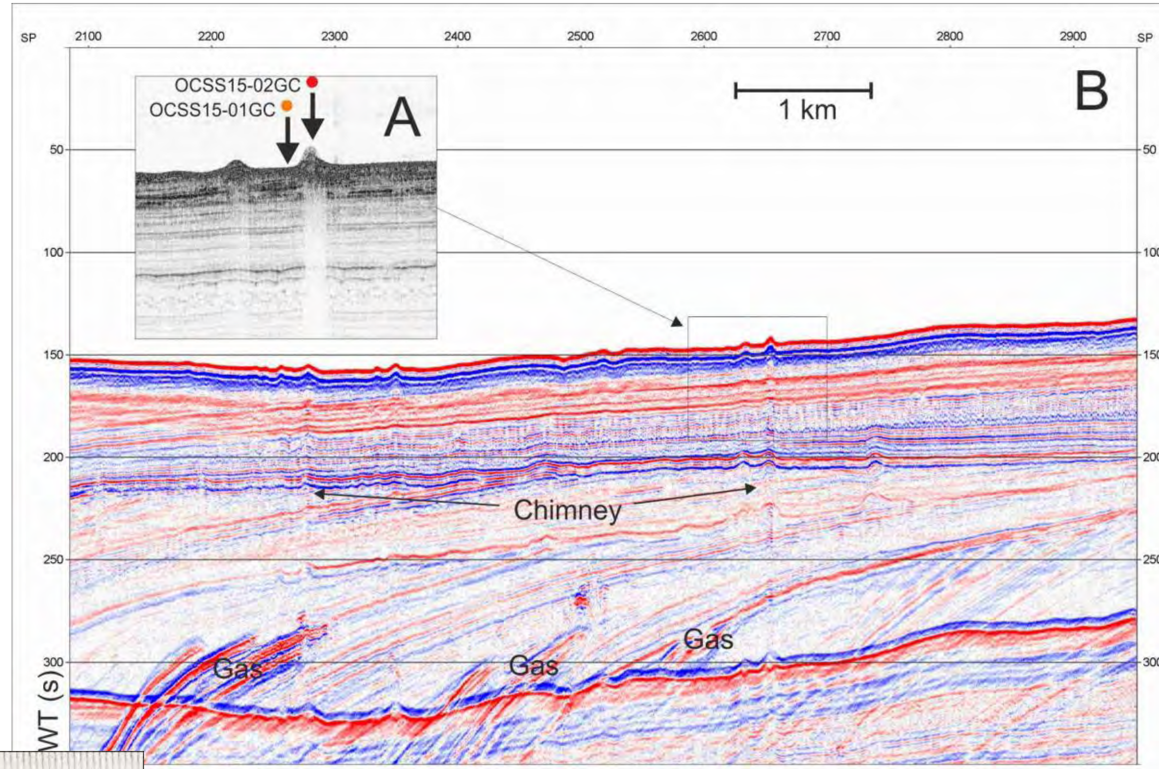




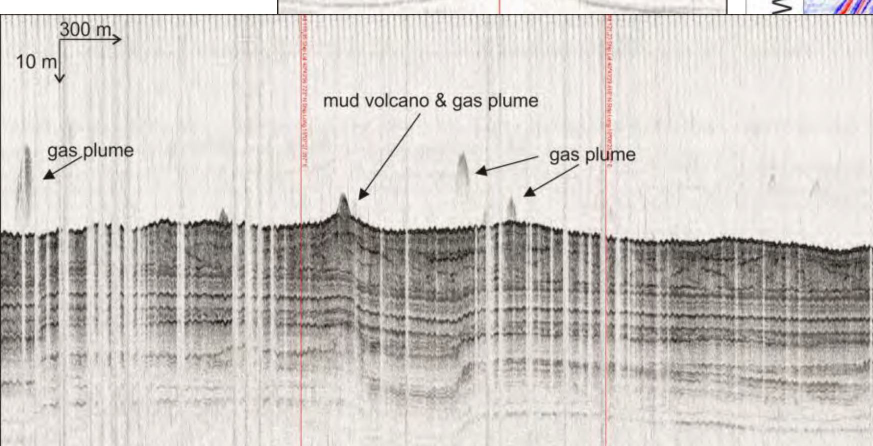
Otranto Channel

CHIRP profile (OCSS15 cruise) with a mound on which the corals were sampled





A) Chirp profile crossing some of the mud volcanoes calibrated by two gravity corers during the OCSS15 acquisition project. This CHIRP line was acquired on the seismic profile (B) of the same cruise: the sea bottom features are related to gas accumulations evidenced by some inclined bright spots. The image in B is a preliminary seismic stack section.



Detail of the CHIRP line with evidence of gas plumes

Figures from Geletti et al., 2018 and 2020

Conclusion - 1

The Multi-Channel Seismic Reflection (MCS) method is:

- The most widespread method for the geophysical prospecting of the subsoil, fundamental in the exploration of hydrocarbon reservoir.
- It provides more detailed information than any other non-invasive method on stratigraphy, structure and properties of materials.
- It uses arrival times, amplitude and phase of the echoes from the discontinuity in the elastic properties present in the subsoil to obtain its position and physical properties (acoustic impedance, velocity propagation of seismic waves, elastic parameters, ...).

Disadvantages of the MCS method:

- High costs of data acquisition (R/V OGS Explora ship time - > 15-20 K€ a day)
- Complex signal processing required
- Numerous specialized people needed
- For a survey, numerous permits and authorizations are required

Conclusion - 2

The seismic reflection interpretation attributes geological meaning to geophysical data.
Interpretation provides information on:

- geometry of stratigraphic sequences and structural/tectonic elements
- seismic wave velocity
- Lithological characteristics

Applications for reconstructions of 2D section, structural maps, fault systems, slumping and seismic hazard.
The interpretation is made by a team of geologists / geophysicists / physicists with different skills who work in synergy.

“Interpretation is a combination of both art and science “ (Lines and Newrick, 2004)

Questions

1. What is a seismic section?
2. What is the difference between seismic and geological section?
3. What is the vertical scale in a seismic section?
4. Which is the difference between seismic stack section and migrated section?
5. What is a diffraction?
6. What is a «bow-tie» event?
7. What is a multiple reflection?
8. What are the advantages of a migrated section?
9. Which seismic parameter is fundamental in depth migration?
10. Which is the first reflection in a marine seismic section?
11. What is the *acoustic basement*?
12. What is a « bright spot» in a seismic section?
13. What are the seismic characters that identify the possible presence of gas in the sediments?
14. What are the gas seeping structures?
15. What is the best acoustic method to study these structures?

Bibliography:

- AN INTRODUCTION TO GEOPHYSICAL EXPLORATION, di Philip KEAREY, Michael BROOKS, Ian HILL; (2002) – Blackwell Science – ISBN 0-632-04929-4.
- MARINE GEOPHYSICS, E. J. W. JONES; (1999) – Wiley – ISBN 0-471-98694-1
- SEISMIC DATA ANALYSIS (Vol. I & II), Öz YILMAZ; (2001) – SEG – Vol. I ISBN 1-56080-098-4; Vol. II ISBN 1-56080-098-2
- Lines and Newrick - FUNDAMENTALS OF GEOPHYSICAL INTERPRETATION
- Sheriff and Geldart - EXPLORATION SEISMOLOGY
- Anstey - SEISMIC INTERPRETATION - The Physical Aspects
- Herron – FIRST STEP IN SEISMIC INTERPRETATION
- Hovland & Jadd - Seabed Pockmarks and Seepages
- Jadd & Hovland – Seabed Fluid Flow

Websites:

- ViDEPI: http://unmig.sviluppoeconomico.gov.it/videpi/
- Virtual Seismic Atlas: http://see-atlas.leeds.ac.uk:8080/home.jsp