

Prototyping and testing a new volumetric curvature
tool for modeling reservoir compartments
and leakage pathways in the
Arbuckle saline aquifer:
reducing uncertainty in CO₂ storage and permanence

Project Number (DE-FE0004566)

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Developing the Technologies and Building the
Infrastructure for CO₂ Storage

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Acknowledgements & Disclaimer

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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 CO₂ storage capacity in geologic formations to within \pm 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 CO₂ 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 CO₂ sequestration within Arbuckle strata

– Develop technologies that demonstrate 99% storage permanence and estimate capacity within $\pm 30\%$.

- 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

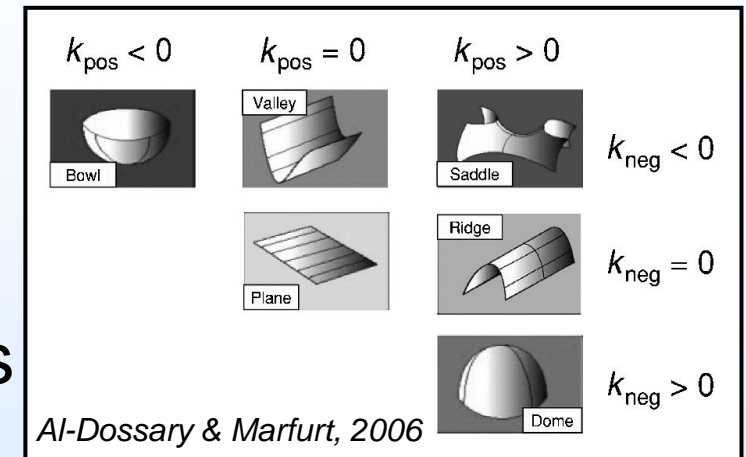
- Merge, reprocess, interpret PSDM 3-D seismic
- PSTM & PSDM VC-processing (Geo-Texture)
 - Pre-processing: Raw, Basic PCA, Enhanced PCA, Robust PCA
 - Lateral wave-length resolutions: high (~50-ft), medium (~150-ft), long (~500-ft)
- Build pre-spud fault & geocellular property models
- Locate, permit, 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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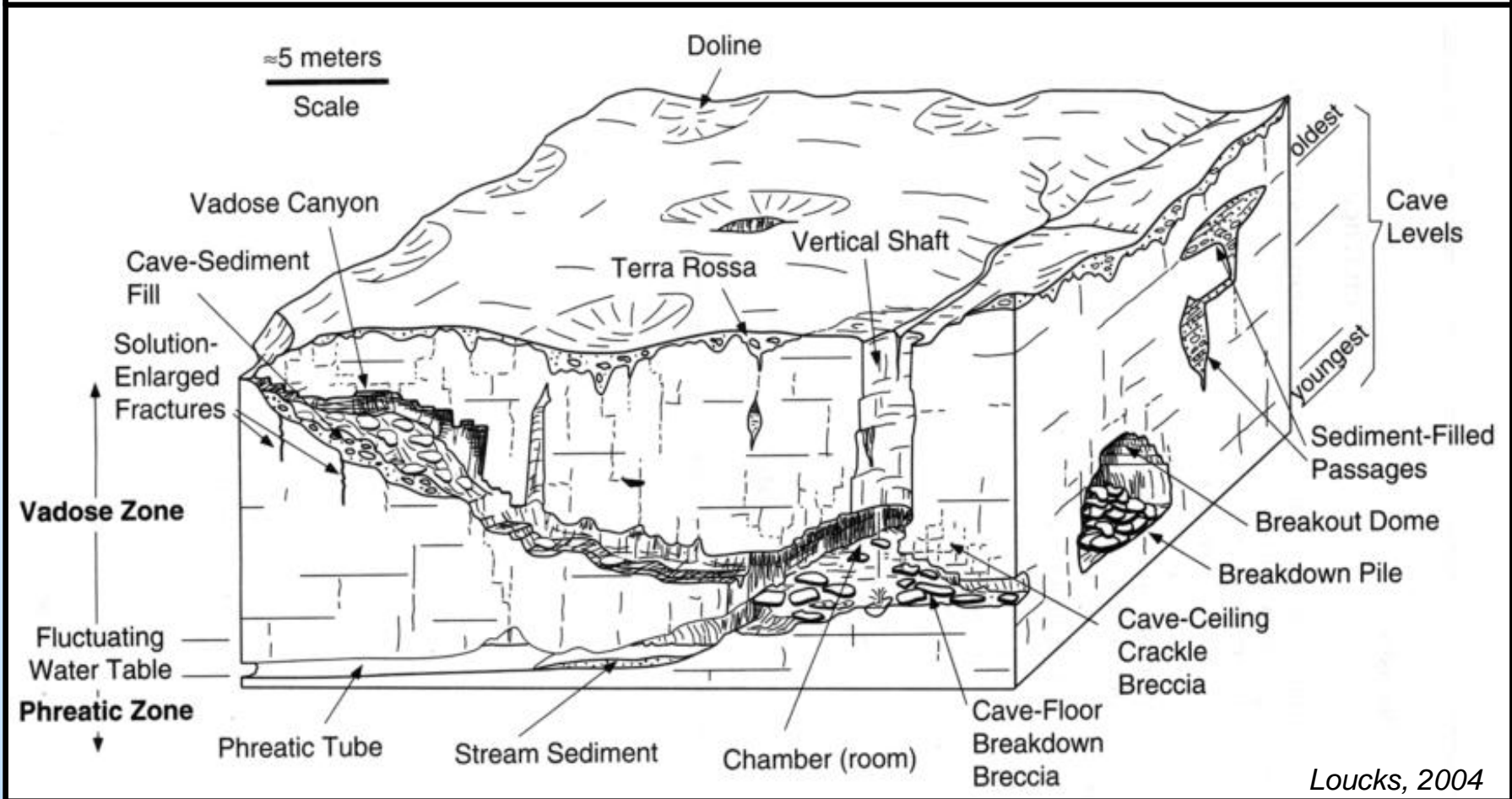
Background: Volumetric Curvature

- 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

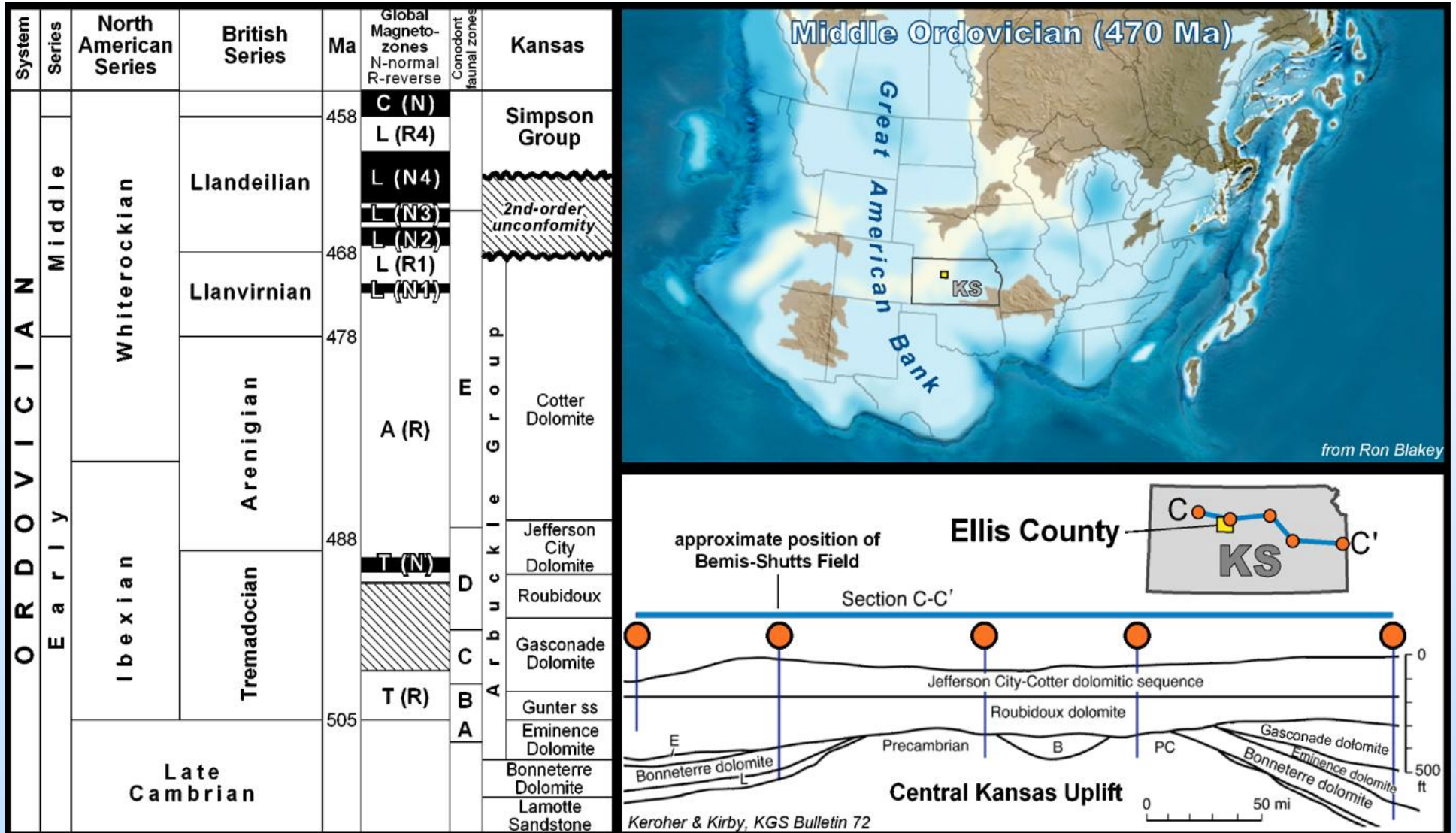


Background: Paleokarst

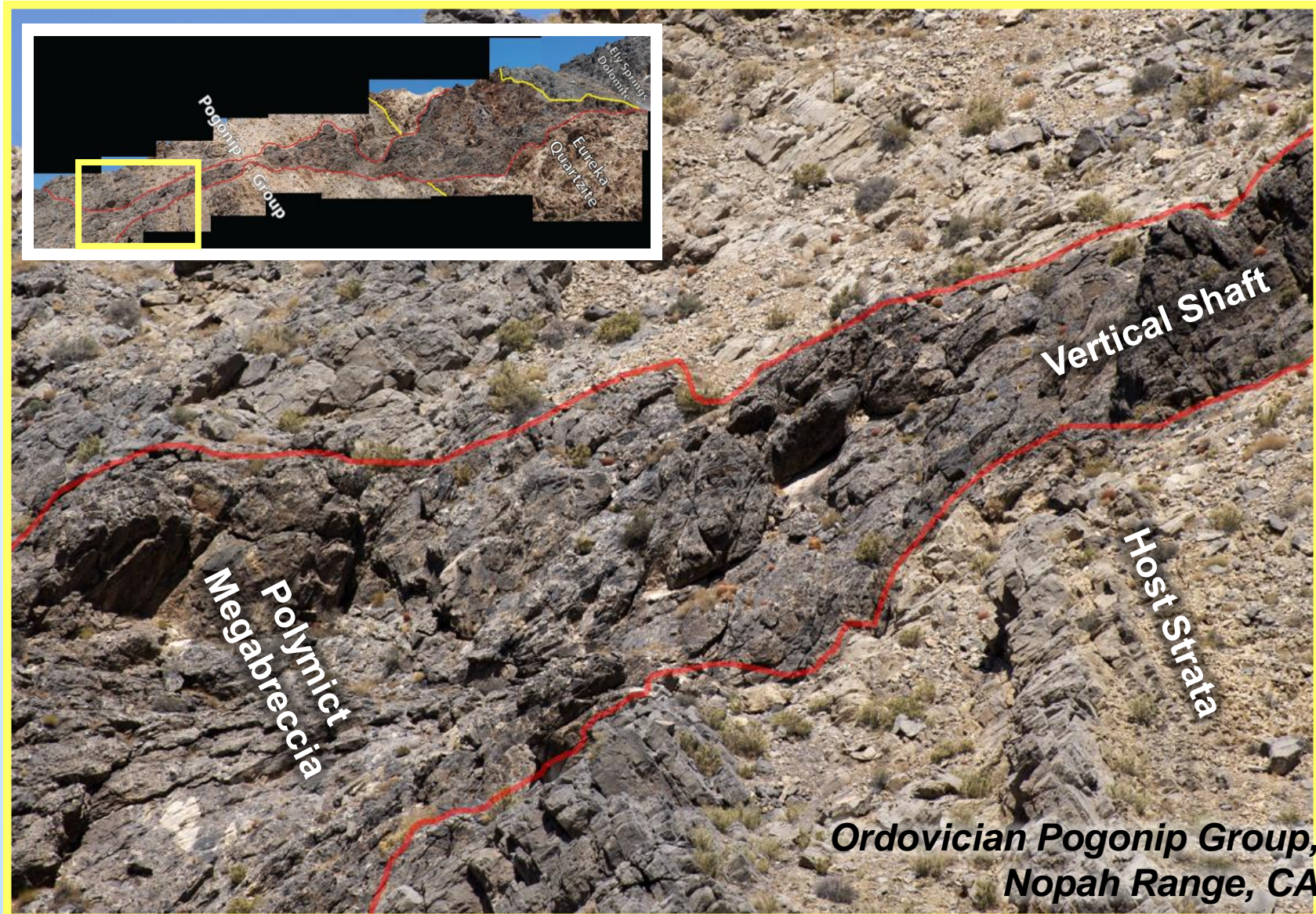
VC provides evidence of paleokarst: faults, fractures, flexures, sags



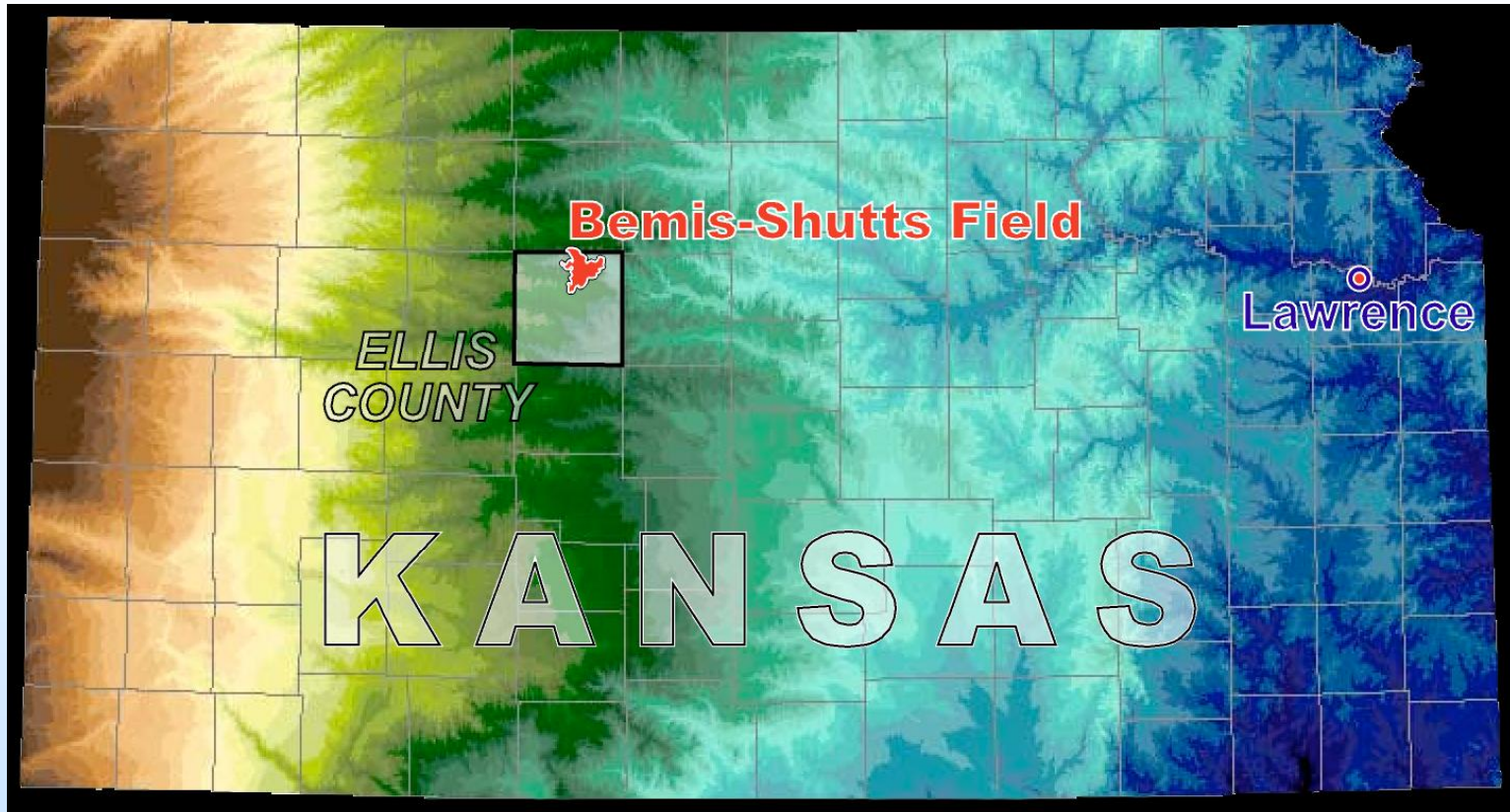
Background: Arbuckle Group



Background: Paleokarst— *Non-stratiform* Reservoir Architecture

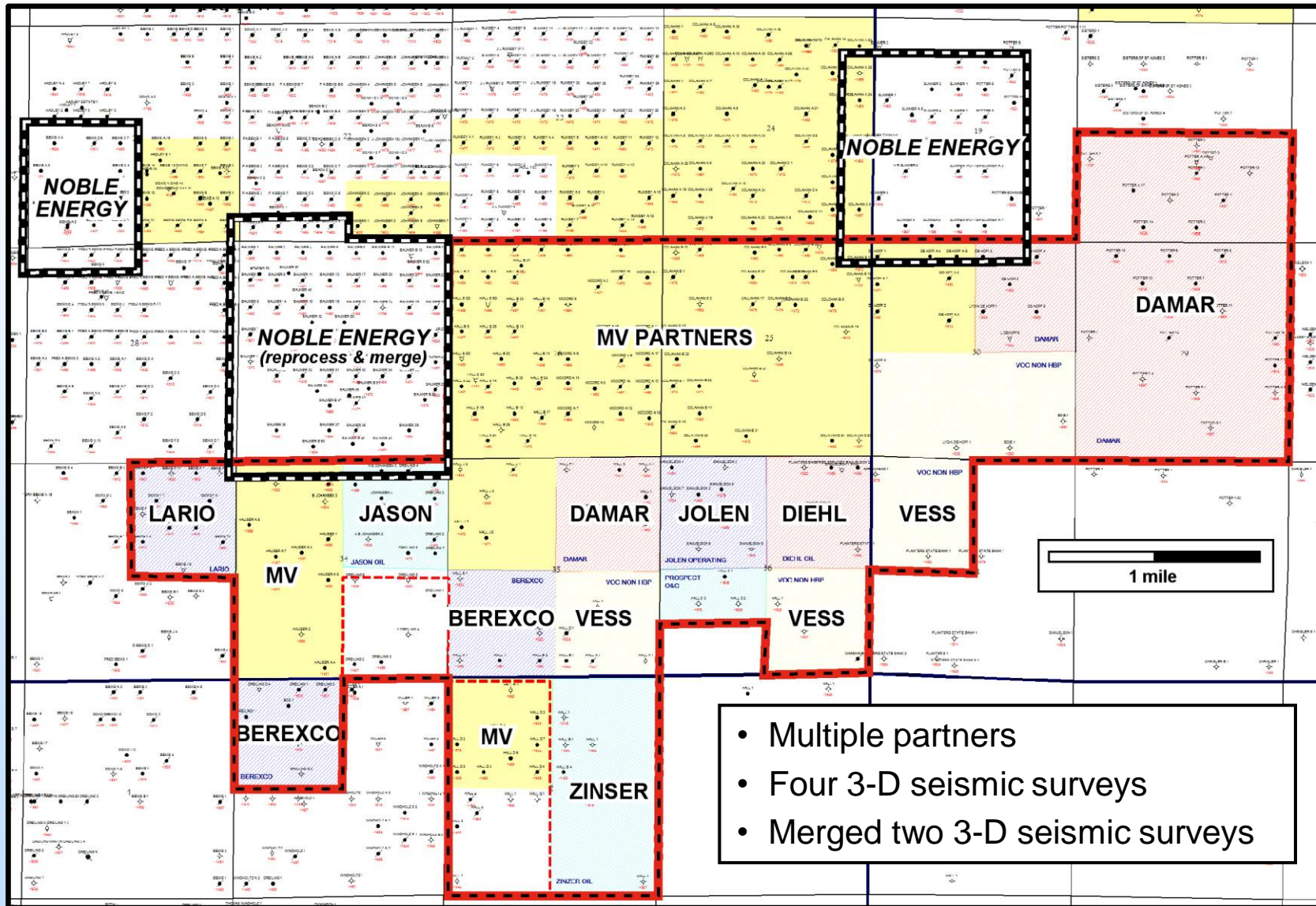


Location: Bemis-Shutts Field



- Discovered 1928
- Arbuckle production—Ordovician paleokarst (Mississippian overprint)
- 615 open wells

Location: southeast Bemis-Shutts

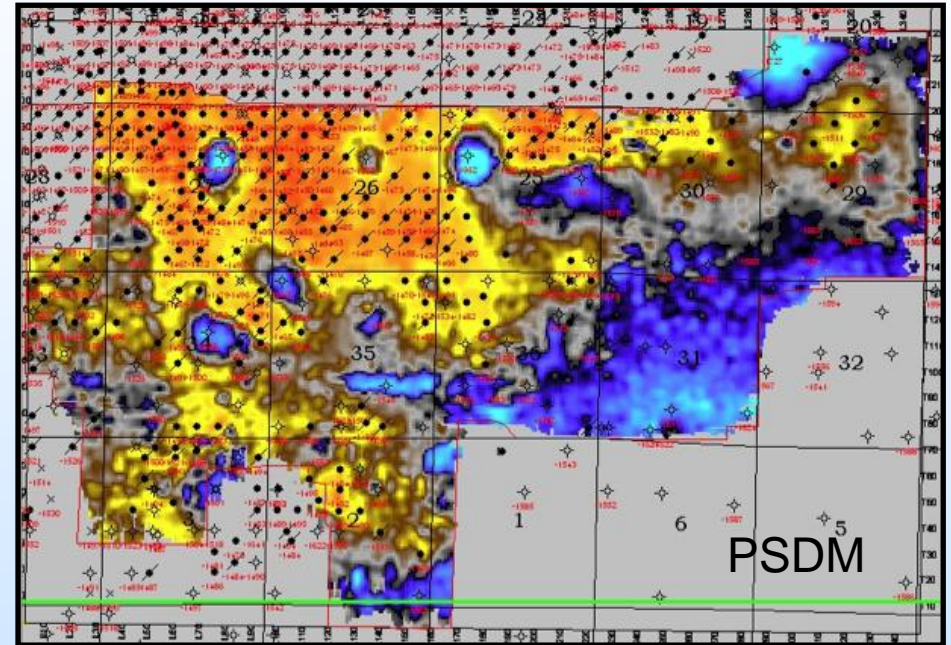
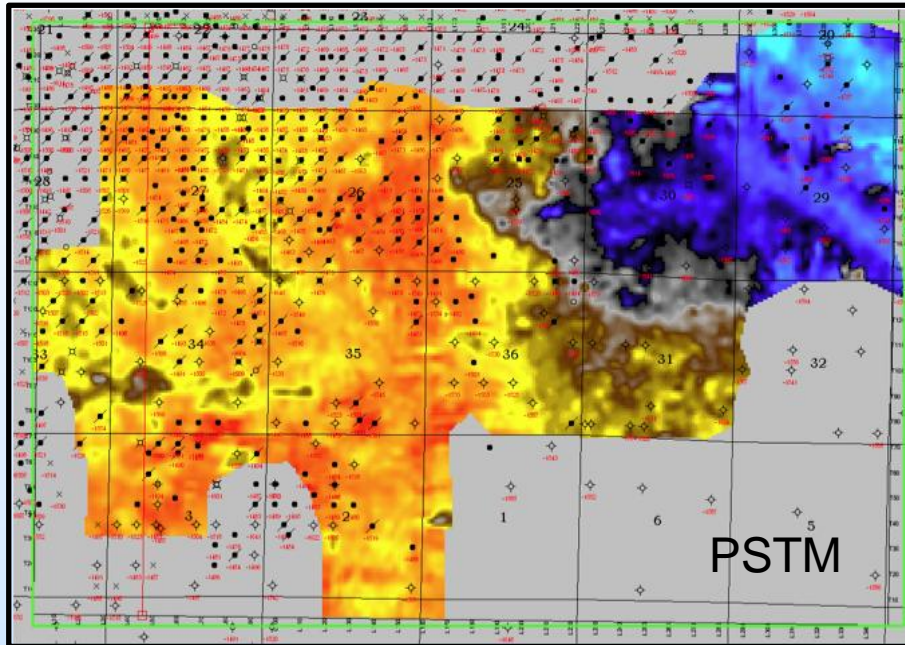


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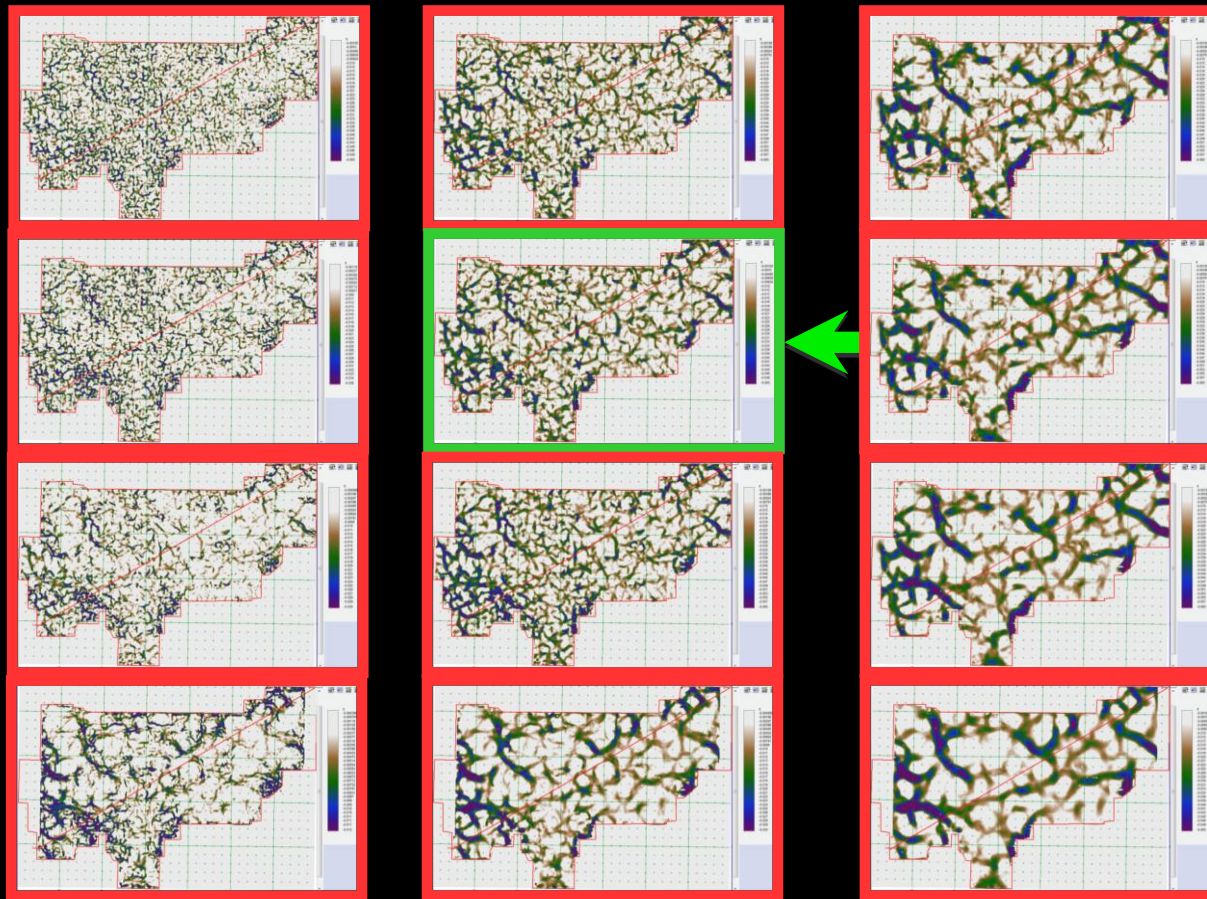
PSTM–PSDM Comparison

Top Arbuckle surfaces showing paleokarst



PSTM structure significantly different
PSTM and PSDM *VC-attributes* are significantly different

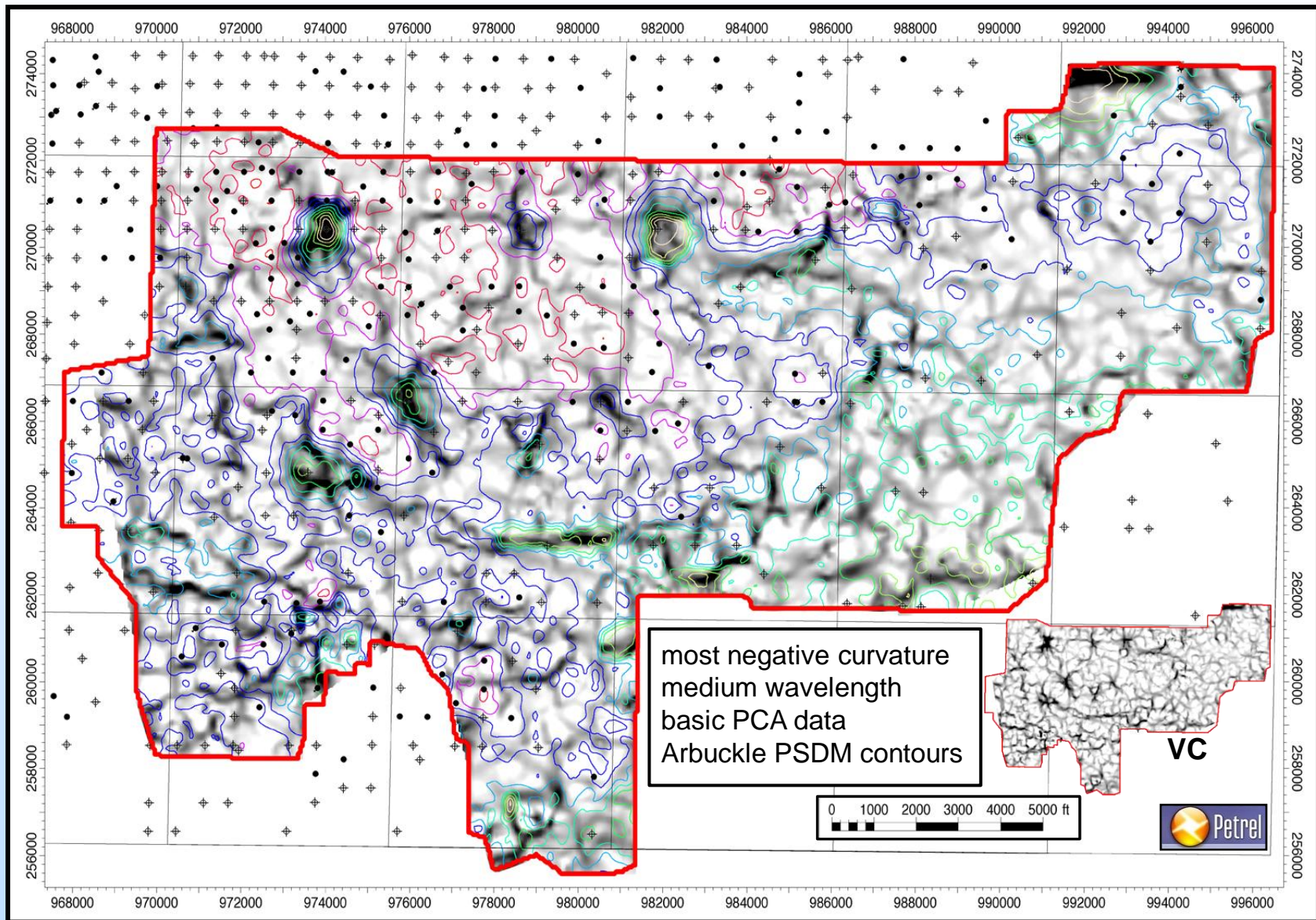
PSDM VC-Processing Results



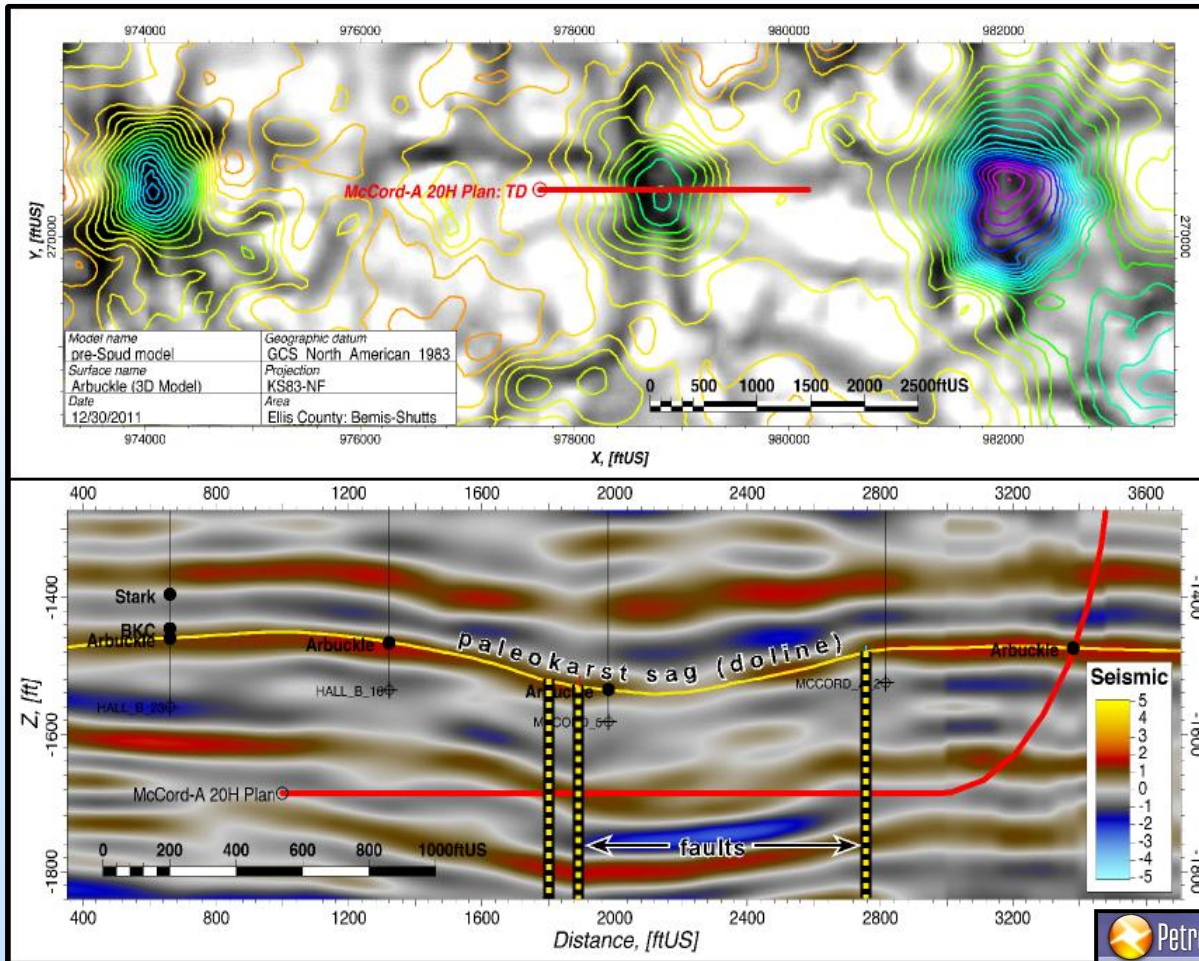
Most Negative Curvature
Medium Wavelength
Basic PCA Data

Geo-Texture
TECHNOLOGIES

Pre-spud VC-Attribute

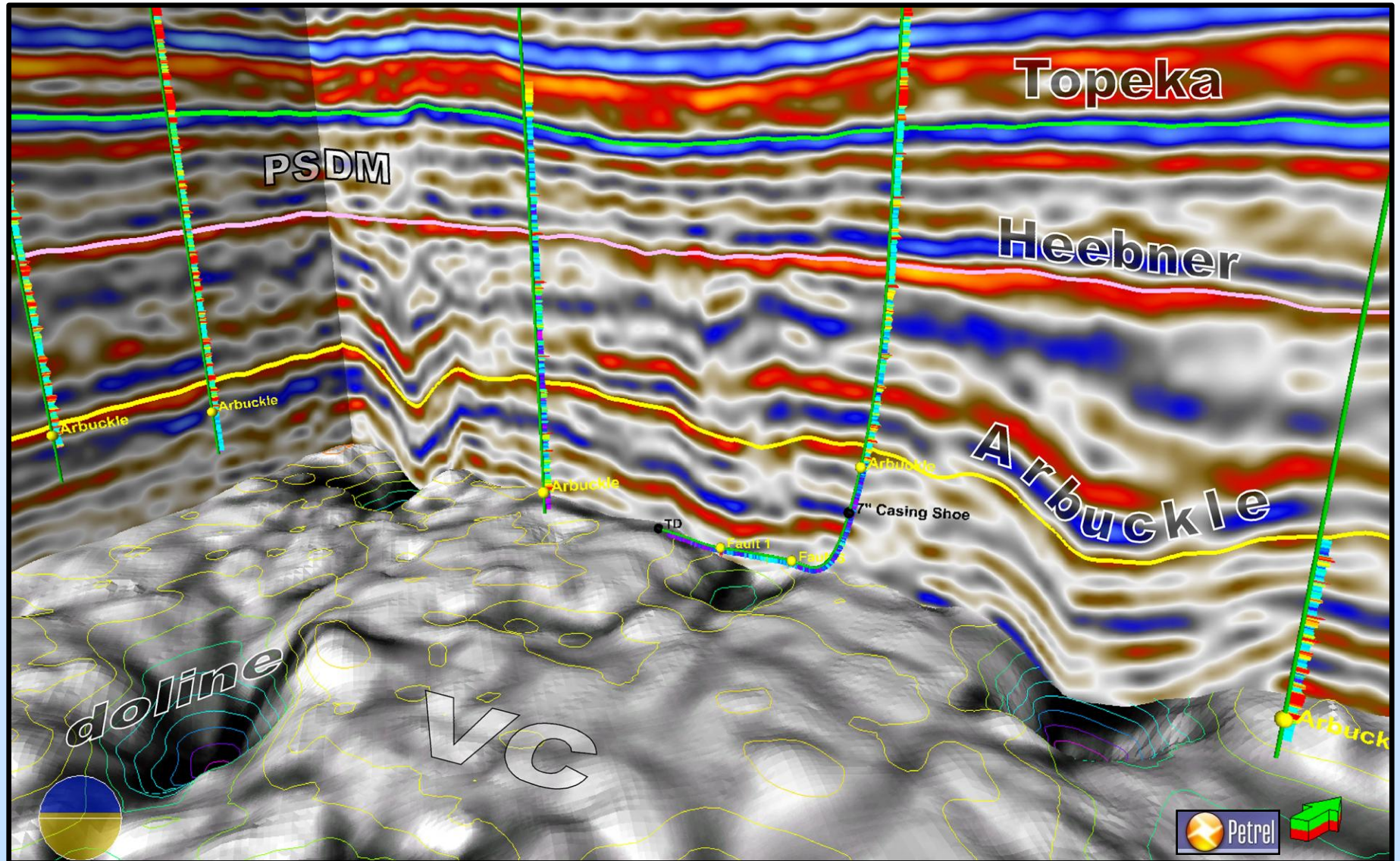


Test Boring Plan



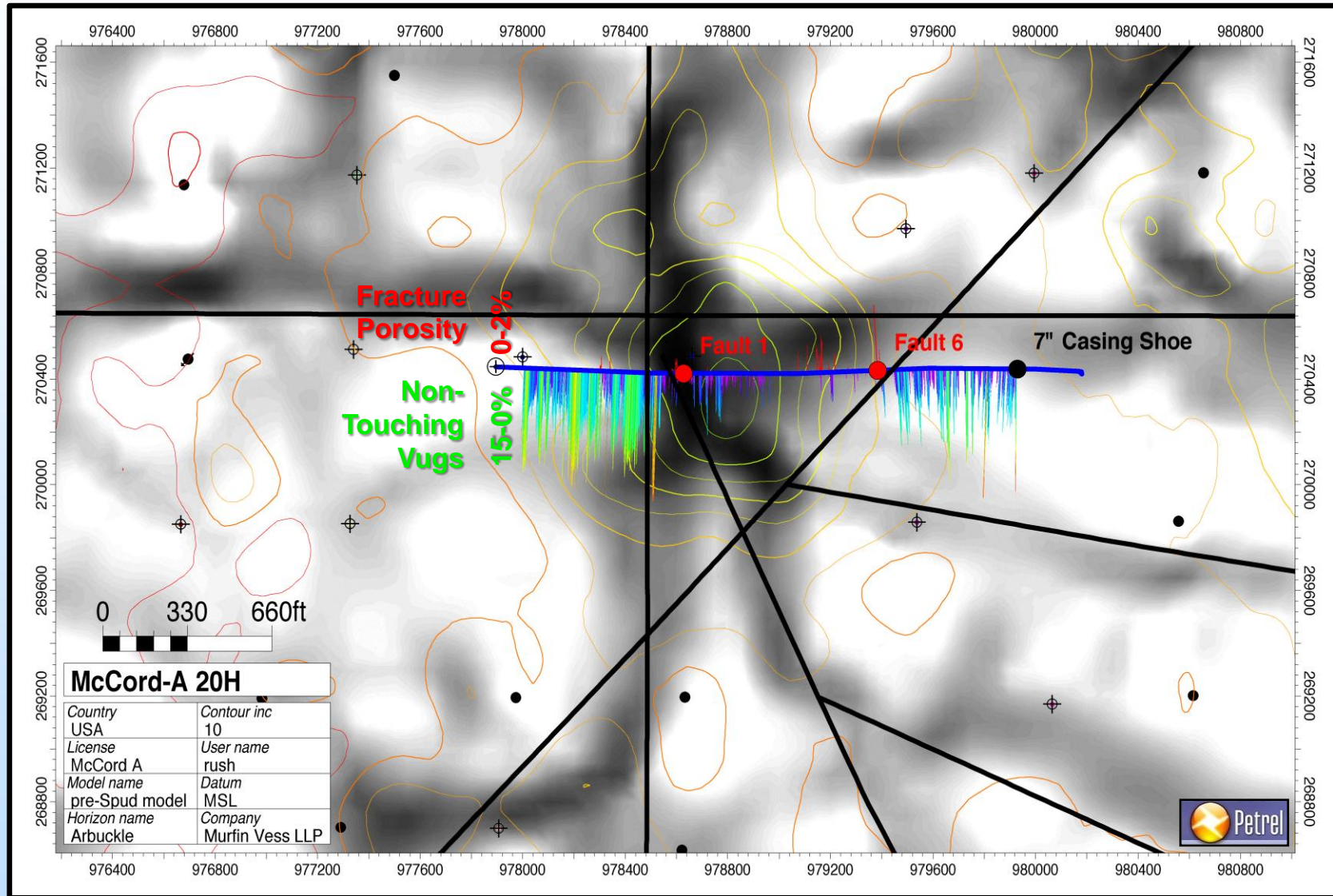
- Grass roots
- Set 7 inch casing
- Drill 6 1/8-inch hole to TD
- Land 400-ft below
- 1800-ft lateral in/out paleokarst
- Tool-push OH logs
 - Triple combo
 - Full-wave sonic
 - Image Log
- Set plug
- Drill stem test

Actual Test Boring

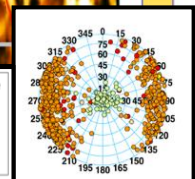
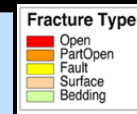
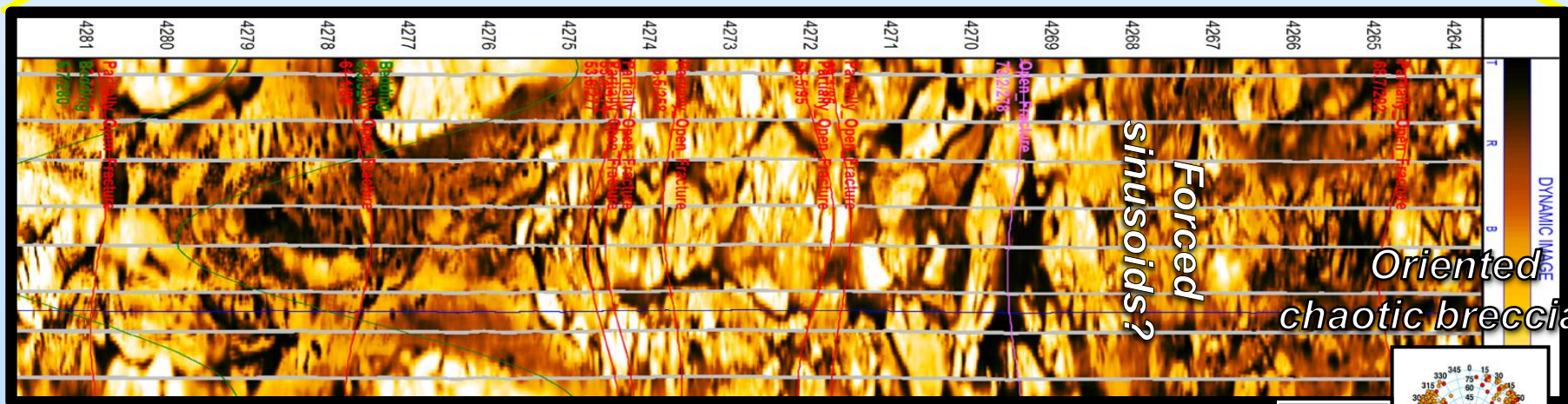
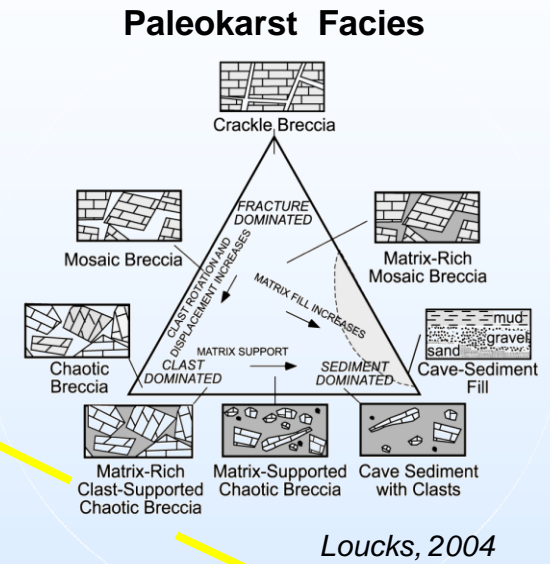
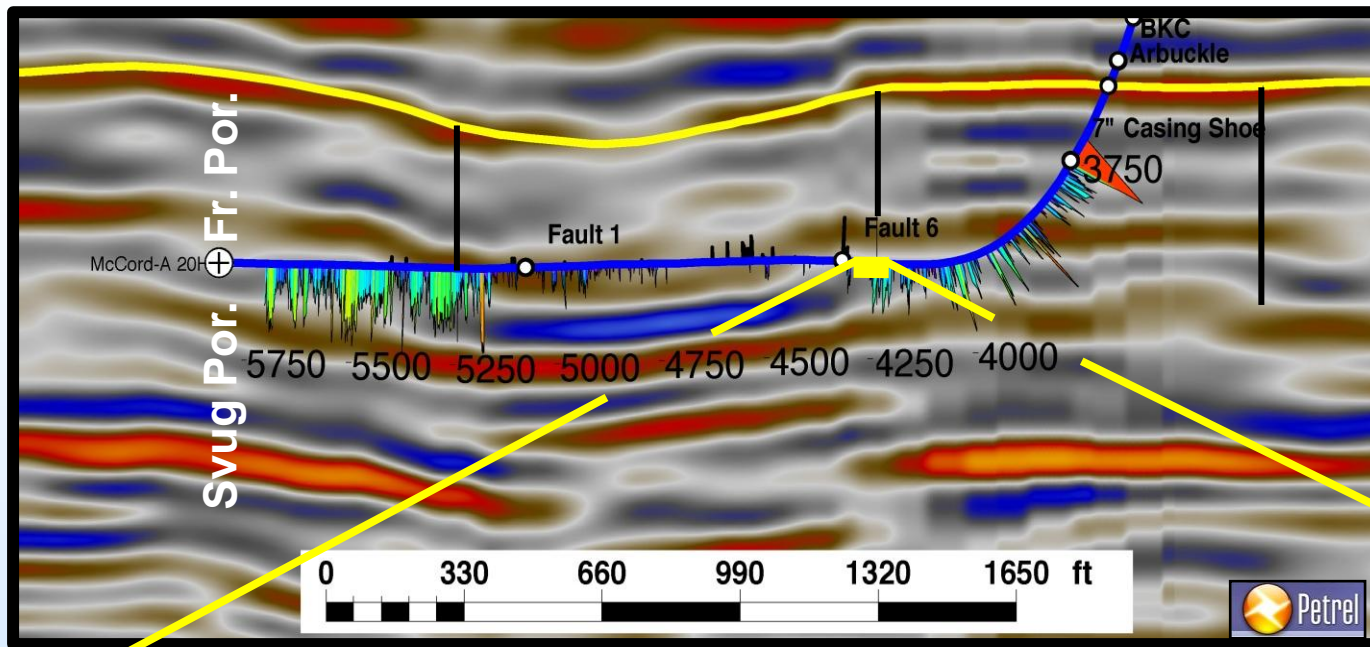


Fracture & Non-touching Vug Porosity

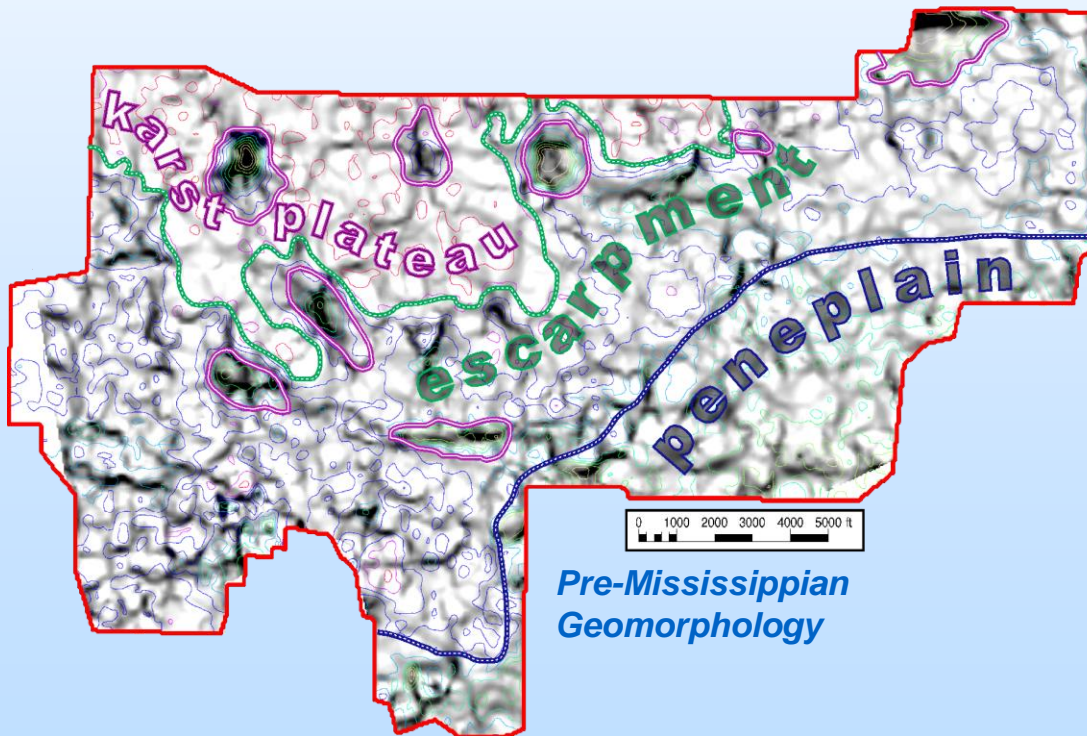
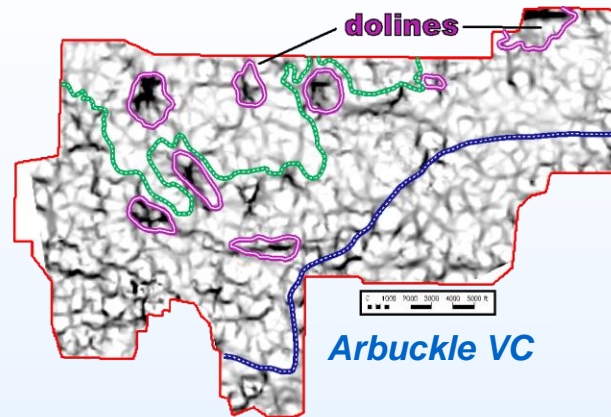
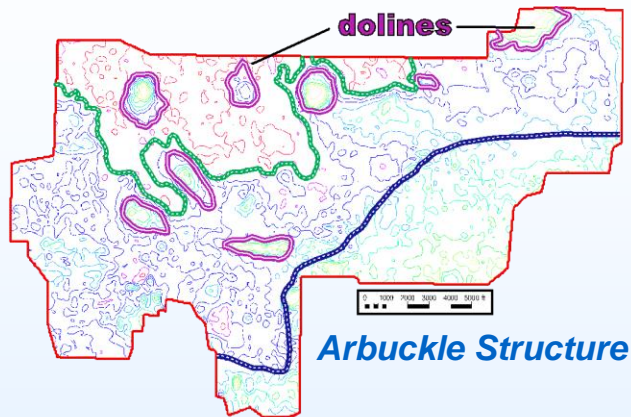
VC, fault model, and top Arbuckle contours



Damage Zone Associated with Fault-Bounded Paleokarst



Key Findings & Interpretations to Date

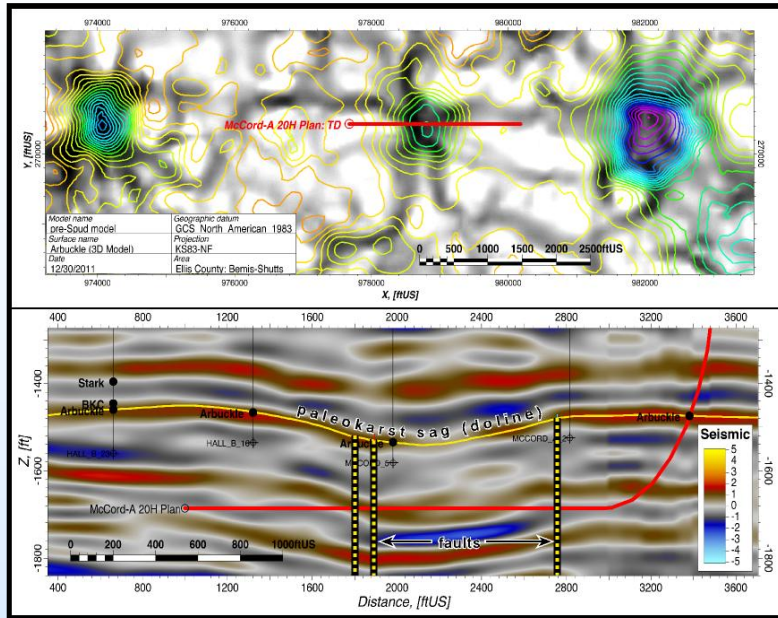


- Fault-bounded doline confirmed
- Dolines coincident with VC-identified radial lineaments
- *Spoke-like*, interior drainage
- Headward-eroding escarpment
- Disappearing streams/springs/ fluvial plains
- Fracture system Ordovician-age
 - *does O-age reduce seal risk?*

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Accomplishments to Date



- ✓ Merge & reprocess seismic
- ✓ LAS 3.0 format from scans
- ✓ Generate PSDM volume
- ✓ Process PSTM/DM VC-volumes
- ✓ Generate pre-spud VC-attributes
- ✓ Generate fault & property models

- ✓ Drill 1800-ft horizontal boring across VC-constrained doline
- ✓ Tool-push: 1) *triple combo*, 2) full-wave sonic, 3) micro-imager
- ✓ Complete formation evaluation
- ✓ Simulated & history matched pre-spud model
- ✓ Completed inversion and porosity probability cube

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Summary

- 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

