Hydrocarbon Resource Characterization and Modeling: Past, Present and Future*

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Abstract

As the demand for fossil fuels continues to grow and fields mature, hydrocarbon resource characterization has become increasingly important. Optimal valuation and exploitation of a field requires a realistic description of the reservoir, which in turn requires integrated reservoir characterization and modeling using all the available data and rigorous quantification of the uncertainty. Based on our research and experience with worldwide hydrocarbon resource characterization projects, we present a historical review of various phases of petroleum geology and reservoir characterization, which illustrates how the challenges were met in the past and what new technologies will be emerging in the future. Important past developments include the transition from general petroleum geology to reservoir geology, from disciplinary-focused reservoir description to integrated reservoir characterization, from 2-D subsurface mapping to 3-D reservoir modeling, and from reservoir deterministic analysis to uncertainty analysis. With emergence of unconventional resources and the maturation of many of the world's conventional fields, an integrated, multidisciplinary approach using new innovative technologies, including all the geoscience and engineering disciplines, is even more critical to meet the challenges posed in developing these fields.

References Cited

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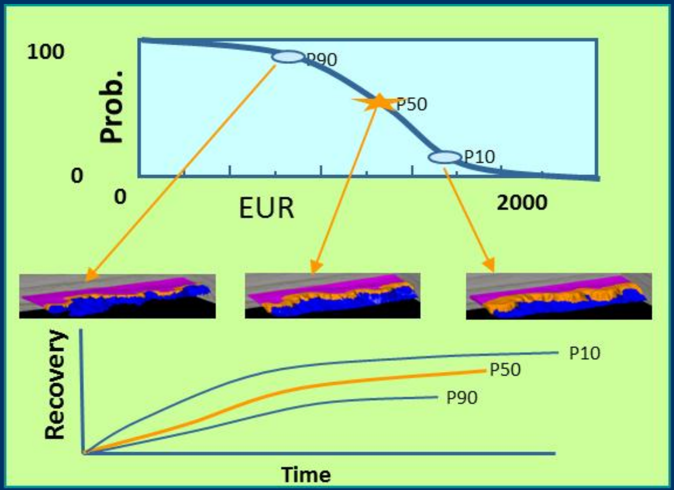
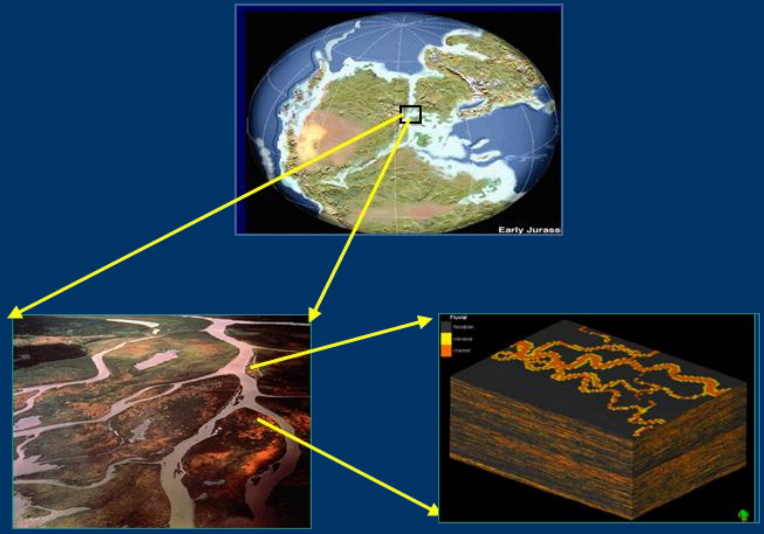
Outline

- Previous methods of interpretation
- Present methods
  - Example: Rocky Mountain tight sand reservoir
- What's next
  - Unconventional reservoirs
- Summary





Where have we been?

Last 30 years

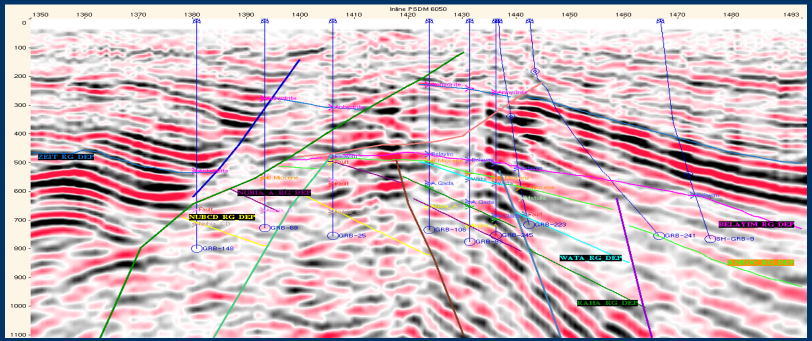
E&P technology and business cycles

- 2D, 3D Seismic, seismic stratigraphy
- Sequence stratigraphy
- Geostatistics
- Reservoir simulation
- Drilling and logging breakthroughs
- Rapid changes in computing

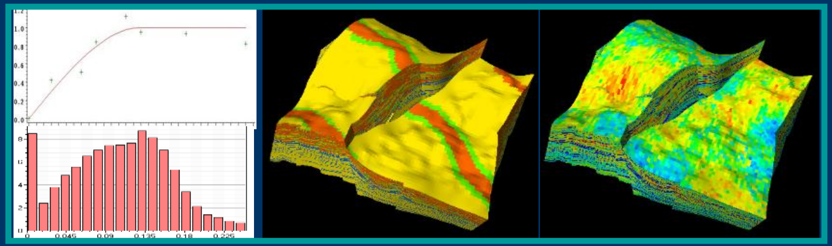
Last 5 years

Integrated Reservoir Modeling

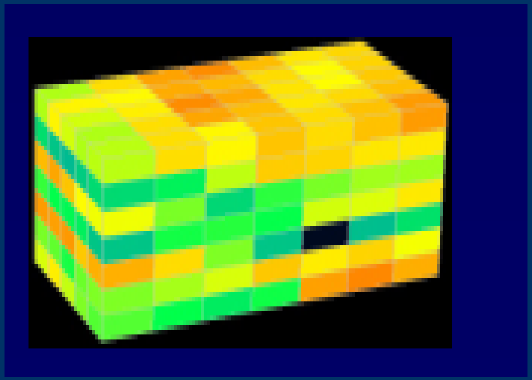
- PC based modeling packages
- From seismic to reservoir simulation



Seismic stratigraphy, interpretation …



Geostatistics, stochastic reservoir modeling



Reservoir Simulation

What are we doing?

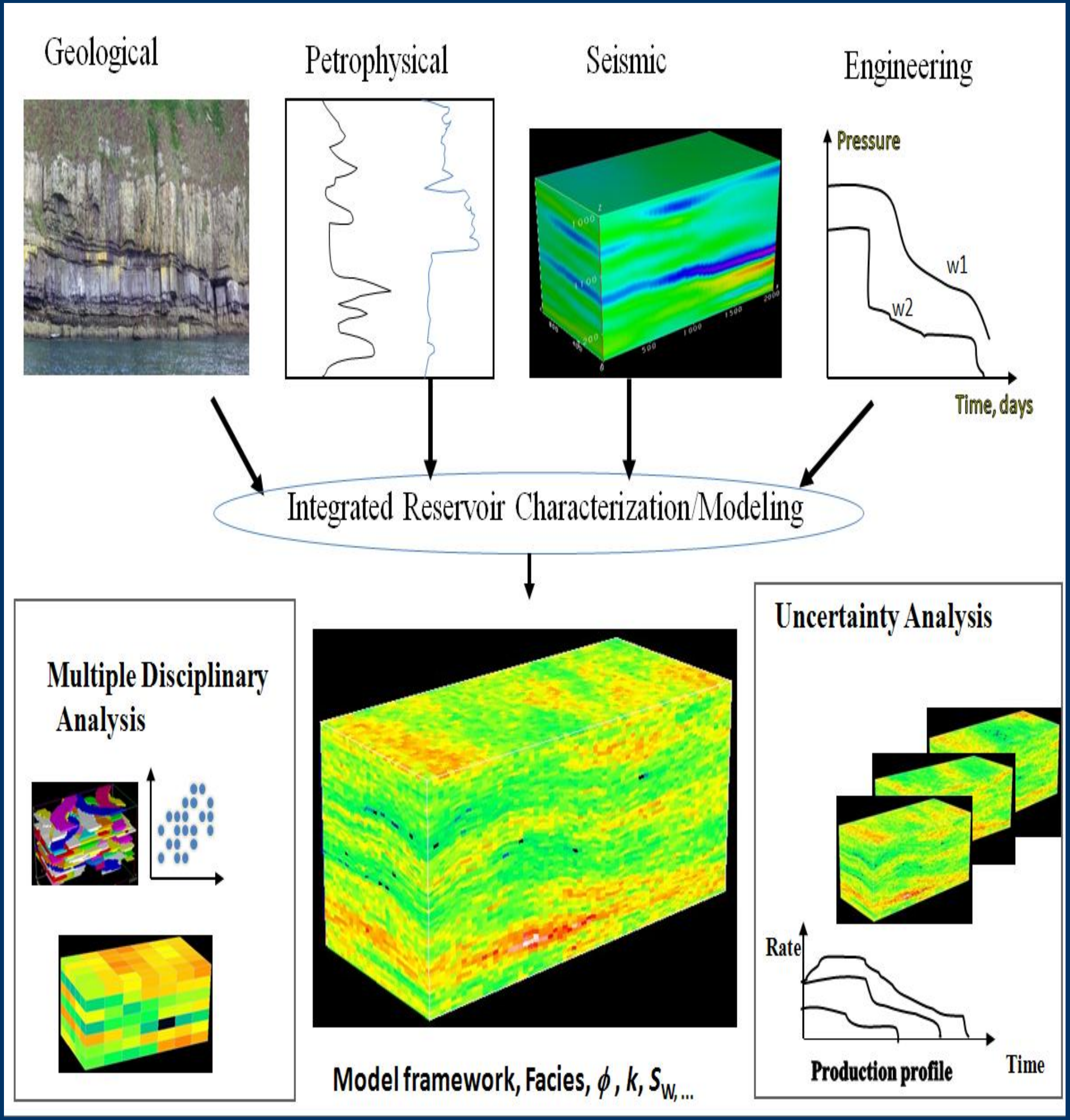
Integrated Reservoir Modeling

- Integrating multiple disciplines
- Integrating various data sources
- Integrated reservoir modeling platform

  Geologic modeling and reservoir simulation in one platform

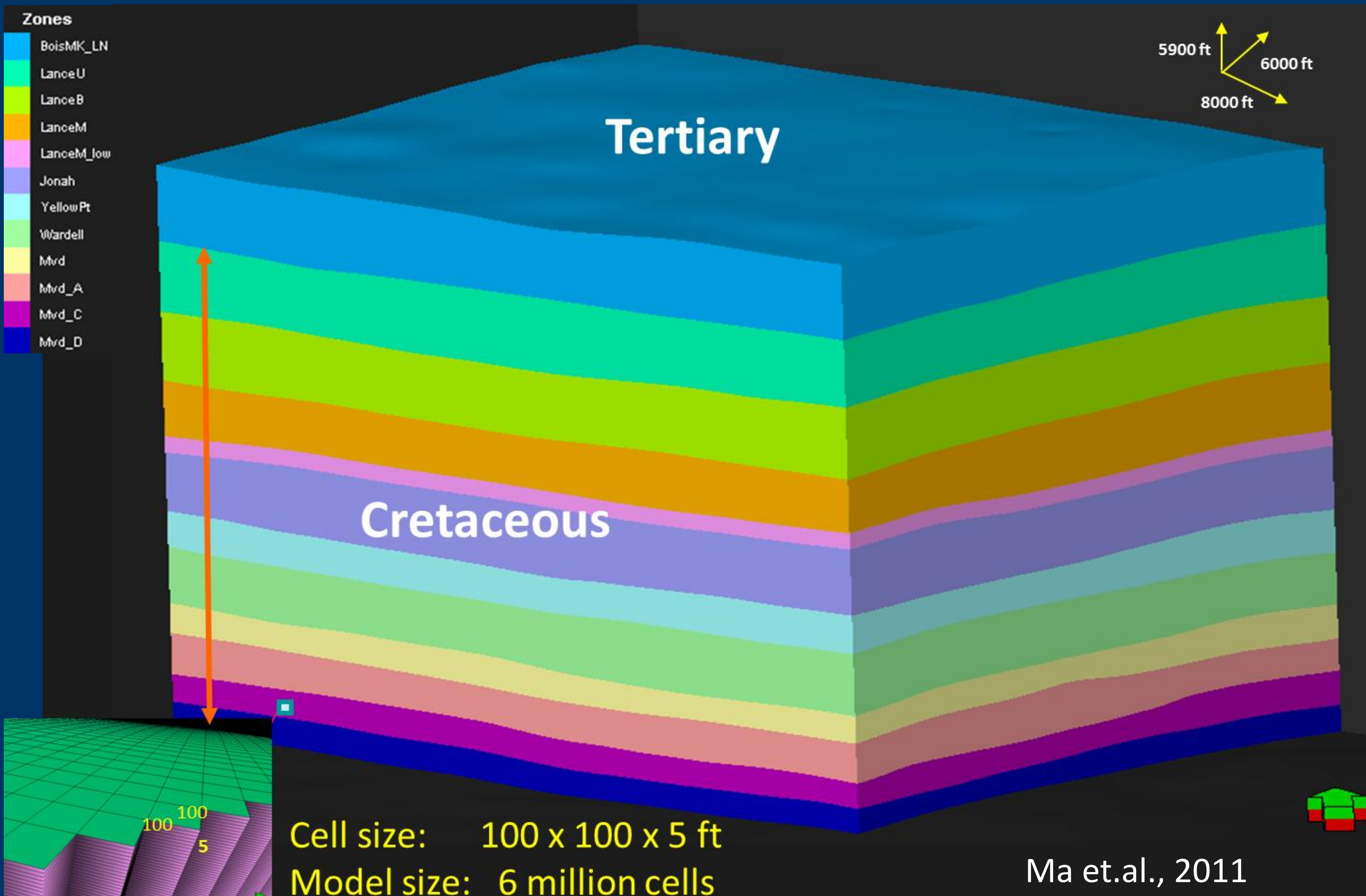
Reservoir Characterization/ Modeling as a core facilitator in field development

- Reservoir model is a basis for field planning.
- Living model as resource repository
- An example is now presented

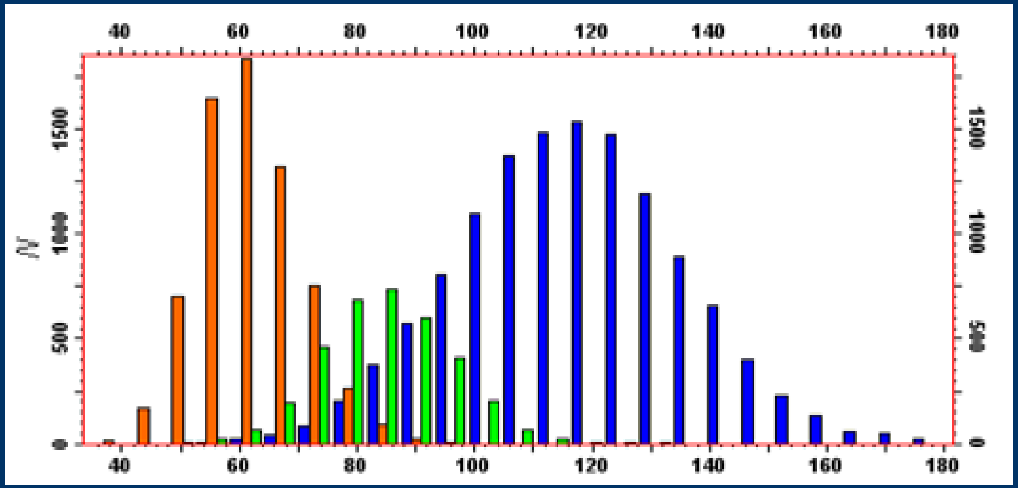


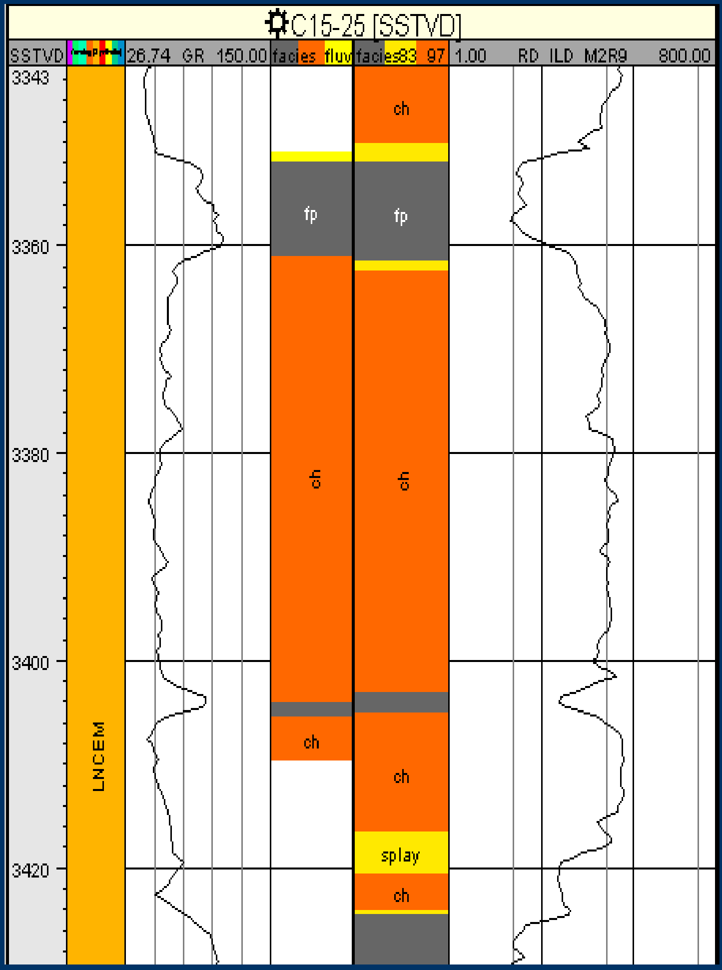
Yu et al., 2001

Rocky Mountain Tight Gas Sand Example



Predicted Log Facies versus Core Facies

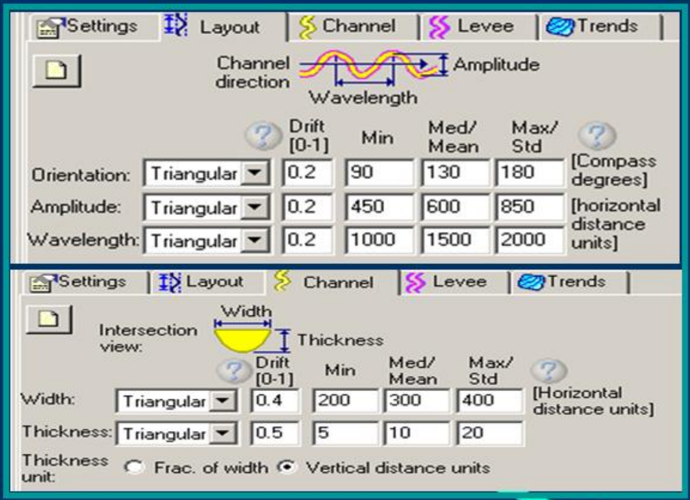




- Use GR and Resistivity logs to predict facies
- Prediction versus reality
- Log response matches well with logs

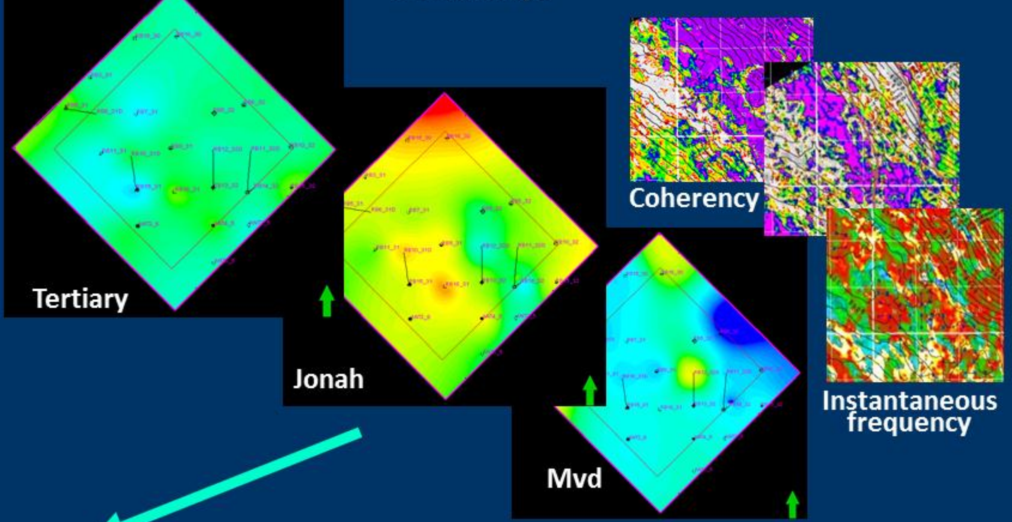
Fluvial Object-based Modeling Workflow

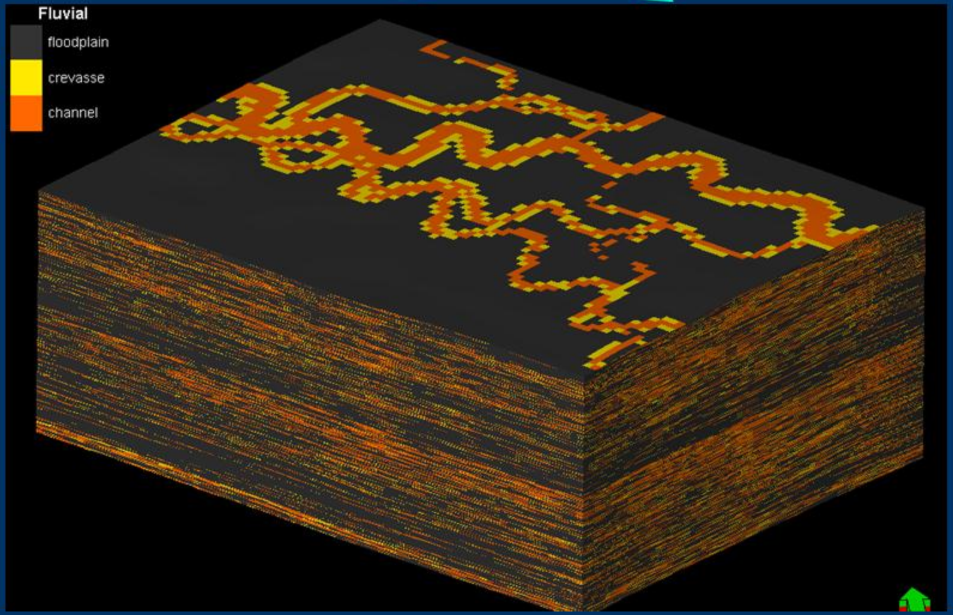
Parameter specification



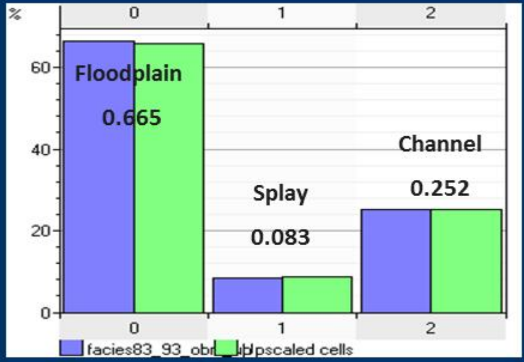
Trend maps

Seismic attributes

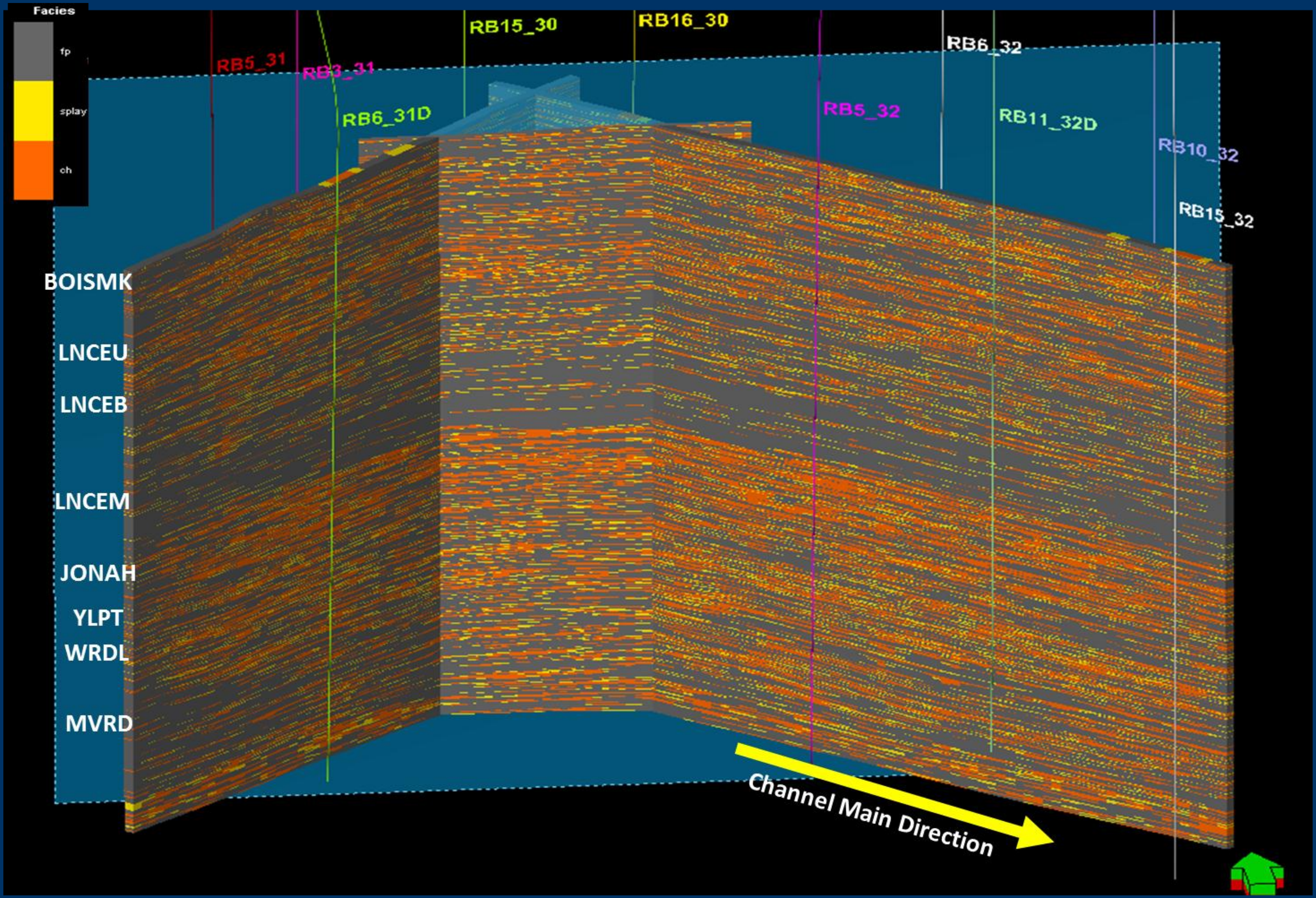




Facies fraction is honored



Facies Model Stacking Patterns



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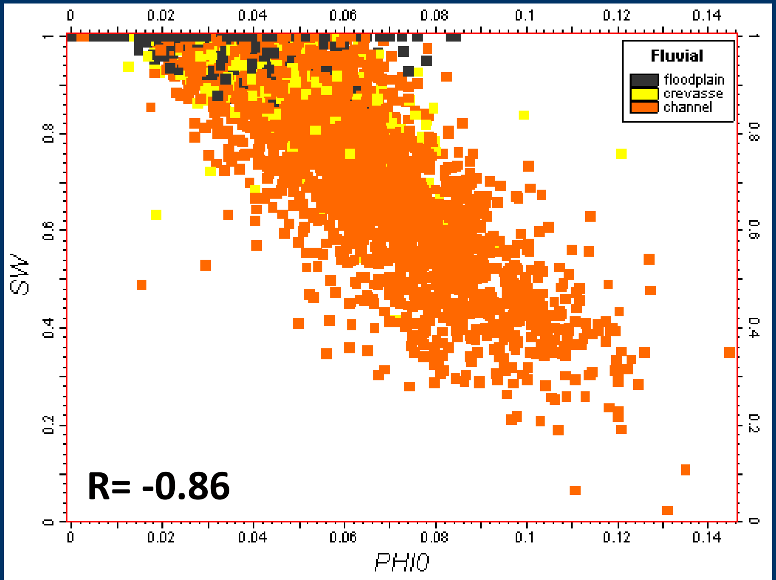
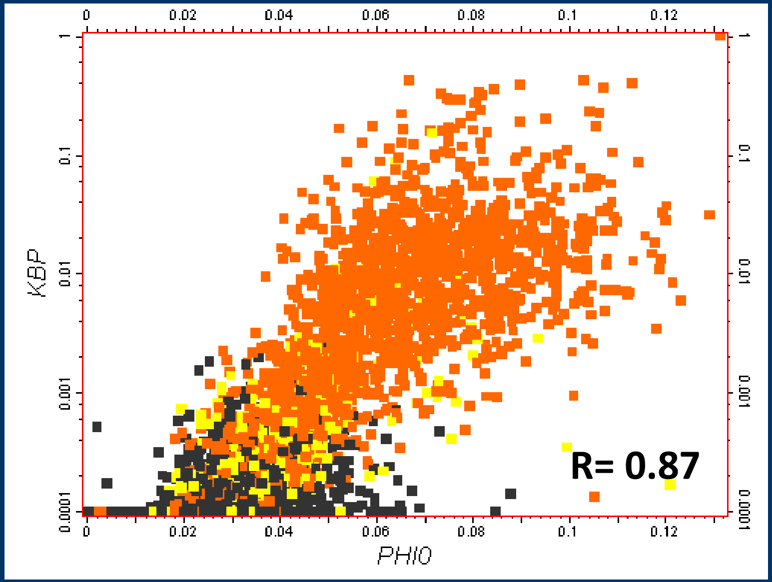
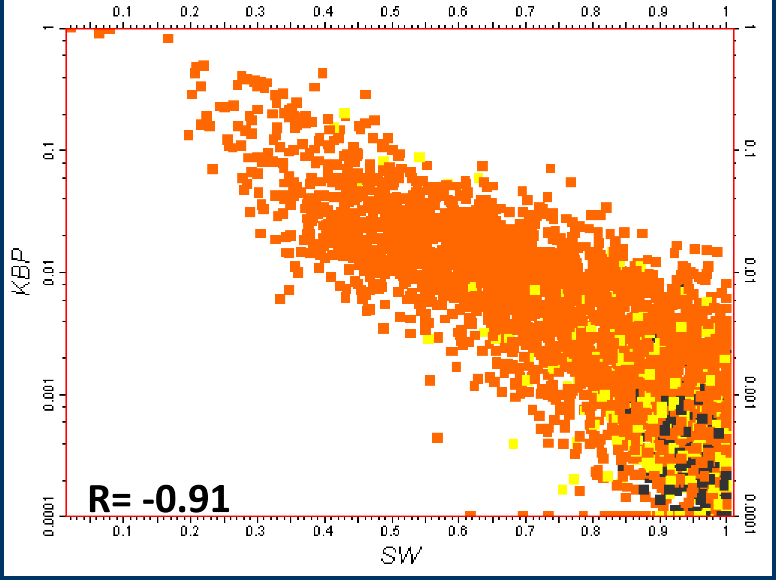
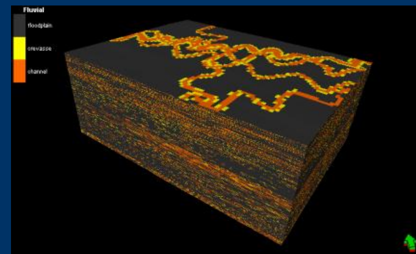
Petrophysical Property Relationships Based on Well Logs



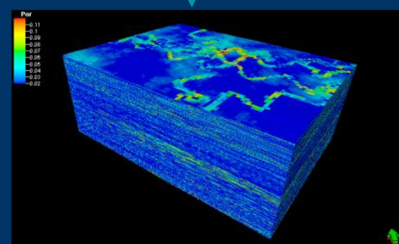




Petrophysical Property Modeling Workflow



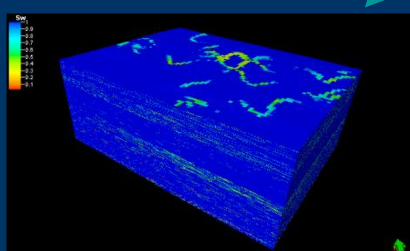
OBM Fluvial Facies by Unit

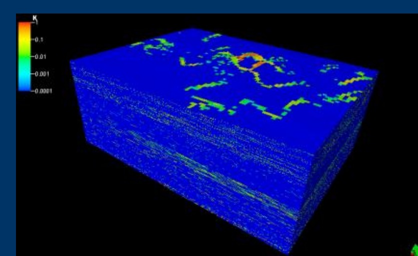


PHI: SGS by Unit & Facies

SW: CoCoSim with PHI
by Facies & Units

Kbp: CoCoSim with PHI
by Facies & Units

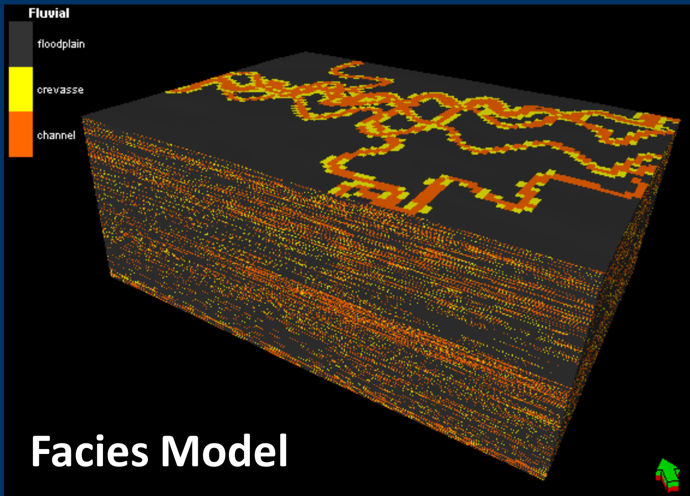


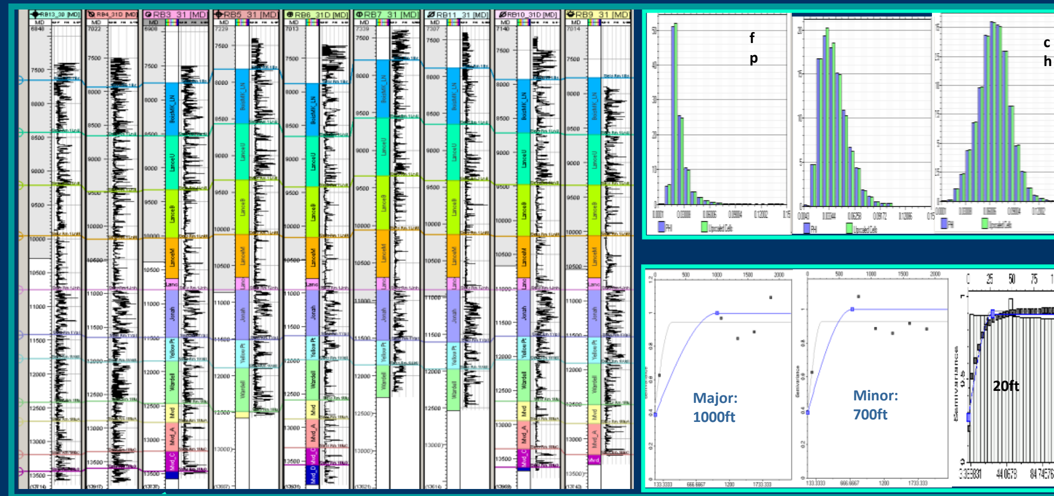


Geostatistical Methods Used

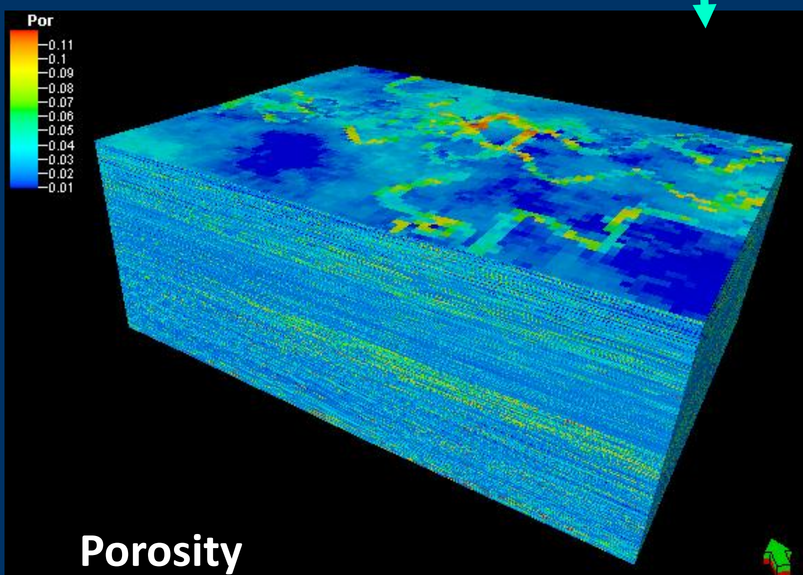
- SGS: Sequential Gaussian Simulation
- CoCoSim: Collocated Co-Simulation

Porosity Modeling

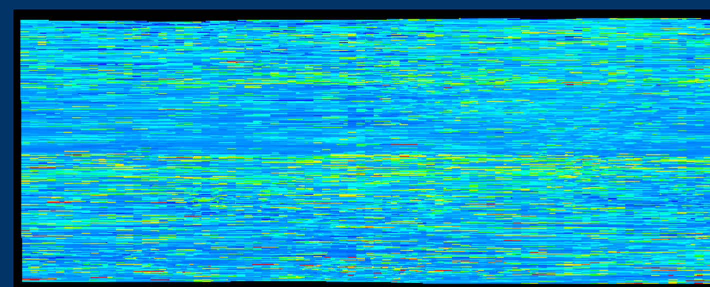




SGS

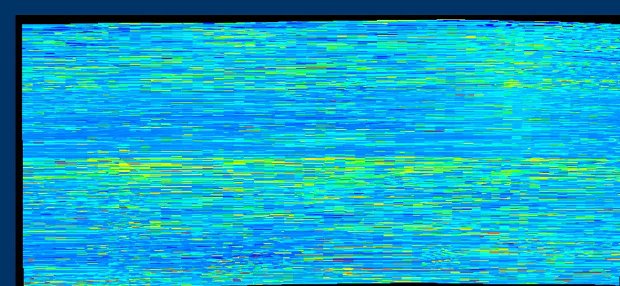


NW



SE

SW



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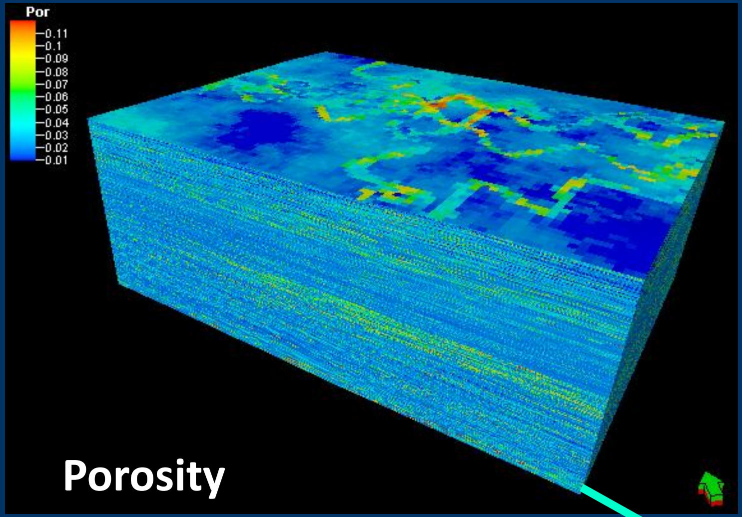
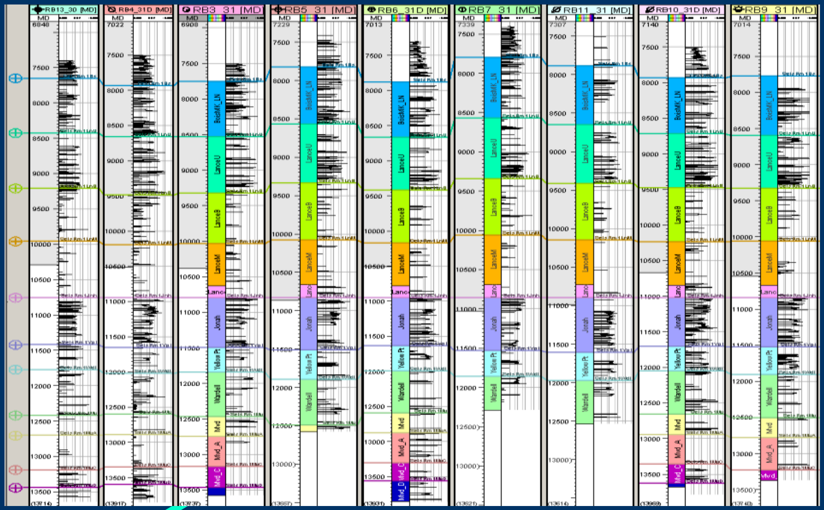
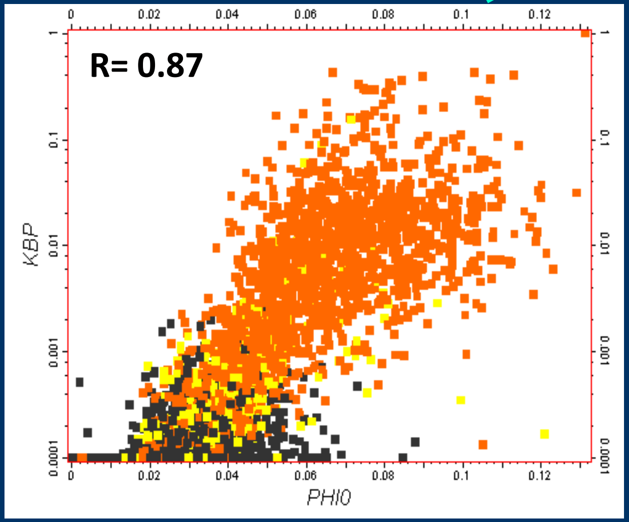
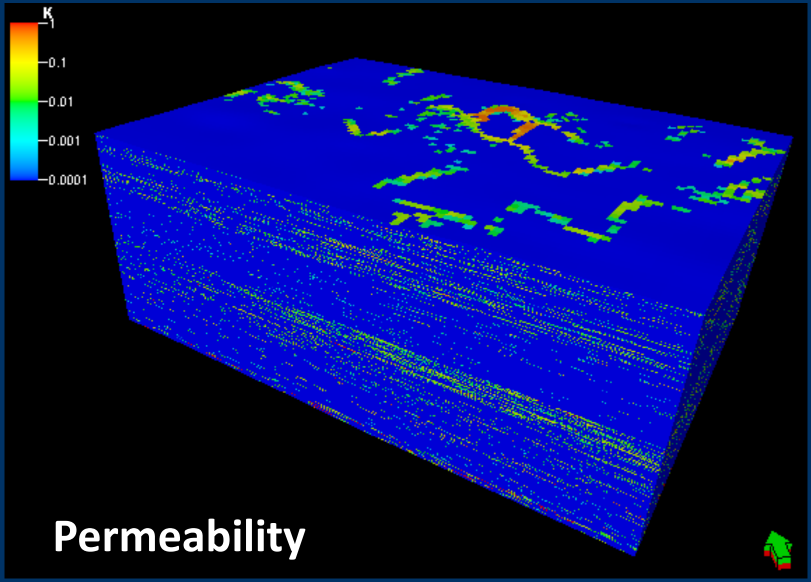
Permeability Modeling





CoCoSim





Where are we heading?

- Unconventional reservoirs demand greater integration, earlier
  - Reservoir and completion quality
- Broader deployment of modeling in production and completion design (hydraulic fracturing)
- Fast track reservoir modeling in field development
- Quantify impact of uncertainty on performance predictions
- Real time reservoir management with reservoir modeling a core facilitator
- Every field has a living model (conventional and unconventional)
- No boundary between geoscience and engineering models

Shale Resource Assessment
Characterizing Controls on Reservoir Productivity

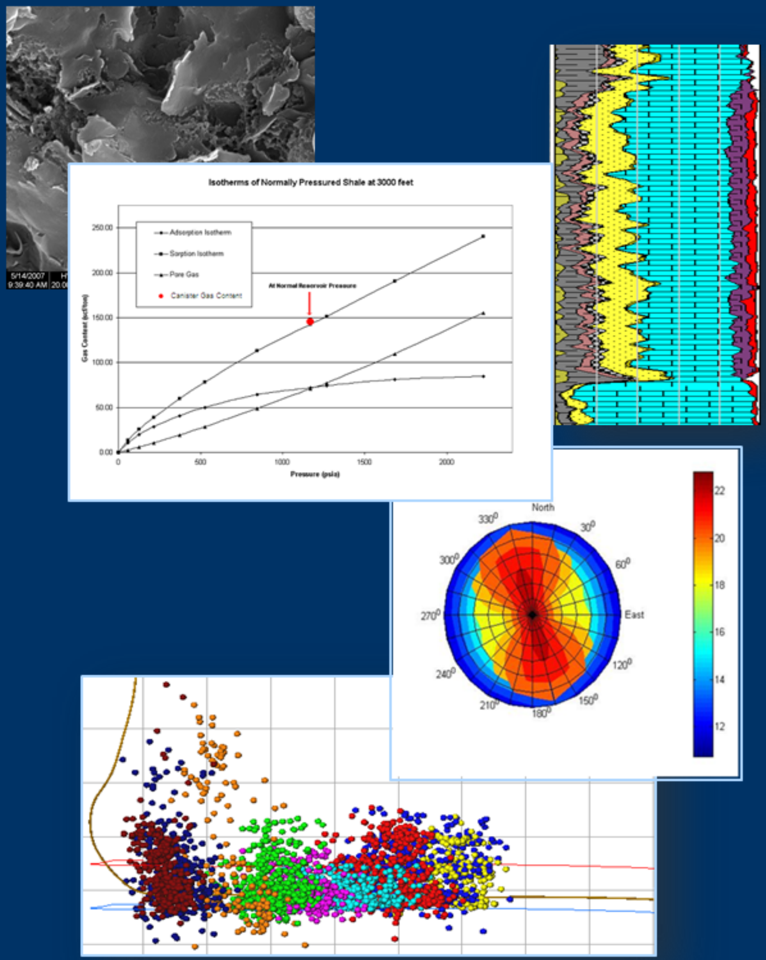
Defining Reservoir Quality

- Hydrocarbon in place
- Porosity/Permeability
- Organic content and Maturation
- Pore Pressure

Defining Completion Quality

- Fracture Containment (anisotropy, in-situ stress)
- Rock mechanics (surface area per reservoir volume)
- Ability to retain surface area
- Fracture conductivity
- Fluid sensitivity

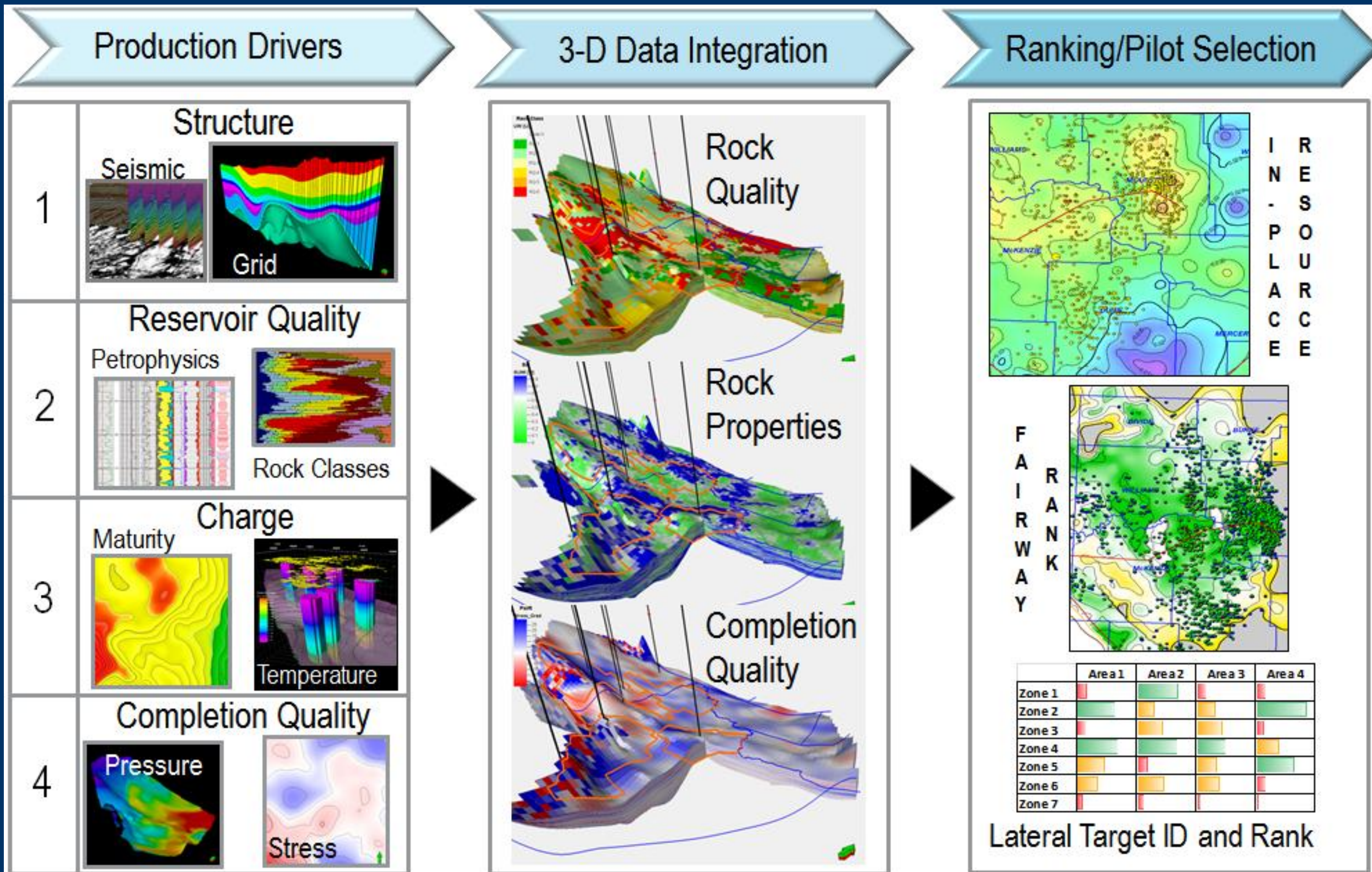
Reservoir Quality + Completion Quality = Economic Success



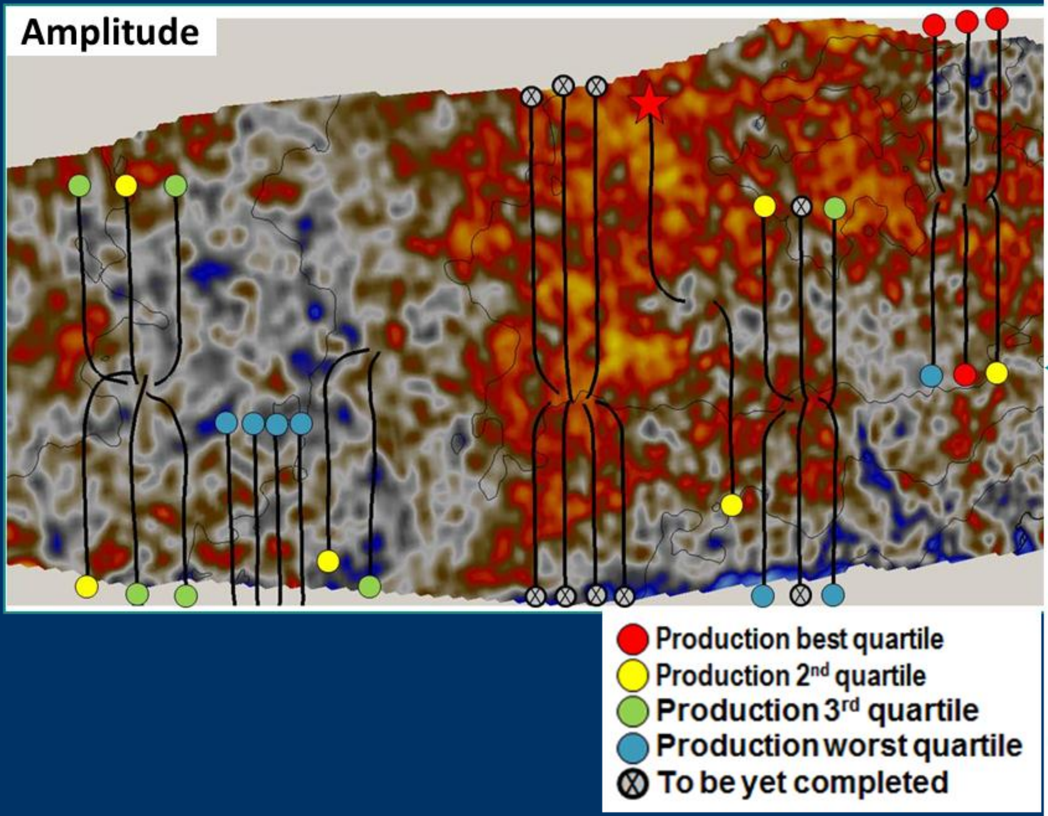
Production Drivers and Well Measurements: Assessing Data Gaps

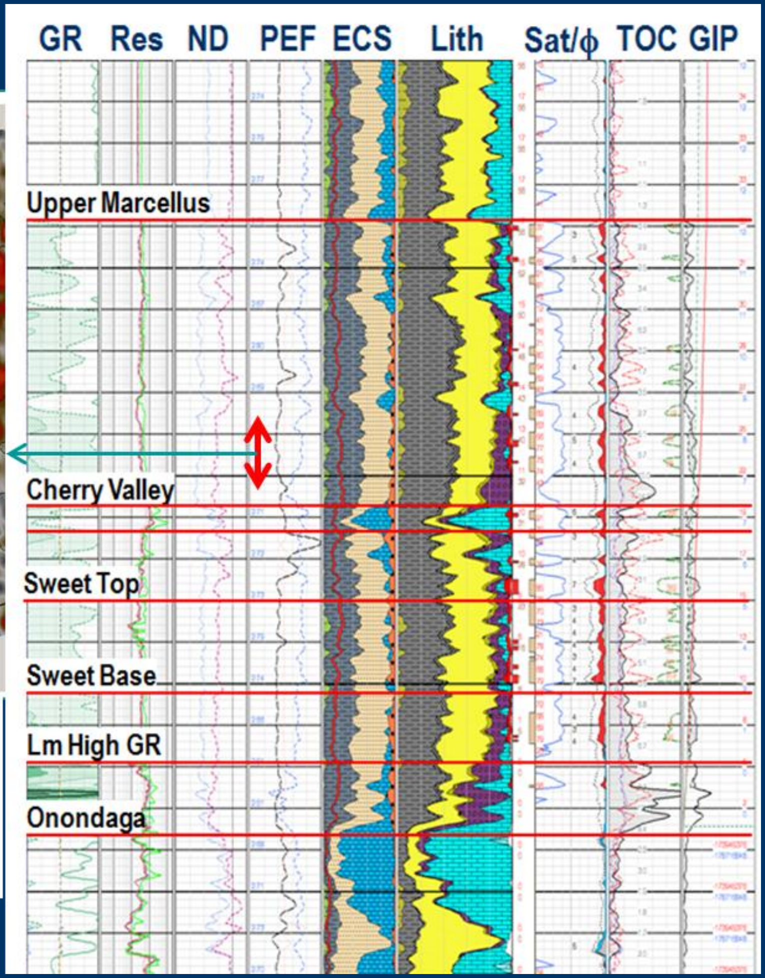
Production Driver	Why is it important	Measurements
Reservoir quality (porosity, permeability, saturation)	Hydrocarbon storage, oil-in-place, and matric contribution to flow	Triple combo, NMR, lithology and mineralogy logs, core calibration, seismic inversion
Structure (fractures and structural complexity)	Fractures provide system permeability and reservoir connectivity, structure impacts ability to stay in zone	Conventional and LWD image logs, dipole sonic anisotropy, 3-D seismic and attributes
Charge access	Thermal maturation impacts fluid properties and pore pressure	Lithology and mineralogy logs
Fluid properties and pressure	Downhole pressure, oil properties	PVT and in-situ pressure sampling
Geomechanics	Stress orientation and magnitude for fracture containment, achieving transverse hydraulic fractures, wellbore stability	3-D sonic measurements, mechanical earth modeling, microseismic monitoring, seismic inversion
Well Placement	Intercept best quality reservoir for production, optimal stimulation, avoiding near-wellbore pinch-off	Vertical and lateral well placement from high-end depth imaging, real-time geosteering with image logs
Well performance	Validation of hydraulic fracturing success and need for well placement	Production logging (vertical and horizontal), correlation of seismic attributes with production

Unconventional Resource Assessment Workflow



Delineating "Sweet-Spots" with Seismic Attributes

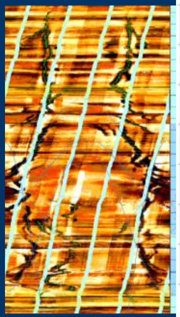


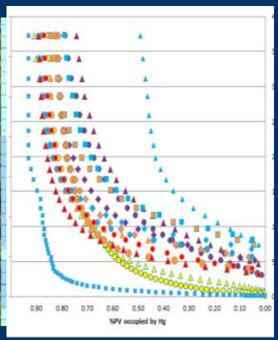


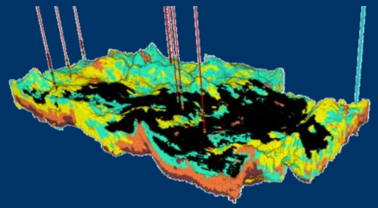
Integration of petrophysical log data, completions and seismic to select drilling locations and explain production

Kaufman, et.al., 2013
SPE 164345

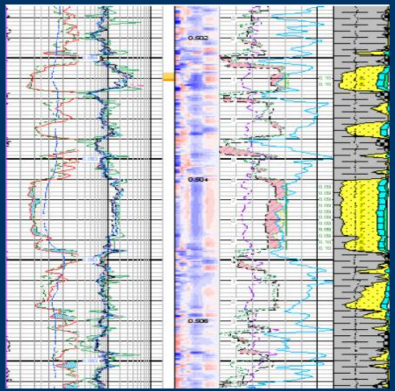
Completion and Development Workflow



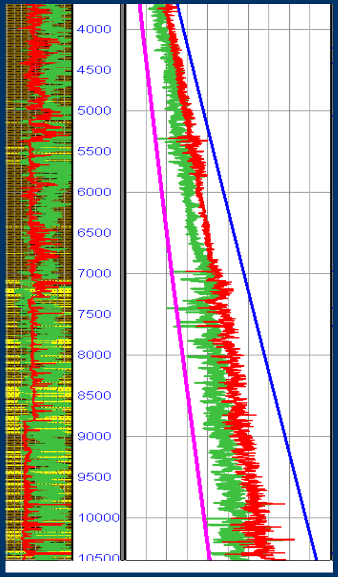


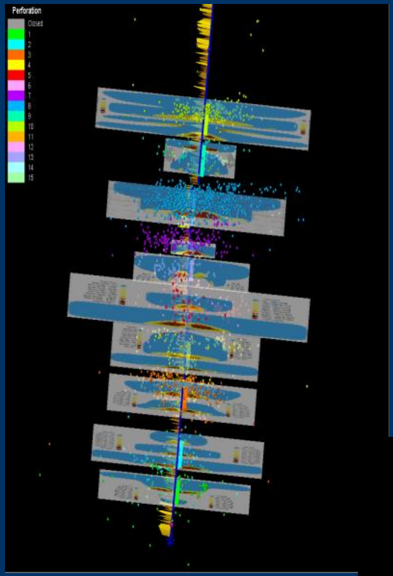


Production Mechanism

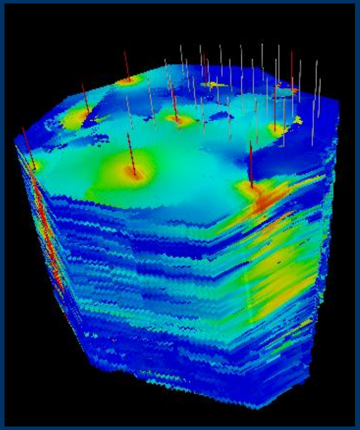


Stress State and Completion Strategy



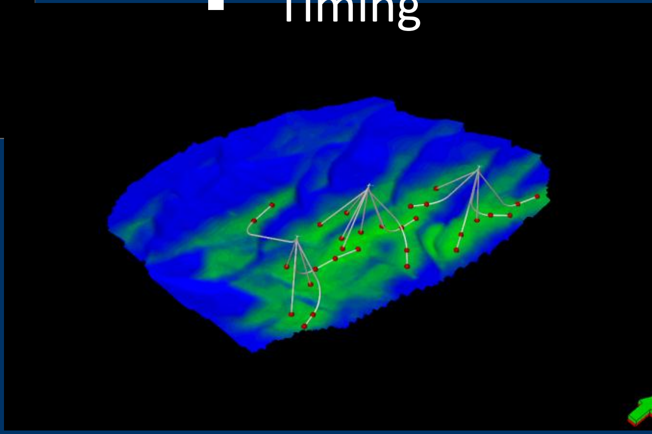


- How to complete
- Number stages
- Fluid and proppant



Development Strategy

- Spacing
- Timing



Summary

- Modeling is being used throughout the life cycle of the field
  - Resource assessment (appraisal)
  - Field development
  - Completions
- Unconventional reservoirs demand greater integration, earlier
- Broader deployment of modeling in production and completion design (hydraulic fracturing)
- Understanding of reservoir and completion quality critical in economic success of unconventionals