Imaging and monitoring with Virtual Sources

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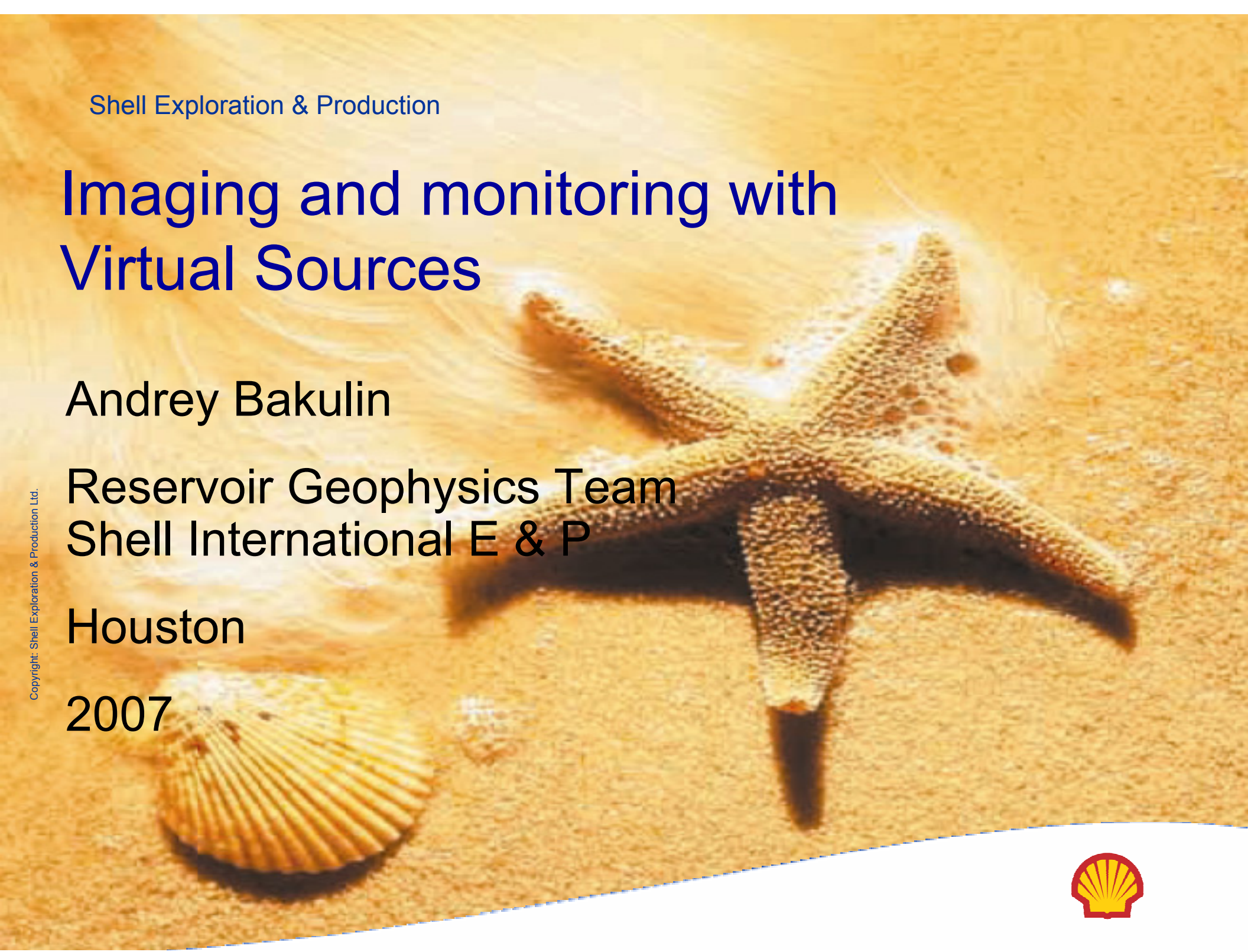
Houston

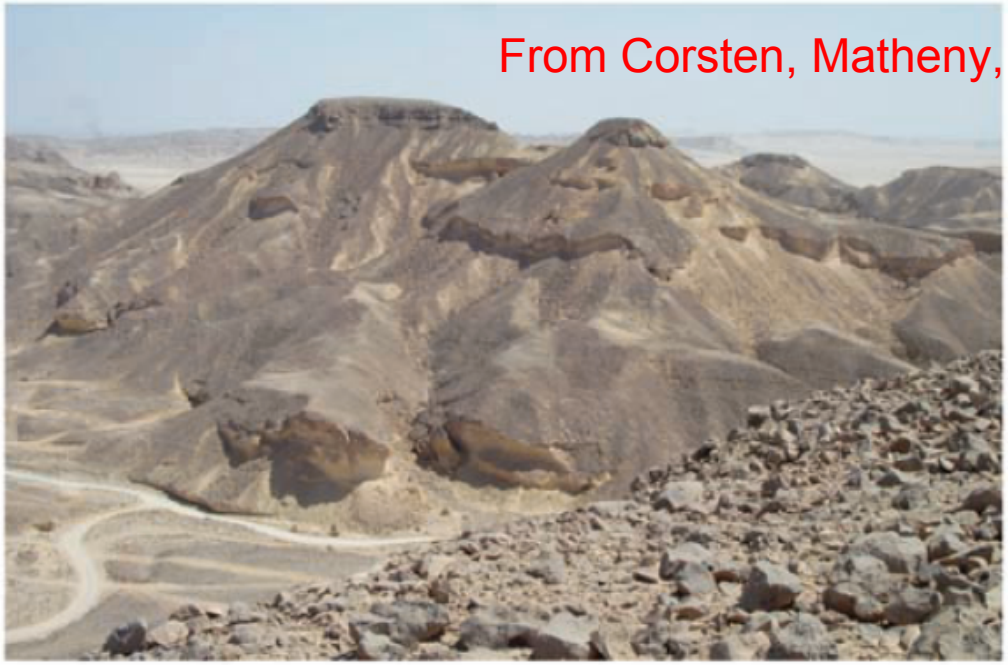
2007



Outline

- Motivation
- Virtual Source Method
- Peace River Synthetic
  - Imaging
  - Downward radiation pattern
  - Increased aperture in complex overburden
  - Monitoring with different acquisition geometries
- Peace River field experiment (changing overburden)
- Virtual Checkshots
- Shear-wave seismic
- Removing artifacts by wavefield separation and best practice
- Onshore monitoring with Virtual Source: Shell vision
- Conclusions

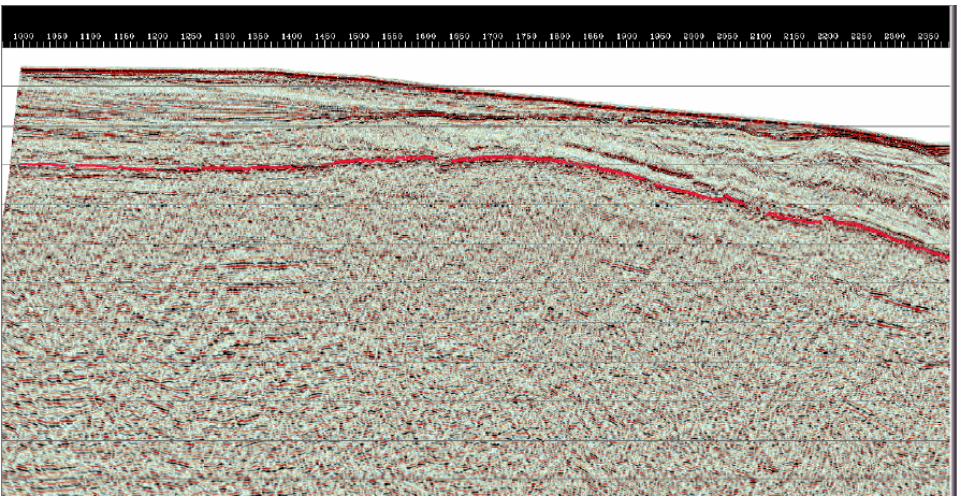
Motivation for Virtual Source



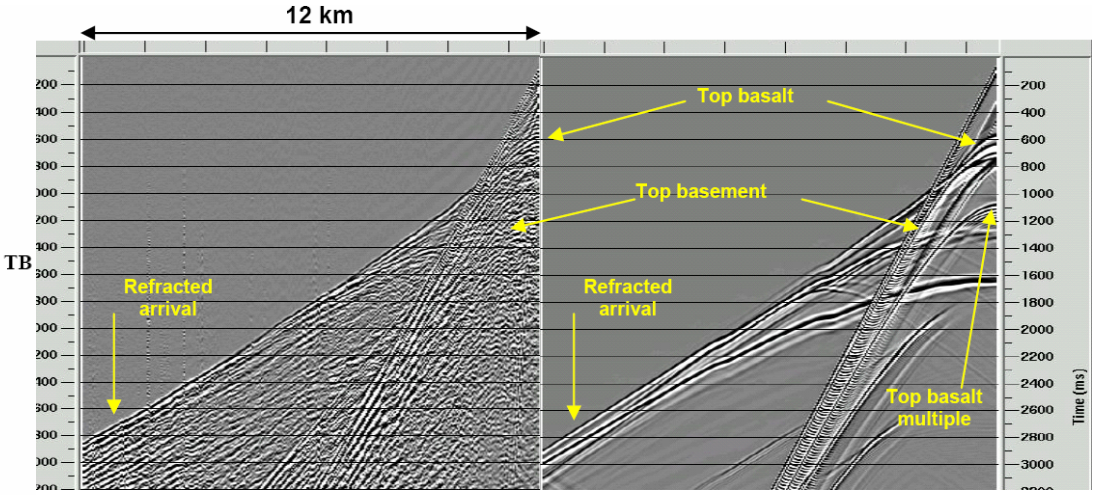
From Corsten, Matheny, Engbers (PDO), 2005, TLE

Motivation for Virtual Source

Sub-basalt: Dallagher and Dromgoole , 2005

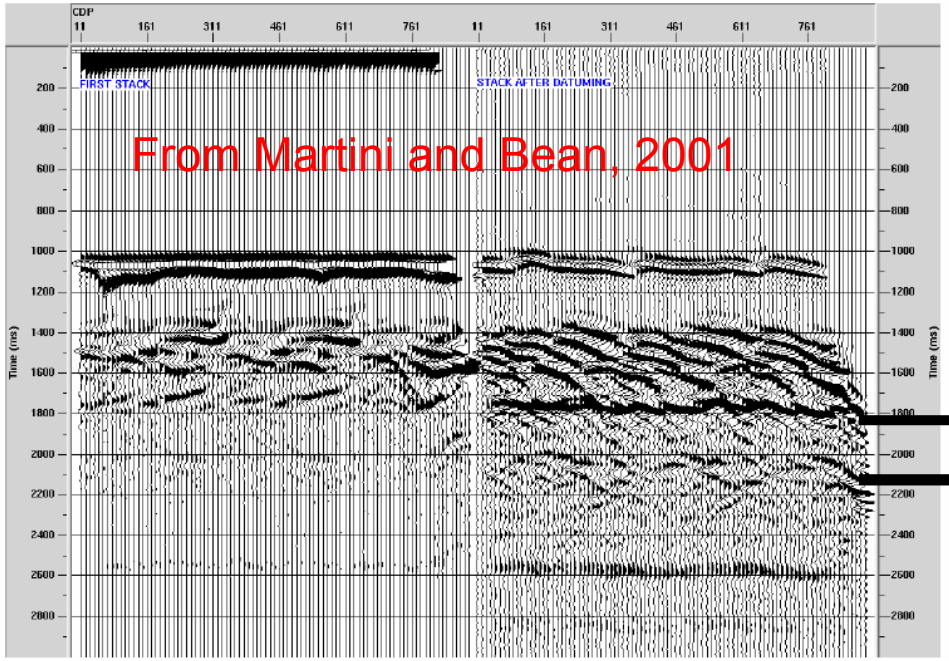


Sub-basalt seismic: Colombo et al, 2005



Before datuming

After datuming



T1

T2

Repeatability from surface

Surface seismic:
fixed vibrator on a concrete road

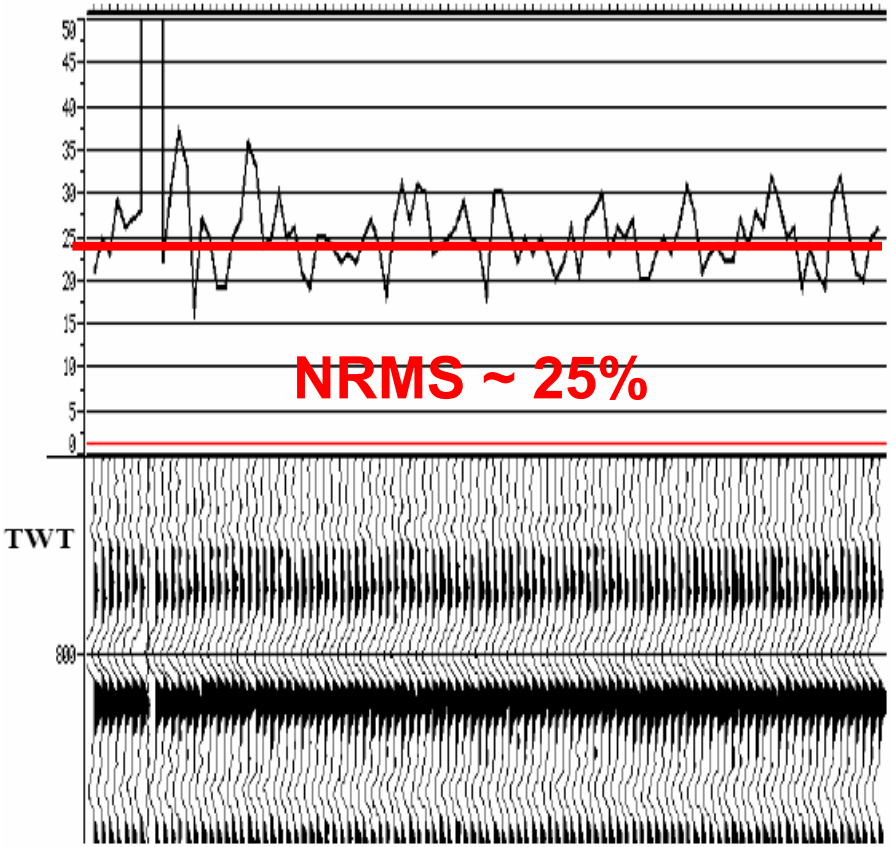


Figure 1: Below: One hundred Nomad 65 repeated sweeps recorded by the vertical fiber optical sensor at 110 m above the reservoir in a time window of 100 ms in the target area (offset 717 m). Above: the corresponding NRMS values from one trace to the next, centered around 25%. The NRMS measure is defined as NRMS = 2*RMS(A-B)/[RMS(A)+RMS(B)].

VSP: surface source, buried phone

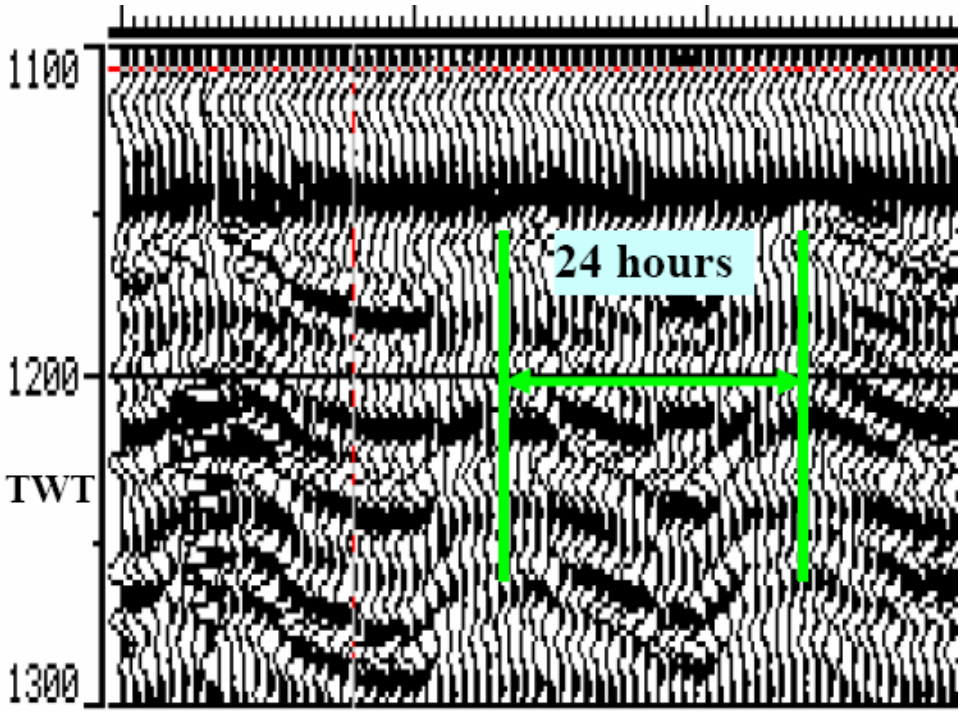


Figure 3: 3 days of continuously recorded seismic data at a buried geophone. The piezoelectric source is located at the surface.and the geophone offset is 426 m. The calendar time interval between two traces is 1 hour. The daily variation of the seismic signal in the weathered zone interferes with a seismic event located below the reservoir.

From Faure and Spitz, 2006

Repeatability downhole

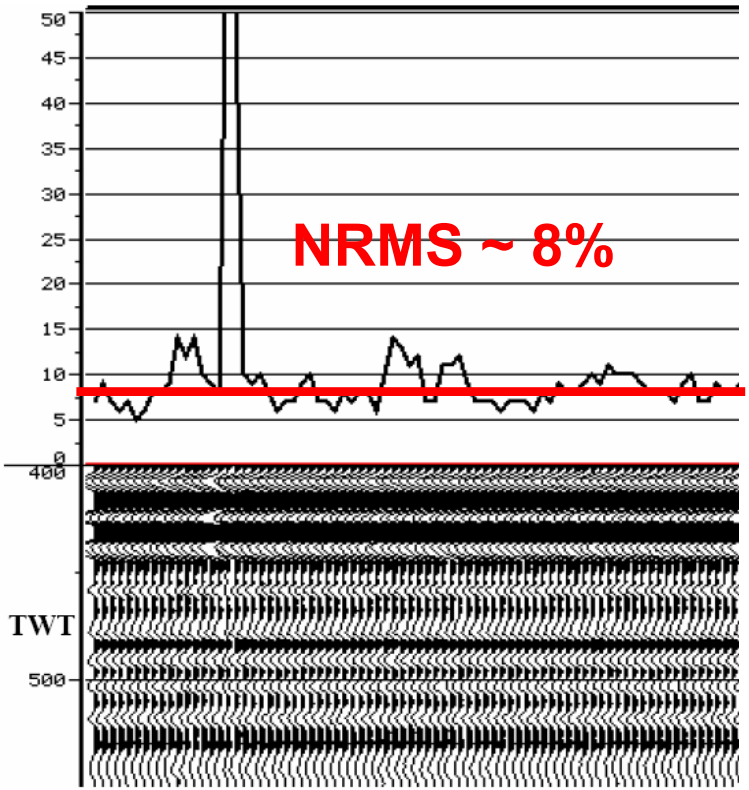
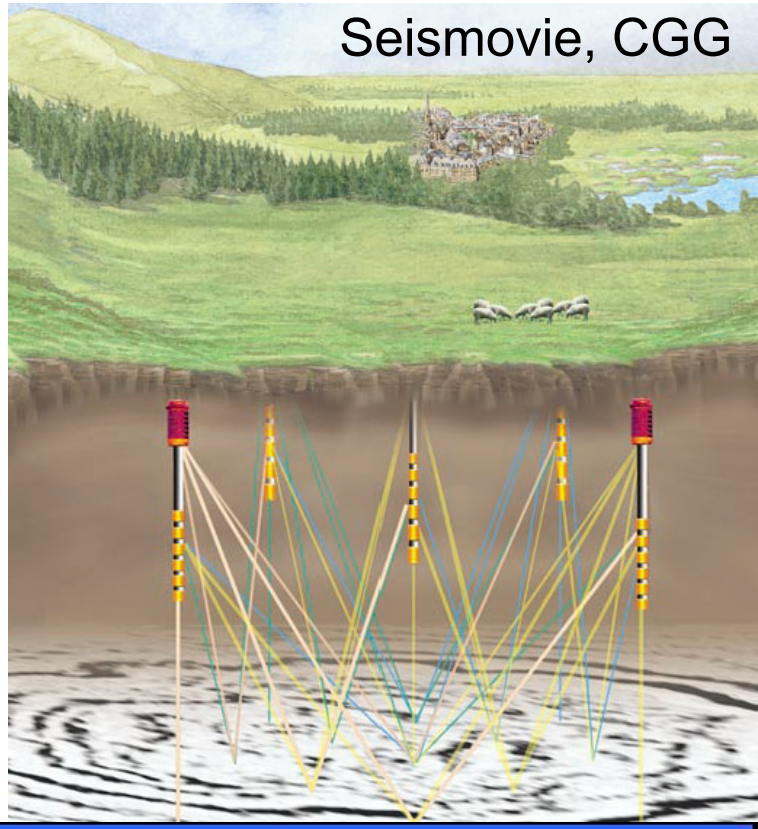
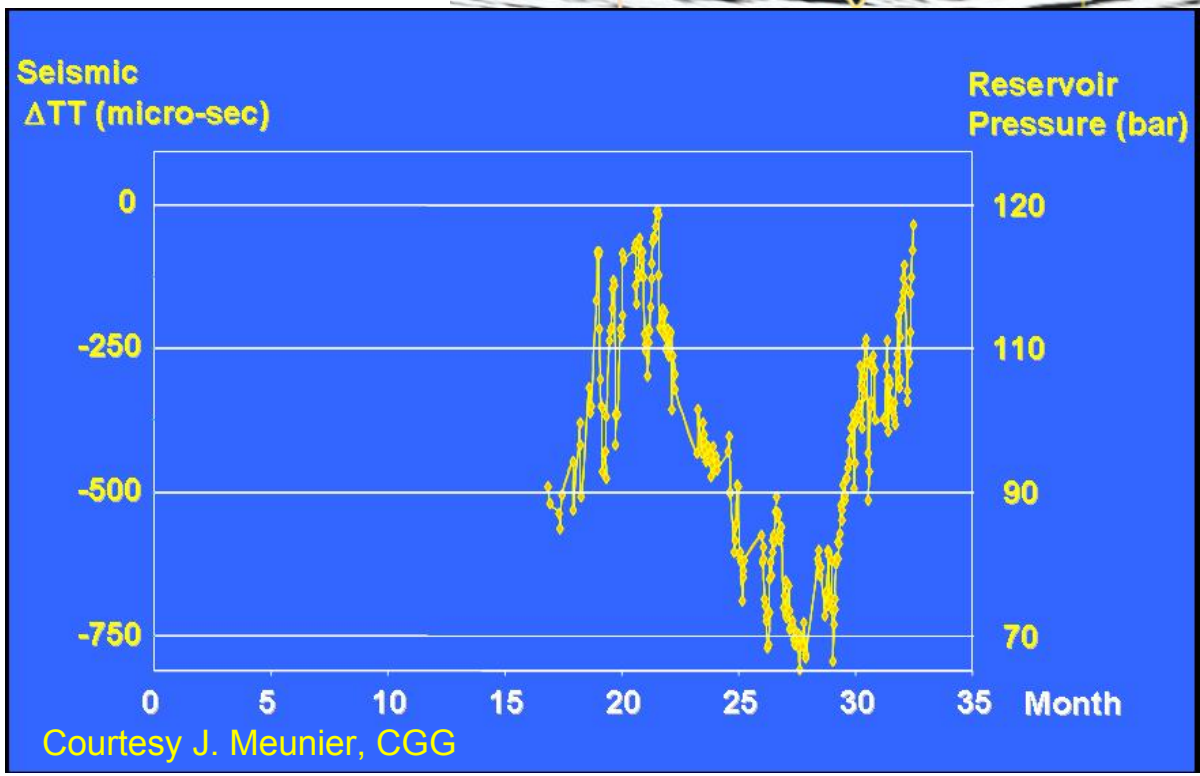


Figure 2: Below: 3 days of continuously recorded seismic data at a buried geophone in a time window including the target reservoir. The piezoelectric source is buried and the geophone offset is 302 m. The calendar time interval between two traces is 1 hour. Above: the corresponding NRMS values from one trace to the next, computed in a window from 420 to 520 ms in the target area. The NRMS values are centered around 8%.

From Faure and Spitz, 2006

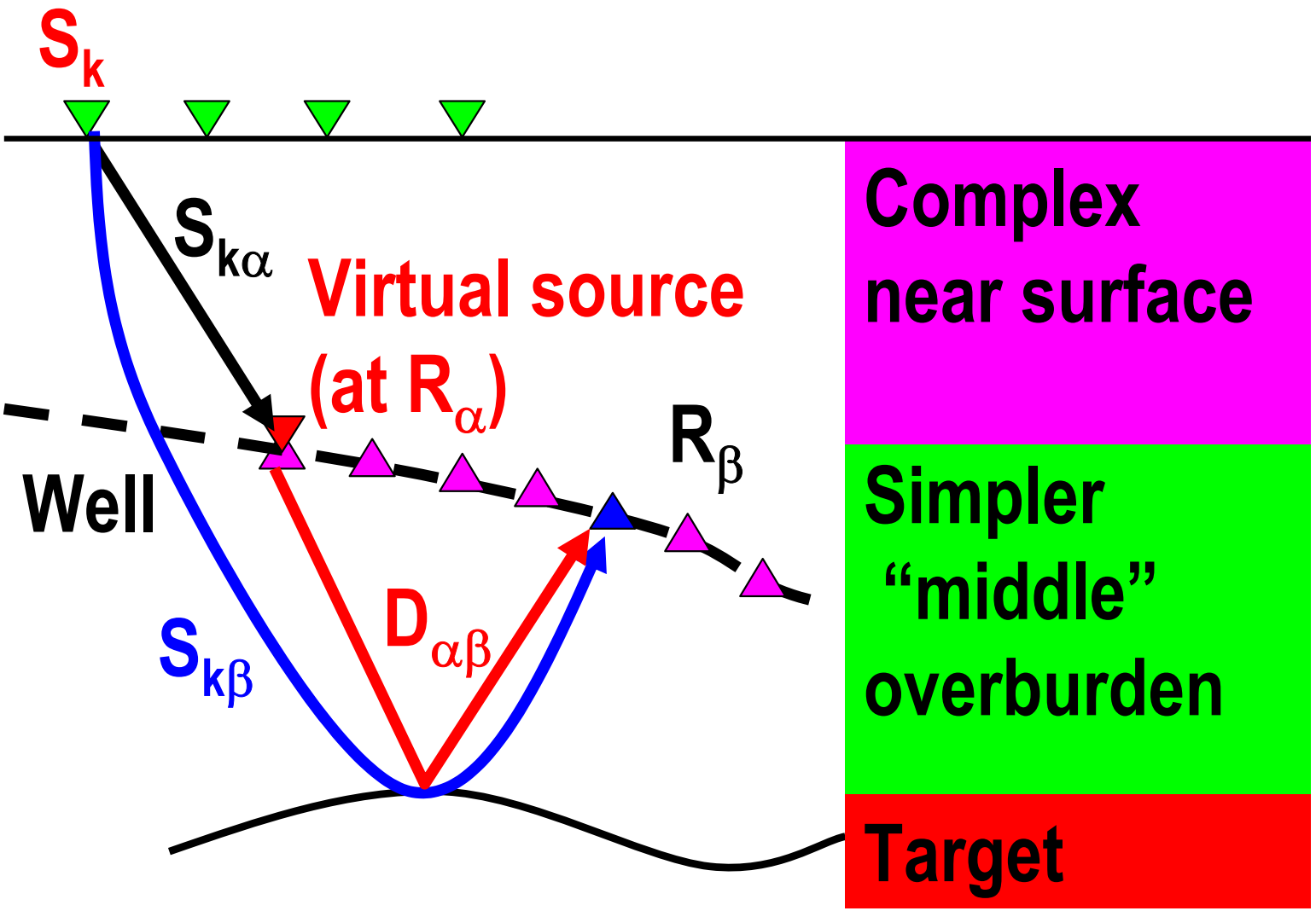




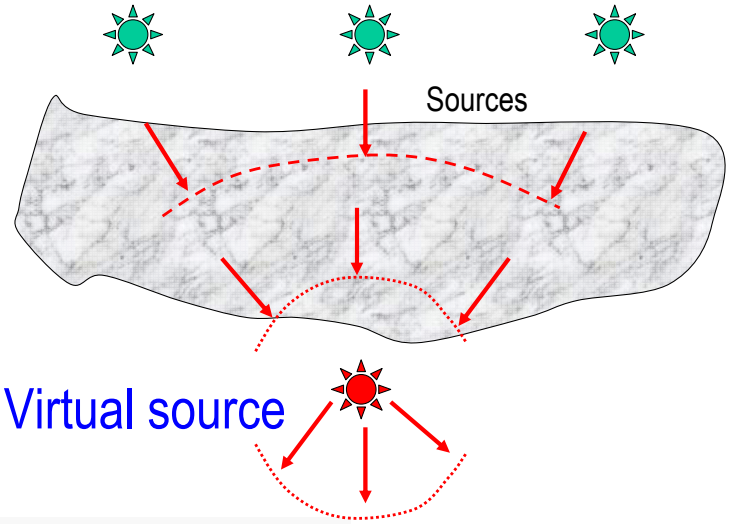
Bakulin and Calvert, 2004, SEG

Virtual Source

Surface array of sources that simulates virtual source



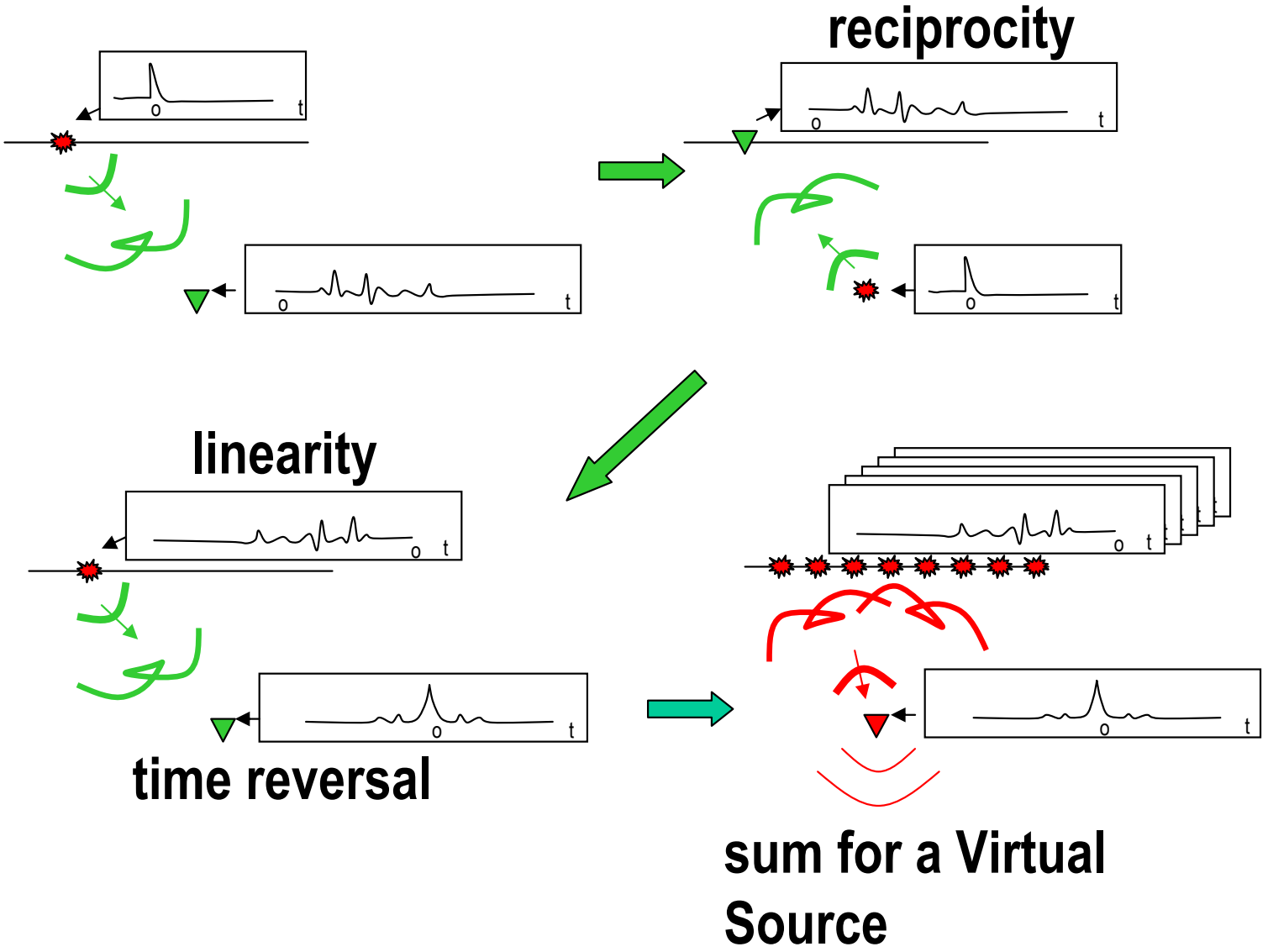
Virtual Source by time reversal



Time Reversal
Without
Acoustic Sink

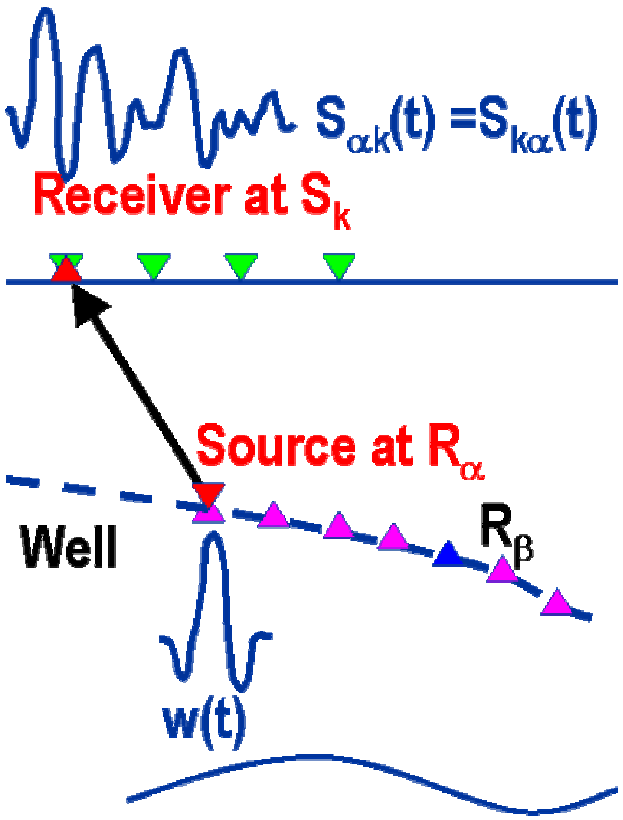
http://www.loa.espci.fr/_julien/sink/sink.html

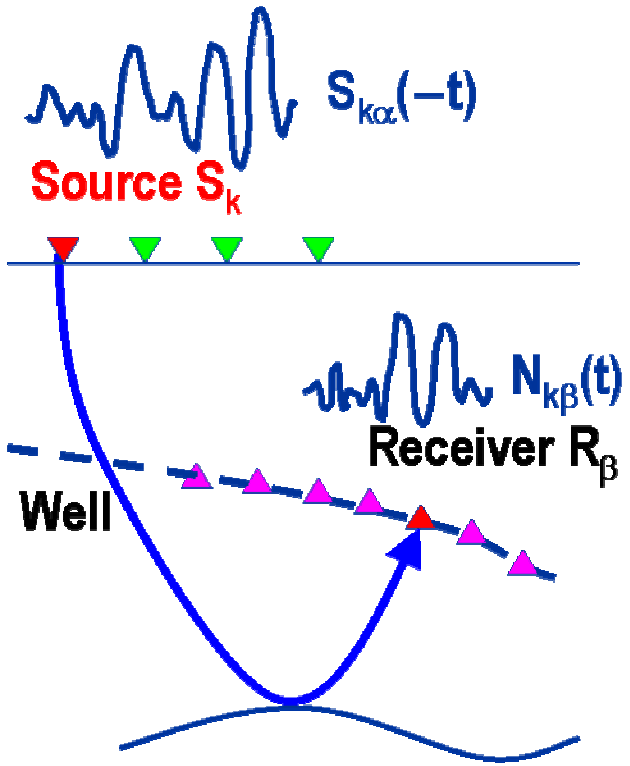
Virtual Source as time reversal on a computer



VS data

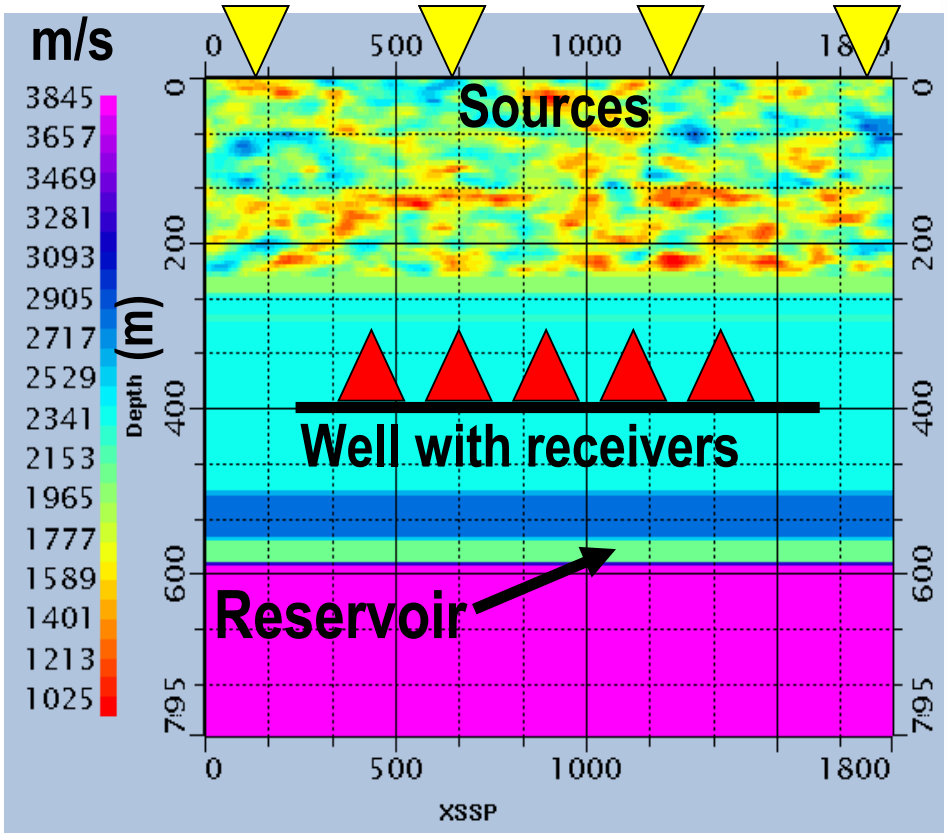
$$D_{\alpha\beta}(t) = \sum_{k=1}^{N} S_{k\alpha}(-t) \star S_{k\beta}(t)$$

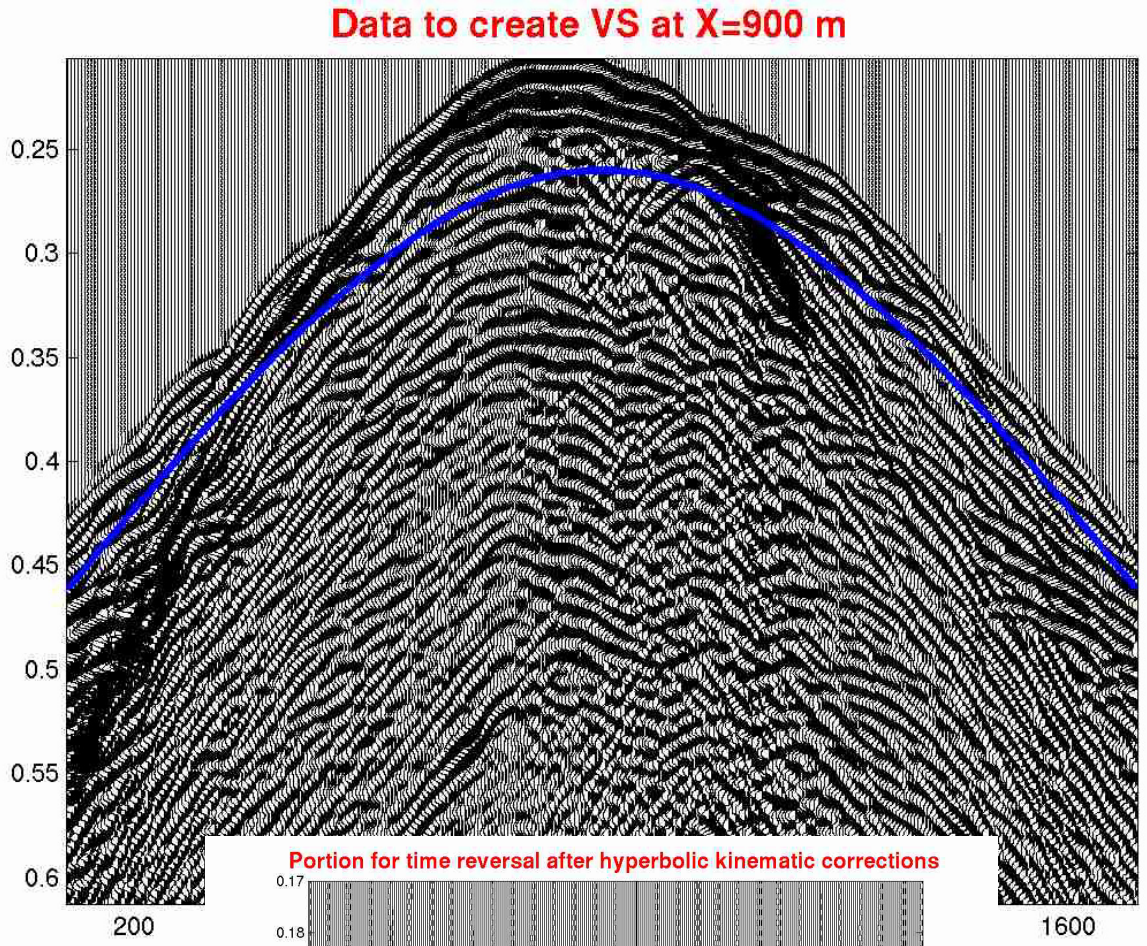


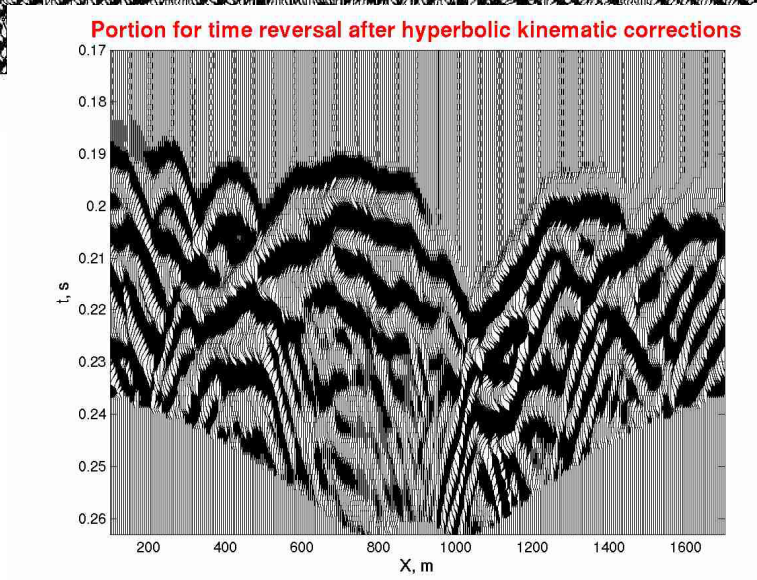


Synthetic model with horrible overburden

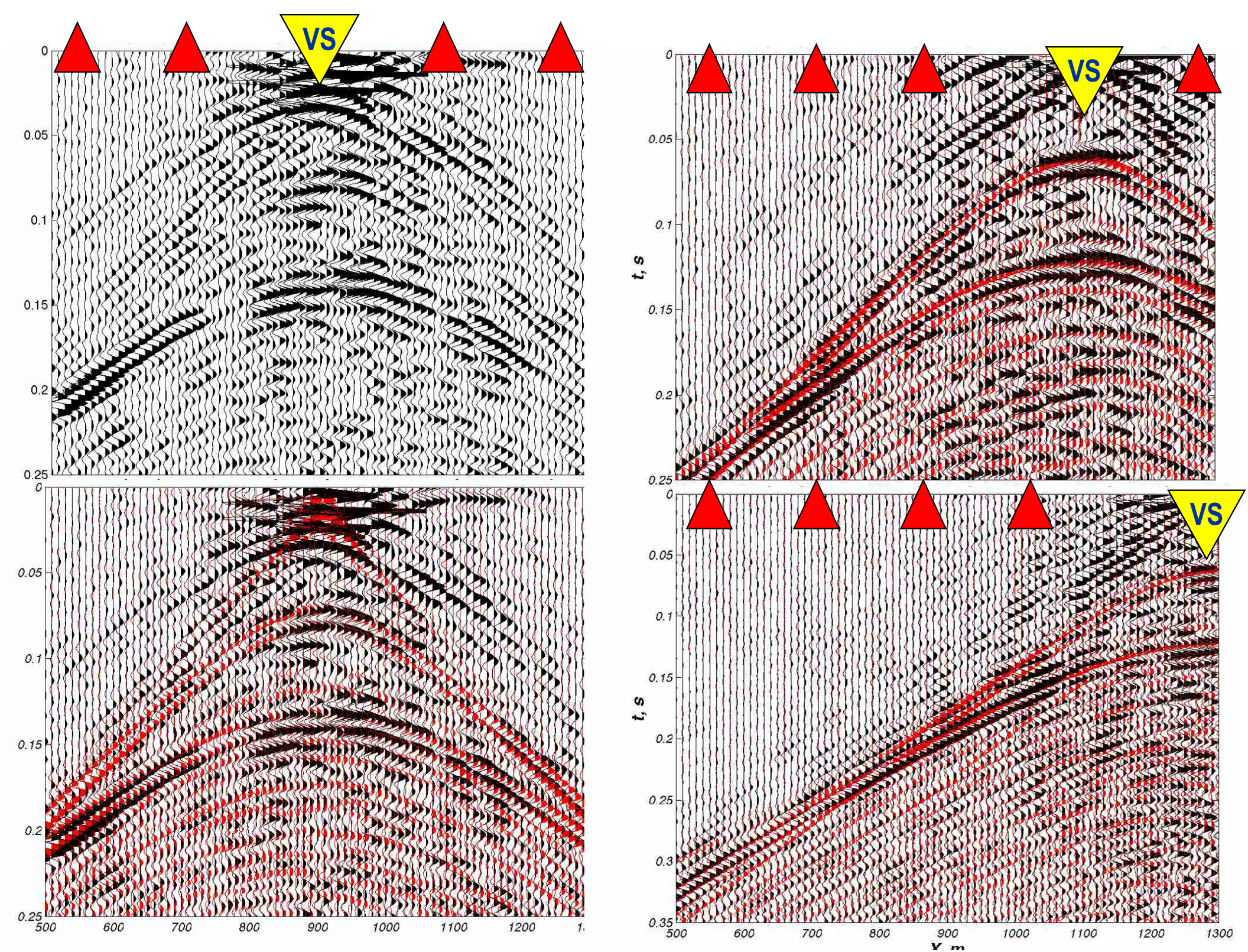
(full elastic finite-difference modeling)





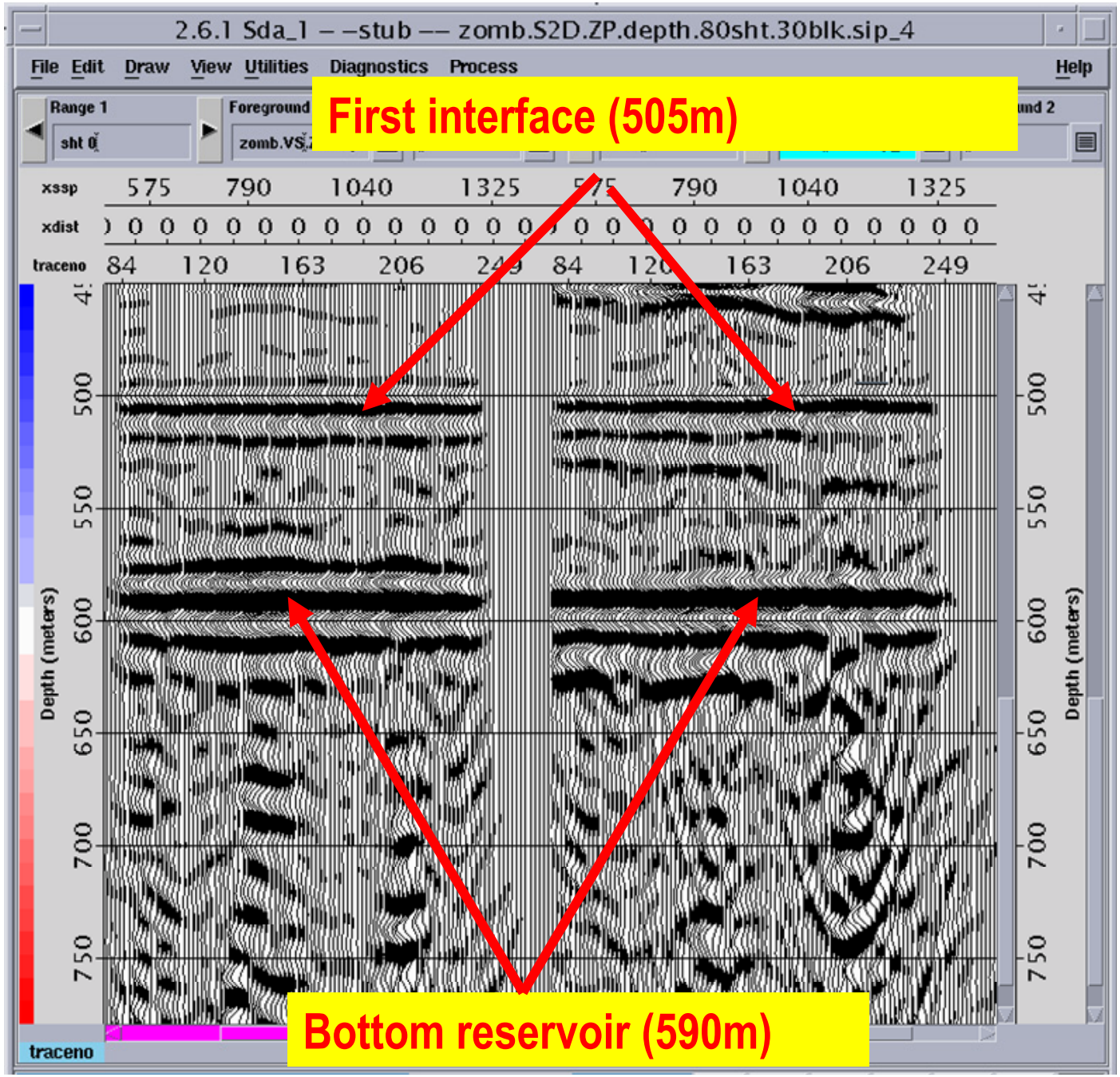


Bakulin and Calvert, 2004, SEG;
2006, Geophysics

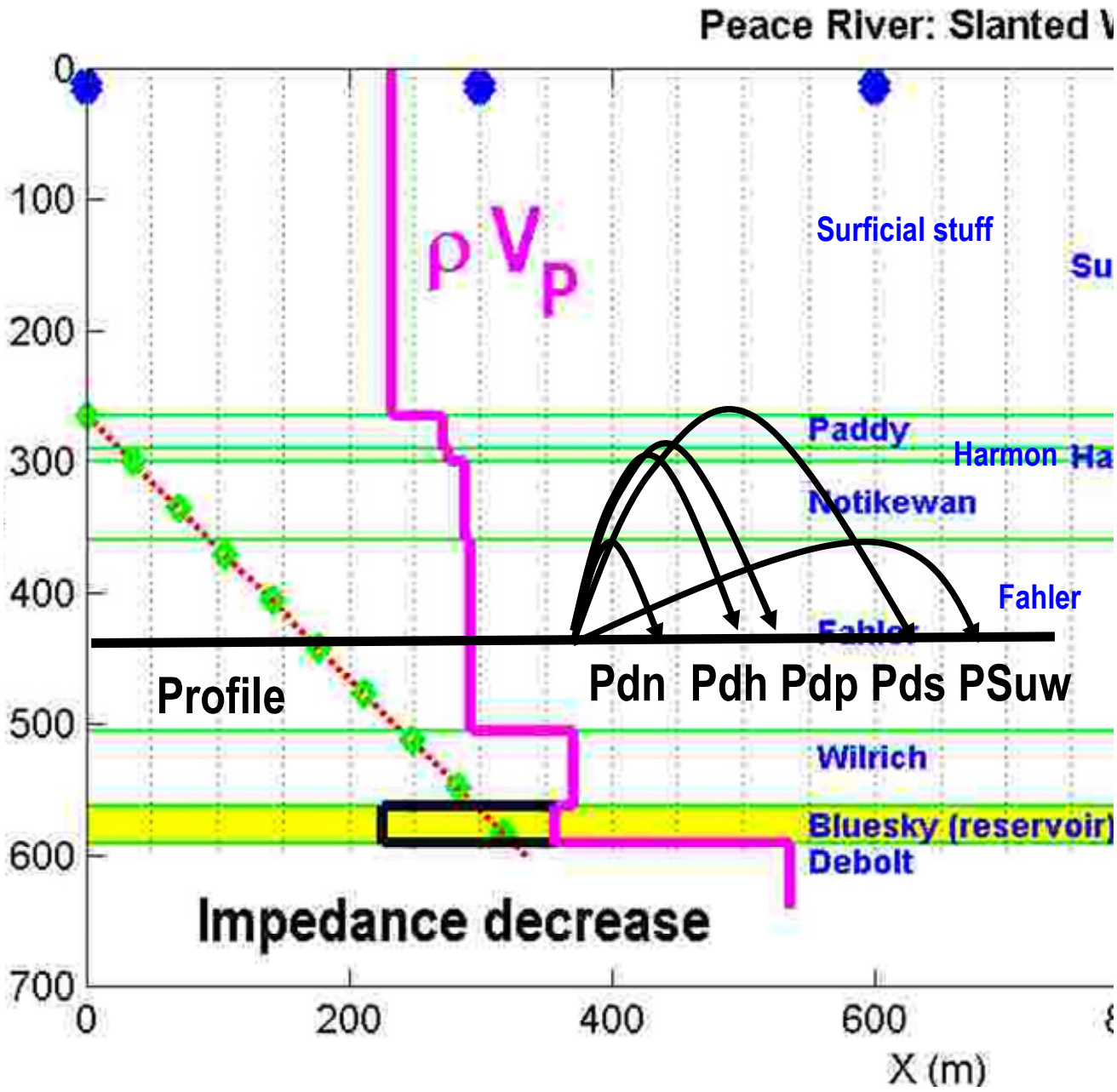

VS
VS
VS
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
t, s
500
600
700
800
900
1000
1100
1200
1300
X, m

VS data:

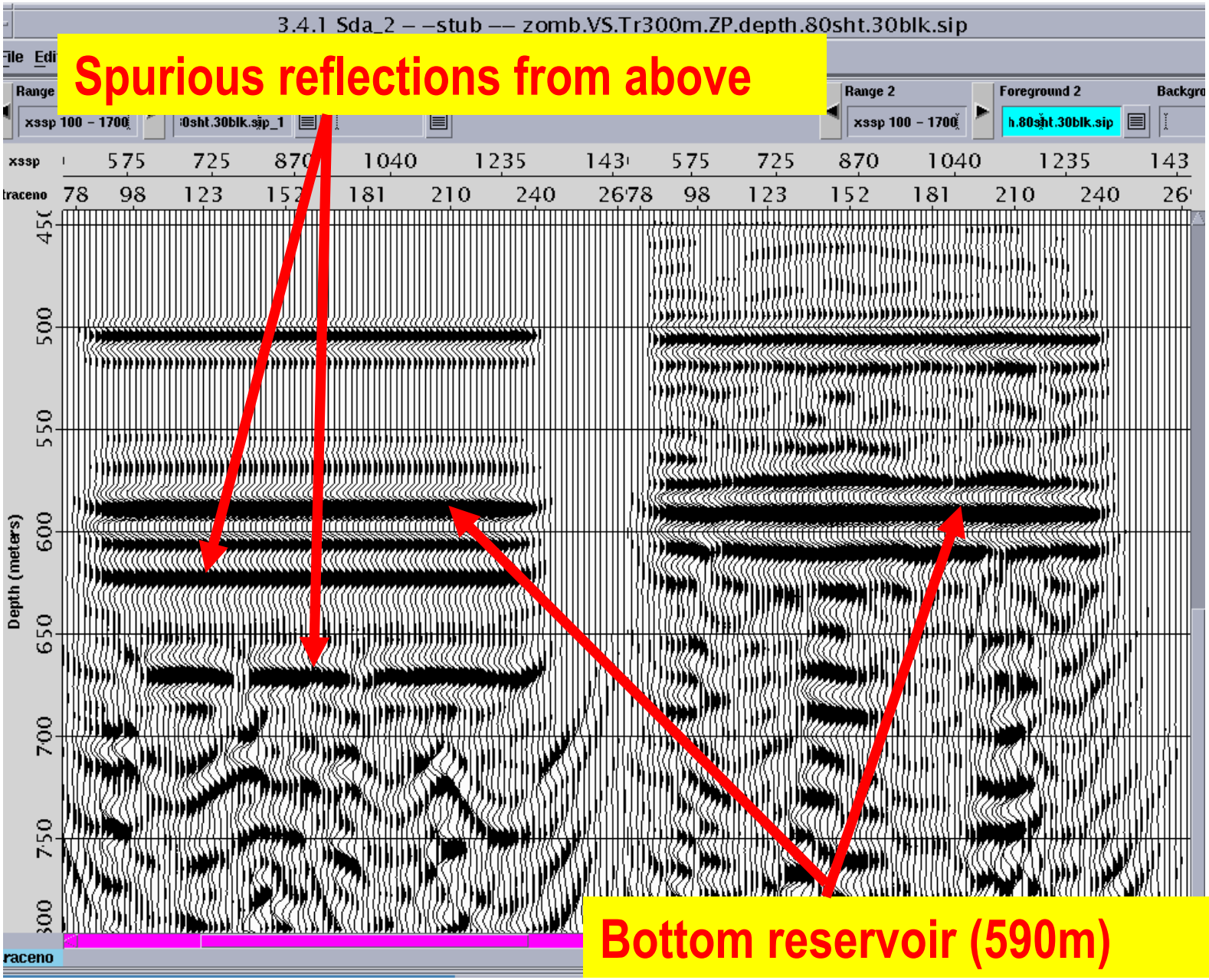
Surface data:
migrated with exact velocity model of the overburden



Downgoing waves

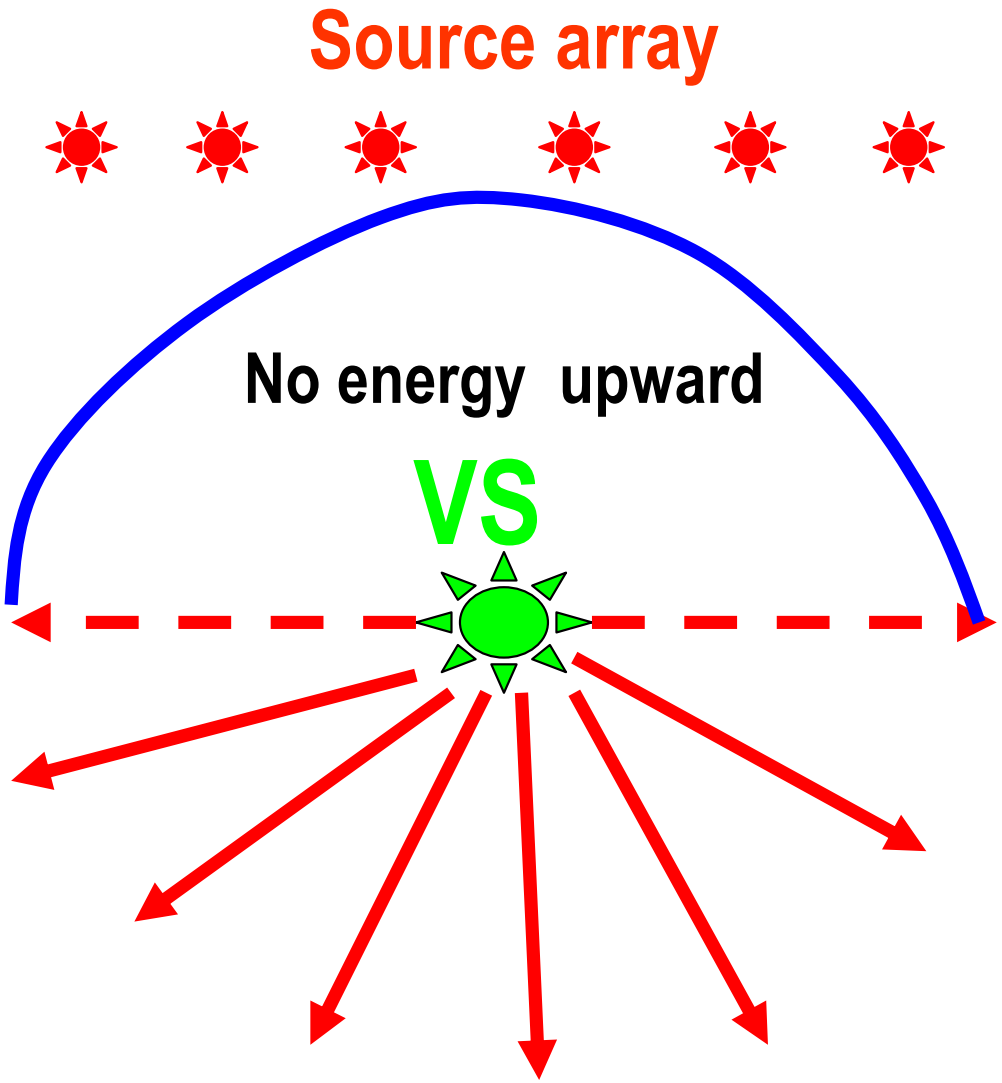


Real downhole data VS data

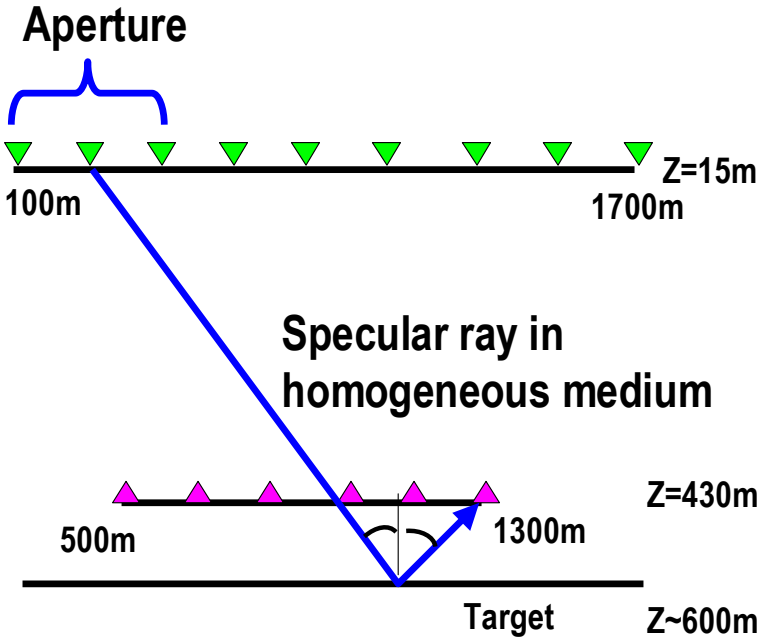


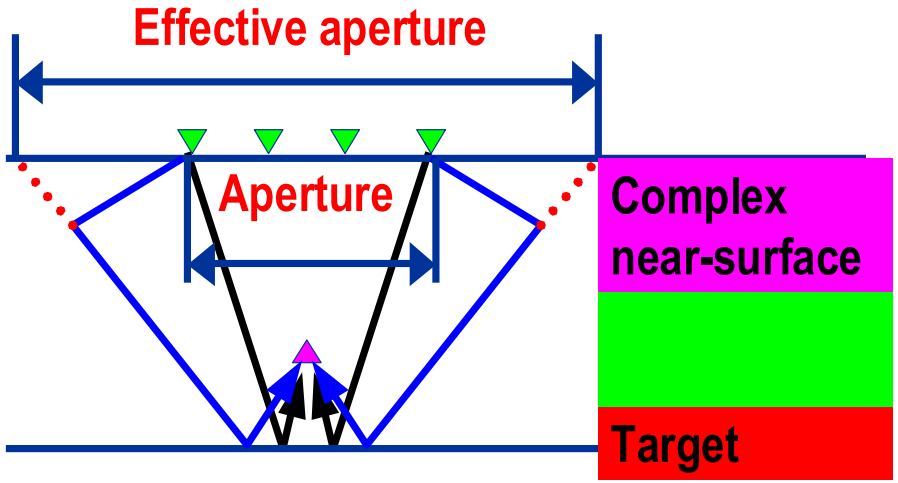
Radiation pattern of Virtual Source

- Plane array of sources *above* simulates VS with radiation pattern mainly radiating along downward hemisphere
- To excite the other half additional array is needed below VS

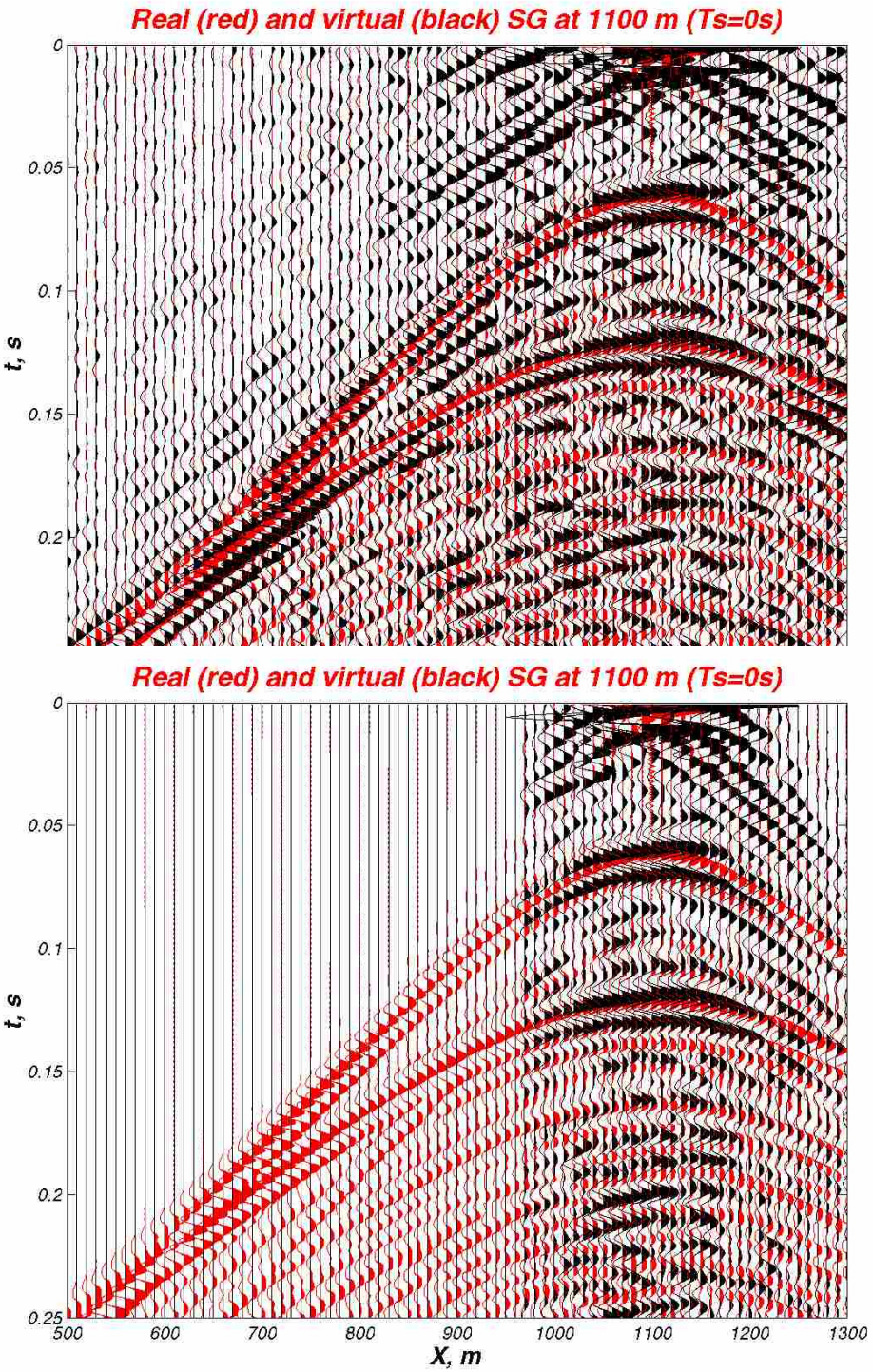


Overburden complexity helps!

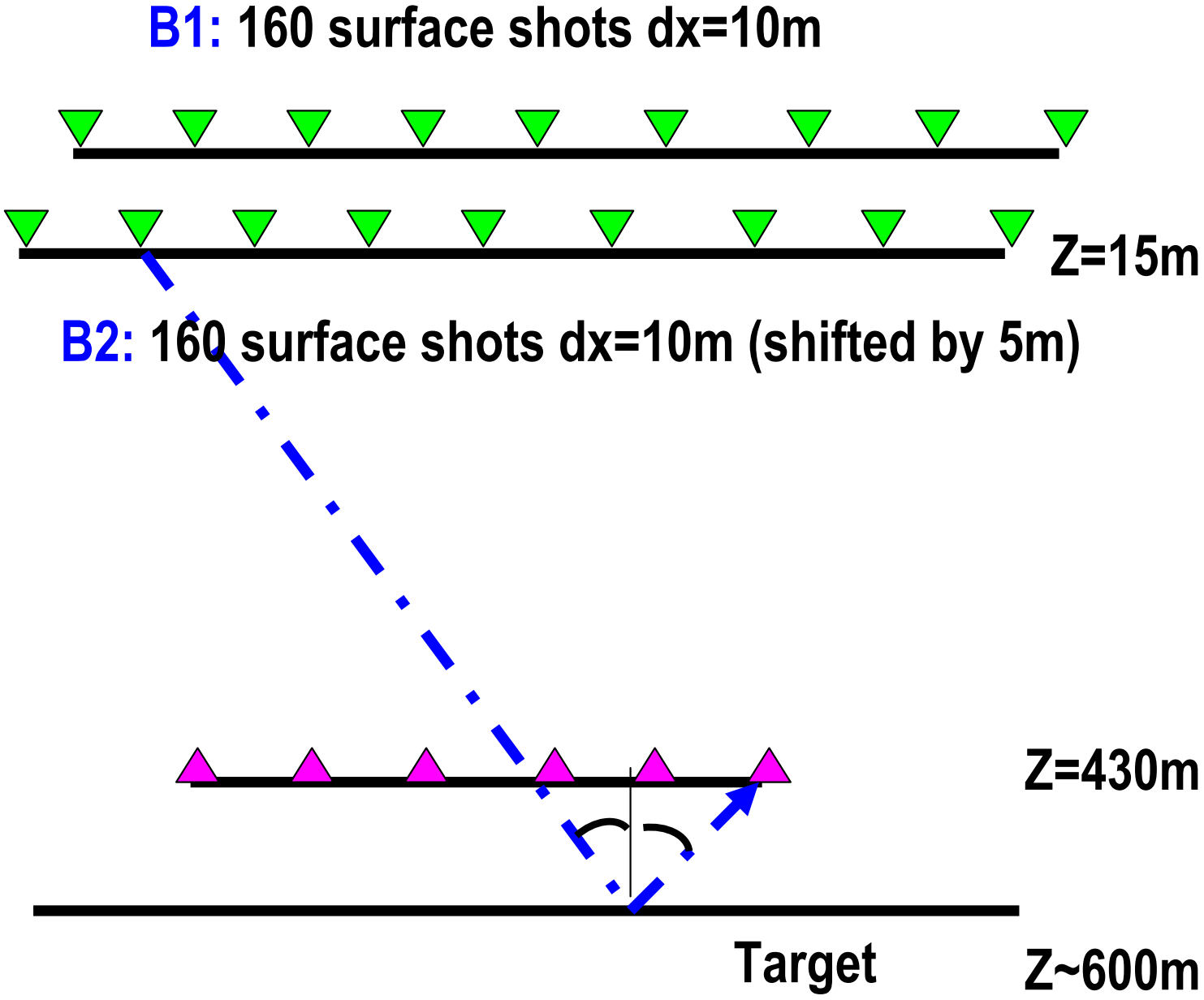




Full aperture (top) vs. ±200m around specular ray



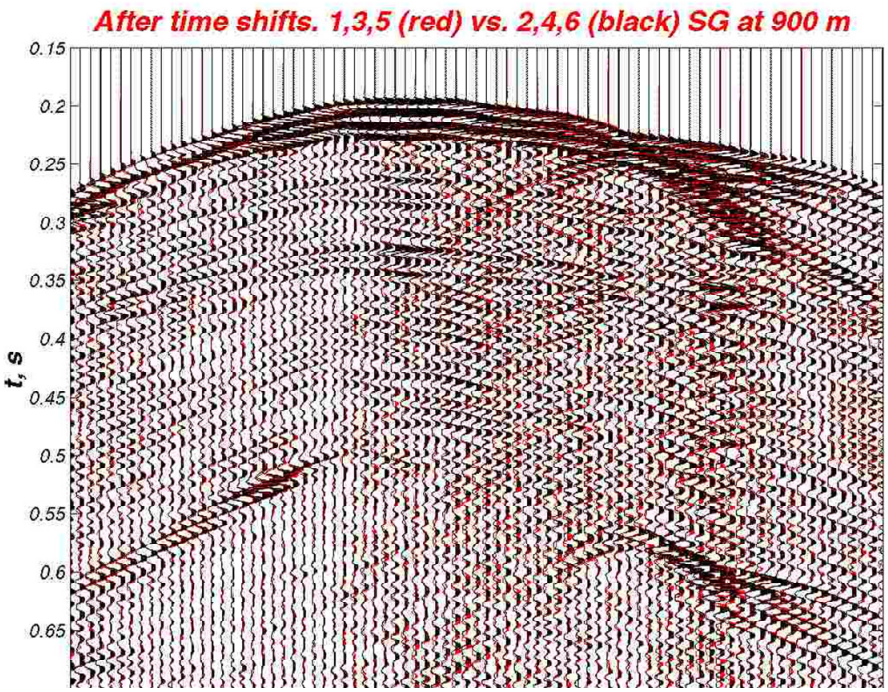
Monitoring: Virtual Source helps to correct for non-repeatable acquisition geometry

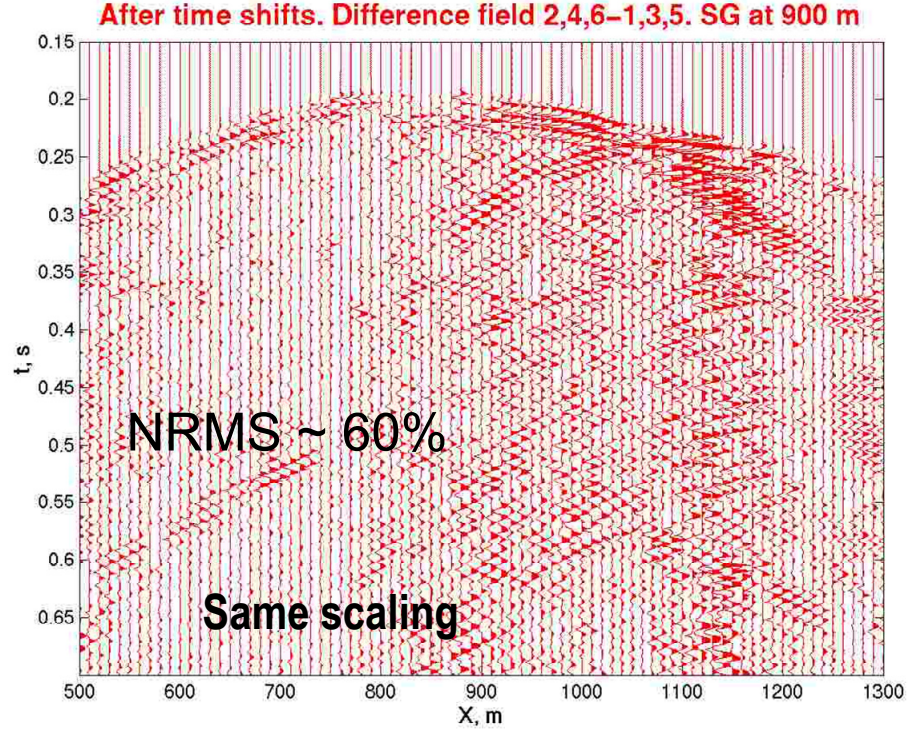


VSP

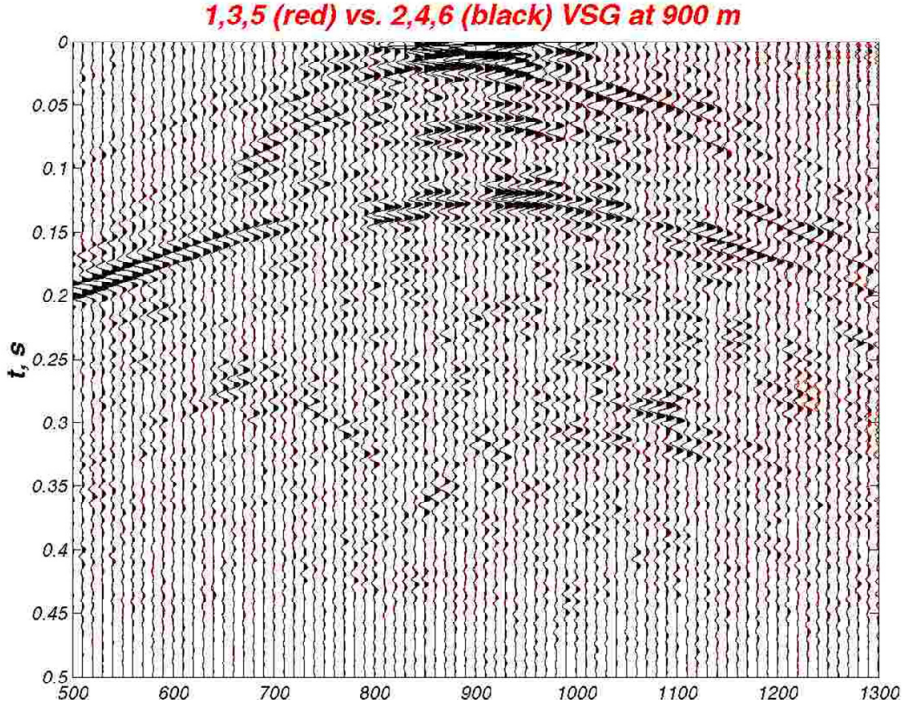
Virtual Source

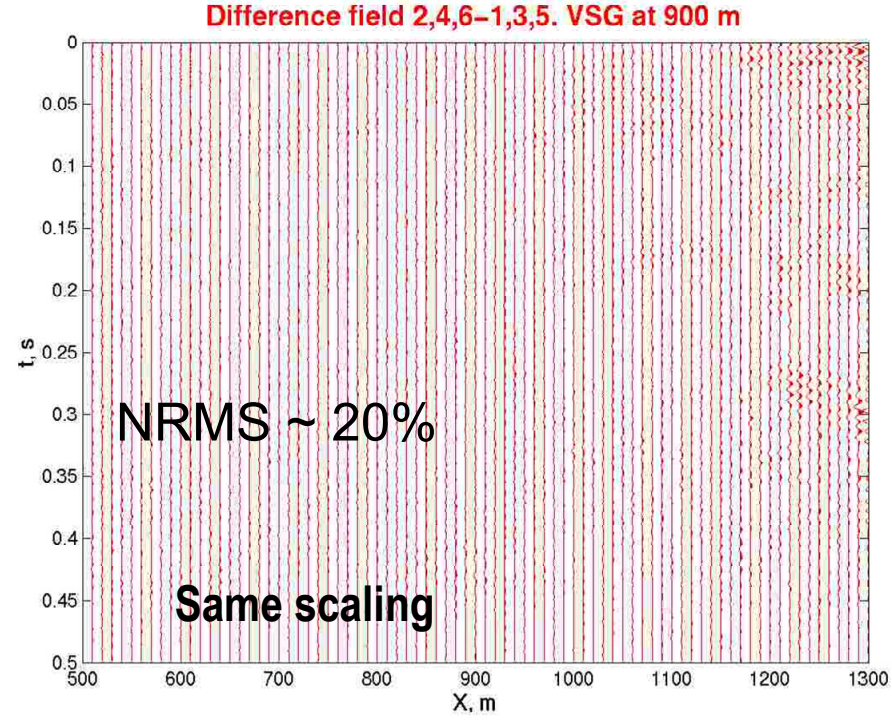
After "4D static" (time shifts introduced to match 1 and 2)





VS gathers from dataset 1 and 2, and difference (bottom)

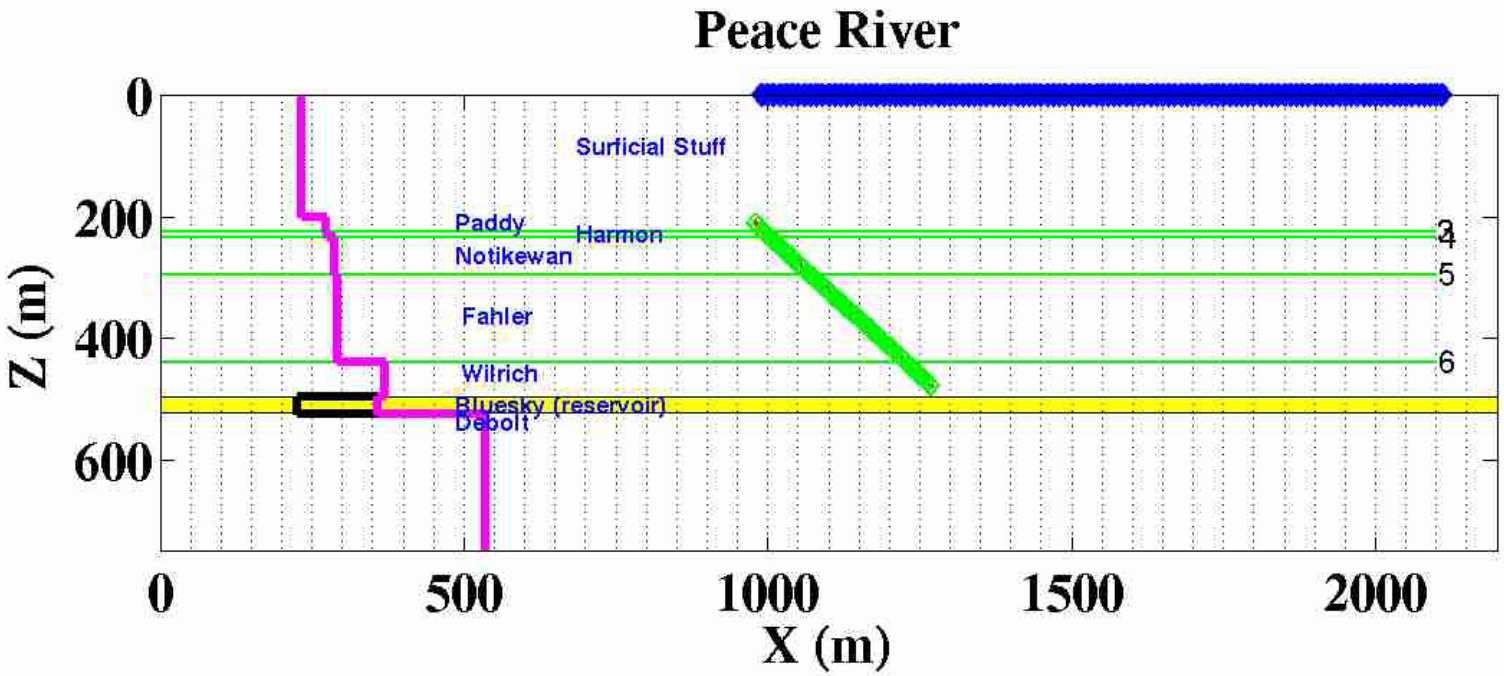




Peace River 4D VSP

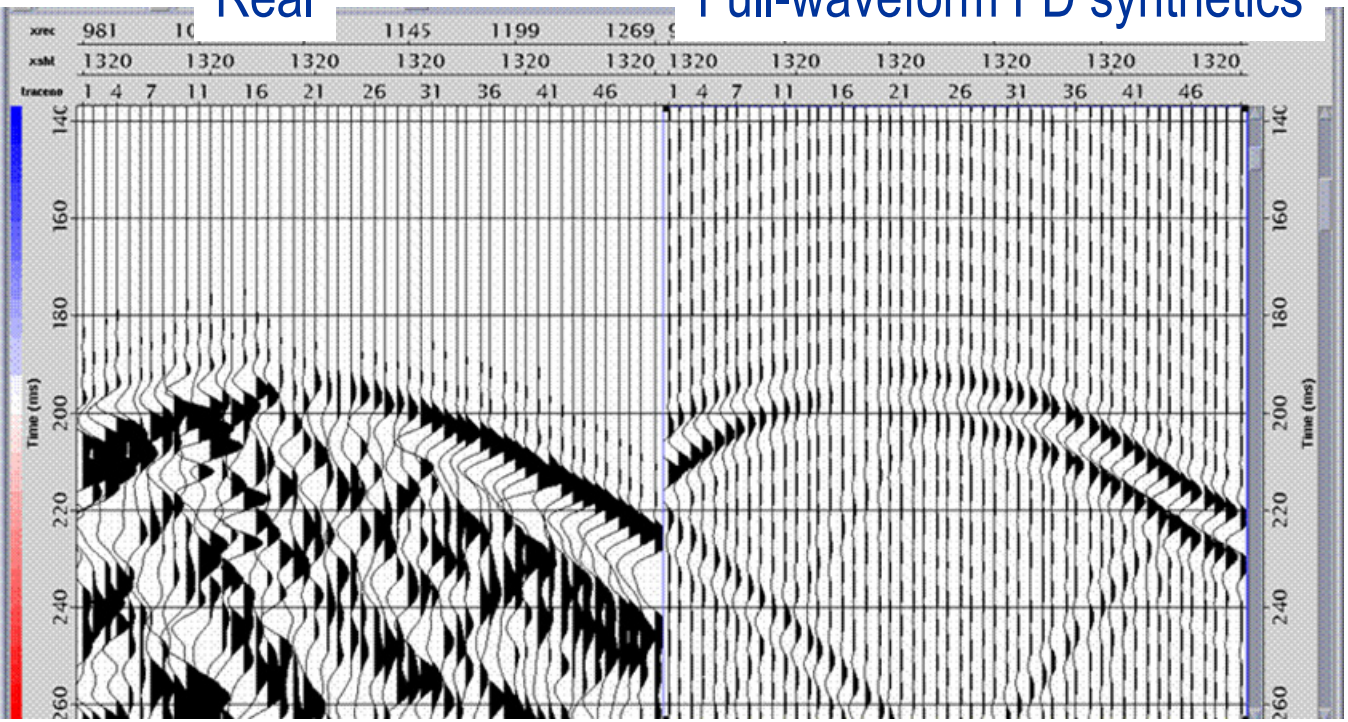
Bakulin and Calvert, 2004, SEG;
2006, Geophysics

- Baseline - September 2002 (before steam injection)
- Monitor – December 2002
  (after steam injection)



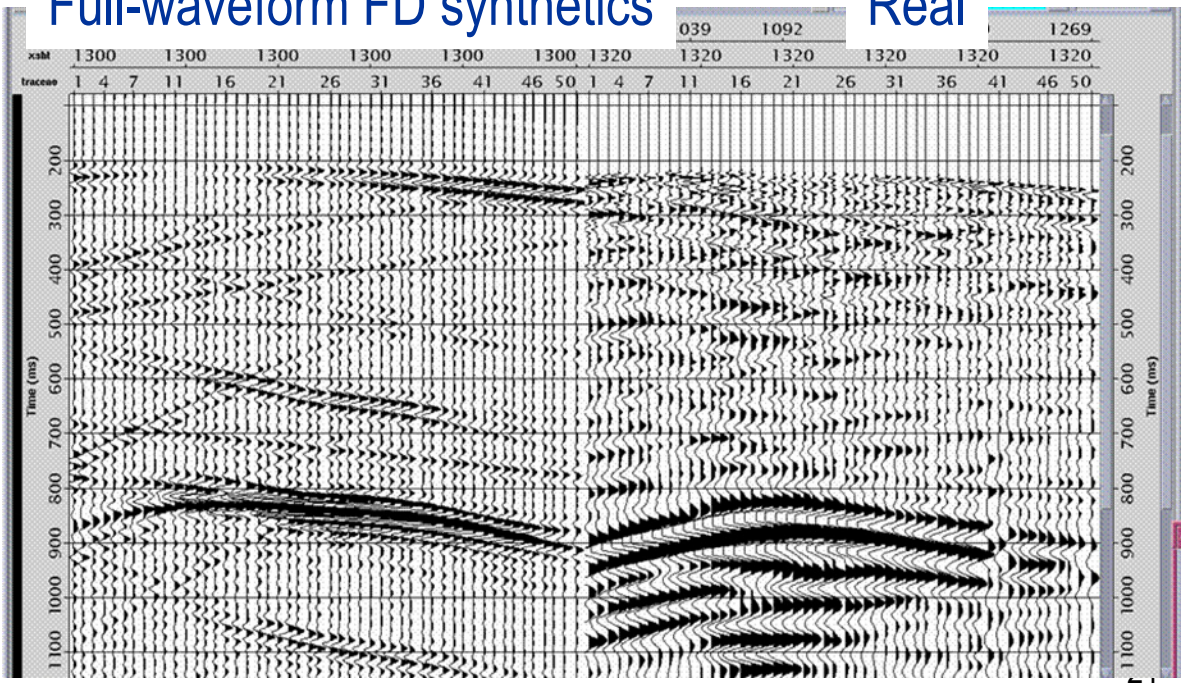
Real

Full-waveform FD synthetics

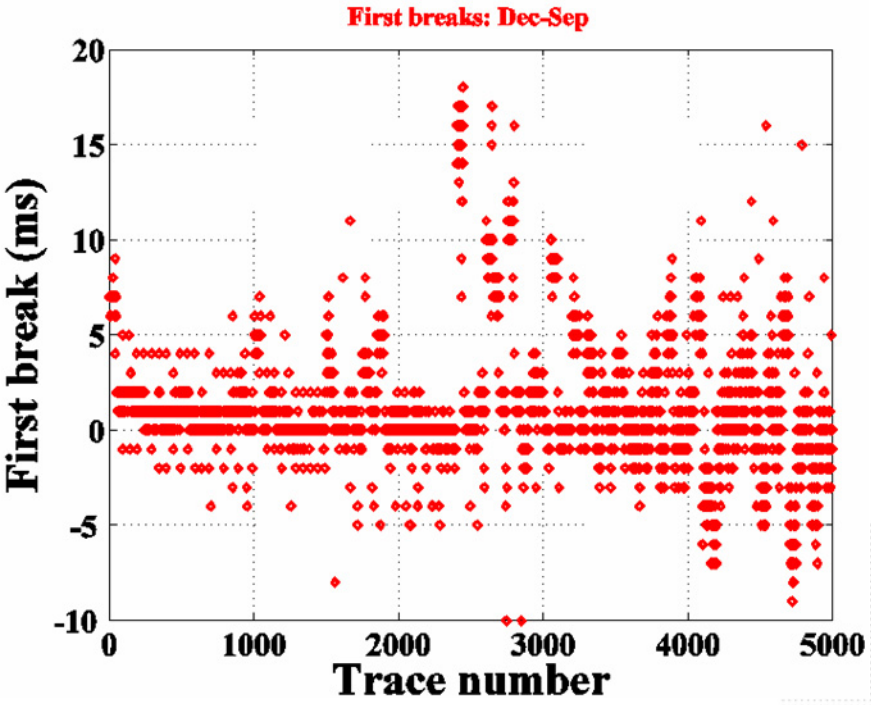


Full-waveform FD synthetics

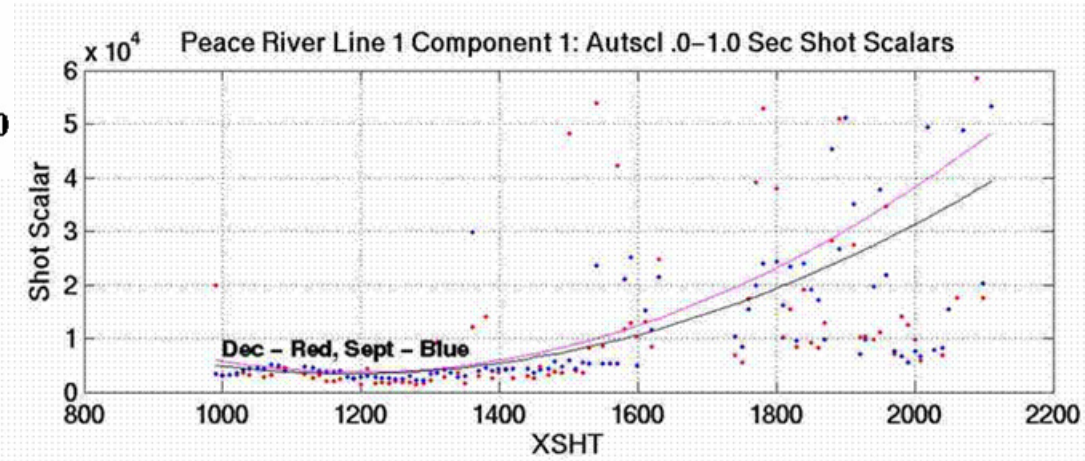
Real

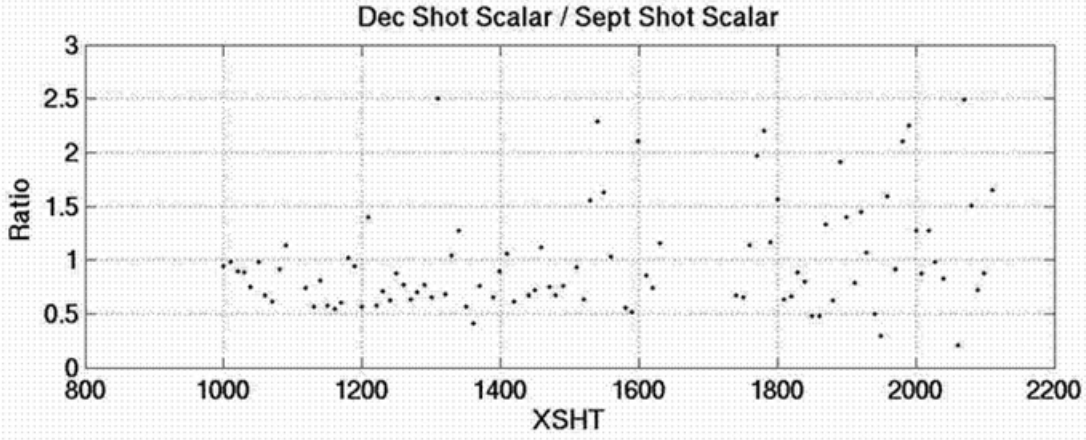


4D static

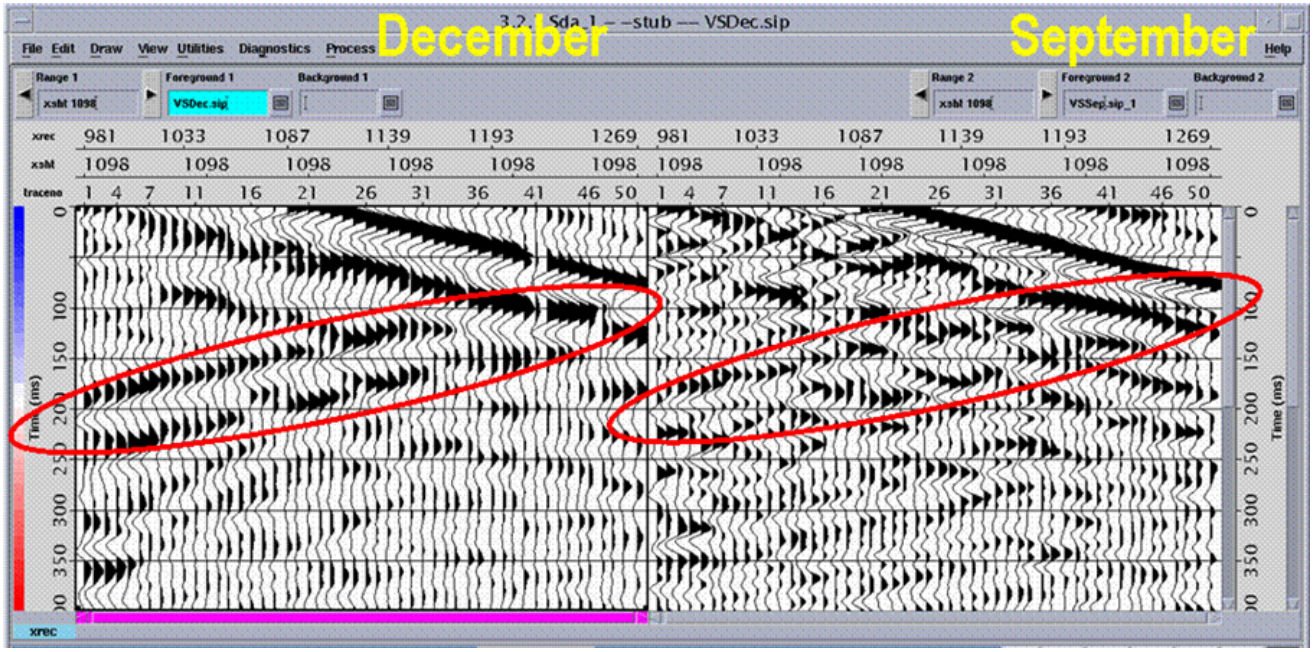


Shot scalars

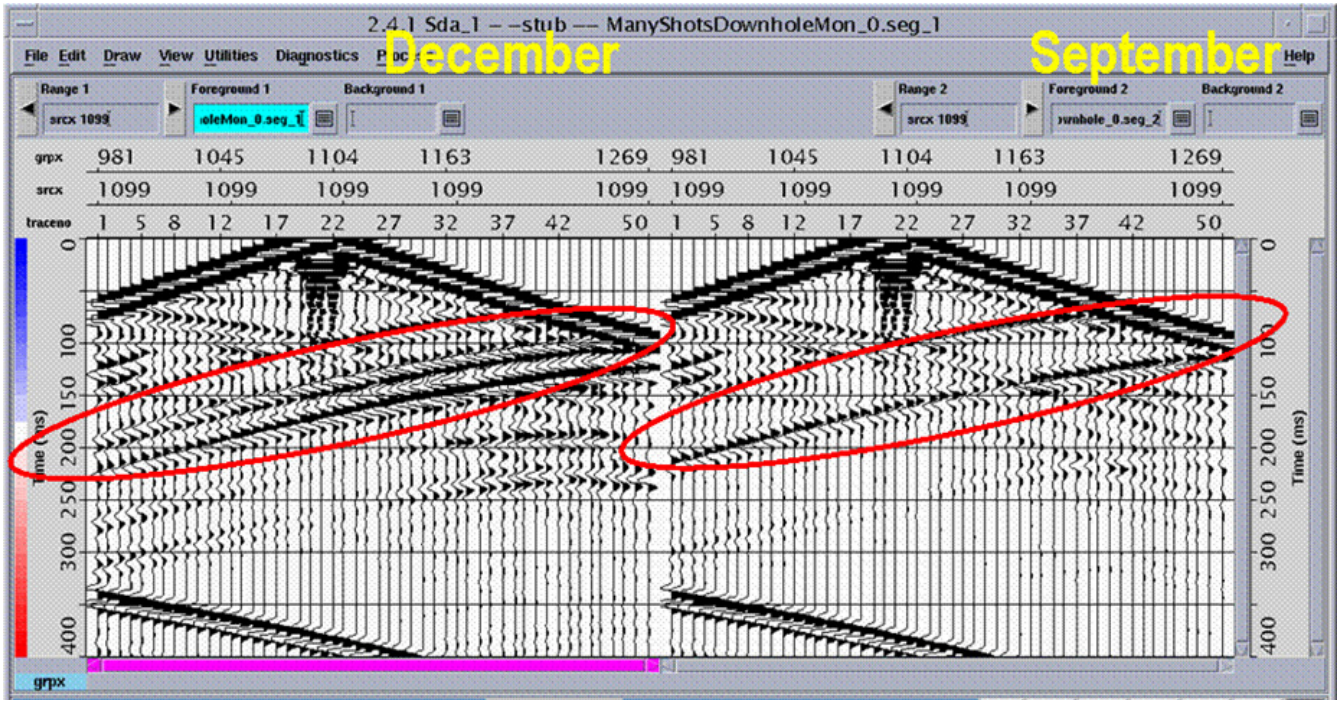




Pre-stack VS



Synthetic VS

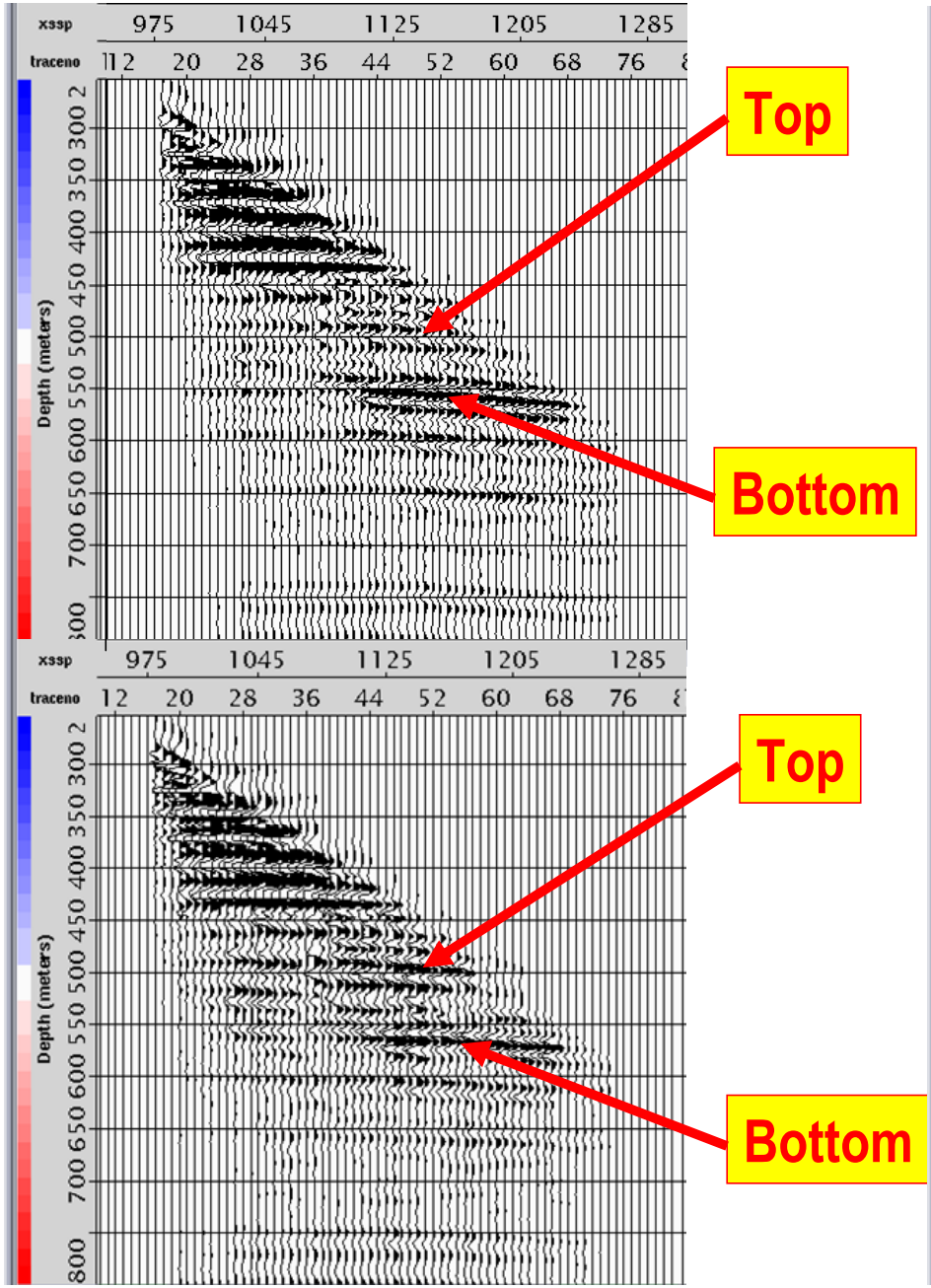


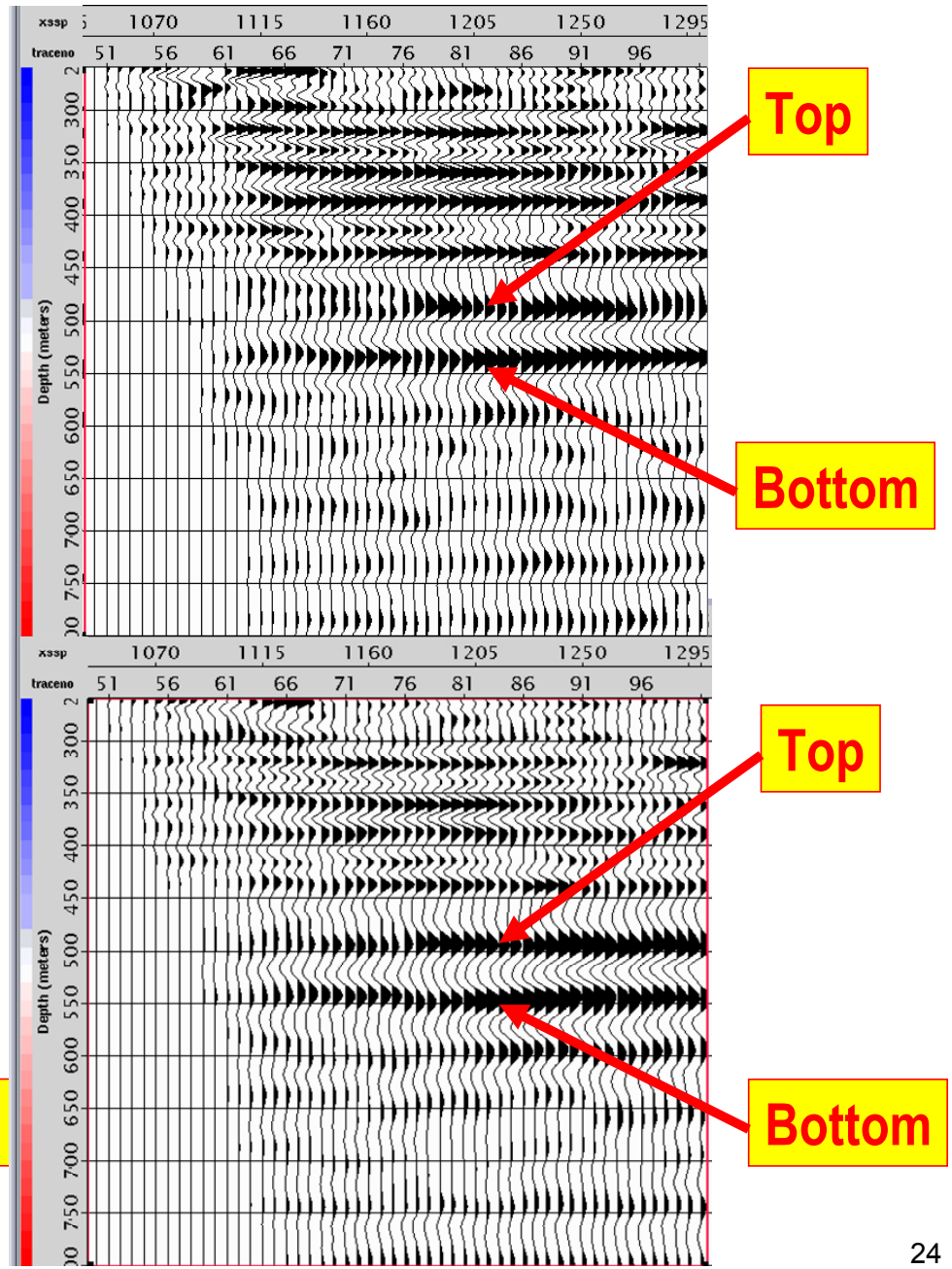
Virtual Source

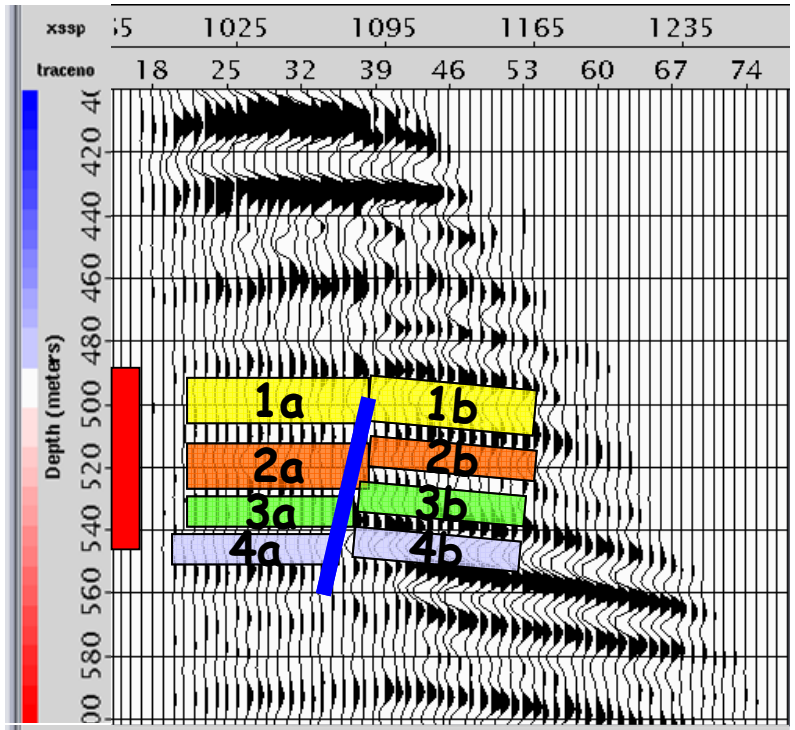
4D surface seismic

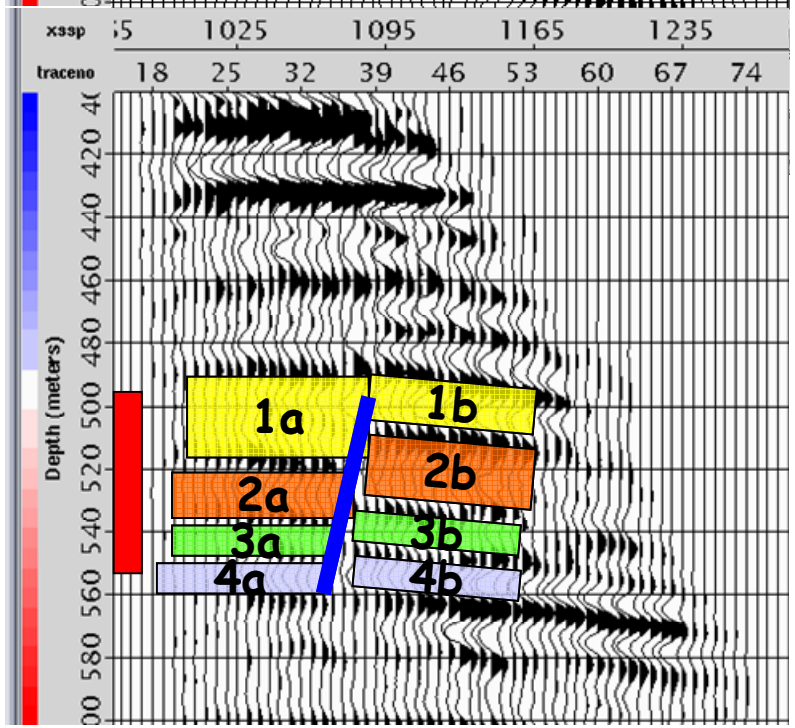
base

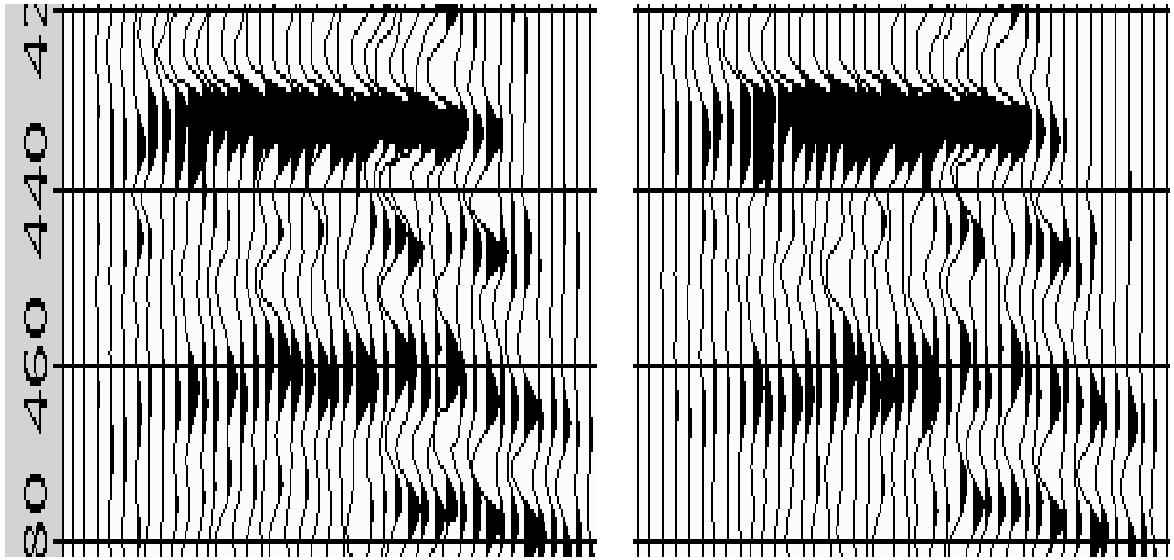
monitor







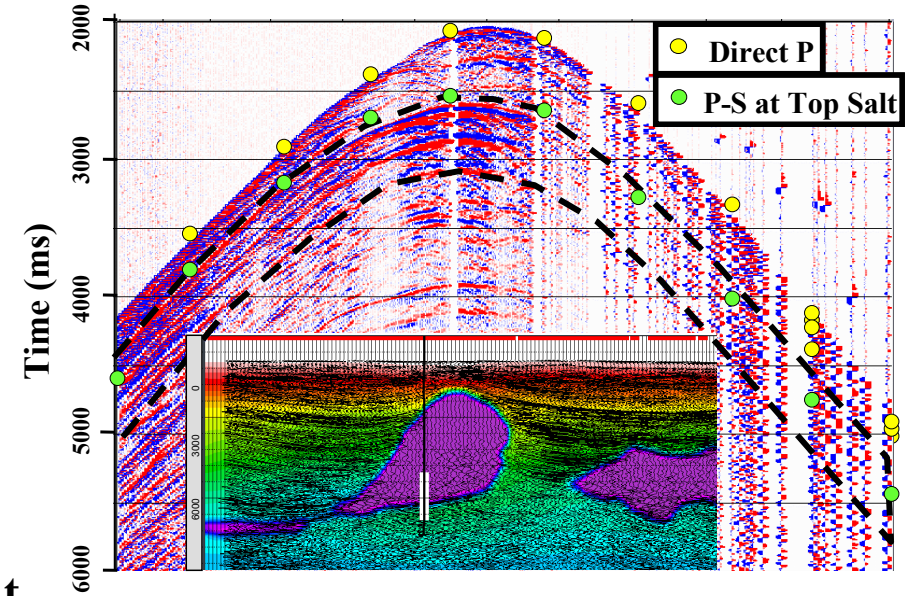




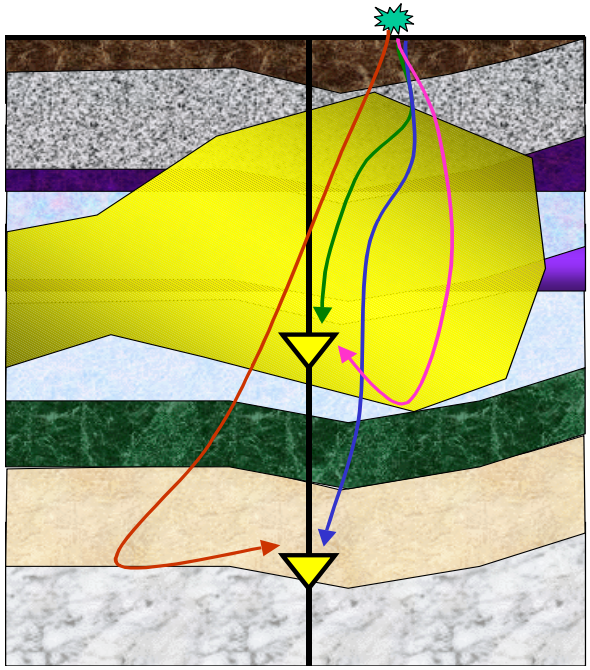
- Highly repeating overburden detail
  - despite 4D statics (surface to well)
  - despite imprints of different near-surface conditions
  - despite difference in shot wavelets and frequency

- The reservoir shows considerable changes – which are real

Virtual Checkshots: deepwater Gulf of Mexico



(a) **Classical Checkshot**

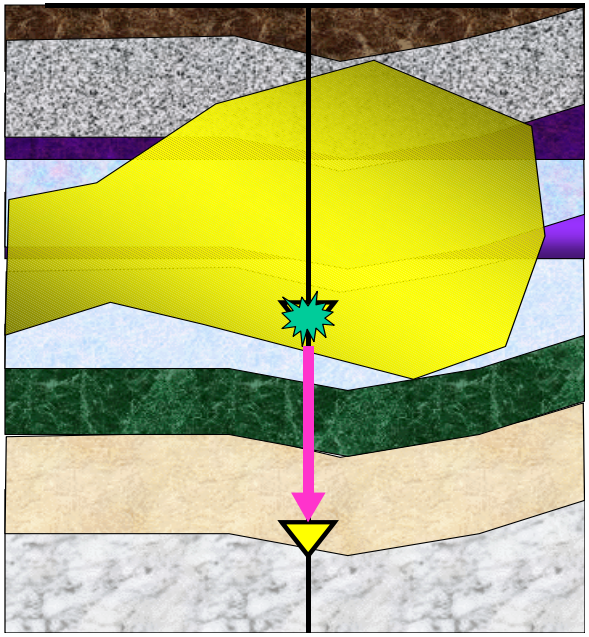


- Waveform distortions

→ what to pick ?

- Raypath excursions

(b) **Virtual Checkshot**



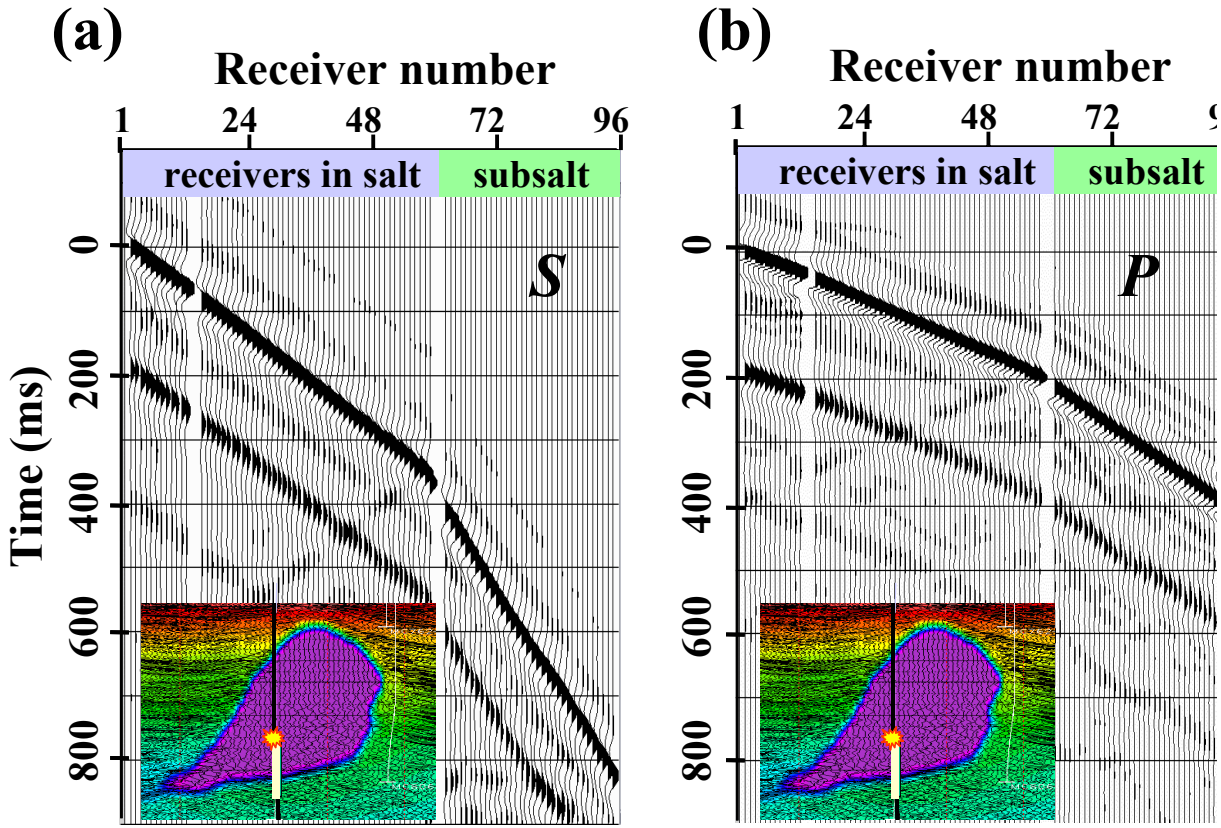
- Below the complicated overburden
- Short ray-path - along the well

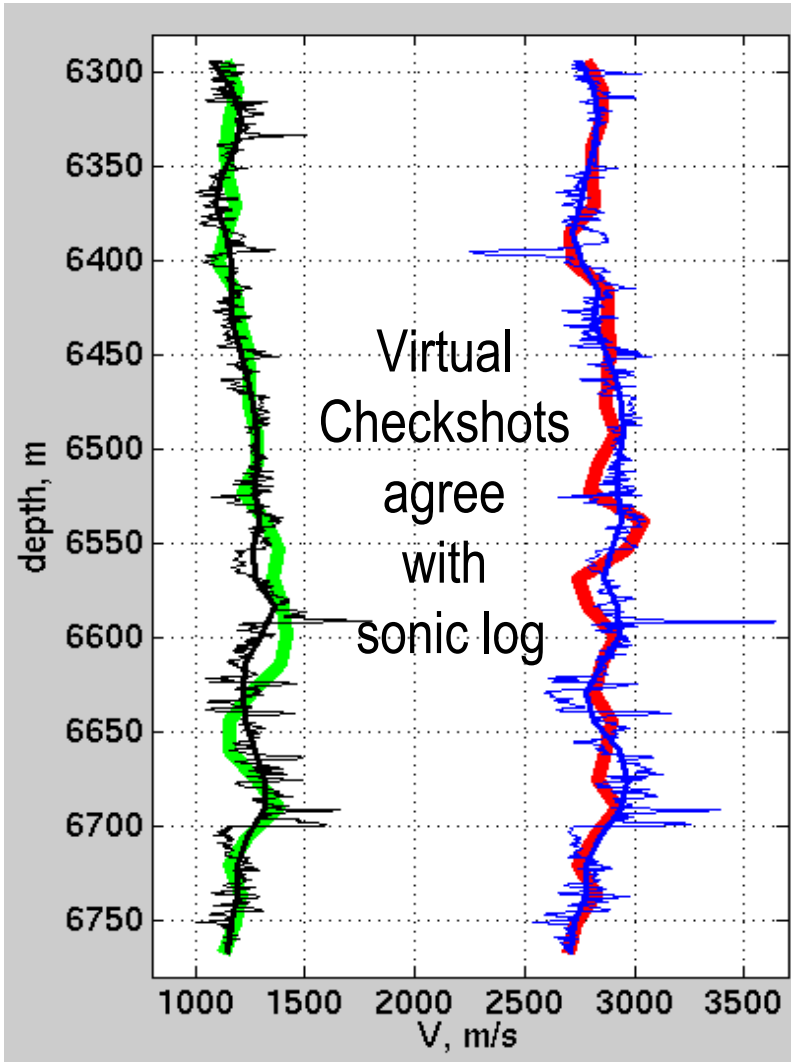
(+) zero-phase wavelet (+) P or S source

Bakulin et al, 2007, Geophysics

Bakulin et al, 2007, Geophysics

P- and *S*- Virtual Checkshots



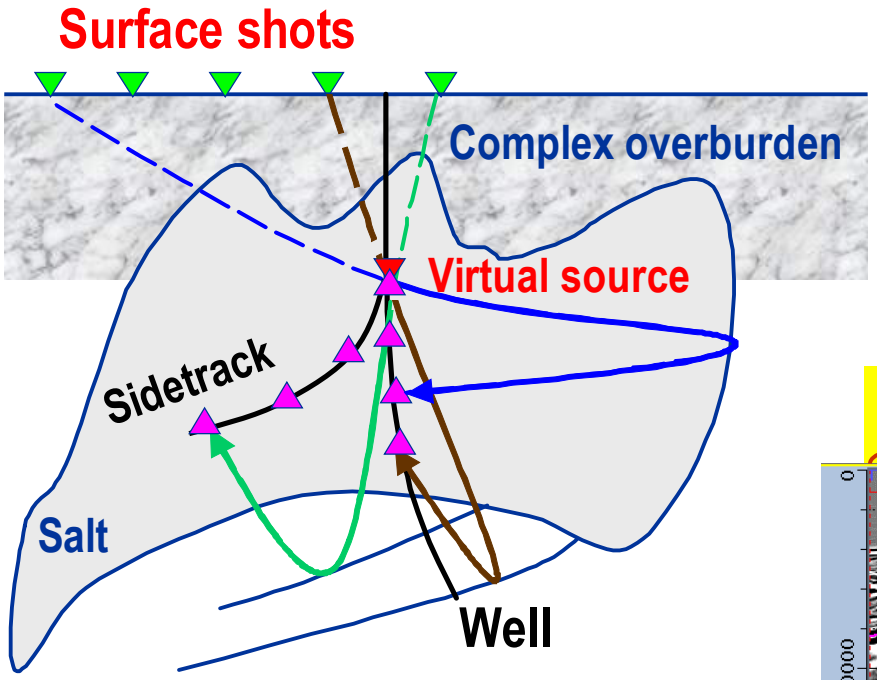


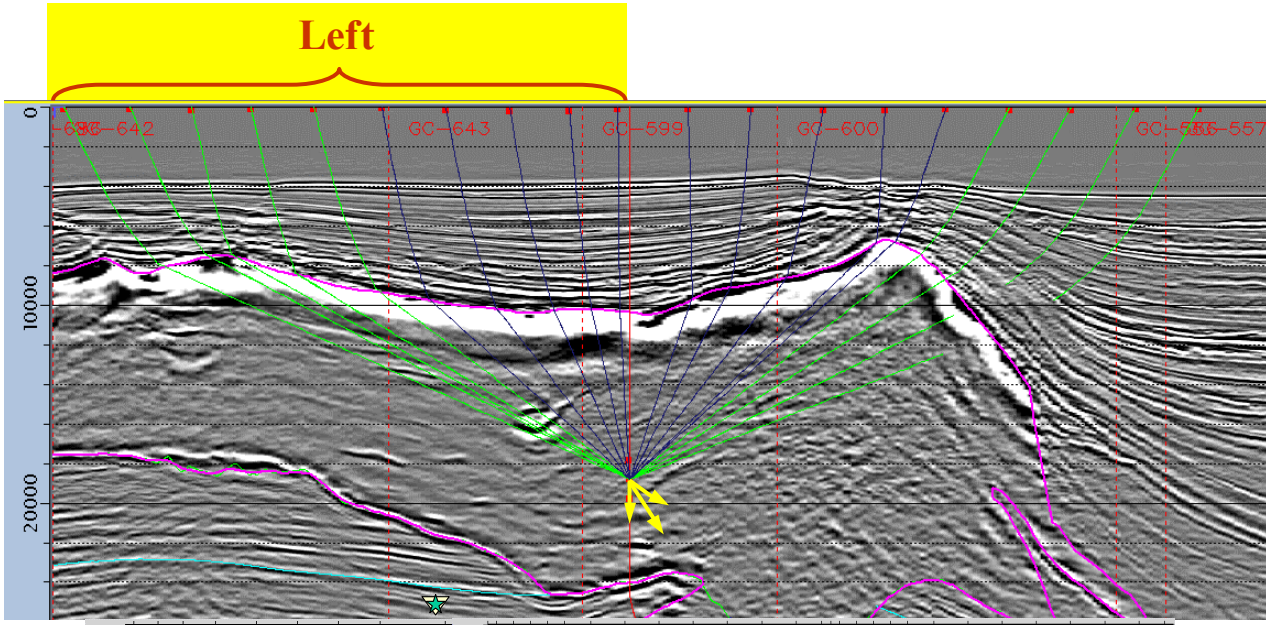
Beyond checkshots:

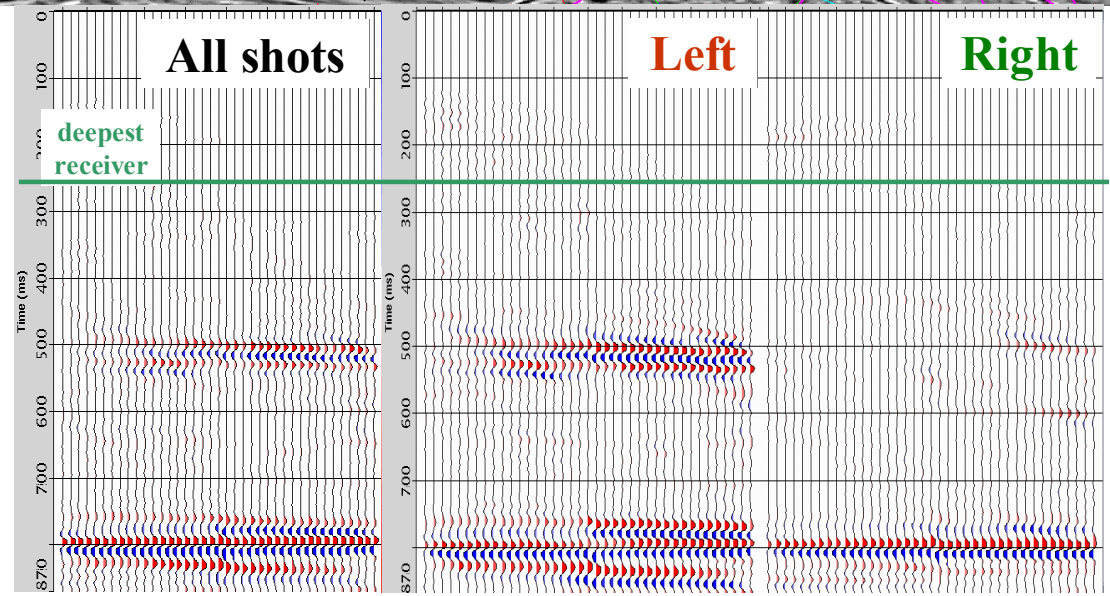
- process the full Virtual Source wavefield
  - P-P, P-S and S-S reflection (with airguns)

Mateeva et al., 2007, SEG

Steering Virtual Sources

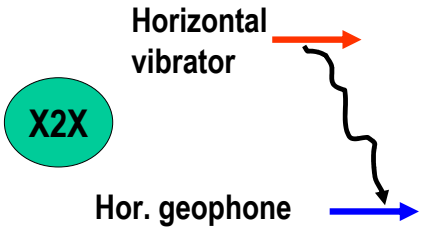


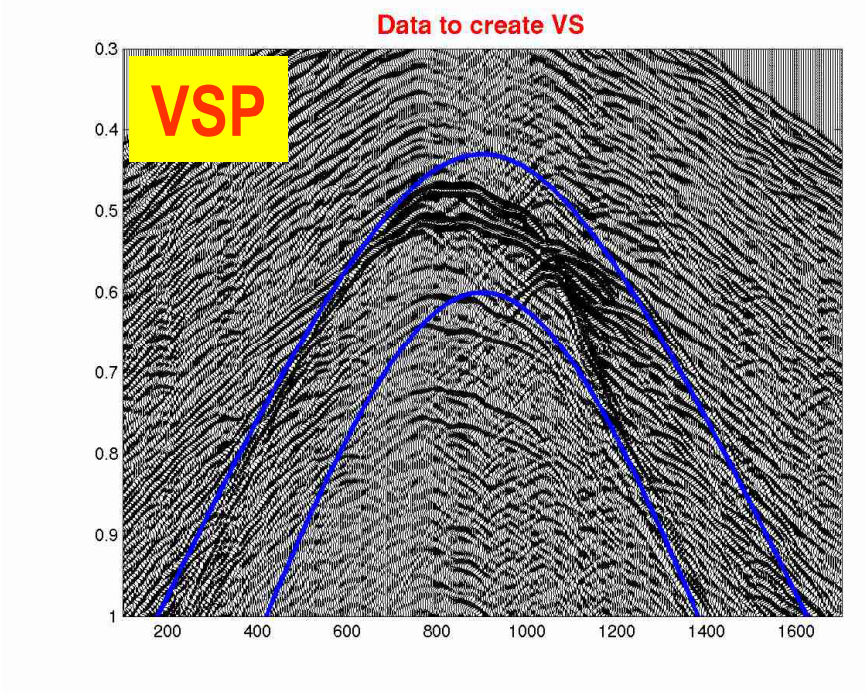


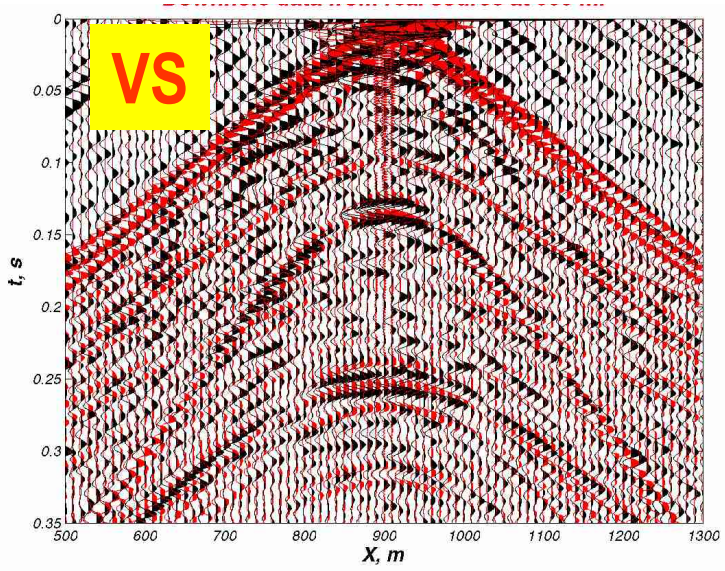


Bakulin and Calvert, 2005, SEG

Shear-wave (SS) seismic

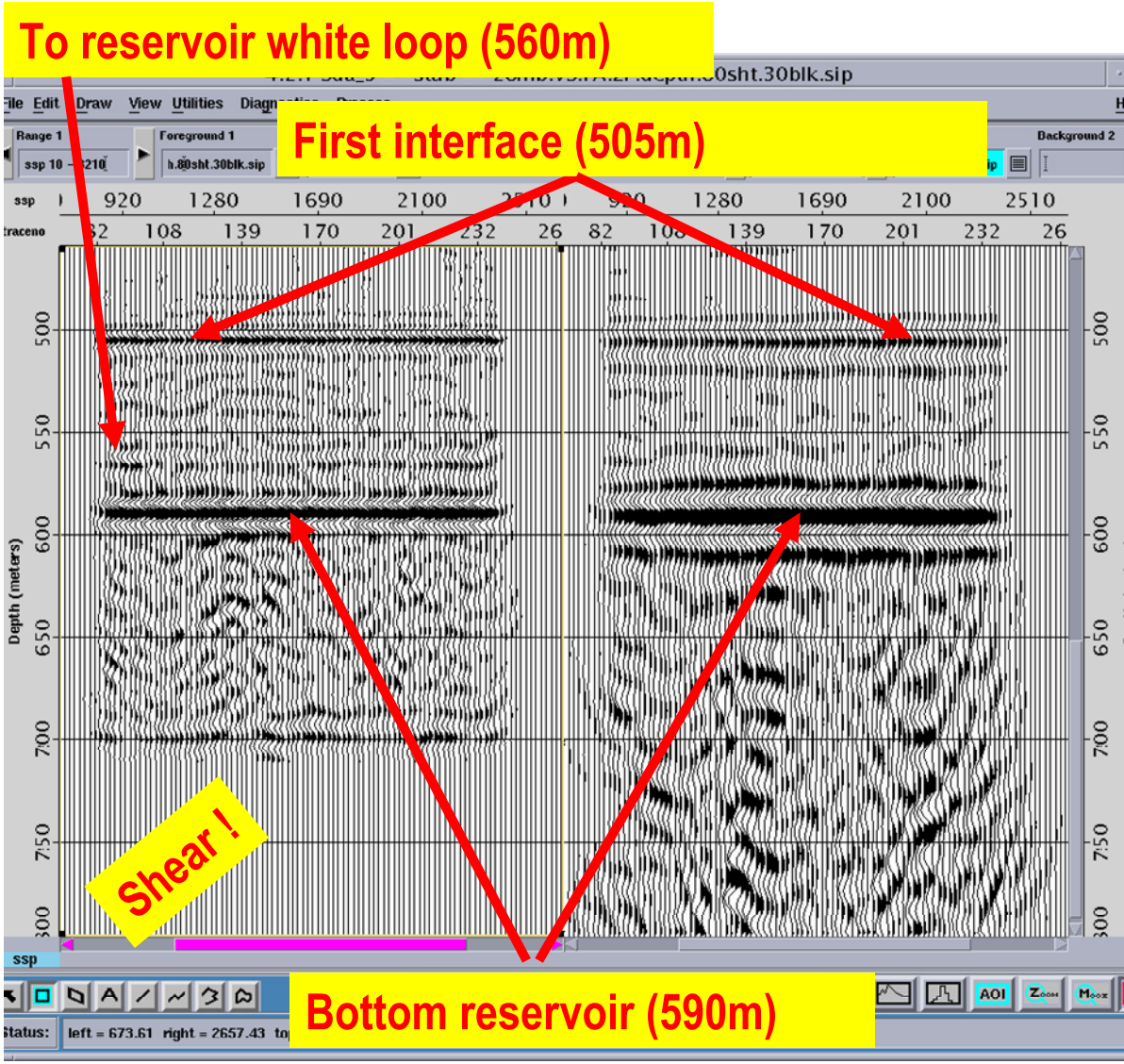




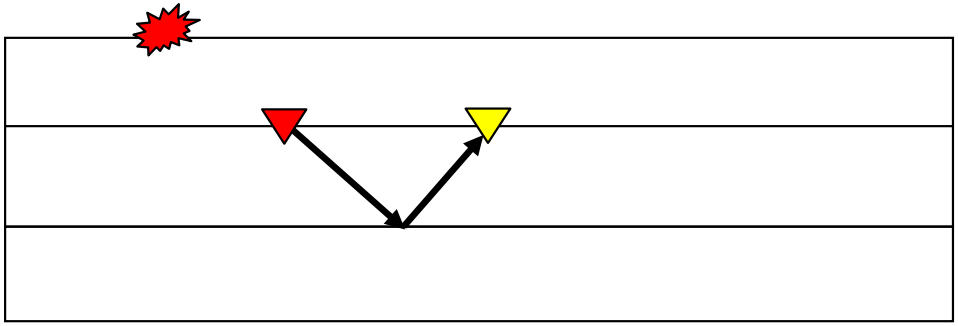


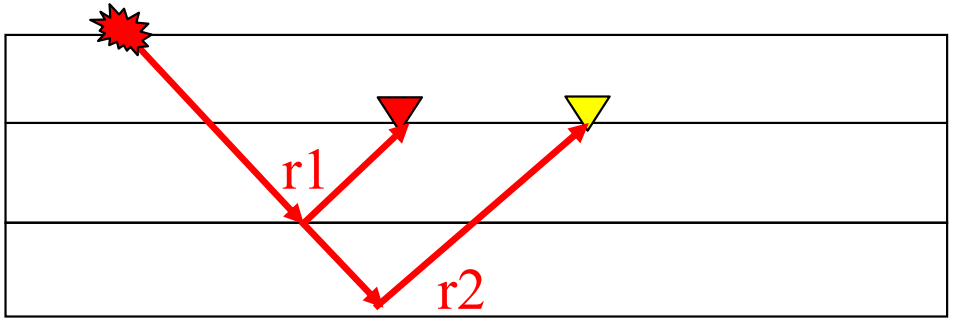
VS *S*-wave image (full aperture)

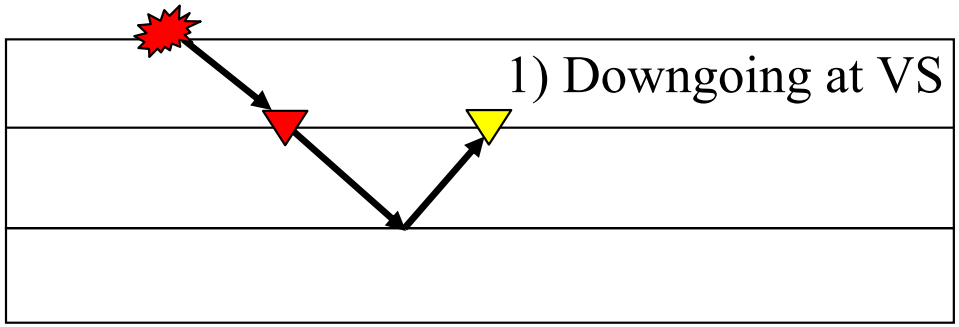
VS *P*-wave image (full aperture)

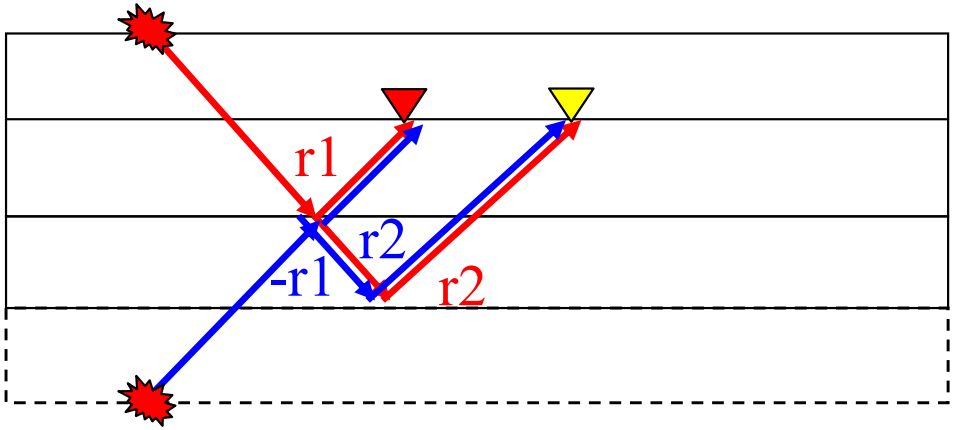


Wavefield separation improves VS data

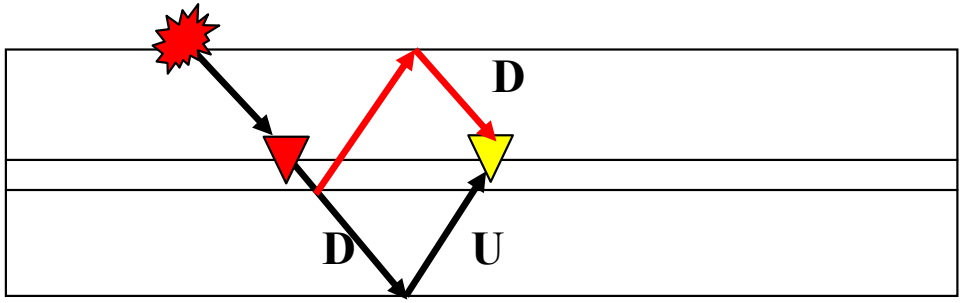


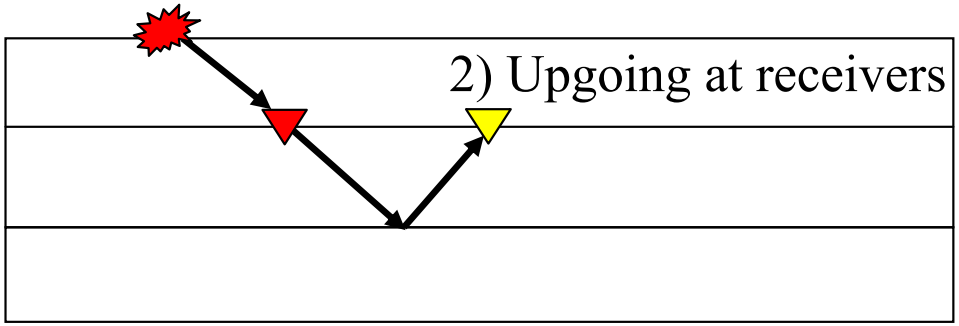






Snieder, et al., 2005

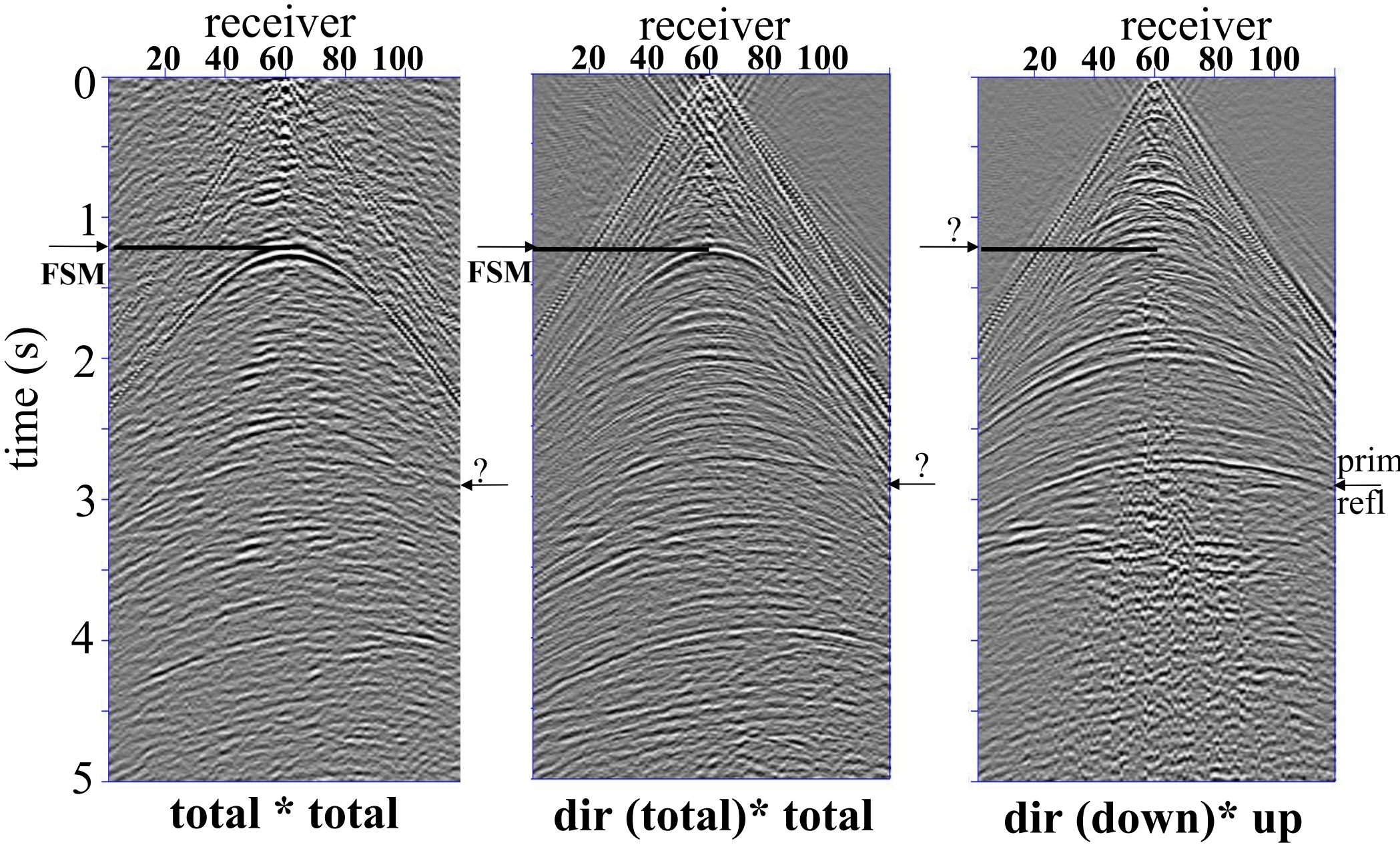




Mehta, Bakulin et al, 2007, Geophysics

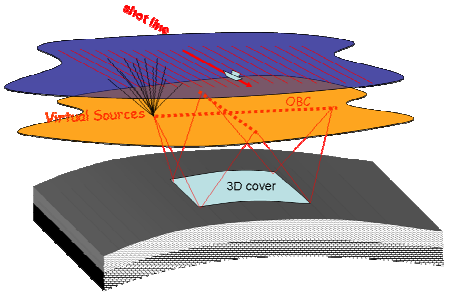
Mehta, Bakulin et al, 2007, Geophysics

Mars OBC : VS gather

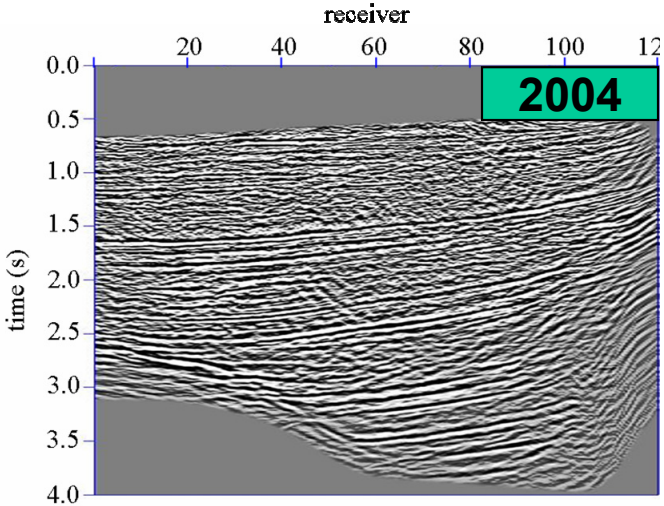


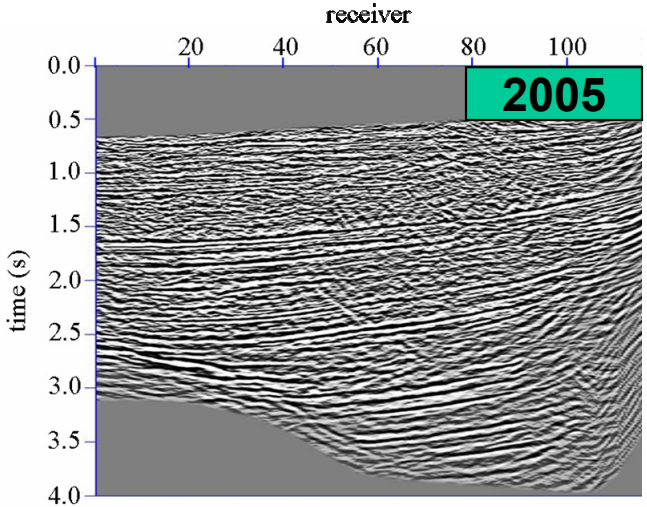
Mars 4D OBC

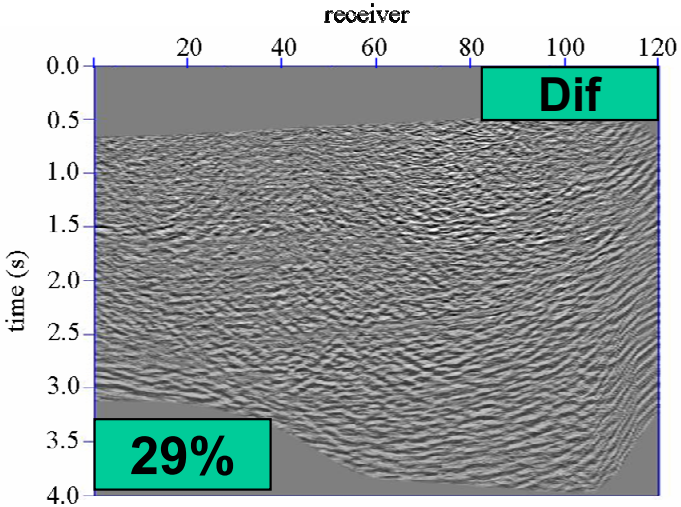
Mehta, 2007, PhD



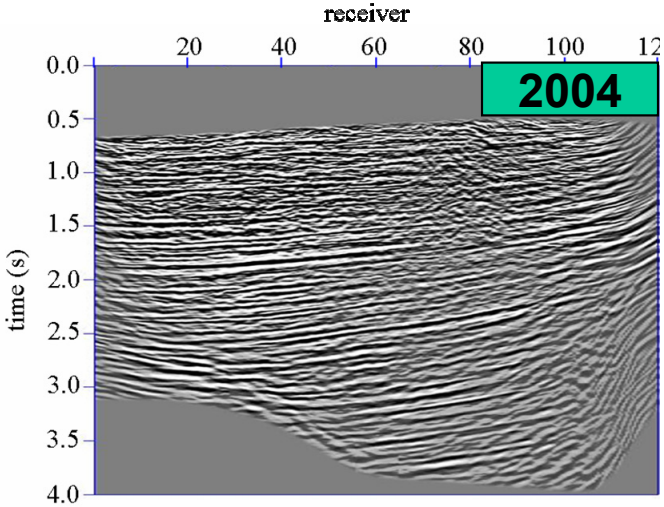
Ocean-bottom seismic (sea surface to seabed)

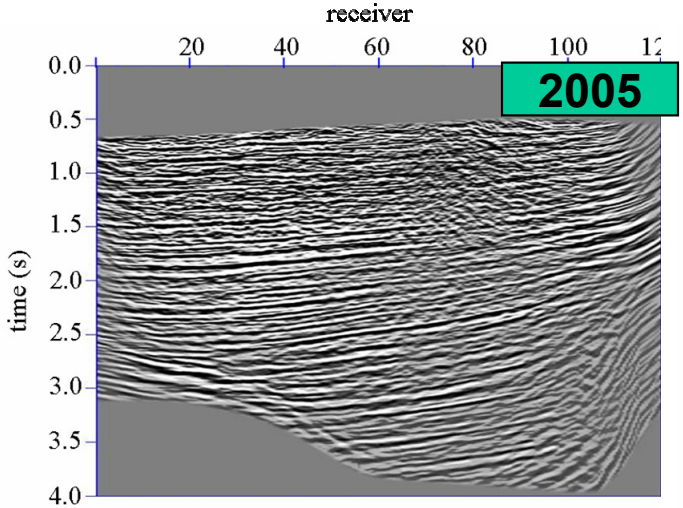


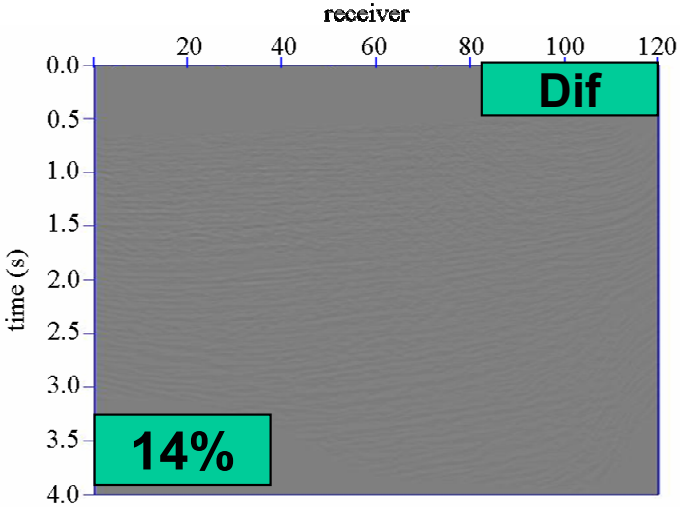




Virtual Source redatuming (seabed to seabed)

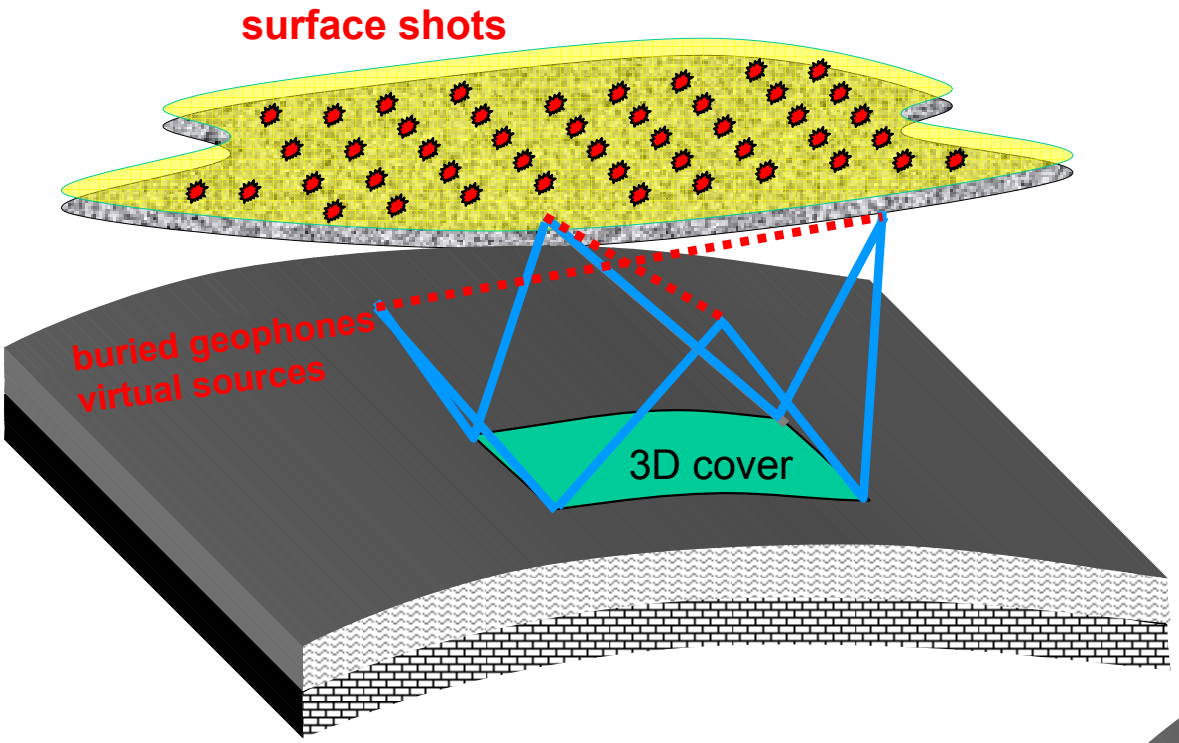




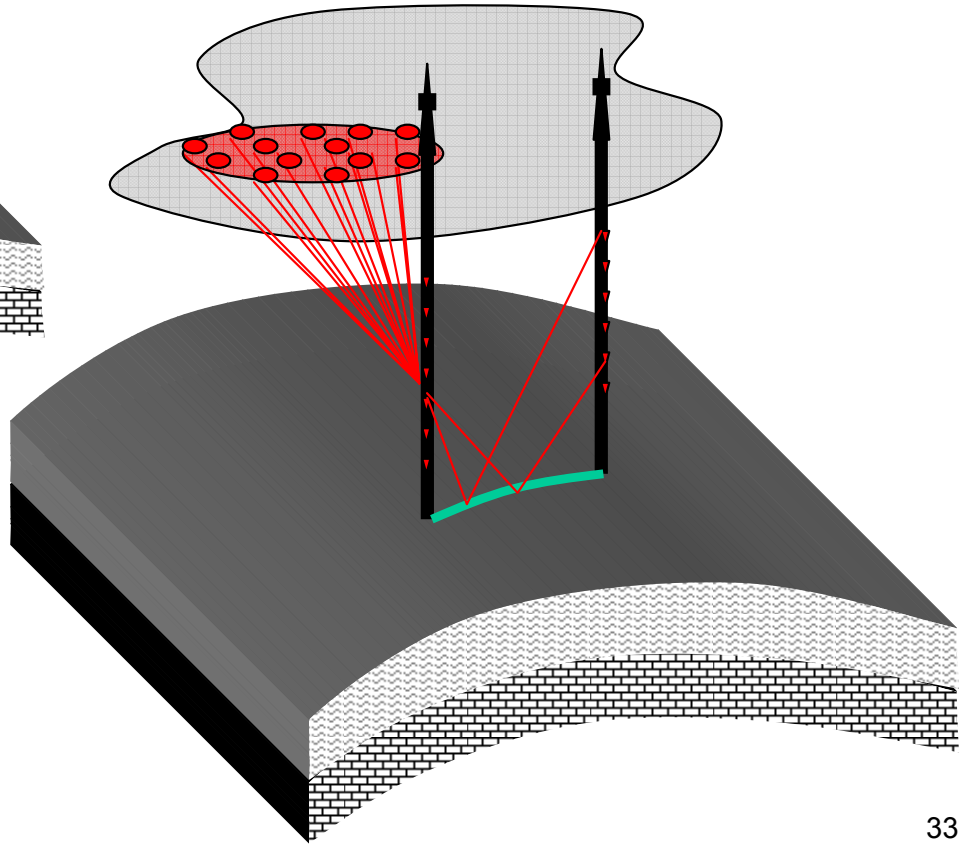


VS automatically corrects for changes in sea water level, sea surface roughness, water velocity (T,S), non-repeatable source positions

Towards Areal Field Monitoring



Virtual Cross-Well

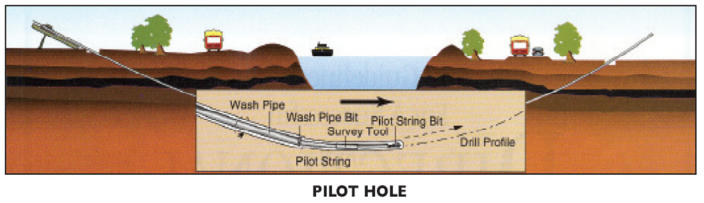


Virtual Cross-Spread

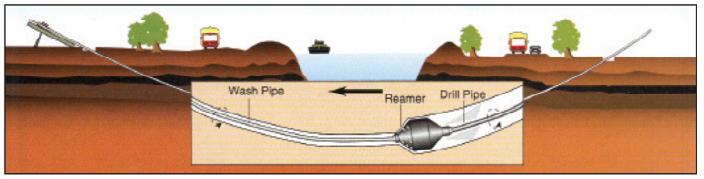
Deployment

- U-shaped well:
  - Plenty of experience with pipeline and telecommunications cables
  - Fit-for-purpose for shallow wells
  - Greatest flexibility in cable deployment options
  - Easiest deployment: simply pull cable behind the drill pipe
- Inside coiled tubing:
  - Successes with hydrophones
  - Mixed results with geophones
  - Needs testing: geophone coupling, helical wrapping
  - Novel idea: cement in place with Shell Universal Fluid

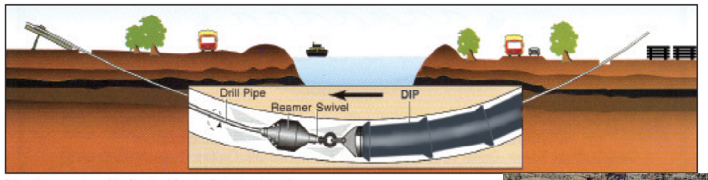
Bakulin et al, 2007, SEG



PILOT HOLE

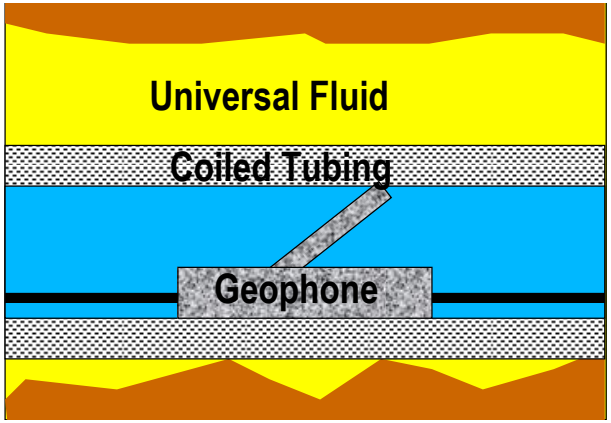


PRE-REAMING



Schematics are courtesy of the Directional Crossing Contractors Association PULL-BACK

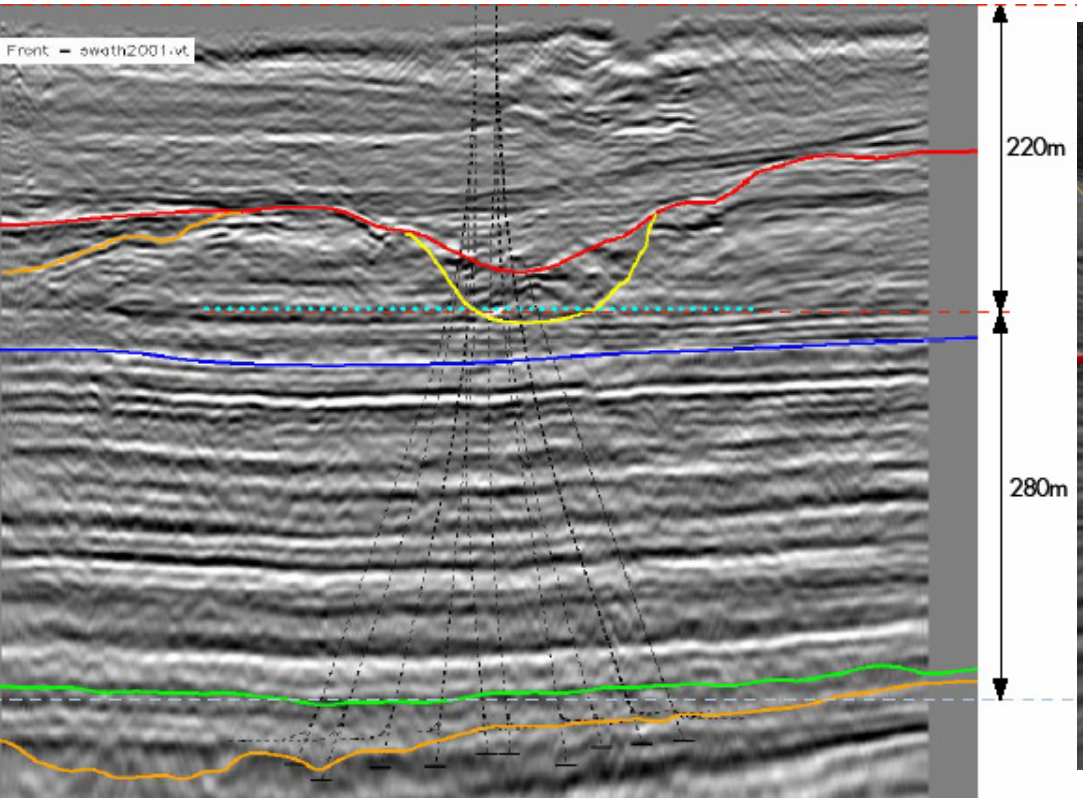
H
D
D

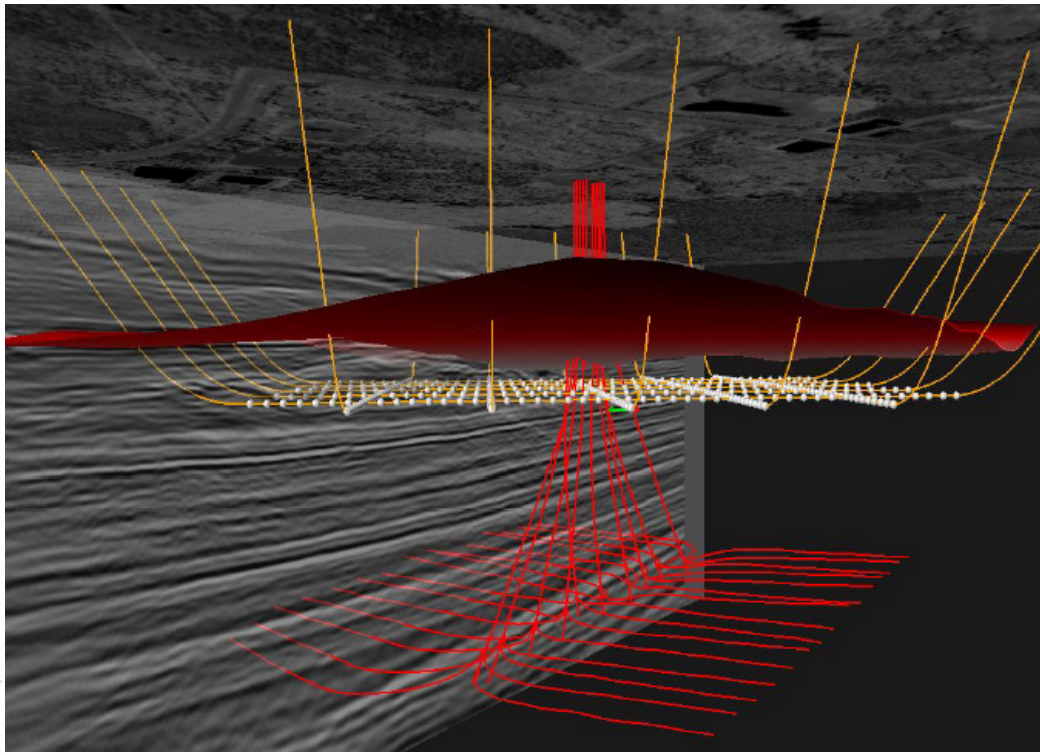


Bakulin et al, 2007, SEG

Peace River: grid of wells

Grid of U-shaped wells, horizontal section ~ 1000 m, depth ~ 200-300 m





Conclusions

- Virtual Source Method is a new way of imaging/monitoring below very complex near surface using downhole geophones
- Does not require velocity model between surface and geophones in a well
- Increased overburden complexity may indeed enhance the VS approach
- VS has advantageous downward radiation pattern
- Substantially higher frequency images compared to surface seismic – no mis-stacking
- Automatically takes care of 4D static and other changes in the near surface
- May relax requirements to repeat surface shots positions exactly
- Much more repeatable data compared to surface seismic or conventional VSP
- Field trial program is on the way to expand the applications especially related to monitoring