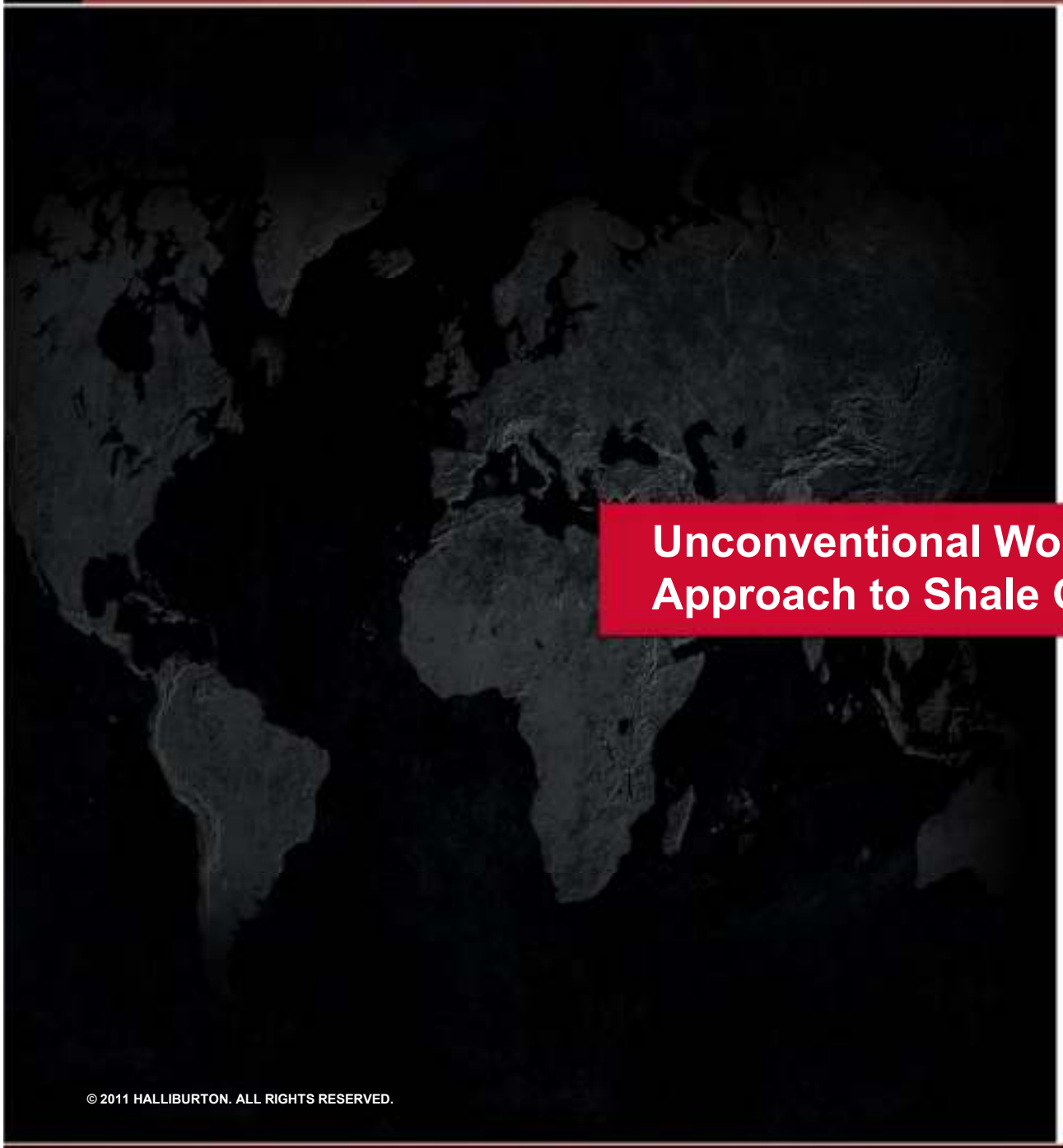

Unconventional Workflow: A Holistic Approach to Shale Gas Development

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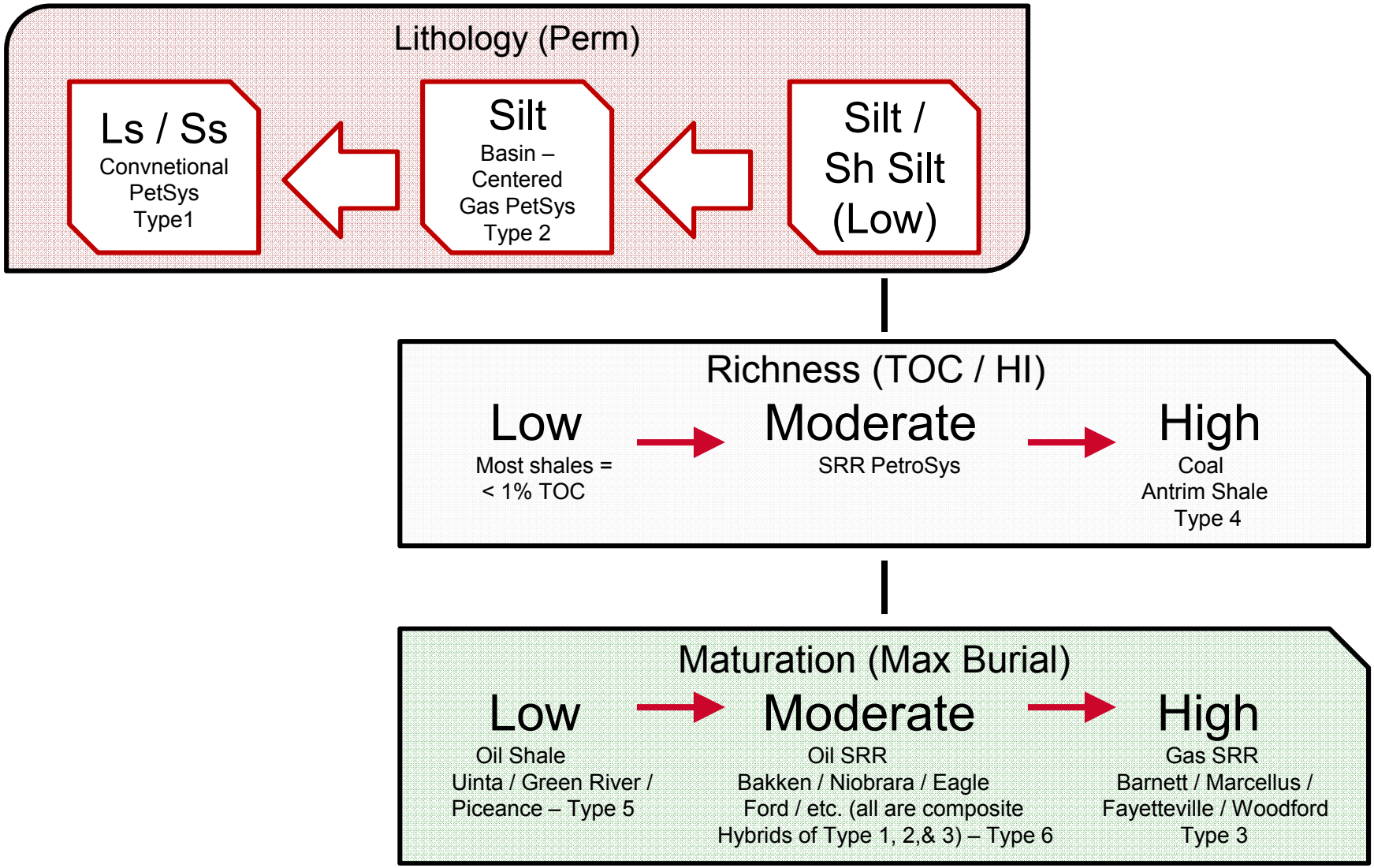
Content

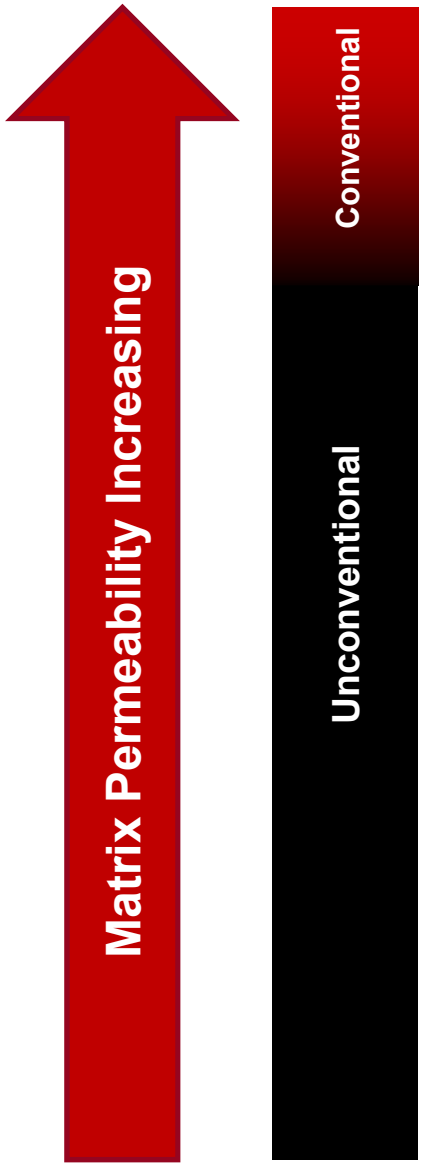
- Hydrocarbon Reservoir Type Classification
  - Perspective: Source Rock Reservoirs (SRR)
  - Technology and Permeability
  - SRR Challenges
  - Unconventional Thinking
- Source Rock Reservoir: Insite to Execution
  - Gated Source Rock Evaluation Decision Tree
  - SRR Candidate Frac Zone Selection Process
- Critical Success Factors and Key Elements
- Cypher Workflow
- Case History – Eastern Hemisphere

Hydrocarbon Reservoir Type Classification



Ls – Limestone, Ss – Sandstone, Sh Silt – Shaly Silt, TOC – Total Organic Content, HI – Hydrogen Index

Gas Reservoir Types



Conventional Gas

- MilliDarcy range (>1mD)
- Fluid type varies
- Rock type varies

Complex Gas

- Retrograde gas with high dew point
- MilliDarcy range (relatively low permeability ~1mD or less)
- Sandstone

Tight Gas

- Micro darcy range
- Dry gas – wet gas
- Primarily sandstone

CBM

- Flow mostly through fractures (cleats)
- Adsorbed dry gas
- Coal

Shale Gas - Source Rock Reservoir (SRR)

- **NanoDarcy range**
- **Dry gas – wet gas**
- **Mostly free gas – some adsorbed gas**

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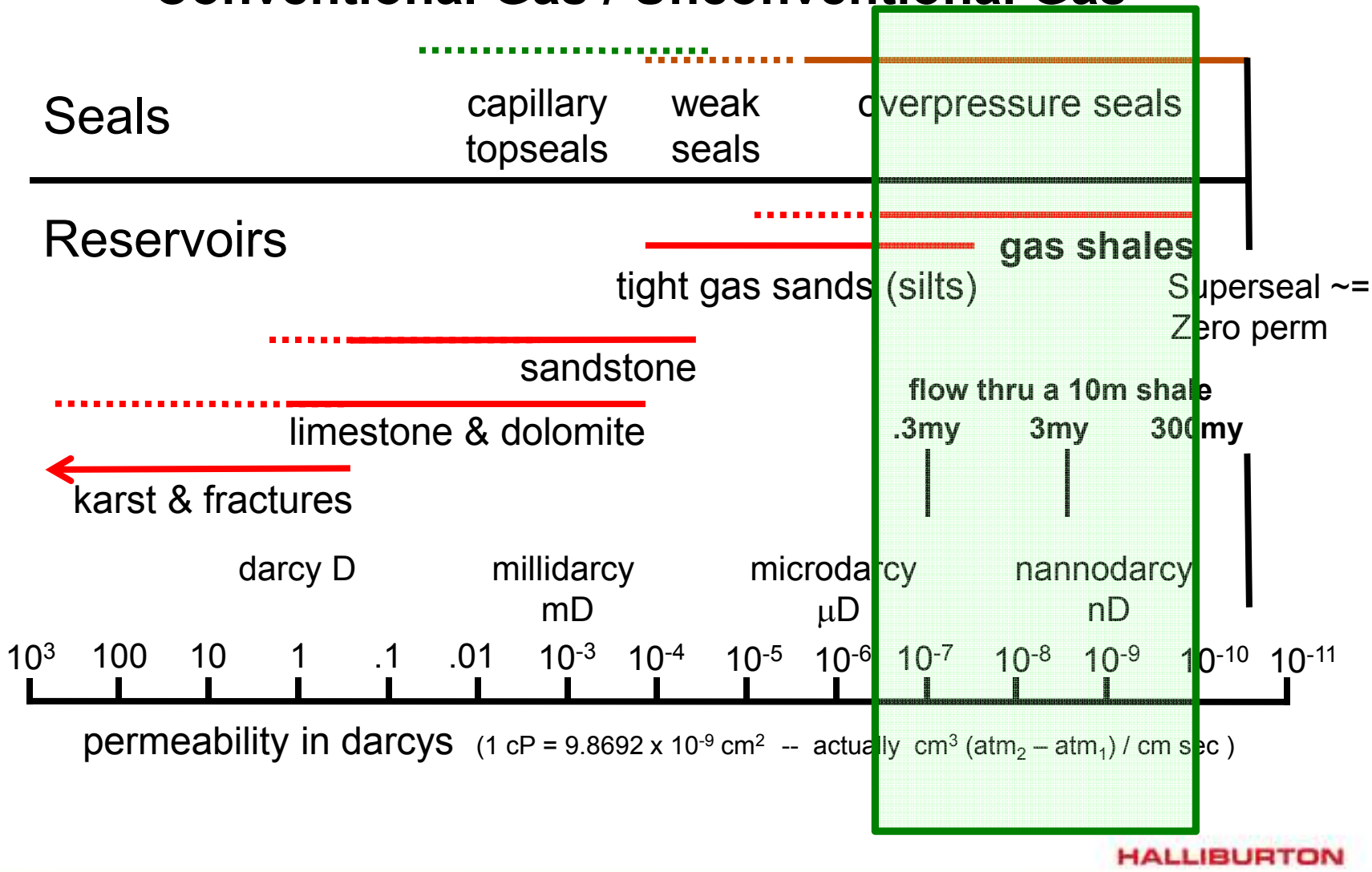
Perspective – SRR

Conventional Gas / Unconventional Gas



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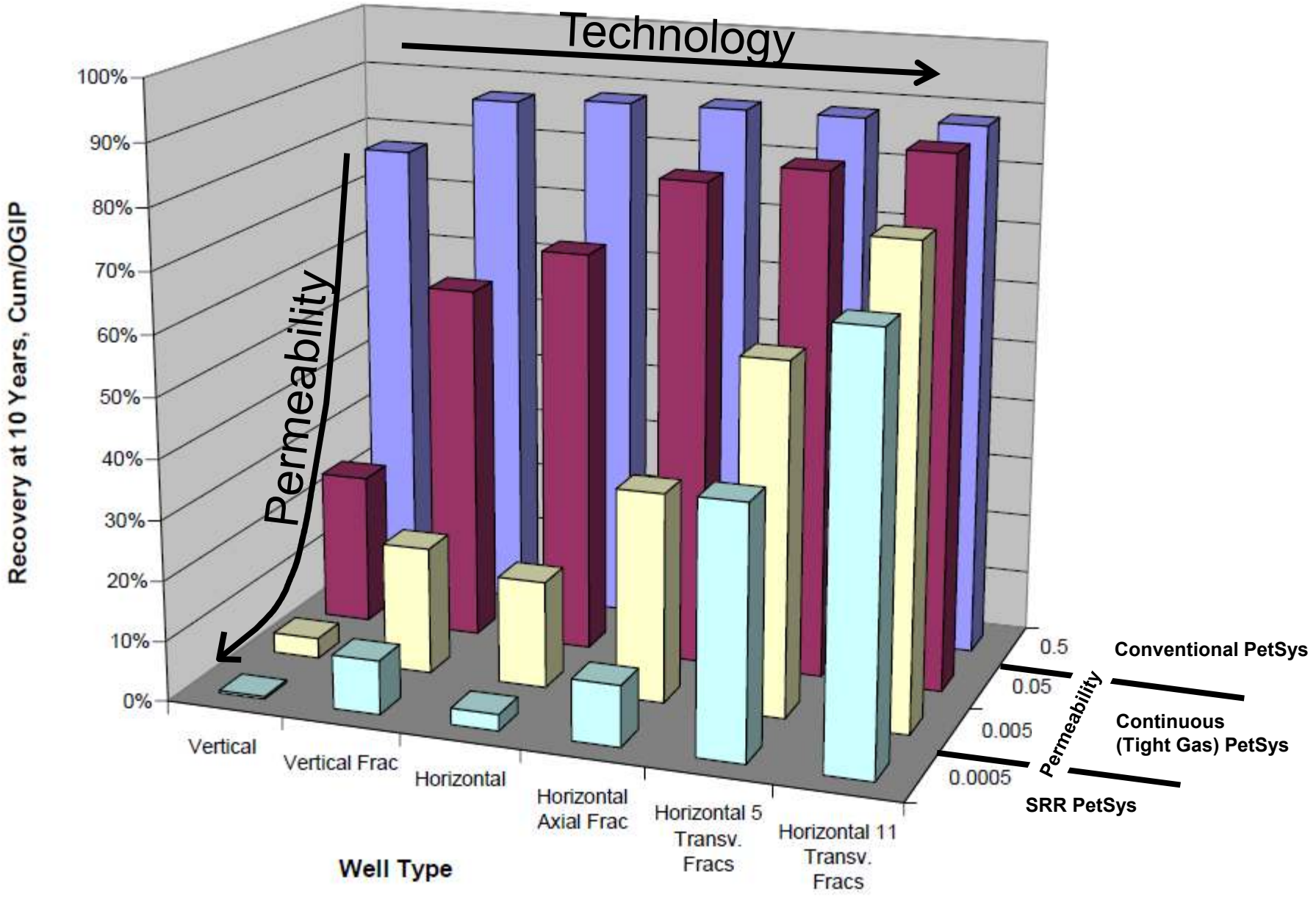

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SRR Challenges

- Difficult-to-produce formations
- Larger amounts of data & engineering manpower
- Reservoir highly heterogeneous (faulted or fractured)
- Wide range of mineralogy
- Well bore rugosity, bore hole breakout
- Horizontal wells drilled parallel - shmin.
- Organic Shale:
  - Clay minerals < 40%
  - Fine-size (<0.06mm) quartz and feldspar,
  - Plus organic material
- Compartmentalized, stacked, or layered reservoirs
- Sensitivity to fluid damage and capillary pressure

SRR – Unconventional Thinking

Low Perm Gas Reservoirs

- Uplifts / traps
- Geological Risk
- Matrix density (ρ_b)
- Hydrocarbon saturation
- Marine shale (high clay content)
- Mineralogy
- Determine reservoir volume
- Pre-Frac reservoir analysis
- Reserves concentrated
- Planar fractures
- ***HFSP - effective drainage area**
- Water conformance (shut-off)

Source Rock Reservoirs

- Continuous / naturally fractured
- Engineering Challenge
- Brittleness (E,υ)
- TOC & R_O
- Organic shale (low clay content)
- Particle size
- Stimulate reservoir volume (SRV)
- Post-Frac reservoir analysis
- Reserves across larger areas
- Degree of fracture complexity
- ***HFSP - effective SRV**
- Water management

*Horizontal Frac Stage Placement (HFSP)

Source Rock Reservoir: Insite to Execution

Evaluate Potential (Data Screening)

Organic Shale Interval
- Petroleum System

Review of data
- Seismic
- Geological
- Geomechanical
- Geochemical

Petrophysical
- Mineralogy, Φ, TOC,
- Ro, Brittle, k
- Thickness
- Fluid typing

Identify data gaps
- Seismic, core, well log etc.

First pass – SRR analogs

Hydraulic fracturing
- Wells
- Identify production potential

Production Well Test
- Initial Production
- PTA & Decline Curve analysis

Shale Formation Characterization

Reservoir Extension
- Seismic Delineation
- Estimation of Mechanical Properties
- Estimated Principal Stress Directions
- Identification of Natural Fractures
- Geochemical Properties
- Petrophysical Properties
- Estimated Mineralogy
  - Geochemical log
  - Chemostratigraphy
  - Cores XRD

DFIT Analysis

Refine SRR Analog

Data Validation and Evaluation

Sweet Spot Selection
- Thickness > 200'
- TOC > 1%,
- Free porosity > 4%
- Ro (Gas Chromatograph)
- Permeability > 100nD
- Brittleness index > 25%
- Pressure gradient

Hydraulic Fracturing
- Completion
- Perforation Strategy
- Operational Execution
- Material Selection
  - Fluids & Proppant
- Stimulation Design
  - Job Size, HHP
  - Logistics
  - Environmental Impact

Evaluation
- Production Potential
- Frac Monitoring

Production History Match
- Flowing Tubing Pressure
- Production Rate
- Fluid Production

Potential Delineation Program

Lessons Learned / What works

Aerial Continuity and extent
- Seismic
- Pilot Wells

Evaluation

Production History Match

Fine tune field development analog

Well Placement
- Reservoir drainage

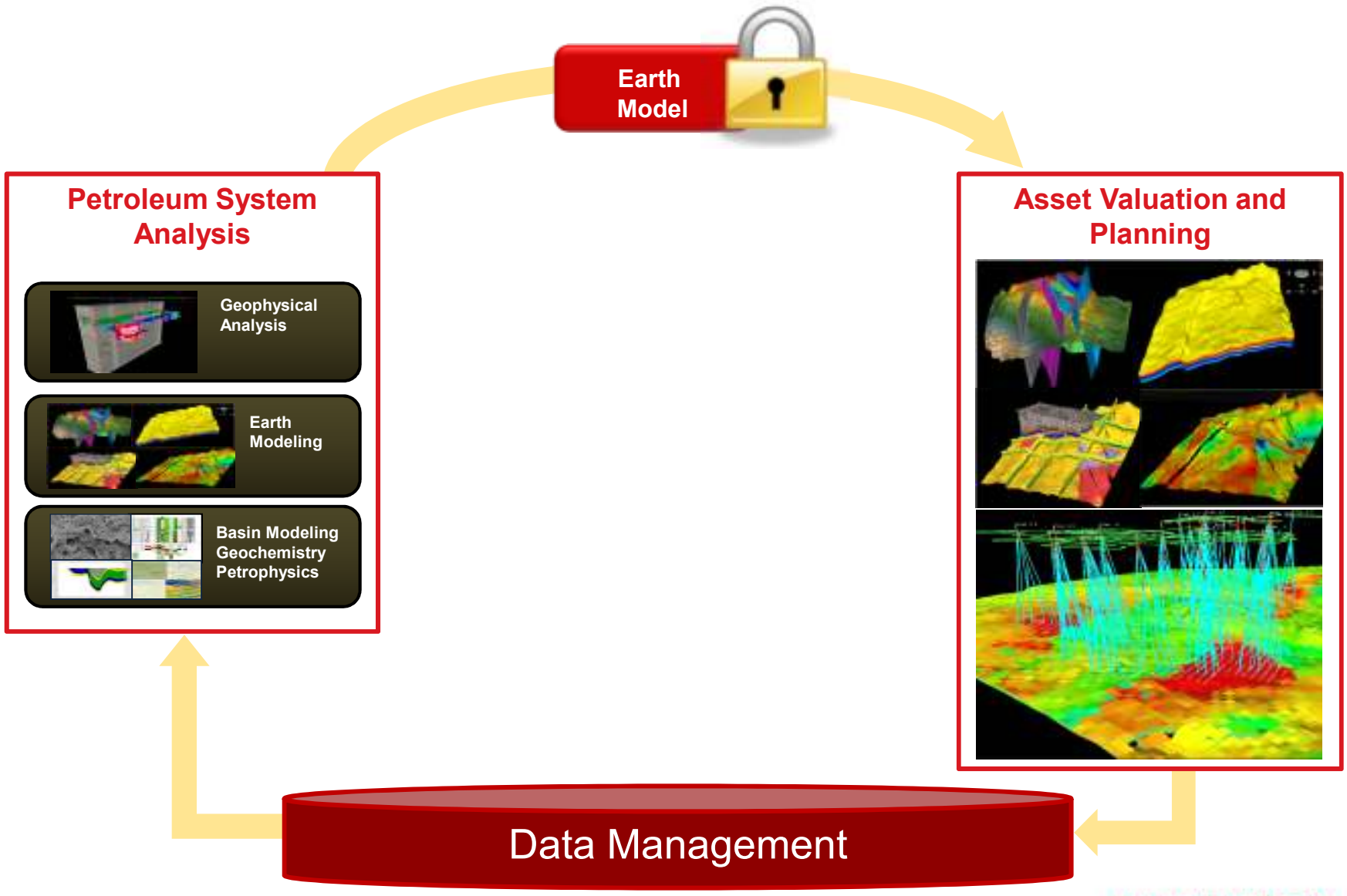
Well architecture to maximize production
- Vertical / high angle
- Horizontal
- Multilateral

Water Management

Logistics

HSE

Customer Reservoir Modeling



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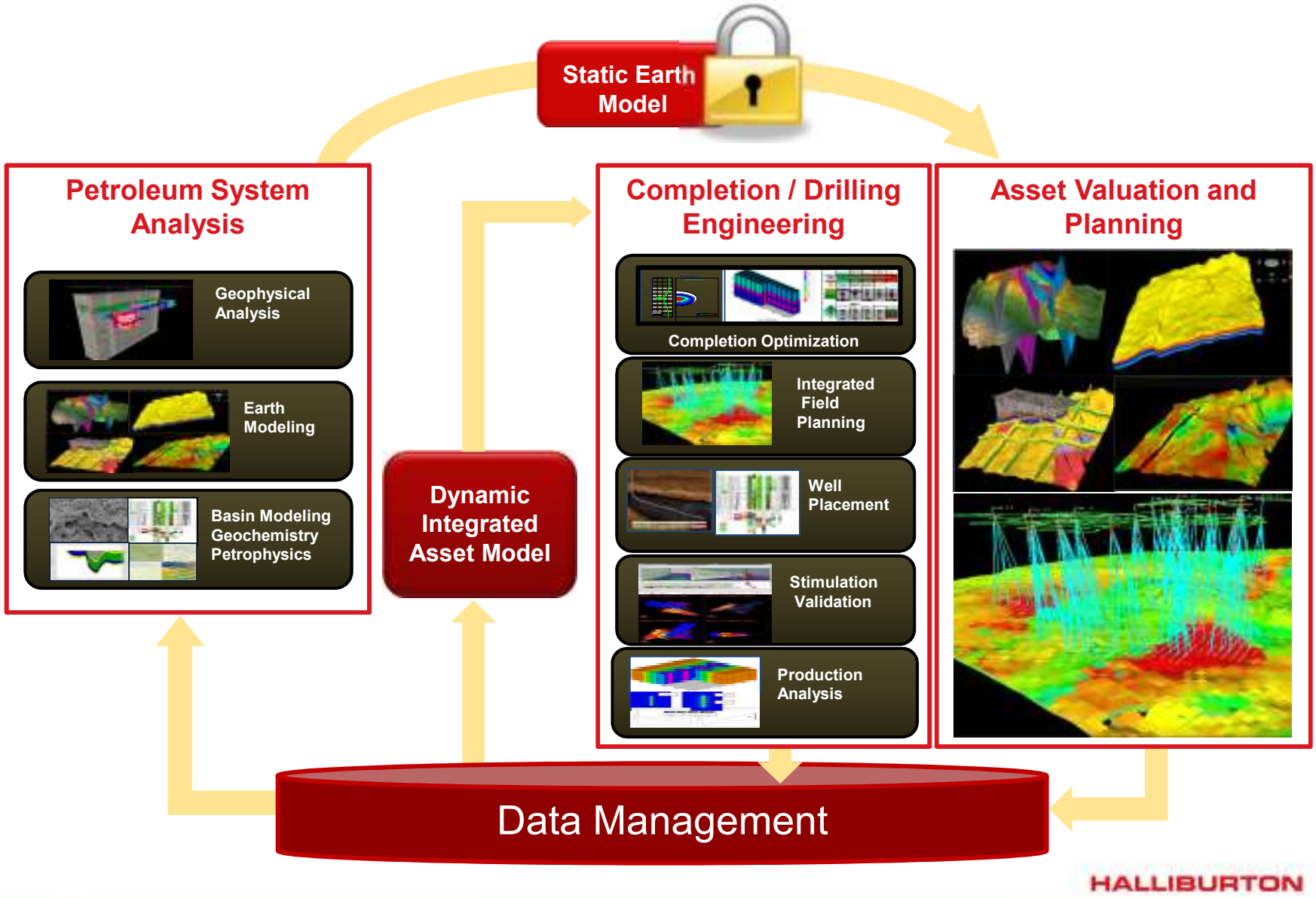
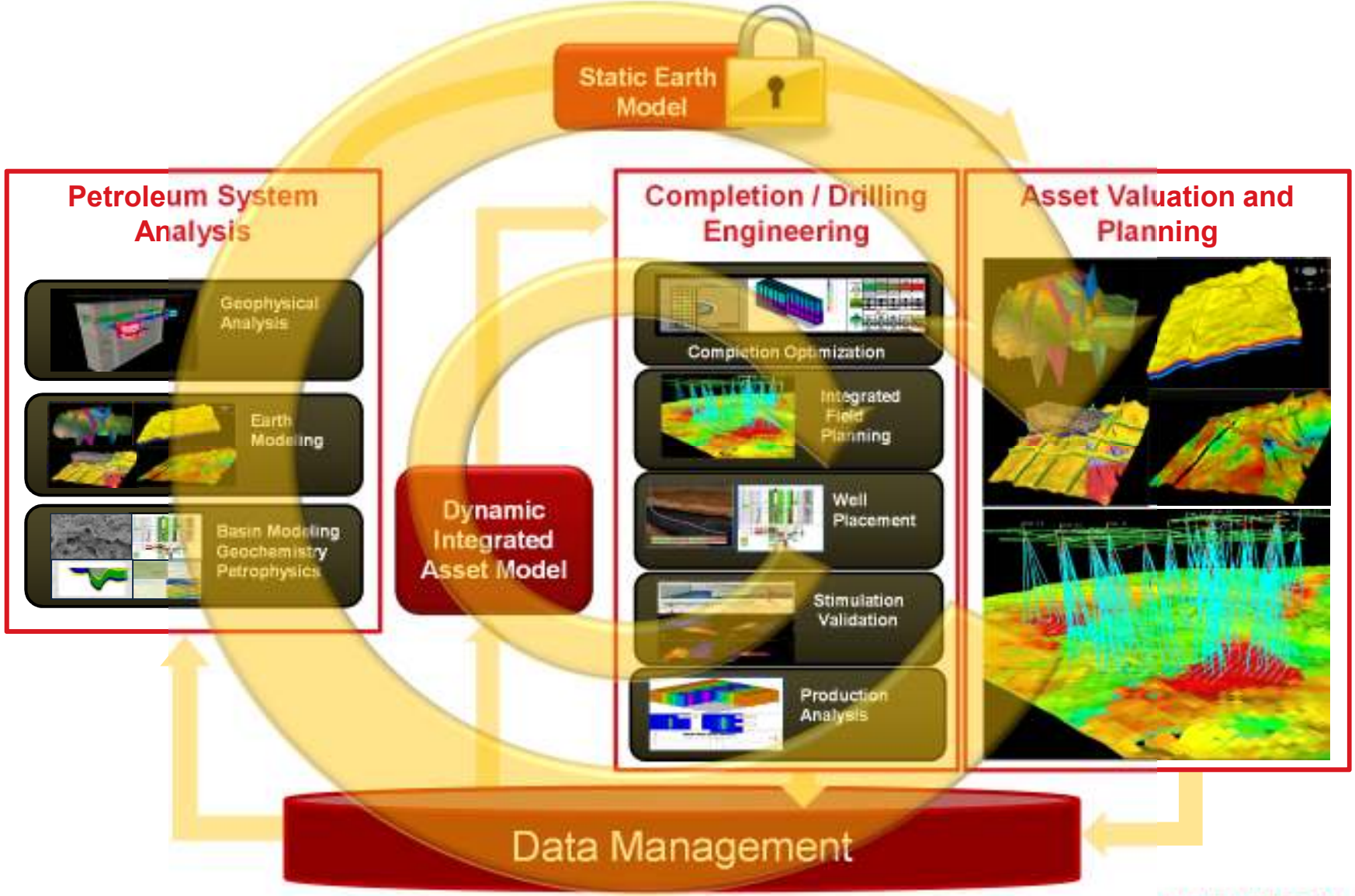
CYPHER Service



CYPHER Service



Summary

- Shale reservoirs are complex petroleum systems
  - Cross discipline approach is necessary
- Transitioning from vertical to horizontal wells with stimulation requires improved modeling to properly place and stimulate wells
- The Field Development plans should take into consideration continuous learning and improvement:
  - Well placement
  - Stimulation Effectiveness
  - Reservoir Contact
- Maximized Recovery Factor and Optimize Asset Performance