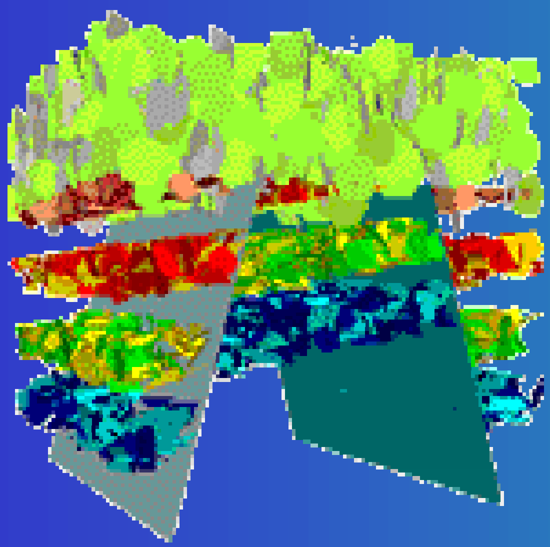
Discrete Feature Network Methods for IOR in Heterogeneous Reservoirs



W. Dershowitz[1], T. Cladouhos[1],

P. LaPointe[1], and E. Wadleigh[2]

[1]Golder Associates, Inc, Redmond WA

[2]Marathon Oil, Midland TX

NPTO Research Contract
DE-AC26-98BC15101

- **Project Team**

  Golder: DFN Technologies

  Marathon: IOR Applications

  MIT: DFN Data Analysis/Synthesis

- **Project Scope**

  DFN Data Analysis Tools

  DFN Model Development for Study Sites

  IOR Design Using DFN Technologies

  IOR/DFN Demonstration Application

  Technology Assessment

  Technology Transfer

Abstract of Paper for Presentation to DOE Reservoir Conference, Dallas, June 28-30, 1999

Discrete Feature Network Methods for IOR in Heterogeneous Reservoirs

W. Dershowitz[1], T. Cladouhos[1], P. LaPointe[1], and E. Wadleigh[2]

[1]Golder Associates, Inc, Redmond WA

[2]Marathon Oil, Midland TX

Heterogeneities such as fractures, faults, sand/sandstone interbeds, and solution features play a key role in controlling the flow of reservoir fluids (oil and water) and injected materials (water, steam, surfactant and gel) to and from wells. Critical improvements in oil recovery efficiency can be achieved through an improved understanding of the connectivity of these features.

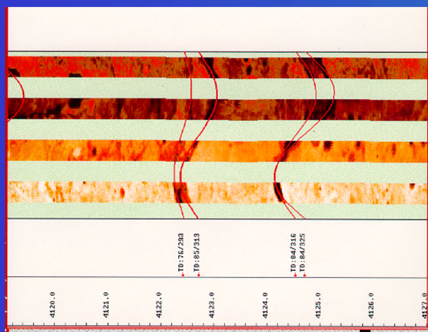
This paper describes the development of discrete feature network (DFN) methods to support IOR activities in heterogeneous and fractured dolomite and sandstone reservoirs. DFN models have been developed to identify the key discrete features that control flow and connectivity, such that the models can be used directly in the design of IOR activities.

This paper describes DFN approach to support IOR activities such as:

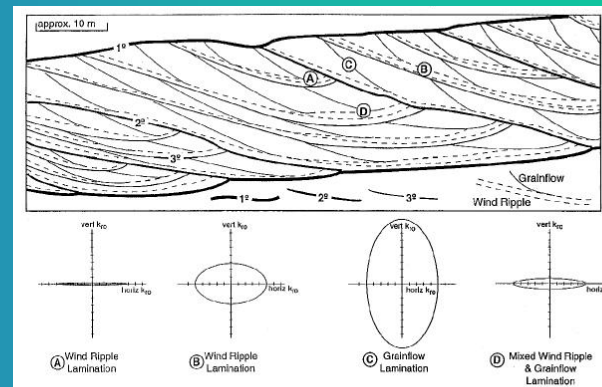
1. surfactant treatments to enhance a gravity stable recovery process,
2. waterflood displacement,
3. alternative gel treatments,
4. improved targeting of water injection,
5. horizontal drilling to connect with low recovery portions of the reservoir,
6. selective reduction in water cycling by improved gel conformance treatment design and placement, and
7. improved completion placement and stimulation for oil recovery under depletion mechanisms.

Examples are provided from project study sites in the Yates, Texas and Oregon Basin, Wyoming fields.

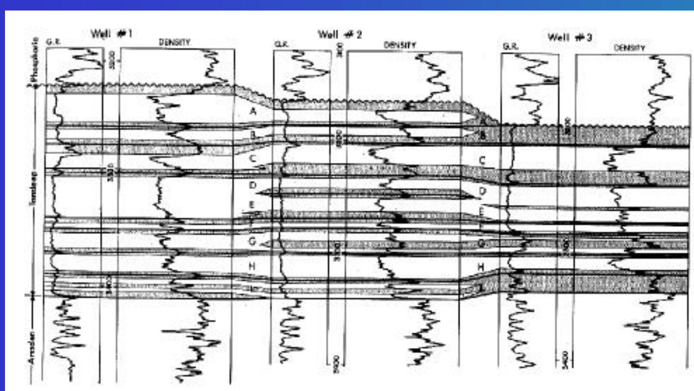
Discrete Features in Heterogenous Reservoirs



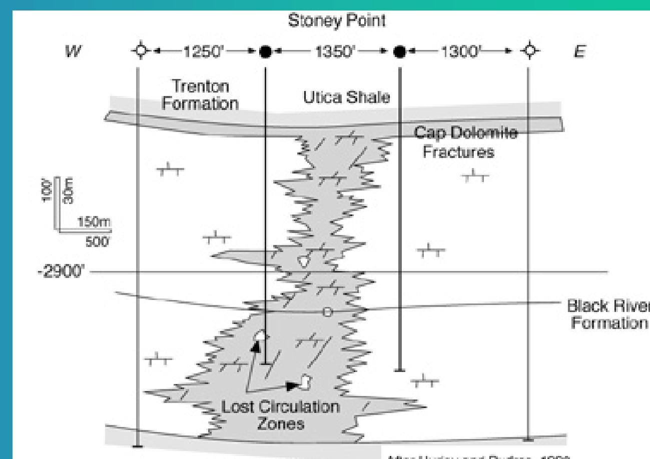
Fractures and faults



Bedding Features



Impermeable dolomite
layers in sandstone



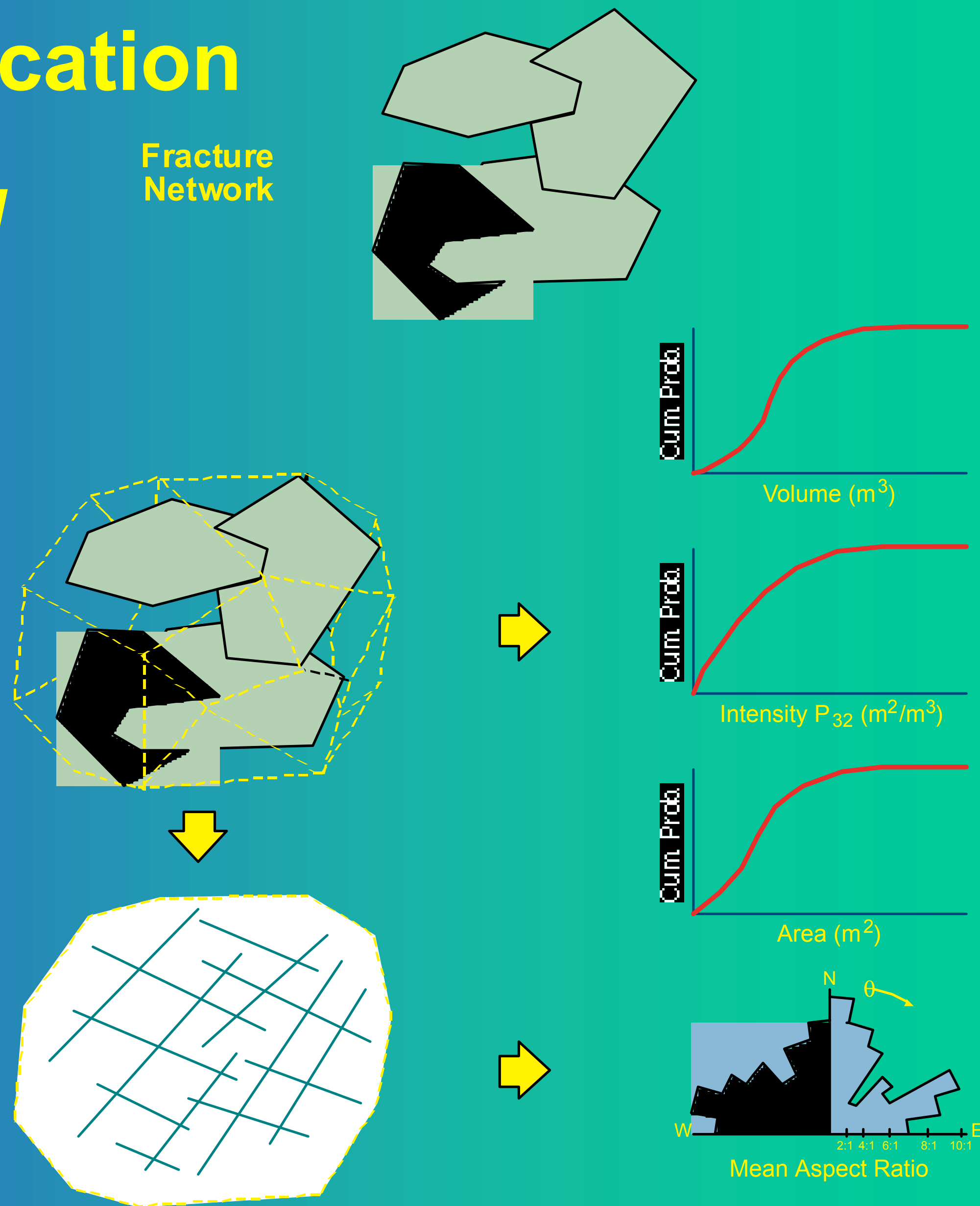
Carbonate Solution Features

Discrete Feature Network Approach
for Heterogeneous Reservoir IOR

- Identify Key Types of Discrete Features:
  Conductors and Flow Barriers
- Analyse Data to Understand Key Discrete Features
  Geology, Geophysics, Production, Well Testing
- Build Three Dimensional Discrete Feature Network Models
  Spatial Structure, Orientation, Size, Shape, Porosity, Permeability Distributions
- Apply DFN Analysis Techniques to Design Appropriate IOR Strategies
  Pathway, Compartmentalization, Connectivity Analyses, DFN Flow Simulations

Example DFN Application

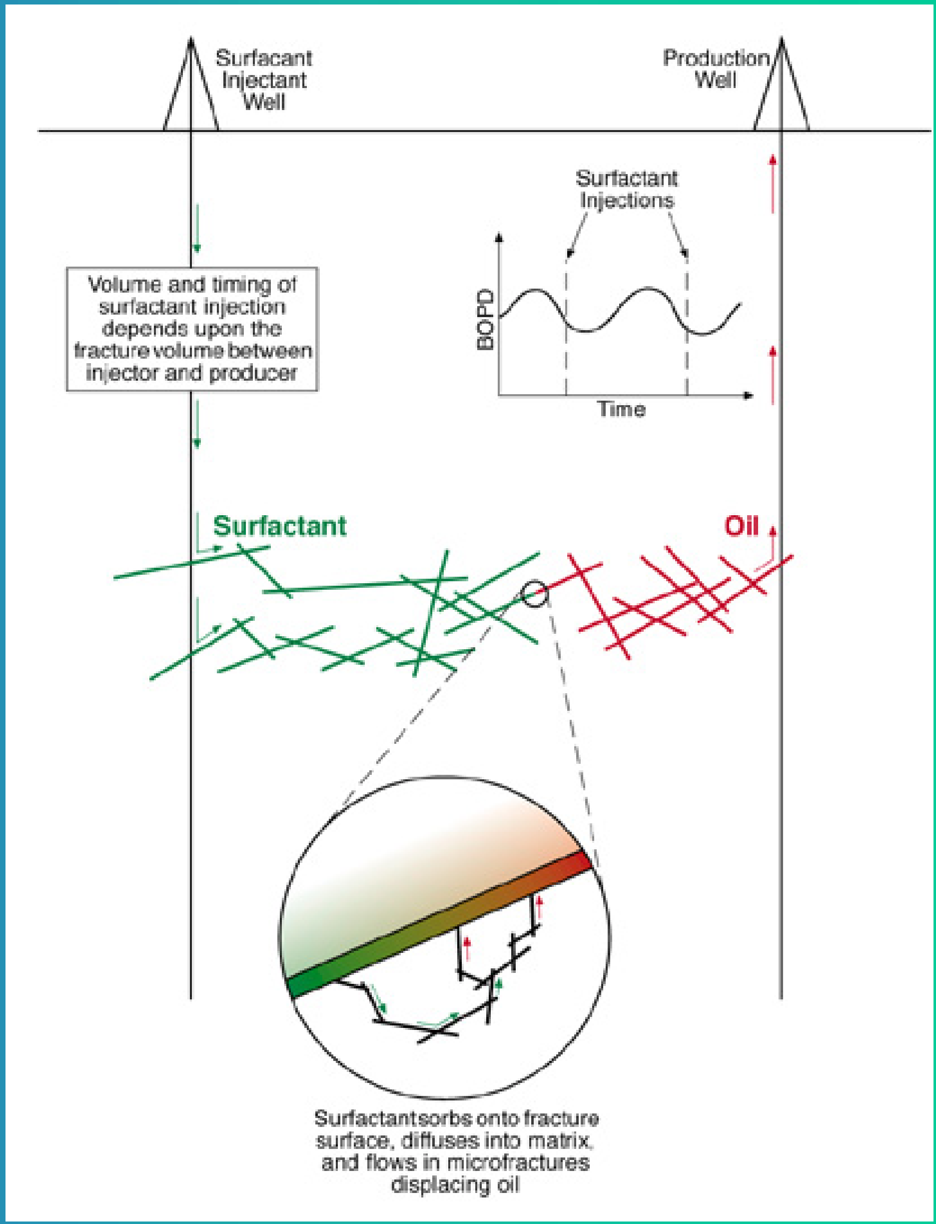
Compartmentalization Analysis for Fractured and Heterogeneous Reservoirs



IOR Issues Addressed by Discrete Feature Network Approaches

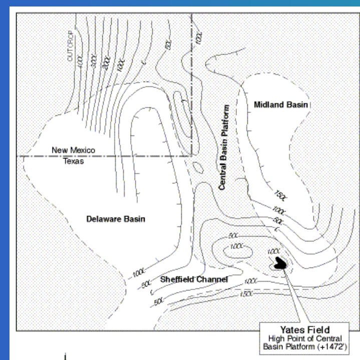
- Dewatering Fractures
  to Access Bypassed Oil
- Directional Drilling and Hydraulic Fracturing
  to Enhance or Reduce Fracture Connectivity
  to Reduce Mud Loss
- Strategic Completion
  to Access Fracture Connectivity
- Gel Placements
  to Reduce Water Cycling
- Surfactant Flood
  to Improve Matrix Oil Mobility
- TAGS Steam Flood
  to Improve Mobility and Production Pressures

Surfactant Design in Fractured/ Heterogeneous Reservoirs



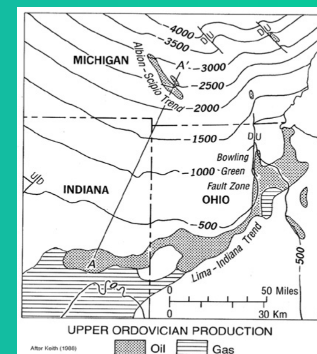
Heterogeneous Reservoir
Project Study Sites

Yates Field, West Texas



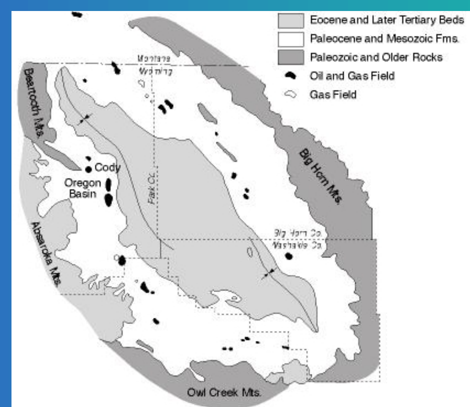
Carbonate Solution Features

Stoney Point, Michigan



Dolomitization

South Oregon Basin, Wyoming



Faults and Fractures

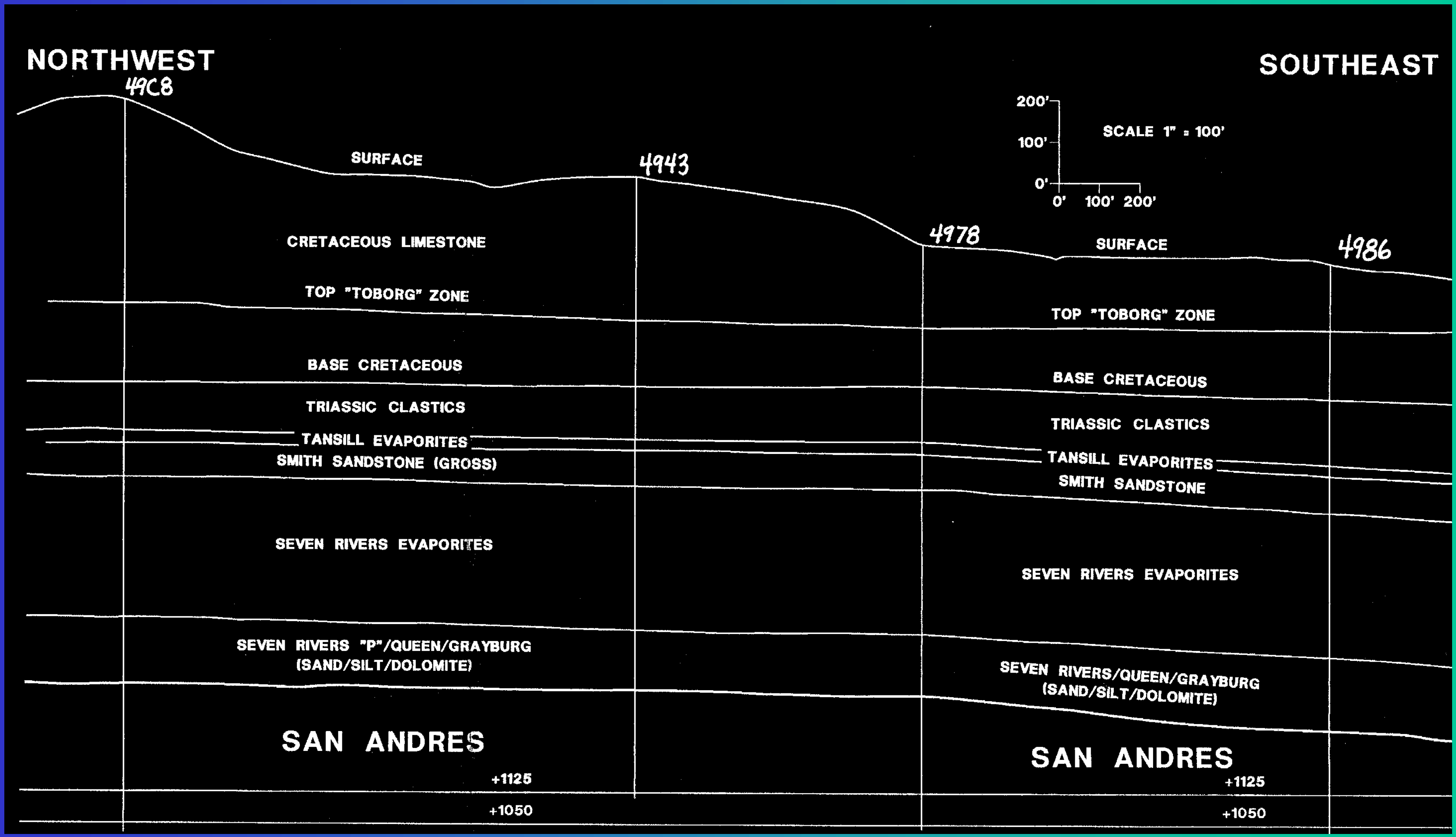
North Oregon Basin, Wyoming

Dolomite Interbeds, Eolian Laminations

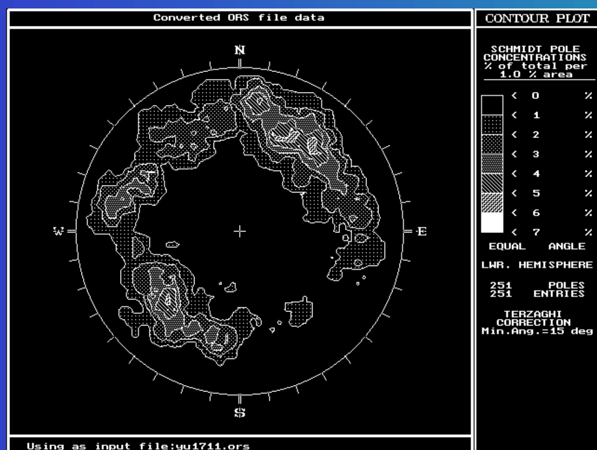
DFN Applications for Project Study Sites

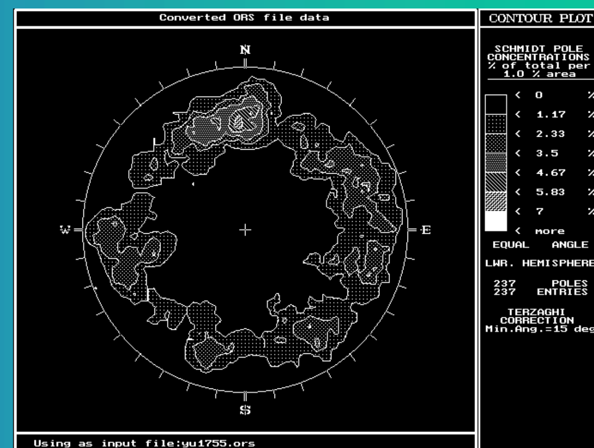
Field	**IOR Design Issue**	**DFN Approach for IOR**
Yates	Strategic Completion to Aid TAGS Steam Flood	DFN Simulation of Strategic Completions
North Oregon Basin	How much surfactant to inject?	DFN Compartmentalization and Pathway Analysis
North Oregon Basin	Best well orientation to minimize gel volume?	DFN Effective Permeability Tensor Calculation, Connectivity Analyses
South Oregon Basin	Best well orientation to access upper Phosphoria?	DFN Effective Permeability Tensor Calculation, Connectivity Analyses
Stoney Point	Well location and orientation for dewatering fractures?	DFN Simulation of Dewatering Operations

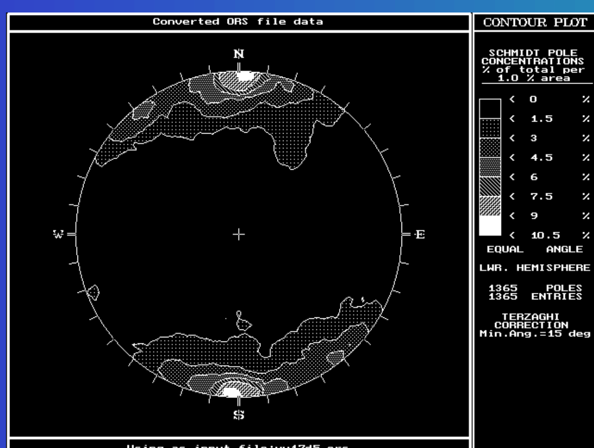
Yates Field, West Texas Study Site

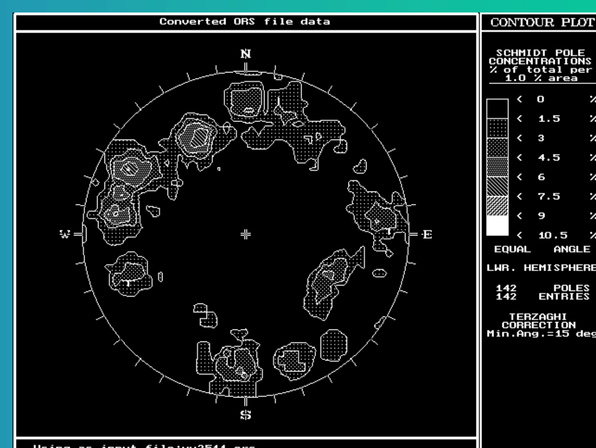


DFN Model Implementation
Fracture Orientation
Yates Field, West Texas



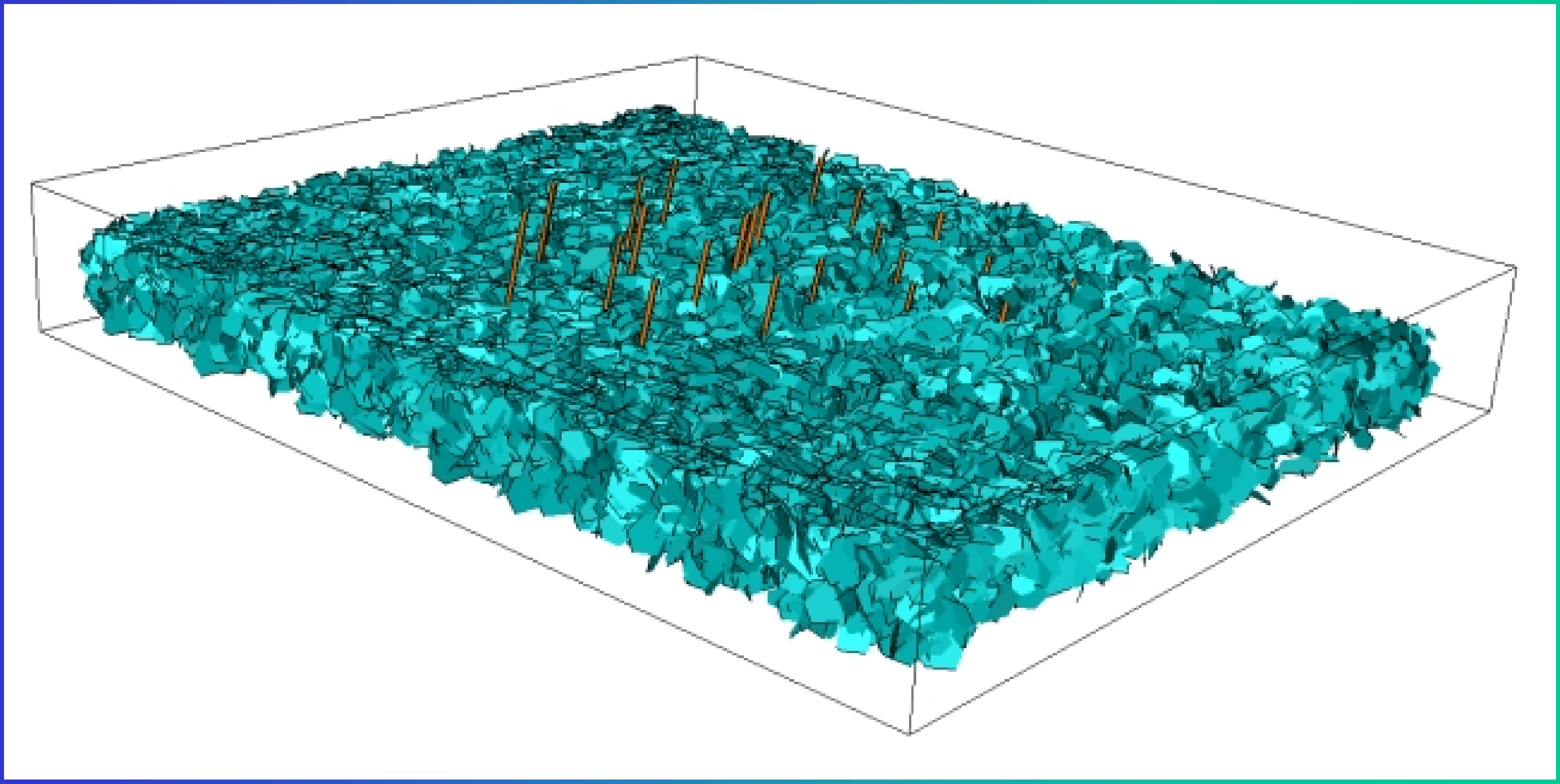




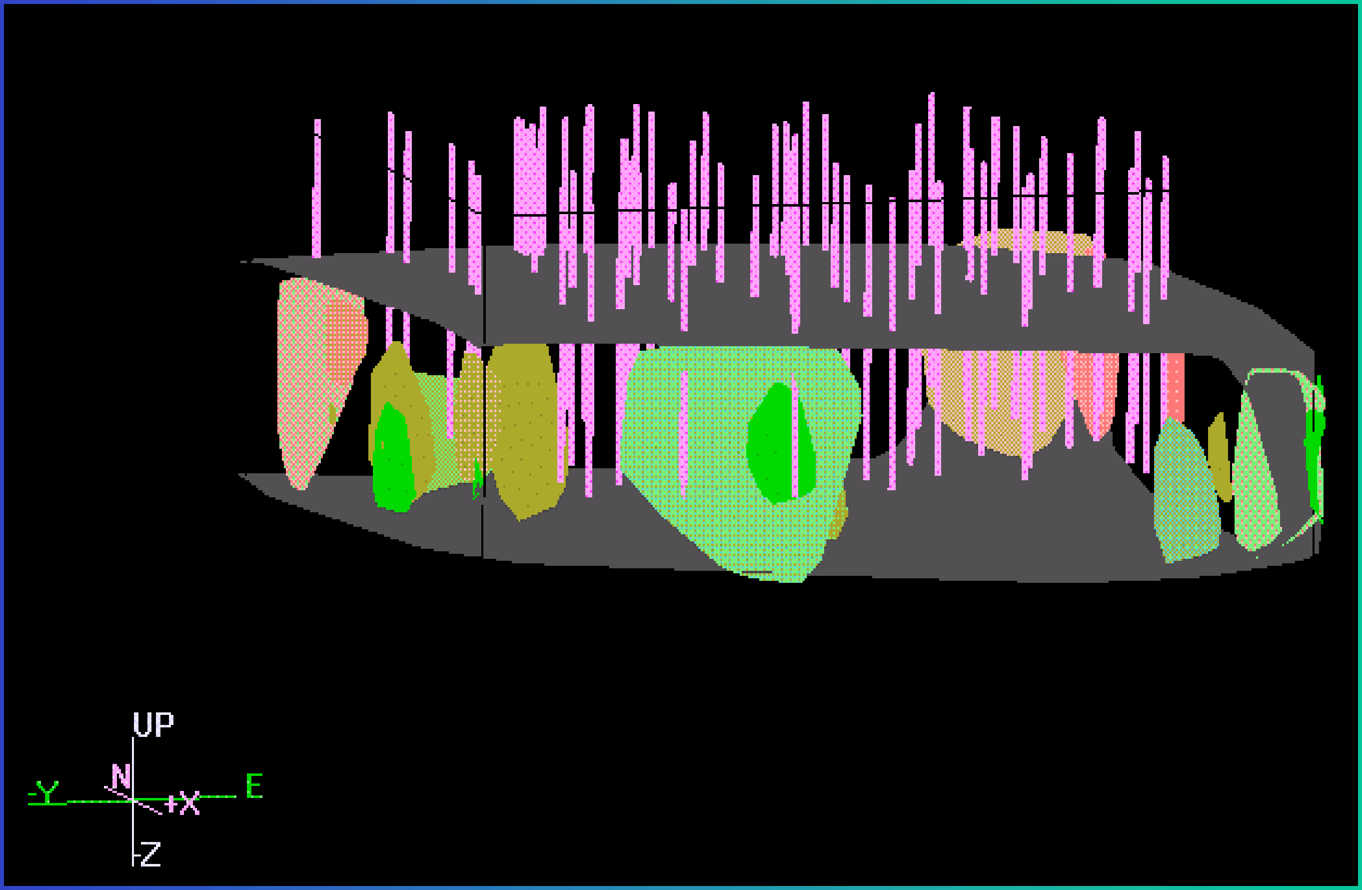


DFN Model Implementation

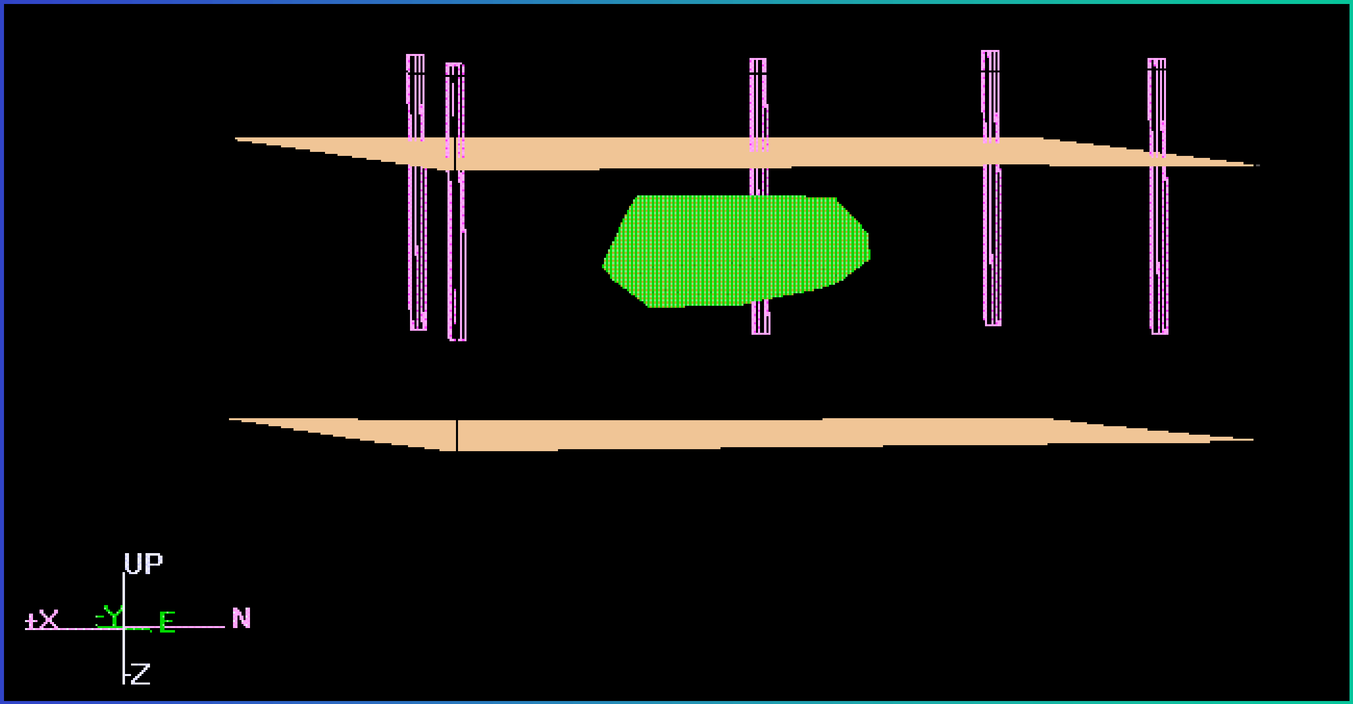
Yates Field, West Texas



DFN Model Application
Compartmentalization
Yates Field,West Texas, Tract 49

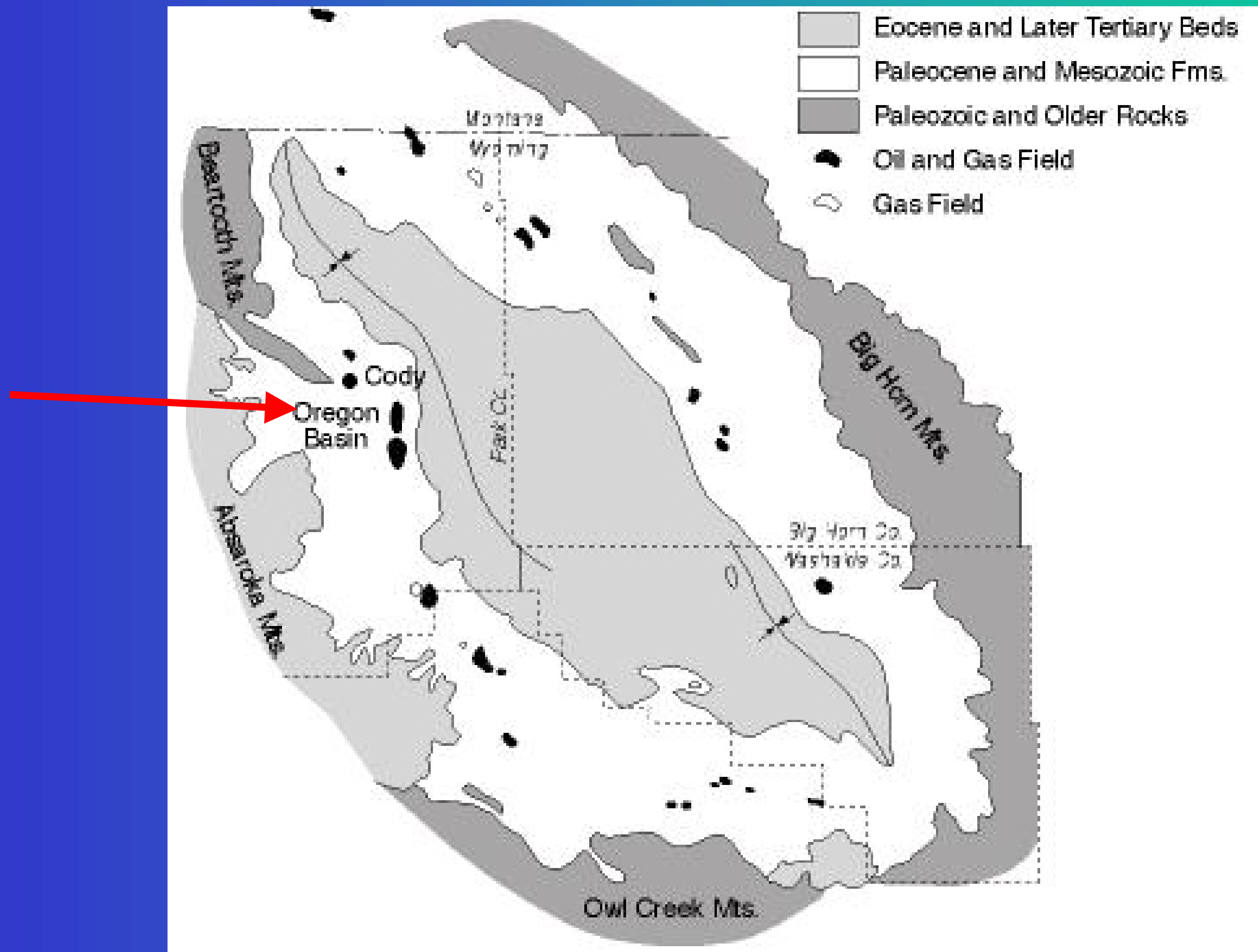


Phase 2
Strategic Completion Design
Yates Field, West Texas

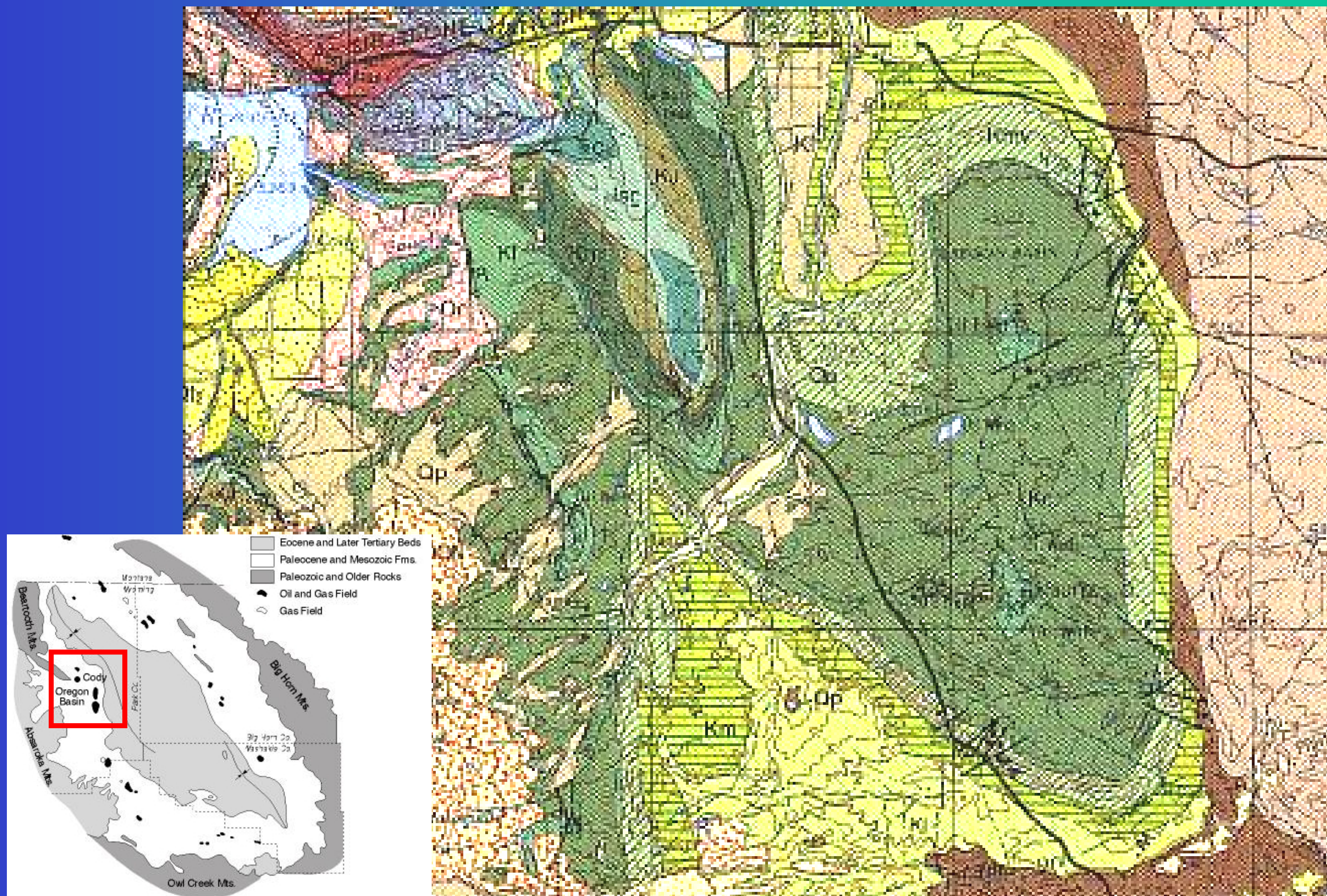


Oregon Basin Study Sites

North Oregon Basin/South Oregon Basin



Oregon Basin Study Sites
North Oregon Basin/South Oregon Basin

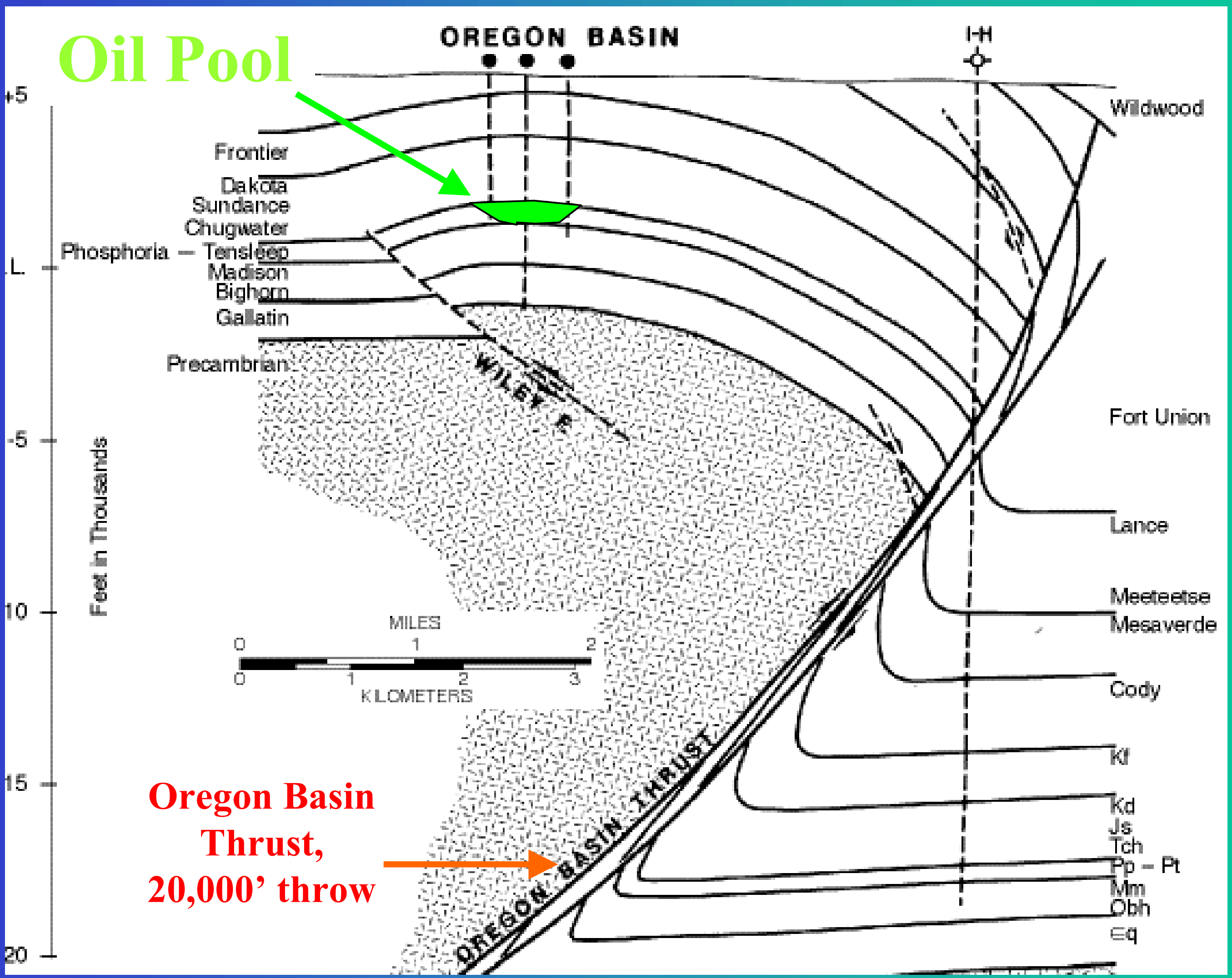


Surficial geology from Pierce, 1997

Relevant Stratigraphy at Oregon Basin

Symbol	Formation	thickness (south dome)	Lithology	Sed.Envir-onment
DINW	Triassic Dinwoody	30-45’	Shale and anhydrite	Marine or estuarine
PHOS	**Triassic-Permian Phosphoria**	250’	Carbonate (called Embar in old reports, Park City in new reports)	Marine
erosional unconformity				
TENS	**Penn. Tensleep**	20-190’	Cross-bedded and massive, well-sorted sandstone with dolomite interlayers	Marine/ eolian (coastal dune)
AMSD	Penn. Amsden	210’	Dolomite, shales and anhydrite. Basal sandstone	
erosional unconformity				
MADI MADB	Lower Miss. Madison	740’	Marine limestone, lower part dolomitized	Marine

Regional Structure at Oregon Basin Sites
North Oregon Basin/South Oregon Basin



North Oregon Basin Study Site

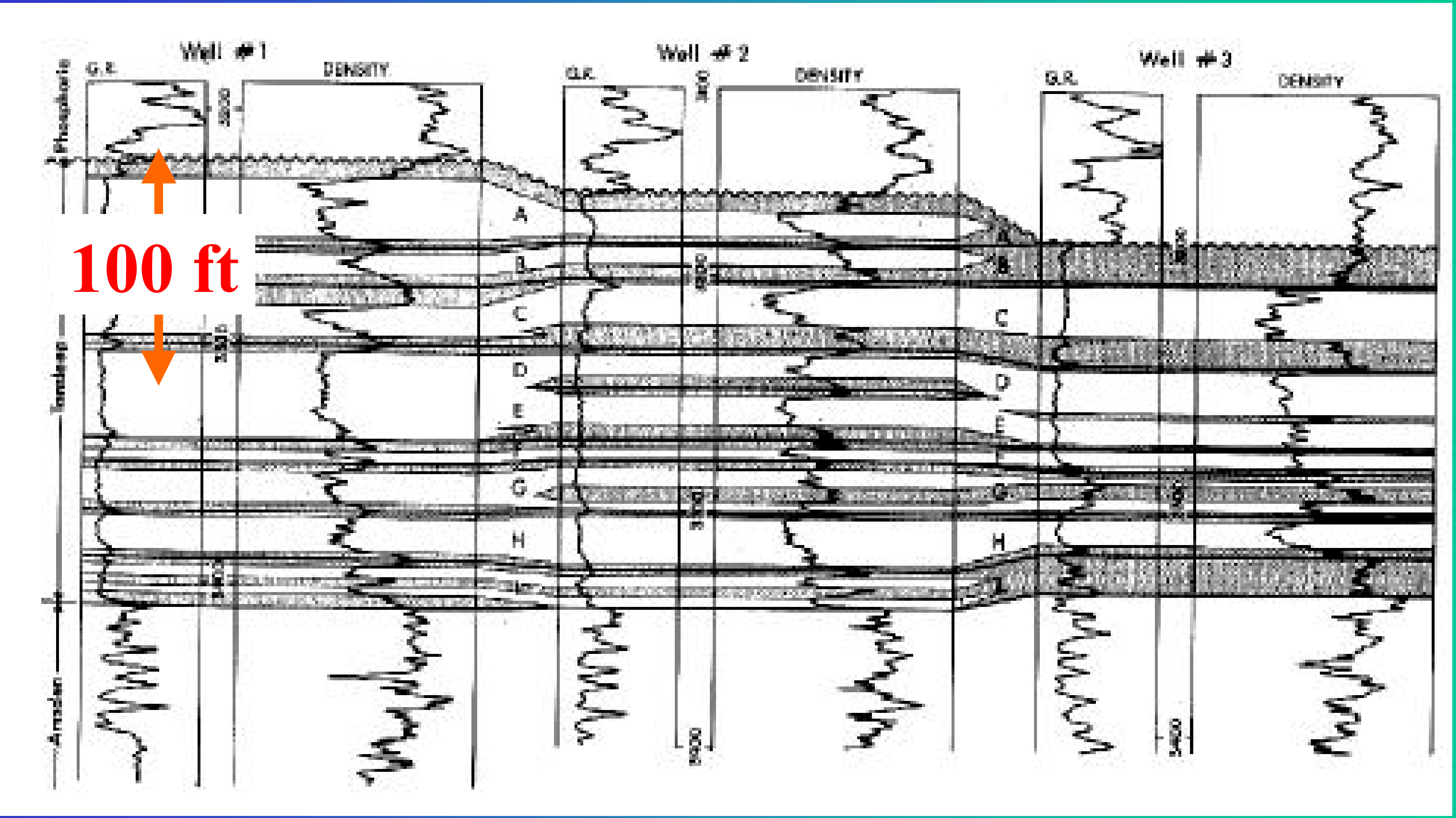
Reservoir development issues

- Upper Tensleep contains bypassed oil
- Coning from lower Tensleep prevents access
- Reservoir compartmentalized by dolomite layers

IOR strategies

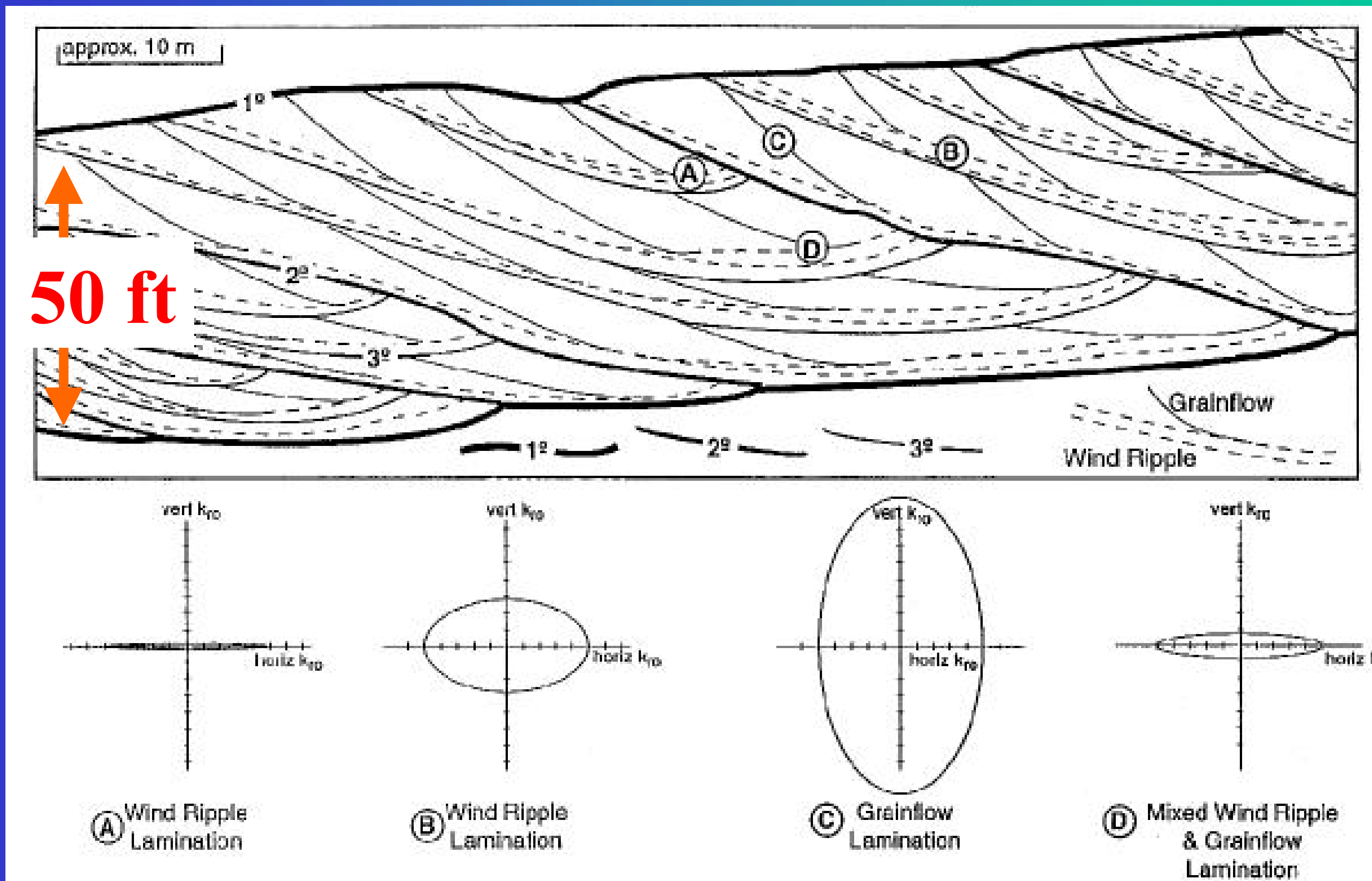
- Gel treatment of lower Tensleep
- Water injection in upper Tensleep
- Horizontal wells in upper Tensleep

Dolomite Layers at North Oregon Basin



from Morgan et al., 1977

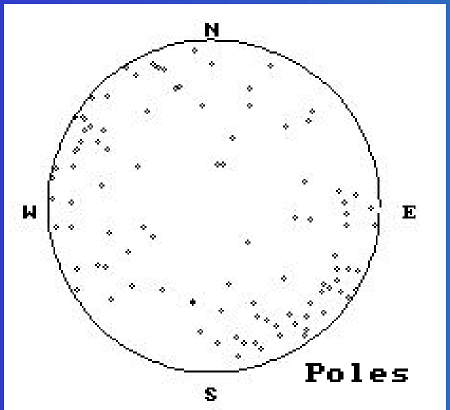
Eolian Laminations at North Oregon Basin

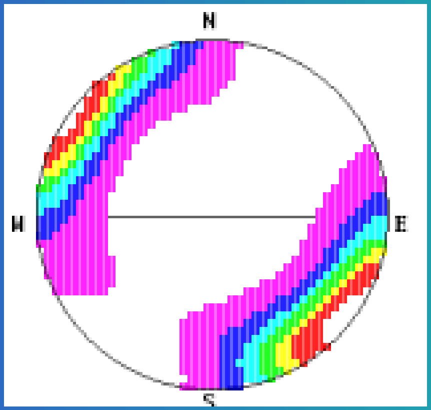


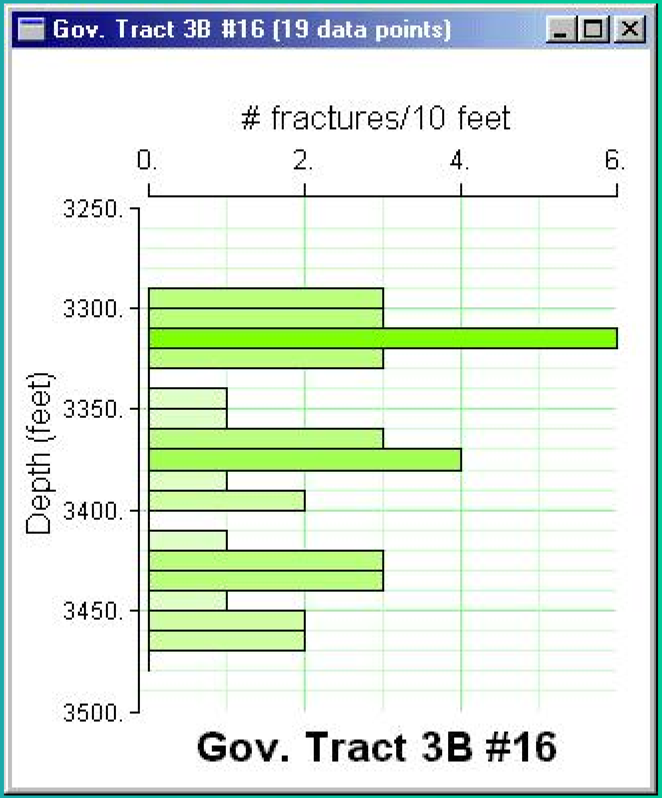
Directional Relative Permeability, K/K_h **Dunn, 1997**

Tensleep Fractures
North Oregon Basin

NE-SW trending w/ scatter





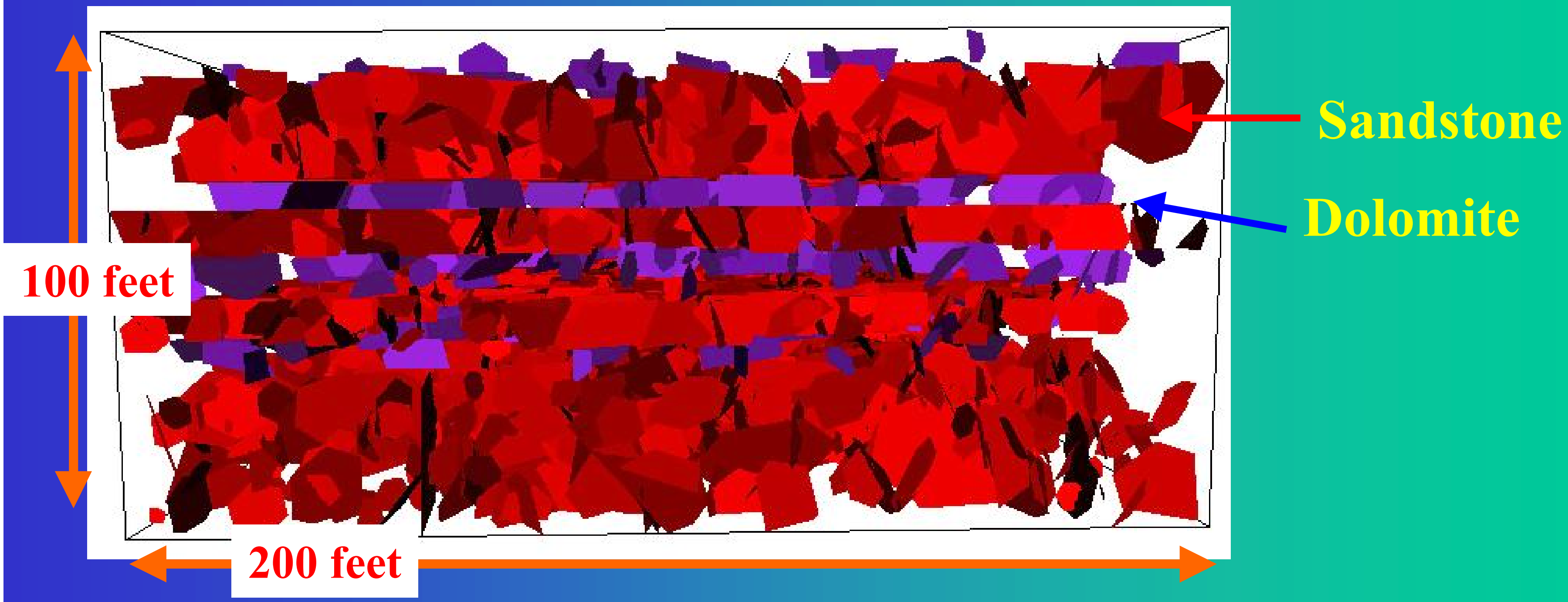


average spacing ~ 10'

no spatial correlation

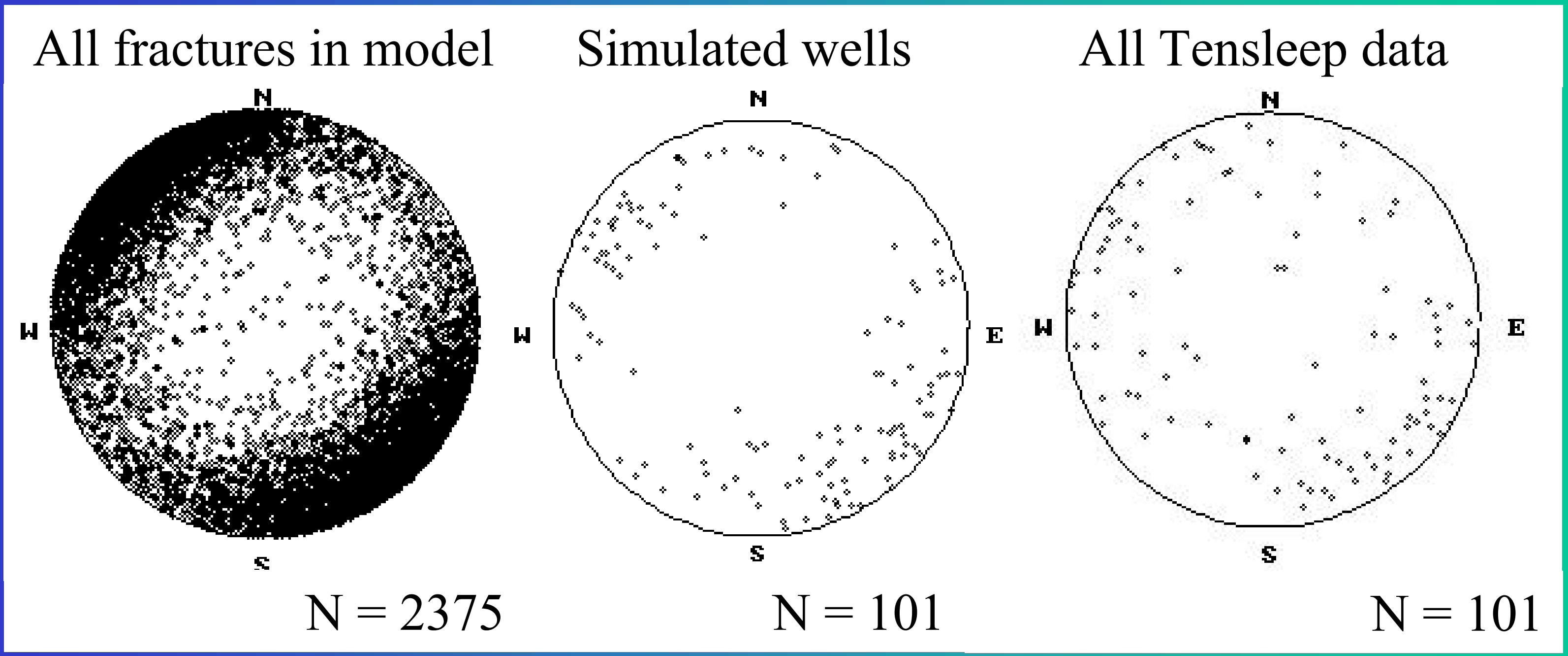
DFN Model Implementation

Tensleep, North Oregon Basin



- Dolomites have 50% conductive fracture intensity as sandstones
- all fractures terminate on layer boundaries

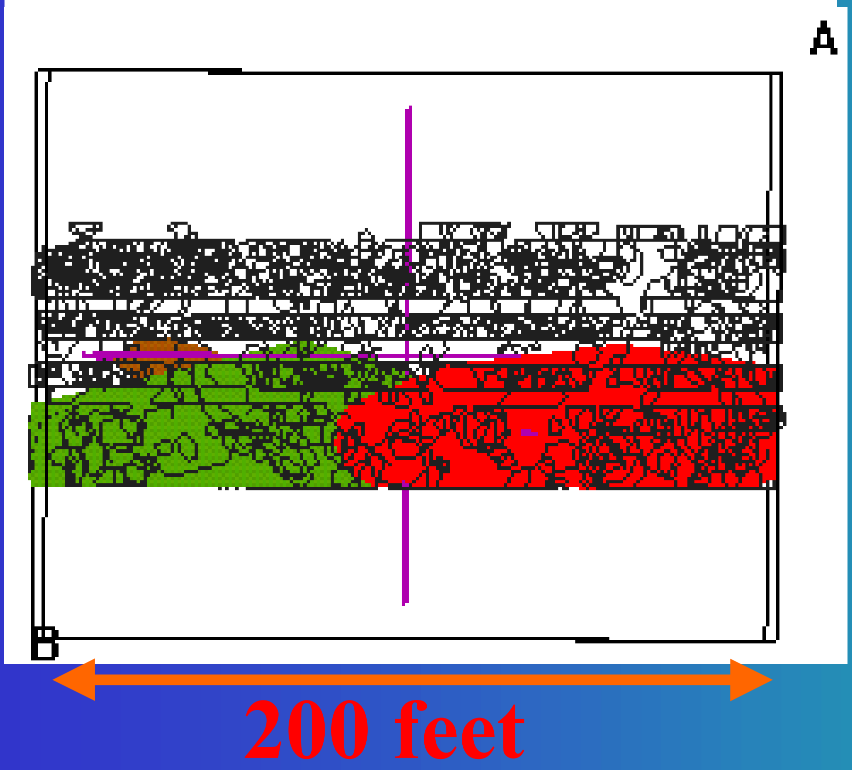
DFN Model Verification
Fracture Orientations
Tensleep, North Oregon Basin



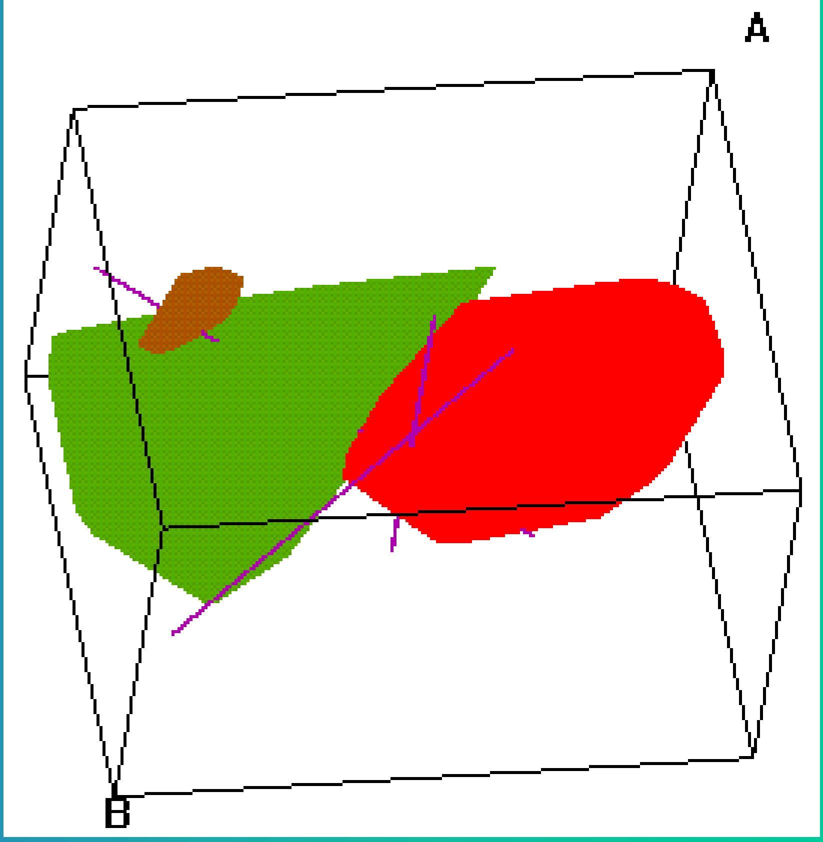
DFN Model Application
Compartment Analysis
Tensleep, North Oregon Basin

Conductive $P_{32} = 0.4\ m^2/m^3$

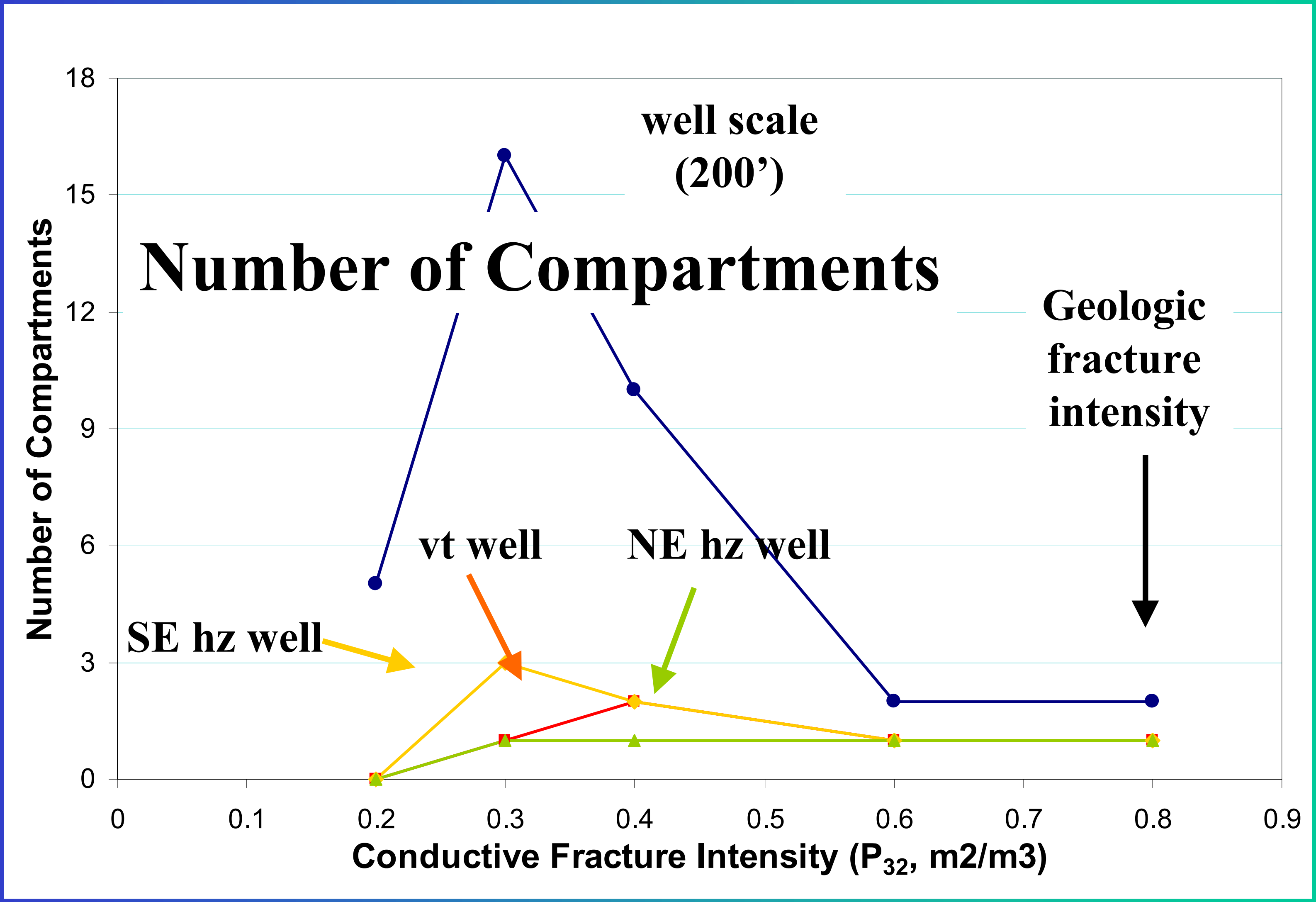
Side view with fractures



Top view w/o fractures

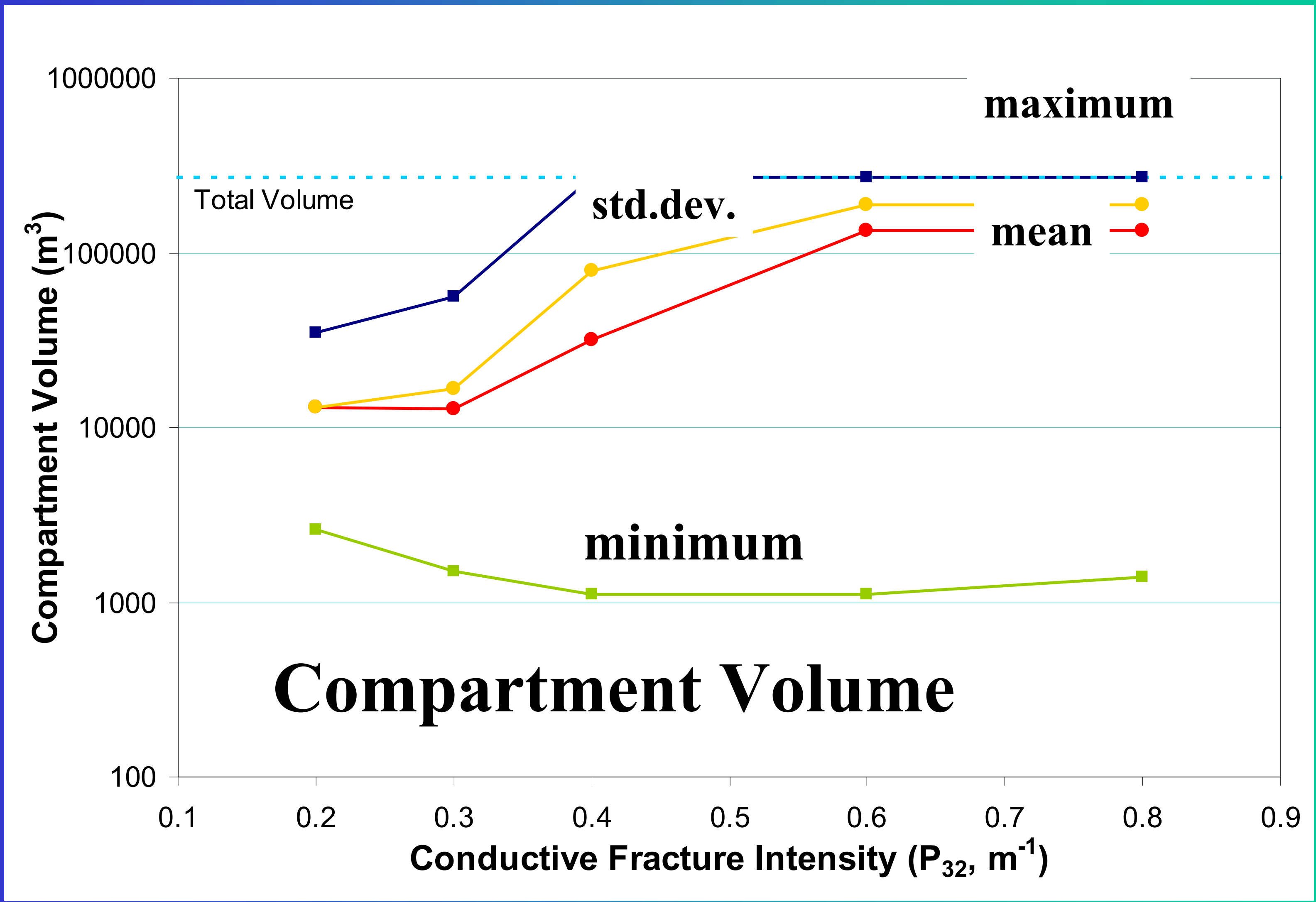


DFN Model Application
Compartmentalization
Tensleep, North Oregon Basin

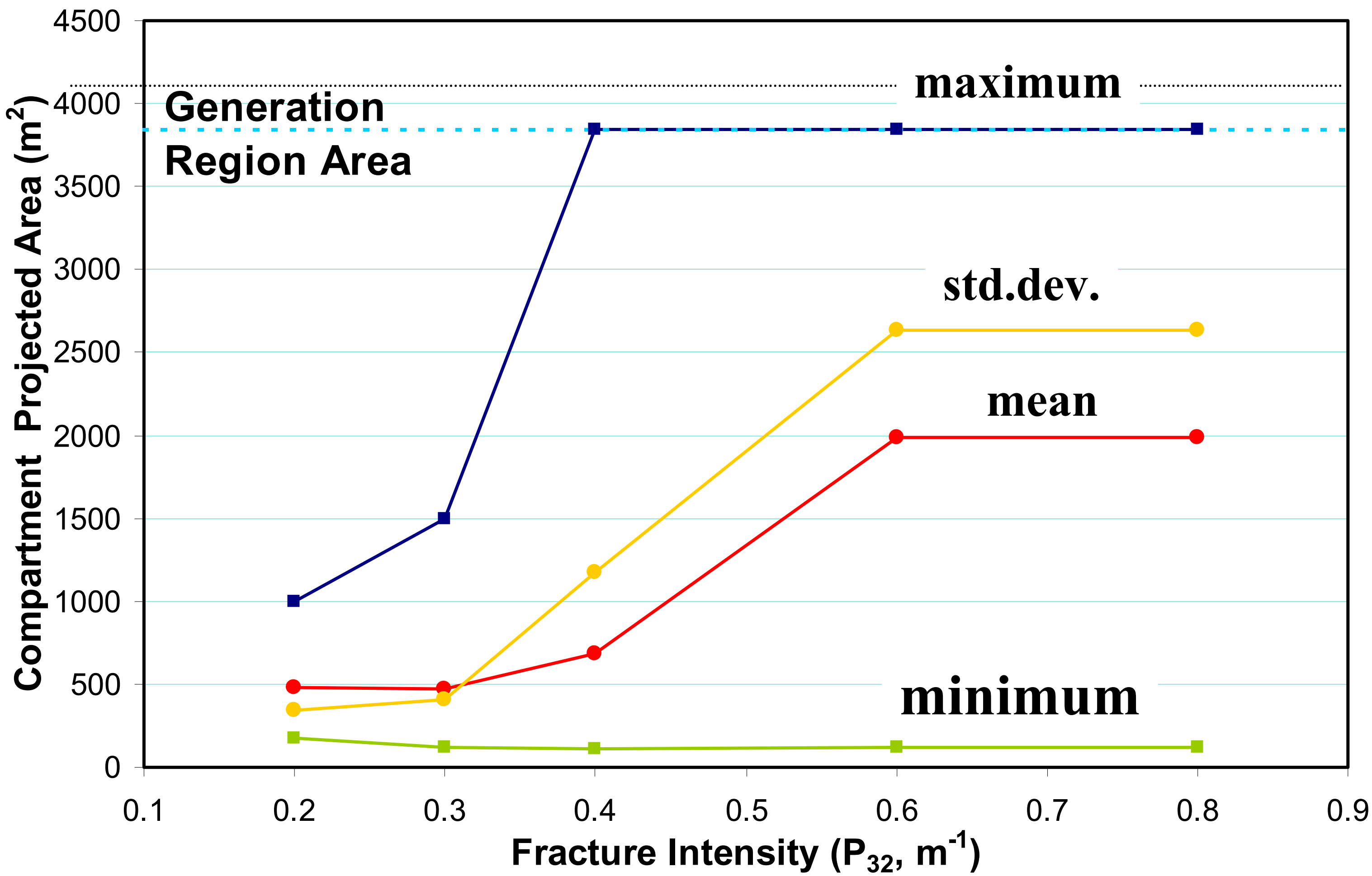


DFN Model Application Compartmentalization

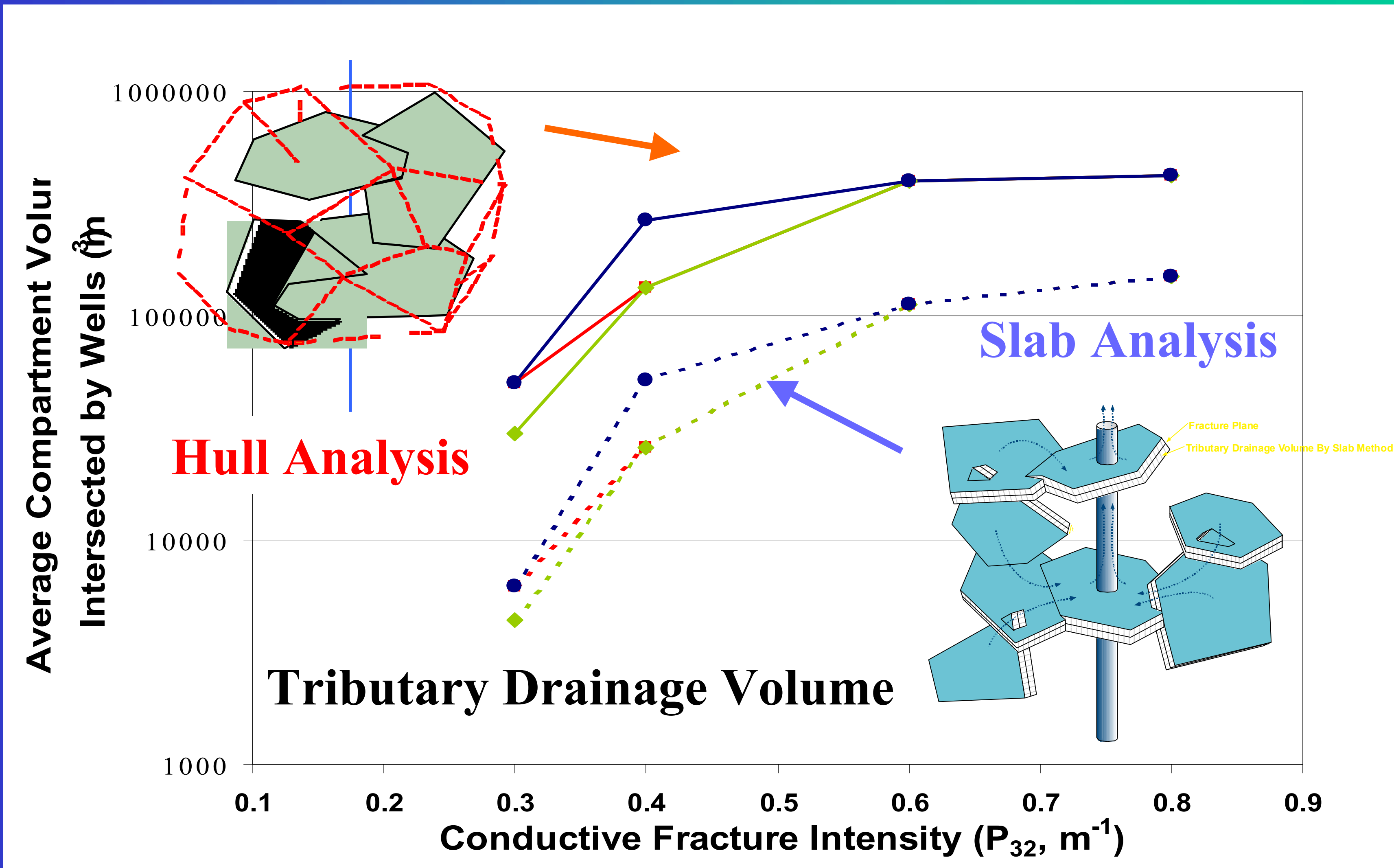
Tensleep, North Oregon Basin



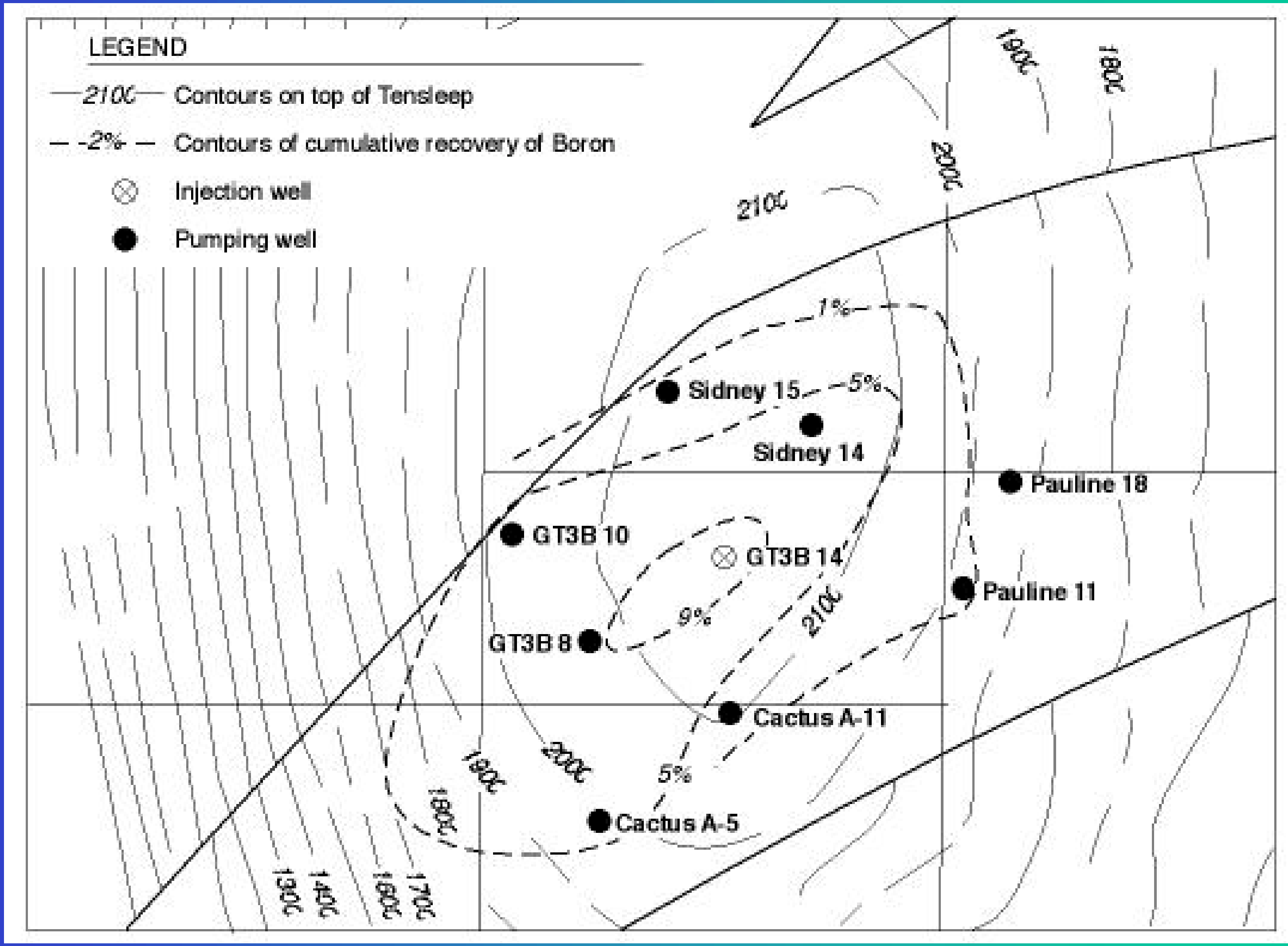
DFN Model Application
Compartmentalization
Tensleep, North Oregon Basin



DFN Model Application Compartmentalization
Tensleep, North Oregon Basin



Phase 2:
Conditioning to Tracer Testing
Tensleep, North Oregon Basin



South Oregon Basin Study Site

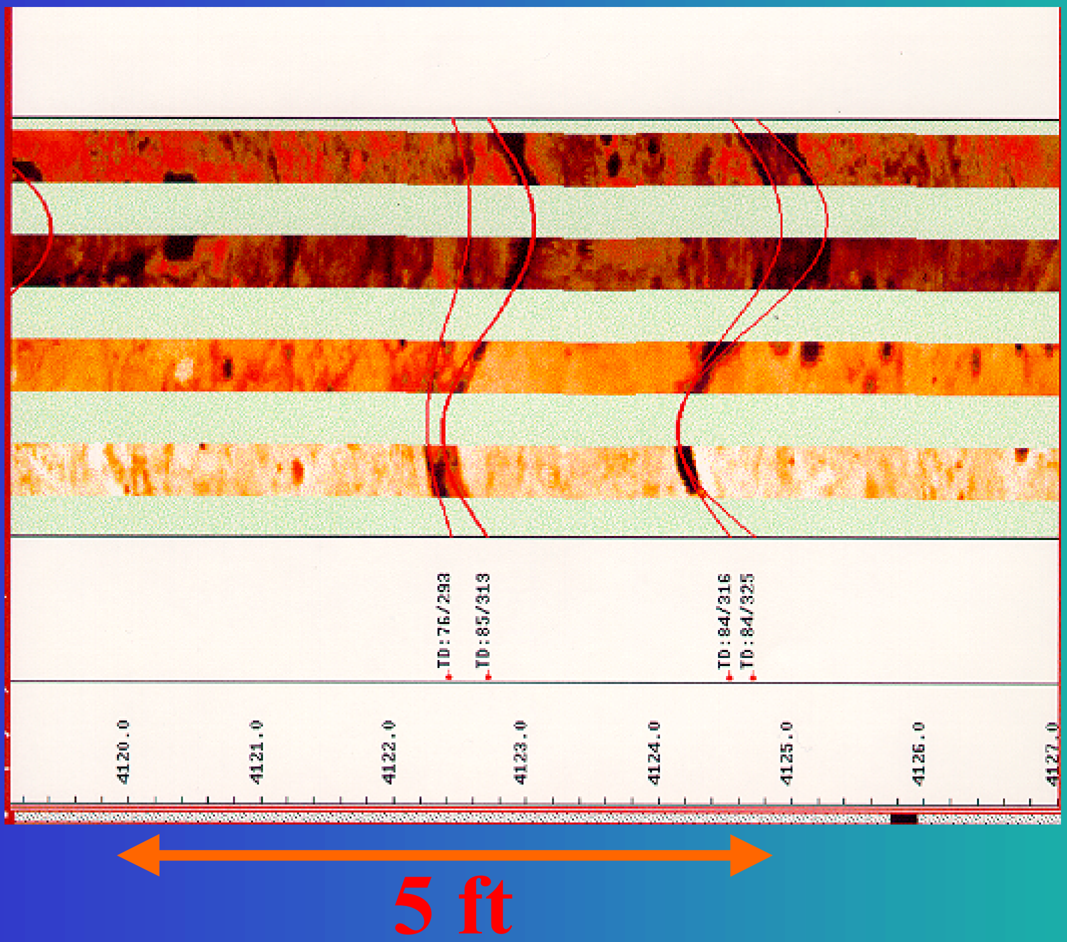
Reservoir Development Issues

- Oil saturation in upper Phosphoria is 80%
- Coning from lower Phosphoria prevents access

IOR Strategies

- Horizontal wells in upper Phosphoria
- Must avoid major faults/fractures to minimize mud loss in drilling

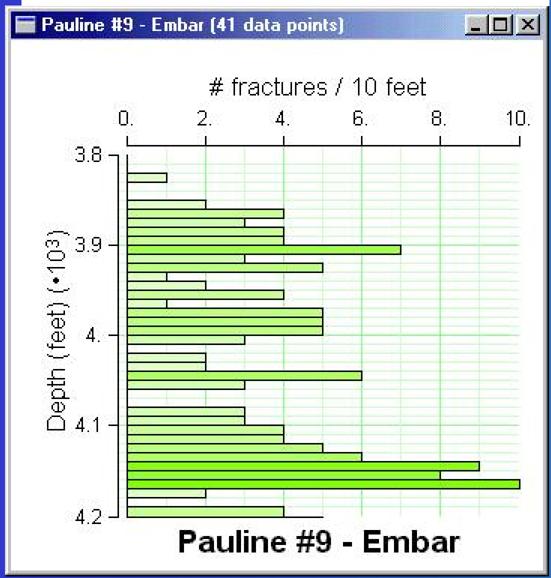
Directional drilling in South Oregon Basin



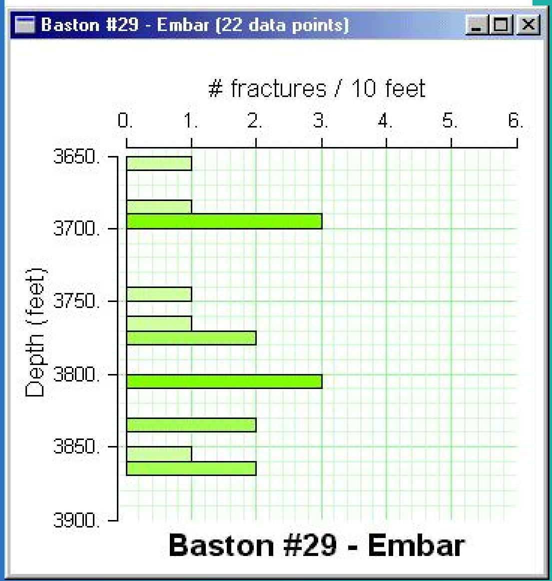
These fractures accounted for 290 bbls/hr mud loss during drilling

Phosphoria Fractures, South and North Oregon Basin

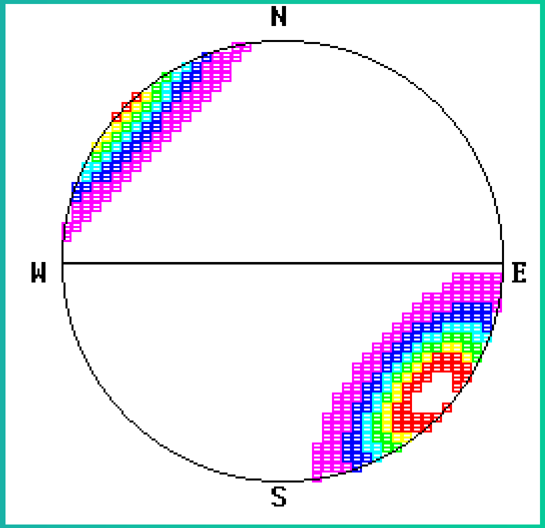
Horizontal Well



Vertical Well

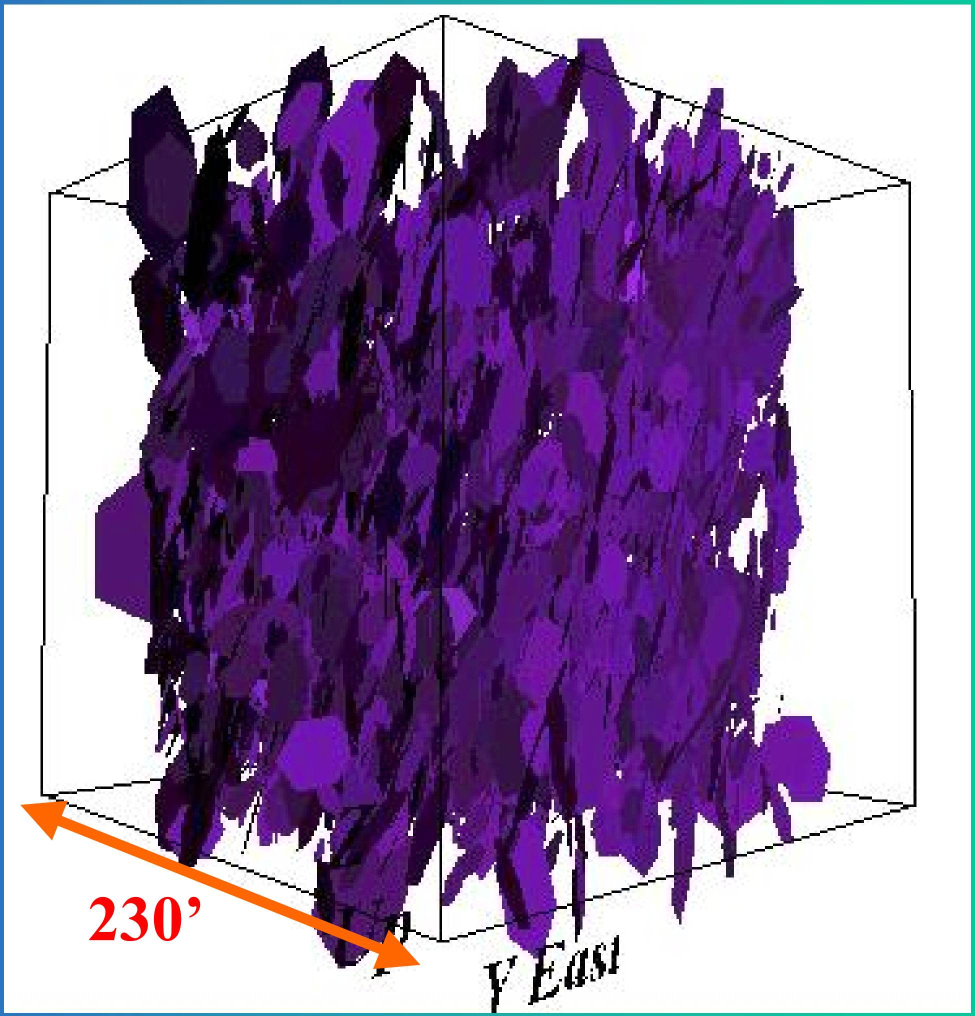


NE-SW trending



Fracture intensity = 1.6 m^2/m^3

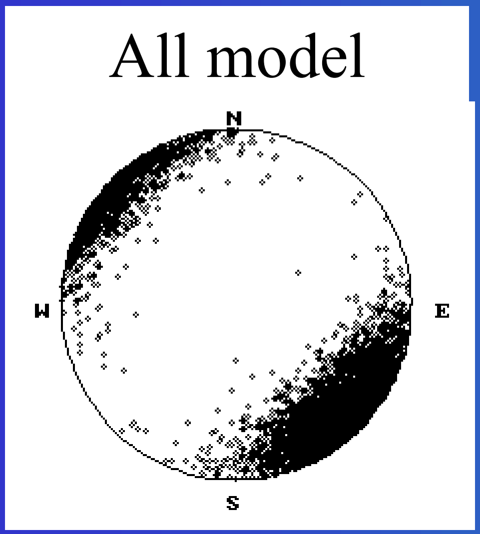
South Oregon Basin (Phosphoria) DFN Model

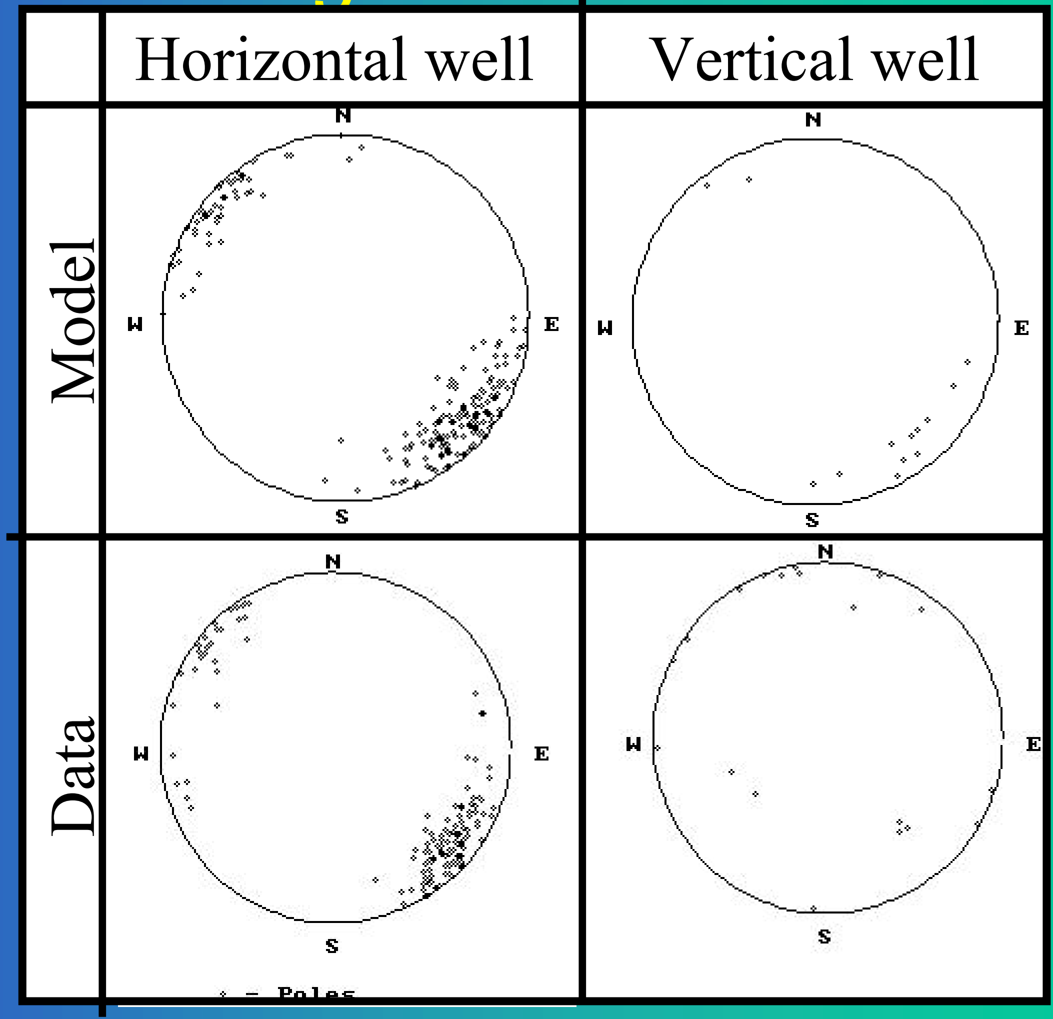


DFN Model Verification

Fracture Orientations

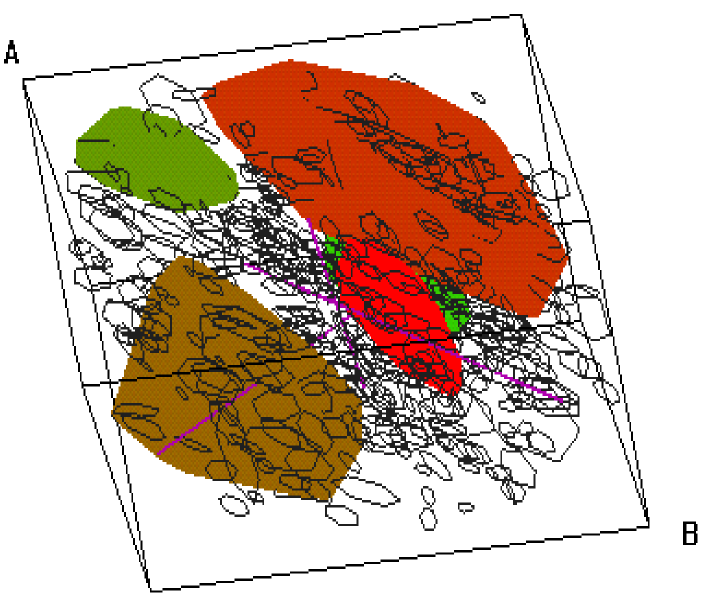
Phosphoria, *South Oregon Basin*





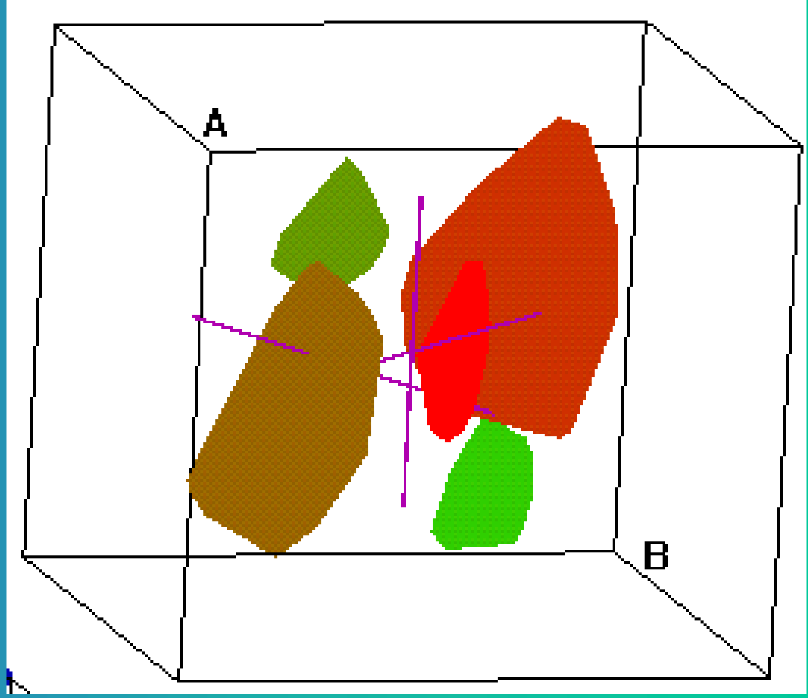
DFN Model Application
Compartmentalization
Phosphoria, South Oregon Basin

Top view w/ fractures



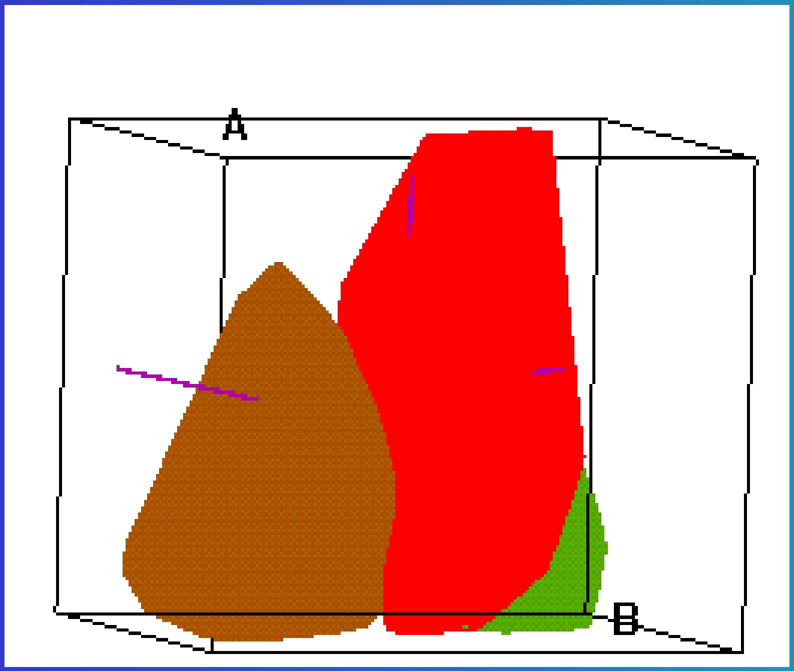
Conductive $P_{32} = 0.2\ m^2/m^3$

Side view w/o fractures

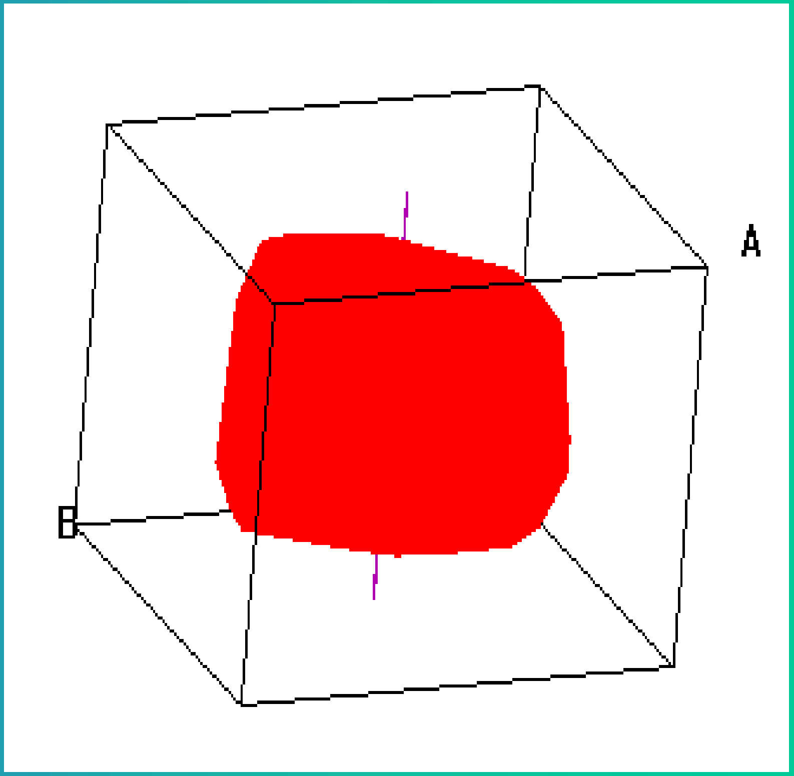


DFN Model Application
Compartmentalization
Phosphoria, South Oregon Basin

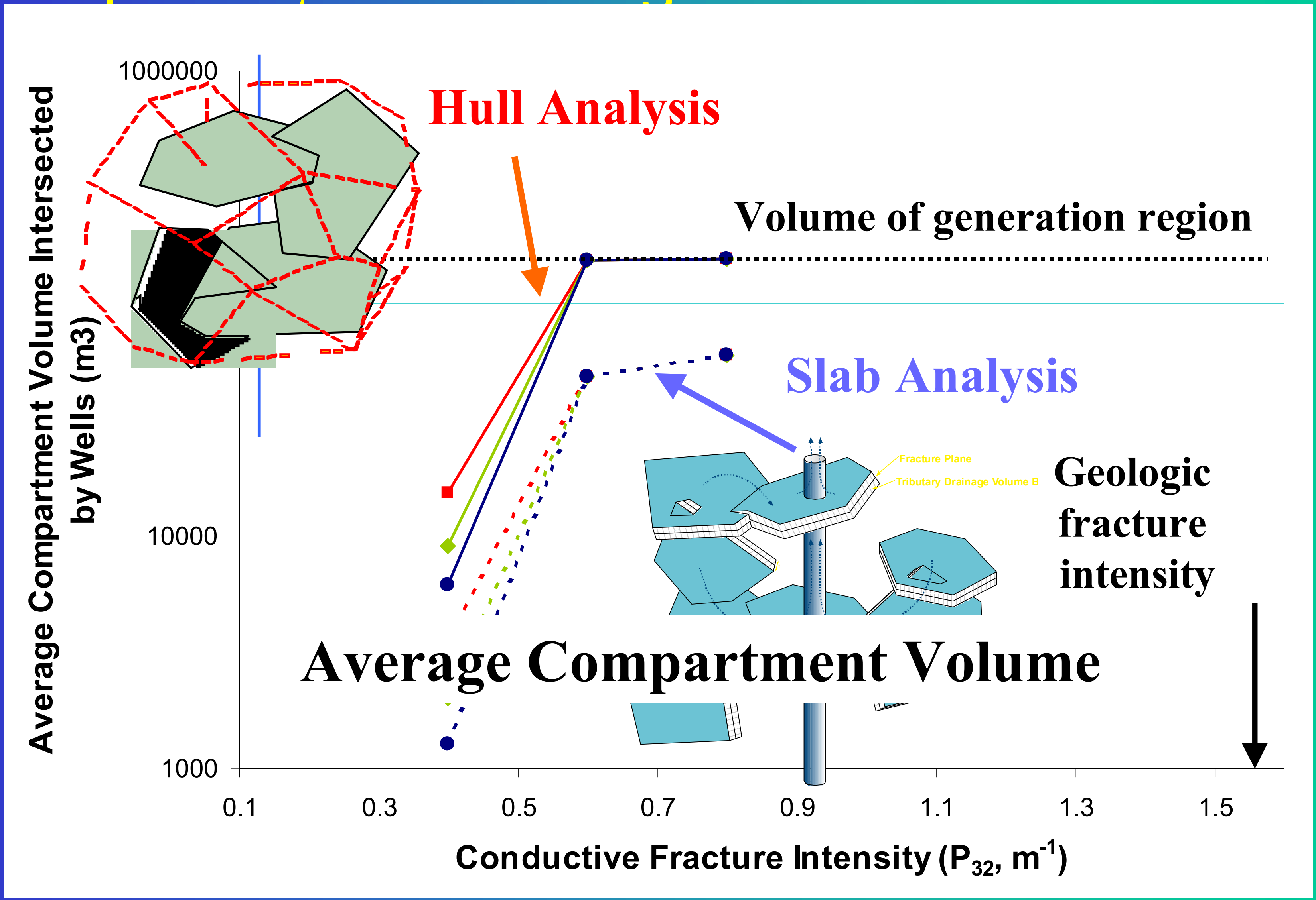
Conductive P_{32} = 0.4 m^2/m^3



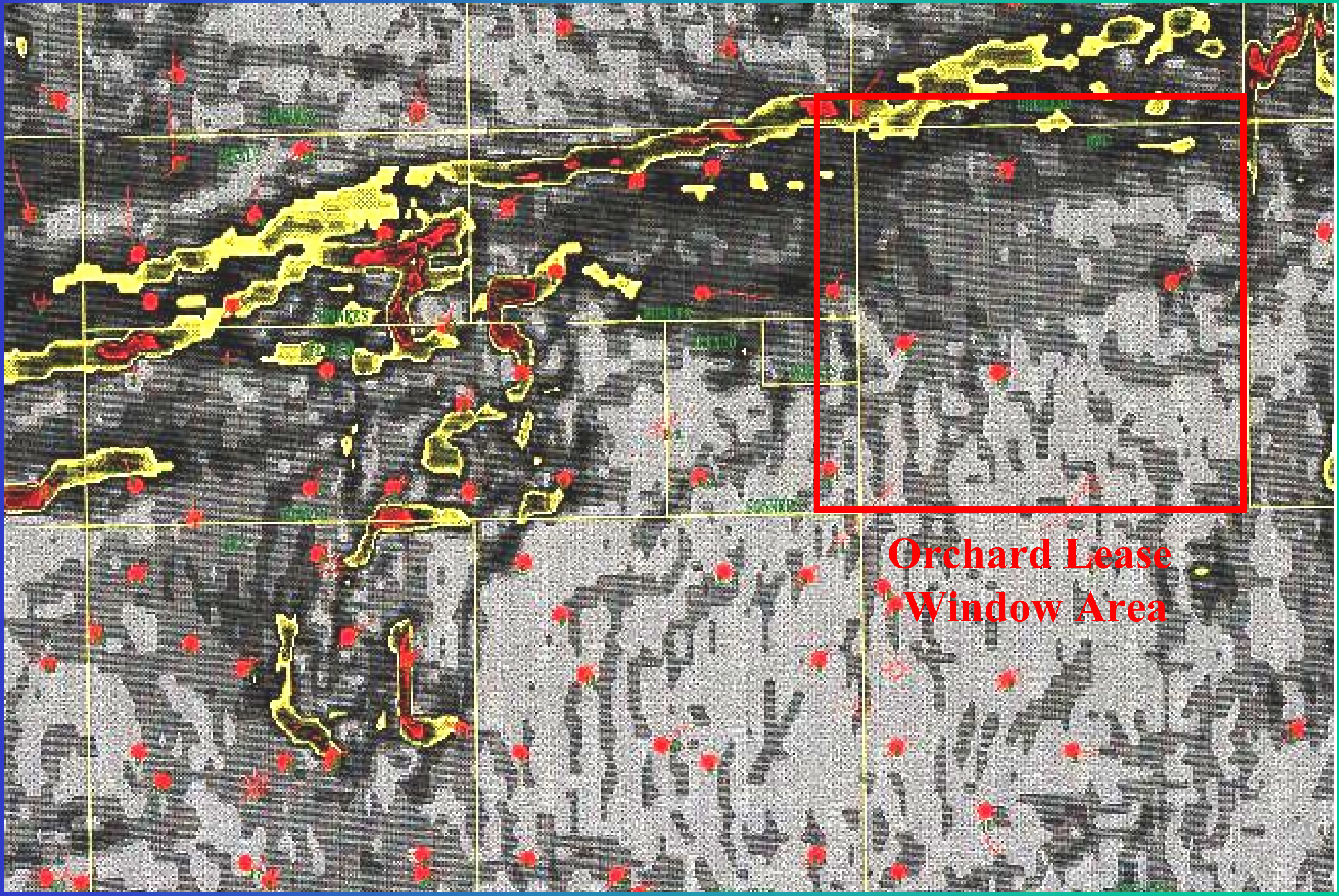
Conductive P_{32} = 0.6 m^2/m^3

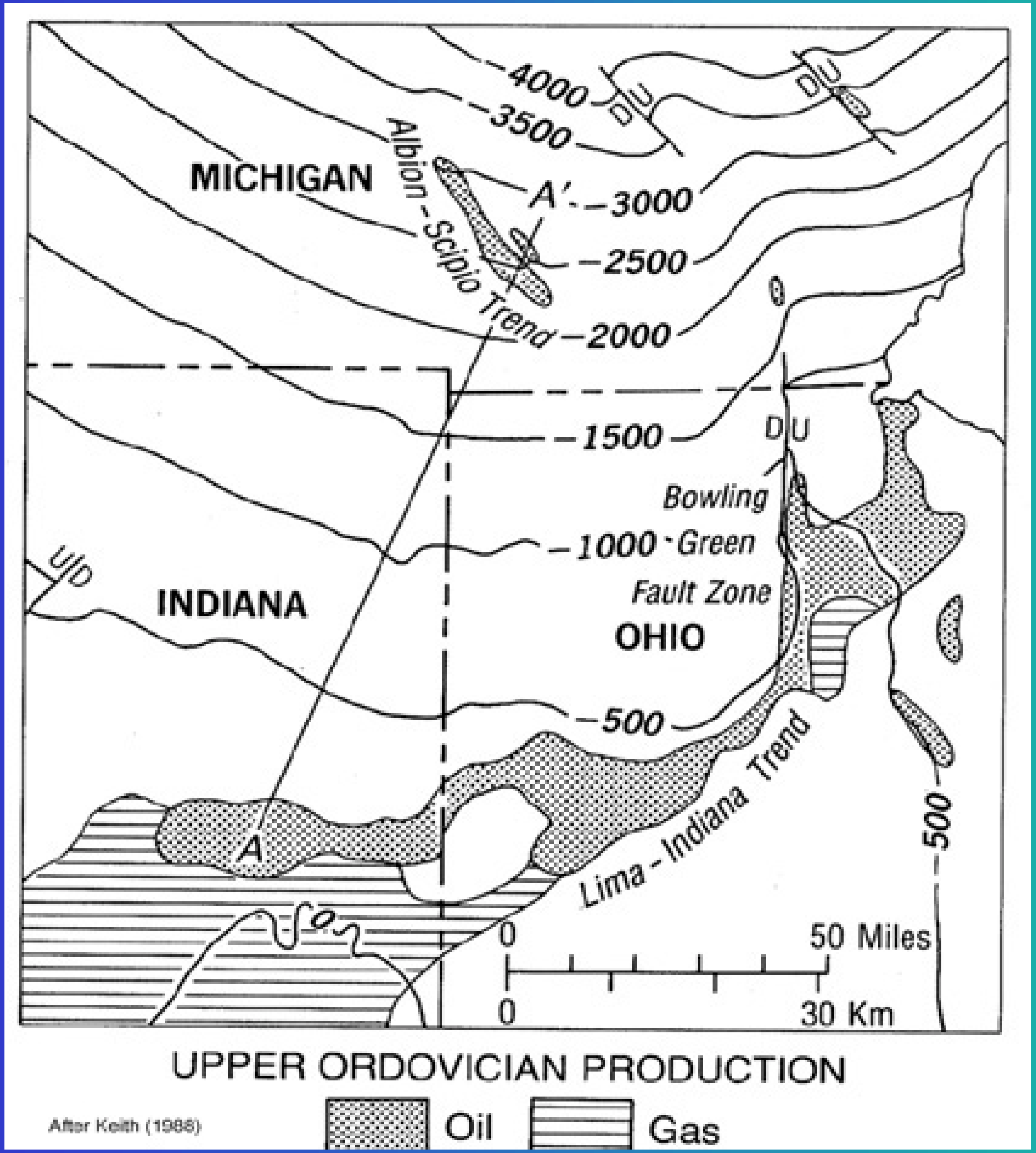


DFN Model Application
Compartmentalization
Phosphoria, South Oregon Basin



Phase 2:
Incorporate Seismic Fault Interpretations
South Oregon Basin

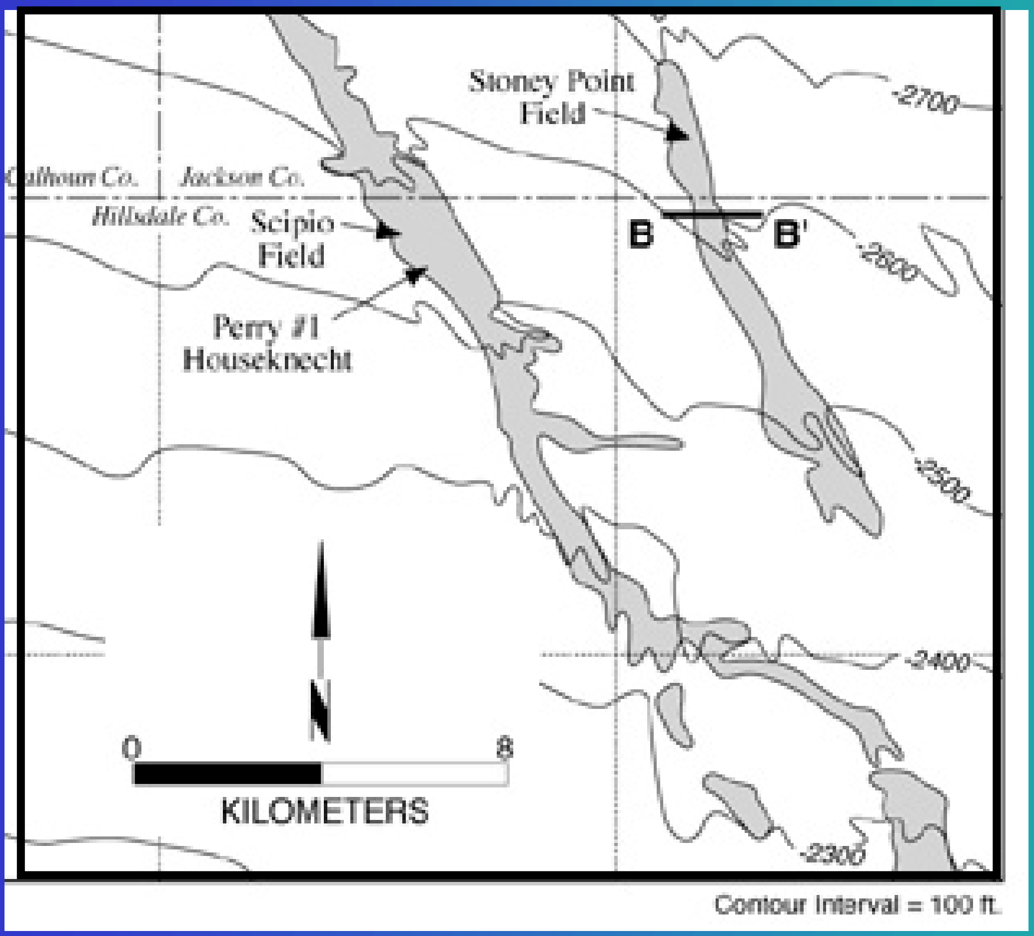




Trenton/Black River Oil: first US discoveries in 1885

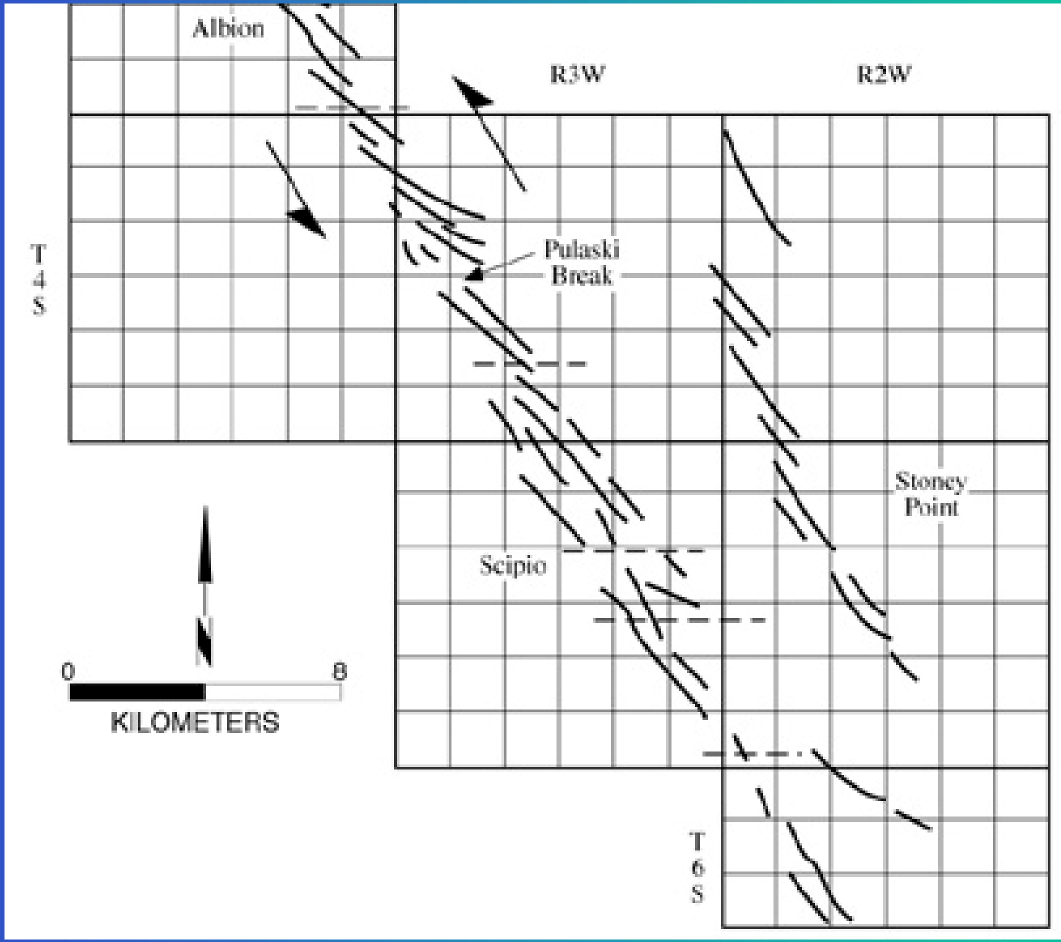
Oil production limited to areas of secondary porosity development (e.g. dolomite)

North Stoney Point, Southern Michigan

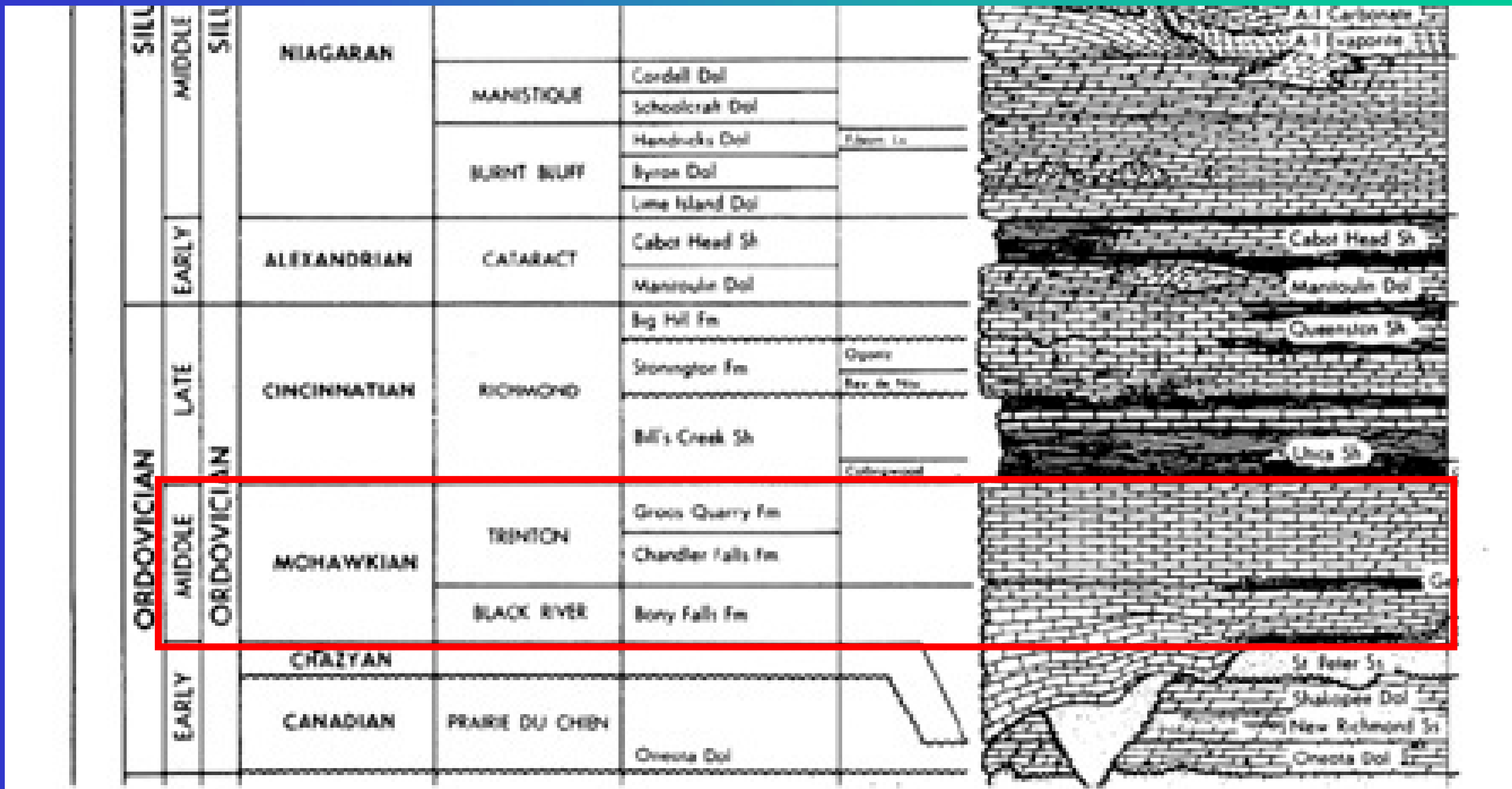


- **Dolomitization occurred above NW trending basement shear faults**
- **Narrow, elongate vertical compartments**
- **Complex water/oil contacts**
- **Conceptual Model of fracturing**

Faults in Paleozoic Cover Rocks at Stoney Point

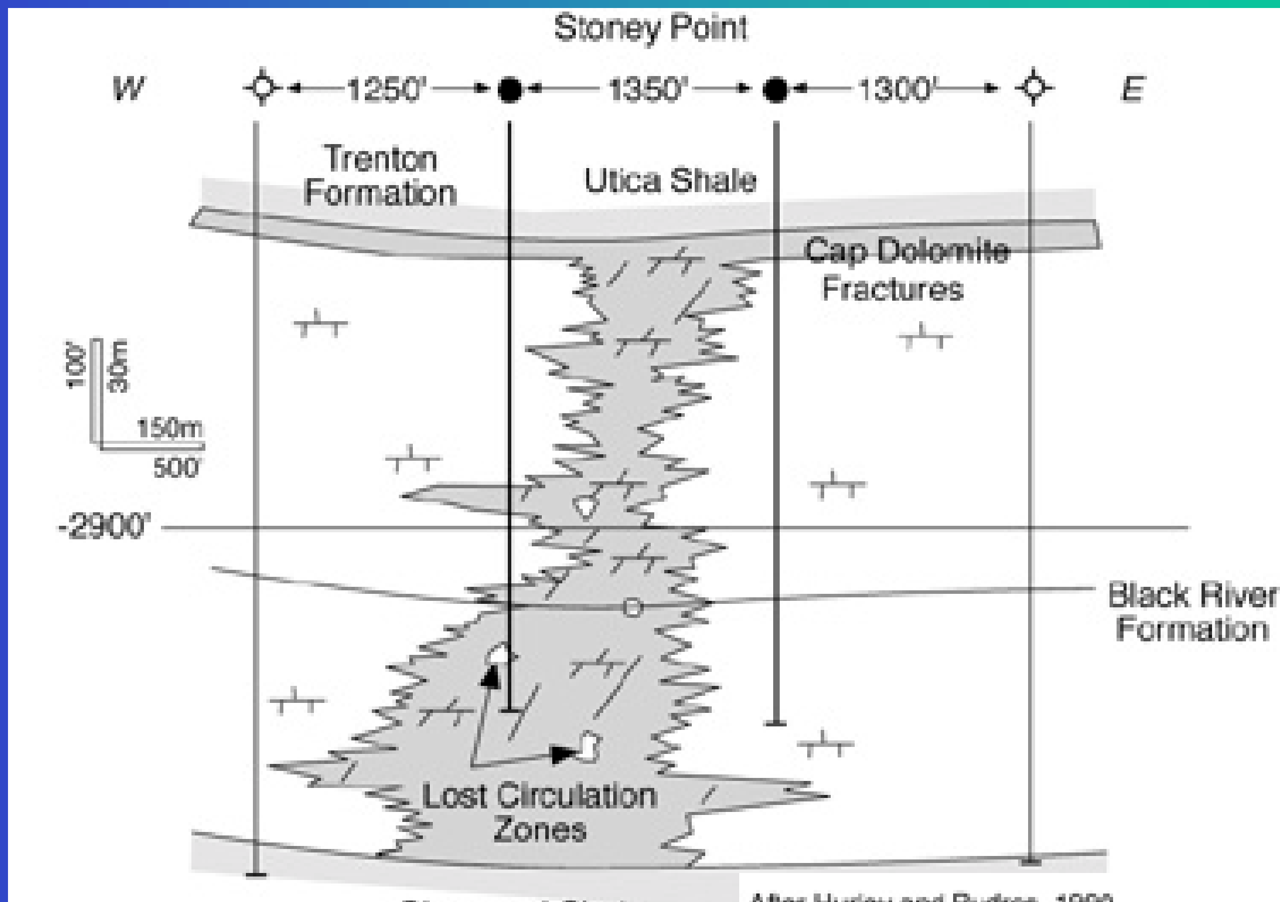


Stratigraphy at North Stoney Point



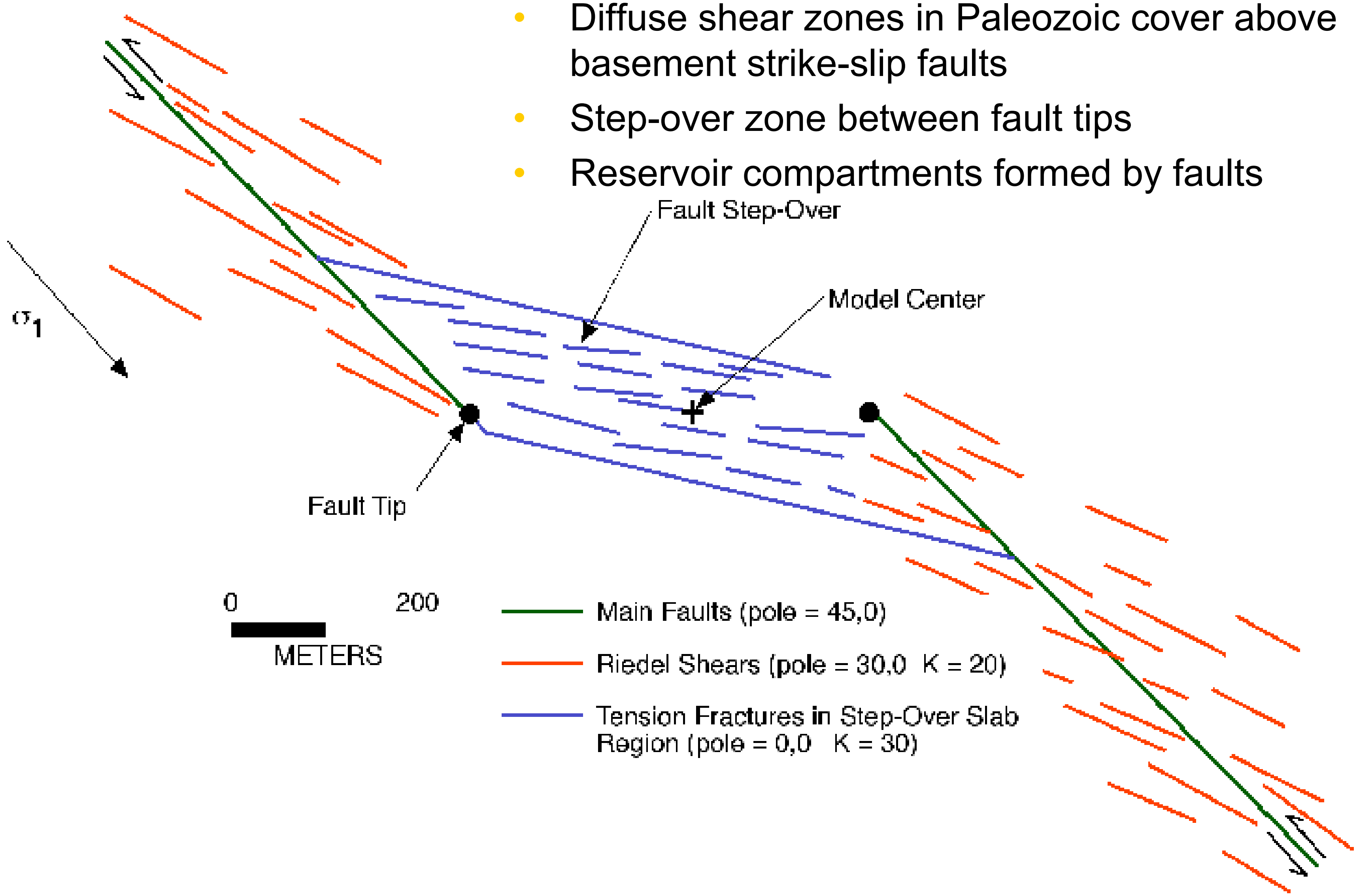
After Prouty (1988)

Carbonate Dissolution
North Stoney Point

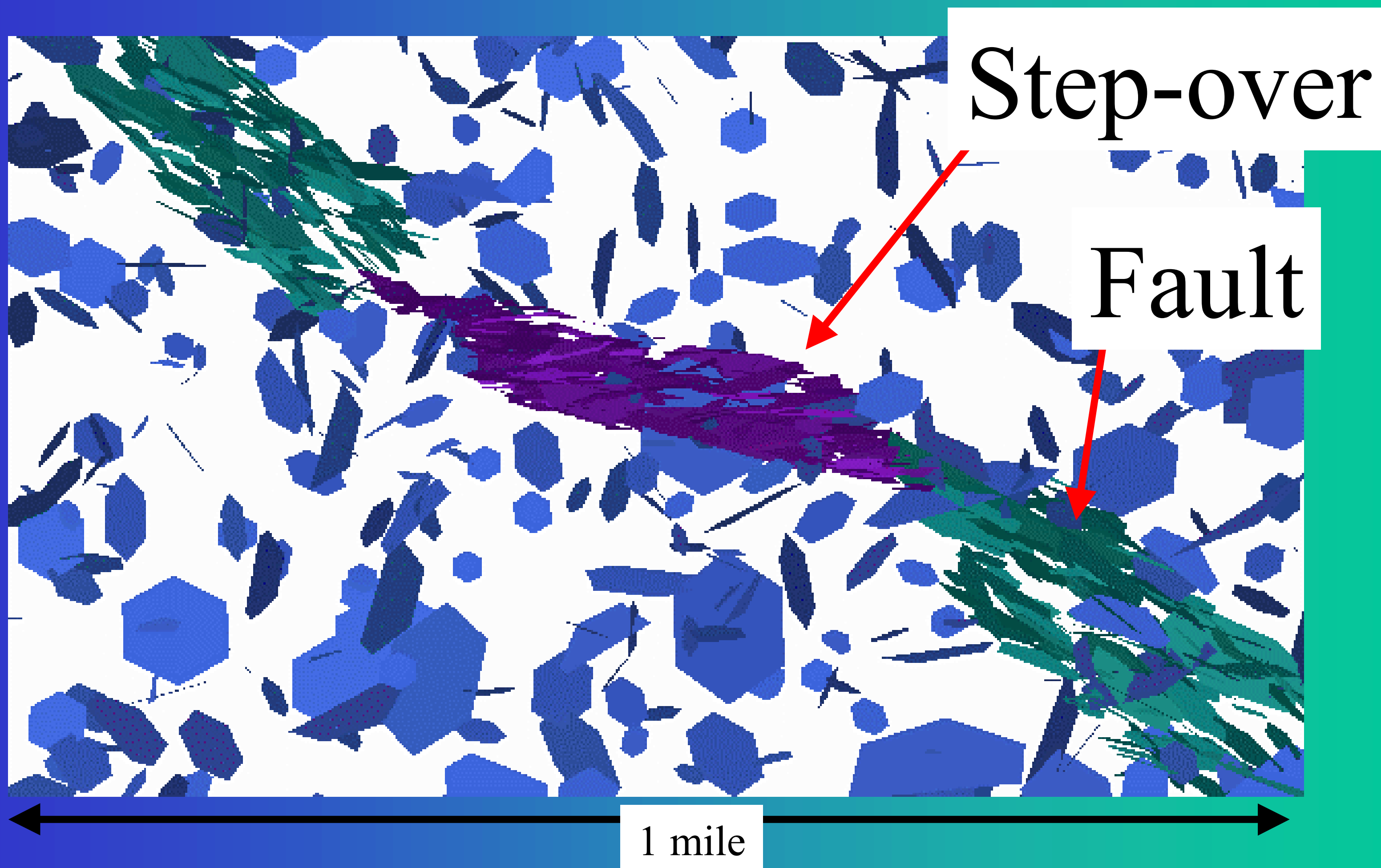


Conceptual Model
North Stoney Point

- Diffuse shear zones in Paleozoic cover above basement strike-slip faults
- Step-over zone between fault tips
- Reservoir compartments formed by faults

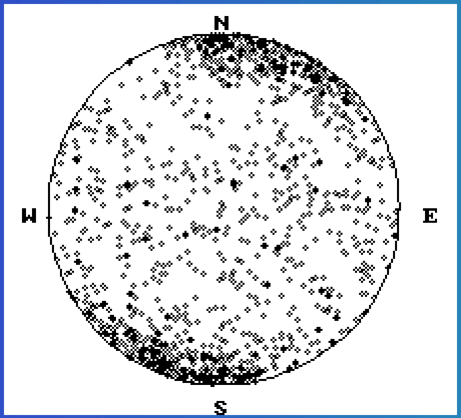


Conceptual Model
North Stoney Point

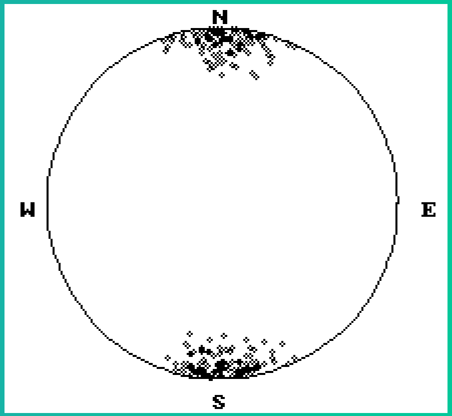


DFN Model Implementation
Fracture Orientations
North Stoney Point, Michigan

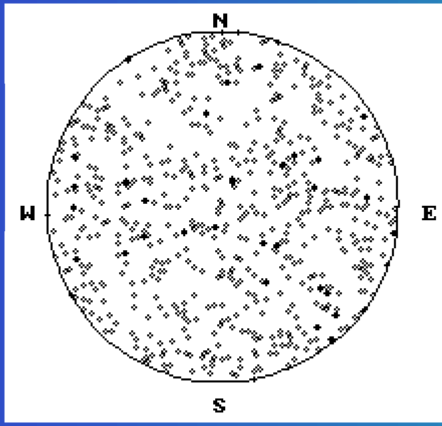
All fracture in model



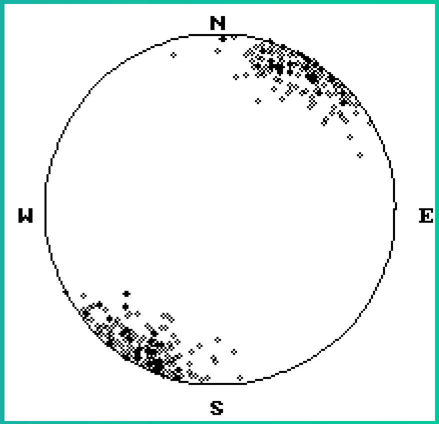
tension fractures in stepover



Background fractures

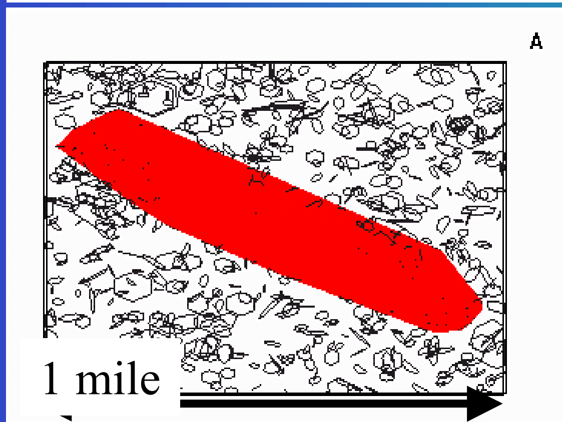


Riedel shears in shear zone

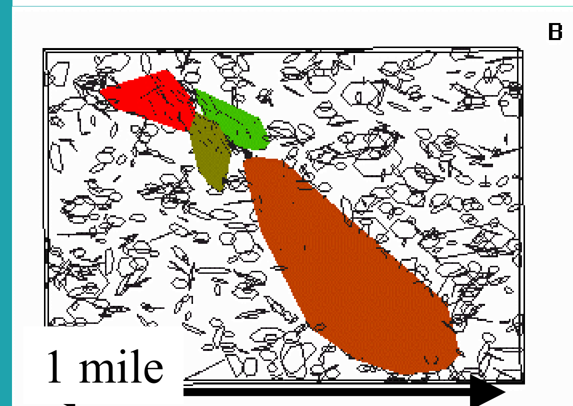


DFN Model Application
Compartmentalization
North Stoney Point

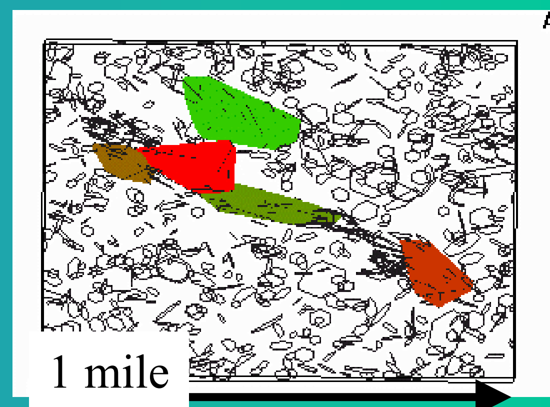
High intensity
(P_{32} =0.05 m²/m³)



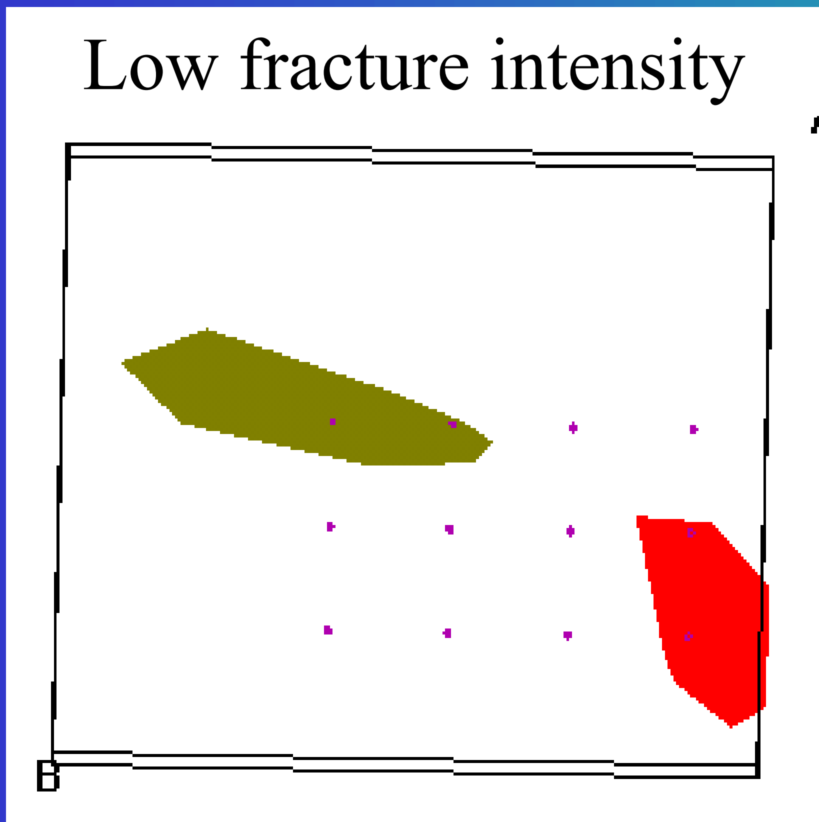
Medium intensity
(P_{32} =0.01 m²/m³)



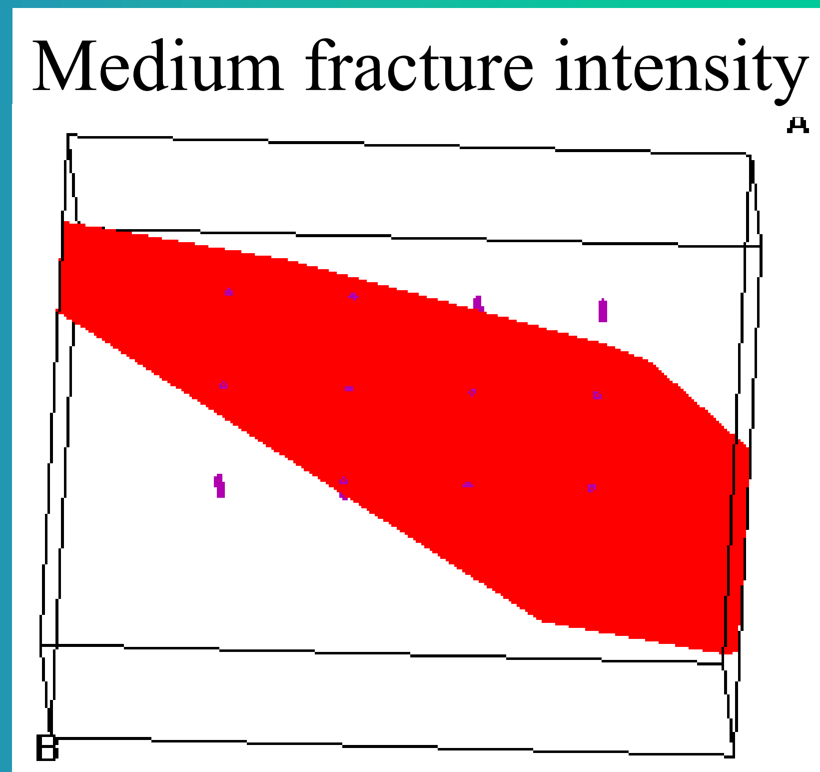
Low intensity
(P_{32} =0.005 m²/m³)



DFN Model Application
Well Field Design Based on Compartments
Phosphoria, South Oregon Basin



4/12 hits
2 compartments



10/12 hits
1 compartment

FETC/NPTO Project Plans: Year 2
DFN Approaches for IOR in Heterogeneous Reservoirs

- Implement algorithms for heterogeneous reservoir DFN data analysis and modelling
- Create models based upon full reservoir structure and lithology
- Incorporate additional data as it arrives
- Determine conductive intensity
- Calibrate DFN Models to tracer and other field tests
- Directly address IOR design using DFN approaches