Shell Exploration & Production

# Virtual Source: new method for imaging and 4D below complex overburden

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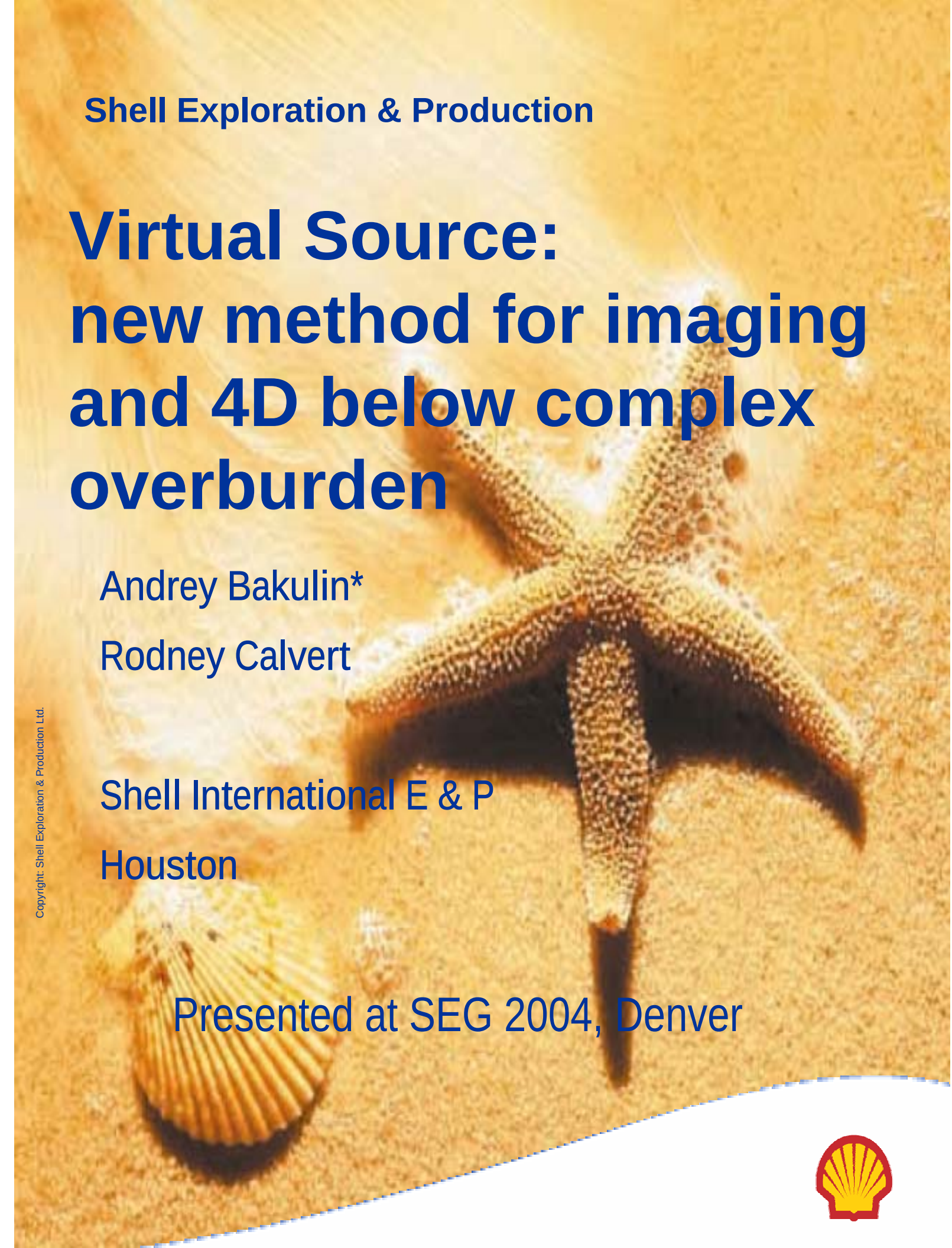
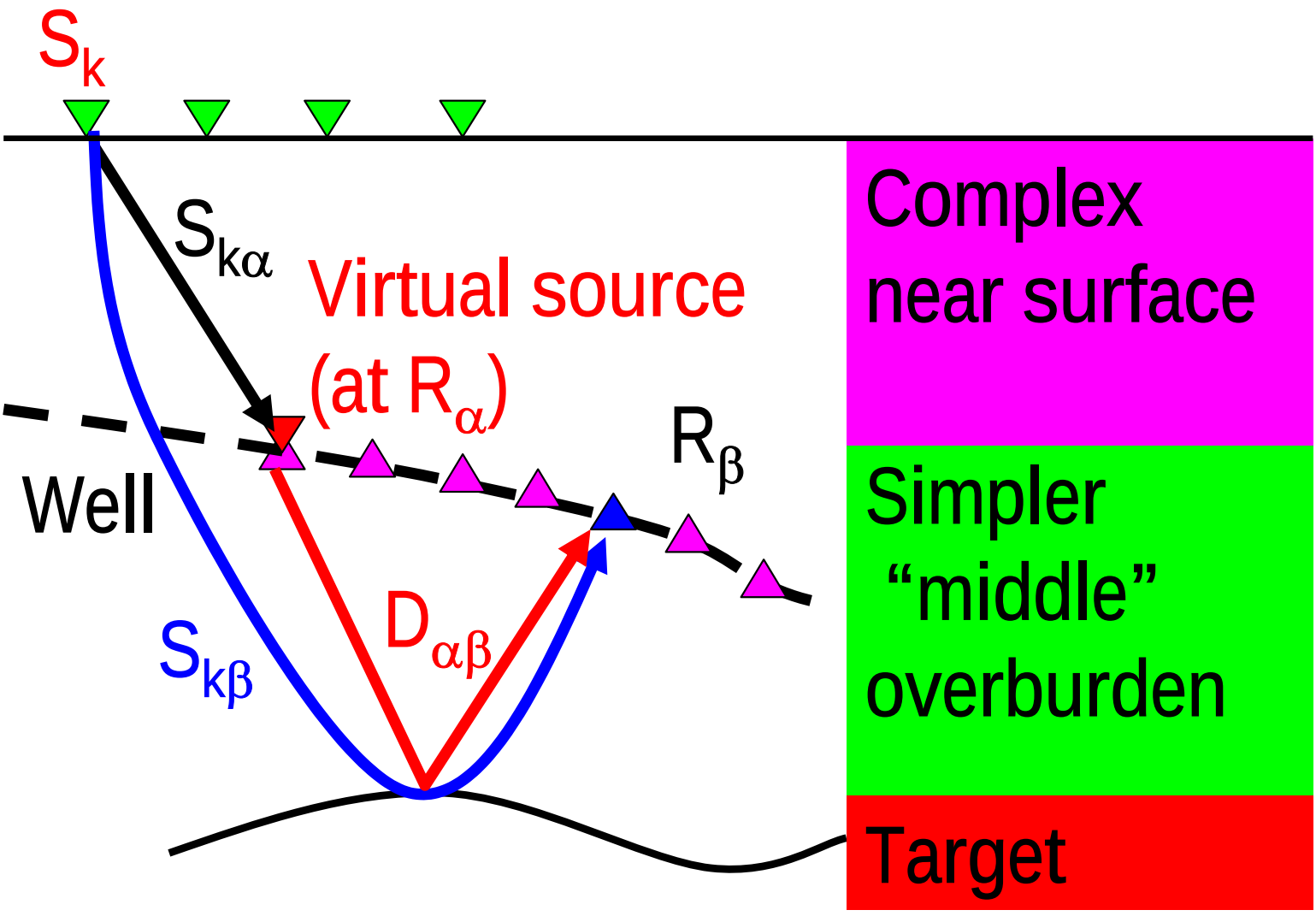
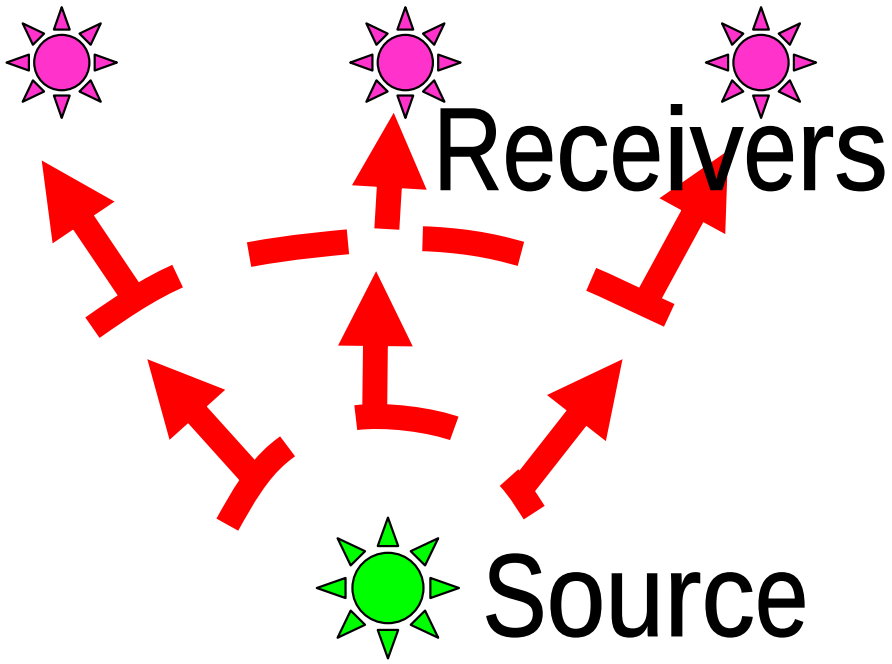


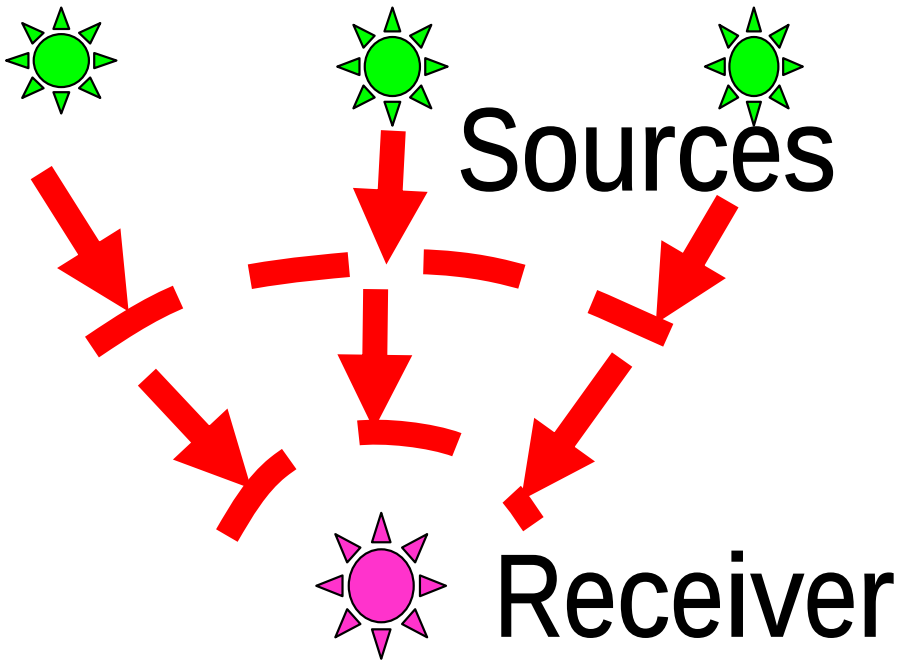
# Virtual Source

Surface array of sources that simulates virtual source

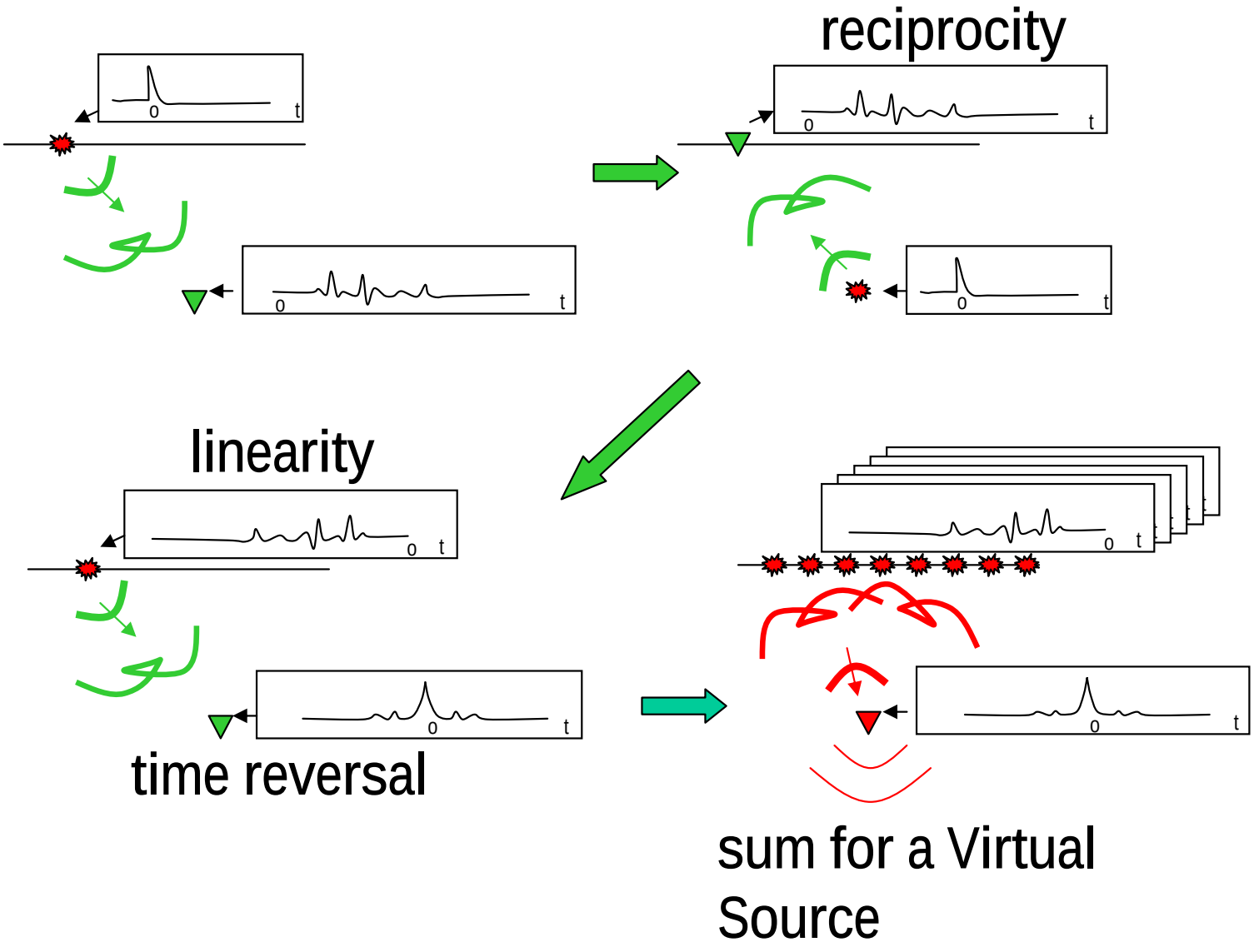


# Virtual Source by time reversal



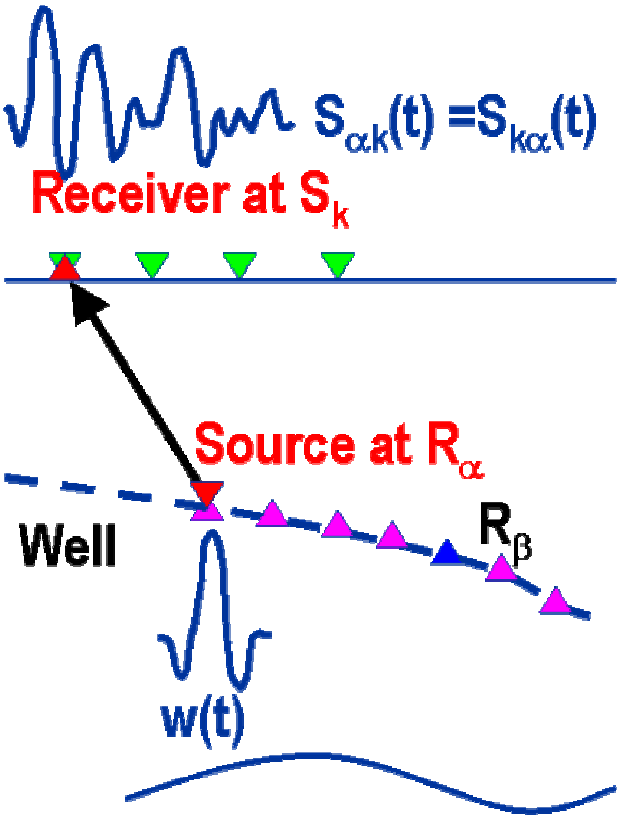



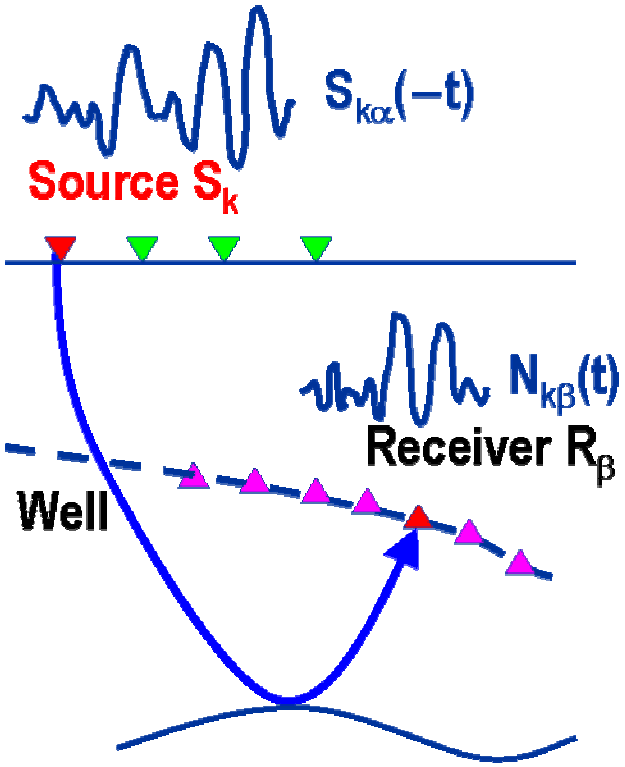
# Virtual Source as time reversal on a computer



# VS data

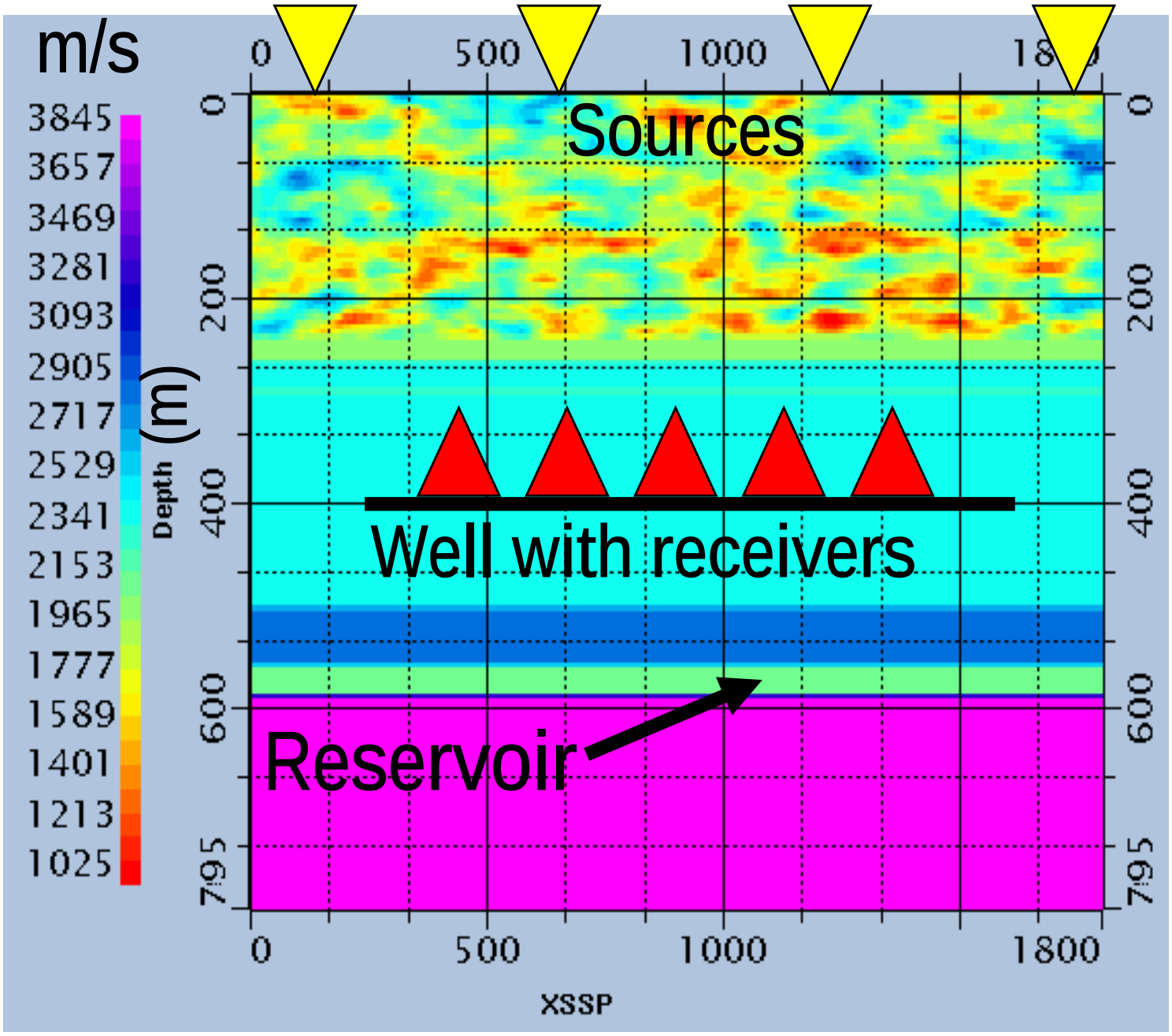
$$R_{\alpha\beta}(t) = \sum_{k=1}^{N} S_{k\alpha}(-t) \star T_{k\beta}(t)$$



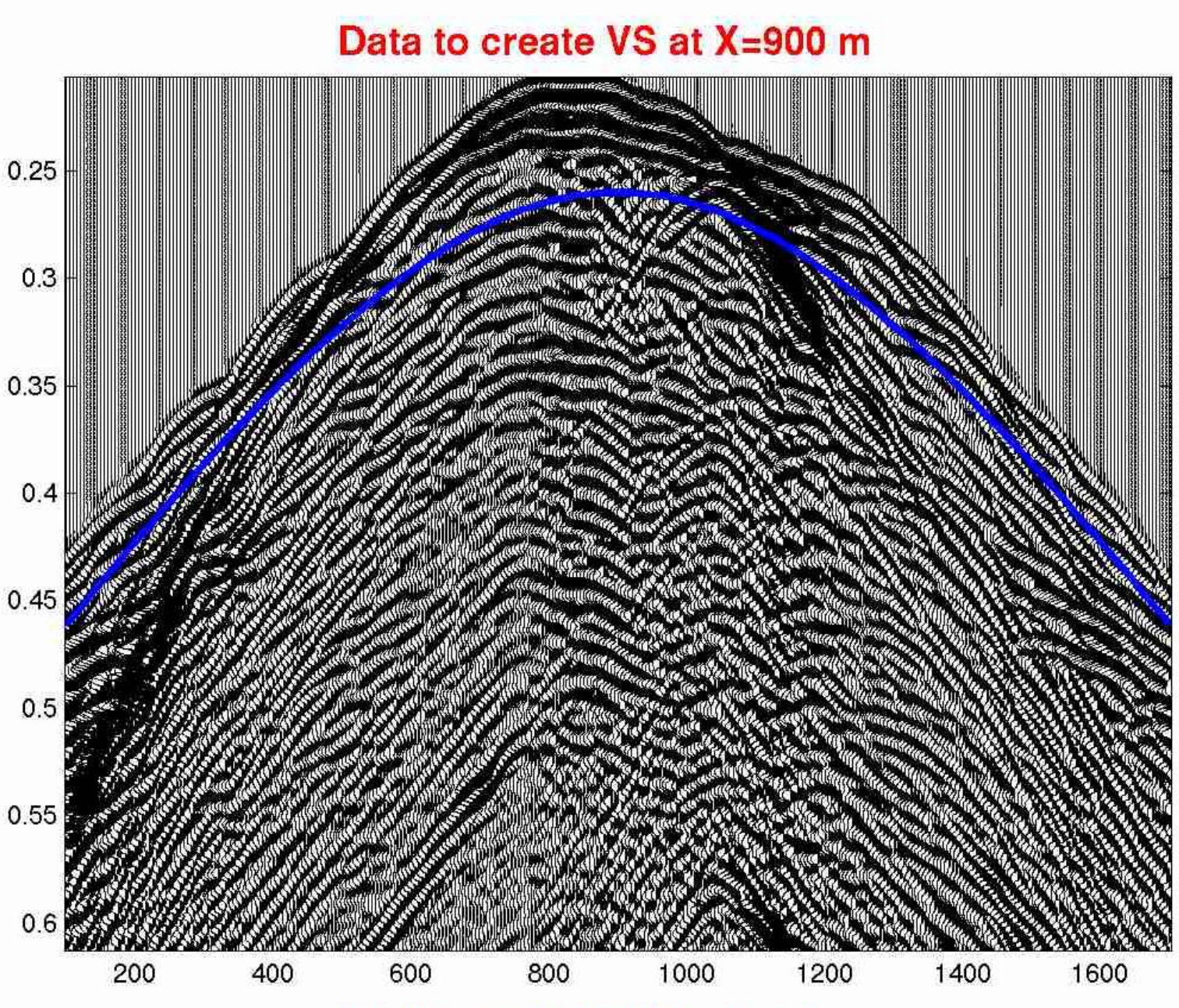



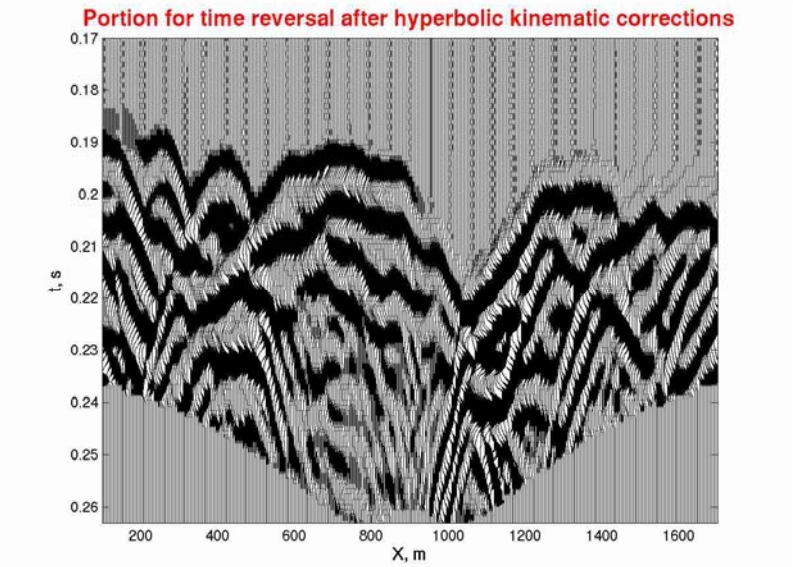
# Synthetic model with horrible overburden

## (full elastic finite-difference modeling)

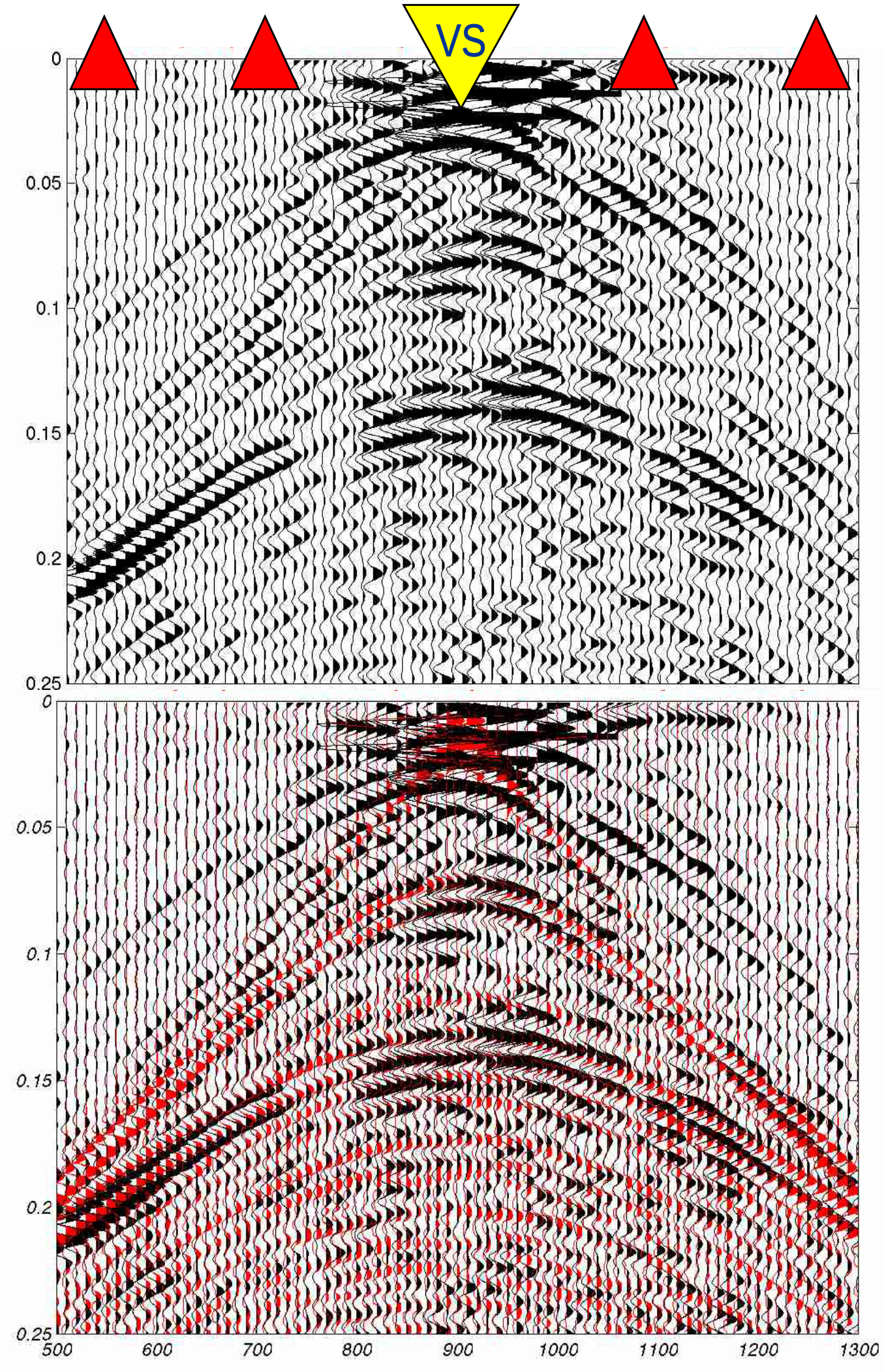


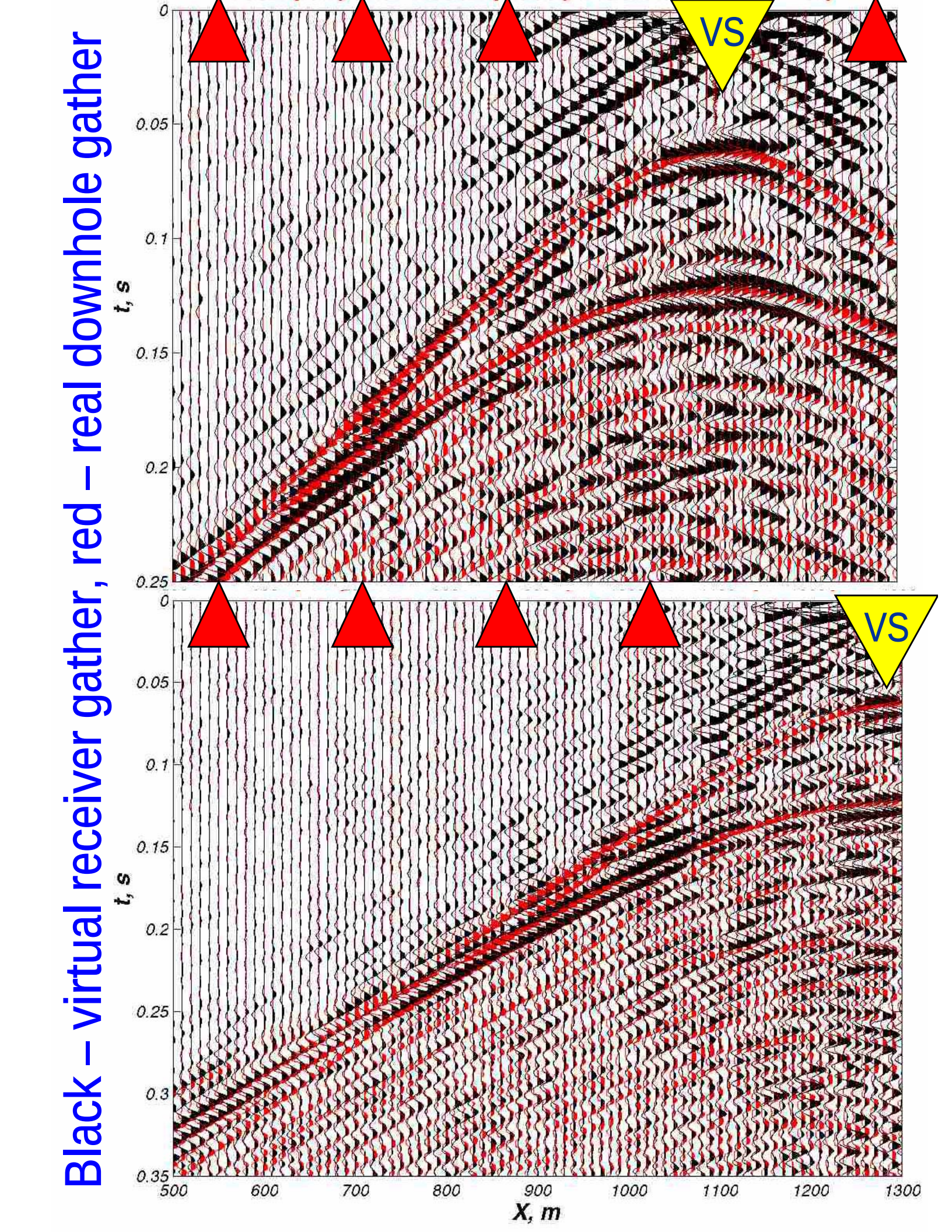
# Receiver gather



Black – virtual source gather, red – real downhole gather

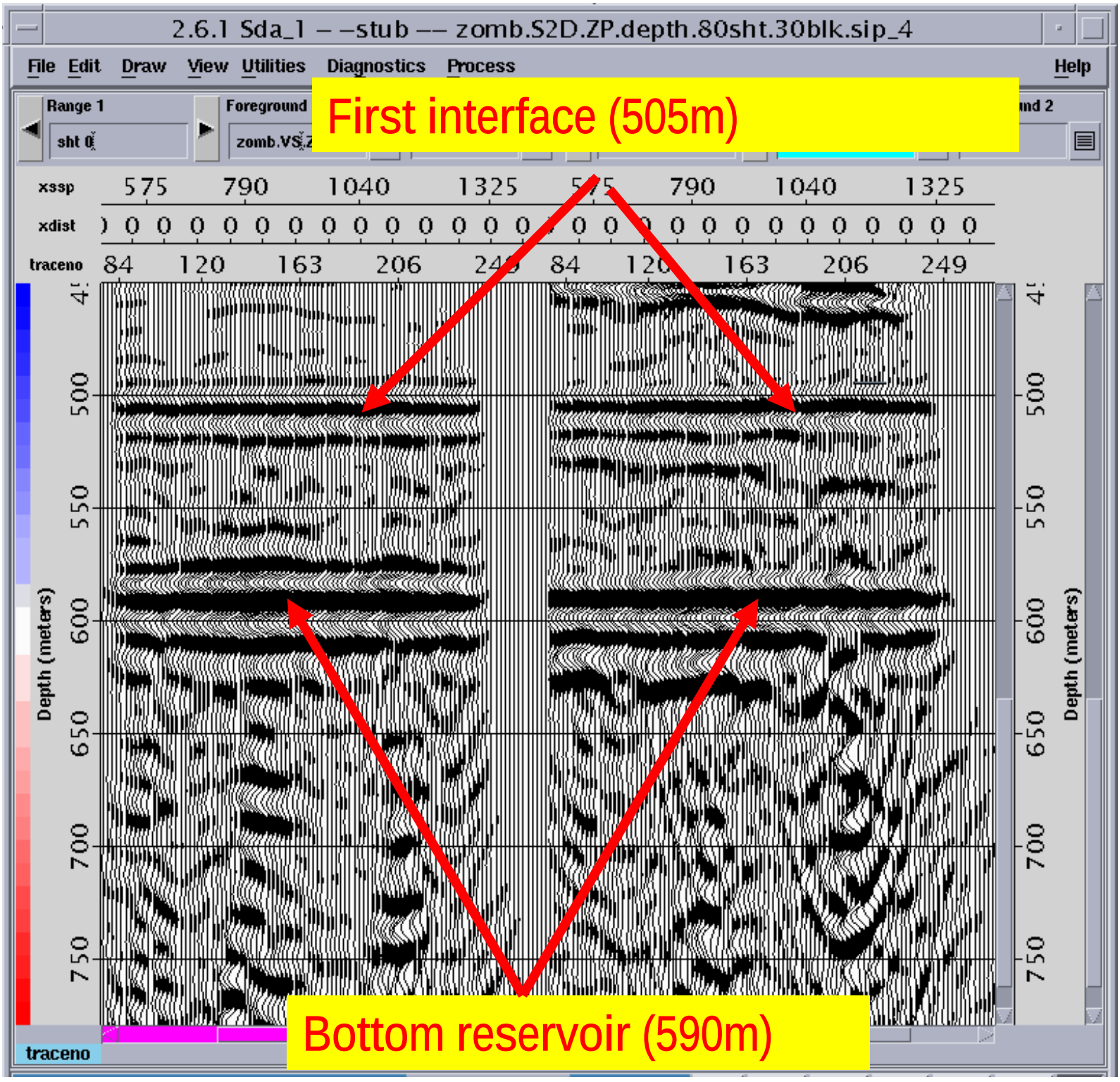



Black – virtual receiver gather, red – real downhole gather
VS
VS
t, s
X, m
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
500
600
700
800
900
1000
1100
1200
1300

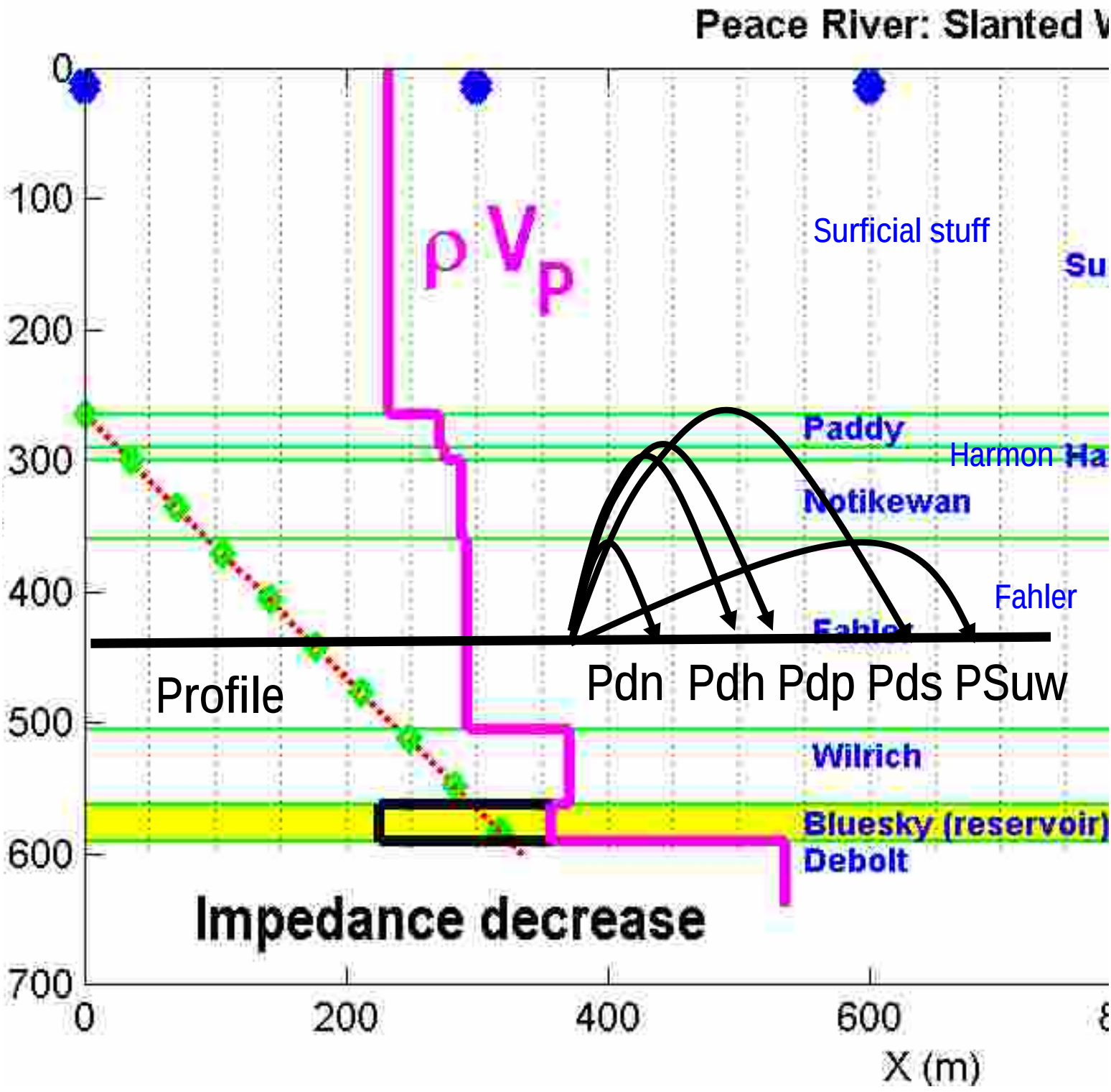
# PSDM comparisons

VS data:

Surface data:
migrated with exact velocity model of the overburden



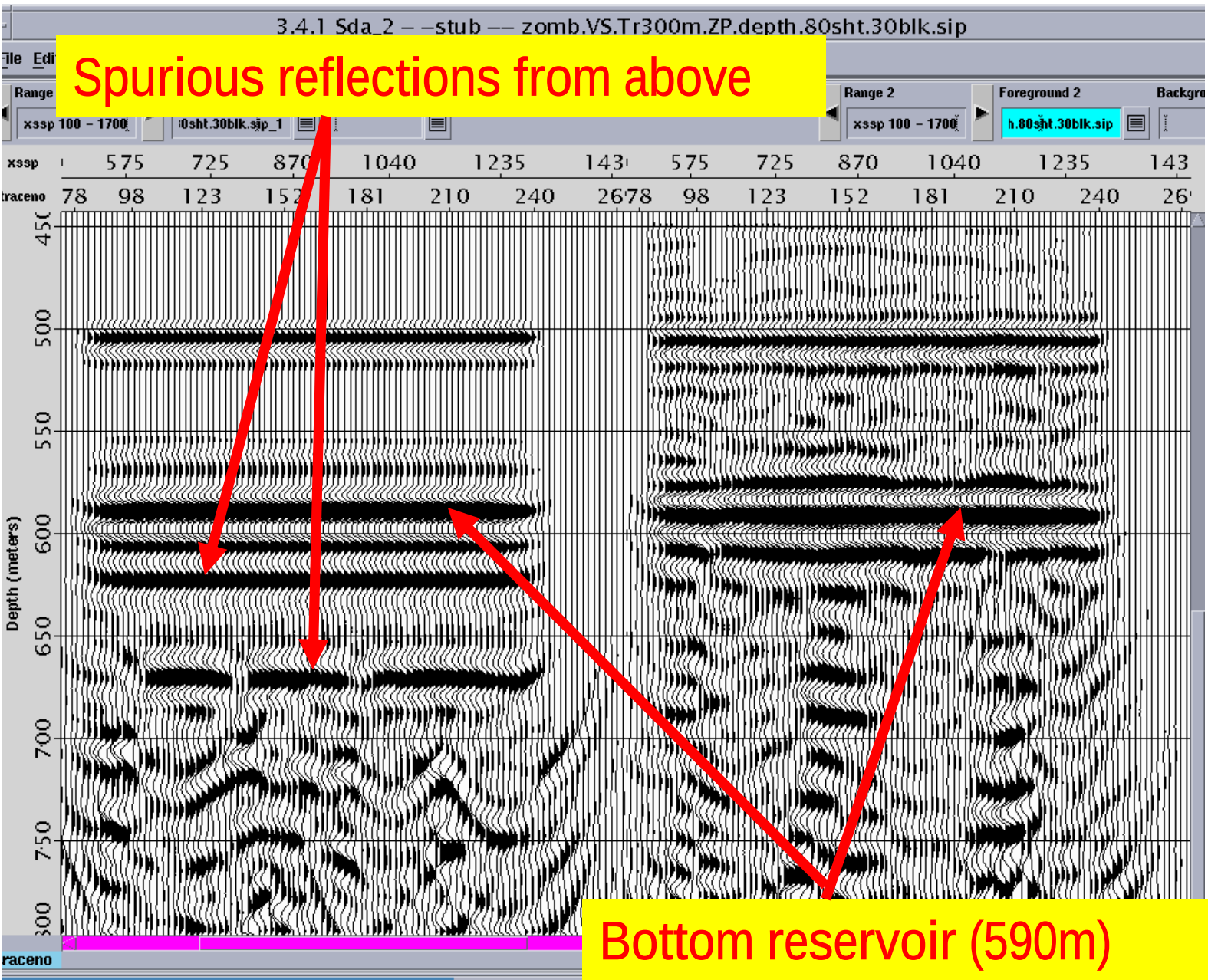
# Downgoing waves



# PSDM

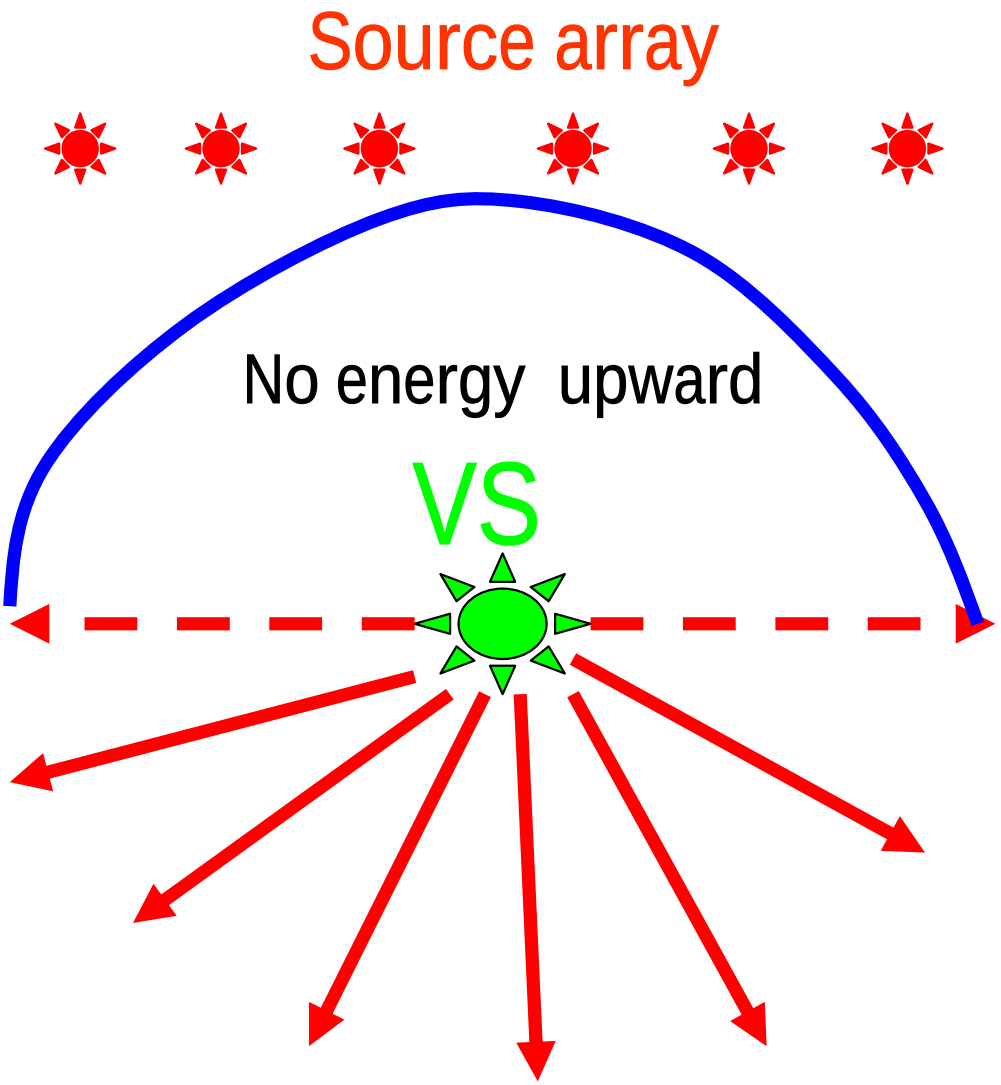
Real downhole data

VS data



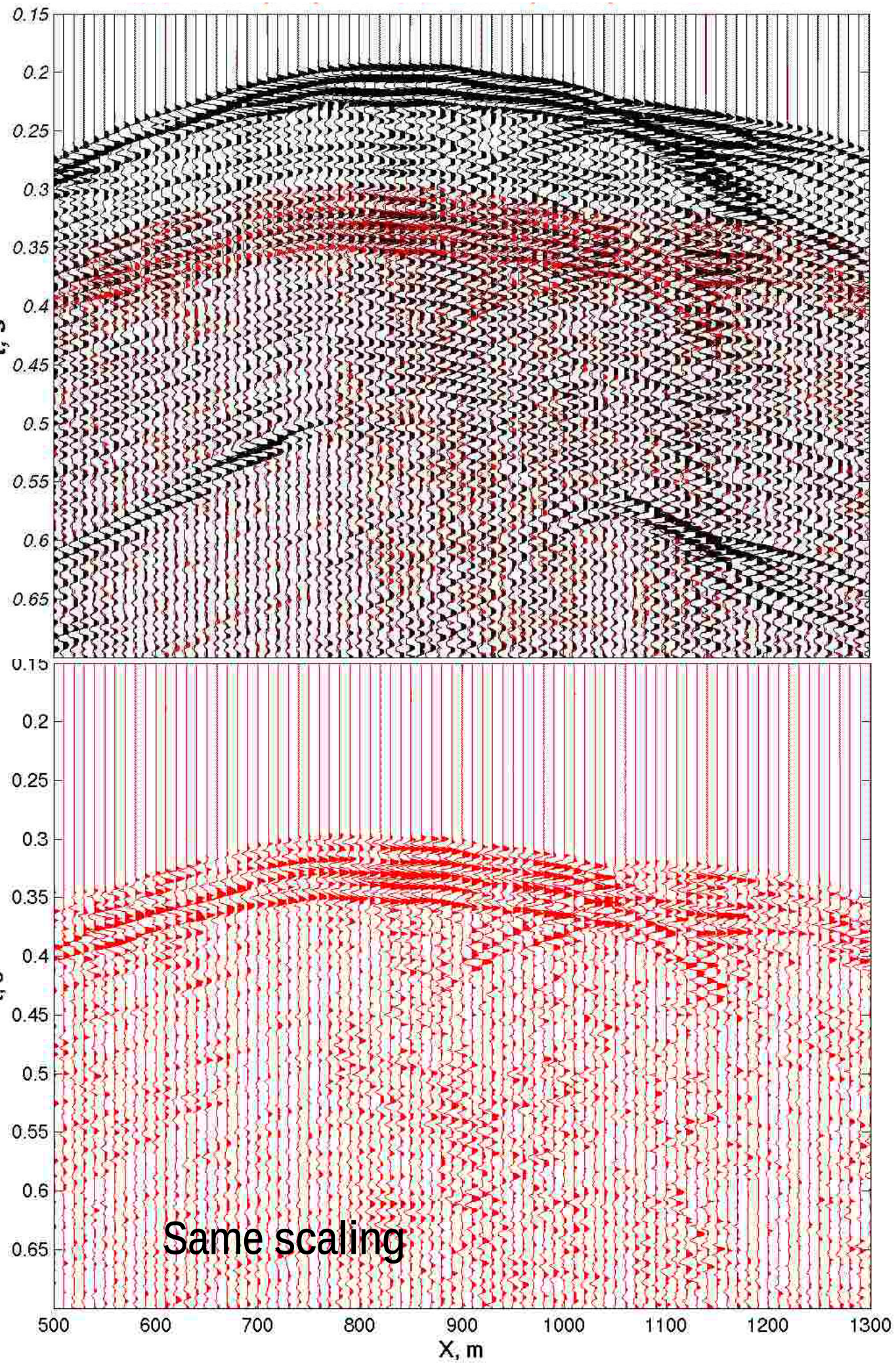
# Radiation pattern of Virtual Source

- 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

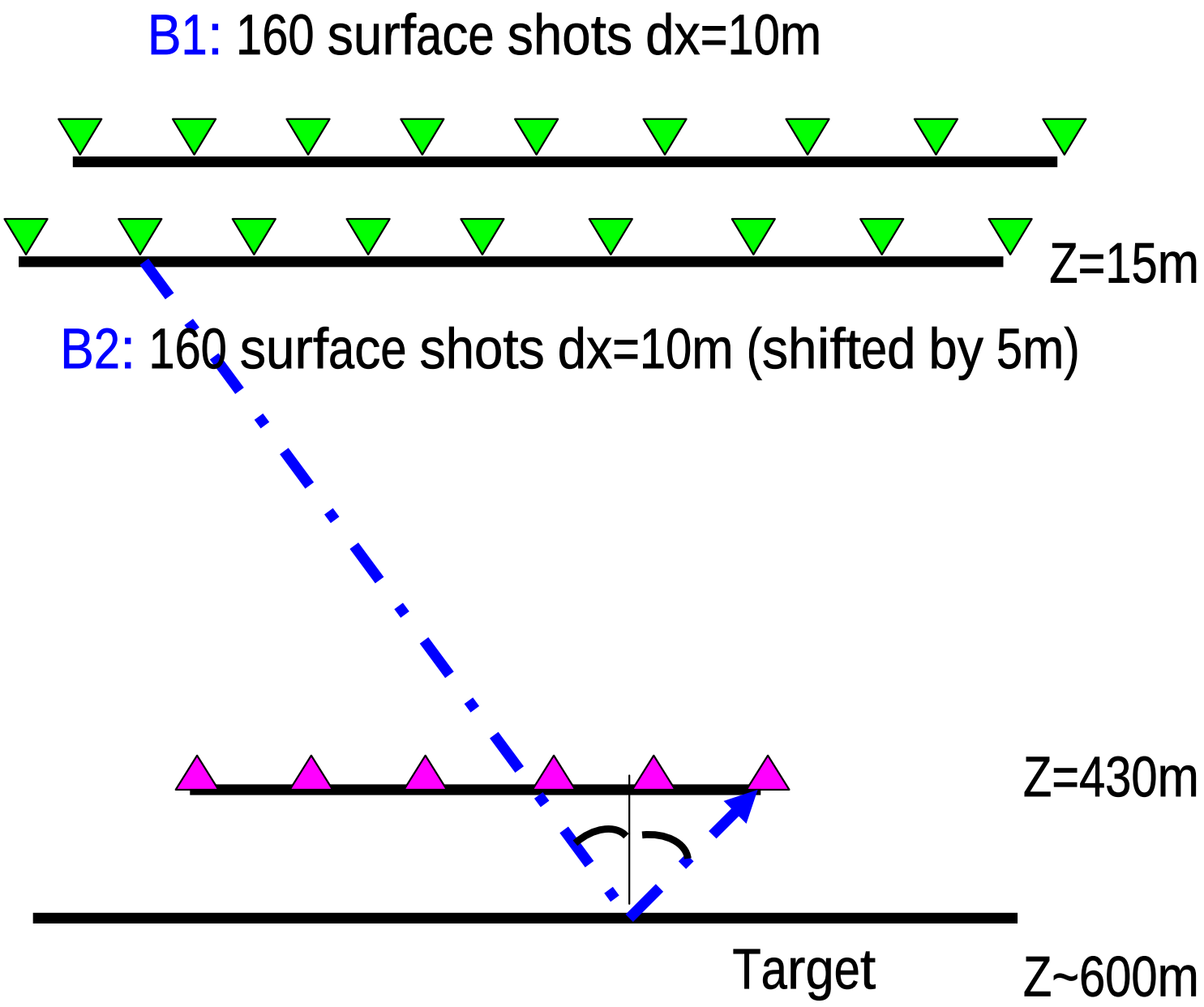


# PERFECTLY REPEATING GEOMETRY

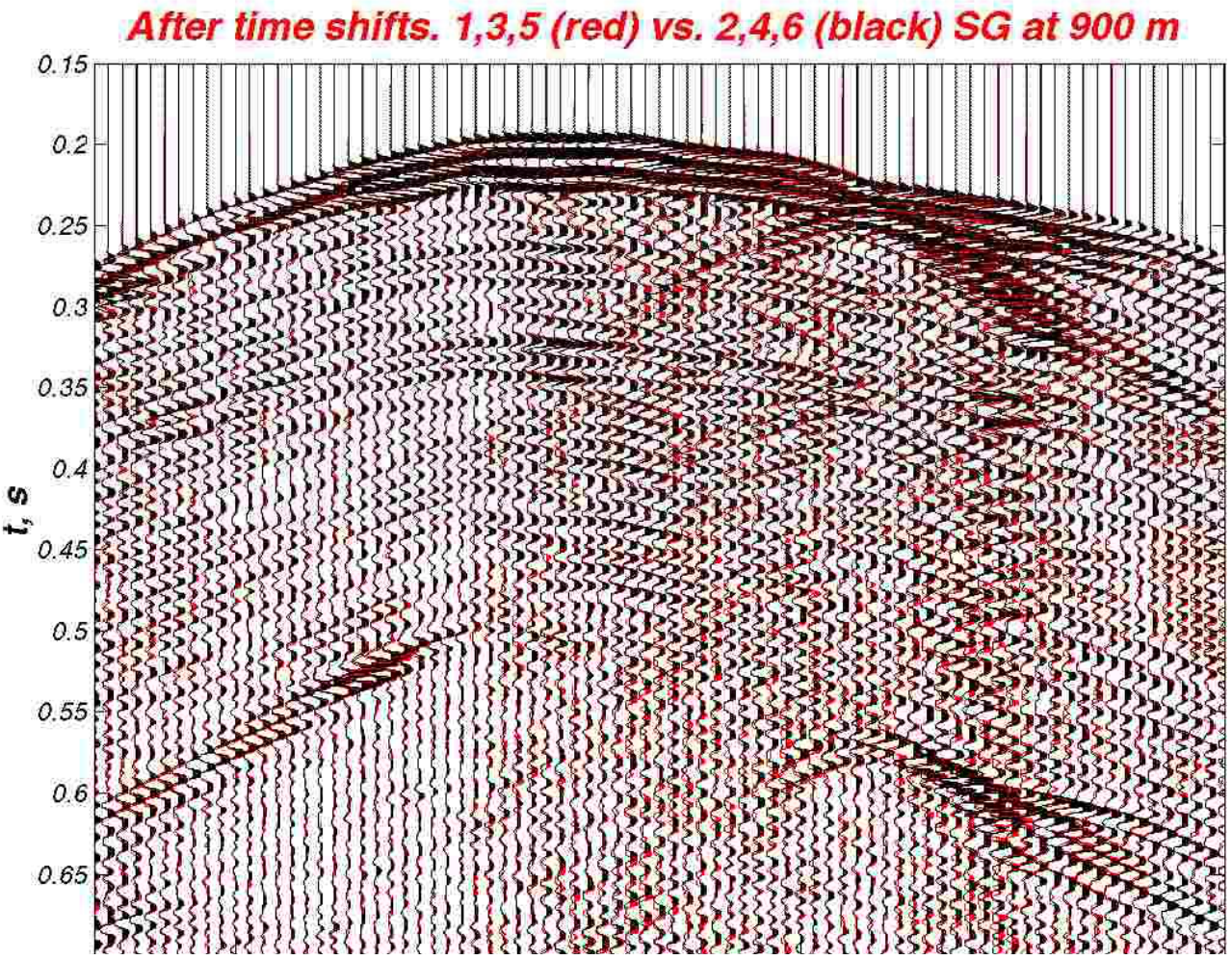
## Surface data: monitor/baseline (top) and difference (bottom)

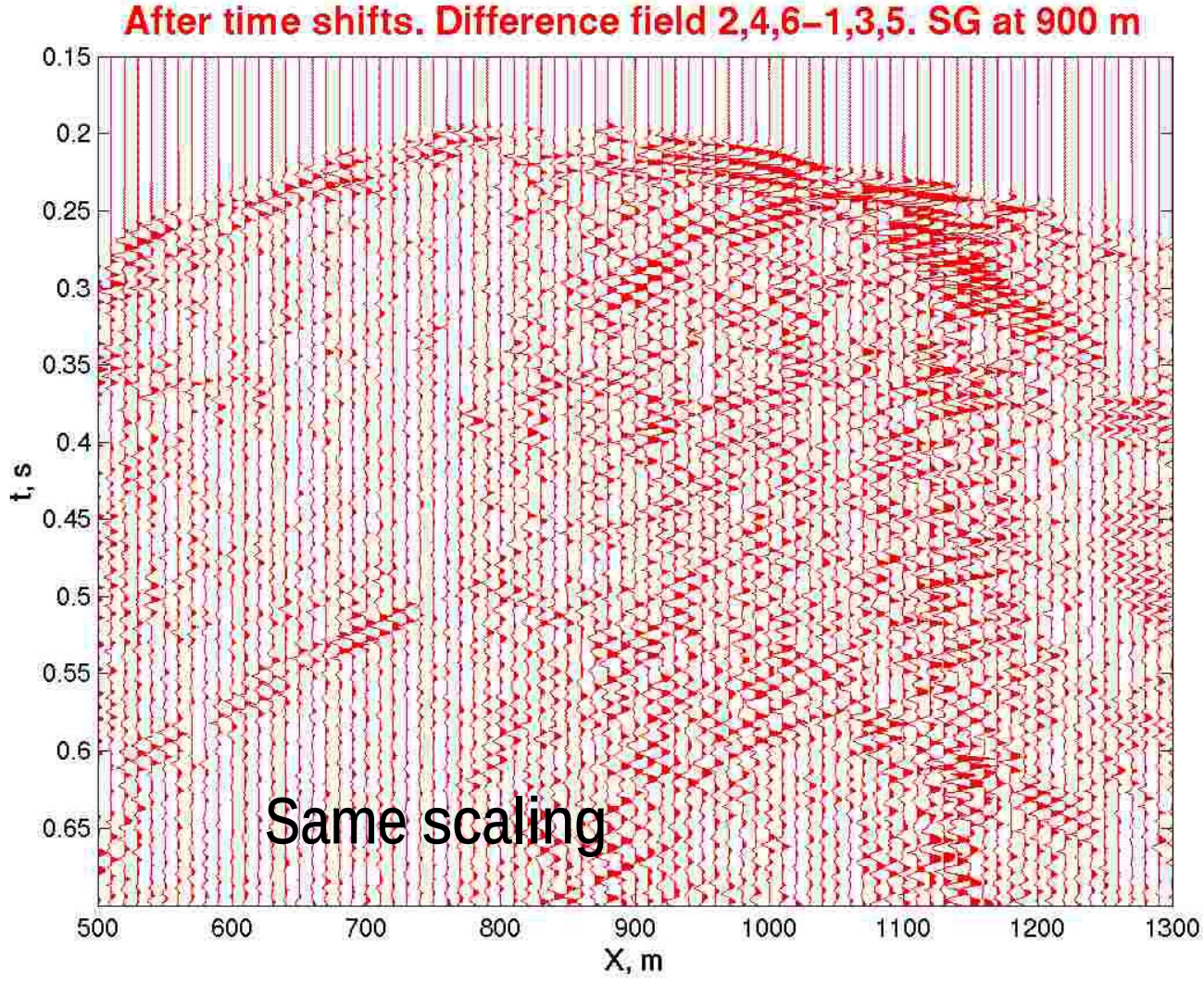


# Comparing baseline shifted by 5m

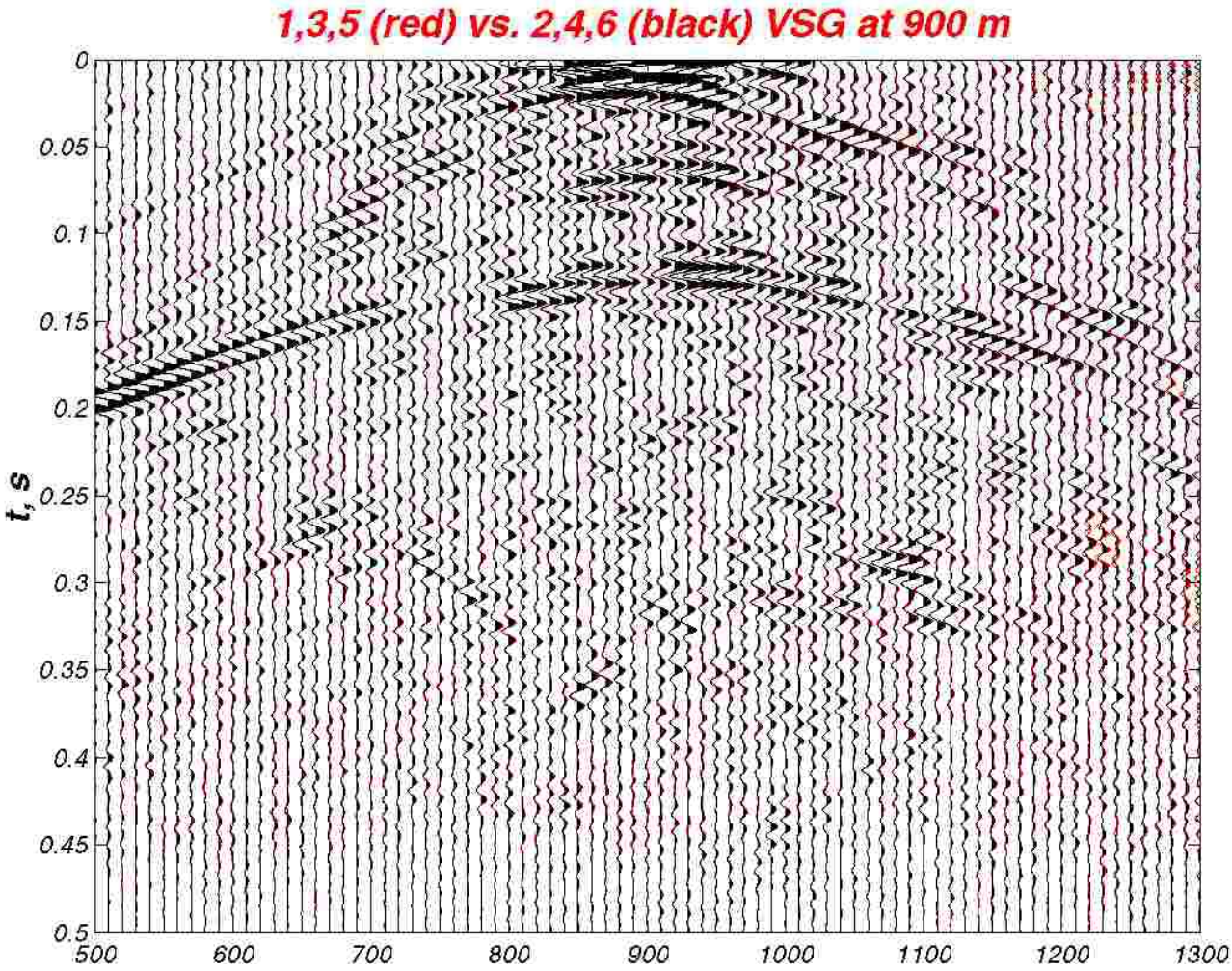


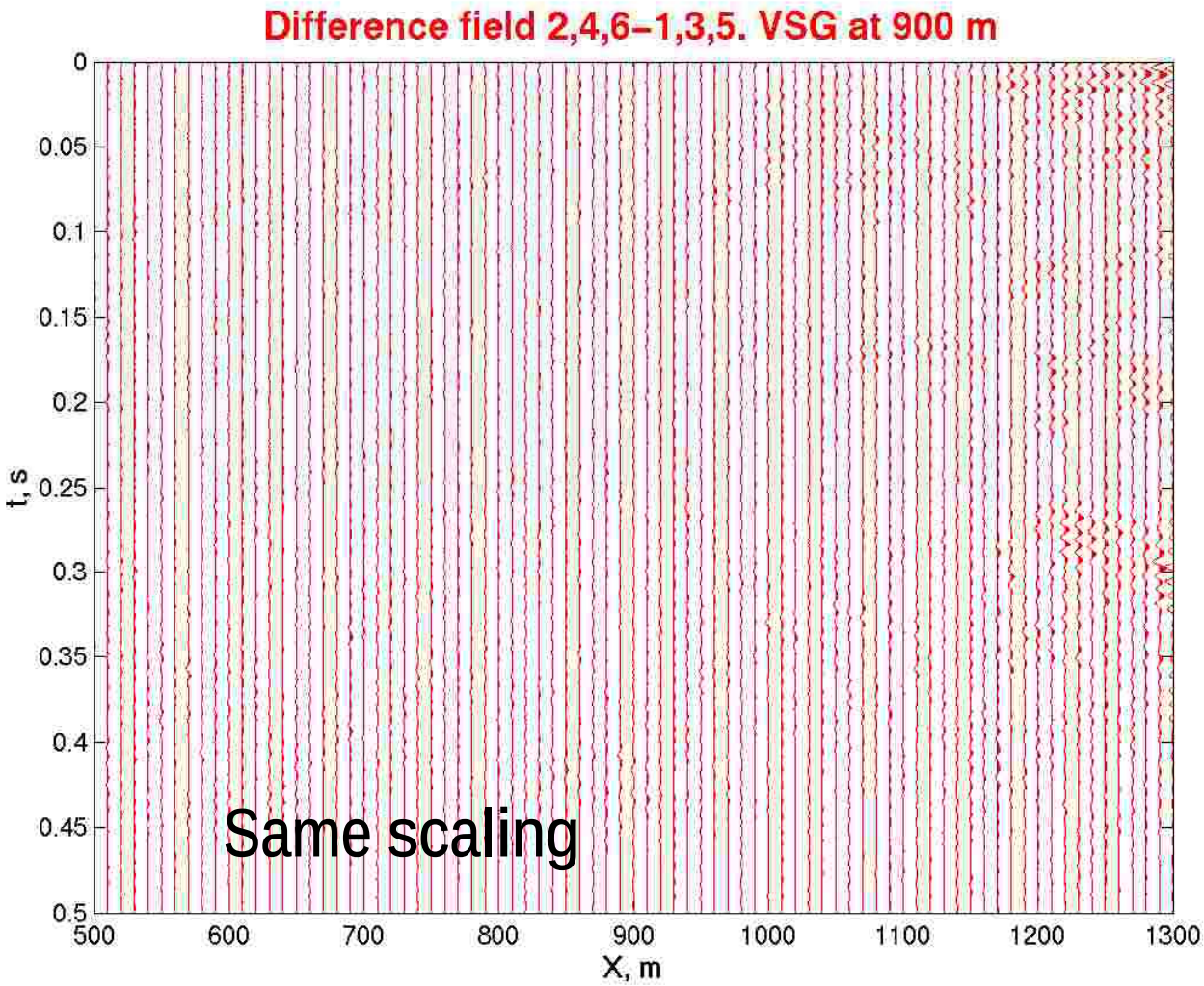
After "4D static" (time shifts introduced to match 1 and 2)



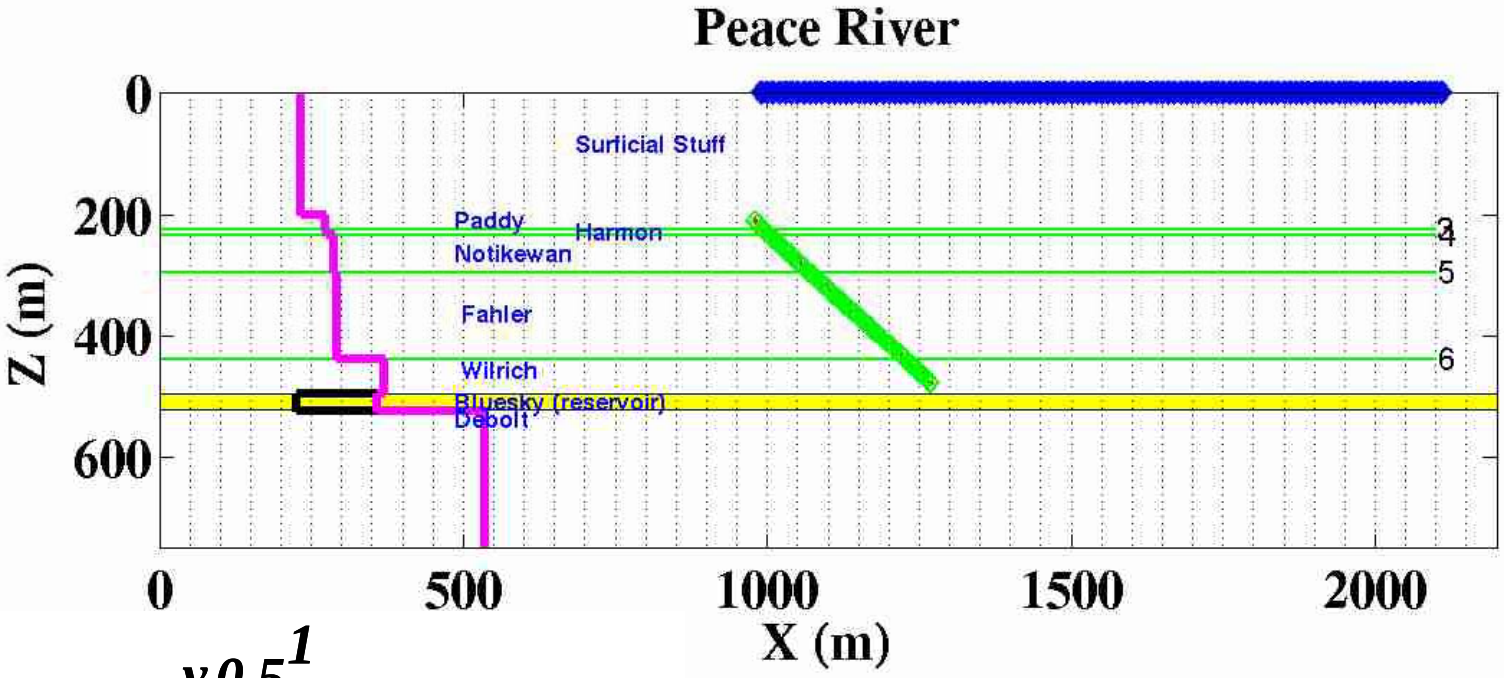
VS gathers from dataset 1 and 2, and difference (bottom)

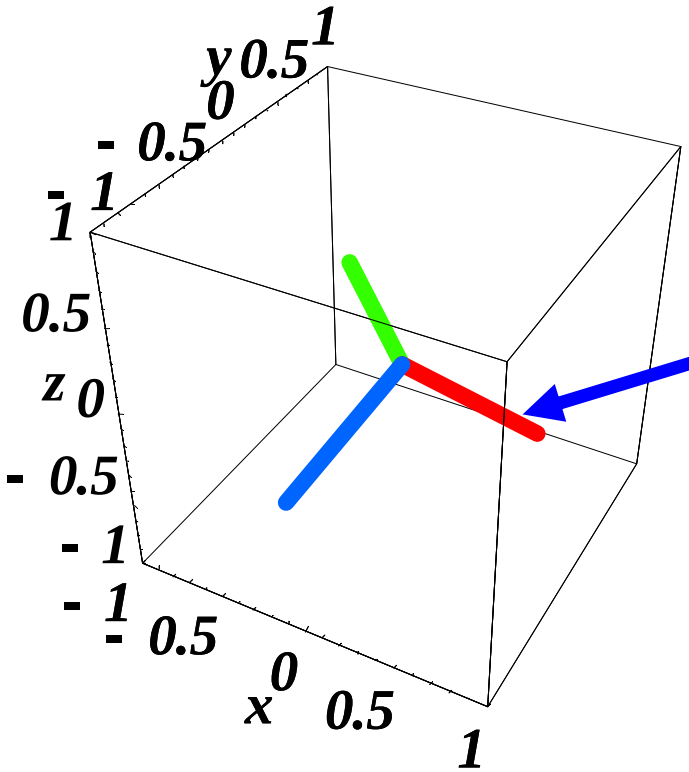


# Peace River 4D VSP

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

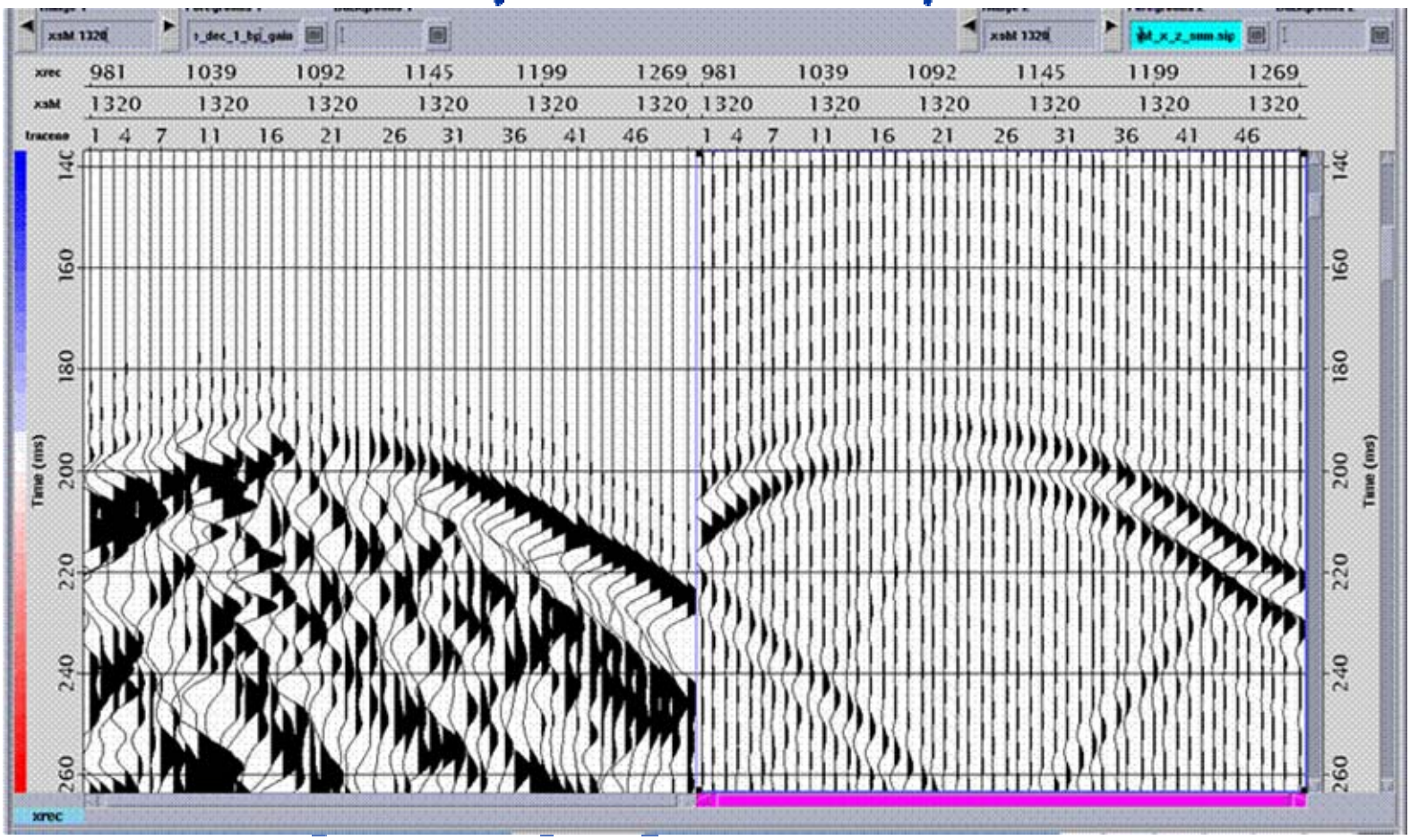


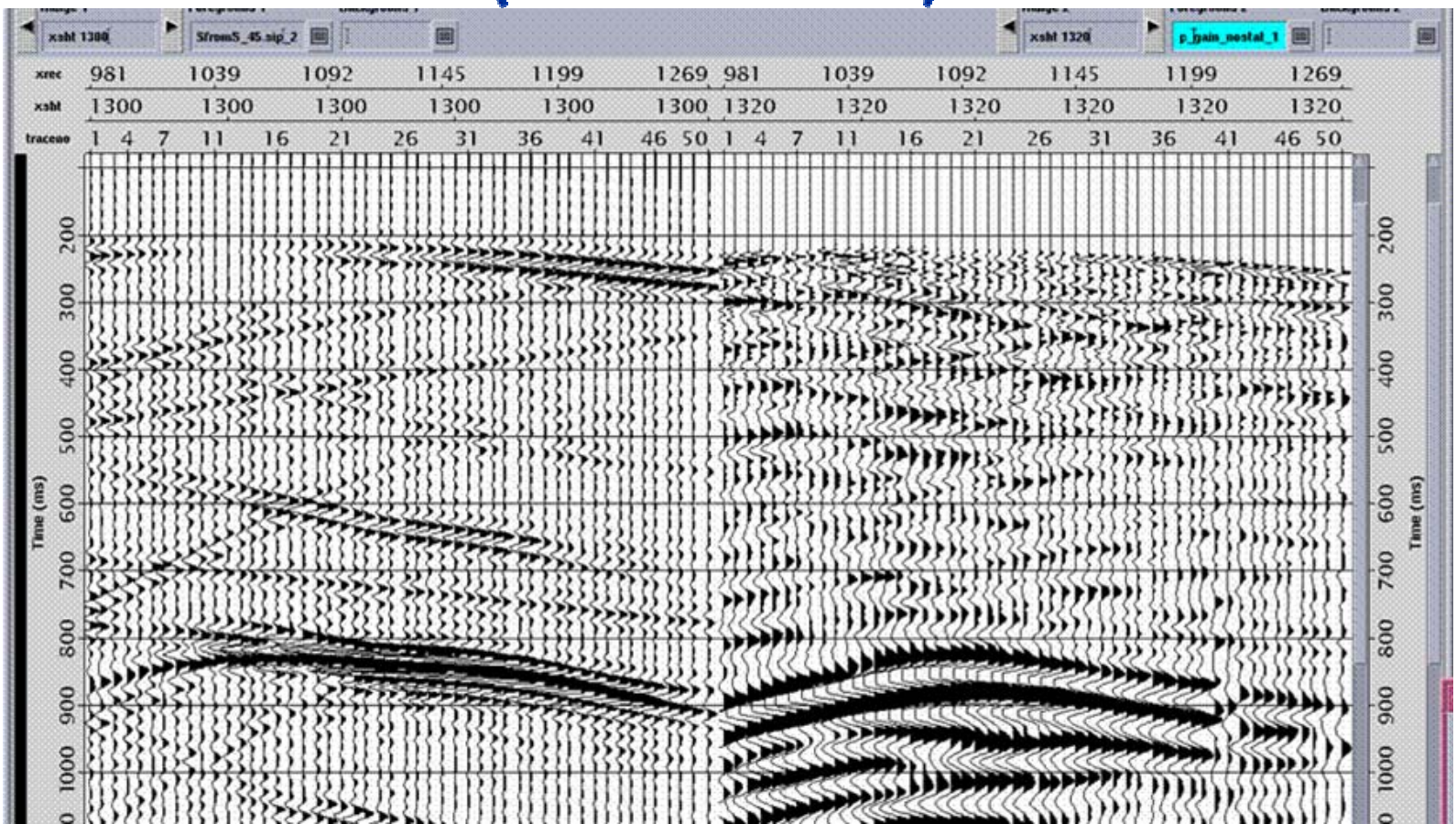

Component used for initial study, along-the-well ($45^0$)

# Comparing synthetic vs. real

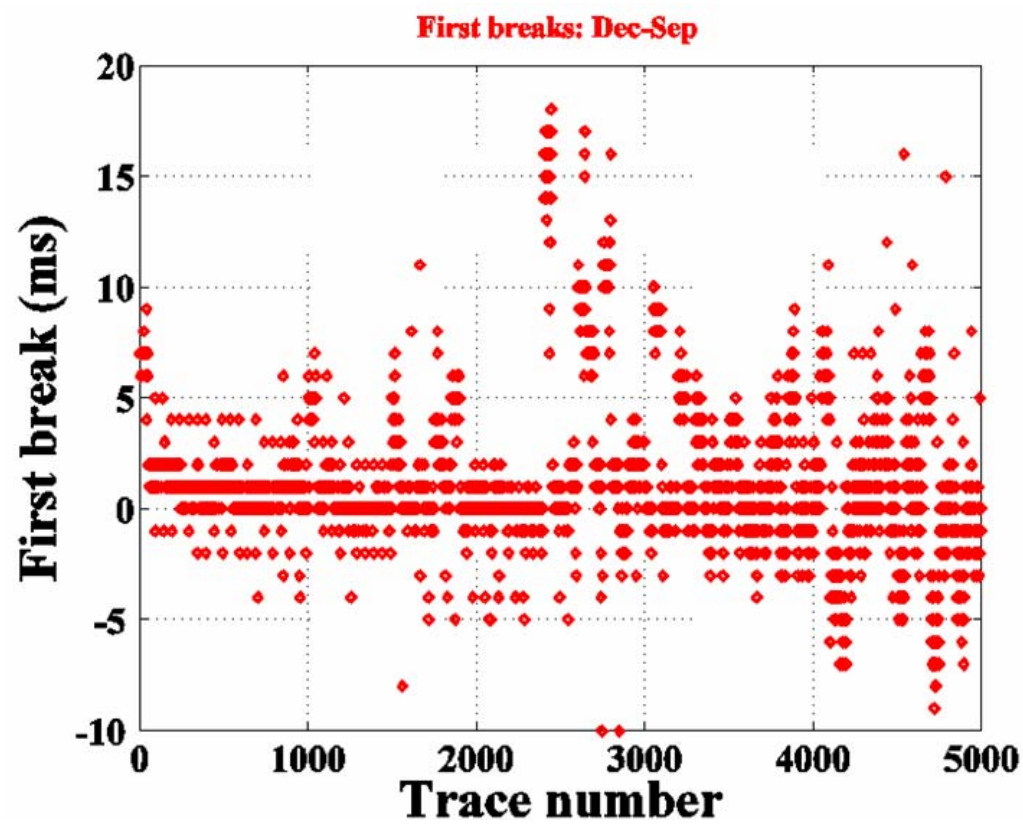
## (first arrivals)

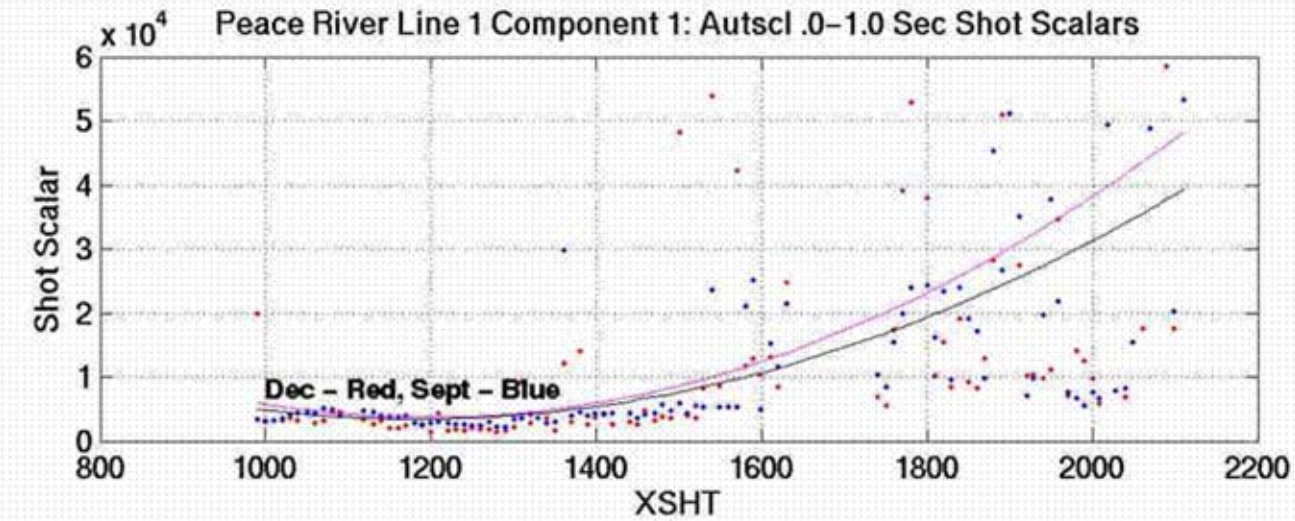


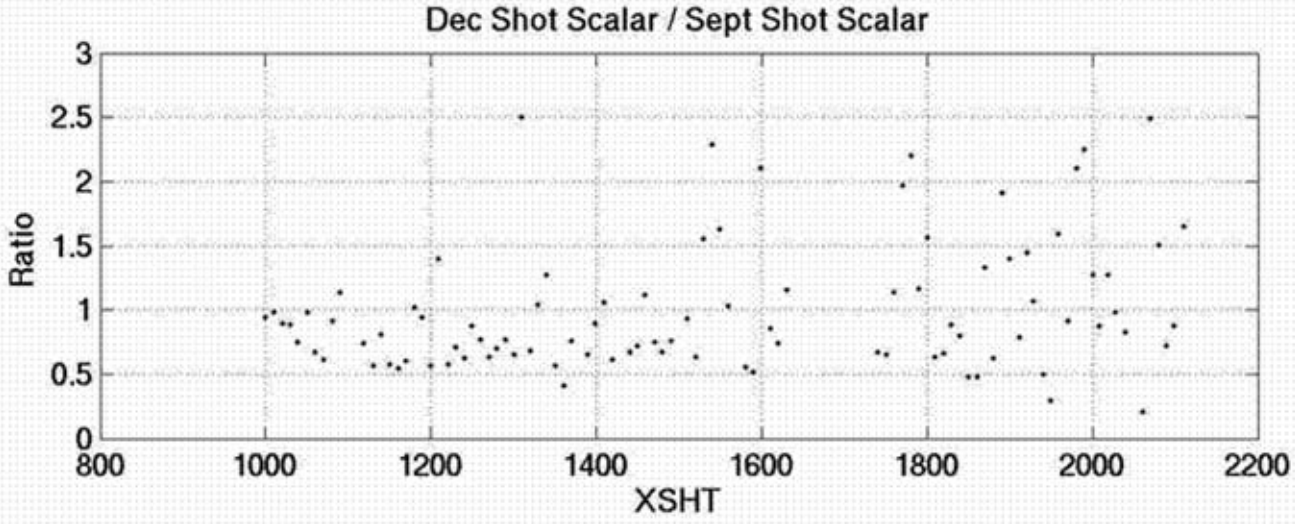

## (later arrivals)



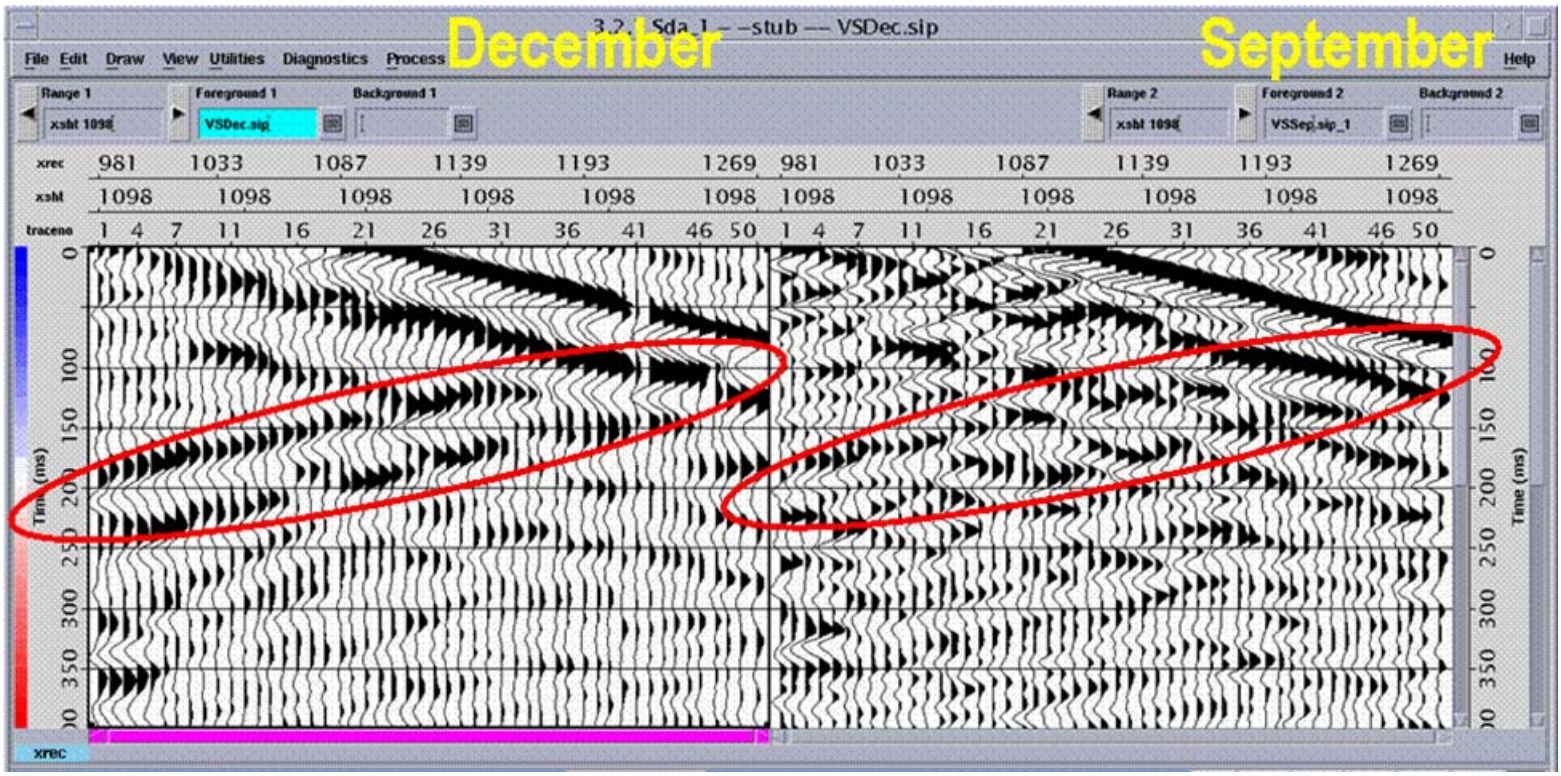
# 4D static


First breaks: Dec-Sep
First break (ms)
Trace number
20
15
10
5
0
-5
-10
0
1000
2000
3000
4000
5000

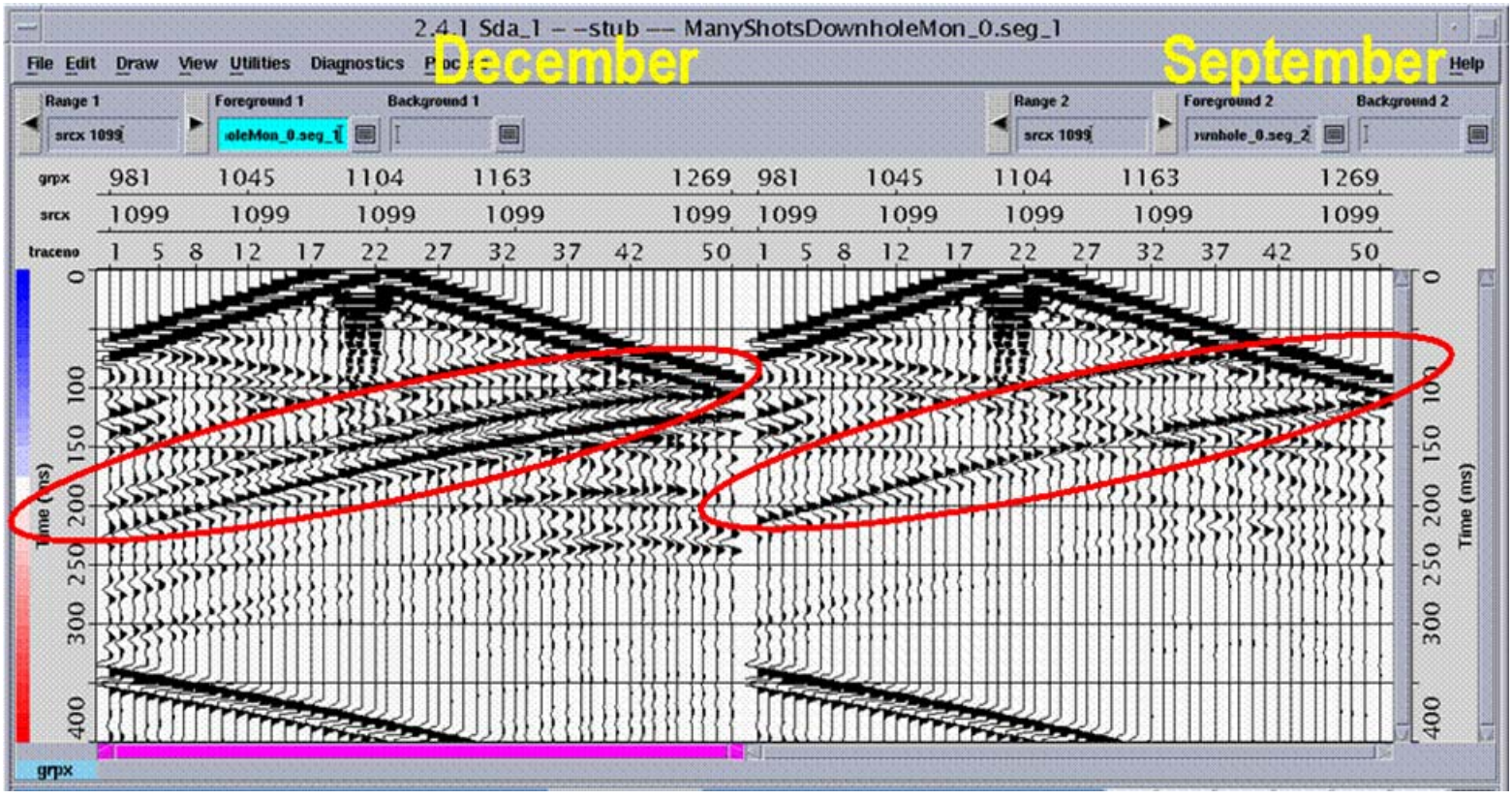

Peace River Line 1 Component 1: Autscl .0–1.0 Sec Shot Scalars
x 10^4
Shot Scalar
Dec – Red, Sept – Blue
XSHT
800
1000
1200
1400
1600
1800
2000
2200


Dec Shot Scalar / Sept Shot Scalar
Ratio
XSHT
0
0.5
1
1.5
2
2.5
3
800
1000
1200
1400
1600
1800
2000
2200

# Pre-stack VS

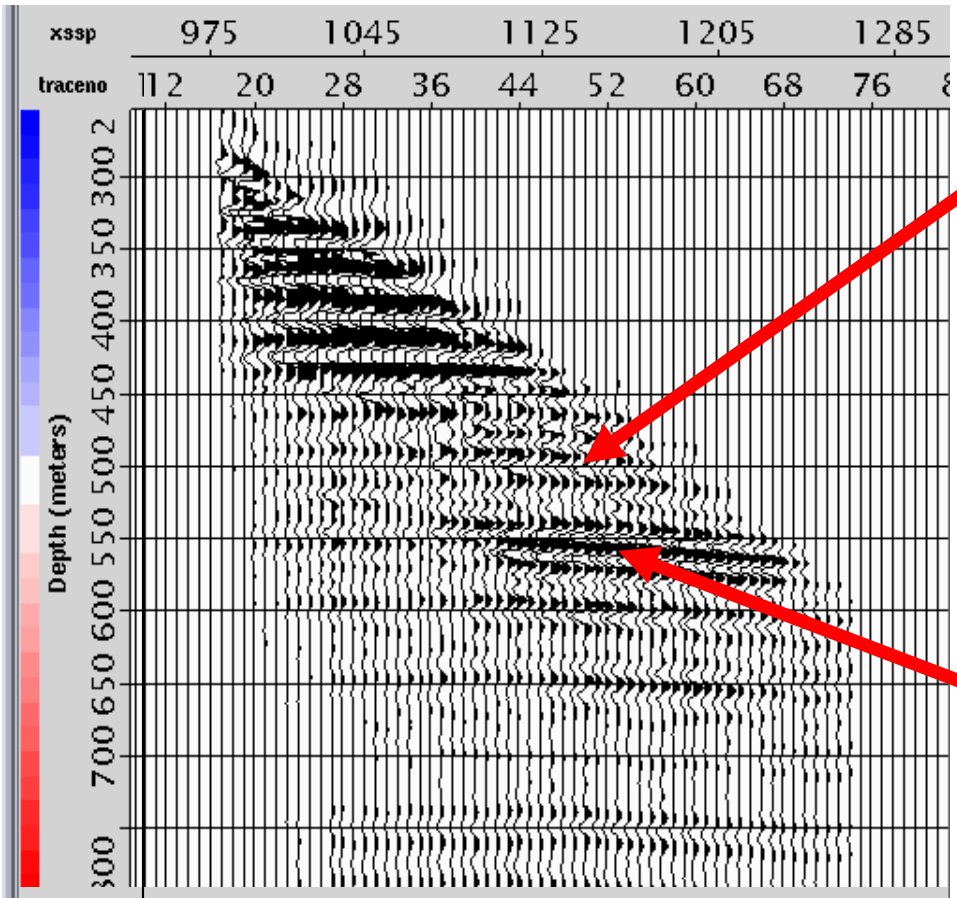



# Synthetic VS



# Virtual Source

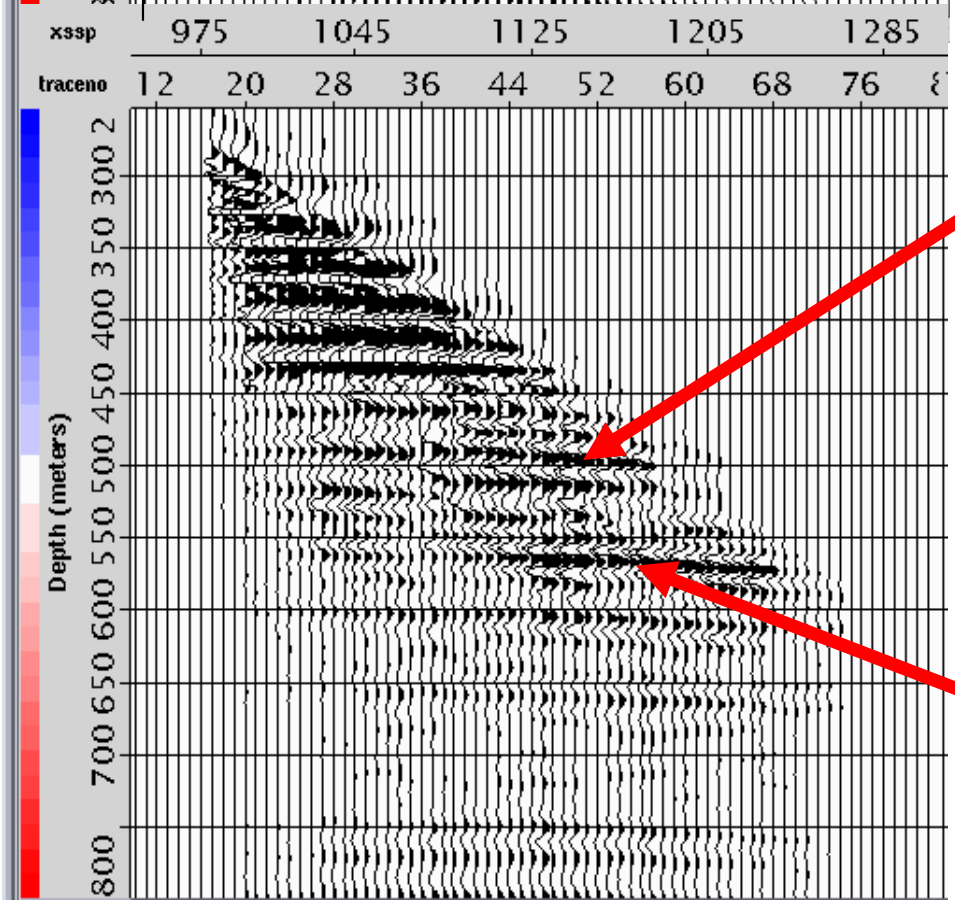
base




Top

Bottom

monitor

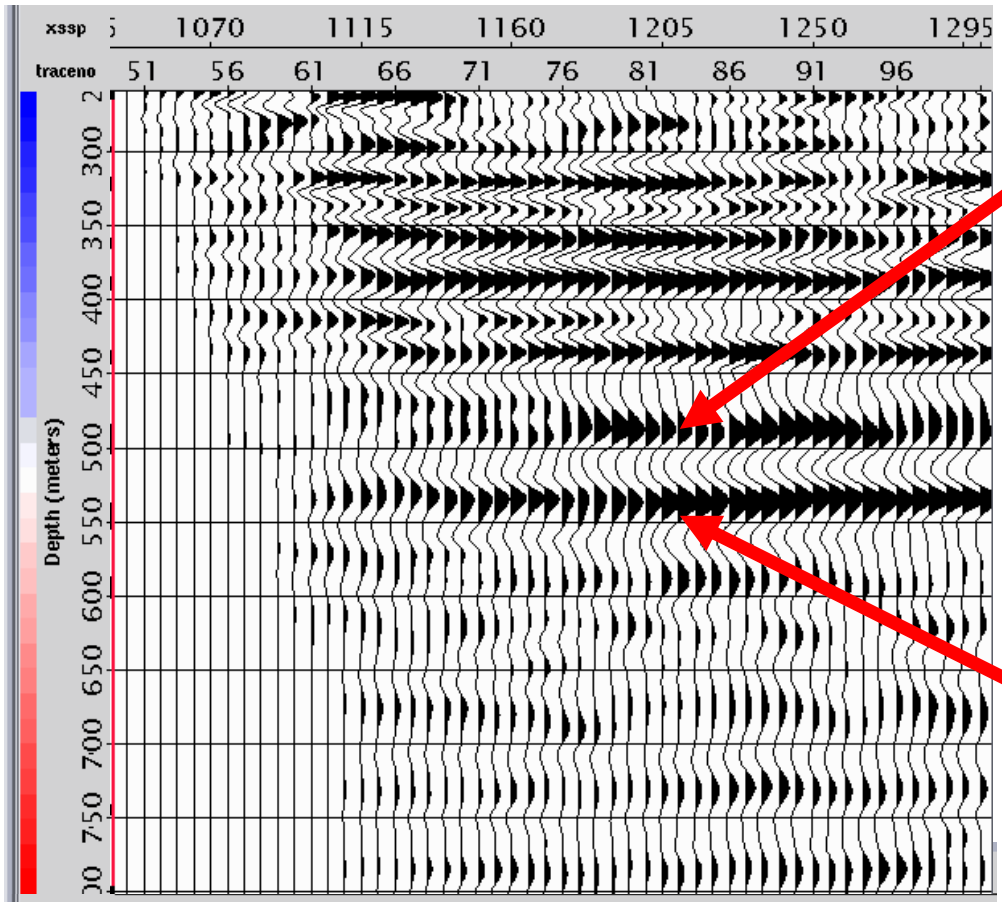



Top

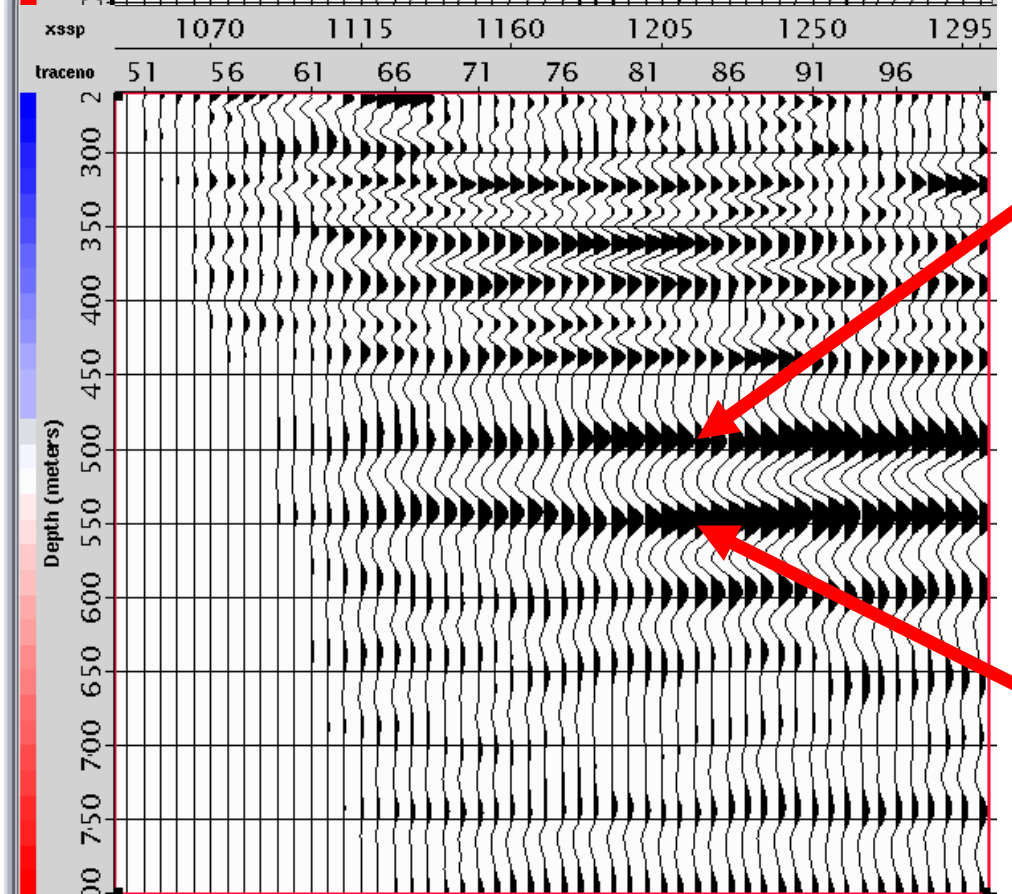
Bottom

# 4D surface seismic

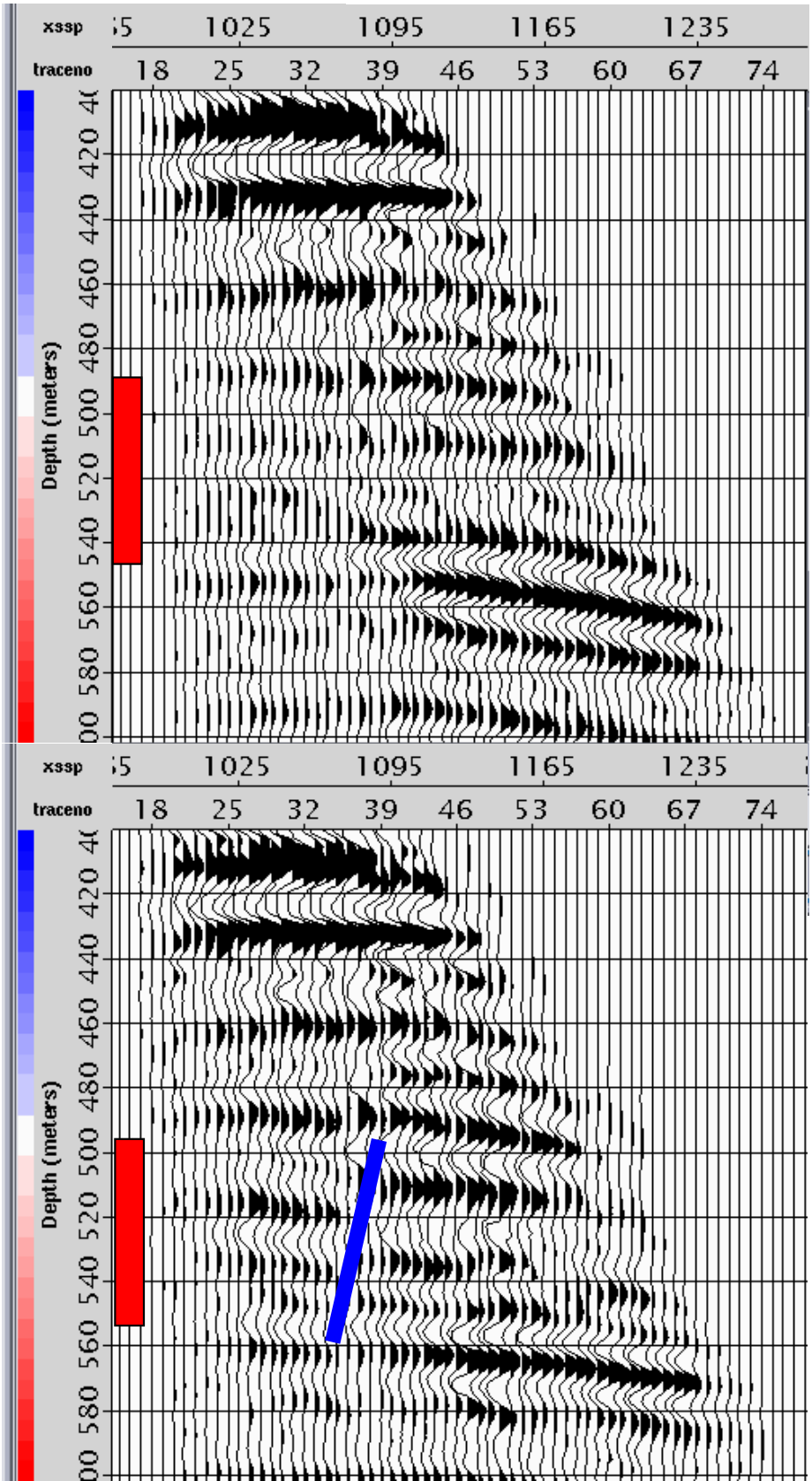
base



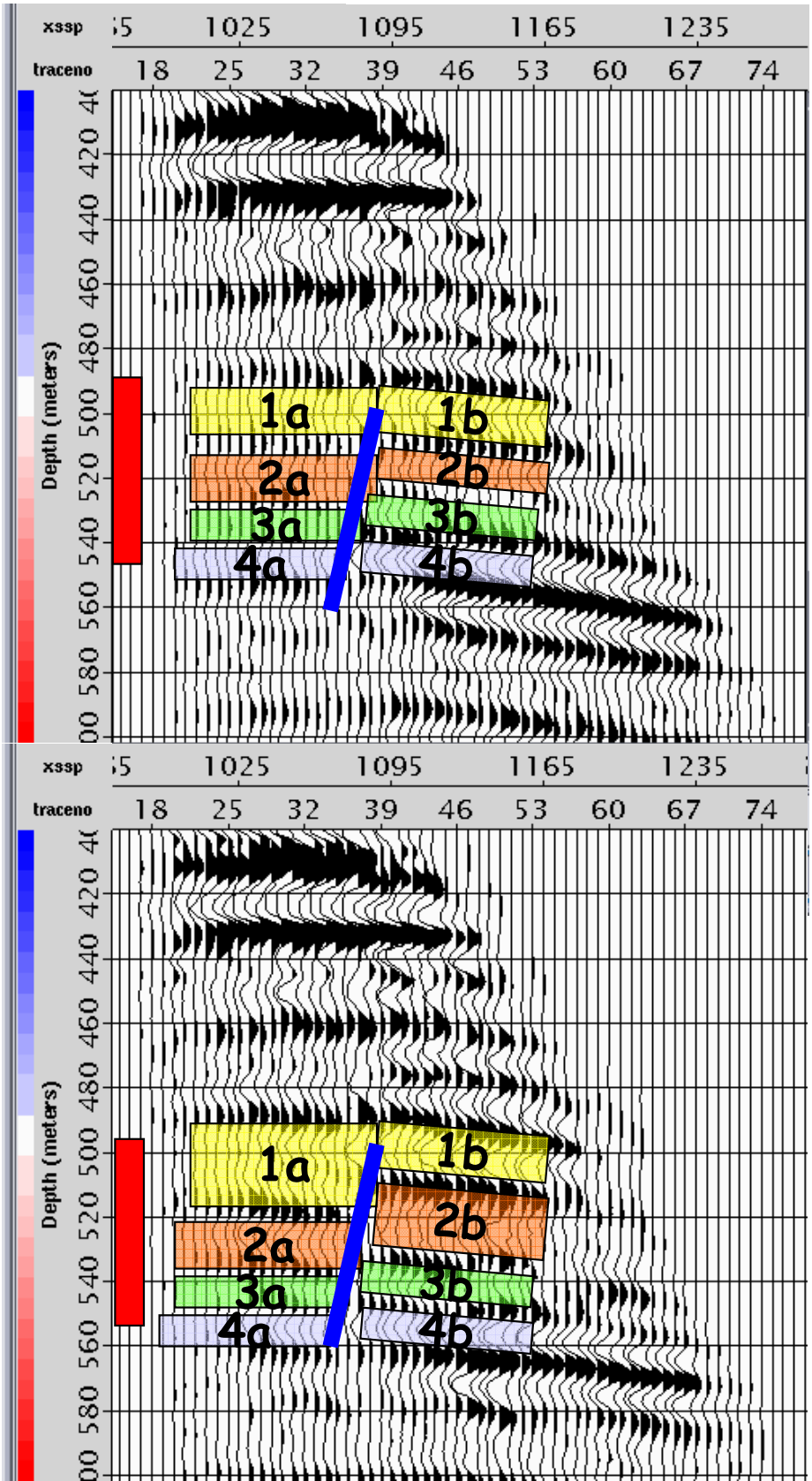

monitor



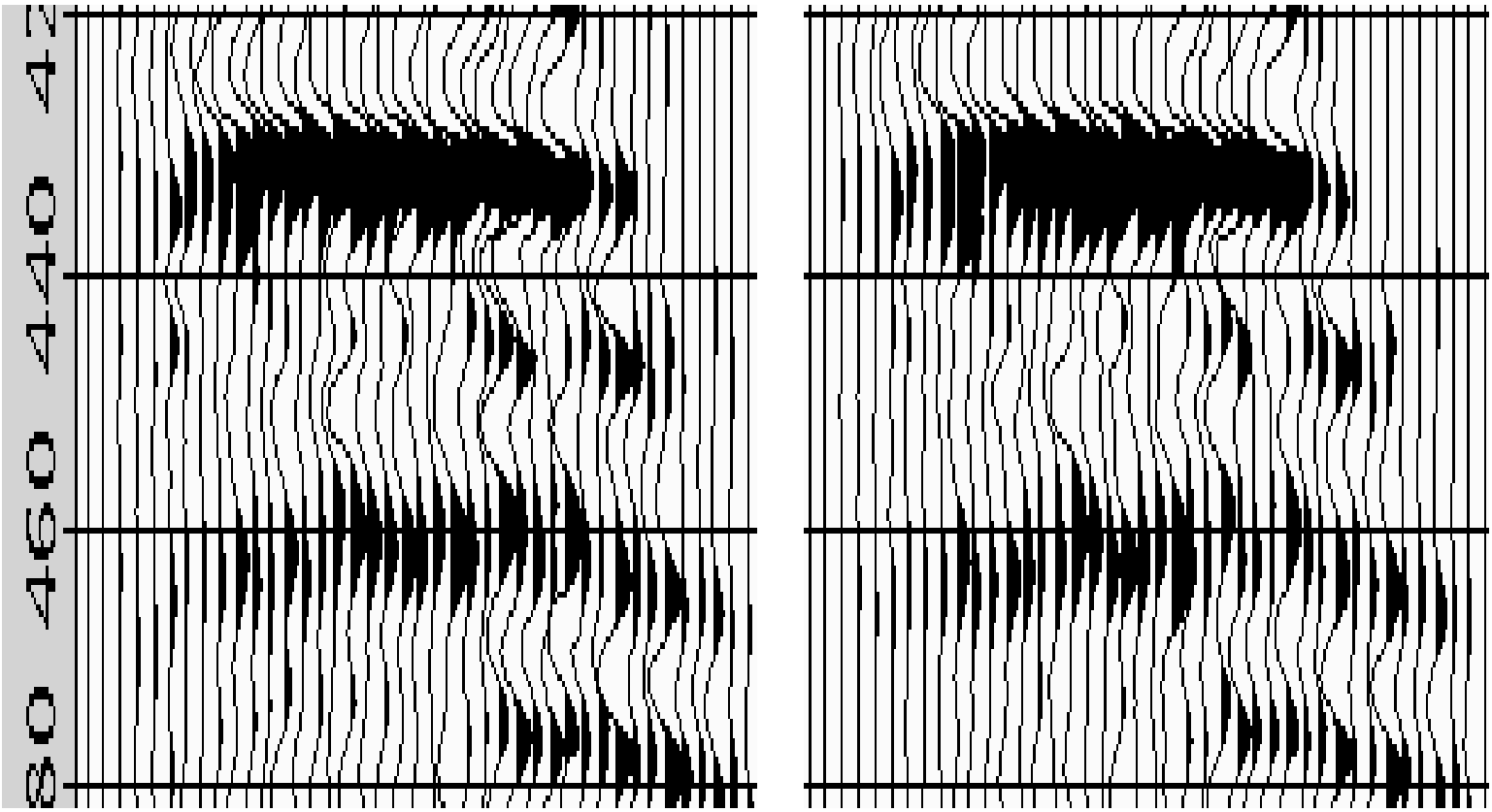
# Is the fault a barrier?



# Track changes in small compartments



# Improved 4D in changing conditions




- 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 Source imaging

- New method for 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

# Virtual Source monitoring

- 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

# Acknowledgements


- Peter McGillivray and Shell Canada
- Charles Jones for help and support
- Paul Milcik for teaching us how to use various imaging tools
- Richard Cook, Barabara Yantis, Boudewijn Salomons and Uwe Kaestner for invaluable insights into seismic migration