Prototyping and testing a new volumetric curvature tool for modeling reservoir compartments and leakage pathways in the Arbuckle saline aquifer: reducing uncertainty in CO$_2$ storage and permanence

Project Number (DE-FE0004566)

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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 CO$_2$ Storage
August 21-23, 2012
Presentation Outline

• Benefits, objectives, overview
• Methods
• Background & location
• Technical status
• Accomplishments
• Summary
Benefit to the Program

• Program goal addressed:
  
  Develop technologies that will support the industries’ ability to predict CO$_2$ storage capacity in geologic formations to within ± 30 percent.

• Program goal addressed:

  This project will confirm—via a horizontal test boring—whether fracture attributes derived from 3-D seismic PSDM Volumetric Curvature (VC) processing are real. If validated, a new fracture characterization tool could be used to predict CO$_2$ storage capacity and containment, especially within paleokarst reservoirs.
Goals and Objectives

Evaluate effectiveness of VC to identify the presence, extent, and impact of paleokarst heterogeneity on CO$_2$ sequestration within Arbuckle strata

– Develop technologies that demonstrate 99% storage permanence and estimate capacity within +30%.
  • Predict plume migration...within fractured paleokarst strata using seismic VC
  • Predict storage capacity...within fractured paleokarst strata using seismic VC
  • Predict seal integrity...within fractured paleokarst strata using seismic VC

– Success criteria
  • Merged & reprocessed PSTM volume reveals probable paleokarst (DP1)
  • Within budget after landing horizontal test boring (DP2)
  • VC-identified compartment boundaries confirmed by horizontal bore-hole (DP3)
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Methods

• Merge, reprocess, interpret PSDM 3-D seismic
• PSTM & PSDM VC-processing (Geo-Texture)
  – Pre-processing: Raw, Basic PCA, Enhanced PCA, Robust PCA
  – Lateral wave-length resolutions: high (~50-ft), medium (~150-ft), long (~500-ft)
• Build pre-spud fault & geocellular property models
• Locate, permit, drill & log horizontal test boring
• Tool-push logging program using Compact Well Shuttle™
  – Triple combo
  – Full-wave sonic
  – Bore-hole micro-imager
• Formation evaluation & image interpretation
• Seismic inversion, variance & ant track
• Revise fault, facies & property models
• Simulate & history match
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Background: Volumetric Curvature

- A measure of reflector shape:
  - Most-positive: anticlinal bending
  - Most-negative: synclinal bending
- Measured at different wavelengths
- Horizon-independent
- Reveals fractures in complex zones where horizons are not track-able
- Curvature and rotation are mathematically independent of coherence and seismic amplitude

Al-Dossary & Marfurt, 2006
VC utility can image faults, fractures, flexures, sags

Loucks, 2004
Background: Arbuckle Group

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<tr>
<th>System</th>
<th>Series</th>
<th>North American Series</th>
<th>British Series</th>
<th>Ma</th>
<th>Global Magneto-zones N-normal R-reverse</th>
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</table>

Map of Middle Ordovician (470 Ma) showing Kansas and the approximate position of Bemis-Shotts Field in Ellis County.
Background: Paleokarst—Non-stratiform Reservoir Architecture

Ordovician Pogonip Group, Nopah Range, CA
Location: Bemis-Shutts Field

- Discovered 1928
- Arbuckle production—Ordovician paleokarst (Mississippian overprint)
- 615 open wells
Location: southeast Bemis-Shutts

- Multiple partners
- Four 3-D seismic surveys
- Merged two 3-D seismic surveys
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PSTM–PSDM Comparison

Top Arbuckle surfaces showing paleokarst

PSTM structure significantly different
PSTM and PSDM VC-attributes are significantly different
PSDM VC-Processing Results

Most Negative Curvature
Medium Wavelength
Basic PCA Data
Pre-spud VC-Attribute

most negative curvature
medium wavelength
basic PCA data
Arbuckle PSDM contours
Test Boring Plan

- Grass roots
- Set 7 inch casing
- Drill 6 ⅛-inch hole to TD
- Land 400-ft below
- 1800-ft lateral in/out paleokarst
- Tool-push OH logs
  - Triple combo
  - Full-wave sonic
  - Image Log
- Set plug
- Drill stem test
Actual Test Boring
Fracture & Non-touching Vug Porosity

VC, fault model, and top Arbuckle contours

Fracture Porosity
Non-Touching Vugs

15.0% 0.2%

Fault 1  Fault 6

7" Casing Shoe

McCord-A 20H

Country  USA
License  Name
McCord A  User name
Model name  rush
pre-Spud model  Datum
Horizon name  MSL
Arbuckle  Company
Murffin Vess LLP
 Damage Zone Associated with Fault-Bounded Paleokarst

Fr. Por.
Svug Por.

Paleokarst Facies

Crackle, Breccia
Mosaic Breccia
Matrix-Dominated Breccia
Matrix-Dominated Fracture Dominate
Matrix-Supported Breccia
Matrix-Supported Chaotic Breccia
Cave Sediment Fill
Cave Sediment with Clasts

Matrix-Rich Breccia
Chaotic Breccia

McCord A 204
Fault 1
Fault 6

7" Casing Shot
3750

Loucks, 2004

Fracture Type
Red: Part/Open Fault
Green: Surface Bedding

Damage Image
Key Findings & Interpretations to Date

- Fault-bounded doline confirmed
- Dolines coincident with VC-identified radial lineaments
- Interior drainage
- Headward-eroding escarpment
- Disappearing streams/springs/fluvial plains
- Fracture system Ordovician-age
  - does O-age reduce seal risk?
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Accomplishments to Date

- Merged & reprocessed seismic
- LAS 3.0 format from scans
- Generated PSDM volume
- Processed PSTM/DM VC-volumes
- Generated pre-spud VC-attributes
- Generated fault & property models

- Drilled 1800-ft horizontal boring across VC-constrained doline
- Tool-pushed: 1) *triple combo*, 2) full-wave sonic, 3) micro-imager
- Completed formation evaluation
- Simulated & history matched pre-spud model
- Completed inversion and porosity probability cube
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- **Key Findings**
  - Direct confirmation of VC-constrained, fault-bounded, paleo-doline
  - PSDM VC attribute significantly different than PSTM
  - VC requires PSDM 3D for complex structural settings
    - Requires horizontal to reduce structural uncertainty? …policy question
  - History match was not a unique solution

- **Lessons Learned**
  - VC attribute(s) not a unique solution
  - Lost-in-hole tool insurance—cost prohibitive

- **Future Plans**
  - Revise models: fault, DFN, facies, property
  - Analyze uncertainty of flux between blocks
  - Simulate & history match new models