ETH zürich

# Advanced geophysical methods for exploration and monitoring

Prof. Johan O. A. Robertsson, Chair of Applied Geophysics, ETH

# Outline

- “Technology & the next trillion barrels”
- The seismic method
- Enabling technology for shale gas E&P
  - directional drilling, fracking
- The role of seismics for better shale gas E&P with minimum environmental footprint
  - where do we drill?
  - how do we produce efficiently?
- Conclusions

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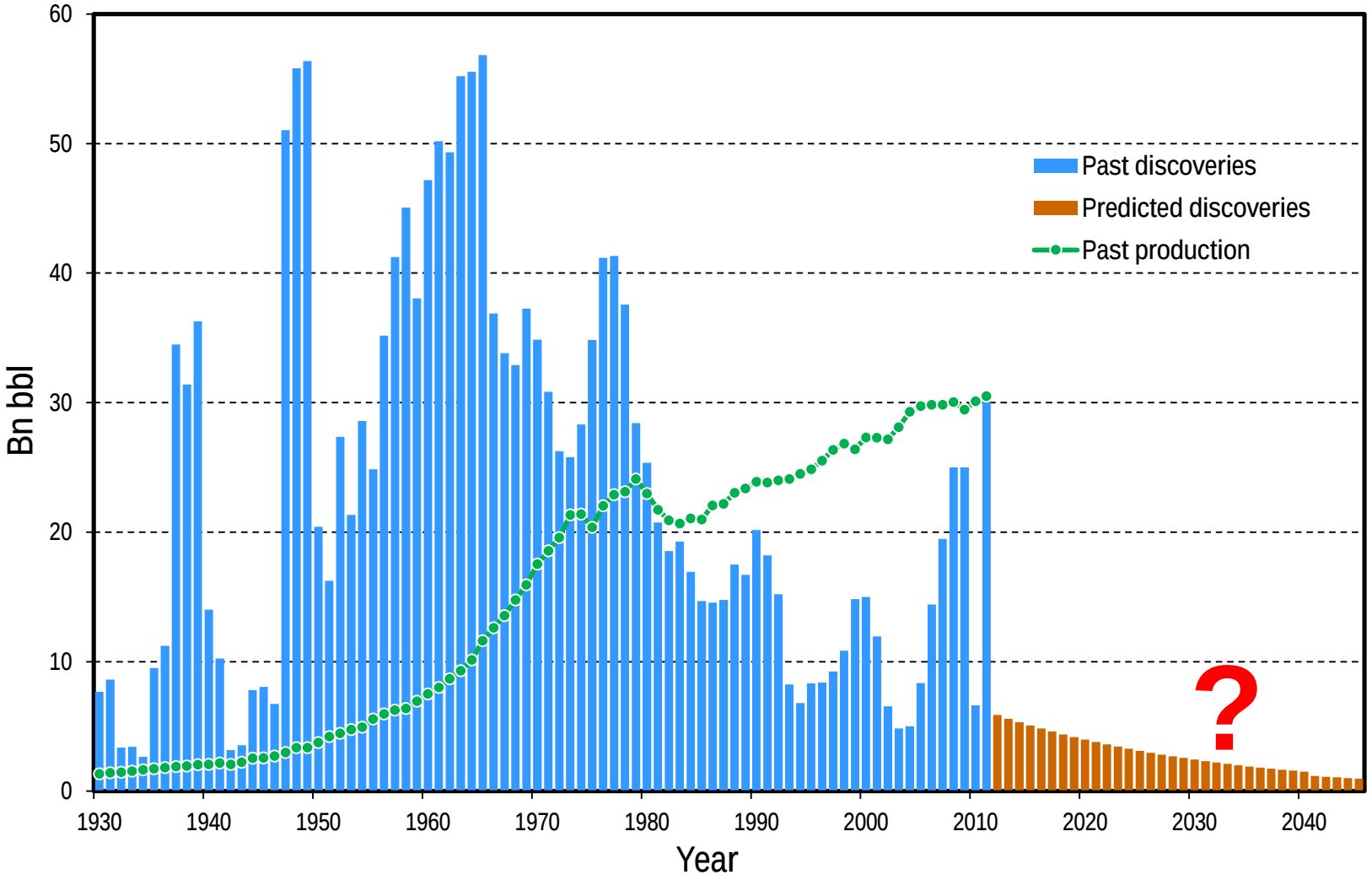
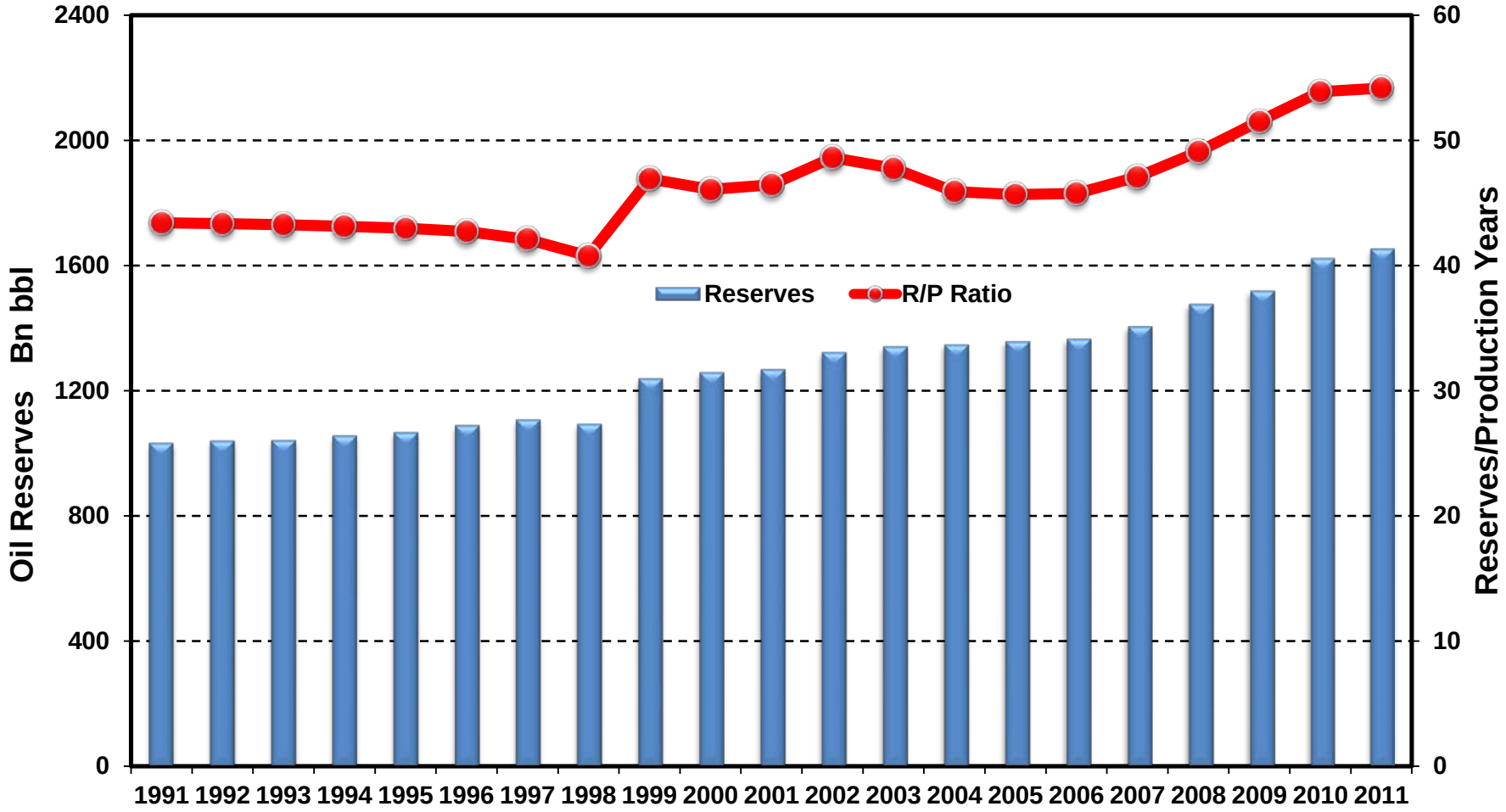
# Liquid Oil Discoveries & Production




*Modified from www.oilposter.org*

# Global Reserves

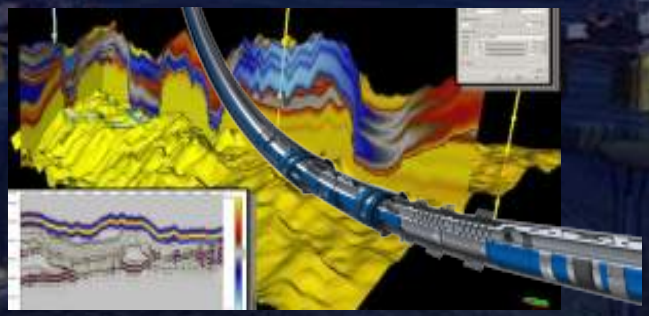



*BP Statistical Review*

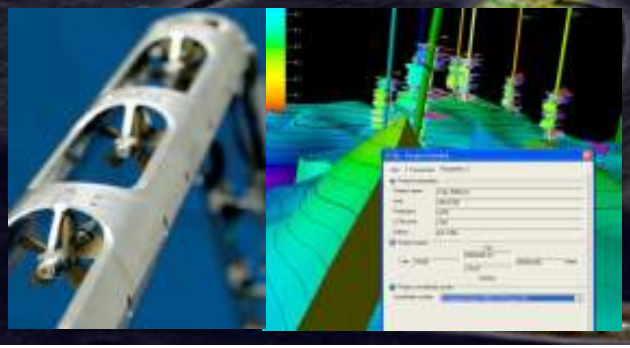
# “Technology & the next trillion barrels”

Exploration to add reserves

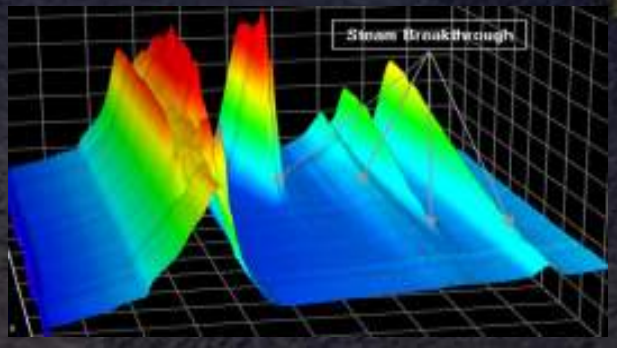
Maximizing reservoir recovery



Boosting production from existing fields



Unlocking unconventional hydrocarbons e.g. shale gas



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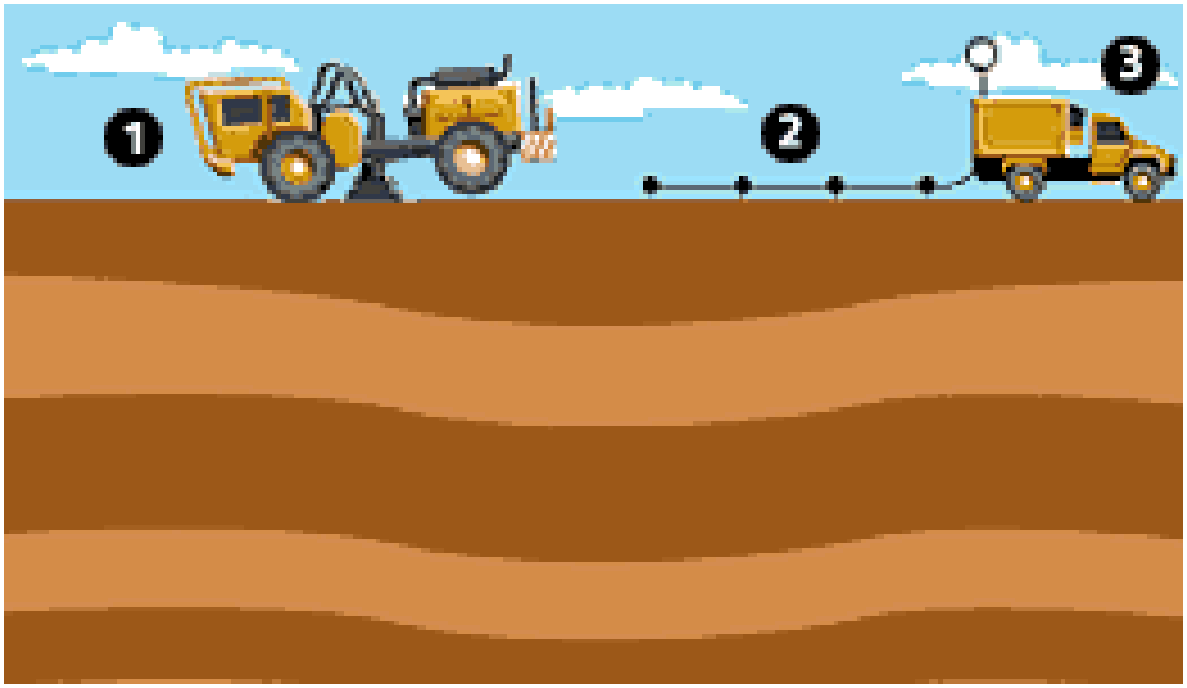
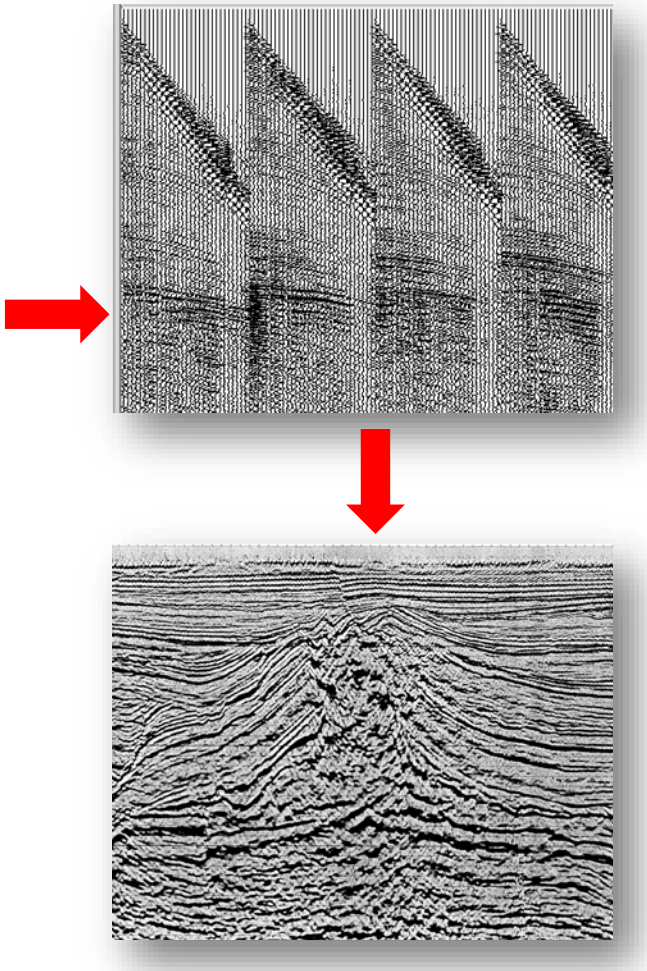
# Exploration seismic imaging



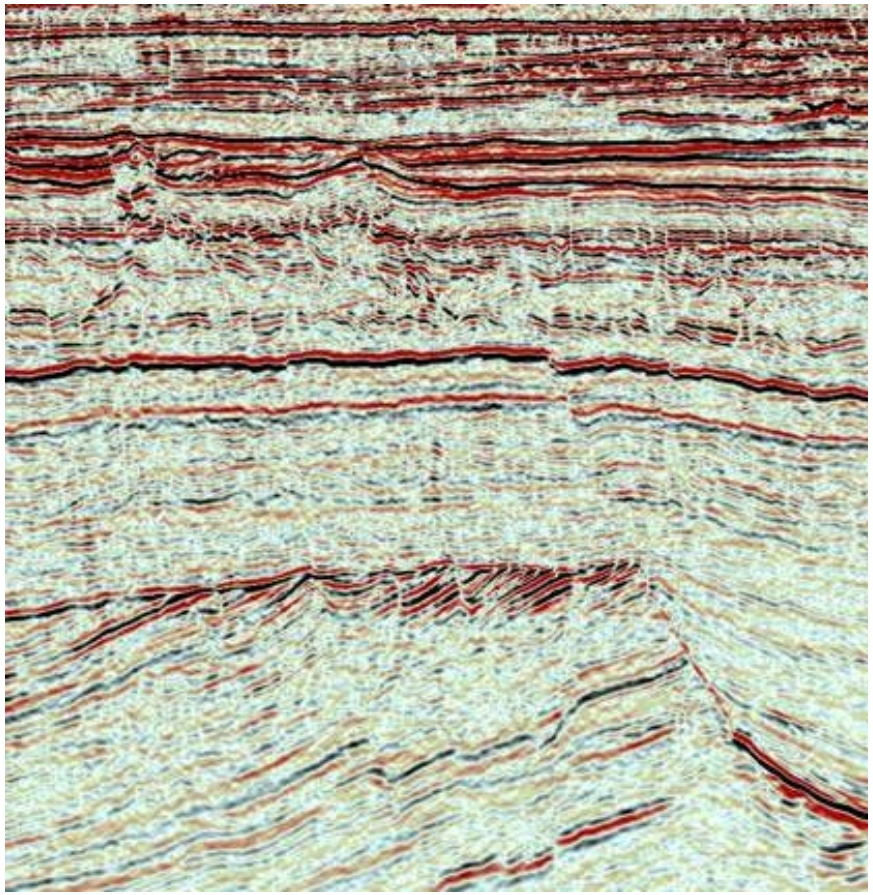
- Top frequency: 100Hz
- Seismics can resolve features as small as 10-50m

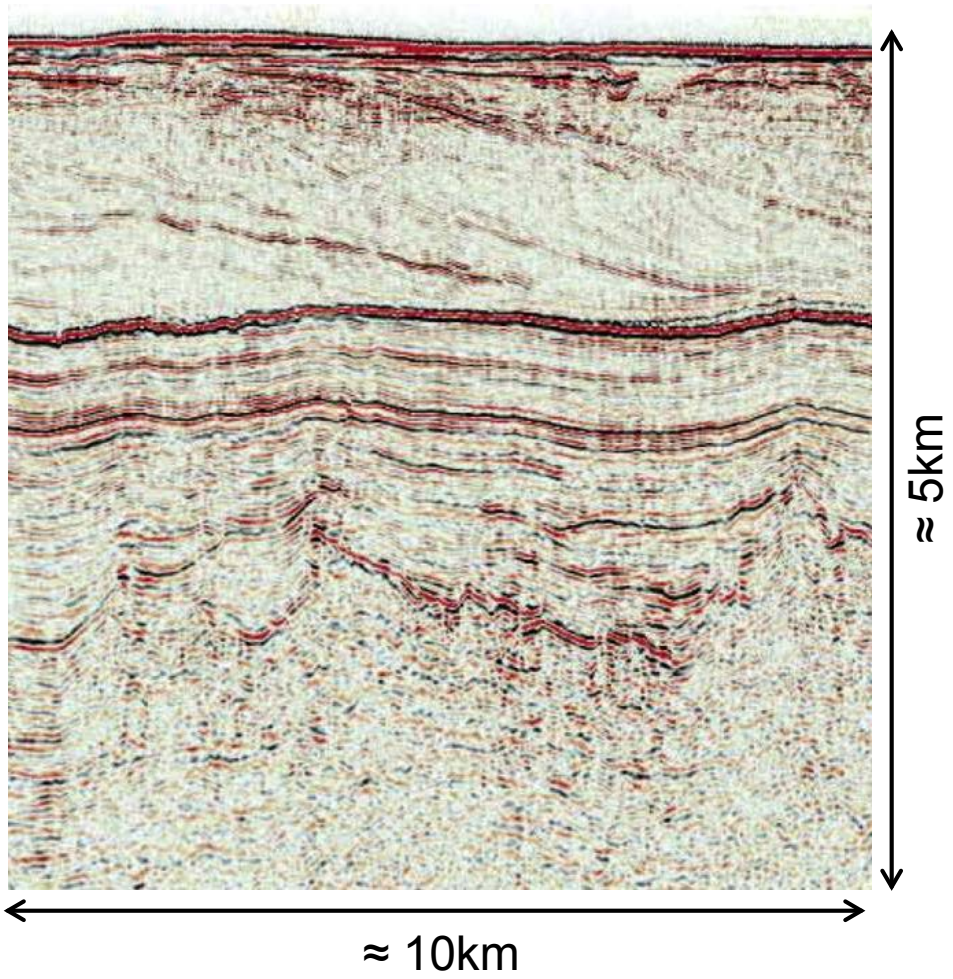
# 3D land seismic crew

# Images from 3D seismic data

Modified from Brown (1996)

# Images from 3D seismic data





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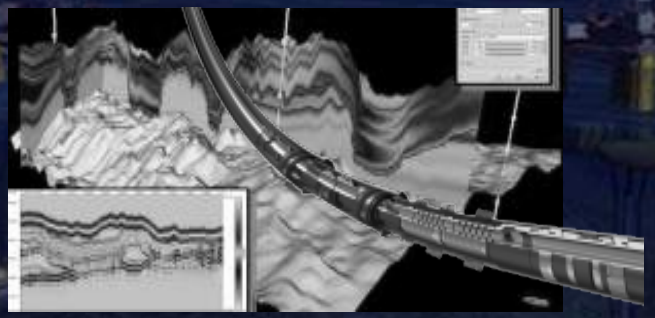

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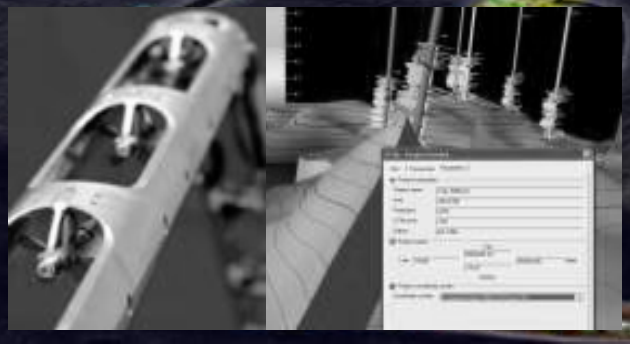
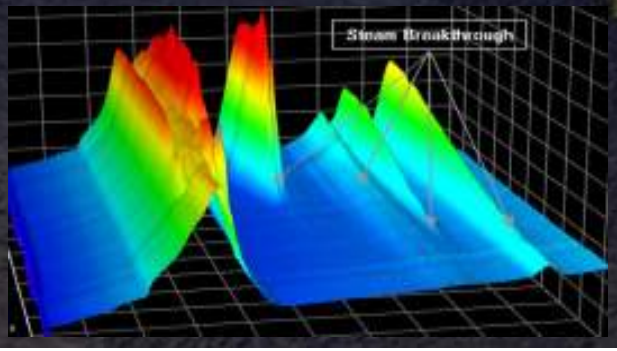


Unlocking unconventional hydrocarbons e.g. shale gas



# Crisis averted

*A number of factors will determine whether of oil can match future demand. By* Carola

From The Sunday Times

November 1, 2009

## Shale gas blasts open world

**American firms have cracked the technology to tap**



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## All change as gas reserves soar

By Jorn Madslien
Business reporter, BBC News, Stavanger

**With coal being too dirty and wind farms and nuclear power plants arriving late, it seems the world is left with a stark choice: keep on polluting or turn out the lights.**

Unless, that is, someone comes

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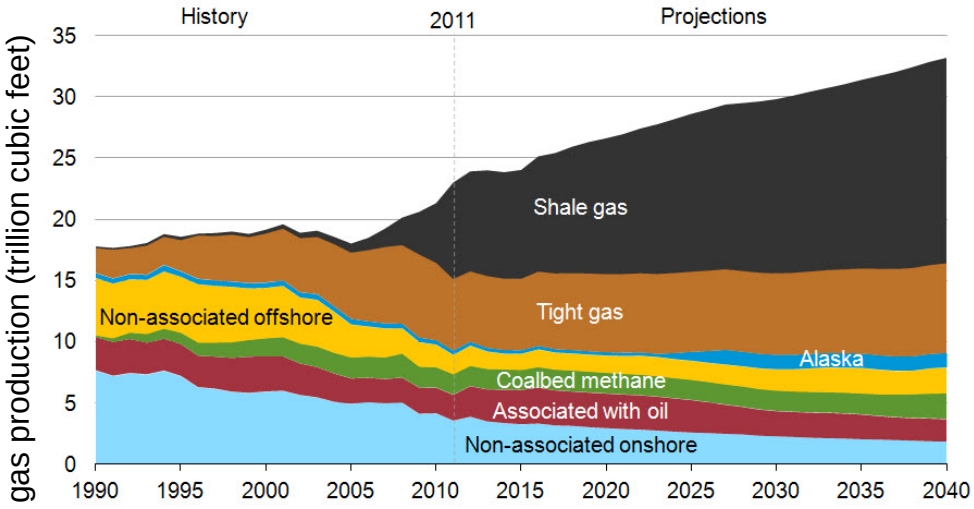
## Shale gas – a fossil fuel with a future

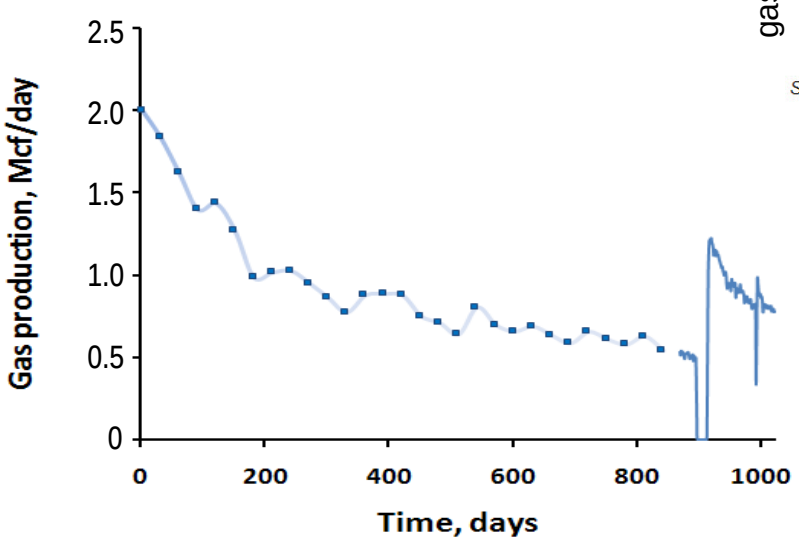
"Everybody knows that this is a game changer," says Aubrey McClendon, chief executive of the $16bn (£10bn) Chesapeake Energy Corporation, the largest independent producer of shale gas in the US.

# Technology behind shale gas boom

- Enabling technology to date
  - directional drilling
  - "fracking"




*Source:* U.S. Energy Information Administration, *Annual Energy Outlook 2013 Early Release*




Average results for refrac in Barnett shale

- 1.0 Mcf/d increase in production
- EUR increase by .7 Bcf
  - ~ 3 month payout

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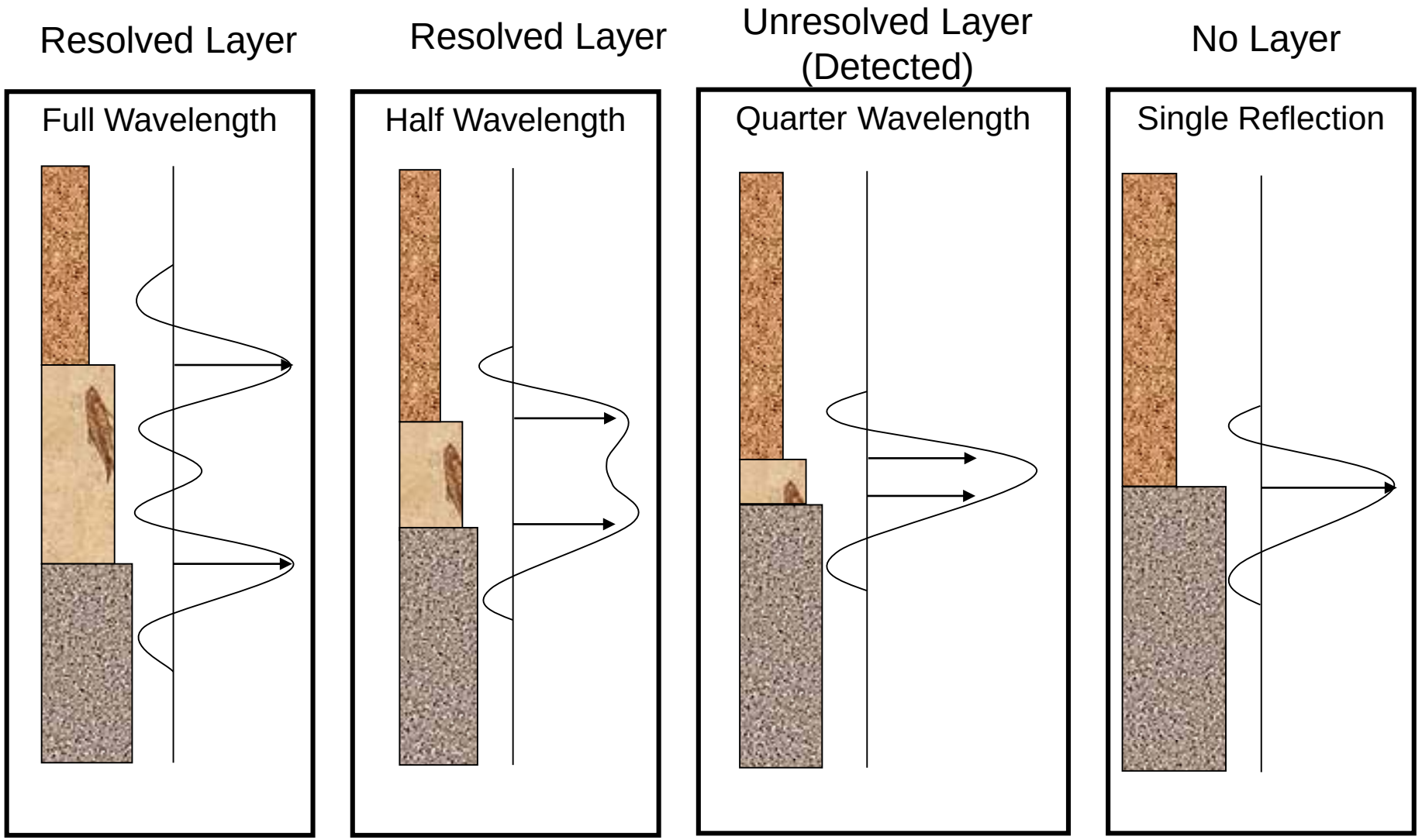
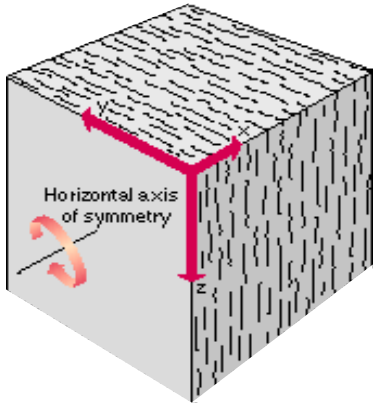
# Seismic resolution limit (typically 10-50m)



# Anisotropy: key to detect features below the seismic resolution

Causes of anisotropy

- intrinsic (“mineral fabric”, e.g., grains in a shale)
- induced (fractures, stress ...)




HTI - horizontal axis transverse isotropy

Observation of azimuthal anisotropy

- wide azimuth survey
- three or more azimuths sectors
  - poststack amplitudes
  - interval velocities
  - AVO attribute analysis

- *“shear waves splitting”*
  - *potentially more sensitive measurement…*

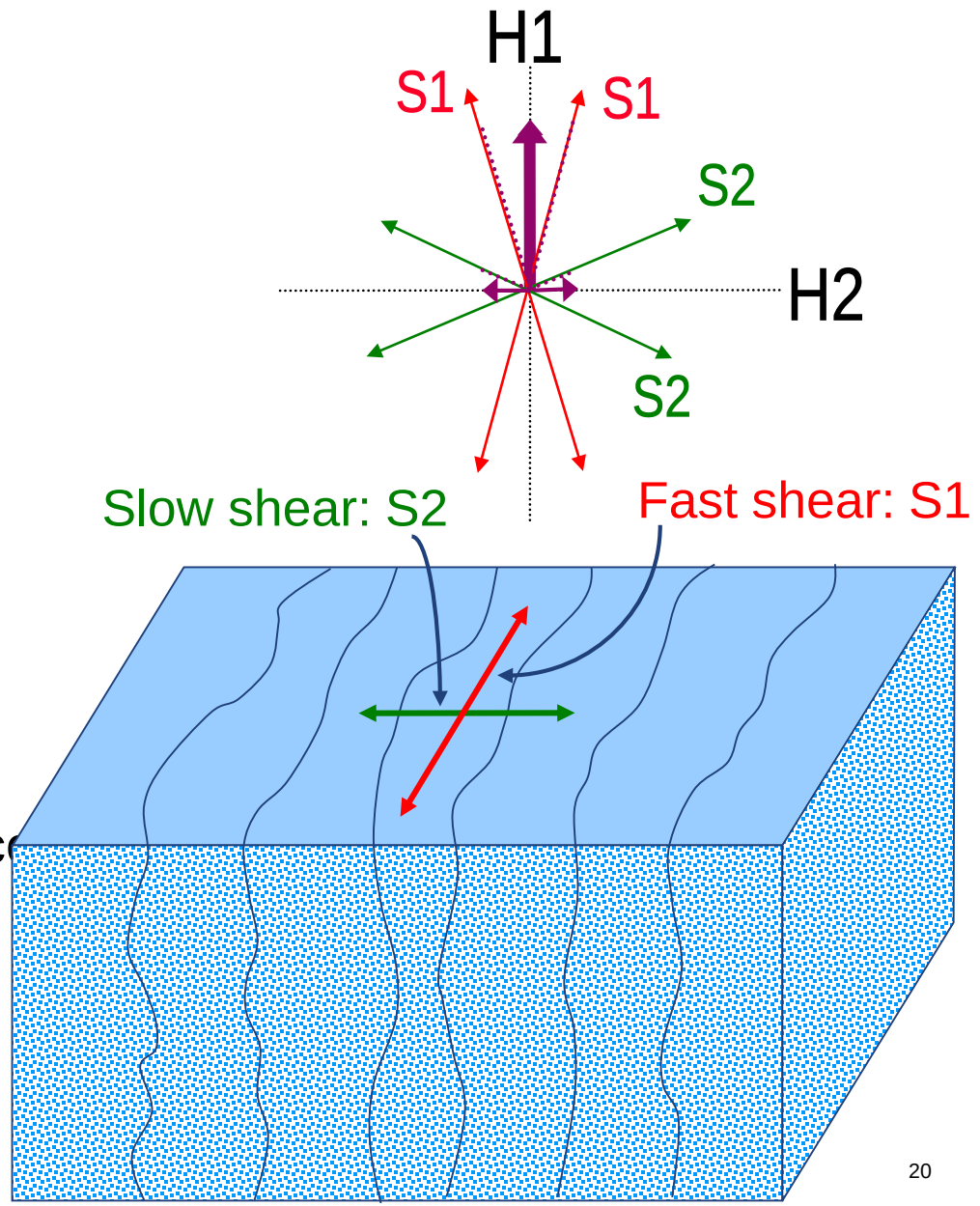
# Shear wave splitting

Principal axes

- can be small velocity difference
- H2 sensitive to changes in axes

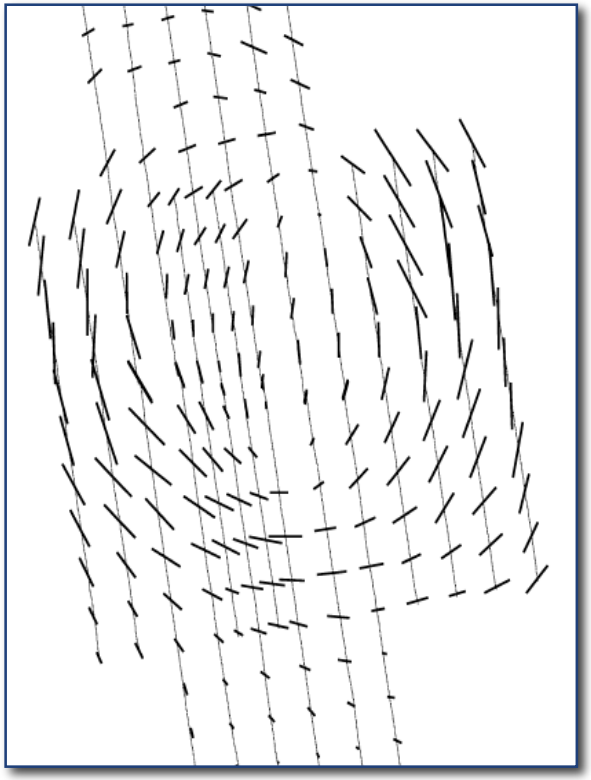
Time delay

- caused by velocity difference
- cumulative effect

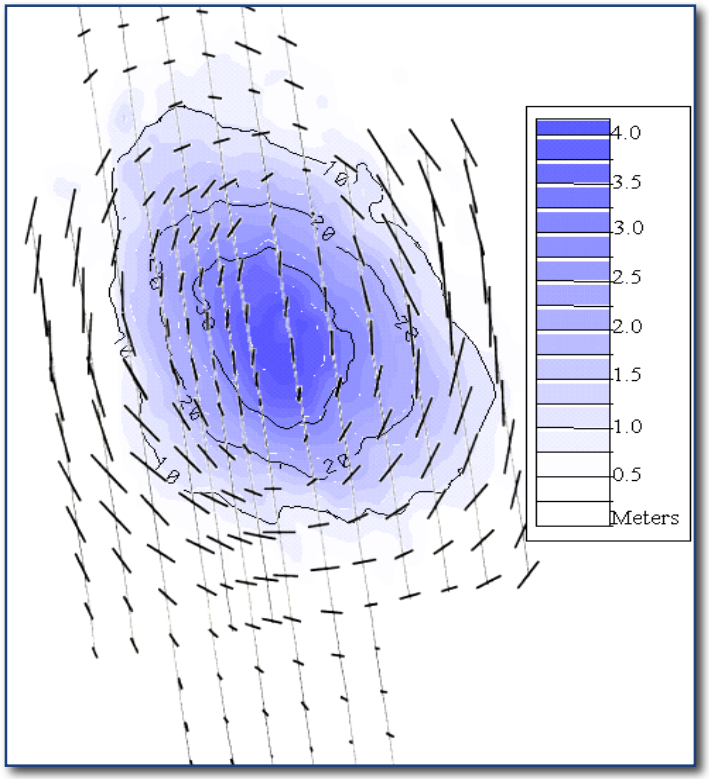


# Subsidence and S-wave derived azimuthal anisotropy in Valhall

Fast S1 direction and relative size of anisotropy (Thin lines denote cables)



Fast S1 direction and size with seabed subsidence (Colour, 0-4m; contours 1-3m)




Change in water depth between 1978 and 2001

**Exploration & Environmental Geophysics, ETH**
http://www.eeg.ethz.ch/

Data courtesy of BP and Valhall partners

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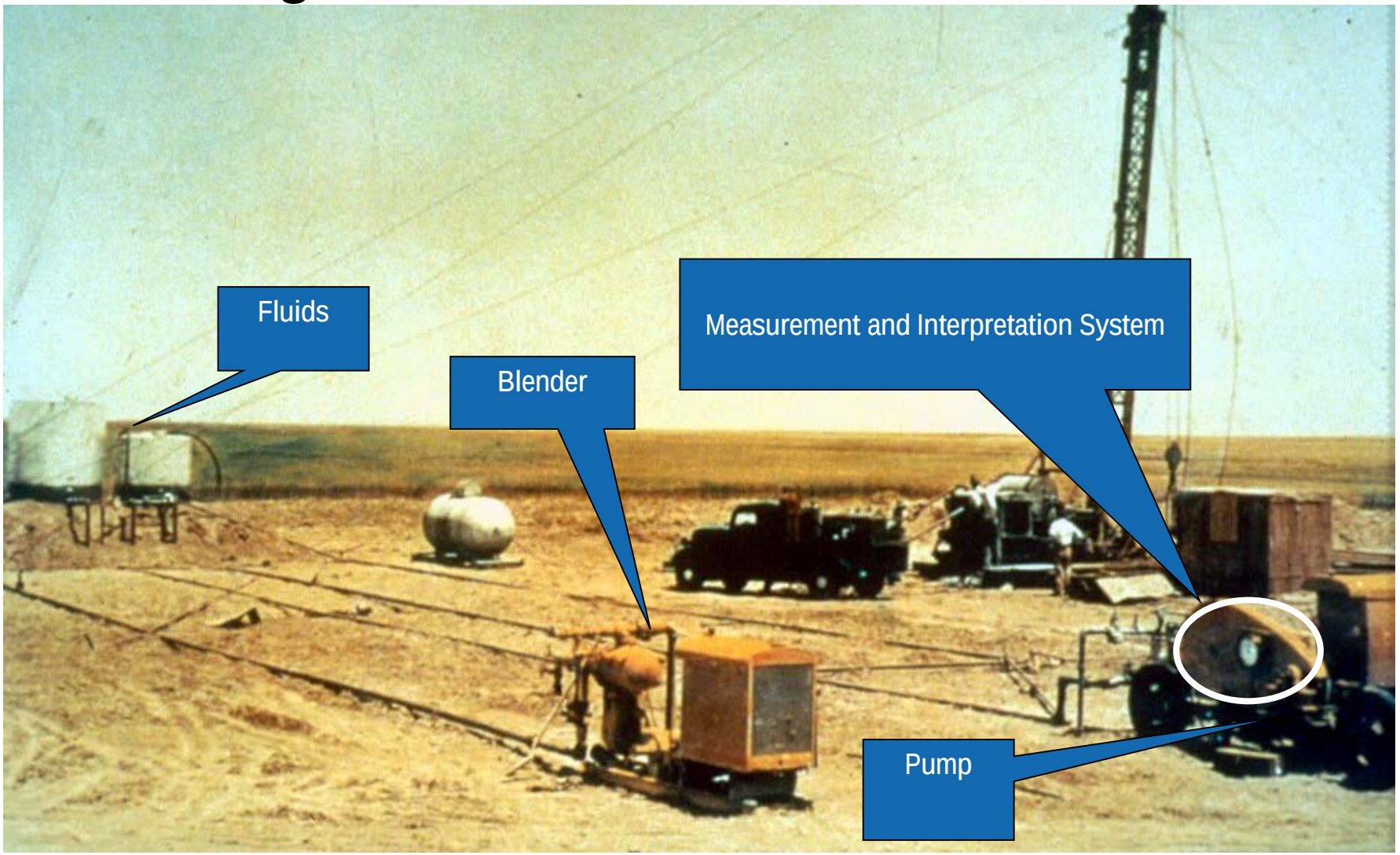
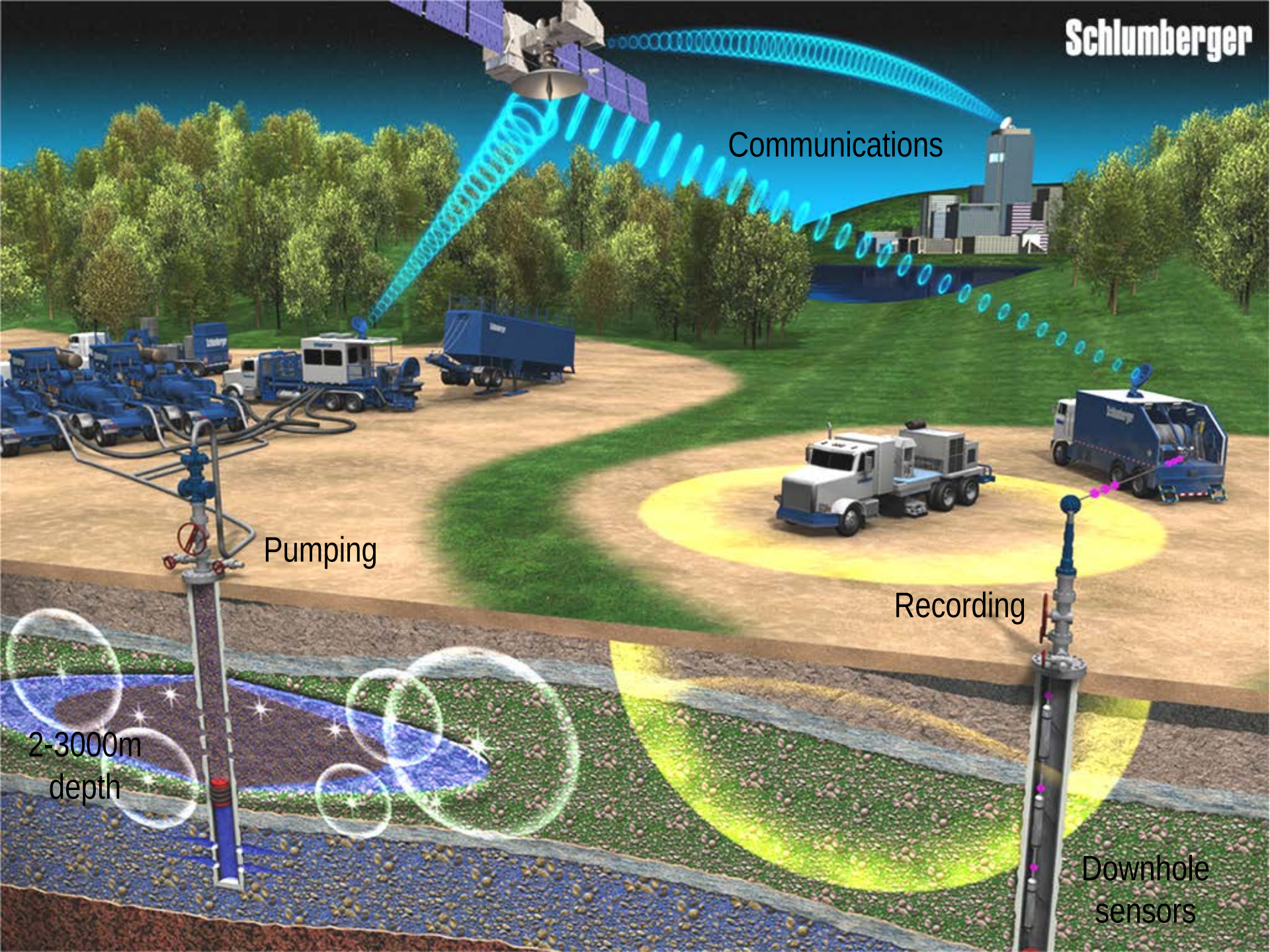
# Fracturing anno 1947



# Fracturing today

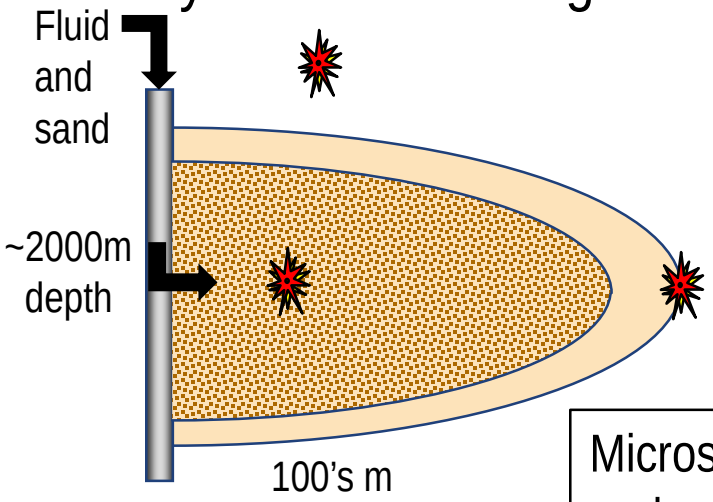
**Exploration & Environmental Geophysics, ETH**
http://www.eeg.ethz.ch/


Schlumberger
Communications
Pumping
Recording
2-3000m
depth
Downhole
sensors

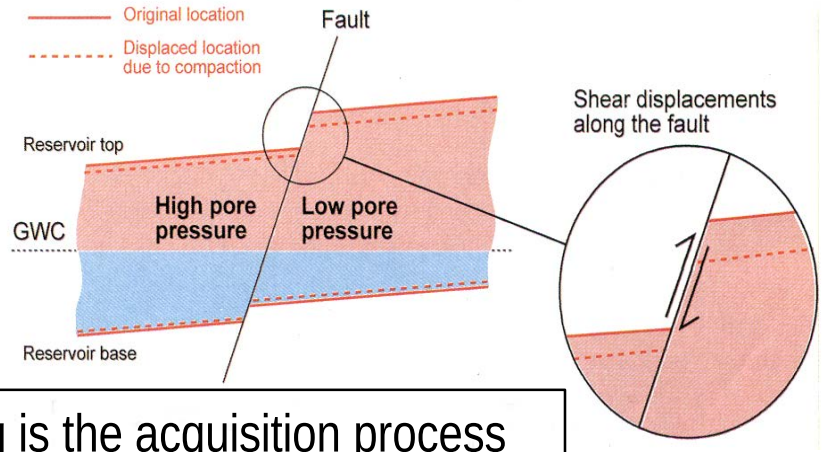
# Microseismicity

- Microseismicity is brittle failure of rock that gives rise to an acoustic emission
- In the oil and gas arena it occurs
  - during the creation of new fractures. e.g. during hydraulic fracturing
  - due to slippage on pre-existing faults
  - these are very quiet events

Hydraulic fracturing




Motion on pre-existing faults

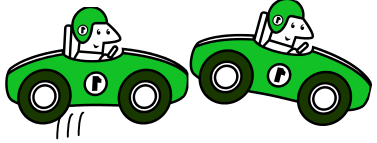



Microseismic monitoring is the acquisition process and analysis of acoustic emissions to determine the location, time and type of failure

# Microseismic monitoring

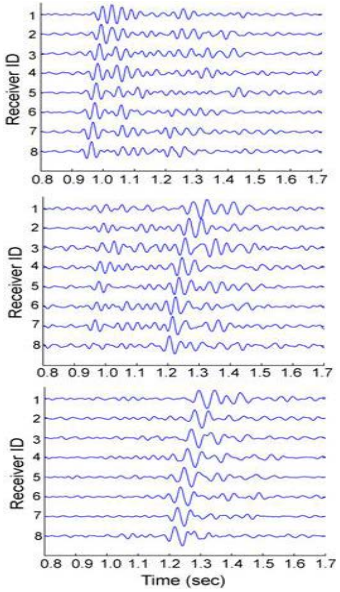
- Small events: -0.5M to -3.5M
  - difficult to detect (we detect them from 2000m)
  - potentially very rich source of information about reservoir characteristics
  - 2011 Blackpool quakes were magnitude 2.3M and 1.5M

-0.5M: stopping a small car from 30 km/h

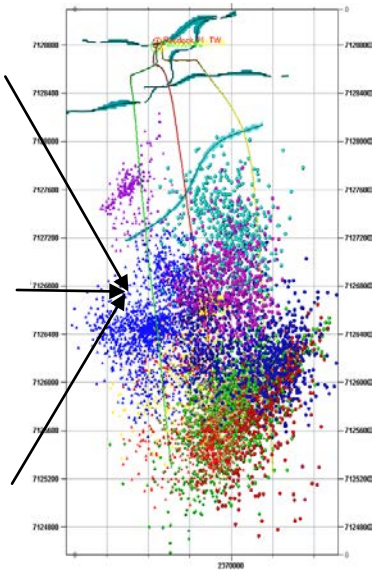


-3.5M: a dropped bag

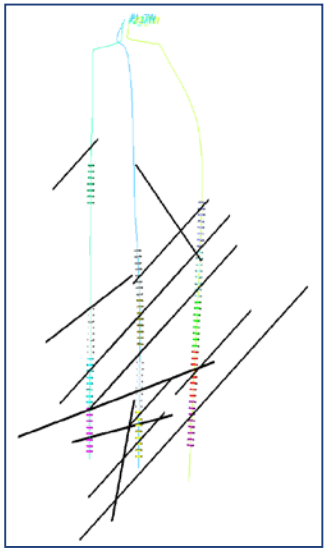
Microseismic waveforms




Microseismic locations



Fault interpretation



Map view

# Rich information from data requires research

Hodogram → Direction → Bearing Location

P-timing, S-timing → Distance Location

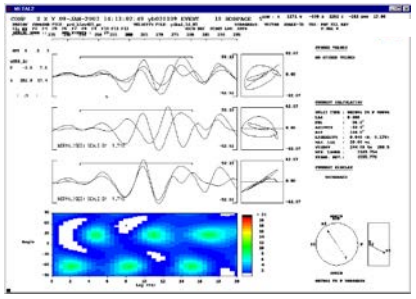
Distance

Noise

Scattering

Duration

Amplitude



Polarity

or

- Fault plane solutions
- Fracture orientation
- Stress field

Source Params

Amp

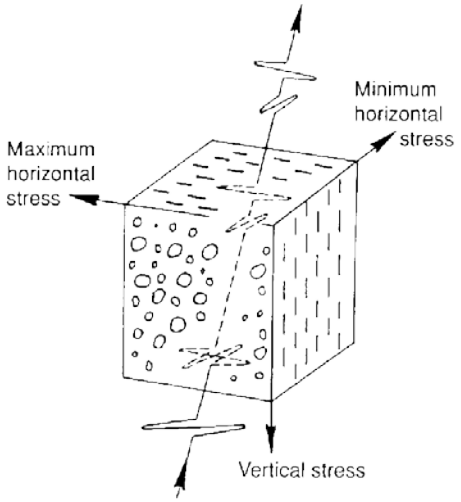
Freq

Shear wave splitting

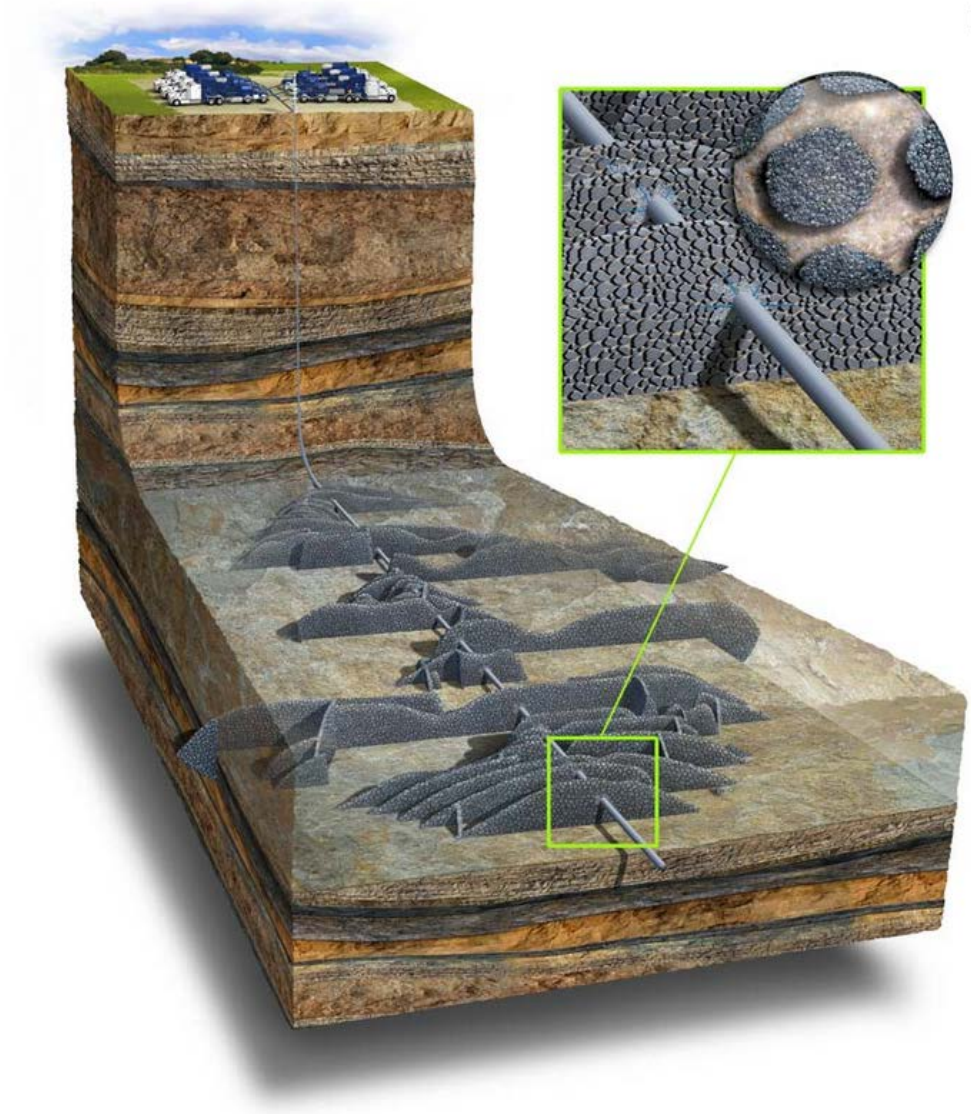
Reservoir properties

Fracture length

Shear wave Splitting

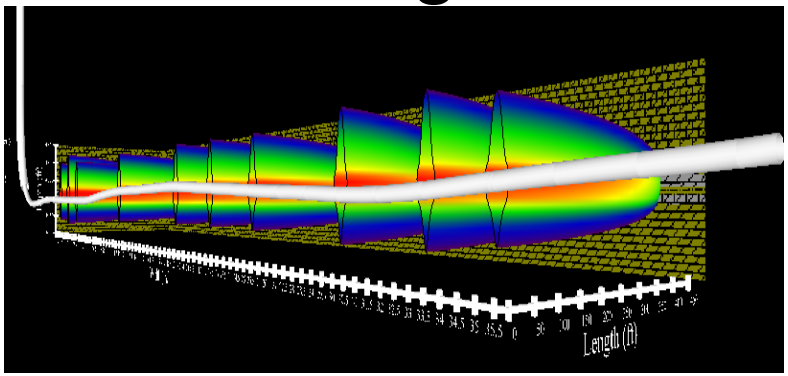


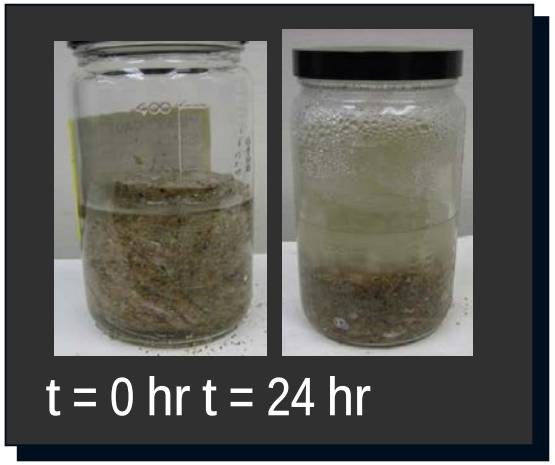
# Closing the control loop: HiWay (Schlumberger)

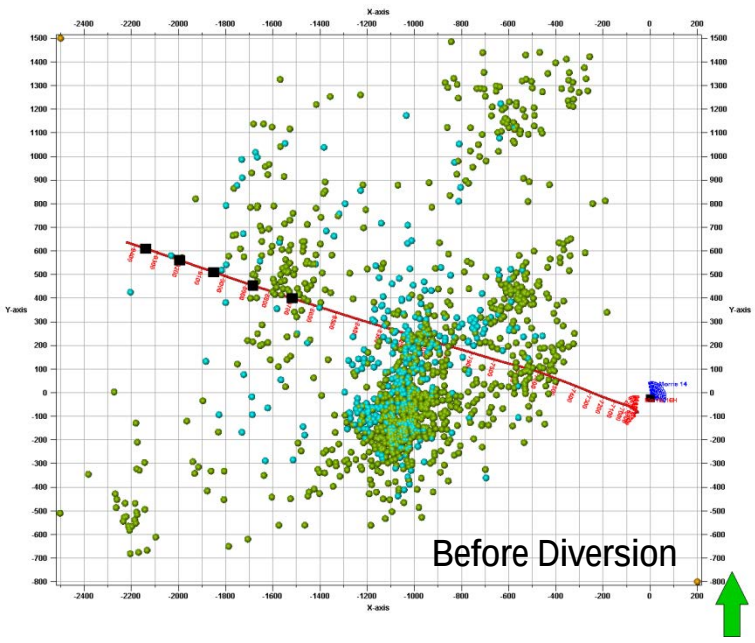


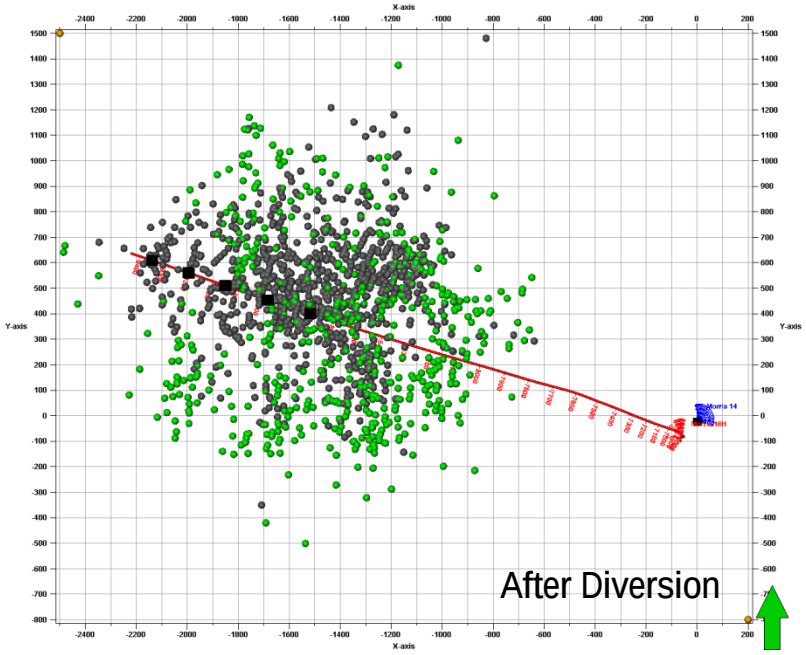
- Sand slugs pumped
- Fracture held open by pillars of sand
- Average benefits
  - production: +20%
  - proppant: -40%
  - water: up to -60% compared to slickwater treatments

# Dynamic diversion using "Fiber Plugs"



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# Conclusions

- Shale gas boom enabled by technology advances over the last decade
  - directional drilling and “fracking”
- Minimum environmental footprint needed to bring shale gas E&P into Europe and other regions
  - optimal well placement, optimized stimulation practices
- Active seismic methods (multicomponent surveys) can be used for placing wells to access natural fractures and in optimal stress regimes (for future stimulation)
- Passive seismic methods (microseismics) enable stimulation control beyond current “pressure / surface flow” control loop

# Acknowledgements


- I am grateful to colleagues in Schlumberger for discussions and slides: Ian Bradford, Phil Christie, Rob Jones, Ed Kragh, Tony Probert
- The example from the Snorre field was provided courtesy of Statoil
- BP Statistical review