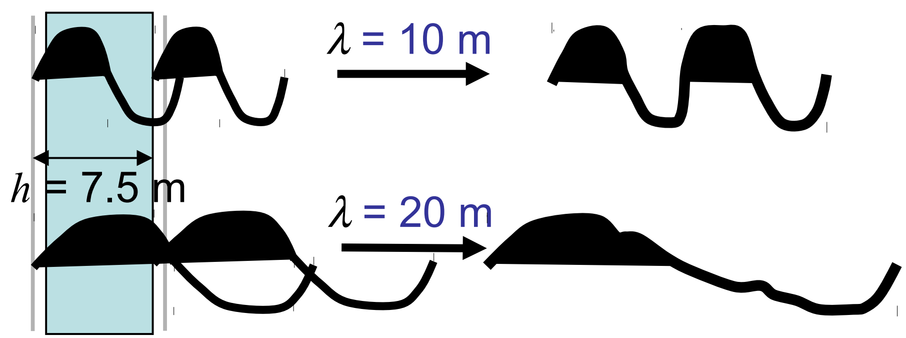
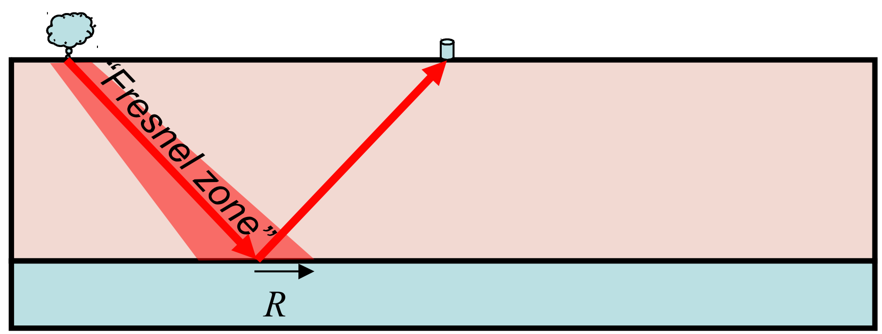
Seismic Data Processing steps (*Burger* §4.5-4.6)

Vertical resolution: Theoretical limit is $h = \lambda/4$ (& in the practical limit, h will have to be $> \lambda/2$)

Horizontal resolution: The first ***Fresnel zone*** (approximate area of the reflector responsible for a signal) for above practical $h_{min} = \lambda/2$, will be $R_{min} = \lambda/2$!



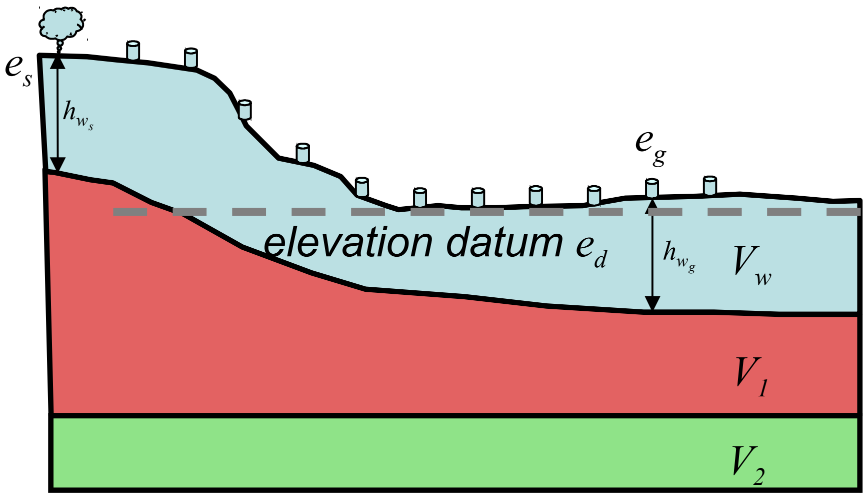


Recall $V = f\lambda$: For V = 1500 m/s, f = 100 Hz, λ = 15 m: h_{min} = 7.5 m = R_{min}

(at geophone frequencies!)

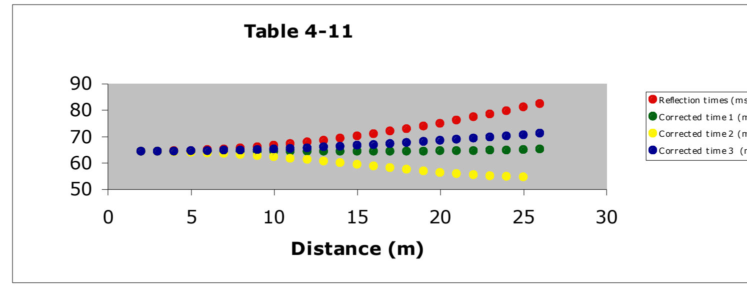
Step I: Static Correction

$$t_{corr} = t_{obs} - \frac{h_{w_s} + h_{w_g}}{V_w} + \frac{h_{w_s} + h_{w_g}}{V_1} - \frac{e_s + e_g - 2e_d}{V_1}$$



Step II: Velocity Analysis

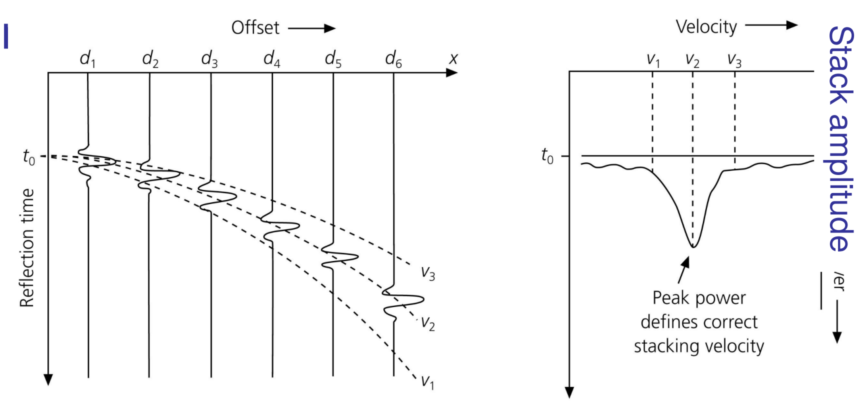
(a) Trial-&-error: At every t_0, try lots of "stacking velocities" V_s to find which best "flattens" the reflection arrival:



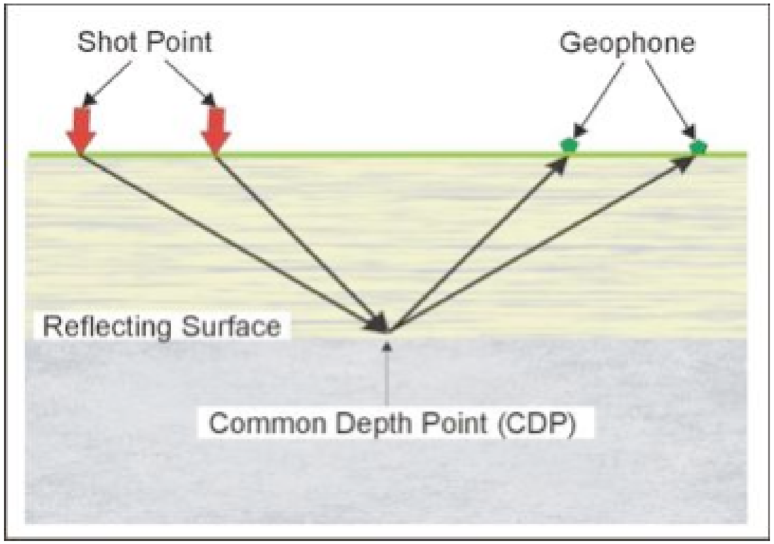
(b) Similar to (a), but for each trial we sum all of the trace amplitudes and find which correction produces the largest stacked amplitude at time t_0:

(c) Assume every t_0 is the onset of a reflectio

Window every geophone trace at plus/ minus a few ms and compare ("cross-correlate") all traces within the window. Stacking velocity V_s that yields the most similar waveform in all windows gives highest cross-corr & is used for that t_0.

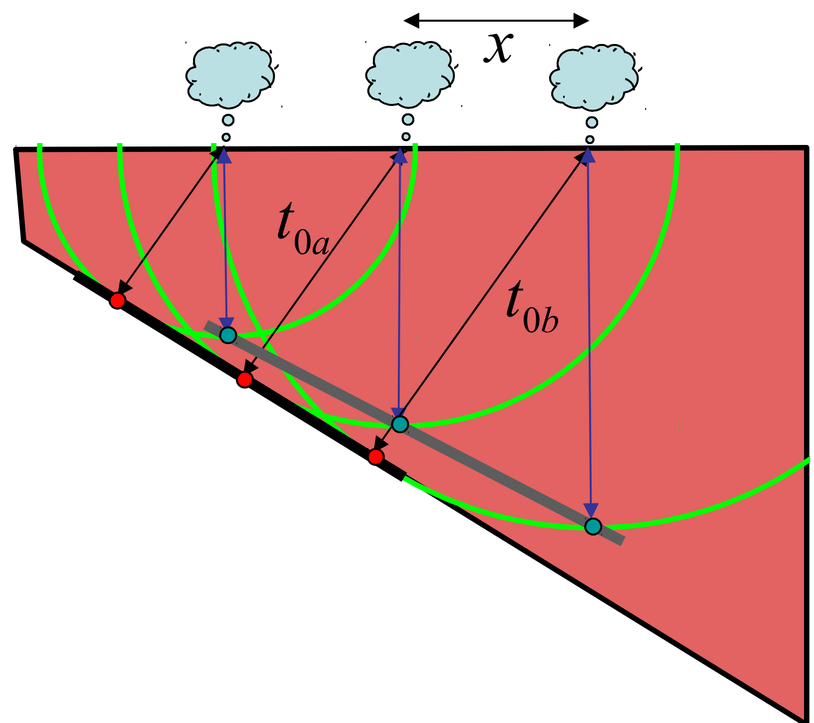


Step III: Common Depth Point Stacking



Step IV: Migration

Seeks to distribute reflection Energy back to its correct position in two-way travel-time. The “true” reflecting surface is defined by a tangent passing through each of the arcs.

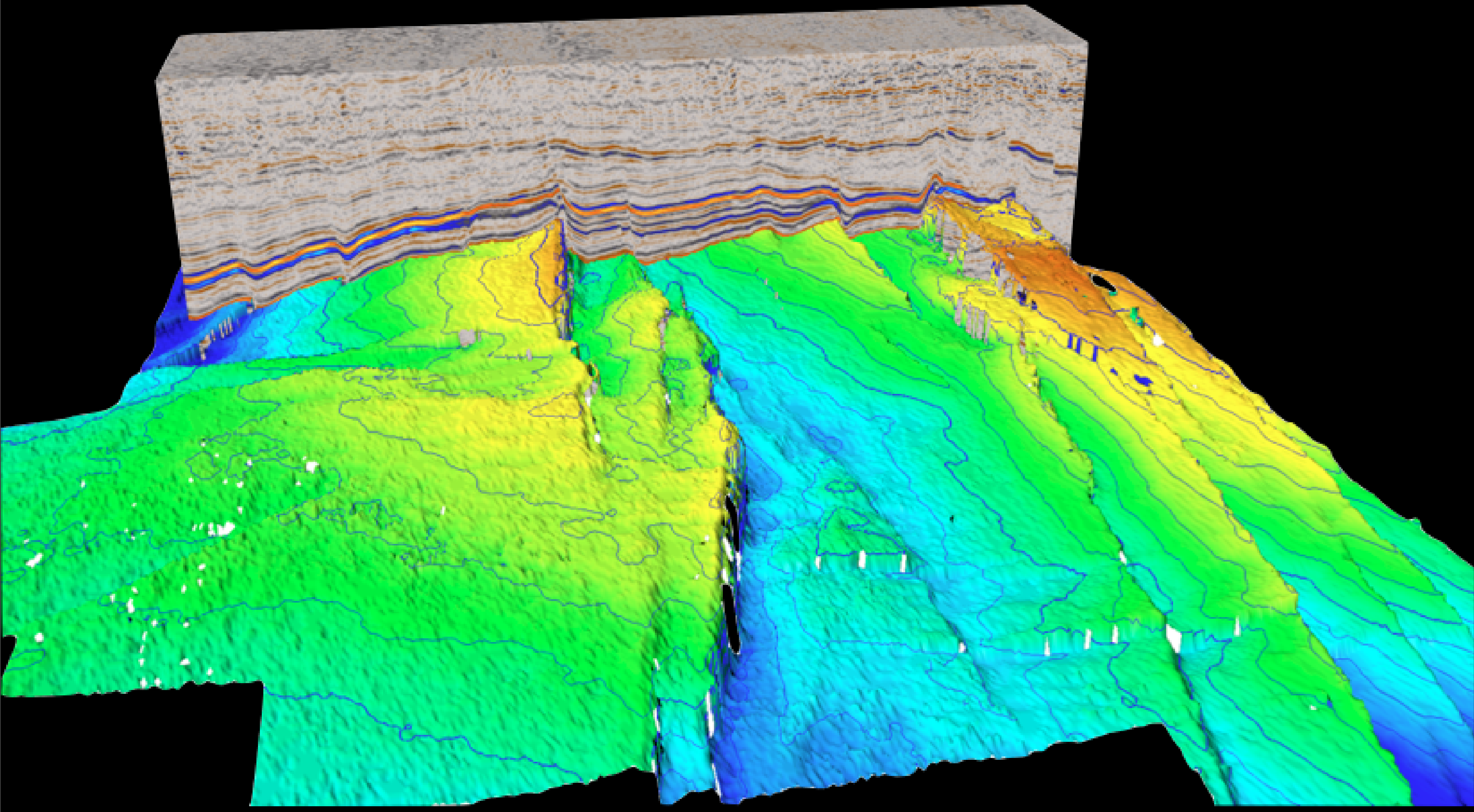


Seismic quality

Depends on:

- Acoustic impedance contrast
- Depth ($\Rightarrow$ frequency)
- Layer thickness ($\Rightarrow$ interference)
- Properties of overlying layers
- Source energy
- Processing parameters
- Acquisition direction
- Instrumentation

Industry Seismic Reflection Interpretation



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Industry Seismic Reflection Interpretation

- Data collection: Huge quantities of data! Redundancy is key!

- 2D profiling still used for initial reconnaissance, but
  3D is industry standard for prospects

- 3D gives higher resolution, better positioning (enables migration of
  "out-of-plane" seismic reflection energy)

- Usually *active source* (explosions, as distinct from natural sources)

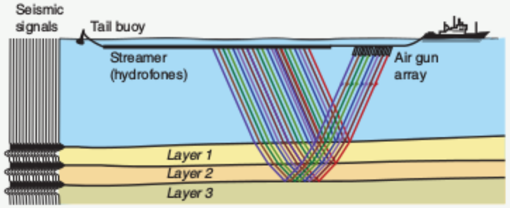
- Industry seismic images the upper 0-8 km of the crust

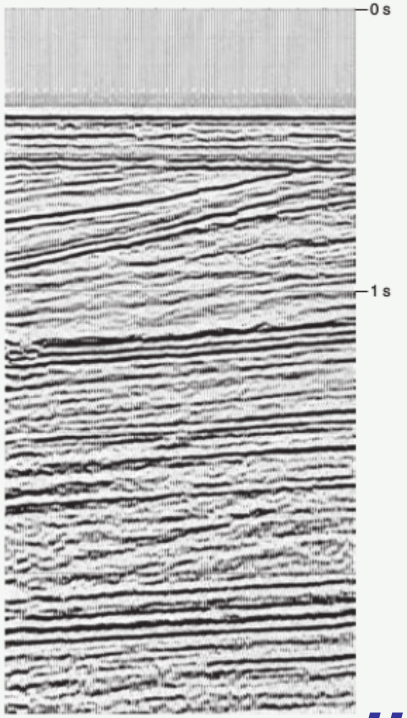
- Deep seismic images the entire crust and the uppermost part of the mantle

2D Seismic Data

Offshore collection of seismic data is done by a vessel that travels at about 5 knots while towing arrays of air guns and streamers containing hydrophones a few meters below the surface of the water. The tail buoy helps the crew locate the end of the streamers. The air guns are activated periodically, such as every 25 m (about every 10 seconds), and the resulting sound wave that travels into the Earth is reflected back by the underlying rock layers to hydrophones on the streamer and then relayed to the recording vessel for further processing.

The few sound traces shown on the figure indicate how the sound waves are both refracted across and reflected from the interfaces between the water and Layer 1, between Layer 1 and 2, and between Layer 2 and 3. Reflection occurs if there is an increase in the product between velocity and density from one layer to the next. Such interfaces are called reflectors. Reflectors from a seismic line image the upper stratigraphy of the North Sea Basin (right). Note the upper, horizontal sea bed reflector, horizontal Quaternary reflectors and dipping Tertiary layers. Unconformities like this one typically indicate a tectonic event. Note that most seismic sections have seconds (two-way time) as vertical scale.





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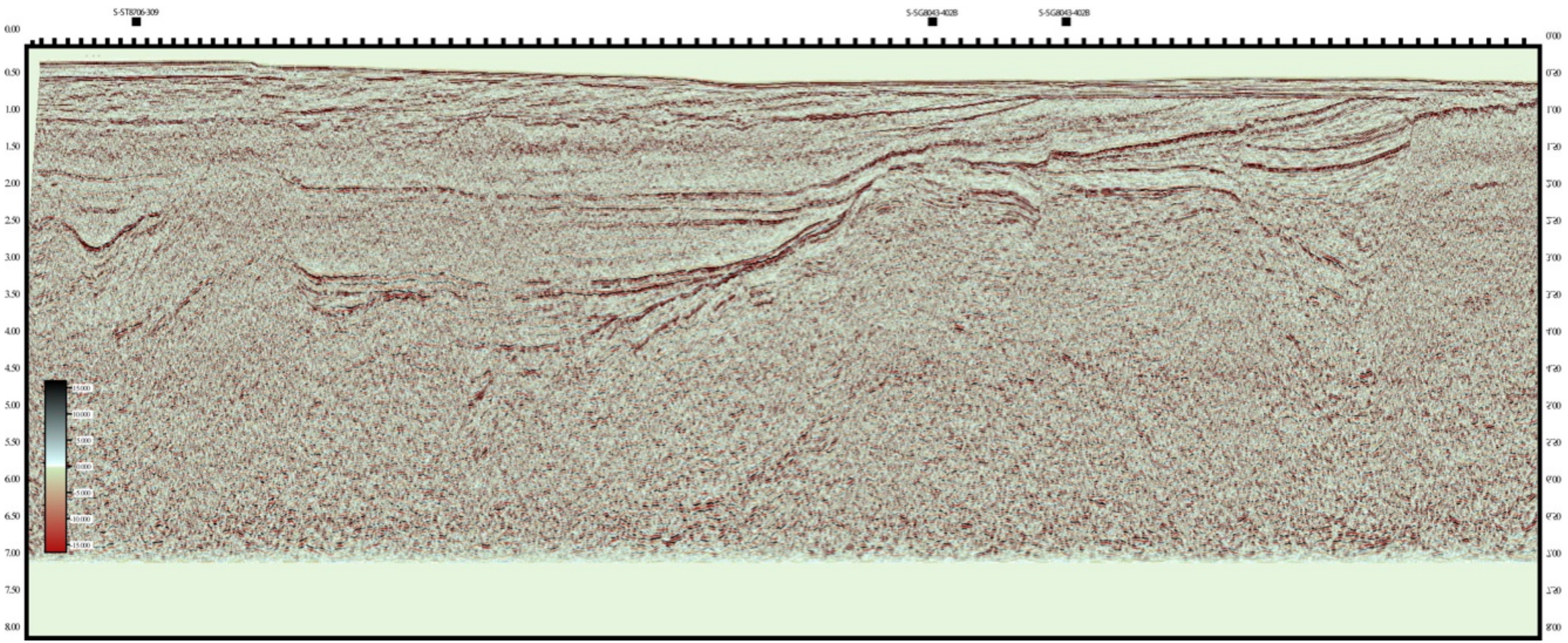
2D Seismic Data

- 2D lines are long profiles that are processed independently
- Generally collected now for regional reconnaissance studies
- Covers large areas and gives an overall picture of the geology



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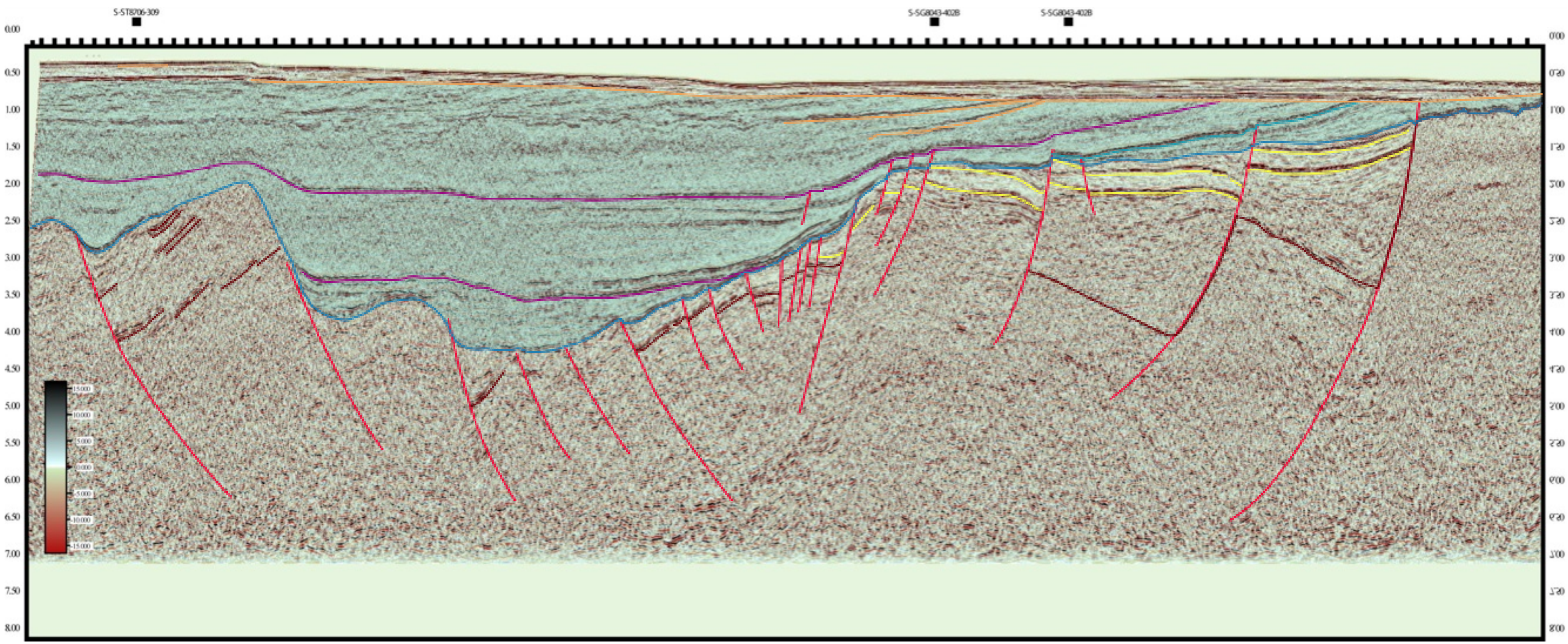
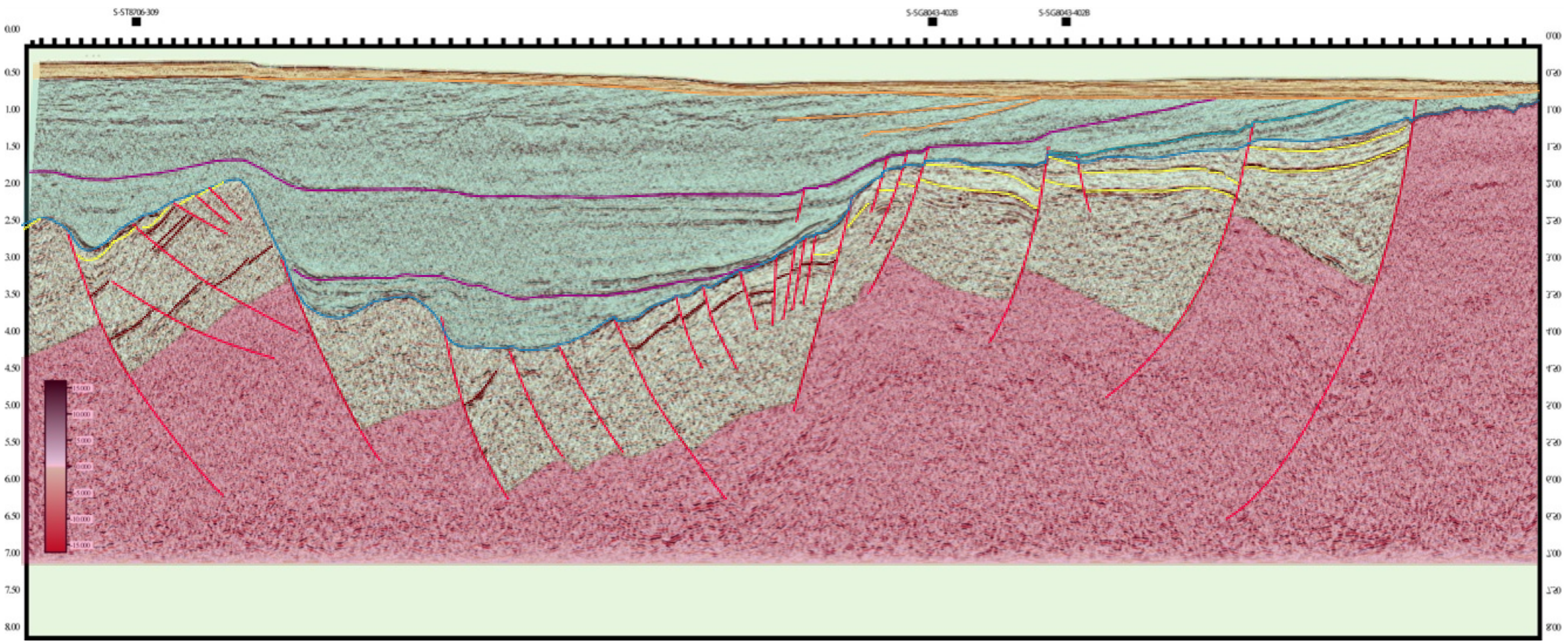
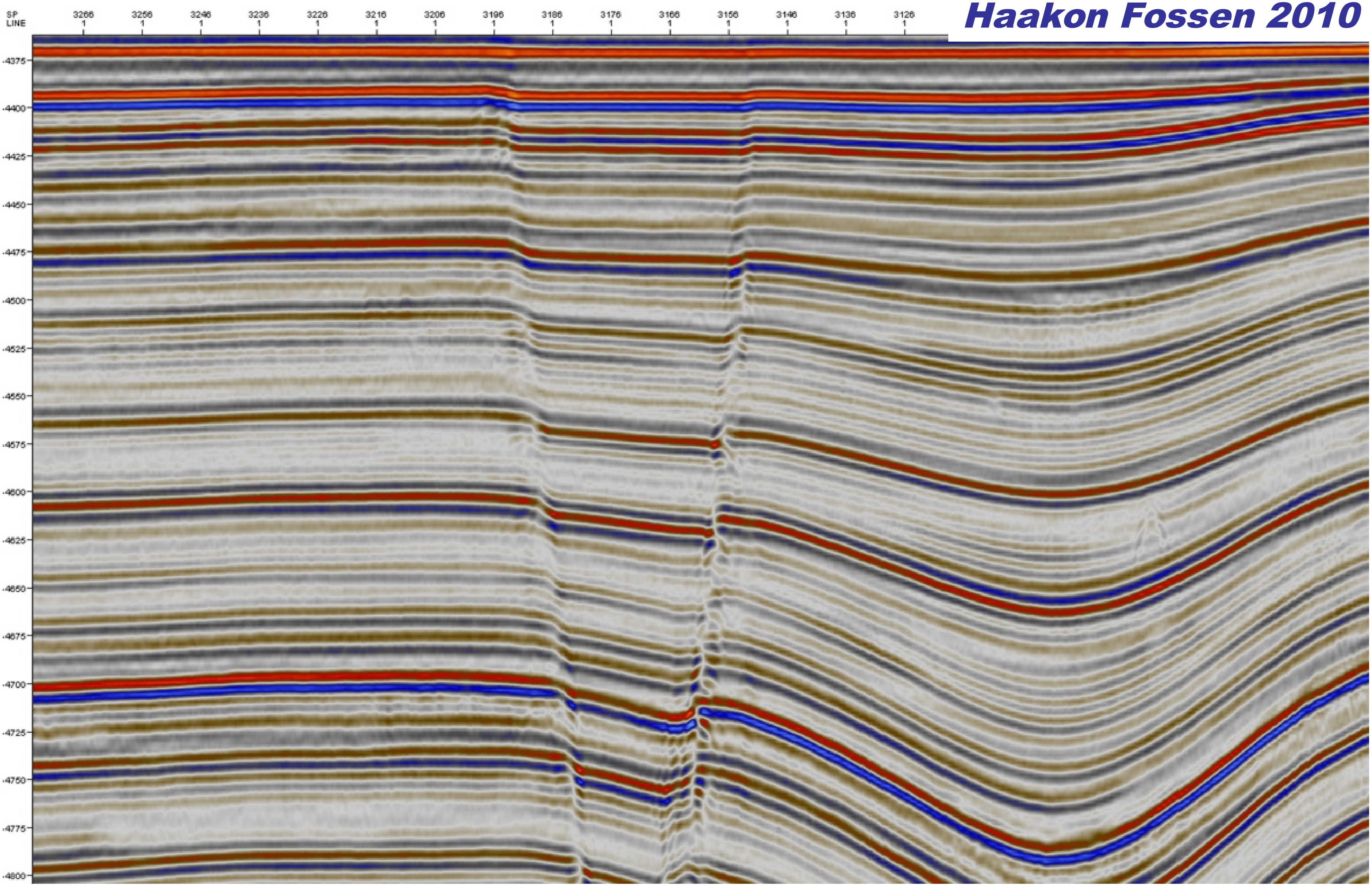
2D Seismic Data



2D Seismic Data



Color convention: Blue for positive amplitude, red for negative…



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Note how weaker amplitude synclinal layers fade out!

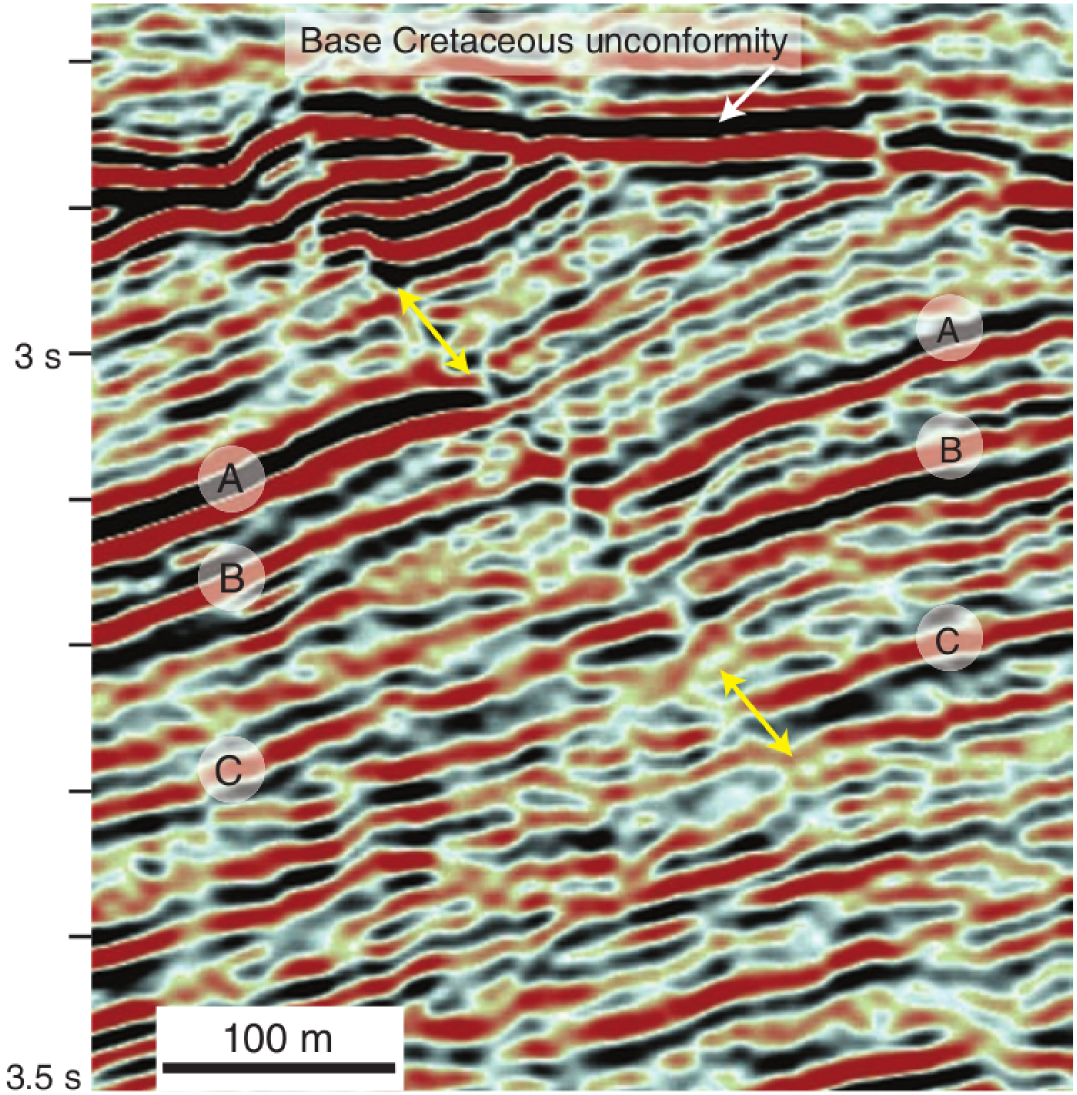

Figure 8.17 A fault imaged in seismic data (arrows). There are no clear reflections from the fault itself. The dip separation is identified by the discontinuity of reflectors (cutoffs). Three-dimensional seismic from the Visund Field, North Sea.

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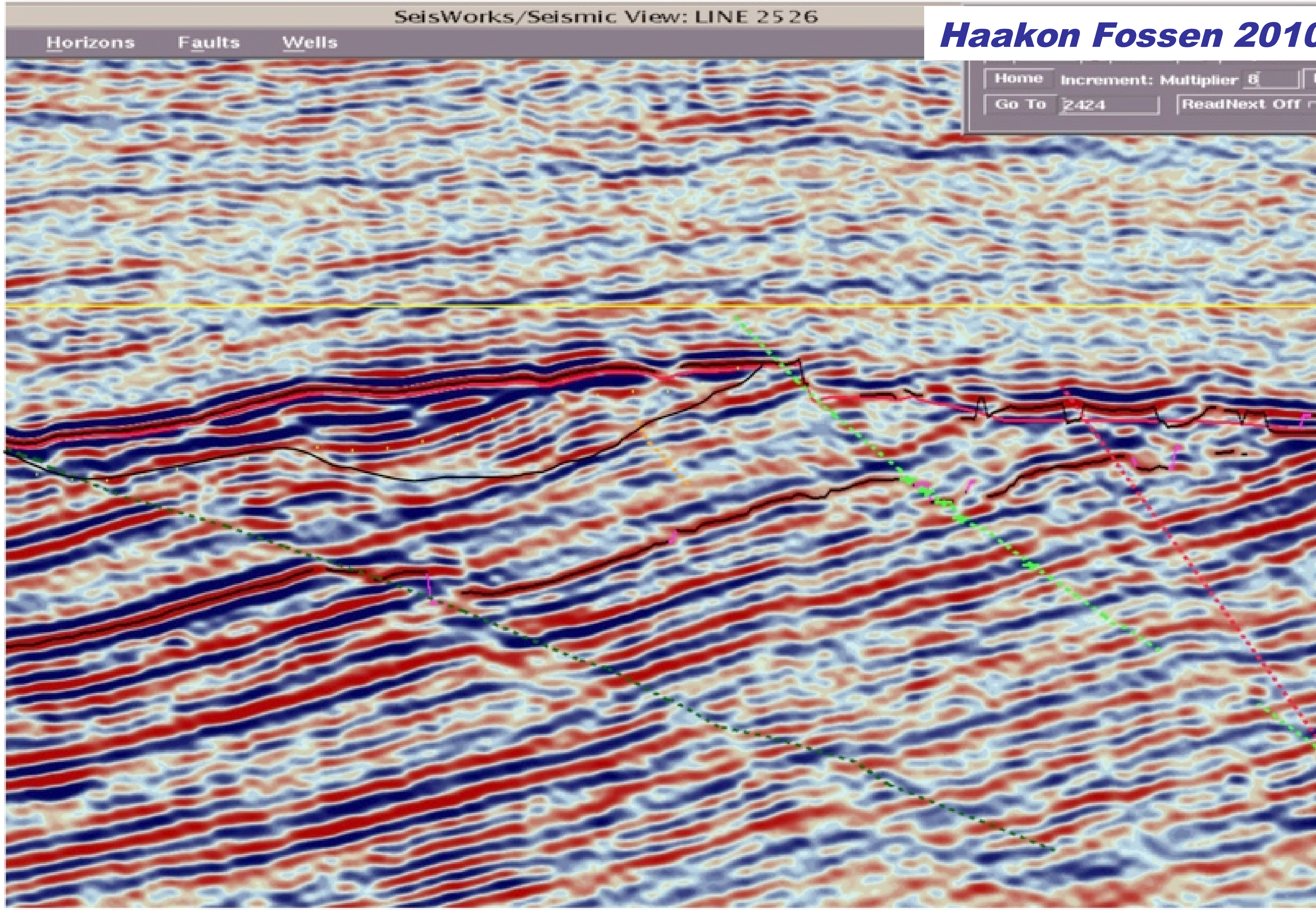

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Lateral resolution: Faults are sharp, imaged offsets less so…

Salt structures

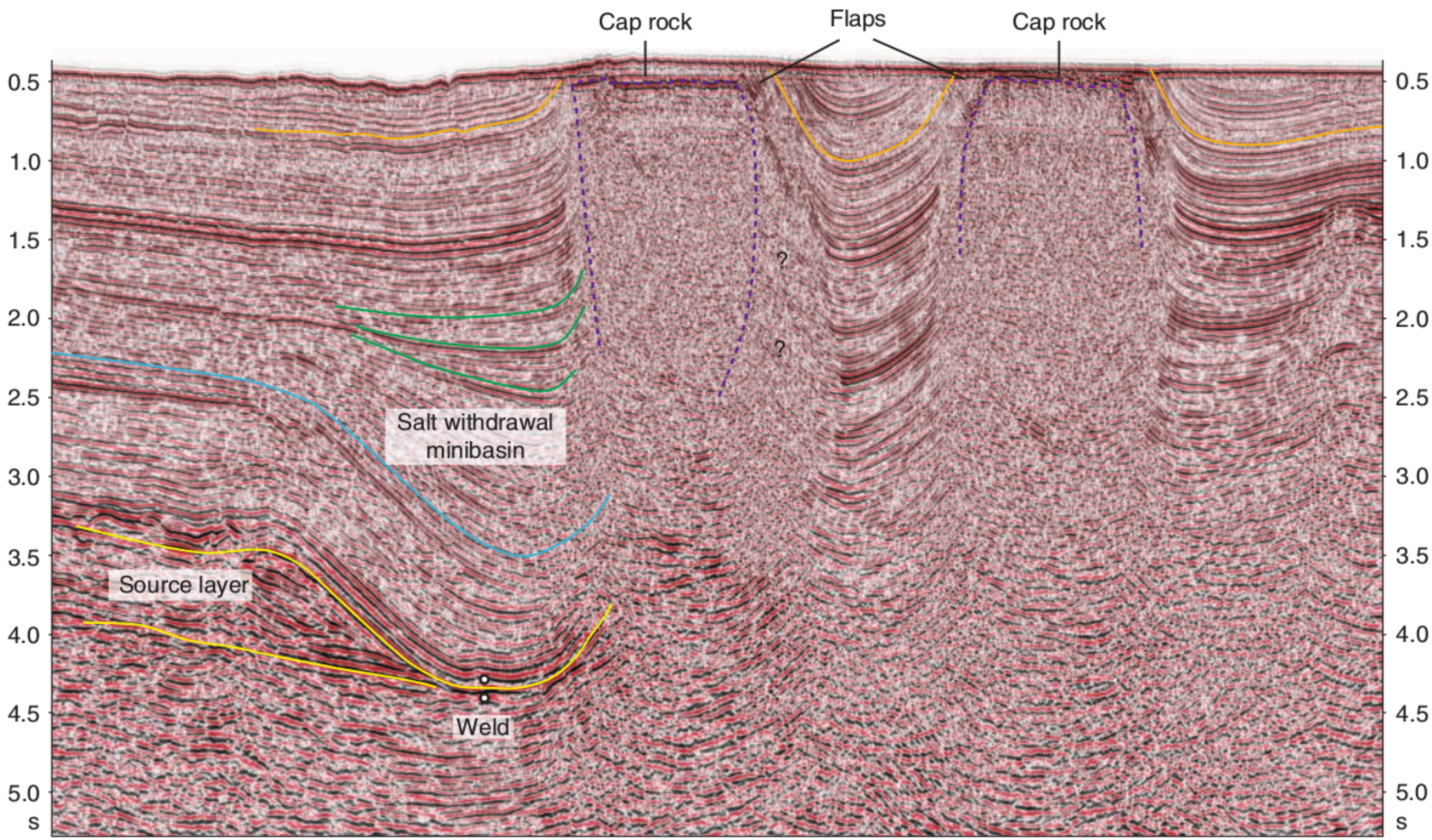

Figure 19.5 Salt structures imaged on seismic 2-D line. The two structures have surfaced (now covered by thin Quaternary cover) and developed reflective caps. Deeper parts of the salt structures are obscured by seismic noise. The source layer has been interpreted based on a salt weld structure. The growth history is recorded in the sedimentary record: thickness changes near the diapirs start above the blue horizon, after deposition of a ~1.5–2 km sedimentary load. Note minibasin above the weld. Data courtesy of the Norwegian Petroleum Directorate.

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Salt structures

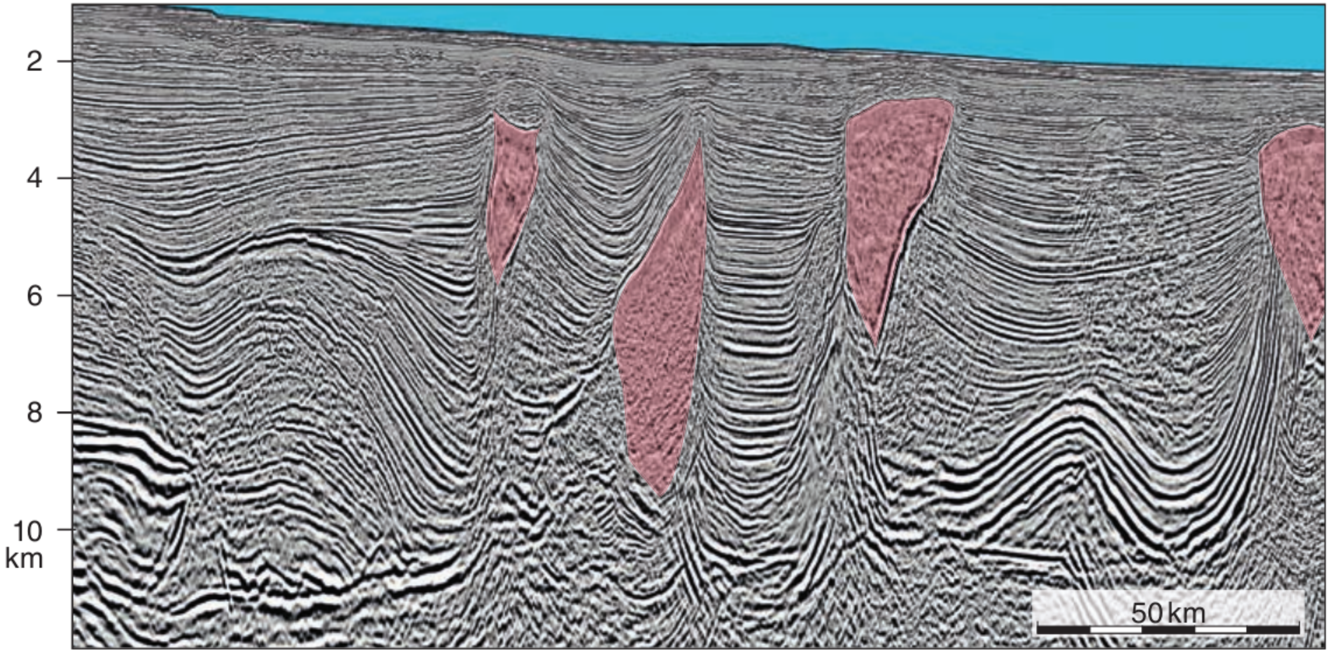


Figure 19.18 Depth-migrated seismic section from the submarine Mississippi Canyon, Gulf of Mexico, showing teardrop diapirs (detached salt stocks). The source salt layer is located at ~10–11 km depth (not interpreted). Folds formed as a result of salt withdrawal in an extensional setting. Image provided courtesy of TSG-NOPEC.

Salt structures

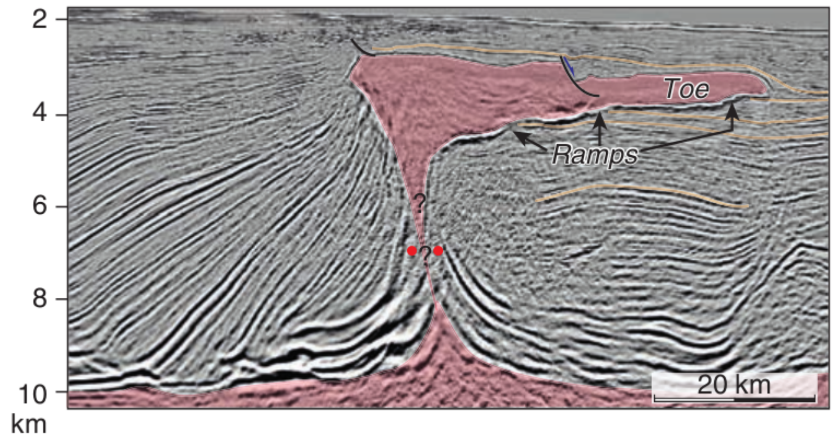
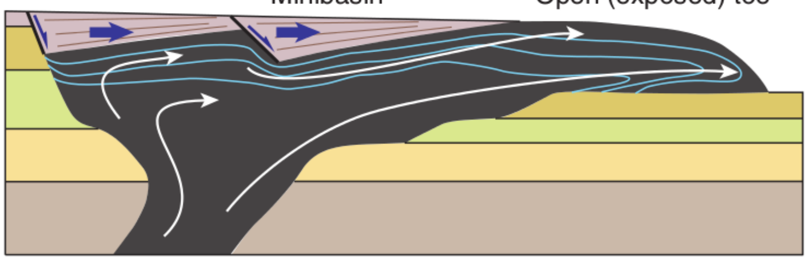


Figure 19.20 Classic salt sheet structure from the Gulf of Mexico (Mississippi Canyon). Image provided courtesy of TSG-NOPEC.



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Salt structures

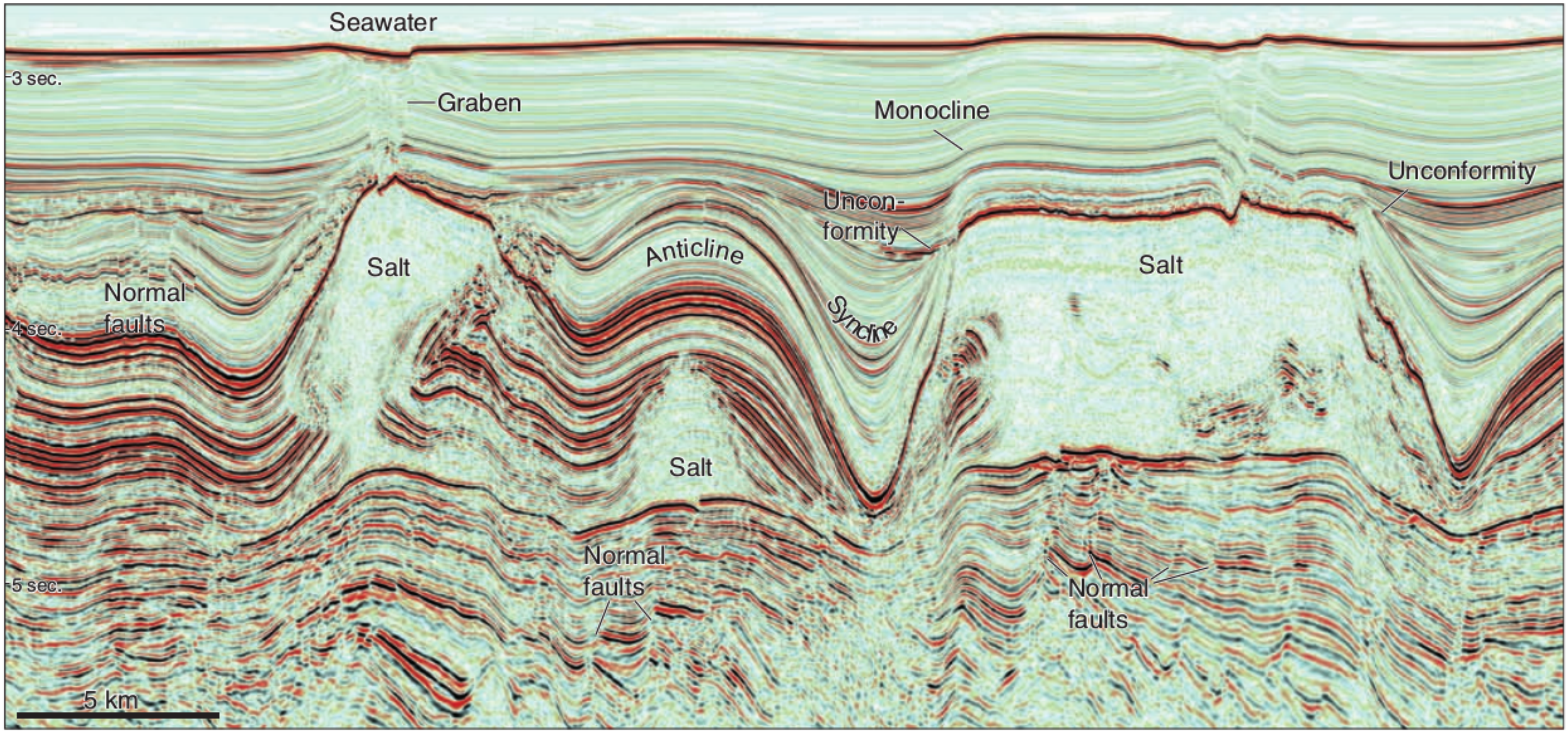

Figure 1.6 Seismic 2-D line from the Santos Basin offshore Brazil, illustrating how important structural aspects of the subsurface geology can be imaged by means of seismic exploration. Note that the vertical scale is in seconds. Some basic structures returned to in later chapters are indicated. Seismic data courtesy of CGGVeritas.

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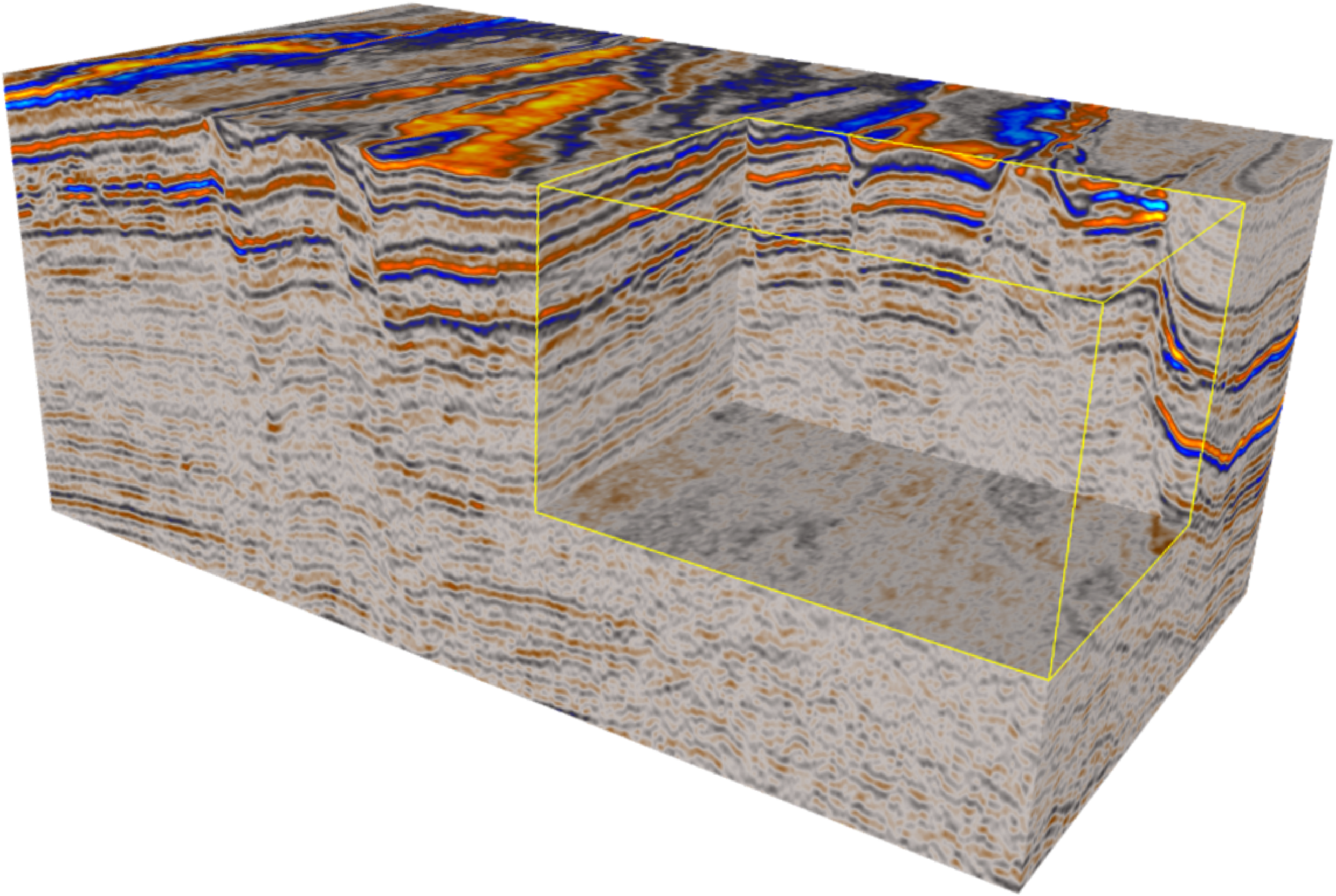
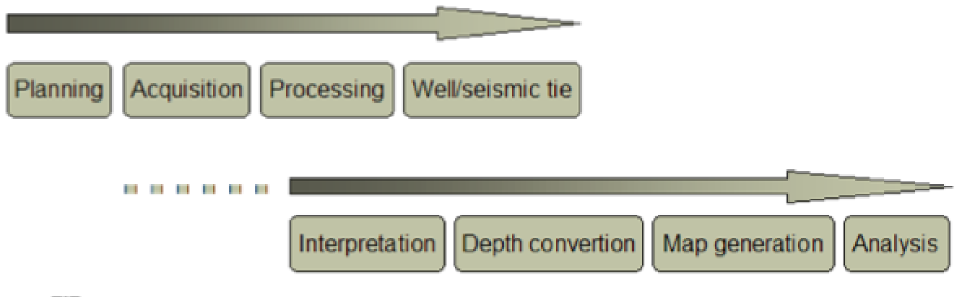
3D Seismic

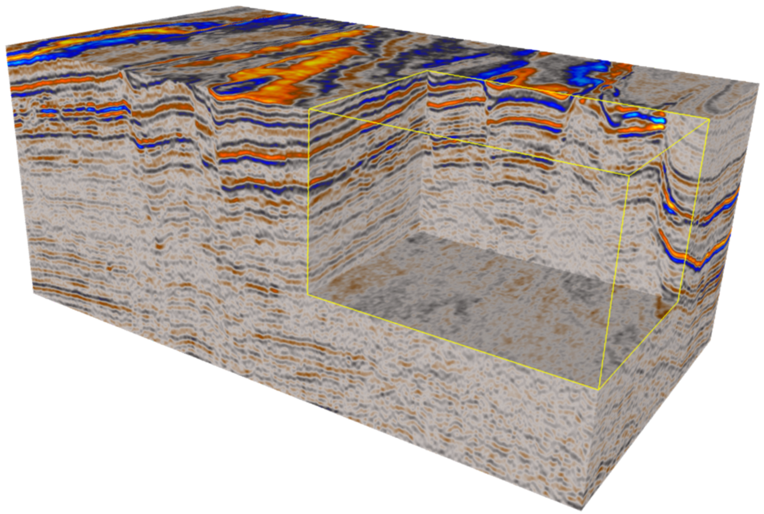


3D Seismic

3D Data:

- Collected by shooting many parallel lines ~25 m apart
- Migrated together to increase accuracy and to create a coherent data volume (cube)
- Collected over all offshore oil and gas fields
- Underpins the geometric understanding of an oil field





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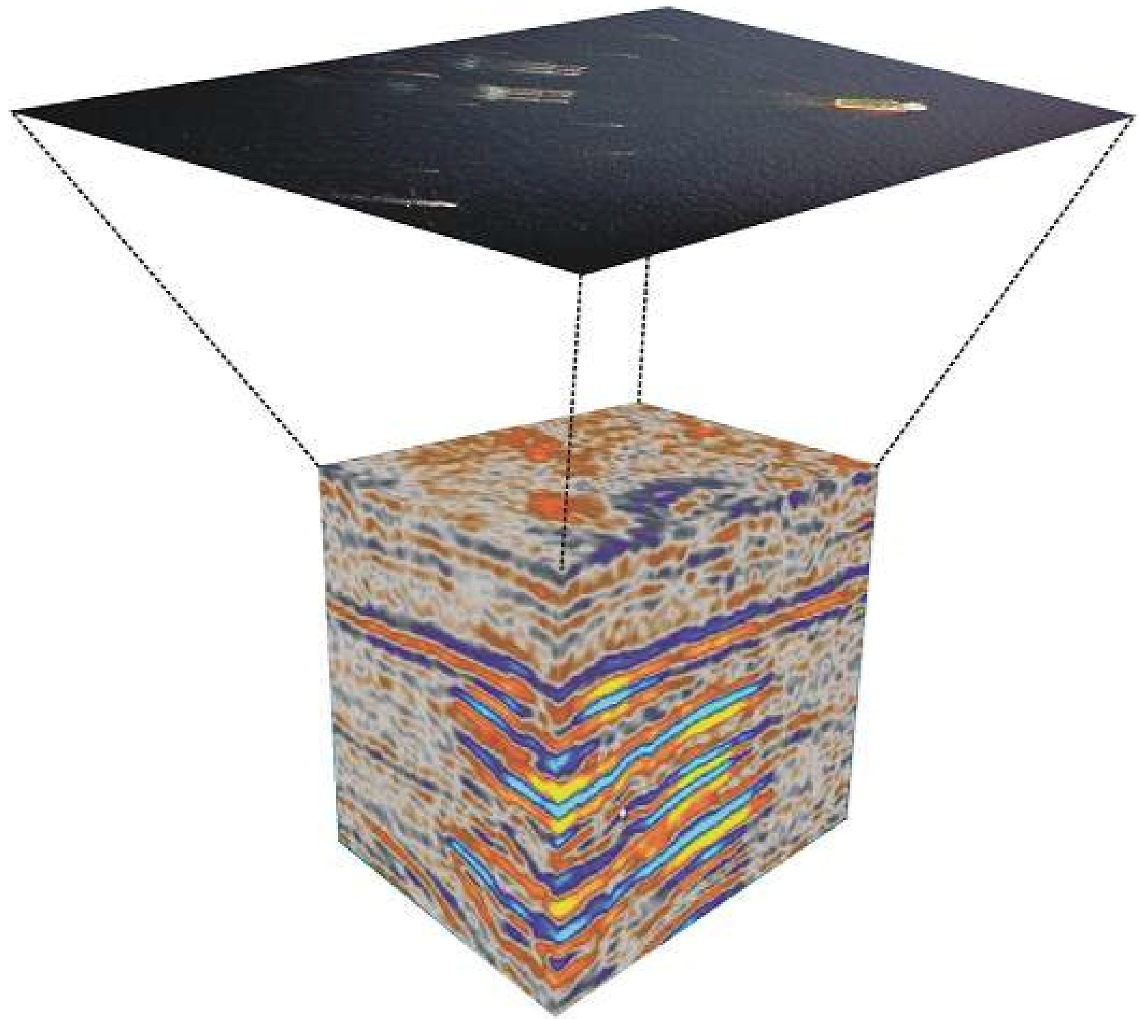
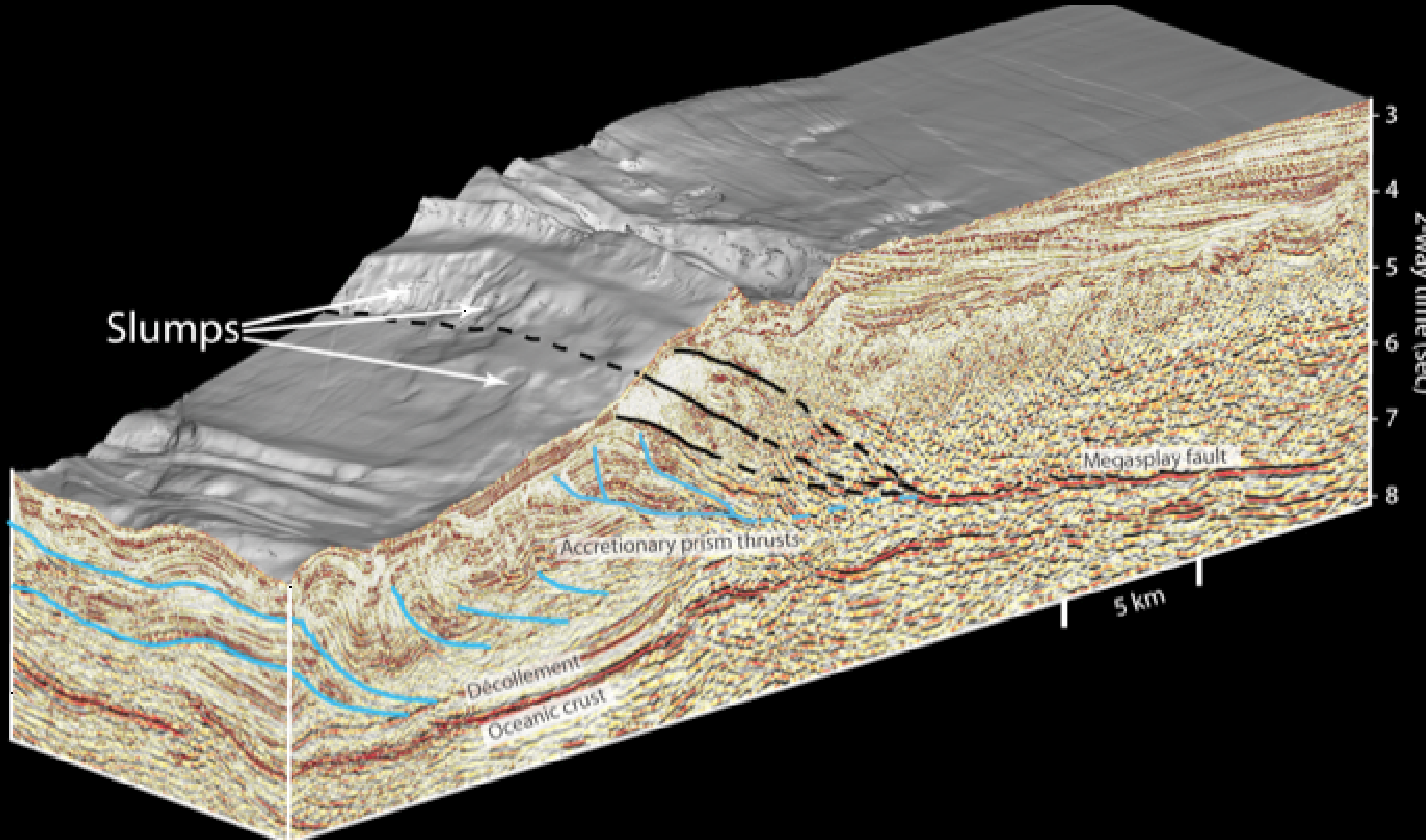
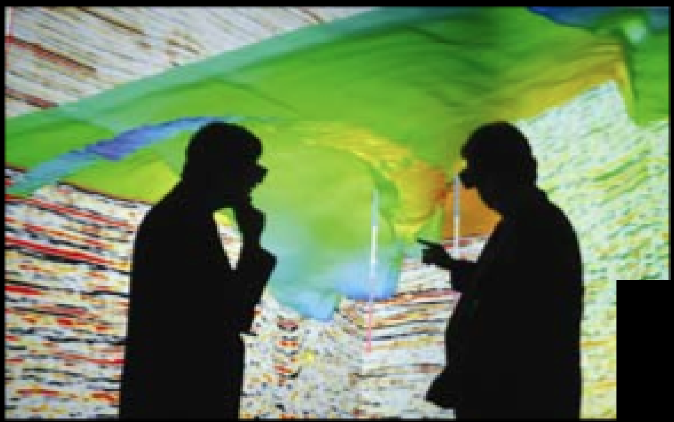
Data acquisition

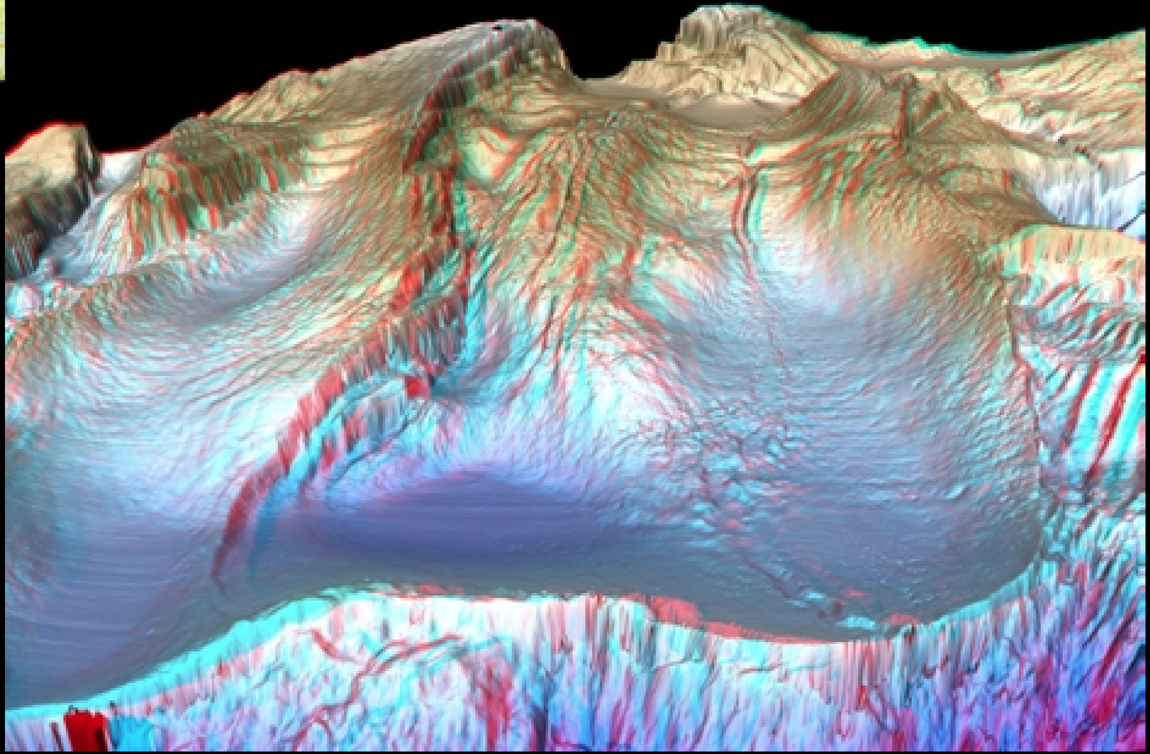


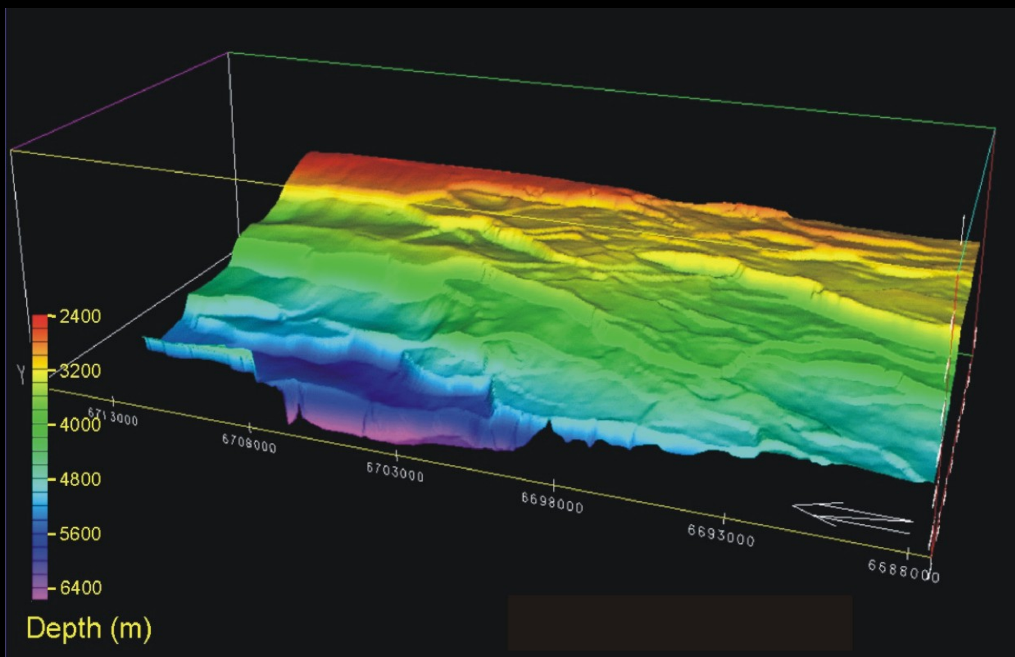


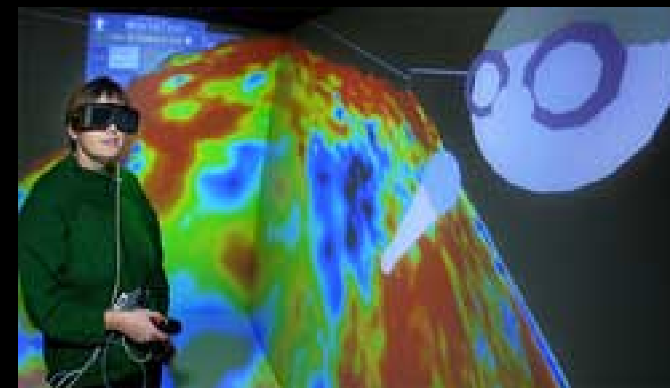
Slumps
Megasplay fault
Accretionary prism thrusts
Décollement
Oceanic crust
5 km
2-way time (sec)
3
4
5
6
7
8

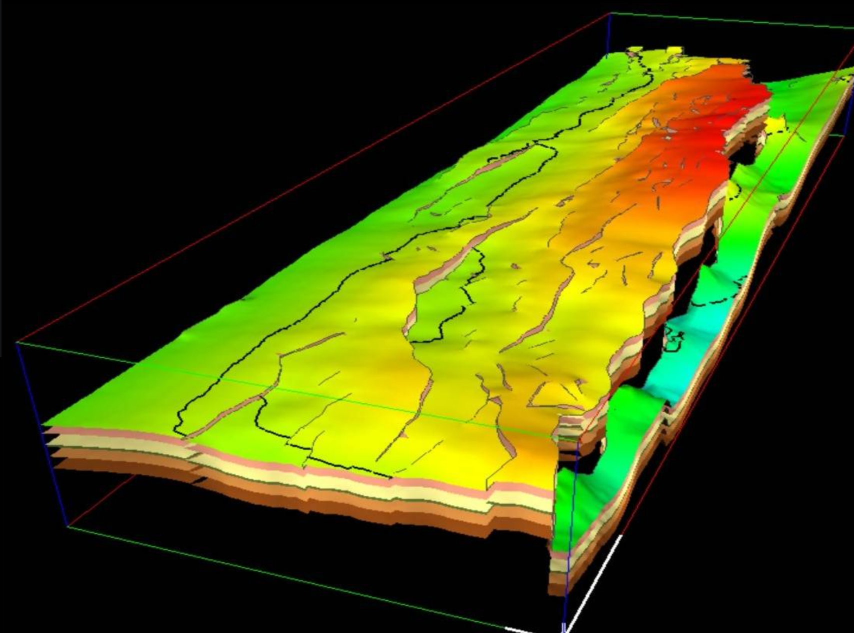
3-D visualization

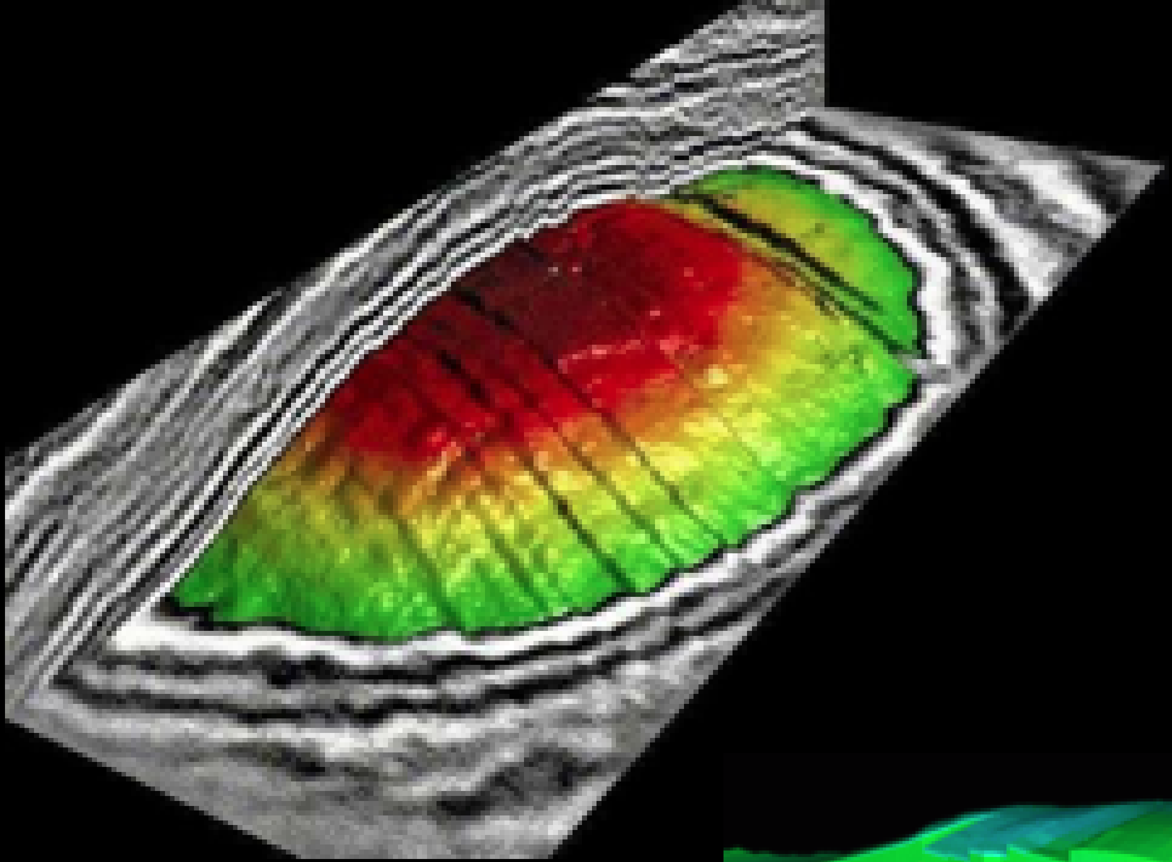
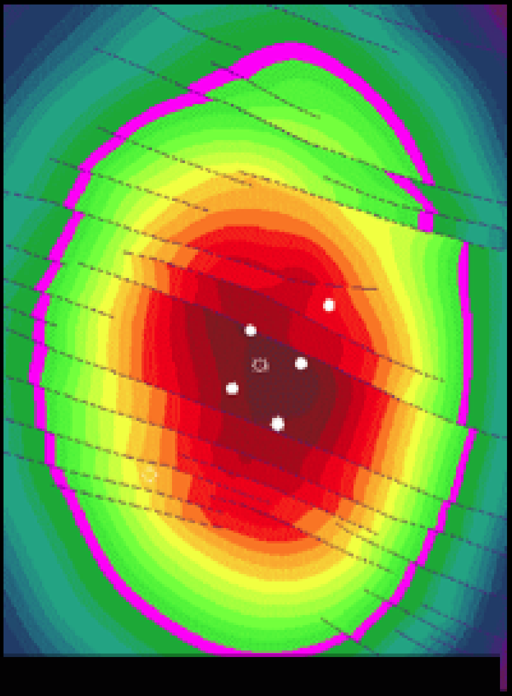
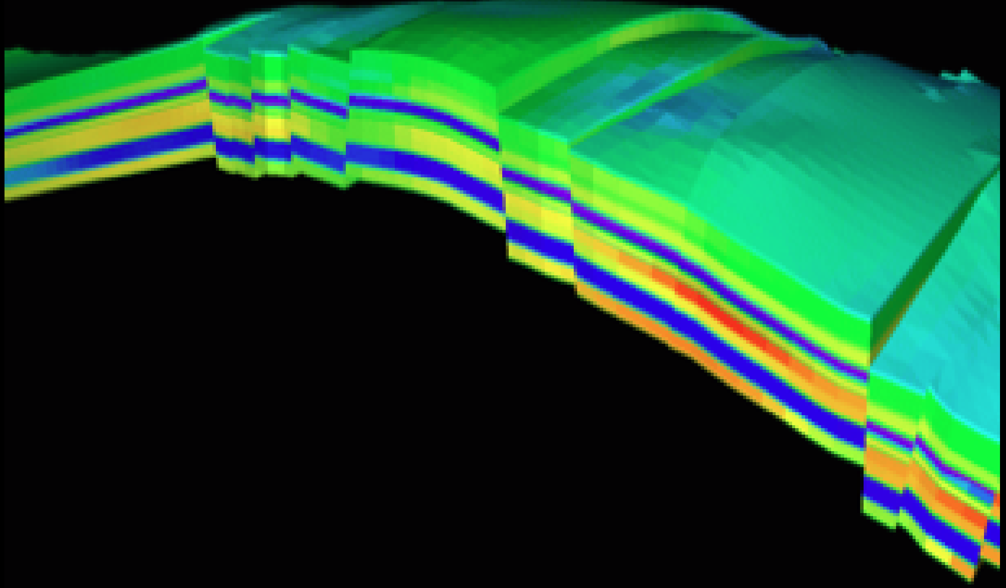





2400
3200
4000
4800
5600
6400
Depth (m)
Y
6708000
6703000
6698000
6693000
6688000

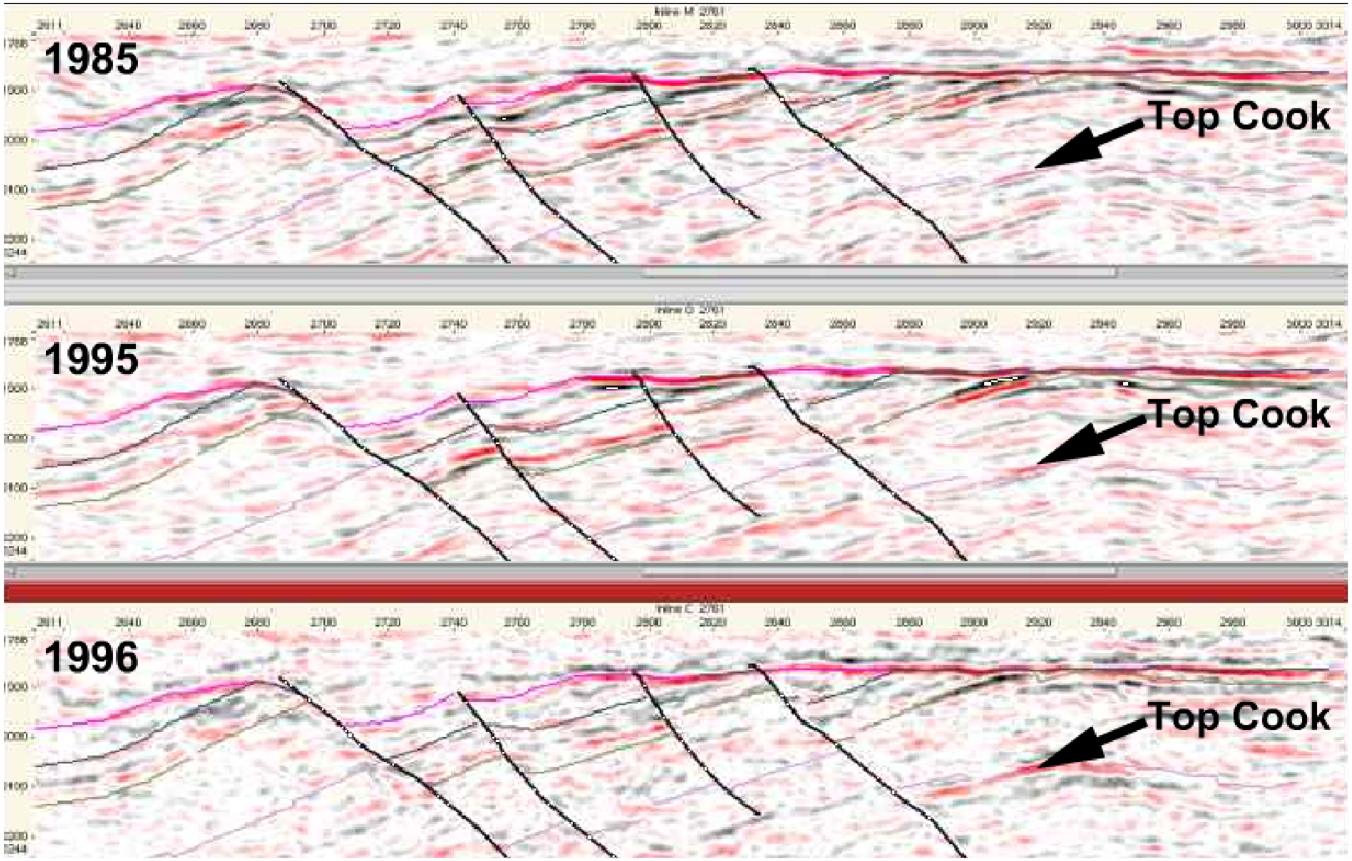




4-D seismic

- 4D seismic data is the combination of several 3D datasets collected at different times and collected/processed in the same way
- The difference tells us where and how changes have occurred in the reservoir during production in the time interval.
- This information is used for optimal positioning of new wells



Seismic inversion

In industry, the process of determining what physical characteristics of rocks and pore fluid could have produced a given seismic image/data set:

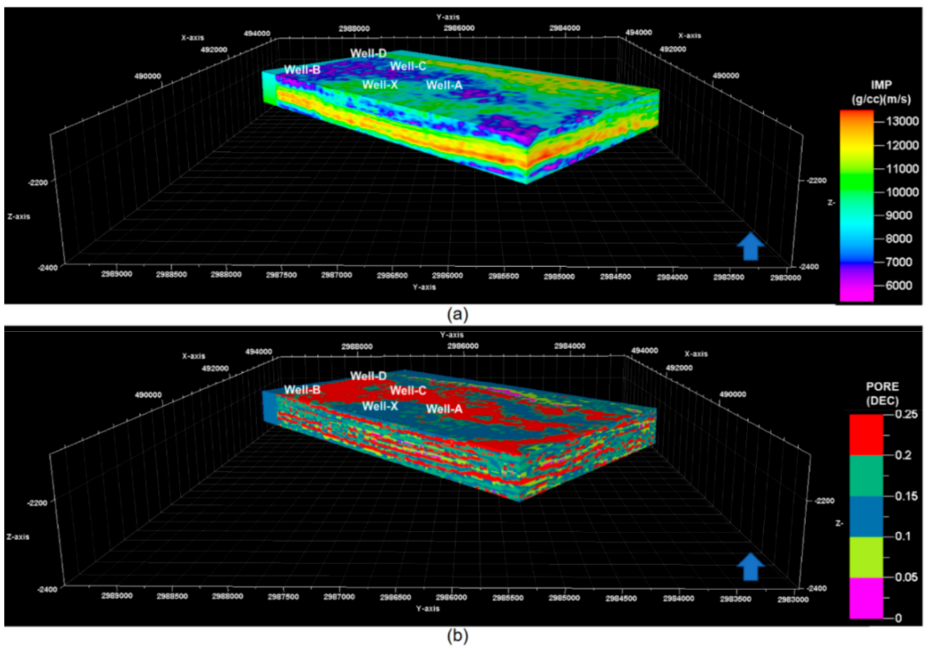
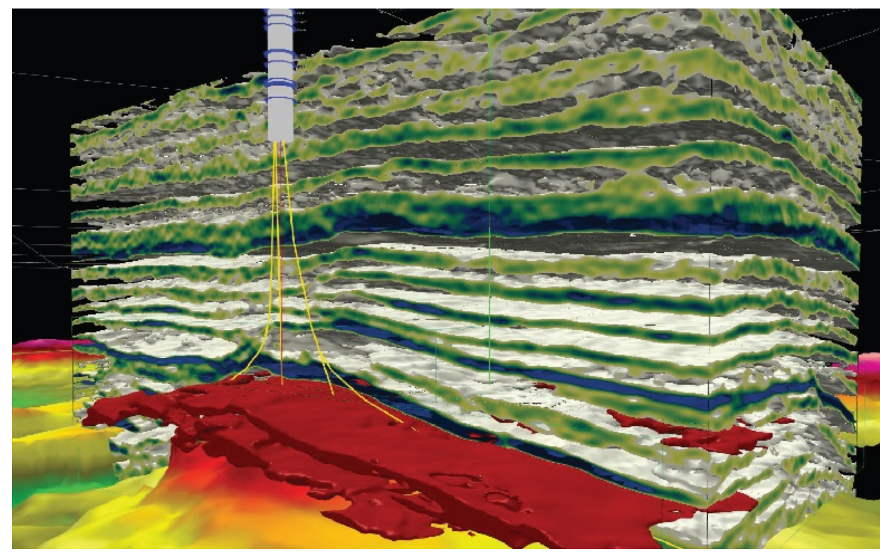
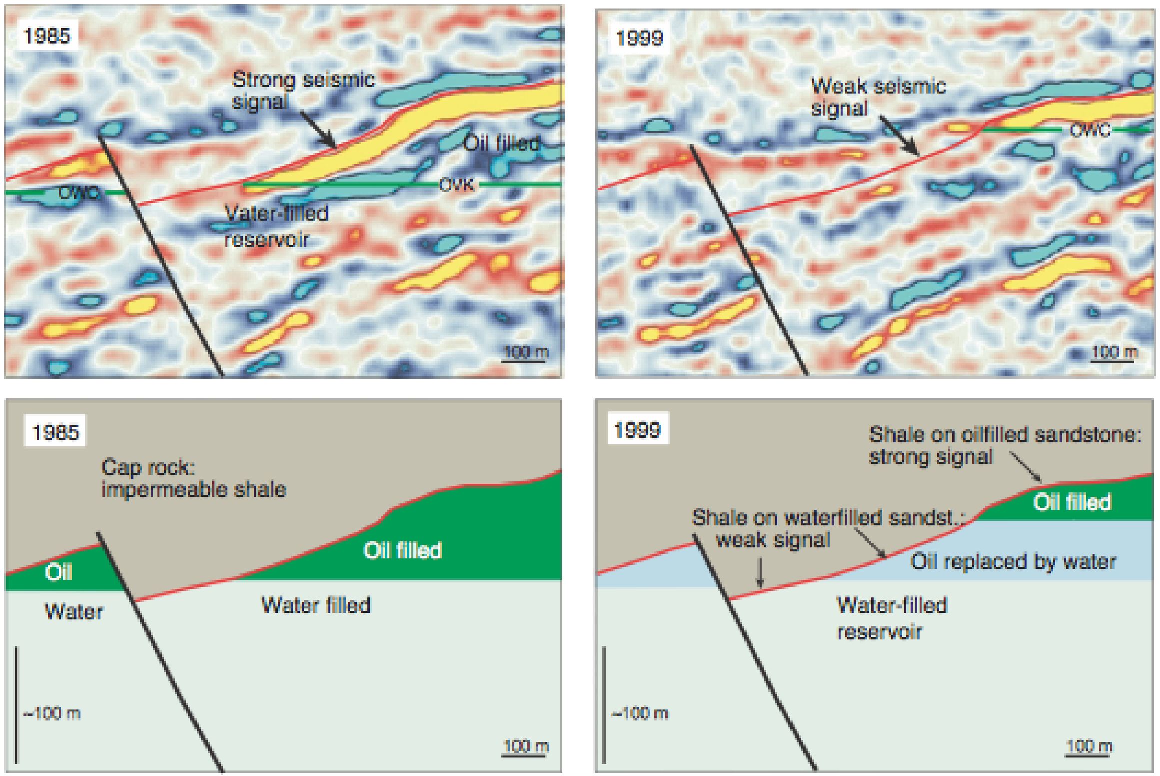


Figure 16. (**a**) 3D AI model, (**b**) seismic inversion of 3D effective porosity models within a specified time window (2160 to 2280 ms) covering target horizons.




1985
Strong seismic signal
Oil filled
OWC
OVK
Water-filled reservoir
100 m
1999
Weak seismic signal
OWC
100 m
1985
Cap rock: impermeable shale
Oil
Oil filled
Water
Water filled
~100 m
100 m
1999
Shale on oilfilled sandstone: strong signal
Oil filled
Shale on waterfilled sandst.: weak signal
Oil replaced by water
Water-filled reservoir
~100 m
100 m