Monitoring and Verification of CO_2 Storage in Geological Formations

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Topics

- Purposes for monitoring
- Monitoring techniques
- Sensitivity and resolution of methods for leak detection
- Costs of monitoring
- Conclusions

Monitoring is Needed to Ensure that Geologic Storage is Safe and Effective

Requirements for Geologic Storage

- Worker and Public Safety
- Local Environmental Impacts to Groundwater and Ecosystems
- GHG Mitigation Effectiveness

Monitoring Needs

Key Monitoring Needs

- Monitor injection well performance
  - Wellhead and formation pressure
  - Injection rates
- Detect leakage and seepage of CO_2
  - Injection well leakage
  - Leakage from the primary storage reservoir
  - Surface seepage from the ground and abandoned wells

Other Purposes for Monitoring

- Establish baseline conditions to assess CO_2 storage impacts
- Identify and confirm storage efficiency and processes
- Calibrate models and confirm performance
- Detect microseismicity associated with CO_2 injection
- Verify inventory for financial transactions and national accounting
- Assess environmental, health and safety impacts of leakage
- Design and evaluate remediation efforts

Well-based Monitoring Techniques

- Injection and production rates
- Wellhead and formation pressures
- Casing and annulus pressure testing
- Temperature
- Well logs
- Fluid and gas composition

Geophysical Monitoring Techniques

- Seismic geophysics
- Electrical and electromagnetic geophysics
- Gravity
- Tilt measurements
- Airborne or satellite-based land surface deformation
- Microseismicity

Courtesy of Tom Daley, LBNL

Surface Monitoring for Seepage Detection and Inventory Verification

- Soil gas and vadose zone monitoring
- Fluid and gas phase tracers
- Eddy covariance flux monitoring
- Flux chamber monitoring
- Atmospheric CO_2 concentration

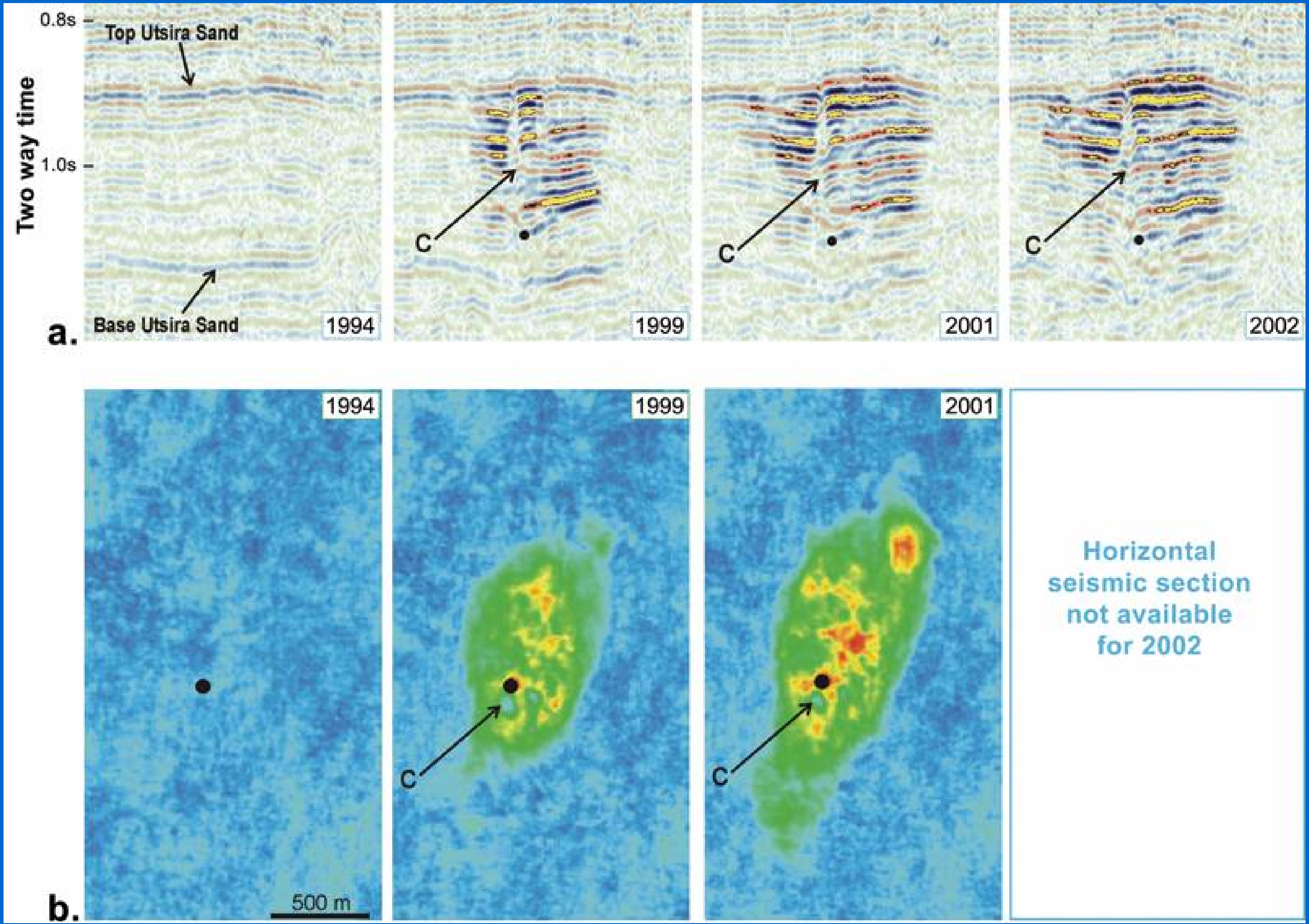
Courtesy of Jennifer Lewicki, LBNL

More than One Approach will Improve Confidence in Monitoring Results

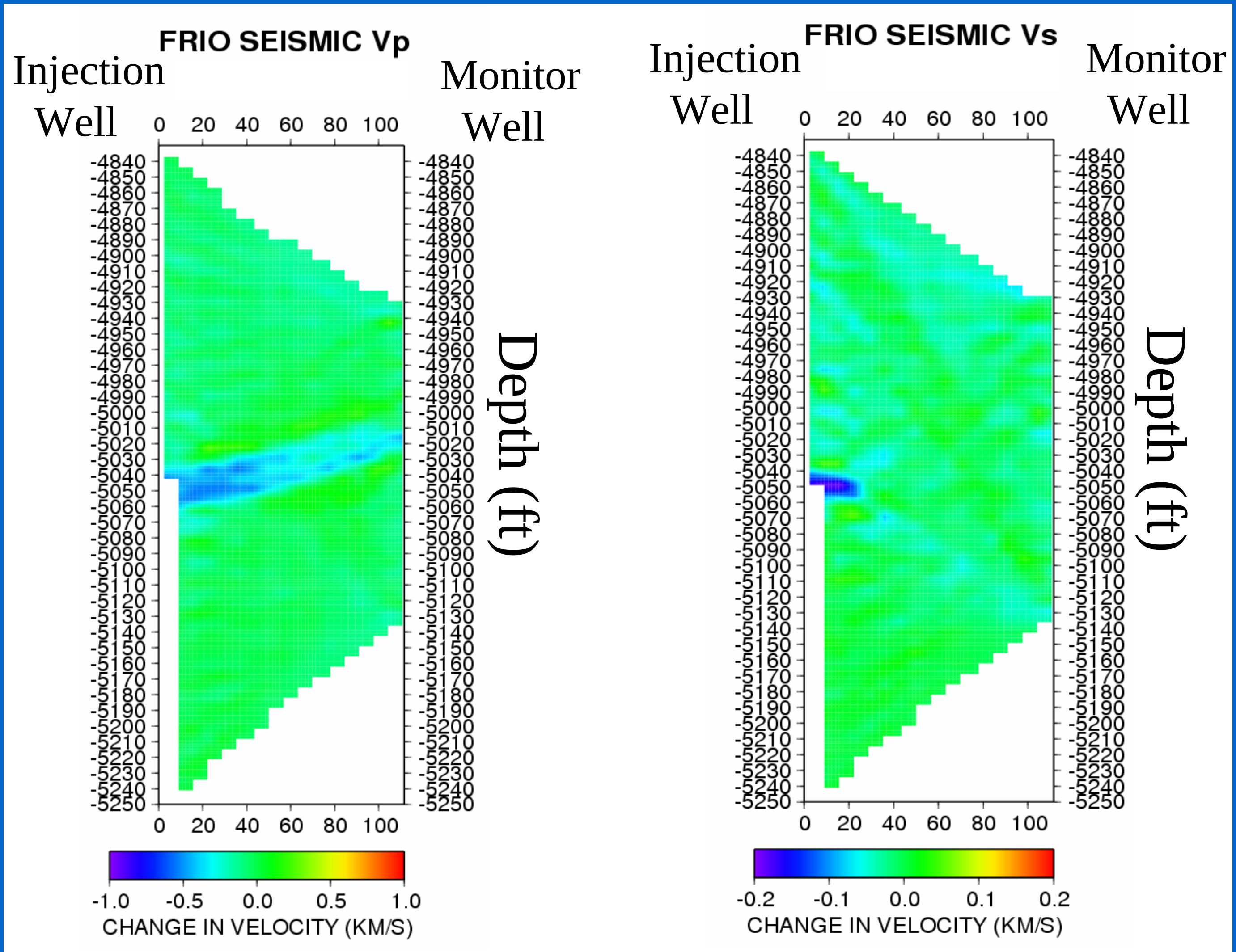
- Likely to be used (green square)
- Possible to use (purple square)

	Wellhead and Formation pressure	Injection and Production Rate	Casing and Annulus Pressure Testing	Casing and Annulus Pressure Testing	Temperature	Well Logs	Fluid and Gas Composition	Seismic Geophysics	Electrical and Electromagnetic Geophysics	Gravity	Land Surface Deformation	Tilt Measurements	Airborne or Satellite Imaging	Soil Gas and Vadose Zone Monitoring	Surface Flux Monitoring	Atmospheric CO_2 Concentration	Micro Seismicity
Baseline	Likely				Likely	Likely	Likely	Likely	Possible	Possible	Possible		Possible	Possible	Possible		Likely
Injection controls	Likely	Likely	Likely	Likely	Likely	Likely											Possible
Location of plume	Possible	Possible				Possible	Possible	Likely	Possible	Possible	Possible	Possible	Possible				Possible
Integrity of wells	Possible					Likely	Possible	Possible					Possible	Possible	Possible	Possible	
Efficiency and processes	Likely	Likely				Likely	Possible	Likely	Possible								
Calibration and performance	Likely	Likely			Possible	Likely	Possible	Likely	Possible	Possible							
Surface seepage													Possible	Likely	Likely	Likely	
Environmental health & safety							Likely	Likely	Possible	Possible	Possible	Possible	Possible	Likely			
Micro-seismicity											Possible	Possible					Likely
Remediation efforts	Possible					Possible	Possible	Likely	Possible				Possible	Possible	Possible	Possible	
Inventory verification	Likely	Likely	Likely	Likely				Likely	Possible	Possible			Possible	Likely	Likely	Possible	

Examples: Seismic Data Collected at Sleipner

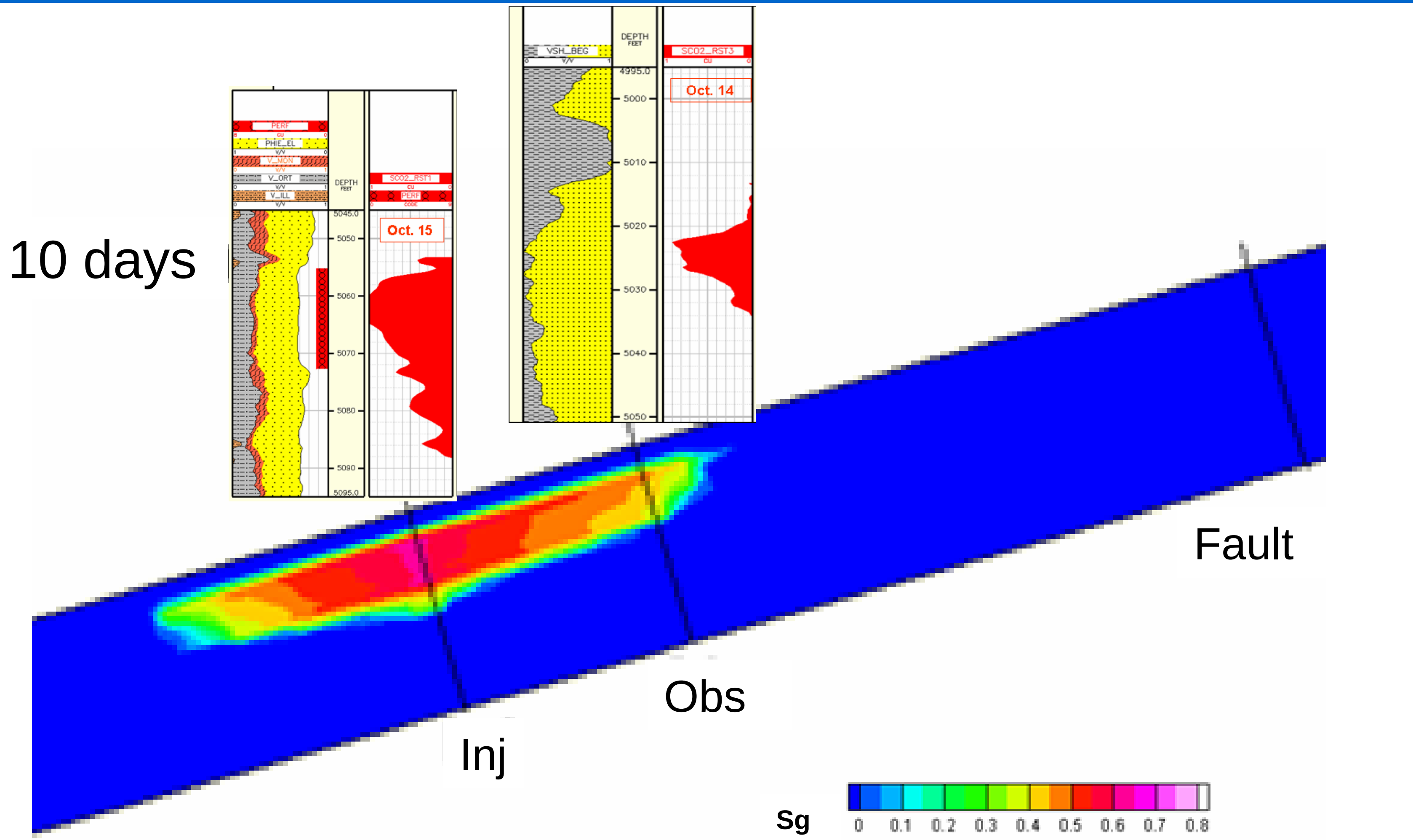


Examples: Seismic Tomography from the Frio Formation



Slide compliments of Tom Daley, LBNL

Examples: RST Logs from Frio Formation Compared to Simulated CO_2 Migration



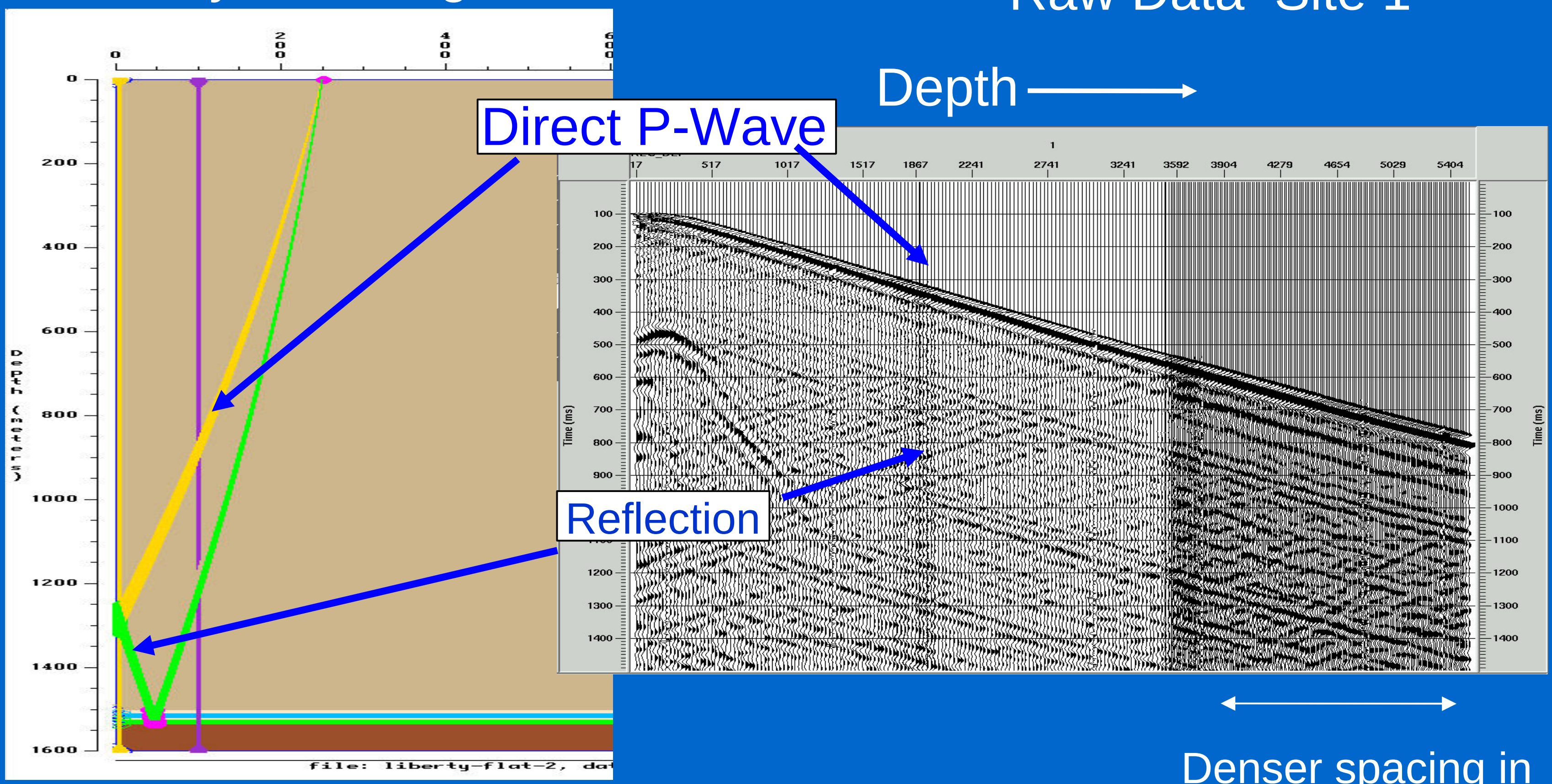
Simulation from Doughty et al., 2005

RST data from Sakurai et al., 2005

Vertical Seismic Profiling for CO_2 Location Detection

Initial Ray Modeling

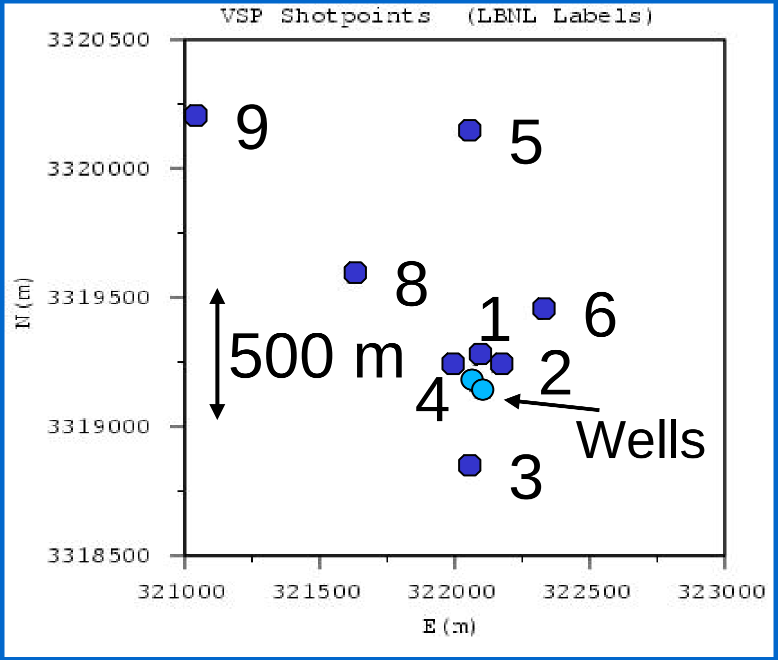
Raw Data Site 1



Denser spacing in reservoir interval

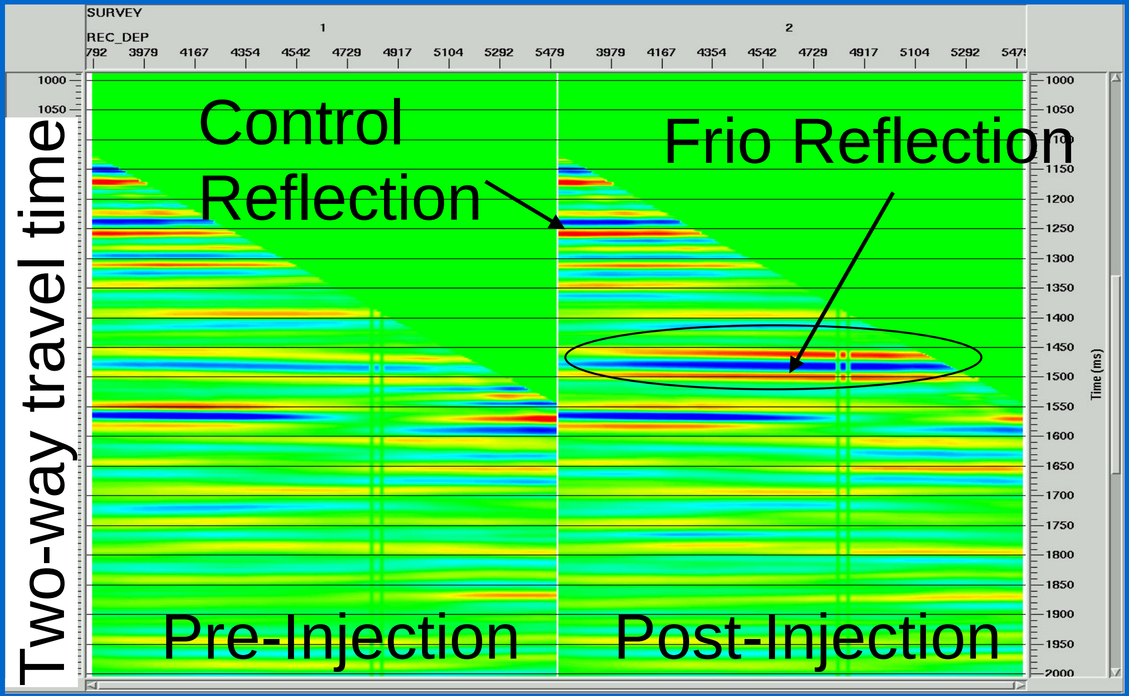
Slide compliments of Tom Daley, LBNL

Frio Brine Pilot:
Vertical Seismic Profiling Results



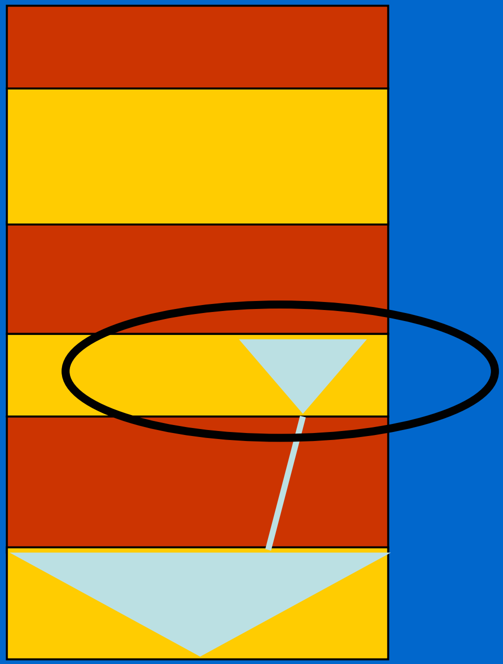
Data and interpretation from Tom Daley, LBNL

Estimated Plume Edge = 85 m



Sensitivity of Seismic Methods

Conceptual Model



Detection Limits at Reservoir Depth

Myer et al, 2002: 10,000 tonnes

Arts et al., 2004: Sleipner, 4,000 tonnes

White el al., 2004: Weyburn, 2,500 tonnes

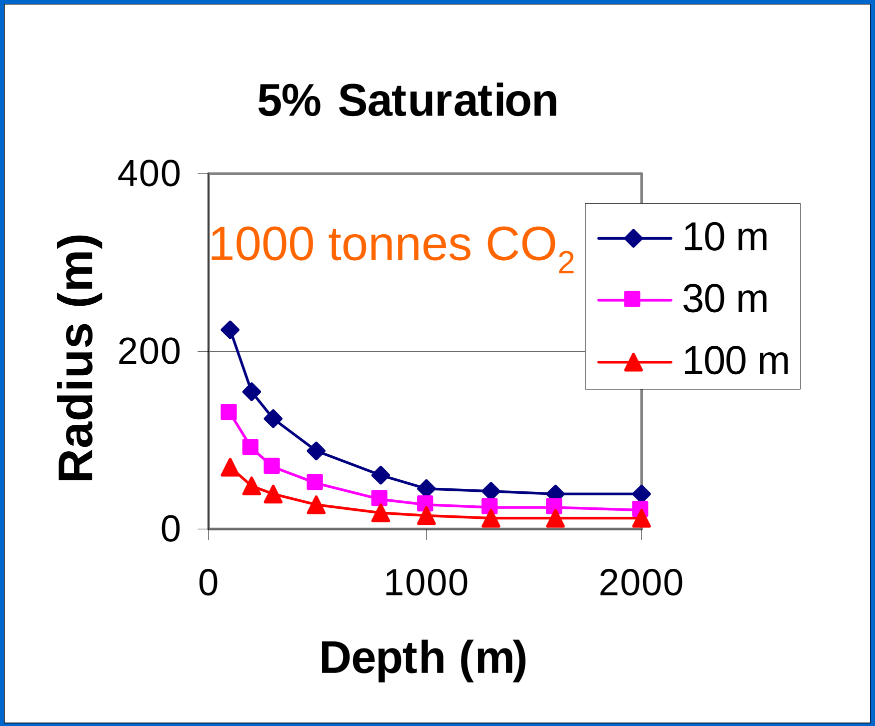
Daley et al., 2005: Frio Formation, 1,600 tonnes

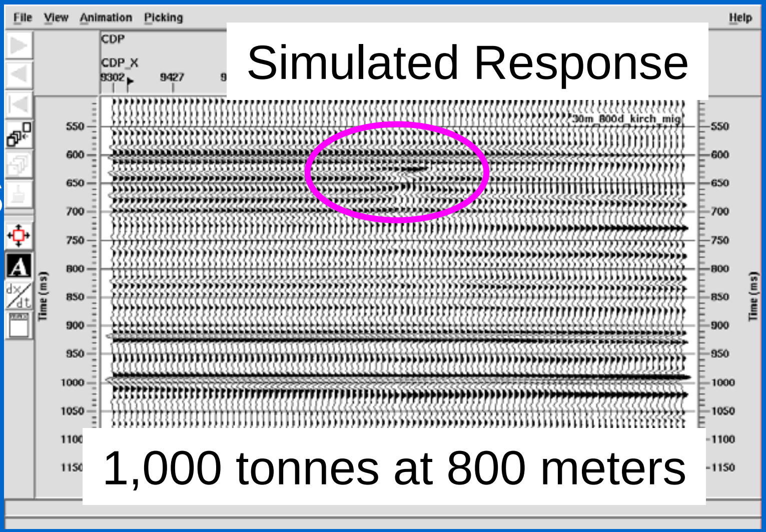
For a 5 MtCO_2/year Storage Project

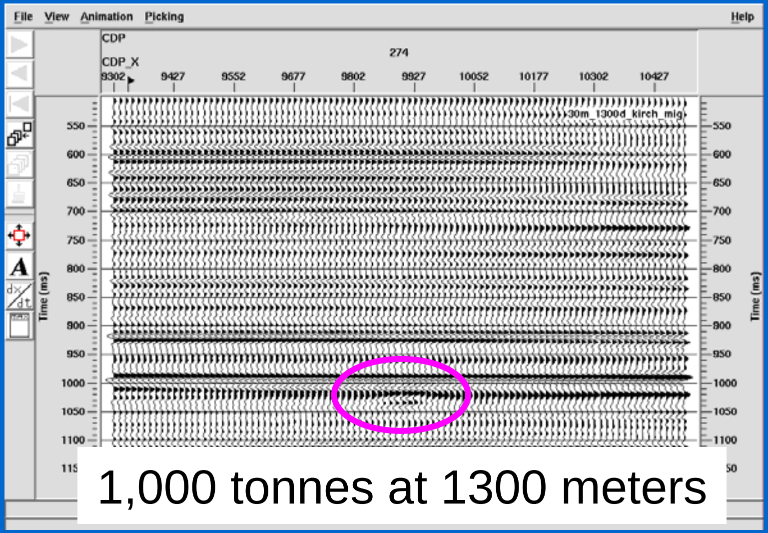
Detection of 0.03% to 0.2% of annual injection rate

Detection Limits Improve Even Further if the CO_2 is Shallower

- CO_2 density contrast increases
- Compressibility contrast increases
- Plume size increases

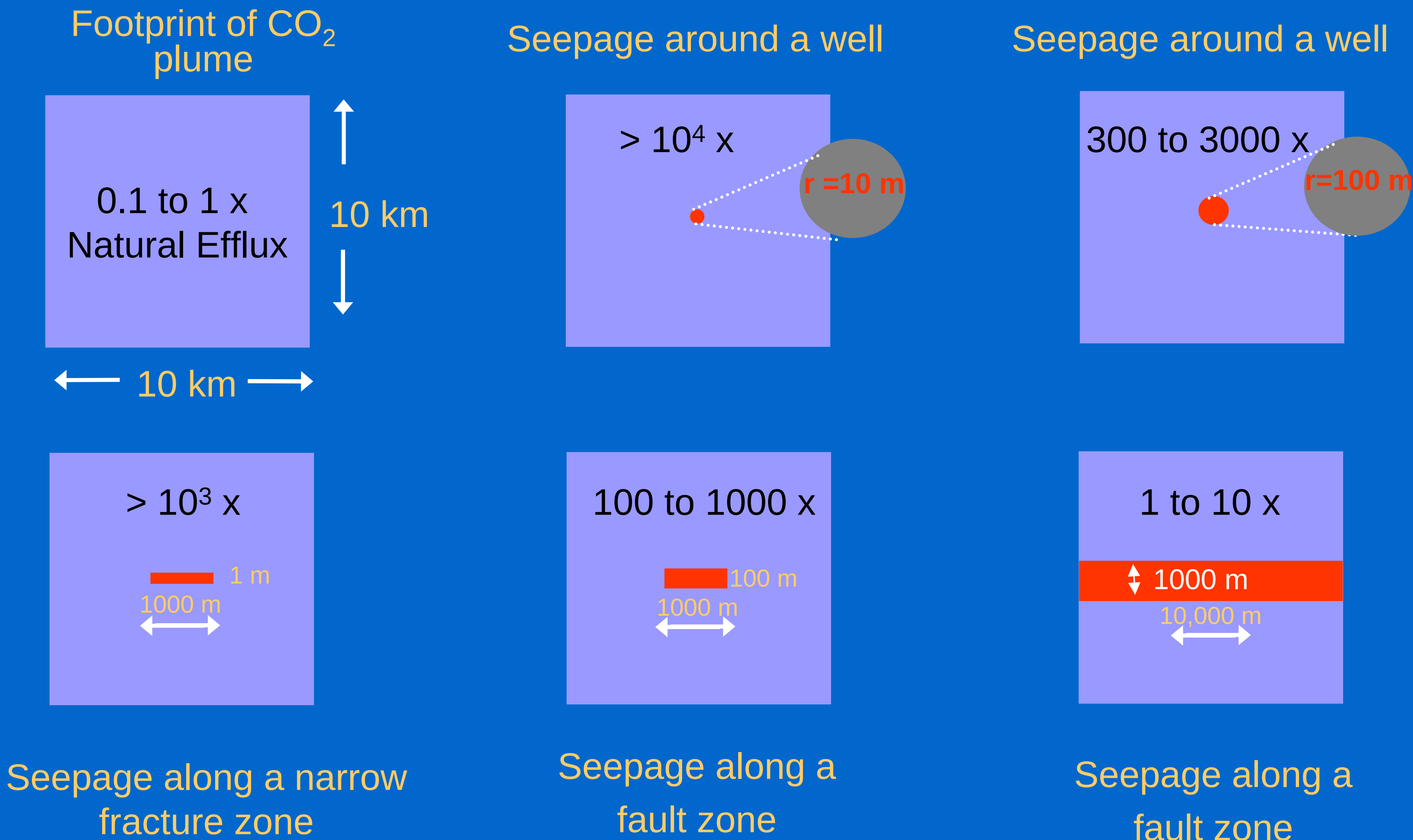






Example Seepage Detection Scenarios

(150 Mt Storage Project): Seepage rate 0.01 to 0.1%/year



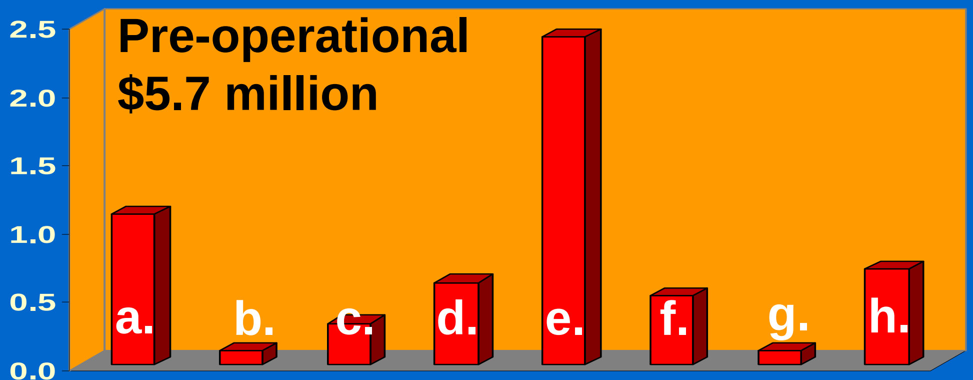
Life Cycle of a Storage Project and Monitoring Requirements

Pre-operation Phase	Operation Phase	Closure Phase	Post-closure Phase
• Site character-ization • Risk assessment • Establish monitoring baseline	• Verify injection rates • Track location of plume • Ensure safe operations • Detect and prevent environmental impacts	• CO_2 injection stops • Surface facilities removed; wells abandoned • Confirm long-term security of storage project	• Completed records given to regulatory authorities • Monitoring may only be needed only if long term storage security not established

0 | 5 | 35 | 55 - 85

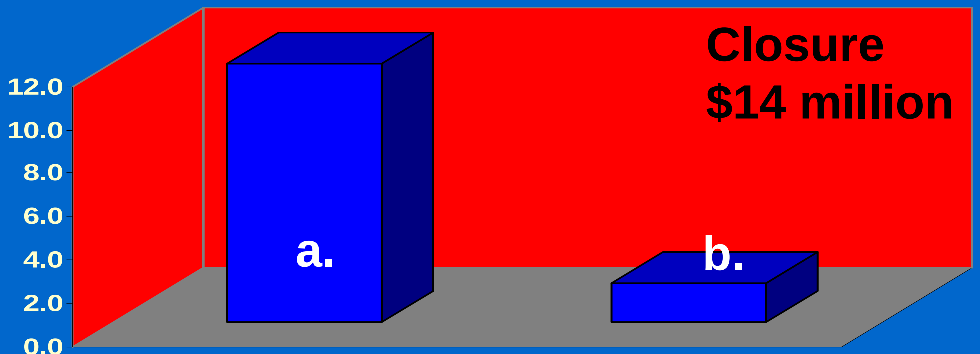
Approximate Time-Line (Years)

Monitoring Cost for Saline Formation



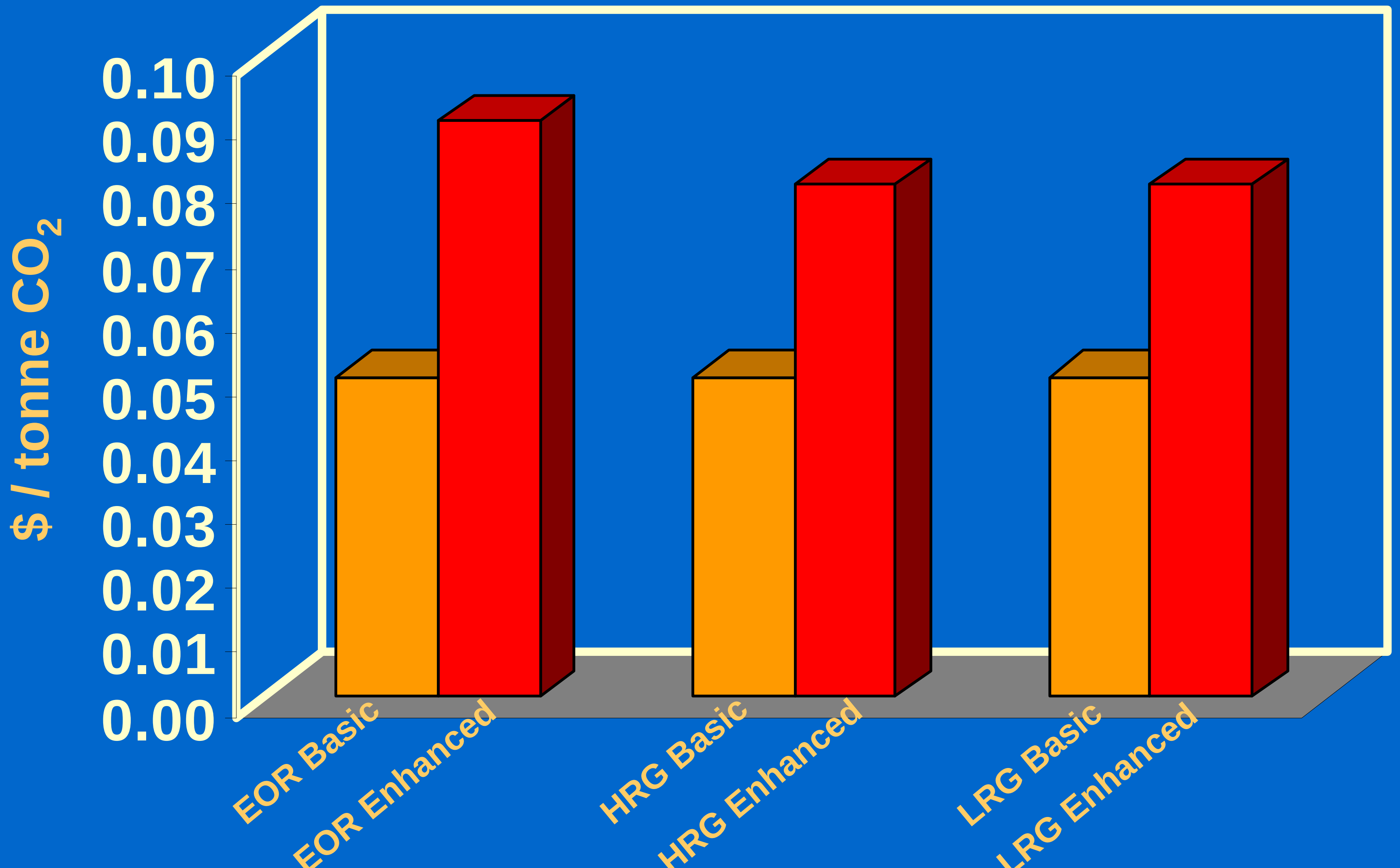
a. Well logs
b. Wellhead pressure
c. Formation pressure
d. Injection and production rate testing
e. Seismic survey
f. Microseismicity baseline
g. Baseline atmospheric CO_2 monitoring
h. Management (15%)

a. Seismic survey
b. Wellhead pressure
c. Injection and production rates
d. Wellhead atmospheric CO_2 concentration
e. Microseismicity
f. Management (15%)



a. Seismic survey
b. Management (15%)

Discounted Costs (@10%)



Conclusions

- Many monitoring options available
- Seismic imaging is currently most promising for subsurface monitoring
- Combinations of techniques provide greater assurance
- Detection of significant leaks (>0.1% to 0.01%/year) may be possible under many circumstances
- Costs of monitoring are small compared to other costs
- Innovations will improve spatial and temporal resolution
- More demonstrations are needed

Frio Brine Pilot, 2004