Use of Reservoir Models and Dynamic Simulation in Development of Mississippian*

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Search and Discovery Article #41341 (2014)**
Posted May 12, 2014

*Adapted from oral presentation given at Mississippian Lime Play Forum, Oklahoma City, Oklahoma, February 20, 2014

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Abstract

The Mississippian is an important oil and gas system in north-central Oklahoma and south-central Kansas. Meramecian and Osagean reservoirs, sub-cropping beneath the Pennsylvanian-Mississippian un-conformity, have been developed by vertical wells since the 1940s and by surging horizontal well activity since 2008. Chesapeake Energy was among the first operators in the “Mississippi Lime” play and initiated the first horizontal well development program in the play with the Howell 1-33H in Woods County, Oklahoma. Since then, there have been more than 1,000 horizontal wells drilled in the Mississippian across Oklahoma and Kansas.

This paper focuses on the construction and uses of three-dimension reservoir models in development of the Mississippian in northwestern Oklahoma. An interdisciplinary combination of cores, well logs, and seismic data are used to build a model of lithofacies, effective porosity, and fluid saturations. These full-field models are used to plan horizontal well trajectories and well spacing decisions for optimal development of the Mississippian reservoirs.

Integrated Study Team

GTG:
Cori Holmes
Martin Dubois

Geology:
Ryan Jordan
Ryan Dayton

Petrophysics:
Adam Haecker

Geophysics:
Alicia Dye
Stephanie Cook
Amanda Trumbo

Engineering:
Saibal Bhattacharya
Nick Penner

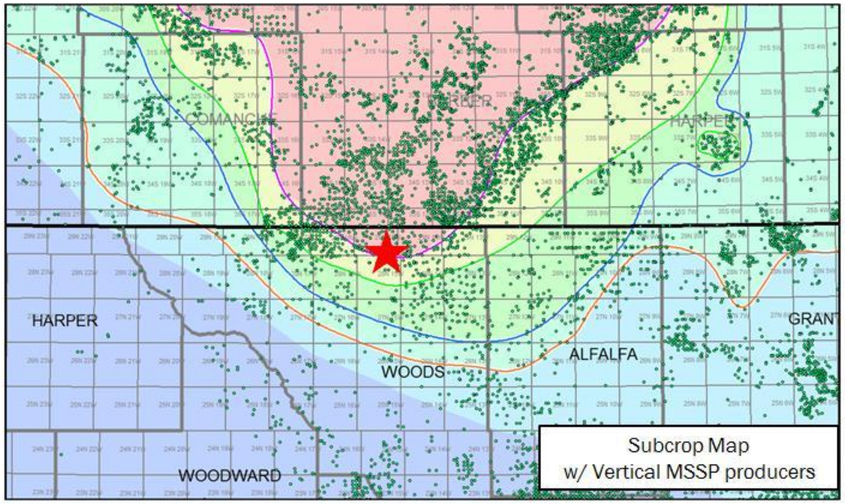
Chesapeake ENERGY

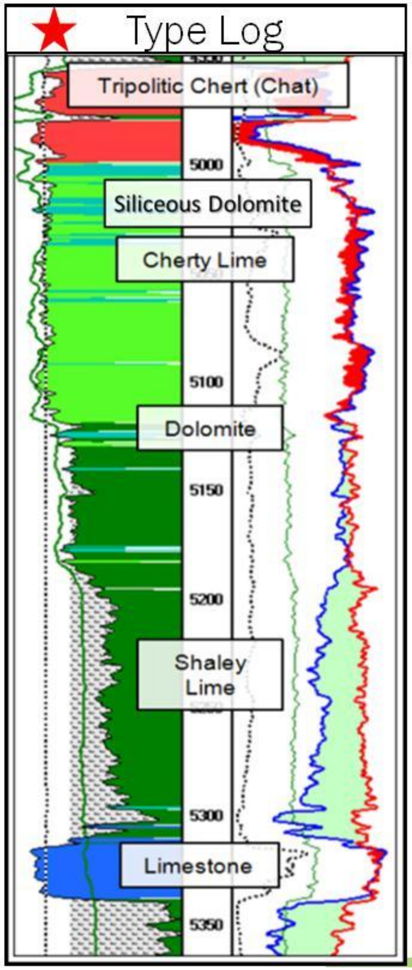
USE OF RESERVOIR MODELS AND DYNAMIC SIMULATION IN DEVELOPMENT OF MISSISSIPPIAN

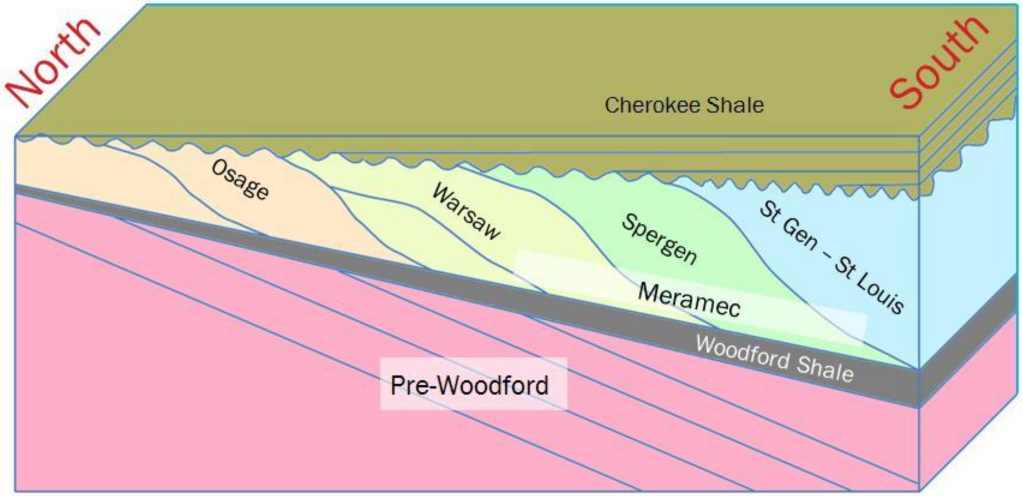
DAN COSTELLO
AAPG MISSISSIPPIAN FORUM
FEBRUARY 20, 2014

CHESAPEAKE IN MISS LIME

- First horizontal well in 2008 (Howell 1-33H)
- 450+ horizontals drilled in Woods and Alfalfa Cos., OK
- Targeting porosity development in Osage and Meramec reservoirs in strat trap beneath Pre-Cherokee unconformity

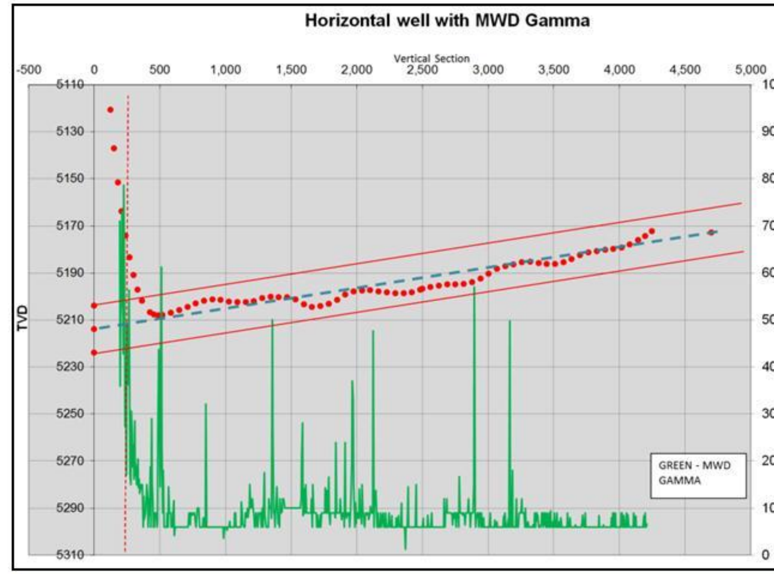




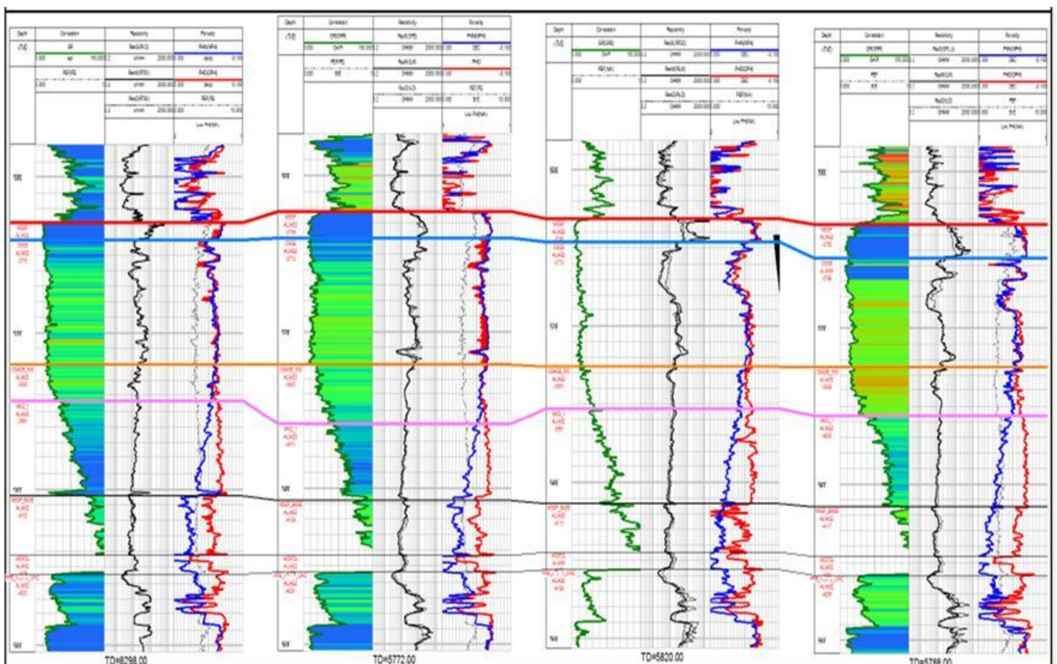


MISS LIME CHALLENGES

- Heterogeneous reservoir with changing lithofacies, structure, porosity, saturations
- Horizontal well targeting (minimal GR character)
- Field development concerns – how many wells per section?

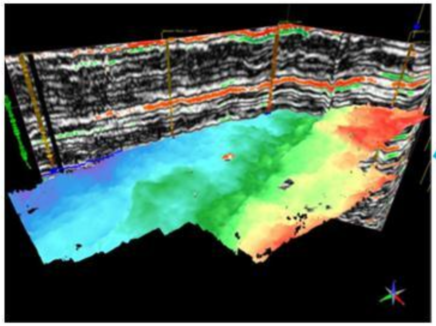


Typical GR in horizontal ranges from 0–30 API; difficult to correlate location in reservoir while drilling

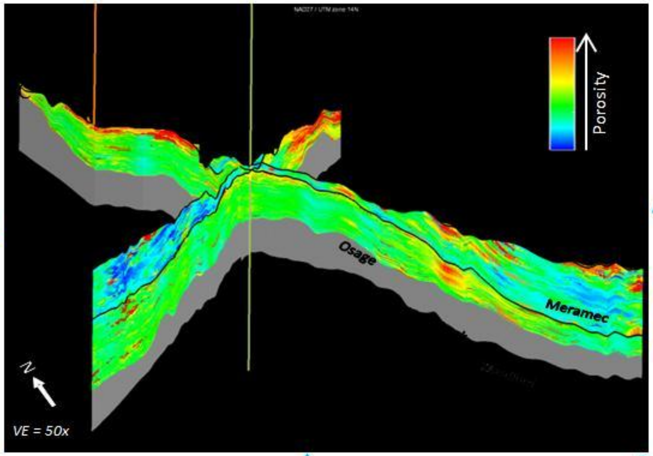


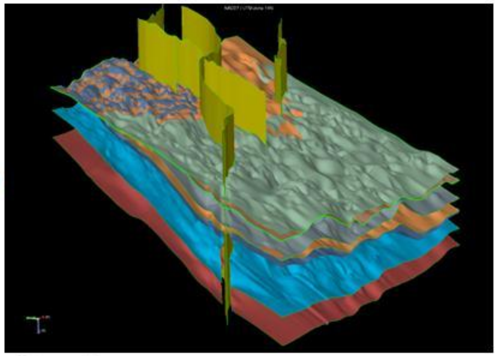
4 wells within one section – shifting pay zones

INTEGRATED, MULTI-DISCIPLINE PROJECT



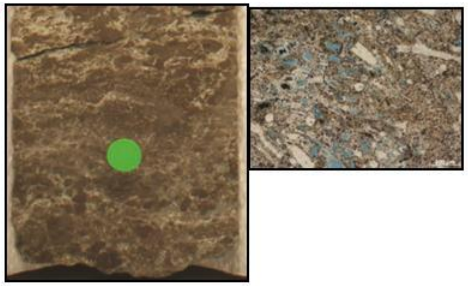
Geophysics: seismic structure, attributes, fault and curvature compartments





Geology:
Formation tops, stratigraphic framework, core lithofacies, lithofacies prediction

Reservoir Engineering:
Fluid compartments, dynamic simulation



Tripolitic chert in core (left) and thin section

Petrophysics:
PEM data, core K-Phi, Pc saturations, FWL, lithofacies prediction

Extensive body of knowledge comes together for a comprehensive solution to aid in well planning and field development

MODEL BUILD WORKFLOW

Chesapeake ENERGY

Structural (Wireframe) Model

Tops & stratigraphy
Structural surfaces
(MSSP & WDFD)
Seismic compartments
- Faults
- Curvature

Structural model
- Multiple zones
- 75-100 layers (varies)
- 330 ft XY dimensions
- 3.6 million cells

Property Model

Well-scale data
- Lithofacies
- Effective Porosity

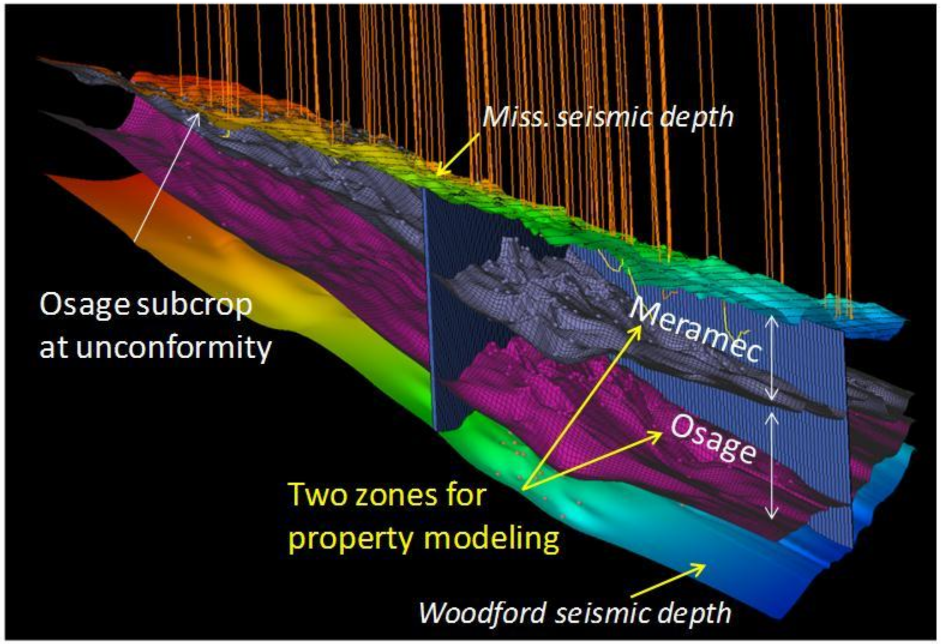
Sw solution
- Compartments (API)
- Free Water Level
- Capillary-pressure-based Sw

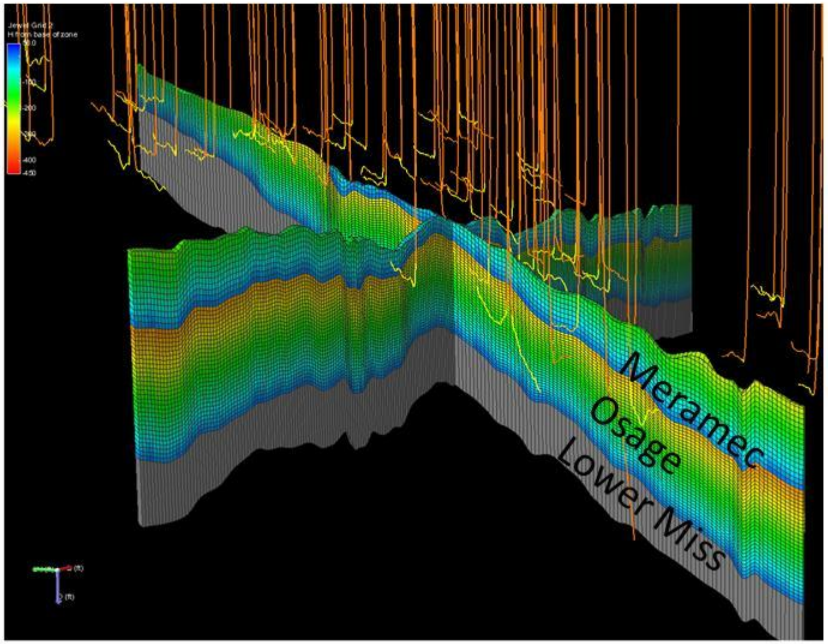
Property cellular model
- Lithofacies
- Porosity
- Permeability
- Water saturation
- Oil/Gas in place

Model validation
- Well targeting and planning
- Dynamic modeling

Model inputs
-1208 wells (vt+hz) with formation picks
-580 petrophysical logs from vertical wells
-5 wells with core
-production data
-3D seismic

MODEL GEOMETRY





- Structural elements: Seismic depth maps (Miss. & Woodford)
- Well formation tops (1208 wells)
- Two-zone model: Meramec and Osage

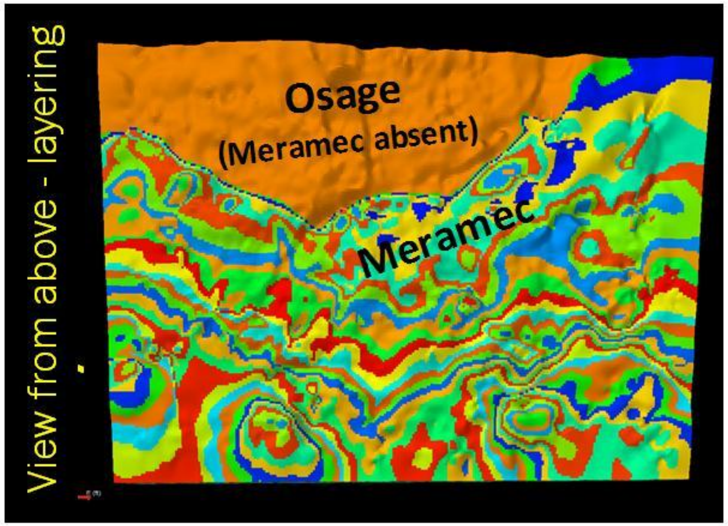
- Layering accurately represents Meramec subcrop at Miss. unconformity surface (0-80 layers)
- Osage layering is proportional (60 layers)
  (color is height above base of zone)

Grid cell dimensions: 330’ x 330’ x 5’

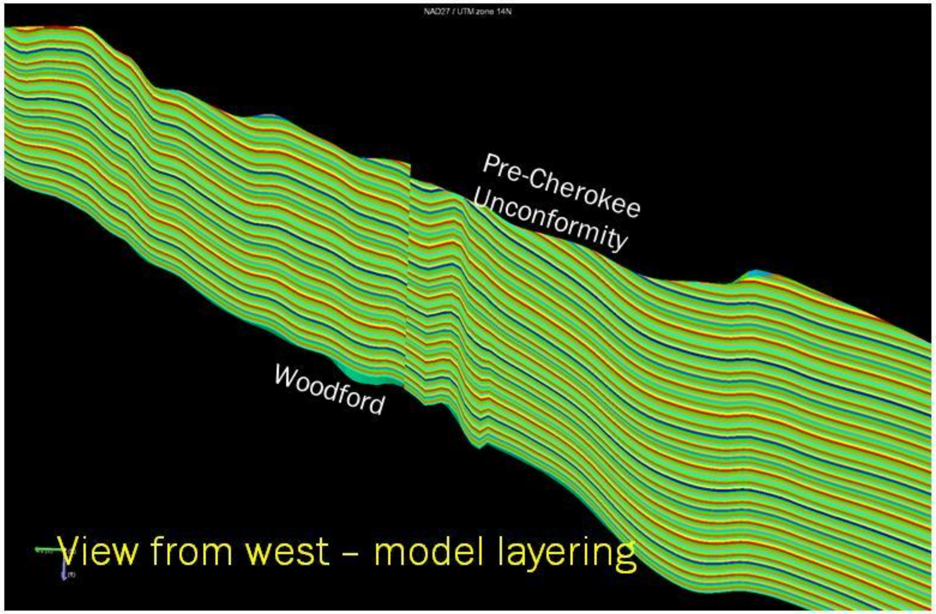
Meramec and Osage reservoirs modeled separately to preserve differences in mineralogy, porosity, etc.

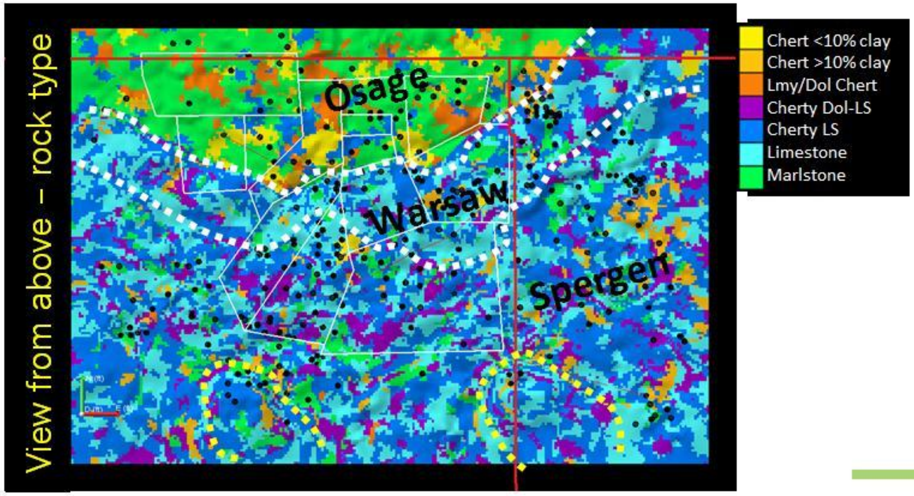
SUBCROPS AND MODEL LAYERING

- Model captures reservoir complexity beneath subcrop as porous zones are trapped beneath unconformity
- Combination of rock type, layering and porosity models leads to accurate reservoir model



Model Subcrops





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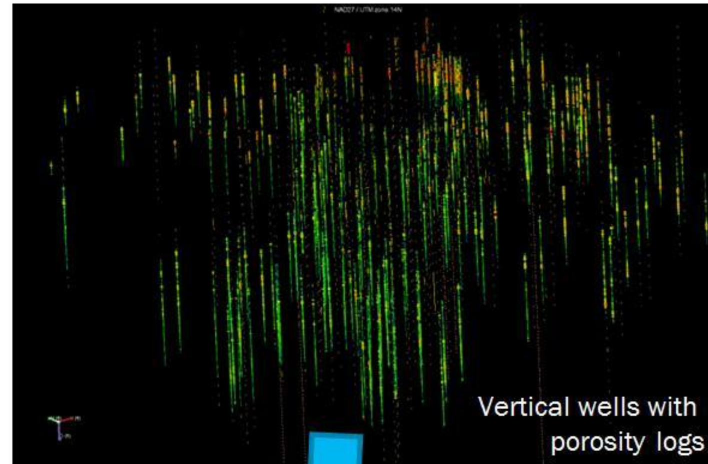
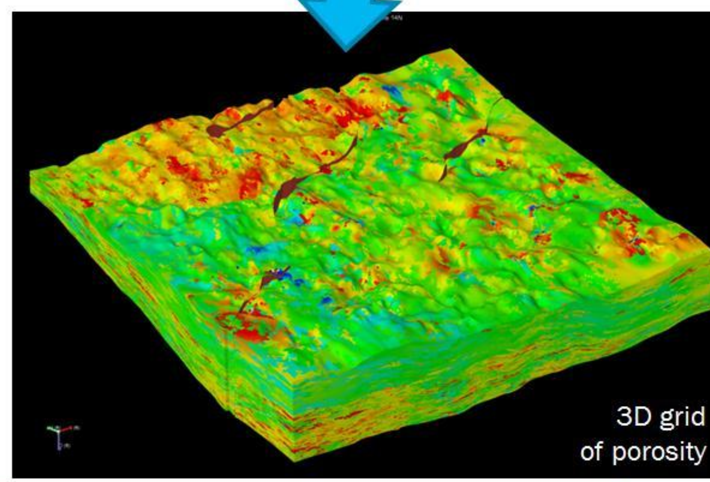
PROPERTY MODELING WORKFLOW

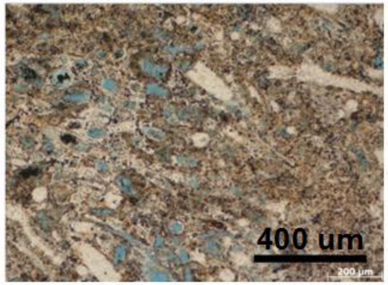
1. Define lithofacies in available wells with cores
2. Tie lithofacies to log properties using neural network
3. Predict lithofacies in wells without core
4. Upscale lithofacies and other logs to grid scale
5. Geostatistical analysis and Gaussian simulation
6. Integrated 3D property model



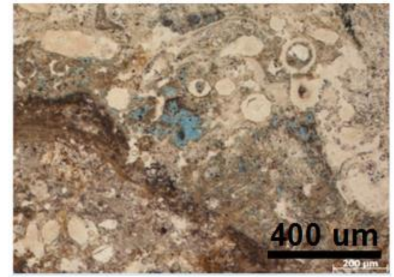


Full-field model relies on properly QC' d and tied input and data from geology, petrophysics, geophysics

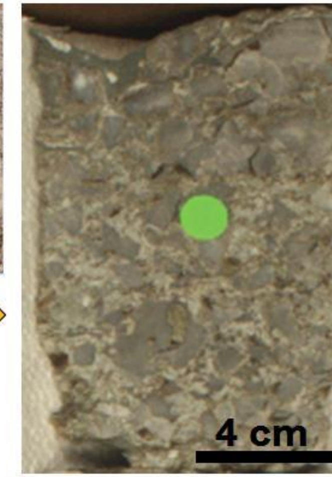
CHERT LITHOFACIES IN CORE

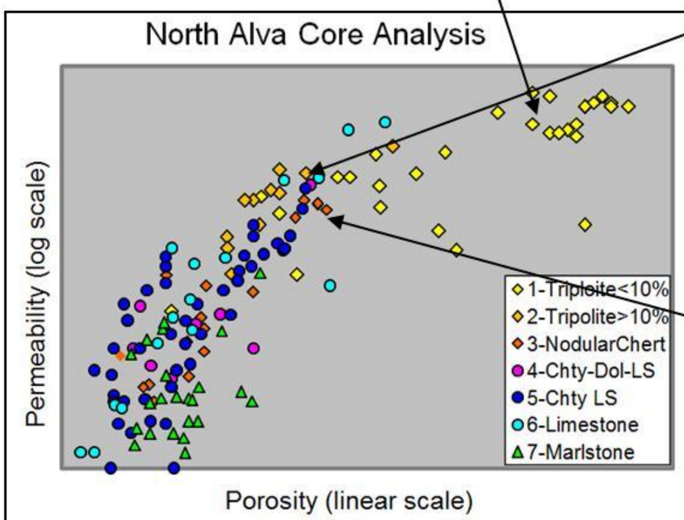


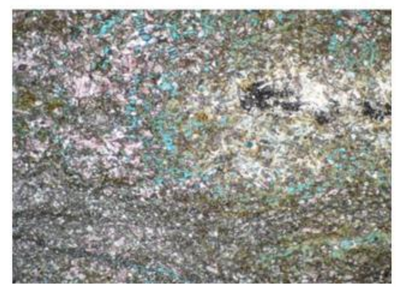
1 Tripolite <10% clay ◇



2 Tripolite >10% clay ◇



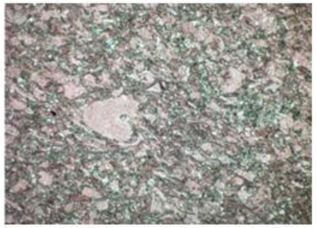




3 Nodular chert, part tripolitic ◆

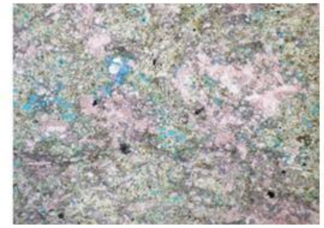
Reservoir model begins with core descriptions (CHK + public inventory) in order to tie back to true reservoir conditions

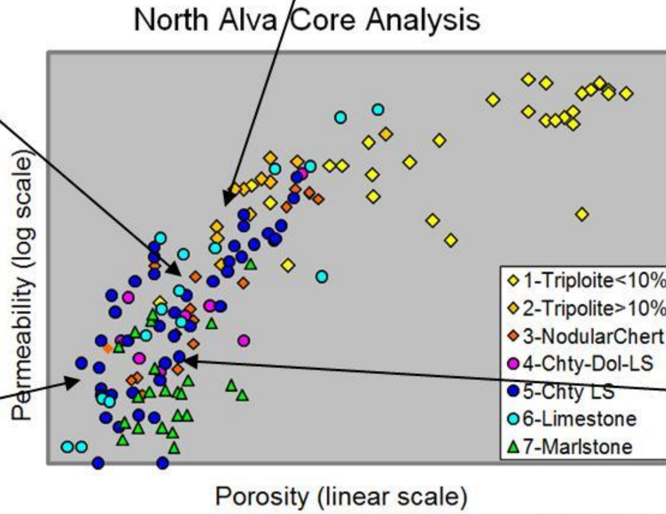
LIMESTONE LITHOFACIES IN CORE



4 Cherty dolomitic limestone (wkst)

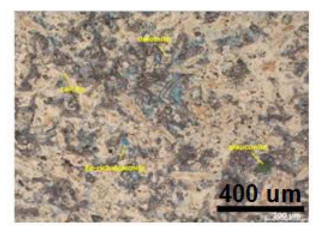
5 Cherty limestone (wkst)

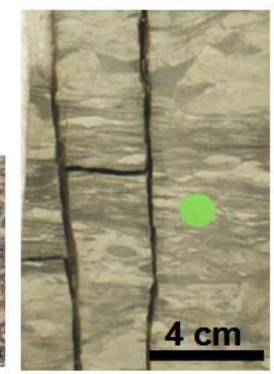




7 Marlstone

6 Limestone (wkst-pkst)





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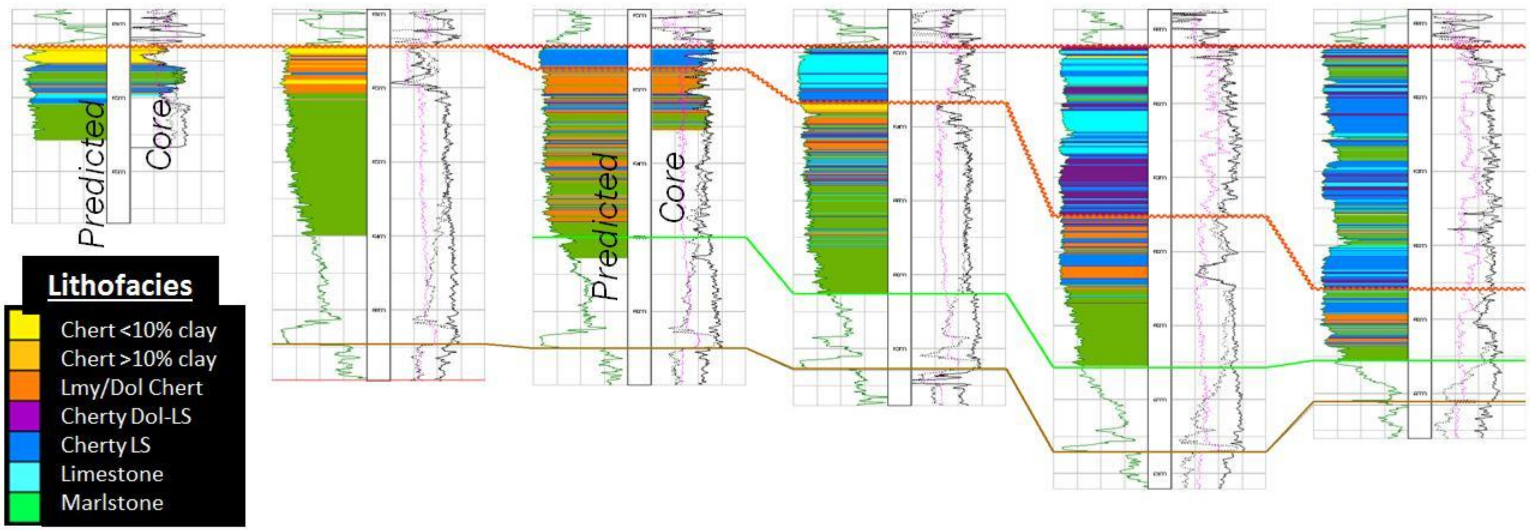
LITHOFACIES PREDICTION IN WELLS WITHOUT CORE

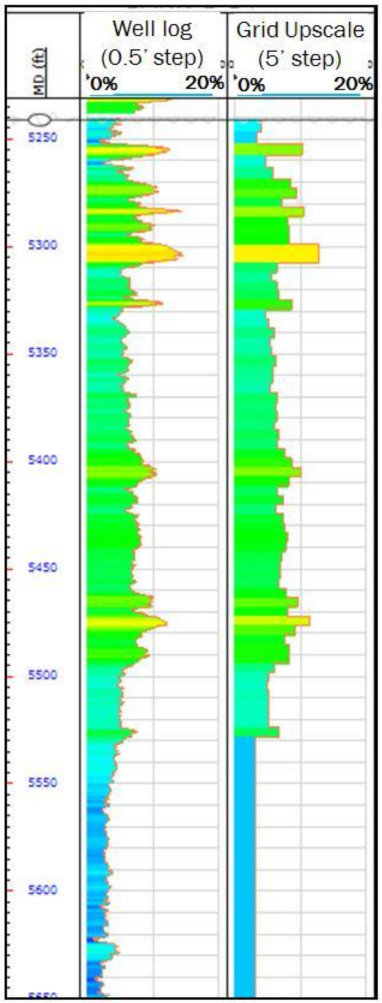
Chesapeake ENERGY

Six Predictor Variables for Lithofacies (core-to-log):

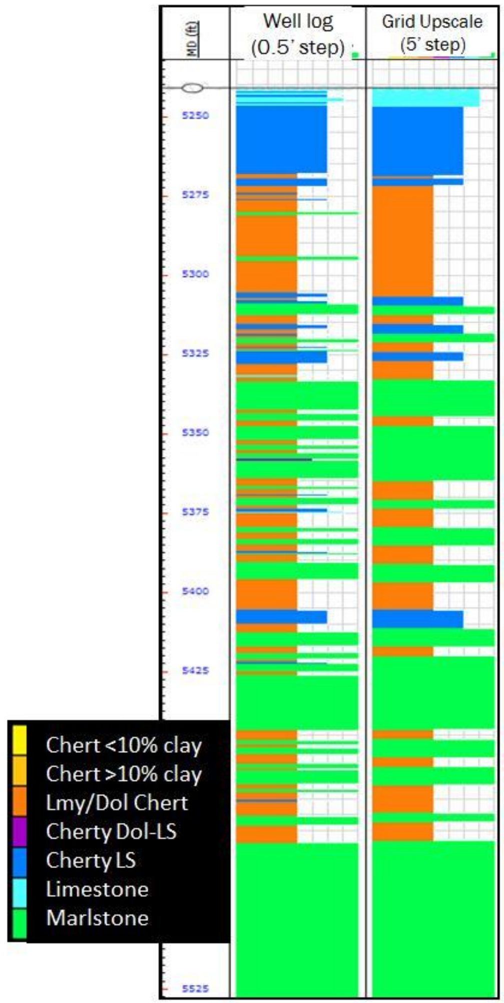
- Gamma Ray
- PE
- Deep resistivity
- Neutron/Density phi xplot
- Neutron – Density phi (difference)
- Stratigraphic indicator



WELL LOG UPSCALING

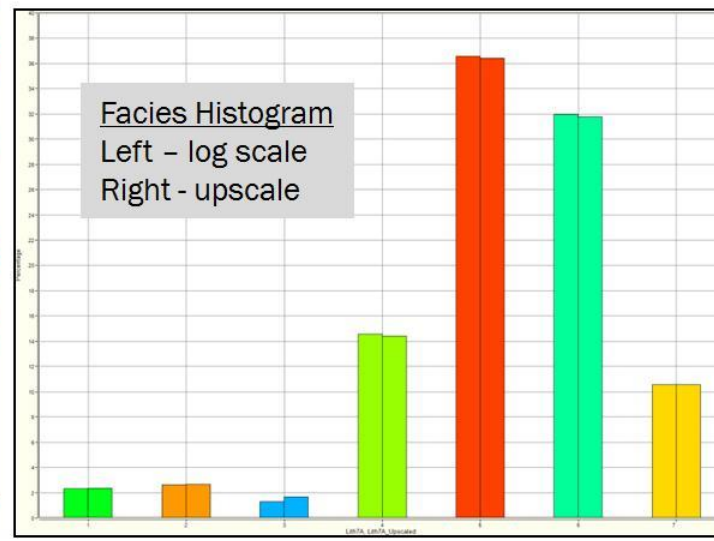


Effective Porosity
Upscale Method: Arithmetic Mean



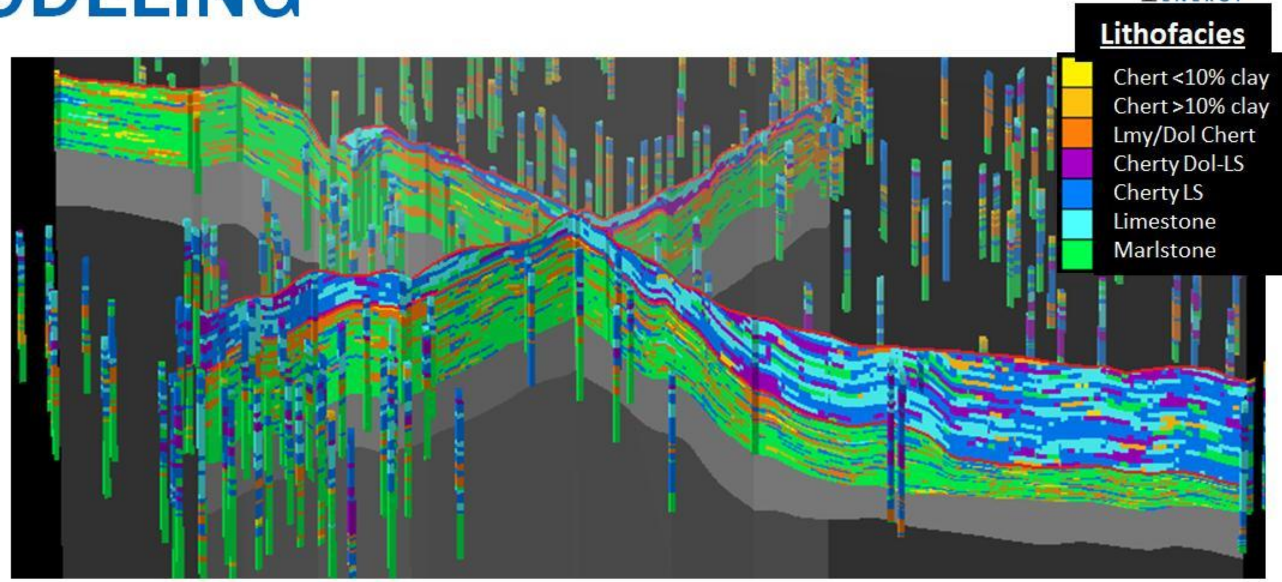
Lithofacies
Upscale method: Most occurring

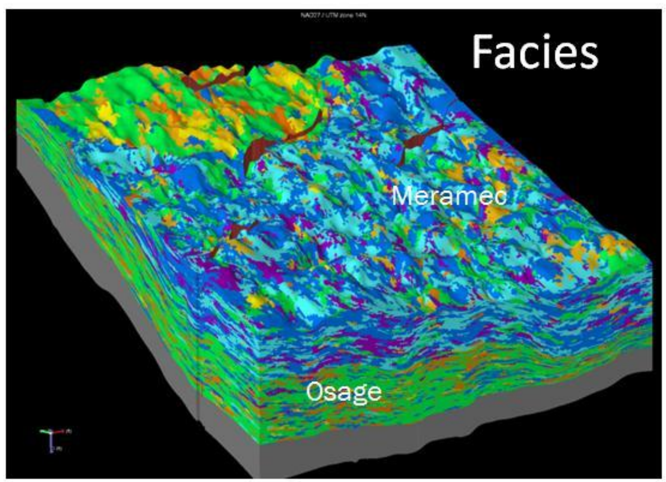
- Input well logs upscaled to grid cell – averaging (PHIE) or most common (facies)
- Overall proportional distribution maintained very well

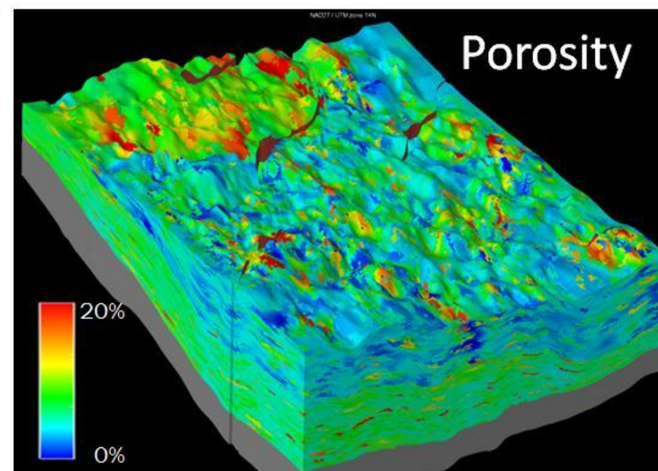


PROPERTY MODELING

- Lithofacies grid populated using Sequential Indicator Simulation (SIS)
- Porosity grid populated using Sequential Gaussian Simulation (SGS)
- Porosity gridding is lithology dependent (higher PHIE in cherts relative to limestones)

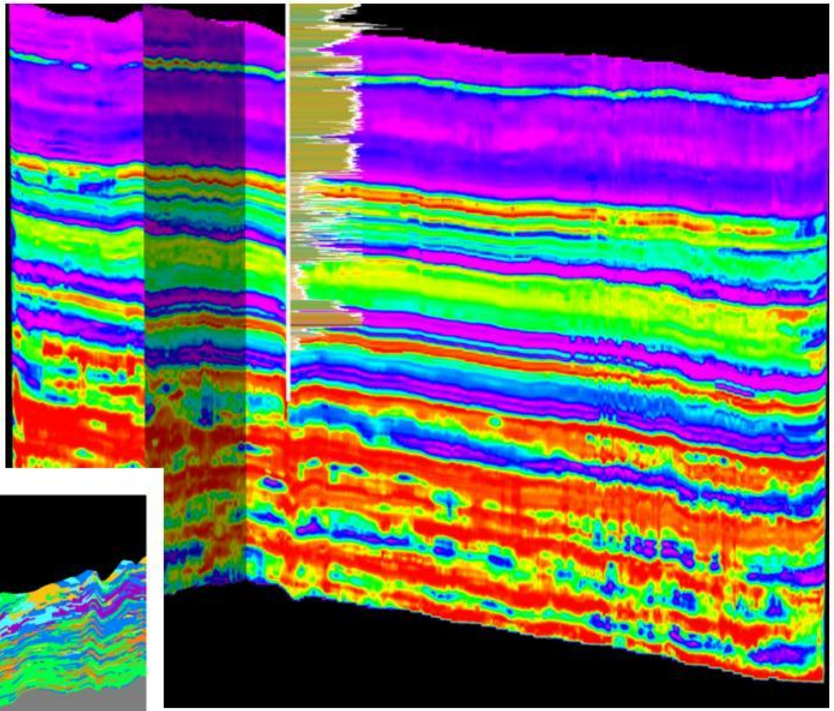


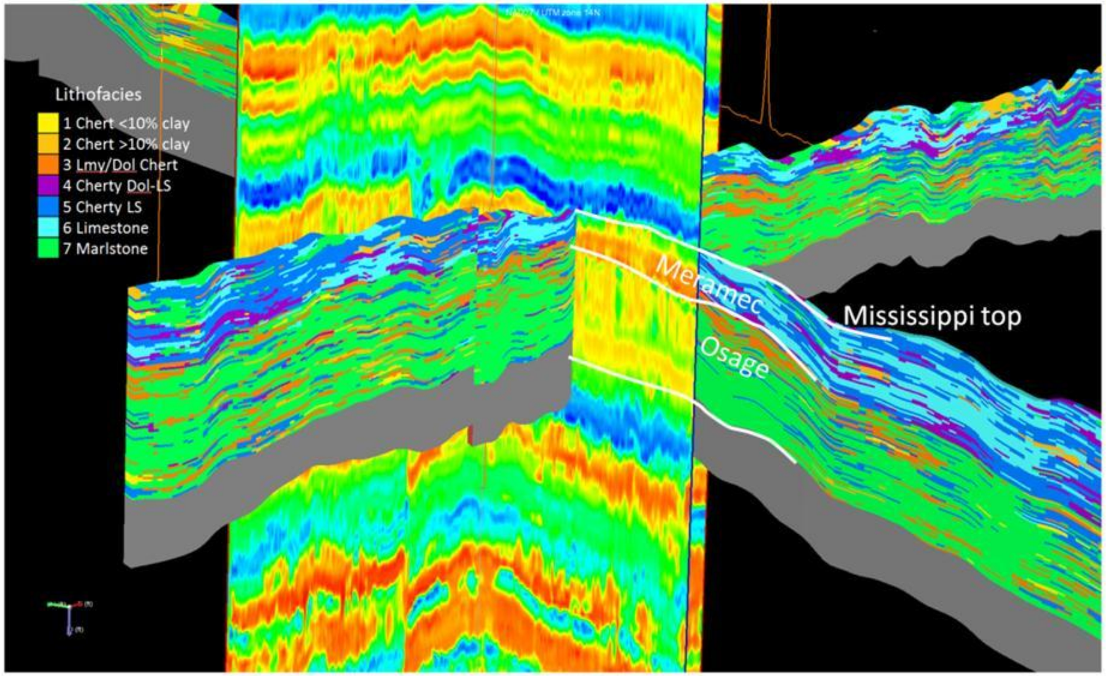




WORKFLOW TO COMBINE JEWELSUITE MODEL & SEISMIC

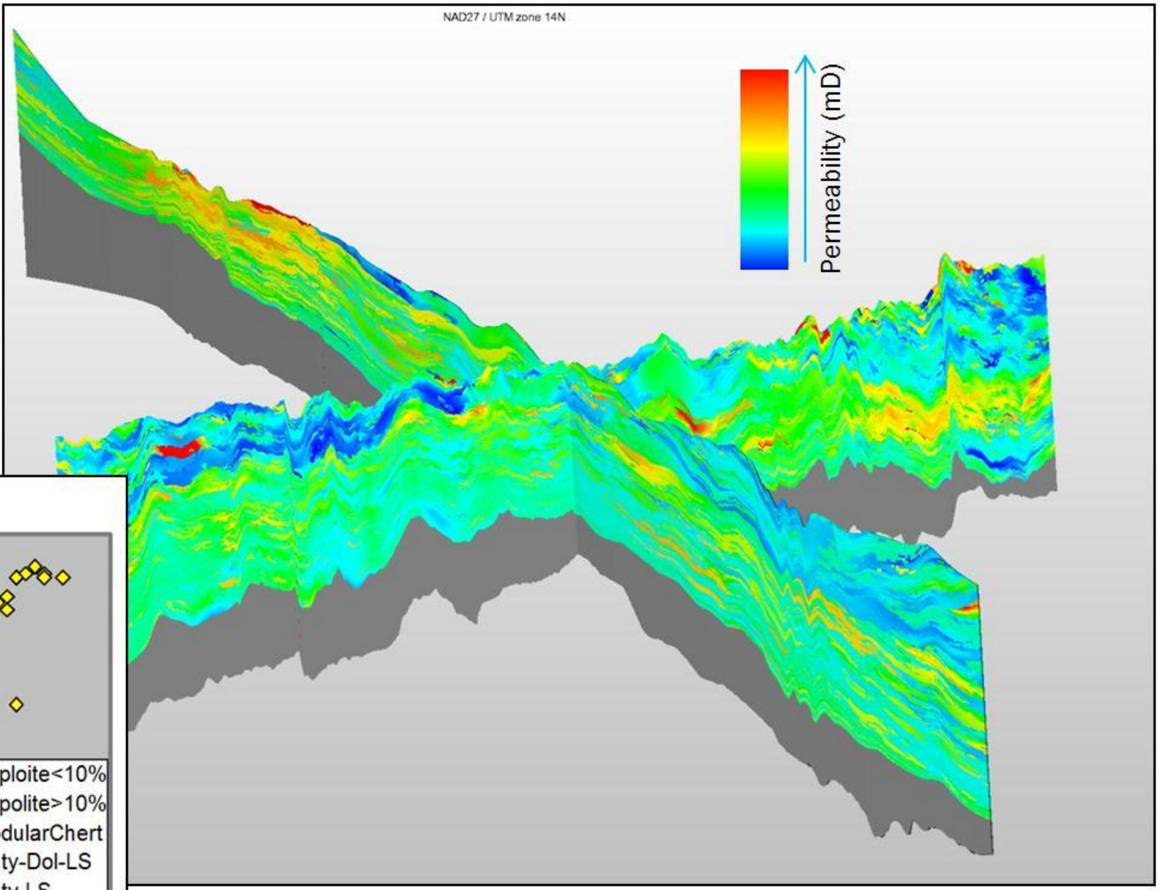
- Iterative process to refine 3D property model using geologic interpretation and seismic
- Seismic attributes correlated with property models (facies, porosity) at well locations and used as soft variable for collocated cokriging

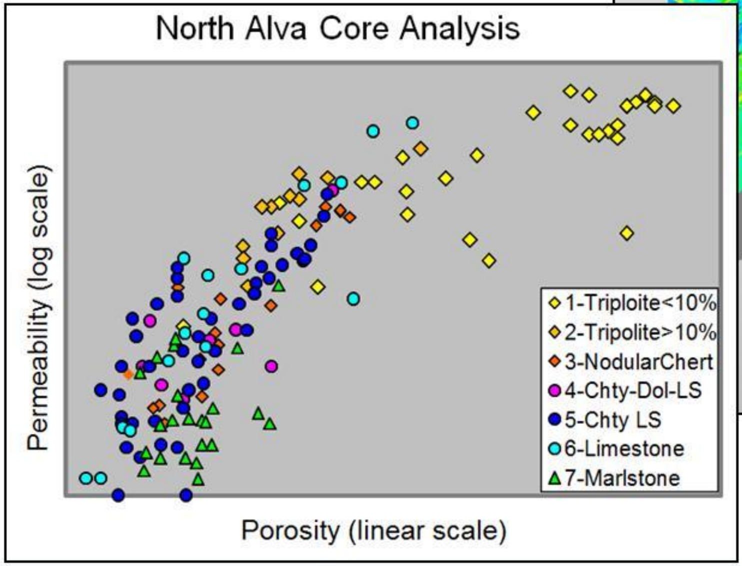




PERMEABILITY MODELS

- Calculate perm XY (kik) cell-by-cell, knowing lithofacies and porosity
- Intervals with hydrocarbon saturation generally have K >0.1 md





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<u>Model validation</u>

- Well targeting and planning
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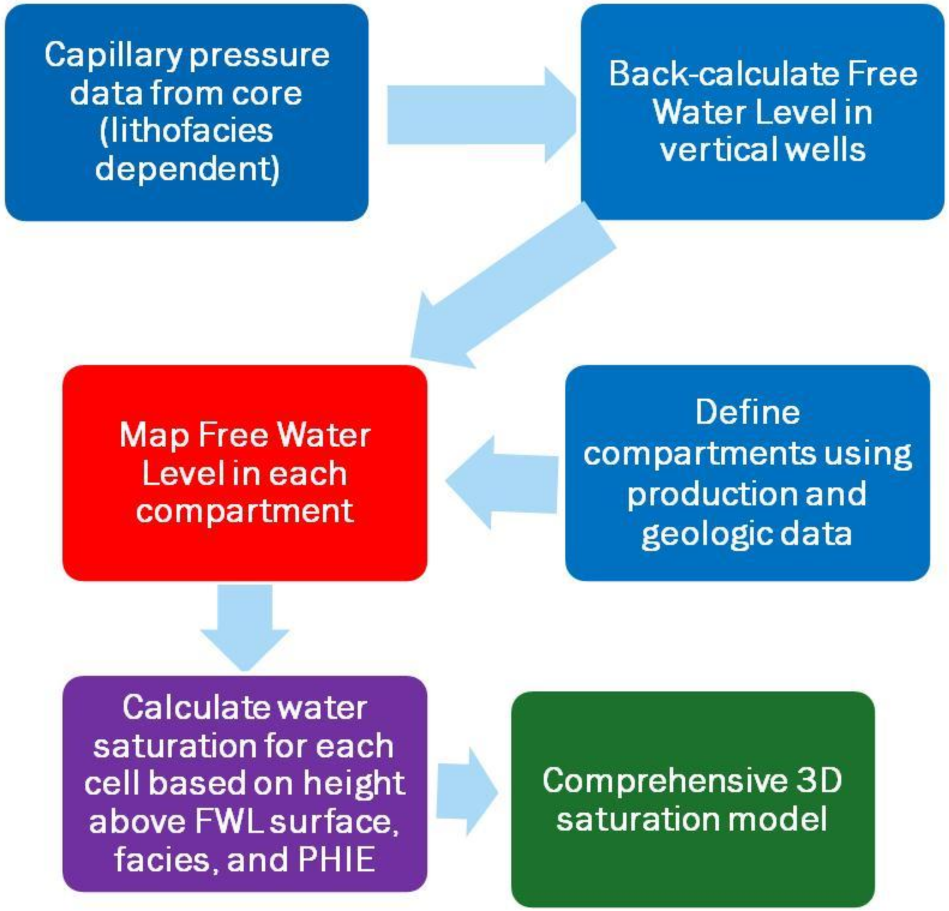
WATER SATURATION WORKFLOW



- Water saturation is not an independent variable and cannot be modeled geostatistically as with other properties

- Primary rock properties (lithofacies, porosity, permeability) need to be modeled first, then Sw can be calculated on a cell-by-cell basis using capillary pressure approach

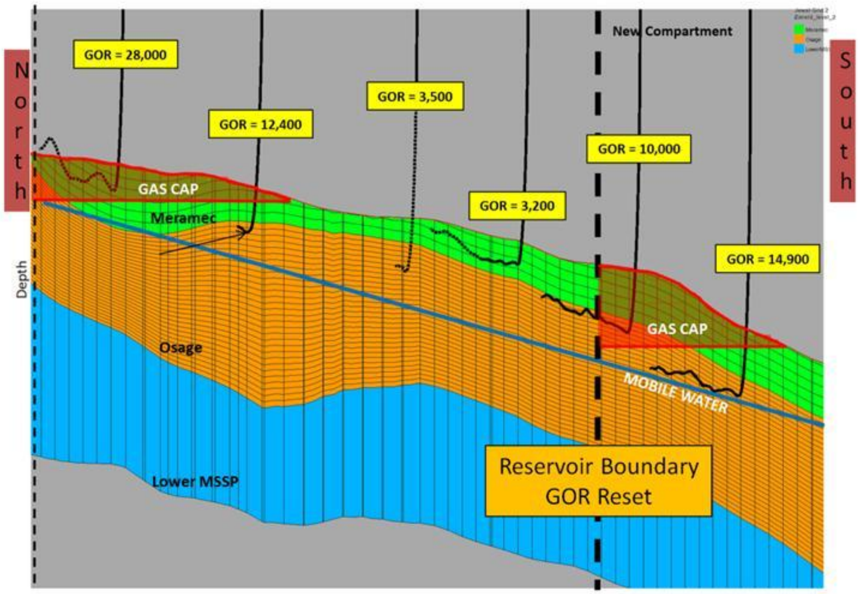
RESERVOIR COMPARTMENTS

Compartment indicators

- API gravity – range from 18 to 35 API
- Highly variable GOR
- Changing oil-water contacts

Compartment boundaries evidence

- Faults with offset
- Positive/negative curvature
- Probable subcrop influence



WATER SATURATION & FREE WATER LEVEL

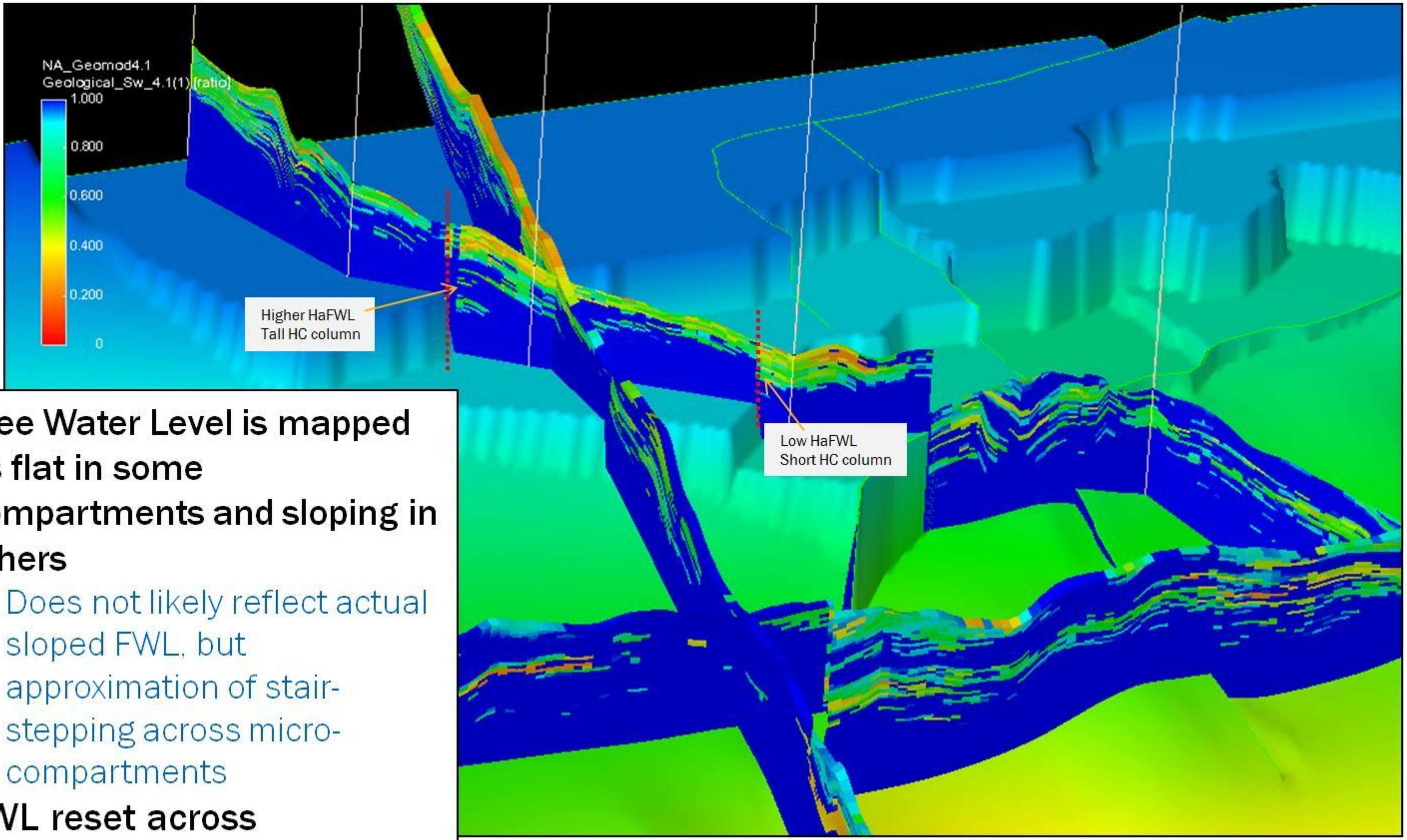
- Capillary pressure data from cores used to develop saturation-height equations (Leverett J-Function)

- These equations used with Archie saturations to back-calculate free water level for control wells, then FWL mapped across compartments

- All reservoirs in transition zone – no free oil

Sw=f(HaFWL, PHIE, K)

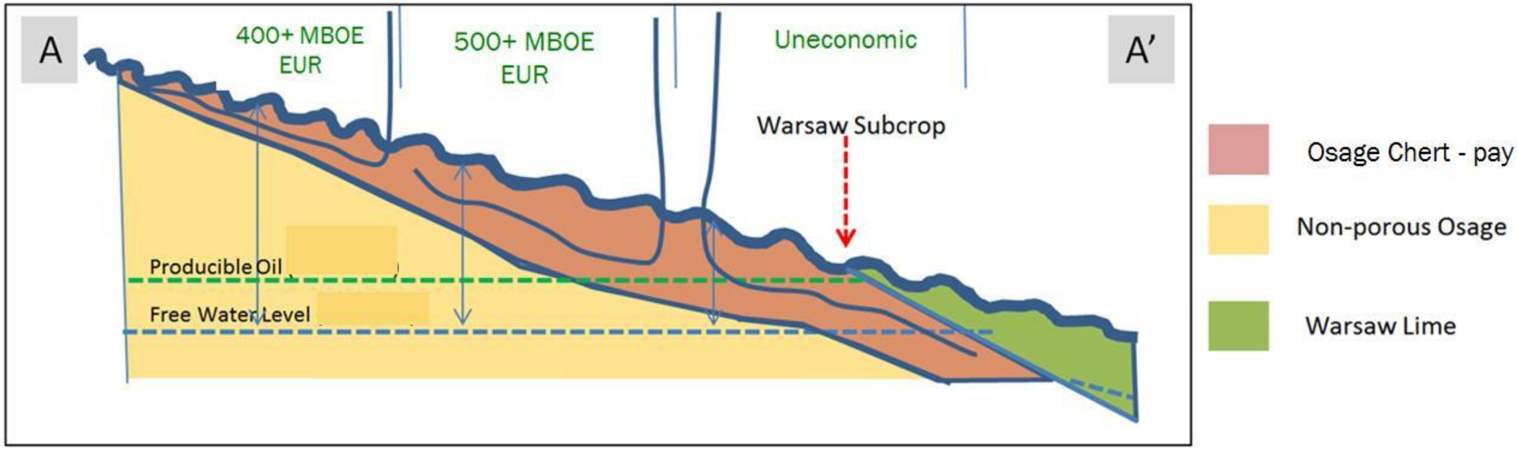
FREE WATER LEVEL - MAPPING



- **Free Water Level is mapped as flat in some compartments and sloping in others**
  - Does not likely reflect actual sloped FWL, but approximation of stair-stepping across micro-compartments
- **FWL reset across compartment boundaries reflected in production**

Blue grid cells indicate high Sw (non-reservoir): Can be either water hazard or tight rock

HYDROCARBON COLUMN



- Critical to land well ~40-50’ above free water level to produce economic well
- Overall production function of height above FWL, storage, and reservoir thickness

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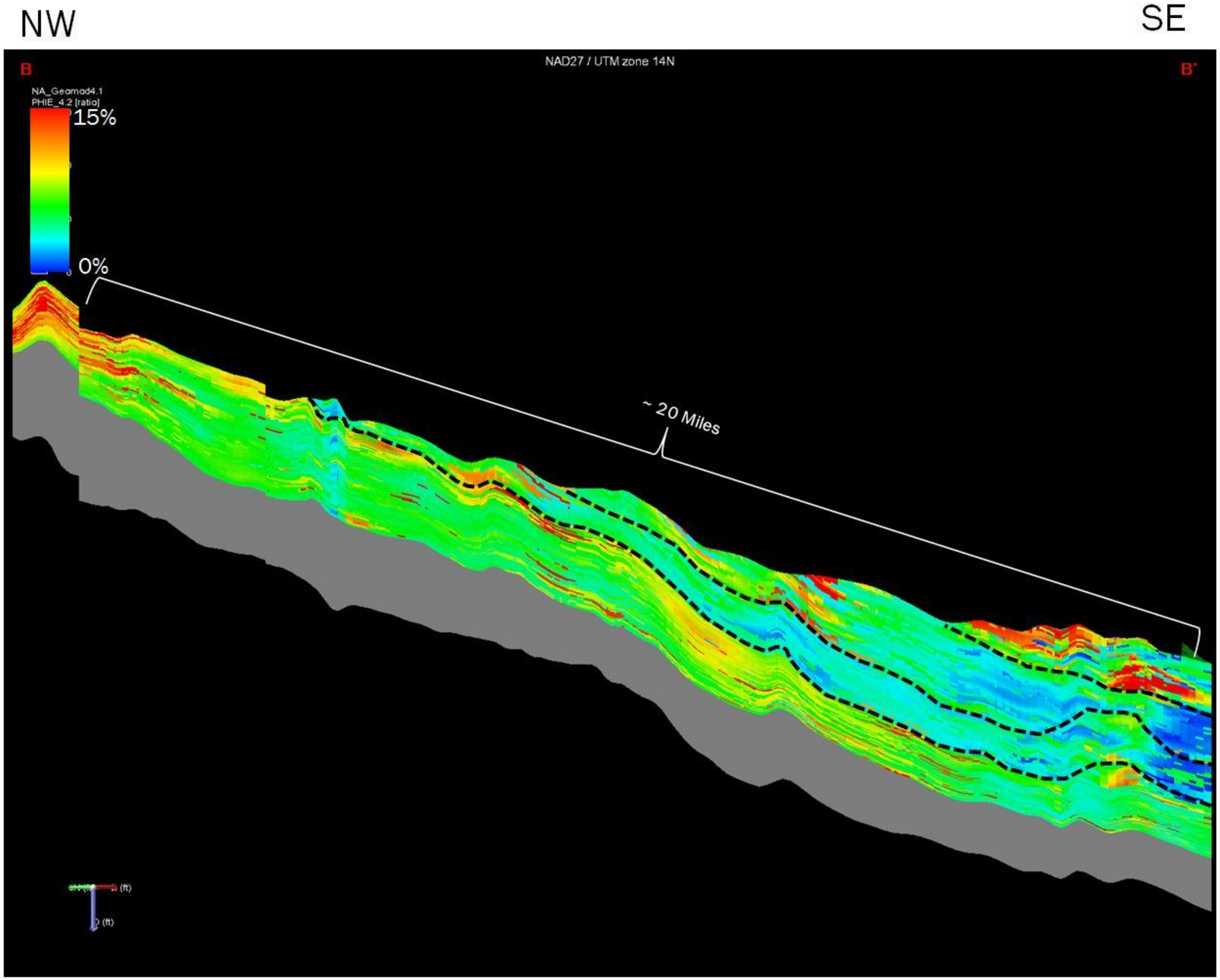
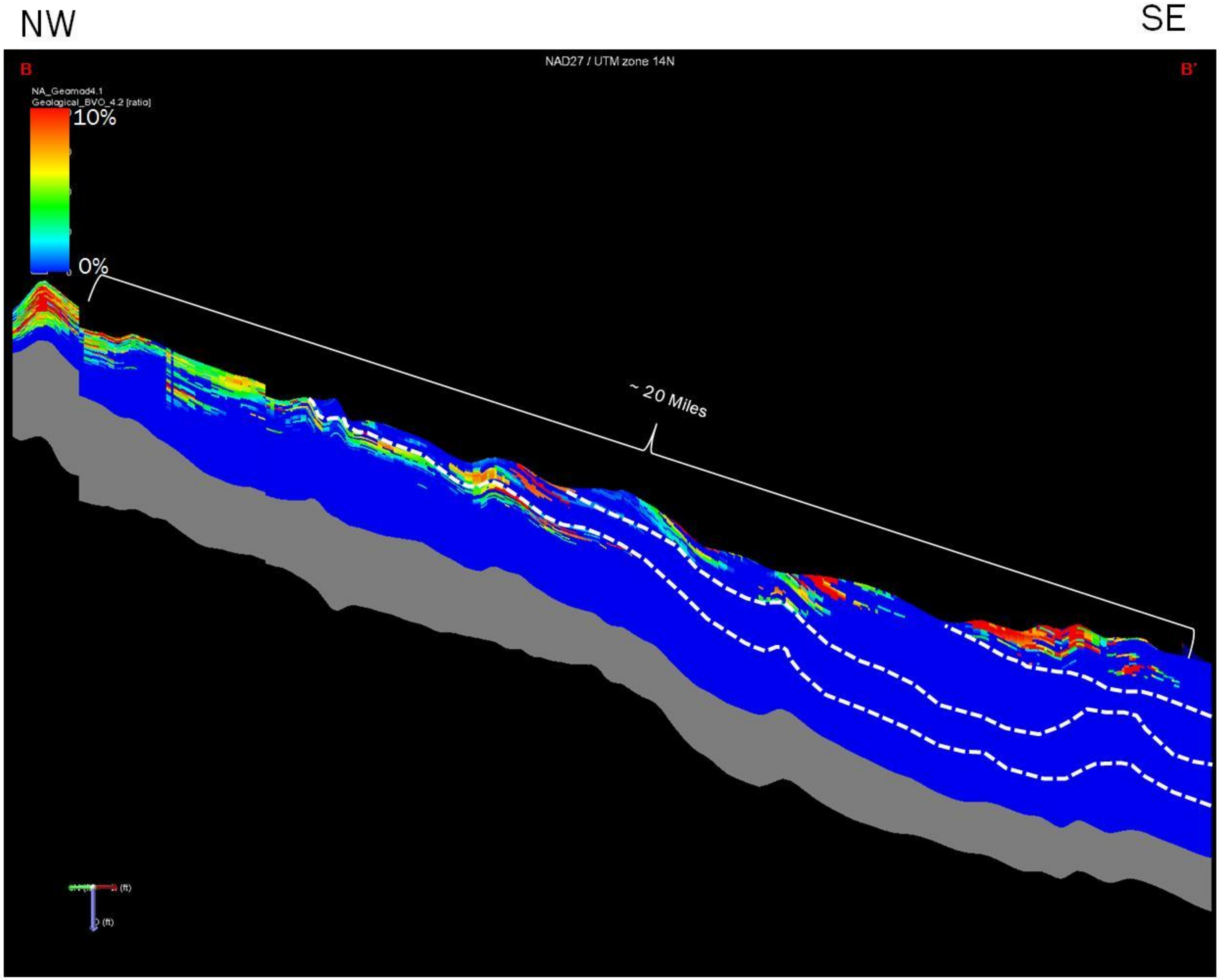
GEOMODEL – REGIONAL STRATIGRAPHY
EFFECTIVE POROSITY



GEOMODEL – REGIONAL STRATIGRAPHY

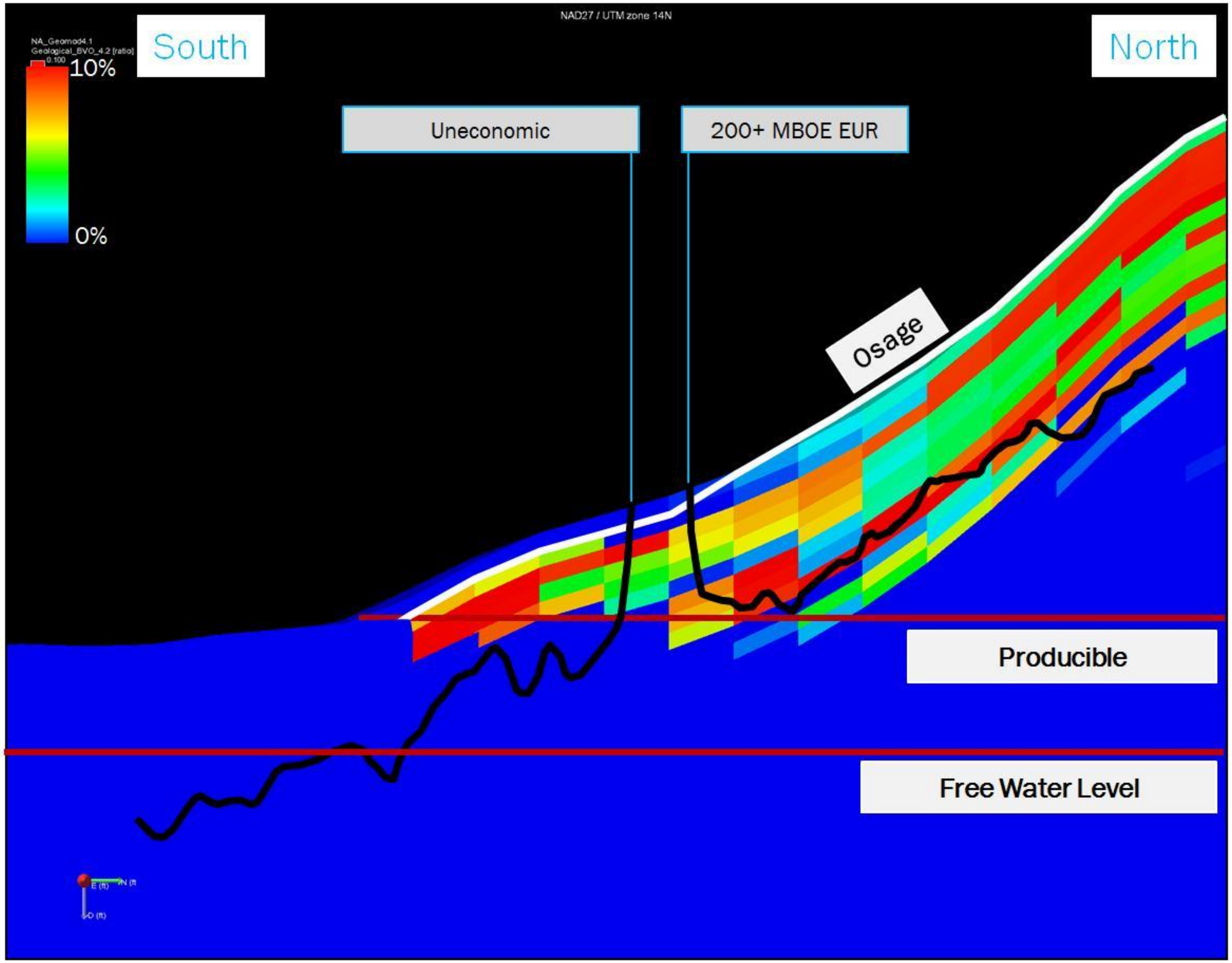
BULK VOLUME HYDROCARBON PHIE*(1-SW)



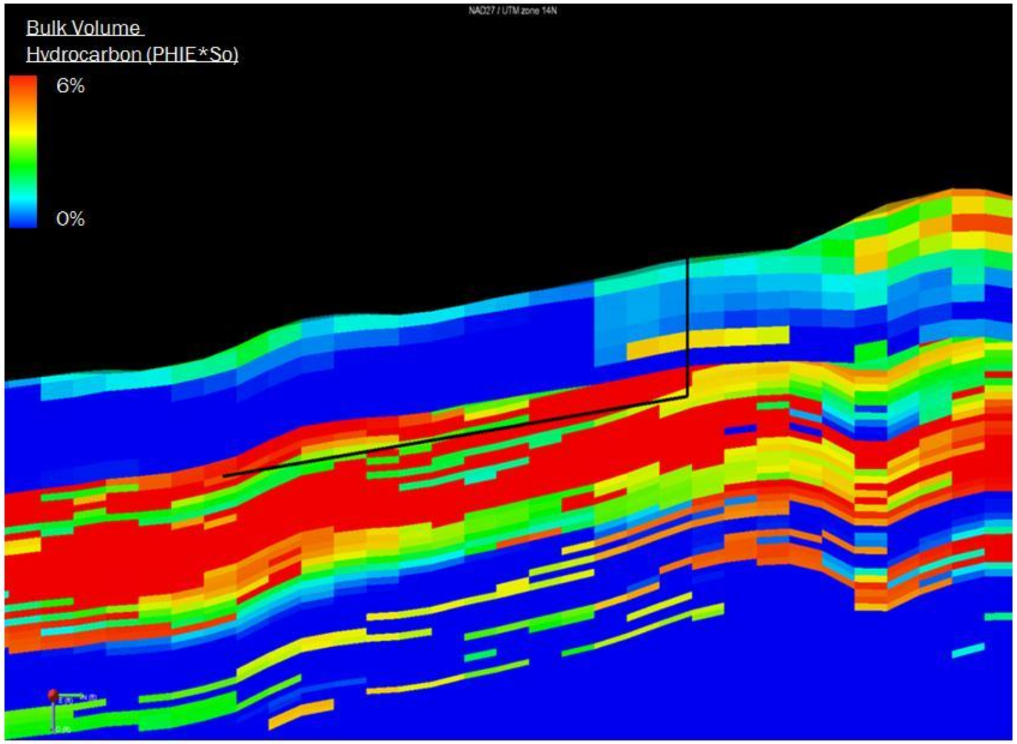
GEO MODEL ADVANTAGES

PRECISION WELL TARGETING EXAMPLE

NORTH ALVA GEOMODEL–POROSITY, FREE WATER LEVEL
BULK VOLUME HYDROCARBON – PHIE * (1-SW)



WELL PLANNING



- **Every well on drill schedule has planned target line projected on grids of facies, porosity, and bulk volume hydrocarbon**
  - Helps to confirm lateral placement chosen from vertical well control

Use of reservoir model displays, along with seismic- and well log cross sections, prove essential for well planning and team communication

CONCLUSIONS

- Understanding reservoir heterogeneity is key to field development and wellbore targeting
- Integrating stratigraphy, petrophysics, geophysics, engineering in geomodel leads to powerful predictive tools
- Reservoir modeling is an iterative process – each well we drill helps us to refine our understanding of the reservoir

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THANK YOU!

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