3-D Geologic Modeling Toward a Site-Specific CO_2 Injection Simulation*

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Abstract

A solid geological model at reservoir scale is the key starting point toward a site-specific characterization of a CO2 sequestration target. In the Dickman Field of Ness County, Kansas, a 3D structure and property model was built for depleted reservoirs of carbonates and clastic rocks through multi-scale data integration. Work flows were designed to handle some of the challenges commonly involved in geological modeling at the reservoir-scale: targeting geological features normally considered as “sub-seismic” and beyond the resolution of conventional seismic stratigraphy; recognizing the lateral heterogeneity in acoustic properties of laterally interwoven clastics and carbonate lithologies on a karst-modified paleo-topography to restore true subsurface geometry; calibrating legacy well logs to obtain reservoir properties with quantified risk assessments; and extracting a fault-fracture framework from multiple seismic attribute volumes to guide the reservoir property gridding.

As a first step, a depth-converted stratgraphic model was established and validated by log interpretations at 17 well sites. Fault and fracture analysis was based on seismic interpretation and volumetric attributes, supported by log and core evidence and understanding of the regional deformation history. A unique set of porosity was assigned to the stratigraphic model through calibrating porosity logs of different types and correlating log to core measurements. Permeability estimation was based on core measurements available in Dickman and the surrounding oil fields. Water saturation measured from flushed cores was calibrated to the in-situ water saturation. The propagation of these reservoir properties through the model was along preferred orientations guided by fracture and acoustic impedance analysis. The resulting property grid was tested by production history-matching simulation. A reasonable match was obtained after two rounds of input parameter adjustment and the inclusion of a capillary zone in the model.

The initial geological model built from heavily drilled reservoirs was extended to deeper saline aquifers with only three-well control, aided by 3D seismic impedance analysis. The grid served as input to CO_2 injection simulations for the deep saline aquifer, a potential carbon capture and sequestration target.

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  - Structure modeling
  - Property modeling
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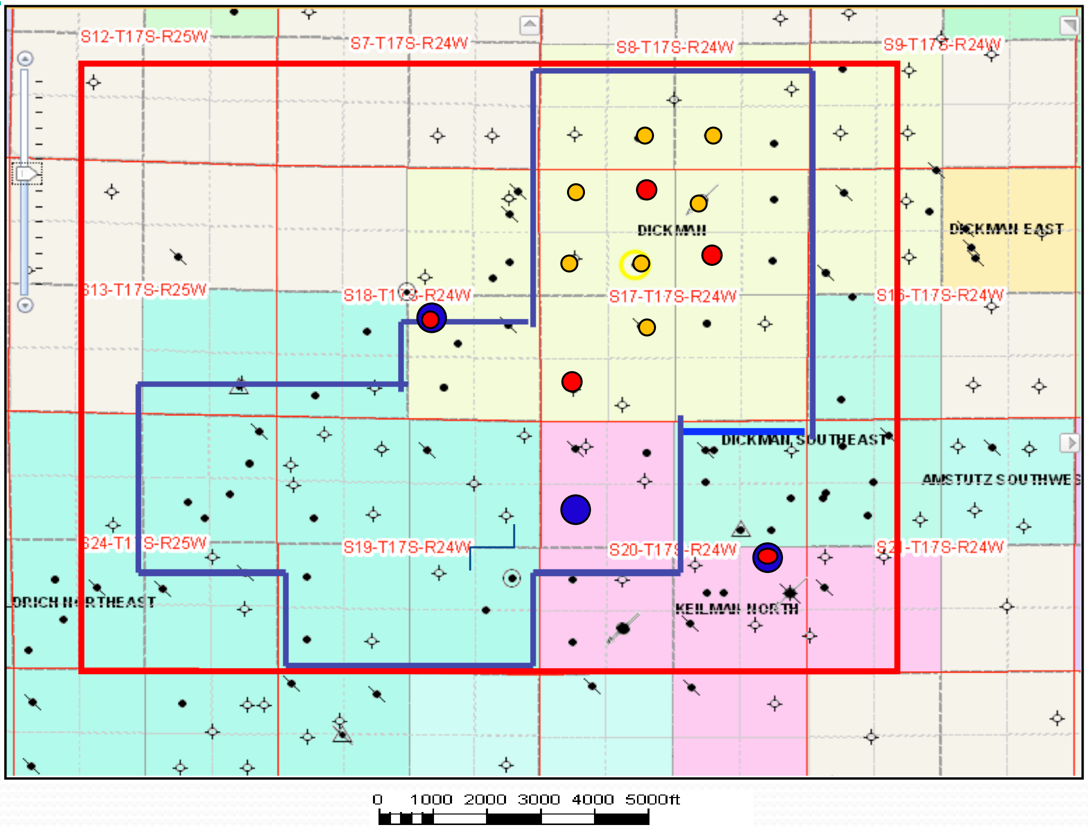
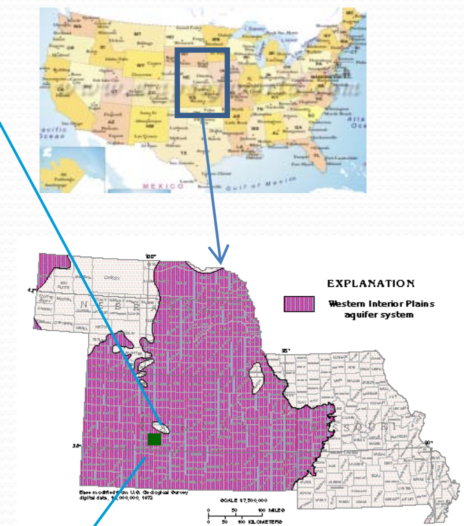
- **Conclusions and discussions**





Western Interior Plains Aquifer

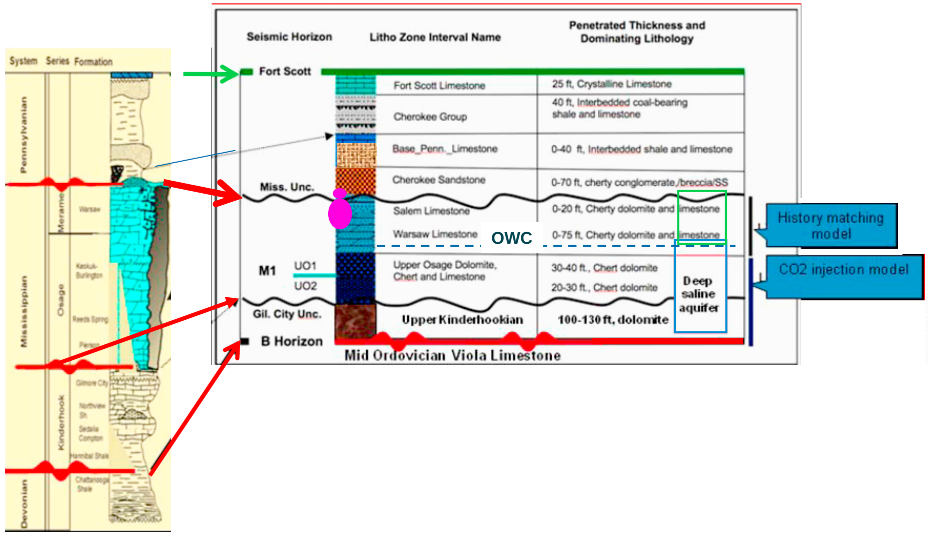
From Jorgensen, D. G. et. al., 1993: USGS professional Paper

Simulation area(6.5 Sq mile) 3D seismic(3.2 Sq mile)

- Three wells with full penetration
- Five wells with sonic logs, no VSP
- Seven wells with cores from reservoir (103 samples)

Three DST logs, 15 wells with production records (6 with both oil and water rates)

Targeted Stratigraphic Windows



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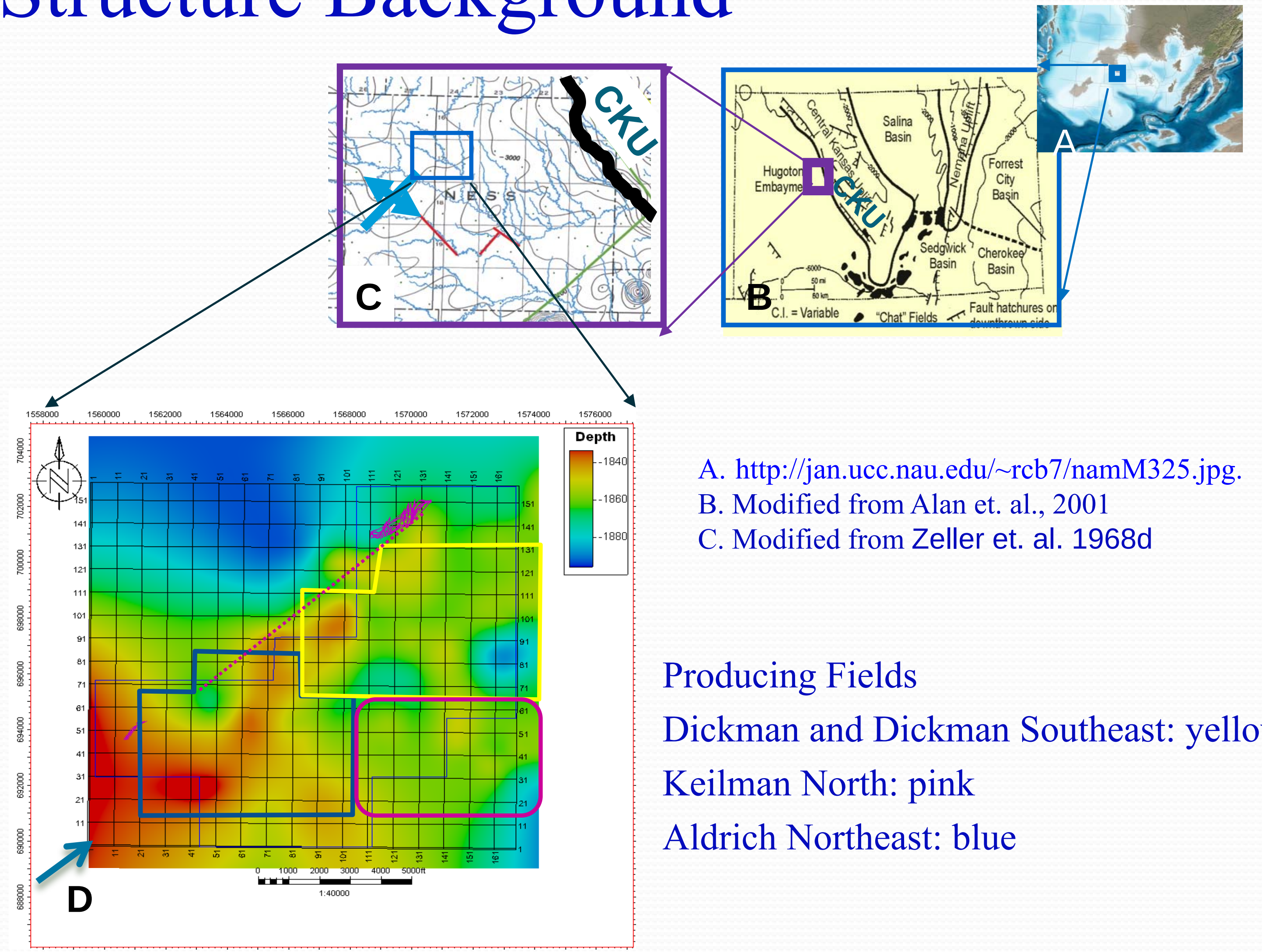
Presenter's notes: Regional (Left) and local (RIGHT) stratigraphic columns showing the targeted windows for geological modeling and history-matching and CO2-injection simulations. The entire vertical window of model is about 220-250 ft in depth (35-40 ms) from the Fort Scott Limestone as hanging datum, to the Gilmore City Limestone top, and then extended to 380 ft (about 60 ms) downward to the Undifferentiated Ordovician, the top of Viola Limestone formation. Symbols in red indicate major and local or minor Unconformities.

Structure Background



A. http://jan.ucc.nau.edu/~rcb7/namM325.jpg.
B. Modified from Alan et. al., 2001
C. Modified from Zeller et. al. 1968d

Producing Fields

Dickman and Dickman Southeast: yellow

Keilman North: pink

Aldrich Northeast: blue

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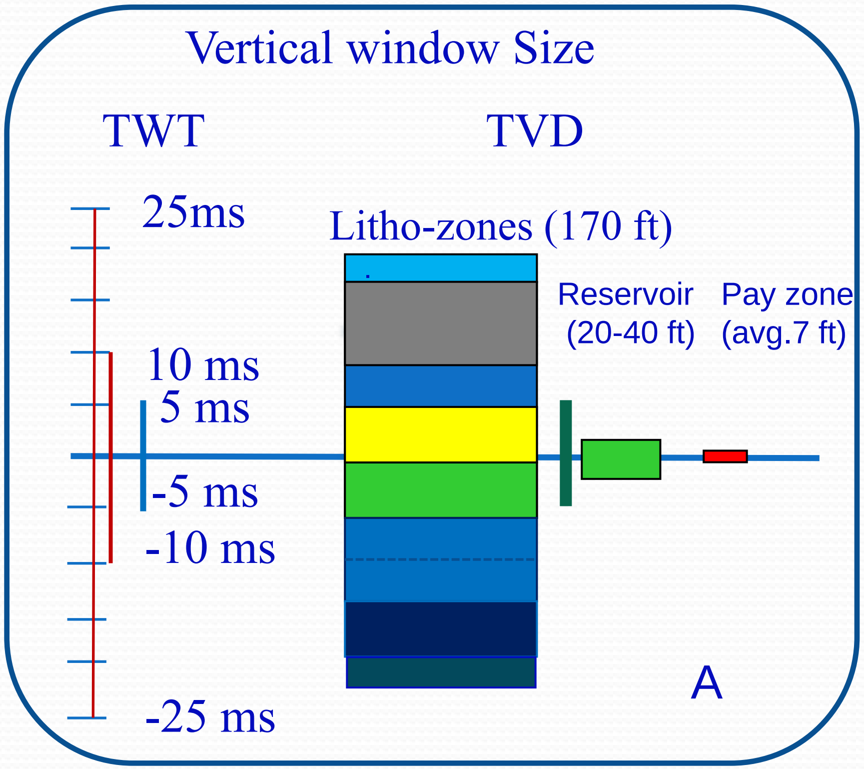
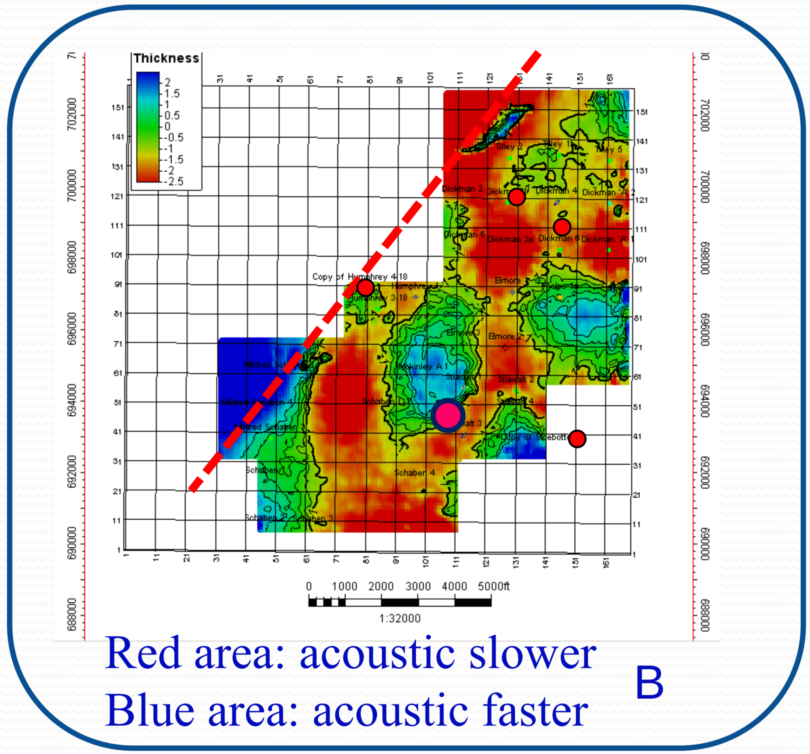
Challenges





A. “Sub-seismic” vertical heterogeneity
B. Lateral heterogeneity due to laterally interwoven lithologies near Miss. Unconformity

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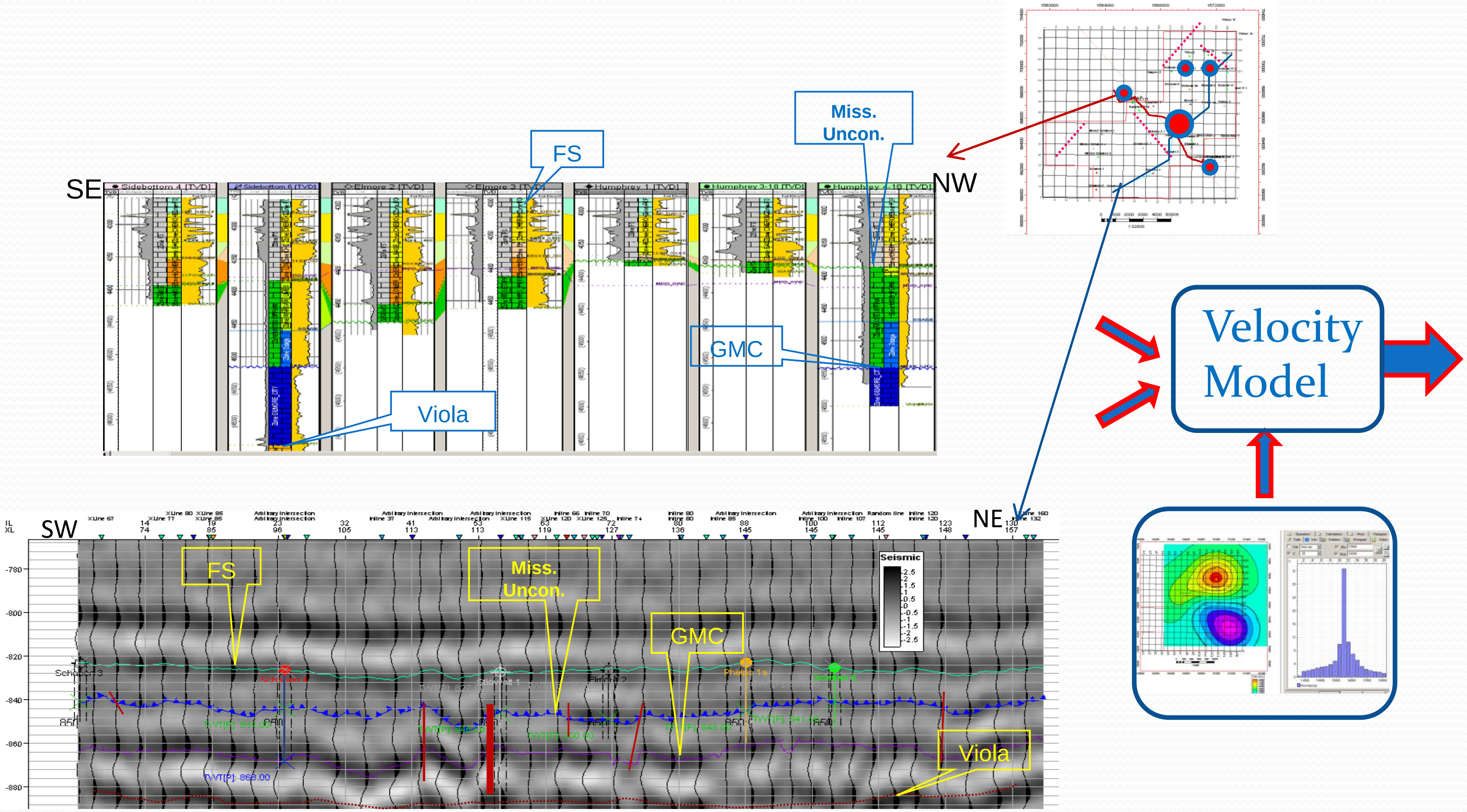
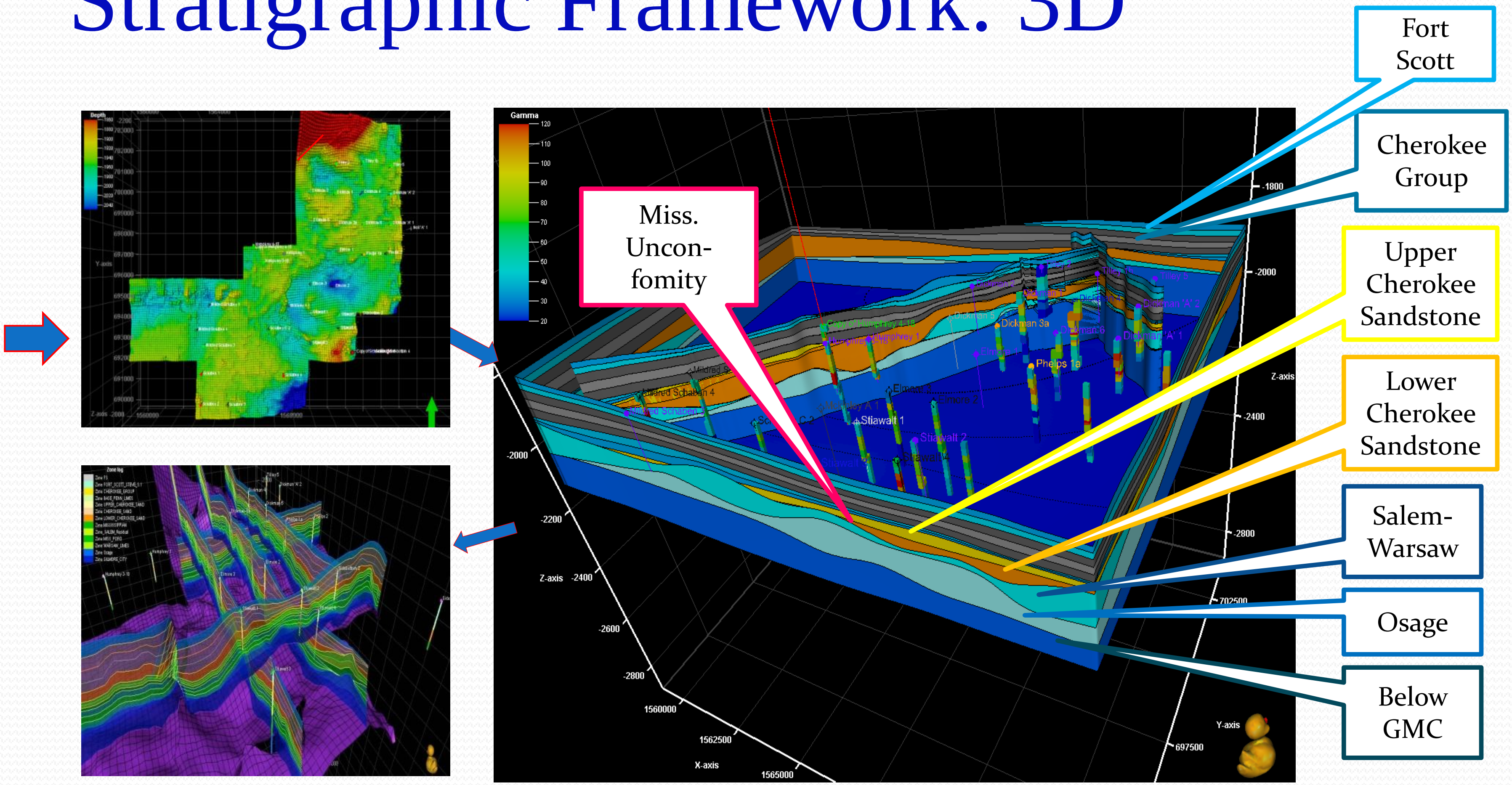
Stratigraphic Framework: 2D



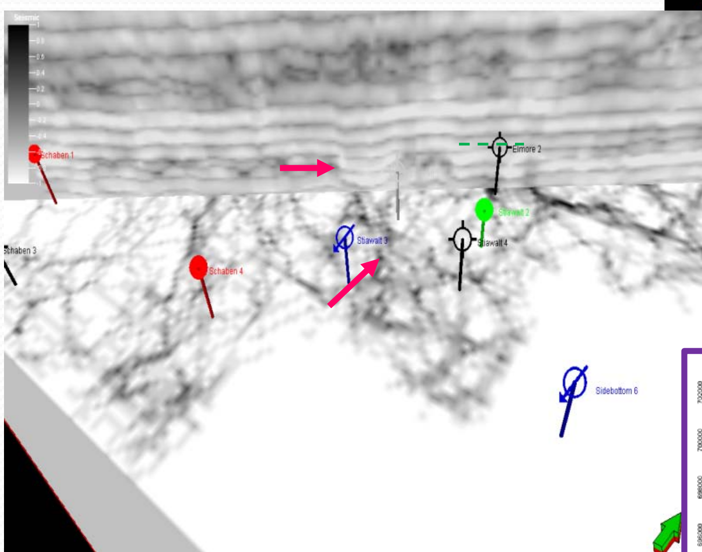
Stratigraphic Framework: 3D

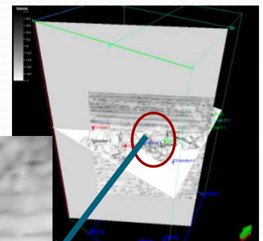


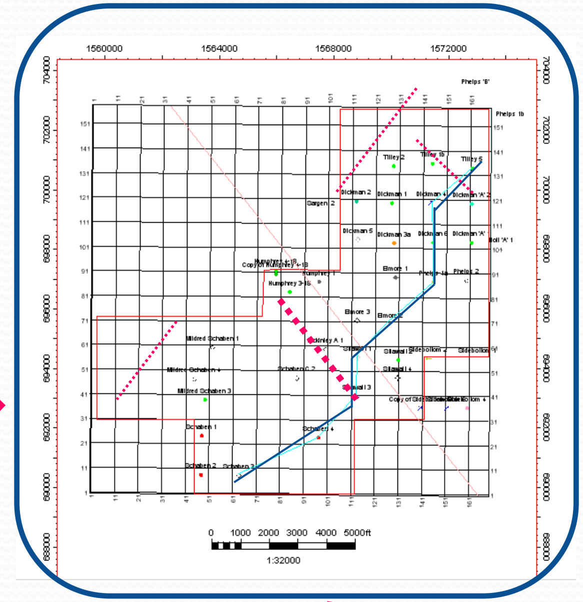
Right: Depth from -1800 to -2200 TVDss, horizontal: vertical scale = 1:10.

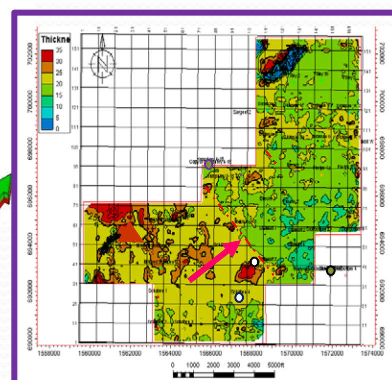
Cell height in sub-zoning (left) is correlated to the maximum detachability of seismic and validated by well data as much as possible.

Fault Interpretations

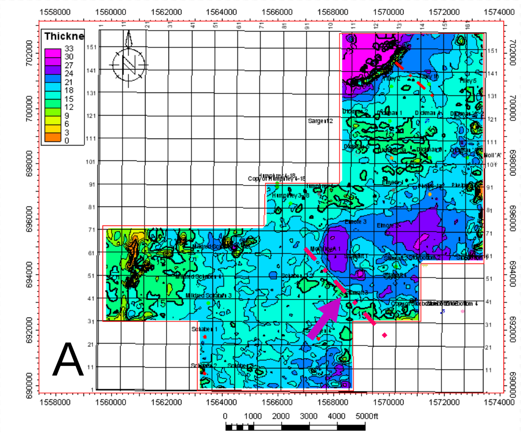


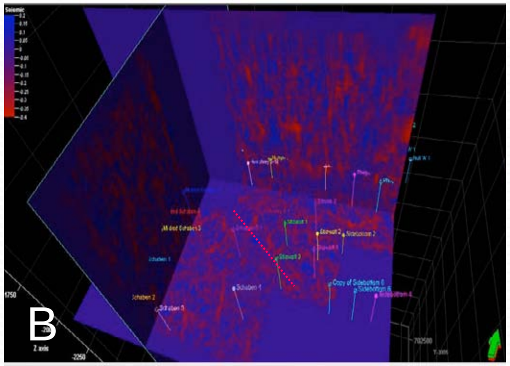


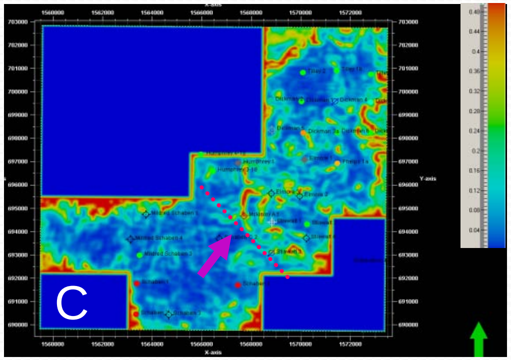


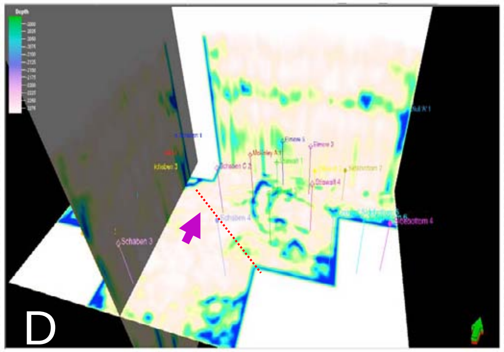


Fault Interpretation: Indirect Indicators









A. Isochron: deeper down-cutting of the Base Penn. channel (pink)

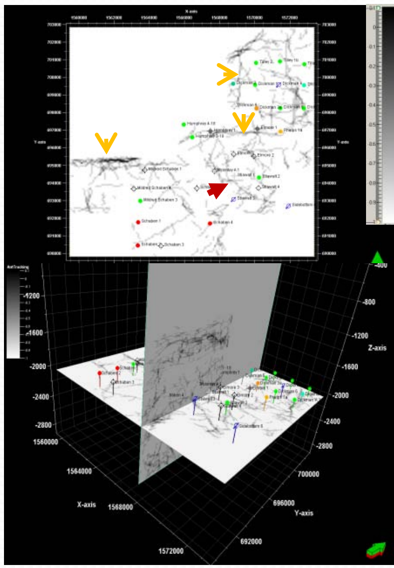
B. Depth slice and profile from maximum negative curvature, higher roughness in red

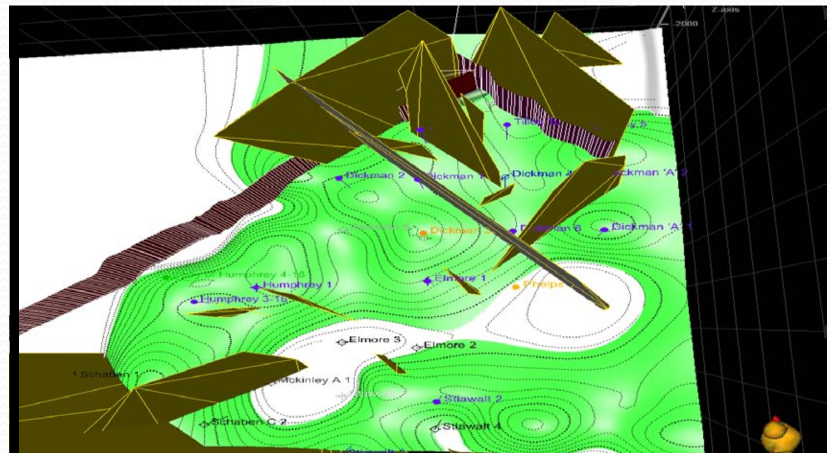
C. Depth slice from variance volume, high edges in red-yellow

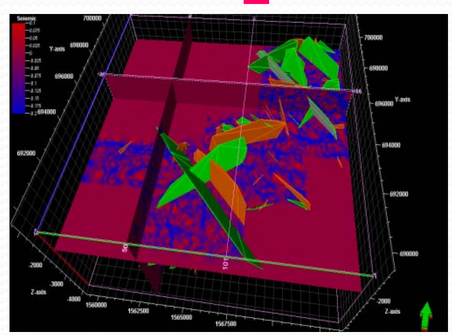
D. Depth slice and profile from chaos volume, high chaos in green

Fracture Interpretations

Attribute volumes used: ANT, maximum negative curvature, variance, chaos, coherence, dip.



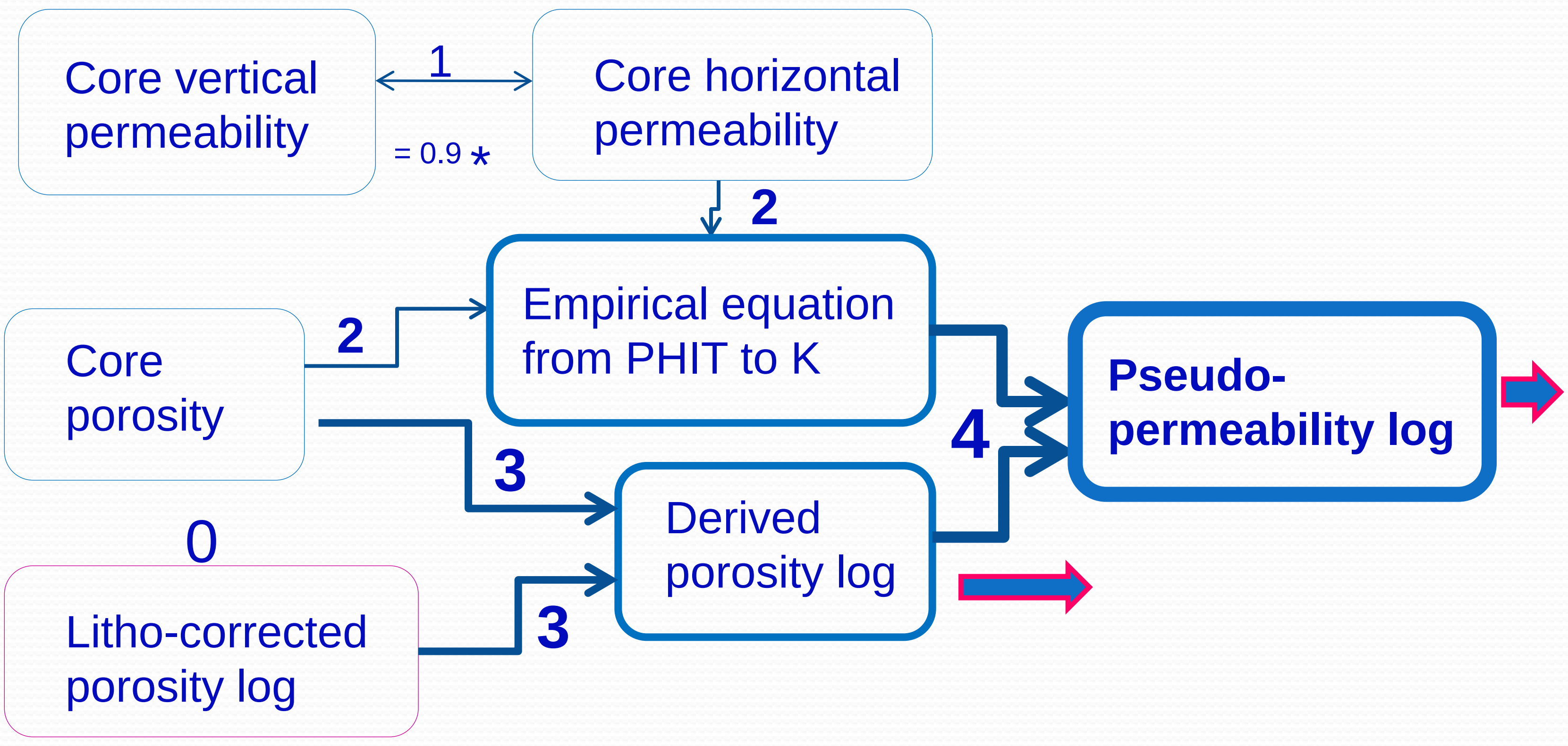




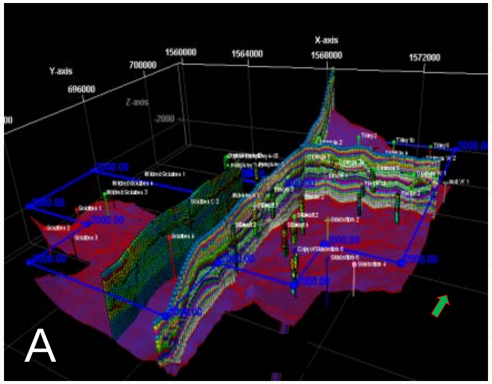
- Regional structure
- Models of carbonate deformation
- Observations

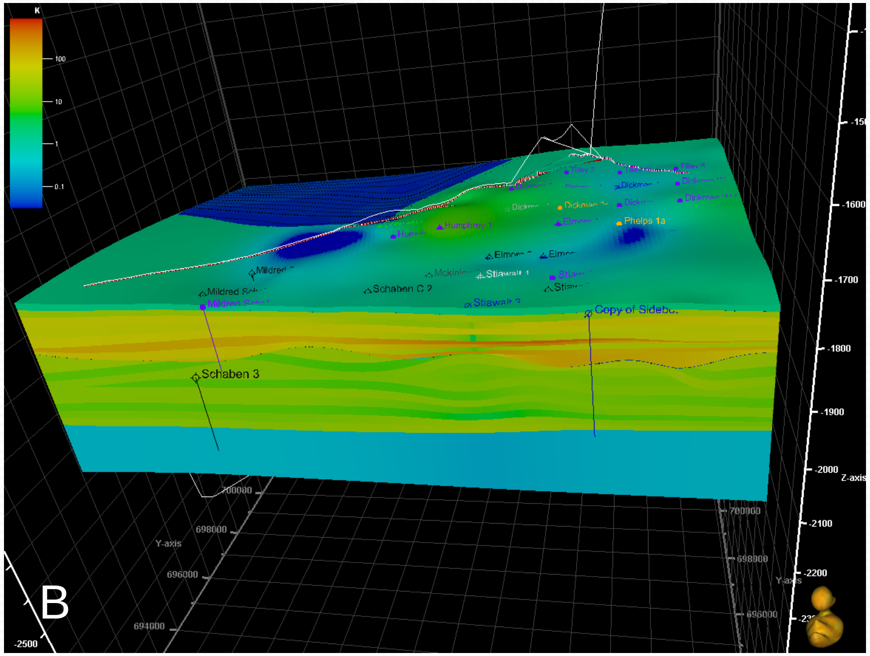
Indicators from
- Electric logs
- Drilling-time logs
- Cores
- Production records

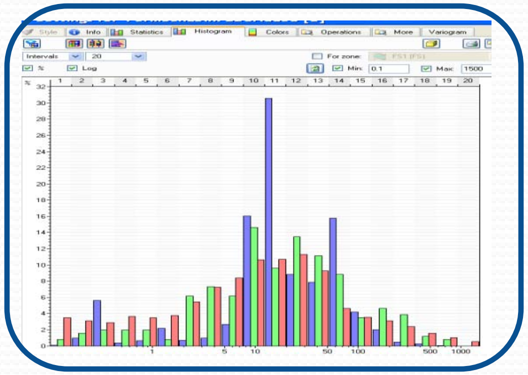
Property Modeling: Data Preparation



Property Gridding

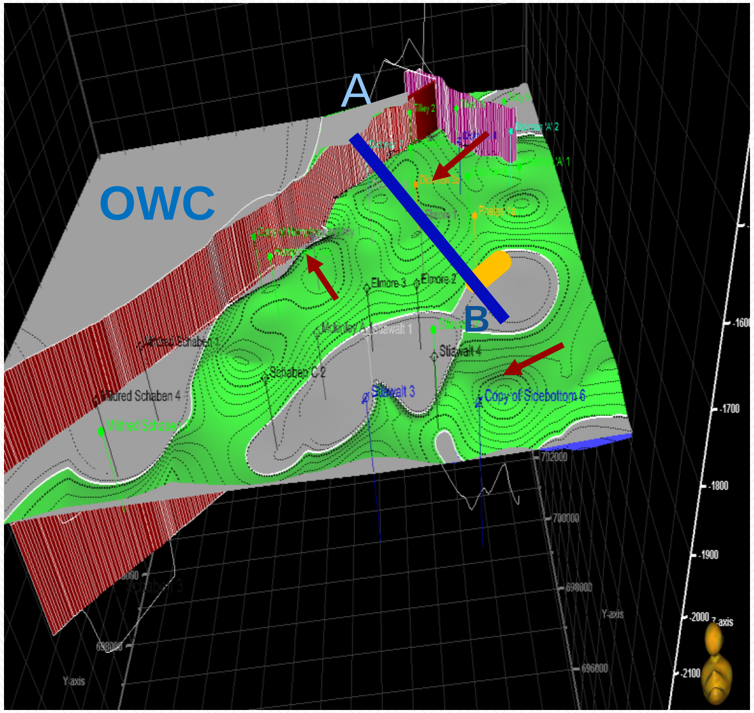


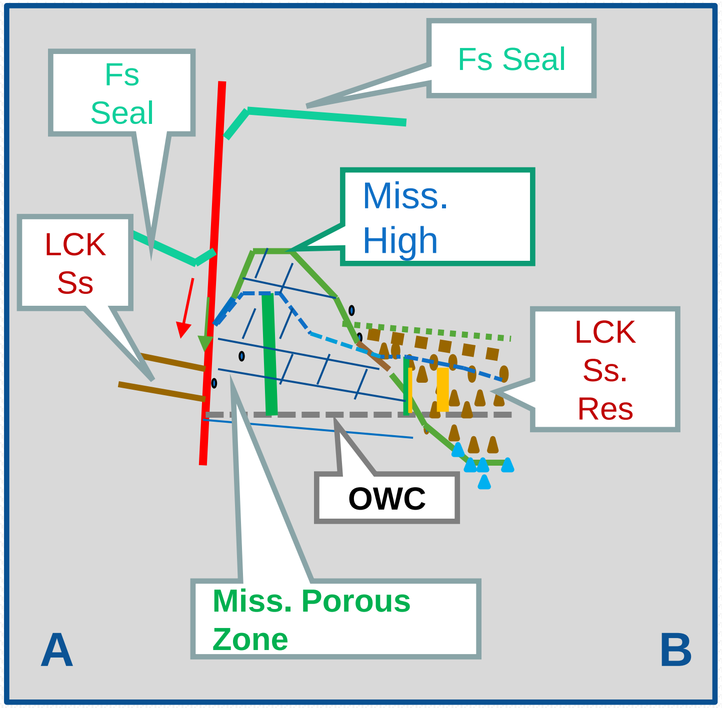




Input grid and pseudo-permeability logs (upper left), resulted 3D permeability grid (right), and statistics (lower left) for input (red), up-scaled (green) logs and gridding results (blue). Arrow and duck head in diagrams point to north.

History Matching Block





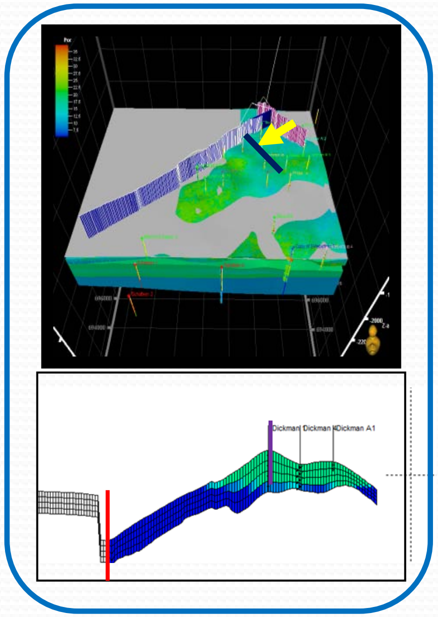
Left: input grid for history matching, with reservoir volume and area of $1.435e^9$ ft^3 , and $6.88e^7$ ft^2, respectively. Green surface: carbonate reservoir top, brown patch: LCK reservoir. Gray plane: oil-water contact. Red arrows: production areas

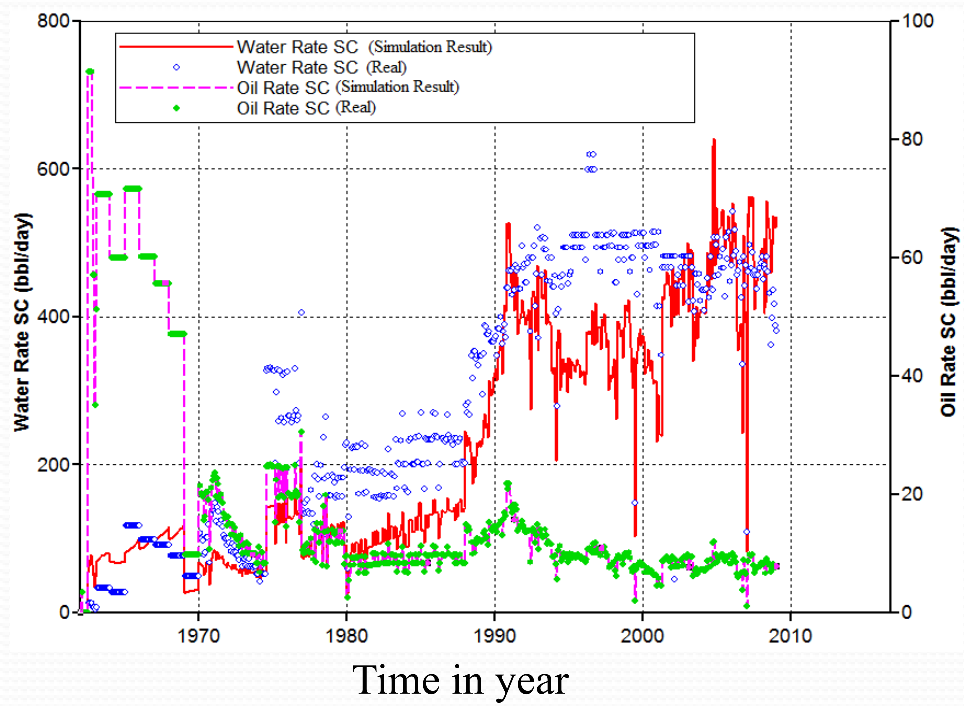
Right: a sketch along A-B. The average thickness of pay-zone is 7 ft.

History Matching: Other Input

- Other input available
  - Oil API = 37
  - Water salinity and density
  - Temperature = 113^{o}F
  - Initial pressure = 2066 psi (estimated from 3 DSTs)
- Calibrated input during history matching:
  - PVT model, relative permeability
  - Input permeability (up-scaling errors)
  - Water saturation (core to in-situ saturation)
  - Capillary transition zones (thickness)

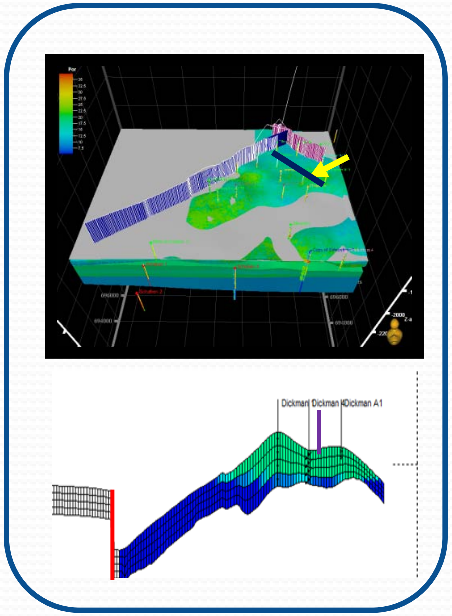
History Matching Results: Good

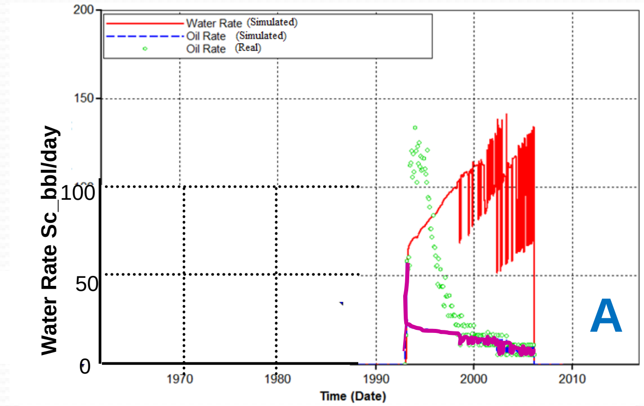


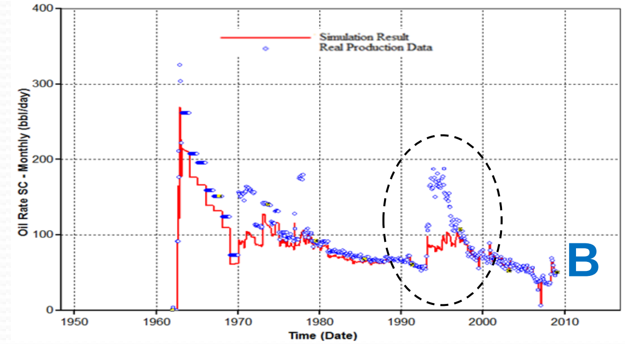


A good match without changing significantly input stratigraphic and property framework

History Matching Result: Problematic

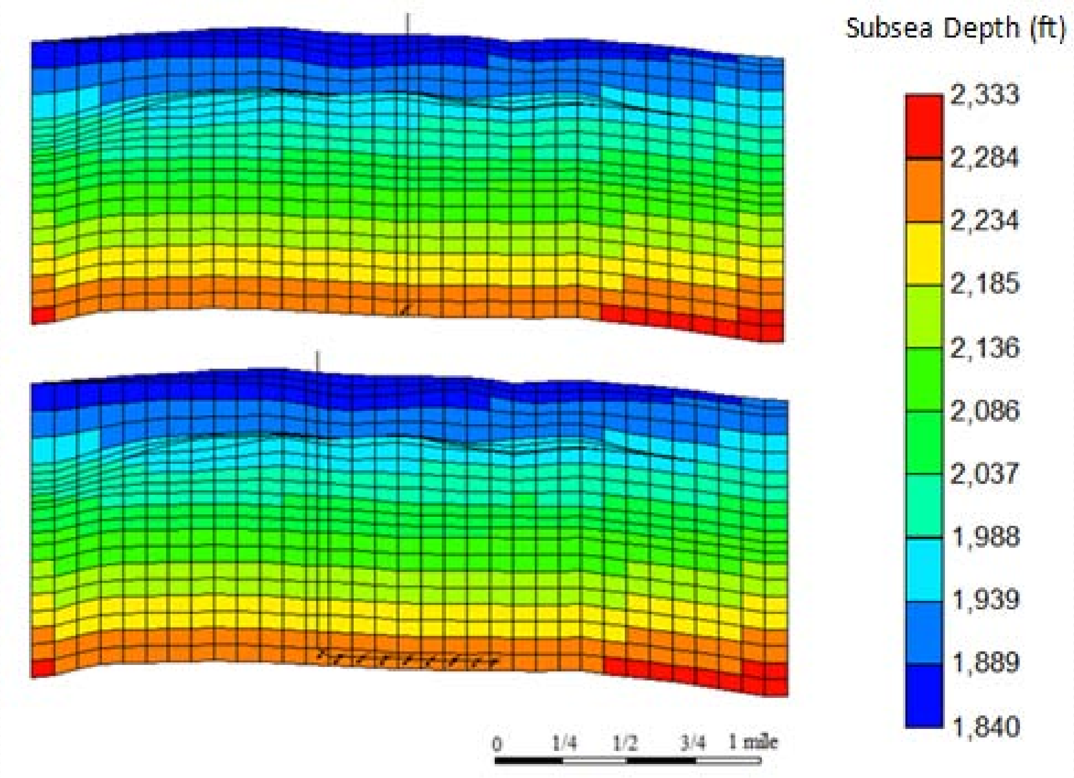






A problematic matches at Dickman A1. The computed oil production rate is much lower than the real rate.

CO2 Injection Model Grid



Vertical (up) and horizontal (down) CO_2 injecting well arrangements.
Both injecting wells are perforated at the bottom of the simulation layer.

Conclusions and Discussions

- Site-specific model for simulation on CO2 injection should be based on multi-scale data integration with proper up-scaling that can optimize data usage and depicture vertical and lateral geological heterogeneities.
- In ancient carbonate study at reservoir scale, pattern recognition from seismic attributes can be more indicative of karst topography and maturity than of original depositional architecture . A good pattern interpretation requires geology and karst geomorphology knowledge and should be supported by log and core evidence.
- Risks in property modeling using non-normalized legacy logs should be fully evaluated.

Conclusions and Discussions

Make more use of seismic impedance volume in guiding property propagation?

Interpretation of intra-strata, or confined features revealed from seismic attributes?

The effectiveness of Gaussian distribution for geological property study?

Thank You !