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)

Jason Rush

(W. Lynn Watney, Joint PI)

University of Kansas Center for Research

Kansas Geological Survey

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 20-22, 2013

Presentation Outline

- Benefits, objectives, overview
- Methods
- Background & setting
- 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 $\pm$ 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 CO_2 storage capacity and containment, especially within paleokarst reservoirs.

Project Overview: 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
  - Within budget after landing horizontal test boring
  - VC-identified compartment boundaries confirmed by horizontal test boring

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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 wavelength resolutions: high (~50-ft), medium (~150-ft), long (~500-ft)
- Build pre-spud fault & geocellular property models
- Locate, permit, drill, and log horizontal test boring
- KO & lateral, slimhole & hostile, logging program with Compact Well Shuttle™
  - Triple combo
  - Full-wave sonic
  - Borehole micro-imager

Weatherford

- Formation evaluation & image interpretation
- Seismic inversion, variance & ant track
- Construct *discrete fracture network* (DFN) Model
- Revise fault, facies, and property models
- Simulate & history match

Petrel 2012
Shared earth–critical insight
Schlumberger

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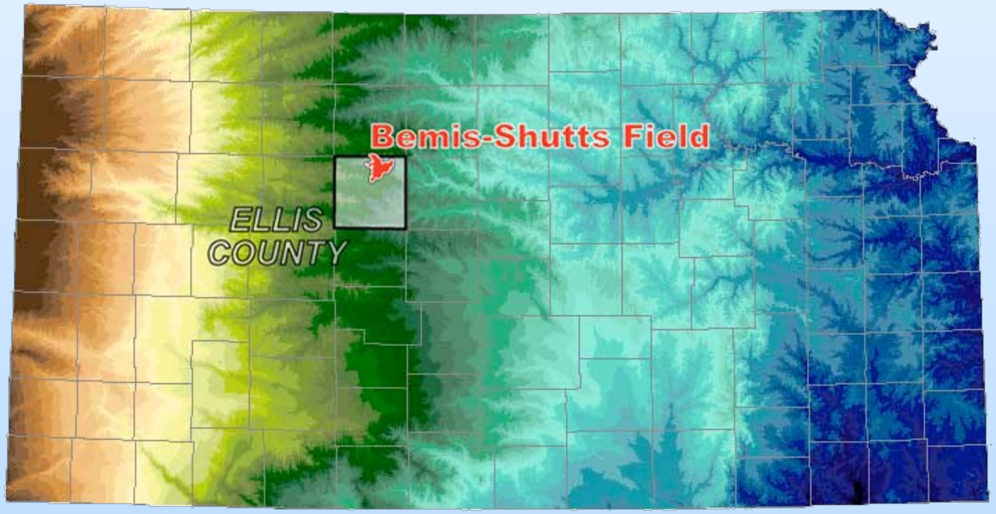
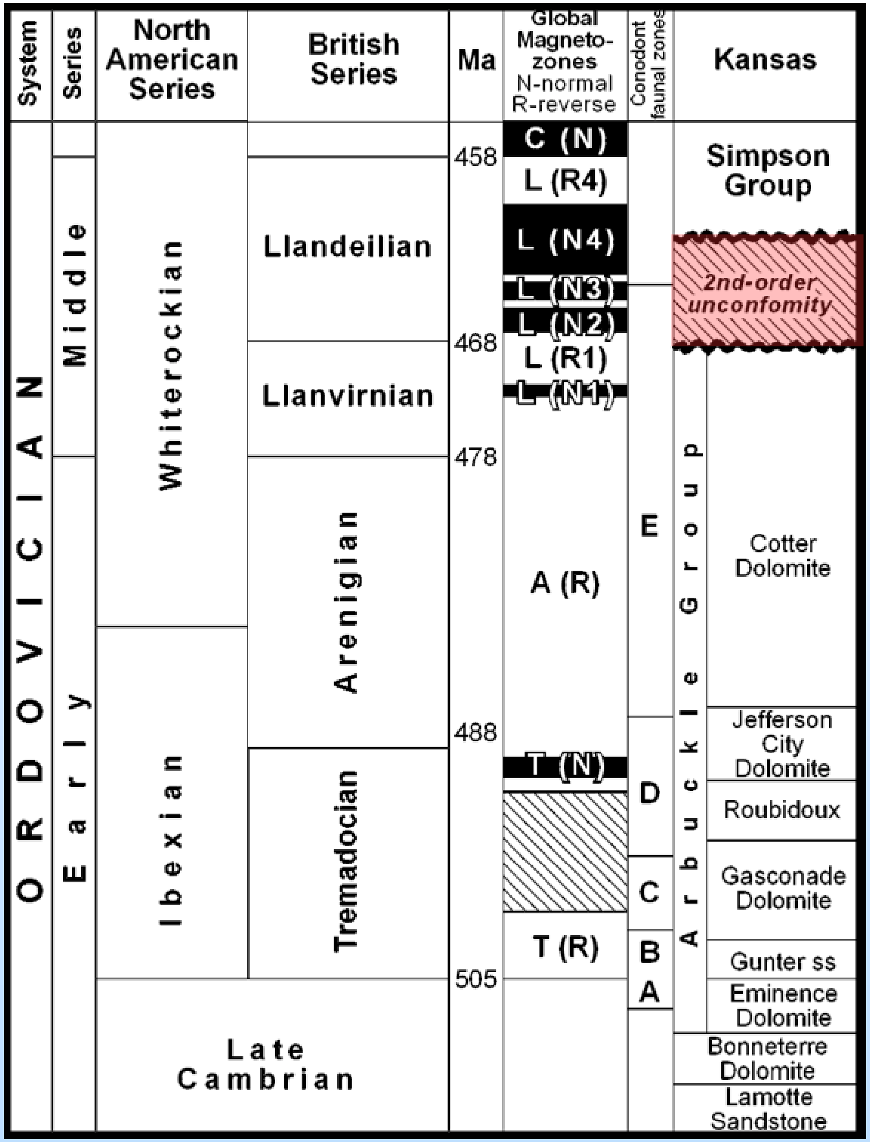
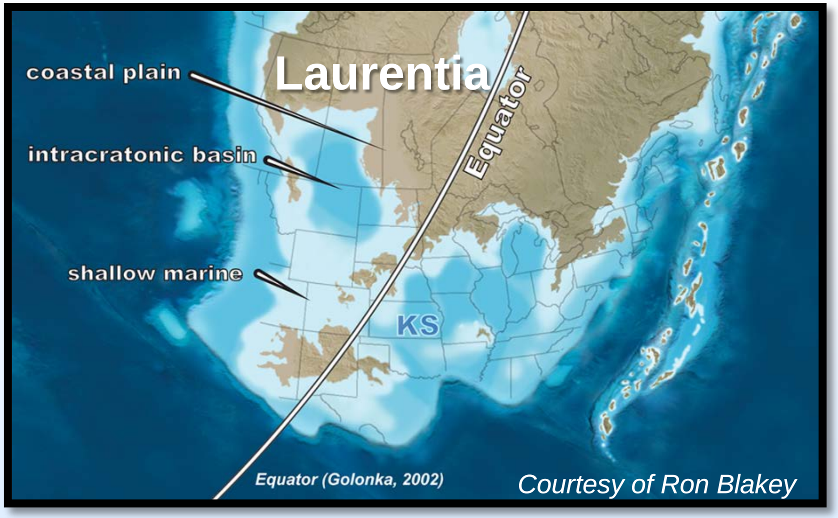
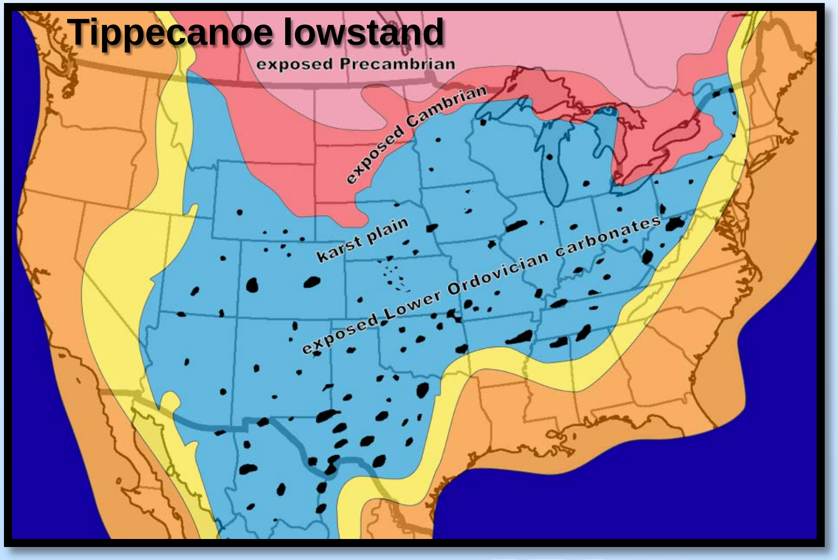


Age & Regional Setting

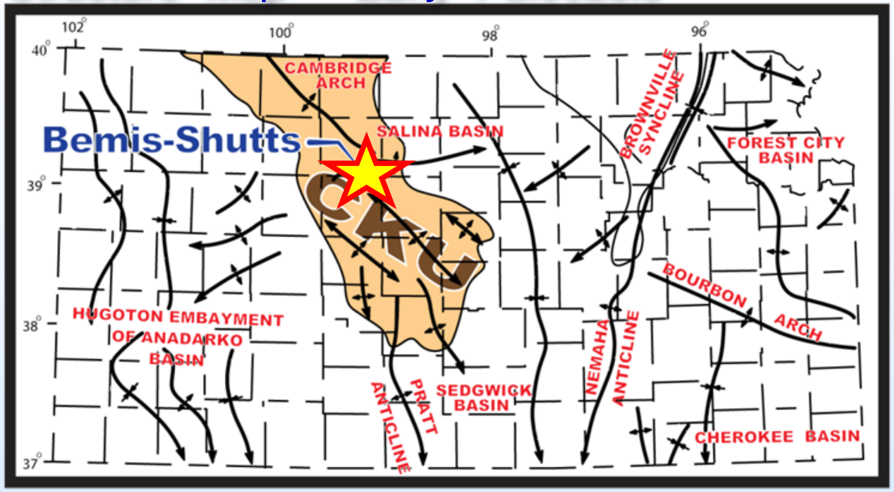




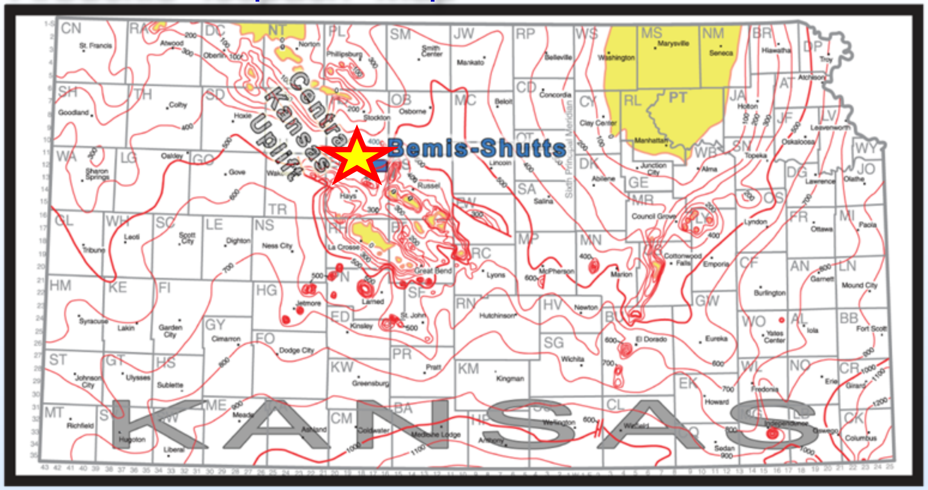


Kansas Setting

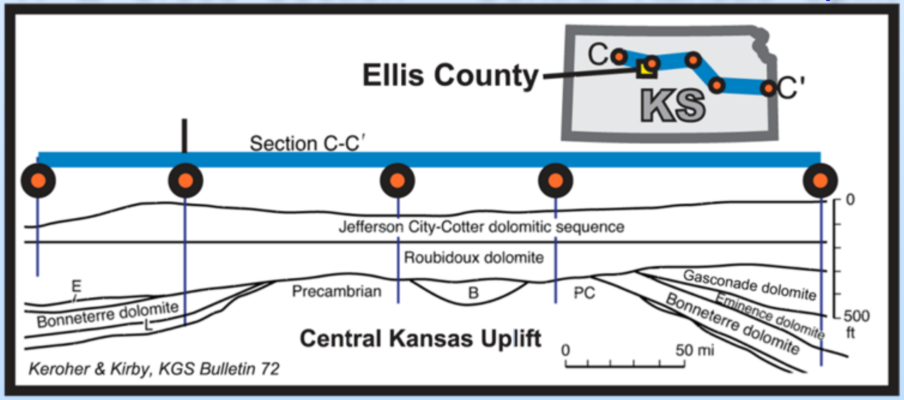
Structure Map — Early Paleozoic



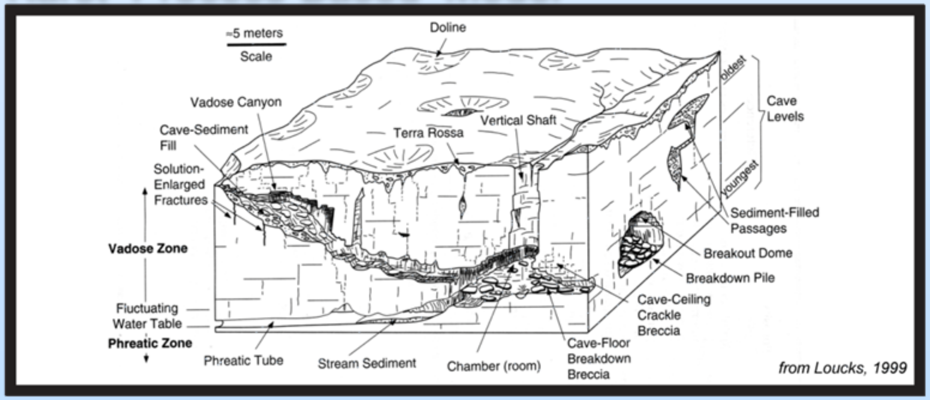
Arbuckle Isopach Map



W–E Cross Section — Central Kansas Uplift



Karst Process-Based Model



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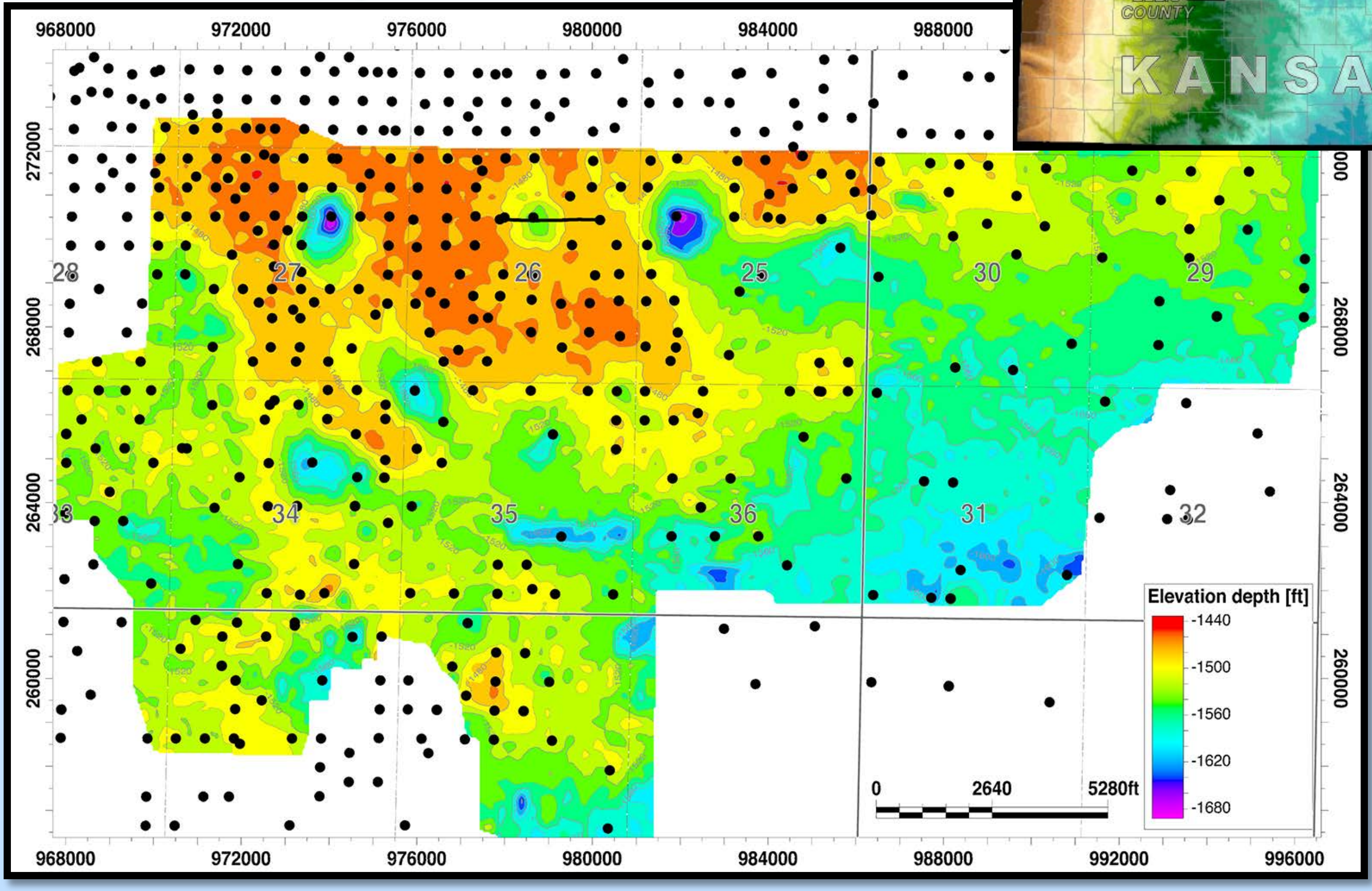
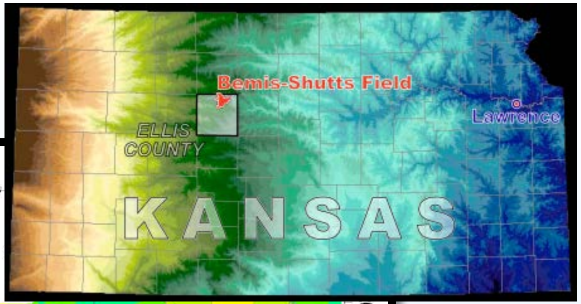
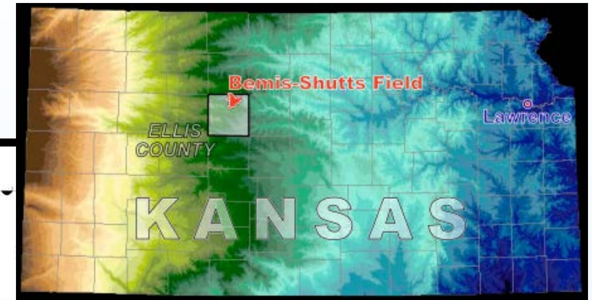
Study Area — Bemis Shutts Field

Structure Map

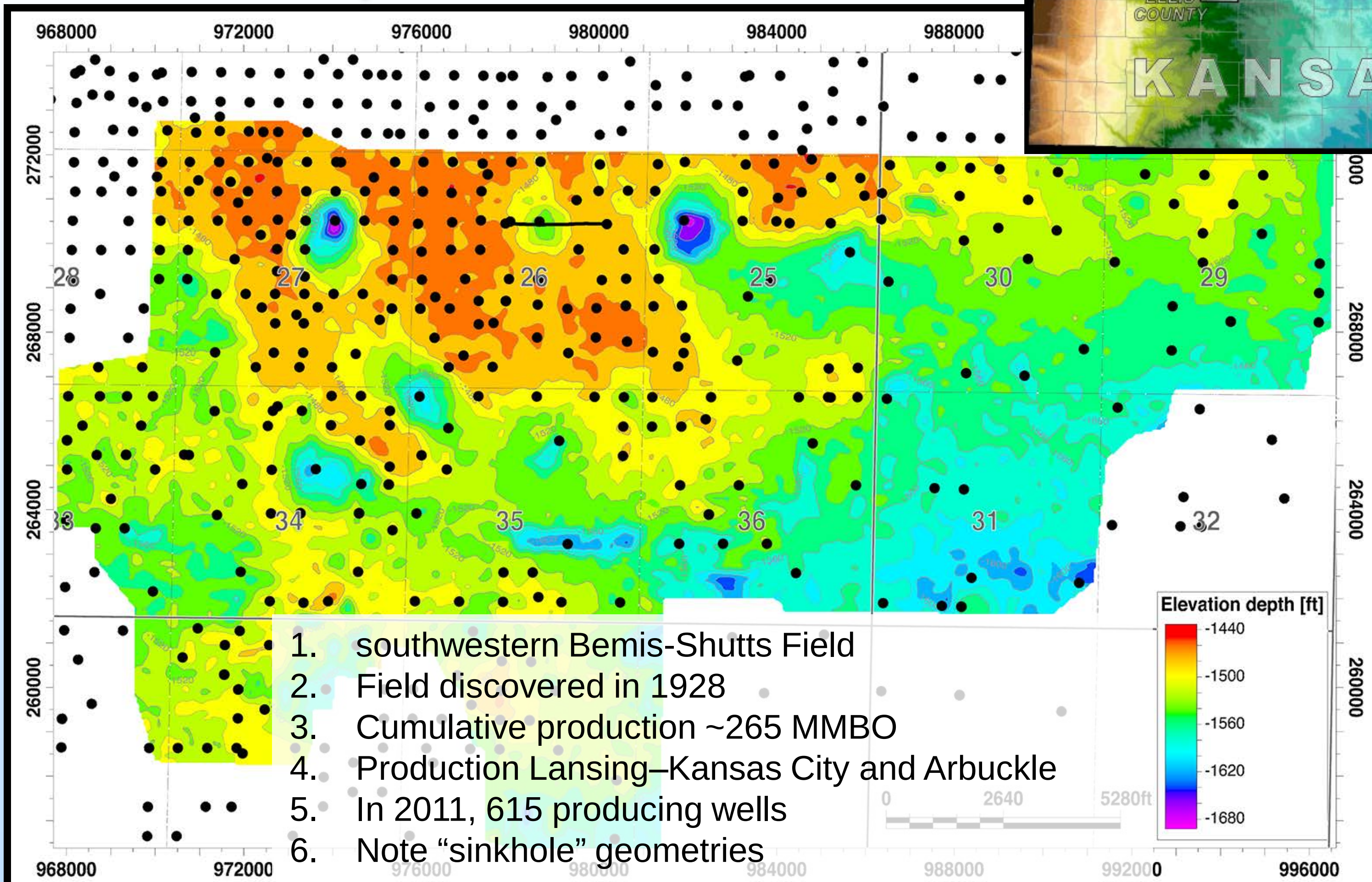




Study Area — Bemis Shutts Field



Structure Map



1. southwestern Bemis-Shutts Field
2. Field discovered in 1928
3. Cumulative production ~265 MMBO
4. Production Lansing–Kansas City and Arbuckle
5. In 2011, 615 producing wells
6. Note “sinkhole” geometries

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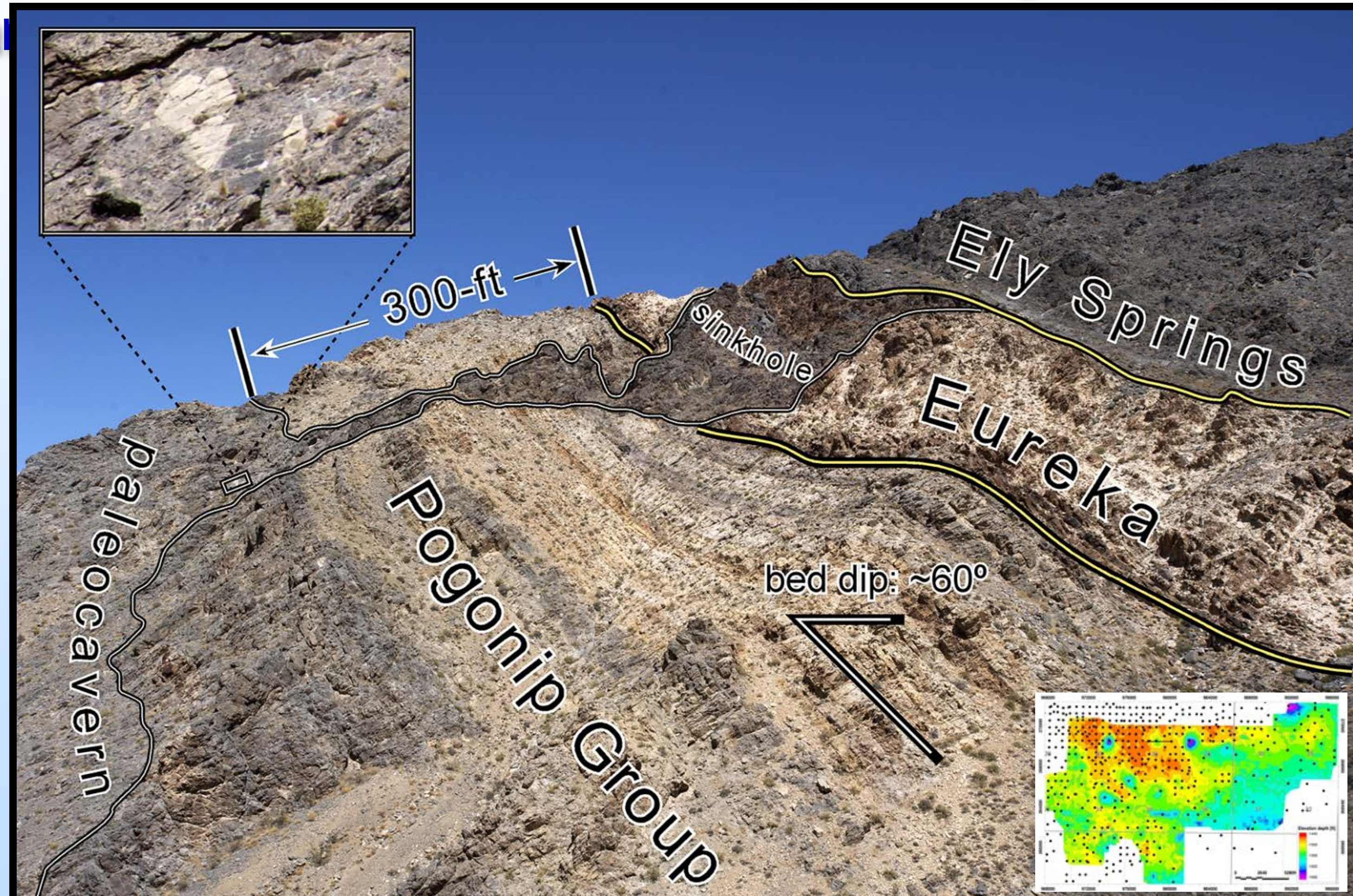
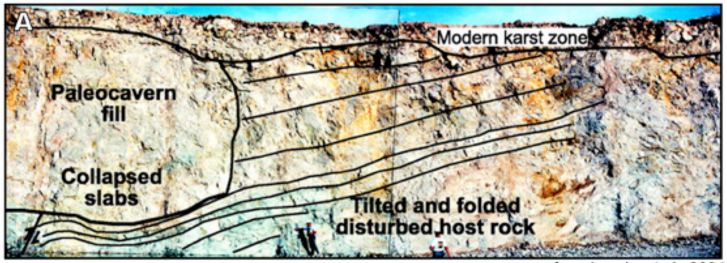
Arbuckle Analog

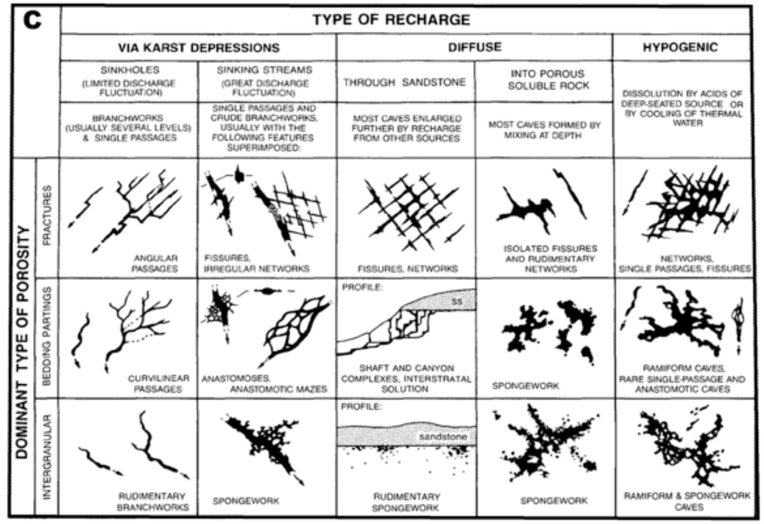
Whiterockian Paleokarst Outcrop Analog — Nopah Ra



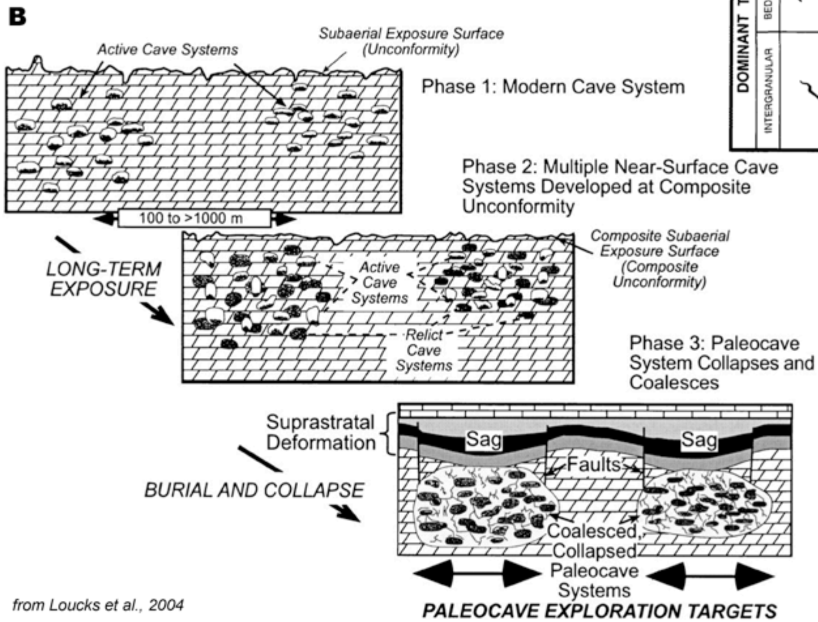
Common Morphologies



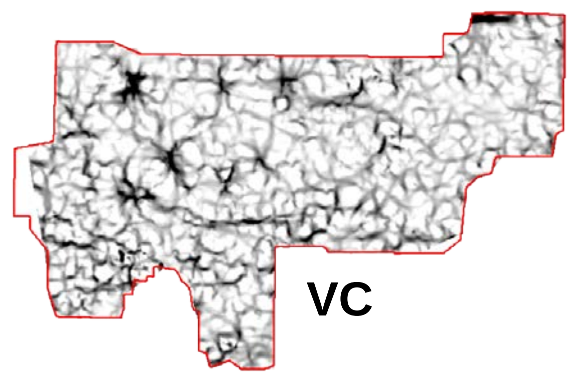
from Loucks et al., 2004



from Palmer, 1991

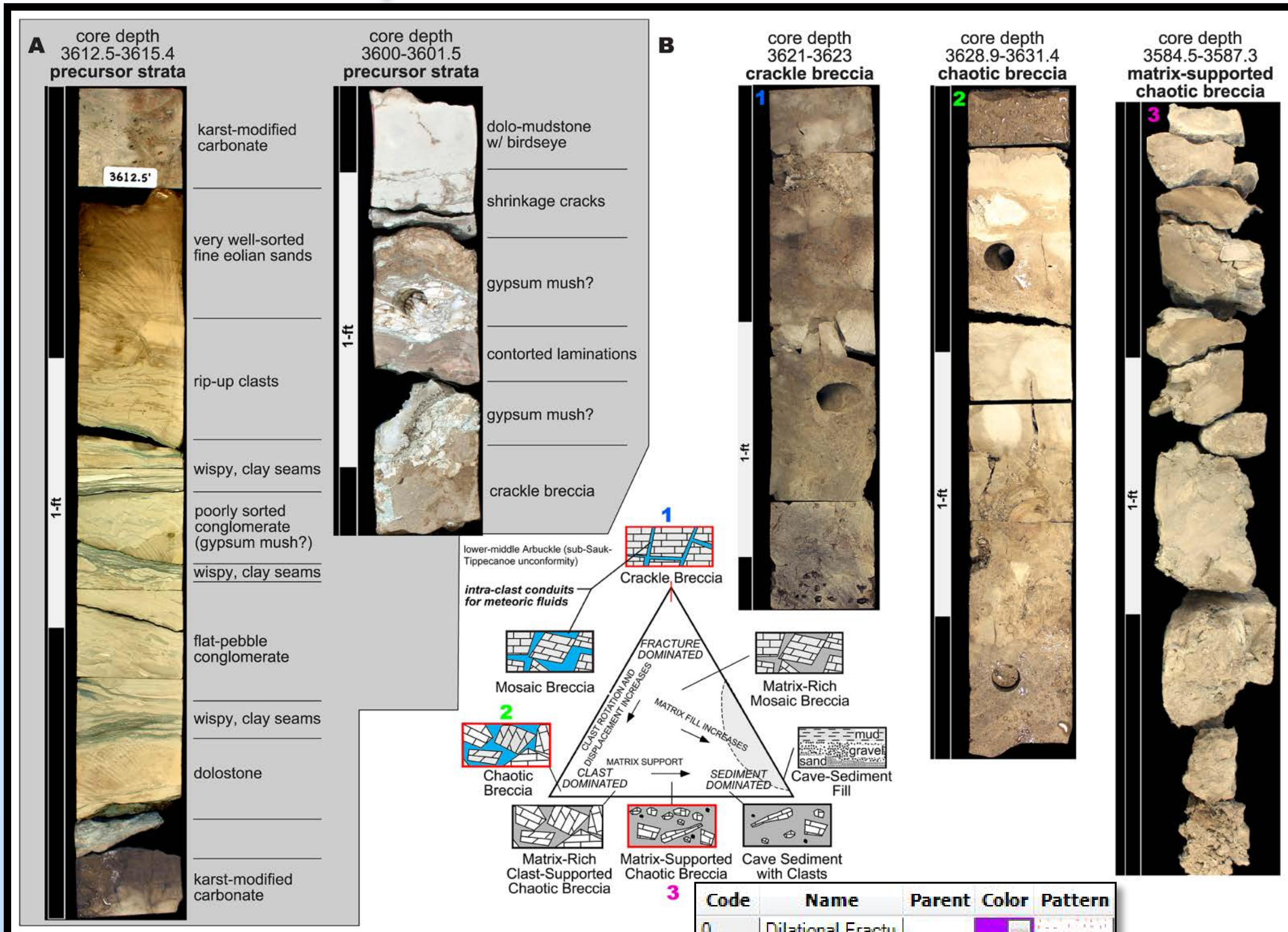


from Loucks et al., 2004



Field Setting

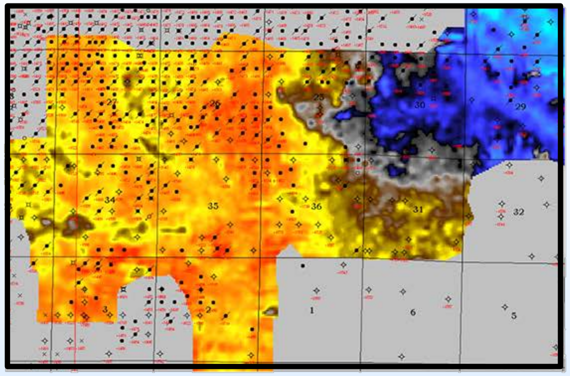
Core Description — Paleokarst Rock



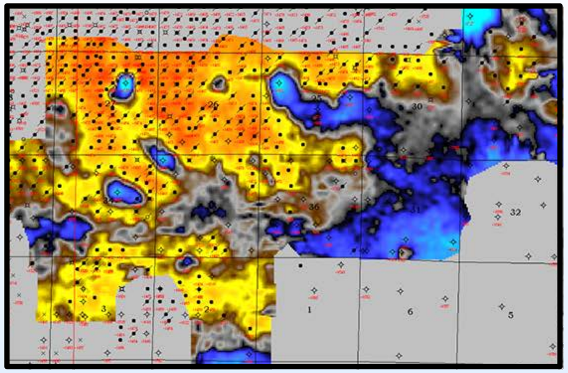
Code	Name	Parent	Color	Pattern
0	Dilational Fractu			
1	Bedding-Dolomi			
2	Matrix-supporte			
3	Crackle Breccia			
4	Chaotic Breccia			

Time & Depth Migration

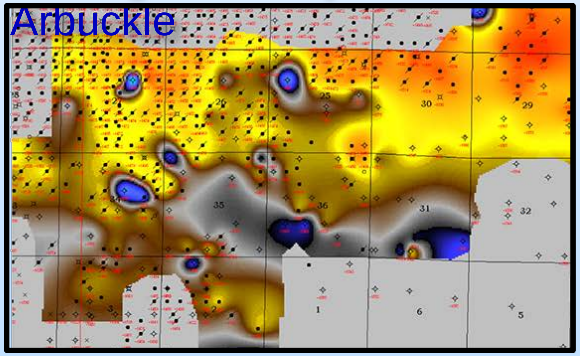
Arbuckle PSTM



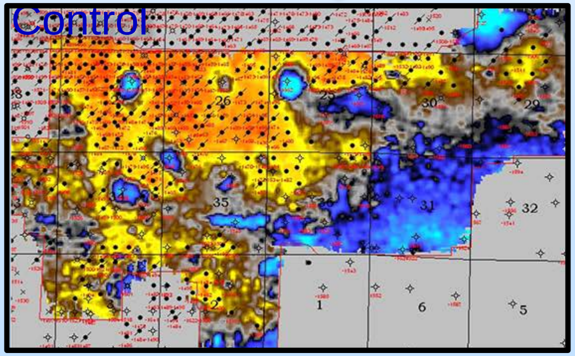
Arbuckle PSDM



Average Velocity to Arbuckle



Arbuckle Velocity & Well Control



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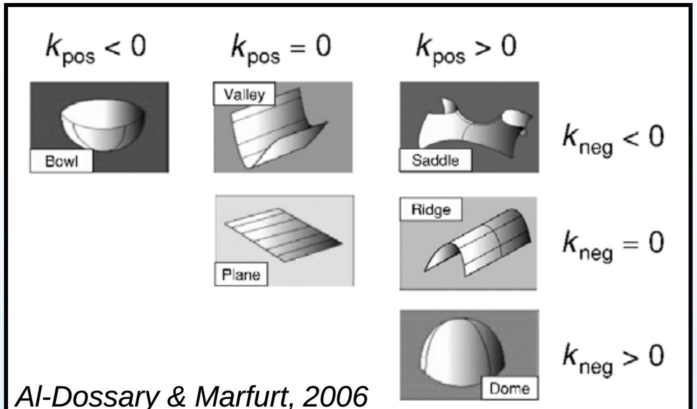
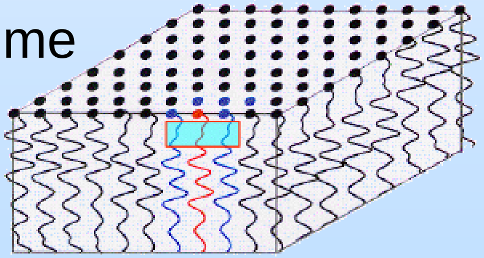
Volumetric Curvature

- A measure of reflector shape:
  - *Most-positive*: anticlinal bending
  - *Most-negative*: synclinal bending

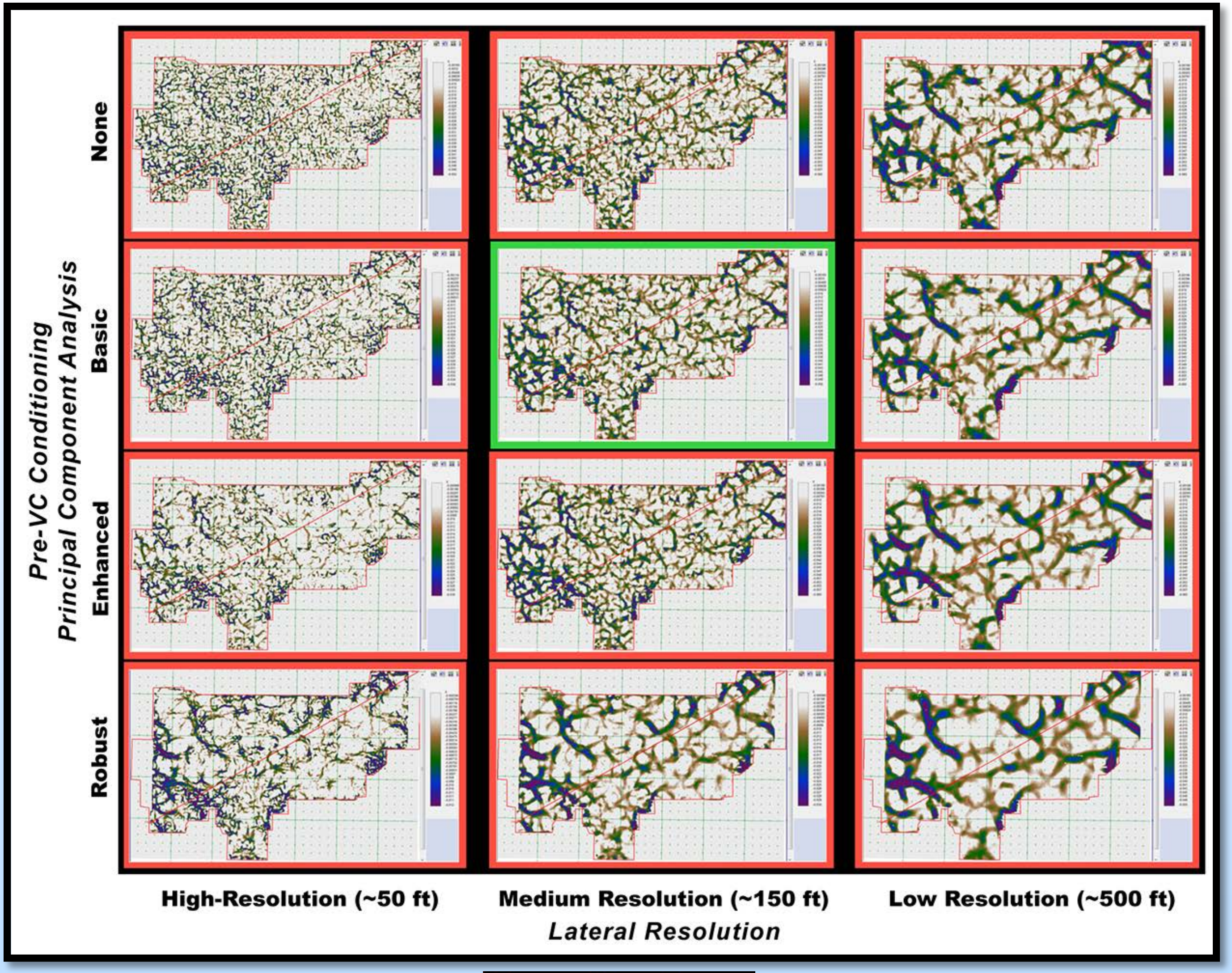


Al-Dossary & Marfurt, 2006

- Multi-trace geometric attribute calculated directly from the 3-D seismic volume
- Calculated using multiple seismic traces and a small vertical window
- The analysis box moves throughout the entire volume
- VC attributes can be output as a 3-D volume
- Provides *quantitative* information about lateral variations



PSDM VC Processing Results



VC-processing by Geo-Texture TECHNOLOGIES

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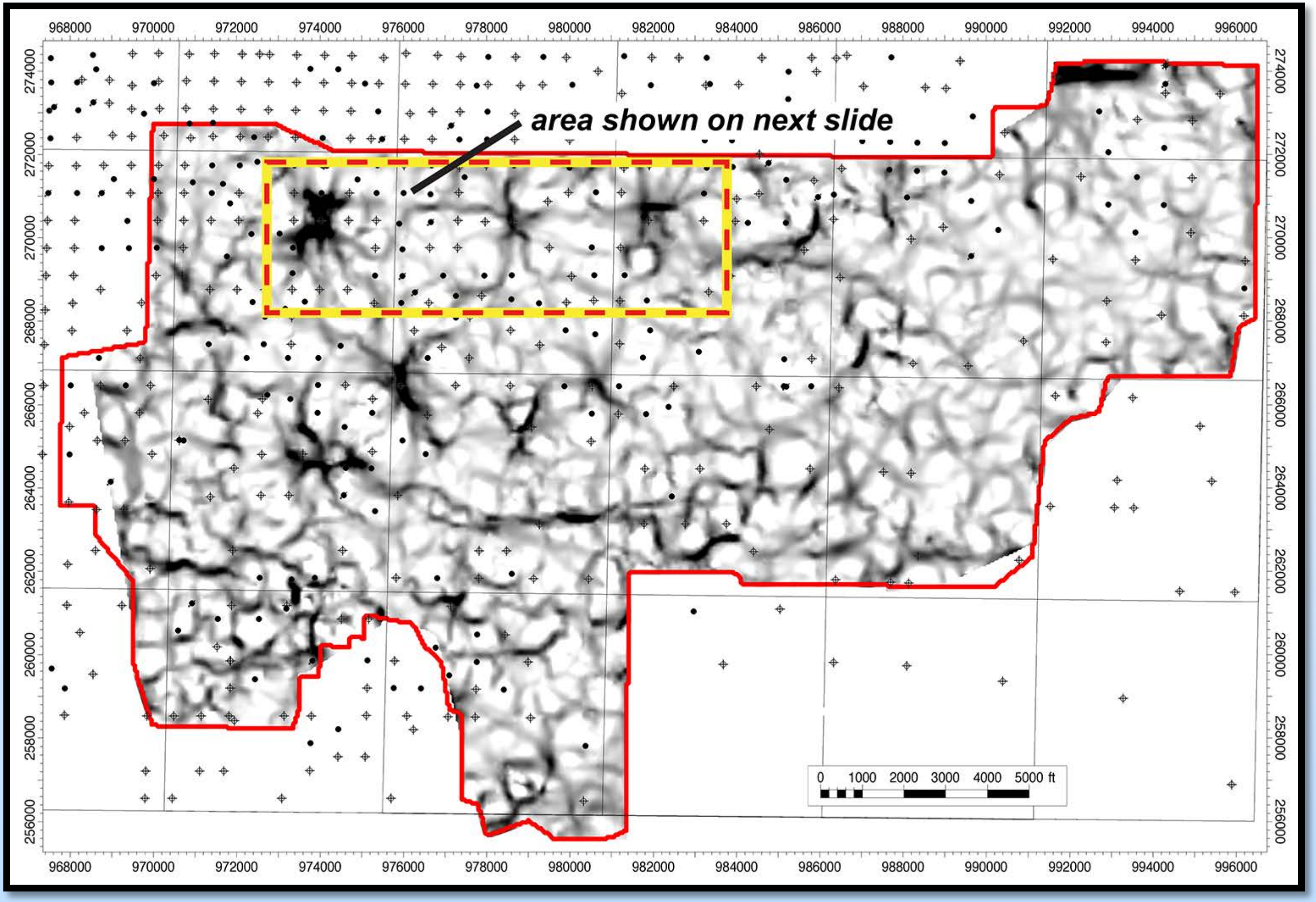
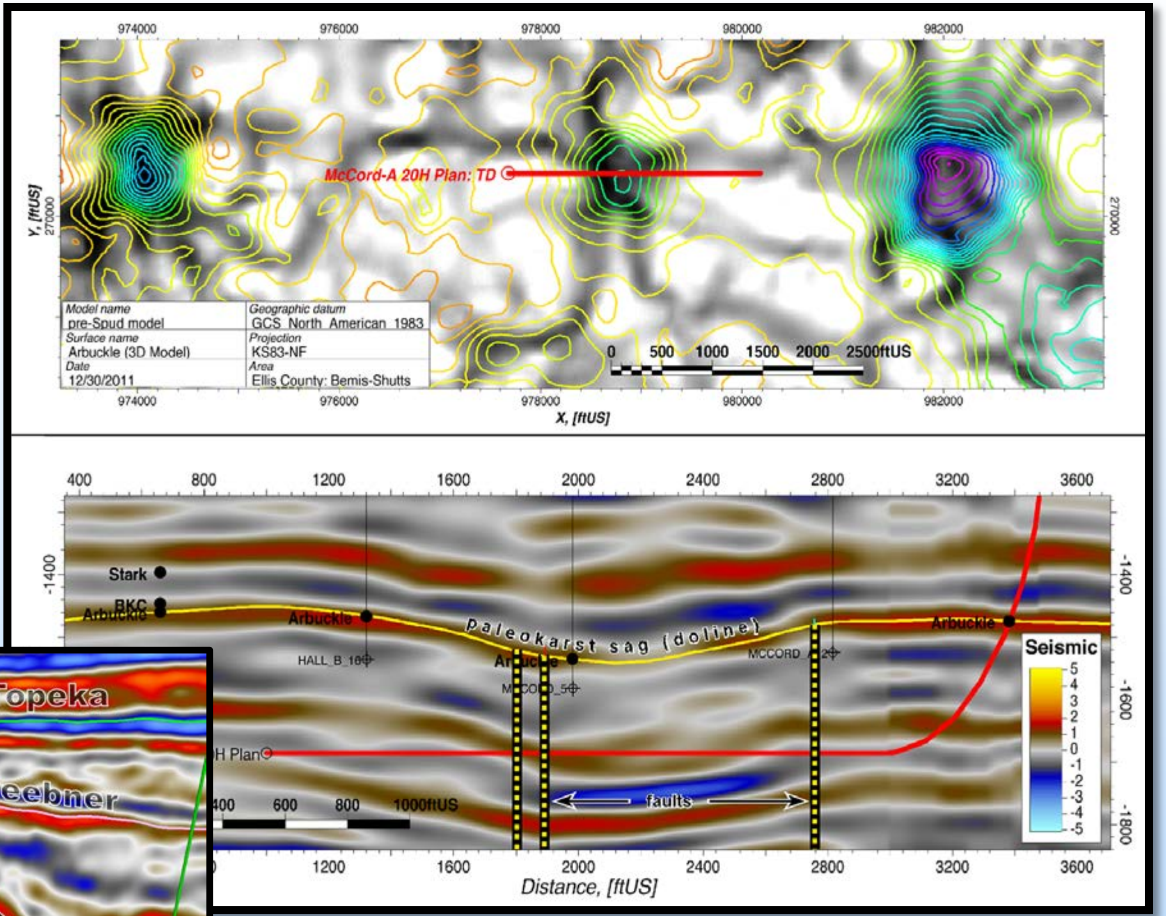
Arbuckle PSDM VC Horizon-Extraction



Proposed Lateral to ***Test*** VC Attributes

Objectives:
- Land well outside paleocavern
- Drill through paleocavern
- TD in "flat-lying" host strata
- Run Triple, Sonic, Image tools

wow…no mud losses



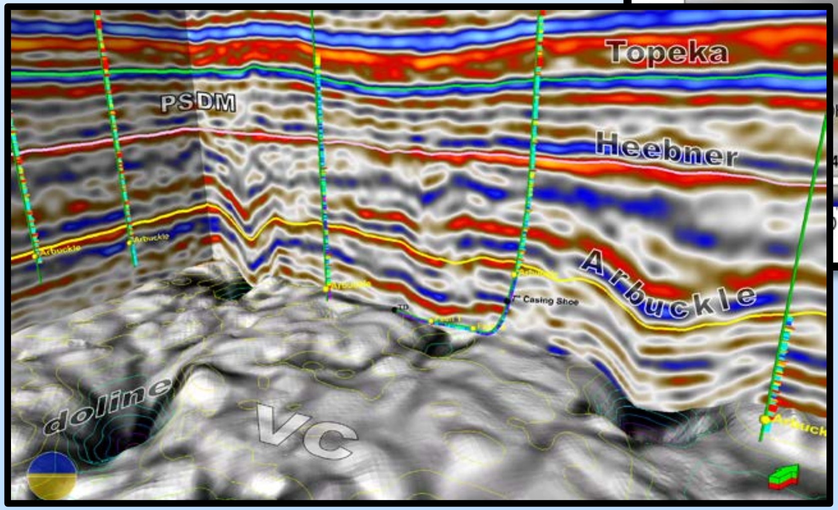
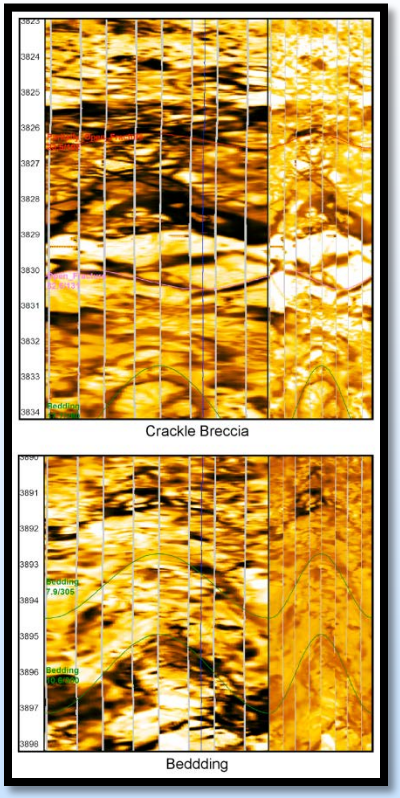


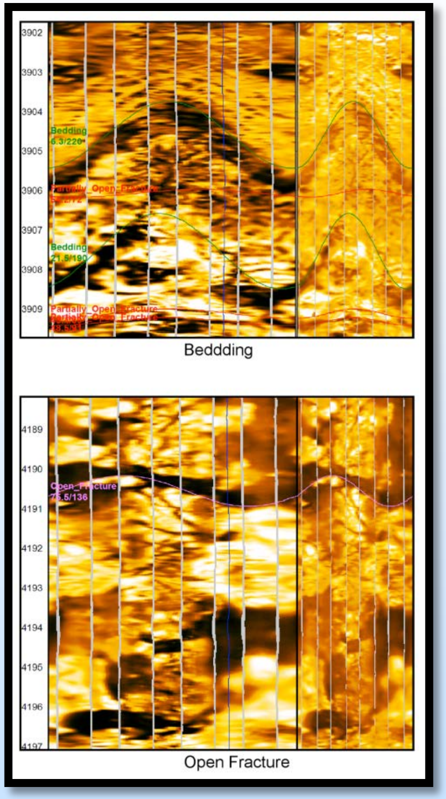
Image Log Facies — Facies Model

Chaotic



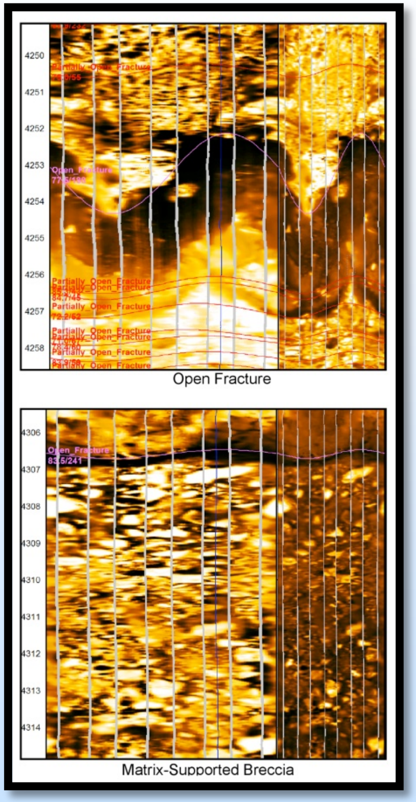
Bedding

Bedding



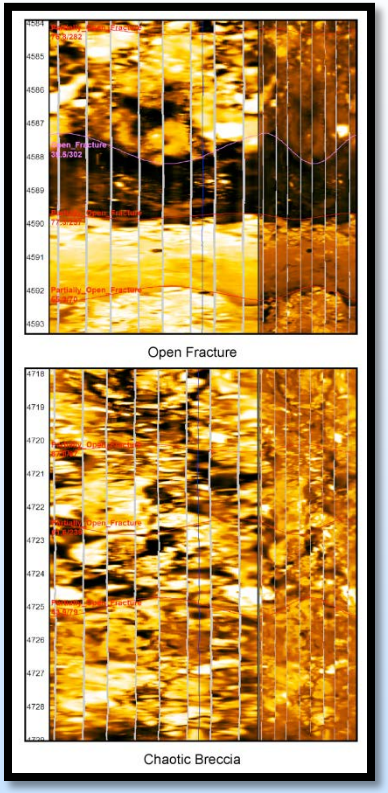
Dilational Fracture

Dilational Fracture

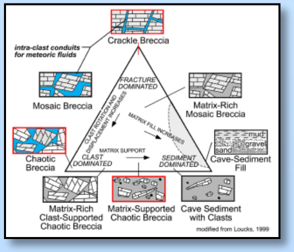


Matrix-Supported

Dilational Fracture



Chaotic



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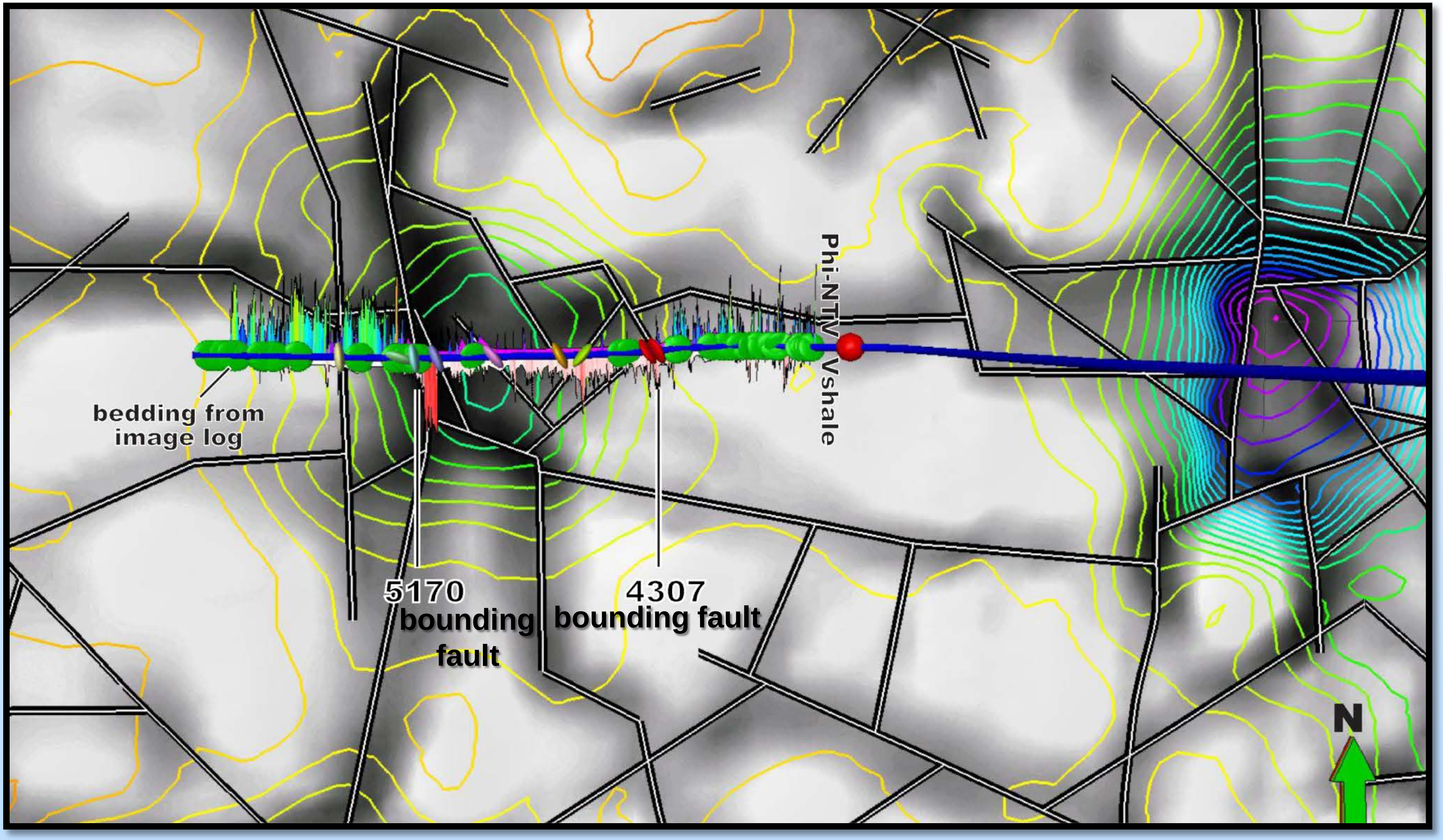
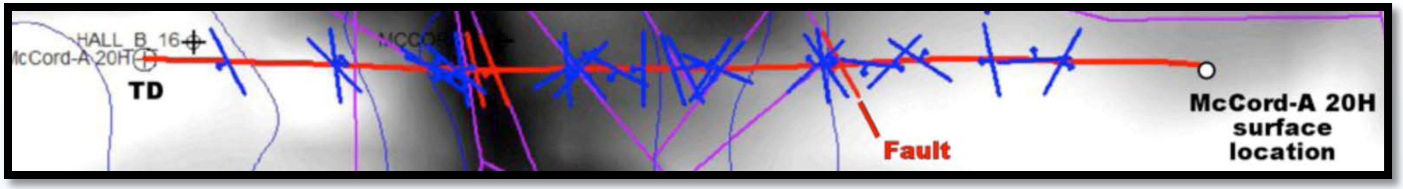
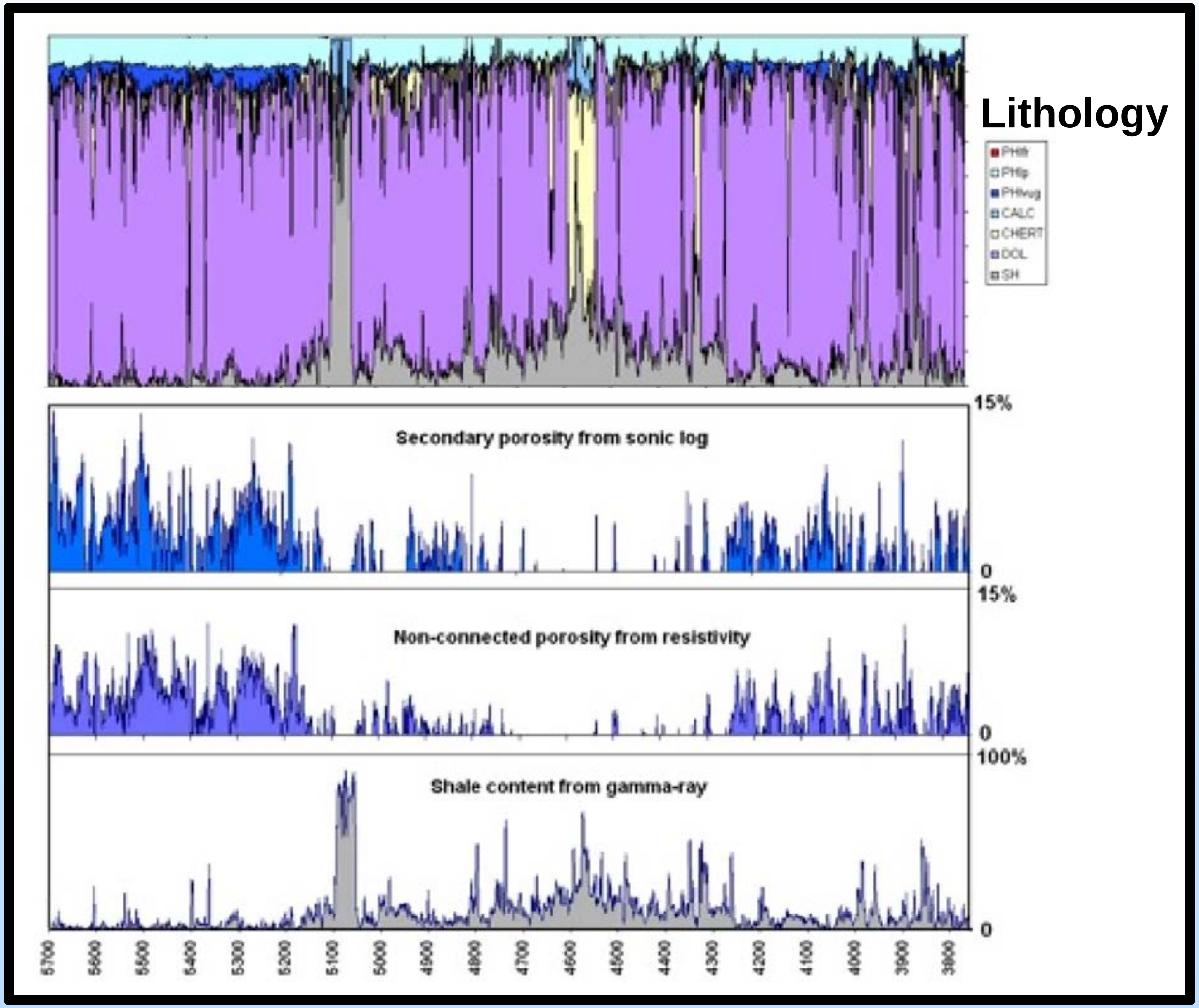
VC-indicated Compartments Consistent with Log Interpretations

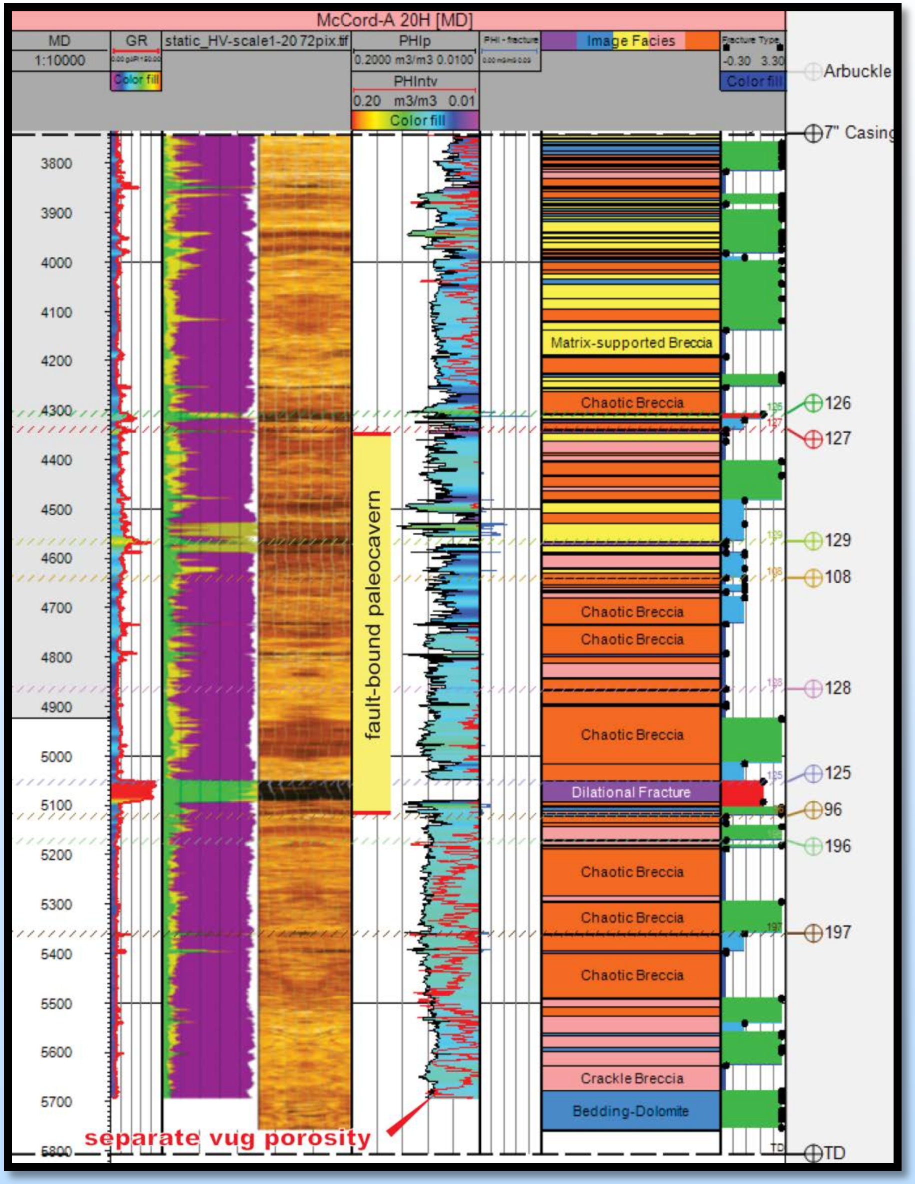


Formation Evaluation

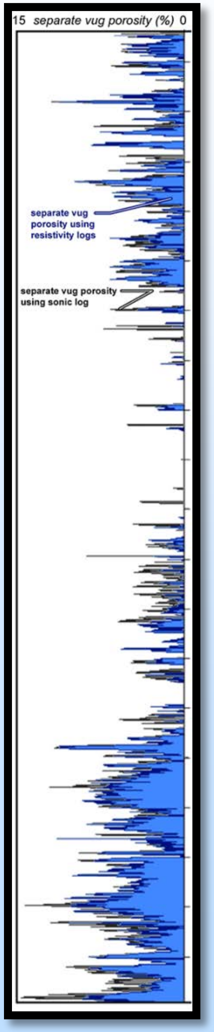


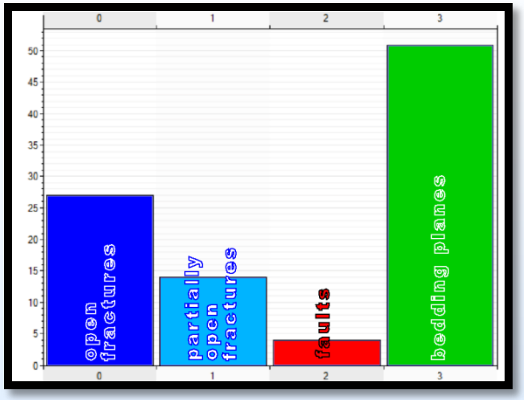


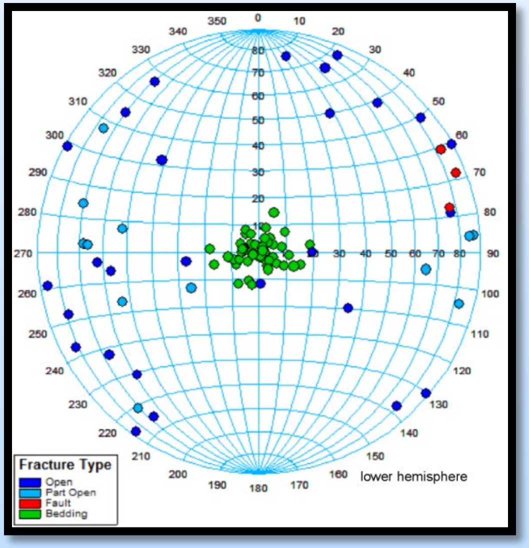
Formation Evaluation



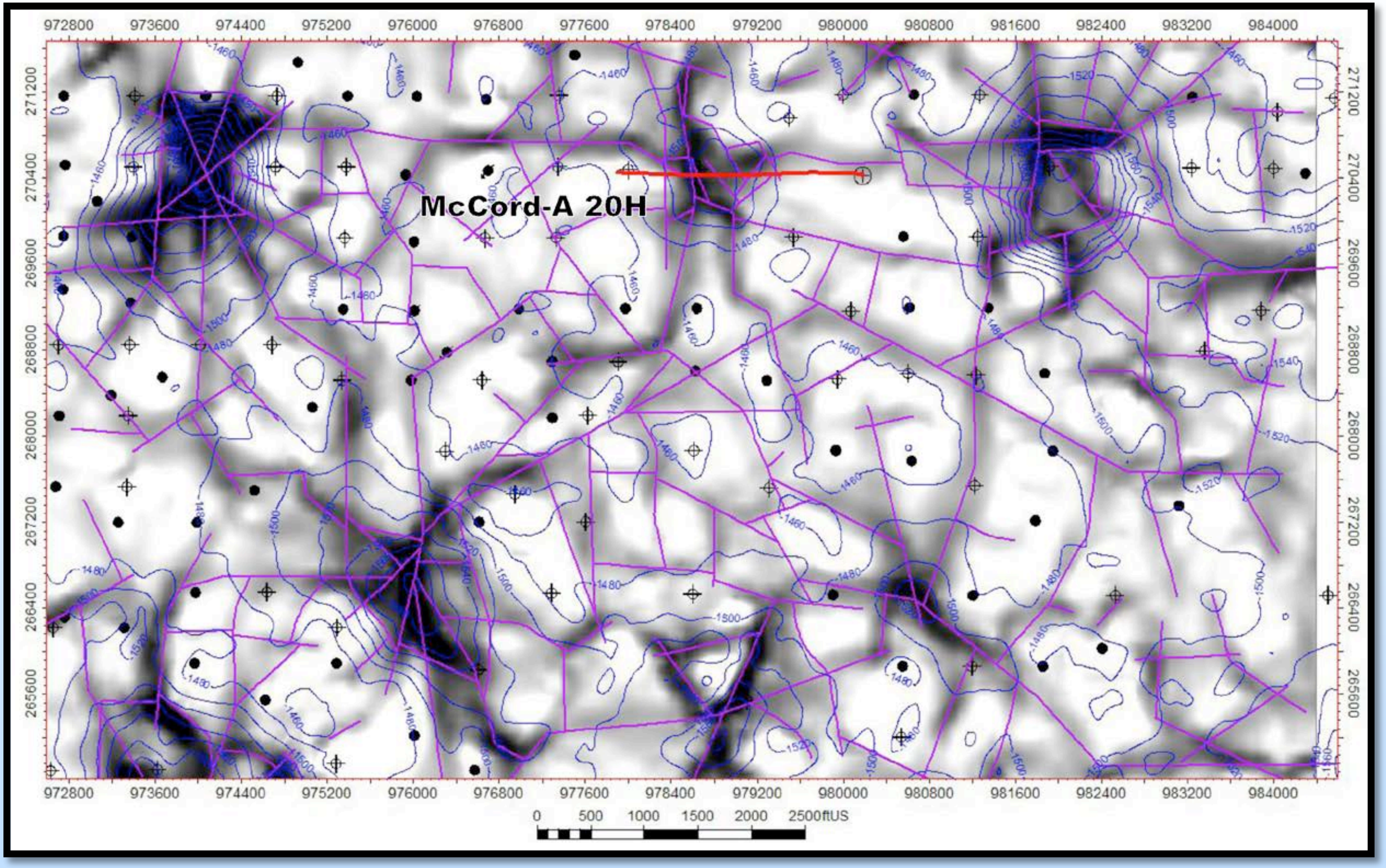
Svug %





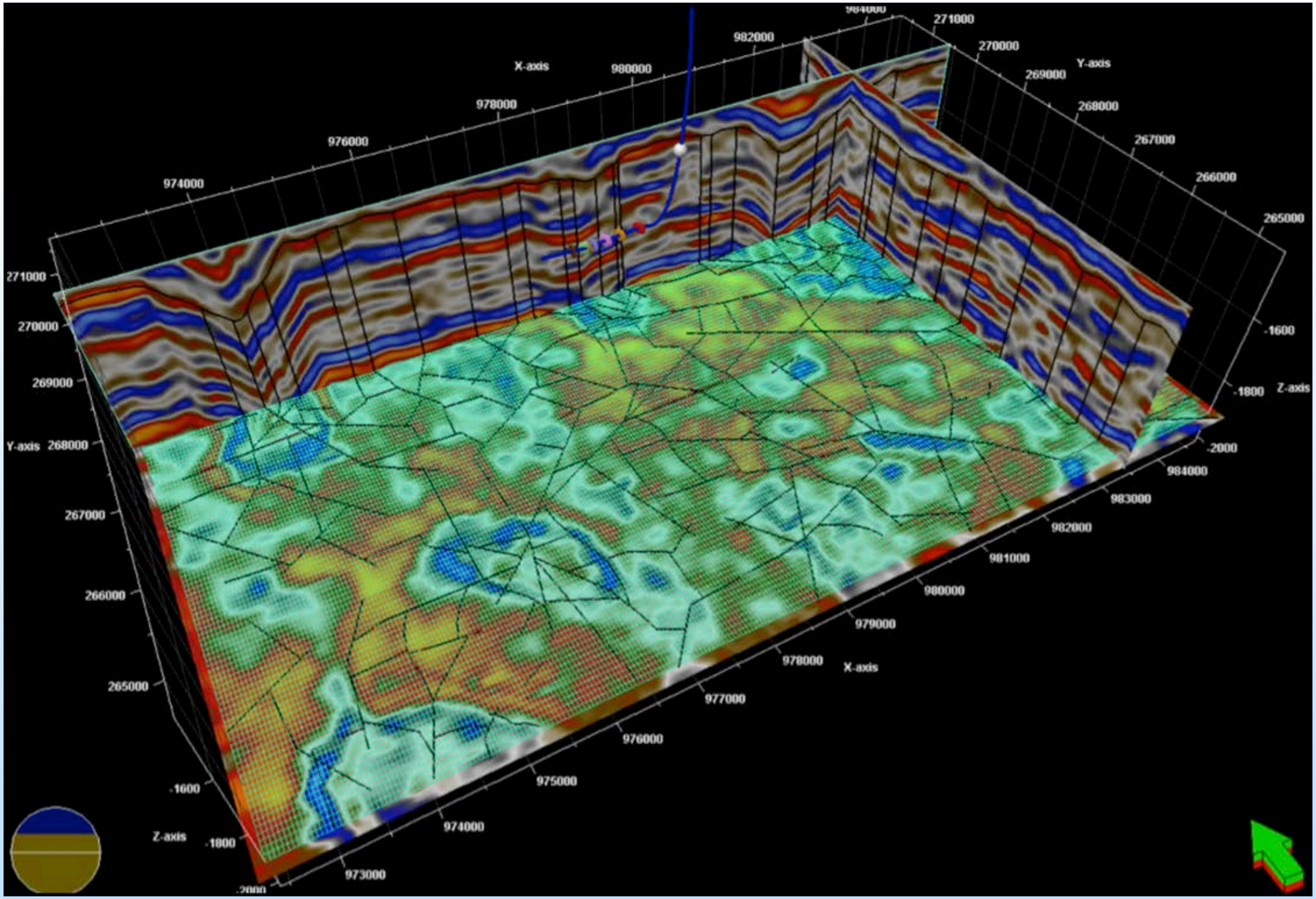


New Field-Wide Fault Model



~201 Faults...thanks to Rock Deformation Research plug-in

VC-Faults *Match* Seismic Faults



Probability Maps for Conditioning Geocellular Models

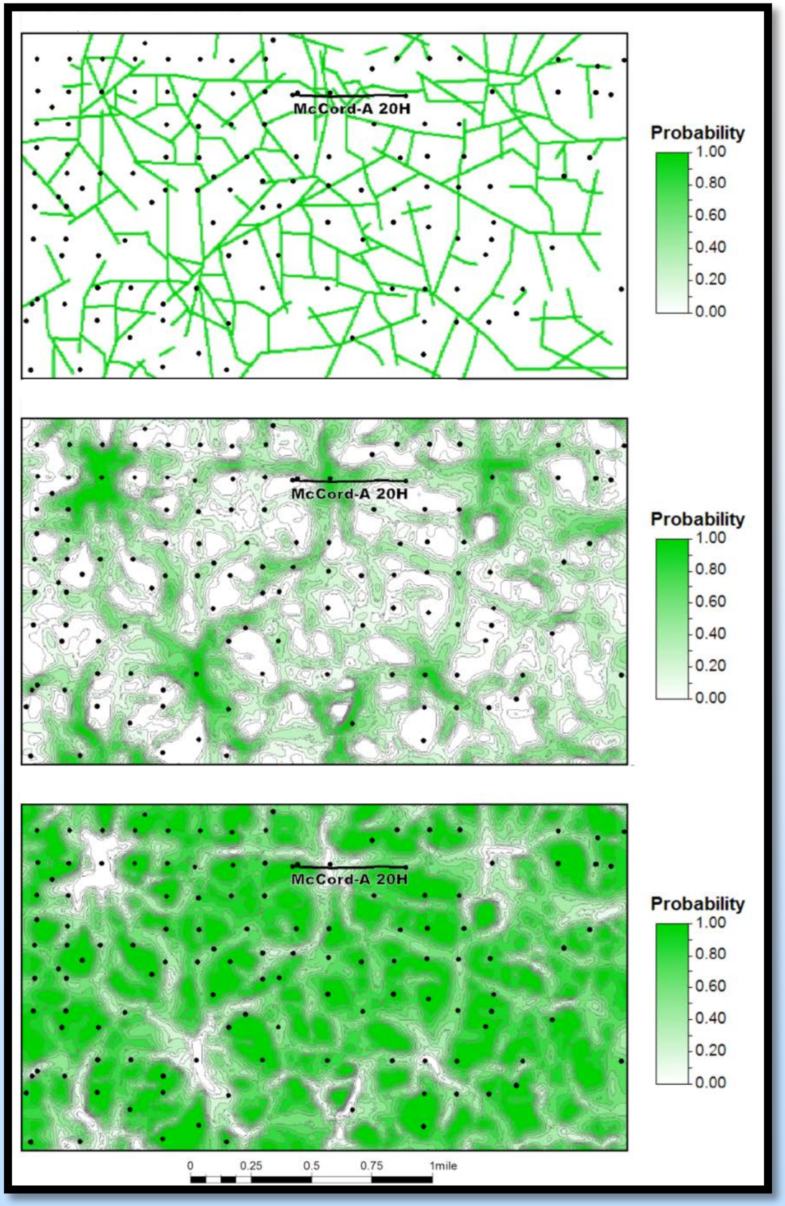
Facies

Code	Name	Parent	Color	Pattern
0	Dilational Fractu			
1	Bedding-Dolomi			
2	Matrix-supporte			
3	Crackle Breccia			
4	Chaotic Breccia			

Dilational Fractures

Crackle & Chaotic Breccia

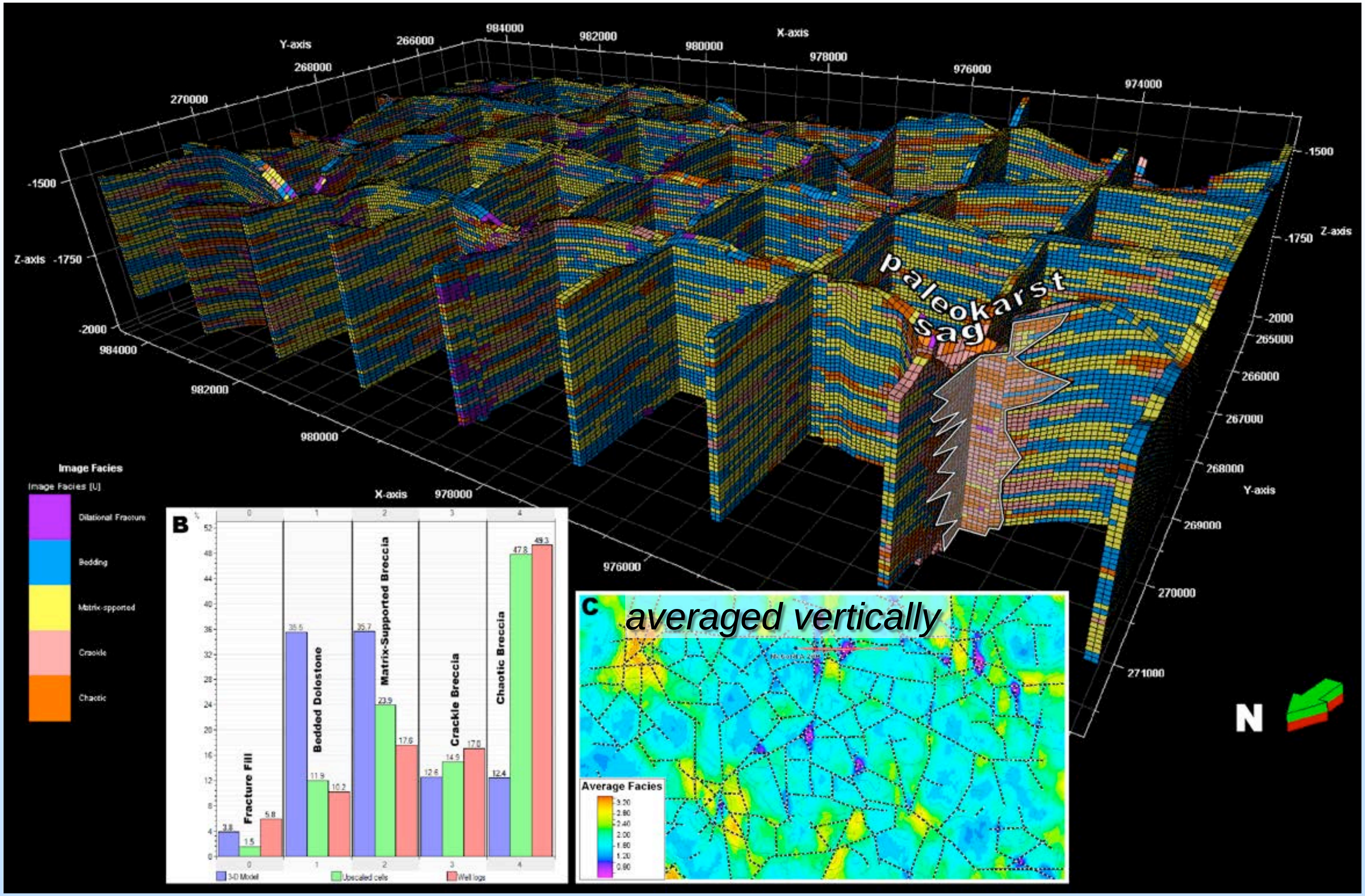
Peritidal Dolostone & Matrix-Supported Breccia



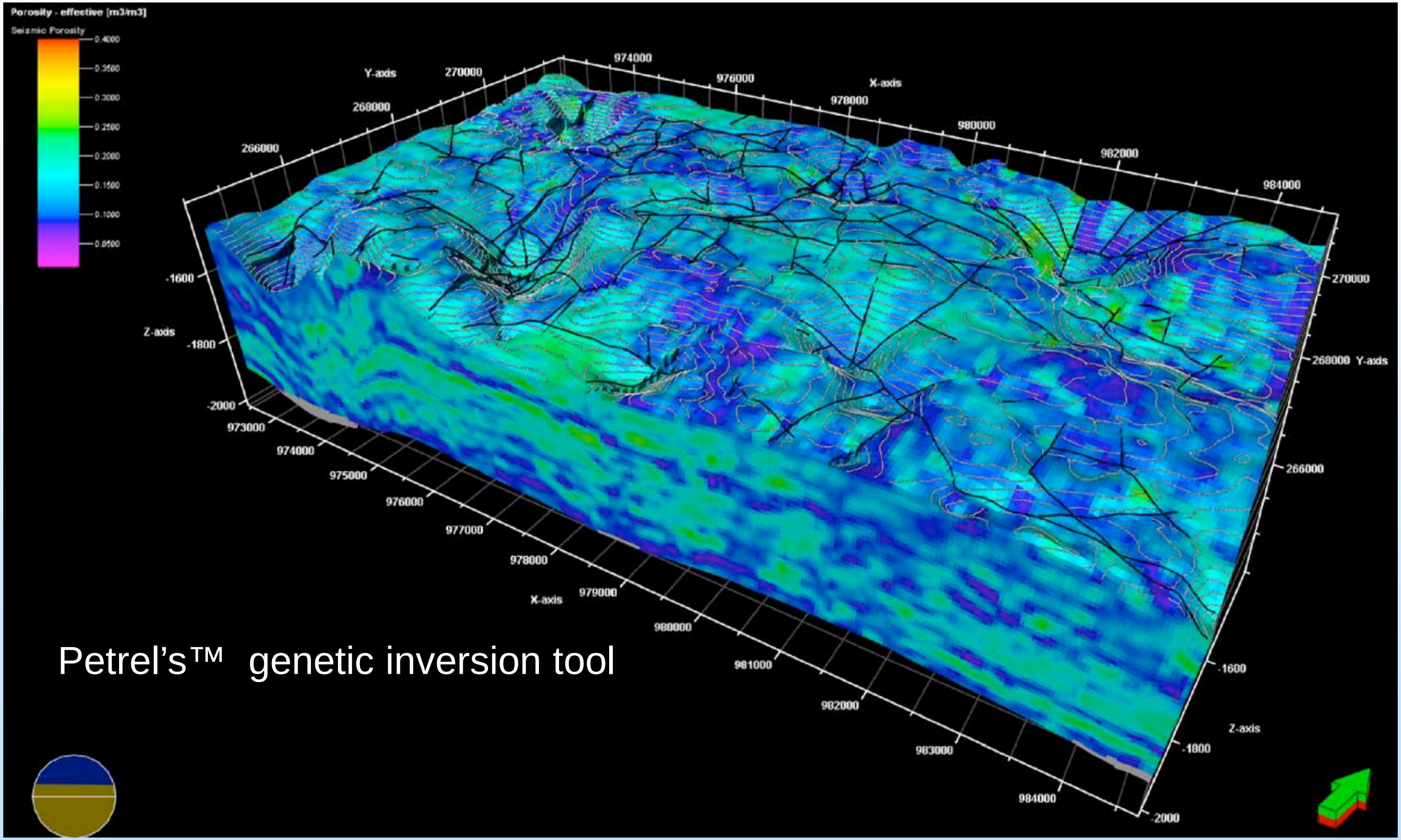
evaporite karst in host strata

- strata-bound breccia
- anhydrite-filled molds
- geochemistry-sulfates

Facies Model



3-D PSDM *Seismic Porosity* Attribute



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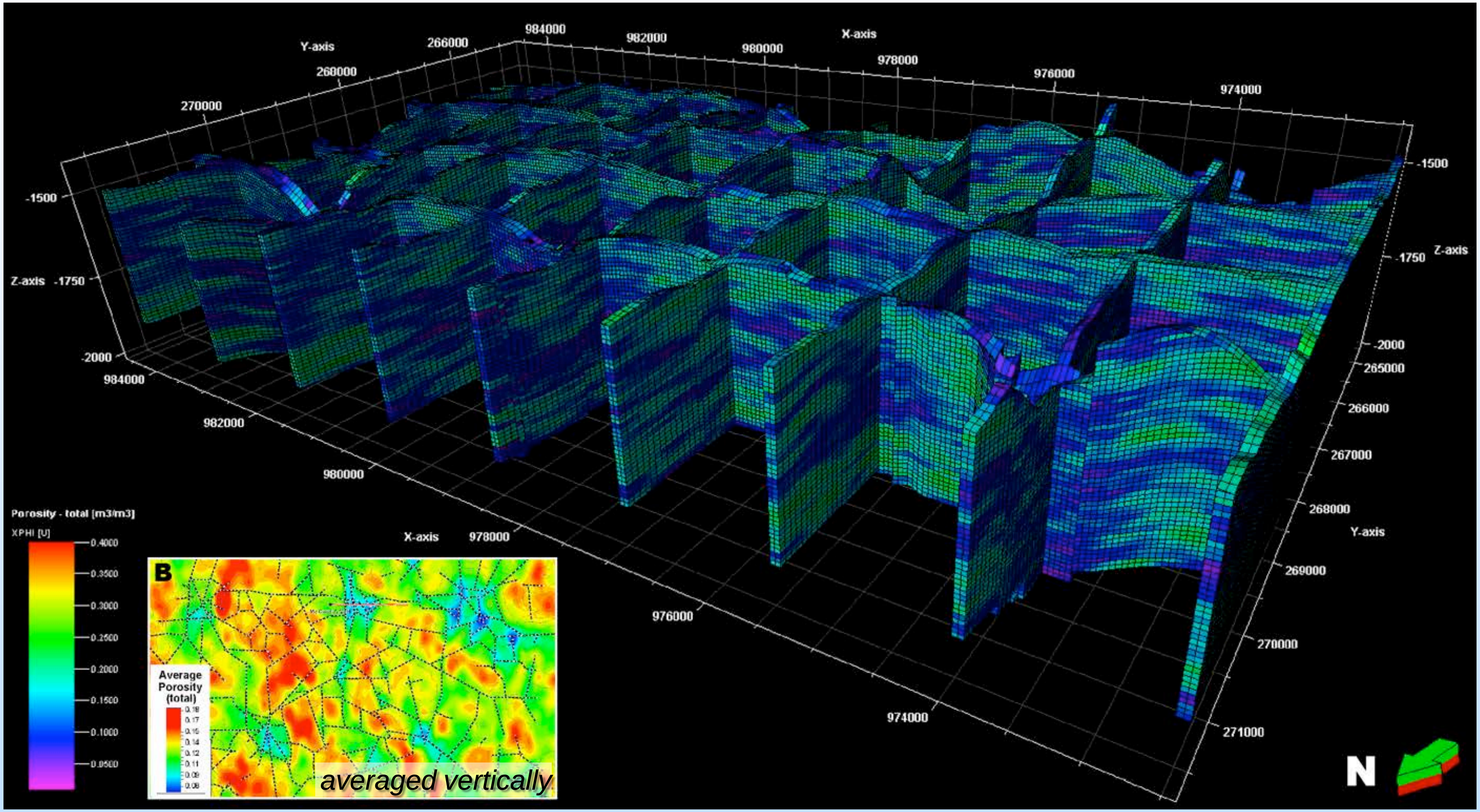
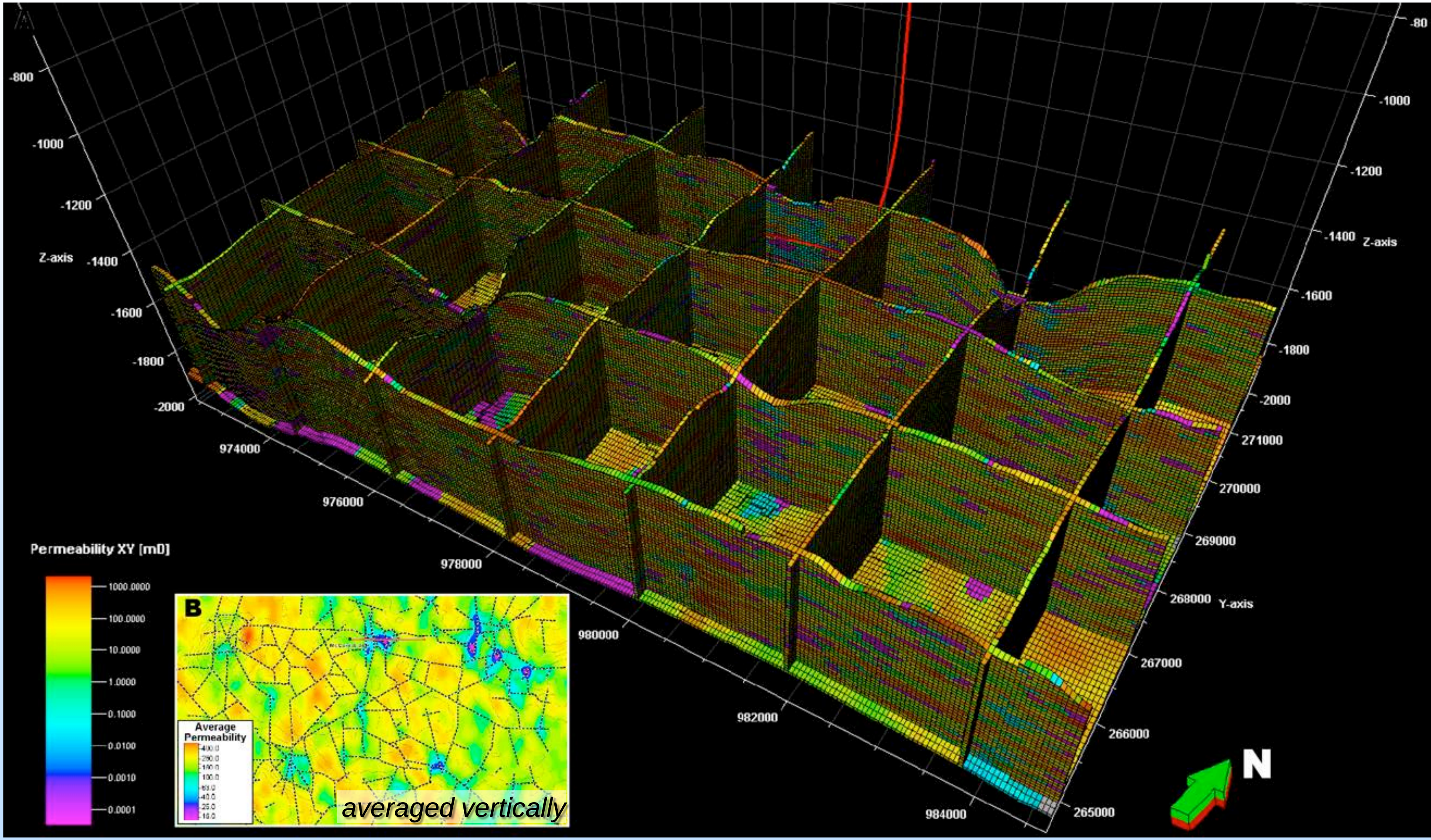
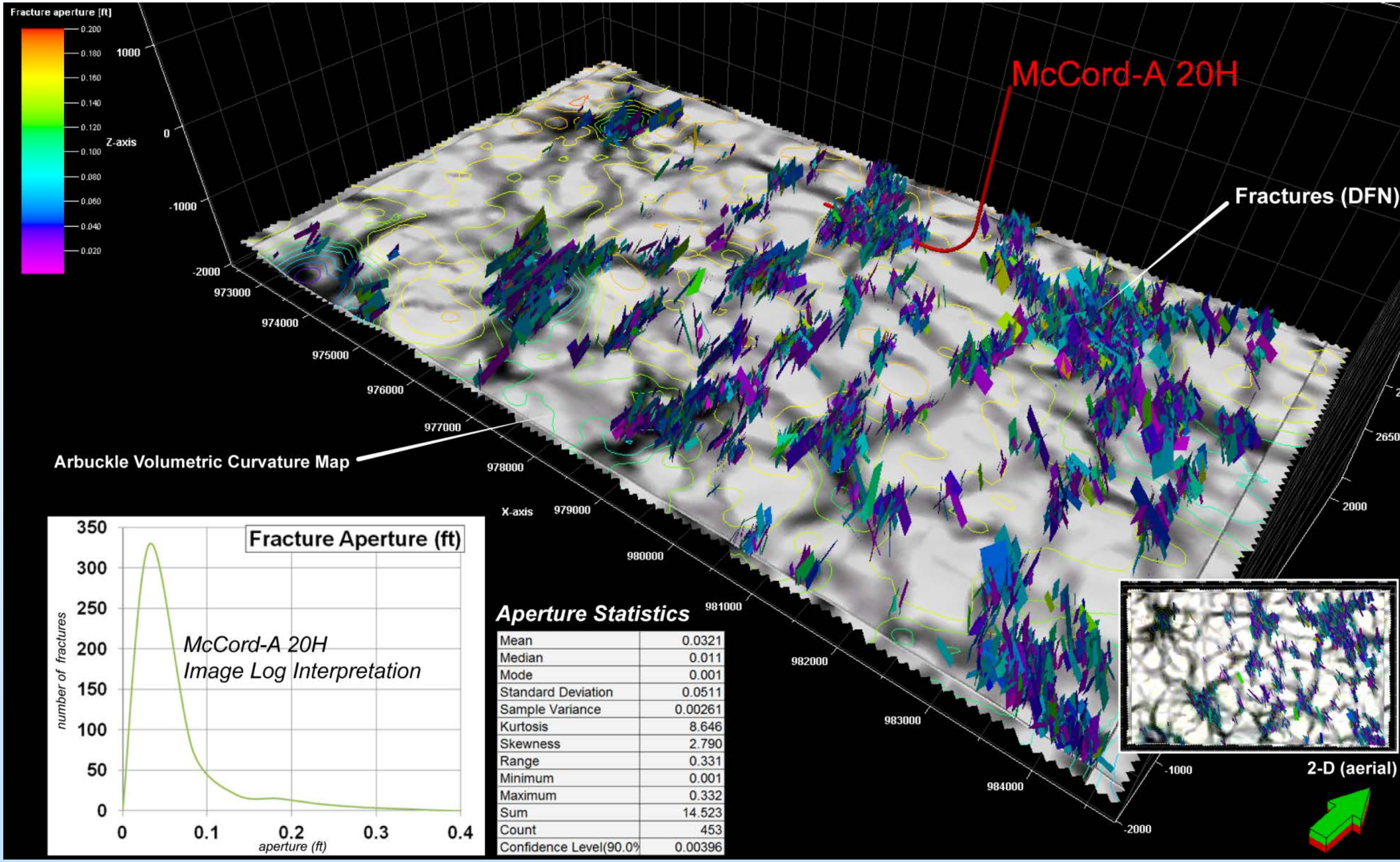
Porosity Model



Permeability Model



Discrete Fracture Network Modeling

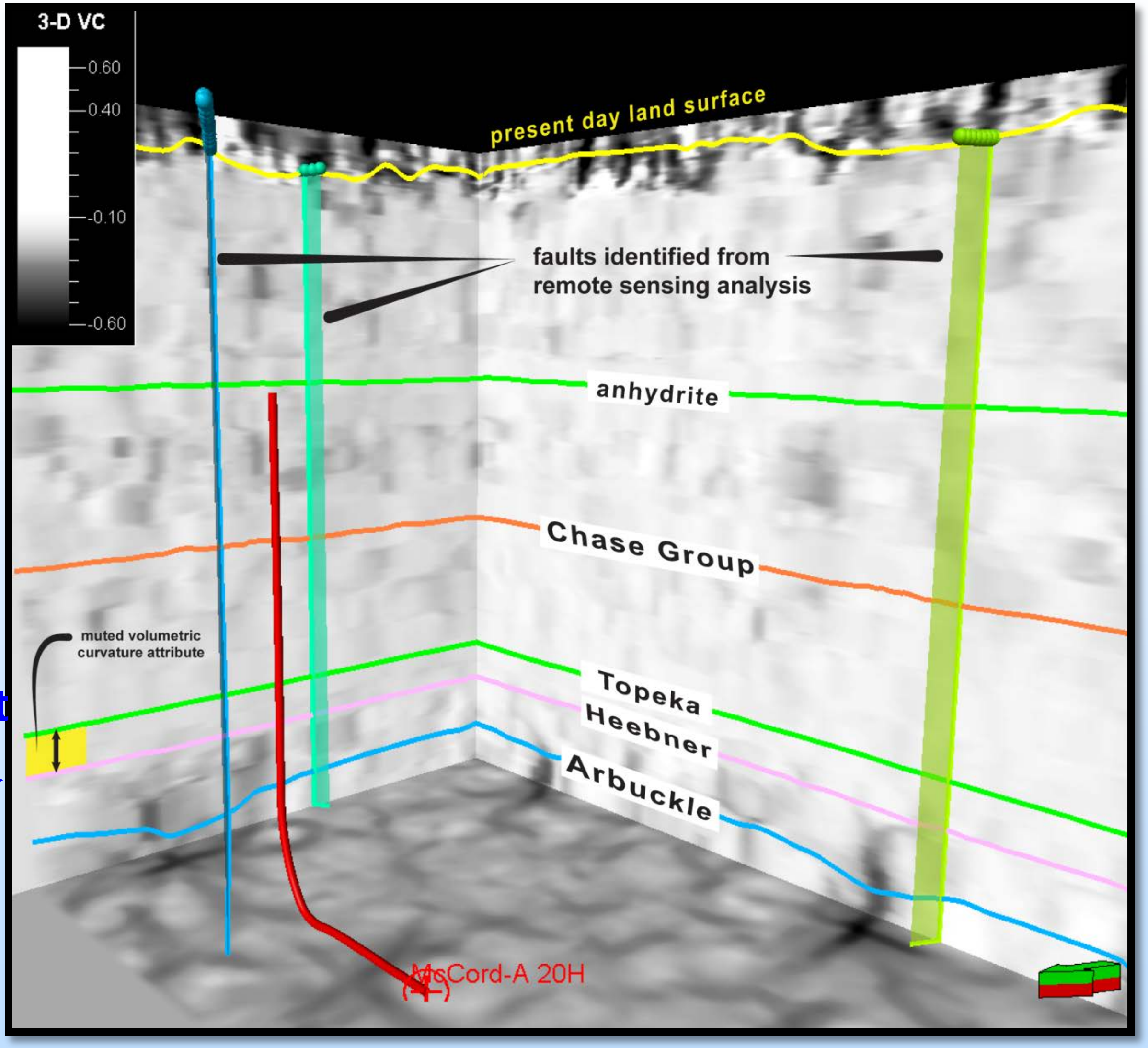


Aperture Statistics

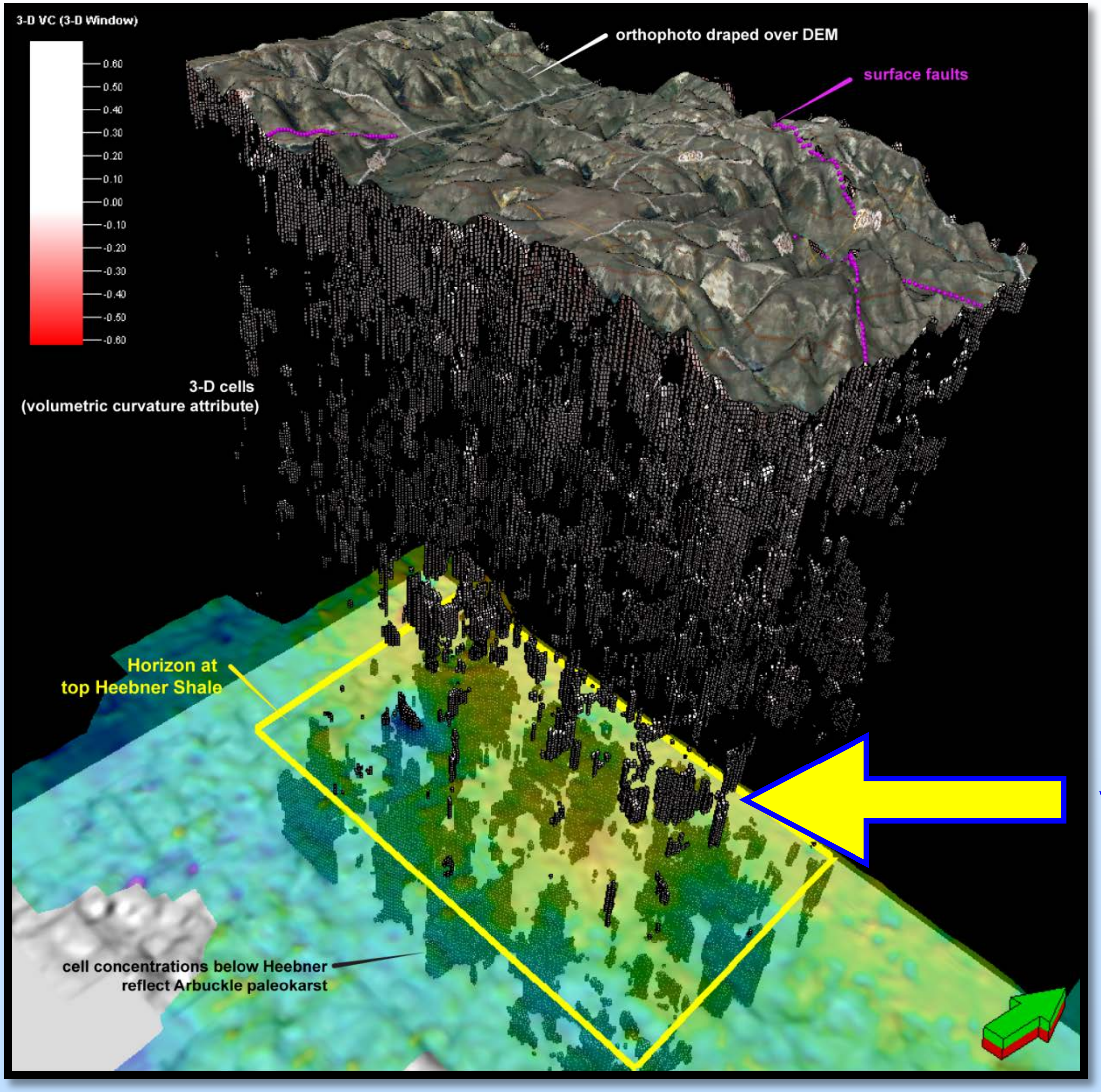
Mean	0.0321
Median	0.011
Mode	0.001
Standard Deviation	0.0511
Sample Variance	0.00261
Kurtosis	8.646
Skewness	2.790
Range	0.331
Minimum	0.001
Maximum	0.332
Sum	14.523
Count	453
Confidence Level(90.0%	0.00396

3-D Volumetric Curvature Volume

VC muted Reflectors flat



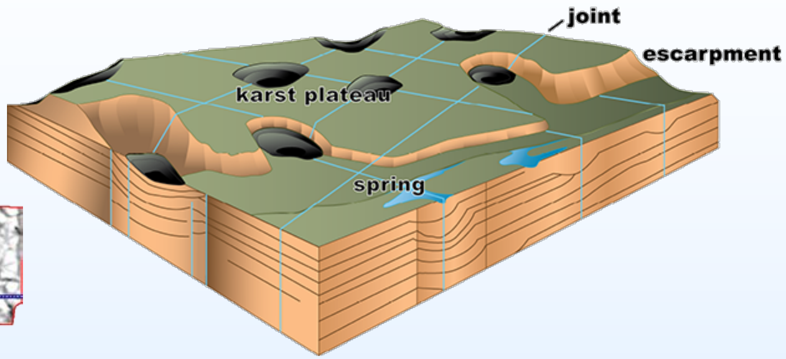
Filtered 3-D VC Geocellular Model

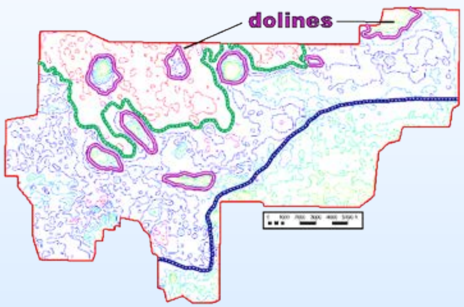


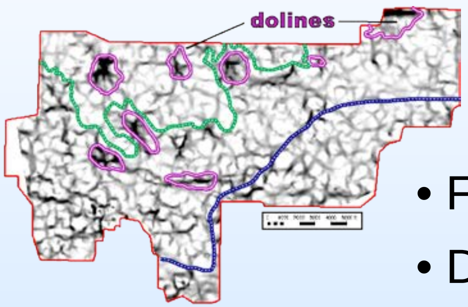
VC cells absent

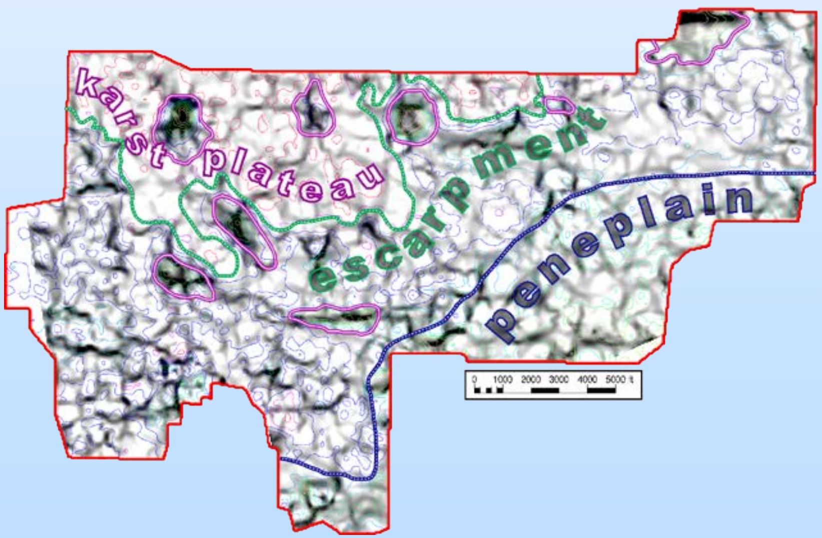
Key Findings & Interpretations to Date

Bemis-Shutts karst model









- Fault-bounded doline confirmed
- Dolines coincident with VC-identified radial lineaments
- Interior drainage
- Headward-eroding escarpment
- Disappearing streams/springs/ fluvial plains
- Fracture system O-age
    - *reduces seal risk?*

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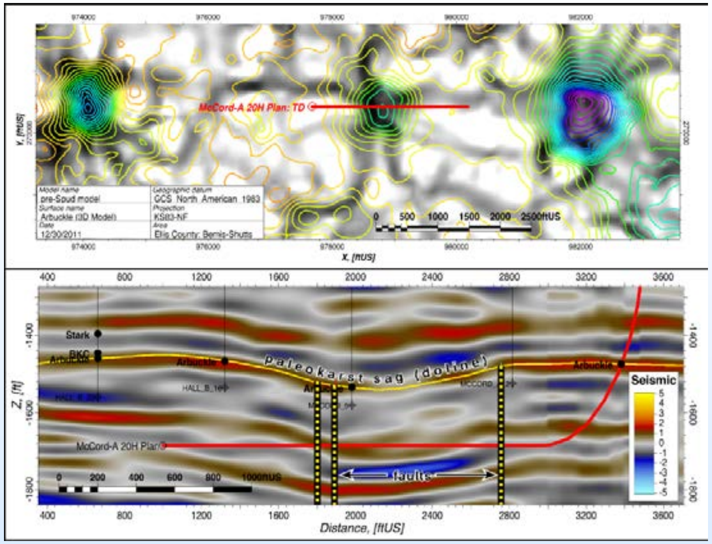
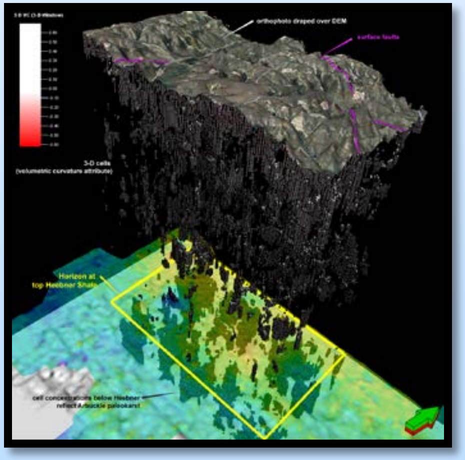
Accomplishments to Date



- Merged & reprocessed seismic
- PSTM & PSDM VC processing
- Built pre-spud model
- Drilled ~1800-ft lateral to test VC
- Ran extensive logging program
- Formation evaluation

- Simulated pre-spud model
- Inversion & genetic inversion
- Probability maps
- Property modeling
- ASME Peer Review
- DFN modeling



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Summary

- Key Findings
  - Direct ***confirmation*** of VC-identified, fault-bound, paleokarst doline
  - ***3-D VC PSDM*** for complex structural settings
  - Pre-spud history-match ***non-unique solution***
  - ***VC-filtering*** reveals vertical extent of faults
- Lessons Learned
  - ***VC attributes fractal***, requires some constraints
  - ***Lost-in-hole tool insurance*** can overwhelm budget
- Future Plans
  - ***Cost analysis*** vs other seismic attributes or interp. methods
  - Analyze uncertainty of ***flux between blocks***
  - ***Simulate*** & history match new models