DE-FE002186

Training Toward Advanced 3D Seismic Methods for CO^2 Monitoring, Verification, and Accounting

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Storage R&D Project Review Meeting

Developing the Technologies and Building the Infrastructure for CO2 Storage

August 21-23, 2012

Outline

- Benefits to the Program
- Project Overview
- Technical Status
- Accomplishments to Date
- Summary

Benefits to the Program

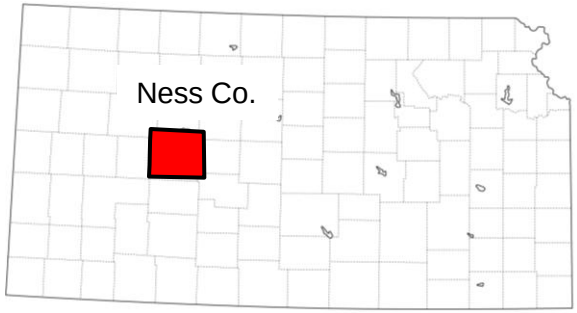
- Project goals
  - Student training in advanced seismic technology suited to CO^2 sequestration
- Project benefits
  - Seismic simulation for acquiring 3D3C seismic data that can be used to improve
    - Pre-injection characterization of CO^2 storages
    - Monitoring
      - During CO^2 injection
      - Long-term post-injection

Project Overview

- Seismic simulation work flow training
  - Based on research results from a Phase II Study (DE-FG26-06NT42734), a site-specific reservoir characterization on Dickman Field
- Major components for training
  - Geological-constraint S-wave estimation
  - Seismic simulation and modeling in 2D and 3D
  - Component rotation to field design for 3D3C data acquisition

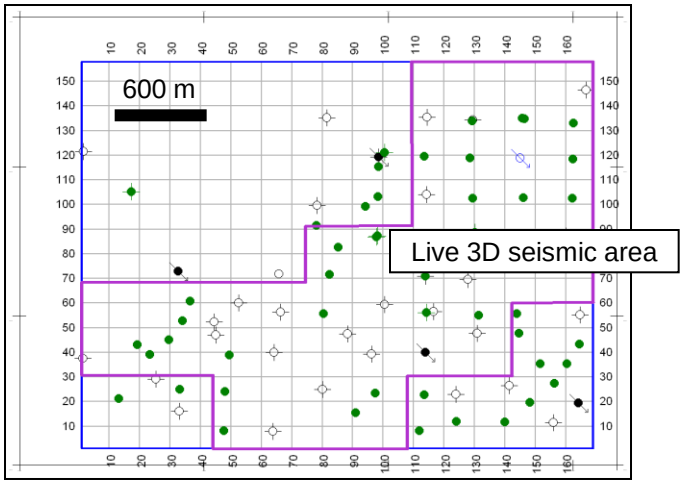
Technical Status

Dickman Project Area



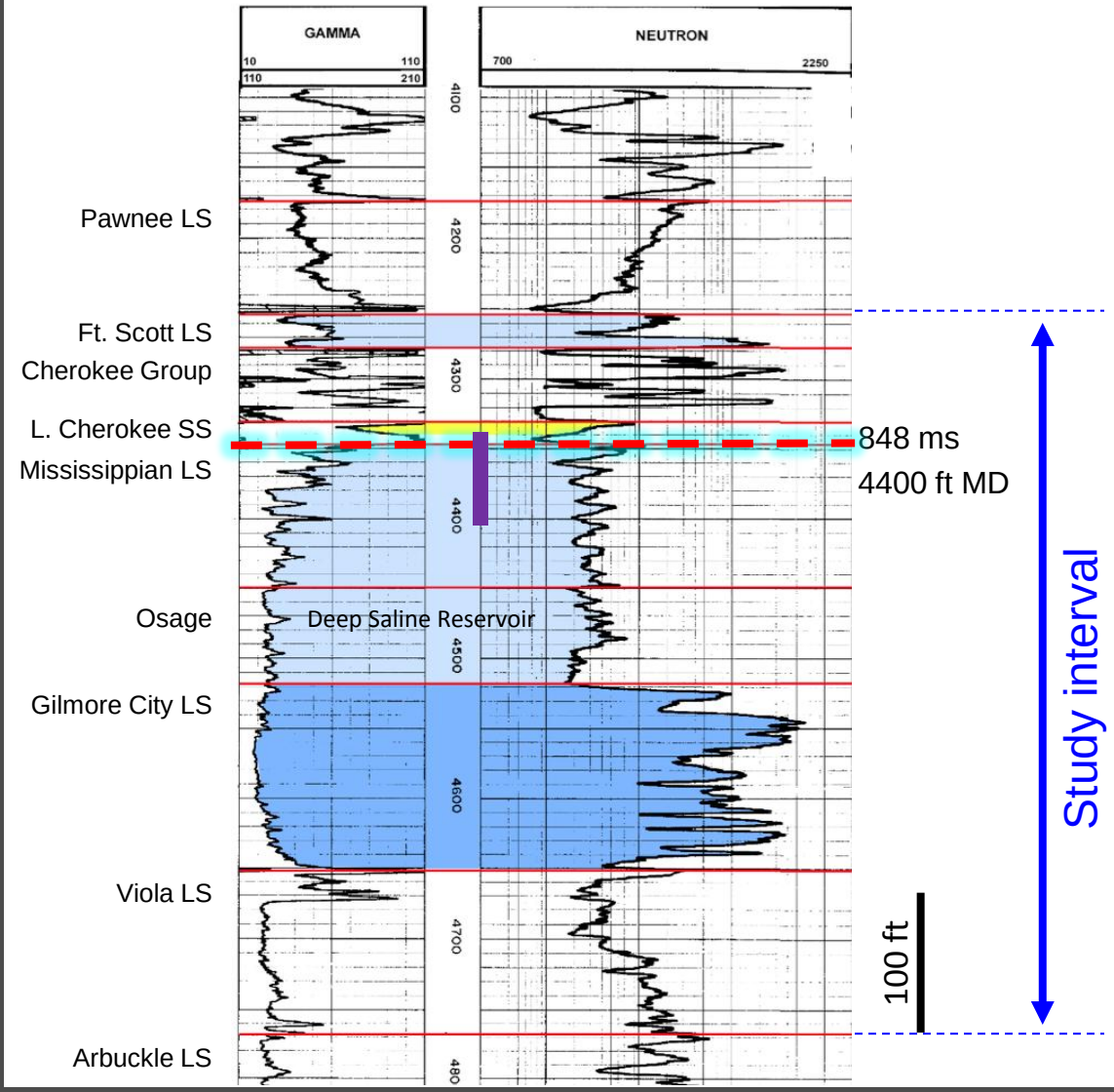
3D Seismic
- 3.325 sq. mi.

142 wells
- 54 in 3D area
- Core (7)
- Digital logs (45)
  - Sonic(5)
  - Density(2)
  - Gamma(43)
  - Resistivity (25)
  - Neutron (27)

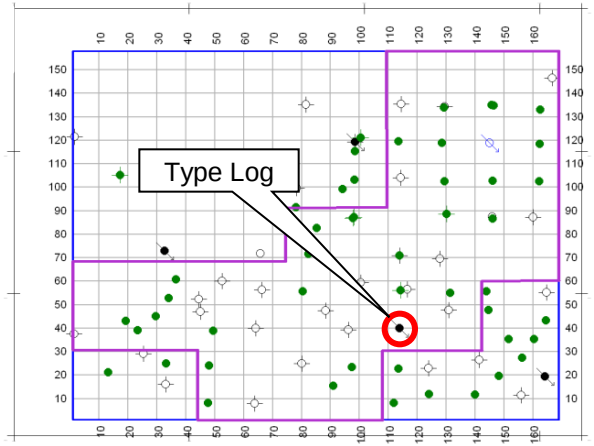


Disc. 1962 Cumm: 1.7 MMBO

Type Section



Annotated type log for Dickman project area (Stiawalt 3 T17S-R24W-S20).

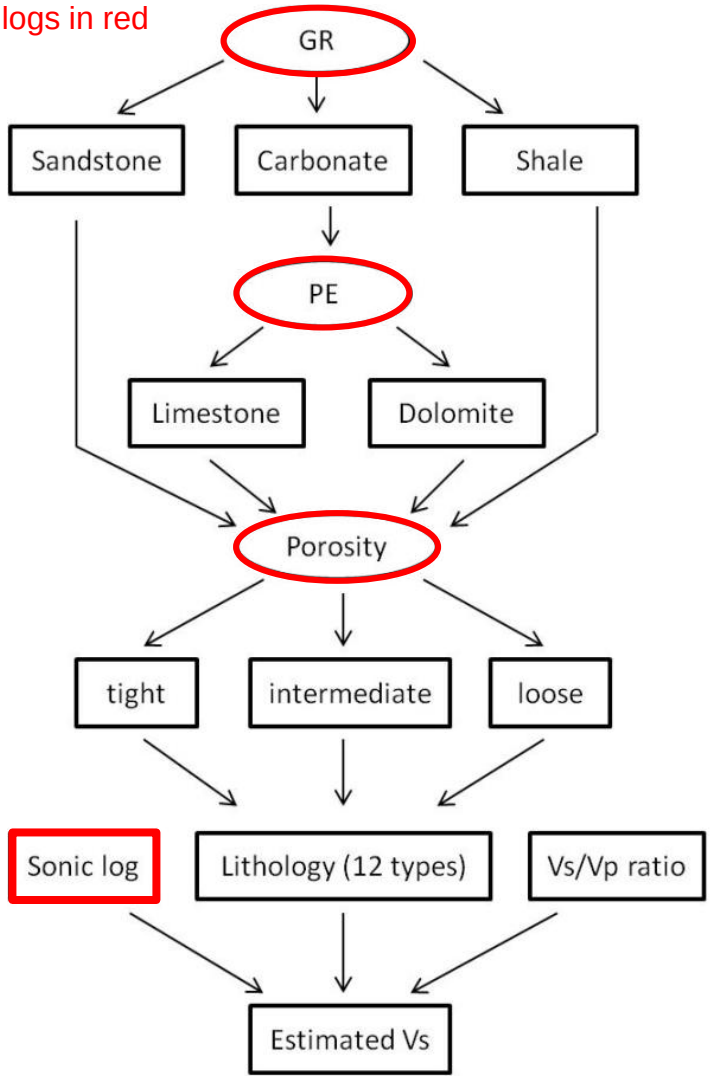


Background Information

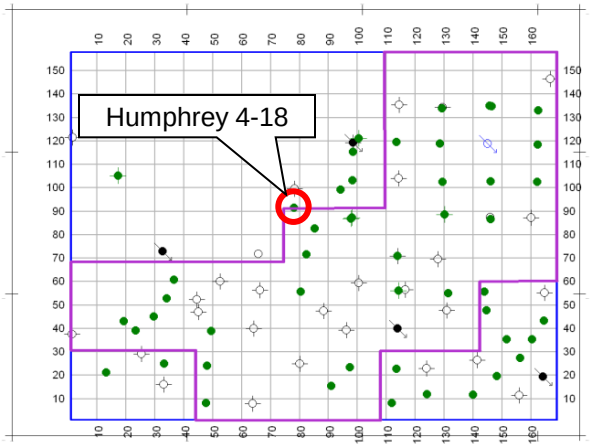
- Field 3D seismic data
  - Single component
    - “P-wave” data
    - Can multicomponent data give more info?
- Available well data
  - Vp sonic only
  - Need to estimate Vs for seismic simulation

Estimating S-Wave Velocity Using Typical Data

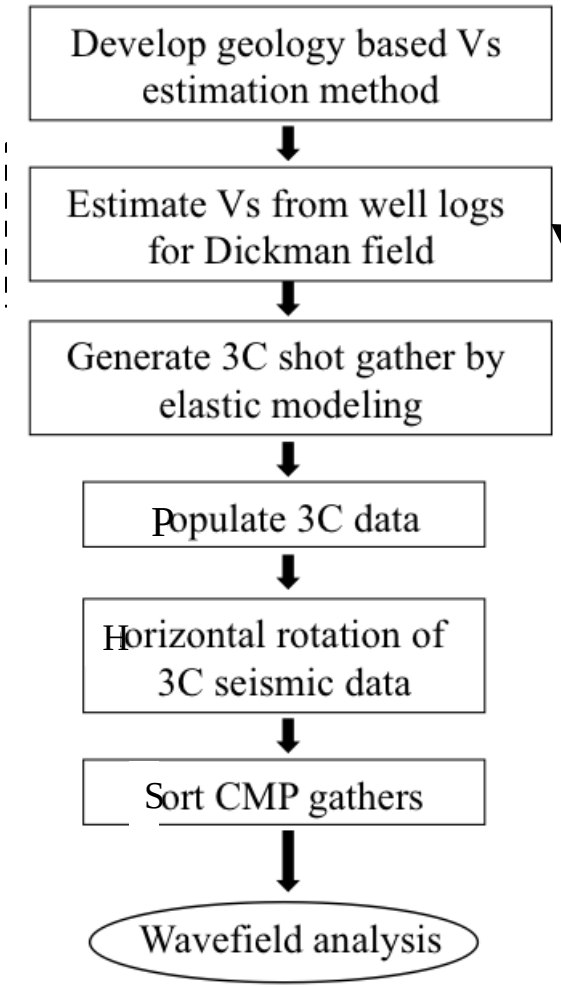
Input logs in red

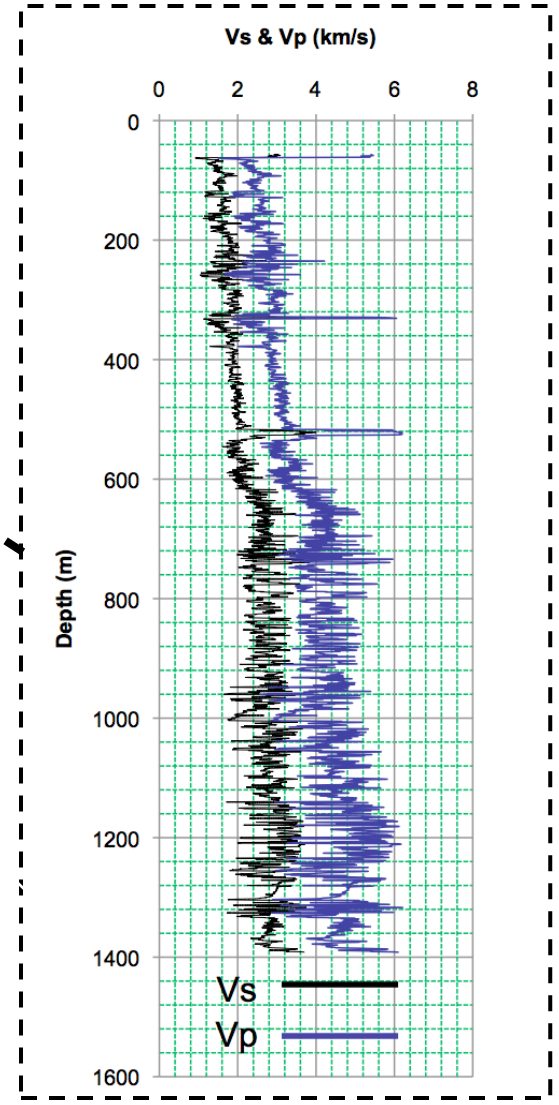


Who Conducted Measurement	Lithology	Vs/Vp
CONOCO Lab	Carbonates	0.42 to 0.50
	Sandstones	0.51 to 0.58
	Shales, Claystones	0.58 to 0.65
Schlumberger	Limestone, dolomite, and anhydrite in various proportions	0.53 to 0.55
	Sandstones and conglomerates with minor carbonates	0.60 to 0.63
Welex (Kithas, 1976)	Limestone	0.53
	Dolomite	0.56
	Sandstone	0.59 to 0.63
	Shale	0.56 to 0.59
	Dolomite, anhydrite	0.52 to 0.55



Workflow in Seismic Modeling



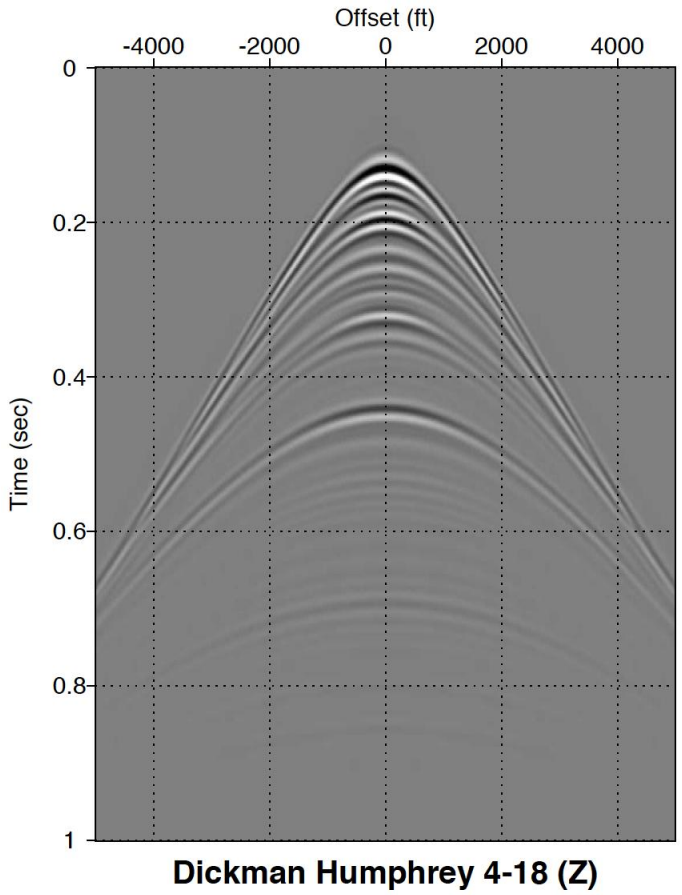


Seismic Simulation: ANIVEC

- Reflectivity modeling
  - Good
    - Elastic
    - Multicomponent data
    - Wave type choices
      - Include/exclude surface waves, shear, etc.
  - Limitations
    - Assumes horizontal layers
      - But this is Kansas! (good assumption)

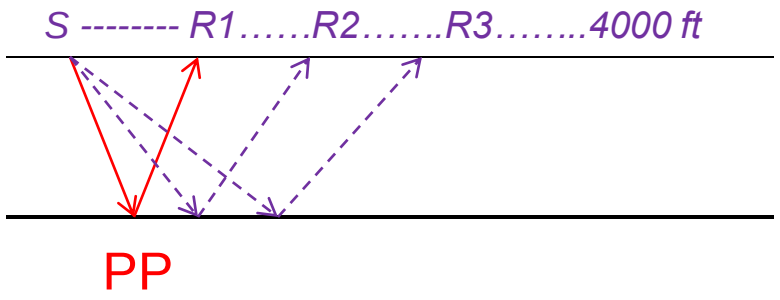
ANIVEC Courtesy: S. Mallick (U. Wyoming)

Seismic Simulation: P-wave only

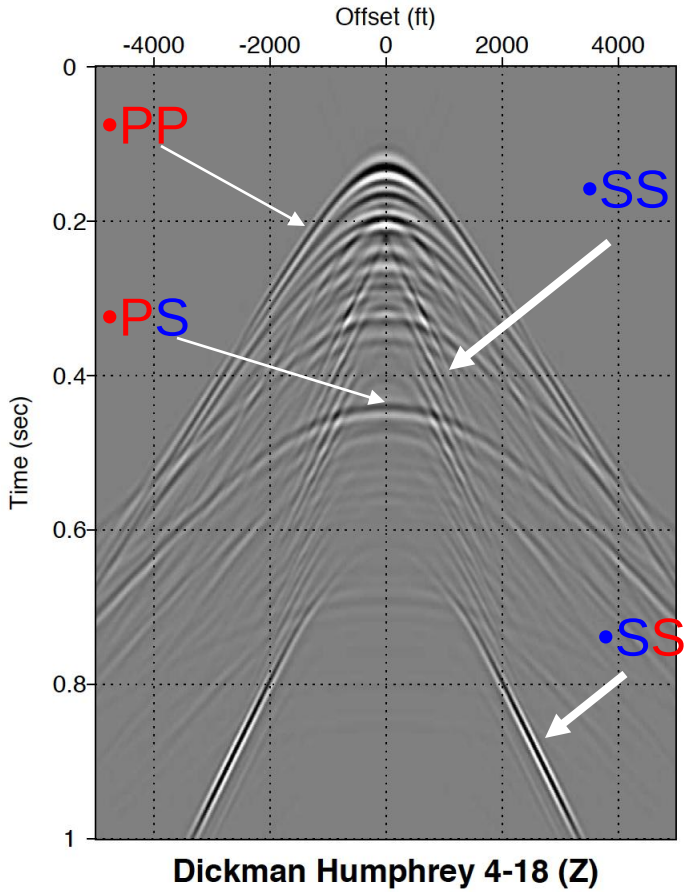


Single component data

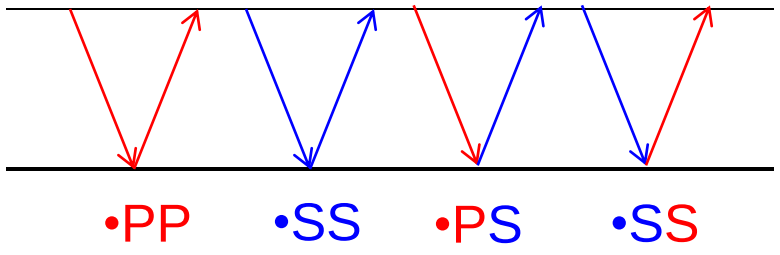
Wave types (acoustic simulation)



Seismic Simulation: P and S waves

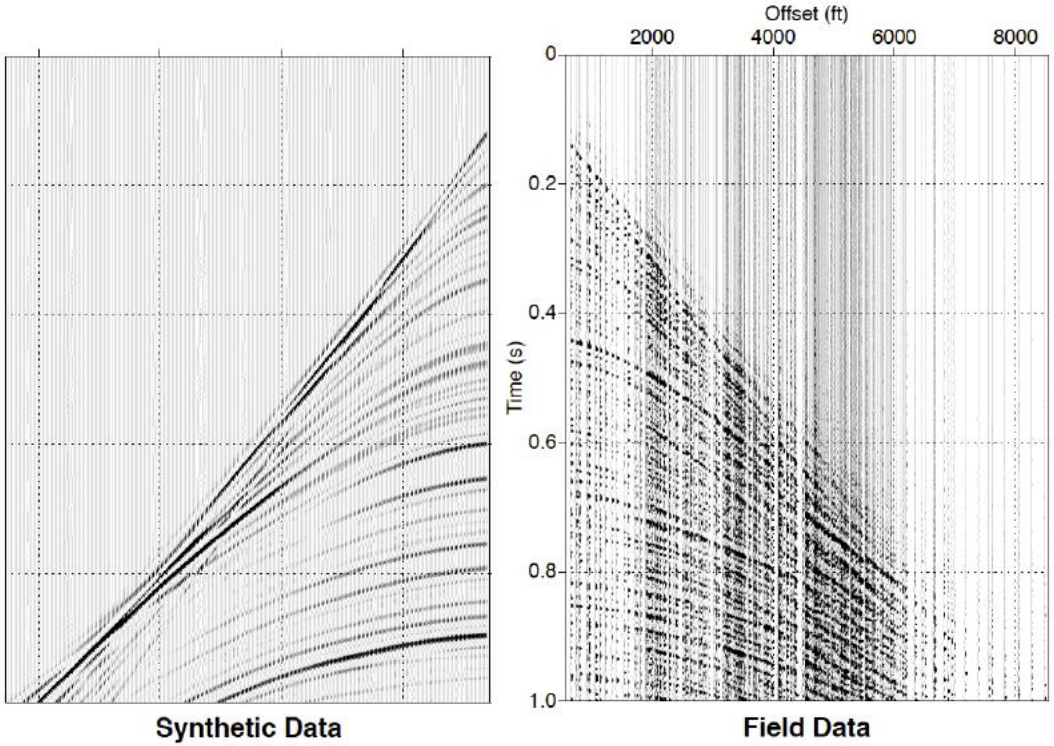


- Multicomponent data
- Wave types (elastic simulation)



S-waves give direct evidence of anisotropy (shear wave splitting) related to fractures.

SS: fast, parallel to the fracture SS: slow, orthogonal to both the fast share wave and the fracture zones.



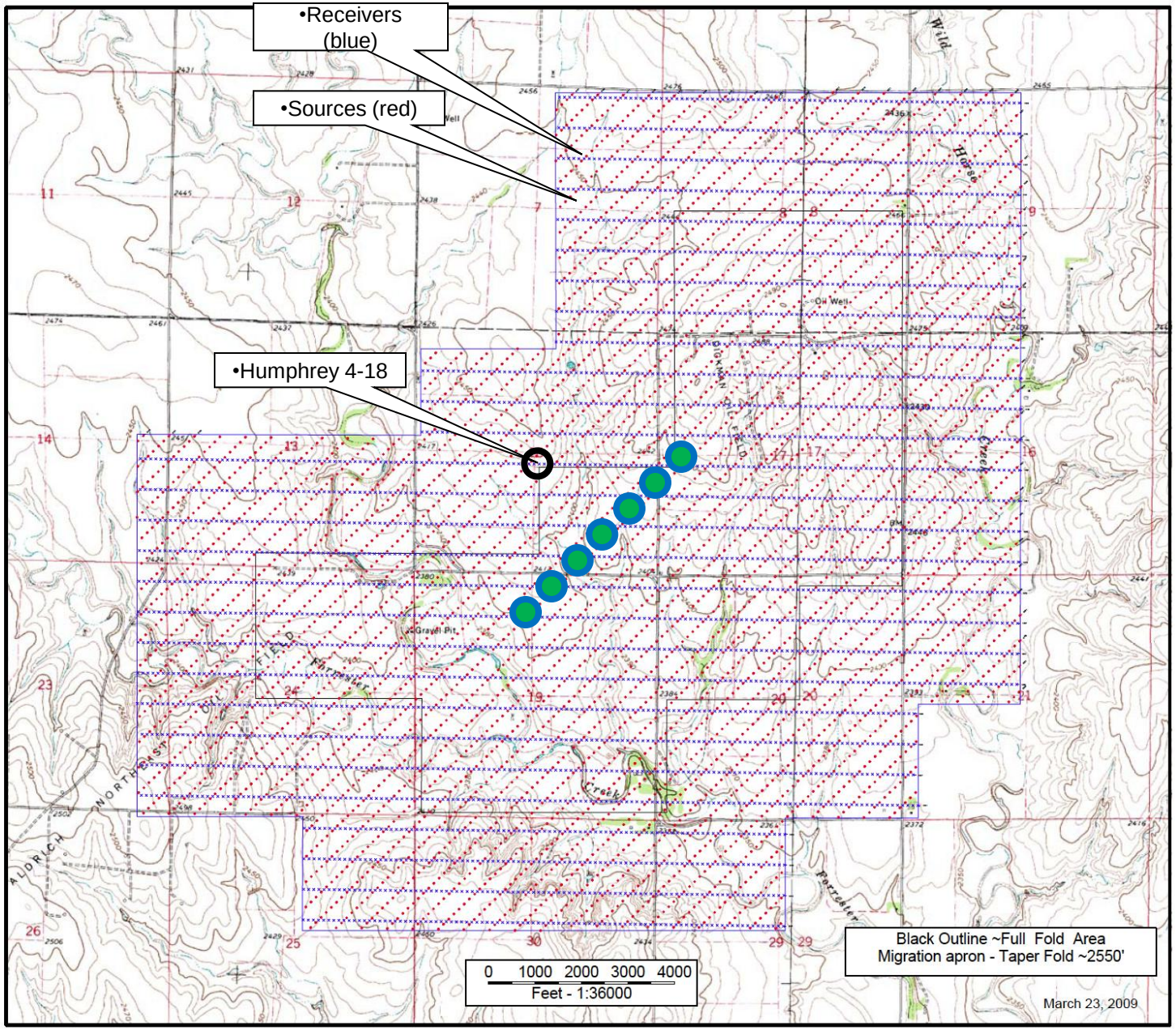
Comparison of field data and acoustic finite difference synthetic seismogram based on Humphrey 4-18 well logs. The field data is a super gather composed of five CMP gathers (4500-4505). Uneven trace spacing in field data results from irregular offset distribution. Correspondence of events is quite good.

Simulation Data to 3D3C Survey Design

- Simulated seismic data
  - Based on 1 well (Humphrey 4-18)
    - Extended laterally by duplicating the log
  - Populating equal offset 2D elastic traces according to survey geometry
    - Receiver offset and components all relative to source
    - Requires component rotation to field components

Dickman 3D
Design Map

Geokinetics



Date: 23-Mar-09
Area (sq.miles): 9.19

Receivers

Line Interval:	660
Line Bearing:	90.75
Group Interval:	110
Total:	3547
Per Square Mile:	386.0

Sources

Line Interval:	550
Line Bearing:	45.75
Group Interval:	110
Inline Interval:	155.56
Total:	4233
Per Square Mile:	460.6

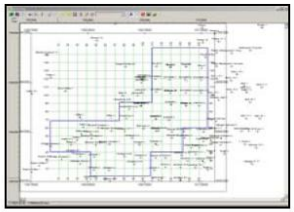
Design

Type:	Slant 45
Bin Size:	55 x 55
Patch Size:	14 x 100
Max.Fold (CMP):	70
Max.Fold (CCP):	~ 80
Roll Lines:	yes
Roll Stations:	yes

Statistics

Xmin:	77.8
Xmax:	7105.40
Ratio:	0.79

Ness County, KS
Kansas South (FIPS 1502)
NAD27, feet



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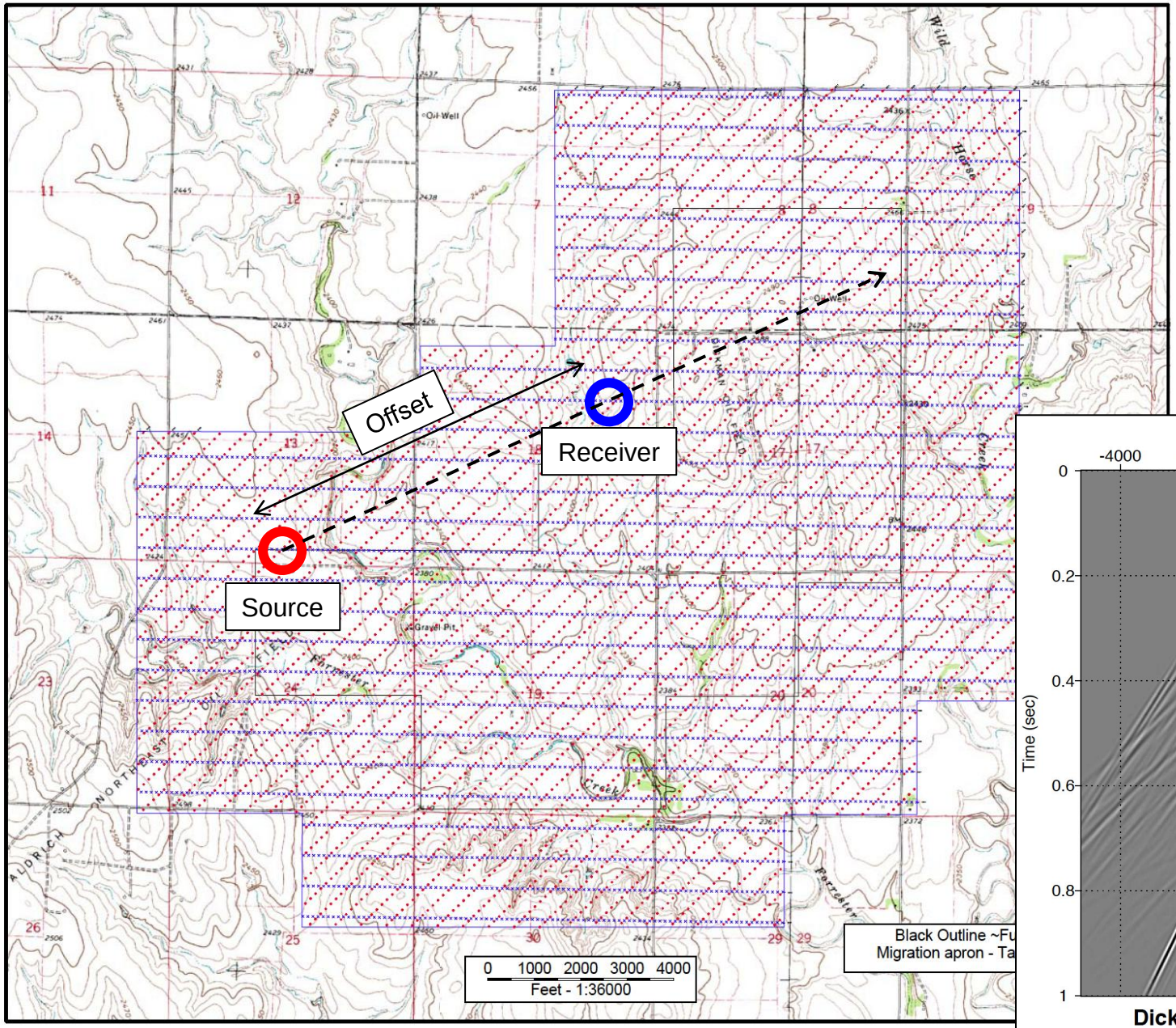

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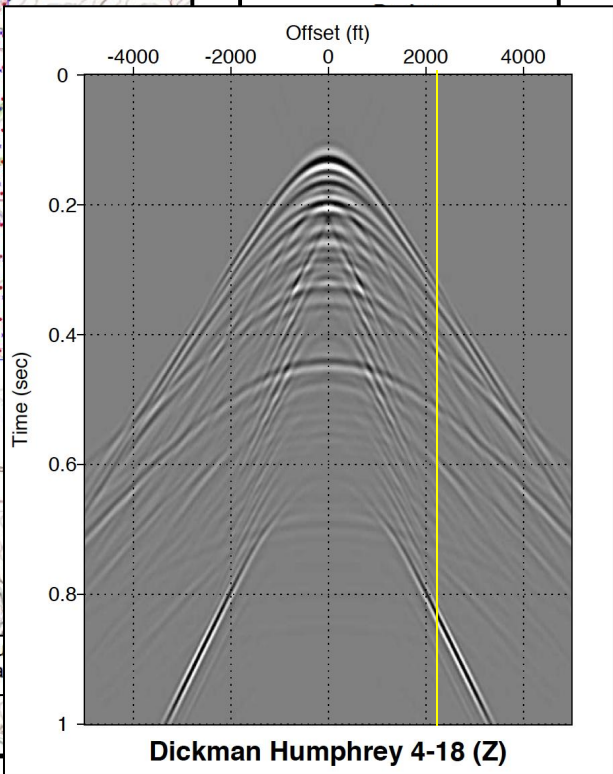
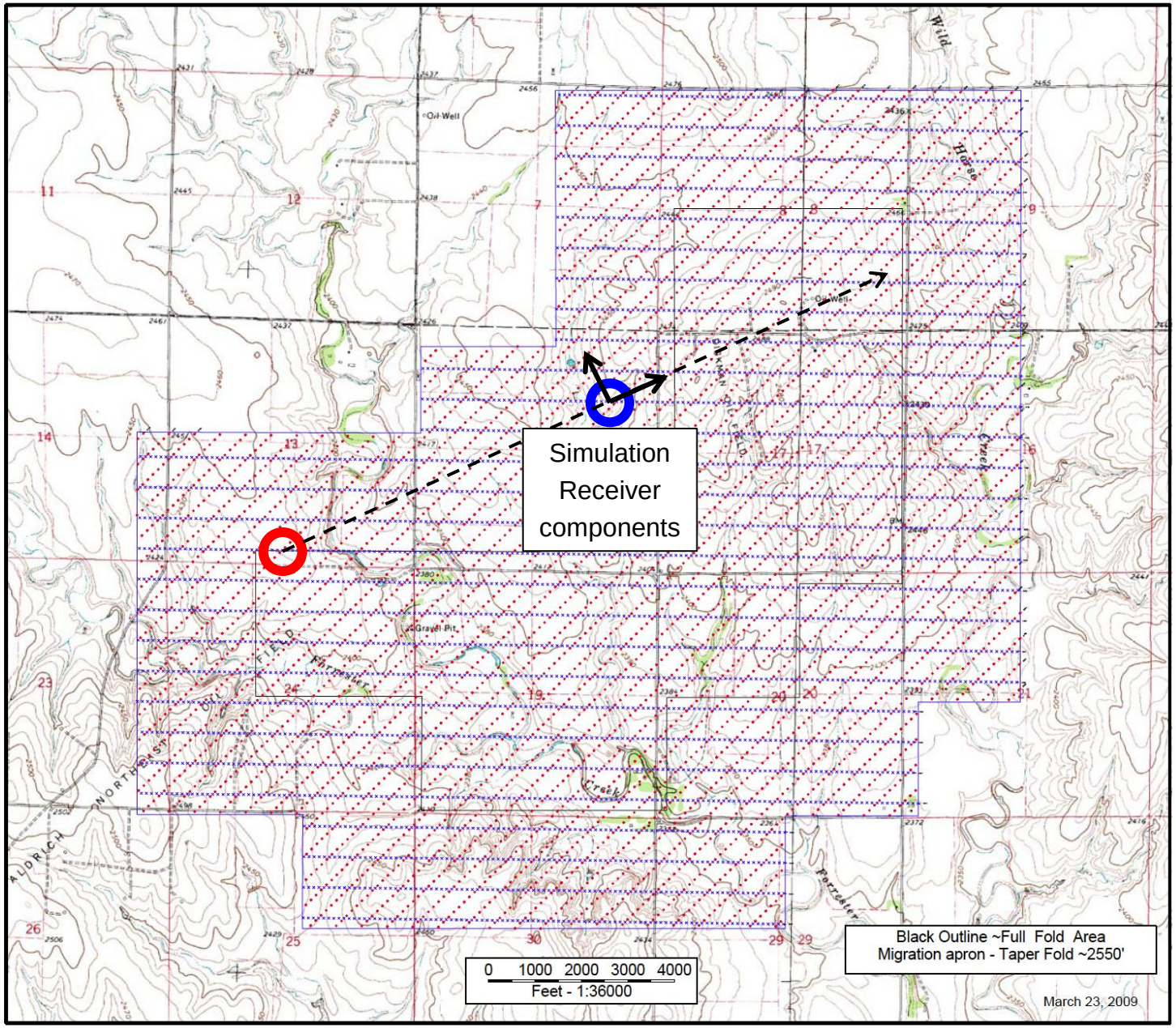


Dickman Humphrey 4-18 (Z)

Dickman 3D
Design Map

Geokinetics



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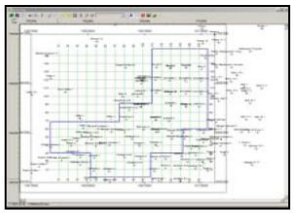

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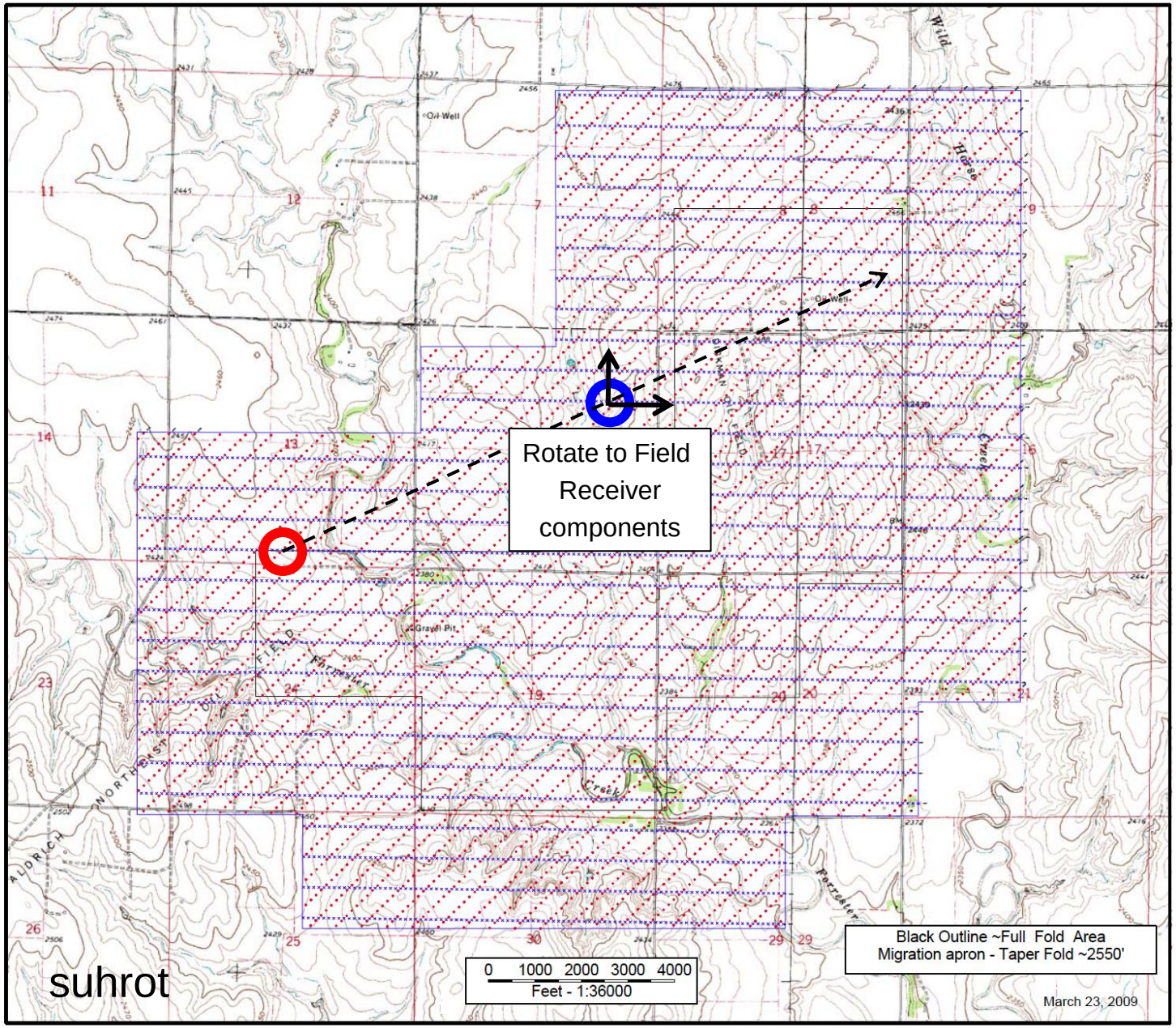

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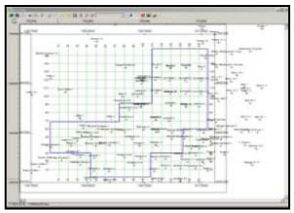


Accomplishments to Date - Training Results

Student Accomplishments

Jintan Li (PhD August 2012)

Flow model to seismic simulation

Qiong Wu (PhD continuing)

Elastic modeling and rotation

Tim Brown (MS July 2012)

Fracture indicators

Johnny Seales (BS Dec 2011)

Subtle channel indicators

Accomplishments to Date - Technical Contributions

- Jintan Li workflow and matlab code
  - *Flow model to seismic simulation*
- Qiong Wu workflow and seismic unix code
  - *Elastic modeling and rotation*
- Tim Brown workflow
  - *Fuzzy logic fracture index from conventional well logs*
- Johnny Seales worflow
  - *Narrow-band seismic calculation and analysis*

Accomplishments to Date -Technology Transfer

Student first-author presentaions

Phan, S. and M., Sen, 2010, *Porosity estimation from seismic data at Dickman Field, Kansas for carbon sequestration*, SEG 2010, Denver

Wu, Q., and C. Liner, *Comparison on shear wave velocity estimation in Dickman field, Ness County, Kansas*, SEG 2011, San Antonia

Seales, J., T. Brown and C. Liner, 2011, *Channel and fracture indicators from narrow-band decomposition at Dickman field, Kansas*, SEG 2011, San Antonio

Accomplishments to Date -Technology Transfer

Other Presentations

Liner, C., Flynn, B., and J., Zeng, 2010, Case History: *Spicing up mid-continent seismic Interpretation*, SEG 2010, Denver

Zeng, J., C., Liner1, P., Geng and H., King, 2010, *3D Geologic Modeling toward a Site-specific CO2 Injection Simulation*. AAPG 2010, Houston

Liner, C, P. Geng, J. Zeng, H. King and J. Li, 2011, *A CO2 Sequestration Simulation Case Study at the Dickman Field*, Ness Co., Kansas, SPE 2011, Denver

Liner, C. 2012, *Geophysical methods for CO2 monitoring and reservoir characterization, invited keynote presentation*, The Australian Society of Exploration Geophysicists, Brisbane

Zeng, J., C. Liner, and J. Seal, 2012, *Study of Faults and Fractures by Multi-scale Data Integration A geological modeling case in the Dickman Field, Ness County, Kansas*, AAPG 2012, Long Beach

Zeng, J., and C. Liner, 2012, *Fault and fracture interpretation using multiple seismic attributes in Mississippian Carbonate reservoirs of the Dickman Field, Ness County, Kansas*, AAPG SW Section Convention, 2012, Dallas-Fort Worth

Summary

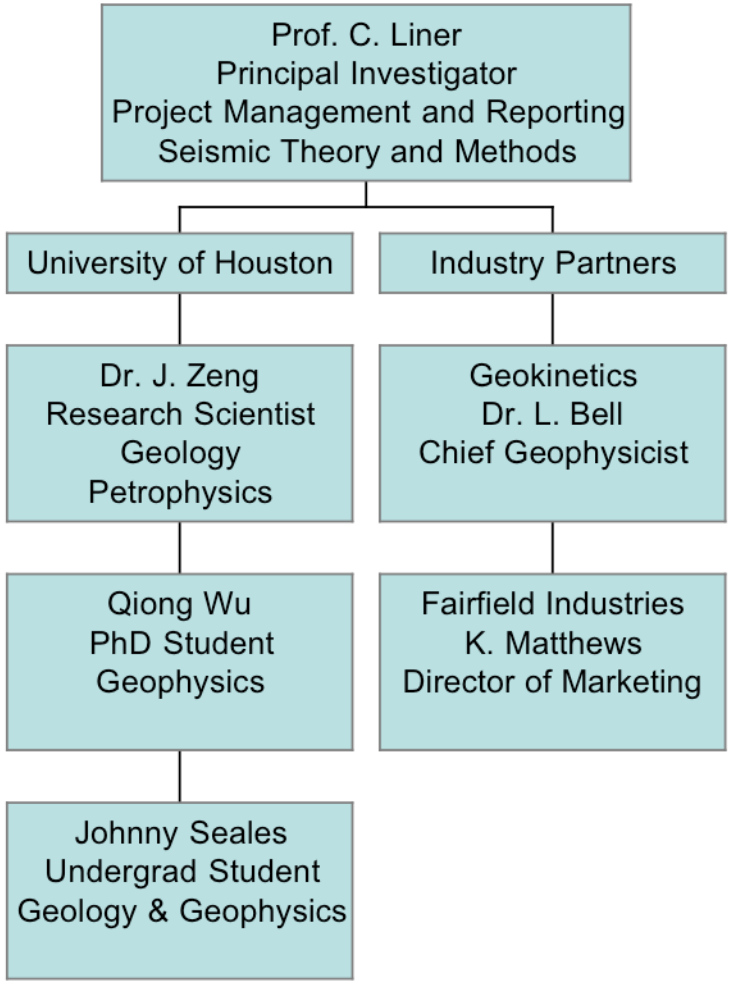
- Key Findings
  - CO2 seismic signal is strong at Dickman
    - Type locality for US Midcontinent
    - Implications for MVA in CCS projects
      - 3D3C seismic data and Time-lapse seismic monitoring
- Lessons Learned
  - Vector seismic adds value
    - S-wave splitting is direct fracture indicator ()
- Future Plans
  - Project funding period completed

Thank you !

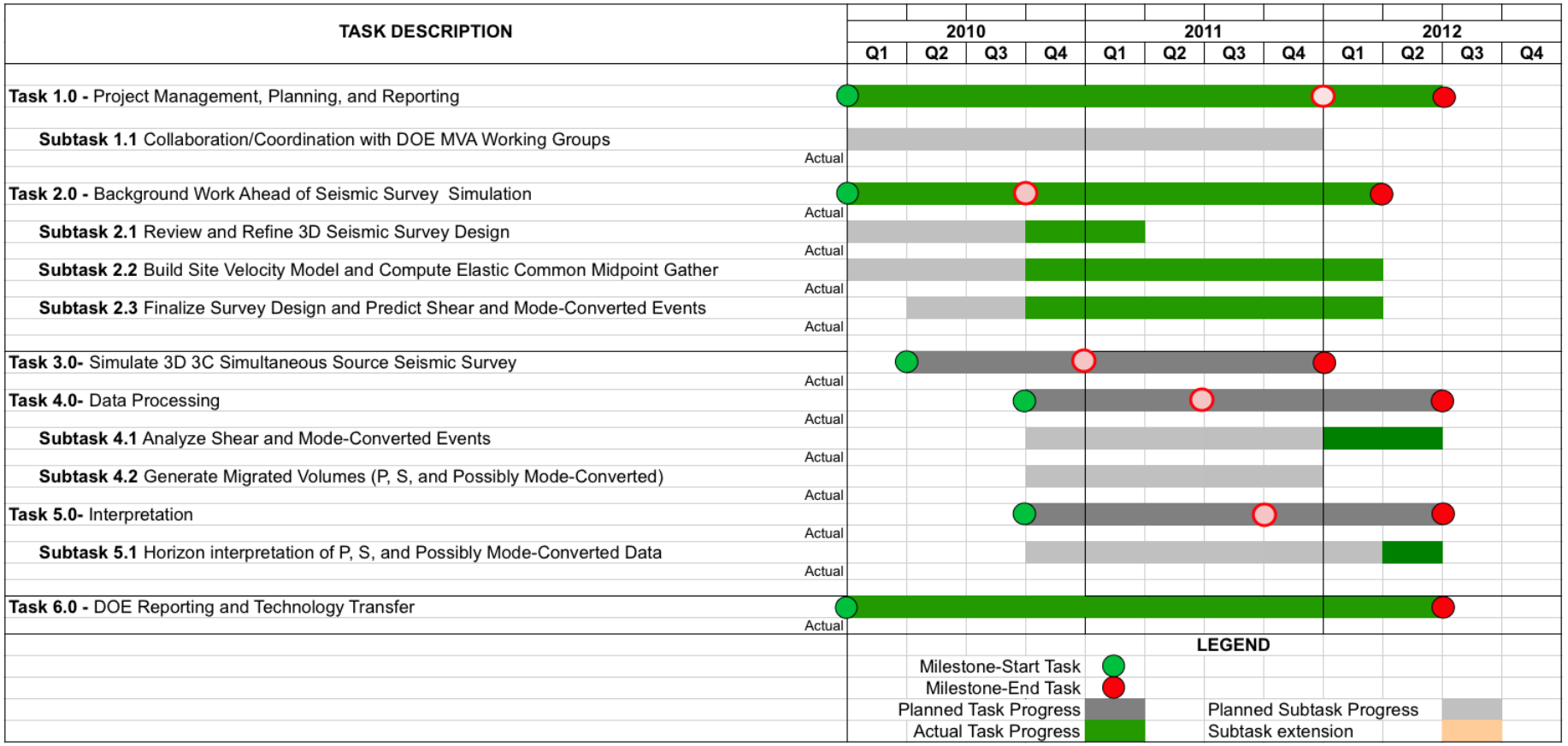
Organization Chart

Completed Students

.....2012.....
Brown, Tim (MS, July)
Fan, Hui (MS, July)
Heather Yao (MS,May)
Halil Celep (MS,May)
.....2011.....
Jonathan Parker (MS,Nov)
Heather King (MS,Nov)
Eric Swanson (MS,Nov)
Shannon LeBlanc (MS, Apr)
Bryan Flynn (MS, Apr)
.....2010.....
Scott Rubio (MS, Nov)
Ana Sanz (MS, Oct)
Craig Hyslop (MS, Jun)
Jennifer Califf (MS, May)
Krista Mondelli (MS, Apr)



Gantt Chart


TASK DESCRIPTION
2010
2011
2012
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
Task 1.0 - Project Management, Planning, and Reporting
Subtask 1.1 Collaboration/Coordination with DOE MVA Working Groups
Actual
Task 2.0 - Background Work Ahead of Seismic Survey Simulation
Actual
Subtask 2.1 Review and Refine 3D Seismic Survey Design
Actual
Subtask 2.2 Build Site Velocity Model and Compute Elastic Common Midpoint Gather
Actual
Subtask 2.3 Finalize Survey Design and Predict Shear and Mode-Converted Events
Actual
Task 3.0- Simulate 3D 3C Simultaneous Source Seismic Survey
Actual
Task 4.0- Data Processing
Actual
Subtask 4.1 Analyze Shear and Mode-Converted Events
Actual
Subtask 4.2 Generate Migrated Volumes (P, S, and Possibly Mode-Converted)
Actual
Task 5.0- Interpretation
Actual
Subtask 5.1 Horizon interpretation of P, S, and Possibly Mode-Converted Data
Actual
Task 6.0 - DOE Reporting and Technology Transfer
Actual
LEGEND
Milestone-Start Task
Milestone-End Task
Planned Task Progress
Actual Task Progress
Planned Subtask Progress
Subtask extension

Bibliography

Liner, C., P. Geng, J. Zeng, H. King and J. Li, 2011, A CO2 Sequestration Simulation Case Study at the Dickman Field, Ness Co., Kansas**:** Society of Petroleum Engineers, Denver, Colorado, USA, SPE145791

Liner, C., 2012, Distinguished Instructor Short Course (DISC), Society of Exploration Geophysicists, 197pp.

Li, J., C. Liner, P. Geng and J. Zeng, 2012, Convolutional Time-Lapse Seismic Modeling for CO2 Sequestration at the Dickman Oil Field, Ness County, Kansas: Society of Exploration Geophysicists(in review)

Zeng, J, C. Liner, P. Geng, and H. King, 2012, 3D Geologic Modeling Toward a Site-specific Co2 Injection Simulation: American Association of Petroleum Geologist Bulletin (in review)