Reflection Seismic Method

Principles

Data acquisition

Processing

Data visualization

Interpretation*

Linkage with other geophysical methods*

Reading:

Gluyas and Swarbrick, Section 2.3

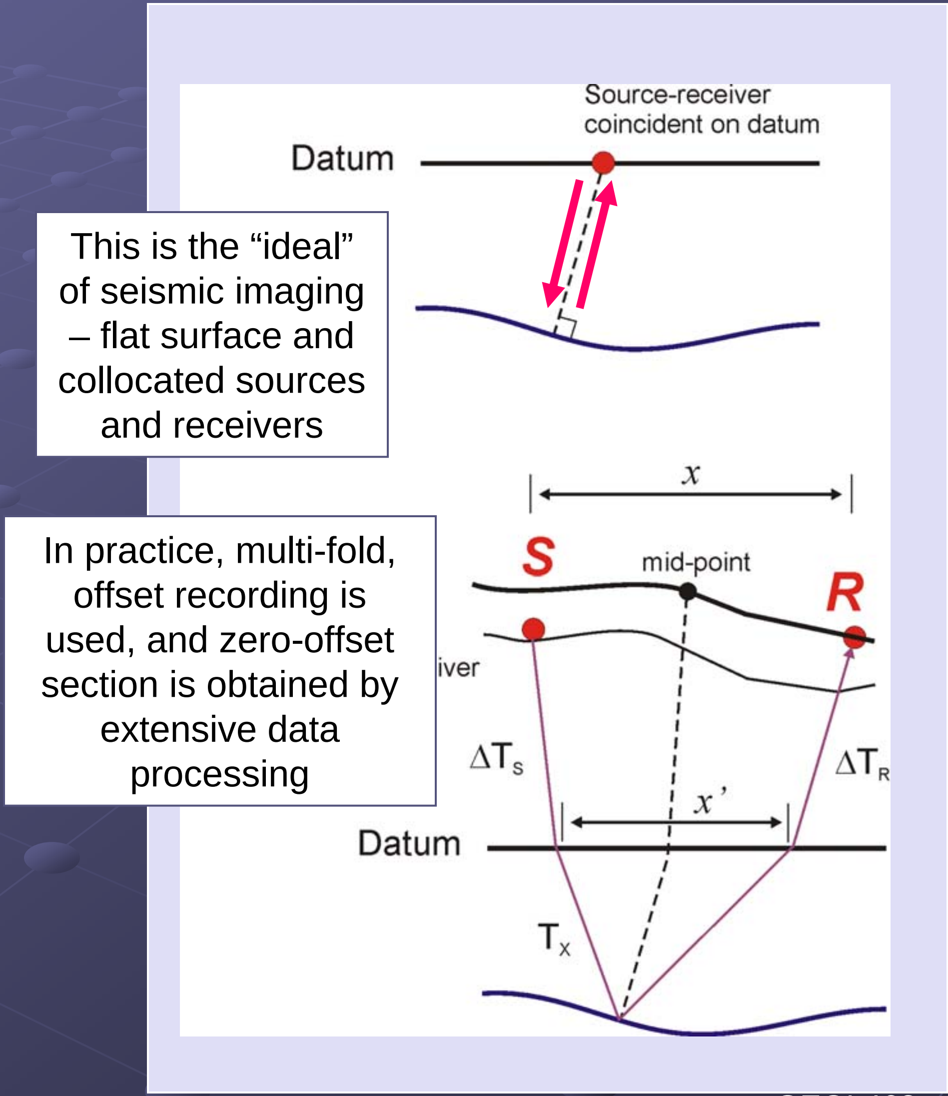
Many books on reflection seismology (e.g., Telford et al.)

Seismic Method

- The only method giving complete picture of the whole area
- Gives by far the best resolution among other geophysical methods (gravity and magnetic)
  - However, the resolution is still limited
- Maps rock properties related to porosity and permeability, and presence of gas and fluids
  - However, the links may still be non-unique
- Requires significant logistical effort
- Relies on extensive data processing and inversion

Seismic Reflection Imaging

- Acoustic (pressure) source is set off near the surface…
- Sound waves propagate in all directions from the source…
- 0.1-10% of the energy reflects from subsurface contrasts…
- This energy is recorded by surface or borehole "geophones"…
- Times and amplitudes of these reflections are used to interpret the subsurface…
- "Migration" (computer processing operation) is used to finally represent ("image") the 2D or 3D structure at depth.



Seismic Impedance

- As any geophysical method, seismic reflection imaging is sensitive to only a specific physical property of the rock
- This property is called acoustic impedance: $I=\rho V$ (density times acoustic velocity)
- Seismic reflection amplitude is proportional to the relative *impedance contrast* across a contact of two layers:

$$R = \frac{I_2 - I_1}{I_2 + I_1} = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$

Resolution

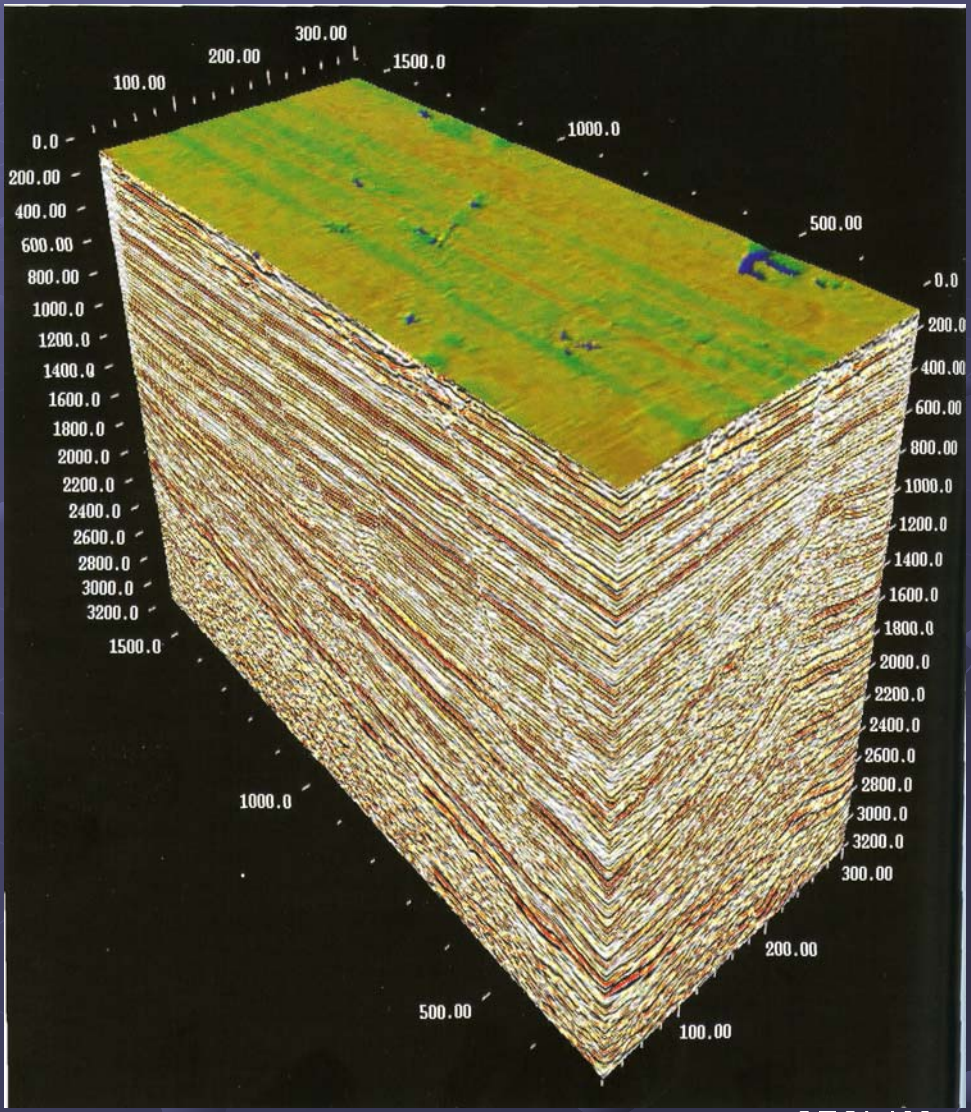
- Resolution is the ability to discern two closely spaced reflectors at depth.
- Seismic resolution is controlled by the bandwidth of the signal, which is typically f=30-140 Hz.
- Reflection frequencies decrease with depth because of *attenuation* of seismic waves, and this also decreases the resolution at depth.
- Vertical resolution is estimated as $\delta z \approx \lambda/4$, where λ is the "dominant wavelength": $\lambda = V/f$. Thus, δz can be 5-10 m.
- Horizontal resolution also decreases with depth:

$$\delta x \approx \sqrt{\frac{z\lambda}{2}}$$

- However, migration somewhat relieves this limit and replaces it with several λ.

Seismic Displays

- Visualization is key to seismic data analysis
- 3D displays are mostly done interactively using workstations
- In this plot:
  - Vertical axis is the two-way reflection travel time,
  - Horizontal axes give the collocated source-receiver coordinates,
  - Color represents reflection amplitudes
  - The color-coded upper surface is the water bottom.
- Note the *acquisition footprint* (striations on the water-bottom surface along the acquisition lines)



Types of Seismic Surveys

- Start with regional 2-D reconnaissance lines
- Following the initial discovery – detailed 2-D or 3-D
- Repeated 3-D surveys ("time-lapse", or 4-D) for monitoring changes in the area during production
- For best survey planning:
  - In most cases, need to have a good idea about the target
  - Use computerized pre-acquisition modelling
- Key considerations:
  - For 2-D – lines should be oriented across-strike of the target structures
  - Cost – minimize the number of source points
  - Achieve sufficient multiplicity ("fold") of coverage
  - Achieve uniformity of coverage of the target horizons
  - "Undershoot" obstacles and survey edges
  - Achieve adequate resolution and fidelity
  - Reduce the acquisition footprint (especially important in 3-D)

Planning and surveying

- Detailed planning and modelling performed prior to acquisition
  - The complete expected seismic image would often be computed from the synthetics
- Complete GPS surveying

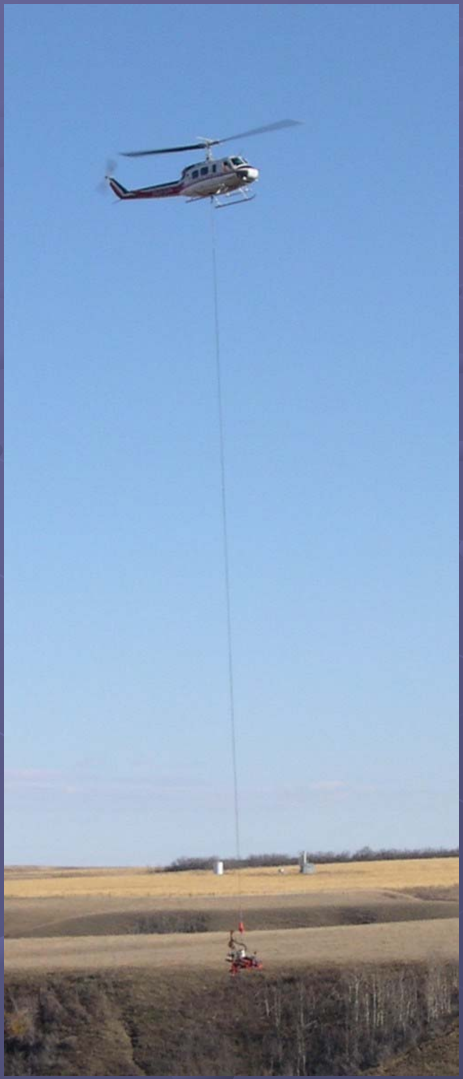
Seismic explosive sources on land

- Gelatin dynamite, ammonium nitrate, pentolite (SEIS-X).
- Packaged in tins, cardboard or plastic tubes ~5 cm in diameter (0.5-5 kg each).
- Connected to make desired charges.
- Detonated using electrical detonators.
- Best explosives will disintegrate from contact with water when not used.

Drilling and Charging

Truck-mounted drill rigs

Drilling and Charging



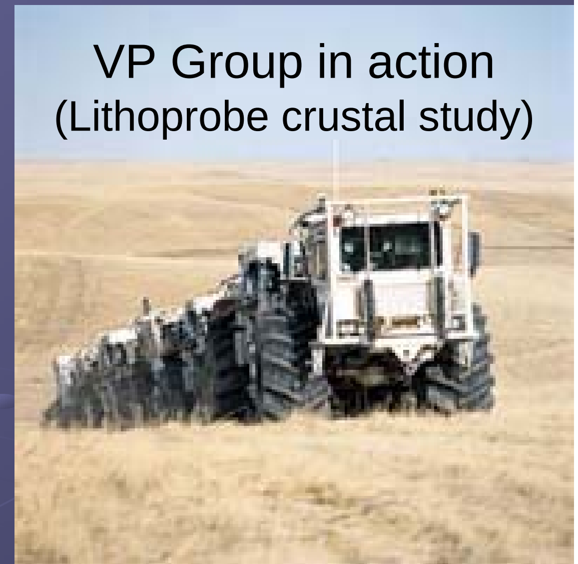
In hard-to-access places, small rigs powered by compressed air can be brought by helicopters

VibroSeis source

- Rather than using explosions, acoustic energy can be distributed in time by using a hydraulic vibrator device
  - Usually mounted on a heavy truck
  - Small borehole vibrators, portable vibrators, and >100-ton stationary vibrators also exist.
- The signal consists of a quasi-monochromatic "sweep" of gradually changing frequency, covering ~20-150 Hz
- To produce stronger signal, vibrators are able to operate synchronously (vibrate in-phase) in a group
- The signal sent into the ground is carefully recorded and afterwards "correlated" with the recordings to produce an equivalent of impulsive excitation

VibroSeis

3-component vibrator



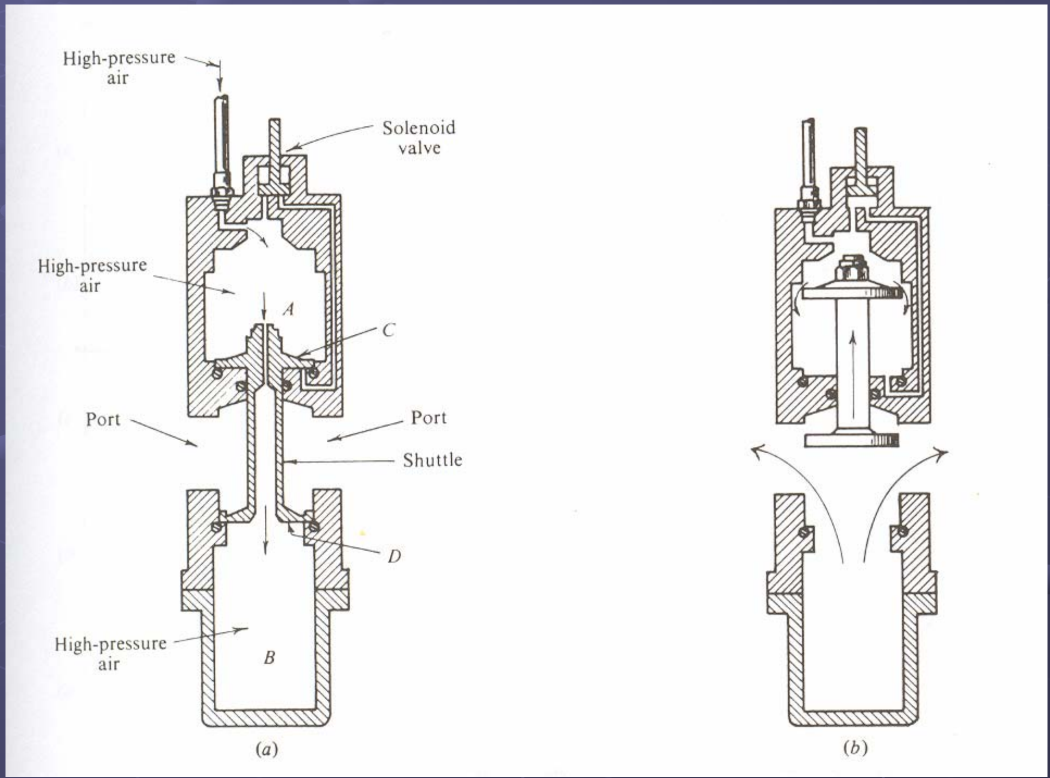
VP Group in action
(Lithoprobe crustal study)

Mini-Vibe (up to ~600 Hz)

Tanker

Marine seismic source - airgun

- High-pressure air bubble released into water
  - Operating pressure 10-15 MPa, released in 1-4 ms;
  - Size (volume of the lower chamber) 10-2000 in^3 (0.16-33 liters);
  - Can shoot every 15-20 sec;
  - Highly repeatable source, consistent signal.



Geophones and Digital Acquisition Systems

New-generation 3-component all-digital VectorSeis geophone

Traditional geophones and cables

Field digitizing unit

Line layout and field operations

Helicopters are often used to move equipment and “roll” the lines while shooting

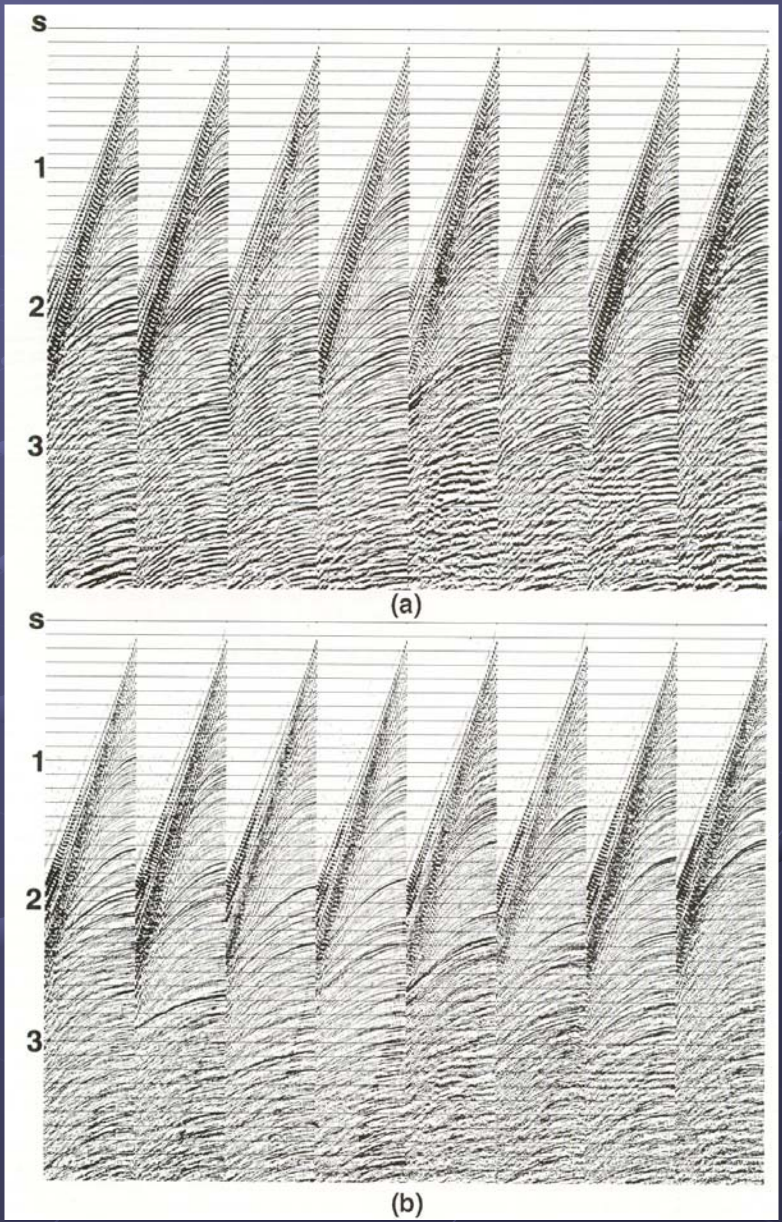
- Geophones are laid out in lines 10-30 m apart
- The lines are connected to a recording truck using extension cables
- Portable telemetered systems are also in common use

Acquisition and QC

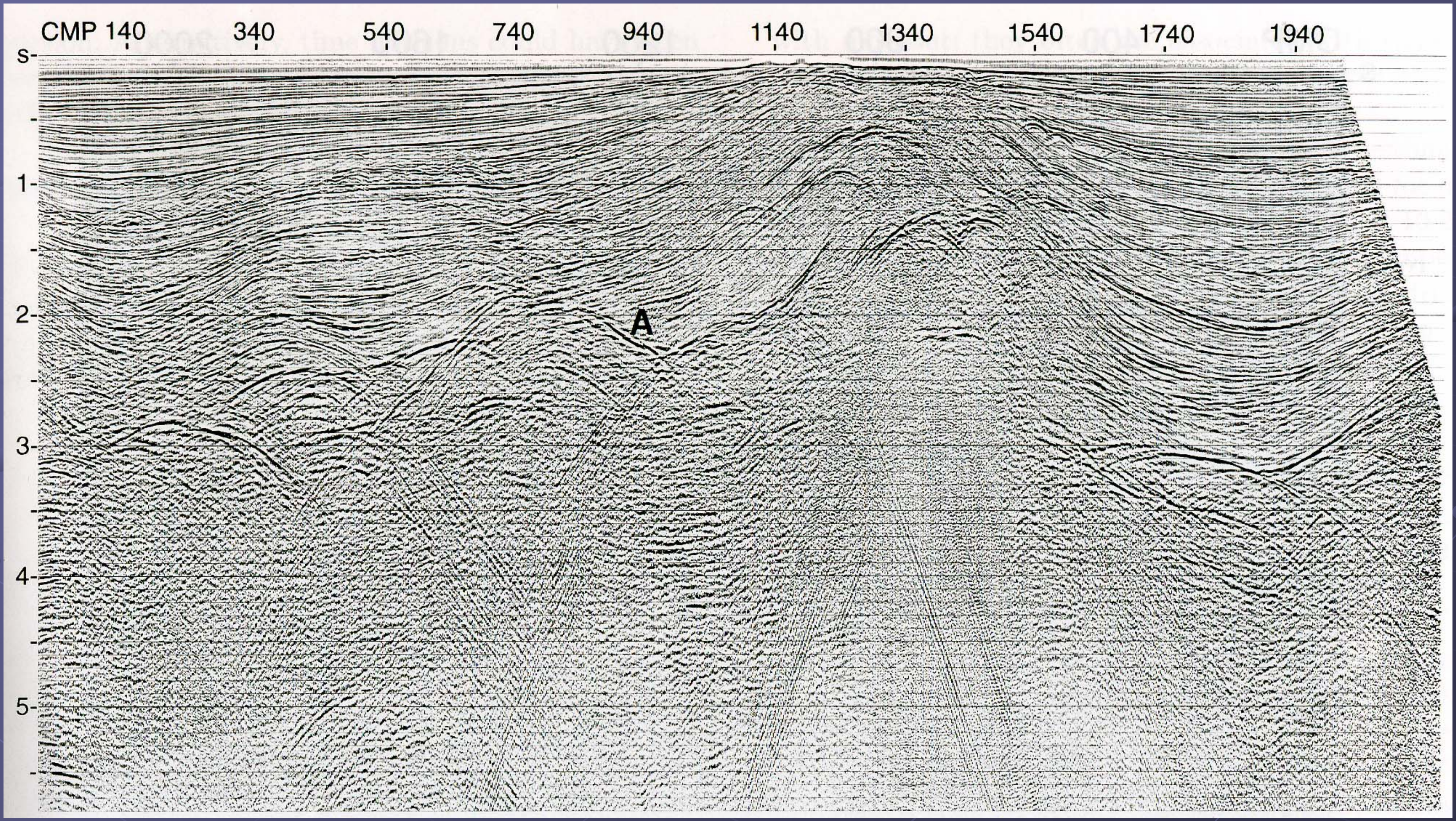
- The entire shooting and recording process is controlled by an operator using an automated acquisition system
- Records are correlated (if VibroSeis) and quality-controlled in the field

Processing

- Seismic time/depth images are obtained through extensive computer processing of many thousands of shot records (like those shown on the right):
  - Time shift ("statics") corrections;
  - Deconvolution (removal of reverberations);
  - Frequency, velocity, and coherency filtering;
  - Suppression of non-reflection events;
  - Velocity analysis;
  - Removal of the effects of source-receiver offsets ("NMO correction");
  - Summation ("stacking") for noise suppression;
  - Migration (placement the events at their correct positions in depth).

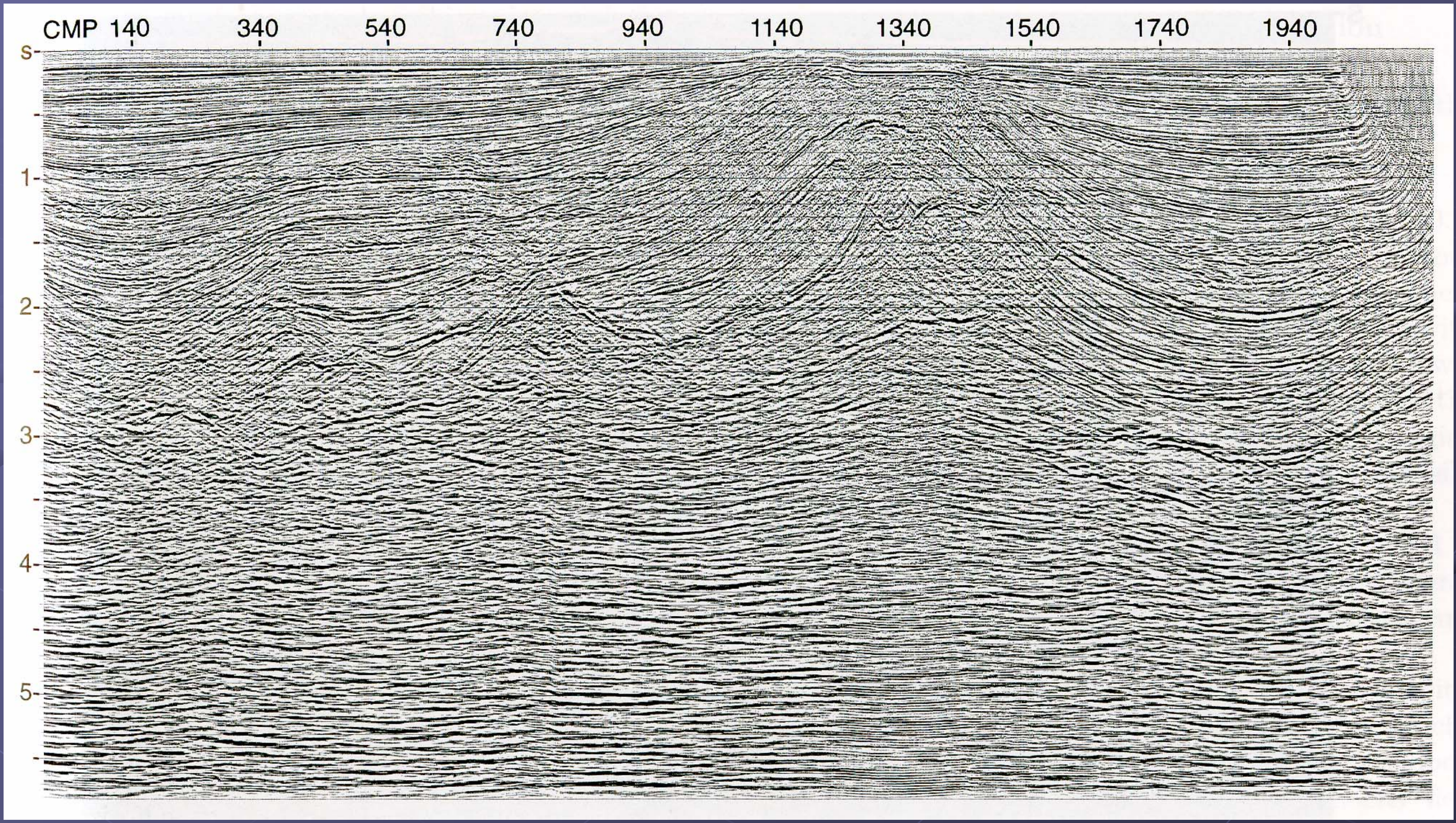


Seismic Images 1: Stack



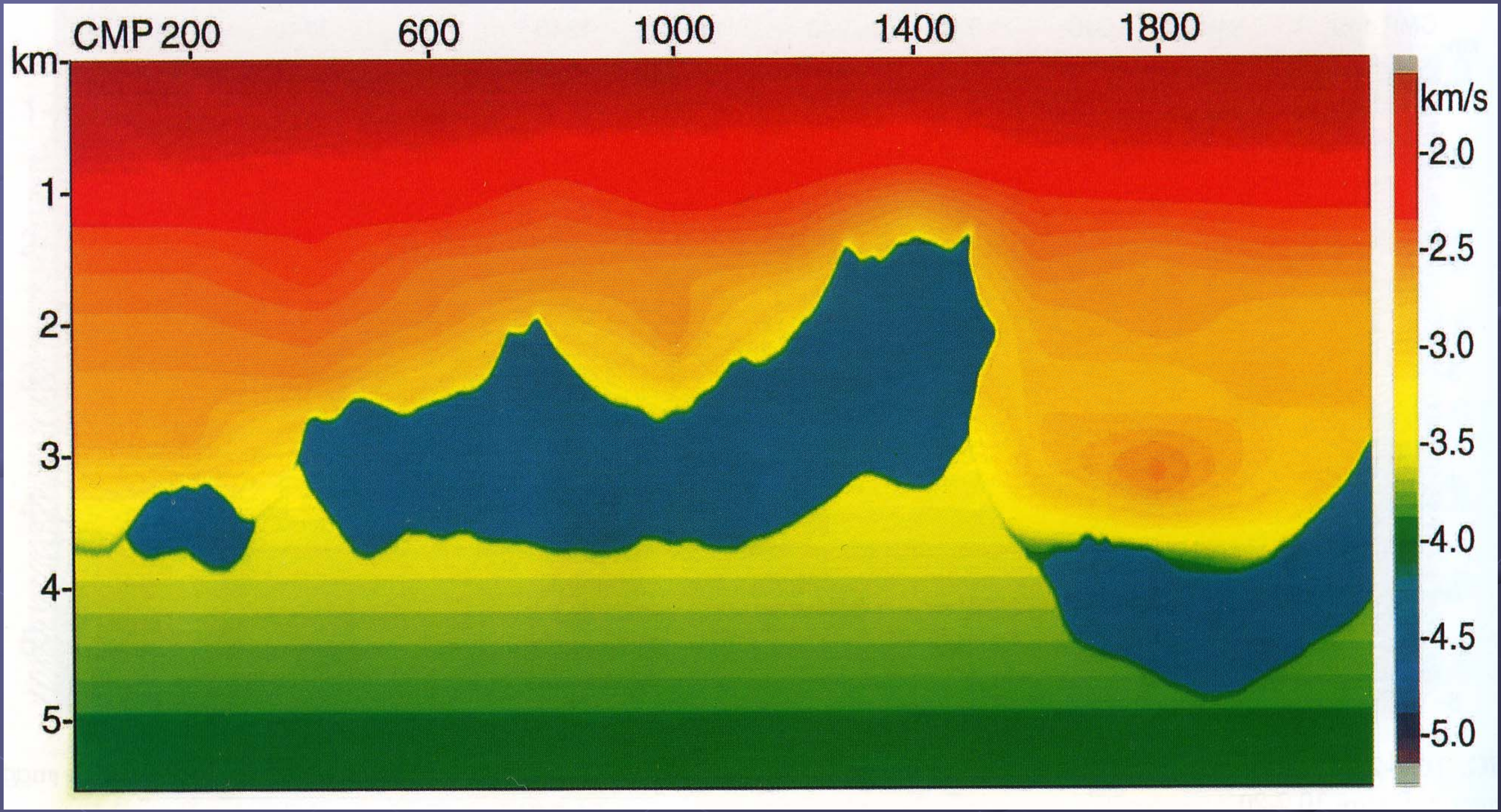
Gulf of Mexico line, unmigrated stacked section. A is the top-salt reflection

Seismic Images 2: Migrated stack



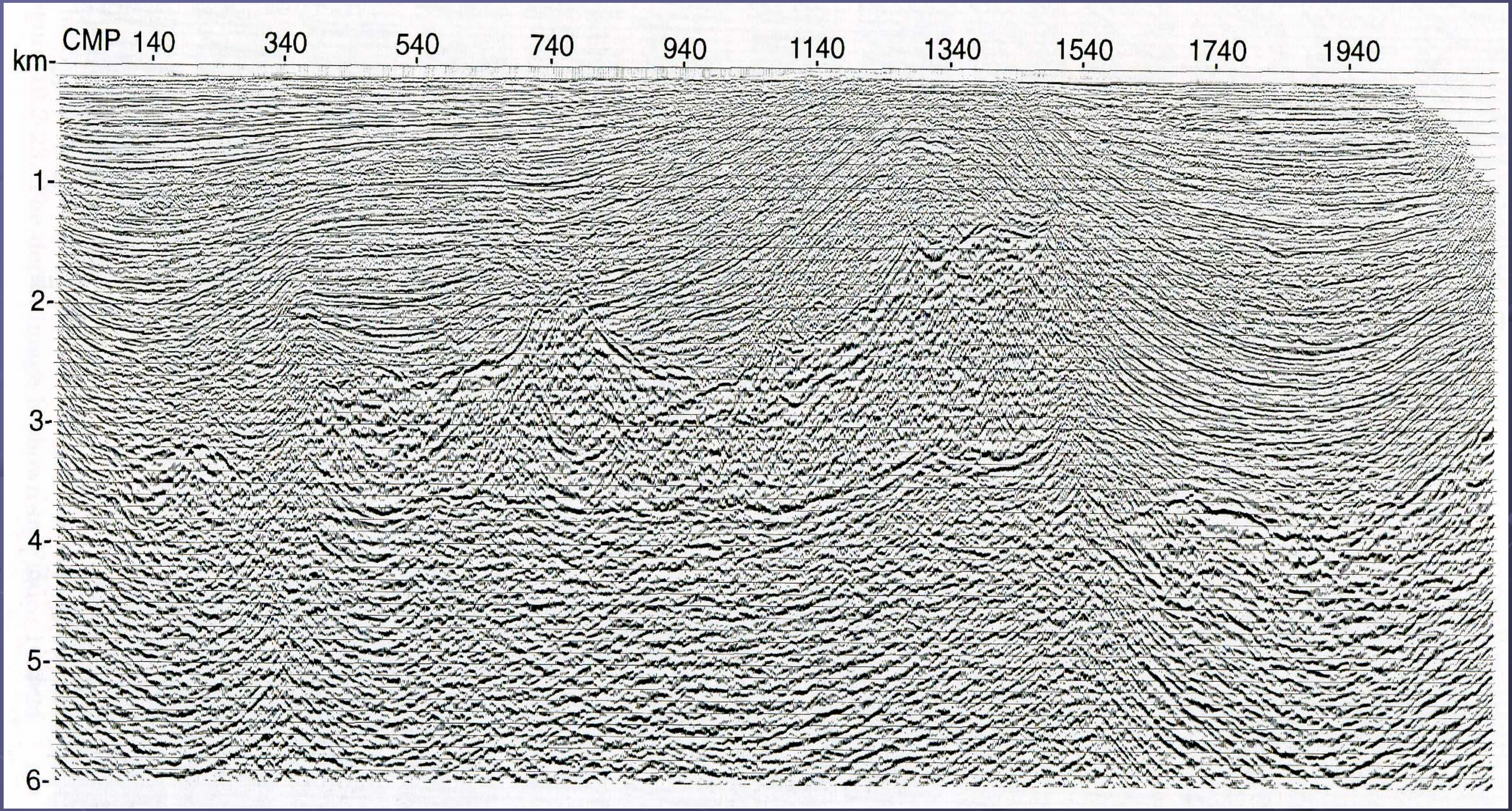
Gulf of Mexico line, post-stack migrated section.

Seismic Images 3: Velocity model



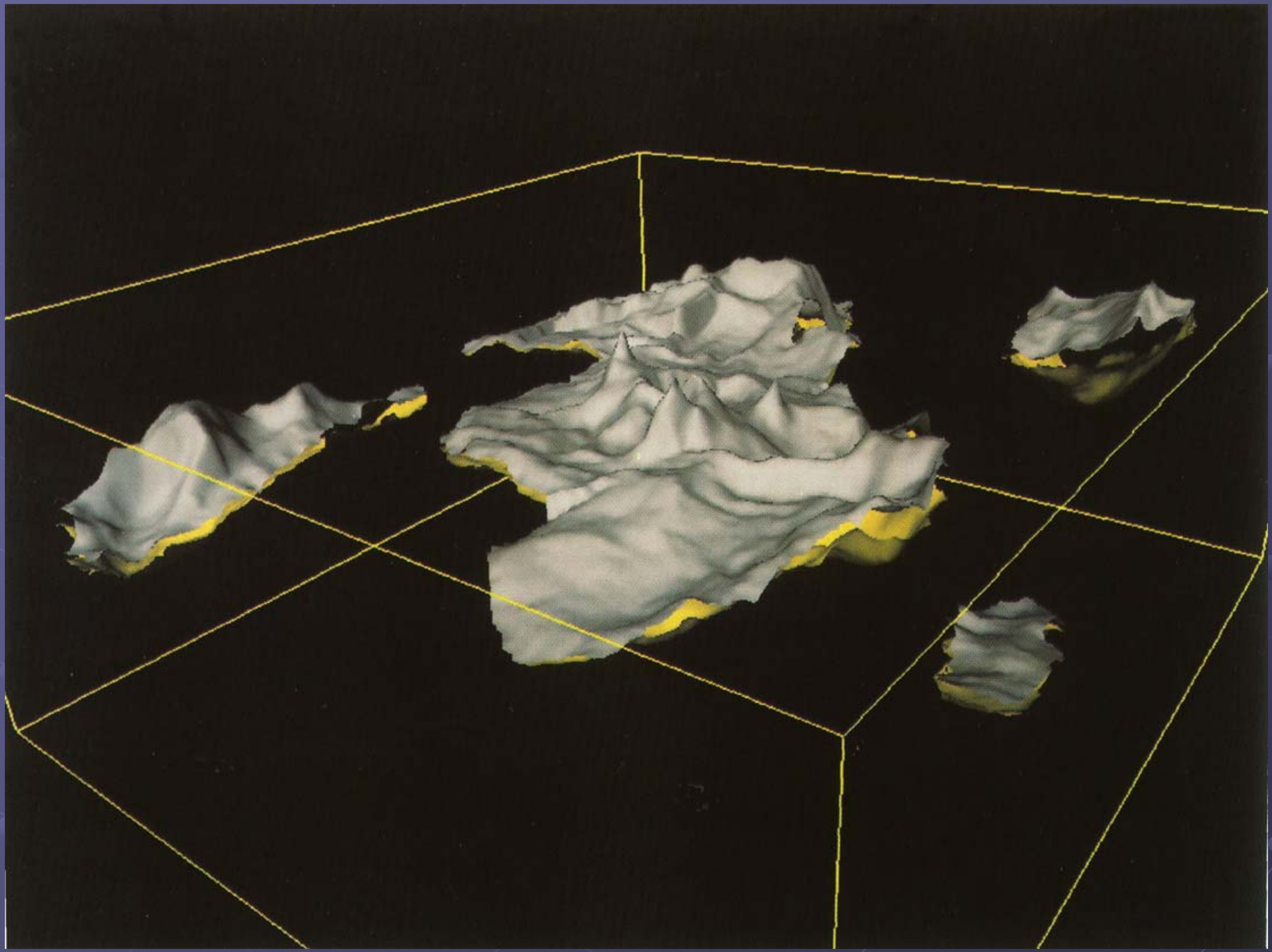
Gulf of Mexico line, final velocity model from tomography and pre-stack coherency analysis.

Seismic Images 4: Pre-stack migration



Gulf of Mexico line, pre-stack migrated section. Note the improved sub-salt imaging.

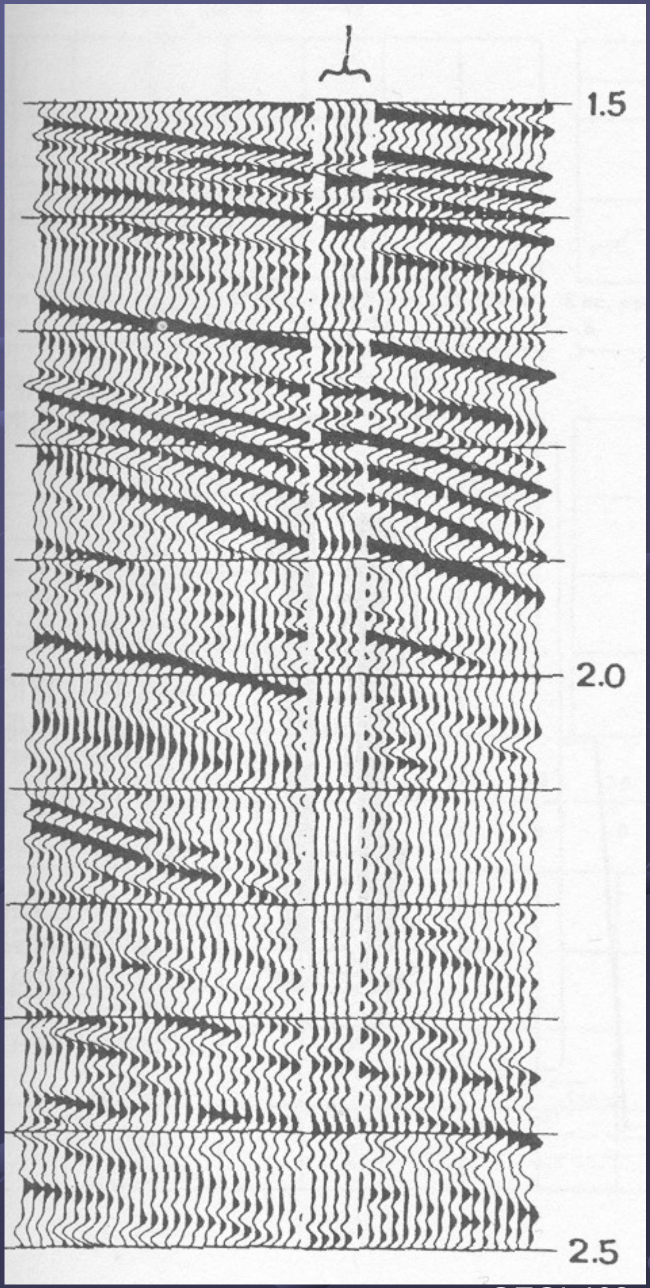
Seismic Images 5: 3-D model



3-D perspective view of detached salt sills from the Gulf of Mexico. Silver is the top-salt surface and gold is the base-salt boundary.

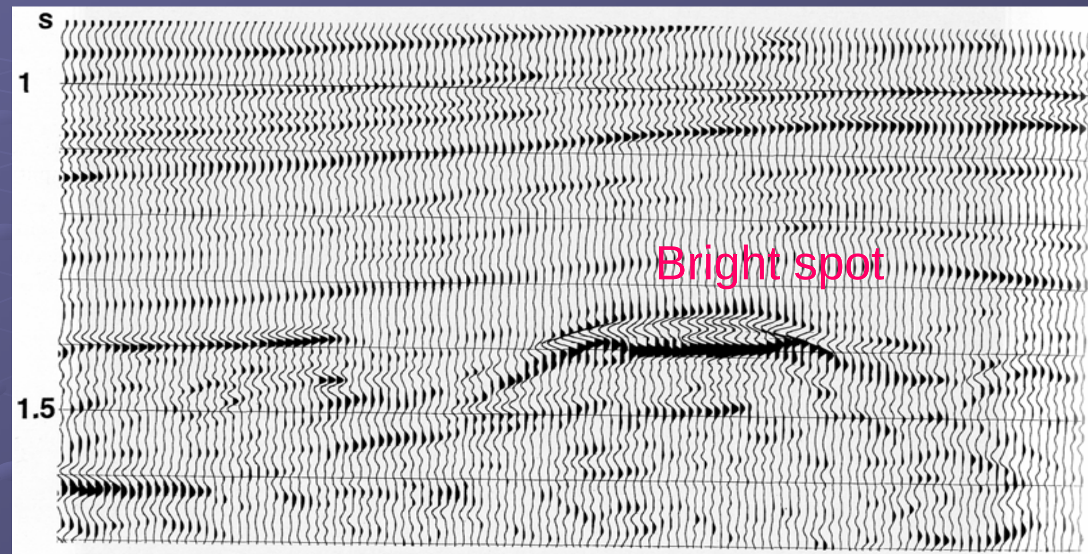
Interpretation

- Seismic sections are processed and correlated with synthetics generated from velocities and densities logged in the adjacent wells
- This process allows to tie the stratigraphic interpretation to the structural images obtained from seismics

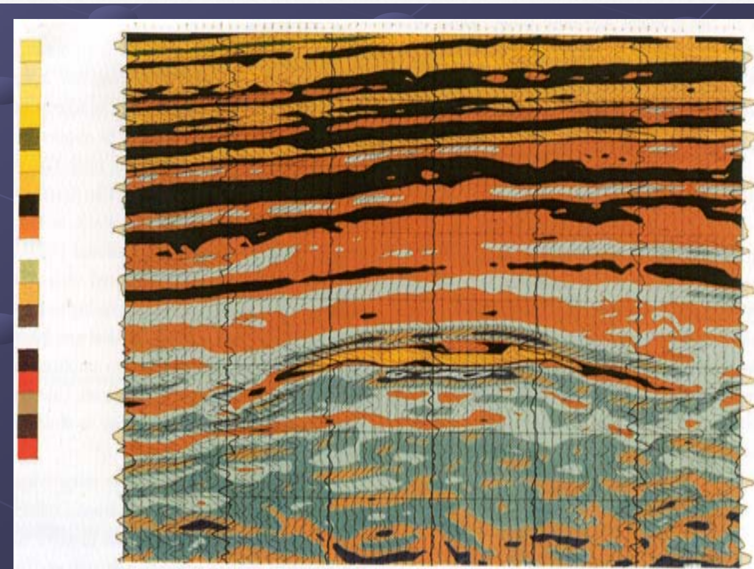


(Acoustic Impedance) Inversion

- The equation for reflectivity: $R = \frac{I_2 - I_1}{I_2 + I_1}$ can be inverted for the impedances *I*.
- This leads to seismic impedance sections that can be directly correlated to acoustic logs and lithology.



Stacked reflectivity section



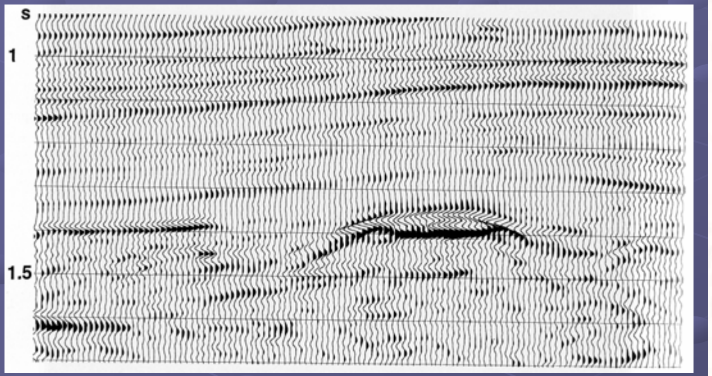
Synthetic sonic log derived from this section

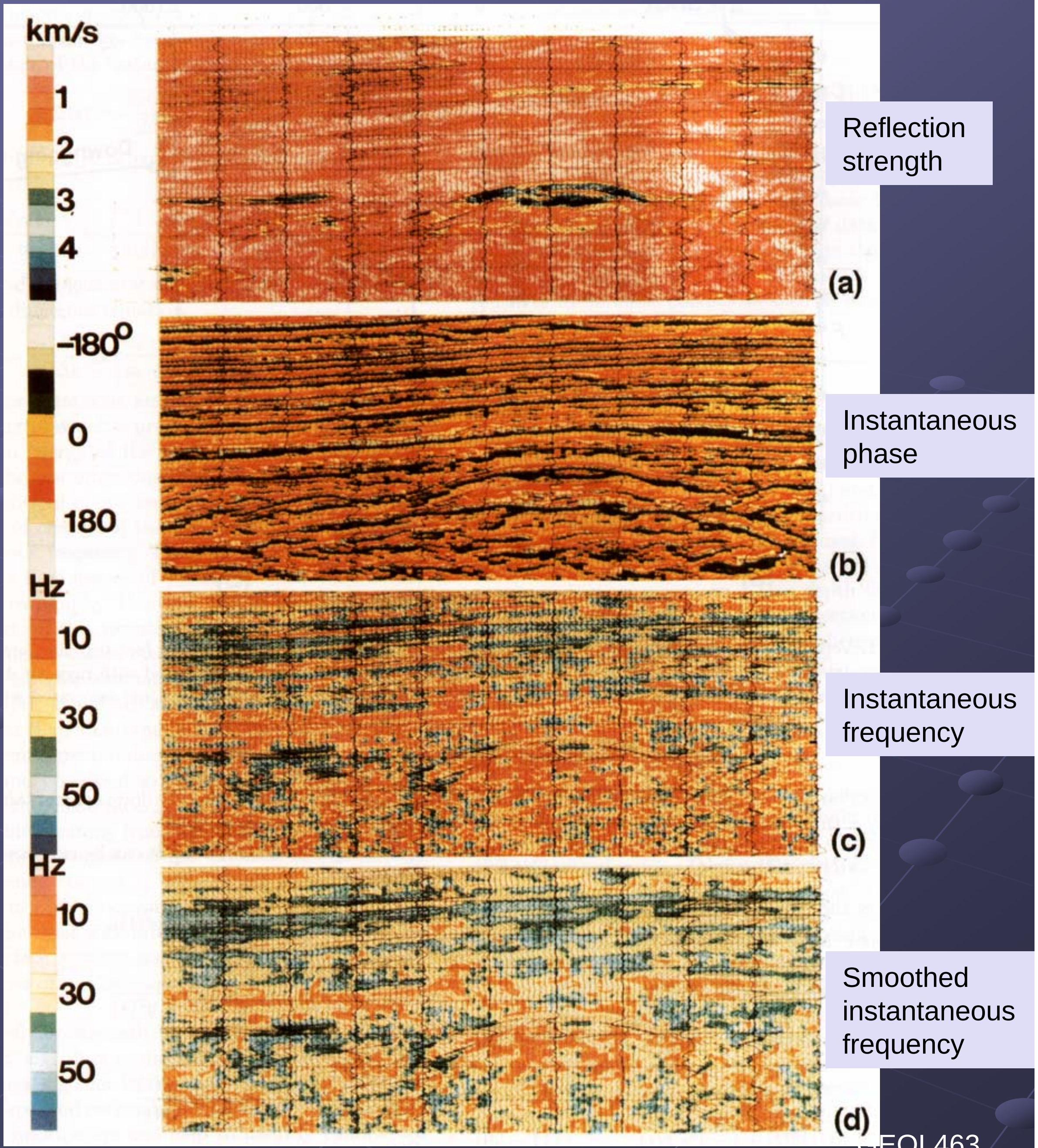
Seismic Attributes

- Seismic interpretation often relies on “attribute” sections and 3D images.
- Attributes are secondary properties derived from pre-stack reflection data or (more often) from the images themselves:
  - Instantaneous (local) amplitudes, phases, frequencies, bandwidths, etc.
  - Local dips and velocities
  - Statistical coherency attributes (especially useful in 3-D for tracing faults)
  - Amplitude versus Offset attributes

Attributes

(some examples for the same "bright spot" section)



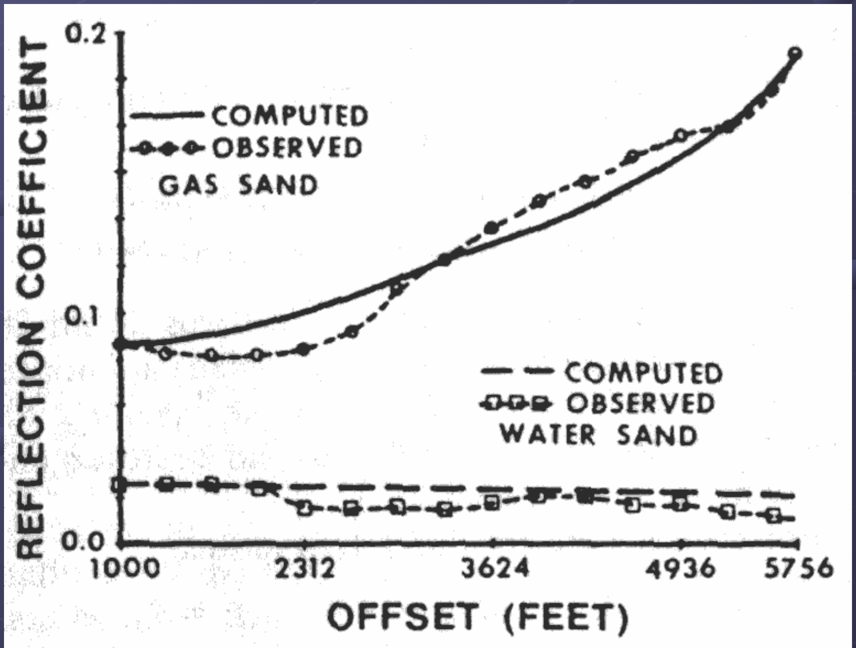


Amplitude-vs. Offset (AVO) properties

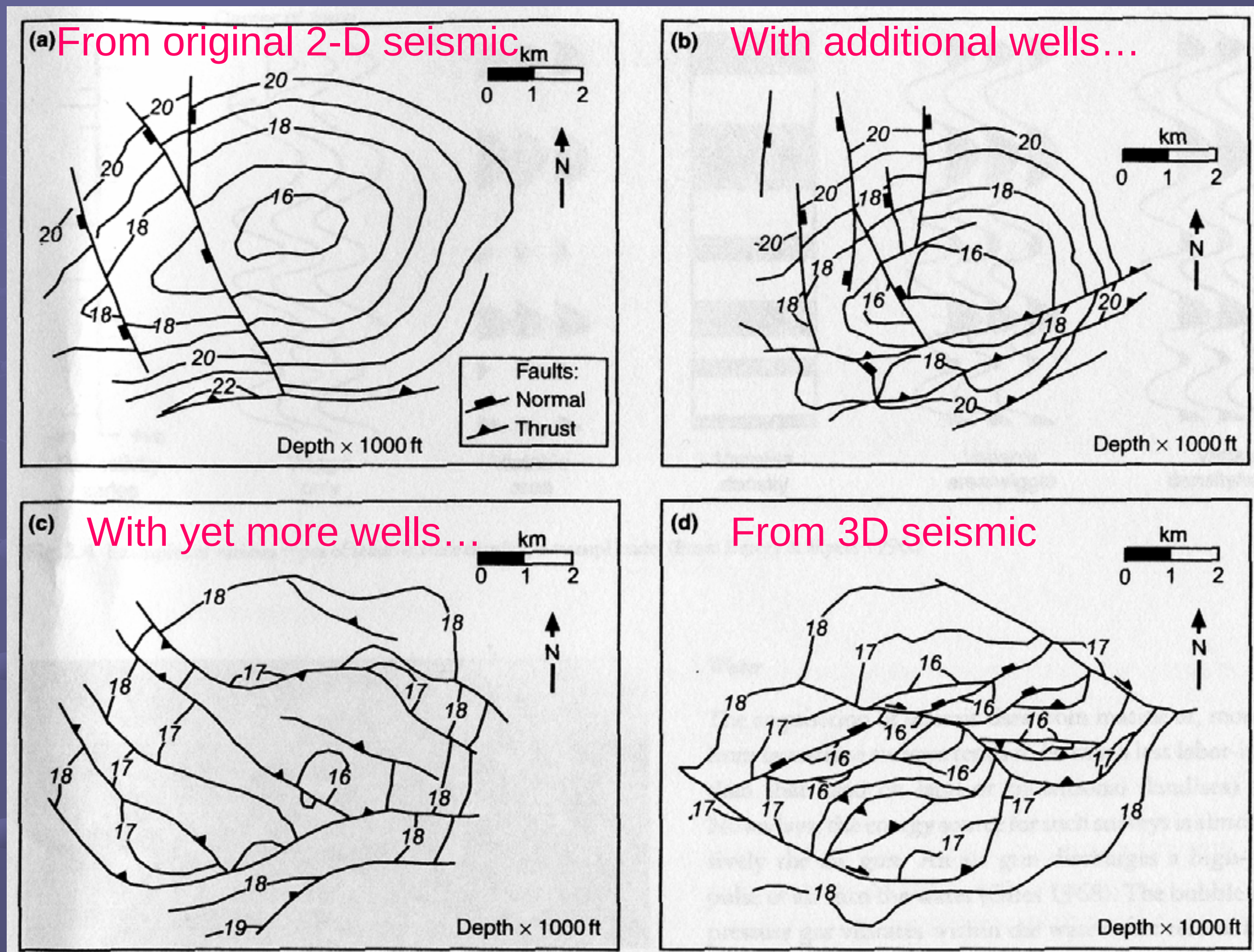
- To extract subtle rock properties, dependences of reflection amplitudes on source-receiver offsets are analysed.
- For example, gas-filled pores tend to reduce V_P more than V_S, and as a result, reflection amplitudes from a gas sand increase with incidence angles (and therefore offsets).
- Such analysis leads to additional AVO attribute sections ("intercept," "gradient," and many other)

$$R(\theta) = R(0)\left(1 + P\sin^2\theta\right)$$

Simplified AVO equation



Benefits of 3-D Seismic Imaging



Structural interpretation of Boqueron field (Venezuela)
(*from Gluyas and Swarbrick*)