Time-Lapse Monitoring of CO2 Injection with Vertical Seismic Profiles (VSP) at the Frio Project

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**Presenting*

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Outline

- VSP Background
- Survey Design and Data Acquisition
- Data Analysis
  - Reflection processing
  - Time-lapse reflection analysis
  - Plume extent analysis
- Conclusions

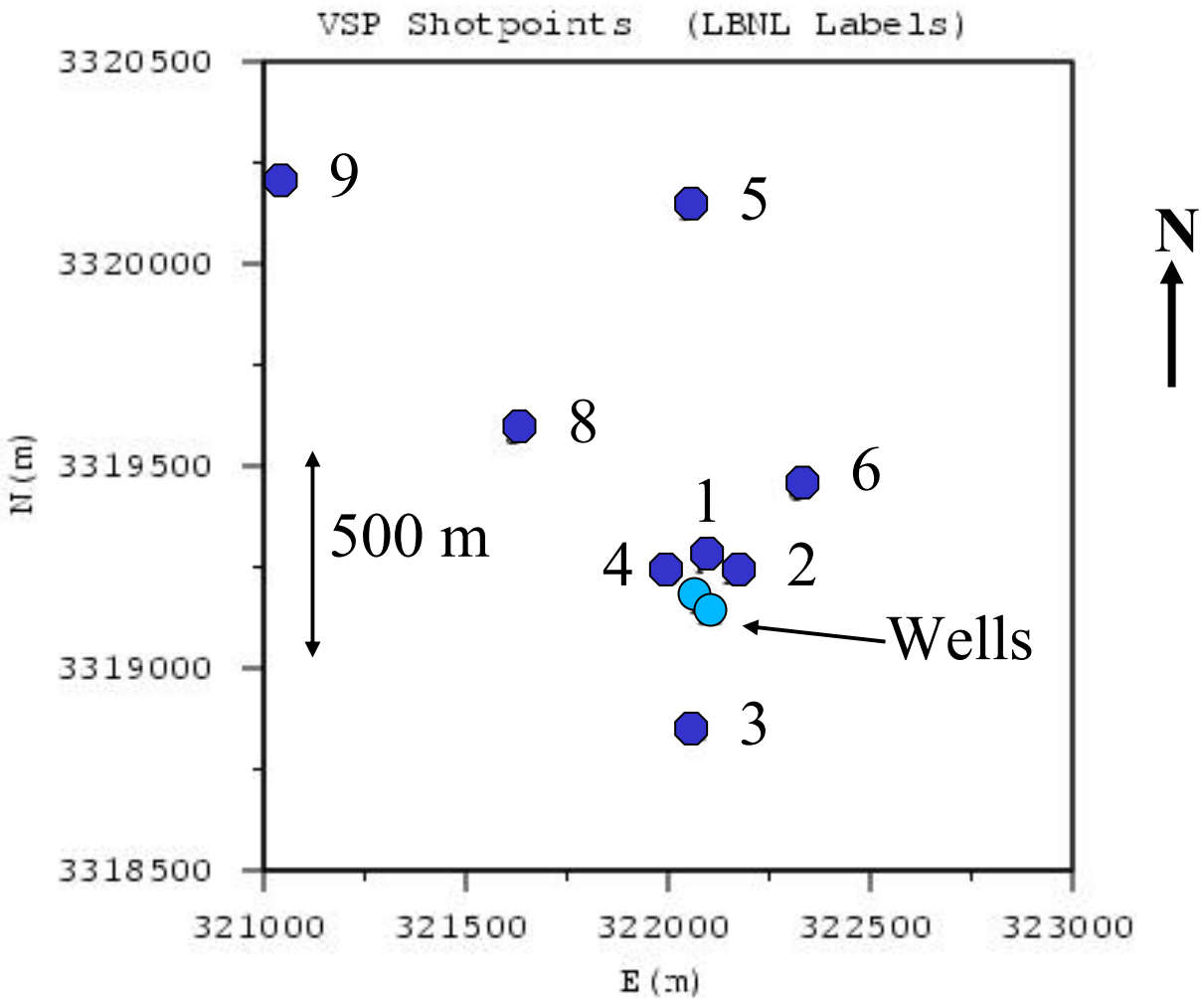
VSP Design and Acquisition Parameters

- VSP designed for spatial monitoring of CO2 plume (100 m offsets) and site geologic structural information (500 – 1500 m offsets – not presented in this talk)
- Explosive source for highest frequency (resolution) and off-road access.
- Source: 3 lb. dynamite in 60 ft shothole, 4 to 10 shots per shot point site
- Number of shot points recorded: 8
- Maximum Well to Source Offset recorded about 1500 m
- Receiver array depth: 0 ft – 5,500 ft, variable spacing 5 – 25 ft
- Geophones: 3-component, clamped to casing, unique 80-level string provided with partial support from Paulsson Geophysics

VSP and Crosswell Site

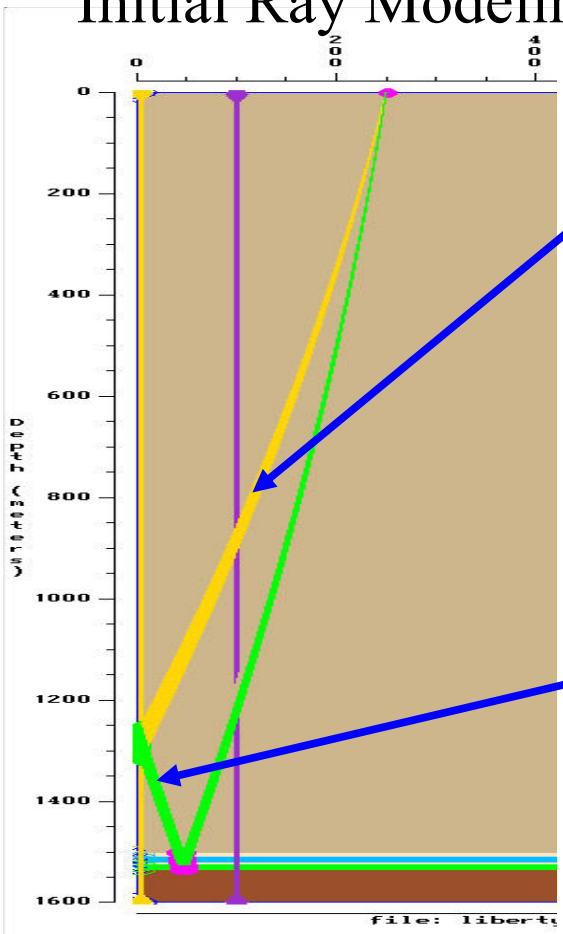
VSP Explosive Source: Shot Hole Drill

VSP Shot Points:
Analysis Focused on Site 1,2,4 – 100 m offset up dip



VSP allows separation of downgoing (direct) wave and upgoing (reflected) wave

Initial Ray Modeling

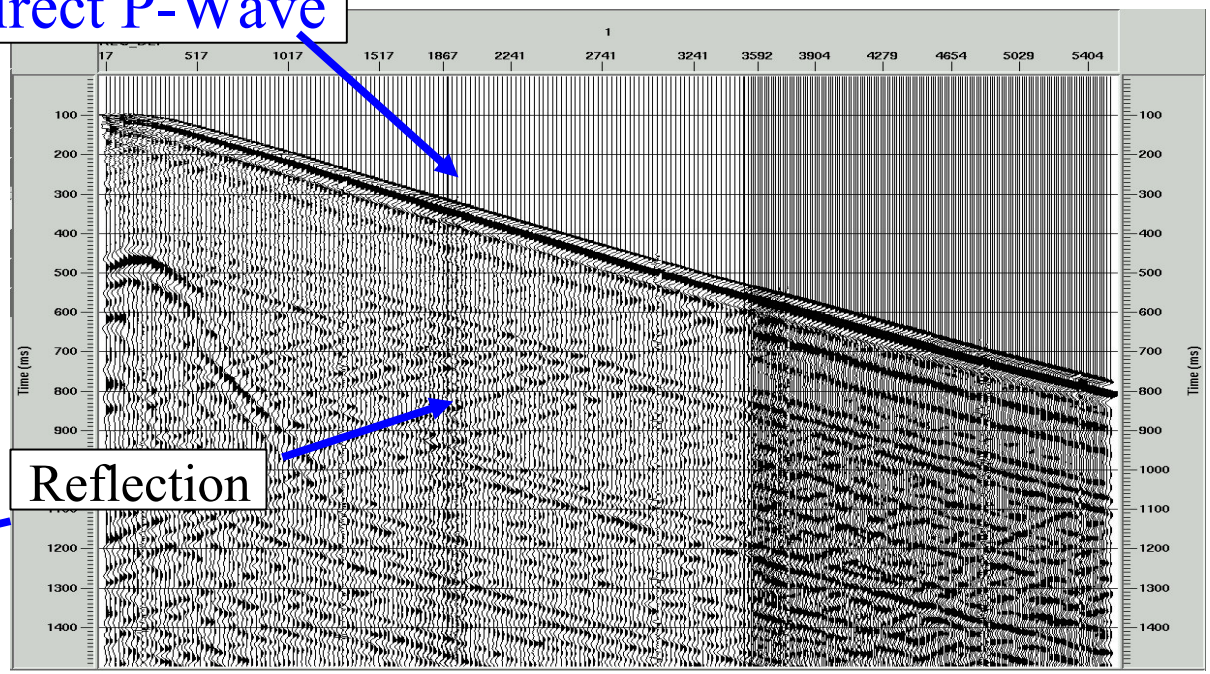


Raw Data Site 1

Depth →

Direct P-Wave

Reflection

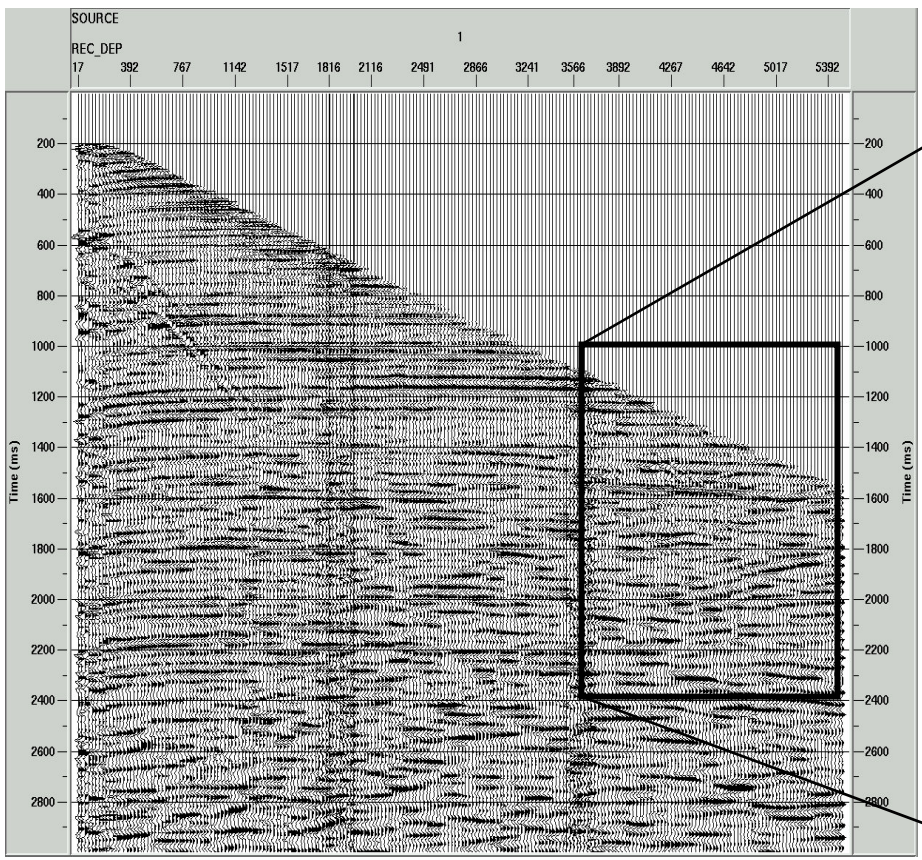


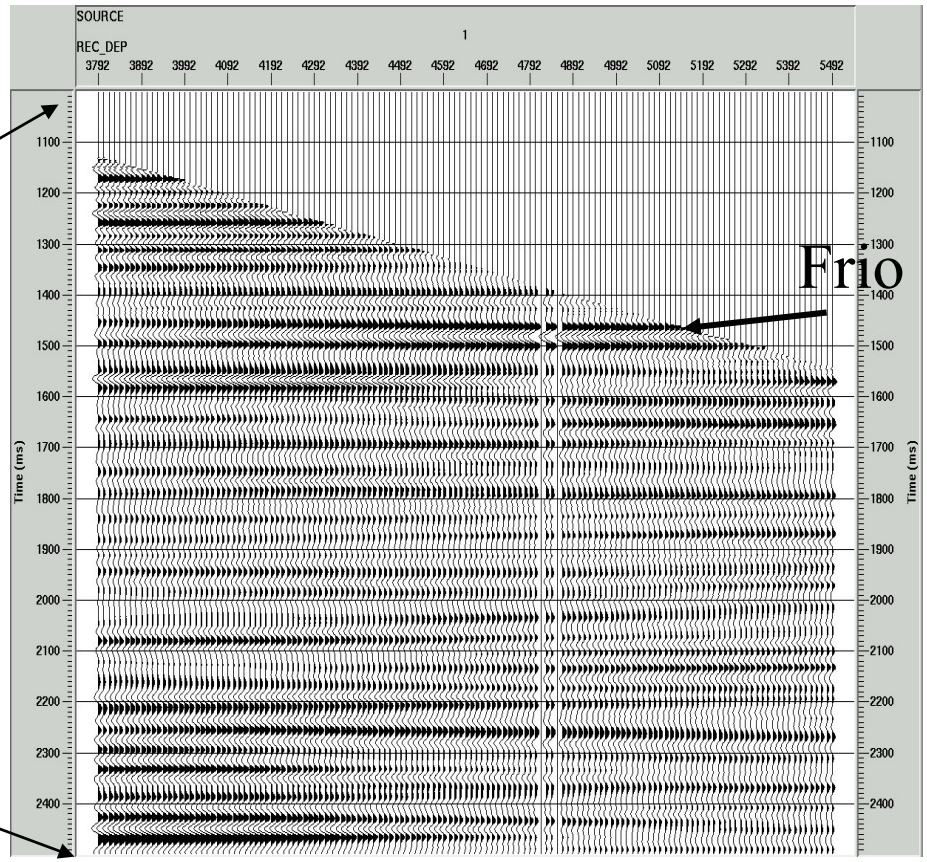
Denser spacing in reservoir interval

Reflection Section Site 1

Entire VSP
Reflection Section

Frio Analysis Window
Enhanced Reflection



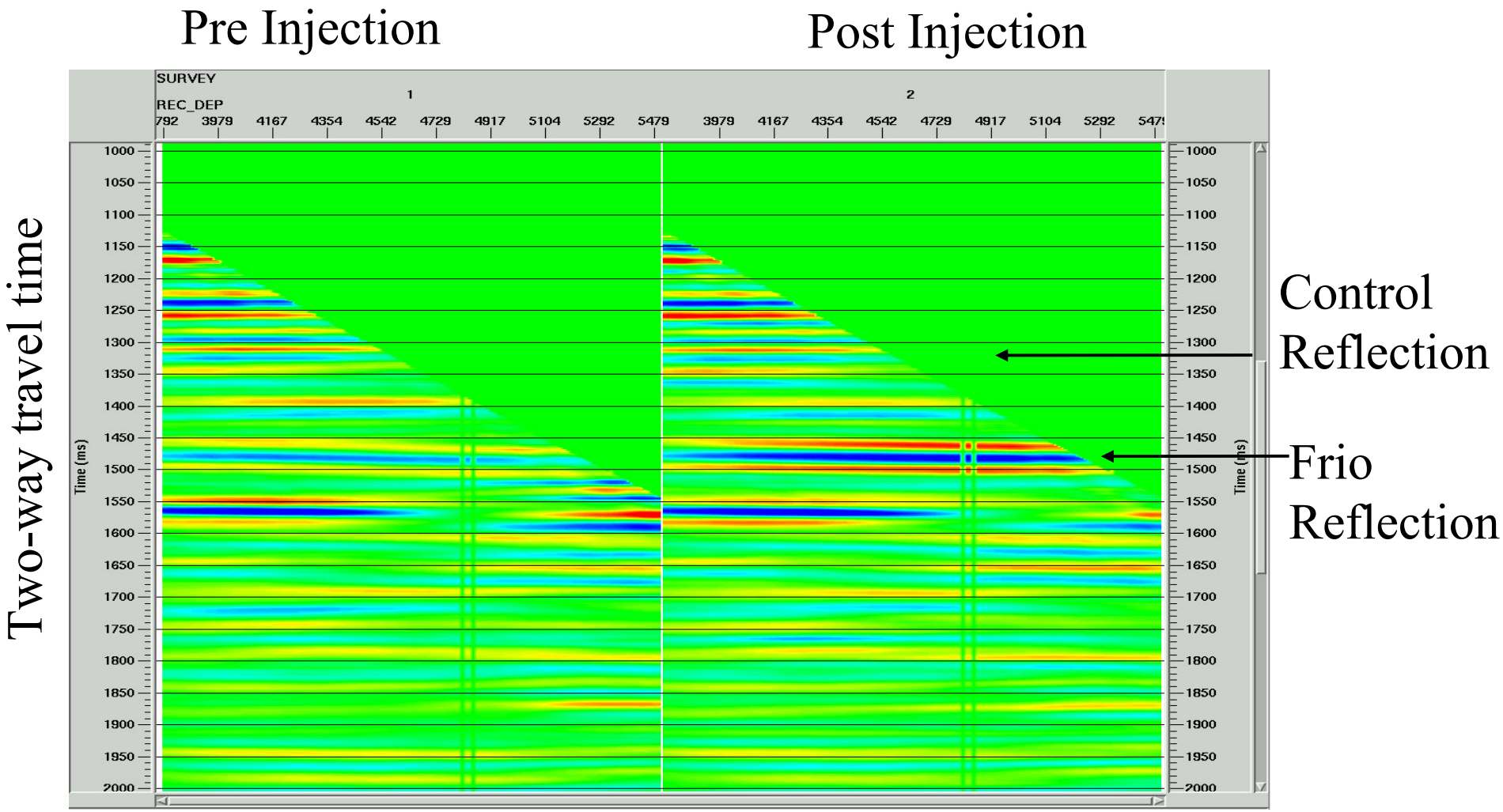


Processing for Time-Lapse Change

- For time-lapse change: normalize reflection amplitude using a shallower reflector above the frio. This removes changes not associated with injection. For example: changes in shallow ground water level and changes in explosive shot energy.
- Plot pre and post injection normalized reflection sections and calculate change in reflection amplitude.

- Will show sites 1 (N), 2(NE) and 4(NW)

Site 1 (North, Up Dip) Reflection Section

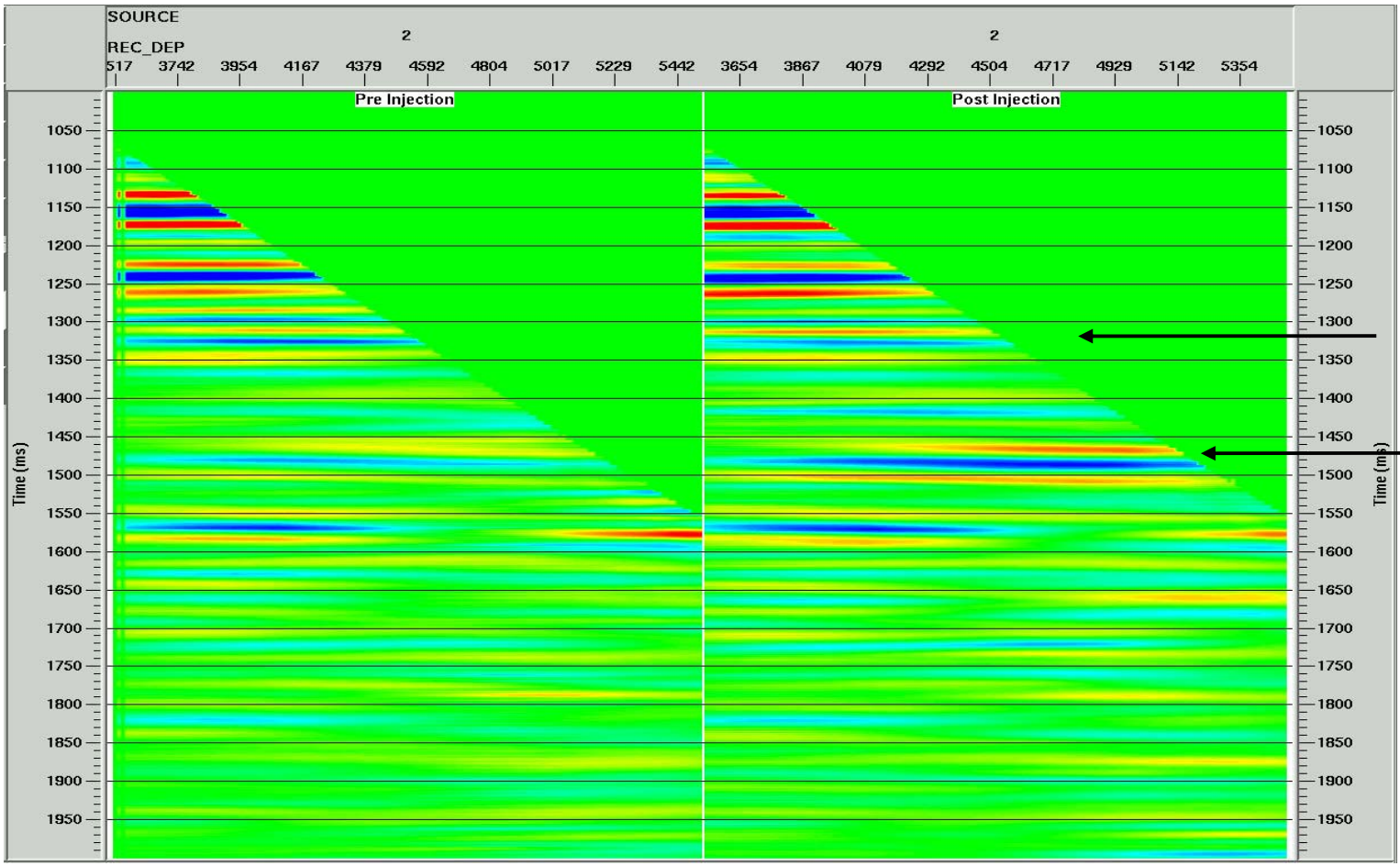


Site 2 (NE) Reflection Section

Pre Injection

Post Injection

Two-way travel time



Control Reflection

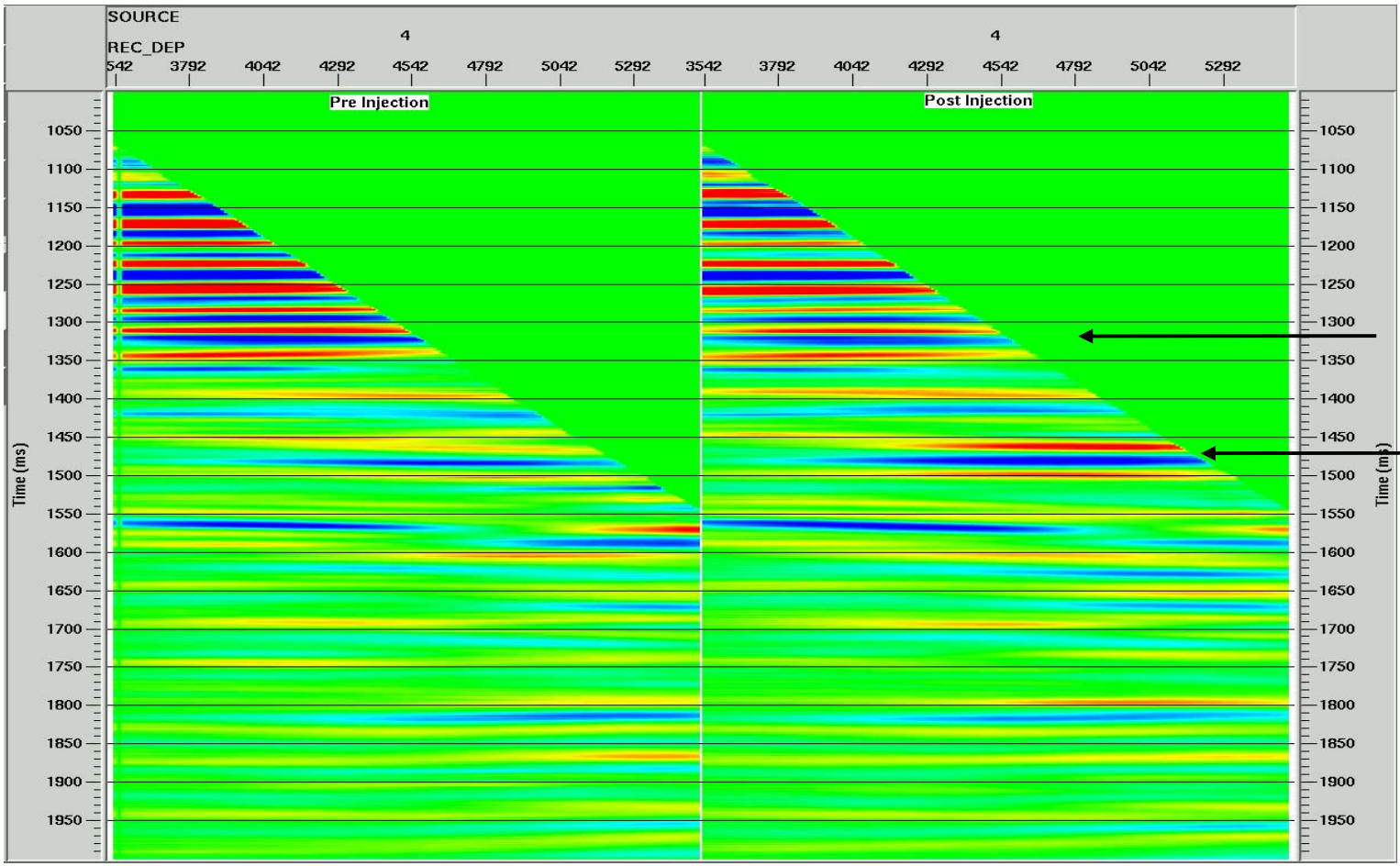
Frio Reflection

Site 4 (NW) Reflection Section

Pre Injection

Post Injection

Two-way travel time



Control Reflection

Frio Reflection

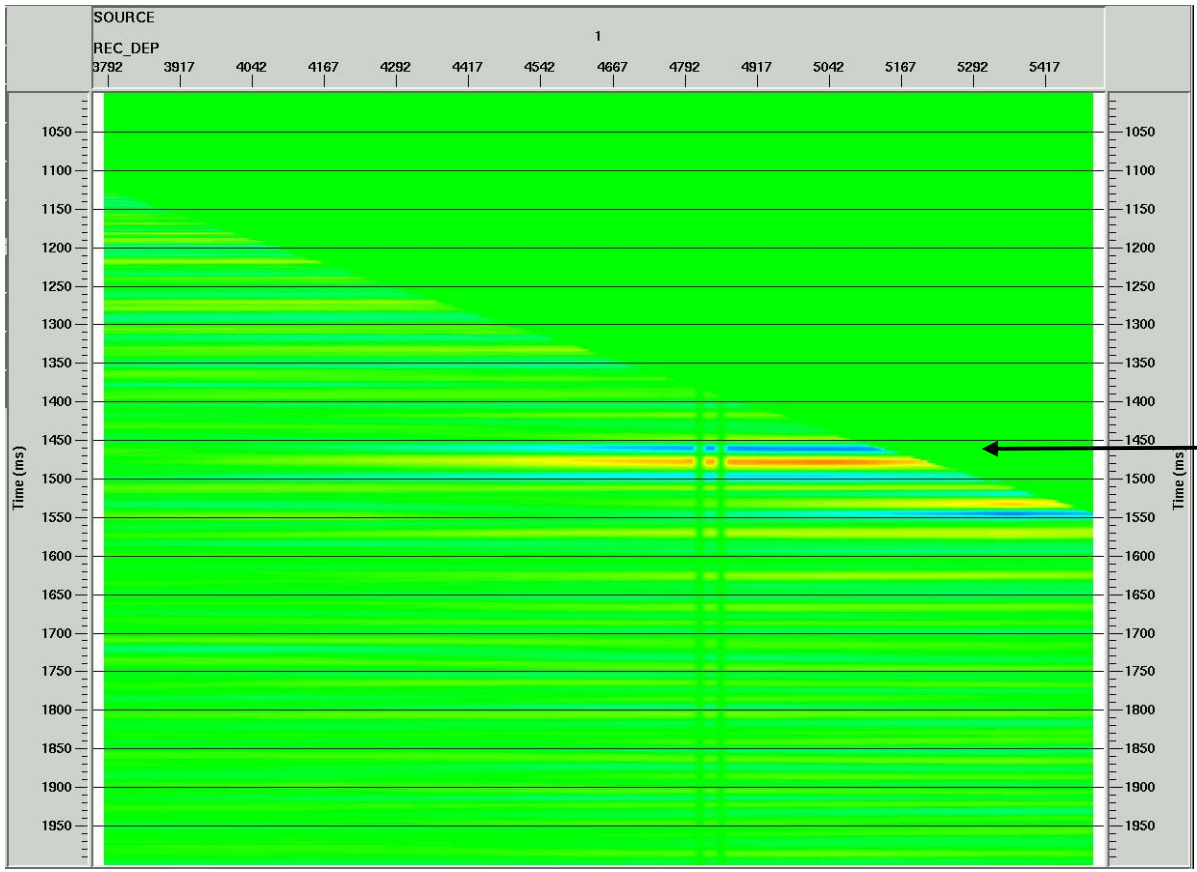
Estimate Plume Edge

- Calculate change in reflection strength for each recording depth.
- Estimate reflection point offset for each recording depth. This estimate is straighforward for horizontal layers. However, the Frio site has strong dip and fault blocks.
- Intial estimate uses constant 15 degree dip ray tracing results.
- Future work will include improved reflection point imaging leading to more accurate estimate of plume edge.

Site 1 Reflection Change (Post – Pre)

Sensor Depth (m) →

Two-way travel time



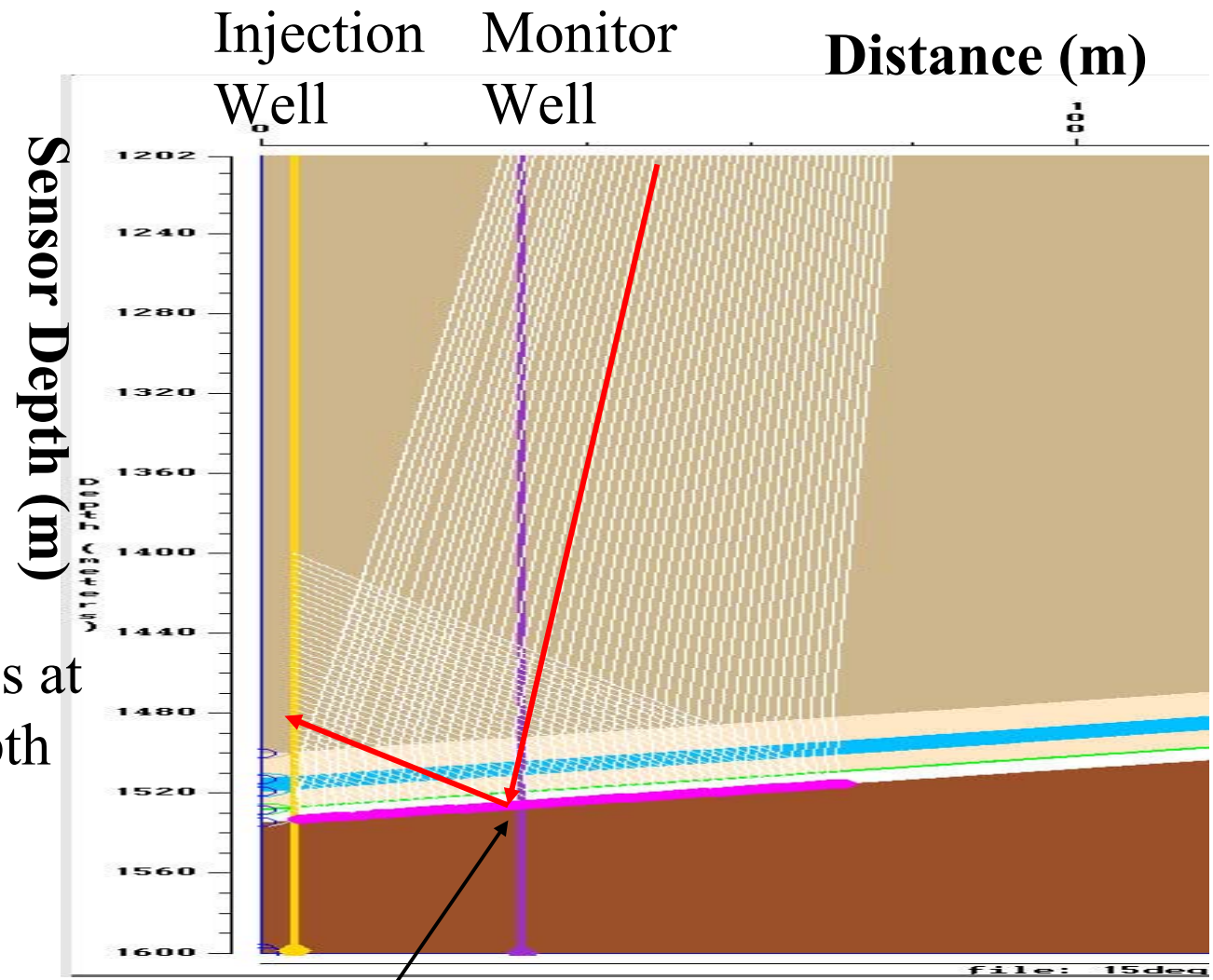
Frio Reflection

Major change in Frio due to CO2 injection.
Smaller change below Frio probably due to transmission through Frio.

Time-Lapse Analysis

- To estimate extent of CO2 plume, need to map sensor depth of recording to reflection point.
- We use ray path modeling for initial estimate.

Mapping of sensor depth to reflection point using raypaths: Source sites 1,2,4 (100 m offset)

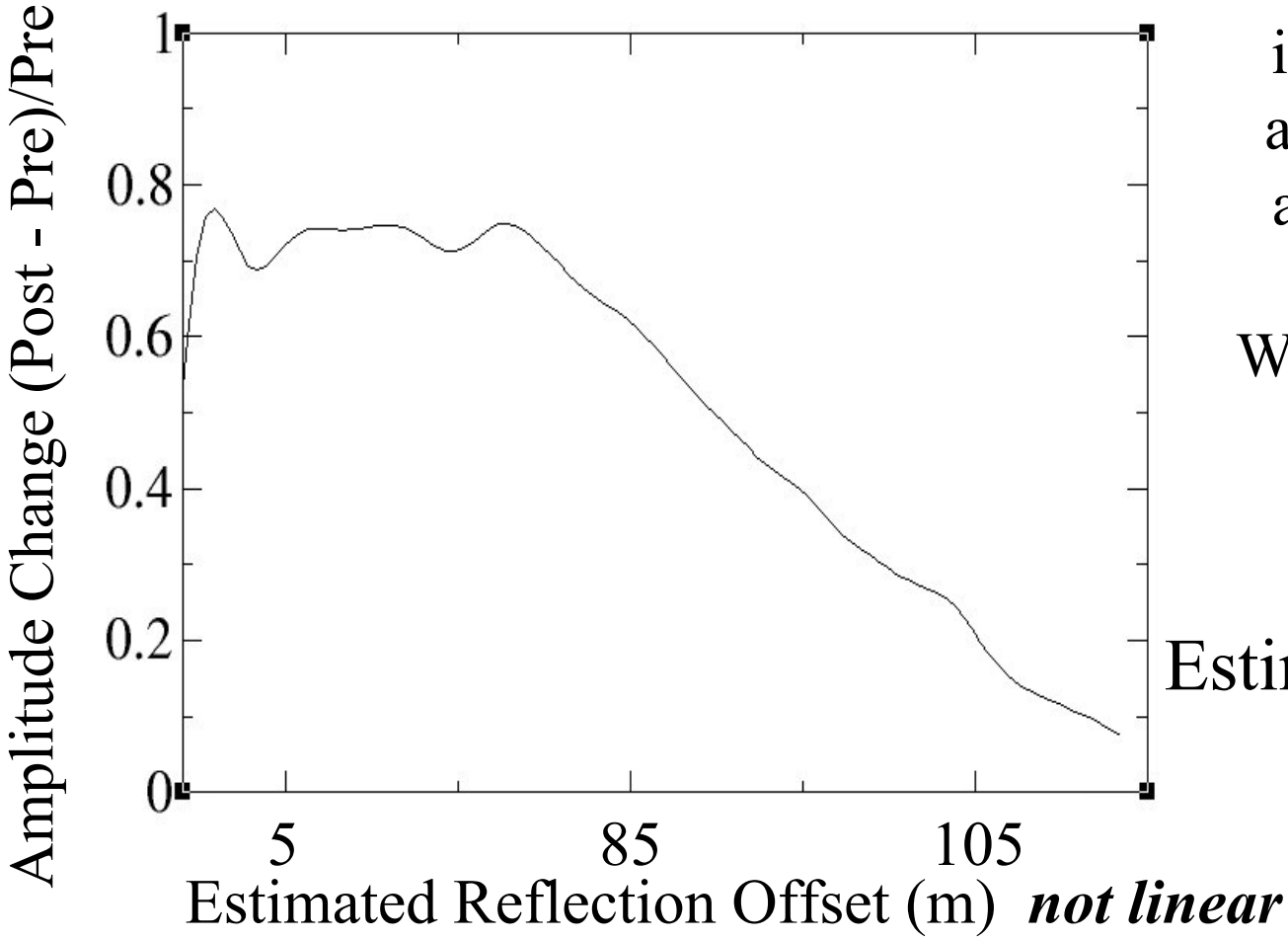


Ray arrives at sensor depth 1480 m = 4860 ft.

Reflection point – 30 m from injection well

Site 1 (North): Estimated Plume Size

Range of CO2 induced reflection amplitude change.



not linear

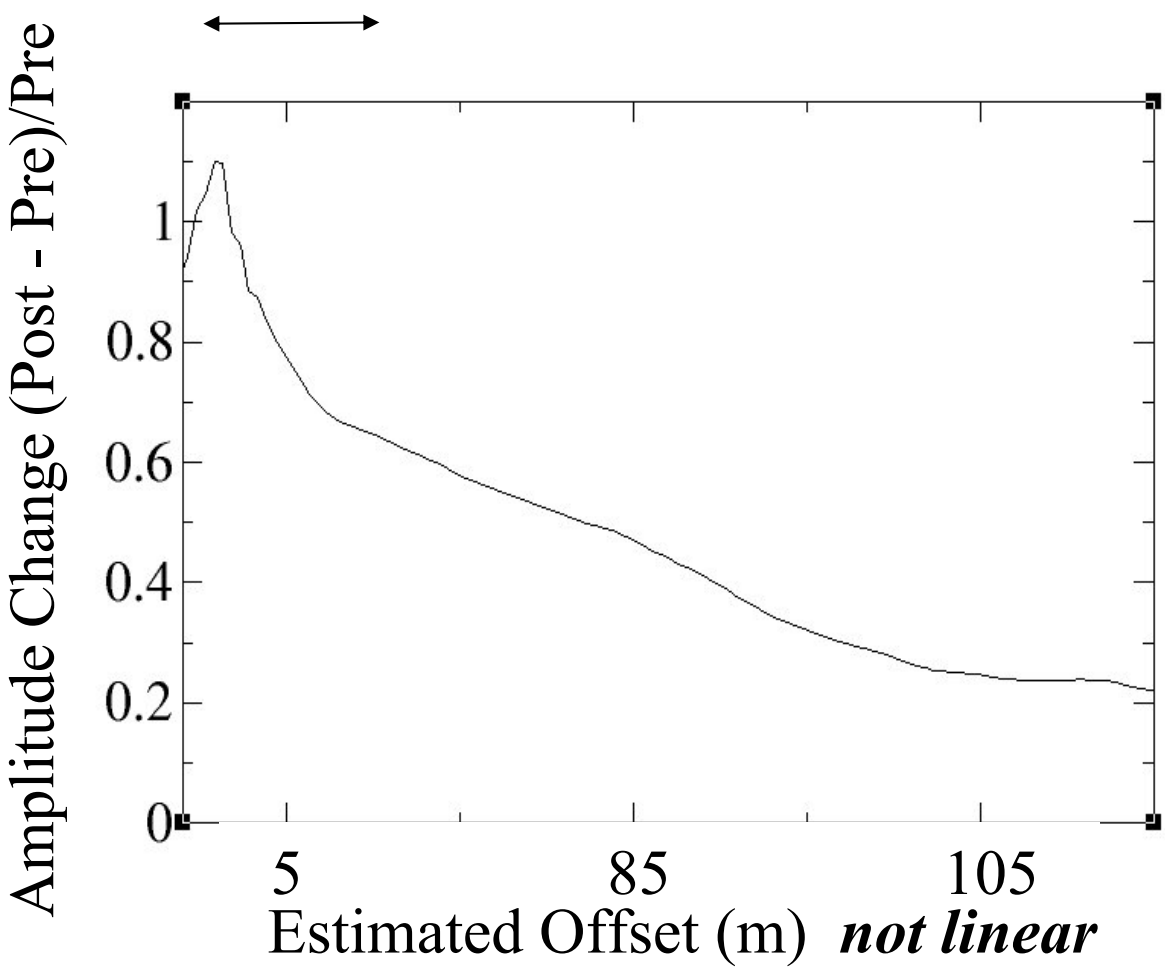
About 70% increase in peak reflection amplitude. This is a strong response.

What is cut-off point For plume edge? Choose 60%

Estimated Plume Edge = 85 m

Site 2 (NE): Estimated Plume Size

Range of CO2 induced reflection amplitude change.



not linear

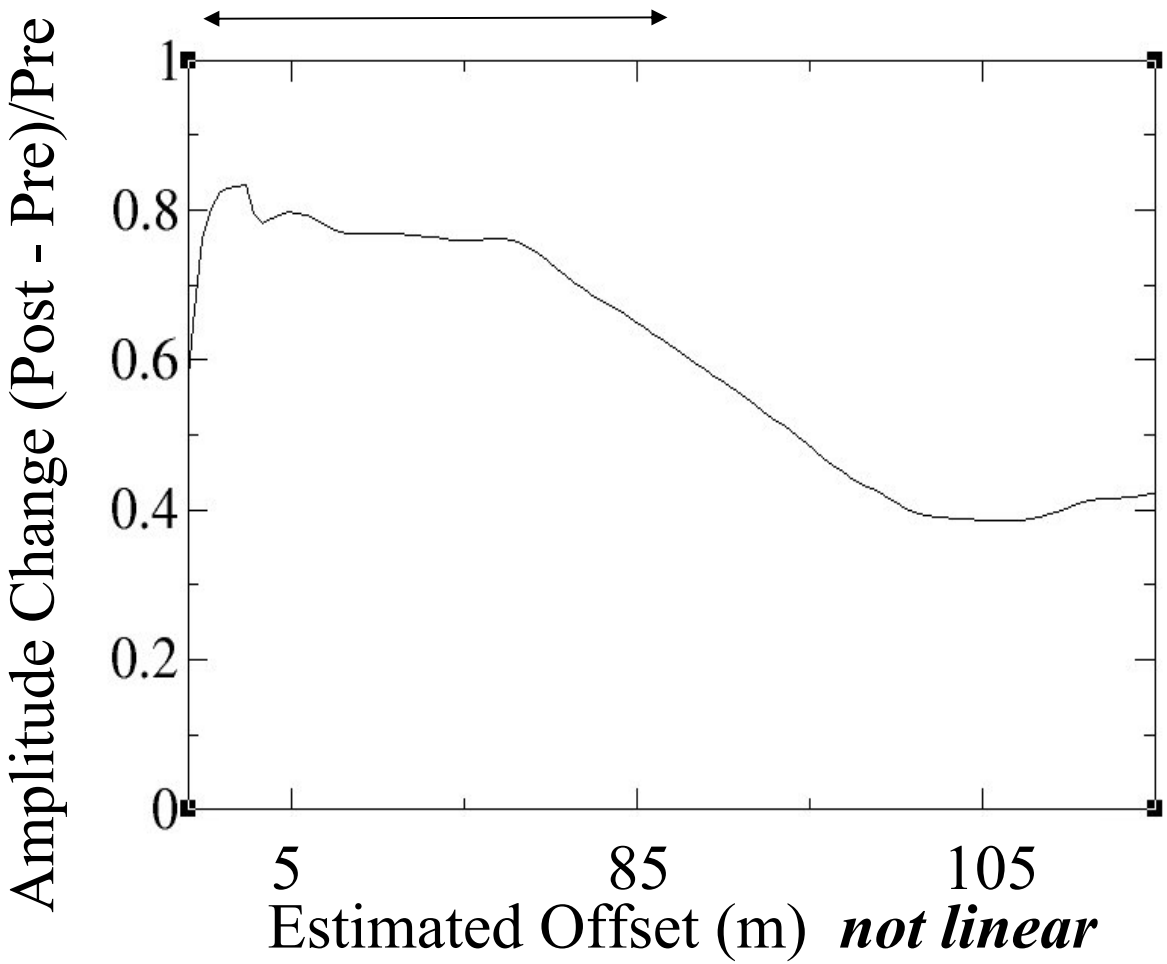
About 110% increase in peak reflection amplitude. This is a strong response.

What is cut-off point For plume edge? Choose 60%

Estimated Plume Edge = 45 m

Site 4 (NW): Estimated Plume Size

Range of CO2 induced reflection amplitude change.



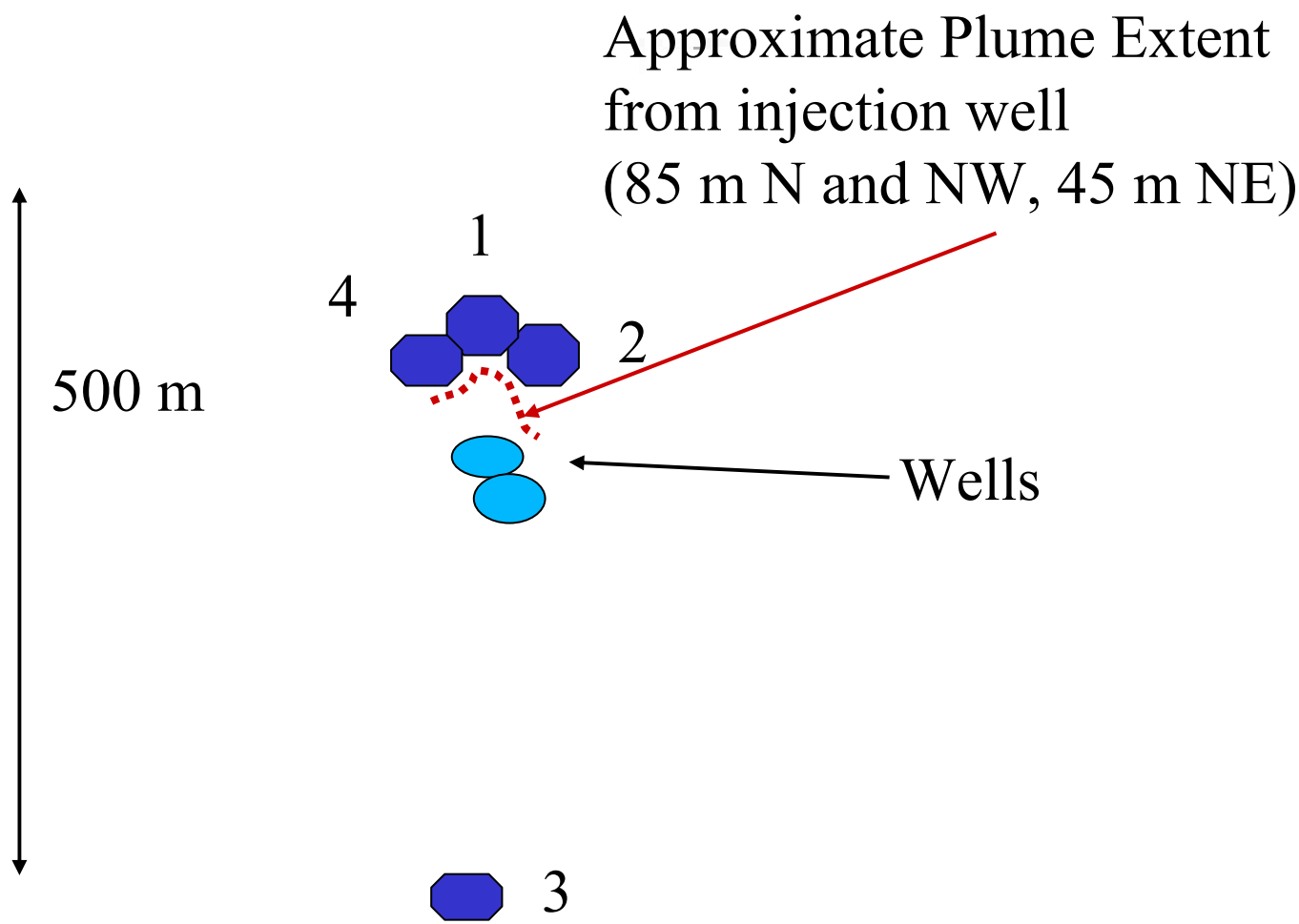
not linear

About 80% increase in peak reflection amplitude.

What is cut-off point For plume edge? Choose 60%

Estimated Plume Edge = 85 m

Current Estimate of Plume Extent survey of Nov 30, 2004



Conclusions

- The VSP method is able to 'see' the relatively small amount (~1600 tons) of CO2 injected in a thin reservoir at depths of 1500 m.
- Time-lapse analysis allows estimate of the spatial extent of the CO2 plume; if the sources are placed correctly and the reflections can be correctly mapped.
- At Frio, a strong increase in reflection amplitude is observed. Is this result to be expected for all saline aquifers?
- The updip component of the plume is estimated to extend about 85 m, as of Nov 30, 2004.