Acoustic Logging and Seismic/Well Integration

- Sonic Waves propagation
- Sonic processing
- LWD vs. Wireline Acoustic logging
- Special applications
  - Dipole ➠ Vs in “slow” formations
  - Cross-Dipole ➠ Anisotropy
  - Stoneley ➠ Permeability
  - Waveform attenuation
- Seismic/wells integration
  - Synthetic seismograms
  - Vertical Seismic Profiles (VSP)

Well Logging Principles and Applications
G9947 - Seminar in Marine Geophysics
Spring 2008

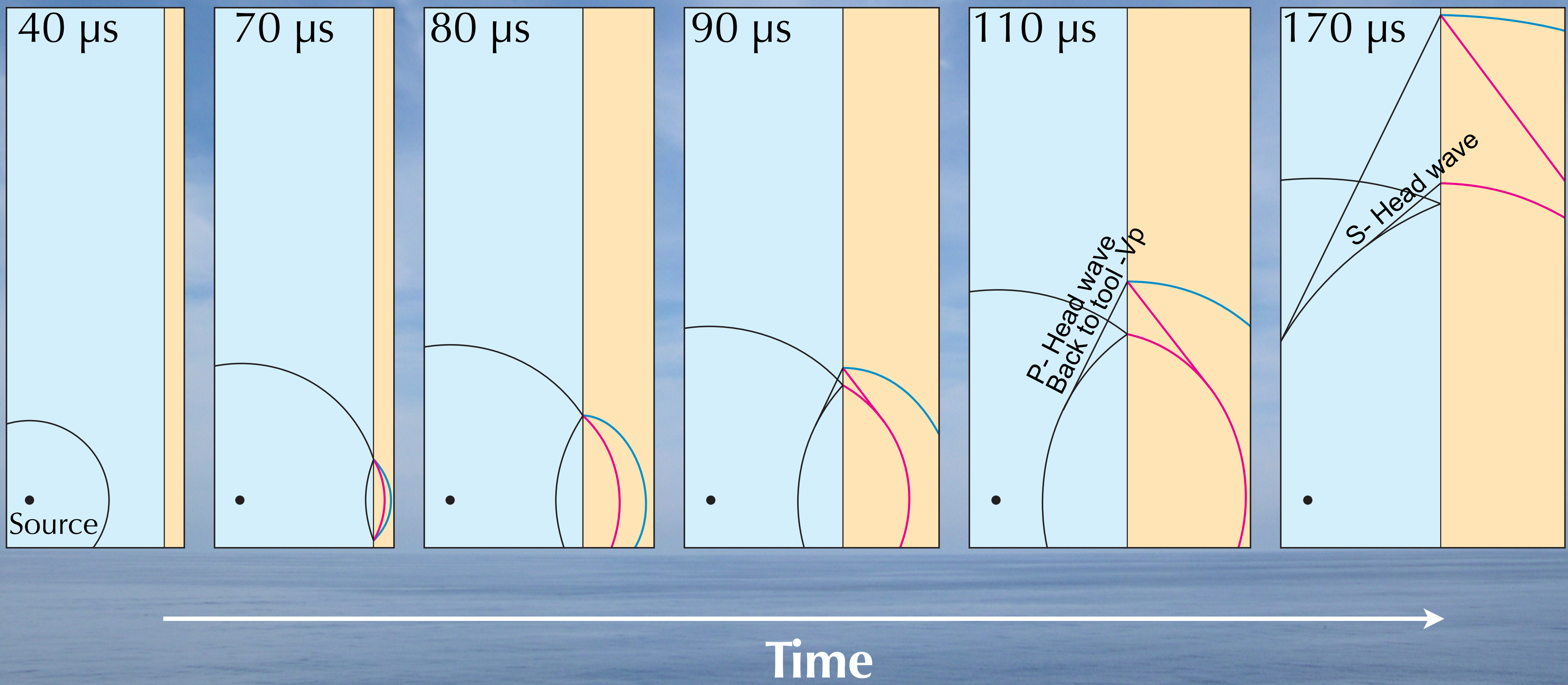
Why Bother About Sonic Velocity ?

- Petrophysical properties:

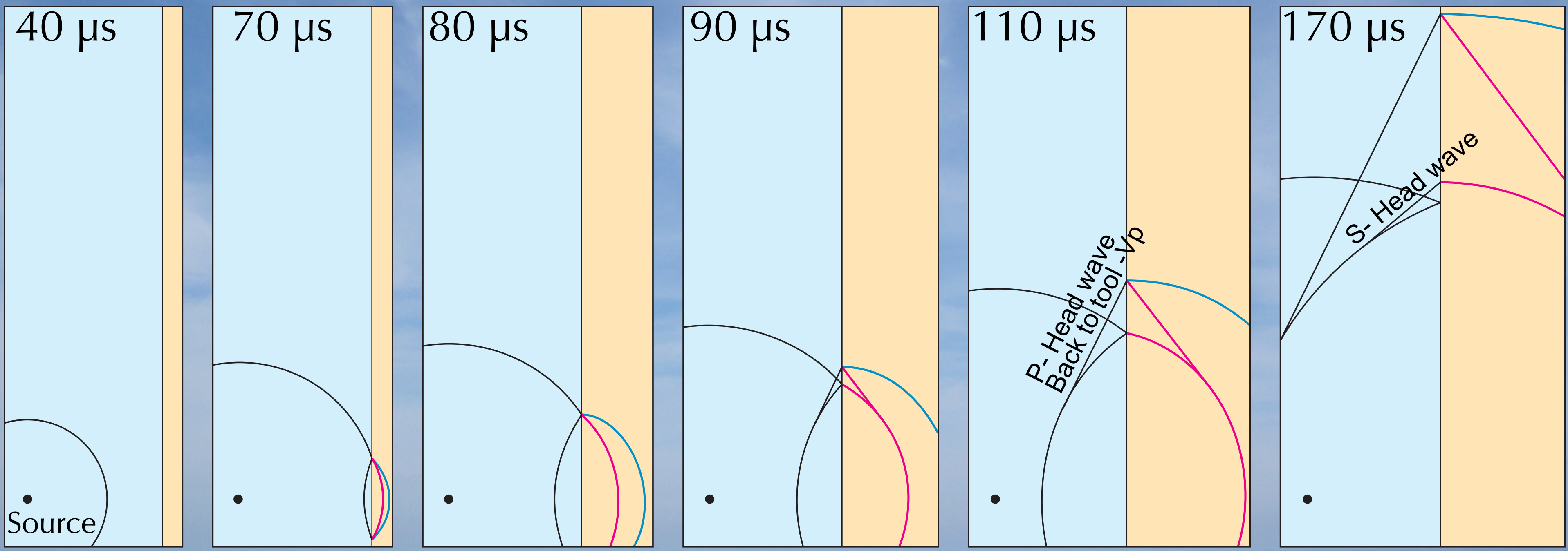
$$K = \rho(V_p^2 - \frac{4}{3}V_s^2) \qquad \mu = \rho V_s^2$$

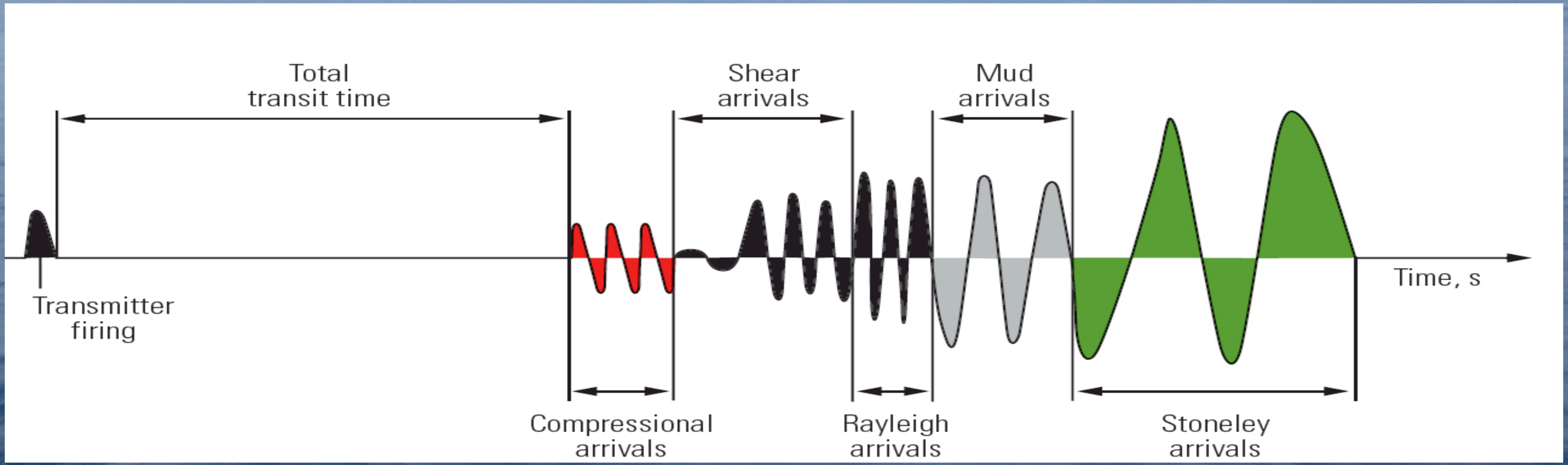
- Pore content identification
  - ➠Free gas, gas hydrate,...
  - ➠Porosity
- Seismic characterization
  - ➠ Seismic layers 2,3..
- Seismic correlation

Wave propagation in a borehole

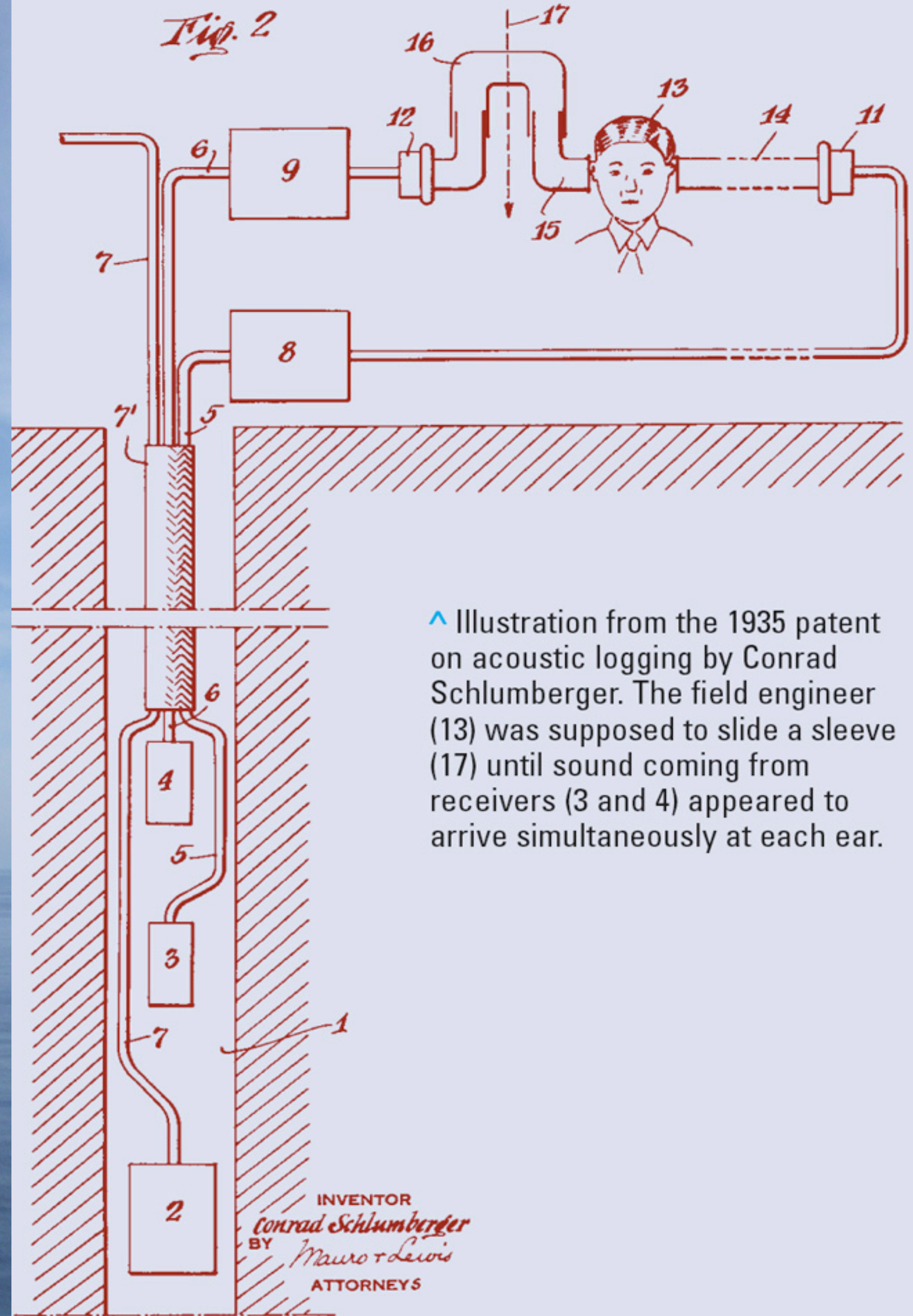


Wave propagation in a borehole



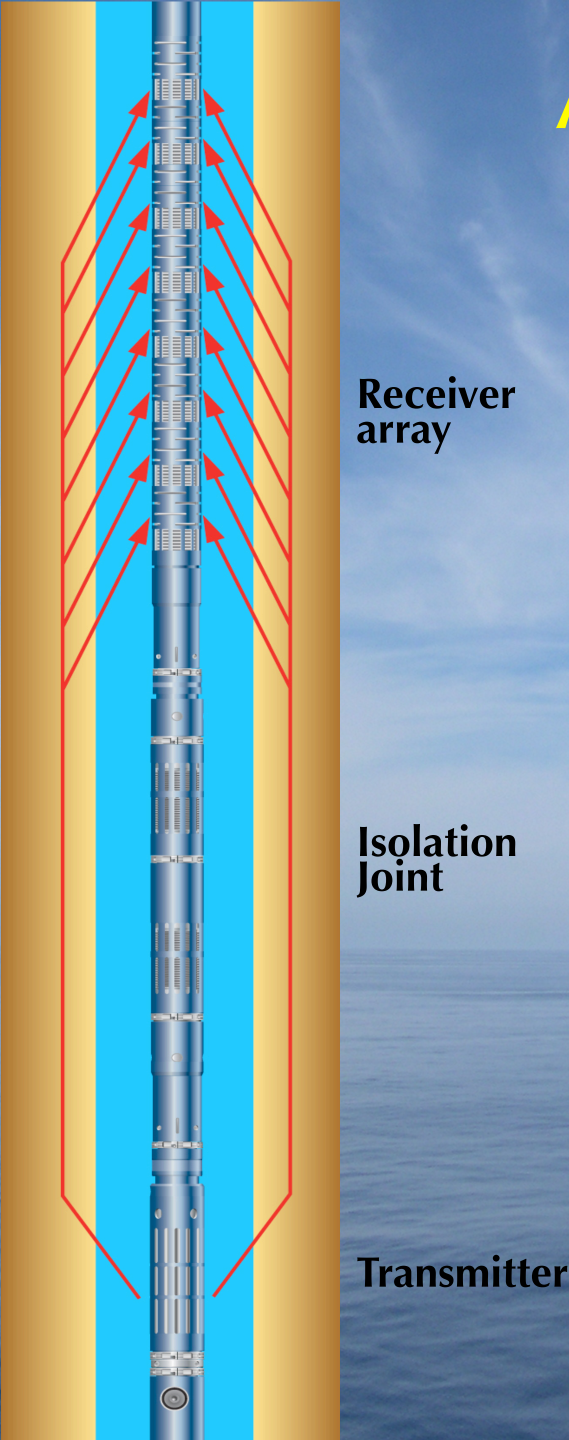


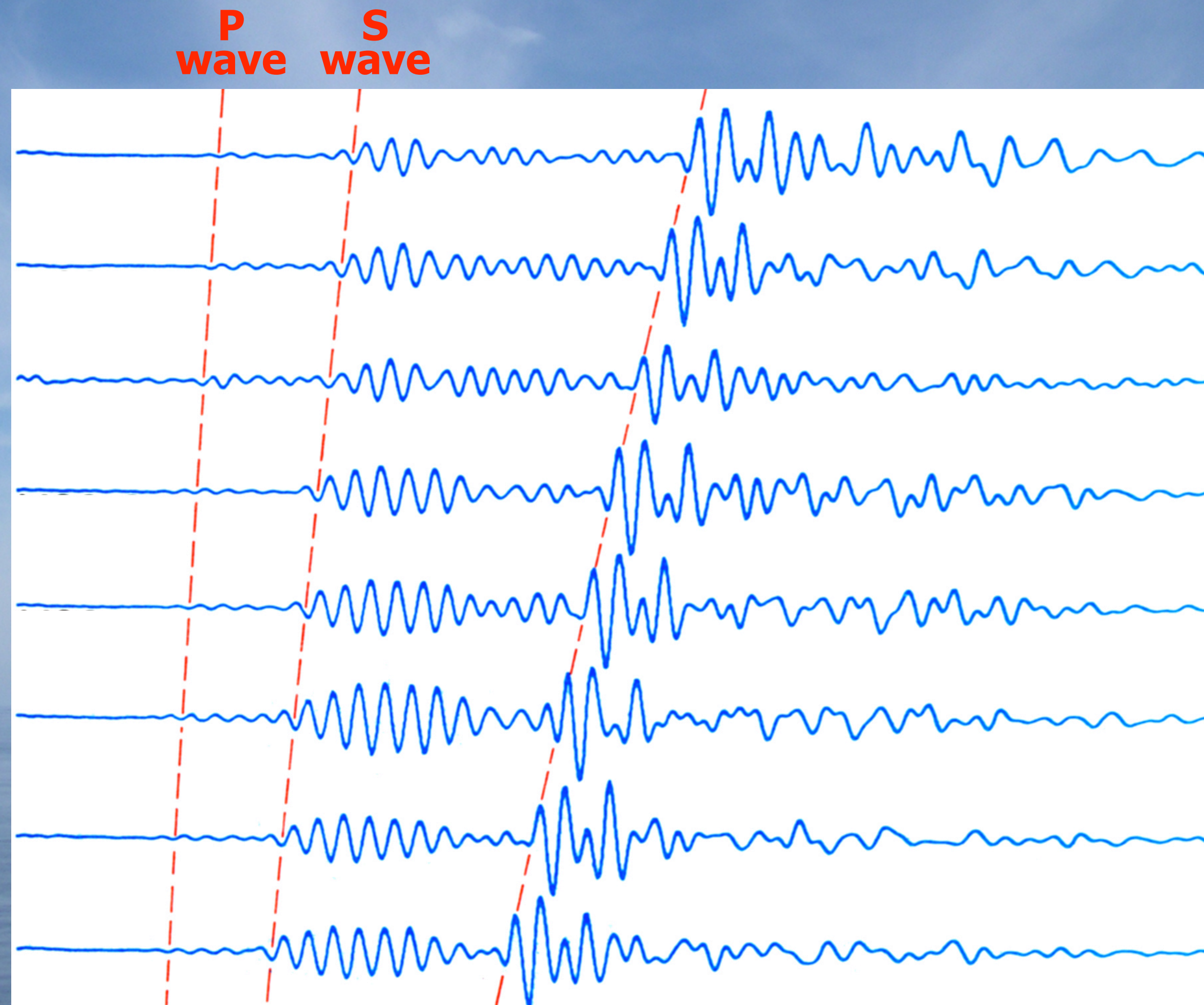
How it could be done …



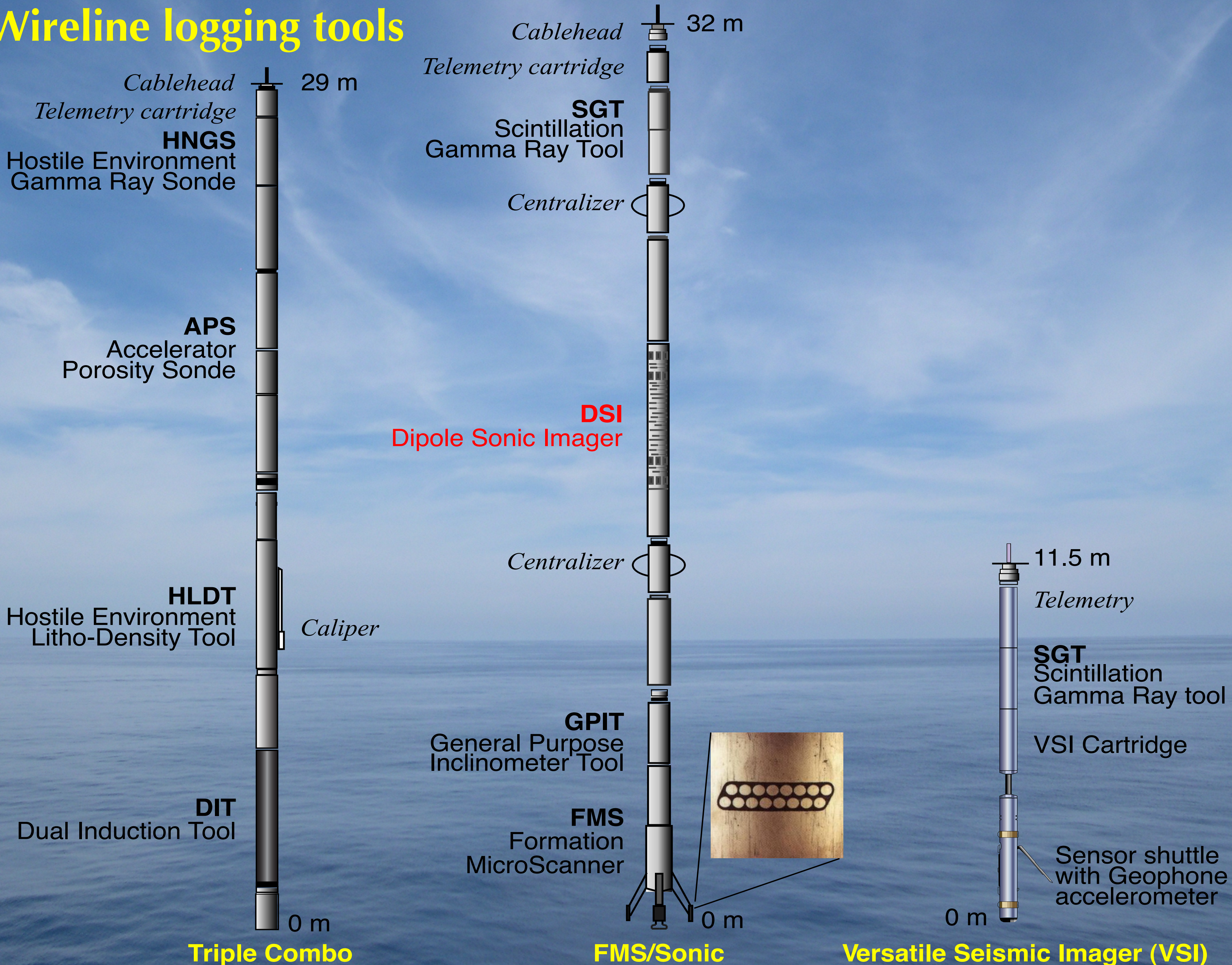
^ Illustration from the 1935 patent on acoustic logging by Conrad Schlumberger. The field engineer (13) was supposed to slide a sleeve (17) until sound coming from receivers (3 and 4) appeared to arrive simultaneously at each ear.

Acoustic Wireline Logging

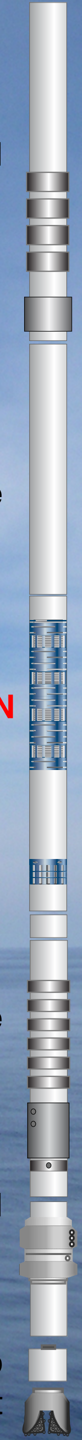




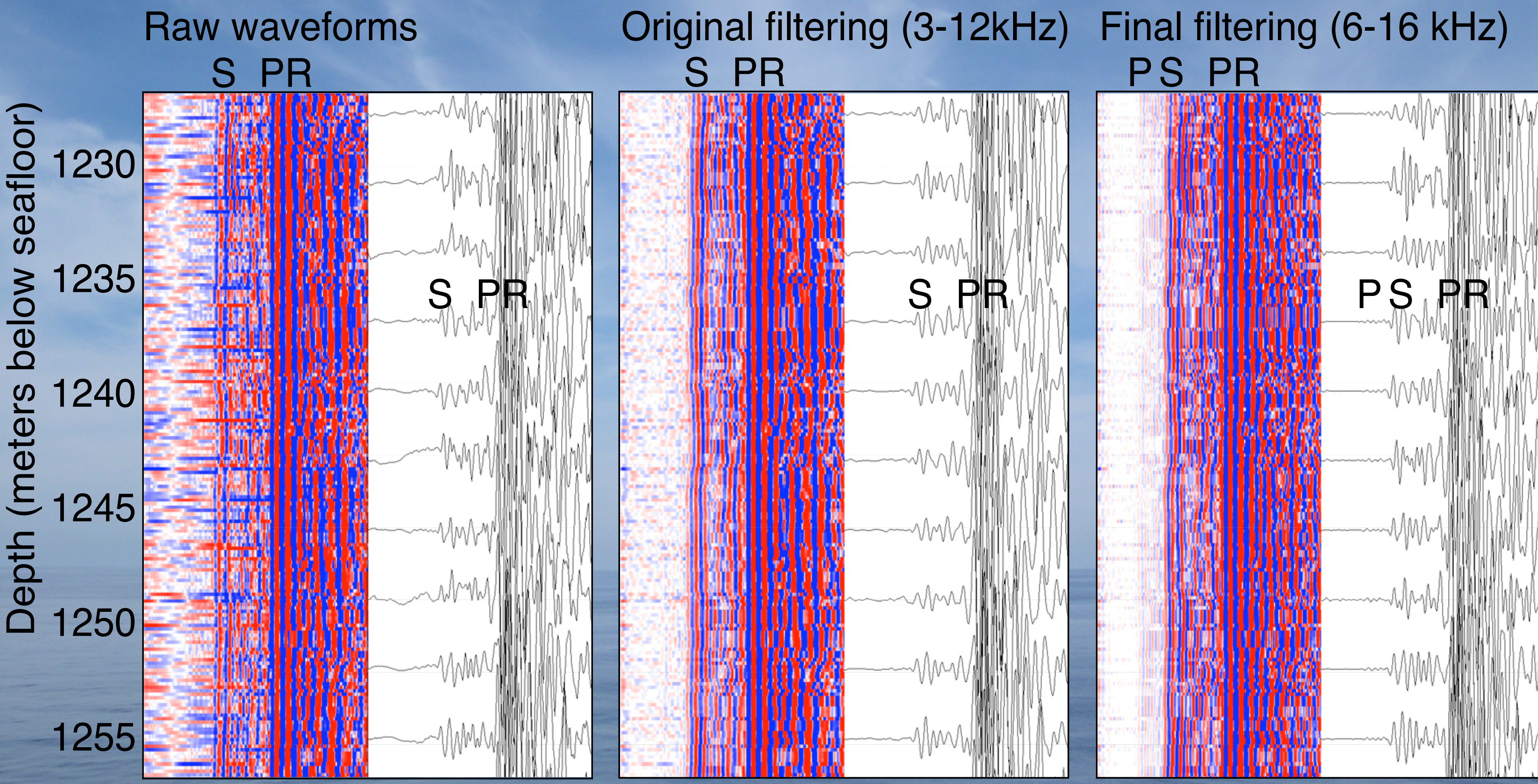
Wireline logging tools



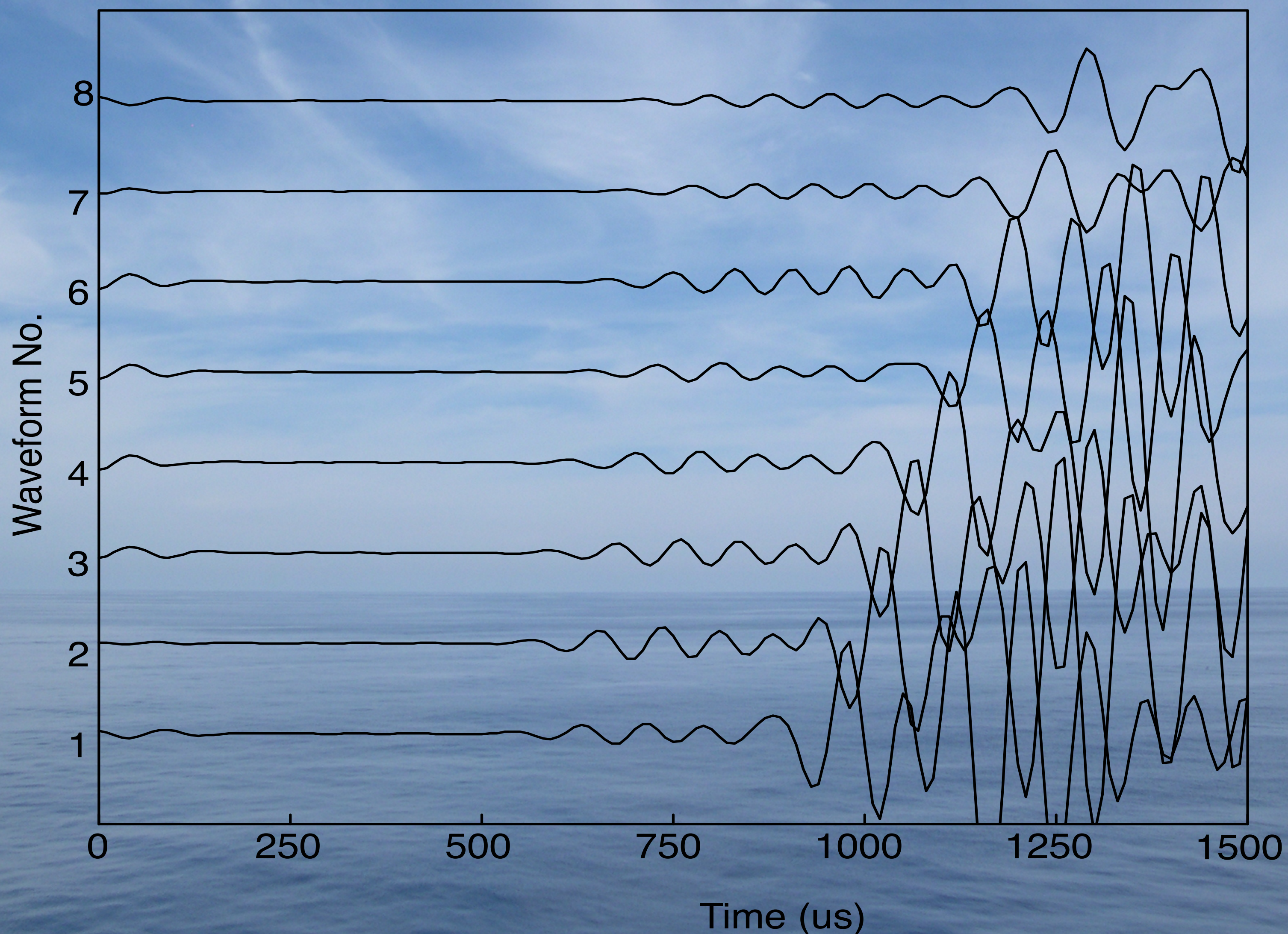
Logging While Drilling (LWD)



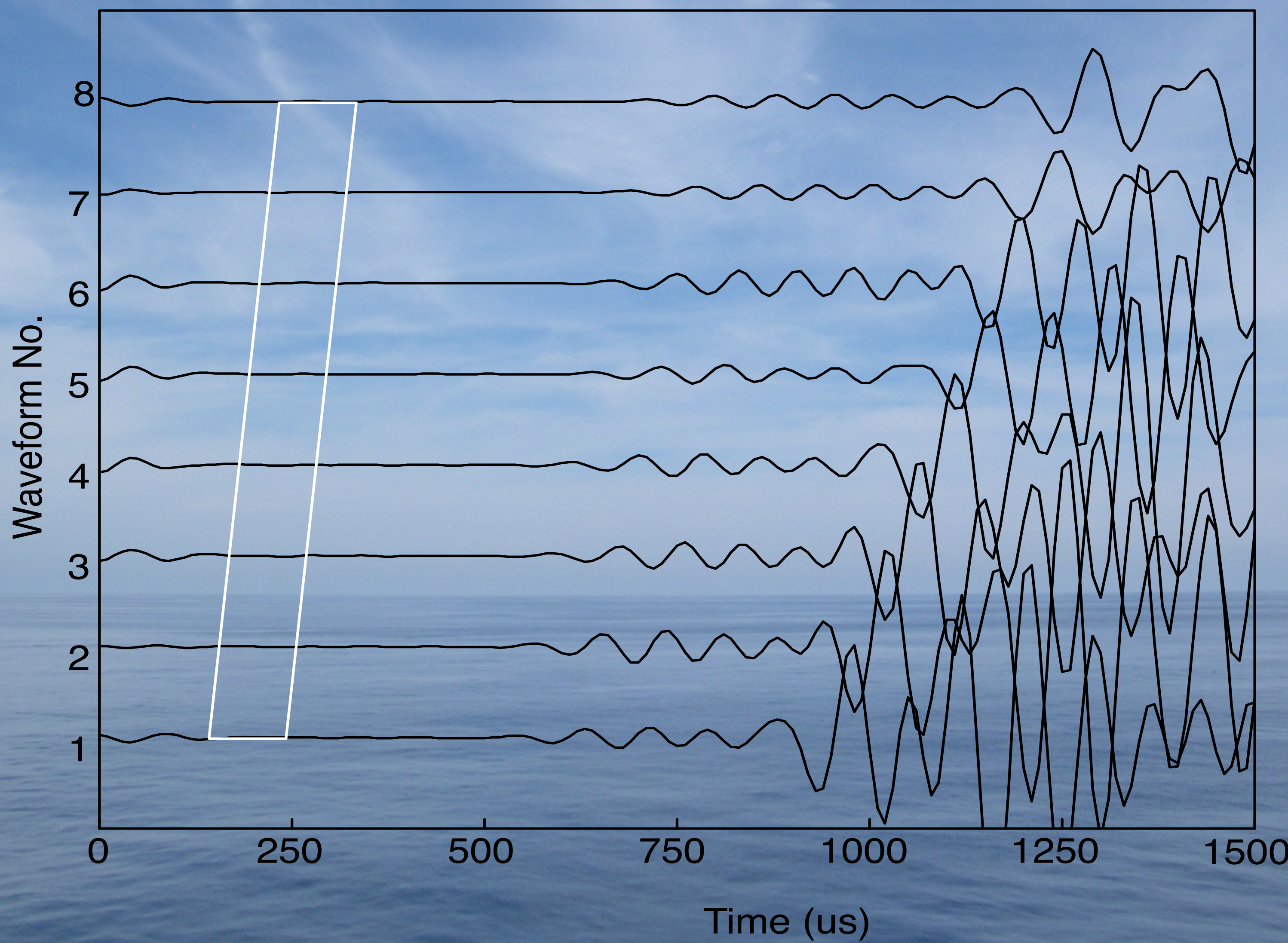
Sonic processing: preprocessing filter



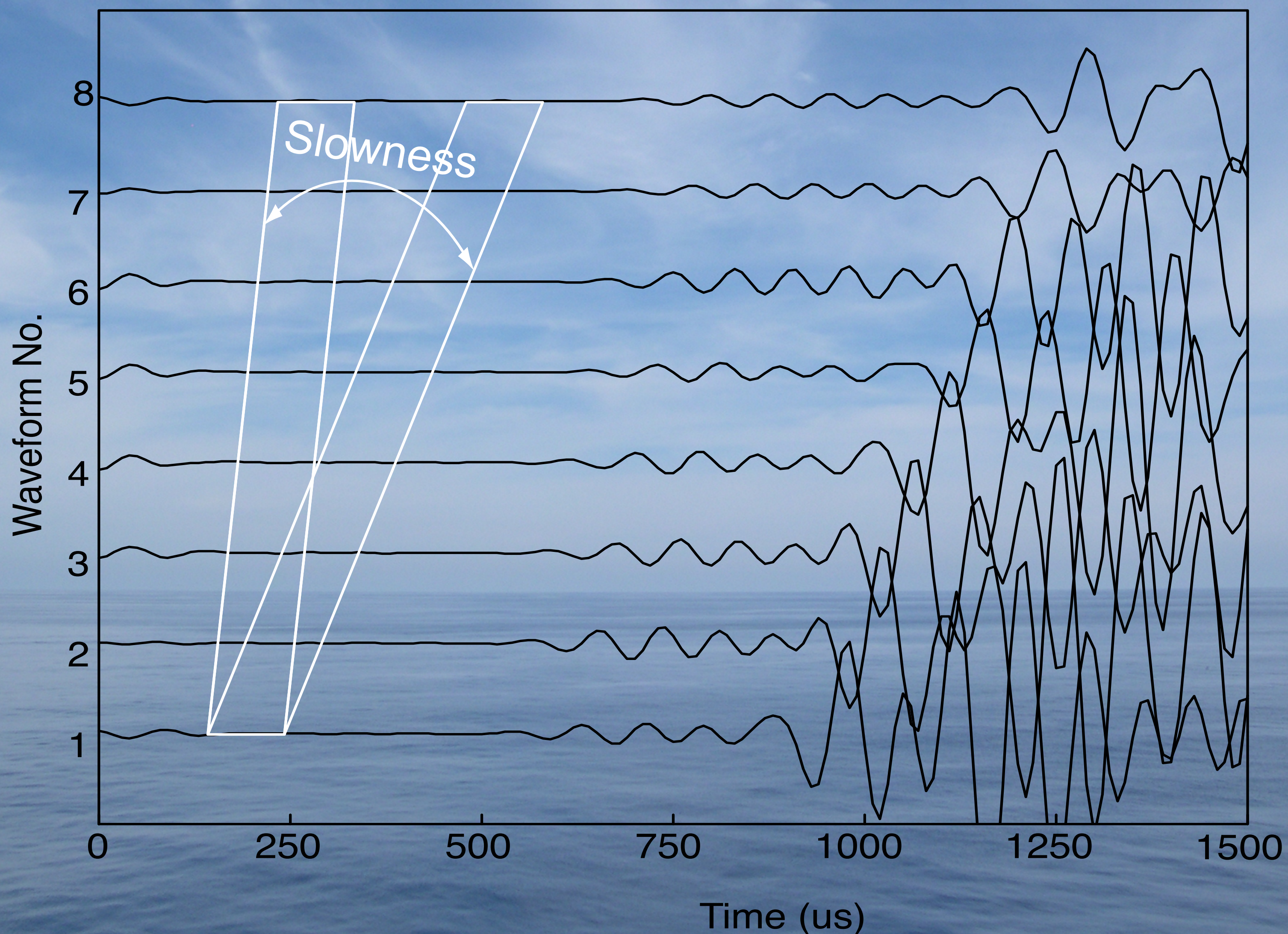
Slowness-Time coherence Analysis



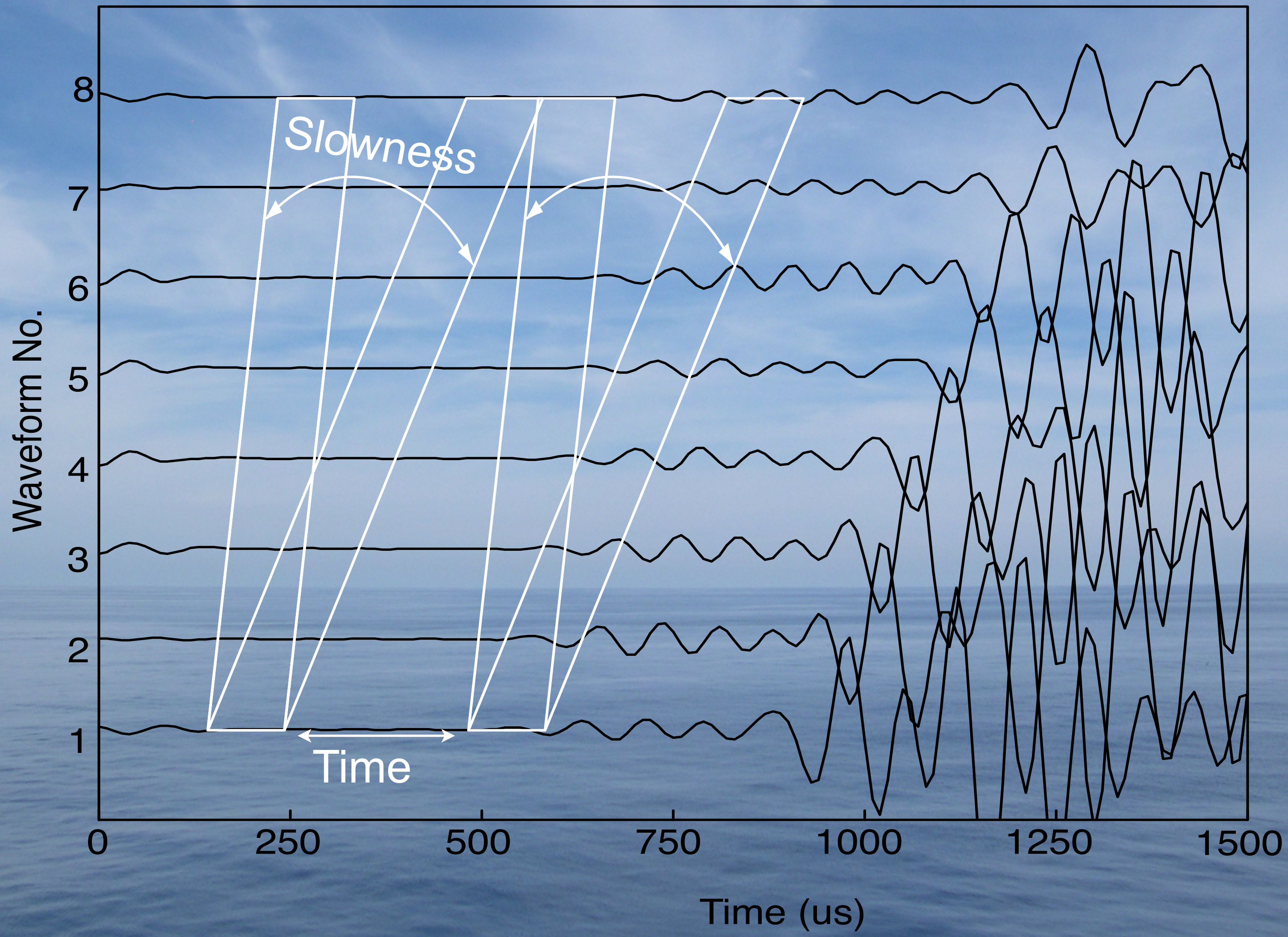
Slowness-Time coherence Analysis



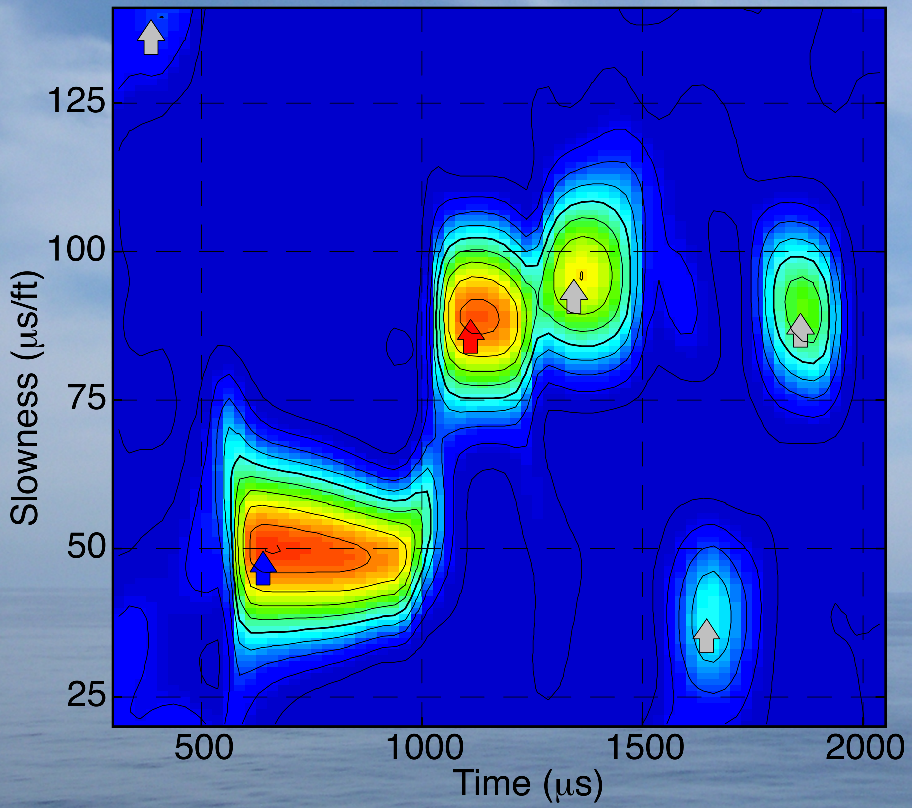
Slowness-Time coherence Analysis



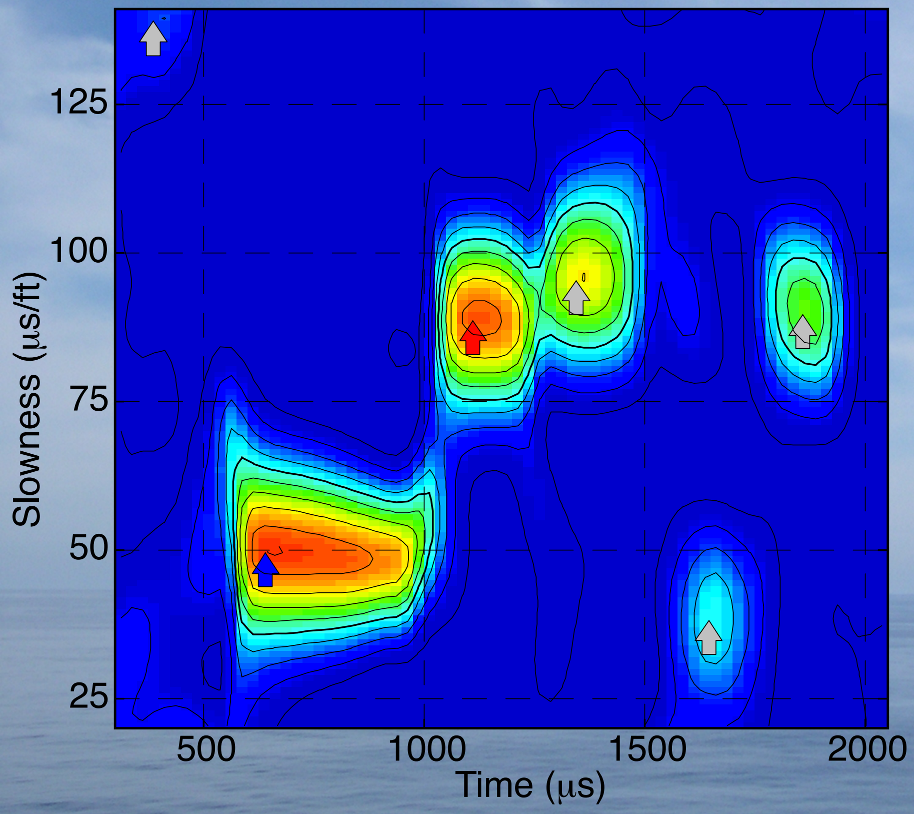
Slowness-Time coherence Analysis



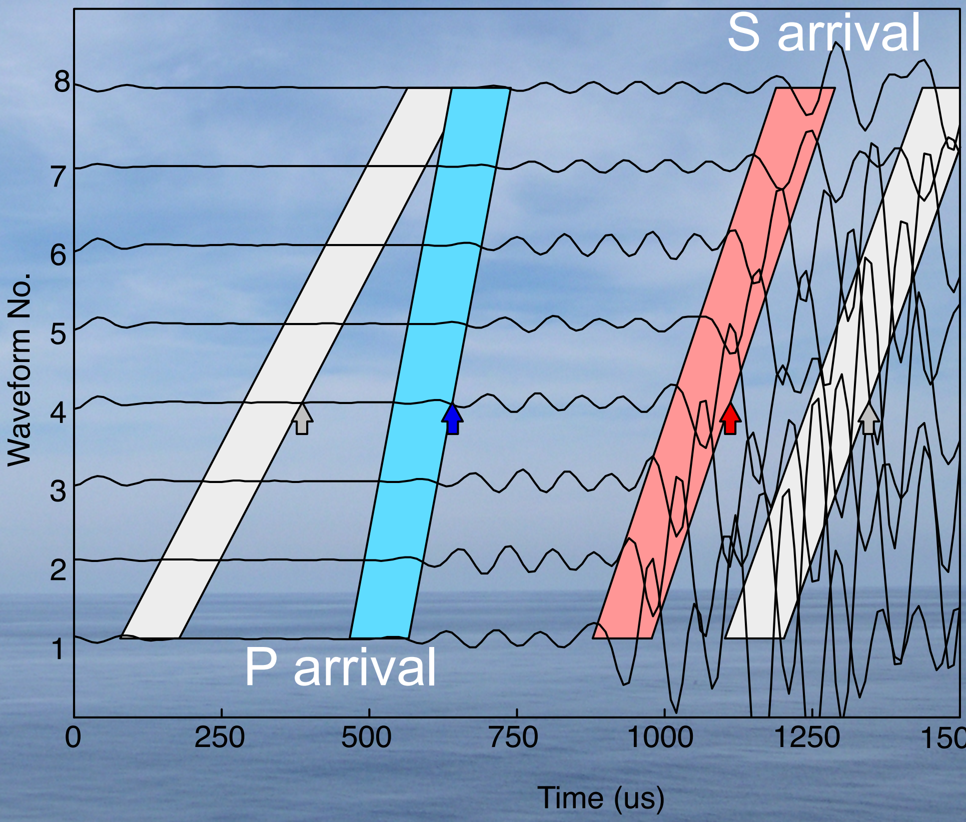
STC results



STC results

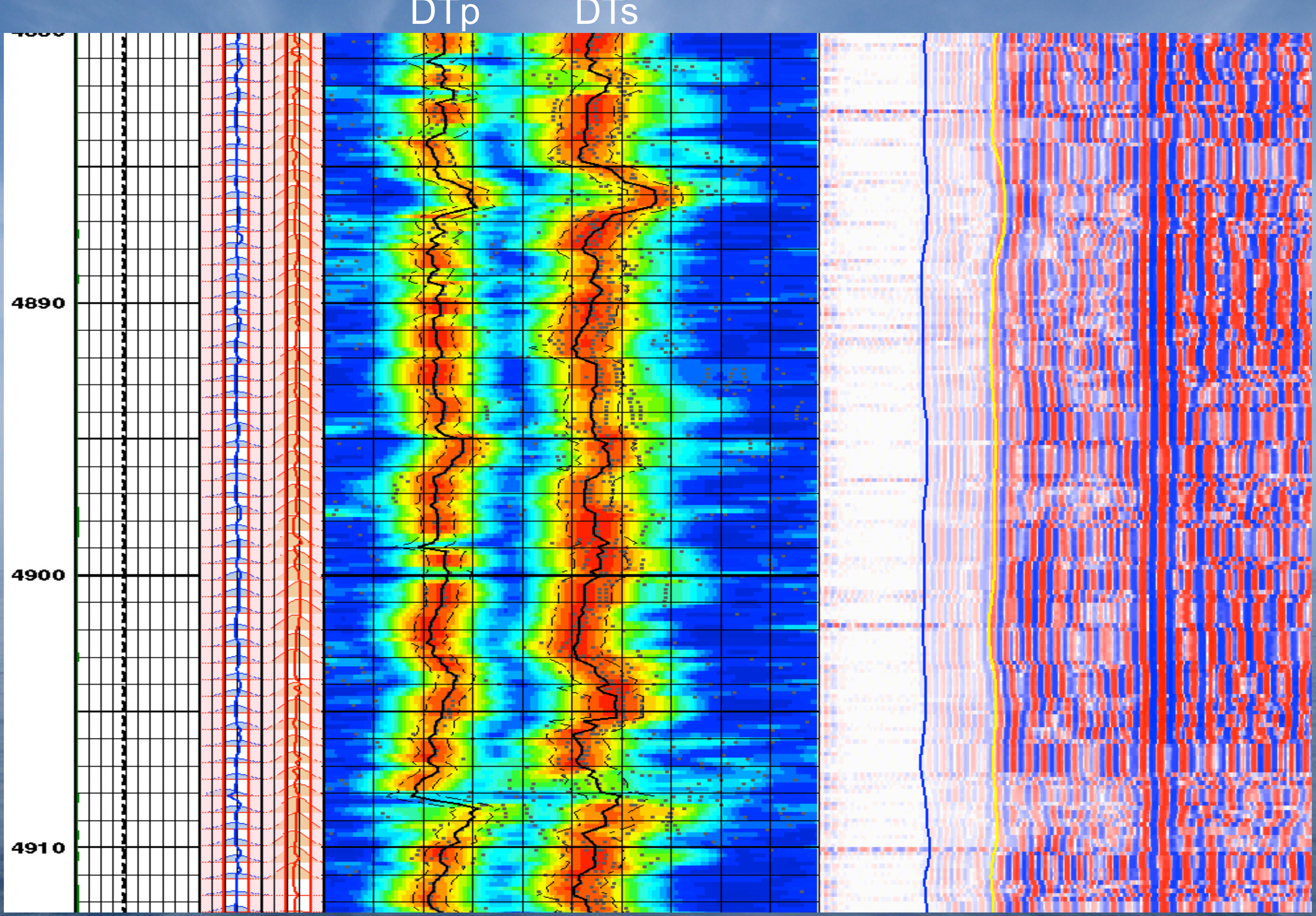


125
100
75
50
25
Slowness (μs/ft)
500
1000
1500
2000
Time (μs)

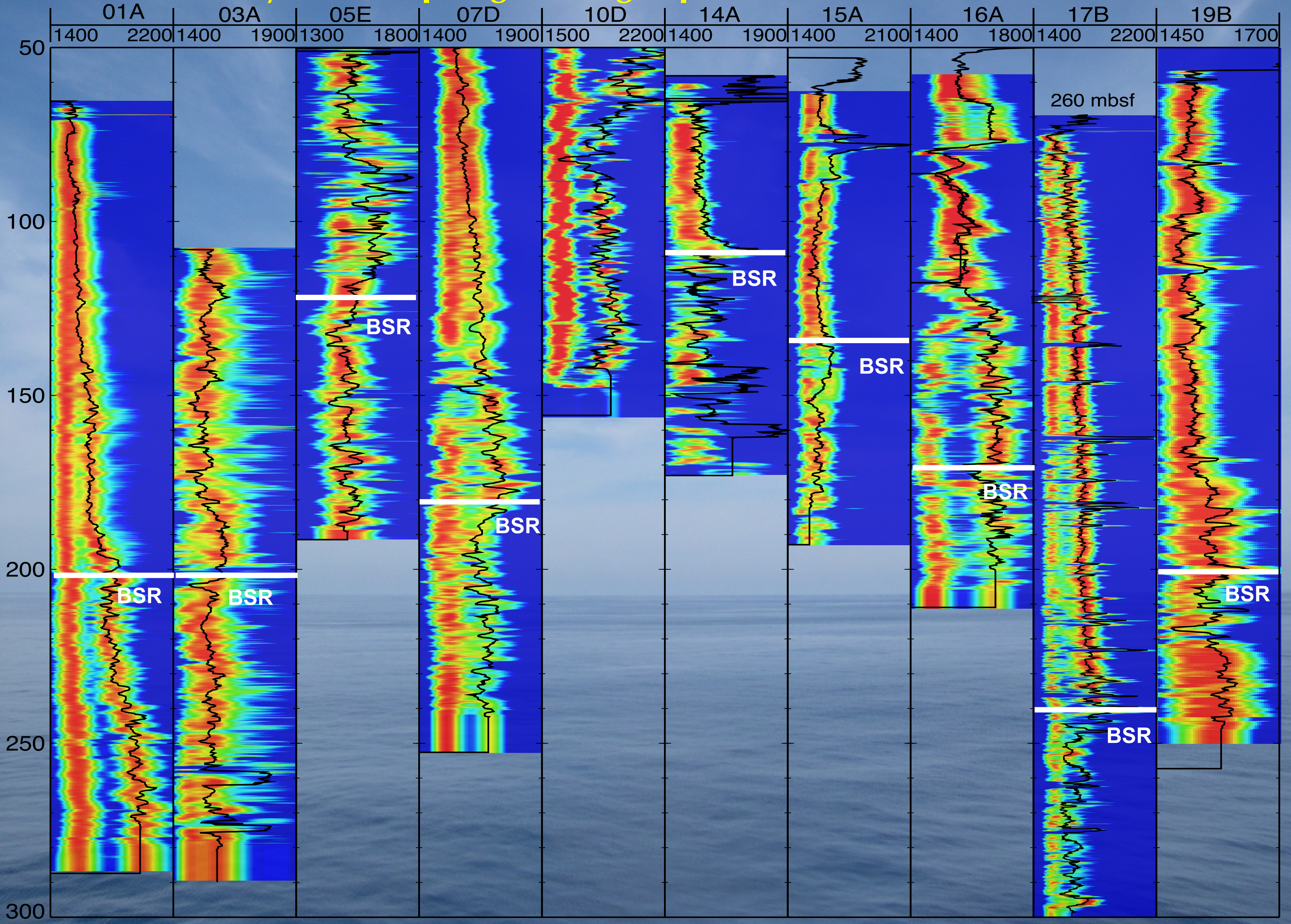


S arrival
P arrival
8
7
6
5
4
3
2
1
Waveform No.
0
250
500
750
1000
1250
1500
Time (us)

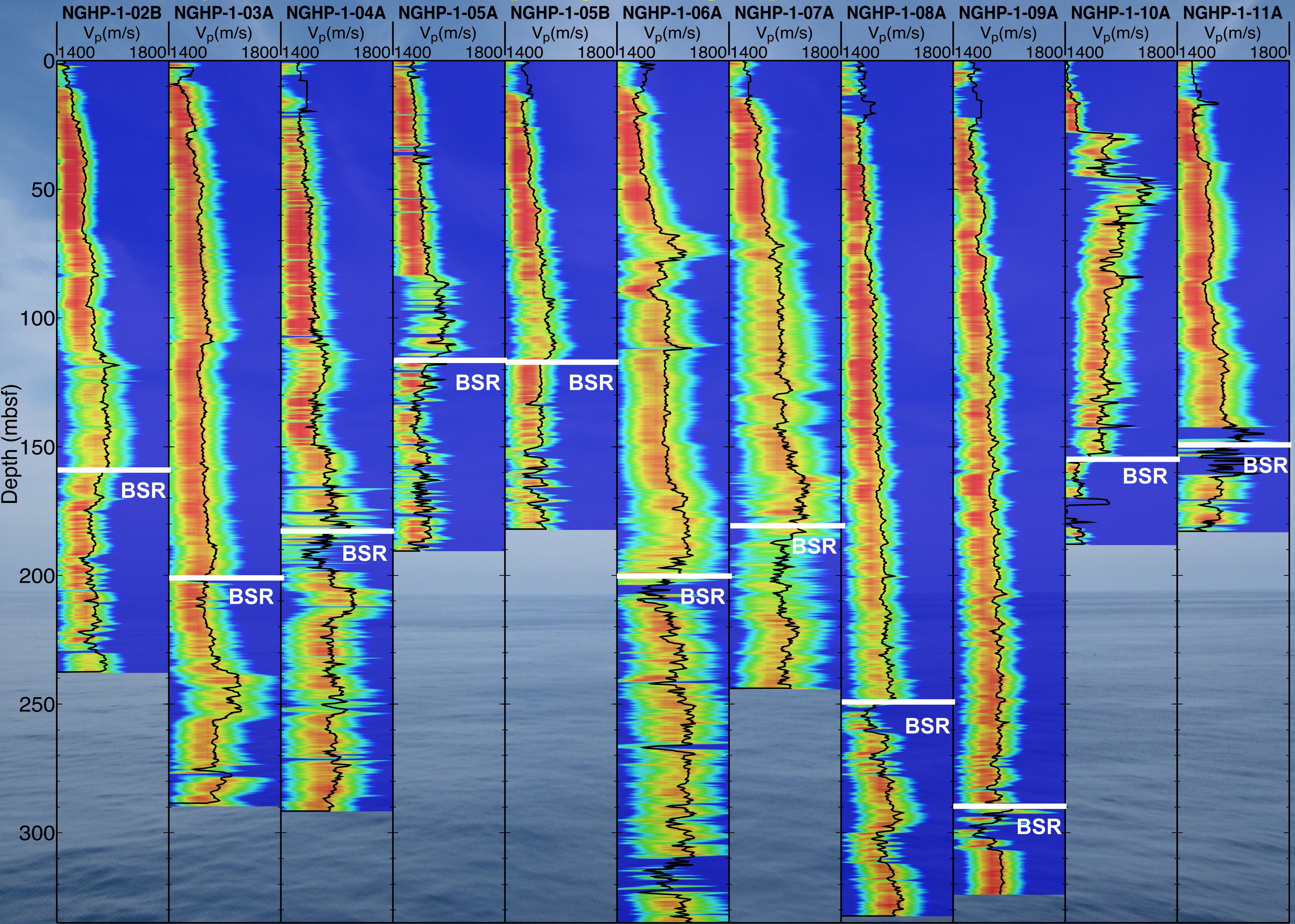
STC final results



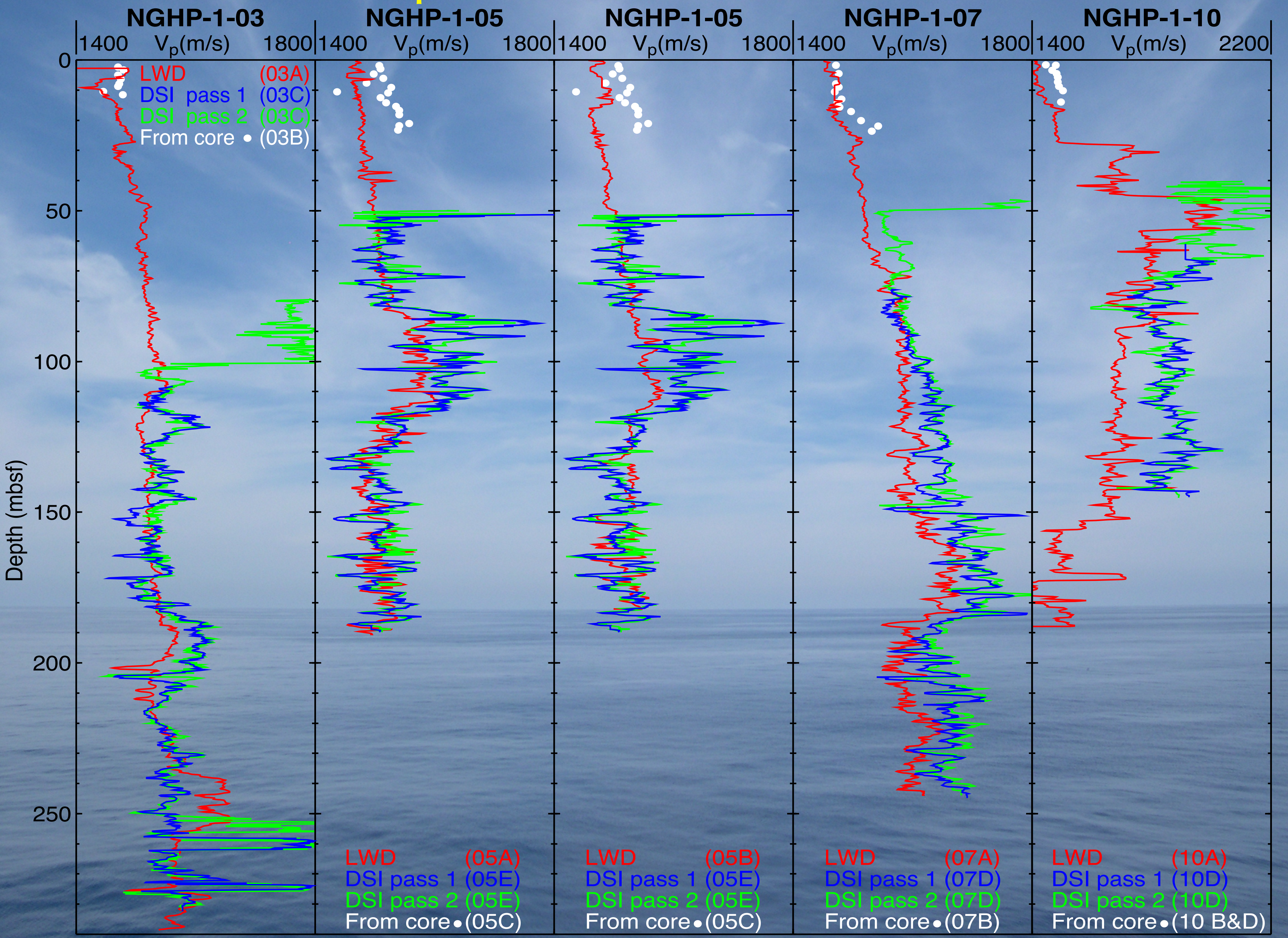
Summary of DSI Vp Logs during Expedition NGHP-1-01(wireline)



Summary of SonicVISION Vp Logs during Expedition NGHP-1-01(LWD)

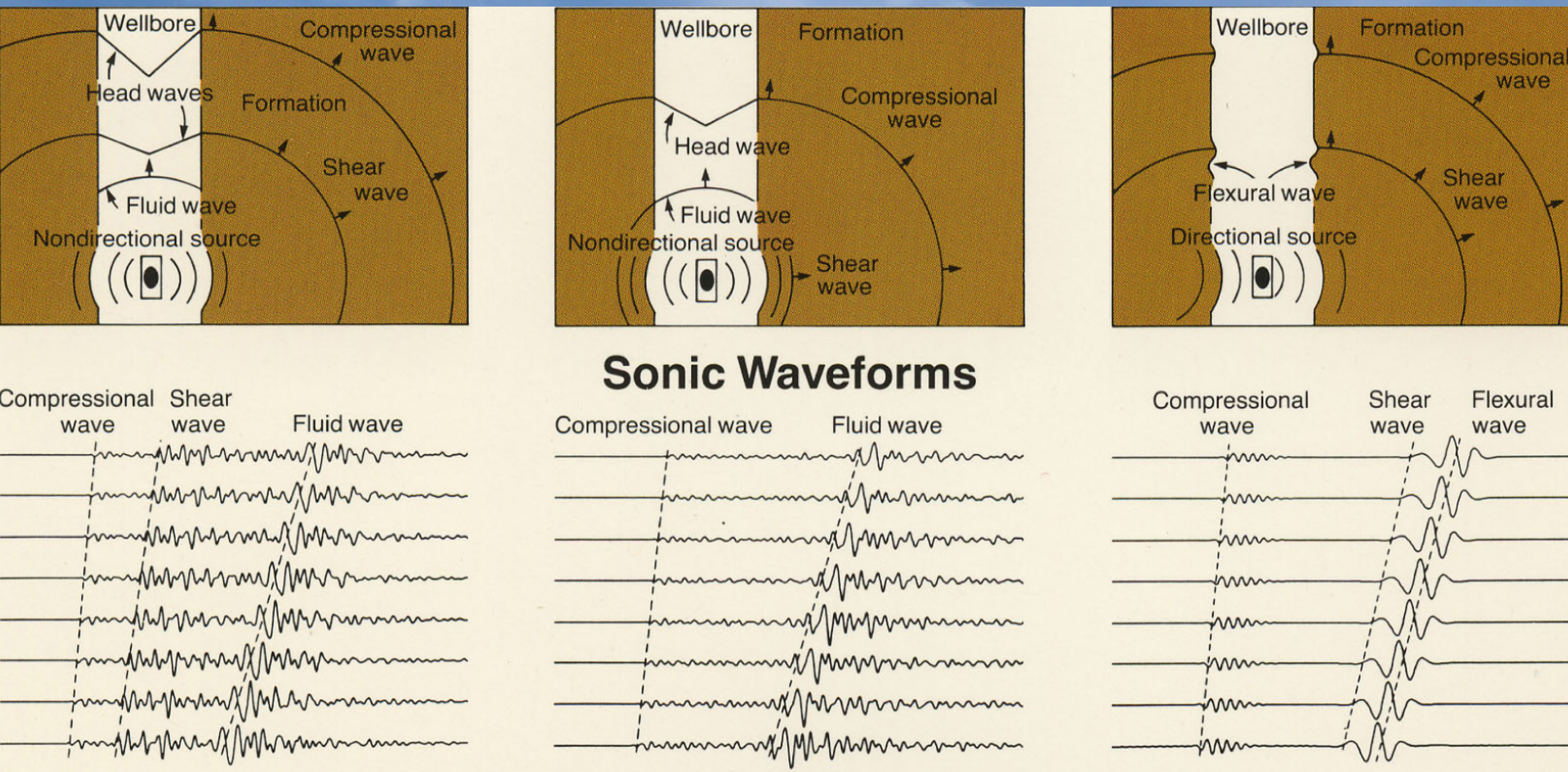


Comparison between LWD and wireline sonic



Logging in Slow formations

Monopole Source | Monopole Source | Dipole Source



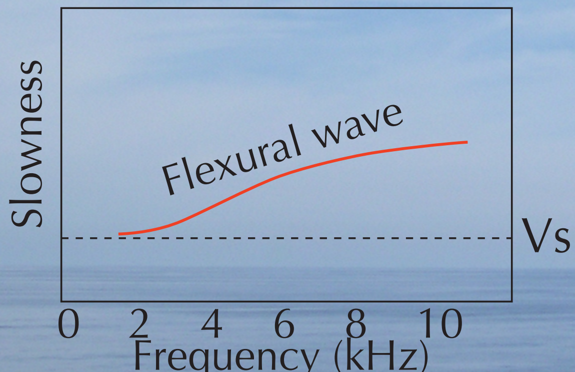
Fast formation:
Vp > Vs > Vfluid

Slow formation:
Vp > Vfluid > Vs

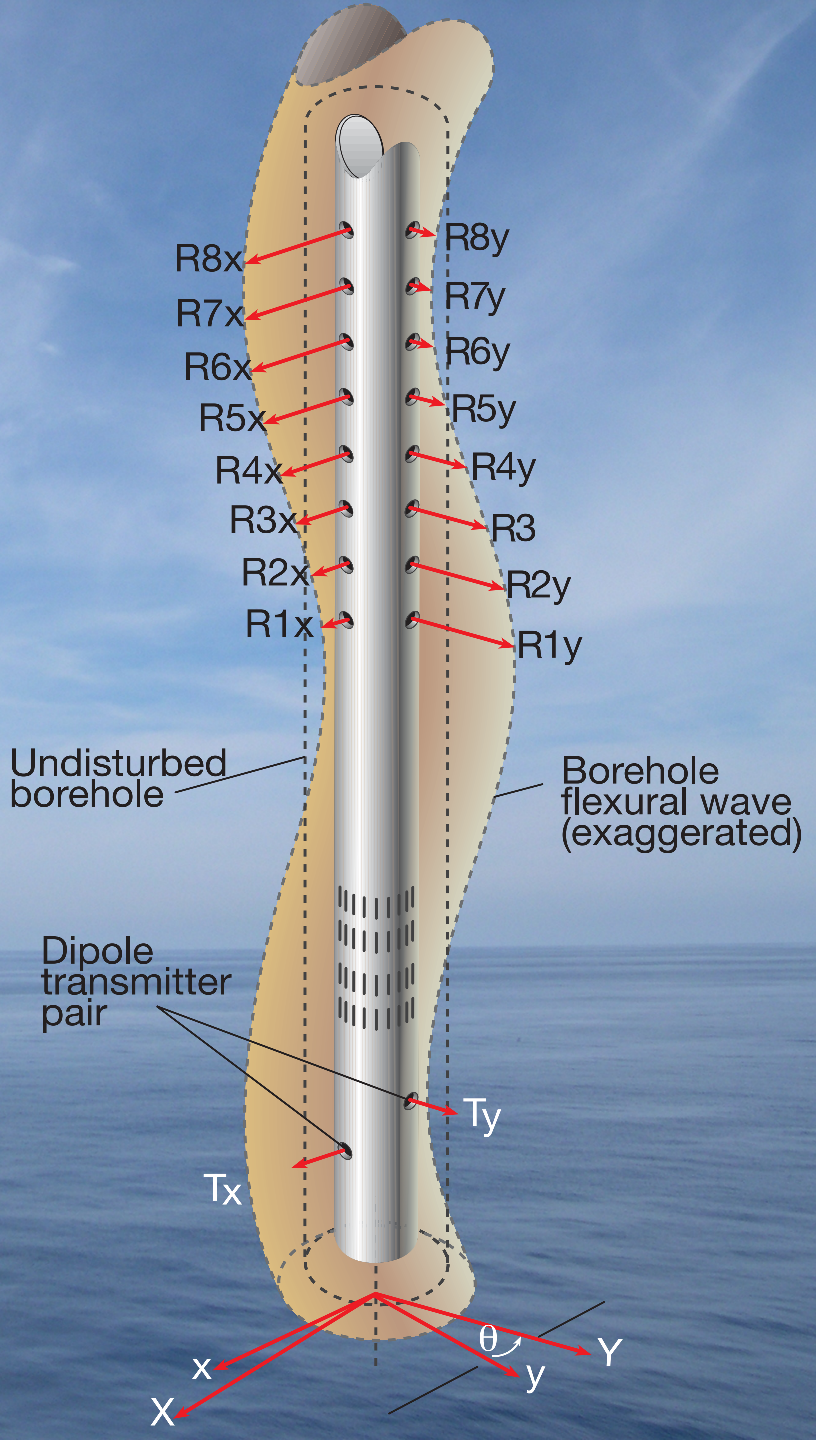
Slow formation:
Vp > Vfluid > Vs

Dipole Logging: Vs in slow formations

- A flexural wave generated by a dipole source travels at a velocity close to Vs that can be recorded even if Vs is lower than the fluid velocity
- The flexural wave is dispersive (velocity changes with frequency), which can be taken into account



- Two orthogonal transmitters can be used, recording two “independent” Vs logs
- Processing uses STC similar to monopole processing - but corrected for the effect of dispersion



Acoustic Logging Sources

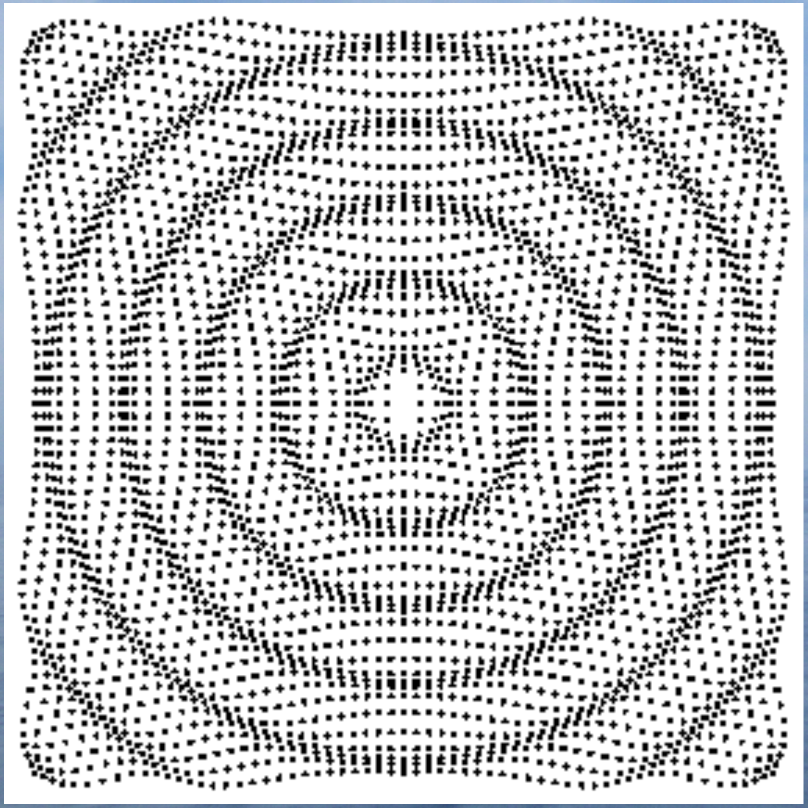
Monopole:
pulse radiates equally in all directions

Dipole
two monopole sources of equal strength and opposite phase

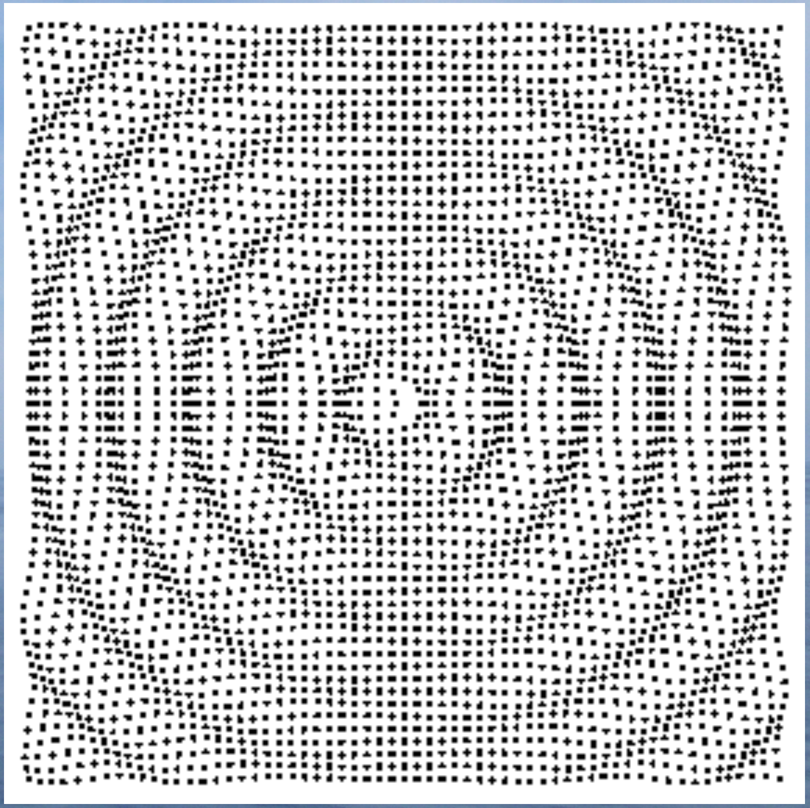
Animations: Dr. Dan Russell, Kettering University: http://www.kettering.edu/~drussell/Demos/rad2/mdq.html

Acoustic Logging Sources

Monopole:
pulse radiates equally in all directions

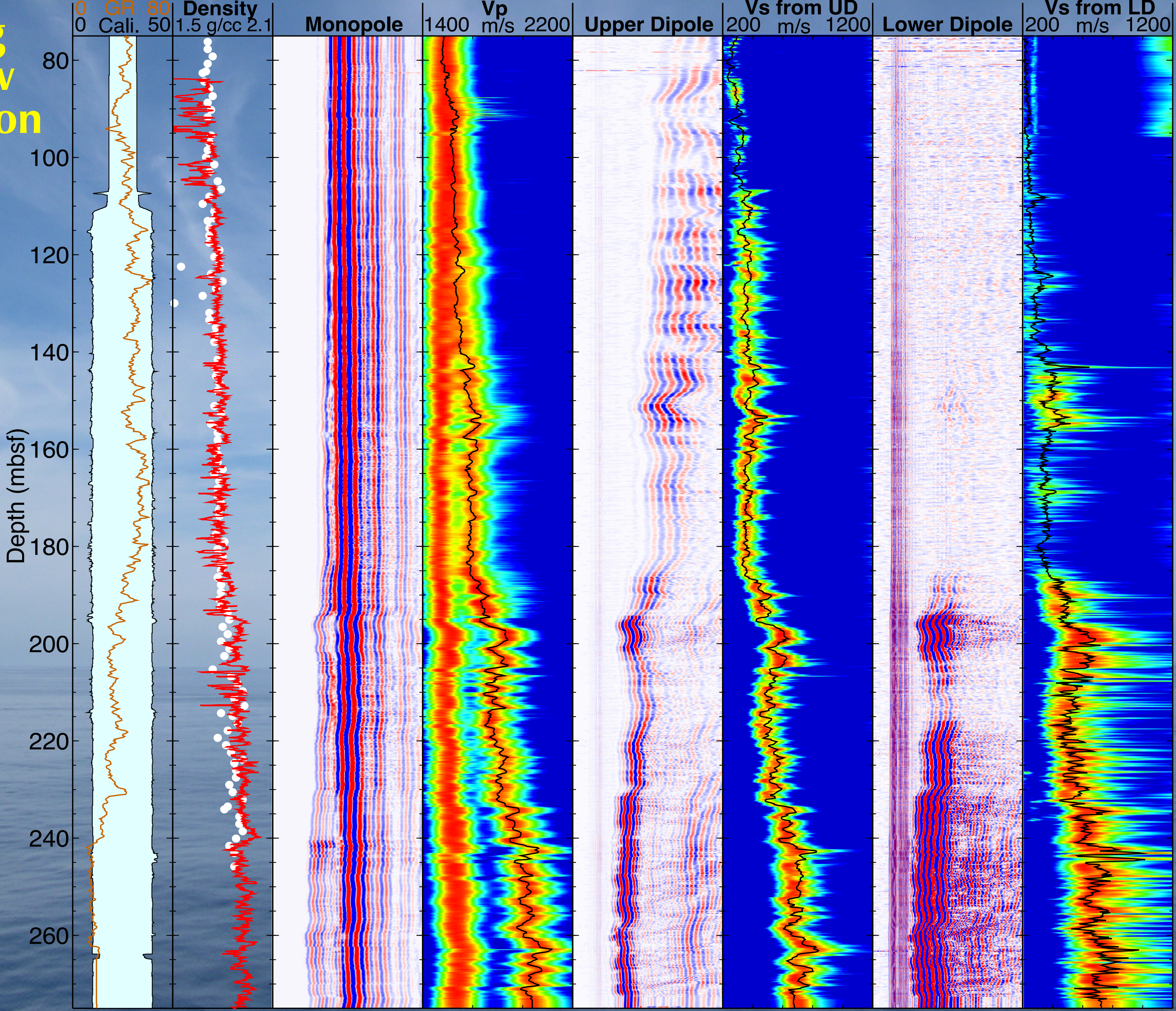


Dipole
two monopole sources of equal strength and opposite phase



Animations: Dr. Dan Russell, Kettering University: http://www.kettering.edu/~drussell/Demos/rad2/mdq.html

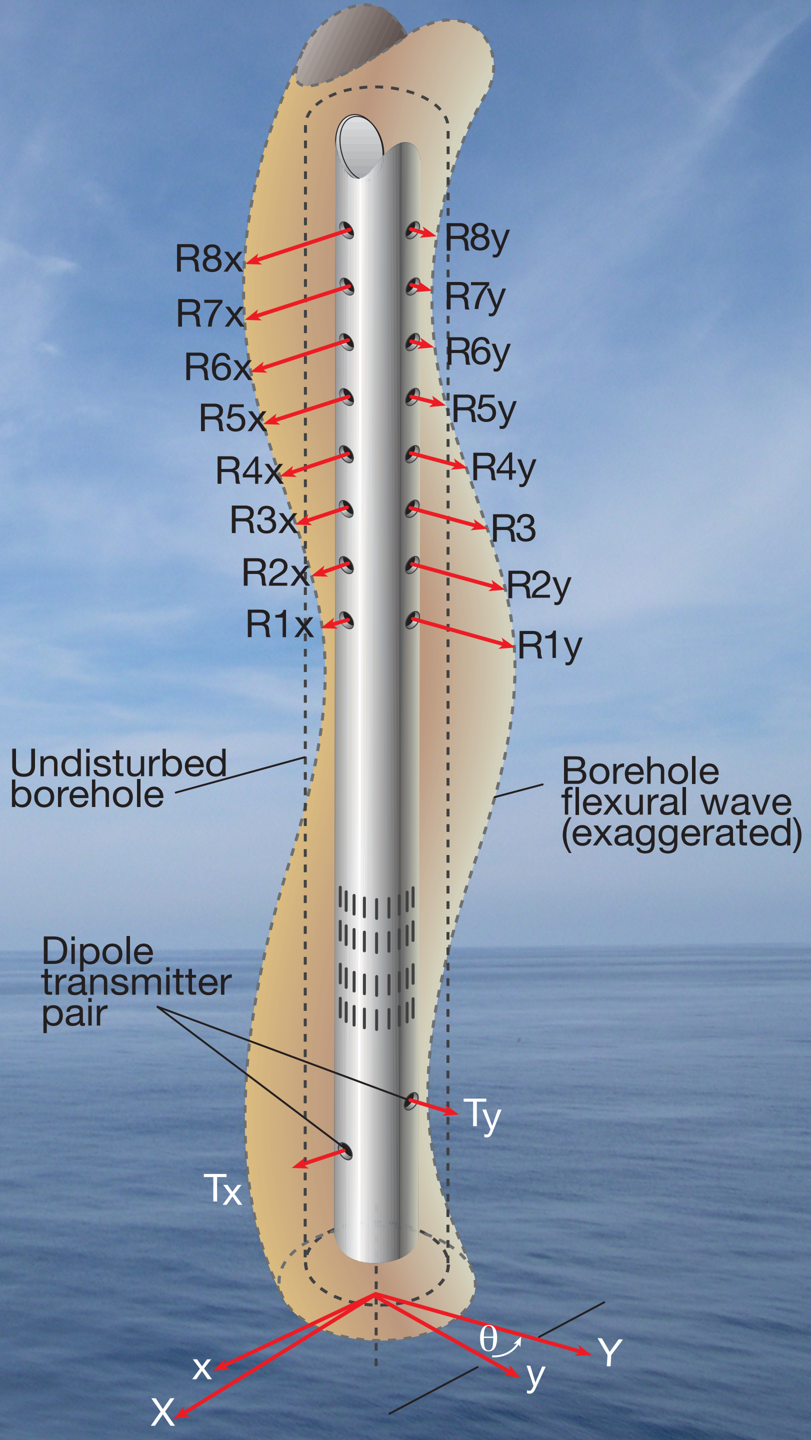
Vs log in slow formation



Cross Dipole Logging

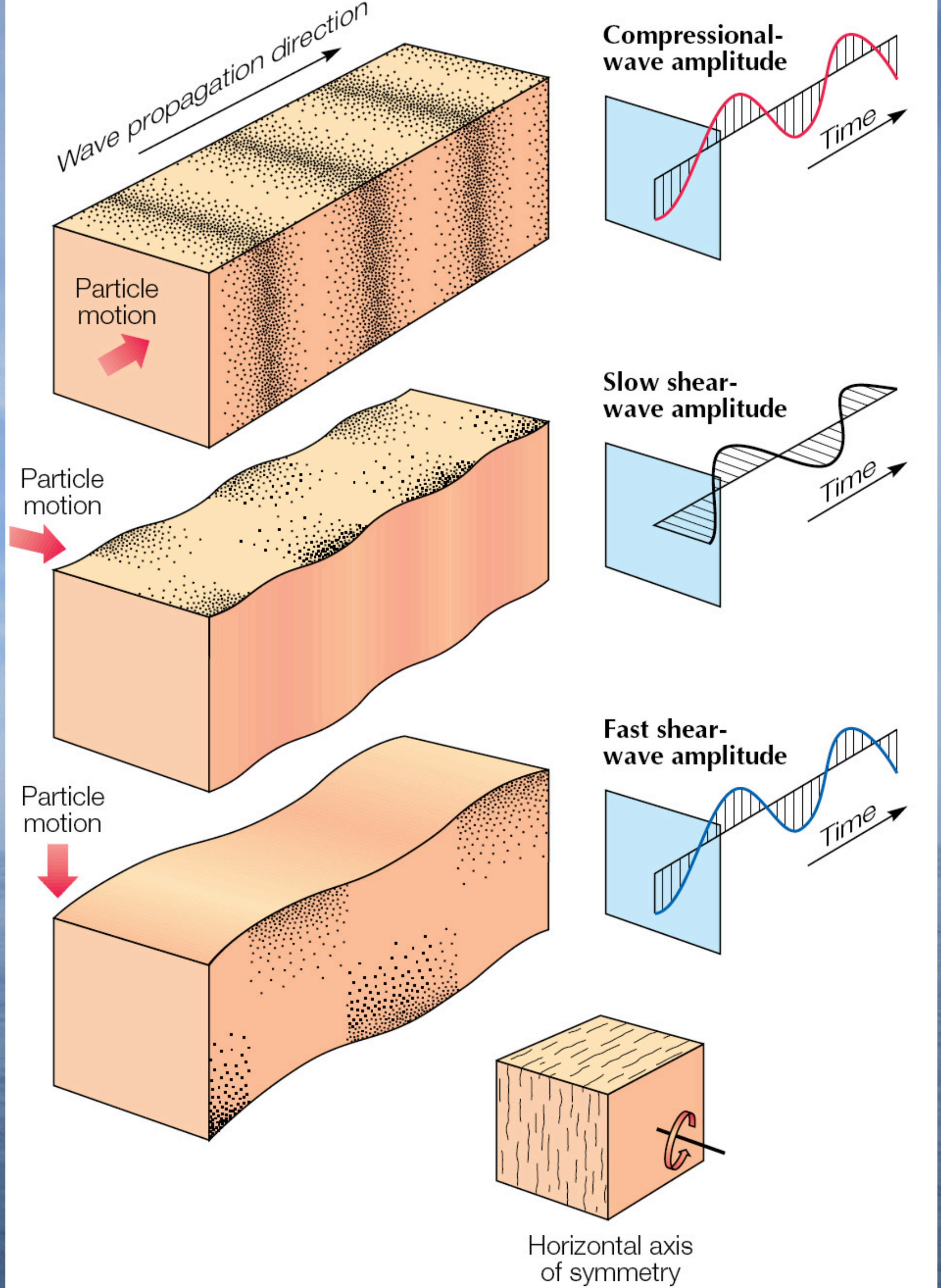
- Two dipole transmitters orthogonal to each other are fired alternatively
- Two arrays of receivers, aligned with the two transmitters
- Waveforms are recorded 'in-line' and 'cross-line'
- Combined analysis of inline and crossline waveforms allows to rotate the waveforms along a slow and a fast azimuth

- Differences in shear velocity can be related to the stress regime around the borehole

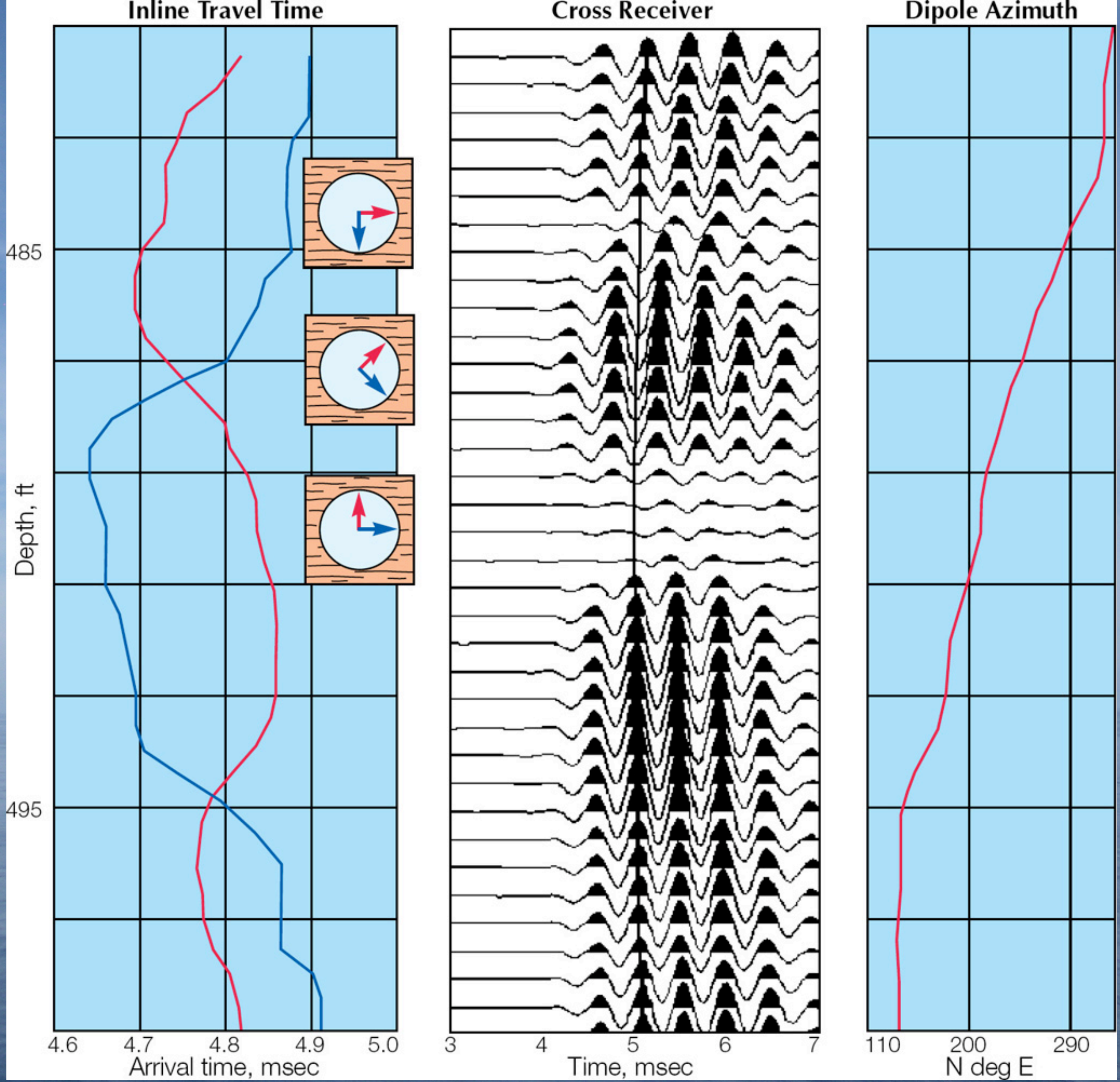


Shear waves splitting

- Wave propagate faster when the direction of particle motion is parallel to the direction of greatest stiffness
- The "fast" shear wave will travel in the direction of maximum horizontal stress



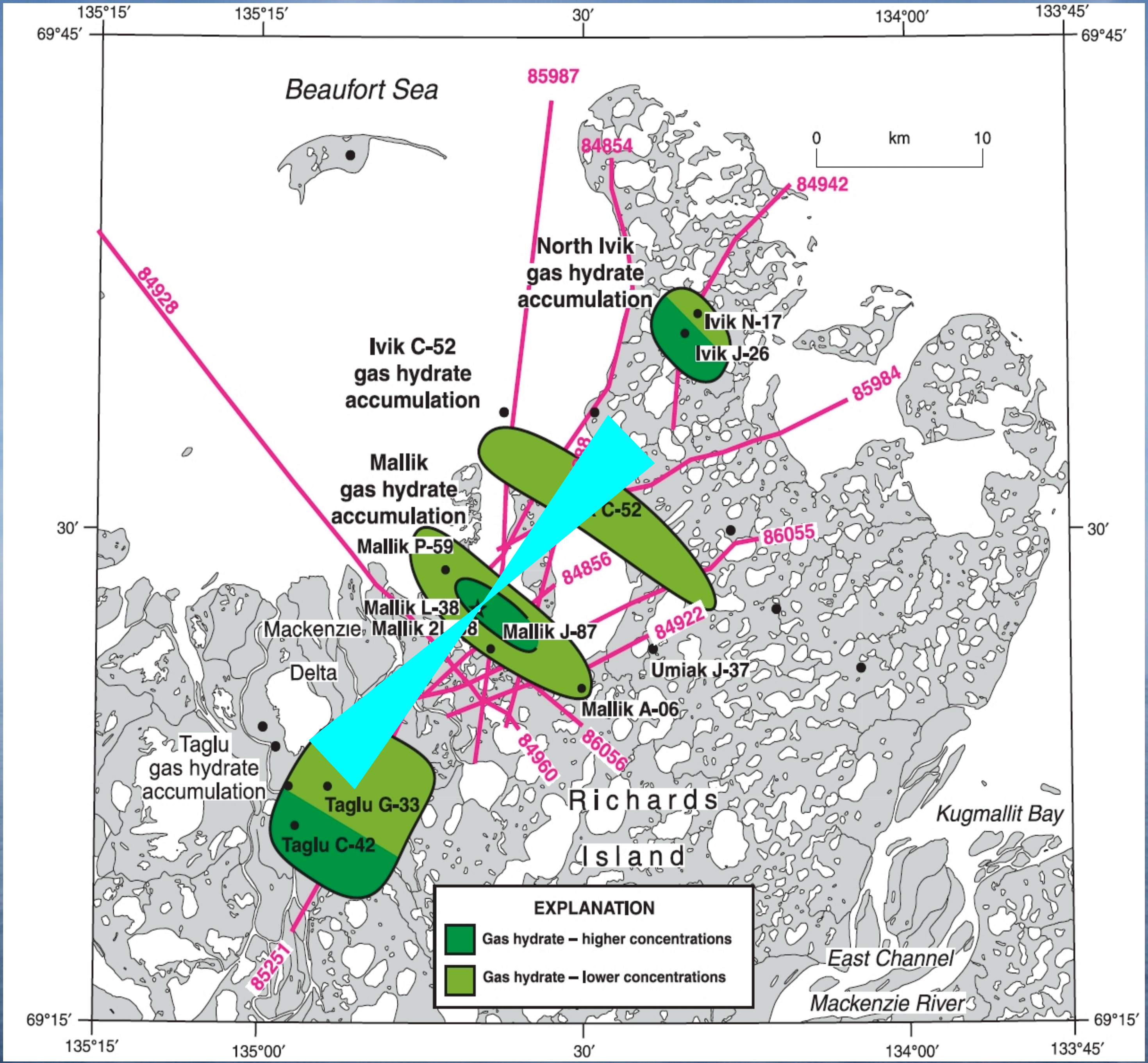
Waveforms rotation



Sonic Anisotropy in Mallik 5L38

Sonic Anisotropy in Mallik 5L38

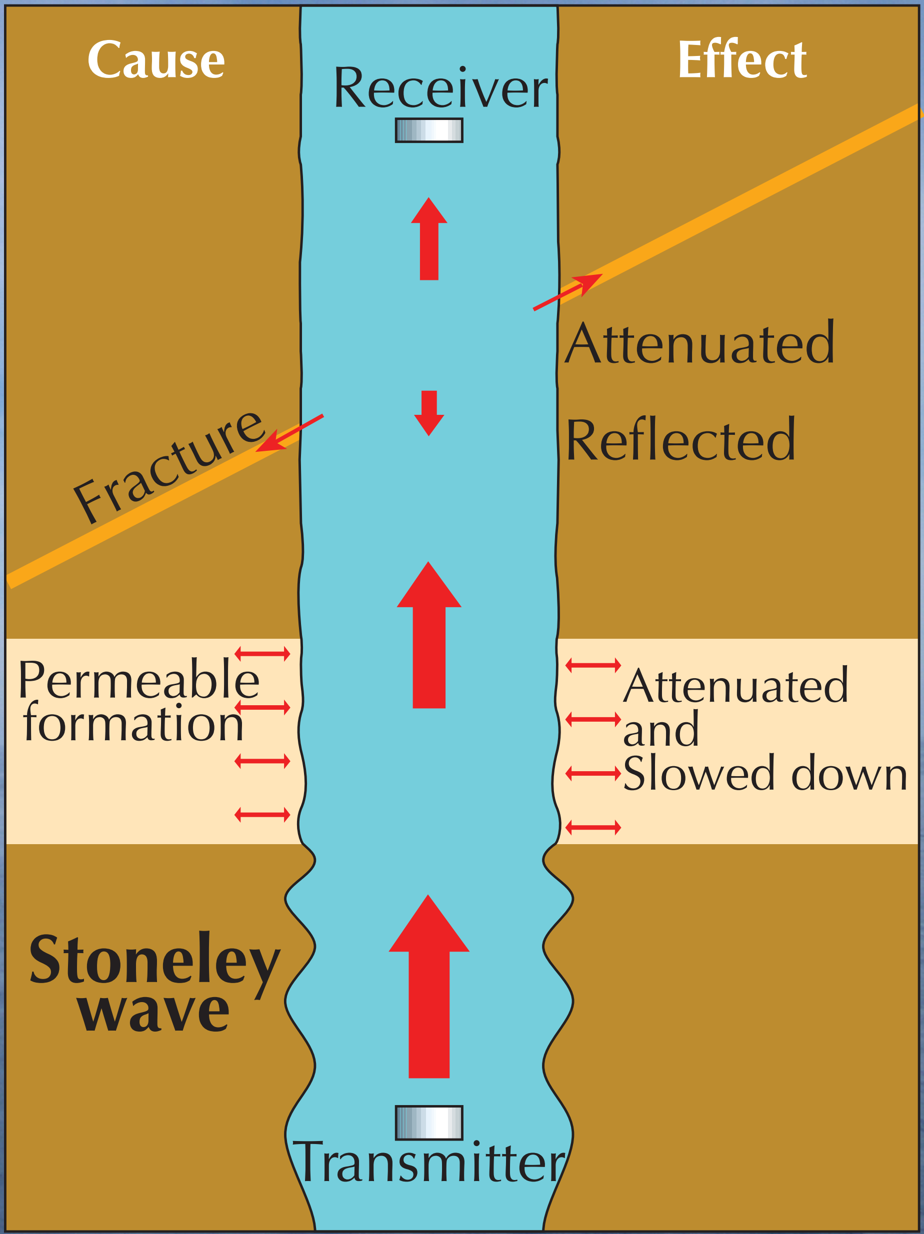
Stress orientation in the Mallik Field



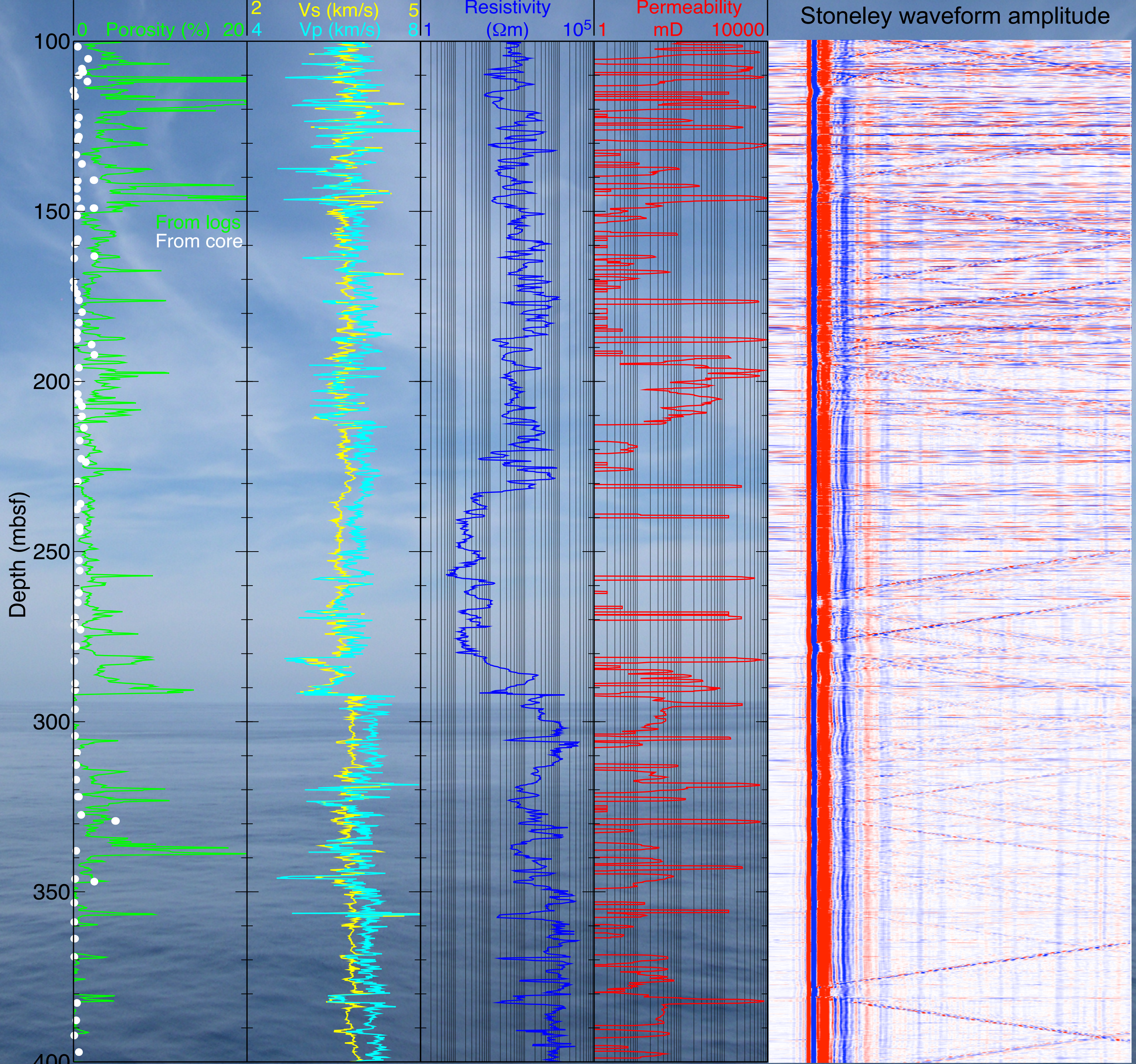
Fast Vs azimuth

Permeability estimation from Stoneley Waves

- When generated at low frequency, Stoneley waves travel as a tube wave
- They loose amplitude at the contact of permeable intervals, and are reflected by fractures.
- **The loss of amplitude can be related to formation permeability**



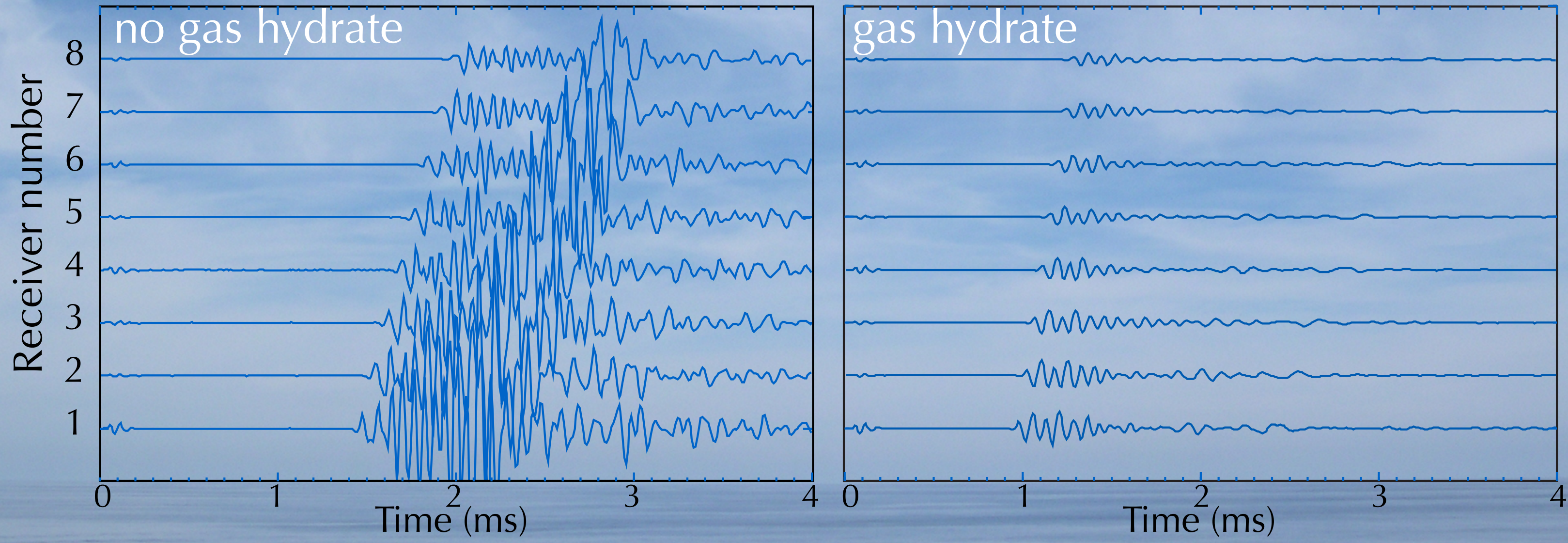
Analysis of Stoneley permeability in oceanic crust



Sonic waveforms attenuation

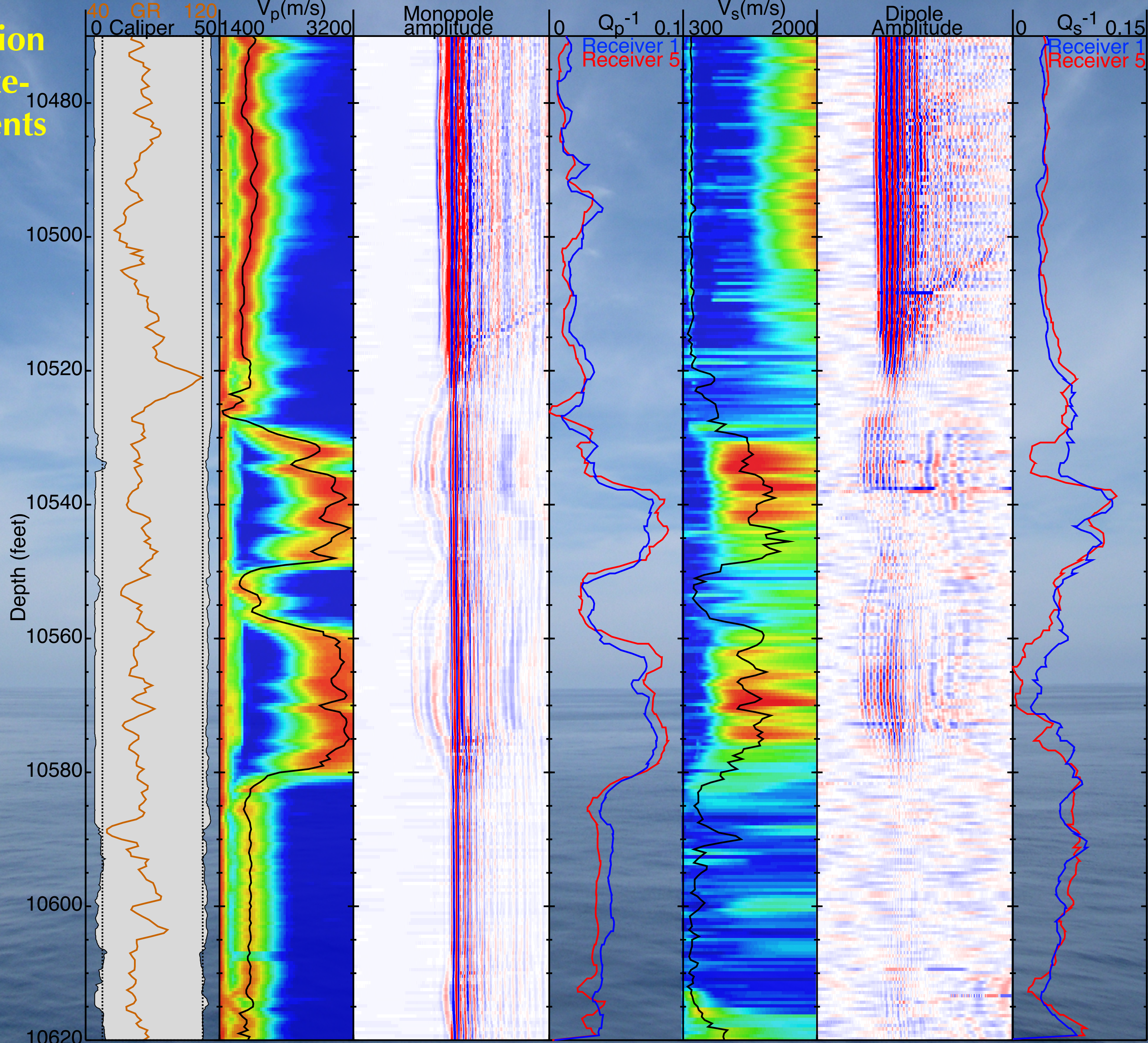
Attenuation ~ loss of energy/wf cycle

$$Q^{-1} = -\frac{1}{2\pi}\frac{\Delta E}{E}$$

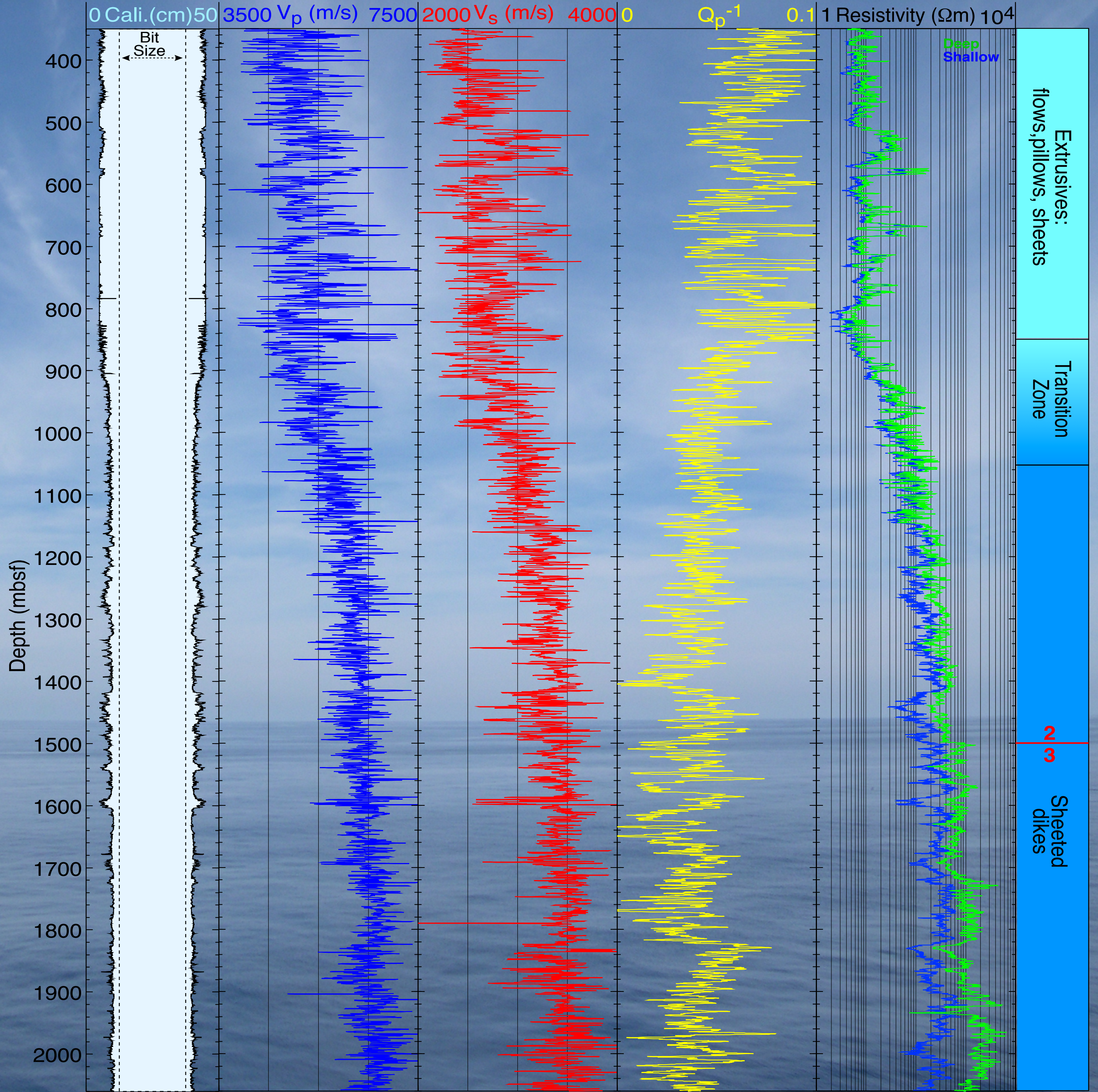


Intrinsic attenuation is mostly due to friction and fluid flow - i.e. the fabric of formation and of the pore space

Sonic Attenuation in Gas Hydrate-bearing sediments



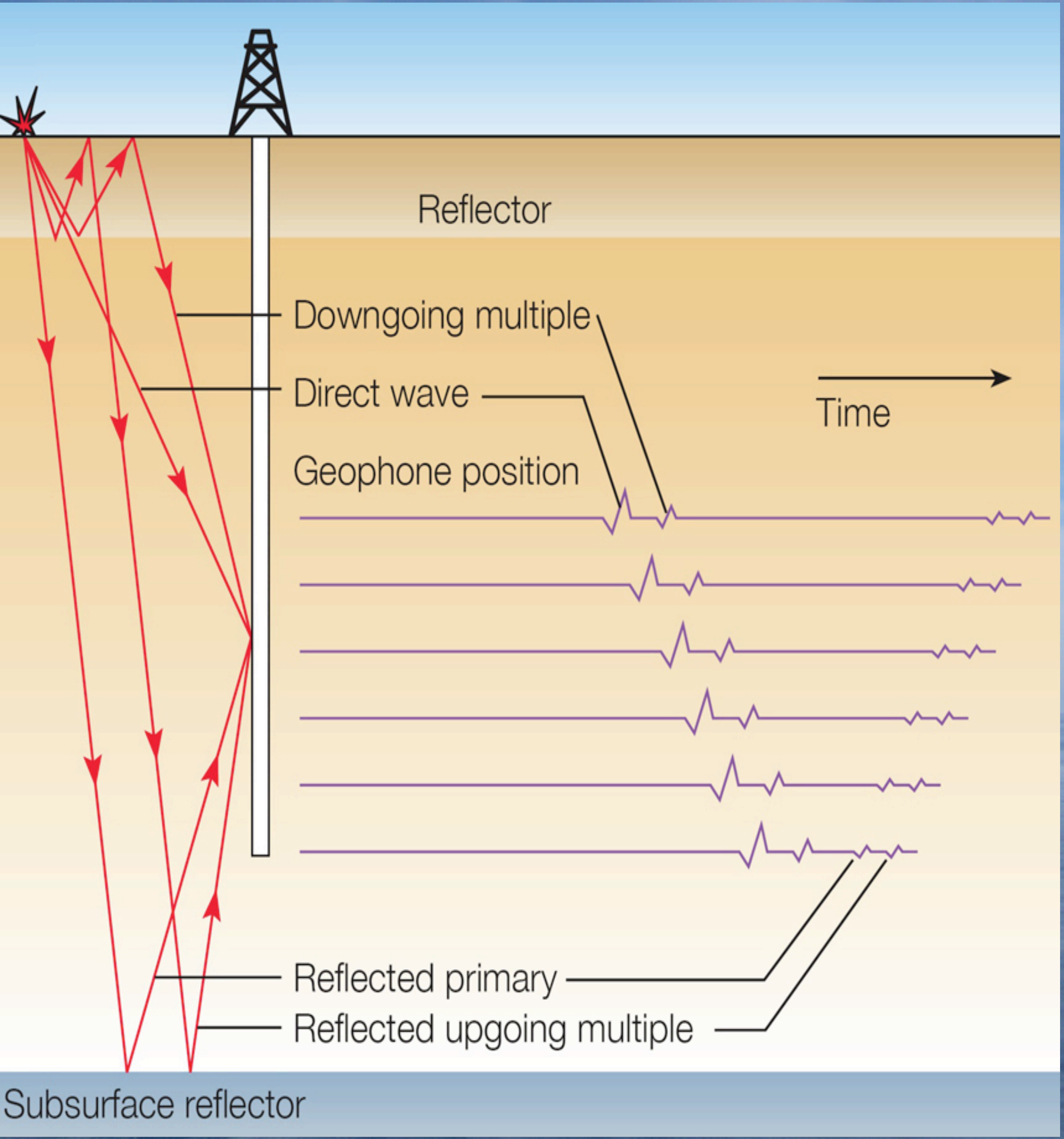
Sonic Attenuation in oceanic crust Hole 504B



Seismic/Well Integration

- Vertical Seismic Profiles (VSP)
- Synthetic seismograms from logs

Vertical Seismic Profiles (VSP)

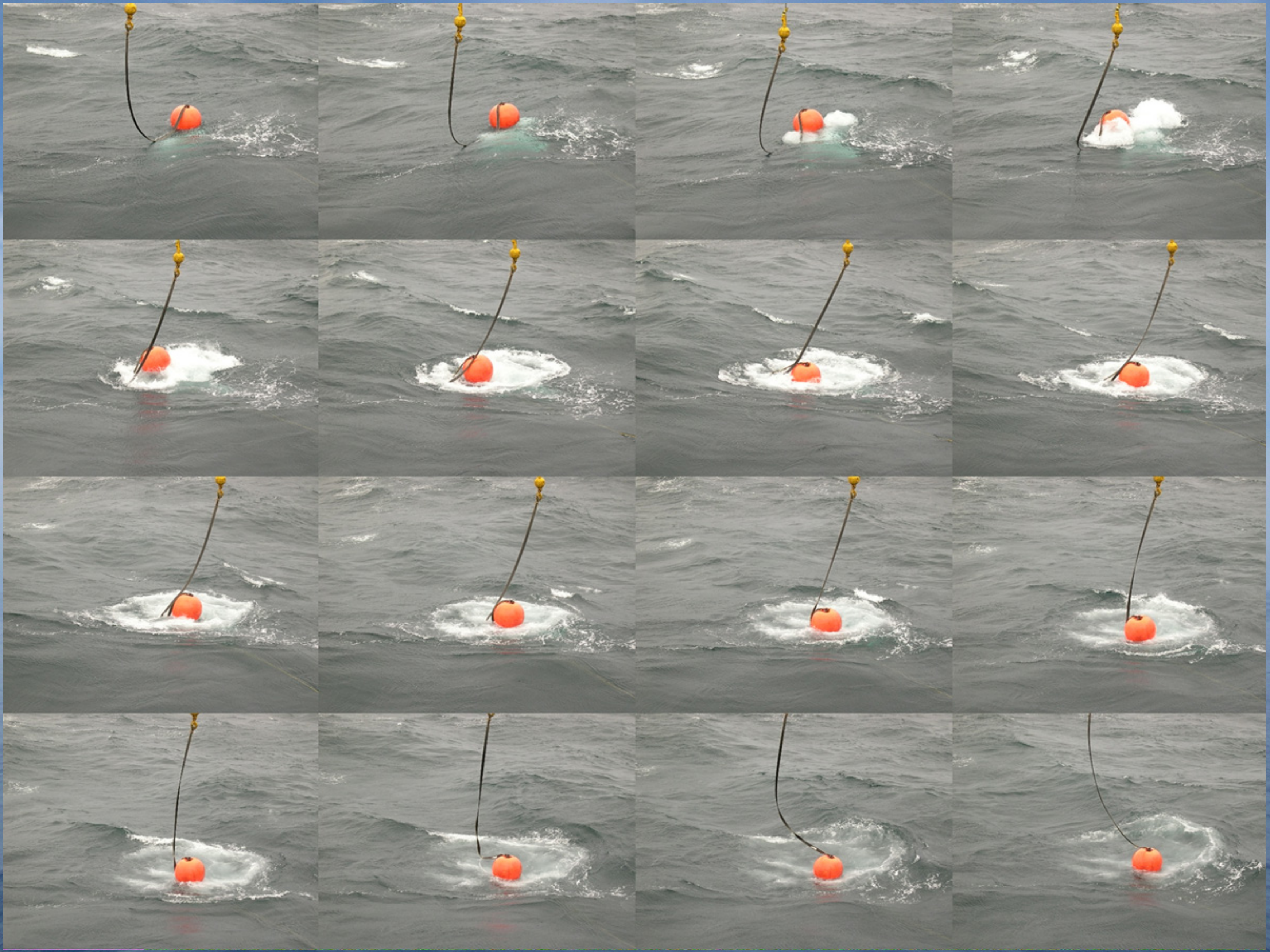


- Time-Depth relationship
- Interval velocity
- Imaging beyond the borehole

VSP tools used in ODP/IODP

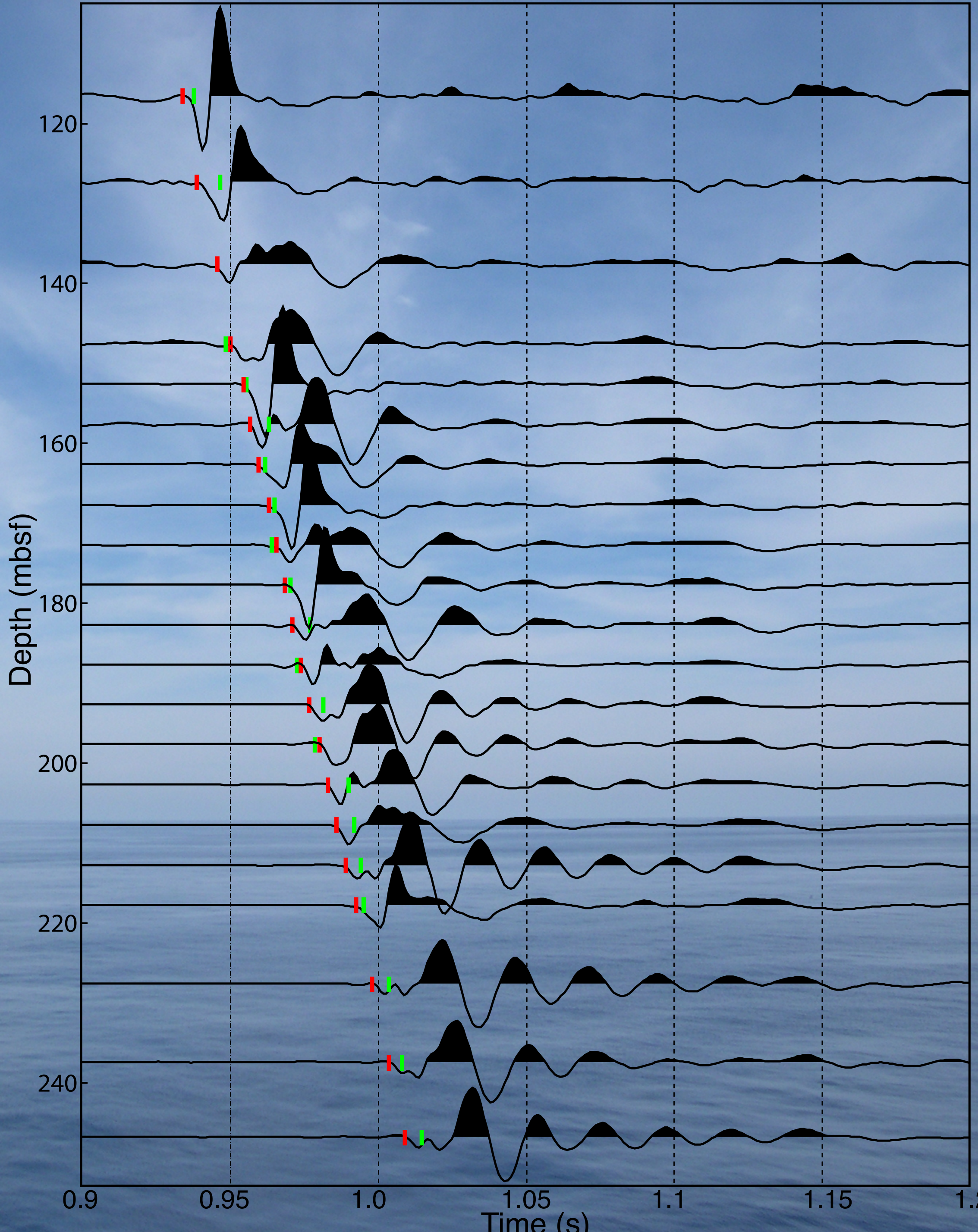
Seismic sorce setup on the JR

And …. action!

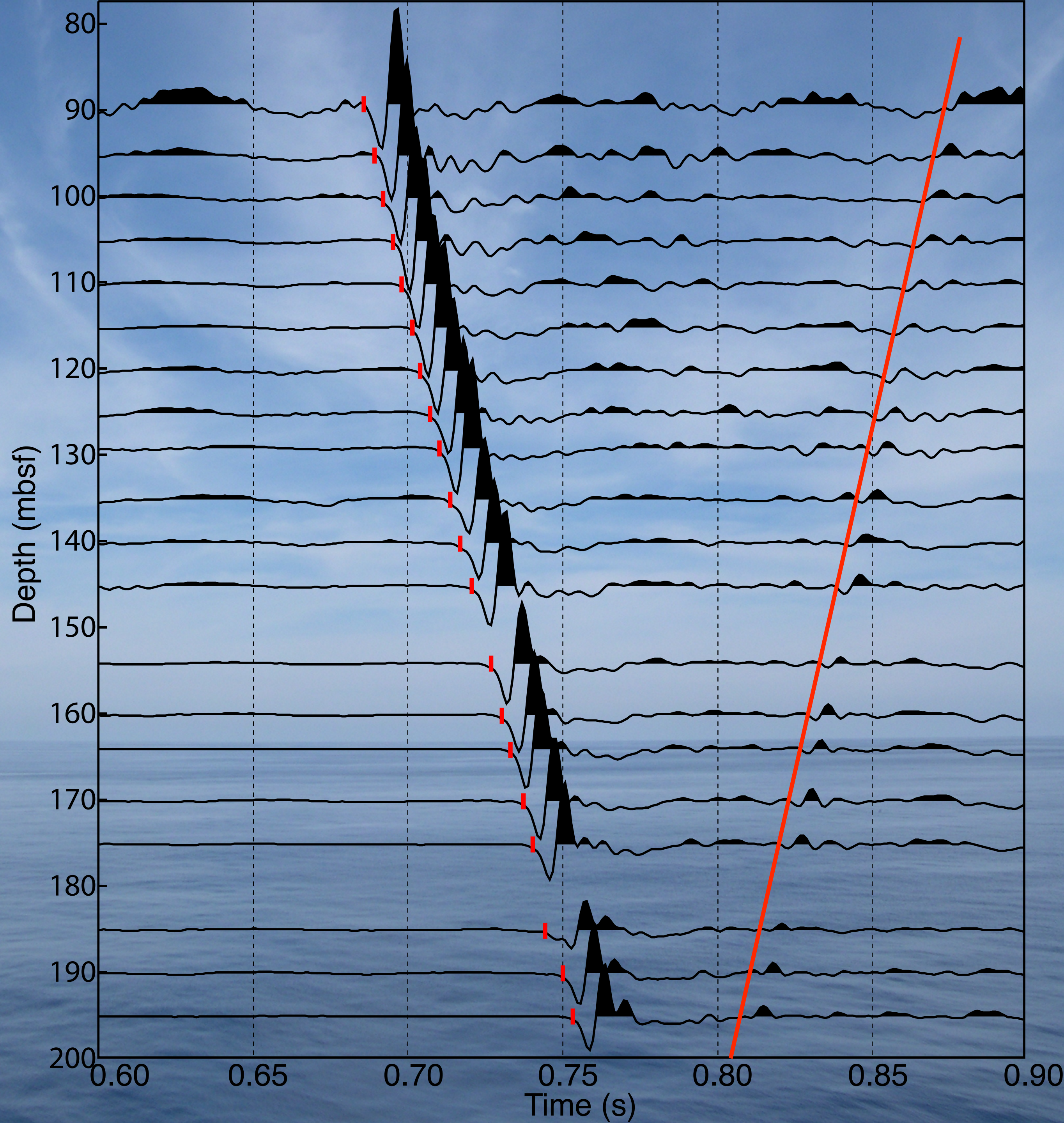


VSP
NGHP-1-07D

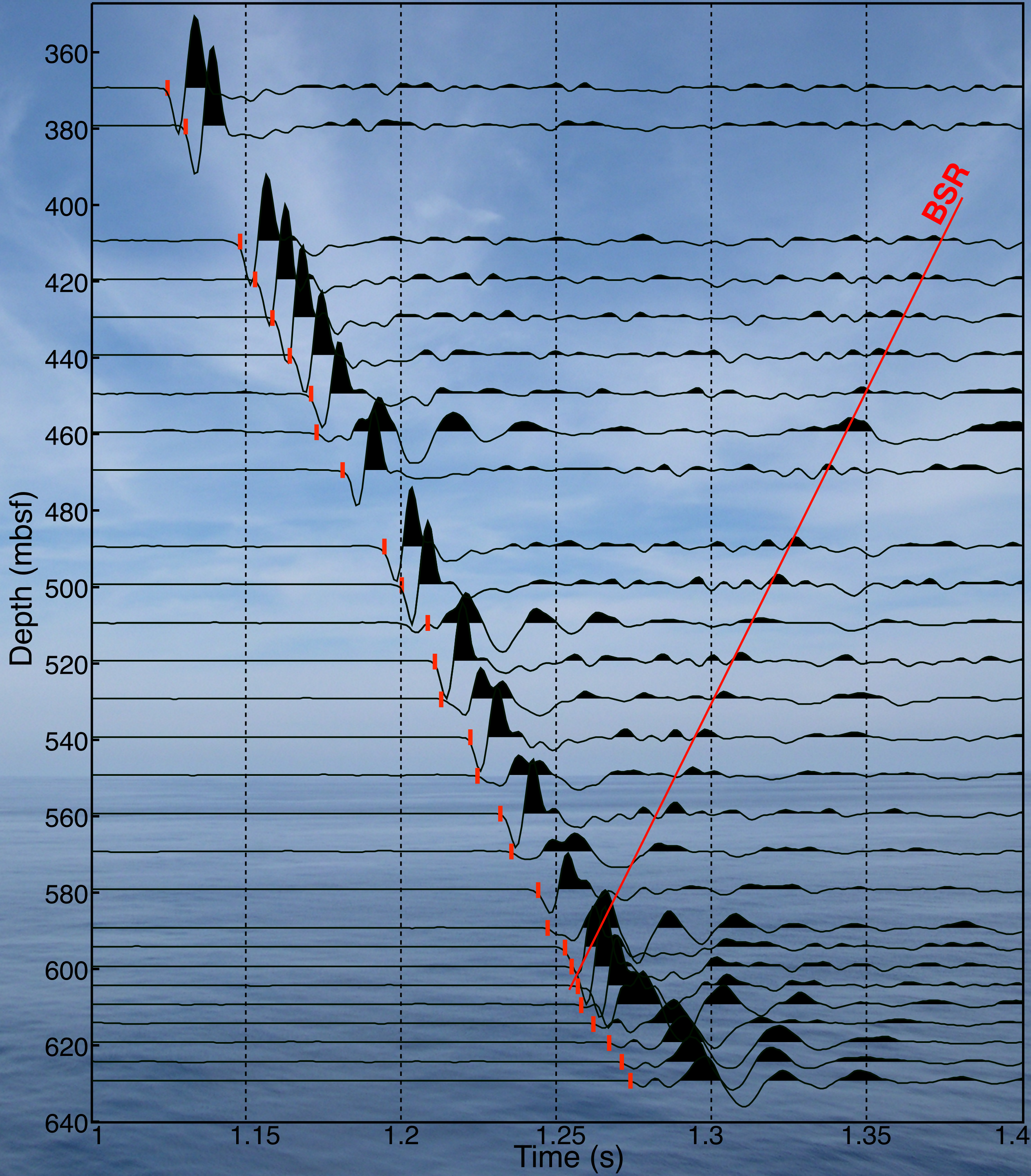
Processing:
- Band pass filter
- First arrival pick
  - I original
  - I new



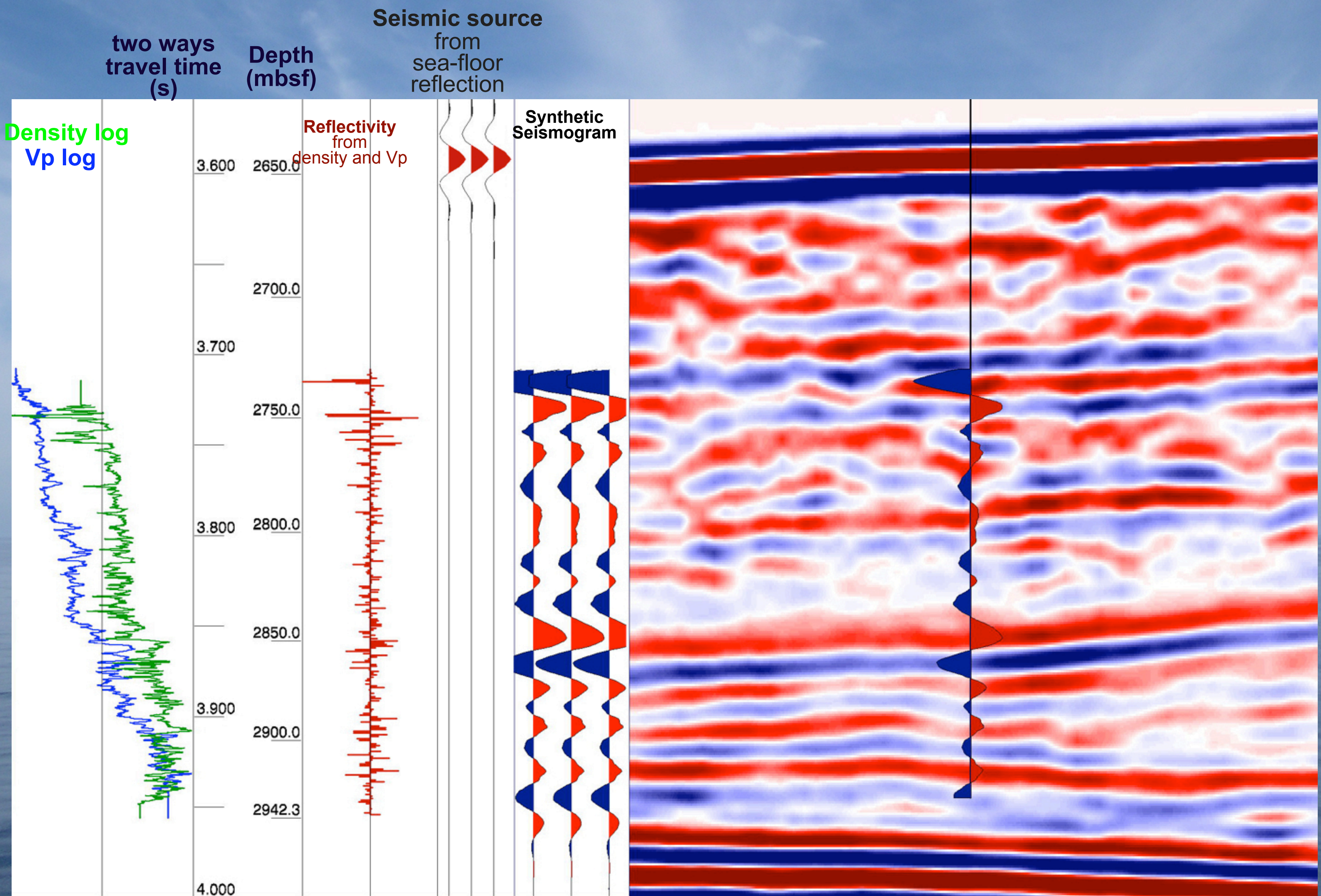
VSP Hole NGHP-1-05E



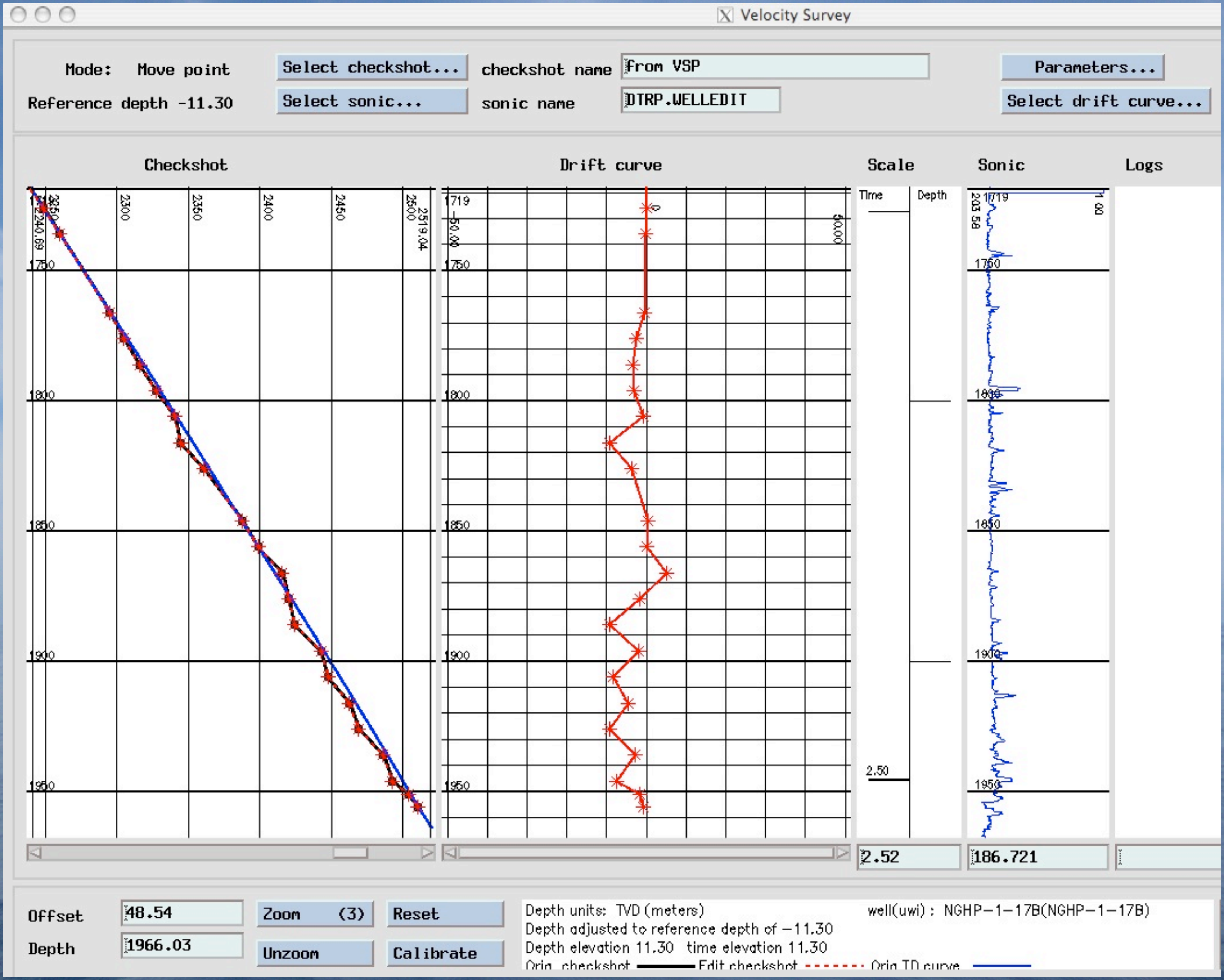
VSP Hole NGHP-1-17B

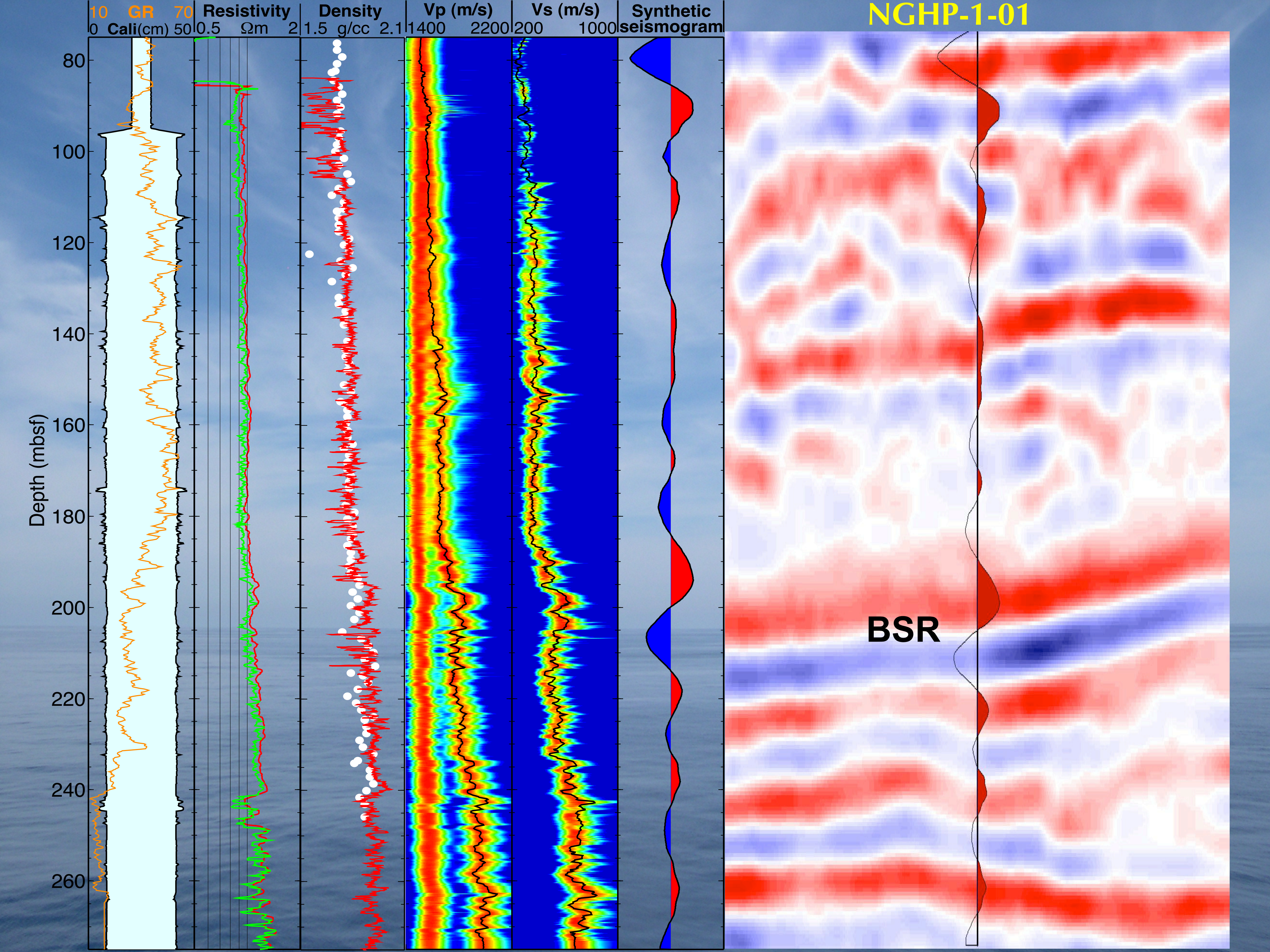


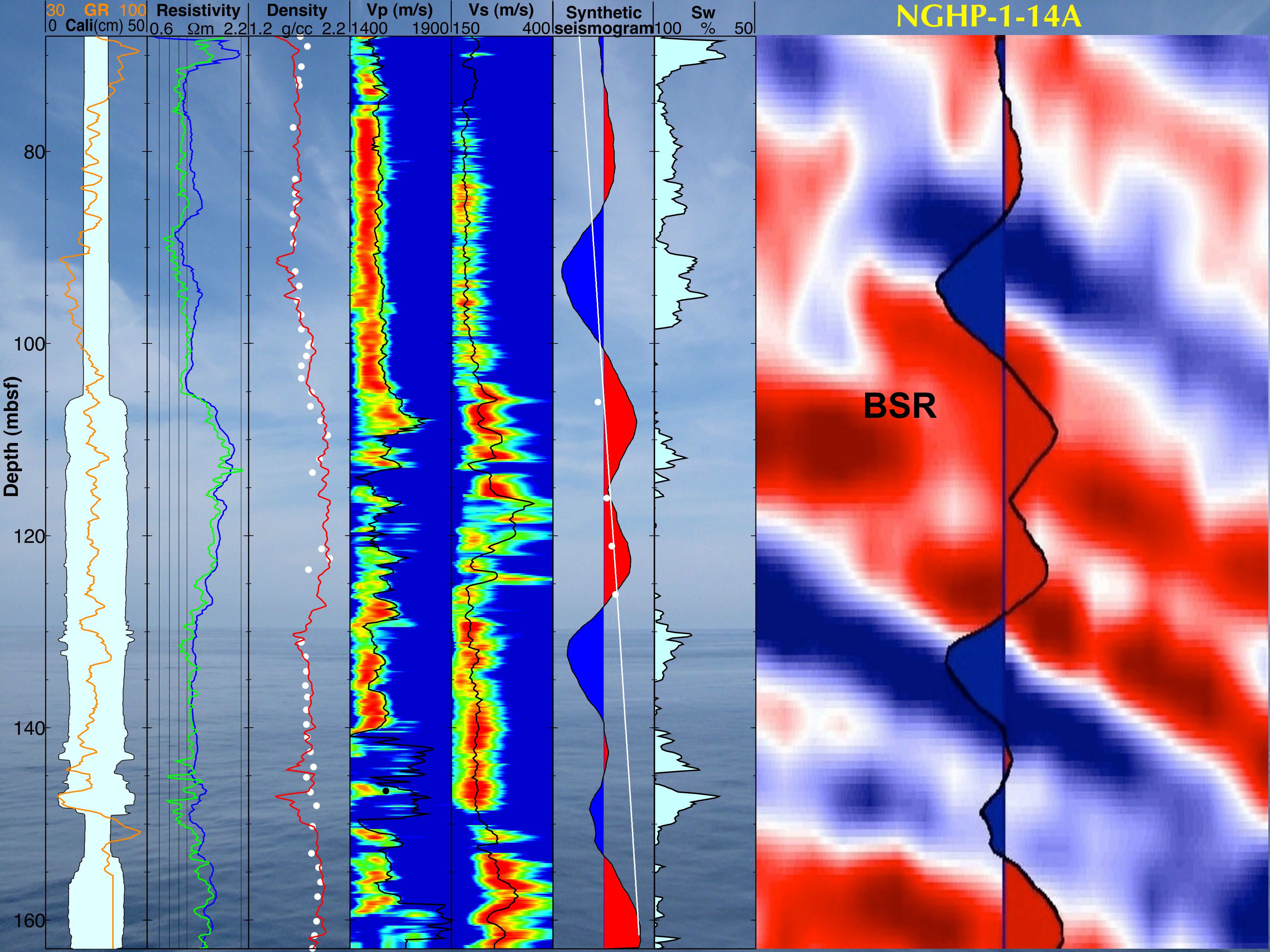
Generating Synthetic Seismograms from logs



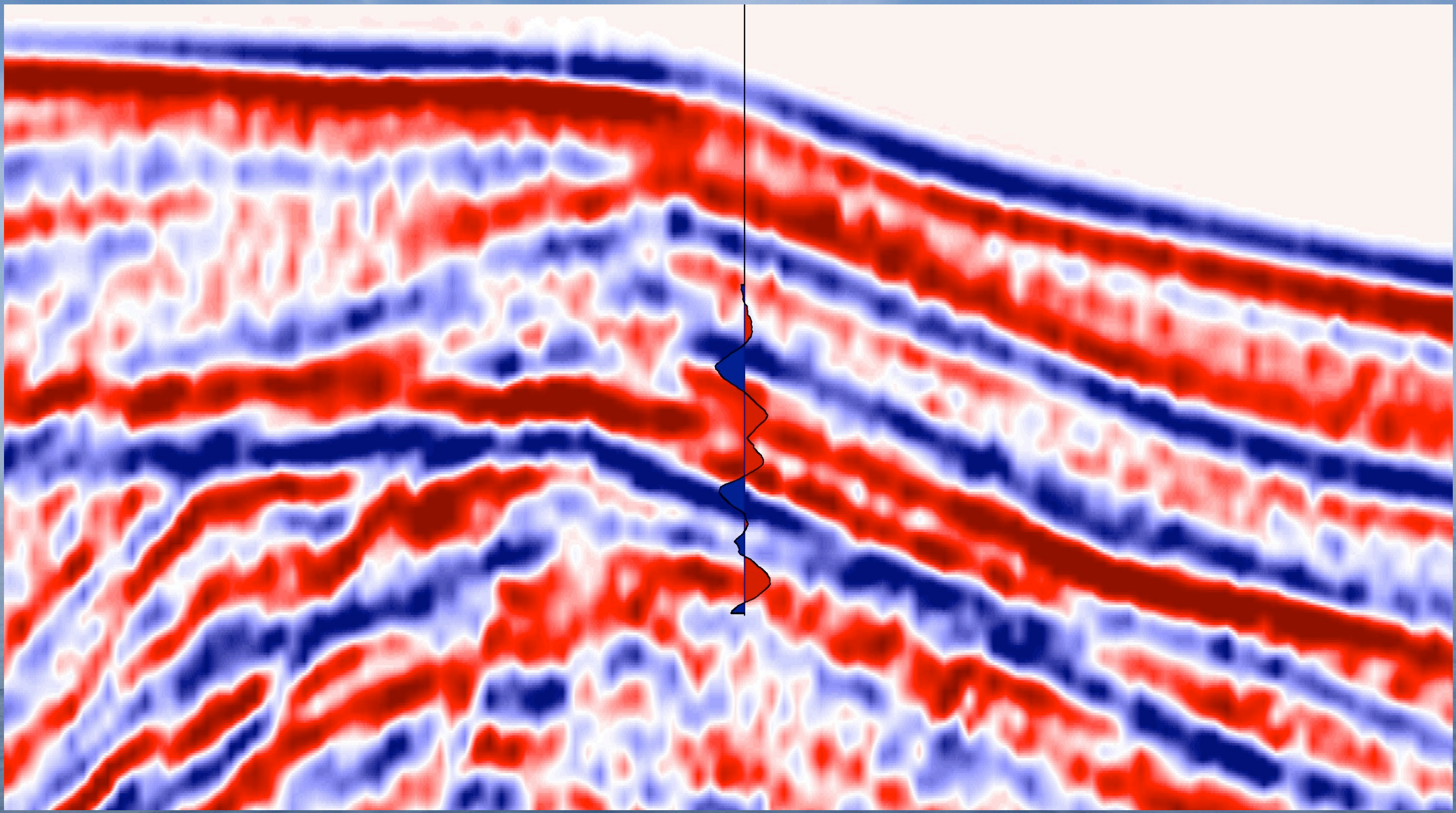
Velocity survey (synthetic seismogram calibration)



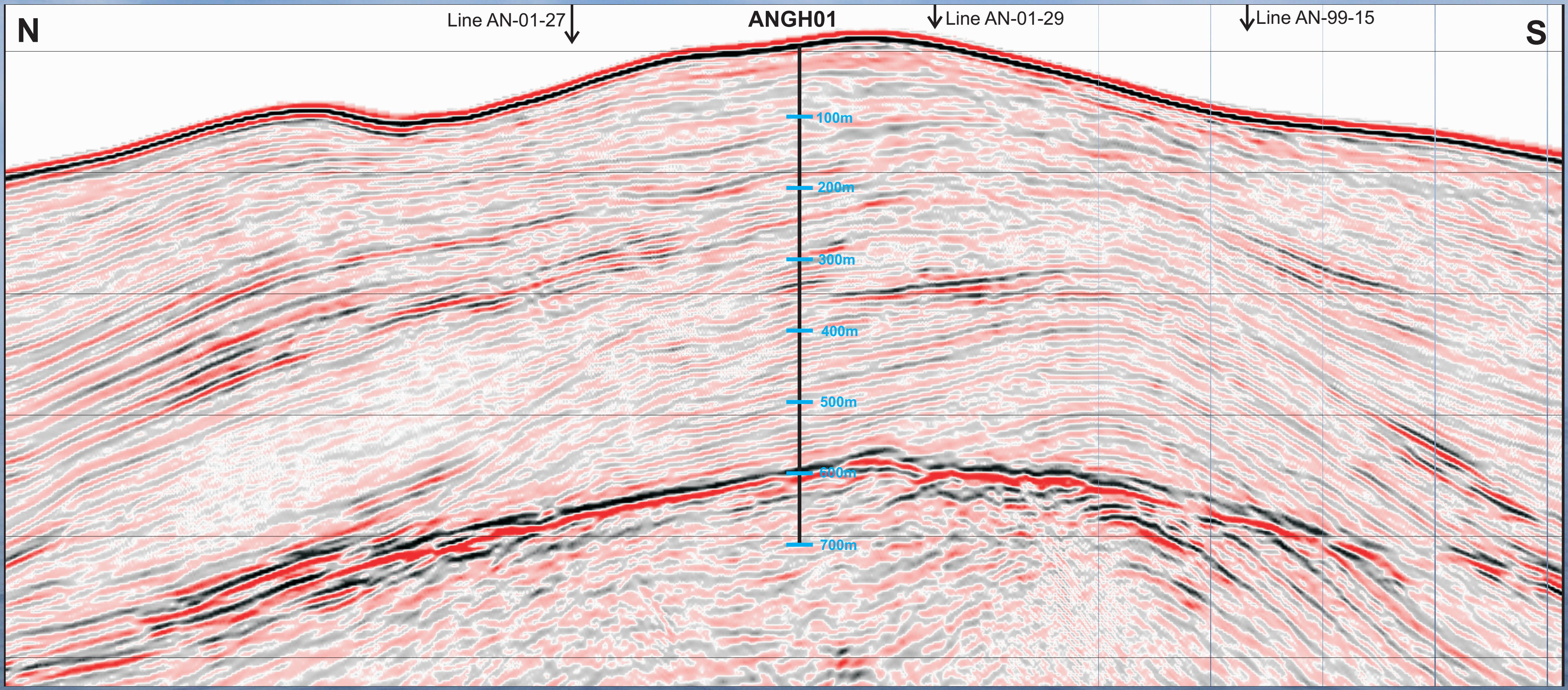

NGHP-1-01
10 GR 70
0 Cali(cm) 50
Resistivity
0.5 Ωm 2
Density
1.5 g/cc 2.1
Vp (m/s)
1400 2200
Vs (m/s)
200 1000
Synthetic seismogram
Depth (mbsf)
80
100
120
140
160
180
200
220
240
260
BSR

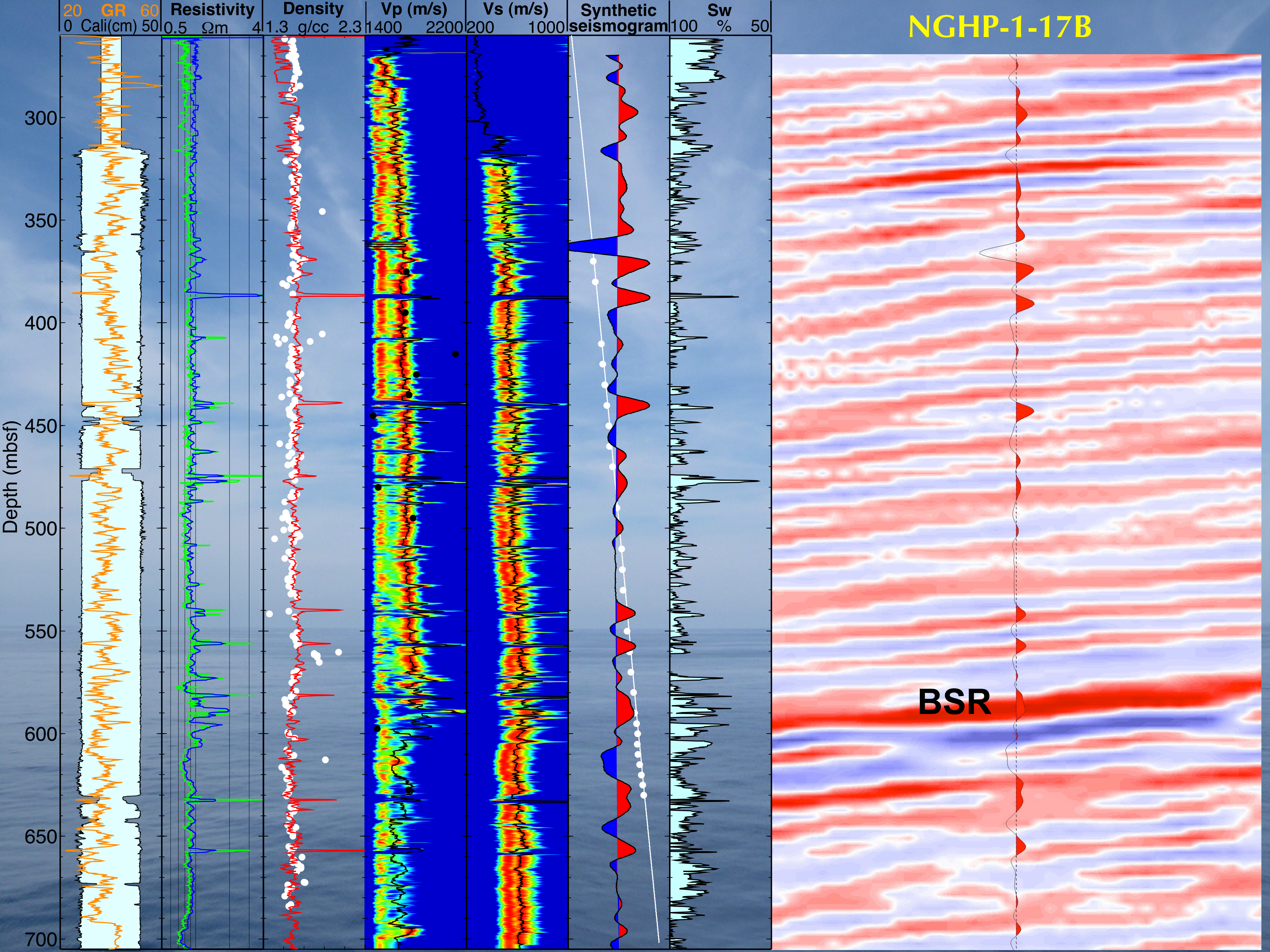

NGHP-1-14A
30 GR 100
0 Cali(cm) 50
Resistivity
0.6 Ωm 2.2
Density
1.2 g/cc 2.2
Vp (m/s)
1400 1900
Vs (m/s)
150 400
Synthetic seismogram
Sw
100 % 50
Depth (mbsf)
80
100
120
140
160
BSR

NGHP-1-14A



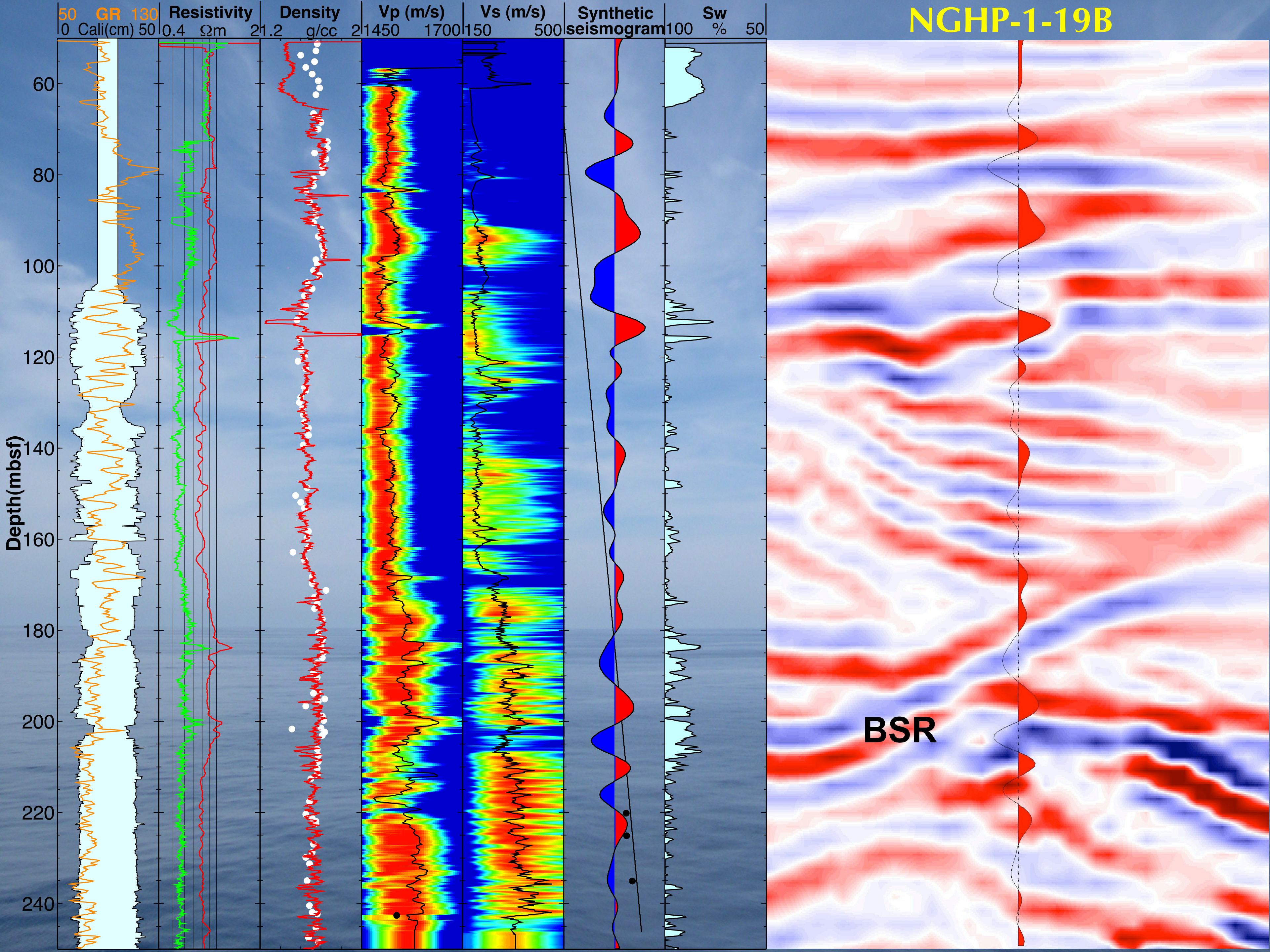
Site NGHP-1-17, Andaman Islands





NGHP-1-17B
20 GR 60
0 Cali(cm) 50
Resistivity
0.5 Ωm 4
Density
1.3 g/cc 2.3
Vp (m/s)
1400 2200
Vs (m/s)
200 1000
Synthetic seismogram
Sw
100 % 50
Depth (mbsf)
300
350
400
450
500
550
600
650
700
BSR

NGHP-1-19B



50 GR 130
0 Cali(cm) 50
Resistivity
0.4 Ωm 2
Density
1.2 g/cc 2
Vp (m/s)
1450 1700
Vs (m/s)
150 500
Synthetic seismogram
Sw
100 % 50
Depth(mbsf)
60
80
100
120
140
160
180
200
220
240
BSR

NGHP-1-19B