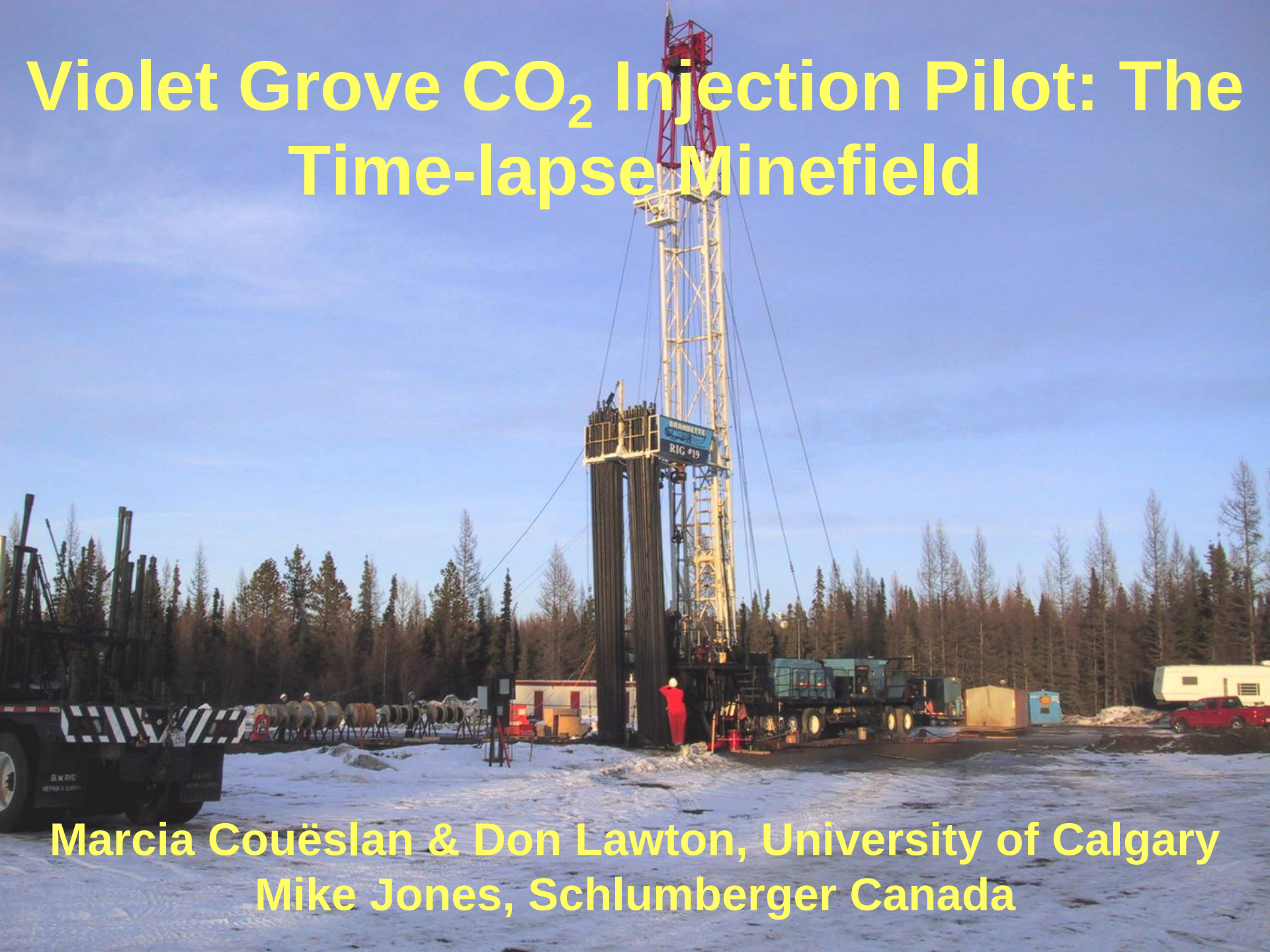
# Violet Grove $CO_2$ Injection Pilot: The Time-lapse Minefield




Marcia Couëslan & Don Lawton, University of Calgary
Mike Jones, Schlumberger Canada

# Outline

- Introduction
- Field Background
- Time-lapse Surveys
  - Importance of Repeatability
  - Time-lapse Results
  - Supporting Evidence
- Conclusions
- Recommendations
- Acknowledgements

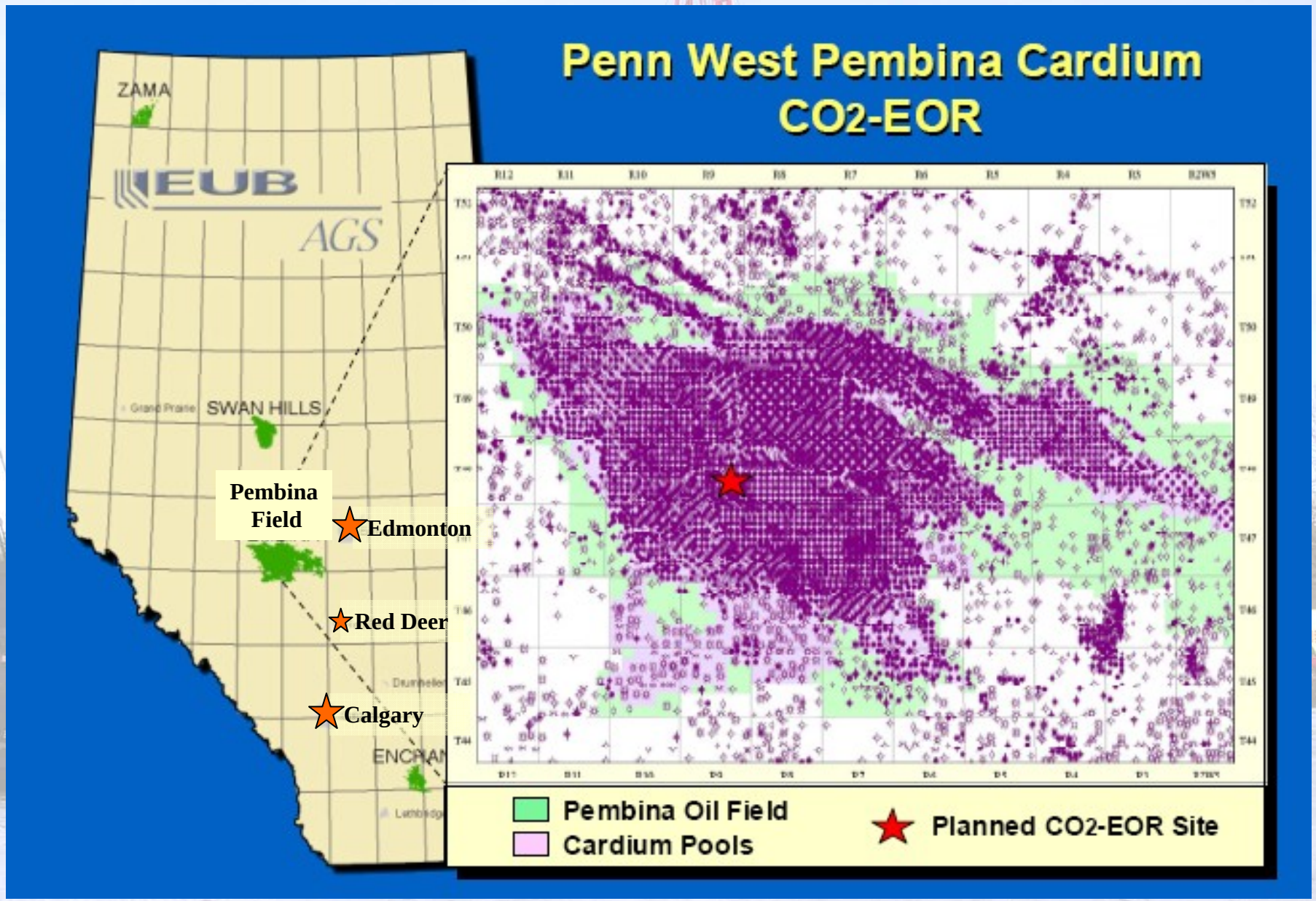
# Introduction

The Penn West Project is

- A pilot project that injects $CO_2$ into the reservoir for EOR and sequestration purposes.

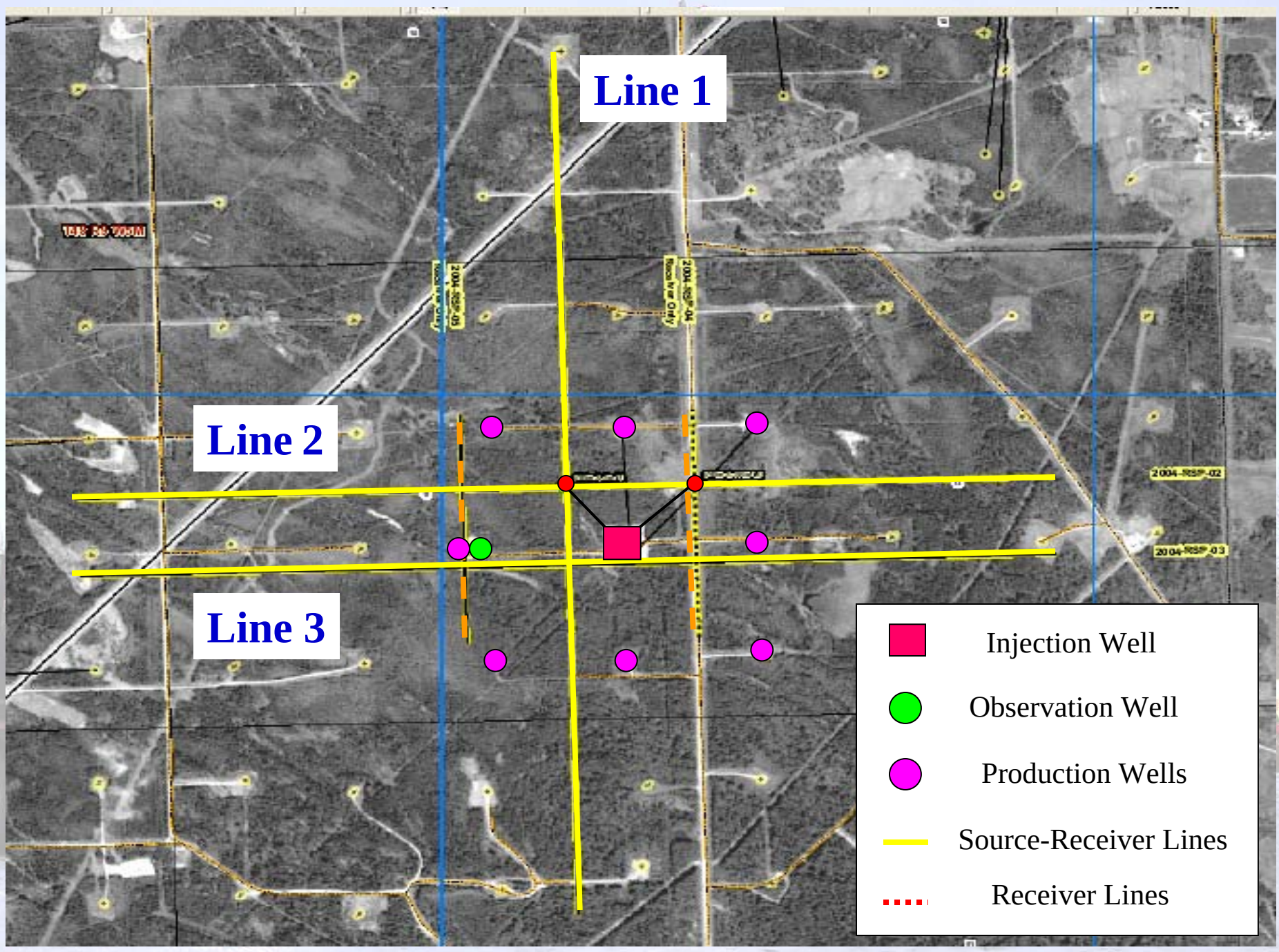
- Uses an innovative surface and borehole seismic program that has been designed to monitor injected $CO_2$.

# Project Background



# Project Background

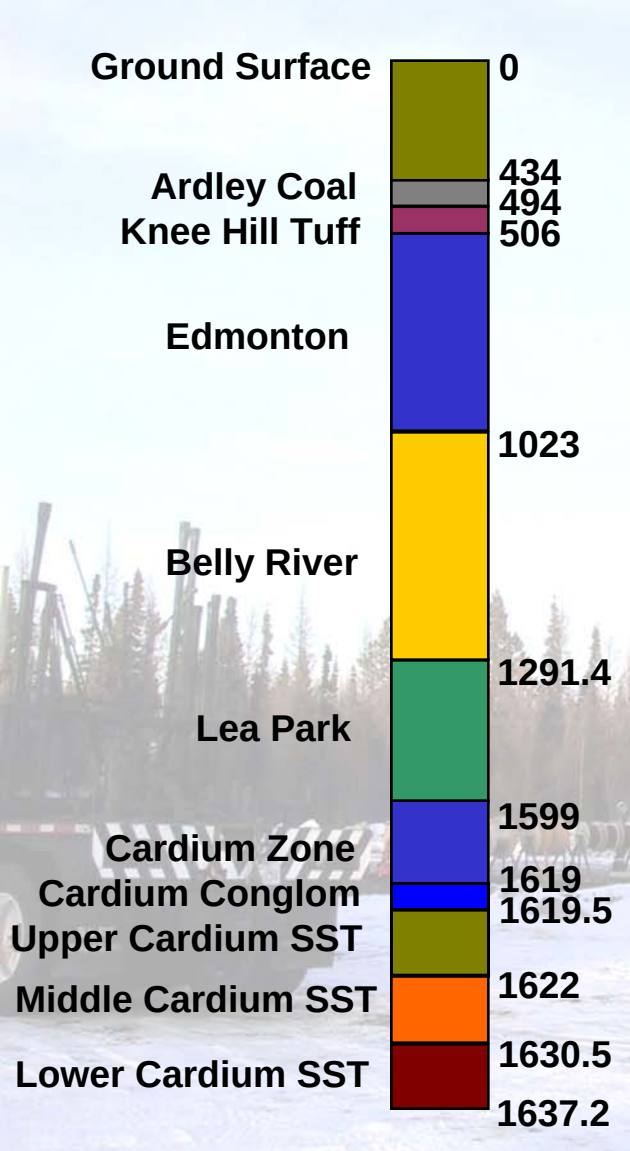
- $CO_2$ injection for EOR and sequestration
- $CO_2$ is delivered by tanker truck from a gas plant 50 km away
- Supercritical $CO_2$ is injected
  - At a rate of ~ 70 tonnes/day at ~ 20 MPa
- The average Canadian produces ~5 tonnes of $CO_2$ per year

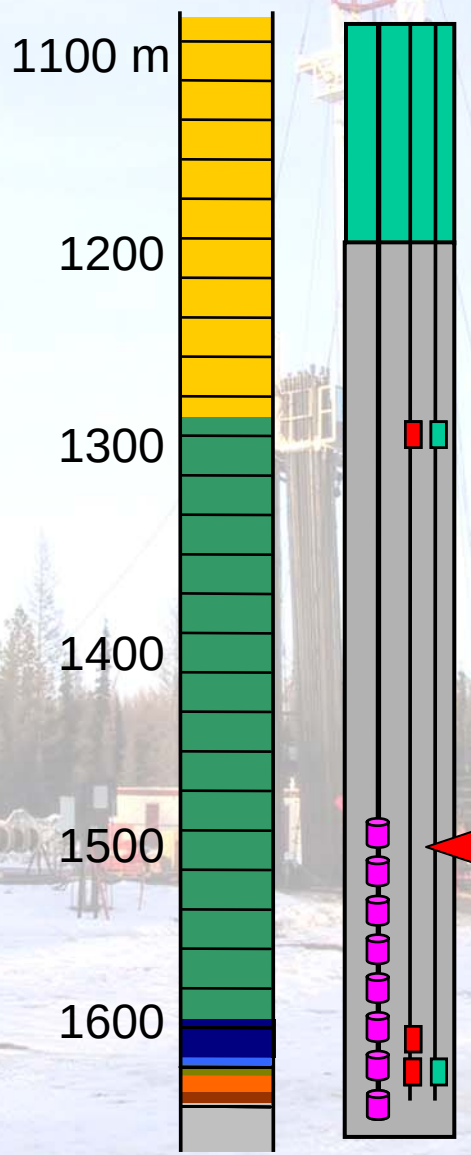

Line 1
Line 2
Line 3
2004-RSP-03
2004-RSP-04
2004-RSP-02
2004-RSP-03
Injection Well
Observation Well
Production Wells
Source-Receiver Lines
Receiver Lines

# Project Background

- Monitor well equipment was installed in February 2005
  - 8 geophone arrays
  - 6 pressure/temperature sensors
  - 2 fluid sampling ports
- Baseline seismic survey was acquired in March 2005
- $CO_2$ injection commenced the next week

# Project Background




Cement Top at 1200 m

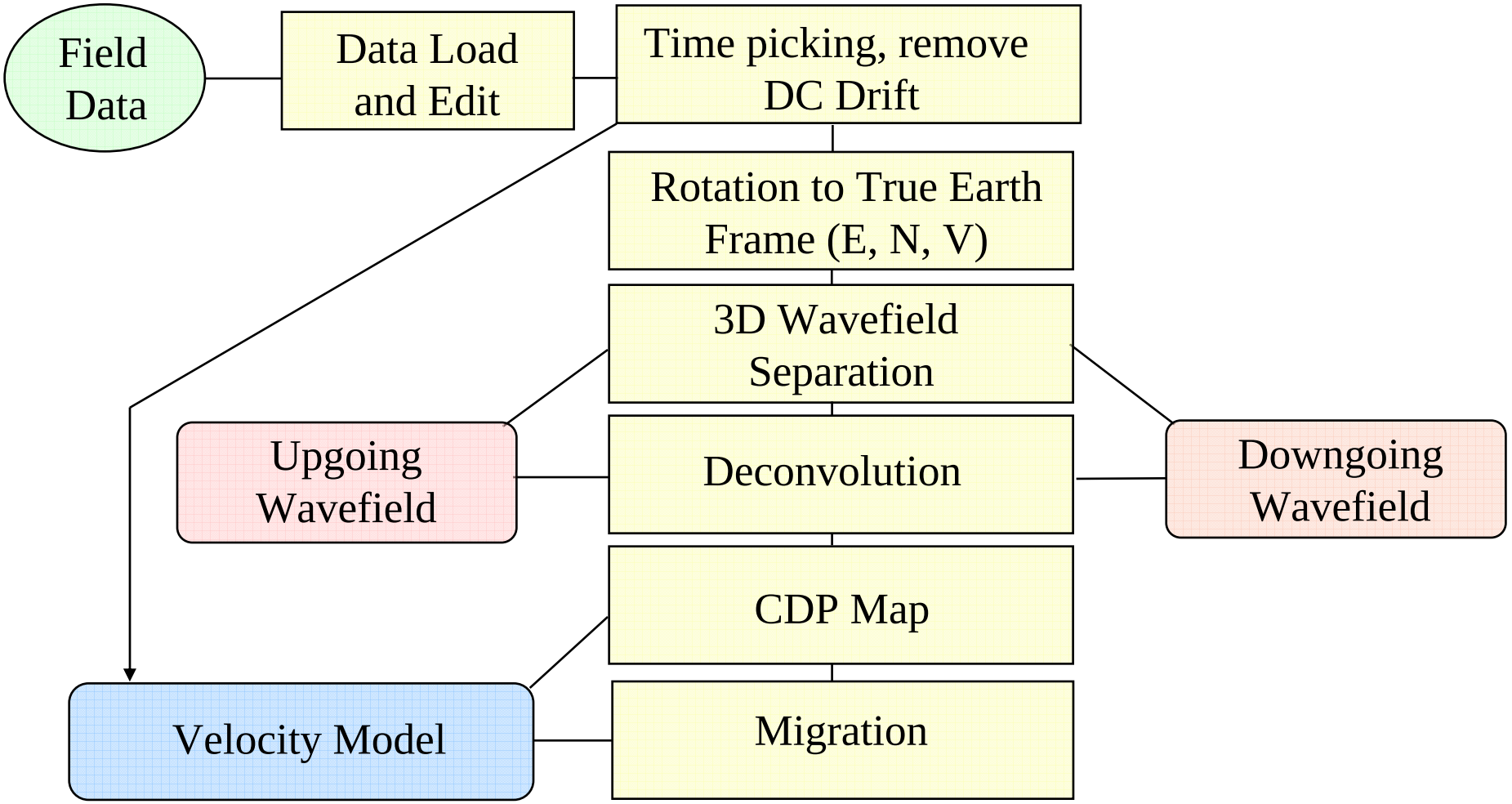
8 geophone array, from
1500 to 1640 m
at a 20 m spacing

Courtesy of Rick Chalaturnyk
University of Alberta

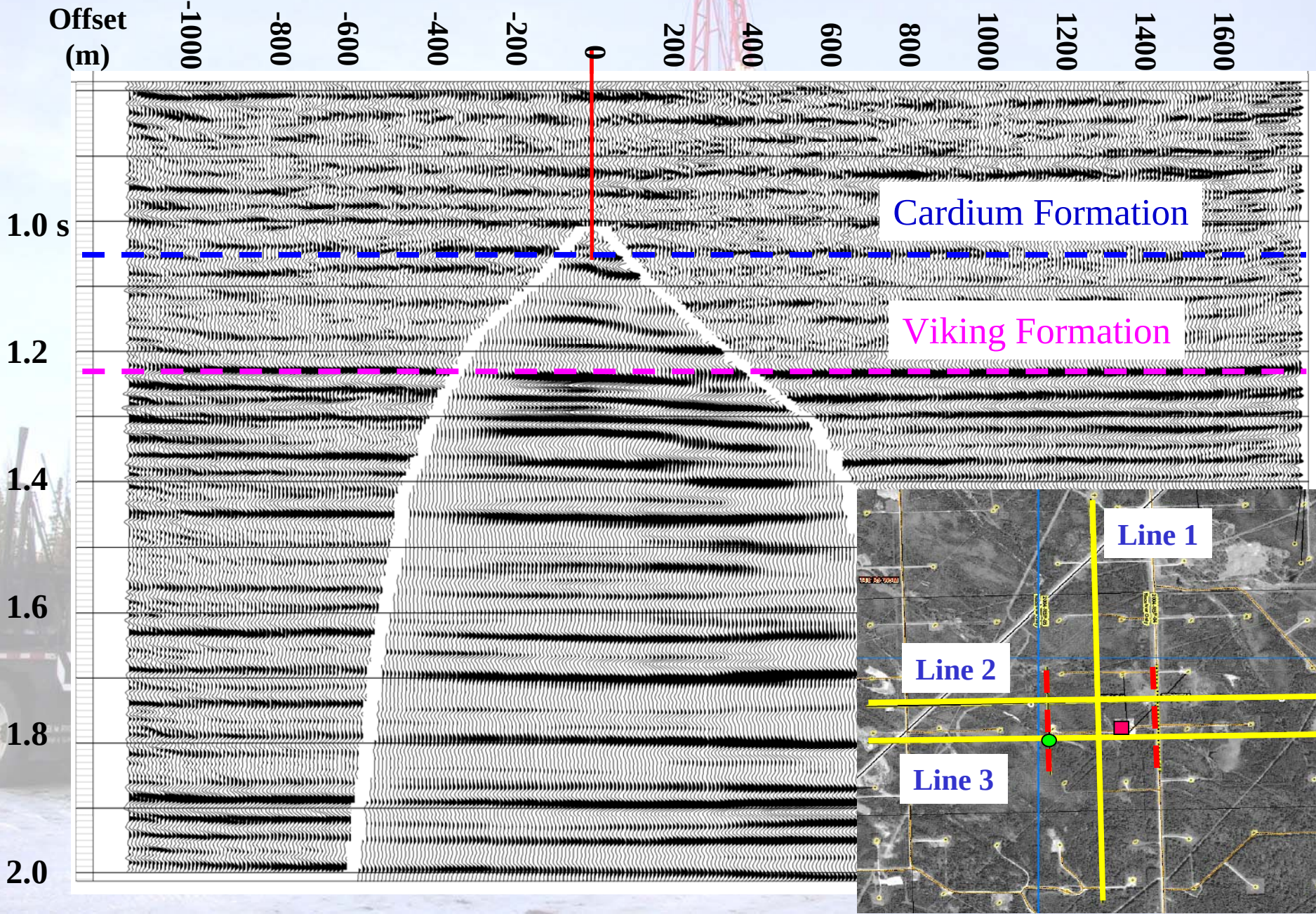
# Advantages of Fixed VSP Array

- Higher frequency bandwidth than surface seismic data
  - Results in higher vertical and horizontal resolution near the monitor well
- Provides a correlation between the time indexed surface seismic and the depth indexed well logs
- Information gained from the VSP can be used to improve surface seismic processing
  - Velocities, Q Estimation, anisotropy analysis
- Allows for passive seismic monitoring

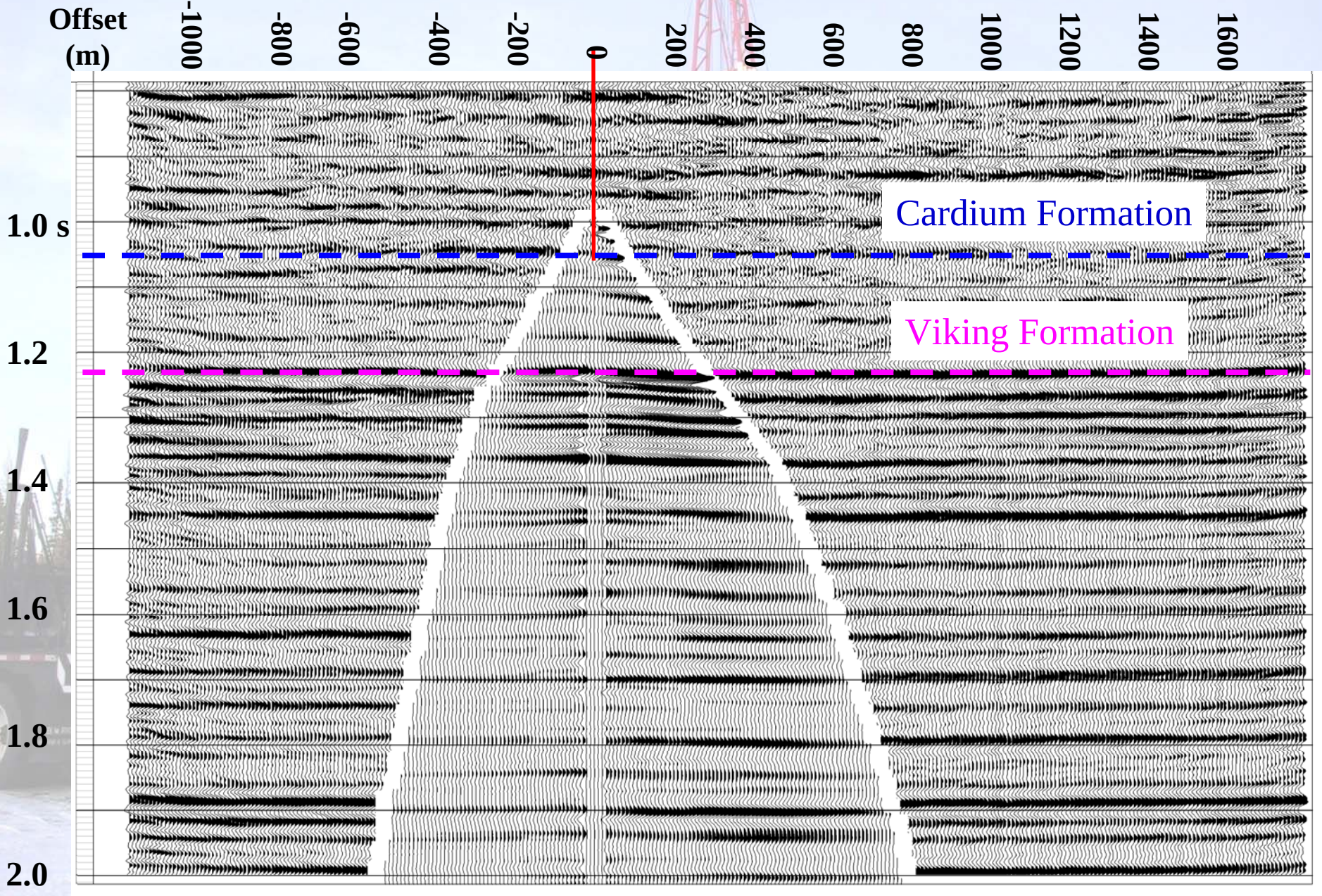
# Processing Flow



# Line 3: PP Surface Seismic & VSP



# Line 3: PP Surface Seismic & S-VSP



# Time-lapse Surveys

- Time-lapse surveys are required
  - To monitor the $CO_2$ flood in the reservoir
  - To look for leakage pathways in the overburden
- First monitor survey was acquired in December 2005
- Expect to acquire a second monitor survey in early 2007

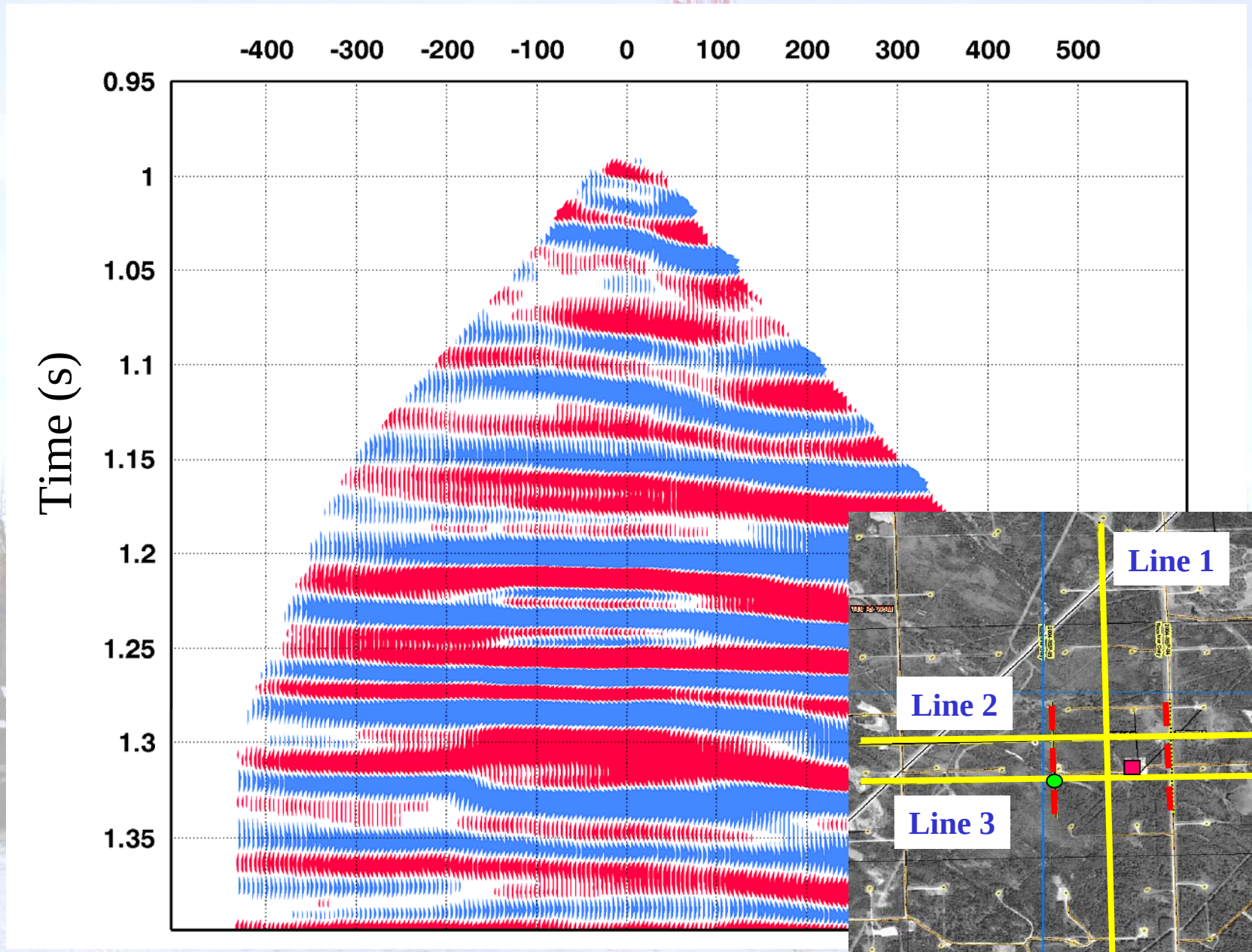
# Time-lapse Surveys

- Properties expected to change:
  - P-wave velocity at the reservoir
  - Fluid composition as the $CO_2$ is injected
- Expected seismic response:
  - Increased travel times
  - Change in reservoir amplitudes
- Geophone array is fixed
  - Can be used to calibrate source variability and overburden travel times between the surveys

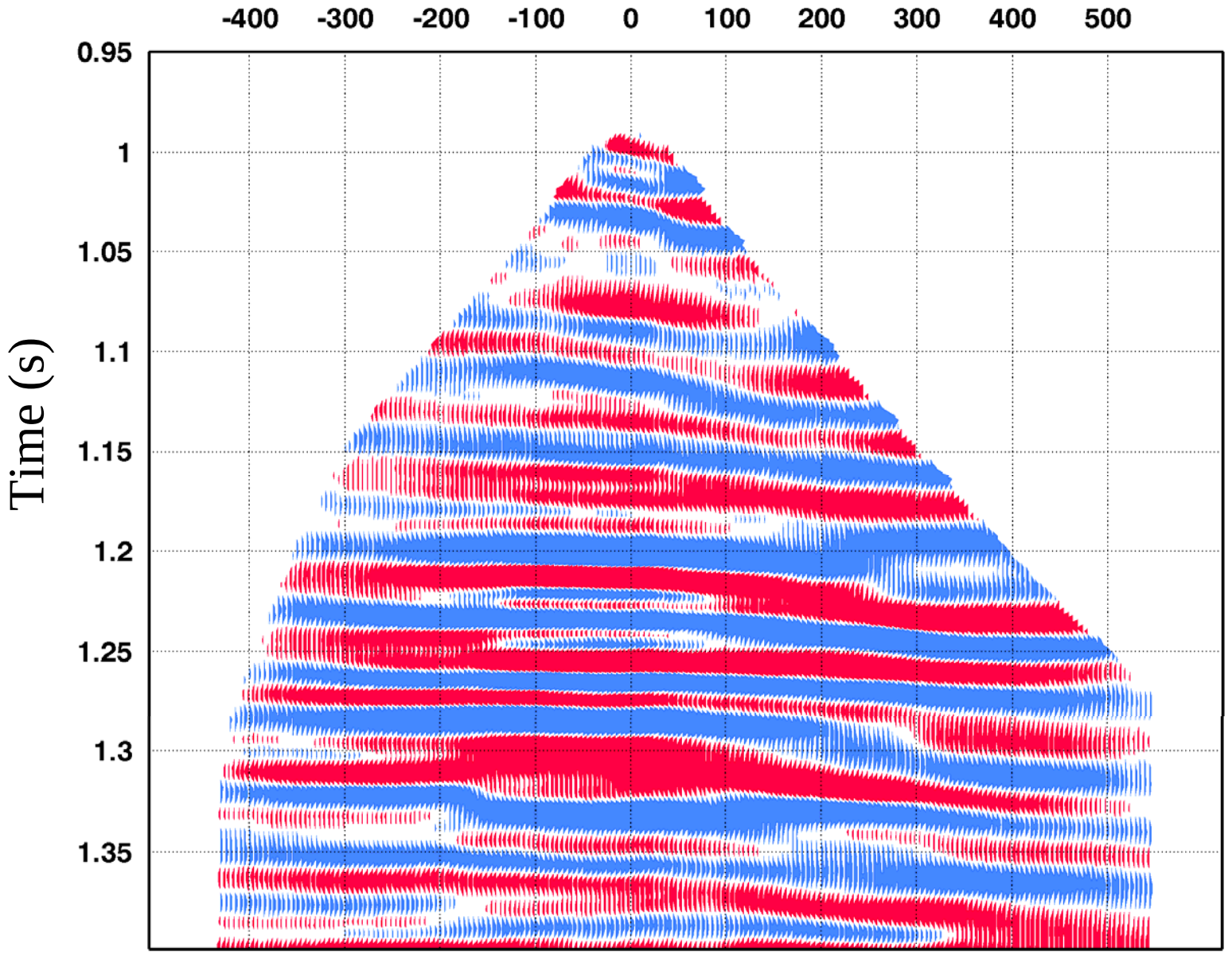
# Why Is Repeatability Important?

- Repeatability is affected by source-receiver geometries, consistency of the source signature, and shot-generated noise
- Seismic noise is often caused by subsurface heterogeneities
- Repeating source-receiver geometries allows the noise to the replicated and differenced away

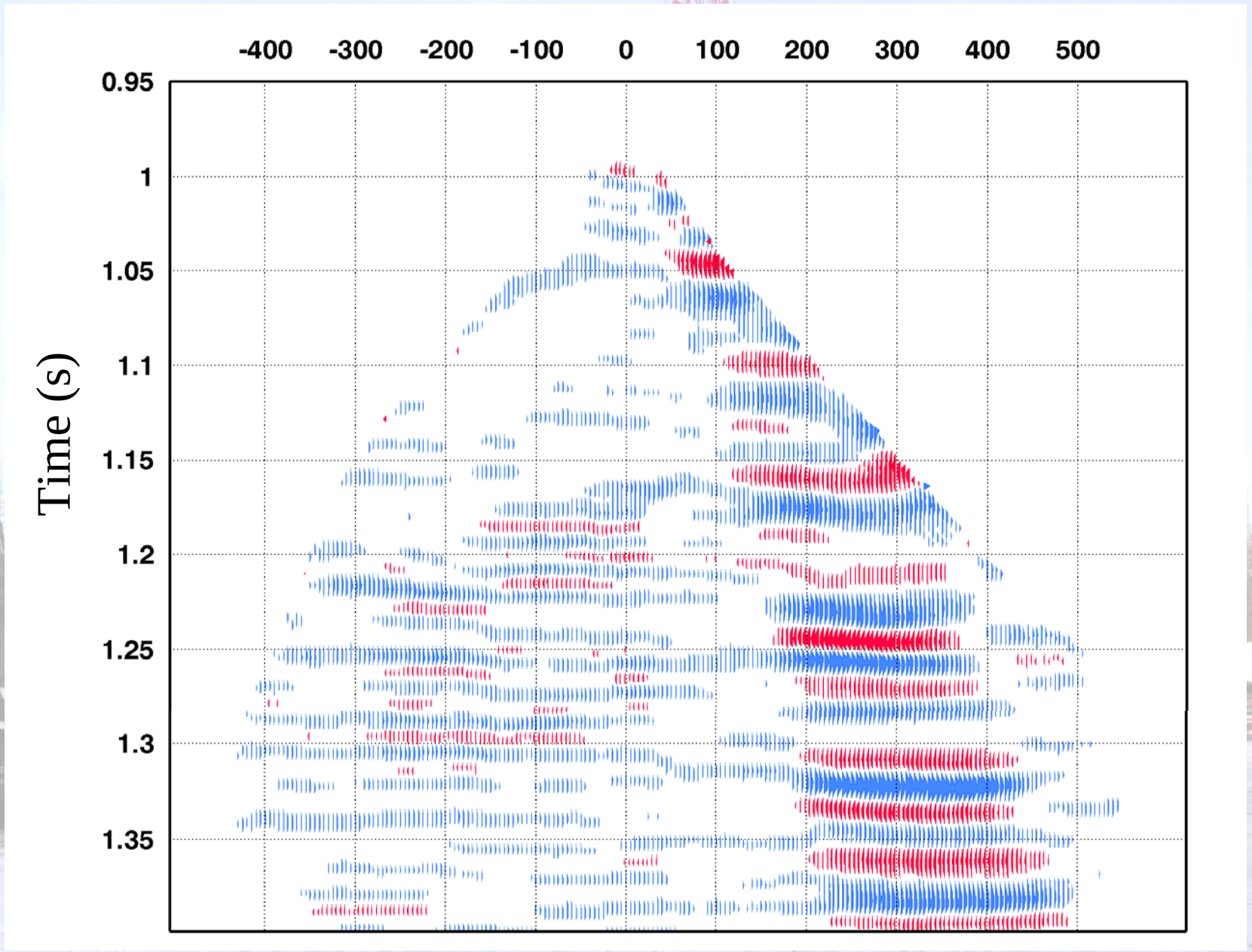
# Line 2 All Shots: Baseline



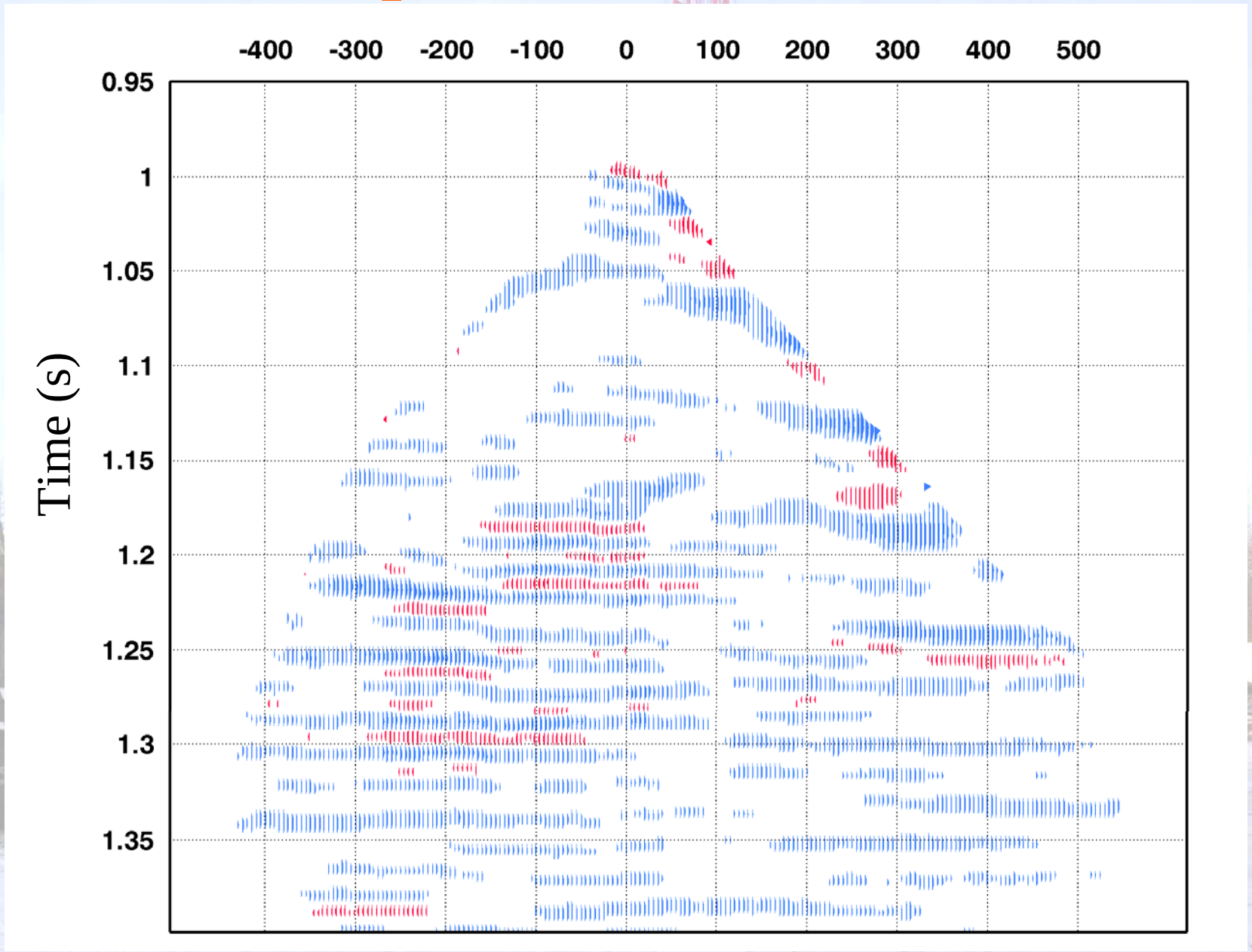
# Line 2 All Shots: Monitor



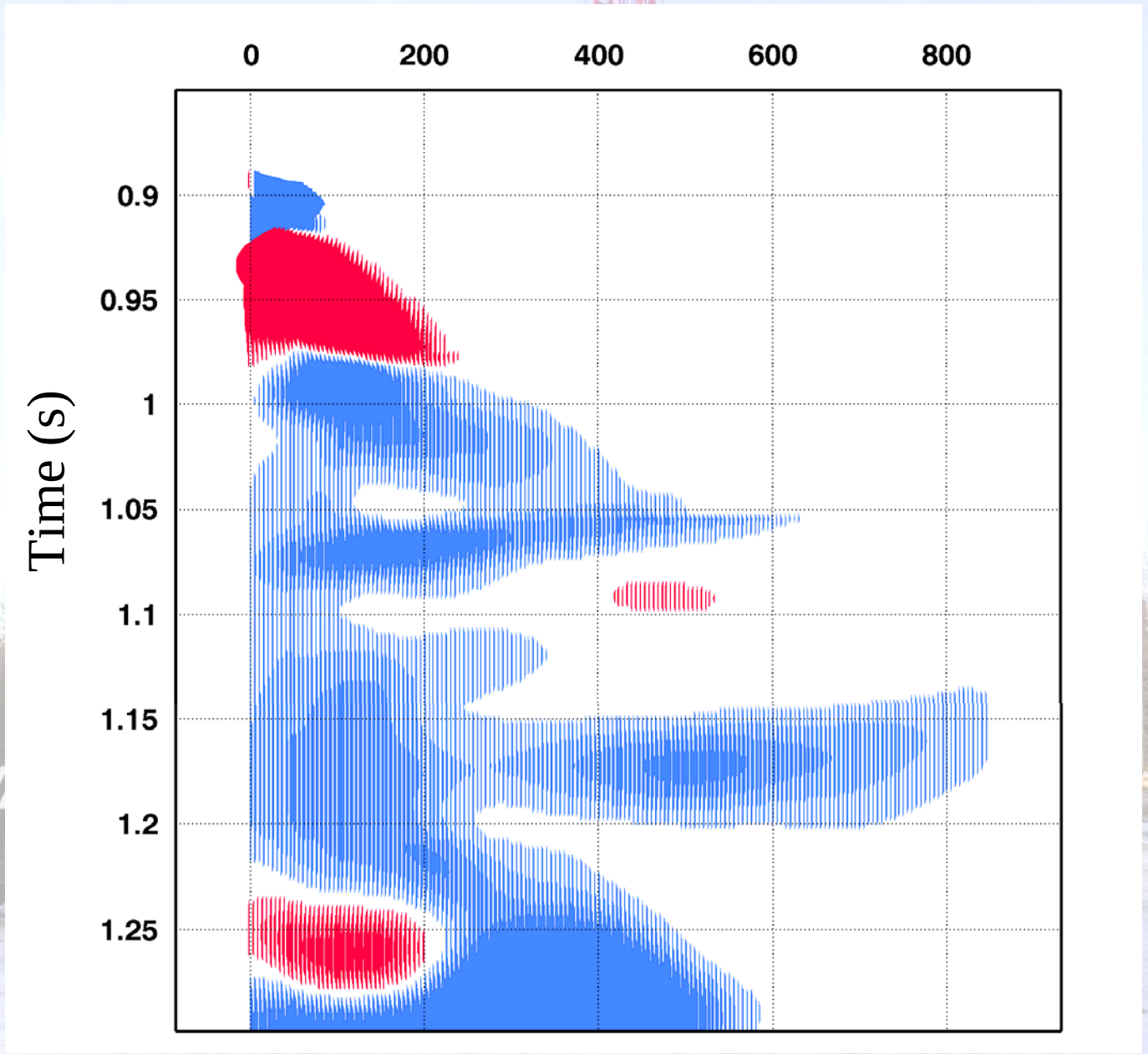
# Line 2 All Shots: Difference



# Line 2 Repeated Shots: Difference



# Finite Difference Modelling: Baseline



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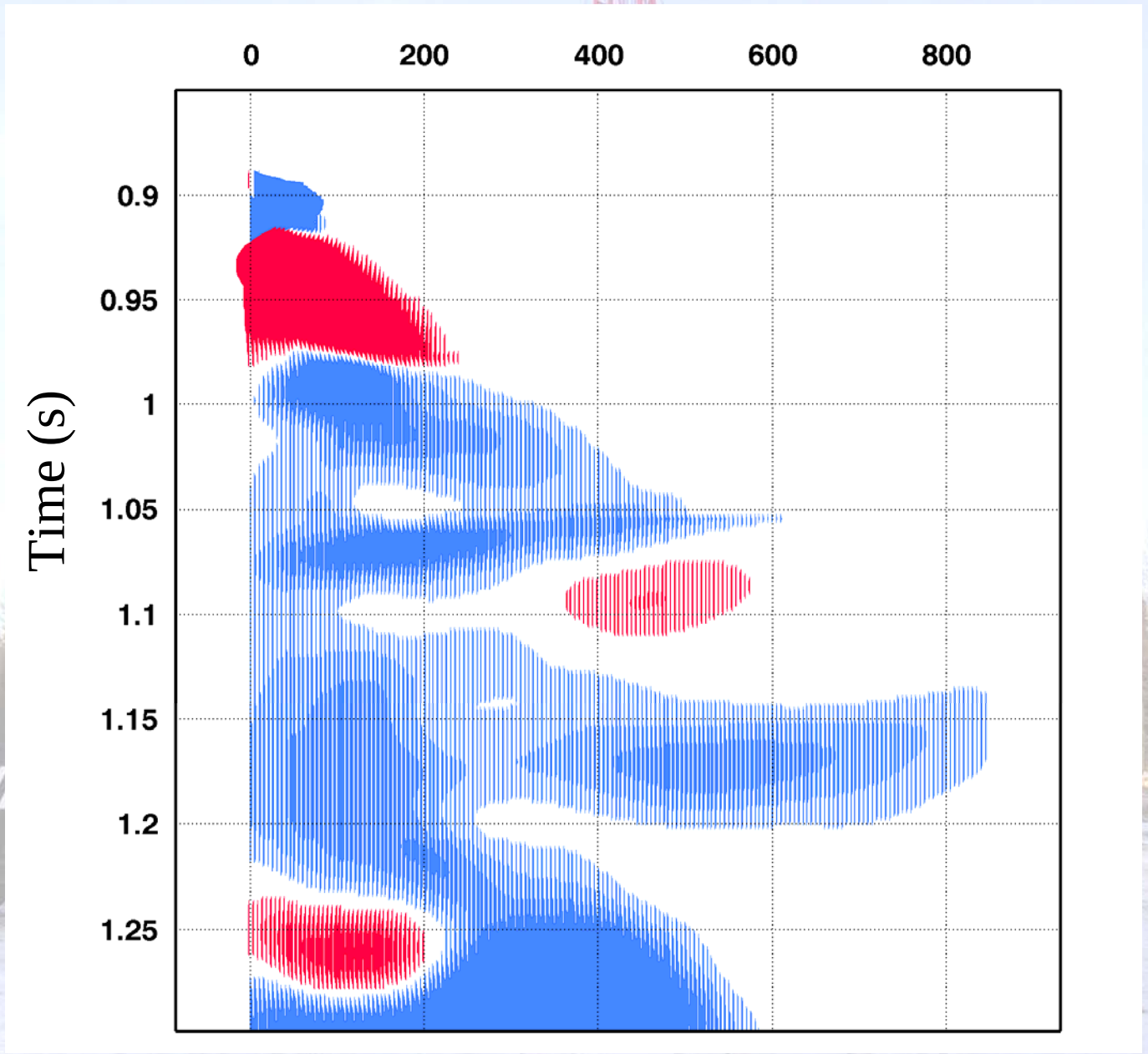

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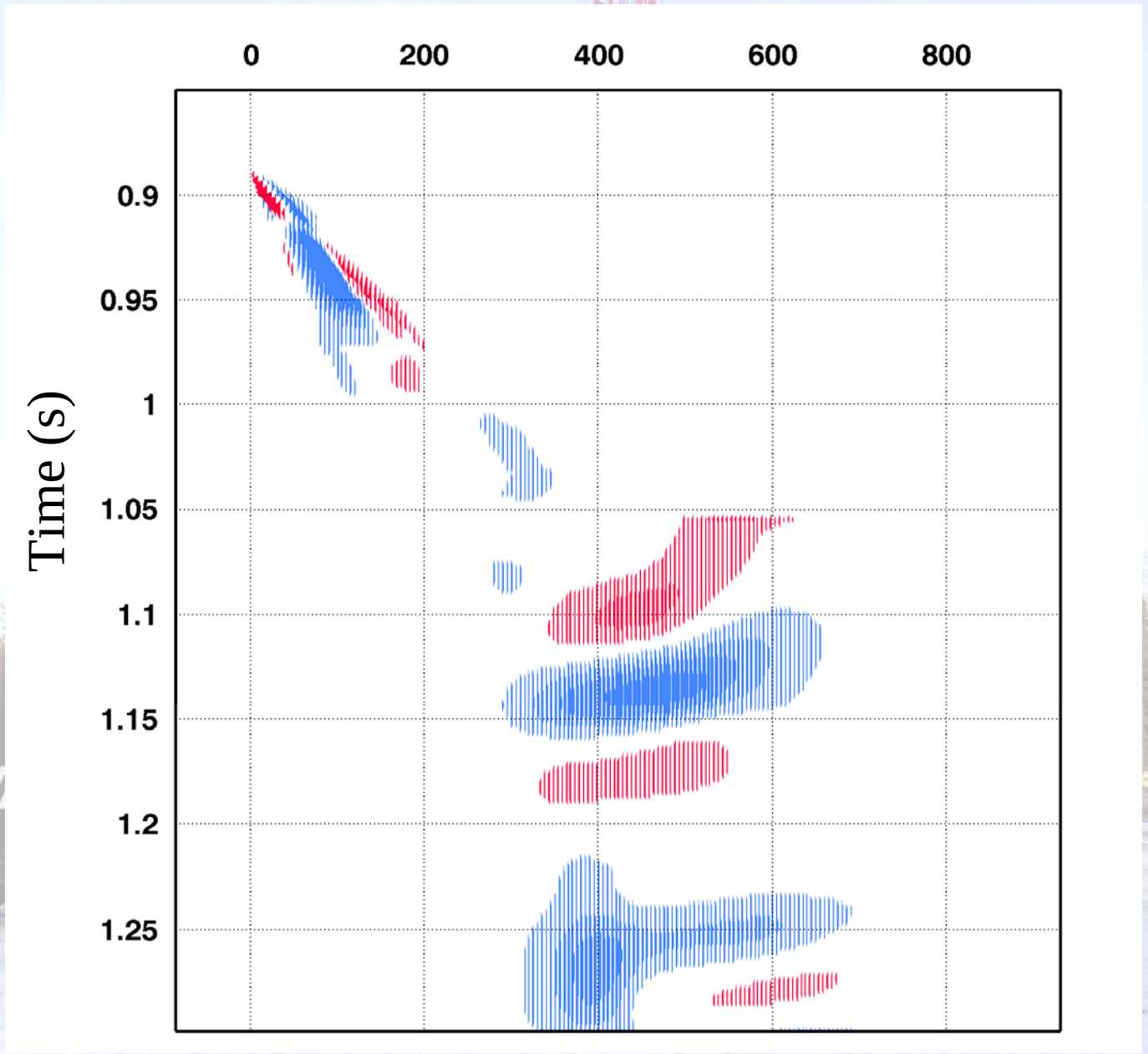
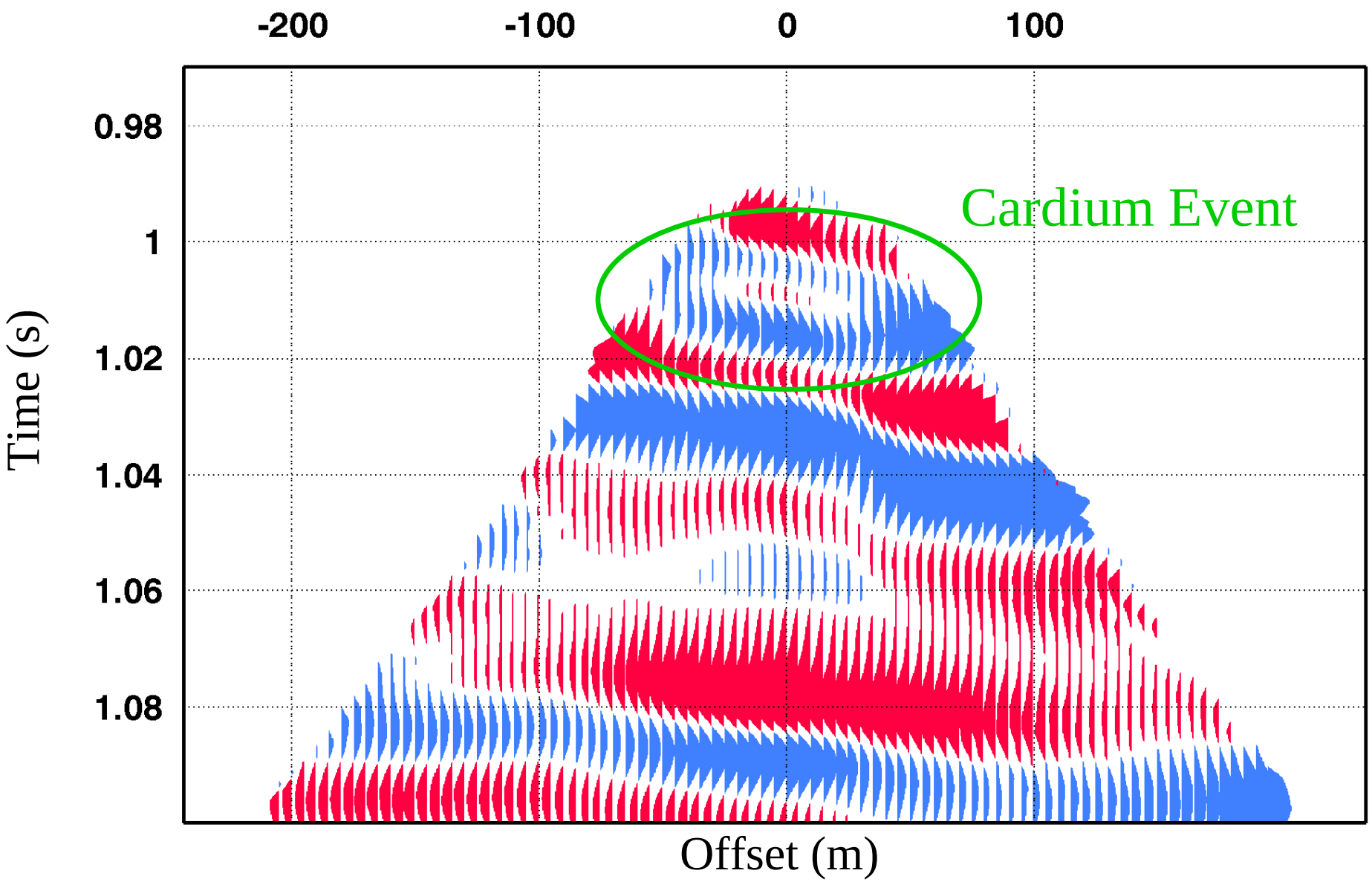
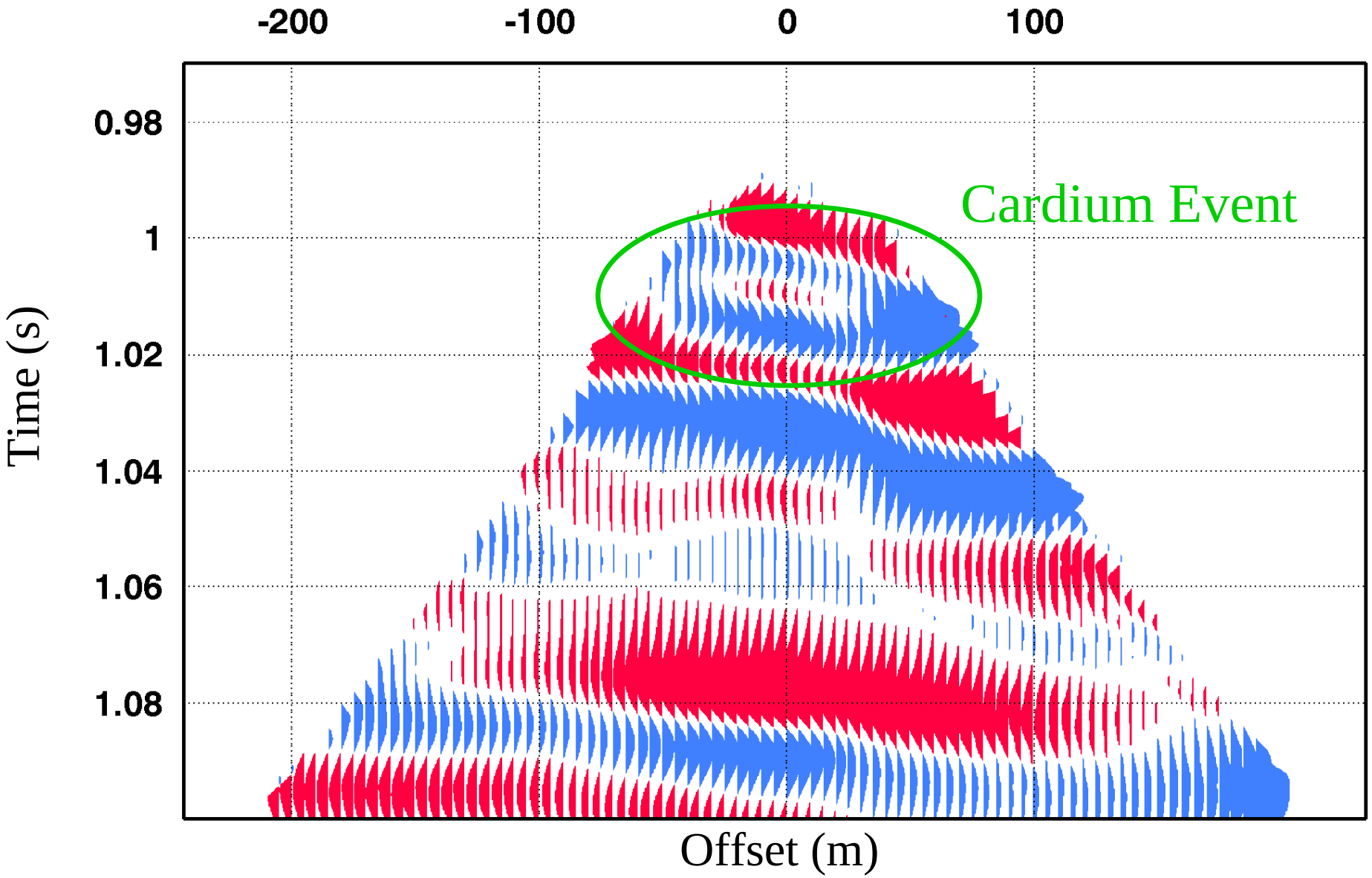


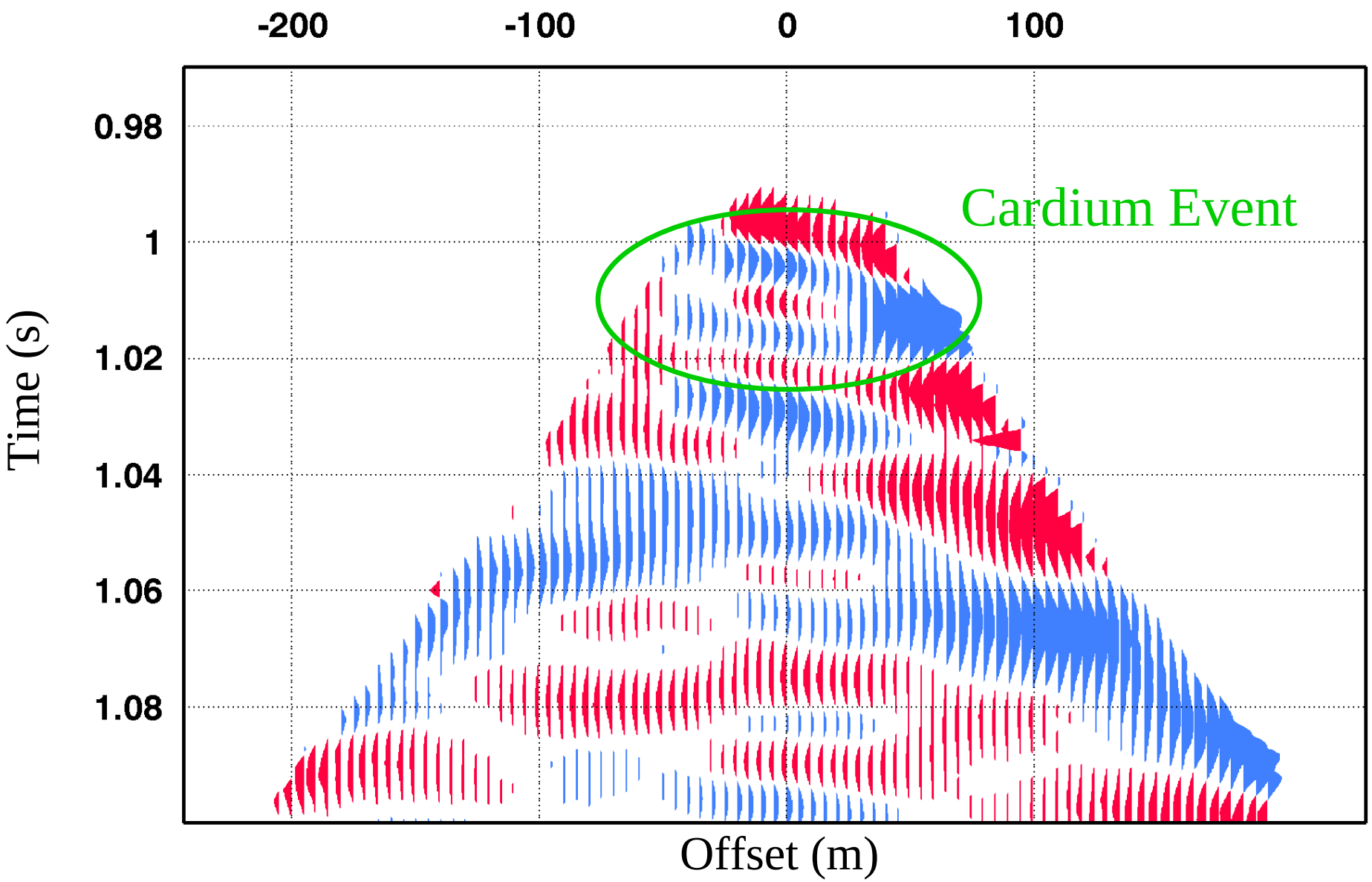
# P-wave Results Line 2: Baseline



# P-wave Results Line 2: Monitor



# P-wave Results Line 2: Difference



# The Supporting Evidence

- Amplitude increases correlate directly to the Cardium event
- Excellent data repeatability
  - Seismic traces, amplitude & phase spectra
- Small time shifts in the crosscorrelations
  - Travel times at base of the reservoir show a systematic increase of 0.2 ms

# Conclusions

- Shot repeatability is extremely important
- P-wave amplitudes at the Cardium on Line 2 have increased since the baseline survey
- Comparison of the datasets, amplitude & phase spectra, and crosscorrelations indicate an excellent tie between surveys
- Expect to see increased time-lapse effects on the next survey as the volume of $CO_2$ in the reservoir increases

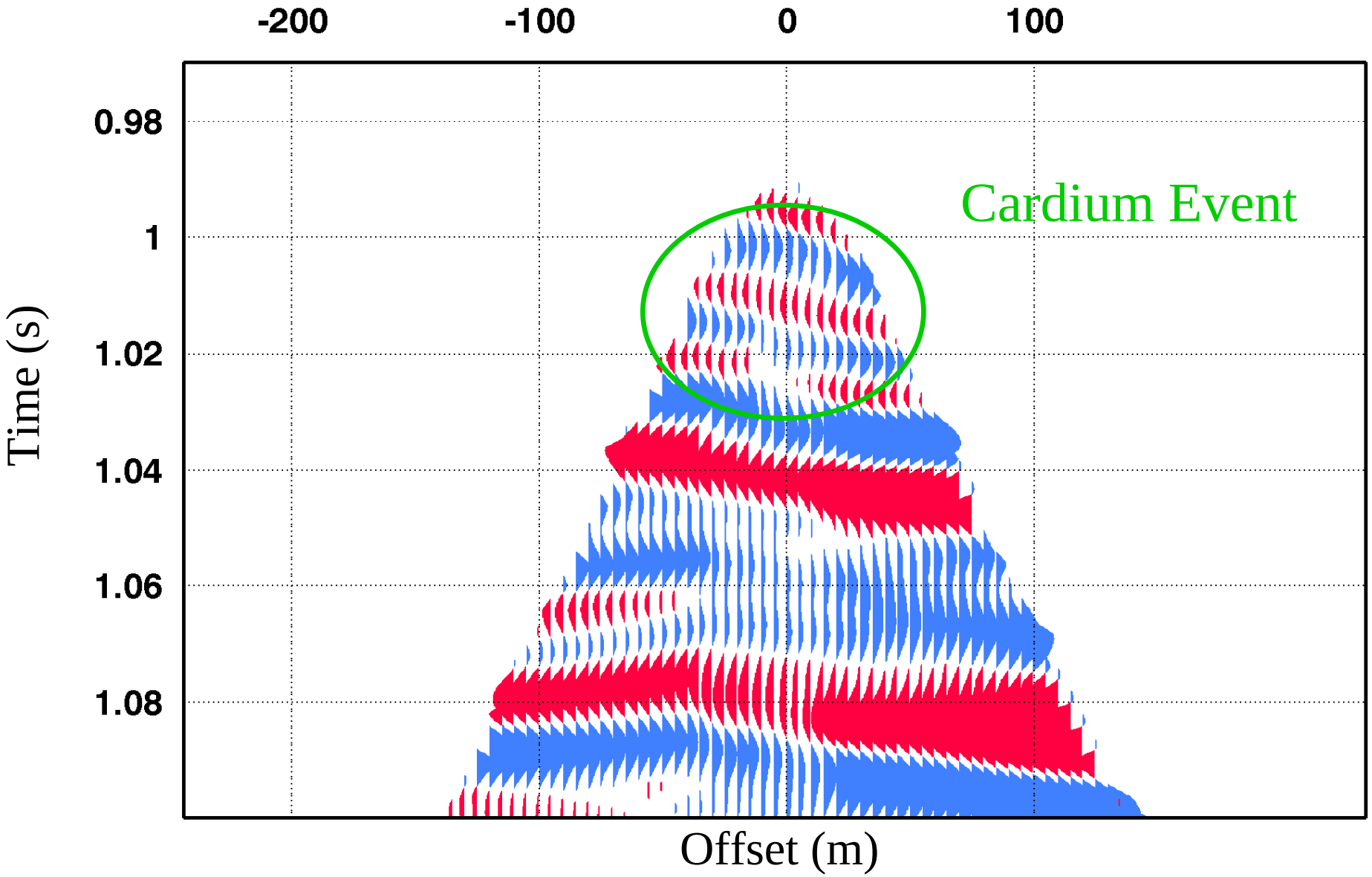
# Recommendations

- Instrument entire well with geophones
  - Will provide high resolution images of the reservoir and overburden around the well
- May want geophone arrays in several wells in the field
  - Merge the volumes for laterally extensive coverage
- Potentially instrument production or injection wells

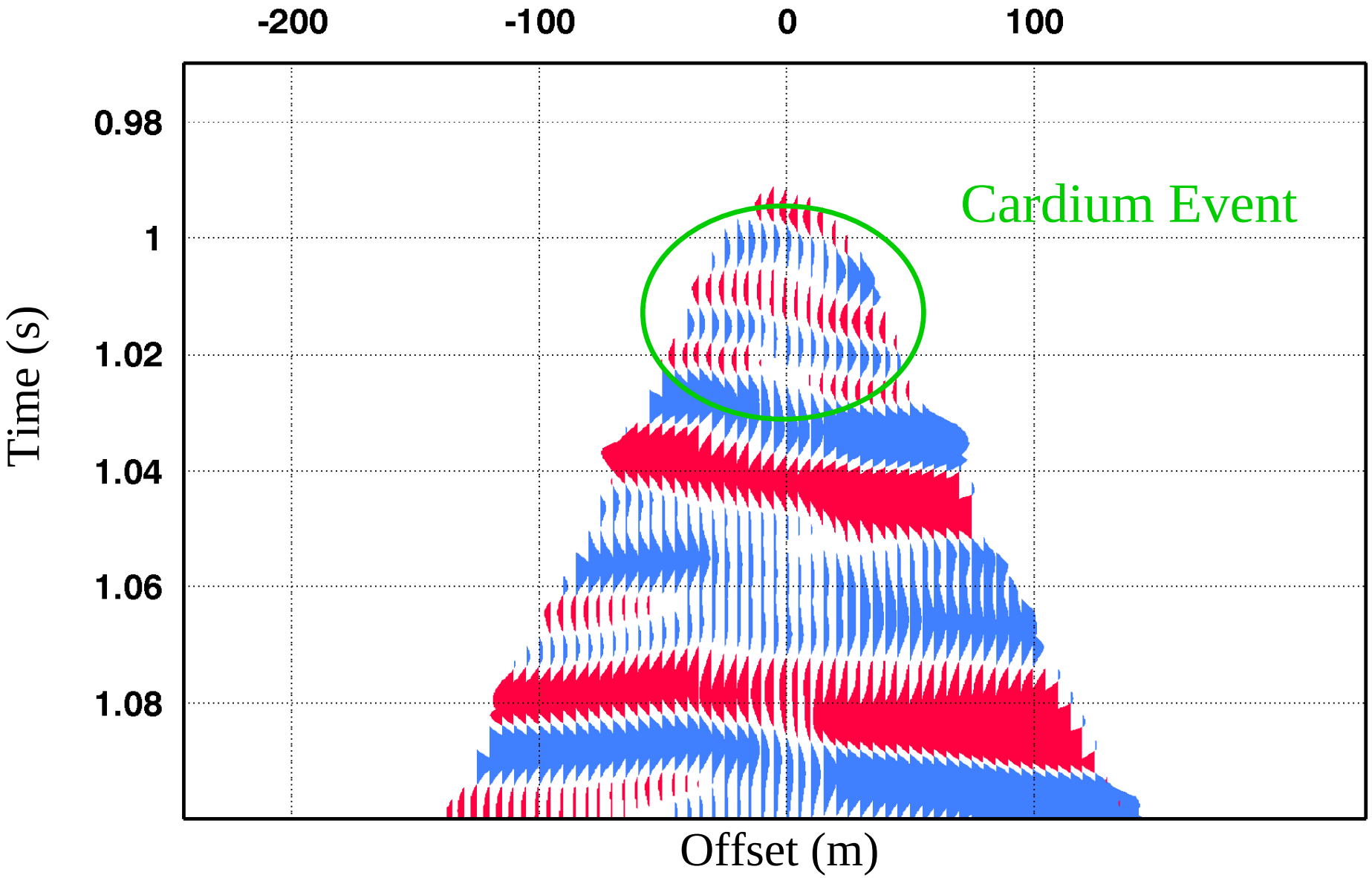
# Acknowledgements


- Scott Leaney and Schlumberger Canada
- Alberta Energy Research Institute (AERI)
- Western Economic Diversification (WED)
- Natural Resources Canada (NRCan)
- CREWES sponsors for financial support
- Penn West Petroleum

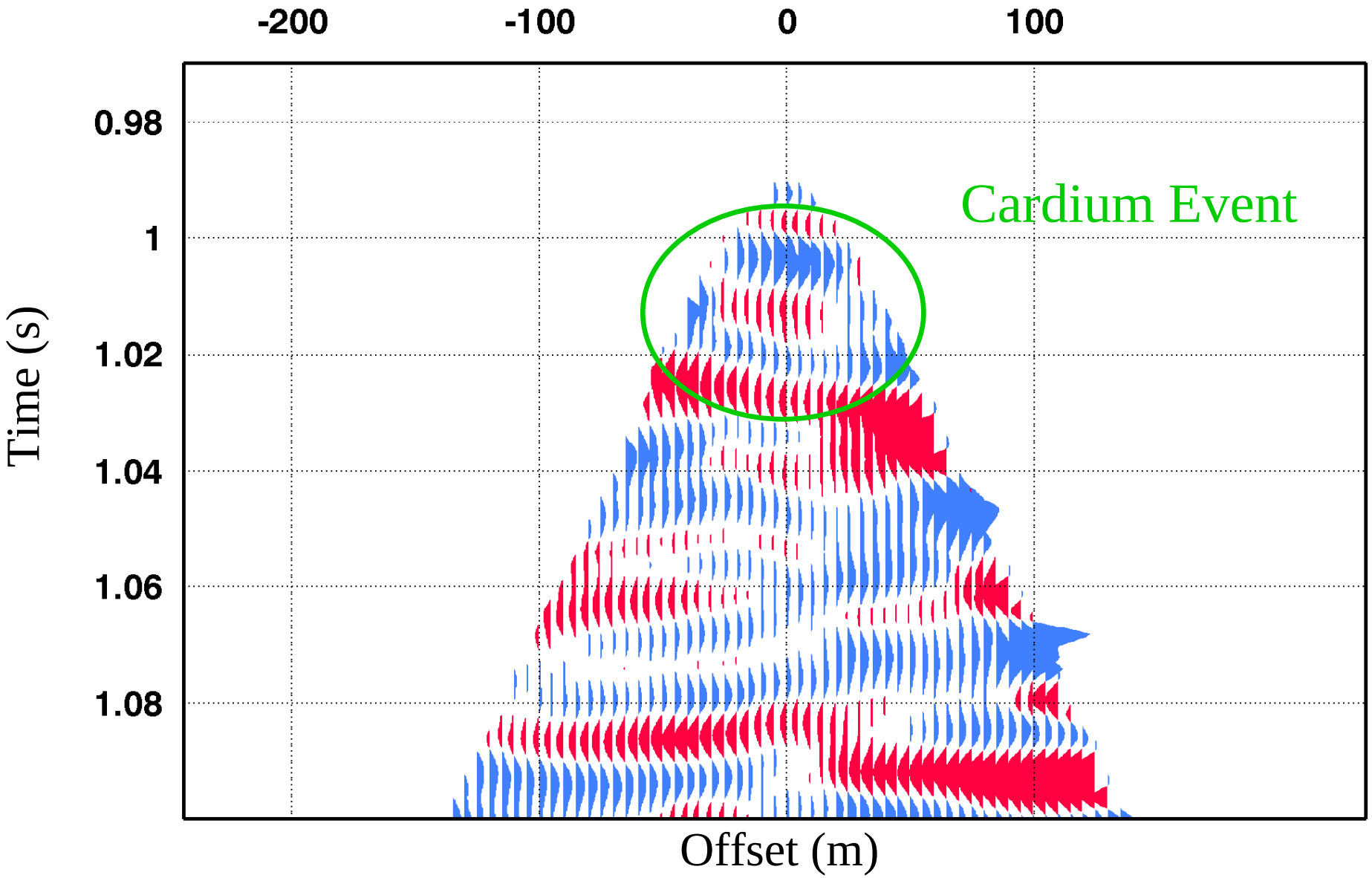
# S-wave Results Line 2: Monitor



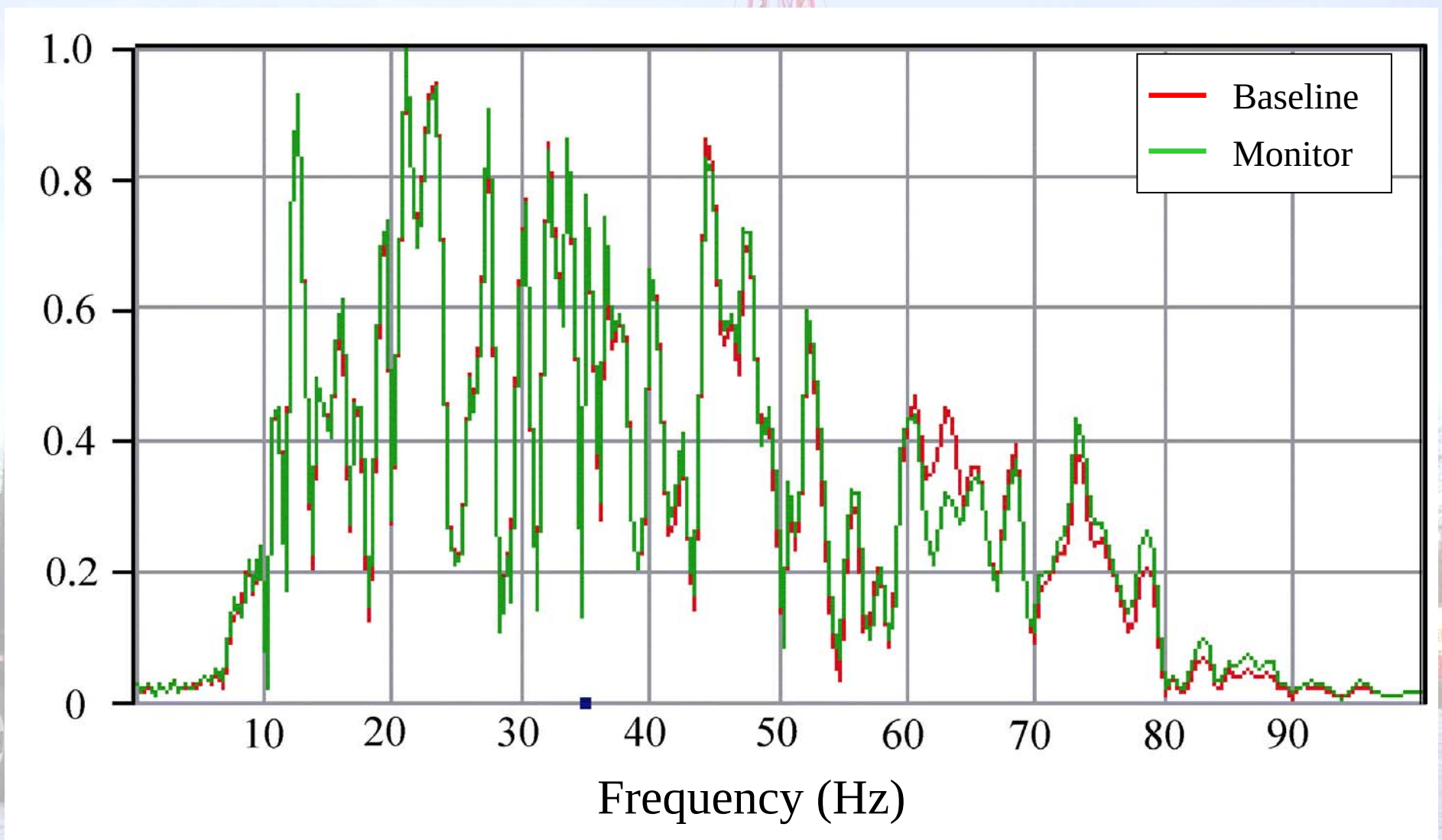
# S-wave Results Line 2: Baseline



# S-wave Results Line 2: Difference



# Comparison of Amplitude Spectra



# Comparison of Phase Spectra