# 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*


**Principal Investigators**

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**Project Kickoff Meeting**

**Nov 19, 2010**


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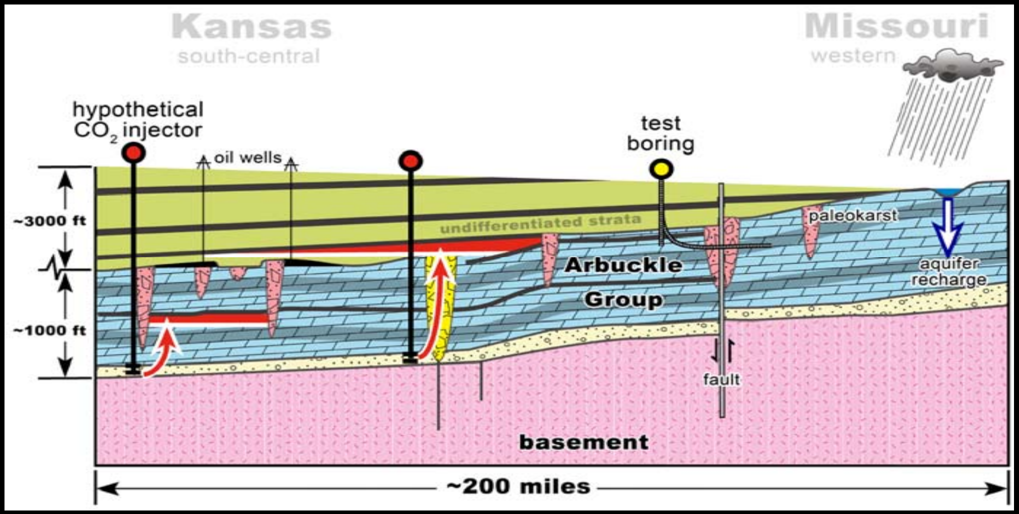
# Problem Statement

*Ordovician strata (e.g., Arbuckle Group Saline Aquifer) extensively karsted worldwide*




- Limited understanding of paleokarst heterogeneity & spatial distribution
- Karst features may be coincident with basement to surface fault systems
- Lateral and vertical transmissibility of karst features/boundaries - unknown
  - Identification of potentially conductive pathways critical to reducing risks related to $CO_2$ storage and permanence

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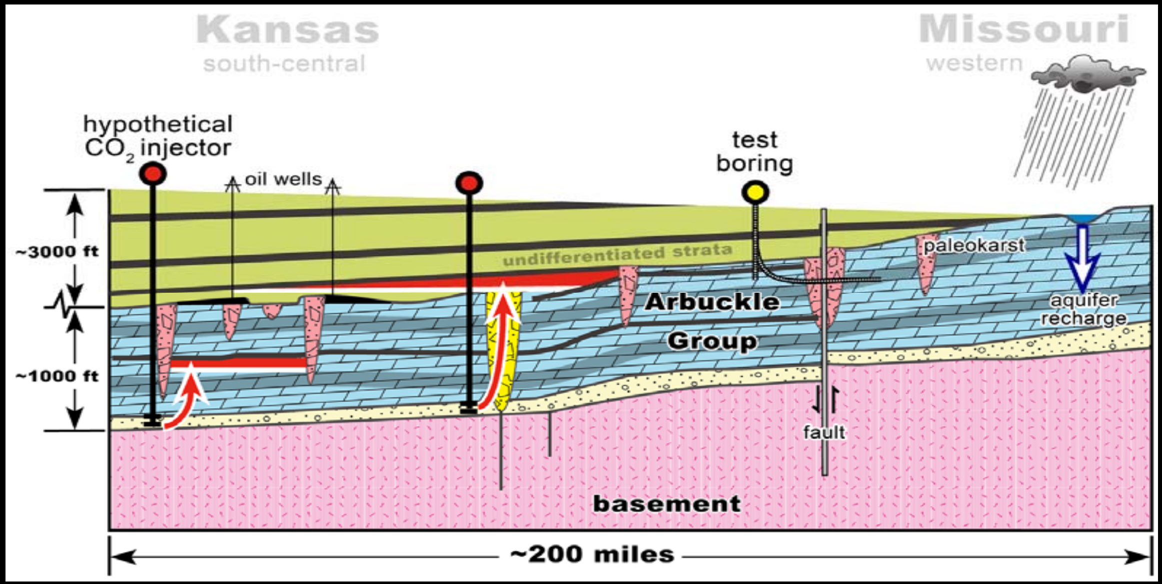
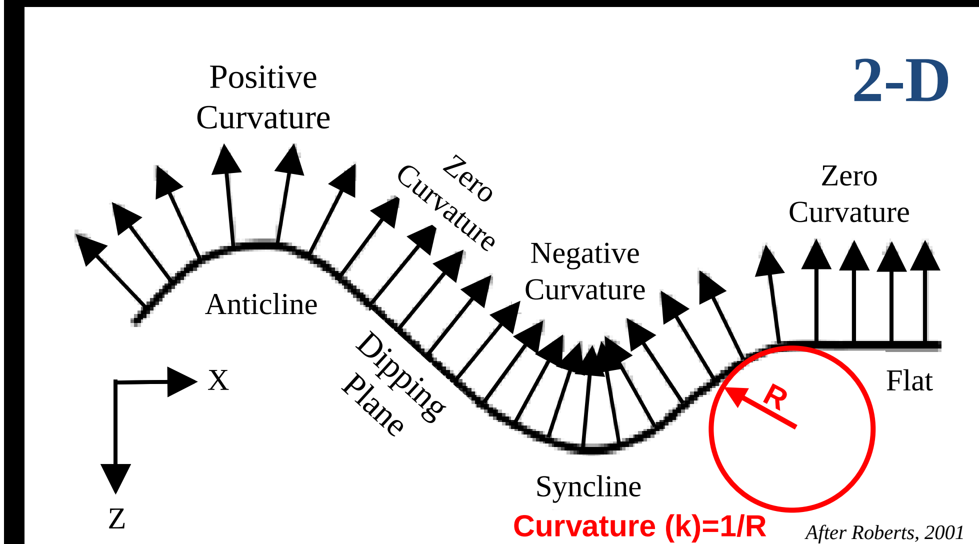
# Proposal to Test & Prototype a New Tool

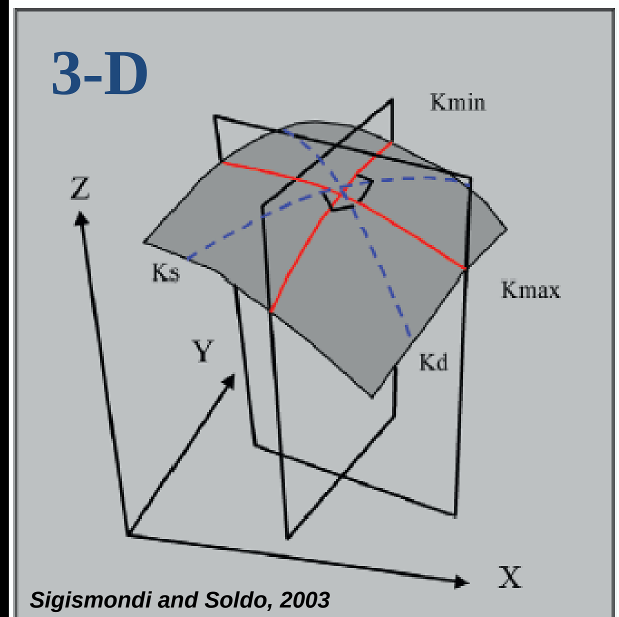



- What is needed? – A cost-effective tool to image karst compartments in the Arbuckle Group Saline Aquifer
  - **Volumetric Curvature (VC) Analysis**

# Volumetric Curvature (VC) Analysis

- **Curvature – A measure of the bending of a surface (~2nd derivative of the surface).**



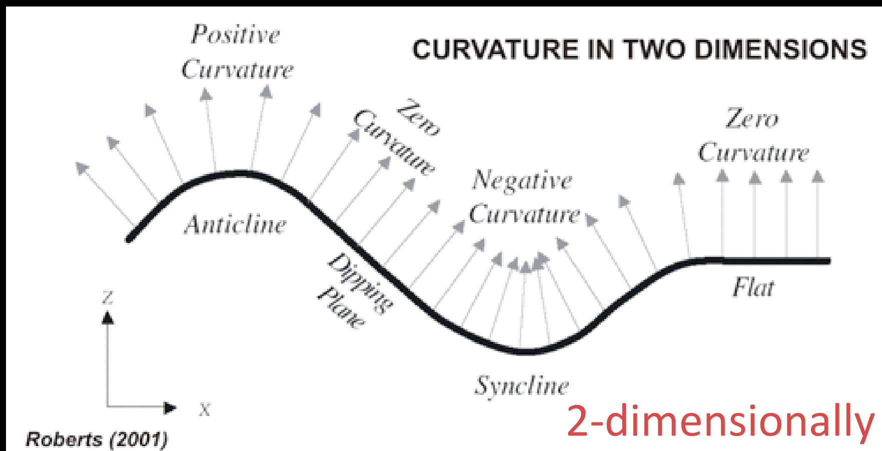

**May be computed at any azimuth about a point**

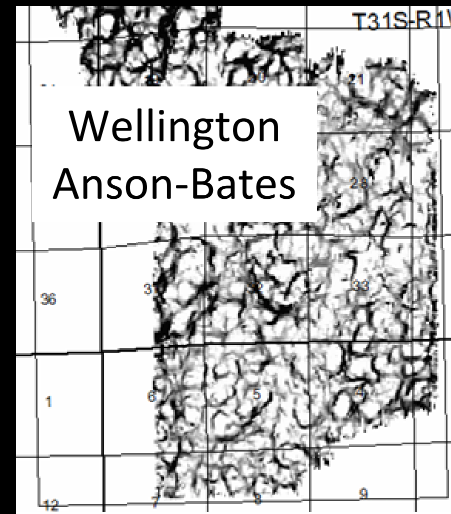
**Generally computed normal to tangent plane**

**<u>Principal Curvatures</u> ($k_{max}$ and $k_{min}$) can be combined to define other curvature attributes**

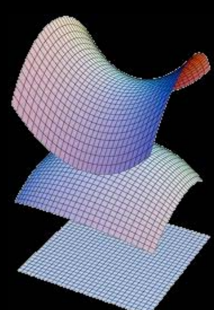
- ***Most-positive* and *most-negative curvatures*, which measure the maximum positive and negative bending of the surface at a given point, are the most useful for delineating subtle faults, fractures, flexures, and folds.**

# Volumetric Curvature (VC) Analysis

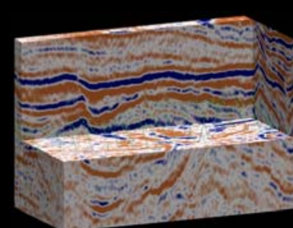



curvature map



3-dimensionally



volumetrically

V.C. used to infer:
- faults
- fracture swarms
- fracture sets
- flexures
- sags
- paleokarst

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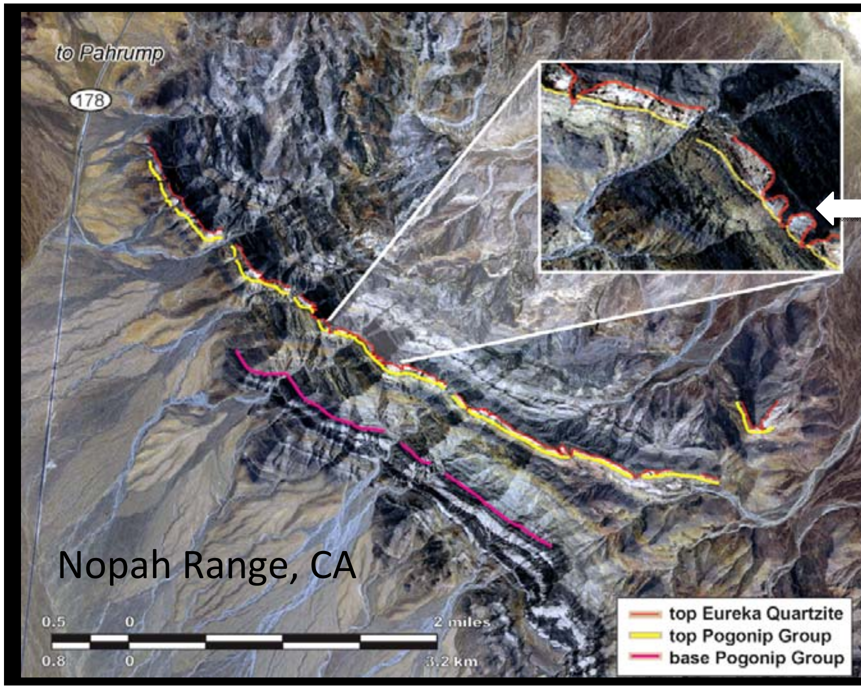
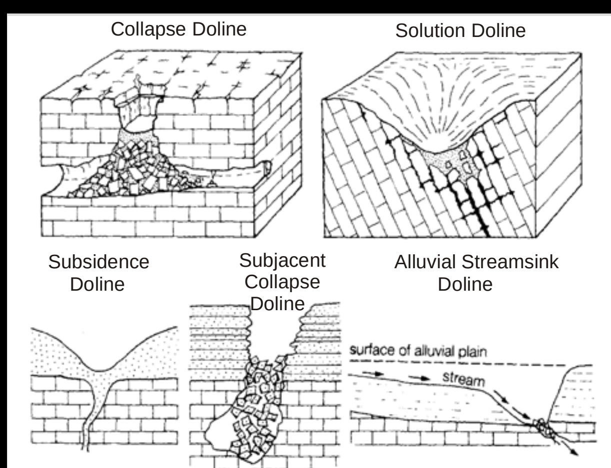
# Arbuckle Outcrop Analog

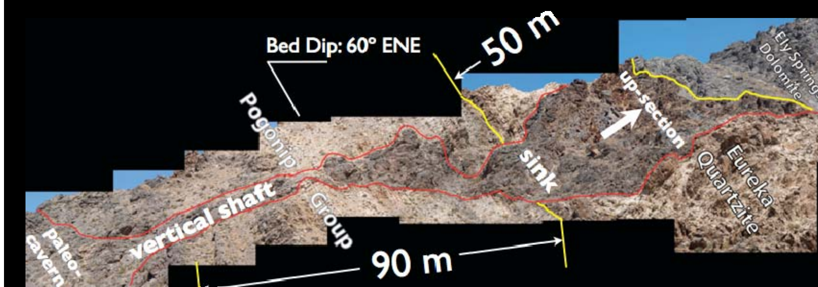
## Ordovician Paleokarst Architecture & Heterogeneity

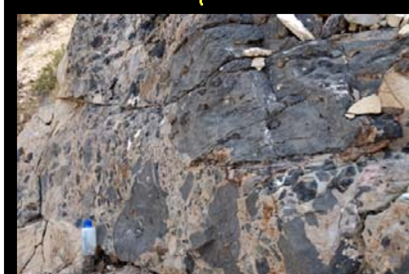



*seismically image impedance contrast*




cross-cuts reservoir bodies with different petrophysical properties



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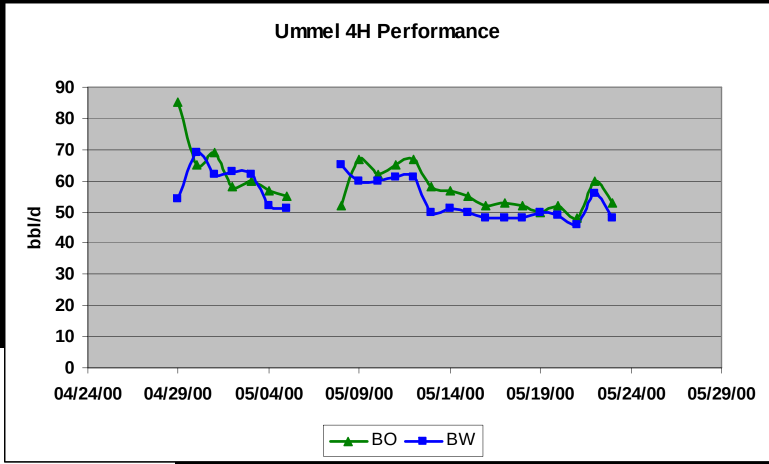
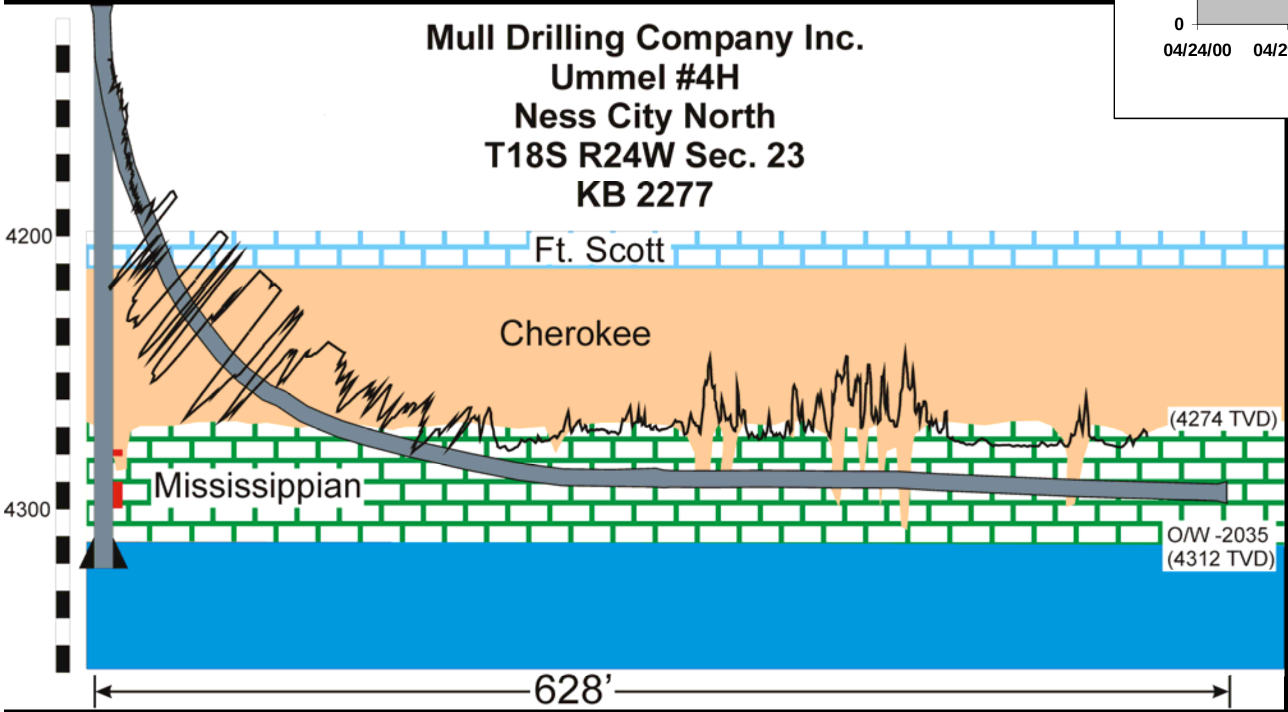
# Evidence of Karst Compartments – DOE funded

## Mississippian Carbonate Reservoir - Kansas



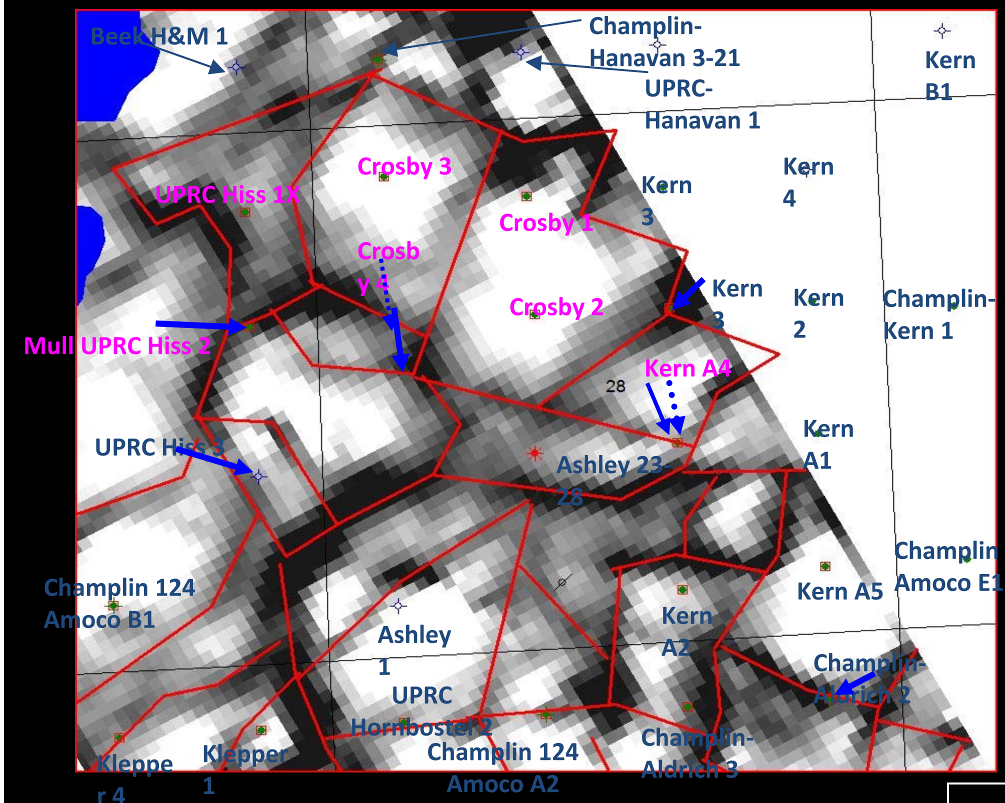



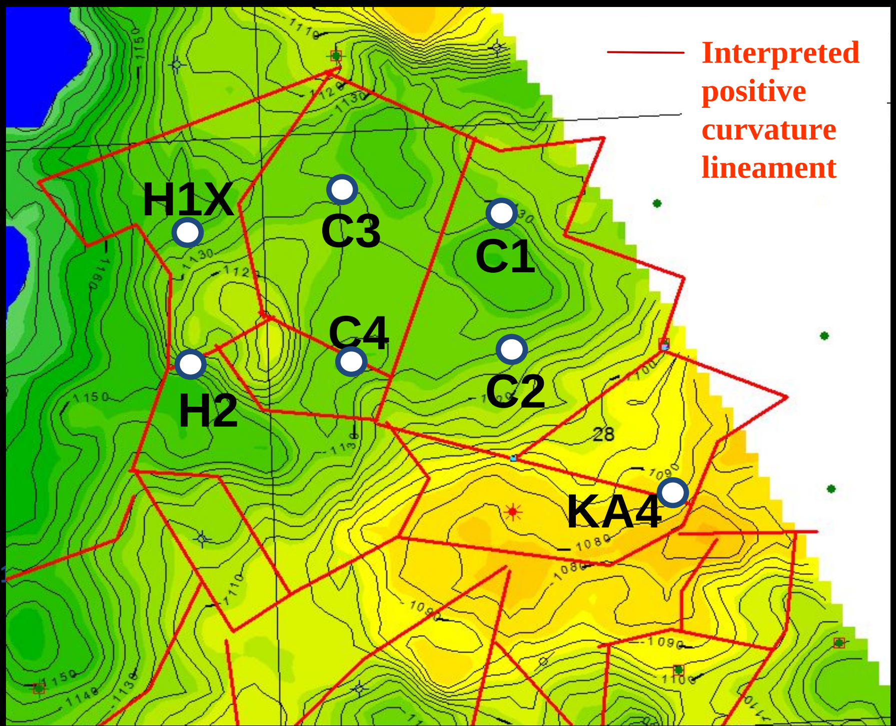

- Well produced openhole for 1 month
- Sudden stop of all fluid production
- Suspect collapse of karst fill in lateral
- Hole cleanup complicated by lost bit

# Previous Application of VC Analysis – DOE funded

## Smoky Creek Field, Cheyenne County, Colorado

Most +ve curvature




Top Spergen Subsea Depth (CI = 5 ft)

Significant production variability between adjacent wells

**RFs – 40 acre spacing**

C1 = 178.5% C2 = 14.9% C3 = 81.8%

C4 = 36.0%

H1X = 40.6% H2 = 48.6% KA4 = 50.5%

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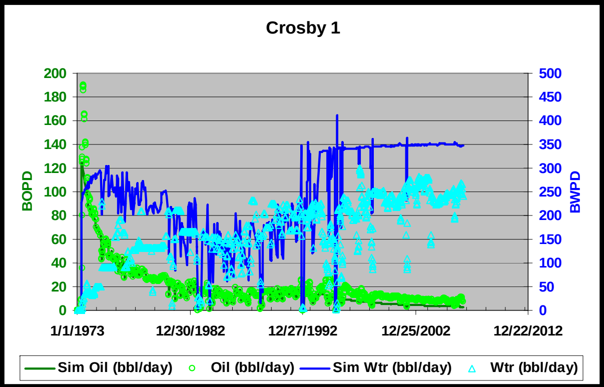
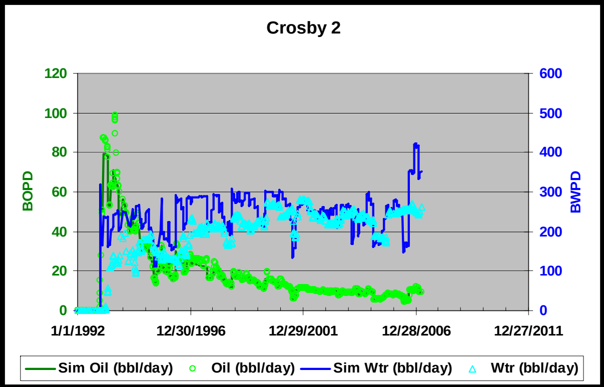
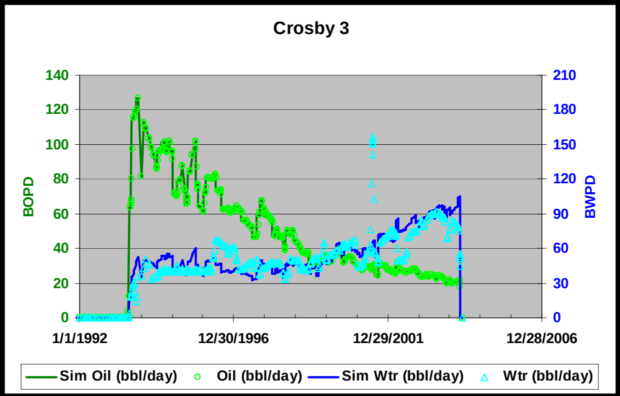
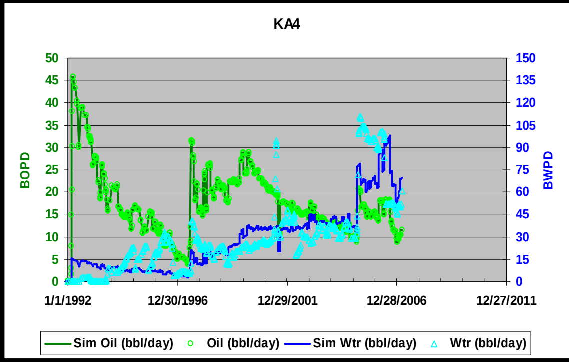
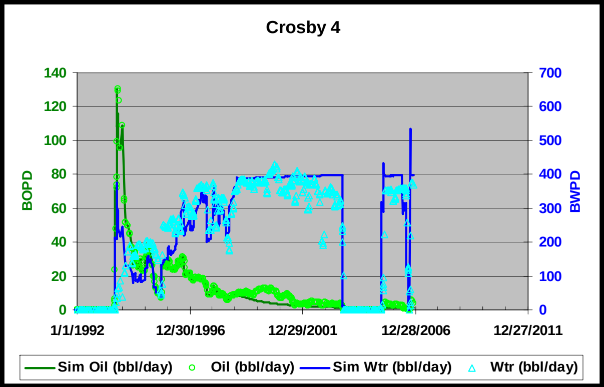
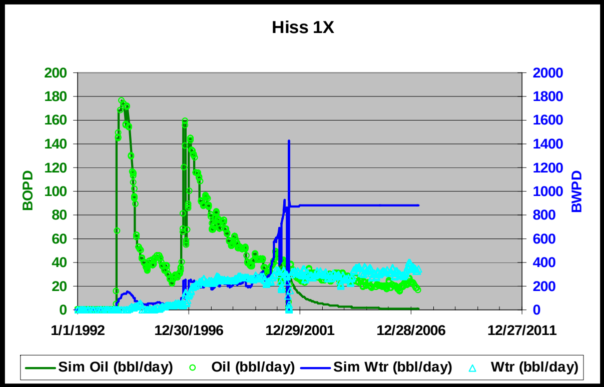


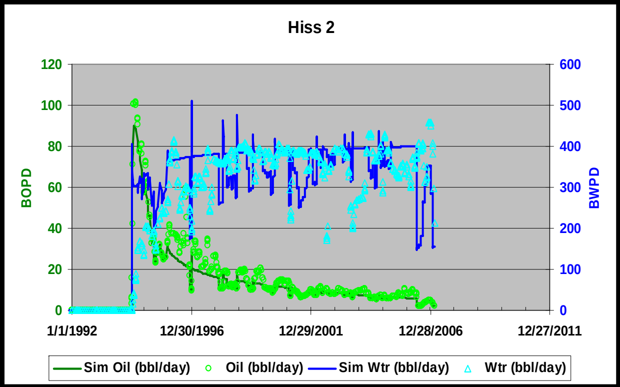



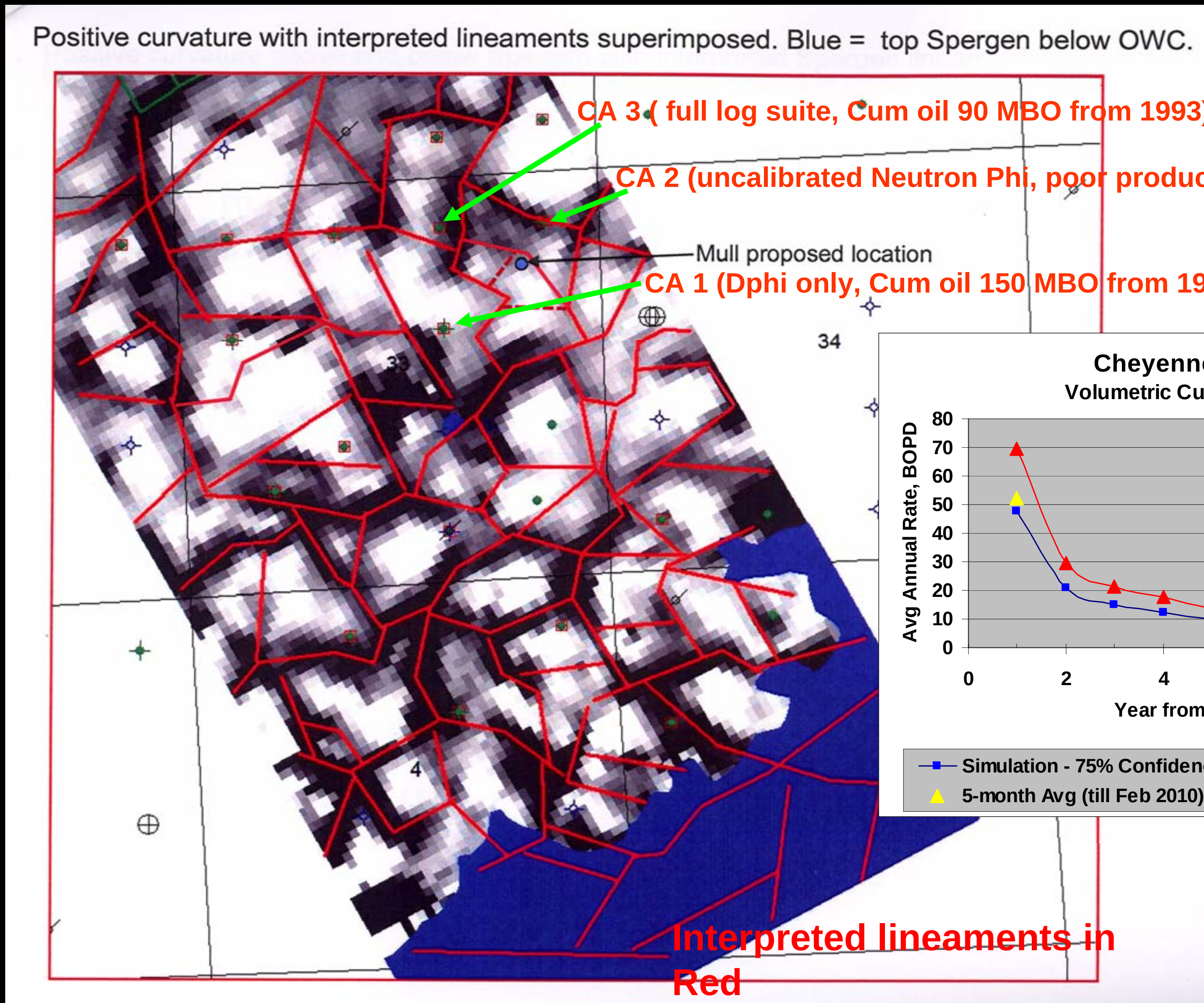



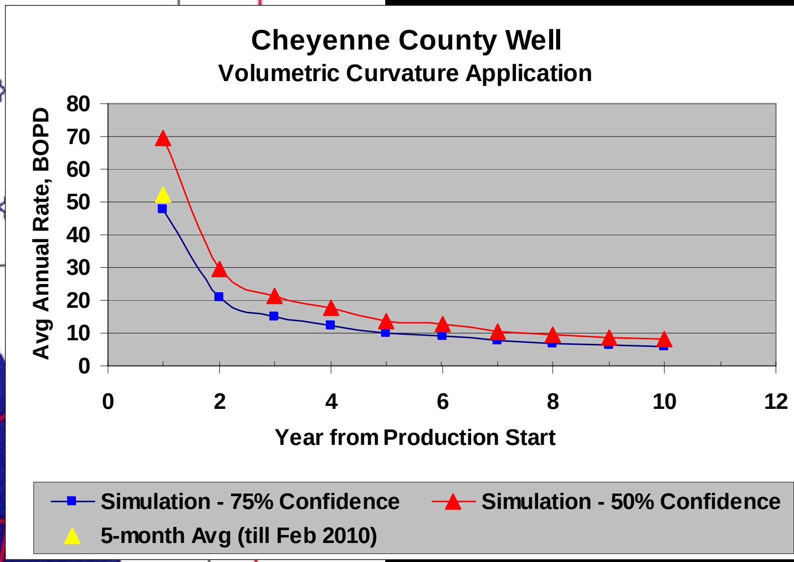



# Previous Application of VC Analysis – DOE funded

## Cheyenne Wells Field, Cheyenne County, Colorado

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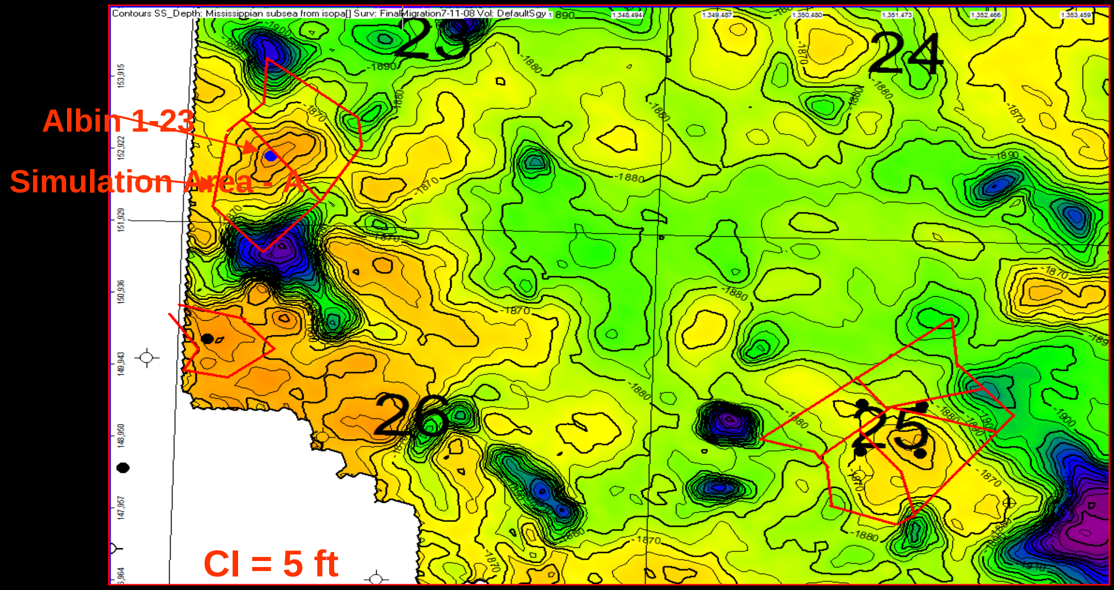
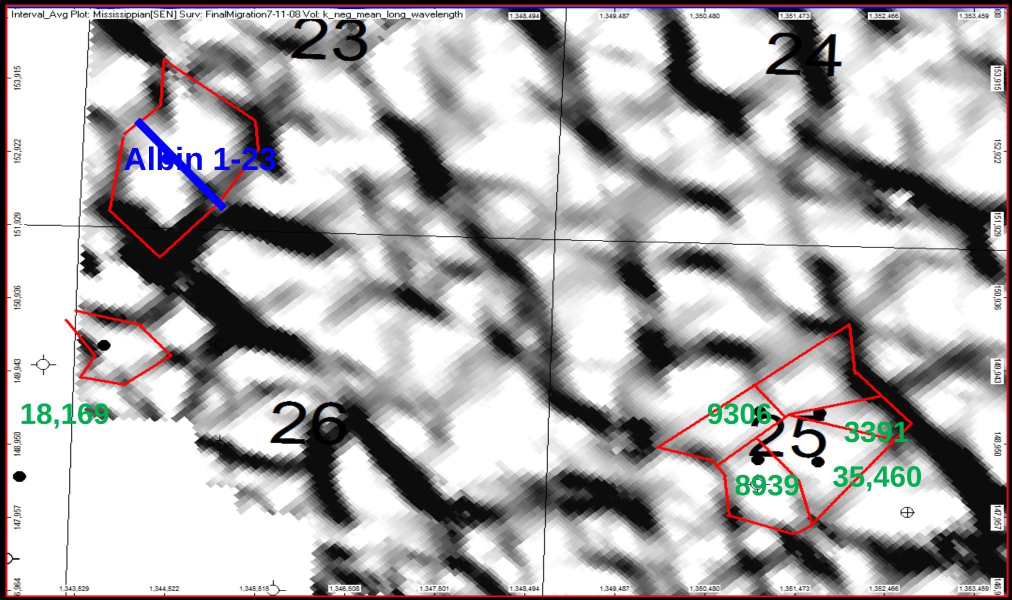
# Previous Application of VC Analysis – DOE funded

## Wildcat Well (Albin 1-23), Gove County, Kansas




Mississipian Subsea, ft




Most –ve curvature map

# Previous Application of VC Analysis – DOE funded

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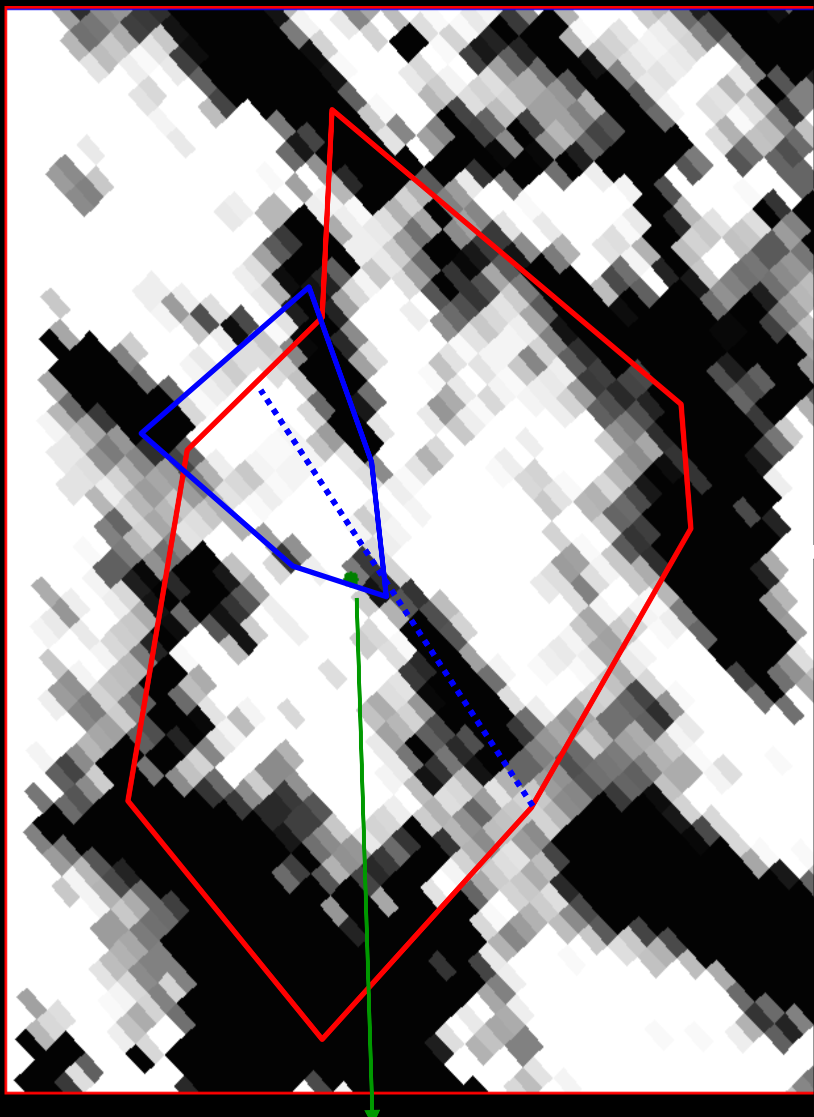
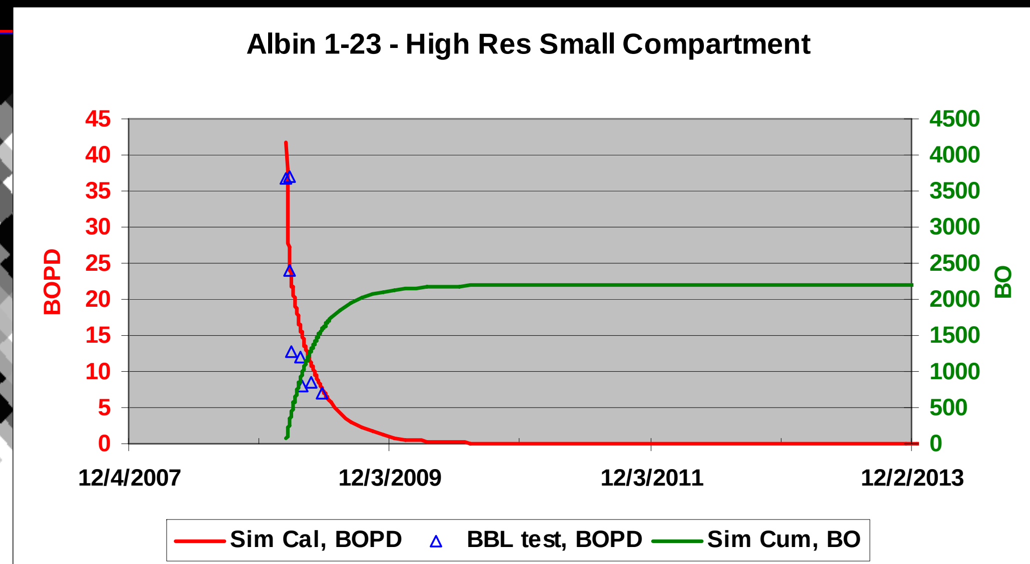
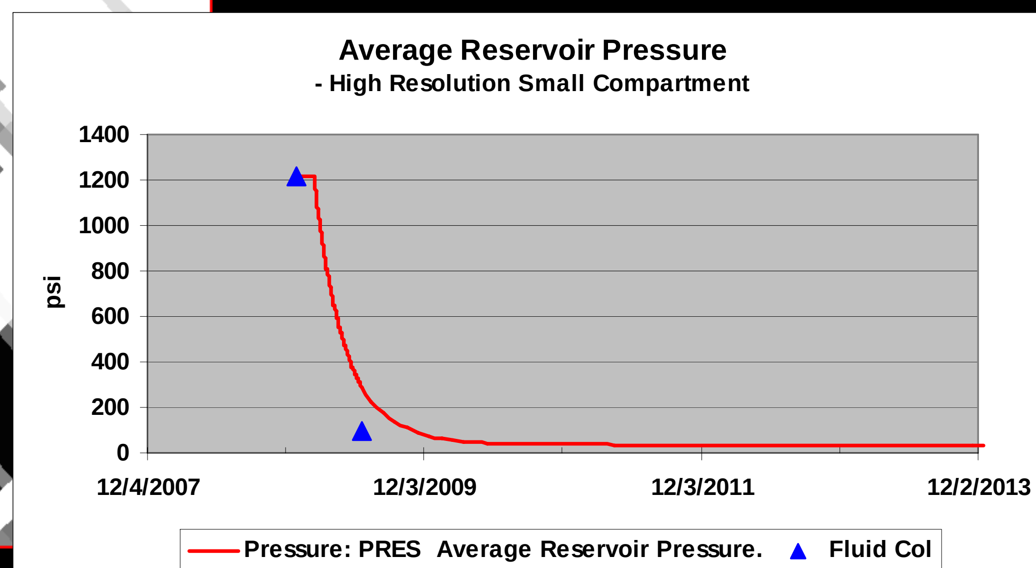
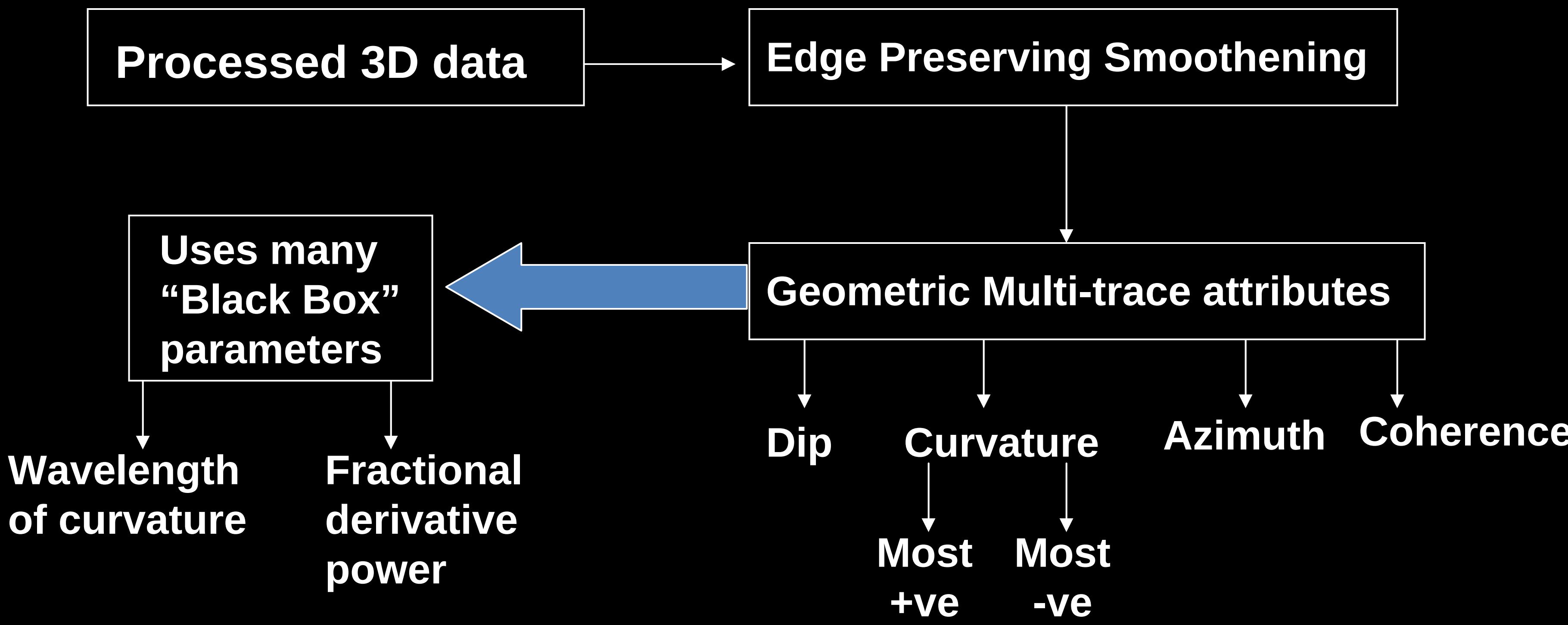


Albin 1-23



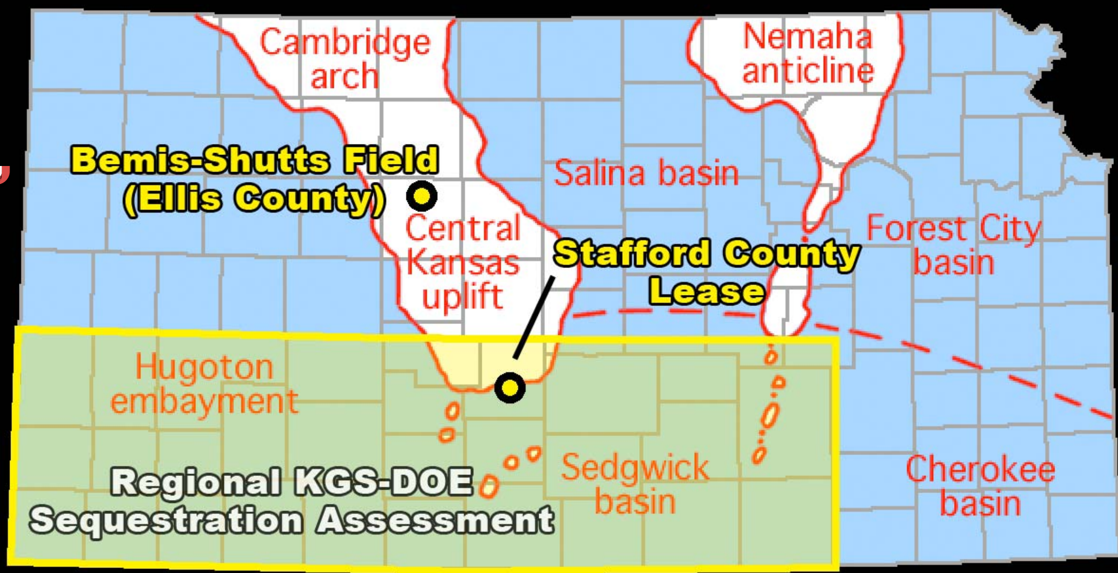



# Volumetric Curvature Analysis - Workflow

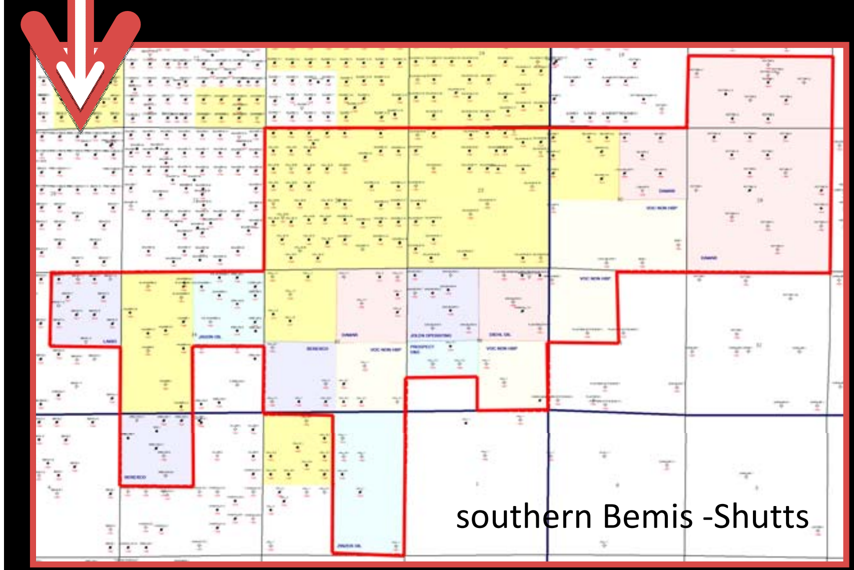



Companies that generate curvature attributes – GeoTexture, Resolve etc.

# Study Area




**Stafford County Lease**
- Mississippi production
- Seismic geometries - evidence of paleokarst
- Industry partner - Murfin
- Seismic donation: 10 $mi^2$
  - cost match: $




**Bemis-Shutts Field**
- Arbuckle production
- Compartmentalized
  - Variable production from adjacent wells
  - Offsetting dry holes – water production
- Seismic geometries - evidence of paleokarst
- Industry partner - Vess-Murfin (MVP LLC)
- Seismic donation : 9.8 $mi^2$
  - cost match: $

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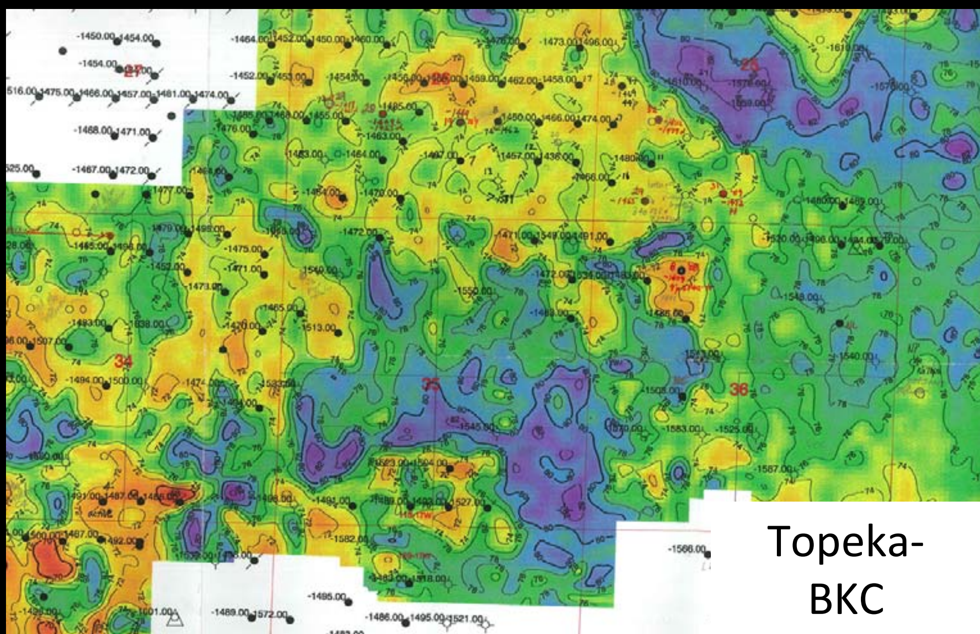
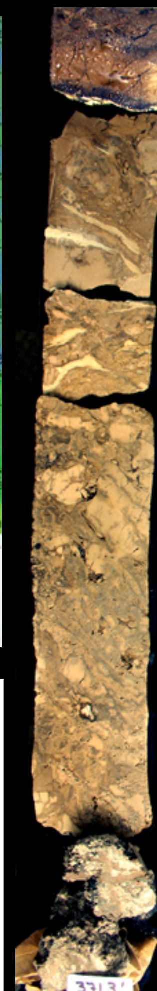
# Study Area 1 - Bemis-Shutts Field

*Seismic Geomorphology, Cores, & Production consistent with  Paleokarst*



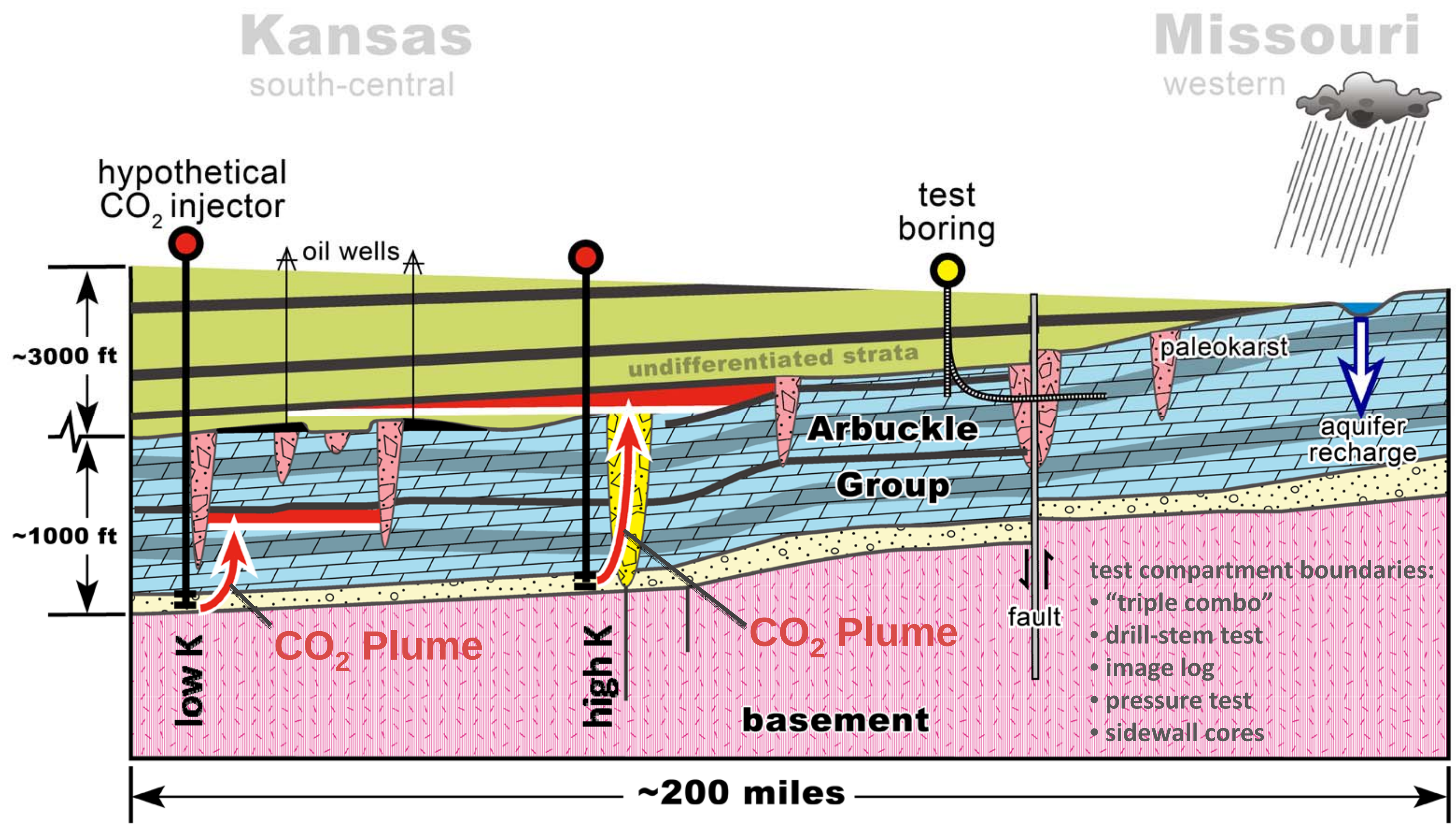





re-entrants, internal sags, and breccias indicate paleokarst

# Arbuckle Model – Bemis-Shutts Field

*Proposed test boring concept*

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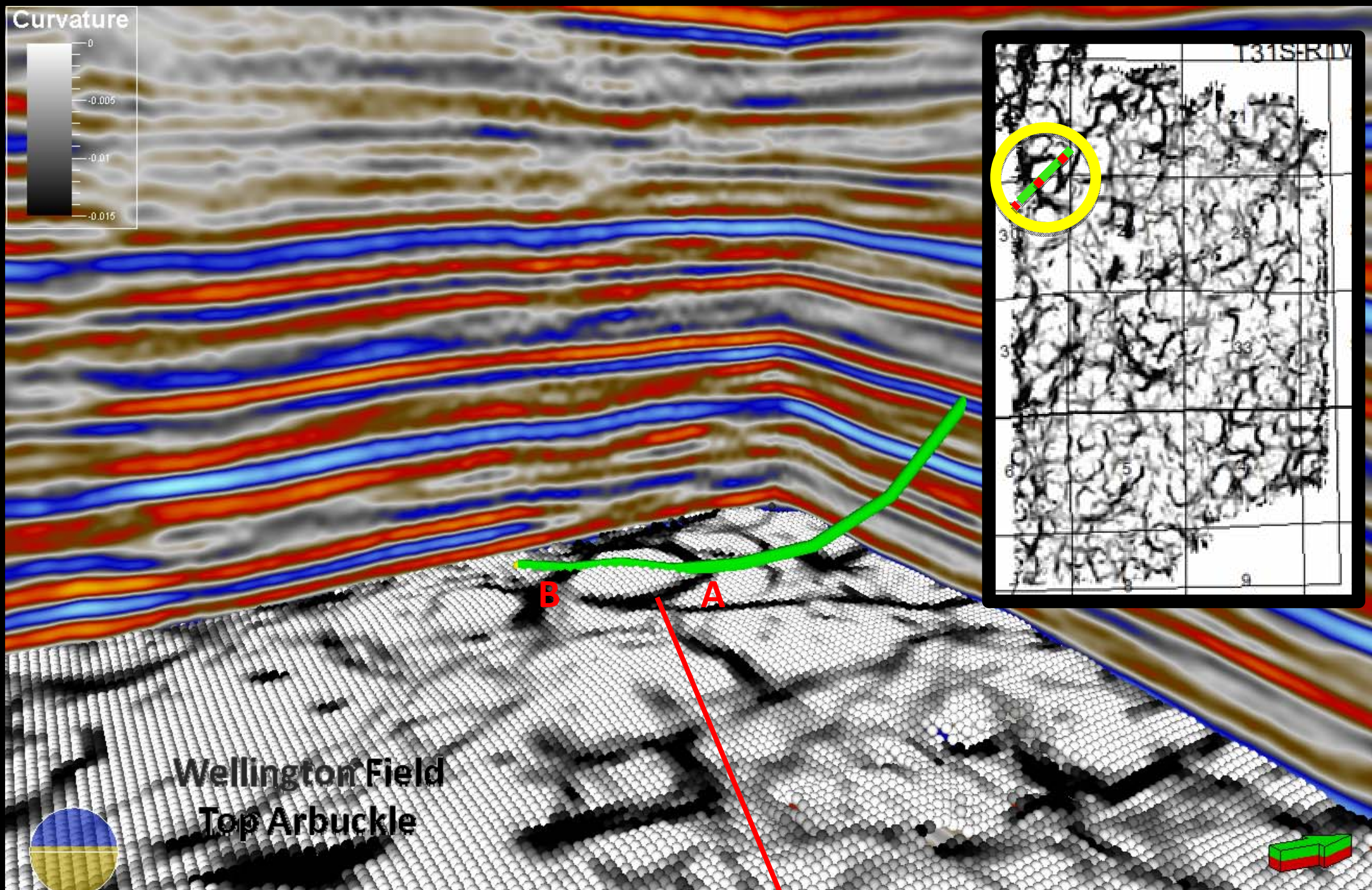
# Proposed Well Placement – Using Wellington VC Analysis

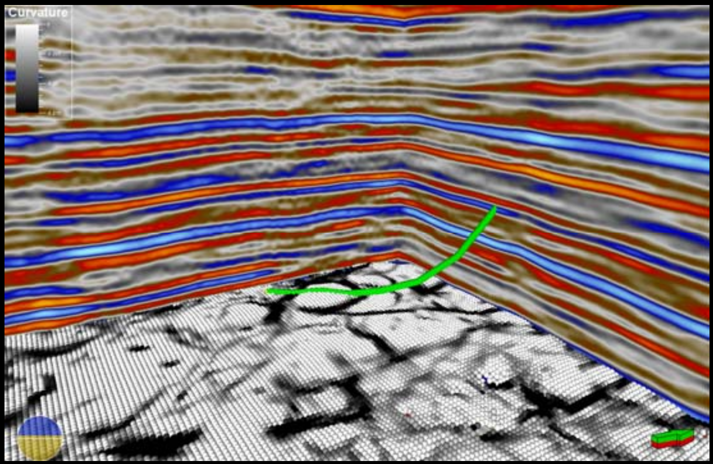
*Paleokarst compartments identified from volumetric curvature (VC) analysis*




Prospective paleokarst compartment

# Pre-Spud Evaluation
## Oct 2010 to Apr 2011

- **Reprocess seismic**
- **Seismic interpretation**
- **Generate volumetric curvature**
  - **Identify karst compartments**
- **Build initial geocellular model**
- **Simulate & history match - performance of existing wells located in identified compartments**
- **Locate test boring**



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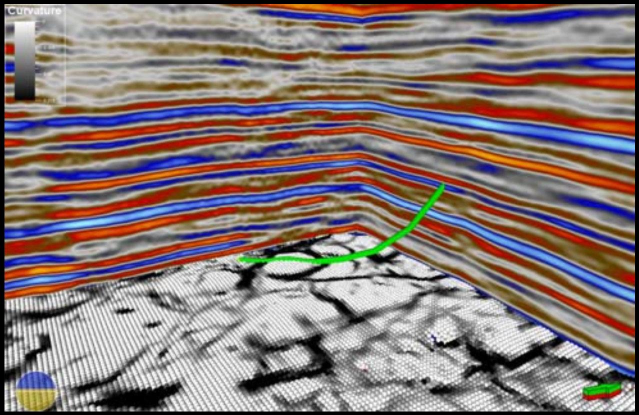
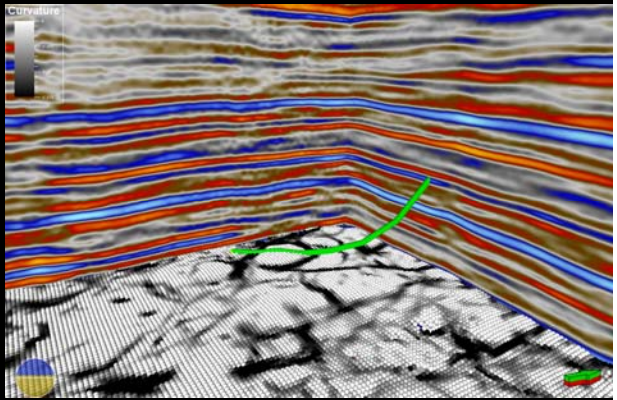
# Drilling Program
## May 2011 to Sep 2011



- Permit well
- Drill & set intermediate casing
- Drill vertical pilot hole to Arbuckle
- Log (“triple combo” & sonic)
- Drill-stem test
- Set plug
- Kick-off – depth dependent on VC interpretation
- Land well uppermost 40’ Arbuckle - directional tools
- Case to landing point
- Drill horizontal lateral (<1500-ft) - directional tools
- Condition hole for logging

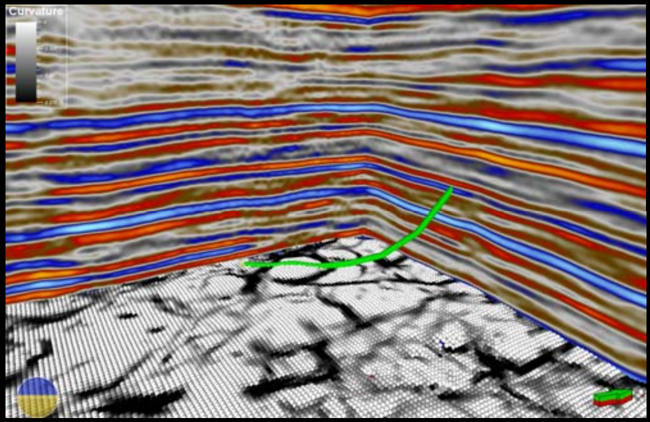
# Wireline Logging Program

- **Vertical pilot (free-fall wireline)**
  - “triple combo”- GR, resistivity, neutron-density
  - full-wave sonic – for synthetic seismic & vuggy porosity
- **Horizontal lateral (tool-push wireline)**
  - “triple combo”
  - image logging
  - pressure tester & fluid sampler
    - within and across the karst compartment boundary
  - rotary sidewall coring
    - within and across the karst compartment boundary



# Validate Karst Compartment Boundary
# Oct 2011 to Sep 2012

- **Explore what geological feature is being imaged by VC analysis – is it a FLOW/NO-FLOW boundary?**
  - **Image analysis**
  - **Pressure analysis**
  - **Fluid chemistry**
  - **Sidewall cores**



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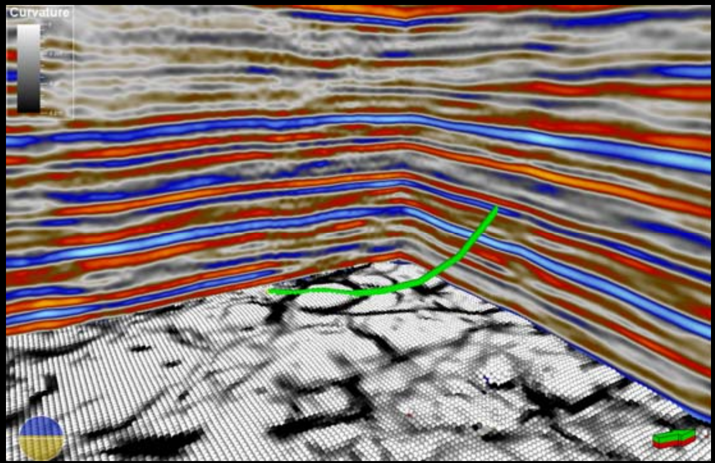
# Validate and Optimize VC Model
# Nov 2011 to Feb 2012

- Reprocessing
- Time-to-depth processing
- Horizon mapping
- Impedance inversion
- Synthetics
- Attribute analysis
  - Curvature analysis
  - Single & multi-trace
- Fault mapping
- Generate curvature volumes

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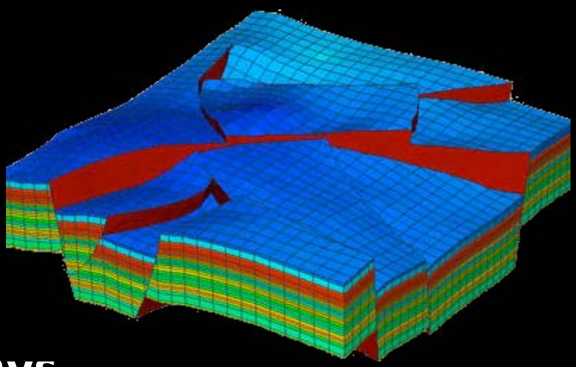
# Revise Geocellular Model

## Feb 2012 to Sep 2012

- Structural
  - Import seismic data & interpretations
  - Fault model
  - DFN
  - Transmissibility of karst compartment boundary – lateral and vertical
- Facies
  - Rock fabric (capillary pressure-specific)
  - Stratigraphic (zones & layering)
  - SIS, facies-based, with 3D property trends
  - Paleokarst facies model
    - Overprint facies model
- Analyze and identify possible leakage pathways
  - Fault offset and seal juxtaposition
  - Shale gouge ratio



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# Reservoir Simulation Studies

## Oct 2012 to Sep 2013

- **Incorporate petrophysical properties of karst fill (compartment boundary)**
  - **Horizontal & vertical permeability**
  - **Capillary pressure curves**
  - **Relative permeability including hysterisis end-points**
- **Evaluate $CO_2$ sequestration potential in Arbuckle Group Saline Aquifer**
  - **Long-term effectiveness of cap rock**
  - **Tonnage of $CO_2$ sequestered in brine (solution)**
  - **Tonnage of $CO_2$ sequestered as residual gas**
  - **Tonnage of $CO_2$ sequestered by mineralization**
- **Simulate permanence of $CO_2$ sequestered in Arbuckle Group Saline Aquifer**
  - **Plume leakage/containment at karst compartment boundary**
  - **Plume growth and migration – near- and long-term**
    - **Plume attenuation with time**

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