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Hydrocarbon Reservoir Type Classification

Lithology (Perm)
- **Ls / Ss**: Conventional PetSys Type 1
- **Silt**: Basin-Centered Gas PetSys Type 2
- **Silt / Sh Silt (Low)**

Richness (TOC / HI)
- **Low**: Most shales = < 1% TOC
- **Moderate**: SRR PetroSys
- **High**: Coal Antrim Shale Type 4

Maturation (Max Burial)
- **Low**: Oil Shale Uinta / Green River / Piceance – Type 5
- **Moderate**: Oil SRR Bakken / Niobrara / Eagle Ford / etc. (all are composite Hybrids of Type 1, 2, & 3) – Type 6
- **High**: Gas SRR Barnett / Marcellus / Fayetteville / Woodford Type 3

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
Conventional Gas / Unconventional Gas

Seals
- capillary
- topseals
- weak
- overpressure seals
- seals

Reservoirs
- gas shales
- tight gas sands (silts)
- sandstone
- limestone & dolomite
- karst & fractures

Permeability in darcys
- darcy D
- millidarcy mD
- microdarcy µD
- nannodarcy nD

(1 cP = 9.8692 x 10^-9 cm^2 -- actually cm^3 (atm_2 - atm_1) / cm sec)
Conventional PetSys
SRR PetSys
Continuous (Tight Gas) PetSys
Shelley et al. 2010 SPE-130108
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 ($\rho_b$)
- 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 ($E,\nu$)
- 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, $\Phi$, TOC, $R_o$, 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 log
  - Chemostratigraphy
  - Cores XRD
- DFIT Analysis
- Refine SRR Analog

**Data Validation and Evaluation**
- Sweet Spot Selection
  - Thickness > 200’
  - TOC > 1%
  - Free porosity > 4%
  - $R_o$ (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

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Customer Reservoir Modeling

Petroleum System Analysis

- Geophysical Analysis
- Earth Modeling
- Basin Modeling
  - Geochemistry
  - Petrophysics

Asset Valuation and Planning

Data Management
CYPHER Service

**Data Management**

**Dynamic Integrated Asset Model**

- **Petroleum System Analysis**
  - Geophysical Analysis
  - Earth Modeling
  - Basin Modeling
- **Completion / Drilling Engineering**
  - Completion Optimization
  - Integrated Field Planning
  - Well Placement
  - Stimulation Validation
  - Production Analysis
- **Asset Valuation and Planning**

**Static Earth Model**

**Dynamic Integrated Asset Model**
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