Historical Transformation of the Petroleum System Concept to Computerized Petroleum System Models and Linked Technologies*

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Abstract

The petroleum system methodology (PSM) evolved as geoscientists recognized the need to consider all elements (source, reservoir, seal, overburden) and processes (trap formation, generation-migration-accumulation) responsible for petroleum accumulations (Dow, 1974; Perrodon, 1992; Magoon and Dow, 1994). Although widespread acceptance was slow, industry now uses PSM because of spectacular failures of the original play fairway concept, such as the Mukluk offshore exploration well in 1984. The most important contribution of geochemistry to PSC is oil-source rock correlation to establish and map petroleum systems (Demaison and Murris, 1984; Tissot and Welte, 1987; Hunt, 1979; Bordenave, 1993). Early oil-source rock correlations were based on few geochemical parameters and simple bivariate plots. Later work emphasized chemometrics of many biomarker and isotope ratios to indicate petroleum systems and the degree of statistical certainty in each correlation (Peters et al., 2007). A milestone book (Welte et al., 1997) revealed growing capabilities of computerized basin and petroleum system models (BPSM), including migration modeling, pressure prediction, and compositional modeling of fluid and vapor compositions. Rapid development of unconventional resources since the early 2000s revitalized the links between geochemistry and BPSM (Hantschel and Kauerauf, 2009).

Prior to ~2010, BPSM and associated visualization software were stand-alone tools to reduce exploration risk. However, integration of BPSM with other tools since ~2010 is a more efficient way to model the subsurface. For example, linked BPSM-seismic facies analysis-pore pressure prediction allows wells to be drilled safely and under budget (Mosca, 2018). BPSM-forward stratigraphic modeling (FSM) improves reservoir assessment using realistic predictions of lithology, migration paths, and accumulations (Tetzlaff and Priddy, 2001). BPSM-complex structural restoration improves assessment of seal integrity, reservoir continuity, and fluid properties (Neumaier et al., 2014). BPSM-FSM-probabilistic prospect assessment improves predictions of generation timing, migration paths, connectivity, and seals and enhances exploration portfolios based on risk-weighted geology. Linked BPSM models can be securely and efficiently run using Cloud technology for faster and more reliable decisions (Schlumberger, 2018).

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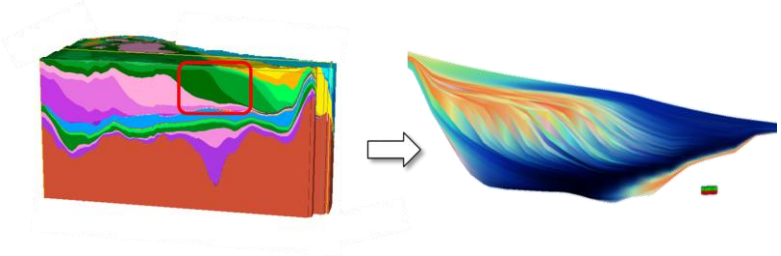
Theme 12: History of Petroleum Geology



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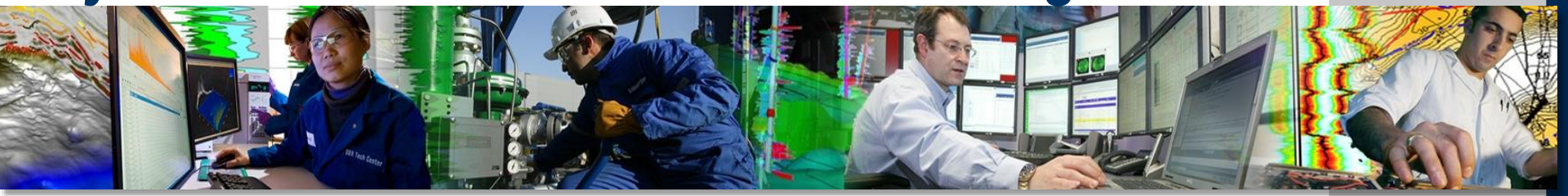
Historical Transformation of the Petroleum System Concept to Computerized Petroleum System Models and Linked Technologies



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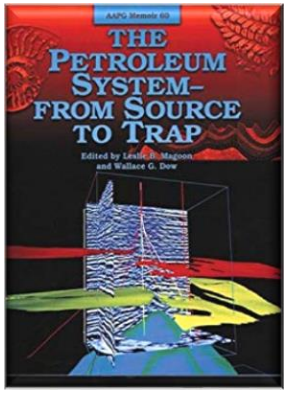
What is a Petroleum System?

- four essential elements, two processes, and all related petroleum that originated from *one* pod of active source rock

1994

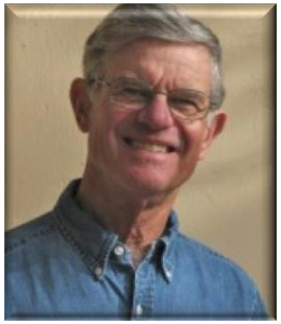


- **Source rock**
- **Reservoir rock**
- **Seal rock**
- **Overburden rock**

} ***Essential Elements***

- **Trap Formation**
- **Generation-Migration-Accumulation**

} ***Processes***



Magoon and Dow (1994) including earlier concepts by Perrodon (1992) and others.

Early Steps in *Computerized* BPSM* were Slow

1969

- Tissot B., 1969. Premiéres données sur les mécanismes et al cinétique de la formation du pétrole dans les sediments. Simulation d'un schéma réactionnnel sur ordinateur. Rev. Inst. Fr. Pet. 24, 470-501.

  → Simple model predicts quantities of petroleum generated from source rock.

- Welte D.H., 1972. Petroleum exploration and organic geochemistry. J. Geochem. Explor. 1, 117-136.

  → Expands to 3D dynamic modeling of source rock during basin evolution.

- Tissot B., J. Espitalié, 1975. L'evolution thermique de la matière organique des sediments. Applications d'une simulation mathematique. Rev. Inst. Fr. Pet. 30, 743-777.

  → First extensive use of chemical reaction kinetics to calculate thermal maturity.

- Welte D.H., A. Yükler, 1981. Petroleum origin and accumulation in basin evolution—A quantitative model. AAPG Bulletin 65, 1387-1396.

  → Replaced "geothermal gradients" with reconstructed basin thermal history.

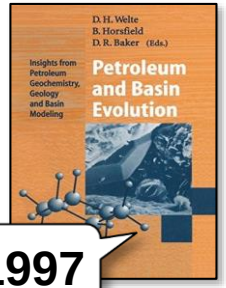
- Welte D.H. and M.N. Yalcin, 1988. Basin modelling—A new comprehensive method in petroleum geology. Organic Geochemistry 13, 141-151.

  → Improved modeling of generation, expulsion, and migration.

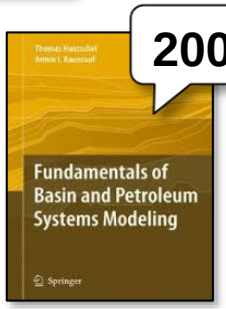
1988

*Basin and Petroleum System Modeling

Computerized BPSM: Input, Simulate, Calibrate, Predict



1997



2009

Geochemical Data
- Organic richness
- Kerogen type
- Kinetics

Seismic and Well Log Data
- Rock unit geometry
- Rock unit lithology
- Rock unit age

Boundary Conditions
- Heat flow history
- Sediment-water temperature
- Paleo-water depth

Simulation (rock): TIMING OF UNITS, DECOMPACTION, TECTONIC EVENTS, THERMAL MATURITY

Simulation (fluid): TEMPERATURE FIELD, CHEMICAL REACTIONS, PORE PRESSURE FIELD, FLUID FLOW

Preliminary output: ***Uncalibrated Model***

Model calibration: **Calibration Data**
- Pore pressure
- Vitrinite reflectance
- Borehole temperature

Peters et al. (2012)

Final output: ***Calibrated* Model**

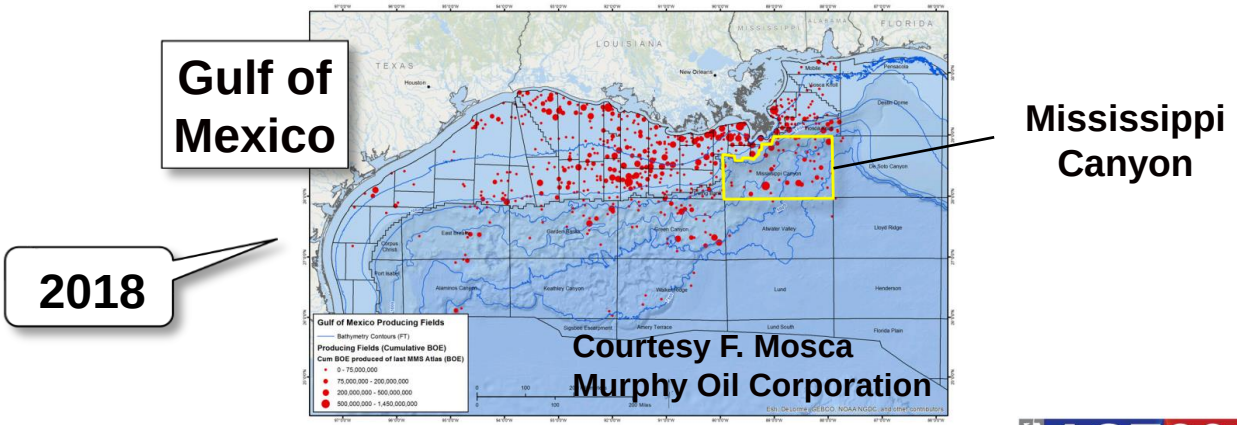
Integrated Modeling: BPSM Linked to Other Methods

1) Pore Pressure Prediction and Seismic Facies Analysis: Gulf of Mexico
2) Complex Structural Restoration: Monagas Thrust Belt, Eastern Venezuela
3) Forward Stratigraphic Modeling: North Slope, Alaska
4) Probabilistic Prospect Assessment: Gippsland Basin, Australia

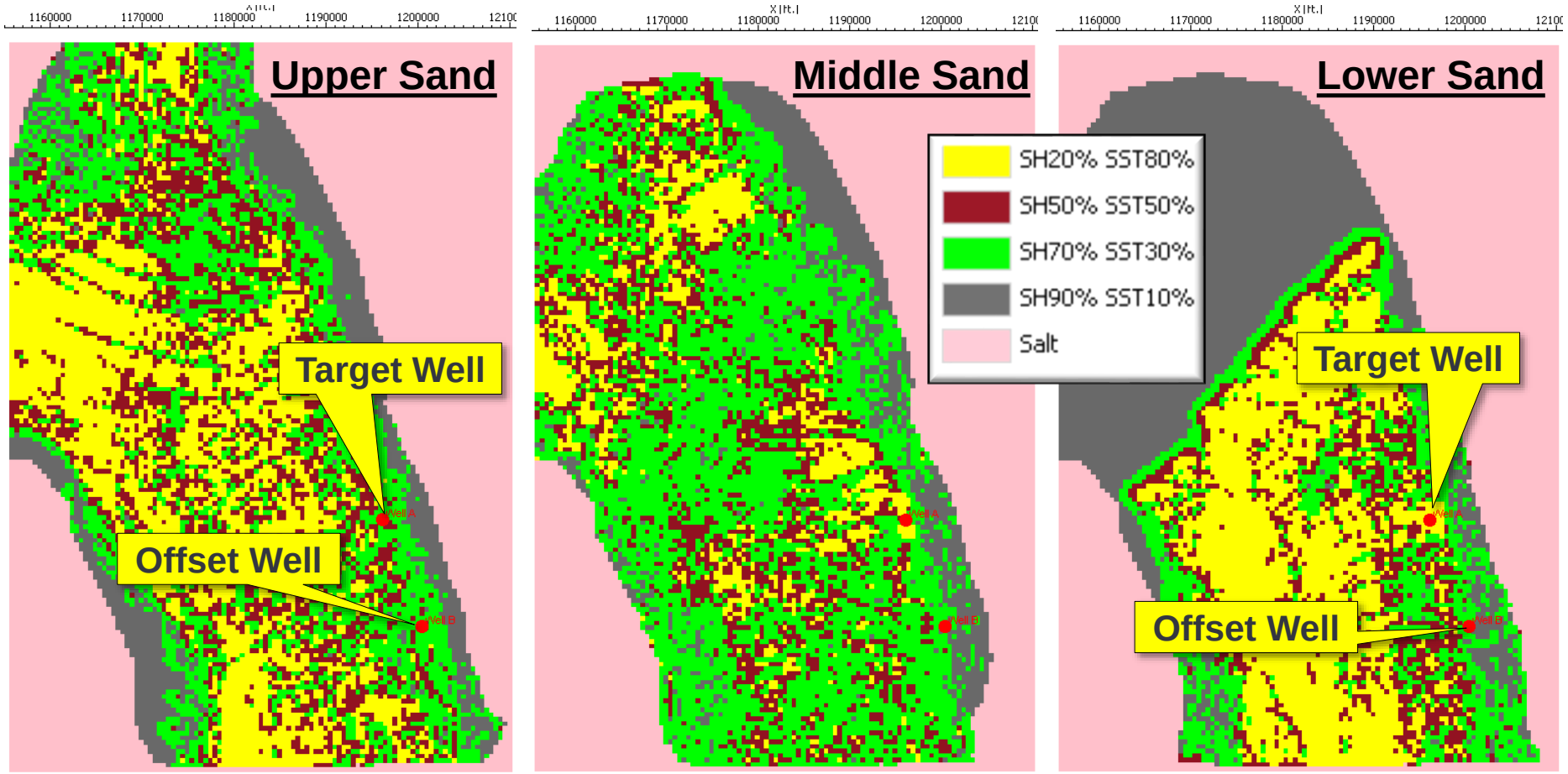
1) Linked BPSM-Pore Pressure Prediction (PPP)

- ***Pore pressure prediction*** **compares pressure estimated from: (i) logs, (ii) seismic velocities/acoustic impedance, (iii) BPSM (3D coupled stress-pressure, mineral diagenesis, rock failure).**
- **Three-step workflow predicts pressure *while* drilling:**

1) **3D calibrated model from regional maps.**
2) **Smaller 3D area of interest (AOI) from high-resolution structure and facies maps for *fast* calculation.**
3) **Predicted pore pressure and fracture gradient compared to well performance.**



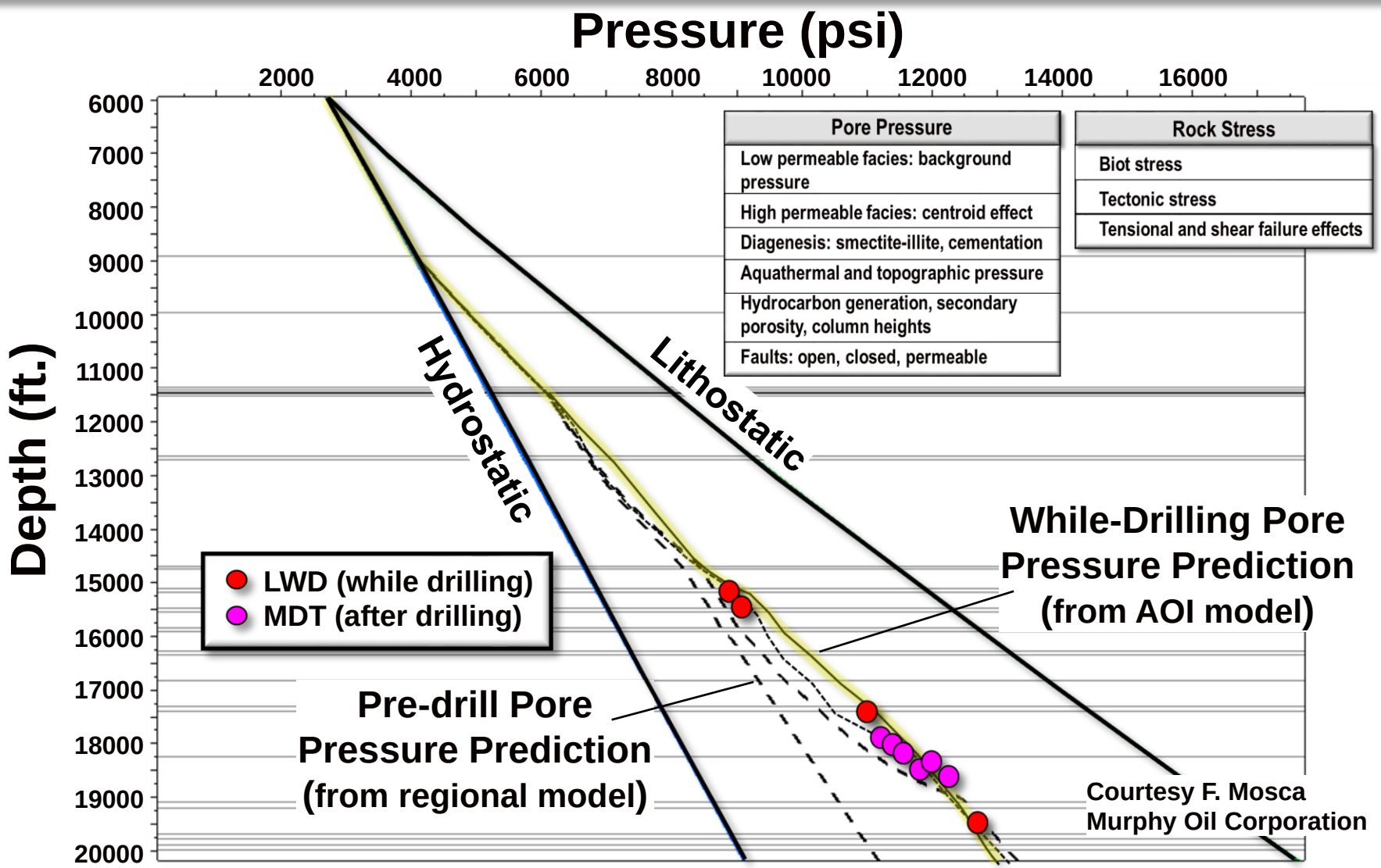
Build AOI Sand Facies Maps from Seismic Attributes



- Connectivity of high perm (sand) and permeability of low perm (shale) layers control the pore pressure.
- Poisson ratios of the sand and shale control the horizontal stress.

Courtesy F. Mosca
Murphy Oil Corporation

Calibrate Pore Pressure While Drilling the Target Well

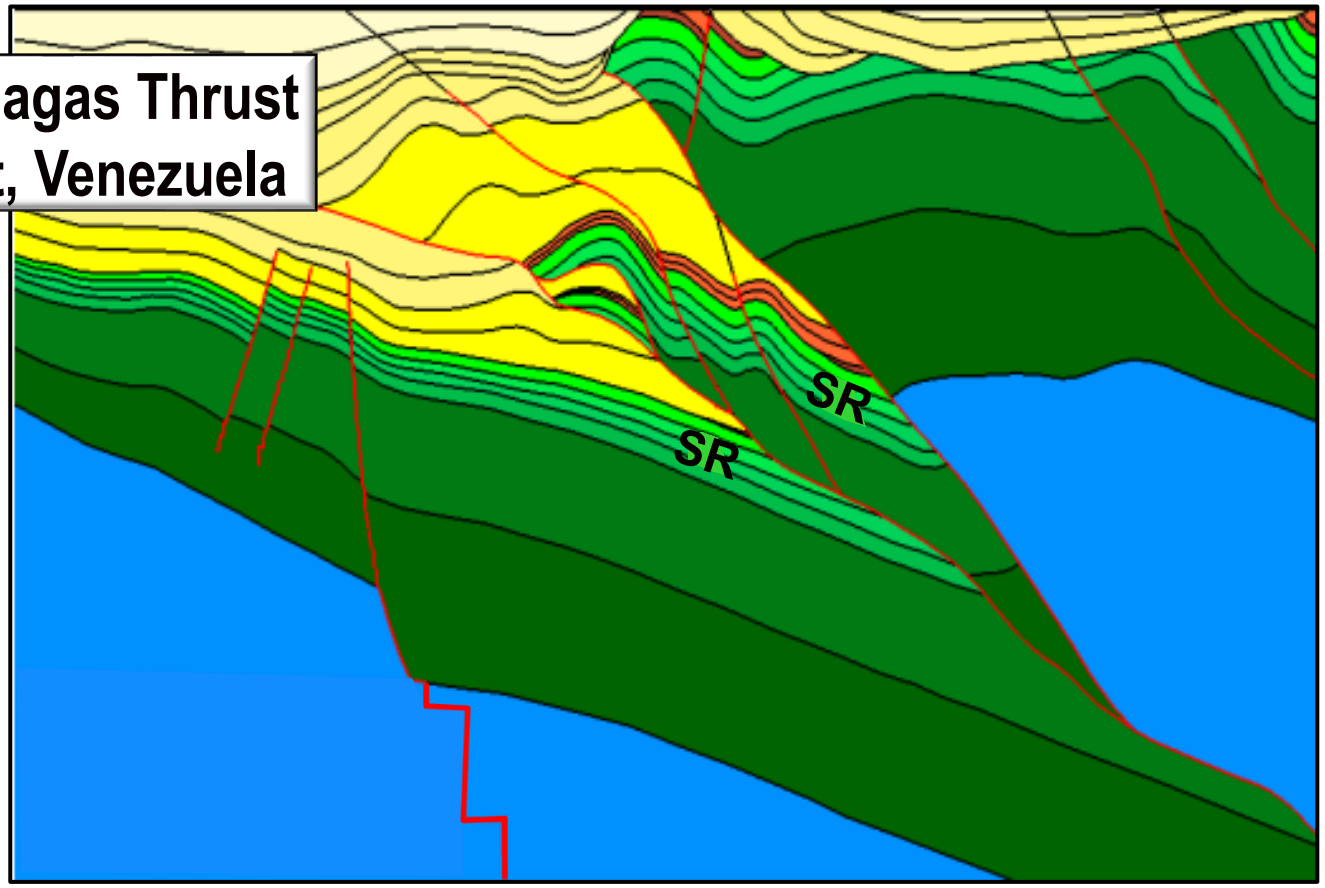


2) Linked BPSM-Complex Structural Restoration (CSR)

2D Present Day Cross Section → 2D Structural Restoration → 2D Geometrical Model Assembling → Petroleum Systems Model

2014

Monagas Thrust Belt, Venezuela



Pleistocene
Pliocene
U. Miocene
M. Miocene
L. Miocene
Oligocene
Paleo/Eocene
U. Cretaceous
L. Cretaceous
Sub-Cretaceous

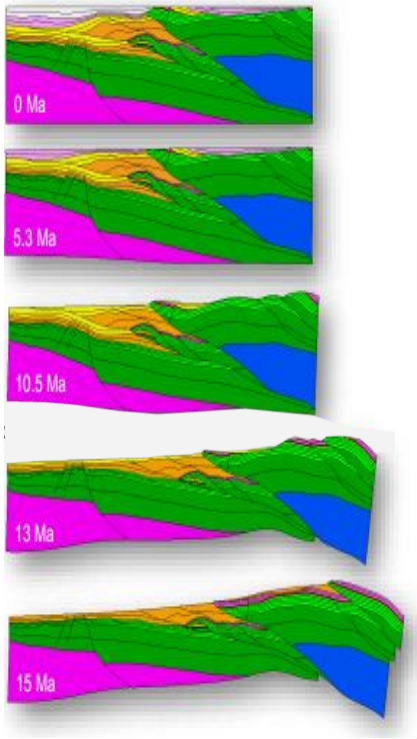
Modified from Neumaier et al. (2014)

SR = source rock

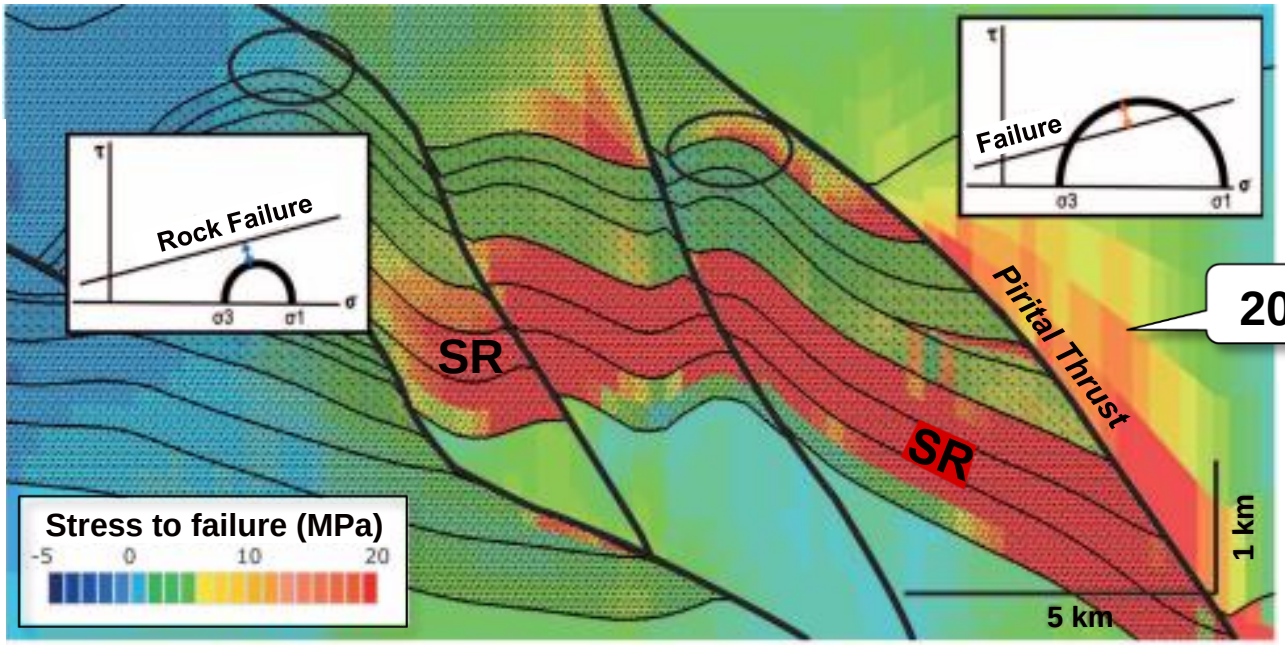
Linked Model Predicts Rock Failure in Prospect at 12 Ma

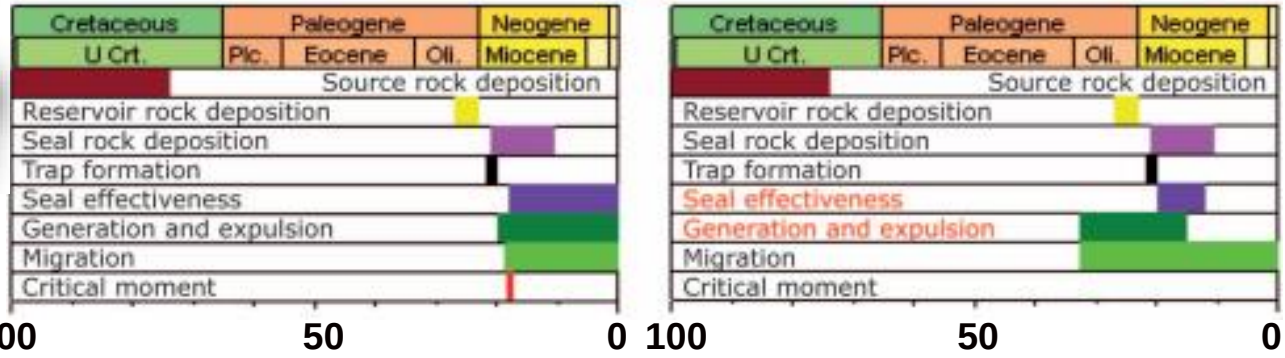
SSE *Santa Barbara field* *Prospect* NNW

Restorations



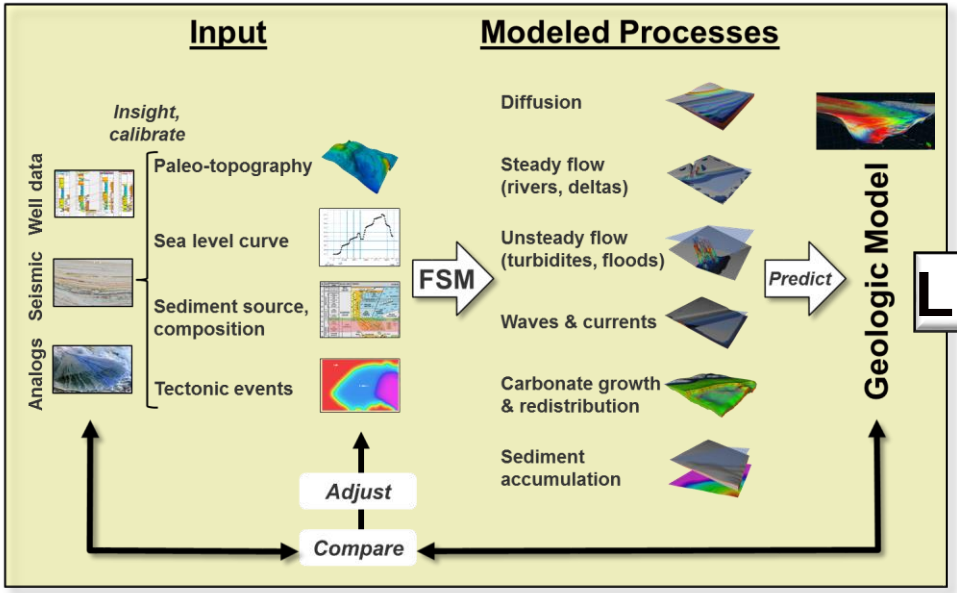
Modified from Neumaier et al. (2014)





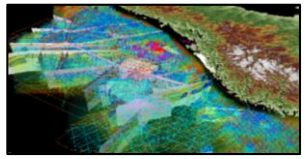
Time (Ma)

FSM Links with Other Tools Throughout E&P Lifecycle

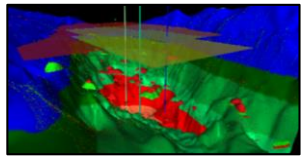


Links

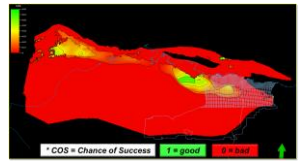
- Seismic Model Interpretation



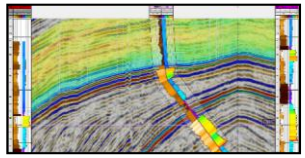
- Source/Migration Charge Modeling



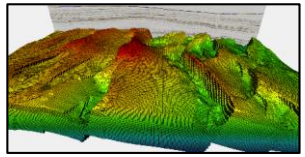
- Play Chance Maps Risk Assessment



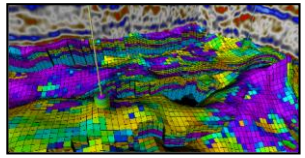
- Structure & Stratigraphic Interpretation



- Reservoir Modeling

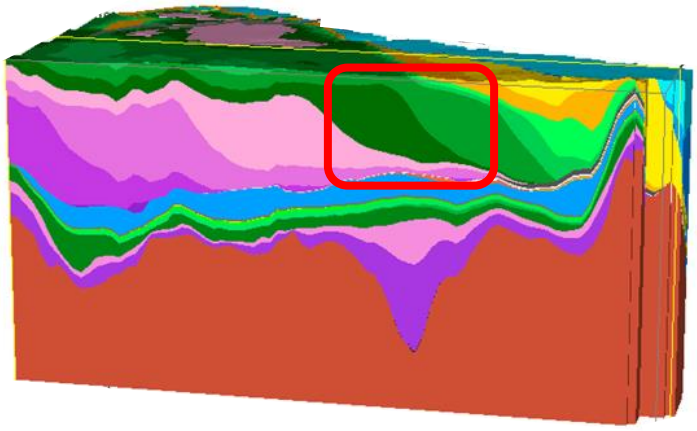


- Multiple Scenarios Uncertainty and Optimization

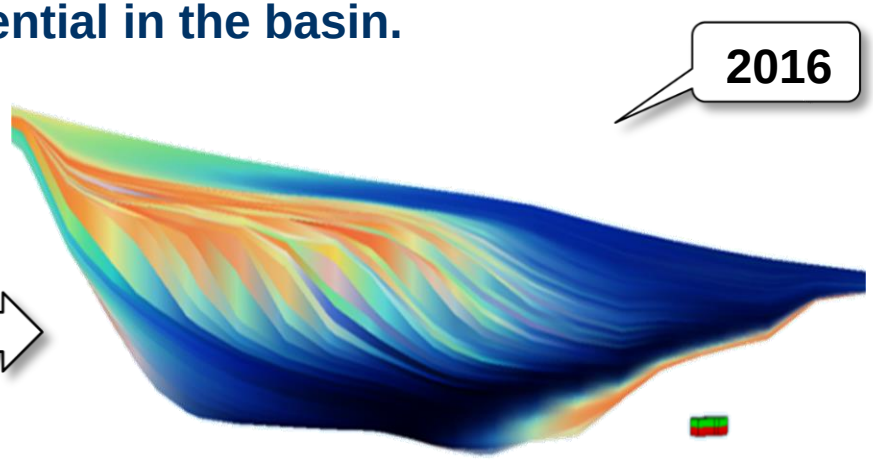


Example of BPSM-FSM: Alaska North Slope Study

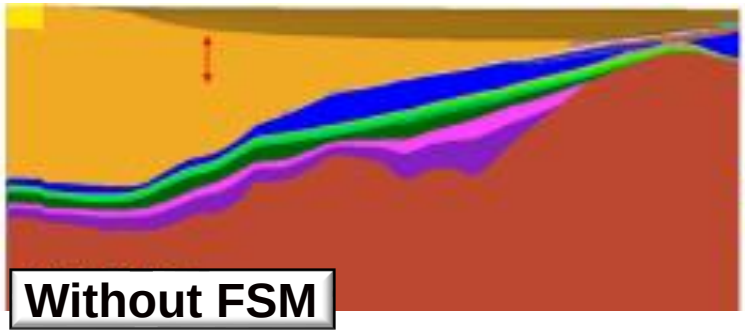
Alaska North Slope: Linked BPSM-FSM incorporates quantitative lithofacies of diachronous Brookian Sequence to improve risk assessment of hydrocarbon potential in the basin.

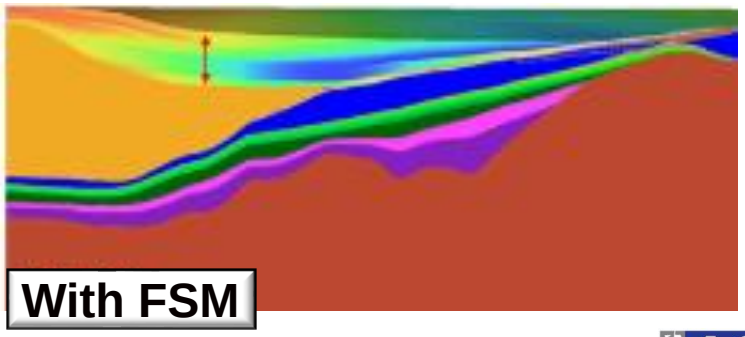


Typical petroleum system model: limited lithofacies heterogeneity



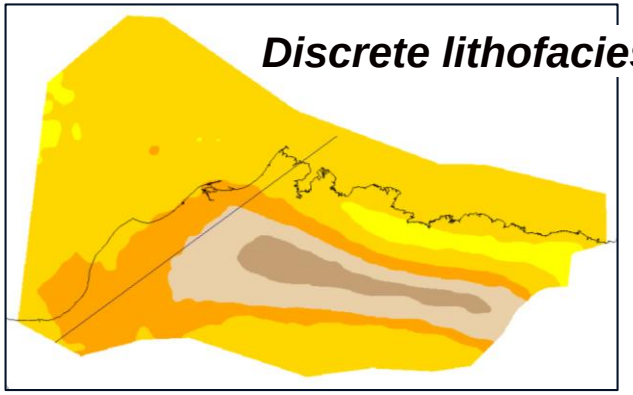
Diachronous deposition of Brookian sequence based on FSM

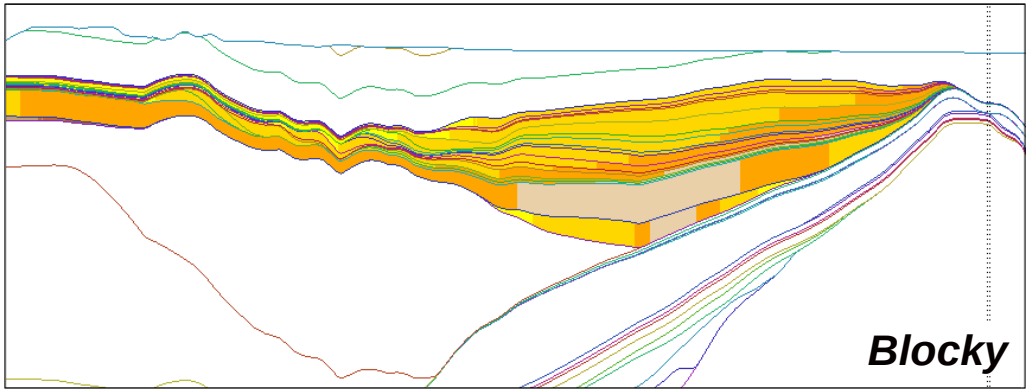




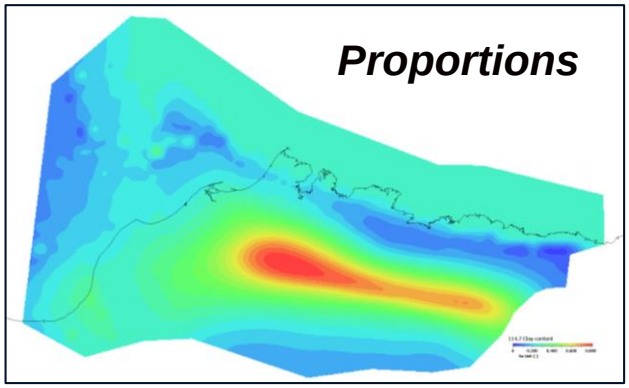
Map-Based Mixed Lithologies: Discrete vs. Proportions

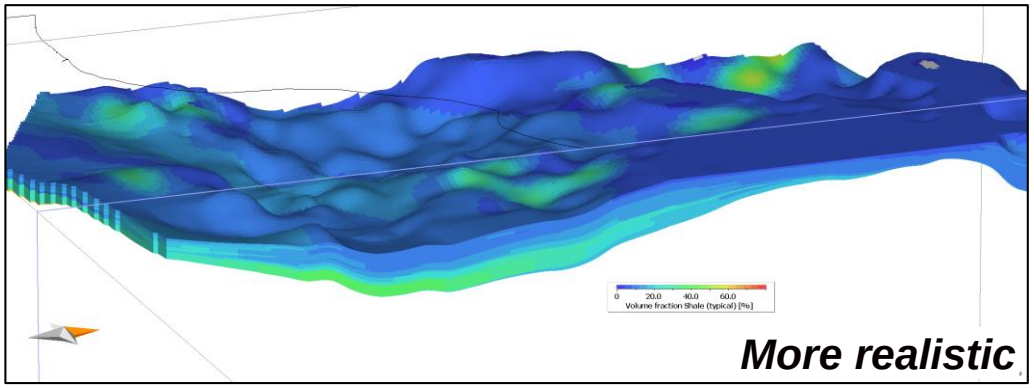
Traditional pre-defined mixed lithologies





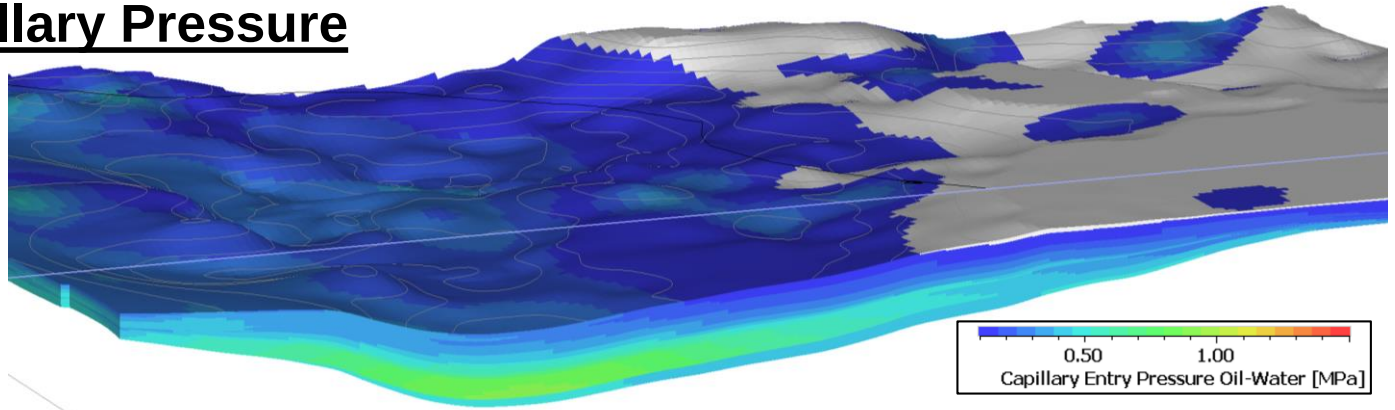
FSM map-based mixed lithologies



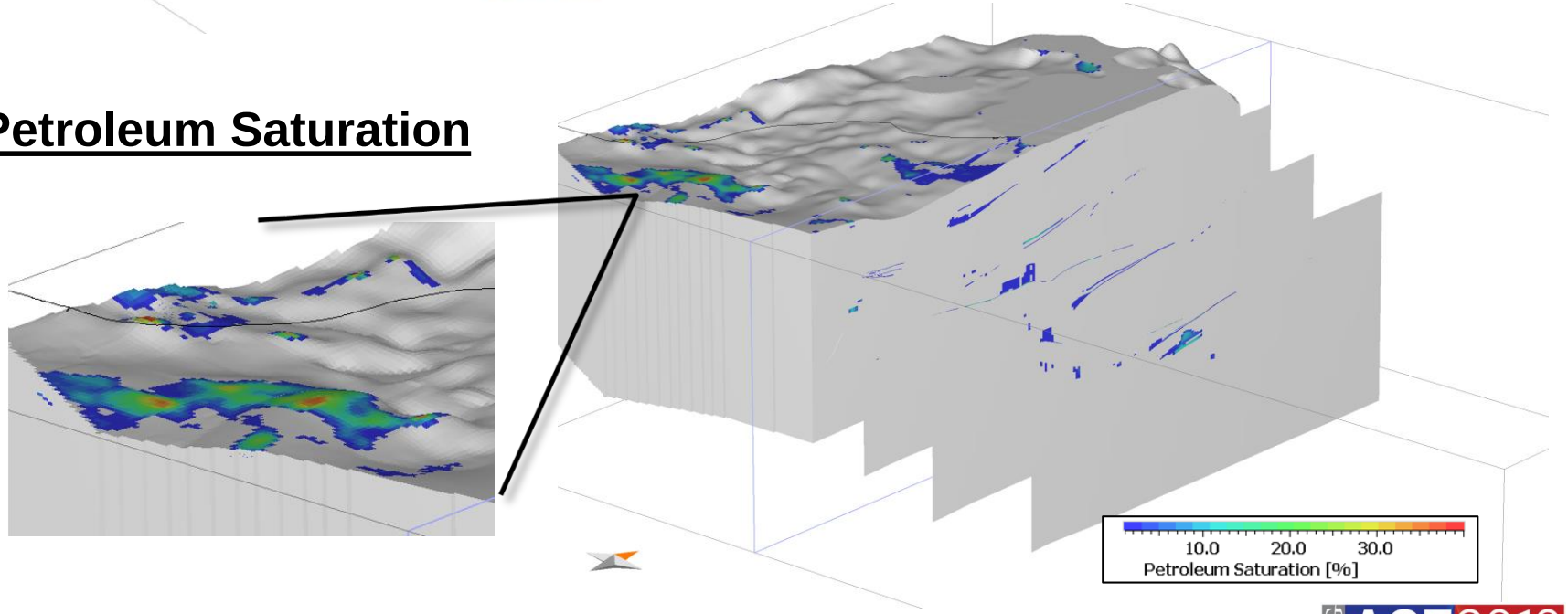


BPSM Overlays Predict Seal Capacity, Migration Paths

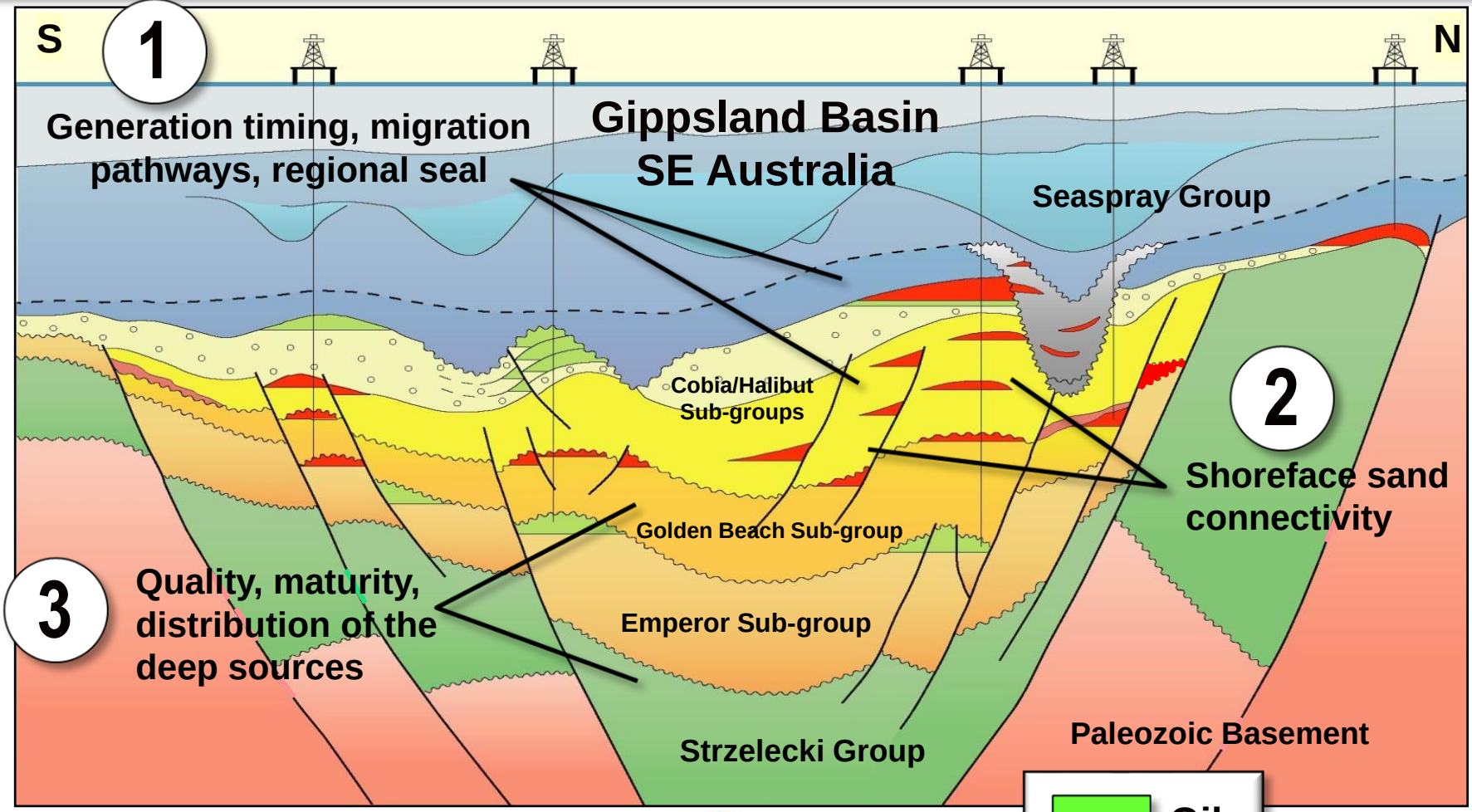
Capillary Pressure



Petroleum Saturation



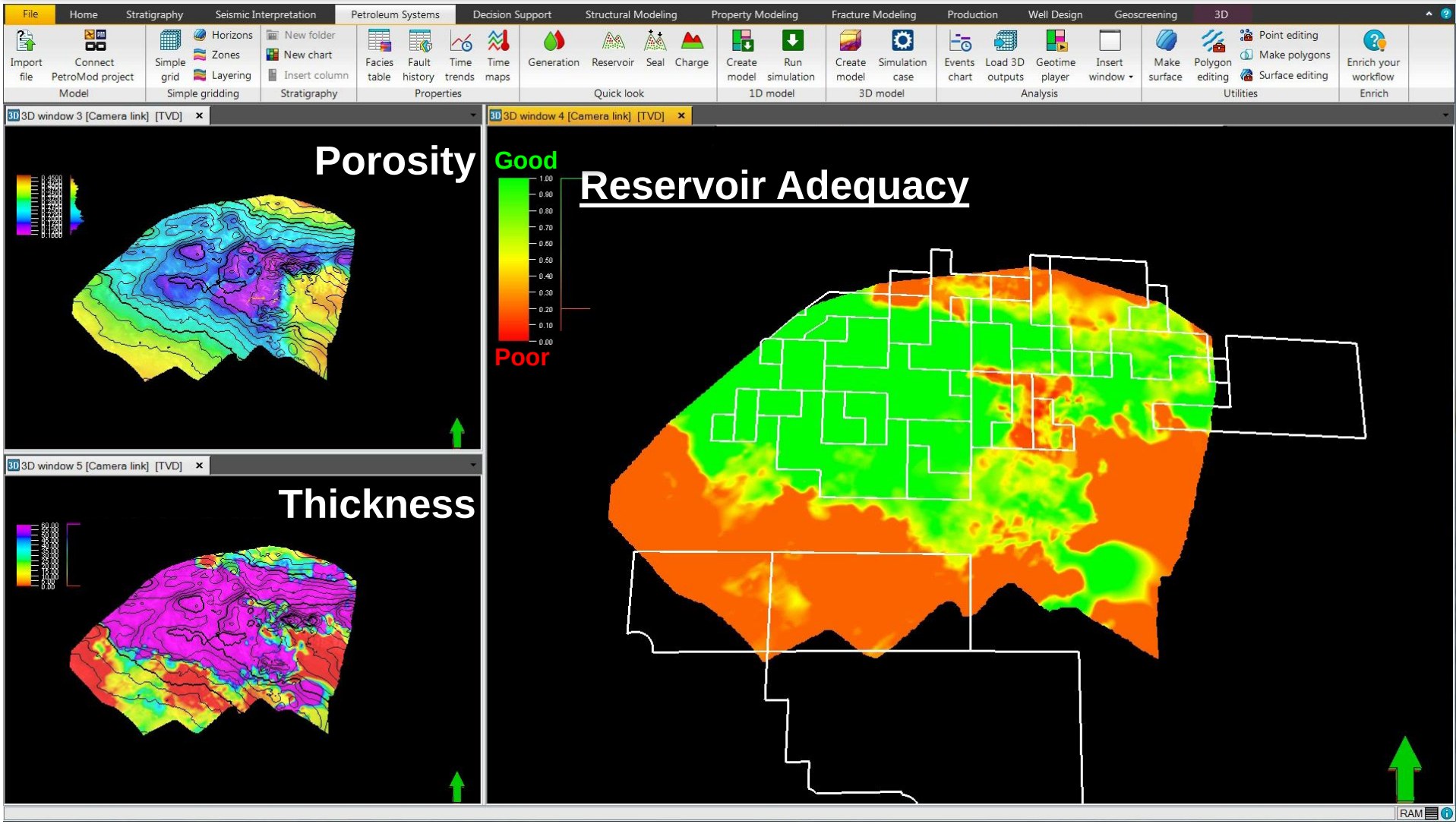
4) BPSM-FSM-Probabilistic Prospect Assessment (PPA)



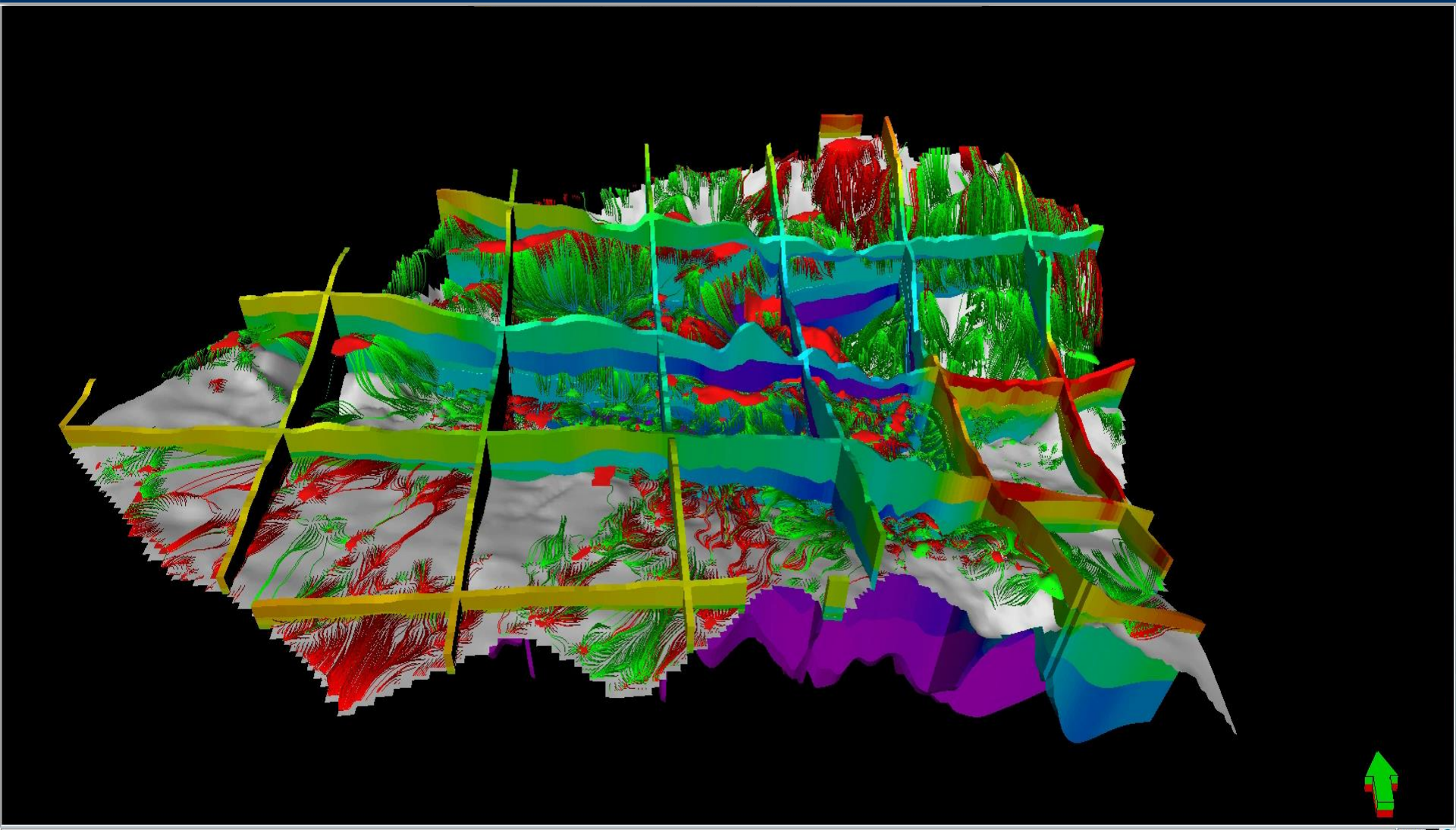
Courtesy of Geoscience Australia

Cloud Technology

Play Chance Maps; e.g., Reservoir Presence, Quality



Total Play Chance Maps Help to Define the Best Areas



Courtesy of Geoscience Australia

Concept $\xrightarrow{Slow}$ Computerized BPSM $\xrightarrow{Fast}$ BPSM-Linked Technologies

- **Transition of petroleum system concept to BPSM was slow, but recent BPSM-linked technologies are an exponential advance.**
- **Linked BPSM-Pore Pressure Prediction allows wells to be drilled safely and under budget.**
- **BPSM-Forward Stratigraphic Modeling (FSM) improves reservoir assessment by predicting lithology composition and distribution, migration paths, accumulations.**
- **BPSM-Complex Structural Restoration improves assessment of seal integrity, reservoir continuity, fluid properties.**
- **BPSM-FSM-Probabilistic Prospect Assessment improves predicted generation timing, migration paths, connectivity, seals; portfolio based on risk-weighted geology.**
- **Complex BPSM-linked models can be efficiently run using Cloud technology for faster and better decisions.**